Universitetet
i Stavanger

DET TEKNISK-NATURVITENSKAPELIGE FAKULTET

MASTEROPPGAVE

Studieprogram/spesialisering: Offshoreteknologi - offshore systemer – retning konstruksjonsteknikk	Vår semesteret, 2012 Åpen
Forfatter: Birgitte Torp	……………………………………… (signatur forfatter)

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Tittel på masteroppgaven:

”Dimensjonering av bunnfast fundament for offshore vindturbin og metode for utmattingsanalyse”

Engelsk tittel:

“Design of a fixed fundation for offshore windturbine and method for fatigue analysis”

Studiepoeng: 30

Emneord: Bunnfast fundament Tripod Utmatting Vindturbin	Sidetall: 120 + vedlegg/annet: 11 vedlegg Stavanger, 14.06.2012

Sammendrag

Hensikten med denne oppgaven var å dimensjonere og analysere et nytt tripodkonstruksjons konsept for fundamentering av en bunnfast offshore vindturbin. Det kan ikke sees å ha blitt tatt i bruk et identisk konsept i nåværende installasjoner, og det var interessant å kunne teste ut en ny ide for en bunnfast fundamentering. Hovedtanken med selve konseptvalget var at det skulle være mest mulig kostnadseffektivt med tanke på de totale sluttkostnader etter planlegging, fabrikasjon, installasjon, drift, vedlikehold og fjerning ved endt levetid. Prosessen for utforming av konsept og bruk av teknologien er omhandlet i egne kapitler i tillegg til at noen eksiterende beregningsmetoder er diskutert.

Det er tatt utgangspunkt i en OC4 vindturbin, 5MW, som er med i et pågående prosjekt for utvikling av simuleringsverktøy for vindturbiner (ref /I-11/ og /I-12/). I OC4-prosjektet er vindturbinen supportert med en jacket struktur, men det er for denne oppgaven valgt å se om det er mulig å supportere denne turbinen med en tripodkonstruksjon.

For å sikre at det valgte designet, og profilstørrelsene, er holdbare med tanke på resonans ble det utført en egenfrekvensanalyse. Resultatene fra egenfrekvensanalysen førte til at hele fundamentkonstruksjonen måtte avstives for å komme innenfor et frekvensområde som var i en akseptabel avstand fra rotorens egenfrekvens. Det ble gjort forsøk på å gjøre konstruksjonen mykere (bruk av slankere elementer) for å øke kostnadseffektiviteten, men kravene til egenfrekvens førte da til at konstruksjonen måtte bestå av profiler som ikke ga akseptable resultater ved kodesjekk i henhold til Norsok N-004 og Eurocode 3. Alternativt kunne det forskes videre på bruk av myke elementer for å kostnadsoptimalisere designet, men det er en tidkrevende prosess og kan omfatte en total revurdering av hele designet (et eksempel på dette er vist i kapittel 6, "Alternativ designløsning for videre arbeid"). Konklusjonen fra egenfrekvensanalysen ble å bruke stive konstruksjonselementer fremfor mykere for den videre analysen. Bruken av stivere profiler førte til at selve utnyttelsen av konstruksjonen ble relativt lav (maks utnyttelse ble på 41%). Selve utnyttelsesfaktoren er et mål på hvor mye som er brukt av konstruksjonens potensial for å motsåt lastpåkjenningene. En utnyttelsesfaktor opp i mot 80 til 90% indikerer en bra utnyttelse av konstruksjonen og er det mest hensiktsmessige med tanke på kostnader. Ut i fra dette kan det konkluderes med at det endelig valgte designet ikke er helt kostnadsoptimalt for de gjeldende dimensjonerende faktorene. En måte å kunne endre designet på for å få det optimalisert, med tanke på utnyttelse, er å undersøke det for vindturbiner med en høyere operasjonsfrekvens på rotoren enn den som er valgt i denne oppgaven. Ved å øke rotorfrekvensens minste frekvens vil det gi designet muligheten til å ha en litt høyere strukturfrekvens noe som igjen gir en høyere utnyttelsesfaktor på grunn av bruken av slankere elementer. Oppsummert kan det sies at det er to faktorer som kan sees videre på når det gjelder kostnadsoptimalisering av det totale prosjektet:

1. Beholde tanken om å designe et fundament til OC4 vindturbinen, men da komme opp med en alternativ designløsning for selve fundamentet (videre optimalisering av løsningen som er presentert i denne oppgaven eller eksempelvis en tripod-jacket

konstruksjon) for å kunne få bedre utnyttelse av konstruksjonselementene men samtidig ha en uendret, eventuelt gunstigere, strukturfrekvens.

2. Beholde fundamentdesignet uendret, men forske på bruken av en vindturbin med andre operasjonsfrekvenser på rotoren. Dette vil føre til at nåværende design kan gjøres slankere (bruk av mindre rørtykkelser) noe som igjen øker utnyttelsesfaktoren til designet og endrer strukturfrekvensen (det må passes på at den nye strukturfrekvensen er innenfor en akseptabel avstand fra den eventuelt nye rotorfrekvensen).

Vurderingene som er utført i forbindelse med egenfrekvensanalysen og kodesjekk for utnyttelse viser nødvendigheten av både det konstruksjonsmessige samt dynamiske perspektivet i en analyse (utforming av design). Det er nødvendig å få begge elementene (både dynamikk og strukturanalyse) på plass for å få et reelt design som kan være operativt – og disse analysene må gjøres parallelt da de har innvirkning på hverandre. Dersom det for eksempel bare tas hensyn til den dynamiske delen kan en risikere å få et uøkonomisk design som i verste fall er nesten umulig å fabrikkere. Tas det derimot bare hensyn til selve strukturanalysen, uten en vurdering av egenfrekvensen, kan et ”perfekt” kostnadseffektivt design oppnås, men som kanskje ikke vil være operativt med tanke på levetid og kollaps ved en eventuell mulig resonans.

På grunn av det kompliserte lastbildet som oppstår for en offshore konstruksjon ble det lagt ned mye arbeid i å finne korrekte aerodynamiske og hydrodynamiske belastninger samt kombinere disse for videre fundamentanalyse. For å kunne finne de aerodynamiske lastene ble programvaren FEDEM Windpower (ref. /L-22/) brukt. Det ble lagt ned en god del arbeid i opplæring av dette programmet for å kunne modellere en vindturbin samt importere fundament for å få en komplett konstruksjon. Det å ha lært hvordan en vindturbin modelleres har vert veldig verdifullt og gitt en bedre totalforståelse for hvordan en slik kompleks konstruksjon fungerer. Programmet Sesam GeniE ble brukt videre for modellering og global analyse av selve fundamentet. Det første forslaget ble modellert med vilkårlig valgte profilstørrelser og brukt videre i FEDEM Windpower for test av import fra ett program til et annet. Det oppstod en del utfordringer i forbindelsen med importen mellom Sesam og FEDEM noe som resulterte i en del arbeid for å få det til å fungere. Videre ble det valgt å ha to modeller i Sesam GeniE; en modell med selve fundamentet og en modell med fundament og turbintårn. Dette for å kunne sammenlikne resultatene samt diskutere usikkerheter i forbindelse med bruk av to analyseprogrammer (FEDEM Windpower for aerodynamikk og Sesam GeniE for hydrodynamikk). I utgangspunktet skal FEDEM Windpower være i stand til å kjøre en komplett analyse av hele konstruksjonen (vindturbin pluss fundament), men mangelen på opplæring i dette førte til bruken av to analyseprogrammer.

Selve lokalanalysen viste seg å bli mer tidkrevende enn først forventet og den ble dermed ikke fullstendig utført. Det ble gjort et forsøk på å importere hele modellen fra Sesam GeniE inn i Abaqus, men etter at analysen ble kjørt viste resultatene usannsynlig store avvik mellom de to programmene Sesam GeniE og Abaqus (analyseresultatene fra Sesam GeniE var positive mens analyseresultatene fra Abaqus var negative). Hva som kan være årsaken til de store avvikene er diskutert i kapittel 5.5.1, ”Resultater fra lokal analyse, Abaqus” og kapittel 5.6, ”Globalanalyse i Sesam GeniE versus lokalanalyse i Abaqus”.

Resultatene fra lokalanalysen viste at det oppstår problemer med knekking i sentersøylen da denne blir belastet med store aksiale krefter og bøyemoment. Et nytt alternativ designkonsept ble utformet hvor knutepunktet for kraftfordeling heves til topp av fundamentet samt at konstruksjonen avstives med flere elementer for å få ned strukturens egenfrekvens. Denne løsningen gir positive resultater både med hensyn til utnyttelse og egenfrekvens (global analyse) og kan være en interessant løsning for videre arbeid. På grunnlag av at konstruksjonen opplever knekking og for store deformasjoner er det vurdert at det ikke er hensiktsmessig å utføre en detaljert utmattingsanalyse basert på spenningsverdiene i knutepunktene. Dette fordi konstruksjonen i utgangspunktet ikke har noen signifikant levetid på grunn av knekking og for stor deformasjon av elementene. På grunnlag av dette, i tillegg til tidsperspektivet, er selve metoden for utmattingsanalysen beskrevet i kapittel 5.7, ”Metode for utmattingsanalyse”. i stede for en detaljert analyse.

Oppsummert kan de sies at den valgte designløsningen ikke er optimal for OC4 vindturbinen, men at den eventuelt passer bedre for mindre vindturbiner med andre designegenskaper. I tillegg kan løsningen passe bedre for mindre havdyp hvor lengden på sentersøylen da kan reduseres slik at det øverste knutepunktet kommer i toppen av fundamentet og kreftene fordeles i overgangen mellom turbintårn og fundament. Skal det lages et tripodfundament for OC4 vindturbinen er det mer hensiktsmessig å se på en løsning som vist i kapitel 6, ”Alternativ designløsning for videre arbeid”, eller en alternativ løsning til denne. Det kan konkluderes med at det bør være mulig å laget et tripodfundament for OC4 vindturbinen som et alternativ til dagens fire bens jacket løsning.

Forord

Følgende rapport er utarbeidet som avsluttende oppgave for masterstudiet i Offshore teknologi – offshore systemer med fordypning i konstruksjonsteknikk ved Universitetet i Stavanger. Oppgavens tittel er utarbeidet sammen med Ove Tobias Gudmestad, faglig ansvarlig ved Universitetet i Stavanger, og Sorin Isac, ekstern veileder fra Aibel. Under hele arbeidet har begge veiledet og vært delaktige i diskusjoner av de aktuelle problemstillingene.

En stor takk rettes til dem begge samt stipendiat Lene Eliassen (ved Universitetet i Stavanger) som har vert behjelpelig med opplæring i FEDEM Windpower og Jørgen Korgstad (fra Statkraft) som har vert behjelpelig med tilgang til miljødata.

Til slutt rettes også en stor takk til min familie, spesielt min mann og mine to barn, som har vert tålmodige, støttende og forståelsesfulle under hele prosessen.

Innholdsfortegnlese

Figuroversikt

Tabelloversikt

Forkortelser og definisjoner

ABAQUS = elementanalyse program
Bladed = simuleringsprogram for aerodynamiske og hydrodynamiske krefter
DAF = dynamic amplification factor
DFF = sikkerhetfaktor, utmattelse (”Design Fatigue Factor”).
DNV = Det Norske Veritas
Eurocode = tekniske regler utviklet av den europeiske standardiseringsorganisasjonen for dimensjonering av byggverk i den europeiske unionen.
FEDEM Windpower = simuleringsverktøy for dynamisk analyse av komplette vindturbinsystemer
FLS = utmattingsgrensetilstand (”Fatigue Limit State”)
GELREF1 = benevning i .fem fil som angir materialdata
HMS = Helse Miljø og Sikkerhet
Hz = hertz
IEC = International Electrotechnical Commission
ID = idenitifikasjon
ID = indre diameter (“Inner Diameter”)
ISO = International Organization for Standardization
JONSWAP = Joint North Sea Wave Project
MDOF = flerfrihetsgrad system (”Multi Degree Of Freedom system”)
NORSOK = Norsk sokkels konkurranseposisjon, utgiver av diverse standarder for norsk offshore virksomhet
OC4 = definisjon på vindturbinprosjekt (forskning), 5MW vindturbin
OD = ytre diameter (“Outer Diameter”)
OWEZ = Offshore Windfarm Egmond aan Zee
PM = Pierson-Moskowitz bølgespektrum
SDOF = enkel frihetsgrad system (”Single Degree Of Freedom system”)
SESAM = analyseprogram for strukturanalyse
SWL = stillvannstand (”Still Water Level”)
Turbsim = simuleringsprogram for turbulens
ULS = bruddgrensetilstand (”Ultimate Limit State”)
WLC = bølgelasttilfelle
”ad hoc” = til dette formål

Symboler

A = utsatt areal
$\mathrm{A_i}$ = intervallareal for beregning av $\mathrm{F}_{\text{totalt gjennomsnitt}}$
A = integrasjonskonstant
$A_{footing}$ = arealet på innfesningen
a = sprekklenge (bruddmekanikk)
B = integrasjonskonstant (mekanikk)
B = bredden på innfestningen (fundamentanalyse)
$\mathrm{C_A}$ = formfaktor
C = konstant for et gitt testresultat
$C_{faktisk}$ = faktisk demping
C_M = massekoeffisisenten
C_D = dragkoeffisienten
$\mathrm{C_r(z)}$ = ruhetsfaktor
c = effekt av jordsmonnets skjærstyrke (fundamentanalyse)
c = dempingsfaktor (mekanikk)
C_c = kritisk demping (mekanikk)
D = diameter
D = konstant normalt satt til 1,0 (bruddmekanikk)
d = vanndyp
$\mathrm{F_D}$ = kraft på grunn av demping
$\mathrm{F_I}$ = treghetskraft
$\mathrm{F_k}$ = stivhetskraft
$\mathrm{F_{max}}$ = maks last (aksial eller skjær)
$\mathrm{F_{Res}}$ = resulterende horisontal kraft
$\mathrm{F(t)}$ = total kraft på sylinder (bølgeteori)
$\mathrm{F}_{\text{totalt gjennomsnitt}}$ = vindkraft på en konstruksjon
$\mathrm{F}_{\text{total horisontal}}$ = total vindkraft, inkludert turbulens, på en konstruksjon
$\mathrm{F_t}$ = ekstern kraft
$\mathrm{F_x}$ = skjærkraft om x-akse
$\mathrm{F_y}$ = skjærkraft om y-akse
$F(t)$ = bevegelseslikning (mekanikk)
f_M = masse leddet
f_D = drag leddet
g = gravitasjonskonstanten
H = bølgehøyde
$\mathrm{H_{max}}$ = maks bølgehøyde
Hz = Hertz
$\mathrm{H_s}$ = signifikant bølgehøyde
h = høyde

h_{ref} = referansehøyde
$I_{u(z)}$ = turbulensintensitet i horisontal retning
$I_{v(z)}$ = turbulensintensitet i normal på horisontal retning
$I_{w(z)}$ = turbulensintensitet i vertikal retning
i = en gitt spenningsveksling
K = spenningskonsentrasjonsfaktor
k = bølgetallet
kN = kilo newton
kNm = kilo newton meter
k = stivhetsfaktor (mekanikk)
k_p = ”peak” faktor
k_b = reguleringsfaktor for mangel på korrelasjon av turbulens
L = bølgelengde
$\log a$ = avskjæringen av $\log(\mathrm{N_i})$-aksen på SN-kurven
$\log s$ = standardavviket til $\log(\mathrm{N_i})$
MPa = Mega Pascal
M_{Res} = resulterende bøyemoment
M(t) = moment
M_x = moment om x-akse
M_y = moment om y-akse
m = meter
m_1 = den negativt inverse hellingen til SN-kurven
mm = millimeter
m/s = meter per sekund
m = masse (mekanikk)
m = konstant – stigningsparameter (bruddmekanikk)
N = spenningsvekslinger
N = antall sykluser
N_c = bærende kapasitetsfaktor for utjevning
N_i = antall sykluser før sammenbrudd
N_q = bærende kapasitetsfaktor for overbelastning
N_γ = bærende kapasitetsfaktor for egenvekt
n_i = antall sykluser per spenningsveksling
p = antall spenningsvekslinger
q = effekt av overbelastning
R = middelspenning
R_e = reynolds nummer
r = eksponentfaktor
rpm = rotasjoner per minutt
S = belastningsnummer
S = spenningsvidde, $\Delta\sigma$

$S(\omega)$ = bølgespektrum (energispektrum på havoverflaten)
s = sekund
T = bølgeperiode
T_c = gjennomsnittelig bølgetopp periode
T_z = gjennomsnittelig bølgeperiode
T_0 = bevegelsesperioden (mekanikk)
t = tid
U(z) = gjennomsnittelig luftfart ved en gitt høyde z
u = partikkelhastighet
$\dot{u}$ = partikkelakselerasjon
$V(h)$ = vindskjær
V_{peak} = maks vertikal belastning ved innfestningen (fundamentanalyse)
V_{ref} = vindhastighetsreferanse
ν = viskositeten til vann
x = forflyttning
$\dot{x}$ = fart
$\ddot{x}$ = akselerasjon
$x(t)$ = utrykk for flere løste bevegelseslikninger (mekanikk)
$\dot{x}(t)$ = integralet av $x(t)$
$\dot{x}_0$ = verdi av $\dot{x}(t)$ når $t = 0$
Y = dimensjonssløs konstant som avhenger av geometri og lastbilde
z = høyde over SWL
z_0 = ruhetslengde
ω = bølgefrekvens
ω_N = naturligfrekvens
ω_p = høyeste vinkelfrekvens (av den maksimale verdien av $S(\omega)$)
ω_r = egenfrekvens
ω_0 = bevegelsesfrekvens (mekanikk)
ρ_w = densiteten til vann
ρ_{air} = luft densiteten
ξ_0 = amplitude
ξ = dempingsforholdet = λ ; relativ demping
$\sigma_{F\ total\ horisontal}$ = standardavvik for $F_{total\ horizontal}$
$\sigma_{\max}$ = største spenning
σ_{mean} = middelspenning
$\sigma_{\min}$ = minste spenning
$\sigma_{u(z)}$ = standardavvik basert på valgt sannsynlighetsfordeling
$\sigma_{v(z)} \approx 0{,}75\ \sigma_{u(z)}$
$\sigma_{w(z)} \approx 0{,}50\ \sigma_{u(z)}$
λ = relativ demping
γ = effekt av egenvekt (fundamentanalyse)

Ω = frekvensforholdet mellom egenfrekvens og naturlig frekvens

ΔF = lastvidde

ΔK_{th} = terskelverdien

$\Delta\sigma$ = spenningsvidde

1P = rotorfrekvens

3P = rotorbladfrekvens

1. Introduksjon

Vind er en fornybar energikilde som alltid vil være tilgjengelig og gjennom vindturbiner kan energien i vind omformes til elektrisitet. Bruken av denne energikilden er i stor framgang, og man kan regne med at vindkraft fra offshore vindturbiner vil utgjøre en stor del av vindenergiforsyningen i fremtiden.

Fordelen med utvinning av energi fra offshore vindturbiner er tilstedeværelsen av mer stabile vindresurser, store tilgjengelige områder og sannsynligvis lavere interessekonflikter enn på land. Offshore vindturbiner kan også installeres med større rotor og høyere vingehastighet enn onshore vindturbiner. Ulempene med dagens løsninger er at investering og vedlikeholds- samt driftkostnader er betydelig større enn for onshore vindturbiner. I tillegg ligger det en stor forskjell i selve fundamenteringen. Hovedkonseptene for fundamenteringen kan deles inn i to typer; bunnfast og flytende. Hvilken type som blir brukt avhenger av havdypet i det aktuelle installasjonsområdet. Bunnfaste konstruksjoner kan installeres på havdyp opp til 100 meter, mens flytende konstruksjoner brukes på større dyp.

Denne rapporten vil ta for seg de ulike aspekter innen design og analyse av et bunnfast fundament. Det blir tatt utgangspunkt i at konstruksjonen installeres på grunt farvann (45 meters dyp) i Nordsjøen. Områdedata er hentet fra den engelske østkyst, ref. /L-7/, men det er tenkt at samme data kan brukes for et eventuelt annet område i Nordsjøen. Grunnen til dette valget er for å kunne bruke standard- og reguleringskrav som er gjeldende for norsk sokkel. Arbeidet omhandler i hovedsak generering av dynamiske laster, vurdering av frekvensområder, global og lokal analyse av konstruksjonen og utmattingsproblematikken. . Det har også blitt lagt ned en del arbeid i å vise bruk av eksiterende teknologi samt eksiterende metoder for beregning av utmatting. Utforming av konsept vil i utgangspunktet bli utført i samsvar med økonomiske og installasjonsmessige verdier. Analyseprogrammet SESAM GeniE og FEDEM Windpower vil bli brukt i global analysen og Abaqus vil bli brukt for lokal analyse av knutepunkter.

Hensikten med denne oppgaven er å undersøke et nytt konsept for fundamentering av offshore vindturbiner samt se på metode for utmattingsanalyse. Grunnen til at det er valgt å undersøke et nytt design av tripodfundamentkonseptet er for å kunne se om det er mulighet for å finne et design som kan være kostnadseffektivt og som eventuelt kan ha potensial til å måle seg med nåværende eksisterende design. Med kostnadseffektiv menes det her at designet er:

1. Lett fabrikkerbart med enkle løsninger
2. Enkelt å installere
3. Enkelt å drifte samt vedlikeholde
4. Effektiv med tanke på bruk av stål (mindre stålbruk enn ved en jacket konstruksjon)
5. Fleksibelt med tanke på at det kan forskes på om samme design kan brukes på flere vanndyp (noe som kan føre til at kostnadene holdes nede ved bruk av masseproduksjon)

Det er tatt utgangspunkt i OC4 vindturbin, 5MW, som er med i et pågående prosjekt, (ref /I-11/ og /I-12/), for utvikling av simuleringsverktøy for vindturbiner. I OC4-prosjektet er vindturbinen supportert med en jacket struktur, men det er for denne oppgaven valgt å se om det er mulig å supportere denne turbinen med en tripodkonstruksjon.

Bakgrunnskunnskapen for utførelsen av denne oppgaven er hentet fra fag som er inkludert i studieretningen for offshore teknologi – ”Offshore systemer med fordypning i konstruksjonsteknikk” ved Universitetet i Stavanger.

1.1 Standarder

Det finnes flere europeiske standarder og prosedyrer som beskriver analyse, fabrikasjon og installasjon av offshore vindturbiner og fundamentering av disse. Noen av standardene og prosedyrene er listet nedenfor (alle relevante standarder for oppgaven finnes også igjen i referanselisten):

- DNV-OS-J101 – Design of offshore wind turbine structures (October 2010)
- NORSOK N-001 Integrity of offshore structures (Rev. 7, June 2010)
- NORSOK N-003 Action and action effects (Edition 2, September 2007)
- NORSOK N-004 Design of steel structures (Rev. 2, October 2004)
- Germanischer Lloyd, Rules for Classification and Construction, IV industrial Services, Part 6 Offshore Technology, Chapter 3 "Fixed Offshore Installations" and Chapter 4 "Structural Design"
- IEC 61400-3; Wind turbines – Part 3: Design requirements for offshore wind turbines
- Eurocode 1 og 3 (Eurokode er basert på grensetilstands analyse med sikkerhets faktorer i henhold til ISO 2394 – Generell pålitelighet av konstruksjoner). Eurocode 1 definerer laster og Eurocode 3 inneholder regler for analyse av stålkonstruksjoner.
- Danish Recommendation for Technical Approval of Offshore wind Turbine
    - DS449 – Piled offshore structures
    - DS409
    - DS415 Foundation
- ISO 13819-1:1995 – Petroleum and Natural gas Industries – Offshore structures – Part 1: General requirements
- ISO 13819-2:1995 – Petroleum and Natural gas Industries – Offshore structures – Part 2: Fixed steel structures

Standarder for beregning av utmatting:

- DNV-RP-C203 – Fatigue design of Offshore Steel Structures (October 2011)

Analyser og beregninger utført i denne oppgaven vil i hovedsak følge kriteriene som er gitt i Eurocode, NORSOK og DNV. Grunnen til dette er at installasjonen er forutsatt plassert på Norsk sokkel og norske myndighetskrav er gjeldende. Norske myndighetskrav er tilleggskrav til de europeiske kravene som nasjonen er pliktet til å følge. Grunnen til at det er satt en standard på europeisk nivå er at det skal kunne være fri flyt i handel og produksjon mellom de landene som er tilsluttet de europeiske kravene og at man skal være sikker på at varen eller tjenesten som blir kjøp på tvers av landegrensene er i henhold til de samme kravene som er gjeldende for det landet som varen eller tjenesten skal benyttes i. Grunnen til at det kommer myndighetskrav eller tilleggkrav til de europeiske standardene er at myndighetene i det aktuelle landet anser at det i noen tilfeller må være eventuelt strengere krav til utførelse enn dem som er oppgitt i de europeiske standardene. I tillegg kan det komme egne bransjekrav til standardene. Dette er noe som oppstår når en oppdager at gjeldende standarder ikke tilfredstiller kravene som den aktuelle bransjen setter for prosjektet. Når det gjelder Norsok, som er norske myndighetskrav, kan disse bransjekravene som benyttes i olje og gassindustrien etter hvert bli implementert som standard for vind ettersom som det blir utført revidering.

Når det gjelder analysen i denne oppgaven er det valgt å bruke sikkerhetsfaktorer etter Norsok N-001 for ULS analysen. Disse faktorene blir brukt for bemannede installasjoner og da det følgende prosjekt vil være ubemannet kan det sees på som veldig konservativt å bruke lastfaktorer for bemannede installasjoner. Grunnen til at det er valg å bruke lastfaktorer som er konservative er for å kompensere for den utelatte DAF faktoren i beregningene. På den måten kan vil DAF i en viss grad bli hensyn til når lastfaktorer for en bemannet installasjon er brukt.

Når det gjelder offshore vindturbiner er det satt krav i IEC 61400-3; ”Wind turbines – Part 3: Design requirements for offshore wind turbines” at returperioden for bølger er 50 år. Det vil si at det i gjennomsnitt vil ta 50 år mellom hver gang den oppgitte lasten overskrides. Vanligvis dimensjoneres offshore installasjoner for 100 års returperiode som har en større dimensjonerende verdi enn 50 års returperiode. En av grunnene til at det er valgt en 50 års returperiode for offshore vindturbiner, og ikke 100 års returperiode, er lønnsomheten ved at konstruksjonen ikke trenger å oppfylle krav til den større belastningen en 100 års returperiode gir enn den som oppstår ved en 50 års returperiode. I tillegg kan konsekvensen ved sammenbrudd av en vindturbin sees på som mindre enn for eksempel for en oljeplattform (da med tanke på risikoen og oppretting av eventuelle skader som kan oppstå ved sammenbrudd/kollaps på en bemannet olje og gass installasjon kontra den samme risikoen/kostnaden som oppstår ved samme scenario ved en ubemannet offshore vindturbin).

2. Relevant teori

Følgende kapittel omhandler fire teoriområder; bølgeteori, vindteori, mekanikk/dynamikk og utmatting. Det er valgt å gi en beskrivelse av de viktigste parametrene som inngår i de forskjellige teoriene og som er relevante for analyse av et offshore vindturbinfundament.

2.1 Bølgeteori

En sjøtilstand kan beskrives ved hjelp av regelmessige eller ureglemessige bølger. Bølgene er individuelle og karakteriseres ved høyden, H og perioden T.

2.1.1 Regelmessige bølger

Regelmessige bølger er best beskrevet ved lineær bølgeteori. Denne teorien er godt egnet for forenklede beregninger og den er en byggestein i beskrivelsen av uregelmessige bølger /L-2/. Teorien forutsetter at bølgkrappheten er liten (H/ L <<1) og at vanndypet er mye større enn bølgehøyden (d/H>>1). Følgende uttrykk er gitt for overflateprofilet/bølgeprofilet:

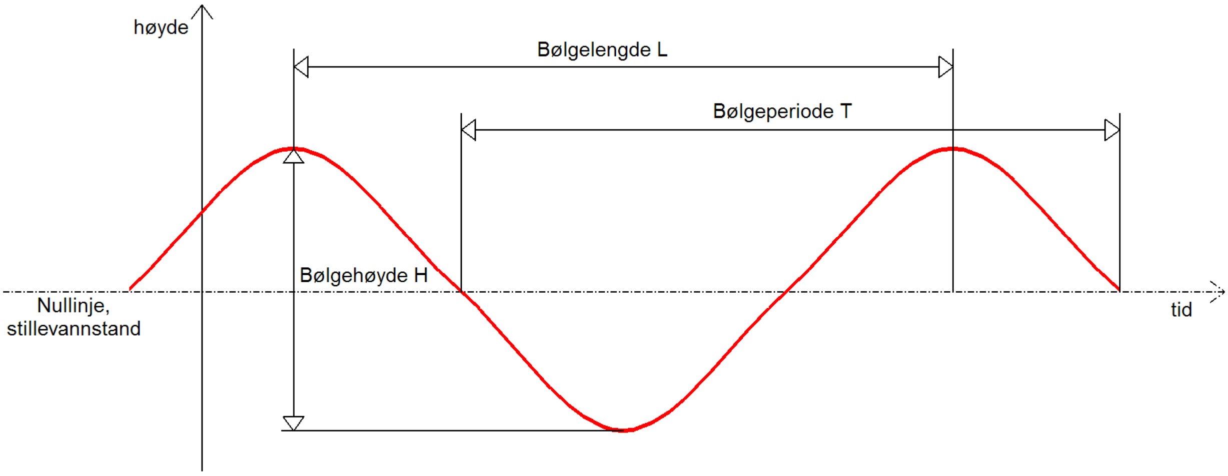
$$\xi = \xi(x,t) = \xi_0 \sin(\omega t - kx) \qquad (2.1)$$

ξ_0 = amplituden

$k = 2\pi / L$ (bølgetallet)

ω = bølgefrekvensen

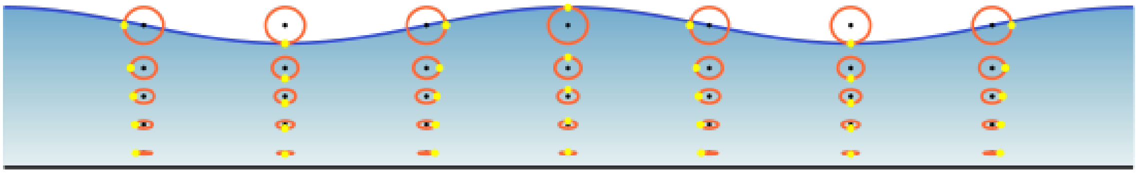
t = tiden



Figur 2.1.1-1 – Illustrasjon av regelmessige bølger

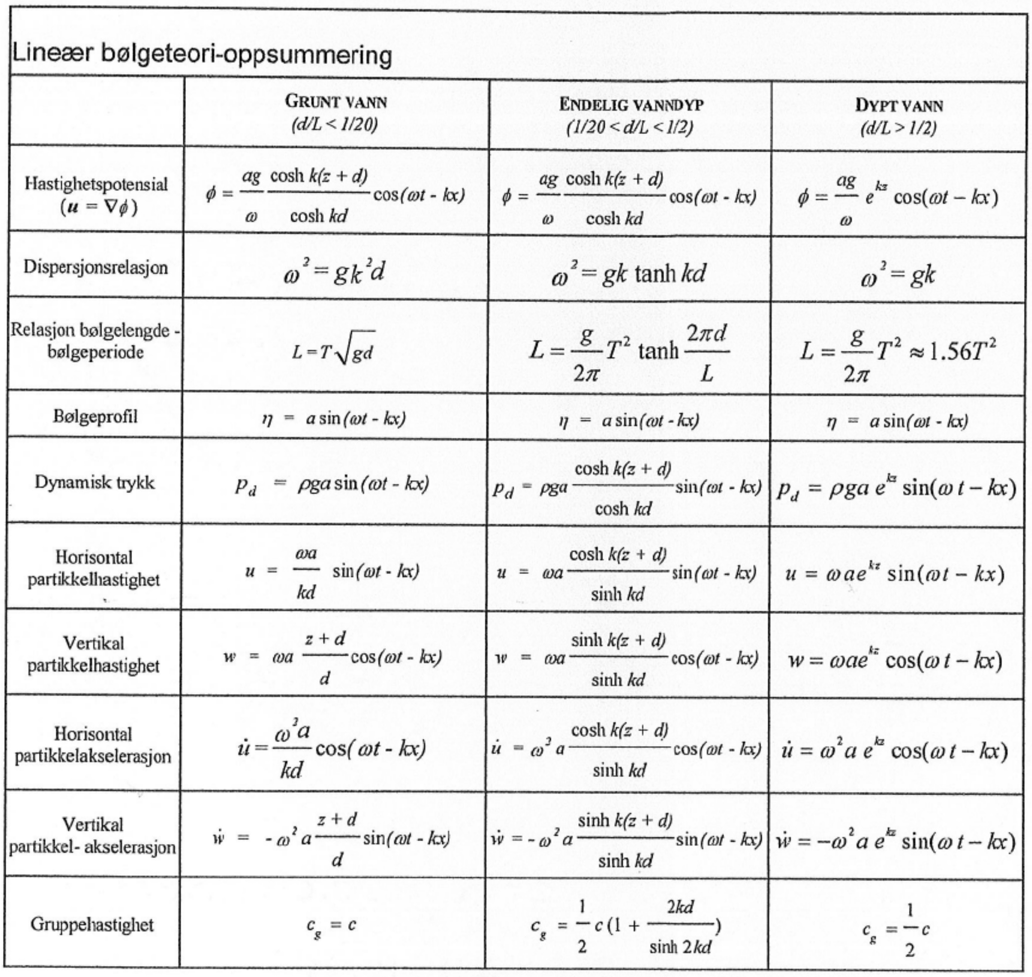
$\xi = \xi_0 \sin(\omega t - kx)$ følger den røde linja på figur 2.1.1-1. $\xi_0 = H/2$

Ut fra lineær bølgeteori kan det vises at vannpartiklene beveger seg i lukkede, elliptiske baner (halvaksene til ellipsene avtar med dypet, ref. figur 2.1.1-2) Dersom vi har bølger på dypt vann (*d*/ L > 1/2) beveger partiklene seg i sirkler ved overflaten. Er man i område med svært grunt vann (*d*/ L << 1/20) er partikkelbevegelsene ellipser men de horisontale aksene er konstante nedover i dypet.



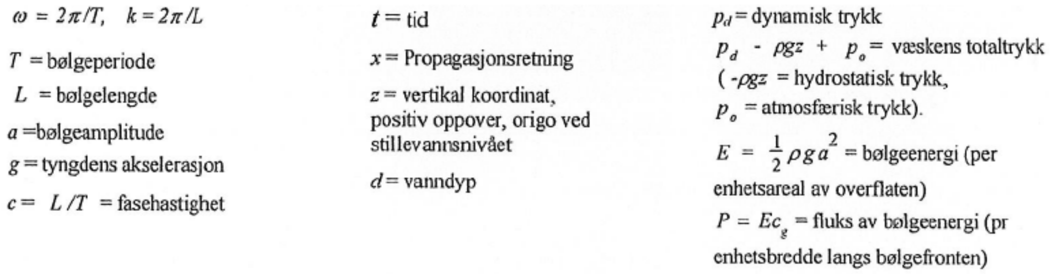
Figur 2.1.1-2 – Vannparktiklenes bevegelser under bølgen

Figur 2.1.1-3 viser bølge kinematikken under en lineær bølge /F-1/



Lineær bølgeteori-oppsummering

	GRUNT VANN (d/L < 1/20)	ENDELIG VANNDYP (1/20 < d/L < 1/2)	DYPT VANN (d/L > 1/2)
Hastighetspotensial $(\boldsymbol{u} = \nabla\phi)$	$\phi = \frac{ag}{\omega}\frac{\cosh k(z+d)}{\cosh kd}\cos(\omega t - kx)$	$\phi = \frac{ag}{\omega}\frac{\cosh k(z+d)}{\cosh kd}\cos(\omega t - kx)$	$\phi = \frac{ag}{\omega} e^{kz}\cos(\omega t - kx)$
Dispersjonsrelasjon	$\omega^2 = gk^2 d$	$\omega^2 = gk \tanh kd$	$\omega^2 = gk$
Relasjon bølgelengde - bølgeperiode	$L = T\sqrt{gd}$	$L = \frac{g}{2\pi}T^2 \tanh\frac{2\pi d}{L}$	$L = \frac{g}{2\pi}T^2 \approx 1.56T^2$
Bølgeprofil	$\eta = a\sin(\omega t - kx)$	$\eta = a\sin(\omega t - kx)$	$\eta = a\sin(\omega t - kx)$
Dynamisk trykk	$p_d = \rho g a \sin(\omega t - kx)$	$p_d = \rho g a \frac{\cosh k(z+d)}{\cosh kd}\sin(\omega t - kx)$	$p_d = \rho g a\, e^{kz}\sin(\omega t - kx)$
Horisontal partikkelhastighet	$u = \frac{\omega a}{kd}\sin(\omega t - kx)$	$u = \omega a \frac{\cosh k(z+d)}{\sinh kd}\sin(\omega t - kx)$	$u = \omega a e^{kz}\sin(\omega t - kx)$
Vertikal partikkelhastighet	$w = \omega a \frac{z+d}{d}\cos(\omega t - kx)$	$w = \omega a \frac{\sinh k(z+d)}{\sinh kd}\cos(\omega t - kx)$	$w = \omega a e^{kz}\cos(\omega t - kx)$
Horisontal partikkelakselerasjon	$\dot{u} = \frac{\omega^2 a}{kd}\cos(\omega t - kx)$	$\dot{u} = \omega^2 a \frac{\cosh k(z+d)}{\sinh kd}\cos(\omega t - kx)$	$\dot{u} = \omega^2 a\, e^{kz}\cos(\omega t - kx)$
Vertikal partikkel- akselerasjon	$\dot{w} = -\omega^2 a \frac{z+d}{d}\sin(\omega t - kx)$	$\dot{w} = -\omega^2 a \frac{\sinh k(z+d)}{\sinh kd}\sin(\omega t - kx)$	$\dot{w} = -\omega^2 a\, e^{kz}\sin(\omega t - kx)$
Gruppehastighet	$c_g = c$	$c_g = \frac{1}{2}c\left(1 + \frac{2kd}{\sinh 2kd}\right)$	$c_g = \frac{1}{2}c$



$\omega = 2\pi/T, \quad k = 2\pi/L$

T = bølgeperiode

L = bølgelengde

a = bølgeamplitude

g = tyngdens akselerasjon

$c = L/T$ = fasehastighet

t = tid

x = Propagasjonsretning

z = vertikal koordinat, positiv oppover, origo ved stillevannsnivået

d = vanndyp

p_d = dynamisk trykk

$p_d - \rho g z + p_o$ = væskens totaltrykk

($-\rho g z$ = hydrostatisk trykk,

p_o = atmosfærisk trykk).

$E = \frac{1}{2}\rho g a^2$ = bølgeenergi (per enhetsareal av overflaten)

$P = Ec_g$ = fluks av bølgeenergi (pr enhetsbredde langs bølgefronten)

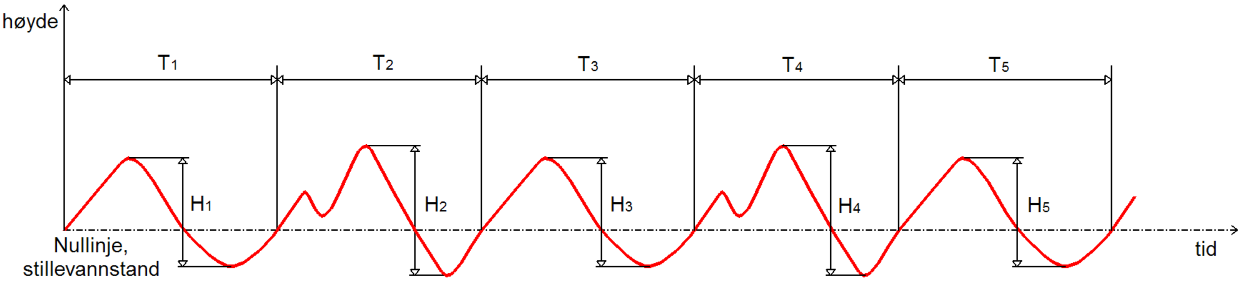
Figur 2.1.1-3 –Lineær bølgeteori oppsummering

For å finne ut hvilken vanndypkategori dataene for en analyse tilhører bli det gjort noen få beregninger. Som utgangspunkt er dispersjonsrelasjonen for dypt vann tatt i betraktning for å finne et uttrykk for bølgelengden, L:

$$\omega^2 = gk \Rightarrow L = \frac{g}{2\pi}T^2 \tag{2.2}$$

2.1.2 Uregelmessige bølger

En realistisk sjøtilstand følger ikke formen for regelmessige bølger, men har en form som beskrives som uregelmessig (ref. figur 2.1.2-1 – Illustrasjon av uregelmessige bølger)



Figur 2.1.2-1 – Illustrasjon av uregelmessige bølger og nulloppkryssning

$T_1, T_2, \ldots, T_5$ er individuelle perioder
$H_1, H_2, \ldots, H_5$ er individuelle høyder

For uregelmessige bølger er bølgeperioden (null-oppkryssingsperioden) definert som tiden det tar en gitt bølge å gå fra stillevannstand og oppover for så å krysse stillevannstand nedover til den igjen når opp til stillevannstanden. Bølgehøyden er definert som avstanden mellom høyeste og minste høyde (målt fra stillevannstand) i en bølgeperiode.

Uregelmessige bølger beregnes med utgangspunkt i bølgespektrum. Bølgespektrum er utviklet etter analyser av bølgemålinger over tid. De mest brukte bølgespektrum (i Nordsjøen, ref. /L-2/) er Pierson-Moskowitz (PM) og JONSWAP. Det sistnevnte benyttes for Nordsjøforhold.

Pierson-Moskowitz bølgespektrum er definert som

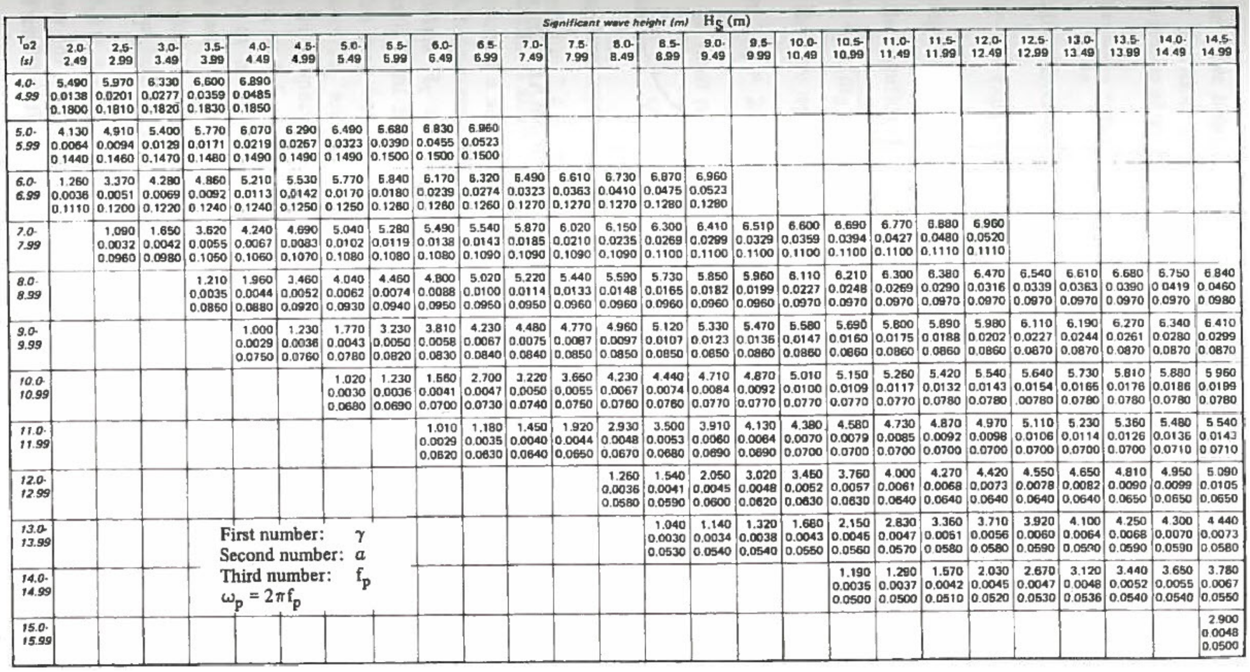
$$S(\omega) = H_s^2 \cdot T_z \cdot \frac{1}{8\pi^2} \cdot \left(\frac{\omega \cdot T_z}{2\pi}\right)^{-5} \cdot \exp\left[-\frac{1}{\pi} \cdot \left(\frac{\omega \cdot T_z}{2\pi}\right)^{-4}\right] \tag{2.3}$$

JONSWAP bølgespektrum er definert som

$$S(\omega) = a \cdot g^2 \cdot \omega^{-5} \cdot \exp\left[-\frac{5}{4} \cdot \left(\frac{\omega}{\omega_p}\right)^{-4}\right] \cdot \gamma^{\exp-\frac{\left(\frac{\omega}{\omega_p}-1\right)^2}{2\omega^2}} \tag{2.4}$$

H_s = signifikant bølgehøyde
T_z = gjennomsnittelig bølgeperiode
$S(\omega)$ = bølgespektrum (energispektrum på havoverflaten)
g = gravitasjonskonstanten
ω_p = høyeste vinkelfrekvens (av den maksimale verdien av $S(\omega)$)

Parametrene a, ω_p og γ er funksjoner av H_s og T_z som blir tatt ut fra tabeller (ref. figur 2.1.2-2 – Tabelloversikt over typisk H_s og T_z for JONSWAP bølgespektrum for Nordsjøforhold)

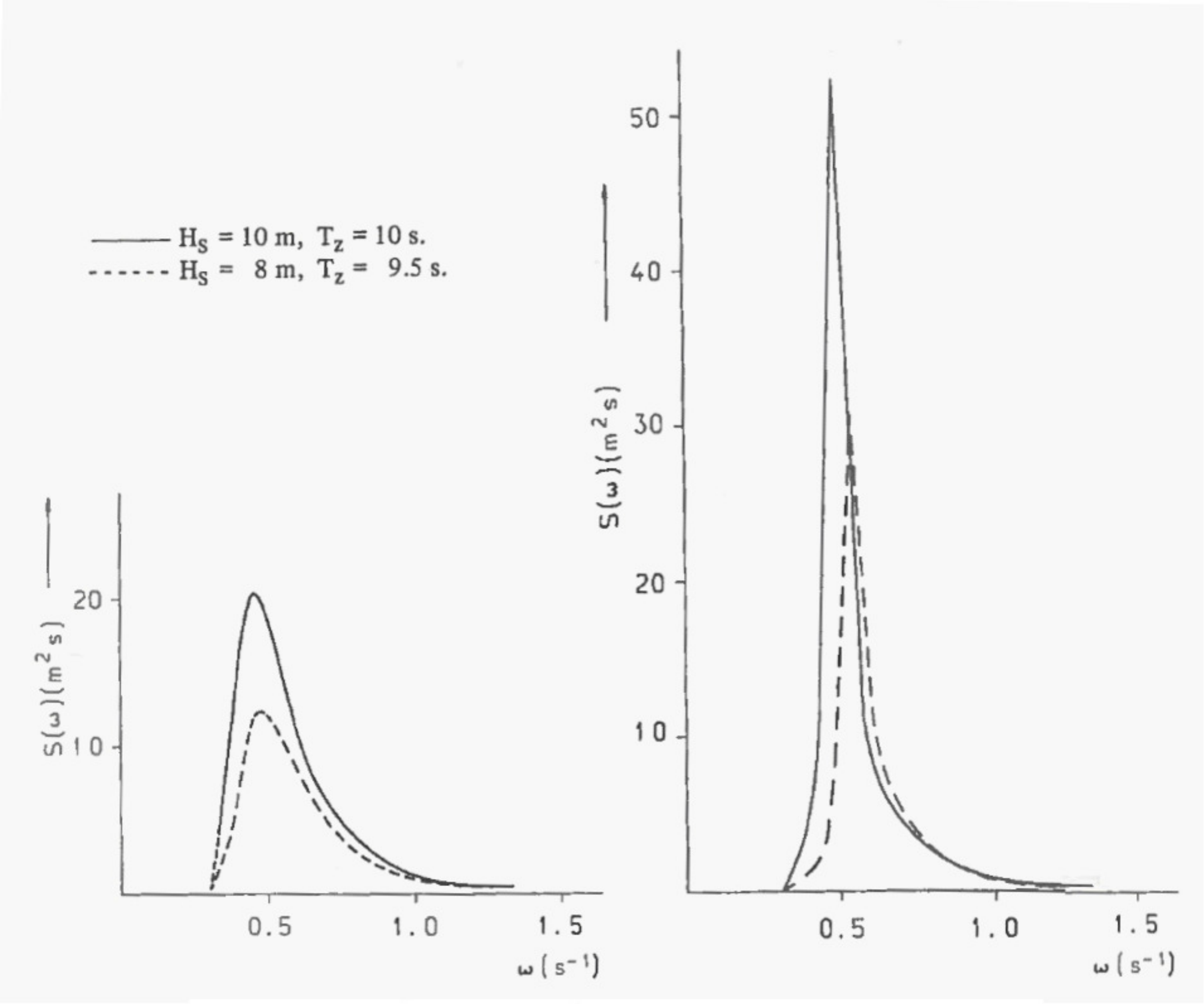


T_{02} (s)	Significant wave height (m) H_S (m)																									
	2.0-2.49	2.5-2.99	3.0-3.49	3.5-3.99	4.0-4.49	4.5-4.99	5.0-5.49	5.5-5.99	6.0-6.49	6.5-6.99	7.0-7.49	7.5-7.99	8.0-8.49	8.5-8.99	9.0-9.49	9.5-9.99	10.0-10.49	10.5-10.99	11.0-11.49	11.5-11.99	12.0-12.49	12.5-12.99	13.0-13.49	13.5-13.99	14.0-14.49	14.5-14.99
4.0-4.99	5.490 0.0138 0.1800	5.970 0.0201 0.1810	6.330 0.0277 0.1820	6.600 0.0359 0.1830	6.890 0.0485 0.1850																					
5.0-5.99	4.130 0.0064 0.1440	4.910 0.0094 0.1460	5.400 0.0129 0.1470	5.770 0.0171 0.1480	6.070 0.0219 0.1490	6.290 0.0267 0.1490	6.490 0.0323 0.1490	6.680 0.0390 0.1500	6.830 0.0455 0.1500	6.960 0.0523 0.1500																
6.0-6.99	1.260 0.0036 0.1110	3.370 0.0051 0.1200	4.280 0.0069 0.1220	4.860 0.0092 0.1240	5.210 0.0113 0.1240	5.530 0.0142 0.1250	5.770 0.0170 0.1250	5.840 0.0180 0.1280	6.170 0.0239 0.1280	6.320 0.0274 0.1260	6.490 0.0323 0.1270	6.610 0.0363 0.1270	6.730 0.0410 0.1270	6.870 0.0475 0.1280	6.960 0.0523 0.1280											
7.0-7.99		1.090 0.0032 0.0960	1.650 0.0042 0.0980	3.620 0.0055 0.1050	4.240 0.0067 0.1060	4.690 0.0083 0.1070	5.040 0.0102 0.1080	5.280 0.0119 0.1080	5.490 0.0138 0.1080	5.540 0.0143 0.1090	5.870 0.0185 0.1090	6.020 0.0210 0.1090	6.150 0.0235 0.1090	6.300 0.0269 0.1100	6.410 0.0299 0.1100	6.510 0.0329 0.1100	6.600 0.0359 0.1100	6.690 0.0394 0.1100	6.770 0.0427 0.1100	6.880 0.0480 0.1110	6.960 0.0520 0.1110					
8.0-8.99				1.210 0.0035 0.0850	1.960 0.0044 0.0880	3.460 0.0052 0.0920	4.040 0.0062 0.0930	4.460 0.0074 0.0940	4.800 0.0088 0.0950	5.020 0.0100 0.0950	5.220 0.0114 0.0950	5.440 0.0133 0.0960	5.590 0.0148 0.0960	5.730 0.0165 0.0960	5.850 0.0182 0.0960	5.960 0.0199 0.0960	6.110 0.0227 0.0970	6.210 0.0248 0.0970	6.300 0.0269 0.0970	6.380 0.0290 0.0970	6.470 0.0316 0.0970	6.540 0.0339 0.0970	6.610 0.0363 0.0970	6.680 0.0390 0.0970	6.750 0.0419 0.0970	6.840 0.0460 0.0980
9.0-9.99					1.000 0.0029 0.0750	1.230 0.0036 0.0760	1.770 0.0043 0.0780	3.230 0.0050 0.0820	3.810 0.0058 0.0830	4.230 0.0067 0.0840	4.480 0.0075 0.0840	4.770 0.0087 0.0850	4.960 0.0097 0.0850	5.120 0.0107 0.0850	5.330 0.0123 0.0850	5.470 0.0136 0.0860	5.580 0.0147 0.0860	5.690 0.0160 0.0860	5.800 0.0175 0.0860	5.890 0.0188 0.0860	5.980 0.0202 0.0860	6.110 0.0227 0.0870	6.190 0.0244 0.0870	6.270 0.0261 0.0870	6.340 0.0280 0.0870	6.410 0.0299 0.0870
10.0-10.99							1.020 0.0030 0.0680	1.230 0.0036 0.0690	1.560 0.0041 0.0700	2.700 0.0047 0.0730	3.220 0.0050 0.0740	3.650 0.0055 0.0750	4.230 0.0067 0.0760	4.440 0.0074 0.0760	4.710 0.0084 0.0770	4.870 0.0092 0.0770	5.010 0.0100 0.0770	5.150 0.0109 0.0770	5.260 0.0117 0.0770	5.420 0.0132 0.0780	5.540 0.0143 0.0780	5.640 0.0154 .00780	5.730 0.0165 0.0780	5.810 0.0176 0.0780	5.880 0.0186 0.0780	5.960 0.0199 0.0780
11.0-11.99									1.010 0.0029 0.0620	1.180 0.0035 0.0630	1.450 0.0040 0.0640	1.920 0.0044 0.0650	2.930 0.0048 0.0670	3.500 0.0053 0.0680	3.910 0.0060 0.0690	4.130 0.0064 0.0690	4.380 0.0070 0.0700	4.580 0.0079 0.0700	4.730 0.0085 0.0700	4.870 0.0092 0.0700	4.970 0.0098 0.0700	5.110 0.0106 0.0700	5.230 0.0114 0.0700	5.360 0.0126 0.0700	5.480 0.0136 0.0710	5.540 0.0143 0.0710
12.0-12.99													1.260 0.0036 0.0580	1.540 0.0041 0.0590	2.050 0.0045 0.0600	3.020 0.0048 0.0620	3.450 0.0052 0.0630	3.760 0.0057 0.0630	4.000 0.0061 0.0640	4.270 0.0068 0.0640	4.420 0.0073 0.0640	4.550 0.0078 0.0640	4.650 0.0082 0.0640	4.810 0.0090 0.0650	4.950 0.0099 0.0650	5.090 0.0105 0.0650
13.0-13.99														1.040 0.0030 0.0530	1.140 0.0034 0.0540	1.320 0.0038 0.0540	1.680 0.0043 0.0550	2.150 0.0046 0.0560	2.830 0.0047 0.0570	3.360 0.0051 0.0580	3.710 0.0056 0.0580	3.920 0.0060 0.0590	4.100 0.0064 0.0590	4.250 0.0068 0.0590	4.300 0.0070 0.0590	4.440 0.0073 0.0580
14.0-14.99																		1.190 0.0035 0.0500	1.290 0.0037 0.0500	1.570 0.0042 0.0510	2.030 0.0045 0.0520	2.670 0.0047 0.0530	3.120 0.0048 0.0536	3.440 0.0052 0.0540	3.650 0.0055 0.0540	3.780 0.0067 0.0550
15.0-15.99																										2.900 0.0048 0.0500

First number: γ
Second number: a
Third number: f_p
$\omega_p = 2\pi f_p$

Figur 2.1.2-2 – Tabelloversikt over typisk H_s og T_z for JONSWAP bølgespektrum for Nordsjøforhold
Ref. /L-11/

PM spektrum gjelder for en fult utviklet sjøtilstand, dvs. når bølgeveksten ikke blir områdebegrenset. JONSWAP spektrum blir brukt når bølgeveksten er områdebegrenset. Dette innebærer tilstander med ekstreme bølgeforhold (ref. figur 2.1.2-3 – PM og JONSWAP spektrum).



Pierson-Moskowitz bølgespektrum

JONSWAP bølgespektrum

Figur 2.1.2-3 – PM og JONSWAP bølgespektrum
Ref. /L-12/

2.1.3 Stokes bølgeteori

Lineær bølgeteori, Airy, er god nok til å beskrive bevegelse av vannpartikler produsert av dypvannsbølger og der steilheten $k \cdot a << 1$. $k \cdot a$ er et ubenevnt tall og er et mål for den maksimale helningen på overflaten. a = amplituden og k = bølgetallet;

$k = \dfrac{2\pi}{L}$ (som også vist under kap. 2.1.1 – Regelmessige bølger)

Skal man se på mer ekte bølger som ikke er sinusformede men består av mer komplekse periodiske funksjoner er det blitt utviklet andre teorier. Stokes (1847), ref./L-19/, klarte å finne relevante løsninger for periodiske bølger. Han så på steile bølger ($k \cdot a >> 1$) og fant ut at den steileste bølgen som kan forekomme er når a/L ≈ 1/14. Denne bølgetypen har flate bølgedaler og hjørneaktige bølgekammer med en hjørnevinkel på 120° (ref. /T-6/).

For mer informasjon angående Stokes bølgeteori henvises det til referanser /T-4/, /T-5/, /T-6/ og /T-7/.

2.1.4 Hydrodynamiske krefter

Vannpartiklene danner dynamiske krefter på legemer nedsenket i vann. Disse kreftene kan reknes ut etter Morisons formel (som er basert på eksperimenter) dersom følgende kriterier er oppfylt:

- Bølgene (sinus- eller cosinus-bølgene) har H/L ≤ 0,14. Det vil si at bølgene ikke bryter.
- Det gjelder for konstruksjonen at D/L < 0,2. Det vil si at diameteren på konstruksjonselementer nedsenket i vann må være mindre enn 0,2 ganger bølgelengden.
- Bevegelsen av konstruksjonen må være liten. A/D må være mindre eller lik 0,2. A = amplituden av forskyvningen.

Morisons formel lyder som følger (for bølge med kombinert drag-kraft og masse-kraft):

$$f(z,t) = \frac{\pi D^2}{4} \cdot \rho_w \cdot C_M \cdot \dot{u} + \frac{1}{2} \cdot \rho \cdot C_D \cdot D \cdot u \cdot |u| \qquad (2.5)$$

Eventuelt bidrag fra havstrømmene legges til i partikkelhastigheten (partikkelhastighet = partikkelhastighet bølge + partikkelhastighet havstrøm). Det kan merkes at for havstrømmer antas det oftest null akselerasjon.

D = diameter
ρ_w = densiteten til vann
C_M = massekoeffisienten
C_D = dragkoeffisienten
u = partikkelhastighet
$\dot{u}$ = partikkelakselerasjon

I Morisons formel har man to ledd, masse leddet, f_M, og drag leddet, f_D. Disse er definert som følger:

$$f_M = (\rho_w \cdot \frac{\pi D^2}{4}) \cdot C_M \cdot \dot{u} \qquad (2.6)$$

$$f_D = \frac{1}{2} \cdot \rho_w \cdot C_D \cdot D \cdot u \cdot |u| \tag{2.7}$$

Den totale kraften som virker på et konstruksjonselement er:

$$F(t) = \int_{-d}^{overflate} f(z,t)dz = \int_{-d}^{\xi} f_M(z,t)dz + \int_{-d}^{\xi} f_D(z,t)dz \tag{2.8}$$

Ved bruk av Morisons formel kreves en undersøkelse om bølgesituasjonen er masse dominerende, drag dominerende eller om begge forhold må tas hensyn til. Dette gjøres på følgende måte:

- For $D/L < 0{,}2$ og $0{,}5 \le D/H \le 1{,}0$ - Masse-leddet dominerer og total kraft på konstruksjonen blir:

$$F(t)_{maks} = \int_{-d}^{0} \frac{\pi D^2}{4} \cdot \rho_w \cdot C_M \cdot \dot{u} \; dz \tag{2.9}$$

- $D/L < 0{,}2$ og $D/H < 0{,}1$ - Drag-leddet dominerer og total kraft på konstruksjonen blir:

$$F(t)_{maks} = \int_{-d}^{\xi_0} \frac{\rho_w}{2} \cdot C_D \cdot D \cdot u \cdot |u| \, dz \tag{2.10}$$

- $D/L < 0{,}2$ og $D/H \in [0.1, 0.5]$ - Både masse- og drag-leddet må tas med i beregningene. Total kraft på konstruksjonen blir da som vist tidligere:

$$F(t) = \int_{-d}^{overflate} f(z,t)dz = \int_{-d}^{\xi} f_M(z,t)dz + \int_{-d}^{\xi} f_D(z,t)dz \tag{2.11}$$

Kreftene som virker vil også gi et moment i konstruksjonens bunn. Dette momentet er gitt ved følgende likning:

$$M(t) = \int_{-d}^{\xi(t)} [f_M(z,t) + f_D(z,t)] \cdot [d + z] \, dz \approx \frac{2}{3} \cdot d \cdot F(t) \tag{2.12}$$

Når det gjelder konstantene C_M og C_D blir de bestemt som vist under:

- C_M settes normalt til 2,0

- C_D bestemmes i sammenheng med Reynolds nummer, R_e, og ruheten (marin begroing endrer ruhet og diameter på elementet) til konstruksjonen. Partikkelhastigheten, som er en del av R_e, forandrer seg med havdybden og gir forskjellige C_D for forskjellige vanndyp.

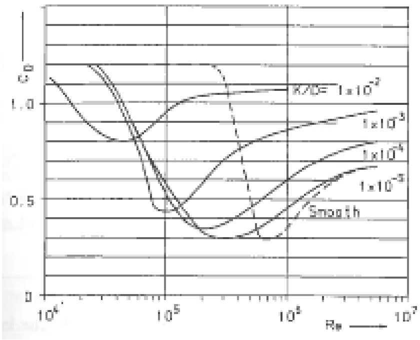
Reynolds nummer er definert som følger:

$$R_e = \frac{u \cdot D}{\nu} \tag{2.13}$$

hvor

u = partikkelhastigheten
D = diameter
ν = viskositeten til vann = $1.0 \cdot 10^{-6}$ m^2/s ved temperatur $20^{o}C$ (ref. /I-16/)

Når R_e er bestemt leses C_D av etter grafen som er vist på figur 2.1.4-1.



Figur 2.1.4-1 – Dragkoeffisient og Reynoldsnummer for forskjellige verdier av ruhet k/D
Ref. /L-1/

Dersom man velger å rekne med forskjellige verdier av C_D deles kraftintegralet opp og beregnes som sum av intervaller. Dette gir en mer nøyaktig utrekning av total kraft på konstruksjonen enn hva en konstant verdi av C_D gir. Men, i de fleste tilfeller kan man se at forskjellen på reknemåten med konstant C_D og variabel C_D gir små avvik i resultatene (dette fordi det største bidraget til krafta ligger i området rundt havoverflaten).

2.2 Vindteori

Vind er luftbevegelser som oppstår når det er trykkforskjell mellom to luftmasser i atmosfæren. Denne trykkforskjellen kommer enten av tyngdekraften eller solas oppvarming av jordoverflaten. Tyngdekraften bidrar til at kald luft, som er tyngre enn varm luft, trekkes mot bakken og skaper et høytrykk langs bakkenivå. Sola varmer opp luft ved jordoverflaten og skaper dermed et lavtrykk langs bakkenivå. Lavtrykket kommer av at den varme lufta langs bakkenivå stiger opp i atmosfæren. Disse trykkforskjellene vil danne luftbevegelser (bevegelser fra områder med høyt trykk til områder med lavt trykk) som inneholder mye lagret energi og det er denne energien som kan omformes til vindkraft.

Vindkraft på en konstruksjon beregnes etter formel (2.14)

$$F_{\text{totalt gjennomsnitt}} = C_A \cdot A \cdot \frac{1}{2}\rho_{air} \cdot [U(z)]^2 \tag{2.14}$$

C_A = formfaktor
A = utsatt areal
ρ_{air} = luft densiteten
$U(z)$ = gjennomsnittelig luftfart ved en gitt høyde z

Vind består av to komponenter, en gjennomsnittelig og en variabel komponent, som begge må tas hensyn til i beregninger. U(z) er den gjennomsnittelige komponenten mens u(z) er den variable komponenten. Formelen for vindkraft basert på både den gjennomsnittelige og den variable komponenten kan skrives som formel (2.13) (tilnærmet formel):

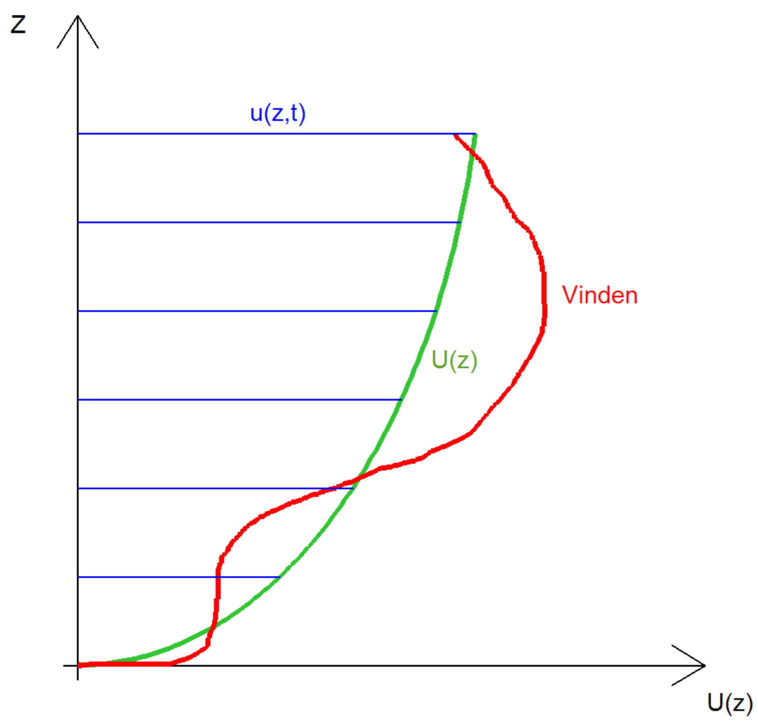
$$F_{\text{total horisontal}} = C_A \cdot A \cdot \frac{1}{2}\rho_{air} \cdot \left\{[U(z)]^2 + [2 \cdot U(z) \cdot u(z)]\right\} \tag{2.15}$$

Turbulens er også bidragsytende i utrekningen av vindkraft. Komponentene som angir turbulens er gitt i tre retninger; x- (horisontal), y- (normal på horisontal) og z (vertikal) retning. Notasjoner for de tre retningene er: u(z,t), v(z,t) og w(z,t). Turbulensintensiteten, I, reknes ut etter formlene (2.14) – (2.16):

$$I_{u(z)} = \frac{\sigma_{u(z)}}{U(z)} \quad \rightarrow \quad \text{horisontal} \tag{2.16}$$

$$I_{v(z)} = \frac{\sigma_{v(z)}}{U(z)} \quad \rightarrow \quad \text{normal på horisontal retning} \tag{2.17}$$

$$I_{w(z)} = \frac{\sigma_{w(z)}}{U(z)} \quad \rightarrow \quad \text{vertikal} \tag{2.18}$$



Figur 2.2-1 –Vindprofil

Turbulens oppstår ofte sammen med vindskjær. Vindskjær er forskjellen i vindstyrke og/eller vindretning mellom to punkter i atmosfæren. Vertikalt vindskjær er når forskjellen er med høyde og horisontalt vindskjær er når forskjellen oppstår mellom to horisontale punkt (ref. /I-15/).

Vindskjær beregnes etter følgende formel (2.19):

$$V(h) = V_{ref} \cdot \left(\frac{h}{h_{ref}}\right)^r \qquad /L\text{-}7/ \quad (2.19)$$

$V(h)$ = vindskjær
V_{ref} = vindhastighetsreferanse
h = høyde
h_{ref} = referansehøyde
r = eksponentfaktor

Valg av sannsynlighetsfordeling er nødvendig for beregninger og $\sigma_{u(z)}$, $\sigma_{v(z)}$ og $\sigma_{w(z)}$ er standardavvik basert på valgt sannsynlighetsfordeling.

$\sigma_{v(z)} \approx 0{,}75\ \sigma_{u(z)}$
$\sigma_{w(z)} \approx 0{,}50\ \sigma_{u(z)}$

$I_{u(z)}$ kan også reknes ut ved hjelp av likning (2.20):

$$I_{u(z)} = \frac{1}{\ln\left(\frac{z}{z_0}\right)} \tag{2.20}$$

z_0 = definerer ruhetslengde som er en områdebasert verdi

Formel (2.21) viser utrekning av total vindkraft inkludert bidrag fra turbulens

$$F_{\text{total horisontal}} = F_{\text{totalt gjennomsnitt}} \cdot \left(1 + 2\frac{u}{U}\right) \tag{2.21}$$

Standardavvik for kraften vil avhenge av turbulensen

$$\sigma_{\text{F total horisontal}} = F_{\text{totalt gjennomsnitt}} \cdot 2 \cdot I_{u(z)} \tag{2.22}$$

$$F_{\text{total horisontal}} = F_{\text{totalt gjennomsnitt}} + (k_p \cdot \sigma_{\text{F total horisontal}}) \tag{2.23}$$

k_p = ”peak” faktor og er avhengig av sannsynlighetsfordeling og sikkerhets nivå

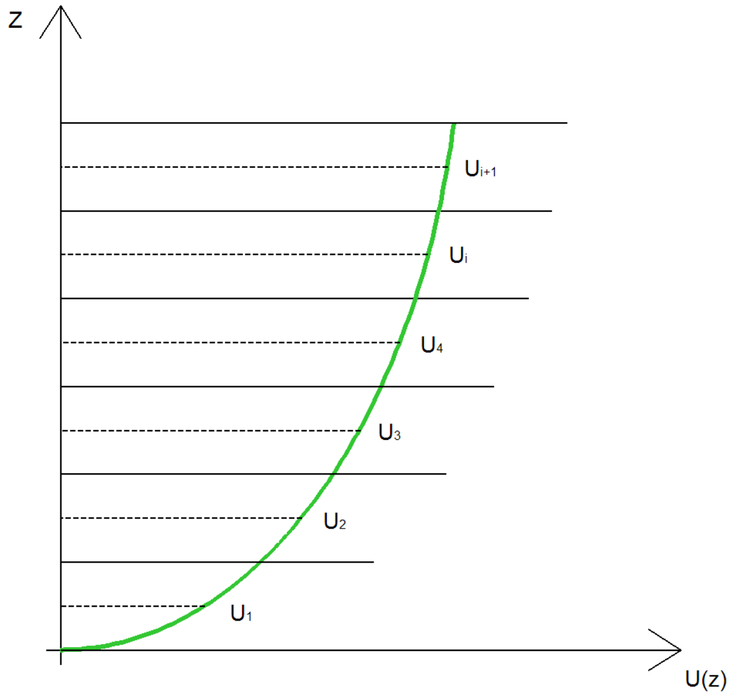
$$F_{\text{total horisontal}} = F_{\text{totalt gjennomsnitt}} \cdot \{1 + (k_p \cdot 2 \cdot I_{u(z)})\} \tag{2.24}$$

I kalkulasjonen hvor man deler konstruksjonen opp i intervall (ref. figur 2.2-2 - Intervallinndeling) må man regulere verdien for k_p slik at man unngår å summerer maksimal kraftverdi for hvert valgt konstruksjonintervall. k_p reguleres da etter formel (2.25):

$$k_p \rightarrow k_p \cdot \sqrt{k_b} \tag{2.25}$$

k_p representerer valg av sikkerhetsmargin (hvor mange standardavvik av turbulens man må vurdere)

k_b faktor som regulerer for mangelen på korrelasjon av turbulens over konstruksjonen



Figur 2.2-2 –Intervallinndeling

$$F_{\text{totalt gjennomsnitt}} = \sum_{i=1}^{N} \left\{ C_A \cdot A_i \cdot \frac{1}{2} \rho_{air} \cdot (U_i(z))^2 \right\} \tag{2.26}$$

A_i = bredde · høyde av intervallet

2.3 Mekanikk/Dynamikk

Utgangspunktet for mekanikk er at en konstruksjon utsatt for krefter betraktes som et massepunkt (dvs at all masse er konsentrert i ett punkt og legemet ikke har noe utstrekning). Dette er et idealisert utgangspunkt og dynamikk bygger videre på dette. Dynamikk kan beskrives som læren om krefter og kraftsystemer som endrer et legemes bevegelse. Ved hjelp av dynamikk kan man bestemme et legemets bevegelse (gitt at kreftene er kjent) eller man kan bestemme kreftene som virker på et legeme (gitt at dets bevegelse er kjent). De dynamiske effektene må tas hensyn til ved dimensjonering av konstruksjoner.

Dynamisk teori kan deles inn i to systemer:

1. SDOF – en-frihetsgrad system (”single degree of freedom system”). Dette systemet er det enkleste å bruke i beregninger. Formen omhandler bare en bevegelsesretning og en bevegelsesfrekvens og de fleste konstruksjoner kan beregnes etter denne modellen.
2. MDOF – flerfrihetsgrad system (”multi degree of freedom system”). Dette systemet omhandler flere frihetsgrader og er dermed mer krevende beregningsmessig. Et MDOF system kan transformeres til et sett med flere SDOF systemer. Det kalls da for et lineært system og er lettere å løste.

Utledning av bevegelseslikningen basert på SDOF system:

Tar utgangspunkt i en konstruksjon med masse m som blir belastet med en ekstern kraft, F_t. Videre er konstruksjonen belastet med F_I (treghetskraft), F_D (kraft pga. demping) og F_k (stivhetskraft)

I følge Newtons 2 lov kan F_I bestemmes som

$$F_I = -m\ddot{x} \tag{2.27}$$

Dempingskraft F_D (pga tap av energi) kan ved lineær demping bestemmes som

$$F_D = -c\dot{x} \tag{2.28}$$

Stivhetskraft F_k kan for lineære systemer bestemmes som

$$F_k = -kx \tag{2.29}$$

x = forflyttning
$\dot{x}$ = fart
$\ddot{x}$ = akselerasjon

Den totale kraftsummen som virker på konstruksjonen skal være lik null. Dette fører til at man får følgende likning:

$$F_I + F_D + F_k + F_t = 0 \qquad (2.30)$$

$$\rightarrow \qquad -m\ddot{x} - c\dot{x} - kx + F_t = 0 \qquad (2.31)$$

En omrokering av ovenstående likning fører til et uttrykk for bevegelseslikningen:

$$F(t) = m\ddot{x} + c\dot{x} + kx \qquad (2.32)$$

Bevegelseslikningen brukes videre i beregningen av de to situasjonstilfellene under:

1. Fri svingning med ingen ytre påkjenning
2. Dempet system med ingen ytre påkjenning

Bevegelseslikningen for **fri svingning** ($F(t) = 0$ og $c = 0$) kan skives som:

$$m\ddot{x} + kx = 0 \qquad (2.33)$$

Dette er en andregrads differensiallikning og når den løses med rammebetingelser blir resultatet som følger:

$$x(t) = A\sin\omega_0 t + B\cos\omega_0 t \qquad (2.34)$$

Integrasjonskonstantene A og B bestemmes ut fra startbetingelsene ved t = 0

$$\begin{aligned} &x(t) = 0 \\ &x(0) = A \\ &0 + B = 0 \rightarrow B = 0 \\ \\ &\dot{x}(t) = A\omega_0 \cos\omega_0 t \\ &\dot{x}(0) = A\omega_0 \cdot 1 = \dot{x}_0 \end{aligned} \qquad (2.35)$$

$$A = \frac{\dot{x}_0}{\omega_0} \qquad (2.36)$$

Ved bruk av foregående beregninger får man følgende bevegelseslikning:

$$x(t) = \frac{\dot{x}_0}{\omega_0}\sin\omega_0 t \qquad (2.37)$$

hvor bevegelsesfrekvensen $\omega_0 = \sqrt{\frac{k}{m}}$ (2.38)

Bevegelsesperioden, T_0, for et system kan beskrives som

$$T_0 = \frac{2\pi}{\omega_0} = 2\pi \cdot \sqrt{\frac{m}{k}} \tag{2.39}$$

Bevegelseslikningen for et **dempet system** med $F(t) = 0$ og $c \neq 0$ kan skives som:

$$m\ddot{x} + c\dot{x} + kx = 0 \tag{2.40}$$

For å finne en løsning av denne likningen antar man følgende uttrykk for x, $\dot{x}$ og $\ddot{x}$:

$$\begin{aligned} x &= Ce^{st} \\ \dot{x} &= Cse^{st} \\ \ddot{x} &= Cs^2e^{st} \end{aligned} \tag{2.41}$$

Dette gir den karakteristiske likningen for s:

$$s^2 = \frac{c}{m}s + \omega_0^2 = 0 \tag{2.42}$$

Løsningen for likningen over er gitt som:

$$s_{1,2} = -\left(\frac{c}{2m}\right) \pm \sqrt{\left(\frac{c}{2m}\right)^2 - \omega_0^2} \tag{2.43}$$

$$x(t) = C_1e^{s_1t} + C_2e^{s_2t} \tag{2.44}$$

Demping vil dra ut energi fra systemet så effekten av demping er en avtagende bevegelse.

Et dempet system deles inn i 3 kategorier

1. Høy demping $\left(\frac{c}{2m}\right) > \omega_0$ (2.45)
2. Kritisk demping $\left(\frac{c}{2m}\right) = \omega_0$ (2.46)
3. Lav demping $\left(\frac{c}{2m}\right) < \omega_0$ (2.47)

Høy demping

$$s_1 = -\left(\frac{c}{2m}\right) + \sqrt{\left(\frac{c}{2m}\right)^2 - \omega_0^2} < 0 \tag{2.48}$$

$$s_2 = -\left(\frac{c}{2m}\right) - \sqrt{\left(\frac{c}{2m}\right)^2 - \omega_0^2} < 0 \tag{2.49}$$

Siden s_1 og s_2 er negative vil forflyttningen avta med tiden.

$x(t) = C_1 e^{s_1 t} + C_2 e^{s_2 t}$ er bevegelseslikningen for høy demping (2.50)

Kritisk demping

$$s_1 = s_2 = s \tag{2.51}$$

$$s = -\frac{c}{2m} \tag{2.52}$$

Dermed blir bevegelseslikningen

$$x(t) = C_1 e^{s_1 t} + C_2 t e^{s_2 t} \tag{2.53}$$

Da $\left(\frac{c}{2m}\right) = \omega_0$ fører dette til at $c\ = 2m\omega_0 = C_c$ = ”kritisk demping” (2.54)

Normalt ser man på relativ demping som kan beskrives som

$$\lambda = \frac{faktisk\ demping}{kritisk\ demping} = \frac{C_{faktisk}}{C_c} \tag{2.55}$$

Lav demping

Her får man imaginære røtter fra $s_{1,2} = -\left(\frac{c}{2m}\right) \pm \sqrt{\left(\frac{c}{2m}\right)^2 - \omega_0^2}$

Dette gjør at utrykket blir

$$s_{1,2} = -\left(\frac{c}{2m}\right) \pm i\sqrt{-\left(\frac{c}{2m}\right)^2 + \omega_0^2} \tag{2.56}$$

Bevegelseslikningen blir da:

$$x(t) = e^{-\left(\frac{c}{2m}\right)t}\left\{A\sin\sqrt{-\left(\frac{c}{2m}\right)^2 + \omega_0^2 t} + B\cos\sqrt{-\left(\frac{c}{2m}\right)^2 + \omega_0^2 t}\right\} \tag{2.57}$$

Ny frekvens pga svingninger blir $\omega_0' = \sqrt{-\left(\frac{c}{2m}\right)^2 + \omega_0^2}$ (2.58)

A og B bestemmes ut fra startbetingelsene ved t = 0 og frekvensendringen kan skrives som

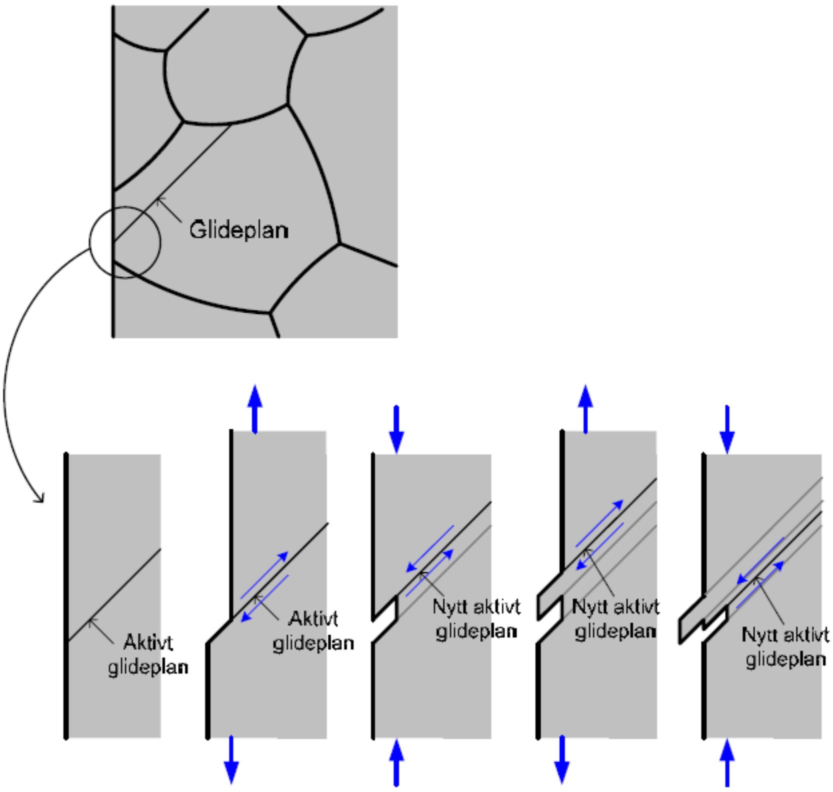
$$\omega_0' = \omega_0\sqrt{1-\lambda^2} \quad (2.59)$$

hvor $\lambda = \frac{c}{2m\omega_0}$ (2.60)

2.4 Utmatting

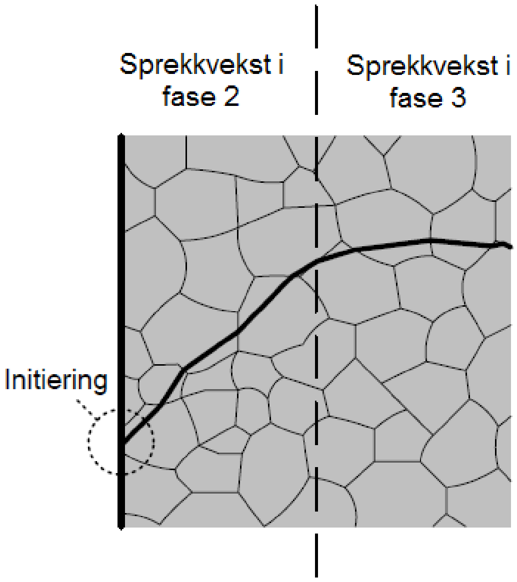
Utmatting oppstår i en konstruksjon som følge av gjentatte lastsvingninger. Lastsvingningene medfører spenninger i konstruksjonen som ofte er så lave at de ikke gir synlige deformasjoner, men på et mikroskopisk nivå kan man se at utmatting skyldes gjentatt plastisk deformasjon. Selve prosessen kan deles inn i tre faser (ref. /L-3/). Tidsperspektivet for hver fase er avhengig av spenningsforhold og materialegenskaper til konstruksjonskomponentene.

1. Første fase, initieringen, omhandler dannelsen av mikroskopiske tøyninger langs glideplanet i et metalls korn. Disse tøyningene skaper defekter i metallets overflate som igjen er utgangspunktet for en fremtidig utmattingssprekk, se figur 2.4-1



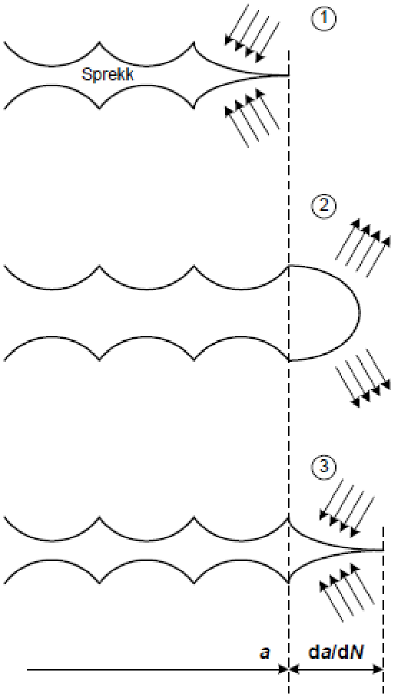
Figur 2.4-1 –Illustrasjon av initiering av utmattingssprekk
Ref. /I-6/

2. Den andre fasen, fase 2, omhandler ekspansjon av utmattingssprekken, det vil si øking av sprekkens størrelse. Sprekken vil vokse langs glideplanet med høy skjærspenning, typisk 45° på overflaten, se figur 2.4-2. De belastninger sprekken er utsatt for vil enten bidra til å åpne eller, i noen tilfeller, lukke sprekken. Sprekken vil få et bruddmønster som likner på havbølger eller årringer.



Figur 2.4-2 –Illustrasjon av sprekkvekst fase 2 og fase 3
Ref. /I-6/

3. Siste fase, fase 3, i sprekkdannelsen er når sprekken når sin kritiske størrelse. Vekstretningen dreier nå til 90° på den største hovedspenningen. Konstruksjonen vil da oppleve et avrivningsbrudd (restbrudd). Dette er et hurtig brudd og materialet vil oppføre seg sprøtt selv om det ellers har en seig oppførsel. Figur 2.4-3 illustrerer sprekkveksten i denne fasen. For en oppsummering, se tabell 2.4-1.



Figur 2.4-3 – Detaljert illustrasjon av sprekkvekst i fase 3
Ref. /I-6/

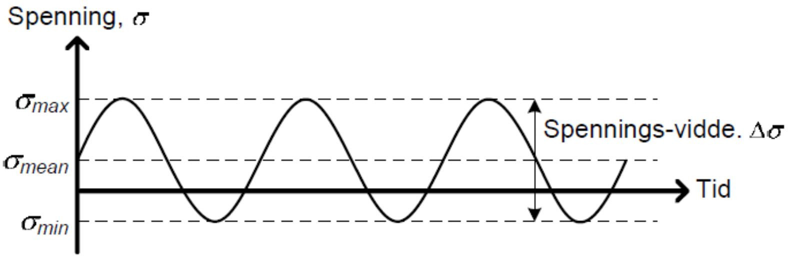
Tabell 2.4-1 - beskrivelse av punktene i figur 2.4-3.

Punkt 1	**Punkt 2**	**Punkt 3**
Sprekken er lukket med skarp sprekkspiss ved minimum belastning	Sprekken er åpen med et spenningsfelt ved sprekksissen i strekk (maksimal belastning). Spenningsfeltet medfører stor plastisk deformasjon ved sprekkspissen. Avrundingsformen impliserer at sprekken vokser et inkrement innover i materialet.	Sprekken lukkes igjen og et spenningsfelt i trykk oppstår ved sprekkens spissende (minimal belastning). Dette trykket får avrundingen i punkt to til å "knekke" innover. Dermed er sprekkspissen igjen blitt skarp og tilveksten beholdt.

Utmattingslevetiden beregnes ved hjelp av SN-kurver (bestemt etter testing av sveisedetaljer) kombinert med Palmgren-Miners summering (lineær skadehypotese) eller ved bruddmekanikk (Paris lov). Fortrinnsvis bør utmattelsesanalyser være basert på SN-kurver og Palmgren-Miners summeringen. Når det er forsvarlig kan analysene alternativt baseres på bruddmekanikk. Dersom estimert levetid, basert på SN-kurver, er for kort for en komponent (og svikt kan føre til alvorlige konsekvenser) bør en mer nøyaktig analyse av større deler av konstruksjonen utføres; eventuelt en bruddmekanikk analyse. For beregninger etter bruddmekanikk må tilstrekkelighetene av disse veldokumenteres, ref. /S-8/ og /L-21/.

2.4.1 S-N kurver

S-N kurver representerer statistiske data basert på tester. Kurvene angir forventet levetid for et material med spenningsvidde *S* som blir utsatt for N antall spenningsvekslinger. En logaritmisk skala blir bruk for å indikere N. Spenningsvidden, ref. figur 2.4.1-1, er avstanden mellom største og minste spenning målt i MPa. I teorien er en konstruksjon sikker mot utmattingsbrudd når tallparet for spenning og antall vekslinger faller under S-N kurven.



Figur 2.4.1-1 –Illustrasjon av spenningsvidde $\Delta\sigma$
Ref. /I-6/

$\Delta\sigma = \sigma_{\max} - \sigma_{\min}$

$\sigma_{\max}$ = største spenning

σ_{mean} = middelspenning

$\sigma_{\min}$ = minste spenning

Middelspenningen kan også uttrykkes gjennom spenningsforholdet R: $R = \dfrac{\sigma_{\min}}{\sigma_{\max}}$

2.4.2 Begrensinger ved S-N kurver

Prøvetallene som er grunnlaget for utforming av SN-kurvene kan inneholde stor spredning. Dette gjør at kurvene ikke er 100% nøyaktige for en virkelig konstruksjon. Motstanden mot utmatting kan også variere fra sted til sted i en konstruksjon noe som fører til at kanskje ikke de mest konservative verdiene fanges opp under en test. Ved bruk av SN-kurver i dimensjonering må man være klar over og ta høyde for denne unøyaktigheten.

2.4.3 Palmgren-Miners summering

Palmgren-Miners summering blir brukt til beregning av utmatting for konstruksjoner som er belastet med mange spenningsvekslinger. Man antar at skaden ved utmatting ved en gitt spenning akkumuleres lineært i forhold til antall spenningsvekslinger. Prinsippet går ut på at man rekner ut skade per spenningsveksling (delskade) og summerer disse for å få samlet skade for konstruksjonen. Hvis N_1 perioder gir brudd ved spenningen S_1, vil n_1 perioder ved samme spenning bruke opp n_1/N_1 del av utmattingslivet til konstruksjonen. Dersom summen av brøkene, $\Sigma n_i/N_i$, for alle spenninger i_1, i_2 osv. er mindre enn 1 er konstruksjonen sikker mot utmatting. Formel (2.61) angir Palmgren-Miners summering.

$$\sum_{i=1}^{p} \frac{n_i}{N_i} = D \qquad \text{/L-3/} \quad (2.61)$$

$p =$ antall spenningsvekslinger

$i =$ en gitt spenningsveksling

$n_i =$ antall sykluser per spenningsveksling

$N_i =$ er antall sykluser før sammenbrudd

$D =$ konstant normalt satt til 1,0

Sikkerhetsfaktorer blir brukt ved dimensjonering. Disse kan enten bli gitt som en tillat delskade eller som en faktor, DFF (”design fatigue factor”).

2.4.4 Utmatting beregnet etter bruddmekanikk, Paris lov

Bruddmekanikk kan bli brukt til berekning av utmattingslevetid som et supplement til SN-kurver. Denne metoden er anbefalt for bruk i utvikling av akseptabel defekter, evaluering av akseptkriterier for fabrikasjon og for planlegging av inspeksjon under drift.

Hensikten er å kunne dokumentere at sprekken, som kan oppstå, i løpet av levetiden ikke vil bli så stor at den korresponderer til ustabilt brudd. Beregninger utføres slik at pålitelighetene til konstruksjonen ikke er mindre enn ved bruk av SN-kurver. For å få dette til følges forskjellige metoder som er listet i ref. /S-8/ kapittel 6. Eksempelvis kan det være aktuelt å beregne levetiden til en konstruksjon etter at den er installert og driftsatt. Dette fordi det etter en viss operasjonstid kan oppdages, ved de første inspeksjonene, uønskede sprekker som kan ha innvirkning på konstruksjonens totale levetid dersom de ved en senere anledning kan forårsake utmattingsbrudd. Ved bruk av bruddmekanikk får man normalt sett en kortere levetid enn ved bruk av SN-kurver da bruddmekanikk ikke tar hensyn til oppstarten av sprekken.

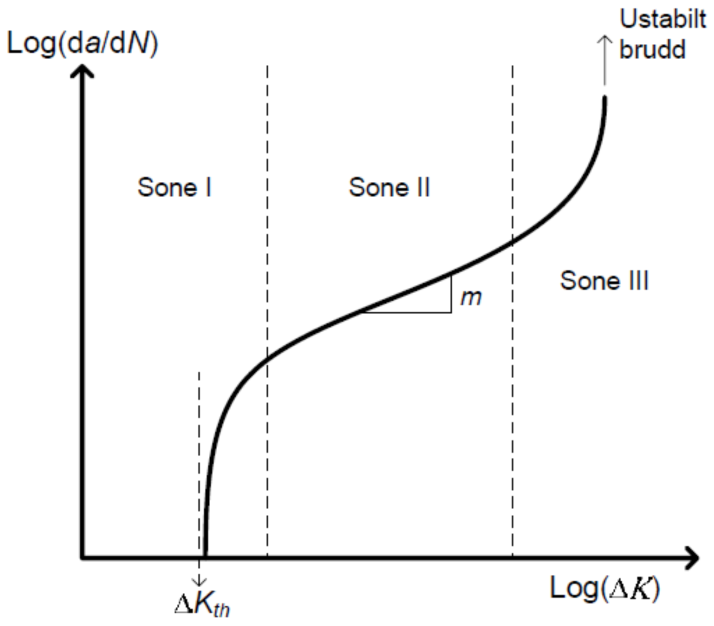
For å kunne beregne utmatting ette bruddmekanikk brukes formel (2.62). Paris lov:

$$\frac{da}{dN} = C(\Delta K)^m \qquad \text{/L-5/} \quad (2.62)$$

$a =$ sprekklengde
$N =$ antall sykluser
$C =$ konstant for et gitt testresultat
$m =$ konstant (stigningsparameter) fra testresultat
$K =$ spenningskonsentrasjonsfaktor
$K = Y\sigma\sqrt{\pi a}$ hvor Y er en dimensjonssløs konstant som avhenger av geometri og lastbilde

Paris lov er formulert ut fra sprekkvekstdiagrammet, sone II, i figur 2.4.4-1 som viser hvordan sprekkveksthastigheten avhenger av ΔK.

$$\Delta K = Y\Delta\sigma\sqrt{\pi a}$$



Figur 2.4.4-1 – Sprekkvekstdiagram
Ref. /I-6/

ΔK_{th} = terskelverdien. For ΔK verdier under denne verdien får vi ingen sprekkvekst.

2.4.5 Fremgangsmåte for beregning av utmattelseslevetiden for en konstruksjon

I beregning av utmattingslevetiden til en konstruksjon er man interessert i den langsiktige spenningsfordelingen. Denne fordelingen kan finnes ved tre forskjellige metoder:

1. Deterministisk analyse
2. Stokastisk analyse
3. Forenklet analyse

En deterministisk analyse er basert på en relativ enkel beskrivelse av miljødata og belastninger. Ikke-lineære spenningsrelasjoner er tatt hensyn til og beregningsprosedyren er enkel å følge. Denne type analyse blir brukt med forsiktighet ved dynamiske effekter da disse effektene er vanskelige å forklare på en forsvarlig måte.

En stokastisk analyse krever en mer detaljert beskrivelse av miljødata og laster. Ikke-lineære effekter blir ikke tatt med like lett som i en deterministisk analyse. En simulering over tid kan utføres men dette medfører høye kostnader for komplekse konstruksjoner. I en stokastisk analyse blir dynamiske effekter bedre tatt vare på enn i en deterministisk analyse.
I en tidlig design fase kan det være lurt å bruke en forenklet analyse. Denne analysen er basert på enkle beskrivelser av både miljødata og tilhørende respons.

2.4.6 Faktorer som påvirker utmattingslevetiden

Det finnes flere faktorer som påvirker utmattingslevetiden for en konstruksjon. I praksis vil det ikke være mulig å ta hensyn til alle faktorene under dimensjonering og vanligvis tas det bare hensyn til de faktorer som vurderes til å ha betydelig innvirkning på konstruksjonen.

Noen av de viktigste faktorene er gitt i tabell 2.4.6-1:

Tabell 2.4.6-1 - faktorer som påvirker utmattingslevetiden
Innhold i tabellen er hentet fra ref. /I-3/.

Faktorer	**Utdyping**
Spenninger	Selve spenningsfordelingen over tverrsnittet, restspenninger og middelspenninger påvirker utviklingen av utmattingsbrudd
Lastretning	Utmattingsstyrken for ikke isotropiske materialer avhenger av lastretningen og retningen av de viktigste spenningene
Geometri	Hakk og variasjon i en del av tverrsnittet fører til spenningskonsentrasjoner hvor utmattingsbrudd kan inntre
Materialtype	Utmattingslevetid, samt oppførsel under dynamiske lastpåkjenning, varierer mye for ulike materialer
Materialkvalitet	Ruhet i en overflate kan forårsake de mikroskopiske spenningskonsentrasjonene som reduserer utmattingsstyrken
Interne defekter	Porøsitet og inneslutninger; størrelse og fordeling er viktig
Materialets kornstørrelse	Liten kornstørrelse fører til lengre utmattelseslevetid (da sett bort fra eventuelle overflatedefekter som skraper og liknende)
Korrosjon	Oppstår i aggressive miljøer (miljøer som inneholder CO_2 og H_2S) og det er viktig å ta stilling til korrosjonsutmatting
Temperatur	Ekstremt høye eller lave temperaturer kan redusere utmattingsstyrken. Høye temperaturer håndteres ofte under begrepet kryputmatting og beregnes som et tillegg til Palmgren-Miners summen. Lave temperaturer gir redusert seighet i de fleste stålmaterialer og materialet blir sprøtt. (Seigheten til metaller er et uttrykk for evnen materialet har til å bli deformert uten å bryte sammen). I flere materialer endres bruddegenskapene seg fra å være duktile til sprø med en relativt liten temperatursenkning
Belastningsrekkefølge	Små spenningsvariasjoner fulgt av store spenningsvariasjoner gir hurtigere utmattingsbrudd enn store spenningsvariasjoner etterfulgt av små
Lastfrekvensen	Dersom en gjør tester i et korrosivt miljø med høy frekvens får en høyere utmattingsstyrke enn for tester med langsomme frekvenser i samme miljø. Dette fordi det ved lavere frekvens er mer tid for en eventuell korrosjon til å utvikle seg og materialegenskapene blir svakere og dermed utmattingsstyrken mindre

2.4.7 Usikkerhetsfaktorer forbundet med utmattingsanalyse

Det er mange forskjellige usikkerheter knyttet til antagelsen av utmattingslevetiden for offshore konstruksjoner. Disse usikkerhetene kan assosieres med følgende parametere /L-6/:

1. Lastberegninger inkludert:
    - Bølgehøyde
    - Bølgeperiode
    - Bølgefordeling
    - Bølge teorier
    - Hydrodynamiske koeffisienter
    - Marin begroing
2. Spenningsberegninger inkludert:
    - Konstruksjon analyser
    - Beregning av spenningskonsentrasjonsfaktorer
3. SN-data inkludert:
    - Naturlig spredning
    - Overflatebeskyttelse
    - Valg av S-N kurve
    - Definisjonen av svikt
    - Størrelses effekter
4. Fabrikasjonstoleranser
5. Kumulativ skade hypotese

3. Bruk av teknologien

Følgende kapittel omhandler prosessen for konseptvalg, utvikling og prosjektering av fundamenter, bunnfaste fundamenttyper, flytende fundamenter, installasjonsmetode for bunnfaste fundamenter og kostnadsperspektiver.

3.1 Prosessen for konseptvalg

Generelt for et prosjekt kan konseptvalget sees på som en trinnvis prosess: Ref. /F-3/

1. Etablere kriterier
2. Etablere mål og strategier
3. Identifisere og definere konsept som tilfredstiller valgte strategier
4. Endelig konseptvalg basert på de forhåndsgodkjente kriterier

Videre følger en beskrivelse av hva de forskjellige punktene kan omhandle for et offshore vindturbinprosjekt. Punkt en, etablering av kriterier, kan for eksempel inneholde etablering av risikoprofil, fremdriftsplan, kostnader/avkastning ved en antatt produksjon og HMS for fabrikasjon, installasjon, drift og vedlikehold. Punkt to, som viser til definering av mål og strategier, kan innebære krav til levetid, om det skal brukes ny eller kjent teknologi og hvordan den genererte strømmen skal transporters til land. Punkt tre, identifisere og definere konsept, kan omhandle valg av vindturbintype, fundament og produksjonsutstyr som tilfredstiller de valgte kriterier gitt i punkt to. Lokasjon for onshore fasiliteter, hvor mange installasjoner og eventuelt hvilke undervannsfasiliteter som trengs, er også faktorer som må tas hensyn til under dette punktet. I punkt fire tas beslutningen for hvilket konsept som skal velges. Dersom det foreligger flere konsept blir det nødvendig med vurderinger for å finne den mest lønnsomme løsningen. De forskjellige konsepter må vurderes ut fra kostnader og avkastning.

3.2 Utvikling og prosjektering av fundamenter

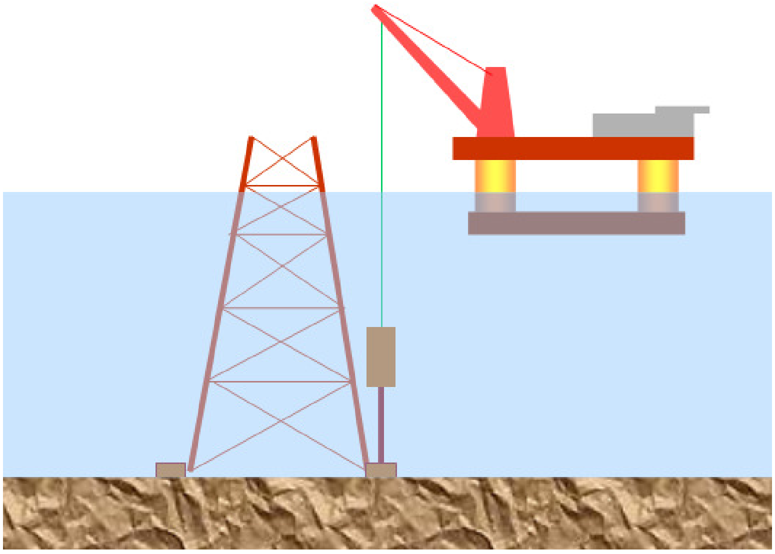
Utvikling, design og installasjon av offshore vindturbinfundamenter utgjør en stor del av det totale prosjektet. Når et konsept skal utvikles må det, som nevnt i kapittel 2.5.1, tas hensyn til levetid, fabrikasjon, installasjon og kostnader. En pålitelighets- og sikkerhetsvurdering må også utføres. Fundamenterkostnadene er knyttet til produksjon, installasjon og drift. Man står ovenfor en stor utfordring for å kunne utvikle det mest kostnadseffektive design som oppfyller alle konstruksjons- og installasjonskrav. Store vanndyp gjør utfordringene knyttet til design mer komplisert. Andre faktorer som spiller inn på valg av fundamentkonsept er dynamiske belastninger og korrosjon. I tillegg må designet utformes så vedlikeholdsarbeid blir mest mulig effektivt. En plan for hvordan installasjonen skal fjernes etter endt levetid bør også ligge til grunn for utformingen.

Generelt skal et offshore design utføres slik at det tilfredstiller krav til sikker og effektiv operasjon og vedlikehold. All design skal gjøres i samsvar med de siste standardrevisjoner og regionale bestemmelser. I prosessen ved utforming av design og konsept må man stole på kjent teknologi samt eventuelt tørre å ta risikoen ved utviklingen av ny dersom dette er bestemt under prosessen for konseptvalg.

Når det gjelder selve designfaktorene er materialvalg en viktig faktor. Materialegenskapene blir evaluert i samsvar med de belastninger konstruksjonen blir utsatt for i tillegg til risiko og konsekvens ved en eventuell konstruksjonssvikt. Materialvalg involverer materialegenskaper for operasjonsforhold, fabrikasjons- og konstruksjonsforhold

Geotekniske forhold må tas hensyn til når valg av innfestningsmetode skal bestemmes. Grunnforholdene kan sette begrensninger for utforming av innfestningsmetode og kan føre til økte kostnader dersom det viser seg å være vanskelige grunnforhold. Typiske problemområder kan være mudderflom, veldig myk eller kalkholdig jordsmonn, soner med aktive jordskjelv, ujevn bunn, sanddyner og fast fjell.

Hvordan konstruksjonen skal festes til havbunnen må også vurderes opp i mot de totale kostnader og totalt design. Dagens mest brukte metode for innfestning av bunnfaste fundamenter til havbunnen er bruk av pæler og ankerpunkter. Dette er en metode som er blitt mye brukt i olje- og gassnæringen for jacketplattformer (fagverksplattformer i stål), figur 3.2-1

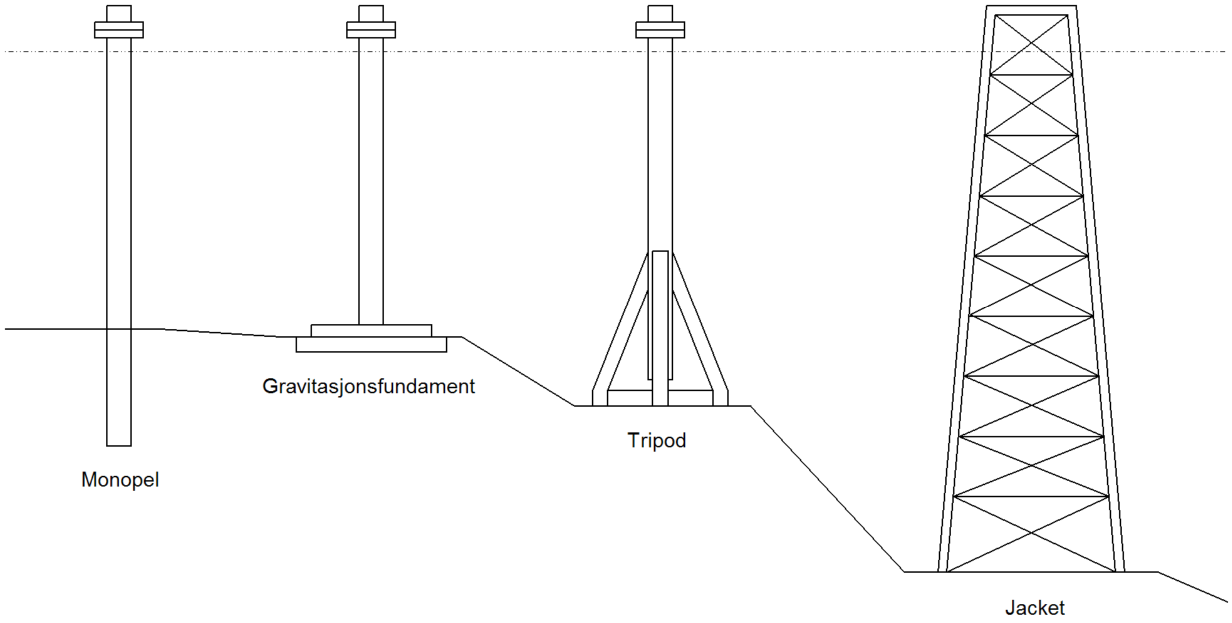


Figur 3.2-1 – Illustrasjon, pæling av jacket
Ref. /F-3/

3.3 Bunnfaste fundamenttyper

Det er utviklet flere konsepter for vindturbinfundamentering offshore. De mest brukte bunnfaste konseptene er oppsummert under, se figur 3.3-1

- Monopel
- Gravitasjonsfundament
- Tripod
- Jacket



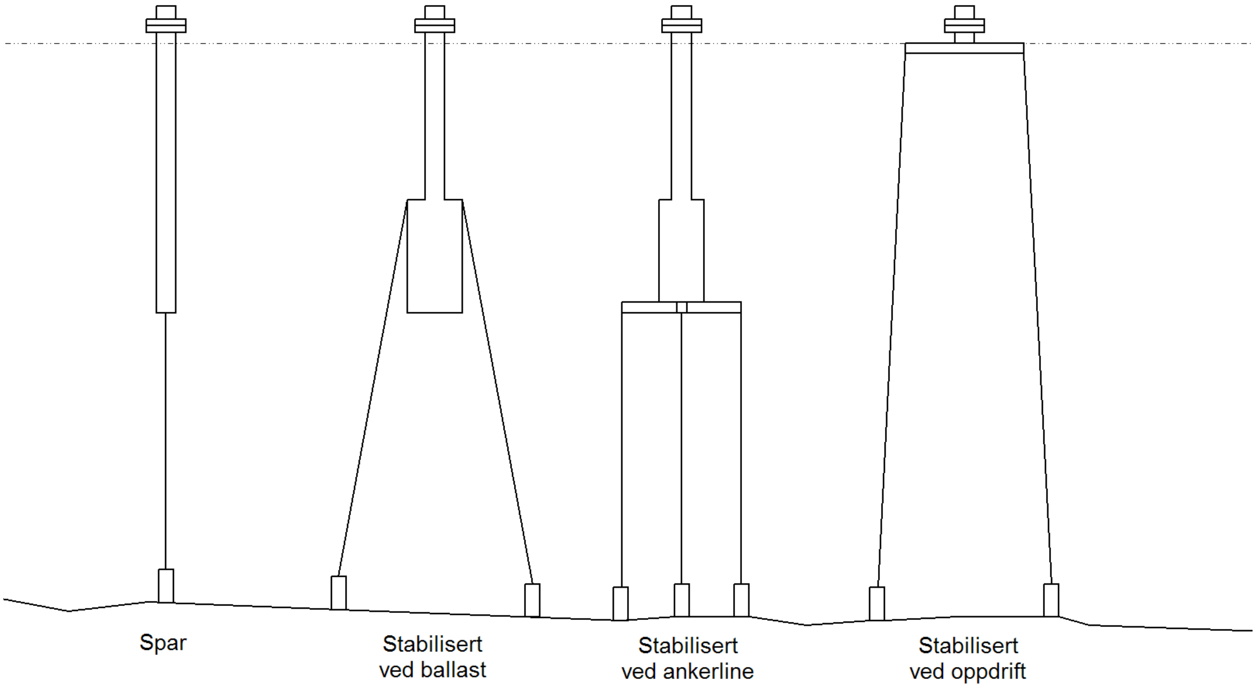
Figur 3.3-1 – Illustrasjon av bunnfaste fundamenttyper

Monopeler er i dag det mest brukte fundamentet. Det karakteriseres ved en stålpæle som bankes eller borres ned i havbunnen. Gravitasjonsfundament var den første type fundament som ble brukt i offshore vindkraft. Fundamentet består av enten betong eller stål. Det plasseres rett på havbunnen og krever at selve turbinen har vekt nok til å holde fundamentet på plass. Ballast kan være nødvendig. Tripod er konstruert som en monopel med tre legger stikkende ut fra selve monopelen. Leggene er pælet, typisk 10-20 meter ned i havbunnen. Jacket er en stålgitterkonstruksjon som ved hjelp av pæler festes til havbunnen. Denne type konstruksjon er bygget på samme prinsipp som jacket konstruksjoner i olje- og gassnæringen.

Monopeler og gravitasjonsfundamenter kan brukes på vanndyp opp til 30 meter. Skal man utføre installasjon på større vanndyp (opp til 60 – 100 meter) må man bruke konstruksjoner utformet som tripod eller jacket. Dette fordi monopeler og gravitasjonsfundamenter på vanndyp over 30 meter, og med økende turbinstørrelse, kan få store utfordringer med tanke på resonans mellom egenperiode og bølgeperiode. Jacket er den konstruksjonstypen det er knyttet mest kjent teknologi til i forbindelse med olje- og gassvirksomheten. Den er allerede utprøvd mange ganger og er smalere og lettere enn en tripod (den er utformet med slankere elementer). Dette gjør selve fabrikasjonen av en jacket billig, men det er viktig å se på total kostnadene for et prosjekt og ikke bare sammenlikne delkostnader. Tripoden har, sammenliknet med jacketen, færre knutepunkt. Knutepunkter blir sett på som svake punkter i en konstruksjon og en tripod har dermed færre svake punkter enn en jacket. Tripodkonstruksjonene er mer robust, lettere å inspisere og lettere å beskyttet mot korrosjon enn jacketkonstruksjonene. I tillegg er det mindre kostnader og usikkerheter knyttet til installasjon av tripoder da det er et ben mindre å pæle til havbunnen. Det skal bemerkes at installasjonskostnadene er vesentlige for offshore vindkraft.

3.4 Flytende fundamenter

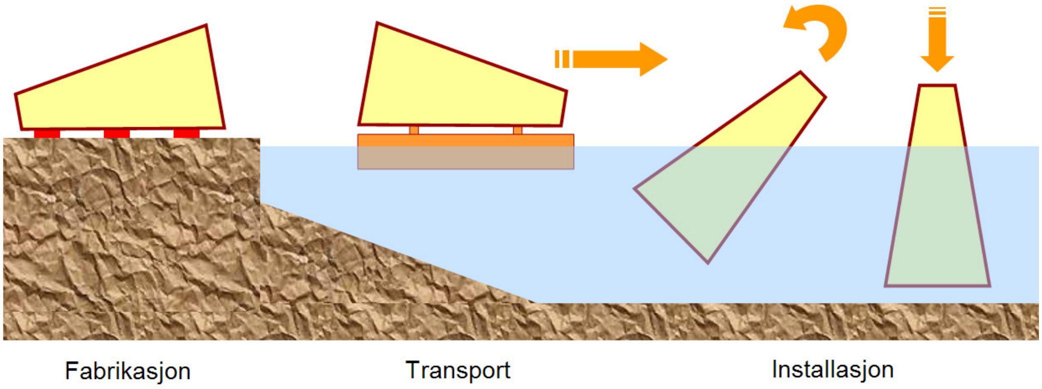
På dypt vann kan det være problematisk å få installert bunnfaste fundamenter og det blir nødvendig med bruk av flytende fundamenter. Teknologien for flytende vindturbinfundamenter er mindre brukt enn teknologien for bunnfaste fundamenter. Mange av de foreslåtte, og noen av de brukte, konseptene for flytende fundamenter er også som de bunnfaste basert på design fra olje- og gassindustrien. Fordeler med installasjon på dypt vann er at vindforekomstene noen steder er sterkere enn de er på grunt vann i tillegg til at den eventuelle visuelle sjenansen reduseres. Ulempen ved denne type installasjoner er kostnadene som vil være betydelig større enn for bunnfaste fundamenter på grunt vann. Noen eksempler på flytende fundamenttyper er vist i figur 3.4-1



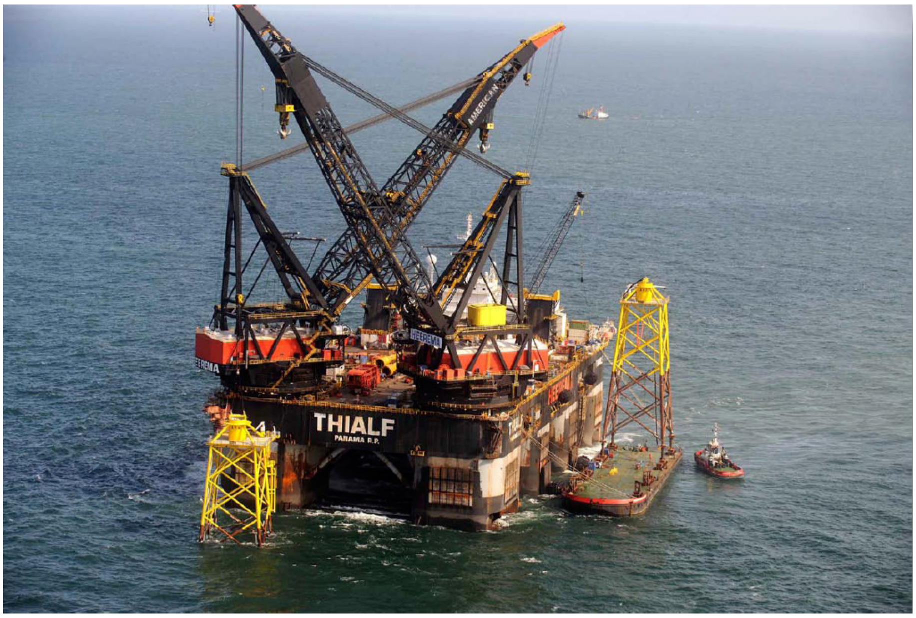
Figur 3.4-1 – Illustrasjon av flytende fundamenttyper

3.5 Installasjonsmetode for bunnfaste fundamenter

Dagens installasjonsmetode innbefatter bruken av tungløft- og oppjekkbare fartøyer som kan ha diverse begrensninger samt et høyt kostnadsperspektiv (figur 3.5-1 og figur 3.5-2). Teknologiutvikling for installasjonsmetode kan redusere kostnadene samt forbedre installasjonsprosessen. Det vil være effektivt om det ble utviklet en metode som minimerer antall tunge løft. Konstruksjon av egne installasjonsfartøyer som kan frakte fundamenter liggende for så lett å kunne snu dem under installasjon ved hjelp av kraner, som er installert på samme fartøy, er et konsept som er under utvikling. Ny konseptutvikling vil skape økonomiske utgifter i form av investeringer for utvinning og produksjon, men det kan være lønnsomt i det lange løp i tilfelle mange fundamenter skal installeres.



Figur 3.5-1 – Installasjonsmetode for bunnfaste fundamenter
Ref. /F-3/



Figur 3.5-2 – Installasjon av jacketfundament, NorWind, Alpha Ventus – store og tunge løft
Ref. /I-7/

3.6 Kostnadsperspektiver

Størrelsen på investeringskostnaden er veldig avhengig av dybde og bunnforhold, avstand til land samt vind og bølgeforhold. I tillegg vil det være betydelig høyere drift og vedlikeholdskostnader med offshore vindturbiner kontra onshore vindturbiner. For å finne totale kostnader for et prosjekt må det reknes med kostnader for material, fabrikasjon, installasjons, transport, sjøsikkring, marine operasjoner, igangsetting, ingeniør arbeid, ledelse, forsikring, drift, vedlikehold og fjerning etter endt levetid. Ut i fra kostnadsperspektivet kan det også bedømmes om det skal planlegges for installasjon på grunt eller dypt vann.

4. Eksisterende metoder for dimensjonering

Vind- og bølgekrefter fører til store dynamiske lastpåkjenninger på offshore konstruksjoner. Disse dynamiske påkjenningene fører igjen til problemer for ingeniører som skal dimensjonere løsninger for offshore bruk. Utmattelsesproblematikken er et viktig tema i denne forbindelse da de dynamiske lastene fører til kontinuerlige spenningsendringer i konstruksjonen som igjen fører til sprekkdannelser og eventuelt brudd etter en viss tid.

I dette kapittel er det valgt å kort oppsummere de vanligste metodene for dimensjonering av innfestning og utmatting av et offshore vindturbin fundament. Det er også valgt å si noen ord angeånde selve innfestningen til havbunnen, selv om dette ikke er videre analysert i oppgaven, da det representerer et kritisk punkt i dimensjoneringen.

Når det gjelder hvilke krafttilstander det skal dimensjoneres for, må man ta hensyn til at vindturbinene ikke opererer i alle vindhastigheter. Når vindhastigheten blir for høy slår vindturbinen seg av for at ikke bladene skal bli skadet. Dette fører til at man ikke dimensjonerer for operasjon under maks vindhastighet på et felt, men for operasjon i moderat vind kombinert med ekstreme bølger som er det dimensjonerende lasttilfellet (ref. /T-1/). Det kan gjøres en sammenlikning for å sjekke ut om det er kreftene ved moderate miljøbelastninger under drift som er mest utslagsgivende for dimensjonering eller om det er maks miljøbelastninger som konstruksjonen blir utsatt for i stillestående tilstand som kan være mest utslagsgivende. Mest sannsynlig er det førstnevnte utslagsgivende da rotorbladene under drift kan sees på som en disk, men stort areal, som blir belastet av vind – og dette fører mest sannsynlig til større kraftbelastning enn det konstruksjonen vil oppleve i stillestående stand med påkjenning av maks miljøbelastning.

Typisk for offshore vindturbiner er at den vertikale belastningen på fundamentet (fra vindturbinen) er relativt liten i forhold til overført momentet og skjærkraft fra vindturbin til fundament og det er disse lastene som er utslagsgivende for dimensjonering av fundament sammen med de hydrodynamiske bølgelastene.

For innfestningen til selve havbunnen er det først og fremt viktig å forsikre seg om at det oppstår en god nok forbindelse mellom fundament og havbunn så ikke uønskede bevegelser inntreffer i strukturen. Innfestningen til havbunnen overfører kreftene fra strukturen til havbunnen og representerer dermed en kritisk del av designet. En klar forståelse for denne kraftoverføringen fører til en økende troverdighet for det totale designet. Et annet kritisk punkt i forbindelse med fundamenteringen er at den skal kunne motstå alle laster som kan bli påført, spesielt gjennom ekstreme værforhold, for ikke å resultere i kollaps. Dersom en kollaps inntrer skaper dette uønskede økonomiske konsekvenser. Disse konsekvensene blir en drivende dimensjonerende faktor i valg av design (i motsetning til offshore installasjoner for olje og gass hvor tap av liv er en hoved faktor).

En brukt metode for å beregne kapasiteten i selve innfestningen (fundament/havbunn) er å se på den bærende kapasiteten til innfestningen. Terzaghi (1943), ref. /L-13/, kom opp med en formel som kan brukes til å fastsette bæreevne.

$$V_{peak} = \left(\frac{1}{2} \cdot B \cdot \gamma \cdot N_{\gamma} + \mathrm{c} \cdot N_c + q \cdot N_q \right) \cdot A_{footing} \tag{4.1}$$

V_{peak} = maks vertikal belastning som kan være ved innfestningen

B = bredden på innfestningen

N_{γ} = bærende kapasitetsfaktor for egenvekt

γ = effekt av egenvekt

c = effekt av jordsmonnets skjærstyrke (som er uavhengig av de mormal-effektive spenningene i massebevegelsene; cohesion, ref. /T-1/, /I-18/ og /I-19/)

N_c = bærende kapasitetsfaktor for jordsmonnets skjærstyrke (som er uavhengig av de mormal-effektive spenningene i massebevegelsene; cohesion, ref. /T-1/, /I-18/ og /I-19/)

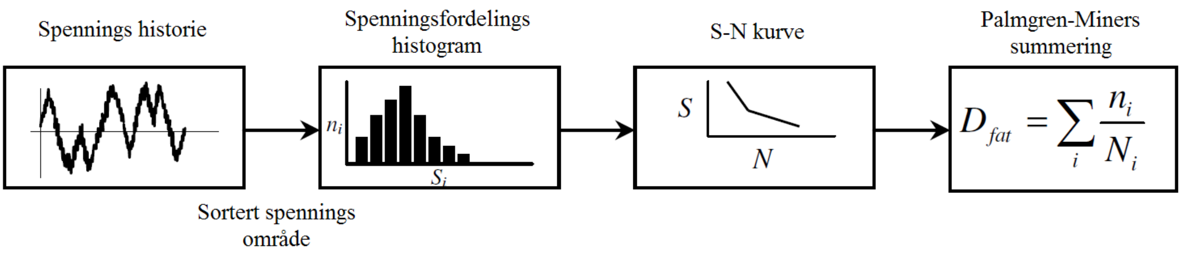
q = effekt av overbelastning

N_q = bærende kapasitetsfaktor for overbelastning

$A_{footing}$ = arealet på innfestningen

Terzaghi (1943), ref. /L-13/, sin overnevnte formel tar ikke hensyn til det kombinerte lastbildet bølger, strøm og vind) som offshore konstruksjoner utsettes for; så videre forskning ble utført av Meyerhof (1951, 1953), ref. /L-14/ og /L-15/, Hansen(1961, 1970), ref. /L-16/ og /L-17/, og Vesic (1975), ref. /L-18/. De foreslo et uttrykk, basert på Terzaghi (1943), ref. /L-13/, sin opprinnelige formel, som angir bæreevne basert på det kombinerte lastbildet. Disse prosedyrene er fremdeles er i bruk og de benytter "ad hoc" faktorer for å beregne form, dybde og last vinkel for videre å kunne justere det aksepterte bærende trykk, /T-1/ og /I-17/.

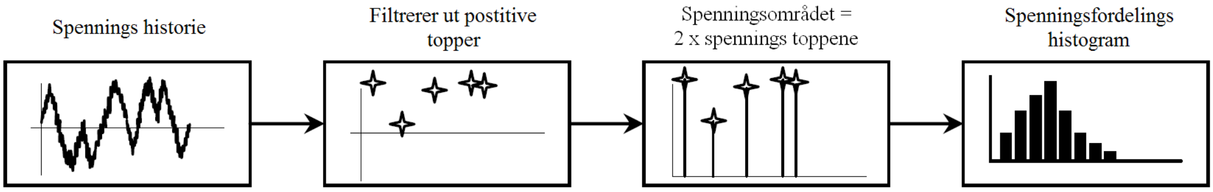
Dimensjonering for utmattelse blir utført ved hjelp av S-N kurver og Palmgren-Miners summering. Teorien for S-N kurver og Palmgren-Miners summering er beskrevet under kapitel 2.4.1, 2.4.2 og 2.4.3. Selve kalkulasjonsmetodene for utmatting ved variabel spenningsvidde innenfor en tidsperiode kan oppsummeres som vist i figur 4-1.



Figur 4-1 – Kalkulasjonsmetode for utmatting ved variable spenningsvidder og bruk av S-N kurver og Palmgren-Miners summering
Ref. /T-2/

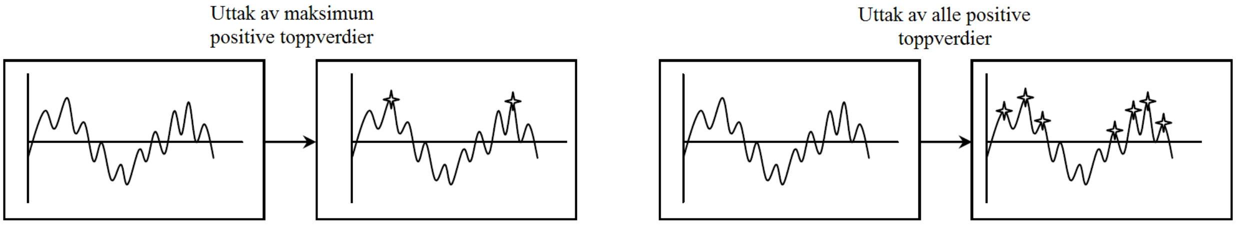
I metoden beskrevet i figur 3-1 er det ikke forklart hvordan man skal ta hensyn til spenningssyklusene. Det eksistere forskjellige metoder som beskriver hvordan man tar hensyn til dette. Disse metodene kan deles inn i metoder basert på tidsdomener eller frekvendomener. Tidsdomenemetodene omhandler telling av maksimalverdier (”Peak counting”) og regnflytmetode (”Rainflow”). Frekvensdomene metodene omhandler bruken av Rayleigh distribusjon, Rice distribusjon og Dirlik likningen.

Metoden for telling av maksimalverdier kan oppsummeres som på figur 4-2. Her blir alle positive topper av spenningshistorien filtrert ut og multiplisert med to for å få spenningsområdet. Videre kan spenningsfordelingshistogrammet lages.



Figur 4-2 – Metode for telling av maksimalverdier, ”Peak counting”
Ref. /T-2/

En vurdering av om det bare er maksimalverdiene for hver kryssing av den horisontale aksen på spennings historie grafen som skal medreknes eller om alle positive topper skal medregnes må gjøres før en analyse. Dersom bare maksimalverdiene for hver kryssing tas i betraktning resulterer dette i et lavt antall spenningsområder, men dersom alle positive topper tas i betraktning resulterer det i et stort antall spenningsområder. Ref. figur 4-3



Figur 4-3 – Illustrasjon; uttak av maksimum positive toppverdier og alle positive toppverdier
Ref. /T-2/

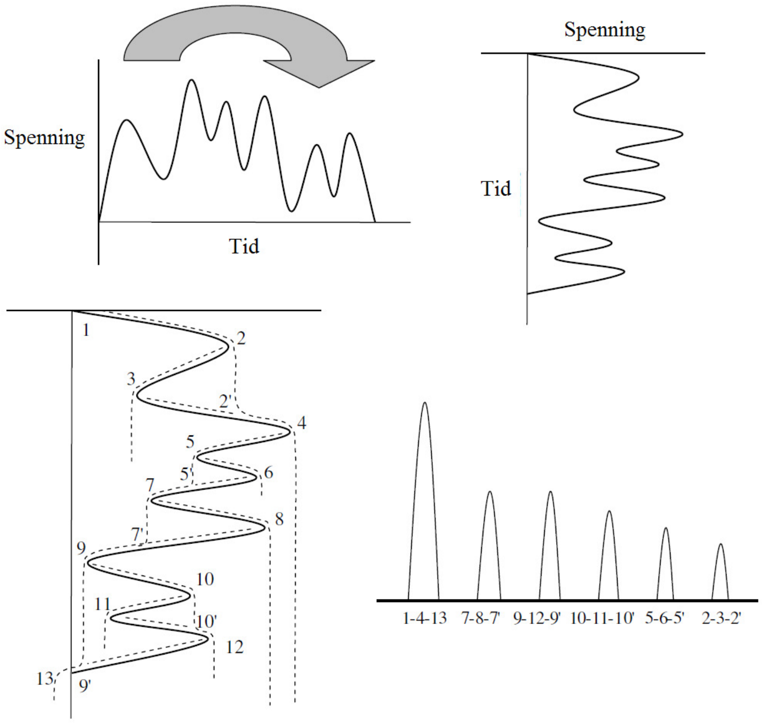
For å kunne medregne alle toppene uten å fordoble dem ble regnflyt metoden (”Rainflow”) oppfunnet. Denne metoden går ut på å snu spennings historie grafen 90 grader mot høyre for så å kunne telle spenningene ved å se på dem som regnvann som triller nedover grafen (ref. fig. 4-4).

Tellingen av spenningene begynner:

- i begynnelsen av serien (1)
- ved hver topp hvor den foregående regnflyten forsvinner vekk (2, 4, 6, ...)
- ved hver bunn (3, 5, 7, ...)

og hver regnflyt stopper:

- i enden av serien (13)
- når den kommer nederst i bunnen (for eksempel serie 2-3)
- når den møter på en flyt ovenfra (for eksempel serie 3-2')



Figur 4-4 – Reinflyt illustrasjon
Ref. /T-2/

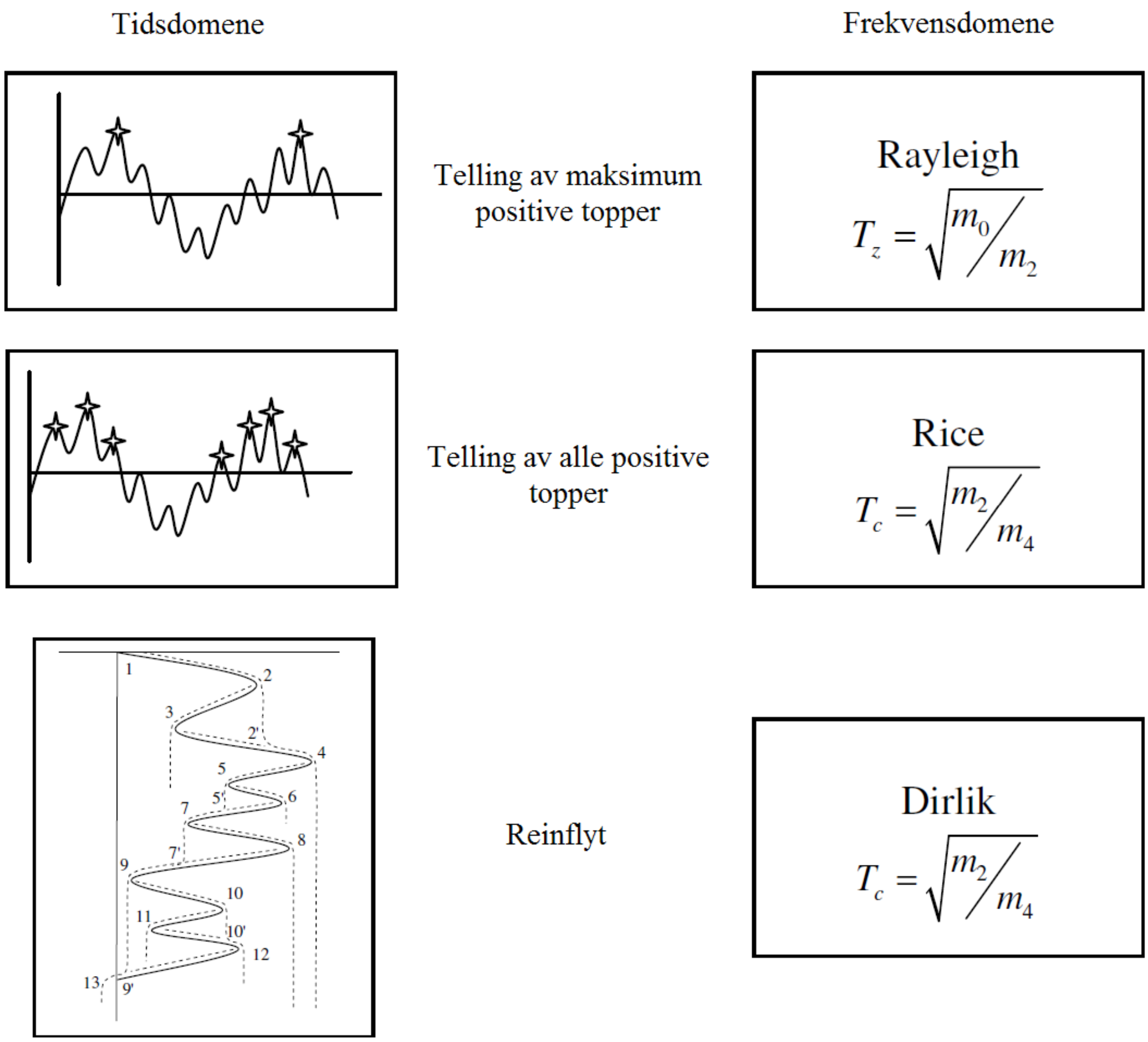
Regnflyt metoden resulterer i spenningsområder som igjen kan brukes i kombinasjon med SN-kurver for å beregne Palmgren-Miners summeringen.

Frekvensdomene metodene omhandler tidsseriene omformet til spektrum. Når det er laget et spektrum for bøyespenninger finnes det flere metoder for å komme frem til spenningsvariasjonene ut fra de spektrale egenskapene. Alle metodene innlemmer de samme basis trinnene:

- bestemme en sannsynlighetsfordeling for spenningstoppene (lokale maksima) basert på de spektrale parametrene fra spennings spekteret

- spenningsområdet antas å være lik det dobbelte av spenningstoppene og distribusjonen av spenningsområdet er antatt å være lik distribusjonen av spenningstoppene
- bestemme det totale antall topper eller områder som forekommer i den aktuelle tidsperioden.

Rayleigh distribusjonen, Rice distribusjonen og Dirlik likningen er beskrevet mer utdypende i kapitel 2.8.4 i ref. /T-2/. Disse tre metodene beskriver spenningsområdet for frekvensdomene metodene. Ref. figur 4-5 for kobling mellom tidsdomene og frekvensdomene metodene.



Figur 4-5 – Tidsdomene og frekvensdomene
Ref. /T-2/

T_z er gjennomsnittelig kryssingsperiode (”average zerocrossing period”) og T_c er gjennomsnittelig topp perioden (”average crest period”).

Når det gjelder bruken av de overstående metodene for utmattelsesberegninger er det flere kombinasjoner som er brukt i allerede utførte prosjekter. Videre vil det nevnes tre forskjellige kombinasjonsmetoder for å rekne ut utmatting som allerede er brukt i dimensjonering av eksisterende installasjoner.

1. Turbinprodusentene beregner utmatting i tidsdomenet for vindlaster på rotoren. For de hydrodynamiske lastene beregner leverandøren av fundamentet utmatting etter en frekvensdomene modell. De to modellene for aerodynamikk og hydrodynamikk kombineres så sammen og den kombinerte utmattingen kalkuleres ved hjelp av det kvadratiske superposisjonsprinsippet av de to separate tilskuddene fra vind og bølger (Utgrunden, Sverige /T-2/).
2. Hele dimensjoneringen blir gjort i ett program og utmatting beregnes etter samme modell for både aerodynamikk og hydrodynamikk (Blyth, østkysten av England /T-2/).
3. Tett samarbeid mellom produsentene av vindturbin og produsentene av fundamentet har forekommet og følgende prosedyre har da blitt fulgt: Design av fundament med innfestning til havbunnen ble utført av fundamentleverandør (et foreløpig design av turbintårnet forelå før dette arbeidet startet). Så ble designet overført til turbinleverandør som designet turbinen til å passe på det allerede utarbeidete fundamentdesignet. Videre utførte turbinleverandør utmattingsanalysen (som på forhånd var foreslått av fundamentleverandør). Til slutt sendtes resultatene til fundamentleverandør som implementerte disse i sine rapporter og stod ansvarlig for dem (Offshore Windfarm Egmond aan Zee, OWEZ, i Tyskland /T-2/).

Det har også vært tilfeller hvor utmatting har blitt neglisjert. Da med grunnlag i at bølgene ble vurdert til å gi et bidrag med meget lave spenningsnivåer og de ble dermed ignorert i analysen. Spenningsbidraget fra vinden alene var også, i dette tilfellet, så lavt at det kom under utmattelsesgrensen til S-N kurven; noe som førte til at utmattelsesberegningene ble neglisjert (Horns Rev, vestkysten av Danmark /T-2/)

Tradisjonelt beregnes utmatting for vindturbiner slik som beskrevet i punkt én over. Det vil si at selve vindturbinen analyseres i tidsdomenet (et stort antall av vind og turbulenstilstander simuleres) og selve fundamentet (eventuelt inkludert turbintårn) beregnes, i et elementprogram, etter frekvensdomene metoden. Resultatene fra de to simuleringene slås sammen og resulterer i et spenningsrespons spektra som angir spenninger langs fundamentet. Dette blir videre brukt til beregning av utmatting. Frekvensdomene metoden er mindre tidkrevende enn tidsdomene metoden, så når den overnevnte prosedyren blir fulgt oppstår det en tidsbesparelse. Tidligere ble hele konstruksjonen (turbin inkludert fundament) kalkulert etter tidsdomene metoden og dette var tidkrevende og design optimaliseringen gikk tregt, /T-3/.

I forhold til å optimalisere dagens metode for utleding av spenningsfordelingene som brukes i utmattingsanalyser arbeides det med å utvikle programmer som er kapable til å analysere hele konstruksjonen (vindturbin og fundament) i ett og samme program. Et eksempel på et slikt program er FEDEM Windpower, /I-9/. Programmet er brukt i simulering av aerodynamiske laster videre i denne oppgave. Et annet program, som ble brukt for Blyth vindfarm på østkysten av England /T-2/, for simulering av aerodynamiske samt hydrodynamiske krefter er Bladed , /I-10/.

Når hele konstruksjonen kan analyseres i ett program elimineres usikkerheter i forbindelse med at resultatene blir mer nøyaktige enn å implementerer resultater fra ett program til ett annet. Det er også mer hensiktsmessig og tidsbesparende å arbeide med ett analyseprogram kontra flere, og det gjør kommunikasjonen mellom turbinleverandør og fundamentleverandører betraktelig enklere da samme modell kan brukes og kommunisere.

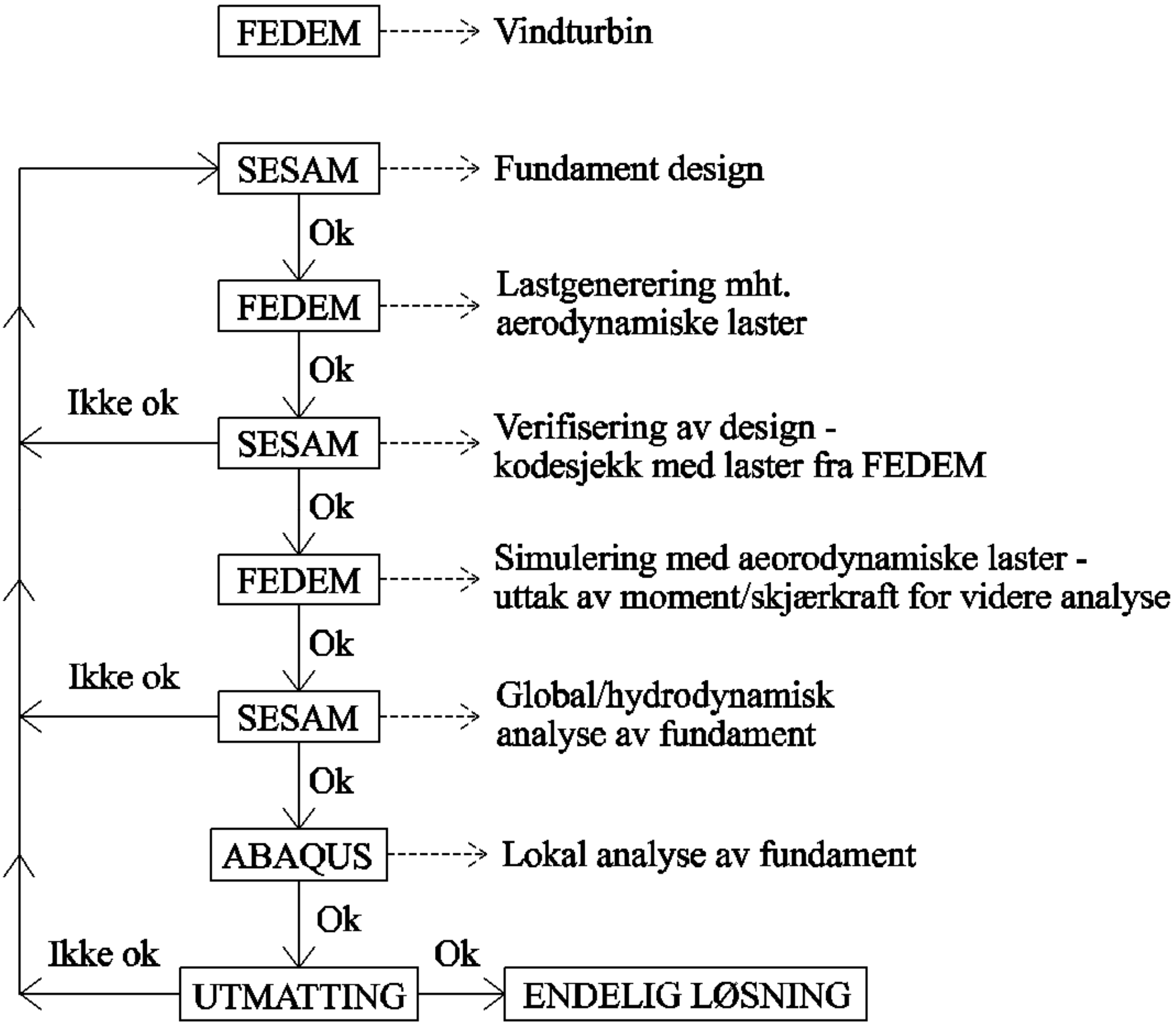
ULS, bruddgrensetilstand, er en av fire grensetilstander;

1. Bruksgrensetilstand,
2. Bruddgrensetilstand,
3. Utmattingsgrensetilstand
4. Ulykkesgrensetilstand

som brukes for dimensjonering og kontroll av konstruksjoner. En grensetilstand har definerte krav som må tilfredstilles dersom konstruksjonen skal betegnes som egnet, ref. /I-20/. Selve bruddgrensetilstanden omhandler en definert kapasitet til hele konstruksjonen. Kapasiteten er bestemt av faren for brudd eller for store uelastiske forskyvninger eller tøyninger som kan ha sammenheng med brudd. Analyser etter ULS er basert på lastfaktorer, lastkombinasjoner, materialfaktorer og materialstyrke. Lastene defineres som karakteristiske laster som eksempelvis permanente laster, variable laster, miljølaster, deformasjonslaster og ulykkeslaster. Eksempel på karakteristiske miljølaster er lastene en får fra en hundreårsbølge (femtiårsbølge for vindturbiner – ref. tabell 5.2.1.2-1) eller femtiårsvind. For å finne de dimensjonerende lastene multipliseres de karakteristiske lastene med lastfaktorer i to kombinasjoner (ofte betegnet som A og B - ref. tabell 5.4.2-1). Lastfaktorene tas fra en kontraktsbestemt standard for det eventuelle prosjekt. Materialstyrken skal være god nok til å kunne motstå lastpåkjenningene. Denne styrken fastsettes statisk, for stål og aluminiumskonstruksjoner, som et 5 %-fraktil. Materialstyrken kombineres med materialfaktorer. Materialfaktorene er avhengig av materialet som brukes. Dersom det er nødvendig å justere sikkerhetsnivået gjøres dette ved bruk av koeffisienter. Sluttkontrollen ved en ULS analyse går ut på å vurdere om den dimensjonerende styrken er større enn de dimensjonerende lastene. Er dimensjonerende styrke større enn de dimensjonerende lastene er konstruksjonen egnet for videre bruk i ULS tilstand, ref /I-20/. Resultatet publiseres ofte ved hjelp av utnyttelsesfaktorer hvor en høyest mulig utnyttelse er å foretrekke for å få en mest mulig kostnadseffektiv konstruksjon. I noen tilfeller kan det være lurt, dersom det på designstadiet er kjent at det i fremtiden kan forekomme modifikasjoner som vil berøre utnyttelsen, å ikke dimensjonere med alt for høy utnyttelse. Dersom det skal utføres modifikasjoner på eksisterende konstruksjoner, og konstruksjonen i utgangspunktet er høyt utnyttet, kan det medføre mer arbeid dersom nye designløsninger må utvikles på grunn av at eksisterende konstruksjon i utgangspunktet ikke har kapasitet til en eventuell ekstra belastning. Dette må vurderes nøye for det aktuelle tilfellet.

5. Analyse

Anvendte analyseprogrammer er Sesam GeniE (for global analyse av fundamentet), FEDEM Windpower (for simulering av dynamiske vindlaster, aerodynamikk) og Abaqus (for lokalanalyse for videre utmatting). En skjematisk presentasjon av fremgangsmåten for programbruken i denne oppgaven er vist i figur 5-1 – Fremgangsmåte for bruk av program.

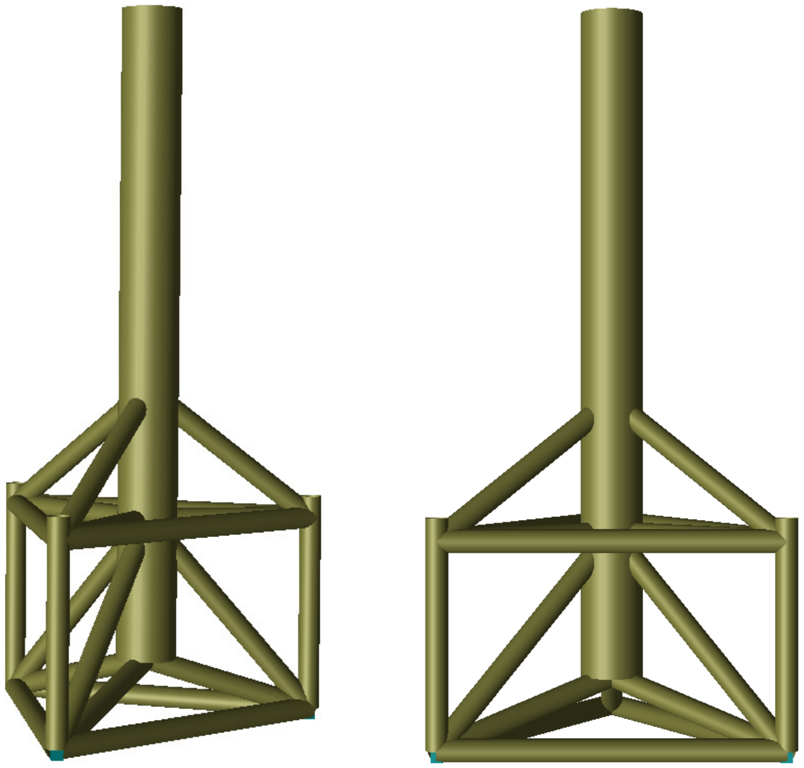


Figur 5-1 – Fremgangsmåte for bruk av program

5.1 Konseptvalg

Konseptvalget er basert på nytt design for et tripod fundament (ref. figur 5.1-1). Valg av designløsning/utforming er gjort med tanke på enkel fabrikasjon, installasjon, drift og vedlikehold. Tanken bak designet er at det skal være kostnadseffektivt å fabrikkere samt kreve minimal installasjonstid. For fabrikasjon er det tatt utgangspunkt i bruk av så slanke elementer og minst mulig knutepunkt som praktisk og konstruksjonsmessig mulig. Enkle løsninger vil gi en kortere og mer kostnadseffektiv fabrikasjon. Når det gjelder installasjon er det tidsbesparende med 3 ankerpunker sammenliknet med en jacket konstruksjon som har 4 ankerpunker. Tidsbesparelsen gjør seg her gjeldende ved at det blir et punkt mindre å pæle. Sentersøylen, som omfatter det største konstruksjonselementet, er plassert i en høyde à 5 meter over havbunnen. Dette for lettere å kunne utføre inspeksjon og vedlikehold av knutepunktene. Som et alternativ kunne det blitt utformet en jackettripod. Denne ville hatt flere knutepunkt en det tripodkonseptet som er utformet, men allikevel ett mindre pælepunkt i forhold til ordinær 4 bens jacket.

Generelt for utforming av konsept for en bunnfast konstruksjon bør følgende designparametere tas hensyn til: vanndyp, bølger, strøm, vind, tidevann, marin begroing, korrosjon, jordskjelv, is (om relevant), snø, geotekniske parametre og temperatur.



Figur 5.1-1 – Fundamentkonsept for analyse

5.2 Laster

Størst bidrag til belastning på konstruksjonen vil komme fra bølger, strøm, tidevann, vind og egenvekt.

Områdedata er hentet fra Doggerbank-området på østkysten av England /L-7/.

5.2.1 Miljølaster

Under følgende kapittel følger en mer detaljert beskrivelse av miljølastene som er gjeldende for oppgaven. Det omhandler vindlaster og bølgelaster (inkludert strømninger).

5.2.1.1 Vindlaster

Laster generert av vind på selve vindturbinen er analysert i FEDEM Windpower. Disse lastene er tatt ut fra programmet, for globalanalysen i Sesam GeniE, som statiske laster (maks moment og maks skjærkraft i x og y retning) i overgang mellom vindturbin og fundament. Ref. tabell 5.4.1.1-1 i kapittel 5.4.1.1 (Resultater av simulering med OC4 vindturbin og tripod) for maks laster gitt ved de representative vindtilstandene.

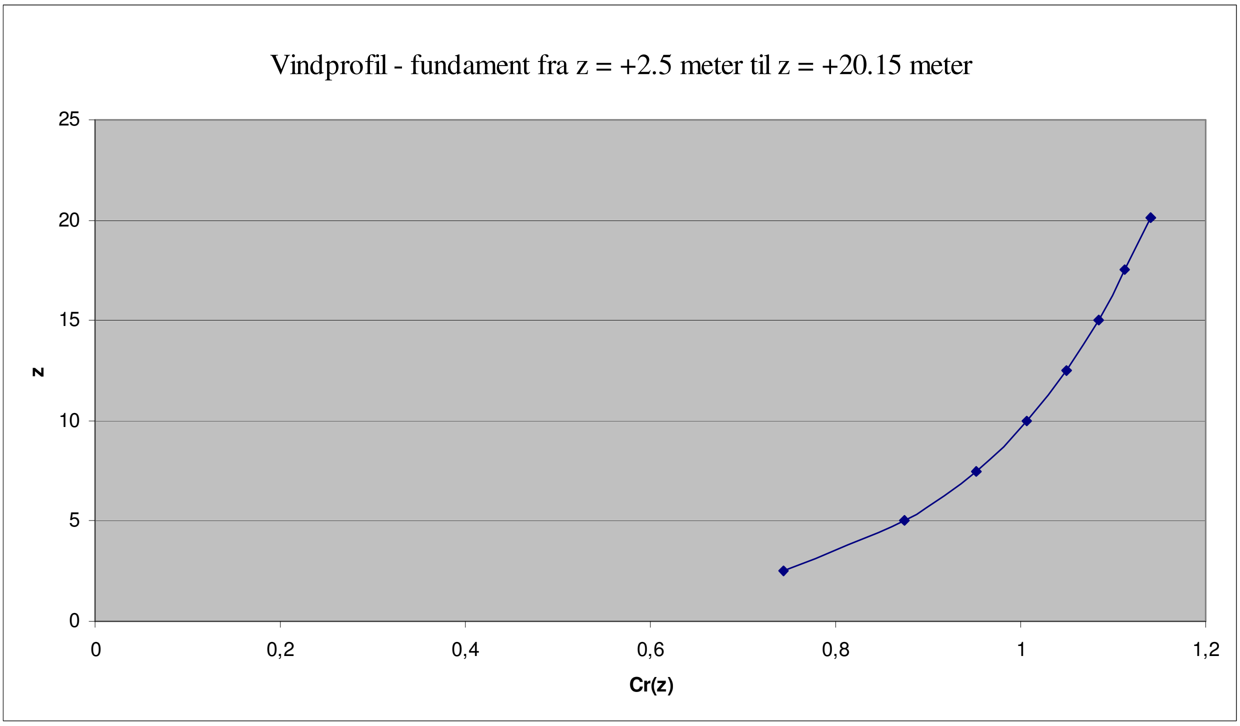
I globalanalysen i Sesam GeniE vil det bli utført to analyser; analyse 1 som inkluderer bare fundament (tripod) og analyse 2 som inkluderer fundament og turbintårn. For analyse 1 vil en del av fundamentet, fra SWL til z = +20.15 meter, også bli utsatt for vind. Denne vindkraften må implementeres i Sesam GeniE. Kreftene fra FEDEM Windpower er tatt ut ved z = +20.15 meter for analyse 1, så vindkrefter som berører konstruksjonen under denne høyden må implementeres i Sesam GeniE. Det samme gjelder for analyse 2. Her må vindkreftene implementeres i Sesam GeniE for hele turbintårnet, da kreftene fra FEDEM Windpower her er tatt ut i toppen av turbintårnet. Måten dette blir tatt hensyn til i Sesam GeniE er at det blir lagt på vindprofiler under de hydrodynamiske beregningene. Figur 5.2.1.1-1 viser vindprofil for analyse 1 og figur 5.2.1.1-2 viser vindprofil for analyse 2.

Det er antatt en gjennomsnittelig vindhastighet U(z) lik 10 m/s. k_t er satt til 0.19 og z_0 er satt til 0.05. Berekninger av $C_r(z)$, ruhetsfaktor, gir da følgende vindprofil for analyse 1 og Analyse 2:

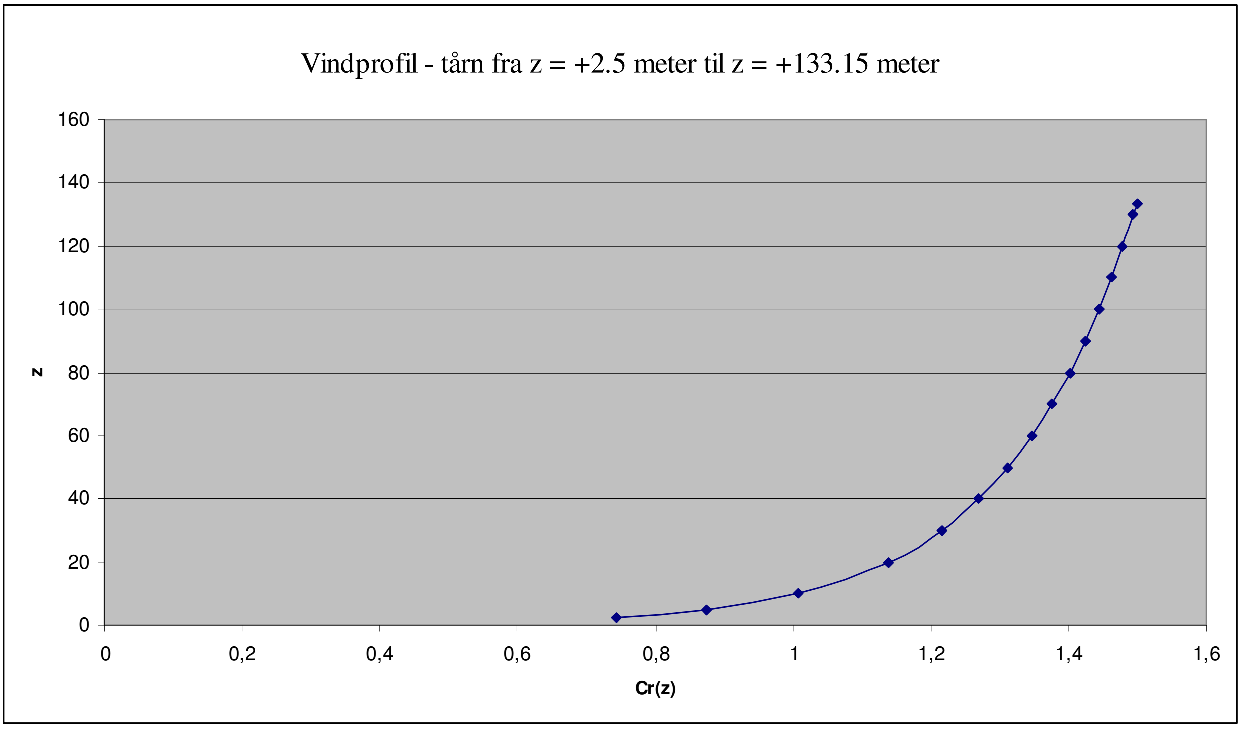
Tabell 5.2.1.1-1 ruhetsfaktorer for Analyse 1 og Analyse 2

Analyse 1
Cr(20.15) = 1.139797947
Cr(17.50) = 1.113007299
Cr(15.00) = 1.083718670
Cr(12.50) = 1.049077574
Cr(10.00) = 1.006680300
Cr(7.500) = 0.952020706
Cr(5.000) = 0.874982335
Cr(2.500) = 0.743284371

Abalyse 2
Cr(133.5) = 1.499068
Cr(130.0) = 1.494021
Cr(120.0) = 1.478813
Cr(110.0) = 1.462280
Cr(100.0) = 1.444171
Cr(90.00) = 1.424153
Cr(80.00) = 1.401774
Cr(70.00) = 1.376403
Cr(60.00) = 1.347115
Cr(50.00) = 1.312474
Cr(40.00) = 1.270076
Cr(30.00) = 1.215417
Cr(20.00) = 1.138378
Cr(10.00) = 1.006680
Cr(5.000) = 0.874982
Cr(2.500) = 0.743284



Figur 5.2.1.1-1 – Vindprofil fra z = +2.5 meter til z = +20.15 meter (Analyse 1)



Figur 5.2.1.1-2 – Vindprofil fra z = + 2.5 meter til z = +20.15 meter (Analyse 2)

For mer utfyllende informasjon angående beregningsmåte for vindprofil refereres det til vedlegg 8, "Marine technology/Environmental Loads, Wind Load on Strutures, Part 1, Jasna Jakobsen".

5.2.1.2 Bølgelaster

Tabell 5.2.1.2-1 angir hydrodynamiske parametere som er benyttet i analysen. Verdiene er hentet fra Doggerbank området på østkysten av England /L-7/.

Tabell 5.2.1.2-1 hydrodynamiske parametere

Tidevann/strømninger*	Periode	Bølger (H_{maks})	Marin begroing		Morison konstanter **	
m/s	*s*	*m*	*Dybde under SWL*	*mm*	C_M	C_D
0,55	14,2	17,5	0-25 m	50	2,0	0,8
			25 m -	90		

* For strøm er det benyttet en lineær endring fra 1,1 m/s i overflaten til 0,5 m/s ved havbunnen. Dette er mer konservativt enn å ha 0,55 m/s for hele konstruksjonshøyden.

** ref. /S-9/ kapittel 6.2.4.2 punkt c). Profilene er vurdert som "rough members"

Videre følger en beregning for å kunne konstantere hvilke type vanndyp område dataene hører til:

$$L = \frac{9.81}{2\pi} 14.2^2 = 314.82\,\mathrm{m}$$

$$\frac{d}{L} = \frac{45}{314.82} \approx 0.143 \Rightarrow \underline{\text{endelig vanndyp}} \left(\frac{1}{20} < \frac{d}{L} < \frac{1}{2} \right)$$

5.2.1.2.1 Regelmessige bølger

Teorien for regelmessige bølger er beskrevet under kapittel 2. Det blir brukt Stokes5 ordens bølgeteori i Sesam GeniE. Returperioden for bølger er 50 år, ref. /S-4/ og /L-7/. Det vil si at det i gjennomsnitt vil ta 50 år mellom hver gang den oppgitte lasten overskrides. Vanligvis dimensjoneres offshore installasjoner for 100 års returperiode som er en større dimensjonerende verdi enn 50 års returperiode. Noen av grunnene til at det er valgt en standard på 50 års returperiode for offshore vindturbiner, og ikke 100 års returperiode, kan være:

- At det er dyrere og ulønnsomt å produsere vindturbiner for 100 års returperiode da det kan kreve en større og tyngre konstruksjon
- At konsekvensen ved sammenbrudd av en vindturbin ikke er like stor som konsekvensen for sammenbrudd av en oljeplattform (da med tanke på risikoen for eventuelt tap av liv, forurensning ved olje og gassutslipp, store kostnader for oppretting av skader og liknende som kan oppstå ved kollaps/sammenbrudd på en bemannet utvinningsinstallasjon for olje og gass). Vindturbinene bør bruke "grønn" hydraulikk olje slik at det ved en eventuell forurensende situasjon skaper minst mulig skade på miljøet.

5.2.2 Statiske laster

De statiske lastene blir definert som moment og skjærkraft som overføres fra vindturbinen til fundament. Samt jevnt fordelt vindlast på vindutsatt del av fundament. Vekt av selve fundament konstruksjon og oppdrift er medreknet her.

5.2.2.1 Laster fra vindturbin

Programmet FEDEM Windpower er, som nevnt i kapittel 5.2.1.1, brukt for simulering av de aerodynamiske lastene som vindturbinen påfører fundamentet.

Det største lastbidraget fra vind til fundament oppstår når vindturbinen er i drift. For vindhastigheter over 25 m/s er ikke vindturbinen operativ. Det fører til at det velges en vindhastighet mellom 0 – 25 m/s som dimensjonerende vindhastighet. I teorien skulle det vert utført flere simuleringer for alle vindhastigheter opp til 25 m/s, men på grunn av tidsbegrensning blir bare en hastighet analysert. Prosedyren for videre beregninger vil være den samme uansett valg av dimensjonerende vindhastighet.

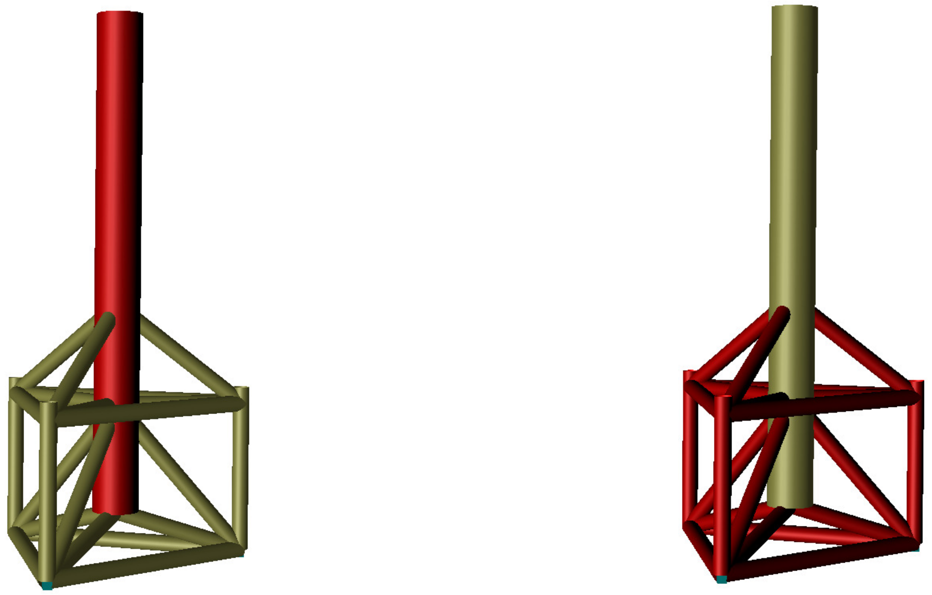
For globalanalysen er det tatt utgangspunkt i maksimalverdiene for moment og skjærkraft. Disse lastene er implementert i Sesam GeniE som punktlaster i henholdsvis topp fundament for analyse 1 og topp vindturbintårn for analyse 2.

5.2.2.2 Egenvekt av fundament

Fundamentets egenvekt blir generert og tatt hensyn til under analysen i Sesam GeniE.

5.3 Sjekk av frekvensområder

For å kunne utelukke faren for resonans er det gjort en del vurderinger med tanke på egenfrekvenser. Disse vurderingene er gjort parallelt med kodesjekkene i Sesam GeniE for å sikre at de endelig valgte profilstørrelsene er i henhold til både kravene i standardene og kravene for egenfrekvens. Tabell 5.3-1, sammen med figur 5.3-1 viser, de alternative profilkombinasjonene som ble utprøvd. Det gjøres oppmerksomt på at alternativ 1 og alternativ 5 er uaktuelle for et eventuelt reelt design da de har uaktuelle profilstørrelser, men de er tatt med i analysen for kalibrering av modellen samt vise hvordan egenfrekvensen endrer seg ved bruk av stive (alternativ 1) og myke (alternativ 5) profiler.



Sentersøyle *Fundament element*

Figur 5.3-1 – Profilillustrasjon

Tabell 5.3-1 – Profilvalg; alternativ 1 – alternativ 5
Dimensjonene er angitt i meter

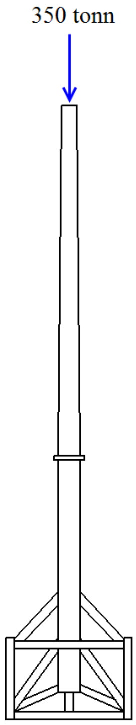
	Alternativ 1*	Alternativ 2	Alternativ 3	Alternativ 4	Alternativ 5
Sentersøyle	5.6 x 1.000	5.6 x 0.150	5.6 x 0.075	5.6 x 0.032	5.6 x 0.020
Fundament element	2.0 x 0.700	2.0 x 0.060	2.0 x 0.060	2.0 x 0.040	2.0 x 0.015

**Dimensjonene i alternativ 1 er valgt kun for illustrasjonsformål*

Kodesjekk i Sesam GeniE viste at fire av de fem alternativene (alternativ 1, 2, 3 og 4) på tabell 5.3-1 tilfredstiller kravene til utnyttelsesfaktor < 1,0. Kodesjekken er mer detaljert beskrevet i kapittel 4.4.2 ”Sesam GeniE analyse av fundament”. Det er utført ULS A og ULS B analyser etter både Eurocode 3 og Norsok N-004. Lastfaktorene som er brukt er for ULS A lik 1.3 for permanente og variable laster og 0.7 for miljølaster. For ULS B analysene er lastfaktorene satt til 1.0 for permanente og variable laster og til 1.3 på miljølaster (ref. /S-10/ kapittel 6.2.1 tabell 1). Da vindturbinen ikke er en bemannet installasjon kan det diskuteres om lastfaktorene som er gitt over er for konservative, men det er valgt å bruke de nevnte faktorene for å kompensere for (inkludere) DAF. Det er valgt å vise alle resultatene, inkludert det alternativet som ikke tilfredstiller kodesjekk, i tabell 5.3-1 for å illustrere egenfrekvensanalysen og hvordan konstruksjonens egenfrekvens forandrer seg med økende stivhet (egenfrekvensen synker med økt konstruksjonsstivhet) for hvert alternativ. Egenfrekvensanalysen er kjørt med bruk av hele konstruksjonen (fundament, turbindtårn og selve turbin (blader, nacelle og hub). Vekt av blader, nacelle og hub er satt på som sentrert punktlast i topp turbintårn (350 tonn, ref. /L-8/). Ref figur 5.3-2 for illustrasjon av belastning ved beregning av egenfrekvens.

Tabell 5.3-2 – Egenfrekvenser

Rotorfrekvens		Strukturfrekvens *(fundament, tårn og turbin)*				
Rotasjonsperiode		Fundament dimensjoner (m)				
1P	3P	Alternativ 1 5.6 x 1.000 2.0 x 0.700	Alternativ 2 5.6 x 0.150 2.0 x 0.060	Alternativ 3 5.6 x 0.075 2.0 x 0.060	Alternativ 4 5.6 x 0.032 2.0 x 0.040	Alternativ 5 5.6 x 0.020 2.0 x 0.015
Oppstarts periode / Operasjons periode (s)		Periode (s)				
8.70 / 4.96	2.90 / 1.65	0.786	1.08	1.282	1.73	2.18
		Kodesjekk (Eurocode 3 og Norsok N-004)				
		Ok	Ok	Ok	Ok	Ikke ok



Figur 5.3-2 – Belastningstilfelle for beregning av strukturens egenfrekvens

Selve rotorfrekvensen er reknet ut etter rotorhastigheten, 12.1 rpm, som er oppgitt i ref. /L-8/ kapittel 1, tabell 1-1. Videre følger beregninger av rotorfrekvensen, 1P, (perioden av selve rotoren) og frekvensen av ett blad, 3P, som tilsier perioden mellom hver gang et turbinblad passerer turbintårnet.

1. Beregninger av 1P:

$$1\,rpm = \frac{1}{60}\,Hz \qquad (5.1)$$

$$12.1\ rpm = \frac{1}{60}\cdot 12.1\ Hz = 0.2016667\ Hz$$

$$0.2016667\ Hz = \frac{1}{0.2016667}\ s = 4.958678\ s$$

$$1P = 4.958678\ sekund$$

$$\underline{1P \approx 4.96\ sekund}$$

2. Beregning av 3P:

   Turbinen består av 3 blader og perioden for hvert blad, 3P, blir 1P/3

$$3P = \frac{4.958678}{3} = 1.652893\ sekund$$

$$\underline{\underline{3P \approx 1.65\ sekund}}$$

Når det gjelder oppstarts frekvensen til rotoren er den satt til 6,9 rpm (ref. /L-8/ kapittel 1, tabell 1-1). Dette vil gi følgende verdier for 1P og 3P

$$1P = 6.9\ rpm = \frac{1}{60}\cdot 6.9\ Hz = 0.115\ Hz = \frac{1}{0.115}\ sekund = 8.695652\ sekund \approx \underline{8.70\ sekund}$$

$$3P = \frac{8.695652}{3} = 2.898551\ sekund \approx \underline{\underline{2.90\ sekund}}$$

Oppsummert er rotorens frekvensområde:

$$\underline{\underline{1{,}65\ sekund \leq rotorfrekvens \leq 2{,}90\ sekund}}$$

Ut i fra beregningene for rotorfrekvensen er konklusjonen at strukturfrekvensen ikke kan ligge i området mellom 1,65 sekund til 2,90 sekund. Dersom strukturfrekvensen ligger innenfor rotorfrekvensens område vil det oppstå resonans og man kan muligens få total kollaps av hele konstruksjonen. For å kunne fastsette akseptable strukturfrekvensområder, utenfor rotorfrekvensområdet, er det utført DAF beregninger.

DAF reknes ut etter likning (5.2):

$$DAF = \frac{1}{\sqrt{\left(1-\Omega^2\right)^2 + \left(2\cdot\xi\cdot\Omega\right)^2}} \tag{5.2}$$

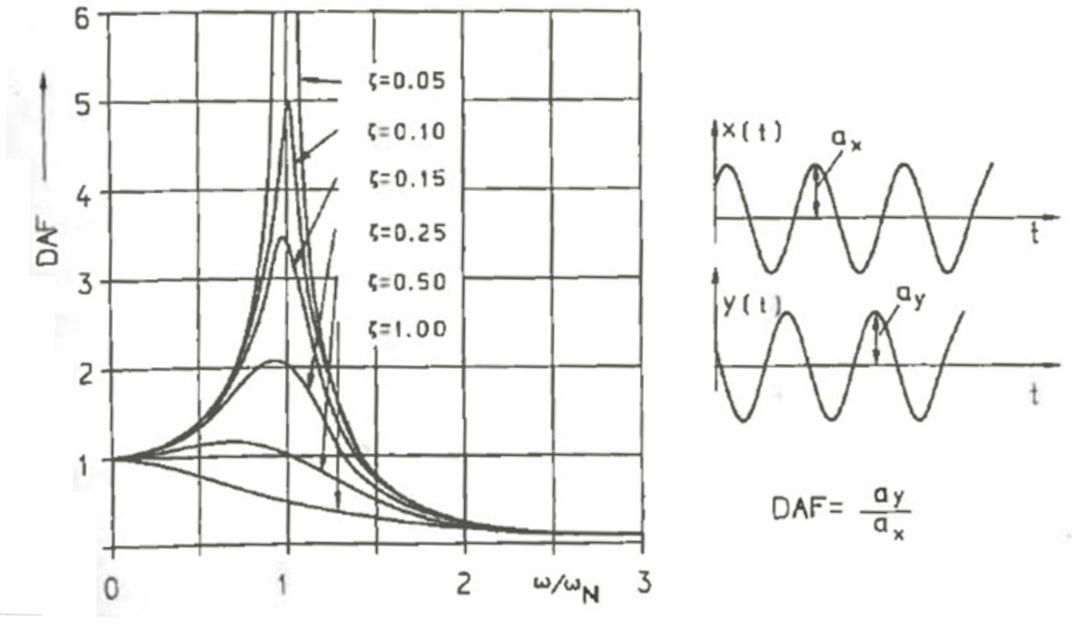
$$\Omega = \frac{\omega_r}{\omega_N} \tag{5.3}$$

$$\xi = \text{ dempingsforholdet } = \frac{C_{faktisk}}{C_c} \tag{5.4}$$

$C_{faktisk}$ = faktisk demping

C_c = kritisk demping

ξ er den samme som λ i likning (2.53), men det er valgt å sette den til ξ i dette kapittelet da det symbolet som er brukt på figur 5.3-3 fra ref. /L-10/.

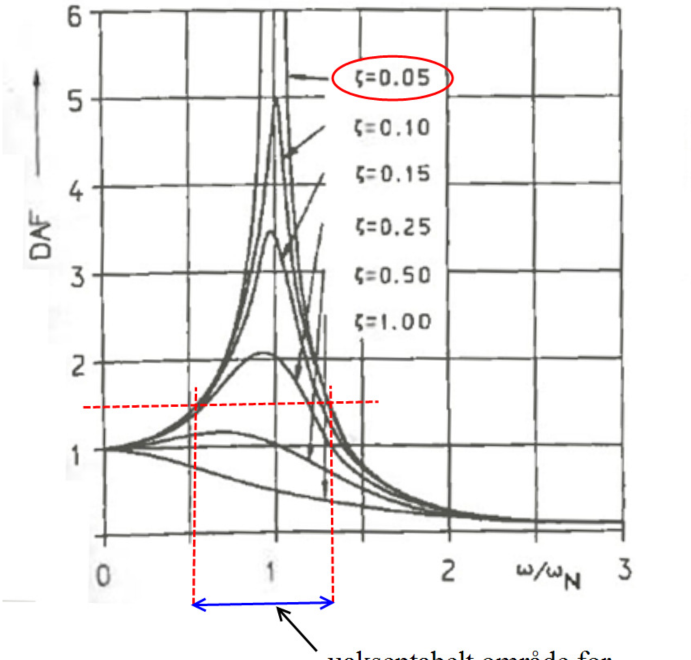


Figur 5.3-3 – Graf – DAF vs. egenfrekvens
Ref. /L-10/

ω_r og ω_N er egenfrekvenser og hvor ω_N er den naturlige egenfrekvensen til systemet. ω_r er den samme som ω på figur 5.3-3 og 5.3-4. Det er valg å gi en litt annen benevning i dette kapittelet enn det er på figuren da ω tidligere, i kapittel 2.1.1 og kapittel 2.1.2, er brukt som benevning på bølgefrekvens.

Det å fastsette $C_{faktisk}$ nøyaktig er veldig omstendelig og krever tunge og komplette elementanalyser. For å kunne gi en nøyaktig verdi må det sees på samspillet mellom alle elementene som inngår i konstruksjonen (innfestning til havbunn, interaksjon mellom seksjoner samt mellom selve turbinen og fundamentet og boltede forbindelser for å nevne noen). Når det gjelder offshore konstruksjoner er det vanlig å arbeide med et dempningsforhold på ca 5 – 10 %. På grunnlag av tidsbegrensning er det valgt å ikke beregne $C_{faktisk}$ nøyaktig men ta utgangspunkt i et dempningsforhold på 5 % for videre beregninger; dvs $\xi = 0.05$

På grunnlag av at det er relativt små bølger som belaster konstruksjonen, ref. tabell 5.2.1.2-1 i kapittel 5.2.1.2, vil det her foreslås at man kan aksepteres en DAF opp mot ca. 1.5. Figur 5.3-4 viser skissert område på graf for DAF versus egenfrekvens hvor strukturfrekvensen ikke kan være. Det vil si: strukturfrekvensen må ligge **utenfor** det angitte området som vist på figur 5.3-4.



uakseptabelt område for
strukturfrekvens

Figur 5.3-4 – Graf – Uakseptabelt område for strukturfrekvens
Ref. /L-10/

For å kunne fastslå hvilke frekvenser som er relatert til DAF = 1.5 er følgende beregninger utført:

$$DAF = \frac{1}{\sqrt{\left(1-\Omega^{2}\right)^{2} + \left(2\cdot 0.05\cdot\Omega\right)^{2}}} = 1.50$$

Løses likningen med hensyn til Ω blir resultatene som følger:

$$\Omega_1 \approx 0.579$$
$$\Omega_2 \approx 1.286$$
$$\Omega_3 \approx -0.579$$
$$\Omega_4 \approx -1.286$$

Verdiene for Ω_3 og Ω_4 er negative verdier og neglisjeres for videre beregninger. Det er kun de positive verdiene som er interessante med tanke på frekvens.

Videre brukes øvre (ω_r = 2.90 sekund) og nedre (ω_r = 1.65 sekund) verdi for rotorfrekvens for å kunne fastslå rammeverdiene til strukturfrekvensen. Ω_1 responderer til den øvre rotorfrekvensen og Ω_2 responderer til den nedre rotorfrekvensen.

ω_r = 2.90 gir en strukturfrekvens på

$$\Omega_1 = 0.579 = \frac{2.90}{\omega_N} \qquad \Rightarrow \qquad \omega_N \approx \underline{\underline{5.01}}$$

ω_r = 1.65 gir en strukturfrekvens på

$$\Omega_2 = 1.286 = \frac{1.65}{\omega_N} \qquad \Rightarrow \qquad \omega_N \approx \underline{\underline{1.283}}$$

Oppsummert kan strukturfrekvensen ha, ut fra DAF-beregningene, en verdi opp til 1.283 sekund eller en verdi over 5.01 sekund for å være i sikker avstand fra resonansproblematikken med rotoren.

$$\mathit{strukturfrekvens} < 1.283\,\mathit{sekund} \quad \text{eller} \quad \mathit{strukturfrekvens} > 5.01\,\mathit{sekund}$$

Videre må faren for resonans med bølgene vurderes. Bølgespekteret (scatterdiagram ref./L-20/) har en minsteperiode for bølger på ca. 3 sekund. Det vil si at det ikke er gunstig for strukturen å ha en frekvens på over 3 sekund da det gir fare for resonans med bølgene. De forestående DAF beregningene kom ut med at strukturen kan ha en frekvens på over 5.01 sekund (for DAF lik 1.5), men denne verdien må ekskluderes da den er i området for bølgefrekvensene. Da øvre verdi på rotorfrekvensen er på 2.9 sekund og nedre verdi på bølgefrekvensen er på 3.0 fører det til at strukturfrekvensen ikke kan være i området over 1.283 sekund. 1.283 sekund blir da den optimale maksimalverdien for strukturfrekvensen og det vil si at strukturfrekvensen må ligge under 1.283 sekund:

$$\underline{\underline{\mathit{strukturfrekvens} < 1.283\,\mathit{sekund}}}$$

For å kunne vurdere hvilket design som skal tas videre må det, i tillegg til å tilfredstille kodesjekk, ha en egenfrekvens i det aktuelle aksepterte området. Ut fra tabell 5.3-2 kan det sees at alternativ 1, 2 og 3 er de alternativene som oppfyller kravene over (både til kodesjekk og egenfrekvens i akseptert område). Men, som nevnt tidligere, ekskluderes alternativ 1 da dette ikke er et realistisk design med tanke på profilstørrelsene.

Videre er det vurdert at alternativ 3 er det beste alternativet for videre utmattingsanalyse da det omfatter slankere profilstørrelse på sentersøylen enn profilet til sentersøylen i alternativ 2. Alternativ 3 er da mer økonomisk lønnsomt samt konstruksjonsmessig løsbart enn alternativ 2 selv om alternativ 2 har en mer akseptabel egenfrekvensen med tanke på dens avstand til rotorfrekvensen (det er ønskelig med størst mulig differanse mellom strukturfrekvens og rotorfrekvens samt lav DAF). Alternativ 3 ligger mer i grenseland når det gjelder avstand til rotorfrekvensen, men det er tidligere konkludert med at det for denne oppgaven er akseptabelt med en DAF opp i mot 1.5 på grunn av belastningen er i form av små bølger.

For videre arbeid kan det være lurt å se på om det aktuelle designet eventuelt kan passe bedre for en mindre vindturbin som avgir mindre krefter samt kan ha en høyere operasjonell rotorfrekvens. Dersom det blir forsket på en turbin med høyere operasjonell rotorfrekvens kommer designet enda bedre ut på sammenlikningen av egenfrekvensene og det kan da med enda større sikkerhetsmargin sies å være ute av fare for resonans.

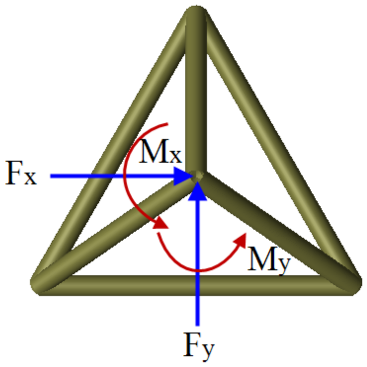
Flere analyser, med bruk av stivere profiler, kunne også blitt utført for å få egenfrekvensen mer ned, men profilstørrelsene i alternativ 2, som har den laveste egenfrekvensen av de reelle designene, er vurdert til å være såpass store at det i utgangspunktet ikke vil være reelt å fabrikkere dem (da med tanke på sentersøyle med tykkelse lik 0.15 meter). Det kunne vert mulig å optimalisere løsningen mer med tanke på å gjøre konstruksjonen mykere for å få høyere strukturfrekvens (opp i et området over 2.90 sekund som er rotorfrekvensens høyeste frekvens), men dette vil være tidkrevende når det eventuelt må ses på nye designløsninger og på grunn av tidsbegrensning blir dette en kilde til videre arbeid. Grunnen til at nye designløsninger må vurderes er at nåværende design, alternativ 5, gir for høye utnyttelsesfaktorer ved bruk av slankere elementer. Et alternativ er å lage en jackettripod som nevnt i kapittel 4.1. En mykere løsning vil mest sannsynlig blir mer økonomisk lønnsom i forhold til en stivere løsning med tanke på fabrikasjonskostnader. Ved et reelt design må dette tas i betraktning og veies opp mot levetid (da denne kan være lenger ved bruk av en stiv konstruksjon). Det vil si at det i praksis ikke er reaktivt gunstig å legge strukturfrekvensen i området over 2.90 sekund da det her er fare for resonans med bølgene. Dette kan gi betraktelig mindre levetid og mindre økonomiske utgifter ved fabrikasjon enn en løsning med lav strukturfrekvens (under 1.283 sekund). I tillegg kan det nevnes at en ny vurdering av DAF faktorer må bli utført for en eventuelt ny designløsning. Dette for å finne ut hvor strukturens egenfrekvens med sikkerhet kan legges og det må tas en vurdering på om det eventuelt er sikkert å legge strukturfrekvensen i området hvor det kan være fare for resonans med bølger.

Vurderingene som er utført i dette kapittelet viser nødvendigheten av å se på både det konstruksjonsmessig samt dynamiske perspektivet av en analyse (utforming av design). Det er nødvendig å få begge brikkene (både dynamikk og strukturanalyse) på plass for å få et reelt design som kan være operativt – og disse analysene må gjøres parallelt da de har innvirkning på hverandre. Dersom man for eksempel bare ser på den dynamiske delen kan en risikere å få et uøkonomisk design som i verste fall er umulig å fabrikkere. Men ser man bare på selve strukturanalysen, uten å ta hensyn til egenfrekvensen, kan man få et ”perfekt” design som er mest mulig lønnsomt å produsere, men som kanskje ikke ville vært operativt med tanke på levetid og kollaps ved en eventuell mulig resonans.

5.4 Global analyse

Globalanalysen omfatter bruken av de to analyseprogrammene FEDEM Windpower og Sesam GeniE. Begge programmene er brukt for å få et mest mulig reelt lastbilde. Da analysen gjelder en konstruksjon som er utsatt for komplekse aerodynamiske krefter, trengs det et analyseprogram som FEDEM Windpower. Videre brukes Sesam GeniE for den hydrodynamiske analysen samt kodesjekk av fundament konstruksjonen.

Bruken av to forskjellige analyseprogram (ett for aerodynamikken og ett for hydrodynamikken) kan medføre en del usikkerheter når det implementeres resultater fra det ene programmet inn i det andre. For å minimere usikkerhetene er det best å ha mest mulig av konstruksjonen i ett program. For å kunne sjekke om det er store avvik i forbindelse med modellering i de to forskjellige programmene vil det bli kjørt to analyser. En analyse vil bli foretatt hvor det blir tatt utgangspunkt i at bare fundamentet er modellert i Sesam GeniE (og det implementeres momenter og skjærkrefter fra FEDEM Windpower som er tatt ut i overgangen mellom fundament og tårn – ref. figur 5.4-1), og en analyse hvor selve vindturbintårnet også er modellert i SESAM GeniE (og det implementeres momenter og skjærkrefter fra FEDEM windpower som da er tatt ut i topp tårn på vindturbin). Ut i fra dette kan en vurdere om det har noe å si om det er modellert mer i det ene programmet eller det andre.



Figur 5.4-1 – Påsatte fra FEDEM Windpower påsatt i Sesam GeniE, z = +20.15m fra SWL

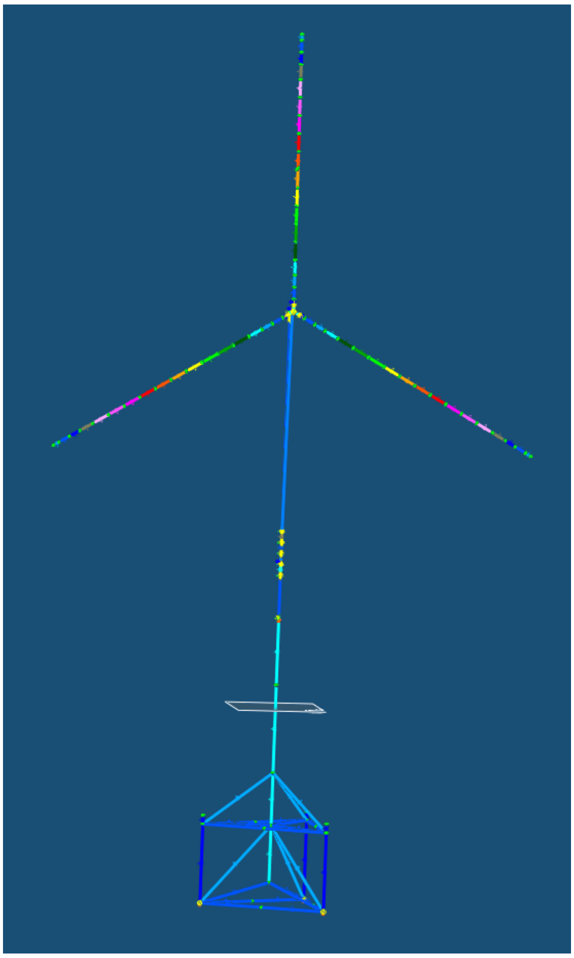
Det har blitt lagt ned en god del arbeid i forbindelse med opplæring og modellering i programmet FEDEM Windpower. Opplæringen har omfattet bruk av programmet (oppbygging av en enkel vindturbin) samt utprøvelse av import av filer(.fem filer generert av Sesam GeniE). Det lå utfordringer i selve importeringen samt sammenkobling av importerte filer med modellert vindturbin.

I tillegg er det også blitt utarbeidet ny kunnskap i forbindelse med bruken av Sesam GeniE. Dette har omhandlet metoder for modellering (oppbygging av modell), påsetting av hydrodynamiske bølgelasert samt vindprofil, utføring av kodesjekk, oppbygging av lastkombinasjoner, generering av strukturanalyse, egenfrekvensanalyse og hydrodynamisk analyse og uttak av analyseresultater.

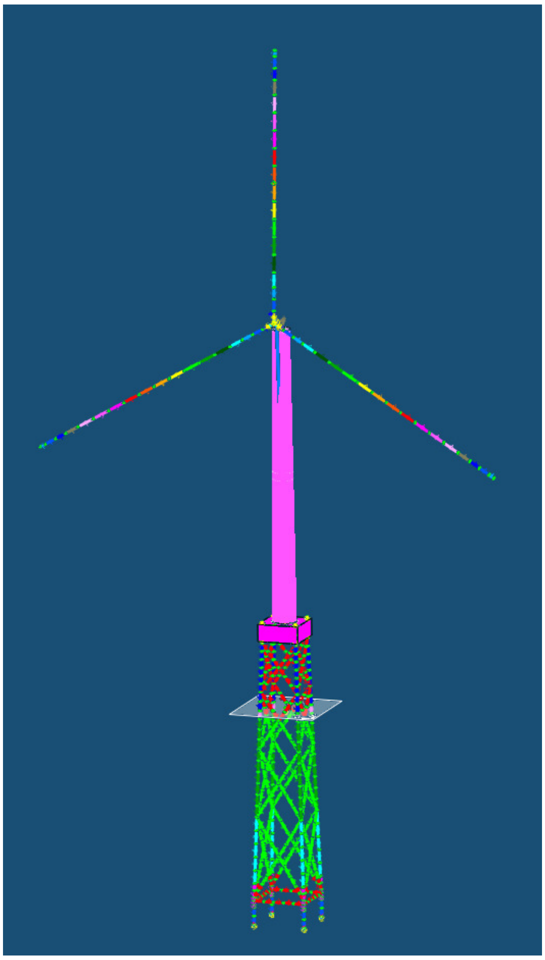
5.4.1 FEDEM Windpower analyse av vindturbin

I analysen er det tatt utgangspunkt i OC4 vindturbinen. Denne vindturbinen er med i et pågående prosjekt for utviklingen av simuleringsverktøy for vindturbiner (ref /I-11/ og /I-12/). Fundamentet (tripod) fra Sesam GeniE er importert i modellen (ref. figur 5.4.1-1) for å kunne få det mest reelle lastbildet.

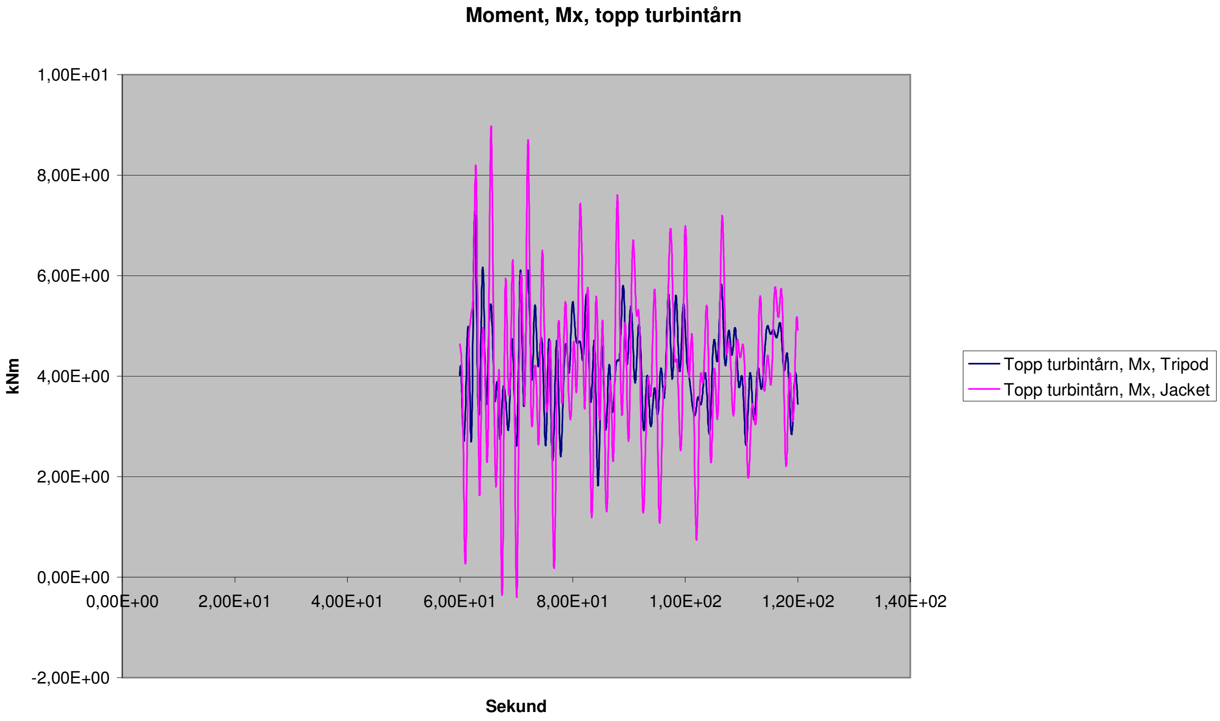
Verifisering av laster (resultater) er utført for å kontrollere påliteligheten av modellen. Det har blitt utført sammenlikninger mot komplett OC4 turbin med jacket fundament. Sammenlikningene har bestått i å kjøre simuleringer uten ytre lastpåkjenninger (aero- og hydrodynamiske laster) men med rotasjon av blader for begge tilfeller, tripod fra Sesam GeniE og jacket fundament fra komplett OC4 modell. Verifiseringen er gjort i overgang tårn/fundament samt i overgang nacelle/turbintårn. Moment og skjærkrefter er sammenliknet. Figur 5.4.1-1 og figur 5.4.1-2 illustrerer OC4 turbinen supportert med henholdsvis tripodfundament og jacket. Figur 5.4.1-3 til figur 5.4.1-10 viser moment og skjærkraft i topp og bunn turbintårn for begge tilfeller, tripod og jacket.



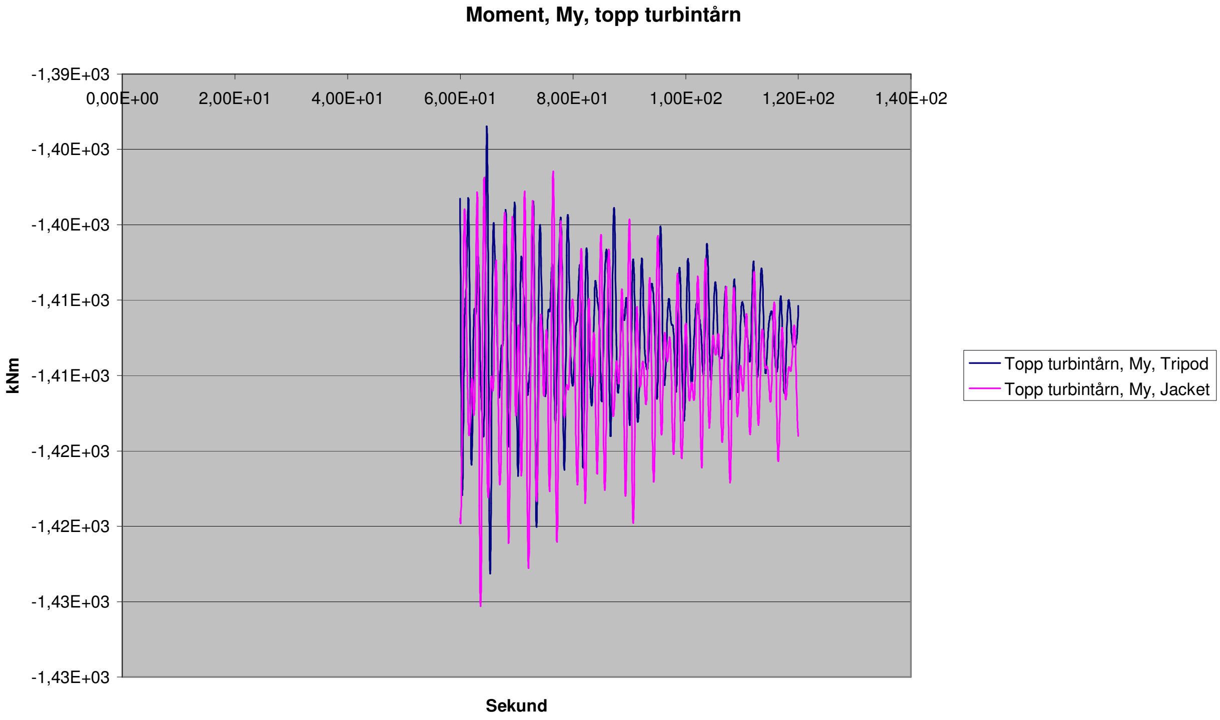
Figur 5.4.1-1 – Illustrasjon fra FEDEM – triodfundament og OC4 vindturbin



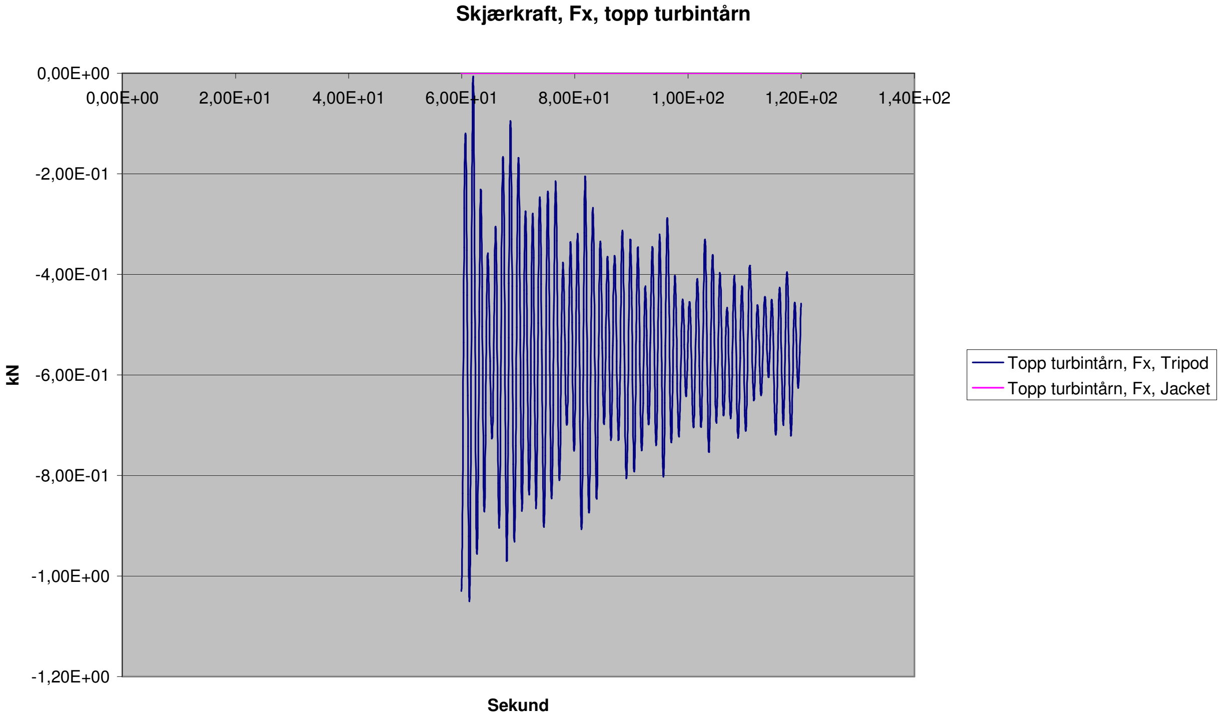
Figur 5.4.1-2 – Illustrasjon fra FEDEM – jacketfundament og OC4 vind turbin



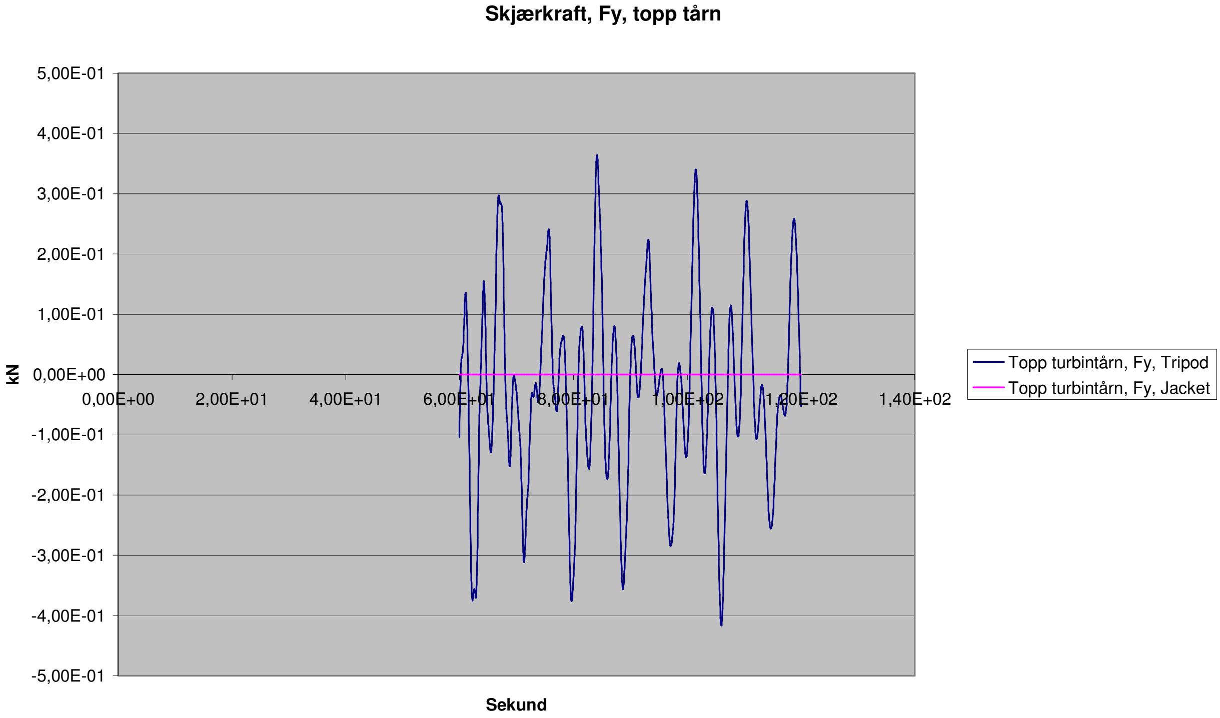
Figur 5.4.1-3 – Moment, Mx, topp turbintårn – tripod- vs. jacket fundament



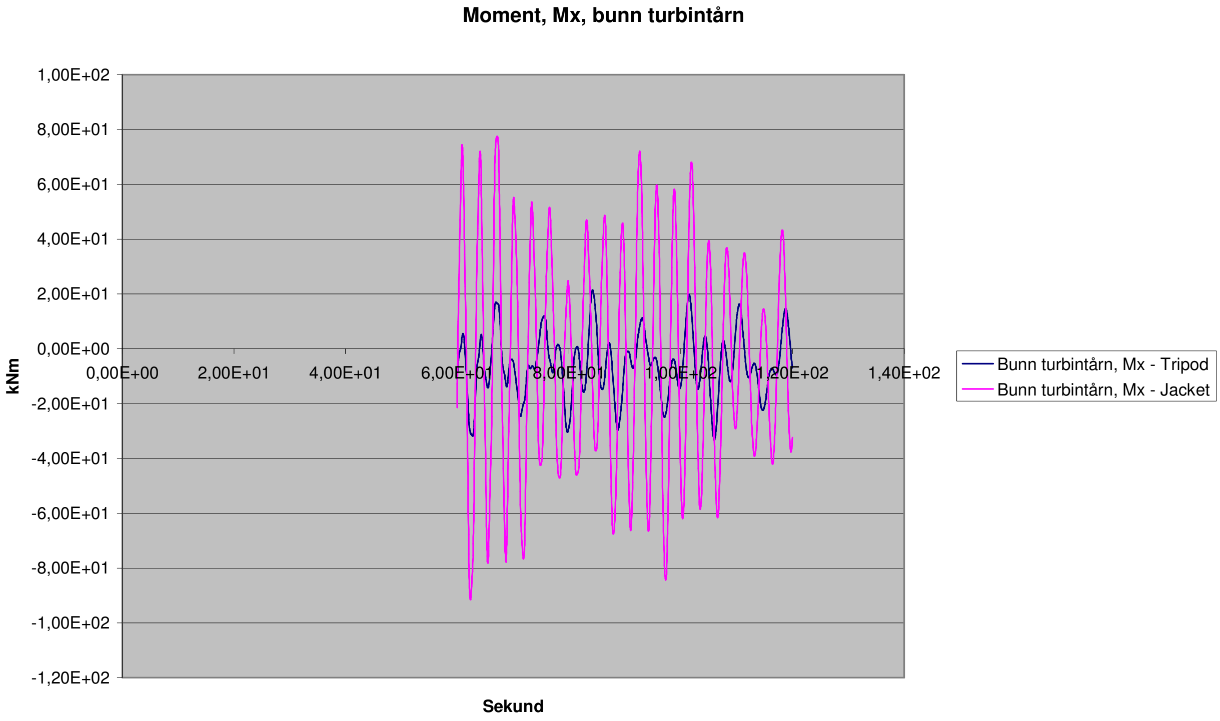
Figur 5.4.1-4 – Moment, My, topp turbintårn – tripod- vs. jacket fundament



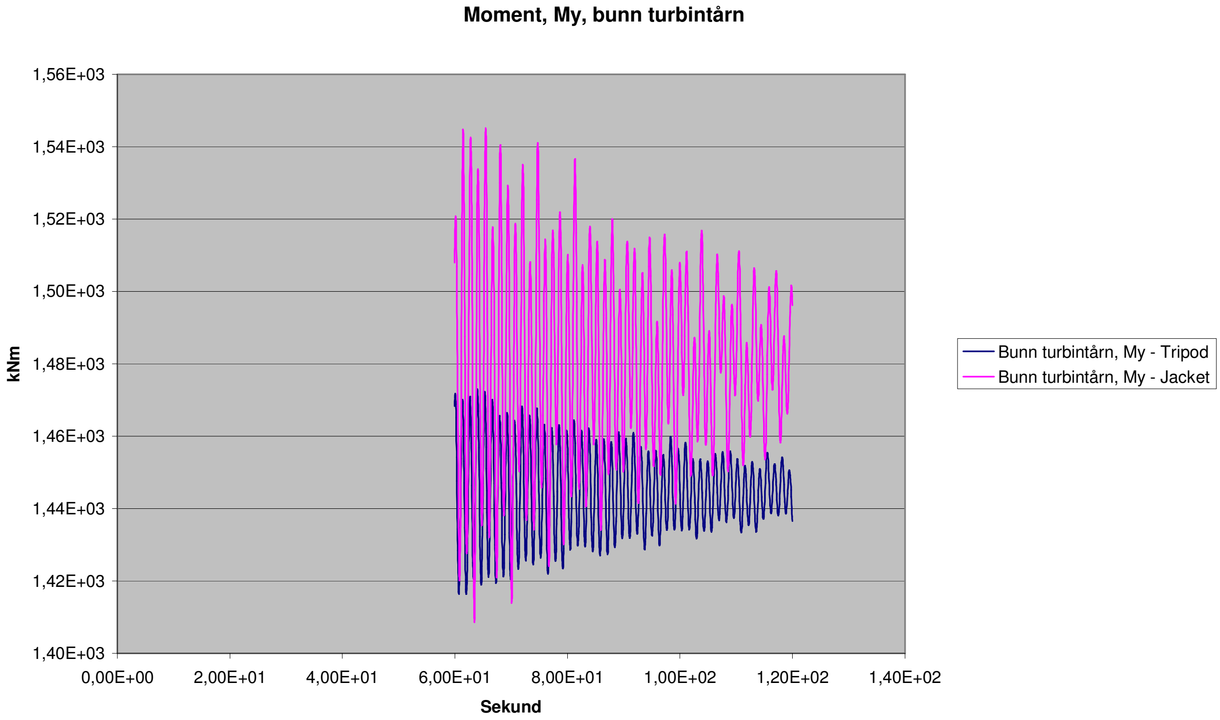
Figur 5.4.1-5 – Skjærkraft, Fx, topp turbintårn – tripod- vs. jacket fundament



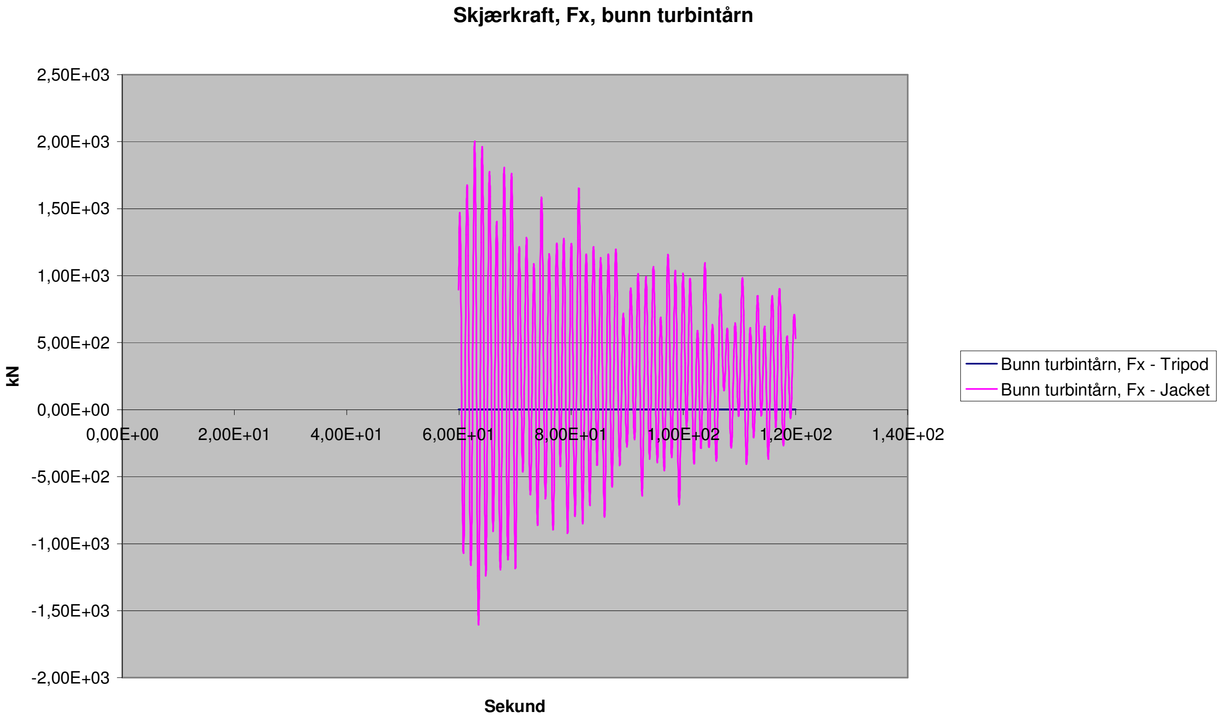
Figur 5.4.1-6 – Skjærkraft, Fy, topp turbintårn – tripod- vs. jacket fundament



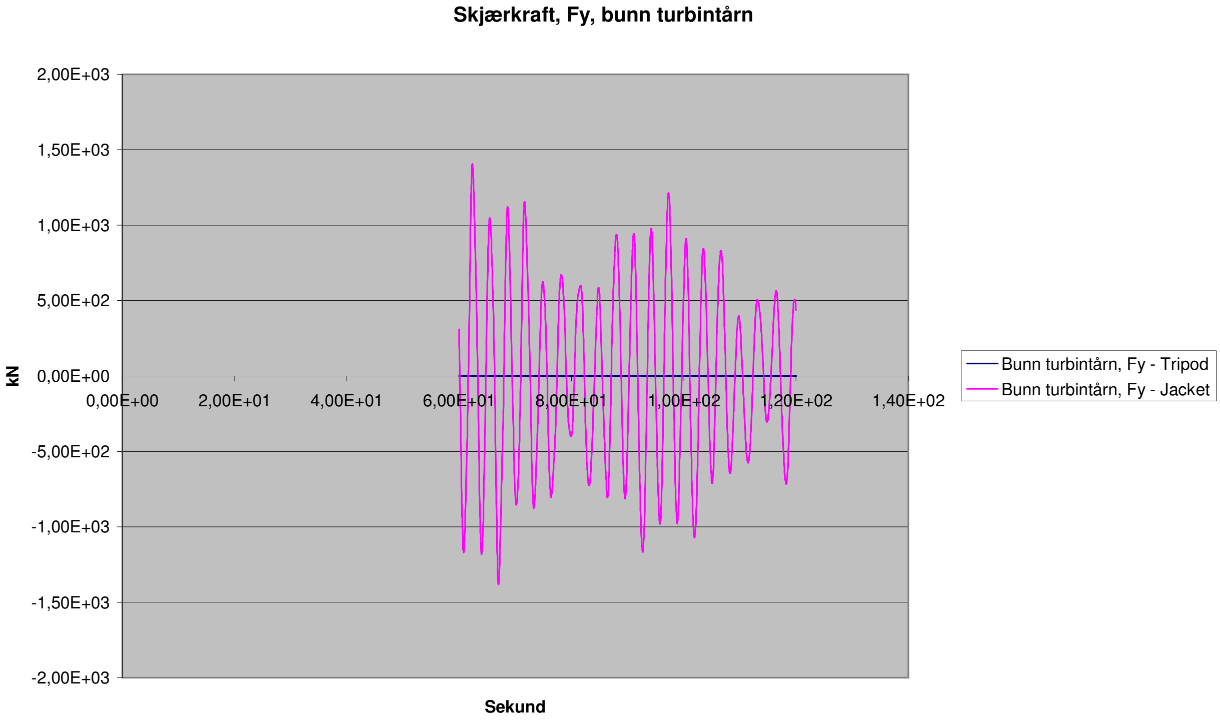
Figur 5.4.1-7 – Moment, Mx, bunn turbintårn – tripod- vs. jacket fundament



Figur 5.4.1-8 – Moment, My, bunn turbintårn – tripod- vs. jacket fundament

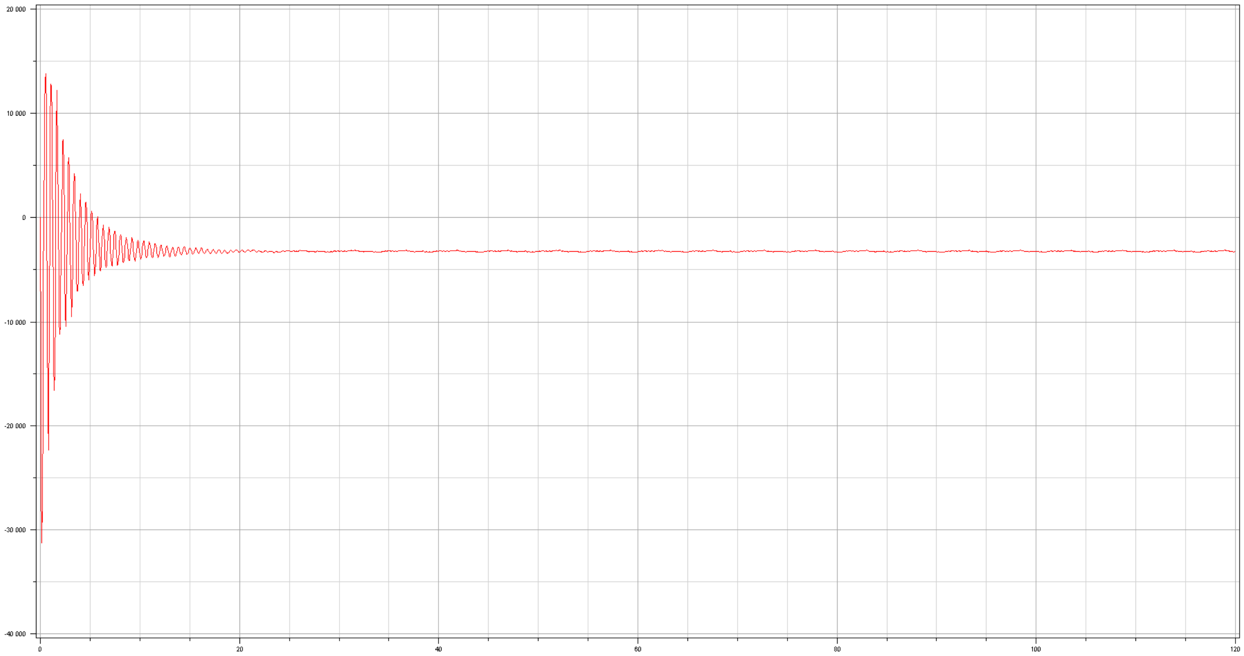


Figur 5.4.1-9 – Skjærkraft, Fx, bunn turbintårn – tripod- vs. jacket fundament



Figur 5.4.1-10 – Skjærkraft, Fy, bunn turbintårn – tripod- vs. jacket fundament

I illustrasjonene er det valgt å vise resultatene for analysene i tidsrommet fra 60 til 120 sekund. Dette fordi de første sekundene i simuleringen fra FEDEM Windpower inneholder litt startproblemer som gir unøyaktige resultater. Figur 5.4.1-11 viser moment om x-akse i bunn turbintårn fra 0 til 120 sekund med påsatt vind, 15 m/s, for å illustrer de store variasjonene som oppstår de første sekundene av simuleringen. Figur er tatt ut fra FEDEM Windpower.



Figur 5.4.1-11 – Illustrasjon, momentgraf fra FEDEM Windpower, vindstyrke 15 m/s

Når det gjelder figurene 5.4.1-3 til og med figur 5.4.1-10 kan det sees et litt stort avvik i verifiseringene for skjærkrefter. Disse avvikene viser seg gjeldende på modellen med jacketfundament. I bunn fundament er det spredning i variasjonen for kreftene, mens det i topp turbintårn er null skjærkrefter i det gitte tilfellet. Studeres tripodfundamentet viser det at skjærkreftene er like i topp og bunn av turbintårnet bare med motsatt fortegn (dvs. positiv kraftverdi i bunn med lik negativ kraftverdi i topp og omvendt).

Momentene for begge tilfellene er så og si innenfor samme lastområde, noe som tyder på at den nye modellen med tripod fundament fungerer korrekt. Det er naturlig at lastene ikke er helt identiske da de to forskjellige fundamentløsningene gir forskjellig bidrag til oppførsel sammen med turbinen.

Ut i fra vurderingene over er det konkludert med at modellen med tripodfundament i FEDEM Windpower kan brukes videre i analysen med god nok nøyaktighet.

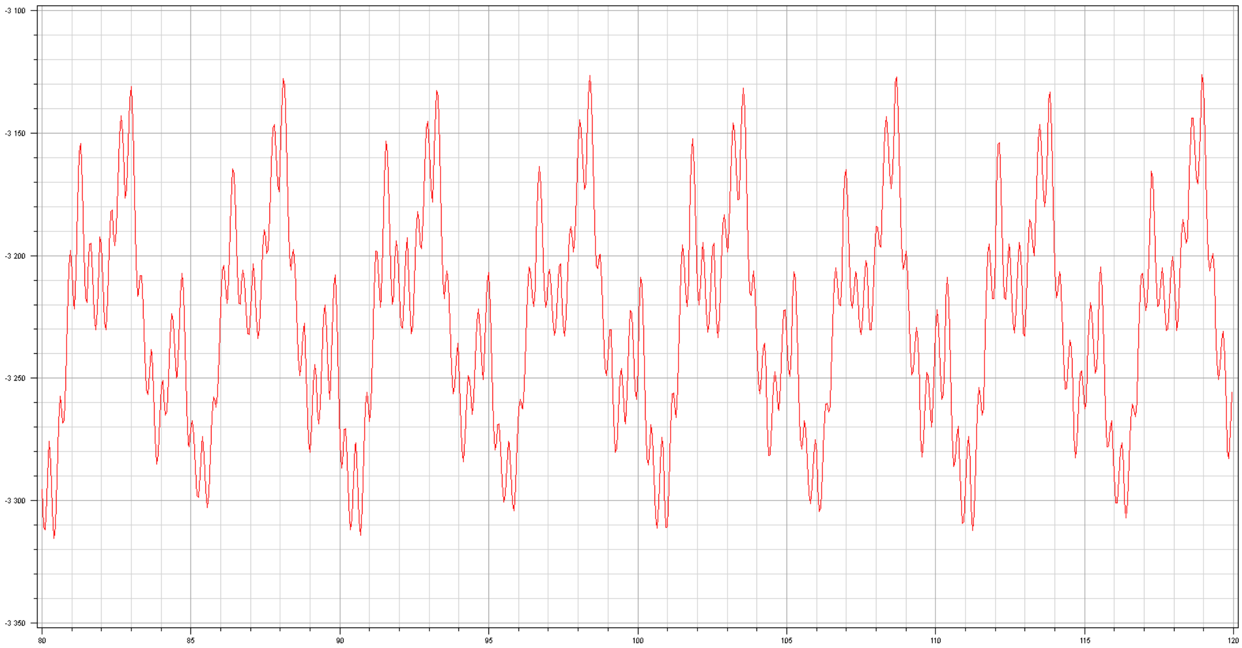
5.4.1.1 Resultater av simulering med OC4 vindturbin og tripod

I henhold til tabell 4.1 i ref /L-7/ er det valgt å kjøre analyse med 5 forskjellige vindhastigheter. Resultatene for disse analysene er representert i tabell 5.4.1.1-1

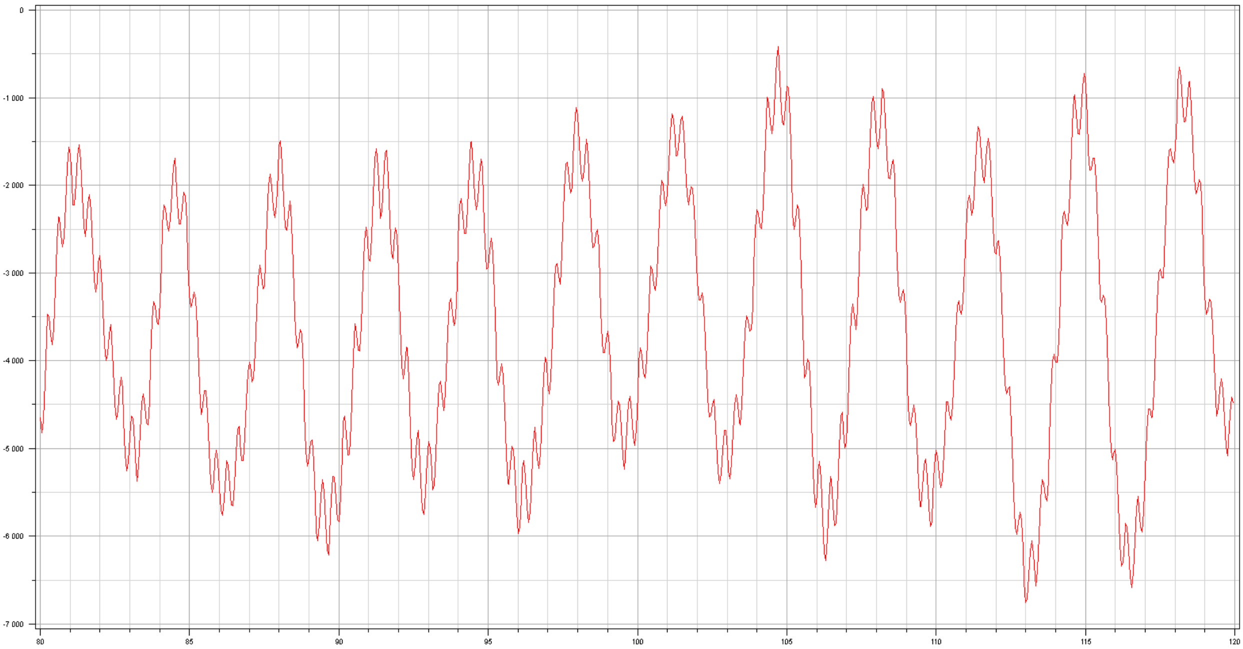
Tabell 5.4.1.1-1 – Maks krefter fra FEDEM Windpower ved forskjellige vindhastigheter

	Uten turbulens		Med turbulens	
Vindhastighet (m/s)	Maks krefter topp turbintårn	Maks krefter bunn turbintårn	Maks krefter topp turbintårn	Maks krefter bunn turbintårn
5	M_x = 591 kNm M_y = -1080 kNm F_x = 182 kN F_y = -1,02 kN	M_x = -648 kNm M_y = -11400 kNm F_x = -182 kN F_y = 1,02 kN	M_x = 1330 kNm M_y = -2530 kNm F_x = 513 kN F_y = 39 kN	M_x = -3520 kNm M_y = -35100 kNm F_x = -513 kN F_y = -39 kN
7	M_x = 1510 kNm M_y = -817 kNm F_x = 319 kN F_y = 2,44 kN	M_x = -1600 kNm M_y = -20900 kNm F_x = -319 kN F_y = -2,44 kN	M_x = 2710 kNm M_y = 3140 kNm F_x = 728 kN F_y = -112 kN	M_x = -5150 kNm M_y = -51600 kNm F_x = -729 kN F_y = 112 kN
10	M_x = 3510 kNm M_y = -344 kNm F_x = 669 kN F_y = -172 kN	M_x = -15200 kNm M_y = -45400 kNm F_x = -669 kNm F_y = 172 kN	M_x = 6490 kNm M_y = 3720 kNm F_x = -1070 kN F_y = -1100 kN	M_x = -9510 kNm M_y = -73600 kNm F_x = 1070 kN F_y = 1100 kN
15	M_x = 4300 kNm M_y = -829 kNm F_x = 496 kN F_y = -69,7 kN	M_x = -9010 kNm M_y = -33400 kNm F_x = -496 kNm F_y = 69,7 kN	M_x = 7690 kNm M_y = 7580 kNm F_x = 1270 kN F_y = -1550 kN	M_x = -112000 kNm M_y = -91000 kNm F_x = -1270 kN F_y = 1550 kN
25	M_x = 4440 kNm M_y = -954 kNm F_x = 397 kN F_y = -145 kN	M_x = -14300 kNm M_y = -27100 kNm F_x = -397 kN F_y = 145 kN	M_x = 7800 kNm M_y = 12300 kNm F_x = 999 kN F_y = -1430 kN	M_x = -105000 kNm M_y = -7380 kNm F_x = -999 kN F_y = 1430 kN

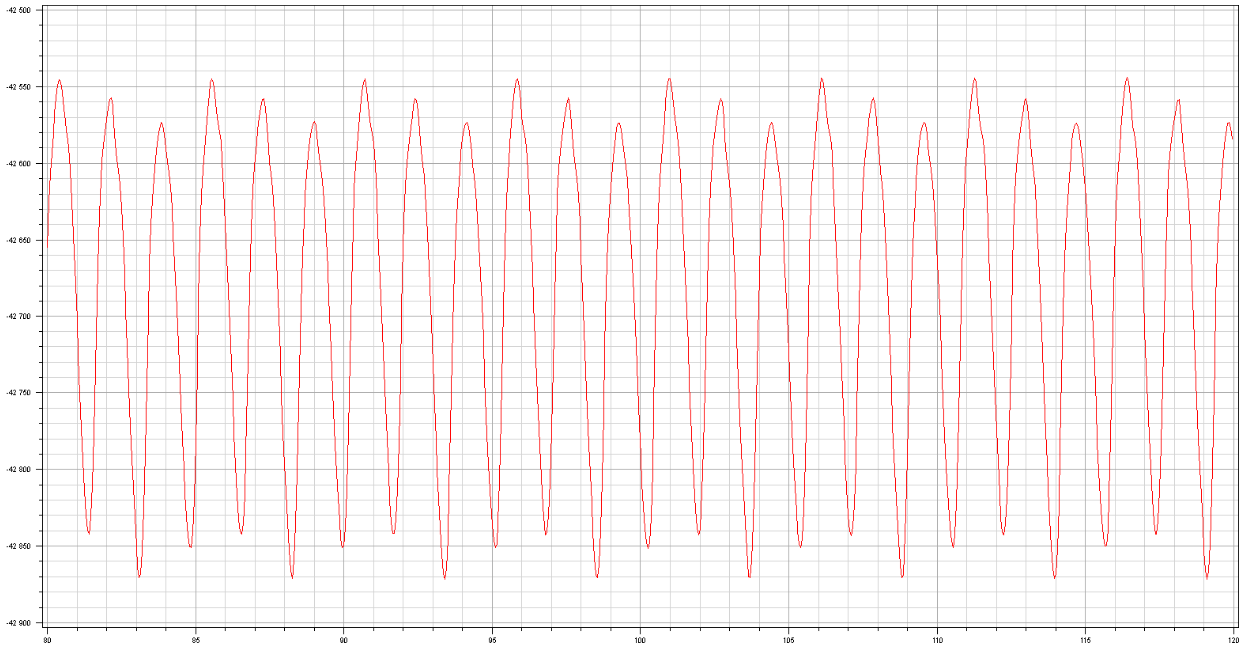
For å illustrere forskjellen i kraftkurvene med og uten turbulens er tatt ut kurver av moment og skjærkraft i overgangen turbintårn/fundament. Det er valg å vise resultater for vindhastighet 15 m/s og fra tidsintervallet 80 – 120 sekund. Dette er et vilkårlig valg da hensikten er illustrasjon av turbulensens og den ville blitt den samme uansett vindhastighet.



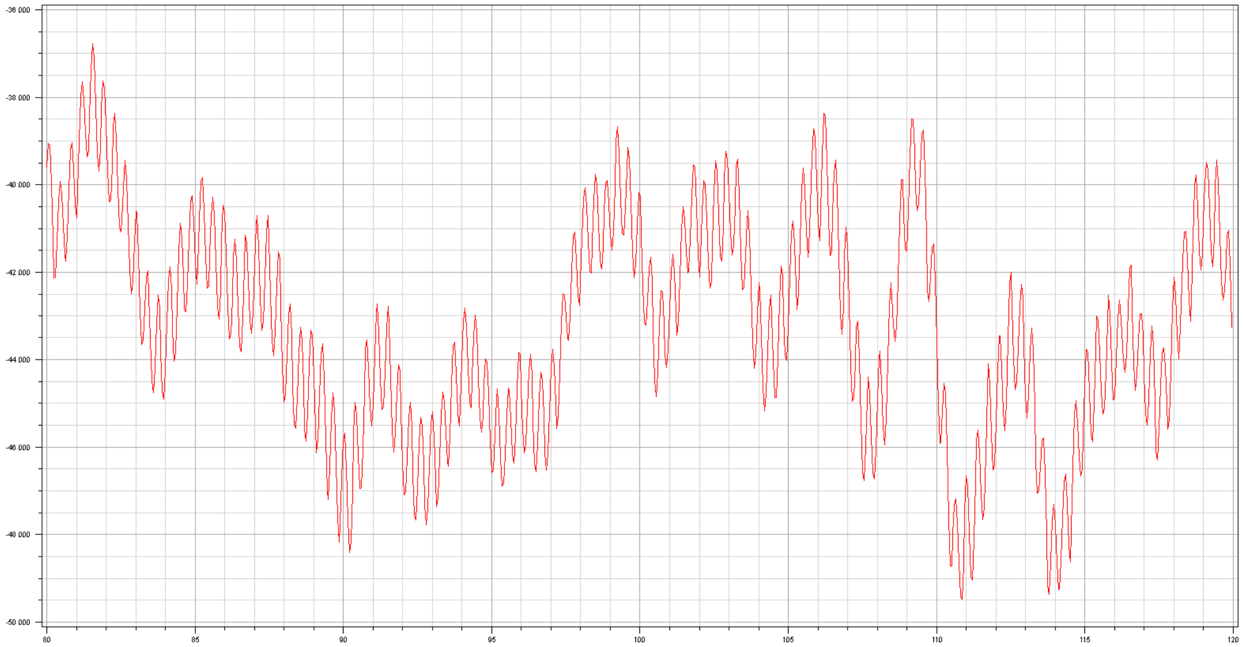
Figur 5.4.1.1-1 – Mx fra FEDEM Windpower, vindstyrke 15 m/s uten turbulens; 80 – 120 s



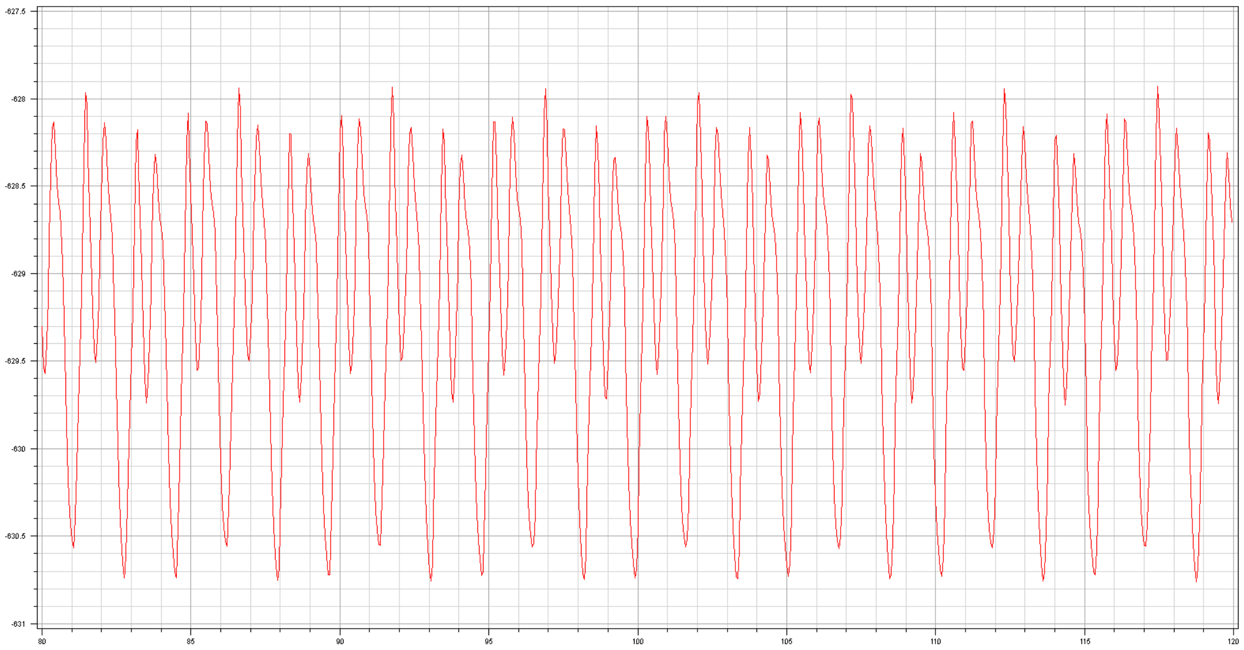
Figur 5.4.1.1-2 – Mx fra FEDEM Windpower, vindstyrke 15 m/s med turbulens; 80 – 120 s



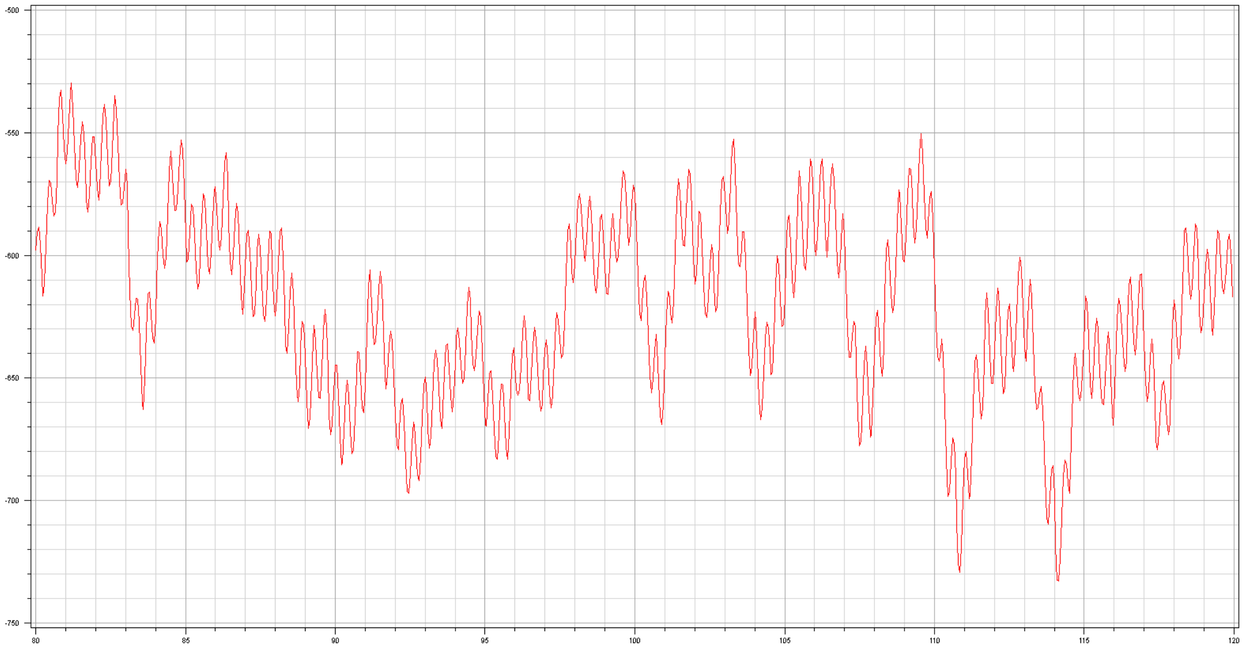
Figur 5.4.1.1-3 – My fra FEDEM Windpower, vindstyrke 15 m/s uten turbulens; 80 – 120 s



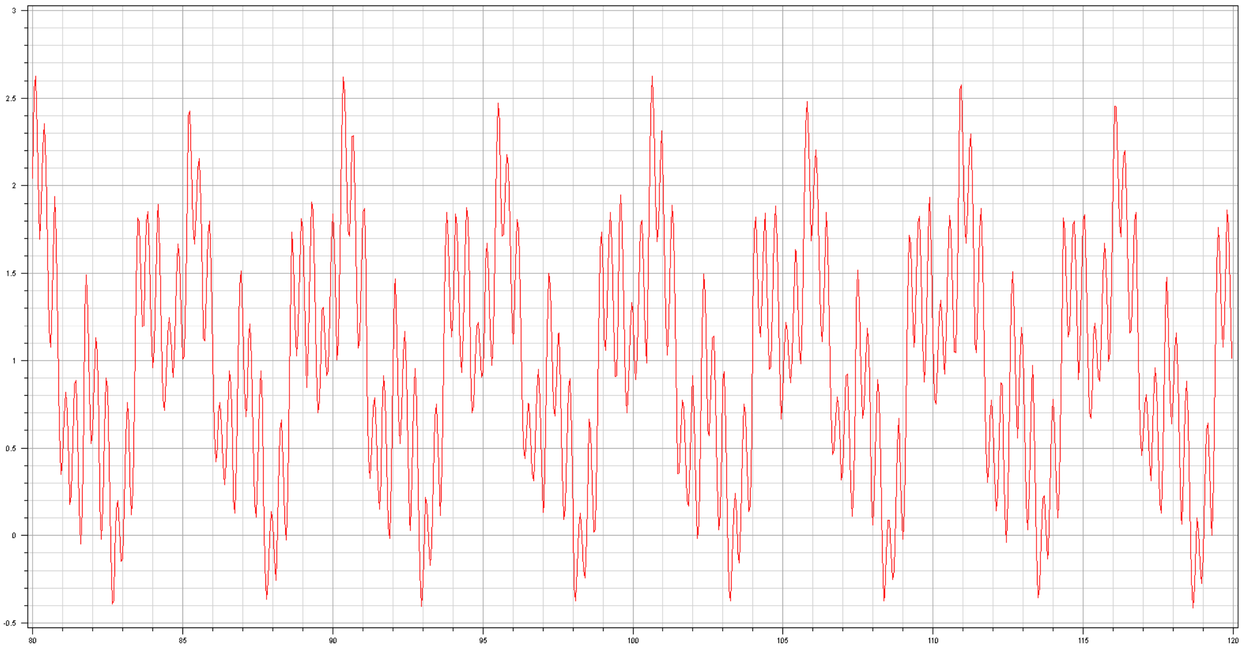
Figur 5.4.1.1-4 – My fra FEDEM Windpower, vindstyrke 15 m/s med turbulens; 80 – 120 s



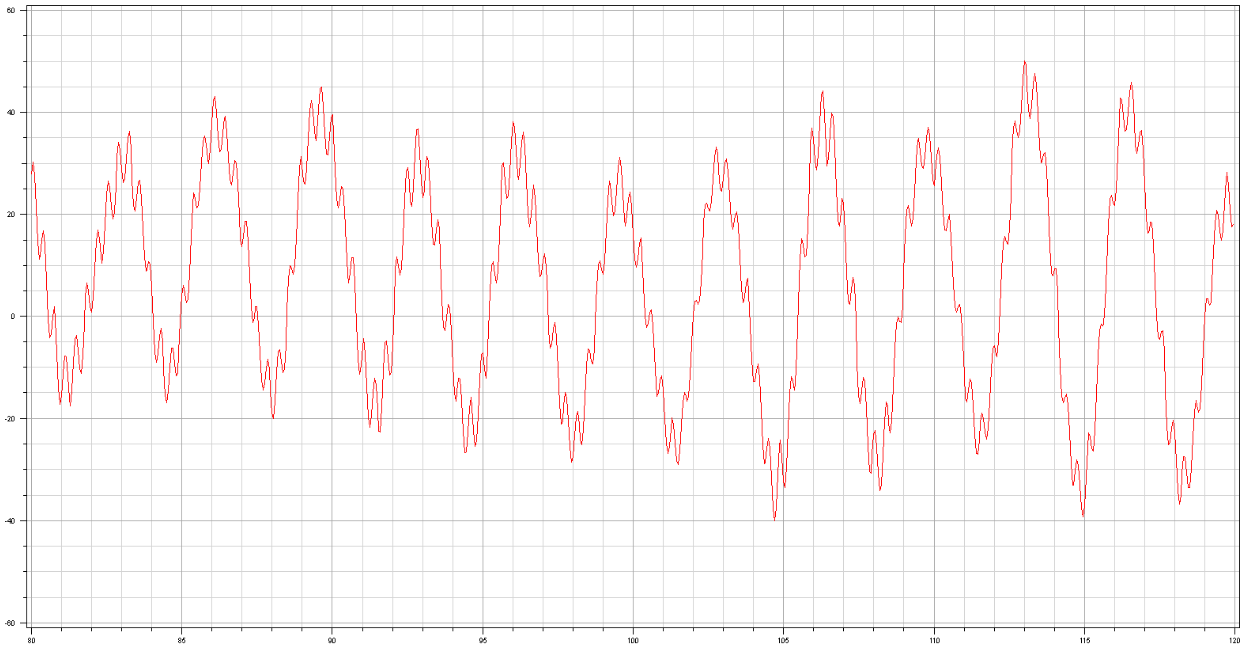
Figur 5.4.1.1-5 – Fx fra FEDEM Windpower, vindstyrke 15 m/s uten turbulens; 80 – 120 s



Figur 5.4.1.1-6 – Fx fra FEDEM Windpower, vindstyrke 15 m/s med turbulens; 80 – 120 s



Figur 5.4.1.1-7 – Fy fra FEDEM Windpower, vindstyrke 15 m/s uten turbulens; 80 – 120 s



Figur 5.4.1.1-8 – Fy fra FEDEM Windpower, vindstyrke 15 m/s med turbulens; 80 – 120 s

Simuleringene med turbulens er utført sammen med programmet Turbsim. Dette er et program som generer vindfiler inkludert turbulens. Som input for generering av turbulens er det to modeller som kan bli brukt; ”dynamic inflow model” og ”equil model”. Forskjellen på disse to modellene er at ”dynamic inflow” modellen er raskere, men litt mer avvikende i resultatene for lave og høye hastigheter, enn ”equil” modellen. Turbulenssimuleringen som er utført i denne oppgaven er gjort med ”dynamic inflow” som input. Det at simuleringstiden er betydelig mindre ved bruk av denne modellen var avgjørende for valget, og det ble vurdert at avvikene i resultatene for de høye og lave hastighetene blir registrert som mulige feilkilder. Selve fremgangsmåten for de videre beregningene er den samme uavhengig av hvilken input modell som brukes i turbulenssimuleringen, men resultatene hadde blitt litt mer nøyaktige ved bruk av ”equil” modellen.

Turbulensintensiteten er gitt som i tabell 5.4.1.1-2 (ref. /L-7/ tabell 4.1) og eksponentfaktoren, r, til vindskjær er satt til 0,11 (ref. /L-7/ kapittel 4.1) og formel (2.19) i kapittel 2.2 – Vindteori.

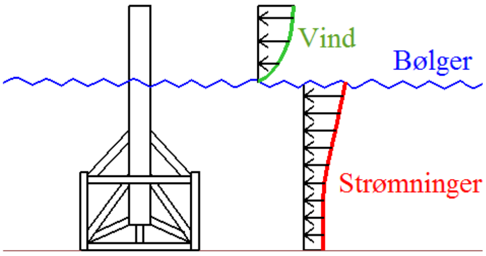
Tabell 5.4.1.1-2 - Turbulensintensitet

Vindhastighet (m/s)	Turbulensintensitet (%)
5	20,7
7	18,1
10	16,8
15	15,7
25	13,4

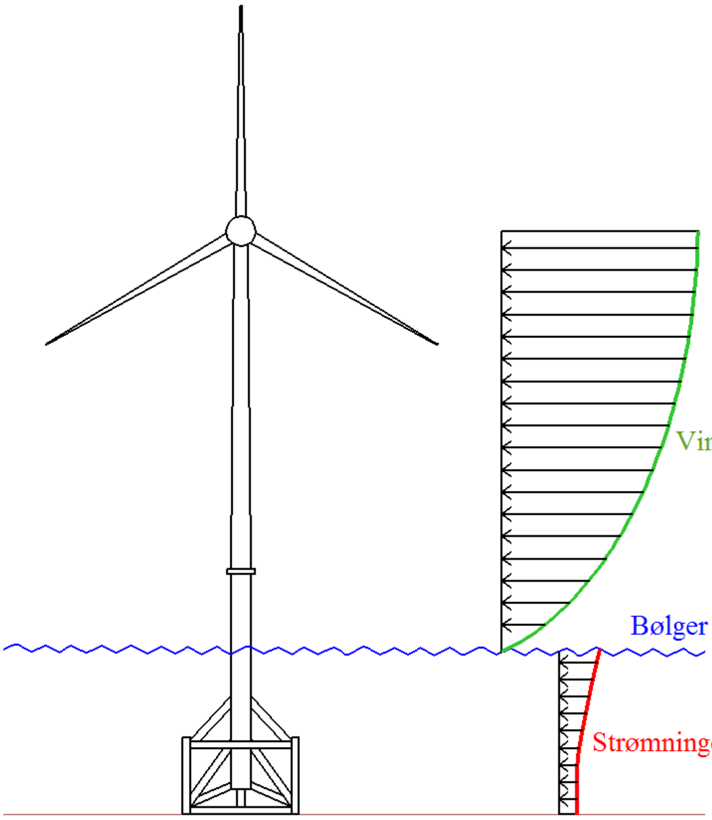
Turbulensintensiteten kan fastsettes etter formlene (2.16) – (2.18) i kapittel 2.2 – Vindteori.

5.4.2 Sesam GeniE analyse av fundament

Som nevnt i kapittel 5.4, Global analyse, er det utført to analyser i Sesam GeniE. Analyse 1 omhandler fundamentet mens analyse 2 omhandler fundament pluss vindturbintårn. Hydrodynamiske krefter (inkludert vindprofil for begge analyser) er påsatt og kodeskjekk utført (ref figur 5.4.2-1 og figur 5-4-2-2).



Figur 5.4.2-1 – Illustrasjon av miljøbelastning i Sesam GeniE; Analyse 1



Figur 5.4.2-2 – Illustrasjon av miljøbelastning i Sesam GeniE; Analyse 2

Kun fundament og turbintårn er modellert i Sesam GeniE

Blader og hub er kun vist på figuren for å gi et total bilde av konstruksjonen..

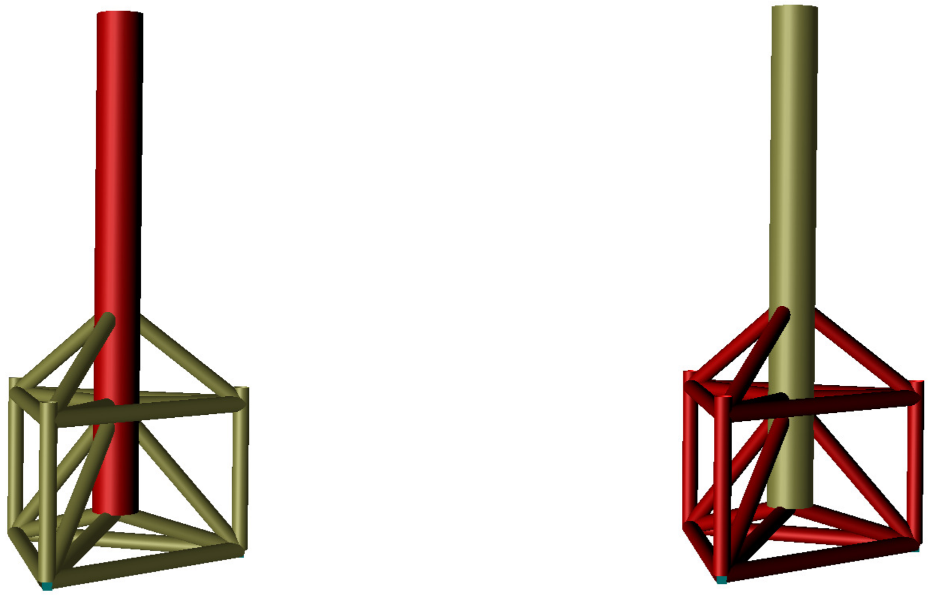
For å forenkle oppgavens omfang er det valgt å sette innfestning til havbunnen som fast innspent. I virkeligheten vil dette ikke være helt nøyaktig da pæler og jordsmonn vil være med å påvirke resultatet av analysen, men da en oppbygging av dette vil være tidskrevende er det valgt å se bort fra dette i denne omgang. Fremgangsmåten for beregningene som er gjort vil være den samme om man tar hensyn til friksjonen i innfesningen til havbunnen eller ikke. Det er tatt hensyn til oppdrift i analysen. For lastfaktorer ref. tabell 5.4.2-1

Tabell 5.4.2-1 – Lasttilfeller, lastkombinasjoner og lastfaktorer benyttet i SESAM GeniE

Last tilfelle	*Beskrivelse*	*Retning*	*Lastfaktor*	
			ULS A	ULS B
Fedem_mx	Moment fra vindturbin (x retning)		1.3	1.0
Fedem_my	Moment fra vindturbin (y retning)		1.3	1.0
Fedem_fx	Skjærkraft fra vindturbin (x retning)		1.3	1.0
Fedem_fy	Skjærkraft fra vindturbin (y retning)		1.3	1.0
Gravity	Egenvekt av konstruksjon		1.3	1.0
vindNord	Eget vindprofil inkludert i den hydrodynamiske analysen	Nord	0.7	1.3
vindSoer	Eget vindprofil inkludert i den hydrodynamiske analysen	Sør	0.7	1.3
vindOest	Eget vindprofil inkludert i den hydrodynamiske analysen	Øst	0.7	1.3
vindVest	Eget vindprofil inkludert i den hydrodynamiske analysen	Vest	0.7	1.3
WLC(1,1)	Maks skjærkraft på grunn av hydrodynamikk	Nord	0.7	1.3
WLC(1,2)	Maks moment på grunn av hydrodynamikk	Nord	0.7	1.3
WLC(2,1)	Maks skjærkraft på grunn av hydrodynamikk	Øst	0.7	1.3
WLC(2,2)	Maks moment på grunn av hydrodynamikk	Øst	0.7	1.3
WLC(3,1)	Maks skjærkraft på grunn av hydrodynamikk	Sør	0.7	1.3
WLC(3,2)	Maks moment på grunn av hydrodynamikk	Sør	0.7	1.3
WLC(4,1)	Maks skjærkraft på grunn av hydrodynamikk	Vest	0.7	1.3
WLC(4,2)	Maks moment på grunn av hydrodynamikk	Vest	0.7	1.3
Last kombinasjon	*Beskrivelse*	*Retning*		
ULS_A_N	Fedem_mx + Fedem_my + Fedem_fx + Fedem_fy + Gravity + vind + WLC(1,1) + WLC(1,2)	Nord		
ULS_A_E	Fedem_mx + Fedem_my + Fedem_fx + Fedem_fy + Gravity + vind + WLC(2,1) + WLC(2,2)	Øst		
ULS_A_S	Fedem_mx + Fedem_my + Fedem_fx + Fedem_fy + Gravity + vind + WLC(3,1) + WLC(3,2)	Sør		
ULS_A_W	Fedem_mx + Fedem_my + Fedem_fx + Fedem_fy + Gravity + vind + WLC(4,1) + WLC(4,2)	Vest		
ULS_B_N	Fedem_mx + Fedem_my + Fedem_fx + Fedem_fy + Gravity + vind + WLC(1,1) + WLC(1,2)	Nord		
ULS_B_E	Fedem_mx + Fedem_my + Fedem_fx + Fedem_fy + Gravity + vind + WLC(2,1) + WLC(2,2)	Øst		
ULS_B_S	Fedem_mx + Fedem_my + Fedem_fx + Fedem_fy + Gravity + vind + WLC(3,1) + WLC(3,2)	Sør		
ULS_B_W	Fedem_mx + Fedem_my + Fedem_fx + Fedem_fy + Gravity + vind + WLC(4,1) + WLC(4,2)	Vest		

Lastfaktorene er tatt etter Norsok N-001, ref. /S-10/ kapittel 6.2.1 tabell 1. Disse faktorene blir brukt for bemannede installasjoner og da følgende prosjekt vil være ubemannet kan det sees på som veldig konservativt å bruke lastfaktorer for bemannede installasjoner. Grunnen til at det er valg å bruke lastfaktorer som er konservative er for å kompensere for den utelatte DAF faktoren i beregningene. På den måten kan de sies at DAF er tatt hensyn til når lastfaktorer for en bemannet installasjon er brukt.

Som nevnt i kapittel 5.3, Sjekk av frekvensområder, er det valgt følgende profilstørrelser som vist på figur 5.4.2-3. Dette er alternativ 3 fra tabell 5.3-1. Valget er gjort med tanke på strukturens egenfrekvens og at faren for resonans med rotorfrekvensen skal være tatt hensyn til.

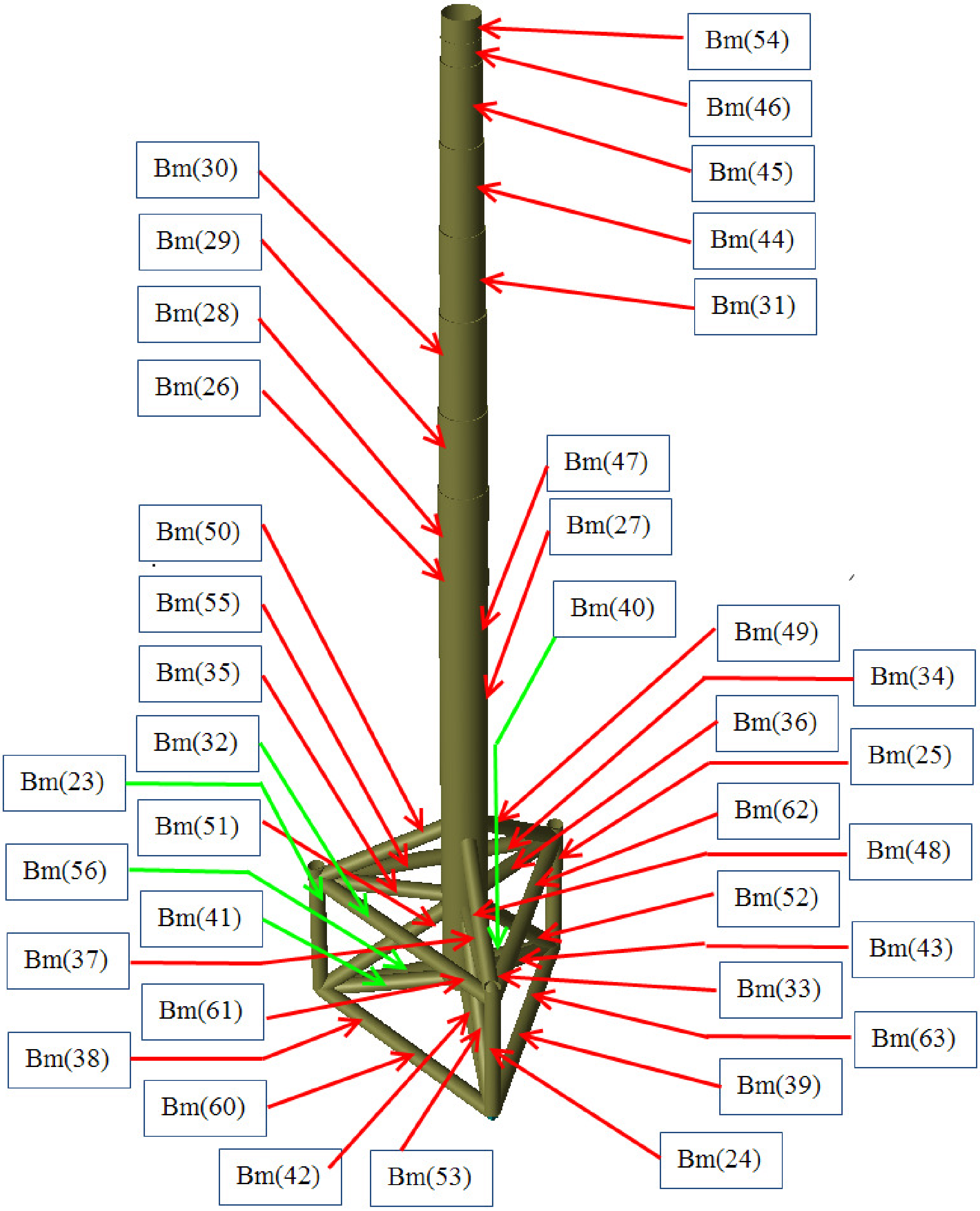


OD = 5.6 m og tykkelse = 0.075 m

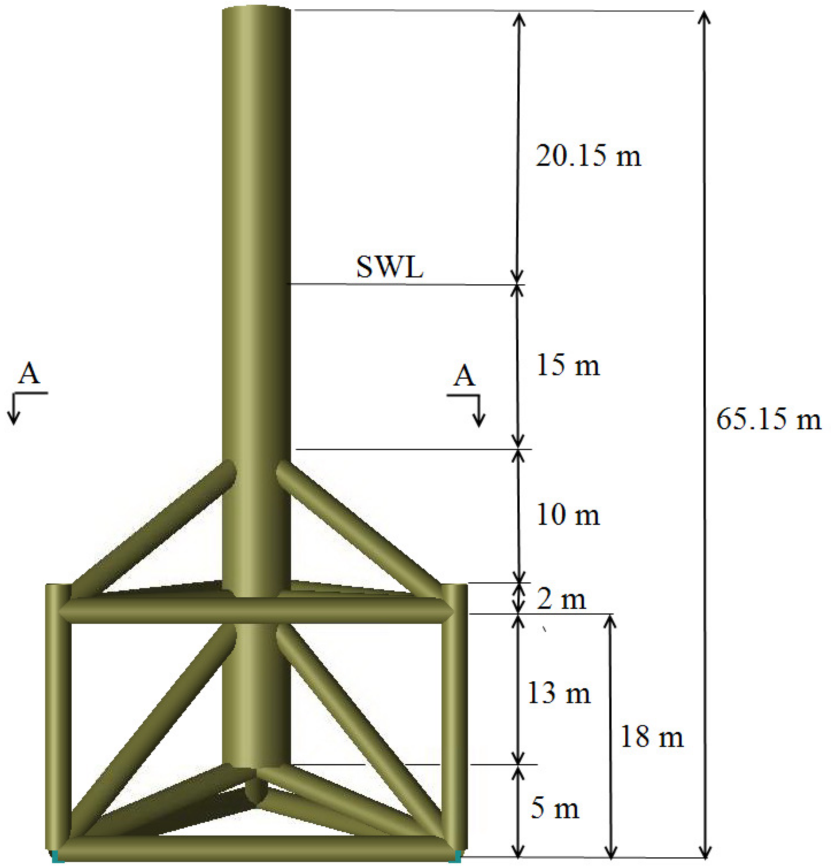
OD = 2.0 m og tykkelse = 0.060 m

Figur 5.4.2-3 – Valg av profilstørrelser (alternativ 3, tabell 5.3-1)

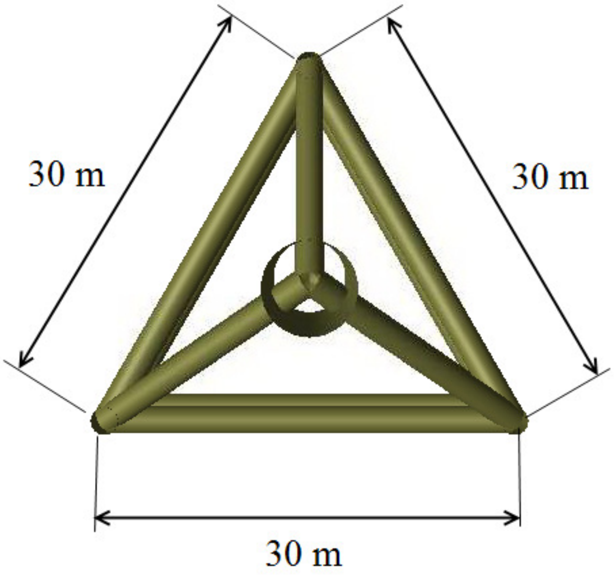
Figur 5.4.2-4 viser benevningen de forskjellige profilene har i Sesam GeniE. Figur 5.4.2-5 og figur 5.4.2-6 viser snitt og plan med målsetting.



Figur 5.4.2-4 – Profilbenevnelse i Sesam GeniE



Figur 5.4.2-5 – Snitt med målsetting



Figur 5.4.2-6 – Snitt A-A – plan med målsetting

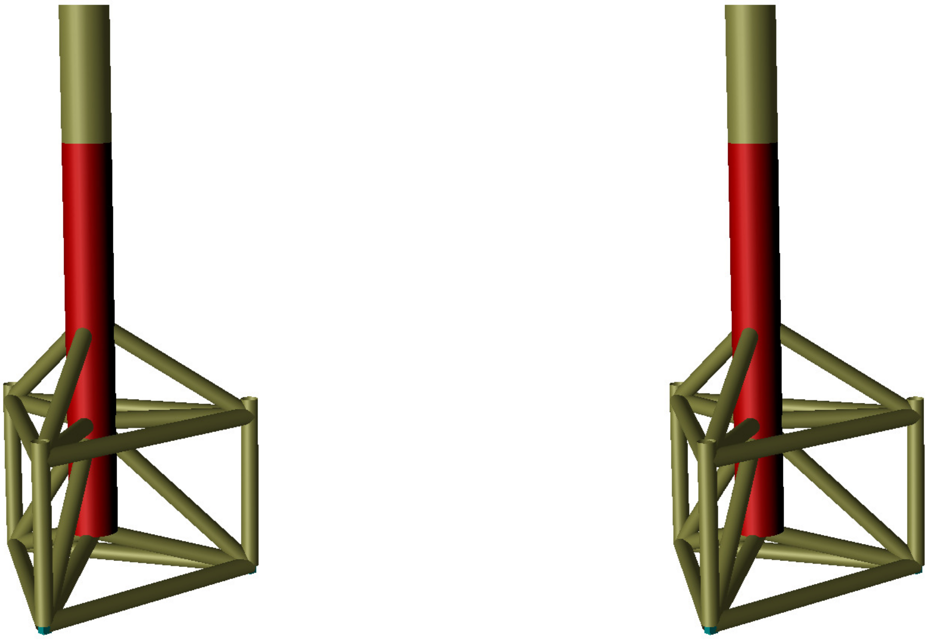
Under kodesjekken i Sesam GeniE er det valg å sjekke etter både Norsok N-004 og Eurocode 3. Grunnen til dette er for å kunne sammenlikne og vurdere forskjellene som eventuelt kommer ved de to kodesjekkene. Eurocode standardene er fundamentale europeiske standarder som ligger som basis i standard-reguleringen, mens Norsok standardene er bransjenæringens tilleggs krav (overordnet standard i oljebransjen) til de europeiske standardene. For offshore struktur-installasjoner er Eurocode 3 den mest brukte standarden for kodesjekk da denne gir en fullgod kodesjekk for alle typer profiler. Norsok N-004 gir ikke samme fullgode kodesjekk for alle type profiler men når det gjelder rørprofiler er kodesjekk etter Norsok N-004 den mest optimale. Denne kodesjekken er tilpasset jacket-design og kan ta hensyn til hydrostatisk trykk på profilene. I tillegg har Norsok N-004 et eget kapittel for sjekk av knutepunkt mellom rørprofiler. Når det kjøres kodesjekk etter Norsok N-004 i Sesam GeniE bruker Seam GeniE Norsok N-004 i de tilfeller hvor det er mest gunstig og Eurocode 3 på resterende tilfeller for å oppnå en best mulig kodesjekk.

5.4.2.1 Resultater Analyse 1 for alternativ 3 (fundament)

Tabell 5.4.2.1-1 – Resultat fra kodesjekk, Analyse 1, Sesam GeniE

Profiler	Lasttilfelle		Status		Utnyttelse		Formel	
	Norsok N-004	Eurocode 3	Norsok N-004	Eurocode 3	Norsok N-004	Eurocode 3	Norsok N-004	Eurocode 3
Bm(23,1)	ULS_B_E	ULS_B_E	Ok	Ok	0,24	0,24	Uf6_27	Uf662
Bm(23,2)	ULS_B_S	ULS_B_S	Ok	Ok	0,00	0,00	Uf6_27	Uf62
Bm(24,1)	ULS_B_W	ULS_B_W	Ok	Ok	0,20	0,20	Uf6_27	Uf662
Bm(24,2)	ULS_B_S	ULS_B_S	Ok	Ok	0,00	0,00	Uf6_27	Uf62
Bm(25,1)	ULS_B_S	ULS_B_S	Ok	Ok	0,23	0,22	Uf6_27	Uf62
Bm(25,2)	ULS_B_N	ULS_B_N	Ok	Ok	0,00	0,00	Uf6_27	Uf62
Bm(27,1)	ULS_B_E	ULS_B_E	Ok	Ok	0,04	0,04	Uf6_27	Uf661
Bm(27,2)	ULS_B_E	ULS_B_S	Ok	Ok	0,24	0,29	Uf6_27	Uf661
Bm(27,3)	ULS_B_E	ULS_B_S	Ok	Ok	0,28	0,33	Uf6_27	Uf661
Bm(32)	ULS_B_N	ULS_B_S	Ok	Ok	0,06	0,08	Uf6_27	Uf62
Bm(33)	ULS_B_W	ULS_B_E	Ok	Ok	0,05	0,07	Uf6_27	Uf62
Bm(34)	ULS_B_E	ULS_B_W	Ok	Ok	0,05	0,08	Uf6_27	Uf62
Bm(35)	ULS_B_W	ULS_B_E	Ok	Ok	0,18	0,20	Uf6_27	Uf62
Bm(36)	ULS_B_N	ULS_B_N	Ok	Ok	0,19	0,18	Uf6_27	Uf62
Bm(37)	ULS_B_E	ULS_B_E	Ok	Ok	0,22	0,23	Uf6_27	Uf62
Bm(38)	ULS_B_N	ULS_B_N	Ok	Ok	0,04	0,06	Uf6_27	Uf62
Bm(39)	ULS_A_W	ULS_A_W	Ok	Ok	0,04	0,05	Uf6_26	Uf62
Bm(40)	ULS_A_E	ULS_A_E	Ok	Ok	0,04	0,05	Uf6_27	Uf62
Bm(41)	ULS_B_E	ULS_B_E	Ok	Ok	0,08	0,09	Uf6_27	Uf62
Bm(42)	ULS_B_W	ULS_B_W	Ok	Ok	0,08	0,09	Uf6_27	Uf62
Bm(43)	ULS_B_S	ULS_B_S	Ok	Ok	0,10	0,10	Uf6_27	Uf661
Bm(47)	ULS_A_E	ULS_A_S	Ok	Ok	0,09	0,13	Uf6_27	Uf661
Bm(48)	ULS_B_W	ULS_B_E	Ok	Ok	0,19	0,32	Uf6_27	Uf62
Bm(49)	ULS_B_S	ULS_B_S	Ok	Ok	0,27	0,27	Uf6_27	Uf62
Bm(50)	ULS_B_E	ULS_B_E	Ok	Ok	0,27	0,30	Uf6_27	Uf62
Bm(51)	ULS_B_E	ULS_B_E	Ok	Ok	0,23	0,23	Uf6_27	Uf661
Bm(52)	ULS_B_S	ULS_B_S	Ok	Ok	0,22	0,22	Uf6_27	Uf661
Bm(53)	ULS_B_W	ULS_B_W	Ok	Ok	0,21	0,21	Uf6_27	Uf662
Bm(55)	ULS_B_E	ULS_B_W	Ok	Ok	0,05	0,07	Uf6_27	Uf62
Bm(56)	ULS_A_E	ULS_A_E	Ok	Ok	0,04	0,05	Uf6_26	Uf62
Bm(60)	ULS_B_N	ULS_B_N	Ok	Ok	0,04	0,06	Uf6_27	Uf62
Bm(61)	ULS_B_N	ULS_B_S	Ok	Ok	0,06	0,08	Uf6_27	Uf62
Bm(62)	ULS_B_E	ULS_B_E	Ok	Ok	0,05	0,08	Uf6_26	Uf62
Bm(63)	ULS_A_W	ULS_A_W	Ok	Ok	0,04	0,05	Uf6_27	Uf62

For at profilene skal kunne bli godkjent i henhold til Norsok N-004 og Eurocode 3 må de ha en utnyttelsesfaktor på mindre enn 1.00. Ut i fra tabell 5.4.2.1-1 viser kodesjekk etter Nordsok N-004 størst utnyttelsesfaktor på 0,28 og kodesjekk etter Eurocode 3 størst utnyttelsesfaktor på 0,33 (ref. figur 5.4.2.1-1). Dette er relativt lave utnyttelsesfaktorer, men dersom profiltykkelsen minkes (med tanke på å øke utnyttelsen), økes også egenfrekvensen noe som igjen er ugunstig med tanke på resonans med rotorfrekvensen. Dersom konstruksjonen skal optimaliseres kostnadsmessig er det gunstig å utnytte profilene mest mulig (høy utnyttelsesfaktor). Referer til kapittel 5.3 som også beskriver valg av profilstørrelser samt diskuterer litt angående økonomiske vurderinger i henhold til kostnader satt opp mot eventuell levetid.



Norsok N-004 (størst utnyttelse 0.28)

Eurocode 3 (størst utnyttelse 0.33)

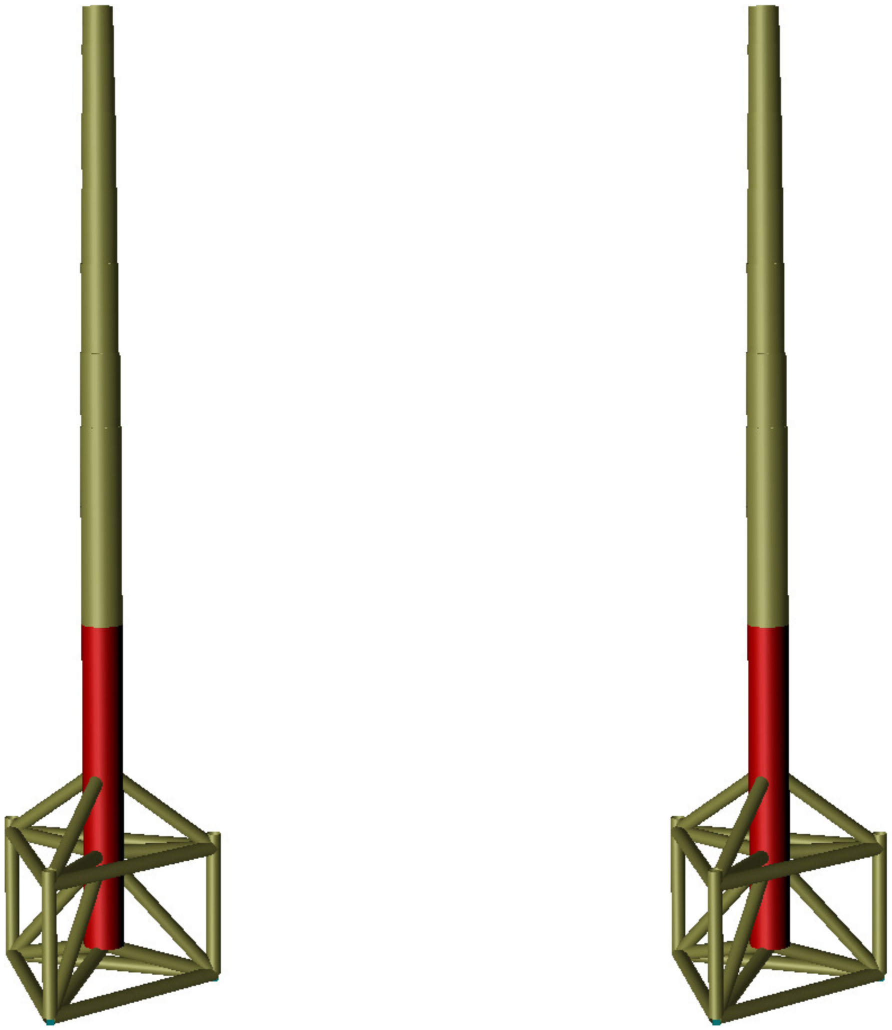
Figur 5.4.2.1-1 – Størst utnyttede profiler i forbindelse med kodesjekk (Analyse 1)

Sammenliknes utnyttelsesfaktorene (i henhold til tabell 5.4.2.1-1) fra de to kodesjekkene (Norsok N-004 og Eurocode 3) ser man at avvikene ikke er store på de fleste elementene. De fleste elementene kommer ut med samme utnyttelsesfaktor i begge tilfeller. Bare noen få elementer kommer ut med forskjellig utnyttelsesfaktor, med en differansen på maks 0.05, som ikke er signifikant. Dette med unntak av Bm(48) som har en differanse på 0.12. Det at det er en liten differanse kan tyde på at det for det gitte tilfelle er like god kodesjekk etter begge standardene men at Norsok N-004 har egne sjekkformler i de tilfellene hvor det er forskjell i utnyttelsen. Forskjellene viser hvilke elementer som blir sjekket etter tilleggskravene i Norsok N-004 når denne standarden er satt som input til kodesjekken.

5.4.2.2 Resultater Analyse 2 for alternativ 3 (fundament og vindturbintårn)

Tabell 5.4.2.2-1 – Resultat fra kodesjekk, Analyse 2, Sesam GeniE

Profiler	Lasttilfelle		Status		Utnyttelse		Formel	
	Norsok N-004	Eurocode 3	Norsok N-004	Eurocode 3	Norsok N-004	Eurocode 3	Norsok N-004	Eurocode 3
Bm(23,1)	ULS_B_E	ULS_B_E	Ok	Ok	0,23	0,23	Uf6_27	Uf662
Bm(23,2)	ULS_B_S	ULS_B_S	Ok	Ok	0,00	0,00	Uf6_27	Uf62
Bm(24,1)	ULS_B_W	ULS_B_W	Ok	Ok	0,26	0,27	Uf6_27	Uf662
Bm(24,2)	ULS_B_S	ULS_B_S	Ok	Ok	0,00	0,00	Uf6_27	Uf62
Bm(25,1)	ULS_B_S	ULS_B_S	Ok	Ok	0,23	0,22	Uf6_27	Uf62
Bm(25,2)	ULS_B_N	ULS_B_N	Ok	Ok	0,00	0,00	Uf6_27	Uf62
Bm(26)	ULS_A_W	ULS_A_N	Ok	Ok	0,09	0,12	Uf6_27	Uf661
Bm(27,1)	ULS_B_W	ULS_B_W	Ok	Ok	0,05	0,06	Uf6_27	Uf661
Bm(27,2)	ULS_B_W	ULS_B_N	Ok	Ok	0,29	0,36	Uf6_27	Uf661
Bm(27,3)	ULS_B_W	ULS_B_N	Ok	Ok	0,34	0,41	Uf6_27	Uf661
Bm(28)	ULS_A_W	ULS_A_N	Feil geometri	Ok	0,23	0,27	Uf6_27	Uf661
Bm(29)	ULS_A_W	ULS_A_N	Feil geometri	Ok	0,22	0,26	Uf6_27	Uf661
Bm(30)	ULS_A_W	ULS_A_N	Feil geometri	Ok	0,21	0,25	Uf6_27	Uf661
Bm(31)	ULS_A_W	ULS_A_W	Feil geometri	Ok	0,21	0,25	Uf6_27	Uf661
Bm(32)	ULS_B_N	ULS_B_S	Ok	Ok	0,06	0,08	Uf6_27	Uf62
Bm(33)	ULS_B_W	ULS_B_E	Ok	Ok	0,05	0,07	Uf6_27	Uf62
Bm(34)	ULS_B_W	ULS_B_W	Ok	Ok	0,05	0,08	Uf6_26	Uf62
Bm(35)	ULS_B_W	ULS_B_W	Ok	Ok	0,22	0,24	Uf6_27	Uf62
Bm(36)	ULS_B_N	ULS_B_N	Ok	Ok	0,22	0,21	Uf6_27	Uf62
Bm(37)	ULS_B_E	ULS_B_W	Ok	Ok	0,18	0,22	Uf6_27	Uf62
Bm(38)	ULS_B_N	ULS_B_N	Ok	Ok	0,04	0,06	Uf6_27	Uf62
Bm(39)	ULS_A_W	ULS_A_W	Ok	Ok	0,04	0,05	Uf6_26	Uf62
Bm(40)	ULS_A_E	ULS_A_E	Ok	Ok	0,04	0,05	Uf6_27	Uf62
Bm(41)	ULS_B_E	ULS_B_E	Ok	Ok	0,08	0,09	Uf6_27	Uf62
Bm(42)	ULS_B_W	ULS_B_W	Ok	Ok	0,08	0,09	Uf6_27	Uf62
Bm(43)	ULS_B_S	ULS_B_S	Ok	Ok	0,10	0,10	Uf6_27	Uf661
Bm(44)	ULS_A_W	ULS_A_N	Feil geometri	Ok	0,18	0,22	Uf6_27	Uf661
Bm(45)	ULS_A_N	ULS_A_N	Feil geometri	Ok	0,15	0,17	Uf6_27	Uf661
Bm(46)	ULS_A_N	ULS_A_N	Feil geometri	Ok	0,06	0,07	Uf6_27	Uf661
Bm(47)	ULS_A_W	ULS_A_N	Ok	Ok	0,11	0,16	Uf6_27	Uf661
Bm(48)	ULS_B_W	ULS_B_W	Ok	Ok	0,33	0,35	Uf6_27	Uf62
Bm(49)	ULS_B_S	ULS_B_N	Ok	Ok	0,27	0,31	Uf6_27	Uf62
Bm(50)	ULS_B_E	ULS_B_W	Ok	Ok	0,24	0,33	Uf6_27	Uf62
Bm(51)	ULS_B_E	ULS_B_E	Ok	Ok	0,22	0,23	Uf6_27	Uf661
Bm(52)	ULS_B_S	ULS_B_S	Ok	Ok	0,23	0,23	Uf6_27	Uf661
Bm(53)	ULS_B_W	ULS_B_W	Ok	Ok	0,24	0,25	Uf6_27	Uf661
Bm(54)	ULS_A_N	ULS_A_N	Feil geometri	Ok	0,06	0,07	Uf6_27	Uf661
Bm(55)	ULS_B_E	ULS_B_W	Ok	Ok	0,05	0,07	Uf6_27	Uf62
Bm(56)	ULS_A_E	ULS_A_E	Ok	Ok	0,04	0,05	Uf6_26	Uf62
Bm(60)	ULS_B_N	ULS_B_N	Ok	Ok	0,04	0,06	Uf6_27	Uf62
Bm(61)	ULS_B_N	ULS_B_S	Ok	Ok	0,06	0,08	Uf6_27	Uf62
Bm(62)	ULS_B_W	ULS_B_E	Ok	Ok	0,05	0,08	Uf6_27	Uf62
Bm(63)	ULS_A_W	ULS_A_W	Ok	Ok	0,04	0,05	Uf6_27	Uf62

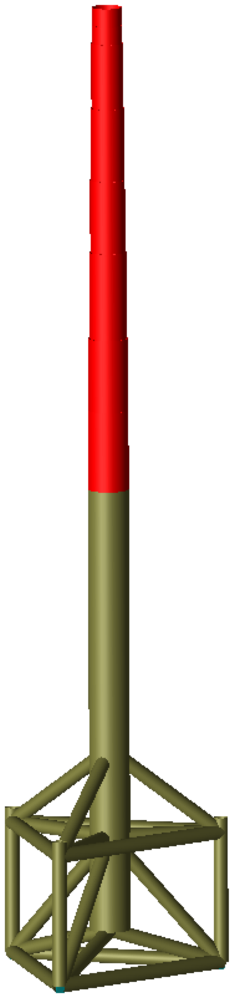


Norsok N-004 (størst utnyttelse 0.34) *Eurocode 3 (størst utnyttelse 0.41)*

Figur 5.4.2.2-1 – Størst utnyttede profiler i forbindelse med kodesjekk (Analyse 2)

Sammenliknes utnyttelsesfaktorene (i henhold til tabell 5.4.2.2-1) fra de to kodesjekkene (Norsok N-004 og Eurocode 3) ser man, som for Analyse 1, at avvikene ikke er store. De fleste elementene kommer også, i denne analysen, ut med samme utnyttelsesfaktor i begge tilfeller, men man kan se at det er flere elementer som har en større differanse, opp mot 0.09 i differanse, enn for resultatene i Analyse 1. Det tyder på at flere elementer i denne analysen har gått under Norsok sine krav når Norsok N-004 er satt som input til kodesjekken.

I tilegg viser kodesjekk etter Norsok N-004 at geometrien ikke er akseptabel for beam (28), (29), (30), (31), (44), (45), (46) og (54). Her er det et eksempel på at Norsok N-004 har strengere krav enn Eurocode 3 som lar geometrien passere i kodesjekken. Når det gjelder elementene som får feilmelding på geometri i henhold til Norsok N-004 er dette elementer i selve turbintårnet (ref. figur 5.4.2.2-2 for illustrasjon av turbintårnelementer med geometrifeil i henhold til kodesjekk etter Norsok N-004 i Sesam GeniE), og det er valgt å ignorere geometrifeilen for denne oppgaven. Det er tatt hensyn til at dimensjoner for turbintårn er tatt hånd om i tidligere kalkulasjoner da disse er fastsatt i ref. /L-7/ kapittel 3.5, tabell 3. For videre arbeid kan dette bli sjekket ytterligere. En mulig årsak til denne feilen kan være at turbintårnet er modellert seksjonsvis i Sesam GeniE, ref. tabell 5.4.2.2-2, og ikke som den konete løsning som er gitt i virkeligheten, ref. tabell 5.4.2.2-3 som er tatt ut fra ref. /L-7/ kapittel 3.5, tabell 3. Det er vurdert at det er tilstrekkelig med seksjonsvis modellering i Sesam GeniE for arbeidet med denne oppgaven.



Figur 5.4.2.2-2 – Geometrifeil på turbintårn, Norsok N-004 kodesjekk i Sesam GeinE

Tabell 5.4.2.2-2 – Tverrsnittsegenskaper for turbintårn modellert i Sesam GeniE

Global høyde, z (m)	Ytre diameter (m)	Vegg tykkelse (mm)
20.15 – 21.15	5.600	32
21.15 – 32.15	5.577	32
32.15 – 42.15	5.381	30
42.15 – 54.15	5.082	28
54.15 – 64.15	4.800	24
64.15 – 74.15	4.565	22
74.15 – 83.15	4.329	20
83.15 – 85.65	4.188	30
85.65 – 88.15	4.000	30

Tabell 5.4.2.2-3 – Originale tverrsnittsegenskaper for turbintårn, ref. /L-7/

Global høyde, z (m)	Ytre diameter (m)	Vegg tykkelse (mm)
20.15	5.600	32
21.15	5.577	32
32.15	5.381	30
42.15	5.082	28
54.15	4.800	24
64.15	4.565	22
74.15	4.329	20
83.15	4.188	30
88.15	4.000	30

5.4.2.3 Sammenlikning av resultatene fra Analyse 1 og Analyse 2

Først og fremst kan det sees at det er samme element i begge analysene som har størst utnyttelsesfaktor (Bm27). Studeres selve utnyttelsesfaktoren ser man at den er forskjellig for de to analysene (med tillegg til de interne forskjeller i hver analyse som knyttes til de to kodesjekkene, Norsok N-004 og Eurocode 3). Årsaken til den interne forskjellen er diskutert i kapittel 5.4.2.

Analyse 1 har, etter Eurocode 3, størst utnyttelse på 33% i element Bm(27) Analyse 2 har størst utnyttelse på 41% i samme element (ser man på utnyttelsen etter Norsok N-004 er det 28% i Analyse 1 og 34% i analyse 2 i Bm(27)). Denne forskjellen i utnyttelse for de to analysene viser at det er knyttet usikkerheter til bruken av to analyseprogrammer (som diskutert i kapitel 5.4). Studeres utnyttelsen som blir generert etter Eurocode 3 er det en differanse på 41% - 33% = 8%.

Analyse 1 omhandler kun fundament modellert i Sesam GeniE og det er i hovedsak bare hydrodynamiske krefter som er påsatt i programmet (da sett bort fra vindprofil som er påsatt på den vindutsatte delen av fundamentet). Resten, krefter generert av vindturbin pluss turbintårn utsatt for aerodynamiske krefter, er generert og tatt ut fra programmet Fedem Windpower.

For analyse 2 er fundamentet pluss turbintårnet modellert i Sesam GeniE. Hydrodynamiske krefer er også her påsatt fundamentet, men det er i tillegg lagt til vindprofil på turbintårnet i Sesam GeniE. Dette for å inkludere vindkrefter som virker på turbintårnet i analysen, Krefter som er implementert i Sesam GeniE fra Fedem WIndpower er i dette tilfellet fra selve turbinen (turbinblader, nacelle og hub; det vil si alt som er festet til toppen av turbintårnet).

Oppsummert kan det sies at forskjellene i analysene kan skyldes, i hovedsak, at implementeringen av vindkreftene blir utført og simulert forskjellig i de to programmene. Måten Sesam GeniE genererer vindprofil (etter manuell input av data) kan gi forskjellige resultater i forhold til hvordan Fedem Windpower generer vindkrefter.

Da vindkreftene er en av hovedbelastningene i dette tilfellet, kan forskjellen i vindgenereringen for de to programmene være utslagsgivende. Dette kan begrunne de forskjellige utnyttelsesgradene som oppstår i de to analysene.

For det gitte tilfellet kan det konkluderes med at forskjellen i utnyttelsen ikke har relativt stor betydning da utnyttelsesfaktorene, 41% versus 33%, totalsett er relativt små (ved et reelt design bør den totale utnyttelsen ligge på rundt 80 – 90 % for de fleste elementer for at designet skal være mest mulig kostnadseffektivt). Ved en høyere utnyttelse (opp mot 90% og over), kan avvik på 8% og eventuelt mer være utslagsgivende da det kan gi en ikke akseptabel utnyttelse om den overstiger 100% for noen elementer. Da blir det viktig å vurdere hvor feilkilden kan ligge og hvilket program, eventuelt implementeringsmåte, som er mest mulig korrekt. Det å kunne utføre hele analysen i ett analyseprogram er det mest effektive da man kan være sikker på at hele konstruksjonen, og de forskjellige analysene, følger de samme retningslinjene. Problematikken med at to eller flere programmer kan operere forskjellig, og ette forskjellige retningslinjer, unngås ved bruken av bare ett program for hele designprosessen. I tillegg kan man ved implementering fra ett program til et annet, ufrivillig, miste nødvendig informasjon. Dette med tanke på at en kan utelate å ta med all relevant data, menneskelig svikt, fra det ene til det andre programmet dersom man ikke har gode rutiner og sjekklister for import. Det er i tillegg mer tidkrevende å skifte fra ett program til ett annet da man mest sannsynlig må importere fra det ene til det andre flere ganger i løpet av designperioden. For hver import er det knyttet usikkerheter i forbindelse med at relevant data kan bli utelatt.

For videre arbeid med denne løsningen kan en manuell beregning av akseptabel knekklende utføres for å lokalisere hvor det øverste knutepunktet kan ligge i forhold til toppen av fundamentet. I tillegg til denne verifiseringen må det også tas hensyn til at knutepunktet ikke må ligge for nær SWL da det i denne sonen oppstår store lastpåkjenninger.

5.4.3 Kobling mellom Sesam GeniE og FEDEM Windpower

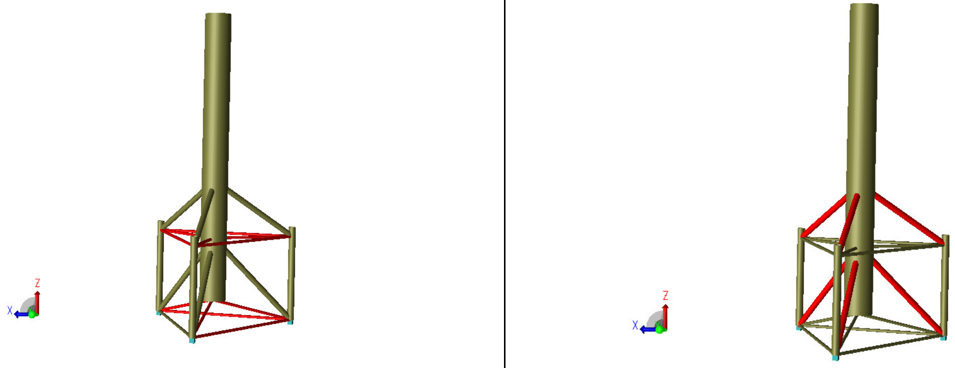
Koblingen mellom de to programmene Sesam GeniE og FEDEM Windpower var ikke utprøvd i forkant av denne oppgaven. Dette medførte en del problemer ved at importen til FEDEM Windpower fra Sesam GeniE ikke fungerte som den skulle ved første forsøk. Selve prosedyren for import fra Sesam GeniE til FEDEM Windpower omhandler en generering av en tekst fil (.fem) fra Sesam GeniE som inneholder geometri beskrivelse, koordinater, materialbeskrivelser samt all nødvendig informasjon angående den modellerte struktur (i Sesam GeniE). FEDEM Windpower har en ”jacket import” funksjon som skal kunne importere .fem filer for så å vise dem med korrekte egenskaper. Da importen, med denne funksjon, først ble utprøvd fungerte det ikke og ingen geometri ble importert. Det ble så utført nye forsøk ved å importere .fem filen som ”load link” (en annen importfunksjon i FEDEM Windpower som kan vise geometrien uten egenskaper etc.). Denne importen fungerte greit og gav en indikasjon på at kommunikasjonen mellom Sesam GeniE og FEDEM Windpower skulle fungere. Videre ble det arbeidet med å finne en løsning på problemet som oppstod ved bruk av ”jacket import” funksjonen. Det ble påpekt fra FEDEM at dersom ”jacket import” funksjonen skulle fungere måtte modellen fra Sesam GeniE være bjelkemodell og ikke skallmodell. Dette var tilfellet, så feilen lå ikke i modellen fra Sesam GeniE. Det viste seg til slutt å være en feil i FEDEM Windpower programmet som gjorde at import av .fem filer ikke lot seg gjøre. Denne feilen lå i at programmet (FEDEM Windpower) ikke klarte å innhente (lese) materialegenskapene fra bjelkeelementene som var registrert i .fem filen. Dermed fikk ingen av bjelkene i FEDEM Windpower materialegenskaper tilegnet seg og importen kunne ikke gjennomføres. Løsningen på dette ble å manuelt endre på materialegenskapene i .fem filen slik at de ble leselige for FEDEM Windpower. Da dette var utført virket importen som den skulle, men for hver revisjon som ble gjort i Sesam GeniE måtte .fem filen revideres for å kunne hentes inn i FEDEM Windpower. Oppsummert kan det sies at det lå en feil i FEDEM Windpower i forbindelse med import av .fem filer som gjelder at referansen til materialegenskapene ikke blir lest. Dette er helt avgjørende for å kunne importere med ”jacket import” men den er ikke avgjørende for import ved ”load link” noe som var årsaken til at man kunne få inn geometrien via ”load link” (men denne geometrien var bare visuelt synlig og ikke løsbar da den manglet materialegenskaper).

Revideringen av .fem filen besto i å bytte ut tall nummer tre i alle linjer som begynner med GELREF1 til samme tall som i tall nummer to som er material ID’en.

Figur 5.4.3-1 viser første utkast for konseptet som var brukt som prøvekonstruksjon for import i FEDEM Windpower. .fem fil for denne ”test” konstruksjonen er forkastet og nye .fem filer ble generert for hvert forsøk av nye profiler i Sesam GeniE.

Pipe1 – OD = 5.6 m og tykkelse = 0.032 m

Pipe2 – OD = 1.5 m og tykkelse = 0.020 m



Pipe3 – OD = 0.6 m og tykkelse = 0.020 m

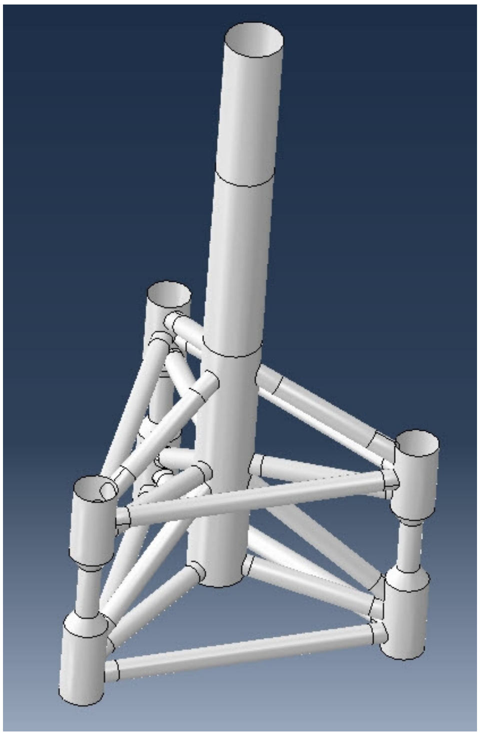
Pipe4 – OD = 1.2 m og tykkelse = 0.020 m

Figur 5.4.3-1 – Profilvalg, førsteutkast for import til FEDEM WIndpower

Vedlegg 1 viser .fem fil generert for konstruksjonen med profilvalg etter alternativ 3, kapittel 5.3, tabell 5.3-1, som er det endelige design.

5.5 Lokal analyse, Abaqus

For å kunne finne spenninger i konstruksjonen er det valgt å utføre en lokalanalyse i Abaqus. Det kunne vert aktuelt å bare modellert et av knutepunktene i konstruksjonen, men det ble valgt, på grunn av tidsbegrensning, å importere geometrien fra Sesam GeniE. En slik import er også tidkrevende og kan inneholde en del usikkerheter (som ved all import fra et program til et annet), men det er raskere enn å bygge opp en ny modell fra bunnen av. Det oppstod en store utfordringer ved videre modellering i Abaqus etter import da det var vanskelig og tidkrevende å få sammenslåingene, mesh, av knutepunktene til å virke. For å få en praktisk mulig modell måtte det små justeringer til med tanke på plassering av skråelementene (med tanke på å få god tilgang til sveis). For å få dette til ble det valgt å øke profildiameteren en god del i visse områder (områdene rundt knutepunktene), ref. figur 5.5-1.

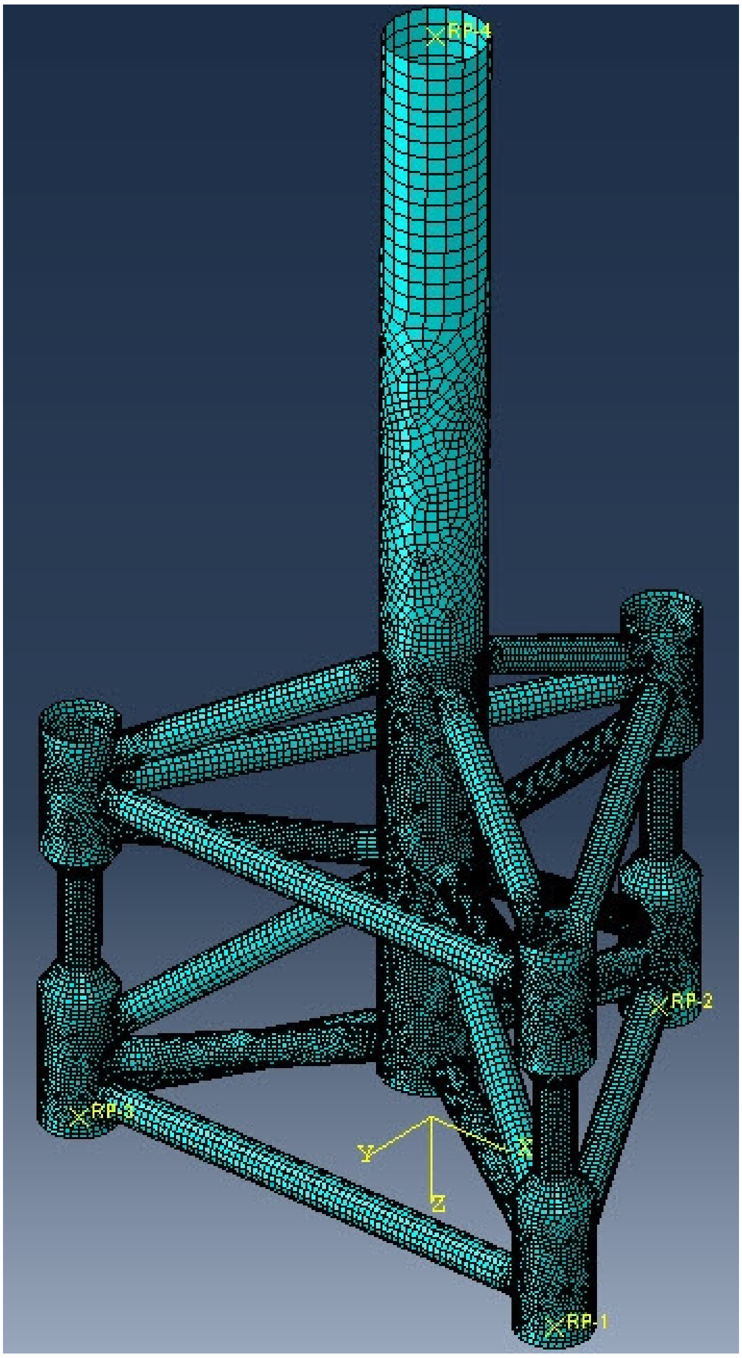


Figur 5.5-1 – Konseptet moddelert i Abaqus

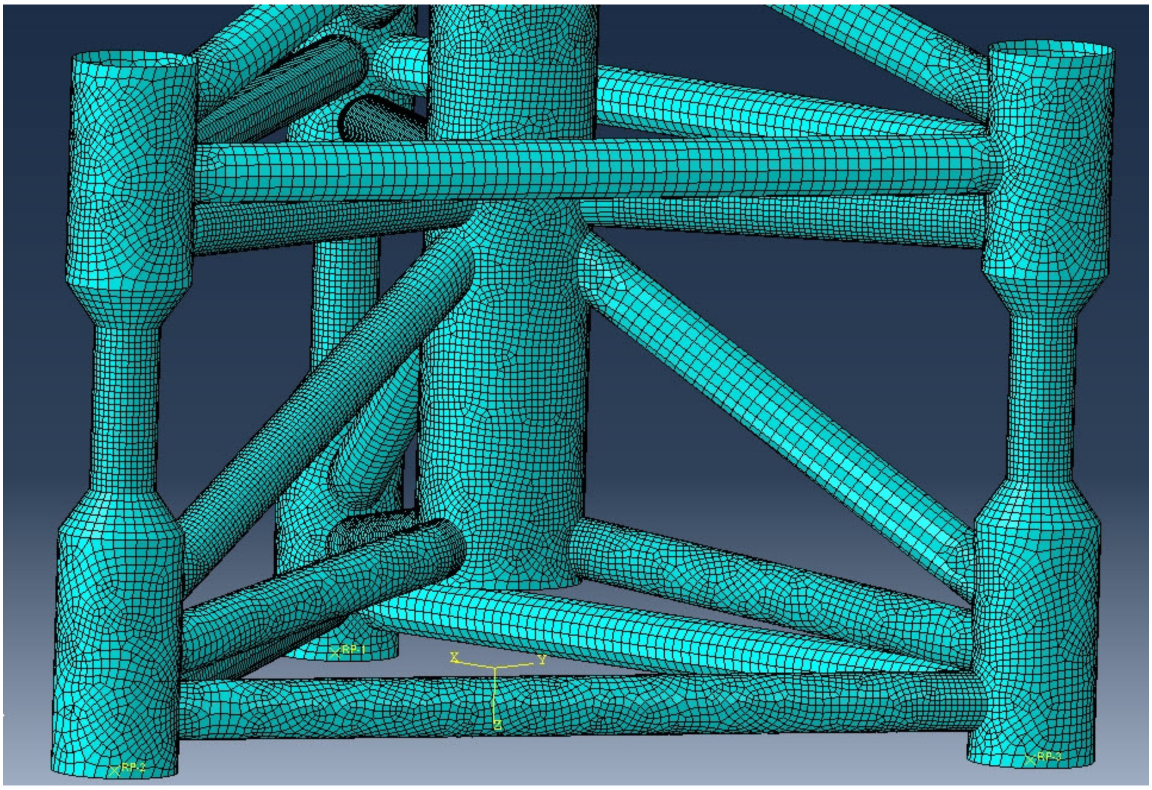
5.5.1 Resultater fra lokal analyse for modifisert alternativ 3, Abaqus

Lokal analysen i Abaqus viser at konstruksjonen ikke er holdbar da det oppstår store deformasjoner og konstruksjonen vil ende i kollaps. Grunnen til dette kan være mange. For det første er det knyttet en del usikkerheter til import av geometrien. Her kan det være benevninger og definisjoner som ikke fanges opp fra det ene til det andre programmet. I tillegg er Abaqus bygget opp slik at det ikke angir hvilke benevninger som skal brukes. Den som bygger opp modellen må selv ha kontroll på hvilke benevninger som brukes og det kan her være lett å gjøre feil som igjen kan gi store utslag på resultatene. På grunn av tidsbegrensning er det ikke nok tid til å gå detaljert igjennom modellen for å finne feilkildene og dette blir kilde til videre arbeid. I tillegg kan det sees på selve designet at midtseksjonen, fra øverste knutepunkt til topp av fundament, er relativt lang (35.15 meter) og seksjonen kan få problemer med å ta opp de aksialkreftene samt moment som er påvirkende. Det kan eventuelt diskuteres om det er reelt eller ikke med en slik løsning, men det kan antas at spennet er for stort slik at det kan føre til knekking. En mer hensiktsmessig løsning kan da eventuelt være å heve knutepunktet opp til toppen av fundamentet. Denne løsningen er presentert i kapittel 6 "Alternativ designløsning for videre arbeid". Opprinnelig er den vindturbinen som benyttes i analysene, OC4 vindturbin, supportert av en jacket konstruksjon som gir en annen lastfordeling enn det opprinnelige konseptet i denne oppgaven. I jacket konstruksjonen blir kreftene umiddelbart fordelt på 4 punkter i overgangen mellom fundament og turbintårn noe som gjør at det ikke oppstår et langt spenn som skal ta opp de totale kreftene. Oppsummert kan det sies at det må en fullgod lokalanalyse til for å kunne trekke en eksakt konklusjon på om eksisterende design er akseptabelt eller ikke, men på grunn av at en slik analyse ikke lar seg gjøre tidsmessig for denne oppgaven blir det konkludert med at designløsningen inneholder usikkerheter. Alternativt kan løsningen analyseres for et eventuelt mindre havdyp og for en mindre vindturbin som gir lavere lastpåkjenninger. Dette er kilde til videre arbeid.

Figurene 5.5.1-1 og 5.5.1-2 viser element modell fra Abaqus

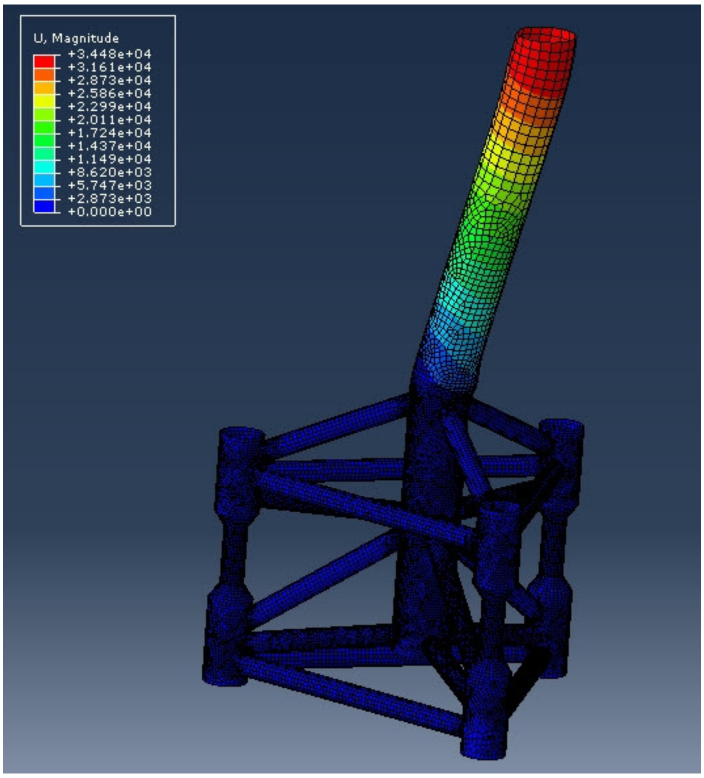


Figur 5.5-1-1 – Elementmodell - Abaqus

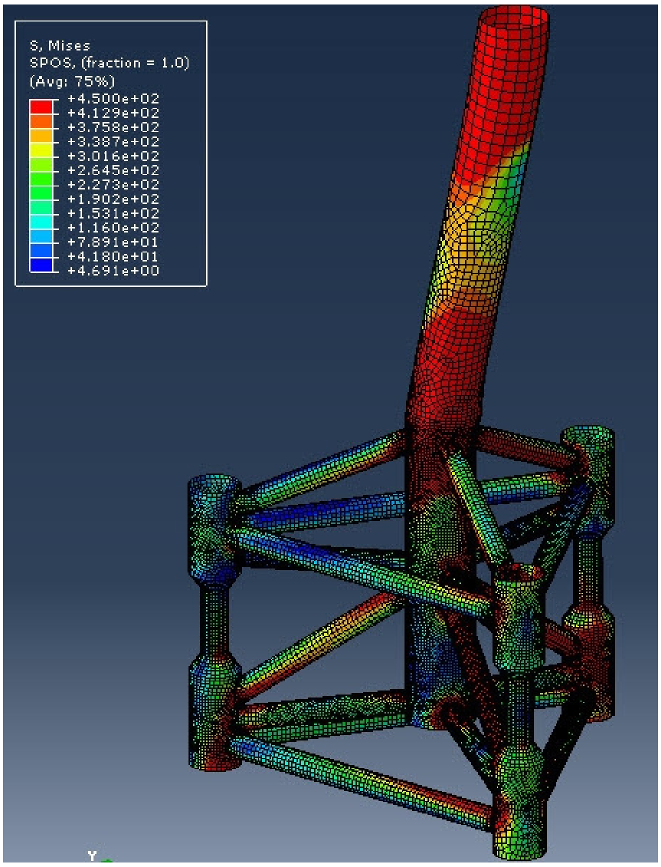


Figur 5.5-2 – Detaljert elementmodell - Abaqus

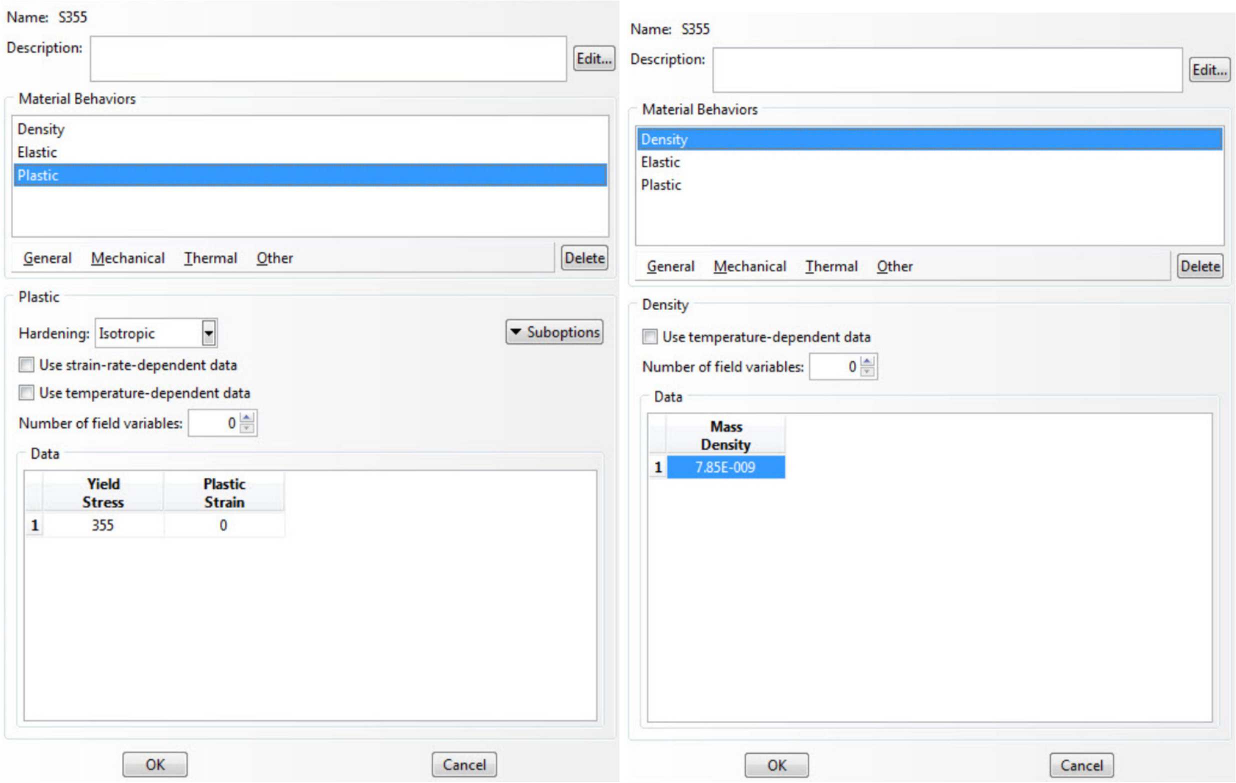
Videre representerer figur 5.5.1-3 og figur 5.5.1-4, henholdsvis deformasjoner og spenninger, som er beregnet for fundamentet. Maks deformasjon finnes i toppen av fundamentet og er 34.48 meter og maks spenning som oppstår i konstruksjonen (røde felt på figur 5.5.1-4) er på 450 MPa. En illustrasjon over hvilken flytespenning som er lagt inn i Abaqus, 355 MPa, samt densiteten til stål, 7850 kg/m^2 er vist på figur 5.5.1-5. Modellen består av 53589 noder og 54613 elementer hvorav 53487 er lineære firkantelementer av typen S4R og 1126 er lineære triangulærelementer av typen S3.



Figur 5.5-3 – Deformasjon, Abaqus



Figur 5.5-4 – Spenninger, Abaqus



Name: S355
Description:

Density
Elastic
Plastic

Plastic
Hardening: Isotropic
☐ Use strain-rate-dependent data
☐ Use temperature-dependent data
Number of field variables: 0

Data

	Yield Stress	Plastic Strain
1	355	0

Name: S355
Description:

Density
Elastic
Plastic

Density
☐ Use temperature-dependent data
Number of field variables: 0

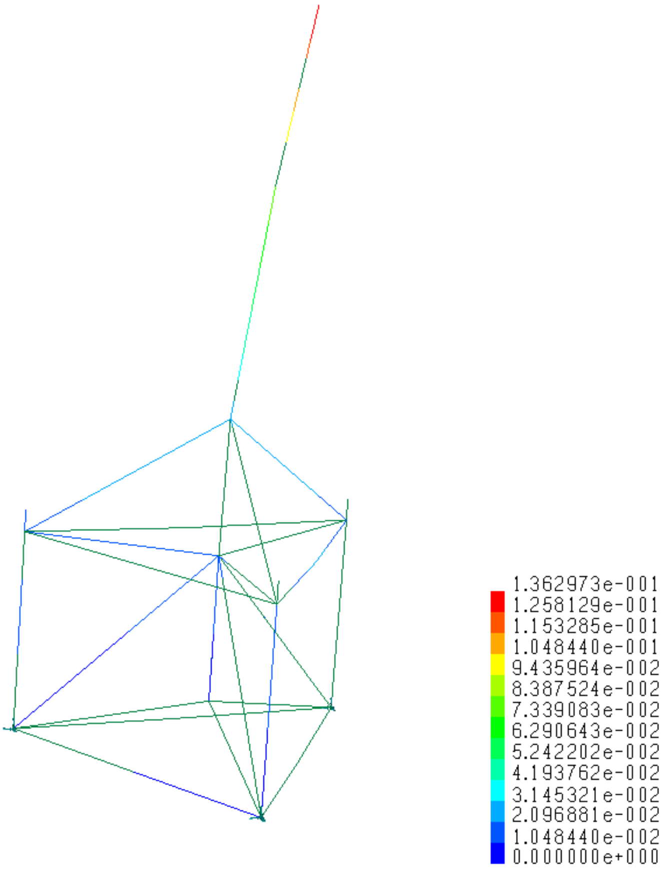
Data

	Mass Density
1	7.85E-009

Figur 5.5-5 – Flytespenning og densitet, Abaqus

5.6 Global analyse i Sesam GeniE versus lokal analyse i Abaqus

Oppsummert kan det sees at global analysen i Sesam GeniE gir positive resultater for designet. Videre viser de negative resultatene fra lokal analysen at de ikke står i samsvar med de positive resultatene fra global analysen. Maks deformasjon i henhold til Sesam GeniE er på 0.136 meter (ref. figur 5.6-1), mens maks deformasjon er på 34.48 meter i henhold til Abaqus (ref. figur 5.5-4). For tilfellet i denne oppgaven skyldes nok de store resultatavvikene mellom global og lokal analysen usikkerheter som beskrevet i kapittel 5.5.1. Generelt er det viktig med lokal vurdering av designet, i tillegg til global, for å kunne få en fullgod analyse. Noe av grunnen til dette er at global analysen som regel er bygget opp av bjelkeelementer som har likt definerte egenskaper over hele elementlengden. Lokal analyser er elementanalyser, finite element analyser, hvor elementene er bygd opp som volumelementer og hvert element deles inn i små definerte elementer, mesh, noe som gir en mer reel modell. Når det gjelder Abaqus modellen i denne oppgaven er den relativt vanskelig å bygge opp da det er utfordrende å få kombinert alle lastene fra hydrodynamikken og aerodynamikken inn i modellen. Det vises, i dette tilfellet, at det kan gi store forskjeller i resultatene fra global og lokal analyse med tanke på at det ut fra globalanalysen kan se ut som designet er akseptabelt men at det ut i fra lokal analysen ikke er akseptabelt (med forbehold om at resultatene fra lokalanalysen er inkludert usikkerheter og avvikene ville kanskje blitt mindre med en grundig gjenomgang av modellen og oppretting av feilkilder). Generelt er det helt nødvendig med begge analysene da lokal analysen er basert på resultater fra global analysen, men en kan ikke konkludere med at designet er akseptabelt bare ut fra global analysen.



Figur 5.6-1 – Deformasjon, Sesam GeniE

5.7 Metode for beregning av utmatting

Videre følger metode for beregning av levetiden til konstruksjonen.

Dersom det hadde vært akseptable resultater fra lokalanalysen i Abaqus ville det blitt tatt ut maks spenninger, $\sigma_{\max}$, og maks last, $F_{\max}$, (aksial eller skjær) fra modellen. Disse lastene ville blitt kombinert med formlene (5.5) – (5.11) for beregning av utmatting etter Palmgren-Miners summering, ref. kapittel 2.4.3. For kalkulasjon ville Palmgren-Miners summering kombineres med resultater fra SN-kurver , ref. tabell 5.7-1 som er tatt fra kapittel 2.4.5 i ref. /S-8/. Hvilken SN-kurve som skal brukes avhenger av hvilke profiler som skal sveises og hvordan de skal sveises. En beskrivelse av hvilke typer pofiler og festemetode (sveis eller bolter) som går under hver kategori er vist i referanse /S-8/, appendix A. For det aktuelle tilfellet ville verdier for SN-kurve W_1 bli brukt da strukturen inneholder sveiser. De aktuelle verdiene som leses fra tabellen er verdiene for m_1 og $\log \bar{a}_1$.

$\log \bar{a}_1 = \log a - 2 \cdot \log s$

$\log a$ = avskjæringen av $\log(\mathrm{N_i})$-aksen på SN-kurven

$\log s$ = standardavviket til $\log(\mathrm{N_i})$

$\mathrm{m_1}$ = den negativt inverse hellingen til SN-kurven

Videre ville det blitt laget tabeller, ref. tabell 5.7-2, for hvert knutepunkt. Maks spenning, $\sigma_{\max}$, og maks kraft, $F_{\max}$, for det aktuelle knutepunkt ville blitt utgangspunkt for beregningene. Tabellen for ett knutepunkt inneholder verdier for 10 forskjellige belastninger (Sesam GeniE gir resultater av 10 forskjellige bølgebelastninger). Forekomst, antall sykluser ($\mathrm{n_i}$) og periode ($\mathrm{T_z}$) hentes fra scatterdiagram og områdedata for det aktuelle området. Lastvidden, $\Delta\mathrm{F}$, tas ut fra lokalanalysen i det aktuelle analyseprogrammet.

Tabell 5.7-1 – Resultat fra SN-kurver
ref. /S-8/

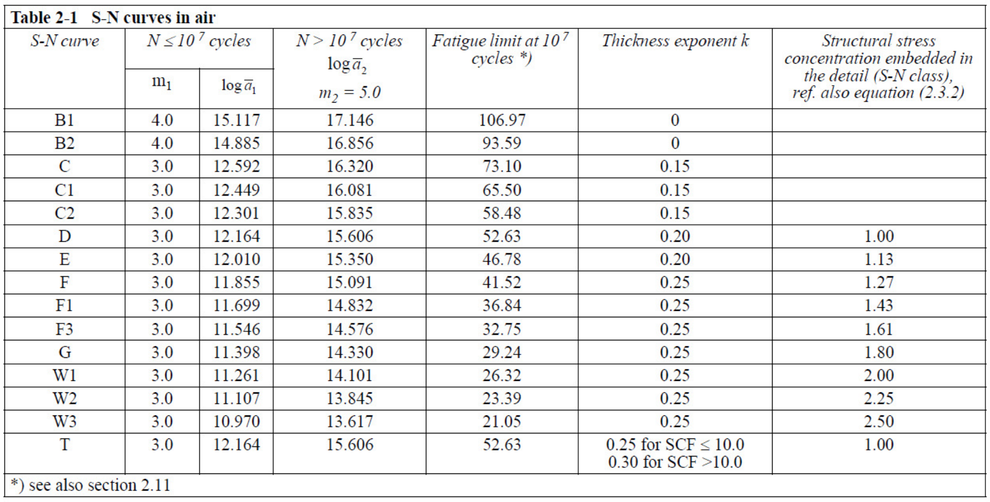


Table 2-1 S-N curves in air

S-N curve	*$N \le 10^7$ cycles*		*$N > 10^7$ cycles* $\log \bar{a}_2$	*Fatigue limit at 10^7 cycles *)*	*Thickness exponent k*	*Structural stress concentration embedded in the detail (S-N class), ref. also equation (2.3.2)*
	m_1	$\log \bar{a}_1$	$m_2 = 5.0$			
B1	4.0	15.117	17.146	106.97	0	
B2	4.0	14.885	16.856	93.59	0	
C	3.0	12.592	16.320	73.10	0.15	
C1	3.0	12.449	16.081	65.50	0.15	
C2	3.0	12.301	15.835	58.48	0.15	
D	3.0	12.164	15.606	52.63	0.20	1.00
E	3.0	12.010	15.350	46.78	0.20	1.13
F	3.0	11.855	15.091	41.52	0.25	1.27
F1	3.0	11.699	14.832	36.84	0.25	1.43
F3	3.0	11.546	14.576	32.75	0.25	1.61
G	3.0	11.398	14.330	29.24	0.25	1.80
W1	3.0	11.261	14.101	26.32	0.25	2.00
W2	3.0	11.107	13.845	23.39	0.25	2.25
W3	3.0	10.970	13.617	21.05	0.25	2.50
T	3.0	12.164	15.606	52.63	0.25 for SCF ≤ 10.0 0.30 for SCF >10.0	1.00

*) see also section 2.11

Tabell 5.7-2 – Tabell for utrekning av parametere for utmattingslevetid

		Belastnings frekvenser					
Belastning nummer	Forekomst	Antall sykluser, n_i	Periode, T_z	Lastvidde ΔF	Spenningsvidde $\Delta\sigma$	Tillatte sykluser, N_i	Skadeforhold, D_i
(Nr.)	%	(Nr.)	(s)	(kN)	(MPa)	(Nr.)	
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							

Antall sykluser, n_i, beregnes etter formel (5.5):

$$n_i = \frac{\text{antall sekund per år}}{T_z} \cdot \text{forekomst} \tag{5.5}$$

Spenningsvidden, $\Delta\sigma$, beregnes etter formel (5.6)

$$\Delta\sigma = \frac{\sigma_{maks}}{F_{maks}} \cdot \Delta F \tag{5.6}$$

Antall tillate sykluser, N_i, før sammenbrudd beregnes etter formel (5.7)

$$\log(N_i) = \log \bar{a} - m_1 \cdot \log \Delta\sigma$$

$$N_i = 10^{(\log \bar{a}_1 - m_1 \cdot \log \Delta\sigma)} \tag{5.7}$$

Verdien for $\log \bar{a}_1$ kan for denne oppgavens tilfelle settes lik 10.861 og m_1 settes lik 3 (ref. tabell 5.7-1).

Skadeforholdet, D_i, beregnes etter formel (5.8)

$$D_i = \frac{n_i}{N_i} \tag{5.8}$$

Når tabellen er utfylt etter formlene (5.5) – (5.8) kan det totale skadeforholdet, D, beregnes etter formel (5.9)

$$D = \sum_{1}^{s} D_i \qquad (5.9)$$

hvor s er belastningsnummer som ville vert 10 for denne oppgaven.

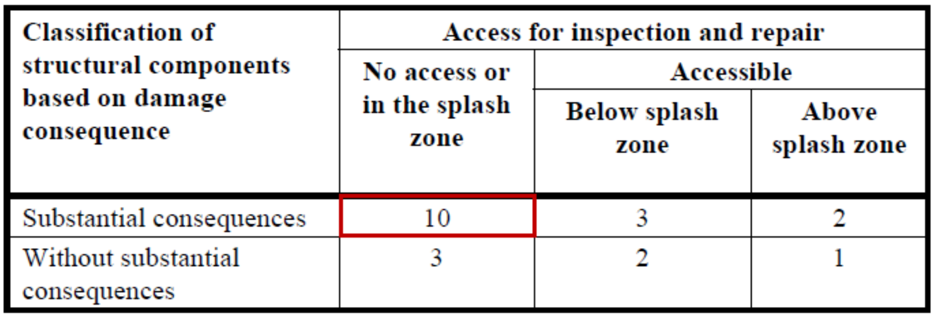
For å finne estimert levetid for konstruksjonen følges berekningene gitt etter formel (5.10) og (5.11)

$$\text{Levetid} = \frac{1}{D} \qquad (5.10)$$

$$\text{Totalt estimert levetid} = \underline{\underline{\frac{\text{Levetid}}{(\text{DFF} \cdot \text{returperiode fra scatterdiagram})}}} \qquad (5.11)$$

DFF ville i dette tilfellet bli satt til 10 da det er en undervannskonstruksjon, ref tabell 5.7-3 hentet fra ref. /S-2/.

Tabell 5.7-3 – DFF faktorer
ref. /S-2/



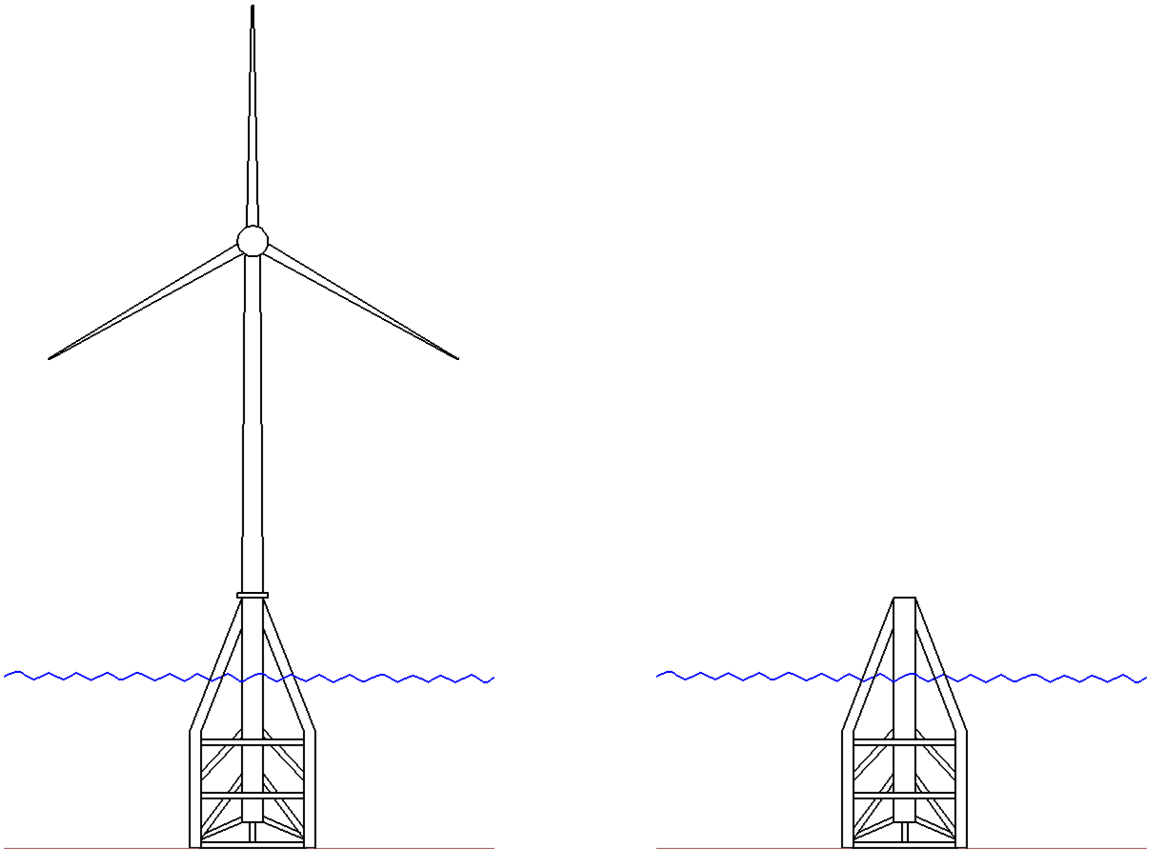
Classification of structural components based on damage consequence	**Access for inspection and repair**		
	No access or in the splash zone	**Accessible**	
		Below splash zone	**Above splash zone**
Substantial consequences	10	3	2
Without substantial consequences	3	2	1

Verdien for ”returperiode fra scatterdiagram” er avhengig av returperioden satt i scatterdiagrammet. Et realistisk tall ville i forbindelse med denne oppgaven ha vært 30 eller 50 år.

Det henvises til referanse /L-21/ for mer utdypende beskrivelse av utmattelsesanalyser.

6 Alternativ designløsning for videre arbeid

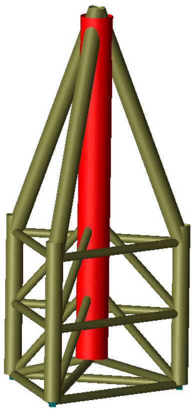
Da det kan diskuteres om nåværende design er optimalt med tanke på langt øvre spenn, 35.15 meter, før kraftfordeling i knutepunkt oppstår er det valgt å skissere opp en alternativ løsning hvor det øverste fundamentknutepunktet er hevet opp til toppen av fundamentet. Det er i tillegg lagt på flere profiler i konstruksjonen, for avstiving, slik at kreftene kan tas opp bedre samt at strukturens egenfrekvens senkes. I tillegg vil dette redusere deformasjonene som oppstår i alle elementene. Figur 6-1 viser konseptet med og uten OC4 vindturbin.



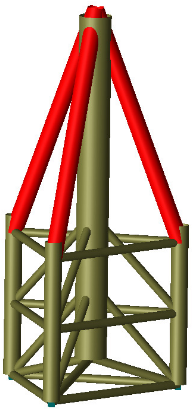
Figur 6-1 – Alternativ designløsning for tripodfundament

Under utforming av et nytt alternativt konsept må det tas hensyn til at konseptet kan ta aksial, skjær og momentkreftene det blir utsatt for. Det vil si at det må være stabilt i alle retninger. Dette må undersøkes nøye, og det er for dette alternativet ikke sjekket om alle punktene er oppfylt i detalj (da det ikke er utført lokal analyse). Merk at konseptet er en videreføring av alternativ 3, tabell 5.3-1, som diskutert tidligere.

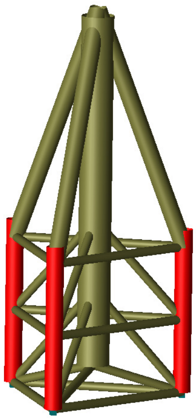
Figur 6-2 viser profilstørrelser brukt i modelleringen av fundamentet og analysen i Sesam GeniE



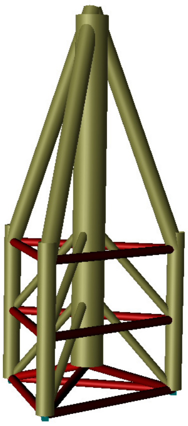
Pipe 5 - OD = 5.6 m og tykkelse = 0.075 m (sentersøyle)



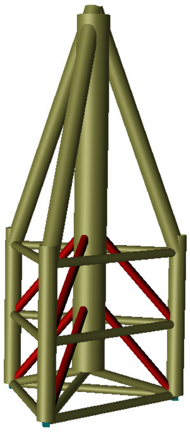
Pipe 6 - OD = 3.0 m og tykkelse = 0.052 m (stivere)



Pipe 7 - OD = 3.0 m og tykkelse = 0.067 m (ytersøyle)

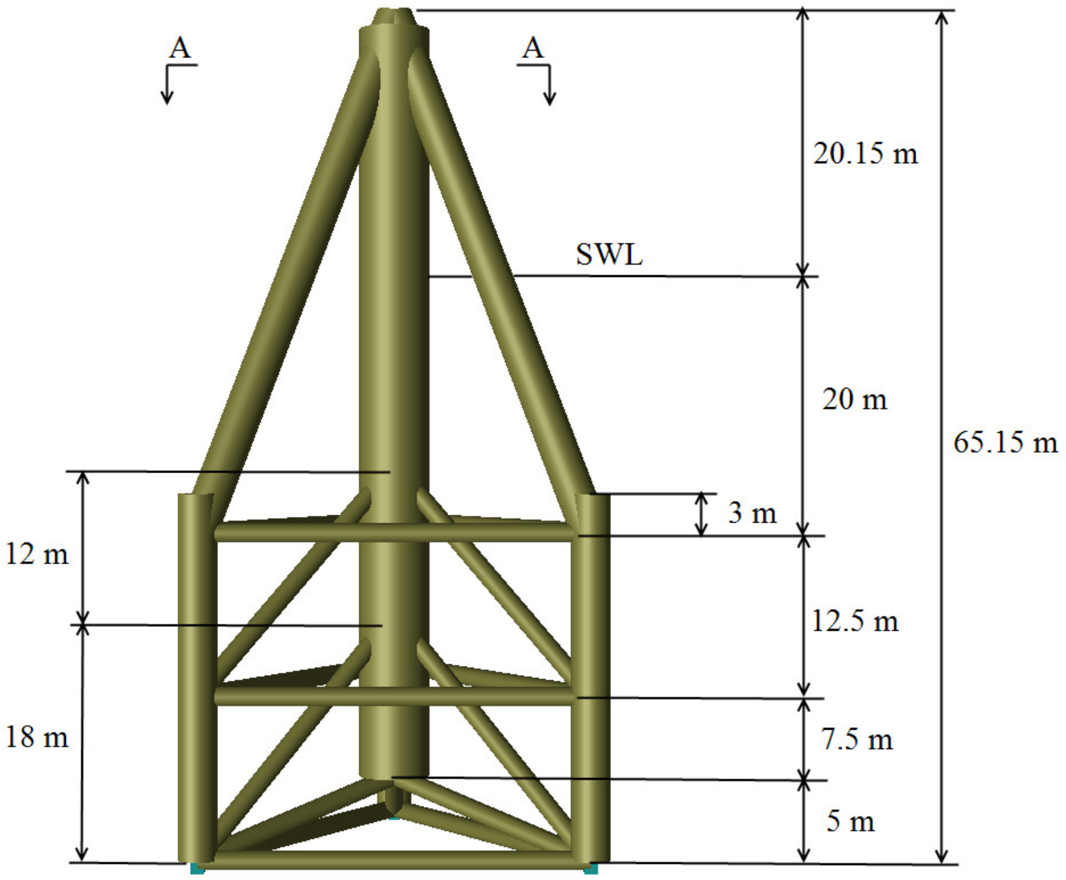


Pipe 8 - OD = 1.5 m og tykkelse = 0.032 m (fundament element)

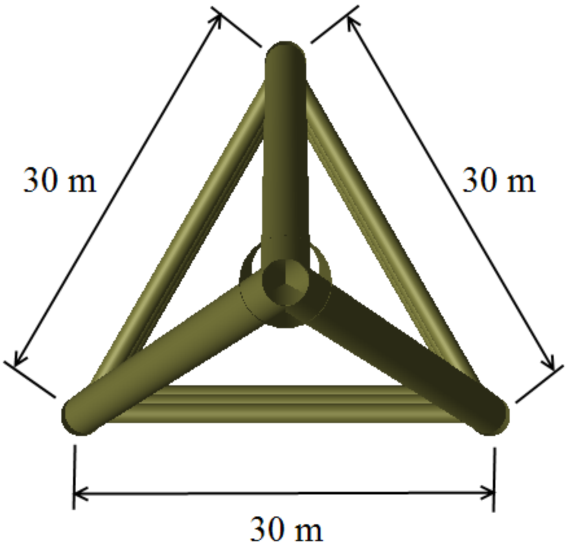


Pipe 9 - OD = 1.5 m og tykkelse = 0.040 m (fundament element)

Figur 6-2 – Profilvalg, alternativ designløsning



Figur 6-3 – Snitt med målsetting, alternativ løsning



Figur 6-4 – Snitt A-A – plan med målsetting, alternativ løsning

Det er også i dette tilfellet utført to analyser i Sesam GeniE; analyse 1 omhandler fundamentet og analyse 2 omhandler fundament inkludert turbintårn. Det er kjørt samme lasttilfeller, lastkombinasjoner og lastfaktorer som vist i tabell 5.4.2-1. Resultatene for de to analysene er representert ved å vise maks utnyttelse. For analyse uten turbintårn er resultatene som følger:

- Maks utnyttelse etter Eurocode 3 lik 95%
- Maks utnyttelse etter Norsok N-004 lik 97%

For analysen inkludert turbintårn er resultatene som følger:

- Maks utnyttelse etter Eurocode 3 lik 87%
- Maks utnyttelse etter Norsok N-004 lik 88%

Maks utnyttelse for begge analysene, samt for begge kodesjekkene, oppstår i en av de 3 ytersøylene. Det kan også i dette tilfellet sees at det er forskjeller i utnyttelsesfaktoren i henhold til de to forskjellige kodesjekkene samt de to forskjellige analysene. Grunnen til dette er diskutert i kapittel 5.4.2 " Sesam GeniE analyse av fundament" og kapittel 5.4.2.3 " Sammenlikning av resultatene fra Analyse 1 og Analyse 2".

Oppsummert for begge analysene har ca. halvparten av elementene en utnyttelse på over 40%, noe som er mer økonomisk i forhold til opprinnelig design hvor maks utnytelse totalt lå på 41% (Eurocode 3, analyse 2 – ref. figur 5.4.2.2-1).

Vektvurdering av den alternative designløsning diskutert i dette kapittel versus den opprinnelige designløsningen, som forøvrig er representert i rapporten, er utført. Vekt av alternativ design er på ca. 2050 tonn og vekt av opprinnelig design er på ca. 2031 tonn, ref. tabell 6-1.

Tabell 6-1 – Vektestimering; alternativ løsning versus opprinnelig løsning

	Alternativ løsning *ref. figur 6-2*			Opprinnelig løsning *ref. alternativ 3, tabell 5.3-1*		
	Dimensjon (m)	Lengde (m)	Vekt (tonn)	Dimensjon (m)	Lengde (m)	Vekt (tonn)
Sentersøyle	5.6 x 0.075	60.15	615	5.6 x 0.075	60.15	615
Fundament element	1.5 x 0.032 1.5 x 0.040	270 150	313 216	2.0 x 0.060	493	1416
Stivere	3.0 x 0.052	132	499			
Ytersøyler	3.0 x 0.067	84	407			

Total vekt:	Alternativ løsning: 2050 tonn	Opprinnelig løsning: 2031 tonn

Vektforskjellen er ikke stor for de to tilfellene, men det kan sies at den alternative designløsningen kan optimaliseres ved for eksempel og redusere størrelsen på sentersøylen. For løsningen som er vist i dette kapittel er sentersøylen utnyttet 38% (Eurocode 3) og denne utnyttelsen kan med fordel økes. Endres profilstørrelsen på sentersøylen til 4.6 x 0.075 meter (det vil si minske ytre diameter med én meter) vil dette føre til en vektminskning på ca 112 tonn. Dette er en betydelig vektreduksjon. Et overslag fra Sesam GeniE, med endret profilstørrelse på sentersøyle, gir ny utnyttelse på 52% (Eurocode 3) for sentersøylen. Det gjøres oppmerksom på at en slik vektoptimalisering må gjøres i samsvar med lokal- og egenfrekvensanalyse for å kunne konstantere at designet er holdbart. Grunnen til at sentersøylen kan optimaliseres i det alternative designet (og ikke i det opprinnelige designet) er at det høye knutepunktet for kraftfordeling gjør at sentersøylen ikke er så belastet i alternativ løsning som i opprinnelig løsning. Vekt er en av hovedfaktorene når det gjelder kostnader i forbindelse med fabrikasjon og det er ønskelige å holde vekten så lav som praktisk mulig for å ha minst mulig materialkostnader.

Vektberegningen for rørprofilene er gjort etter formlene (6.1) og (6.2):

$$Vekt = Areal \cdot Lengde \cdot Densitet \tag{6.1}$$

$$Areal = \pi \cdot \left(\frac{\mathrm{OD}}{2}\right)^2 - \pi \cdot \left(\frac{ID}{2}\right)^2 \tag{6.2}$$

$$Densitet = 7.85 \cdot 10^3\ kg / m^3$$

OD = ytre diameter (”Outer Diameter”)
ID = indre diameter (”Inner Diameter”)

I tillegg er det utført en egenfrekvensanalyse for å kunne konstantere om profilvalgene i figur 6-2 er akseptable med tanke på strukturens egenfrekvens og faren for resonans med rotoren. Som nevnt i kapittel 5.3 ”Sjekk av frekvensområder” må strukturfrekvensen være mindre en 1.283 sekund. Egenfrekvensanalyse i Sesam GeniE viser at strukturfrekvensen for det nye designet, som er presentert i dette kapitel, er 0.846 sekund (ref. vedlegg 9). Denne frekvensen er akseptabel og det kan konkluderes med at designet kan tas videre for lokal analyse. Dersom en vektoptimalisering skal utføres må det utføres nye egenfrekvensanalyser for å sikre at et eventuelt nytt design er innenfor de gitte frekvenskravene.

7 Konklusjon

Denne oppgaven belyser en del temaer som er viktige å ta hensyn til når et nytt design skal utvikles. Nødvendigheten av

- en total kostnadsestimering (som inngår i prosessen for konseptvalg)
- egenfrekvensanalyse
- globalanalyse (samspillet mellom eventuelle aktører dersom det totale designet inneholder leveranser fra flere leverandører)
- lokalanalyse
- utmattingsanalyse

har alle vist seg å være aktuelle i prosessen for å uforme det mest optimale design.

Det å utforme designløsninger for offshore vindmøller er krevende da konstruksjonen blir utsatt for både aerodynamiske og hydrodynamiske krefter som totalt resulterer i store dynamiske bevegelser i konstruksjonen. Nødvendigheten av å utføre egenfrekvensanalyser i samspill med globalanalyser har vist seg å være høyst gjeldende for å kunne finne den mest optimale designløsningen med tanke på både resonans og utnyttelse.

Den endelige designløsningen for denne oppgaven (alternativ 3 fra tabell 5.3-1) ble gjort basert på å tilfredstille kravene for egenfrekvens samt kravene regulert i standardbestemmelsene. Kravene for egenfrekvens førte til at designet måtte være relativt stivt noe som igjen resulterte i en nokså lav utnyttelse av selve konstruksjonselementene (41% på det meste i globalanalyse 2; fundament og turbintårn modellert i Sesam GeniE). Det at konstruksjonen er relativt lavt utnyttet (optimal utnyttelse ville vært på rundt 80 til 90%) fører til at designet ikke er kostnadsoptimalt. Dersom elementene hadde blitt ytterligere utnyttet ville strukturfrekvensen kommet inn i et område hvor det er stor fare for resonans med rotorfrekvensen; noe som ikke er hensiktsmessig. Levetiden ville da blitt betraktelig forkortet dersom en total kollaps inntraff. Når det gjelder design av selve fundamentet må det tas hensyn til at det ikke går i resonans med rotoren og bølgene. Selve vindturbinen må designes slik at den ikke går i resonans med fundamentet og vinden.

En tanke bak oppgaven var å vurdere om det valgte designet kunne være kostnadseffektivt med tanke på design, fabrikasjon, installasjon, drift/vedlikehold samt riving ved endt levetid. Selve kostnadsperspektivet i forbindelse med designet er behandlet i forrige avsnitt. Når det gjelder kostnader knyttet til fabrikasjon omfatter dette at det er få knutepunkt som skal sveises (holder sveisekostnadene nede) samt at konstruksjonen består av enkle designløsninger som er lette å fabrikkere. For installasjon er det tidsbesparende med 3 ankerpunker sammenliknet med en jacket konstruksjon som har 4 ankerpunker. Tidsbesparingen gjør seg her gjeldende ved at det blir et punkt mindre å pæle. Det er optimalt at vedlikehold på konstruksjonen kan utføres med minst mulig vanskeligheter; derav er sentersøyle hevet 5 meter fra havbunnen slik at sveiser knyttet til denne lett kan inspiseres. I tillegg er innfestningspunktet mellom fundament og vindturbin plassert over SWL. Dette, i hovedsak, for å unngå de store vertikale lastpåkjenningene innfestningspunktet ville hatt i vannlinjen og for å forenkle utførelsen av manuell inspeksjon av punktet. For fjerning av installasjonen etter endt levetid gjelder så og si de samme parameterne som for installasjon. Her er det kostnadsbesparende med 3 ankerpunker som skal fjernes i motsetning til 4 som ved en ordinær jacket konstruksjon.

Hvilke reguleringskrav som skulle brukes i oppgaven ble valgt basert på en eventuell installasjon på norsk sokkel. Dermed ble standarder som Eurocode, Norsok og DNV aktuelle for selve fundamentdesignet. Eurocode er et typisk europeisk krav som muliggjør fri flyt i handel og produksjon mellom de landene der disse kravene gjelder. Dette for at det skal være god kontroll på kvalitet og sikkerhet ved kjøp og salg av varer og tjenester i mellom land som styres etter de gitte kravene. Norsok er et eksempel på et norsk myndighetskrav som kommer i tillegg til de europeiske standardene. For denne oppgavens tilfelle ble Norsok brukt på de områder hvor den er dekkende og Eurocode ellers. Det ble i globalanalysen kjørt kodesjekk etter både Norsok og Eurocode for å illustrere forskjellen i resultatene.

Når det gjelder offshore vindturbiner blir disse dimensjonert for en returperiode på 50 år i motsetning til 100 år som er vanlig for olje og gass installasjoner. Grunnen til dette er at det er mer kostnadseffektivt å dimensjonere etter 50 års returperiode kontra 100 års returperiode. Det at installasjonen er ubemannet samt at konsekvensene ved sammenbrudd av en vindturbin kan sees på som mindre enn for eksempel for en oljeplattform er medvirkende til at 50 års returperiode brukes ved dimensjonering.

Det er valgt å bruke tre analyseprogrammer i utførelsen av oppgaven. Fedem Windpower for generering av aerodynamiske krefter, Sesam GeniE for globalanalyse og strukturdesign av fundamentet og Abaqus for generering av spenninger for videre utmattingsanalyse. Samtidig bruk av de to programmene Fedem Windpower og Sesam GeniE førte til en del problemer under import av filer fra Sesam GeniE til Fedem Windpower. En løsning på dette problemet ble funnet, sammen med Fedem Techonolgy AS, og importen fungerer nå som den skal. I tillegg er det knyttet usikkerheter til overføringen av informasjon fra ett program til ett annet. Disse usikkerhetene kan gi variasjoner i analyseresultatene. For å belyse dette problemet ble det valgt å utføre to forksjellige analyser i Sesam GeniE (Analyse 1, fundament, og Analyse 2, fundament og turbintårn). Konklusjonen er at det mest optimale er å kunne utføre hele analysen i ett program (Fedem Windpower er konstruert for å kunne utrøre hele analysen, men på grunn av mangel på opplæring i dette ble ikke det utført i denne oppgaven). Dersom bare et analyseprogram hadde blitt benyttet ville usikkerhetene som oppstår ved import og eksport av data, samt tidsperspektivet, minimaliseres. I tillegg ville hele analysen med sikkerhet blitt kjørt etter samme retningslinjer. Man kan oppleve at forskjellige programmer arbeider etter forskjellige metoder som ikke alltid samsvarer med hverandre. Som eksempel på dette refereres det til vindlastgenereringen utført i denne oppgaven hvor muligheten av forskjellig vindgenereringsmetode i Fedem Windpower og Sesam GeniE diskuteres.

Opprinnelig tanke var å modelleres inn det mest kritiske knutepunktet i Abaqus for så å rekne utmatting på dette. Men da det viste seg å være svært tidkrevende (pga opplæring og vanskelighetgraden av programmet), ble det prøvd ut å importere modellen fra Sesam GeniE inn i Abaqus. Dette førte til resultater som gav store avvik fra resultatene i globalanalysen i Sesam GeniE (resultatet fra lokal analysen i Abaqus viste total kollaps (knekking/deformasjon) av konstruksjonen mens globalanalysen i Sesam GeniE viste at analysen var vellykket med gode marginer). De store avvikene fra de to programmene Sesam GeniE og Abaqus kan tyde på at det har oppstått feilkilder under import/eksport mellom de to programmene og eventuelt at det ligger feil i last/material benevninger. Abaqus er sensitiv på hvordan benevningene blir registrert og en liten feil kan føre til store avvik i resultatene. I tillegg kan en av grunnene være at de to programmene operere etter forskjellige metoder, Sesam GeniE etter bjelkemetoden og Abaqus etter skallmetoden. Skallmetoden er en mer realistisk metode og kan dermed ses på som mest realistisk. Dersom tidsperspektivet hadde vært utvidet, ville en nøyaktig gjenomgang av modellene blitt utført for eliminasjon av eventuelle usikkerheter. I tillegg ville det blitt analysert videre på alternative designløsninger, utformet for bedre å kunne ta opp de store aksial, skjær og momentkreftene. Resultatene fra en eventuell ny lokalanalyse, for et alternativt design, ville så bli brukt videre for utmattingsanalyse, SN-kurver kombinert med Palmgren-Miners summering, for å få en god estimering av levetiden til konstruksjonen.

Et forslag til en alternativ designløsning, "jackettripodløsning", ble utført i kapittel 6, "Alternativ designløsning for videre arbeid". Tanken bak dette var å få frem at en ny designløsning kan være mer kostnadseffektivt (med tanke på bruk av profiler med høyere utnyttelsesgrad) og at den kan ha en mer akseptabel egenfrekvens samt eventuelt komme bedre ut i en eventuell lokalanalyse. For det valgte designet ble både kravene for høyere utnyttelsesfaktor og lavere egenfrekvens oppfylt i henhold til globalanalysen. Den alternative løsningen kan være mer konstruksjonmessig gjennomførbar. Det lave knutepunktet i den opprinnelige løsningen fører til en større knekklengde på sentersøylen og den blir raskt overbelastet. For den alternative løsningen er knutepunktet for kraftfordeling i toppen av fundamentet slik at knekklengden er minimalisert. I tillegg vil det alternative designet ha litt større fabrikasjonskostnader med tanke på sveis og sveiseinspeksjon (flere sveiser å inspisere), men de totale materialkostnadene ville antakeligvis vært mindre da elementer med høy utnyttelse kan føre til mindre materialkvantum sammenliknet med lavt utnyttede elementer.

Oppsummert kan de sies at den valgte designløsningen ikke er optimal for OC4 vindturbinen, men at den eventuelt passer bedre for mindre vindturbiner med andre designegenskaper. I tillegg kan løsningen passe bedre for mindre havdyp hvor lengden på sentersøylen da kan reduseres slik at det øverste knutepunktet kommer i toppen av fundamentet og kreftene fordeles i overgangen mellom turbintårn og fundament. Skal det lages et jacket tripodfundament for OC4 vindturbinen er det mer hensiktsmessig å se på en løsning som vist i kapitel 6, "Alternativ designløsning for videre arbeid", eller en alternativ løsning til denne. Det kan konkluderes med at det bør være mulig å laget et tripodfundament for OC4 vindturbinen som et alternativ til dagens fire bens jacket løsning.

8 Videre arbeid

Følgende kapittel gir en punktvis oppsummering av faktorer som er kilder til videre arbeid i forbindelse med oppgaven

- Gjøre hele analysen i FEDEM Windpower (dette skal være mulig) og eventuelt sammenlikne resultatene for å se om det eventuelt er store avvik. Denne analysen ble ikke utført da det var problematisk for ekstern veileder å få tilgang til FEDEM Windpower.
- På grunn av tidsbegrensning er bare en vindhastighet valgt som utgangspunkt for globalberegningene. I teorien skulle man hatt simuleringer med flere vindhastigheter fra 2 m/s til 25 m/s. For videre arbeid bør man se på alle vindhastigheter for å finne den som er mest utslagsgivende.
- Optimalisering med tanke på utnyttelse av profilstørrelser og strukturens egenfrekvensområde. Da må det også tas en vurdering på levetid da denne kan bli mindre ved en eventuell mykere konstruksjon. Fabrikasjonskostnadene ved en mykere konstruksjon vil mest sannsynlig være lavere enn for en stiv, men levetiden for en stiv konstruksjon vil mest sannsynlig være høyere enn for en myk konstruksjon. En totalvurdering på dette må tas ved en reel gjennomføring av designet.
- Vurdere om det foreslåtte designet kan brukes med en mindre turbin, eksempelvis en 3MW turbin uten at det blir problemer med resonans og at designet dermed kan brukes og være økonomisk lønnsomt.
- Kjøre analyser for ureglemessige bølger og undersøke konstruksjonens oppførsel i henhold til belastningen slike bølger gir.
- Utføre analyser for litt forskjellige havdyp og se om det er forskjeller i resultatene og om det eventuelt trengs justeringer av konstruksjonen dersom den skal brukes ved forskjellige havdyp
- For å få et komplett design må det også sees på og kjøre analyser for selve innfestningen til havbunnen, pæleanalyse
- Grundig gjennomgang av Abaqusmodellen og vurdere om det til slutt er rimelige avvik mellom global og lokal analysen (avvik som teoretisk kan forklares).
- Analyser av alternative design og vektoptimalisering

9 Referanser

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10 Vedlegg

Vedlegg 1 – .fem fil generert av Sesam GeniE for import av fundament til FEDEM Windpower

Vedlegg 2 – Egenfrekvensanalyse/strukturfrekvensanalyse i Sesam GeniE

Vedlegg 3 – Analyse 1, lineær strukturanalyse og hydrodynamisk analyse, fra Sesam GeniE

Vedlegg 4 – Analyse 2, lineær strukturanalyse og hydrodynamisk analyse, fra Sesam GeniE

Vedlegg 5 – "Carbon Trust, Draft, OWA OFFSHORE WIND FARM FOUNDATIONS UK Round 3, Design Basis. Version 2, November 2009"

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Vedlegg 7 – "Description of a basic model of the "UpWind reference jacket" for code comparison in the OC4 project under IEA Wind Annex XXX"

Vedlegg 8 – "Marine technology/Environmental Loads, Wind Load on Strutures, Part 1, Jasna Jakobsen

Vedlegg 9 – Egenfrekvensanalyse/strukturfrekvensanalyse av alternativt design; Sesam GeniE

Vedlegg 10 – Analyse 1, lineær strukturanalyse og hydrodynamisk analyse, alternativt design, fra Sesam GeniE

Vedlegg 11 – Analyse 2, lineær strukturanalyse og hydrodynamisk analyse , alternativt design, fra Sesam GeniE

Vedlegg 1 – .fem fil generert av Sesam GeniE for import av fundament til FEDEM Windpower

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        COMPUTER:  X86 Windows          INSTALLATION:
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        USER:      ofsbilil             ACCOUNT:
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TDSCONC    4.00000000E+00  6.00000000E+00  1.04000000E+02  0.00000000E+00
        Bm33
TDSCONC    4.00000000E+00  7.00000000E+00  1.04000000E+02  0.00000000E+00
        Bm34
TDSCONC    4.00000000E+00  8.00000000E+00  1.04000000E+02  0.00000000E+00
        Bm35
TDSCONC    4.00000000E+00  9.00000000E+00  1.04000000E+02  0.00000000E+00
        Bm36
TDSCONC    4.00000000E+00  1.00000000E+01  1.04000000E+02  0.00000000E+00
        Bm37
TDSCONC    4.00000000E+00  1.10000000E+01  1.04000000E+02  0.00000000E+00
```

```
        Bm38
TDSCONC   4.00000000E+00  1.20000000E+01  1.04000000E+02  0.00000000E+00
        Bm39
TDSCONC   4.00000000E+00  1.30000000E+01  1.04000000E+02  0.00000000E+00
        Bm40
TDSCONC   4.00000000E+00  1.40000000E+01  1.04000000E+02  0.00000000E+00
        Bm41
TDSCONC   4.00000000E+00  1.50000000E+01  1.04000000E+02  0.00000000E+00
        Bm42
TDSCONC   4.00000000E+00  1.60000000E+01  1.04000000E+02  0.00000000E+00
        Bm43
TDSCONC   4.00000000E+00  1.70000000E+01  1.04000000E+02  0.00000000E+00
        Bm47
TDSCONC   4.00000000E+00  1.80000000E+01  1.04000000E+02  0.00000000E+00
        Bm48
TDSCONC   4.00000000E+00  1.90000000E+01  1.04000000E+02  0.00000000E+00
        Bm49
TDSCONC   4.00000000E+00  2.00000000E+01  1.04000000E+02  0.00000000E+00
        Bm50
TDSCONC   4.00000000E+00  2.10000000E+01  1.04000000E+02  0.00000000E+00
        Bm51
TDSCONC   4.00000000E+00  2.20000000E+01  1.04000000E+02  0.00000000E+00
        Bm52
TDSCONC   4.00000000E+00  2.30000000E+01  1.04000000E+02  0.00000000E+00
        Bm53
TDSCONC   4.00000000E+00  2.40000000E+01  1.04000000E+02  0.00000000E+00
        Bm55
TDSCONC   4.00000000E+00  2.50000000E+01  1.04000000E+02  0.00000000E+00
        Bm56
TDSCONC   4.00000000E+00  2.60000000E+01  1.04000000E+02  0.00000000E+00
        Bm60
TDSCONC   4.00000000E+00  2.70000000E+01  1.04000000E+02  0.00000000E+00
        Bm61
TDSCONC   4.00000000E+00  2.80000000E+01  1.04000000E+02  0.00000000E+00
        Bm62
TDSCONC   4.00000000E+00  2.90000000E+01  1.04000000E+02  0.00000000E+00
        Bm63
SCONCEPT  8.00000000E+00  1.00000000E+00  7.00000000E+00  0.00000000E+00
          0.00000000E+00  1.00000000E+00  0.00000000E+00  3.00000000E+01
SCONCEPT  8.00000000E+00  2.00000000E+00  7.00000000E+00  0.00000000E+00
          0.00000000E+00  1.00000000E+00  0.00000000E+00  3.10000000E+01
SCONCEPT  8.00000000E+00  3.00000000E+00  7.00000000E+00  0.00000000E+00
          0.00000000E+00  1.00000000E+00  0.00000000E+00  3.20000000E+01
SCONCEPT  8.00000000E+00  4.00000000E+00  7.00000000E+00  0.00000000E+00
          0.00000000E+00  1.00000000E+00  0.00000000E+00  3.30000000E+01
SCONCEPT  8.00000000E+00  5.00000000E+00  7.00000000E+00  0.00000000E+00
          0.00000000E+00  1.00000000E+00  0.00000000E+00  3.40000000E+01
SCONCEPT  8.00000000E+00  6.00000000E+00  7.00000000E+00  0.00000000E+00
          0.00000000E+00  1.00000000E+00  0.00000000E+00  3.50000000E+01
SCONCEPT  8.00000000E+00  7.00000000E+00  7.00000000E+00  0.00000000E+00
          0.00000000E+00  1.00000000E+00  0.00000000E+00  3.60000000E+01
SCONCEPT  8.00000000E+00  8.00000000E+00  7.00000000E+00  0.00000000E+00
          0.00000000E+00  1.00000000E+00  0.00000000E+00  3.70000000E+01
SCONCEPT  8.00000000E+00  9.00000000E+00  7.00000000E+00  0.00000000E+00
          0.00000000E+00  1.00000000E+00  0.00000000E+00  3.80000000E+01
SCONCEPT  8.00000000E+00  1.00000000E+01  7.00000000E+00  0.00000000E+00
          0.00000000E+00  1.00000000E+00  0.00000000E+00  3.90000000E+01
SCONCEPT  8.00000000E+00  1.10000000E+01  7.00000000E+00  0.00000000E+00
          0.00000000E+00  1.00000000E+00  0.00000000E+00  4.00000000E+01
SCONCEPT  8.00000000E+00  1.20000000E+01  7.00000000E+00  0.00000000E+00
          0.00000000E+00  1.00000000E+00  0.00000000E+00  4.10000000E+01
SCONCEPT  8.00000000E+00  1.30000000E+01  7.00000000E+00  0.00000000E+00
          0.00000000E+00  1.00000000E+00  0.00000000E+00  4.20000000E+01
SCONCEPT  8.00000000E+00  1.40000000E+01  7.00000000E+00  0.00000000E+00
          0.00000000E+00  1.00000000E+00  0.00000000E+00  4.30000000E+01
SCONCEPT  8.00000000E+00  1.50000000E+01  7.00000000E+00  0.00000000E+00
          0.00000000E+00  1.00000000E+00  0.00000000E+00  4.40000000E+01
SCONCEPT  8.00000000E+00  1.60000000E+01  7.00000000E+00  0.00000000E+00
```

```
           0.00000000E+00   1.00000000E+00   0.00000000E+00   4.50000000E+01
SCONCEPT   8.00000000E+00   1.70000000E+01   7.00000000E+00   0.00000000E+00
           0.00000000E+00   1.00000000E+00   0.00000000E+00   4.60000000E+01
SCONCEPT   8.00000000E+00   1.80000000E+01   7.00000000E+00   0.00000000E+00
           0.00000000E+00   1.00000000E+00   0.00000000E+00   4.70000000E+01
SCONCEPT   8.00000000E+00   1.90000000E+01   7.00000000E+00   0.00000000E+00
           0.00000000E+00   1.00000000E+00   0.00000000E+00   4.80000000E+01
SCONCEPT   8.00000000E+00   2.00000000E+01   7.00000000E+00   0.00000000E+00
           0.00000000E+00   1.00000000E+00   0.00000000E+00   4.90000000E+01
SCONCEPT   8.00000000E+00   2.10000000E+01   7.00000000E+00   0.00000000E+00
           0.00000000E+00   1.00000000E+00   0.00000000E+00   5.00000000E+01
SCONCEPT   8.00000000E+00   2.20000000E+01   7.00000000E+00   0.00000000E+00
           0.00000000E+00   1.00000000E+00   0.00000000E+00   5.10000000E+01
SCONCEPT   8.00000000E+00   2.30000000E+01   7.00000000E+00   0.00000000E+00
           0.00000000E+00   1.00000000E+00   0.00000000E+00   5.20000000E+01
SCONCEPT   8.00000000E+00   2.40000000E+01   7.00000000E+00   0.00000000E+00
           0.00000000E+00   1.00000000E+00   0.00000000E+00   5.30000000E+01
SCONCEPT   8.00000000E+00   2.50000000E+01   7.00000000E+00   0.00000000E+00
           0.00000000E+00   1.00000000E+00   0.00000000E+00   5.40000000E+01
SCONCEPT   8.00000000E+00   2.60000000E+01   7.00000000E+00   0.00000000E+00
           0.00000000E+00   1.00000000E+00   0.00000000E+00   5.50000000E+01
SCONCEPT   8.00000000E+00   2.70000000E+01   7.00000000E+00   0.00000000E+00
           0.00000000E+00   1.00000000E+00   0.00000000E+00   5.60000000E+01
SCONCEPT   8.00000000E+00   2.80000000E+01   7.00000000E+00   0.00000000E+00
           0.00000000E+00   1.00000000E+00   0.00000000E+00   5.70000000E+01
SCONCEPT   8.00000000E+00   2.90000000E+01   7.00000000E+00   0.00000000E+00
           0.00000000E+00   1.00000000E+00   0.00000000E+00   5.80000000E+01
SCONCEPT   5.00000000E+00   3.00000000E+01   2.00000000E+00   4.00000000E+00
           1.00000000E+00
SCONCEPT   5.00000000E+00   3.10000000E+01   2.00000000E+00   4.00000000E+00
           2.00000000E+00
SCONCEPT   5.00000000E+00   3.20000000E+01   2.00000000E+00   4.00000000E+00
           3.00000000E+00
SCONCEPT   5.00000000E+00   3.30000000E+01   2.00000000E+00   4.00000000E+00
           4.00000000E+00
SCONCEPT   5.00000000E+00   3.40000000E+01   2.00000000E+00   4.00000000E+00
           5.00000000E+00
SCONCEPT   5.00000000E+00   3.50000000E+01   2.00000000E+00   4.00000000E+00
           6.00000000E+00
SCONCEPT   5.00000000E+00   3.60000000E+01   2.00000000E+00   4.00000000E+00
           7.00000000E+00
SCONCEPT   5.00000000E+00   3.70000000E+01   2.00000000E+00   4.00000000E+00
           8.00000000E+00
SCONCEPT   5.00000000E+00   3.80000000E+01   2.00000000E+00   4.00000000E+00
           9.00000000E+00
SCONCEPT   5.00000000E+00   3.90000000E+01   2.00000000E+00   4.00000000E+00
           1.00000000E+01
SCONCEPT   5.00000000E+00   4.00000000E+01   2.00000000E+00   4.00000000E+00
           1.10000000E+01
SCONCEPT   5.00000000E+00   4.10000000E+01   2.00000000E+00   4.00000000E+00
           1.20000000E+01
SCONCEPT   5.00000000E+00   4.20000000E+01   2.00000000E+00   4.00000000E+00
           1.30000000E+01
SCONCEPT   5.00000000E+00   4.30000000E+01   2.00000000E+00   4.00000000E+00
           1.40000000E+01
SCONCEPT   5.00000000E+00   4.40000000E+01   2.00000000E+00   4.00000000E+00
           1.50000000E+01
SCONCEPT   5.00000000E+00   4.50000000E+01   2.00000000E+00   4.00000000E+00
           1.60000000E+01
SCONCEPT   5.00000000E+00   4.60000000E+01   2.00000000E+00   4.00000000E+00
           1.70000000E+01
SCONCEPT   5.00000000E+00   4.70000000E+01   2.00000000E+00   4.00000000E+00
           1.80000000E+01
SCONCEPT   5.00000000E+00   4.80000000E+01   2.00000000E+00   4.00000000E+00
           1.90000000E+01
SCONCEPT   5.00000000E+00   4.90000000E+01   2.00000000E+00   4.00000000E+00
           2.00000000E+01
SCONCEPT   5.00000000E+00   5.00000000E+01   2.00000000E+00   4.00000000E+00
```

```
          2.10000000E+01
SCONCEPT  5.00000000E+00  5.10000000E+01  2.00000000E+00  4.00000000E+00
          2.20000000E+01
SCONCEPT  5.00000000E+00  5.20000000E+01  2.00000000E+00  4.00000000E+00
          2.30000000E+01
SCONCEPT  5.00000000E+00  5.30000000E+01  2.00000000E+00  4.00000000E+00
          2.40000000E+01
SCONCEPT  5.00000000E+00  5.40000000E+01  2.00000000E+00  4.00000000E+00
          2.50000000E+01
SCONCEPT  5.00000000E+00  5.50000000E+01  2.00000000E+00  4.00000000E+00
          2.60000000E+01
SCONCEPT  5.00000000E+00  5.60000000E+01  2.00000000E+00  4.00000000E+00
          2.70000000E+01
SCONCEPT  5.00000000E+00  5.70000000E+01  2.00000000E+00  4.00000000E+00
          2.80000000E+01
SCONCEPT  5.00000000E+00  5.80000000E+01  2.00000000E+00  4.00000000E+00
          2.90000000E+01
SCONMESH  7.00000000E+00  3.00000000E+01  1.00000000E+00  2.00000000E+00
          2.00000000E+00  1.00000000E+00  2.00000000E+00
SCONMESH  7.00000000E+00  3.10000000E+01  1.00000000E+00  2.00000000E+00
          2.00000000E+00  3.30000000E+01  3.40000000E+01
SCONMESH  7.00000000E+00  3.20000000E+01  1.00000000E+00  2.00000000E+00
          2.00000000E+00  2.10000000E+01  2.20000000E+01
SCONMESH  8.00000000E+00  3.30000000E+01  1.00000000E+00  2.00000000E+00
          3.00000000E+00  1.30000000E+01  1.40000000E+01  1.50000000E+01
SCONMESH  6.00000000E+00  3.40000000E+01  1.00000000E+00  2.00000000E+00
          1.00000000E+00  6.00000000E+00
SCONMESH  6.00000000E+00  3.50000000E+01  1.00000000E+00  2.00000000E+00
          1.00000000E+00  3.20000000E+01
SCONMESH  6.00000000E+00  3.60000000E+01  1.00000000E+00  2.00000000E+00
          1.00000000E+00  1.20000000E+01
SCONMESH  6.00000000E+00  3.70000000E+01  1.00000000E+00  2.00000000E+00
          1.00000000E+00  9.00000000E+00
SCONMESH  6.00000000E+00  3.80000000E+01  1.00000000E+00  2.00000000E+00
          1.00000000E+00  1.90000000E+01
SCONMESH  6.00000000E+00  3.90000000E+01  1.00000000E+00  2.00000000E+00
          1.00000000E+00  2.90000000E+01
SCONMESH  6.00000000E+00  4.00000000E+01  1.00000000E+00  2.00000000E+00
          1.00000000E+00  5.00000000E+00
SCONMESH  6.00000000E+00  4.10000000E+01  1.00000000E+00  2.00000000E+00
          1.00000000E+00  3.10000000E+01
SCONMESH  6.00000000E+00  4.20000000E+01  1.00000000E+00  2.00000000E+00
          1.00000000E+00  1.10000000E+01
SCONMESH  6.00000000E+00  4.30000000E+01  1.00000000E+00  2.00000000E+00
          1.00000000E+00  7.00000000E+00
SCONMESH  6.00000000E+00  4.40000000E+01  1.00000000E+00  2.00000000E+00
          1.00000000E+00  2.70000000E+01
SCONMESH  6.00000000E+00  4.50000000E+01  1.00000000E+00  2.00000000E+00
          1.00000000E+00  1.70000000E+01
SCONMESH  6.00000000E+00  4.60000000E+01  1.00000000E+00  2.00000000E+00
          1.00000000E+00  1.60000000E+01
SCONMESH  6.00000000E+00  4.70000000E+01  1.00000000E+00  2.00000000E+00
          1.00000000E+00  3.00000000E+01
SCONMESH  6.00000000E+00  4.80000000E+01  1.00000000E+00  2.00000000E+00
          1.00000000E+00  2.00000000E+01
SCONMESH  6.00000000E+00  4.90000000E+01  1.00000000E+00  2.00000000E+00
          1.00000000E+00  1.00000000E+01
SCONMESH  6.00000000E+00  5.00000000E+01  1.00000000E+00  2.00000000E+00
          1.00000000E+00  8.00000000E+00
SCONMESH  6.00000000E+00  5.10000000E+01  1.00000000E+00  2.00000000E+00
          1.00000000E+00  1.80000000E+01
SCONMESH  6.00000000E+00  5.20000000E+01  1.00000000E+00  2.00000000E+00
          1.00000000E+00  2.80000000E+01
SCONMESH  6.00000000E+00  5.30000000E+01  1.00000000E+00  2.00000000E+00
          1.00000000E+00  4.00000000E+00
SCONMESH  6.00000000E+00  5.40000000E+01  1.00000000E+00  2.00000000E+00
          1.00000000E+00  3.00000000E+00
SCONMESH  6.00000000E+00  5.50000000E+01  1.00000000E+00  2.00000000E+00
```

```
          1.00000000E+00  2.50000000E+01
SCONMESH  6.00000000E+00  5.60000000E+01  1.00000000E+00  2.00000000E+00
          1.00000000E+00  2.60000000E+01
SCONMESH  6.00000000E+00  5.70000000E+01  1.00000000E+00  2.00000000E+00
          1.00000000E+00  2.40000000E+01
SCONMESH  6.00000000E+00  5.80000000E+01  1.00000000E+00  2.00000000E+00
          1.00000000E+00  2.30000000E+01
SCONPLIS  5.00000000E+00  3.00000000E+01  1.00000000E+00  1.00000000E+00
          1.00000000E+00
SCONPLIS  5.00000000E+00  3.10000000E+01  1.00000000E+00  1.00000000E+00
          1.00000000E+00
SCONPLIS  5.00000000E+00  3.20000000E+01  1.00000000E+00  1.00000000E+00
          1.00000000E+00
SCONPLIS  5.00000000E+00  3.30000000E+01  1.00000000E+00  1.00000000E+00
          1.00000000E+00
SCONPLIS  5.00000000E+00  3.40000000E+01  1.00000000E+00  1.00000000E+00
          1.00000000E+00
SCONPLIS  5.00000000E+00  3.50000000E+01  1.00000000E+00  1.00000000E+00
          1.00000000E+00
SCONPLIS  5.00000000E+00  3.60000000E+01  1.00000000E+00  1.00000000E+00
          1.00000000E+00
SCONPLIS  5.00000000E+00  3.70000000E+01  1.00000000E+00  1.00000000E+00
          1.00000000E+00
SCONPLIS  5.00000000E+00  3.80000000E+01  1.00000000E+00  1.00000000E+00
          1.00000000E+00
SCONPLIS  5.00000000E+00  3.90000000E+01  1.00000000E+00  1.00000000E+00
          1.00000000E+00
SCONPLIS  5.00000000E+00  4.00000000E+01  1.00000000E+00  1.00000000E+00
          1.00000000E+00
SCONPLIS  5.00000000E+00  4.10000000E+01  1.00000000E+00  1.00000000E+00
          1.00000000E+00
SCONPLIS  5.00000000E+00  4.20000000E+01  1.00000000E+00  1.00000000E+00
          1.00000000E+00
SCONPLIS  5.00000000E+00  4.30000000E+01  1.00000000E+00  1.00000000E+00
          1.00000000E+00
SCONPLIS  5.00000000E+00  4.40000000E+01  1.00000000E+00  1.00000000E+00
          1.00000000E+00
SCONPLIS  5.00000000E+00  4.50000000E+01  1.00000000E+00  1.00000000E+00
          1.00000000E+00
SCONPLIS  5.00000000E+00  4.60000000E+01  1.00000000E+00  1.00000000E+00
          1.00000000E+00
SCONPLIS  5.00000000E+00  4.70000000E+01  1.00000000E+00  1.00000000E+00
          1.00000000E+00
SCONPLIS  5.00000000E+00  4.80000000E+01  1.00000000E+00  1.00000000E+00
          1.00000000E+00
SCONPLIS  5.00000000E+00  4.90000000E+01  1.00000000E+00  1.00000000E+00
          1.00000000E+00
SCONPLIS  5.00000000E+00  5.00000000E+01  1.00000000E+00  1.00000000E+00
          1.00000000E+00
SCONPLIS  5.00000000E+00  5.10000000E+01  1.00000000E+00  1.00000000E+00
          1.00000000E+00
SCONPLIS  5.00000000E+00  5.20000000E+01  1.00000000E+00  1.00000000E+00
          1.00000000E+00
SCONPLIS  5.00000000E+00  5.30000000E+01  1.00000000E+00  1.00000000E+00
          1.00000000E+00
SCONPLIS  5.00000000E+00  5.40000000E+01  1.00000000E+00  1.00000000E+00
          1.00000000E+00
SCONPLIS  5.00000000E+00  5.50000000E+01  1.00000000E+00  1.00000000E+00
          1.00000000E+00
SCONPLIS  5.00000000E+00  5.60000000E+01  1.00000000E+00  1.00000000E+00
          1.00000000E+00
SCONPLIS  5.00000000E+00  5.70000000E+01  1.00000000E+00  1.00000000E+00
          1.00000000E+00
SCONPLIS  5.00000000E+00  5.80000000E+01  1.00000000E+00  1.00000000E+00
          1.00000000E+00
SPROSELE  5.00000000E+00  1.00000000E+00  1.00000000E+00  5.00000000E+00
          1.00000000E+00
SPROHYDR  1.70000000E+01  1.00000000E+00  7.00000000E+00  5.00000000E+02
```

```
           1.00000000E+00  5.01000000E+02  0.00000000E+00  5.02000000E+02
           8.99999976E-01  5.03000000E+02  8.99999976E-01  5.04000000E+02
           0.00000000E+00  5.05000000E+02  2.00000000E+00  5.06000000E+02
           2.00000000E+00
GUNIVEC    1.00000000E+00  0.00000000E+00  1.00000000E+00  0.00000000E+00
GUNIVEC    2.00000000E+00  0.00000000E+00  0.00000000E+00  1.00000000E+00
GUNIVEC    3.00000000E+00 -2.17238709E-01 -1.50485486E-01  9.64448810E-01
GUNIVEC    4.00000000E+00 -5.77284455E-01 -3.99896175E-01  7.11916924E-01
GUNIVEC    5.00000000E+00 -4.51674968E-01 -3.12884033E-01  8.35519791E-01
GUNIVEC    6.00000000E+00  0.00000000E+00  3.05396765E-01  9.52225208E-01
GUNIVEC    7.00000000E+00  0.00000000E+00  7.55897522E-01  6.54689908E-01
GUNIVEC    8.00000000E+00  0.00000000E+00  6.09957159E-01  7.92434394E-01
GUNIVEC    9.00000000E+00  2.17238709E-01 -1.50485486E-01  9.64448810E-01
GUNIVEC    1.00000000E+01  5.77284455E-01 -3.99896175E-01  7.11916924E-01
GUNIVEC    1.10000000E+01  4.51674968E-01 -3.12884033E-01  8.35519791E-01
TDNODE     4.00000000E+00  2.00000000E+00  1.03000000E+02  0.00000000E+00
        Jt2
TDNODE     4.00000000E+00  1.20000000E+01  1.03000000E+02  0.00000000E+00
        Jt1
GNODE      1.00000000E+00  1.00000000E+00  6.00000000E+00  1.23456000E+05
GNODE      2.00000000E+00  2.00000000E+00  6.00000000E+00  1.23456000E+05
GNODE      3.00000000E+00  3.00000000E+00  6.00000000E+00  1.23456000E+05
GNODE      4.00000000E+00  4.00000000E+00  6.00000000E+00  1.23456000E+05
GNODE      5.00000000E+00  5.00000000E+00  6.00000000E+00  1.23456000E+05
GNODE      6.00000000E+00  6.00000000E+00  6.00000000E+00  1.23456000E+05
GNODE      7.00000000E+00  7.00000000E+00  6.00000000E+00  1.23456000E+05
GNODE      8.00000000E+00  8.00000000E+00  6.00000000E+00  1.23456000E+05
GNODE      9.00000000E+00  9.00000000E+00  6.00000000E+00  1.23456000E+05
GNODE      1.00000000E+01  1.00000000E+01  6.00000000E+00  1.23456000E+05
GNODE      1.10000000E+01  1.10000000E+01  6.00000000E+00  1.23456000E+05
GNODE      1.20000000E+01  1.20000000E+01  6.00000000E+00  1.23456000E+05
GNODE      1.30000000E+01  1.30000000E+01  6.00000000E+00  1.23456000E+05
GNODE      1.40000000E+01  1.40000000E+01  6.00000000E+00  1.23456000E+05
GNODE      1.50000000E+01  1.50000000E+01  6.00000000E+00  1.23456000E+05
GNODE      1.60000000E+01  1.60000000E+01  6.00000000E+00  1.23456000E+05
GNODE      1.70000000E+01  1.70000000E+01  6.00000000E+00  1.23456000E+05
GNODE      1.80000000E+01  1.80000000E+01  6.00000000E+00  1.23456000E+05
GNODE      1.90000000E+01  1.90000000E+01  6.00000000E+00  1.23456000E+05
GNODE      2.00000000E+01  2.00000000E+01  6.00000000E+00  1.23456000E+05
GCOORD     1.00000000E+00 -1.50000000E+01 -1.03907919E+01  0.00000000E+00
GCOORD     2.00000000E+00 -1.50000000E+01 -1.03907919E+01  1.80000000E+01
GCOORD     3.00000000E+00 -1.50000000E+01 -1.03907919E+01  2.00000000E+01
GCOORD     4.00000000E+00 -7.50000048E+00  2.59958744E+00  0.00000000E+00
GCOORD     5.00000000E+00 -7.50000000E+00  2.59958816E+00  1.80000000E+01
GCOORD     6.00000000E+00  0.00000000E+00 -1.03907919E+01  0.00000000E+00
GCOORD     7.00000000E+00  0.00000000E+00 -1.03907919E+01  1.80000000E+01
GCOORD     8.00000000E+00  0.00000000E+00  0.00000000E+00  5.00000000E+00
GCOORD     9.00000000E+00  0.00000000E+00  0.00000000E+00  1.80000000E+01
GCOORD     1.00000000E+01  0.00000000E+00  0.00000000E+00  3.00000000E+01
GCOORD     1.10000000E+01  0.00000000E+00  1.55899687E+01  0.00000000E+00
GCOORD     1.20000000E+01  0.00000000E+00  1.55899687E+01  1.80000000E+01
GCOORD     1.30000000E+01  0.00000000E+00  0.00000000E+00  5.00000000E+01
GCOORD     1.40000000E+01  0.00000000E+00  0.00000000E+00  6.51500015E+01
GCOORD     1.50000000E+01  0.00000000E+00  1.55899687E+01  2.00000000E+01
GCOORD     1.60000000E+01  7.49999952E+00  2.59958911E+00  0.00000000E+00
GCOORD     1.70000000E+01  7.49999952E+00  2.59958911E+00  1.80000000E+01
GCOORD     1.80000000E+01  1.50000000E+01 -1.03907919E+01  0.00000000E+00
GCOORD     1.90000000E+01  1.50000000E+01 -1.03907919E+01  1.80000000E+01
GCOORD     2.00000000E+01  1.50000000E+01 -1.03907919E+01  2.00000000E+01
BNBCD      1.00000000E+00  6.00000000E+00  1.00000000E+00  1.00000000E+00
           1.00000000E+00  1.00000000E+00  1.00000000E+00  1.00000000E+00
BNBCD      1.10000000E+01  6.00000000E+00  1.00000000E+00  1.00000000E+00
           1.00000000E+00  1.00000000E+00  1.00000000E+00  1.00000000E+00
BNBCD      1.80000000E+01  6.00000000E+00  1.00000000E+00  1.00000000E+00
           1.00000000E+00  1.00000000E+00  1.00000000E+00  1.00000000E+00
GELMNT1    1.00000000E+00  1.00000000E+00  1.50000000E+01  0.00000000E+00
           1.00000000E+00  2.00000000E+00
GELMNT1    2.00000000E+00  2.00000000E+00  1.50000000E+01  0.00000000E+00
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         2.00000000E+00  3.00000000E+00
GELMNT1  3.00000000E+00  3.00000000E+00  1.50000000E+01  0.00000000E+00
         4.00000000E+00  1.00000000E+00
GELMNT1  4.00000000E+00  4.00000000E+00  1.50000000E+01  0.00000000E+00
         5.00000000E+00  2.00000000E+00
GELMNT1  5.00000000E+00  5.00000000E+00  1.50000000E+01  0.00000000E+00
         1.00000000E+00  6.00000000E+00
GELMNT1  6.00000000E+00  6.00000000E+00  1.50000000E+01  0.00000000E+00
         2.00000000E+00  7.00000000E+00
GELMNT1  7.00000000E+00  7.00000000E+00  1.50000000E+01  0.00000000E+00
         1.00000000E+00  8.00000000E+00
GELMNT1  8.00000000E+00  8.00000000E+00  1.50000000E+01  0.00000000E+00
         1.00000000E+00  9.00000000E+00
GELMNT1  9.00000000E+00  9.00000000E+00  1.50000000E+01  0.00000000E+00
         2.00000000E+00  9.00000000E+00
GELMNT1  1.00000000E+01  1.00000000E+01  1.50000000E+01  0.00000000E+00
         2.00000000E+00  1.00000000E+01
GELMNT1  1.10000000E+01  1.10000000E+01  1.50000000E+01  0.00000000E+00
         1.10000000E+01  4.00000000E+00
GELMNT1  1.20000000E+01  1.20000000E+01  1.50000000E+01  0.00000000E+00
         1.20000000E+01  5.00000000E+00
GELMNT1  1.30000000E+01  1.30000000E+01  1.50000000E+01  0.00000000E+00
         8.00000000E+00  9.00000000E+00
GELMNT1  1.40000000E+01  1.40000000E+01  1.50000000E+01  0.00000000E+00
         9.00000000E+00  1.00000000E+01
GELMNT1  1.50000000E+01  1.50000000E+01  1.50000000E+01  0.00000000E+00
         1.00000000E+01  1.30000000E+01
GELMNT1  1.60000000E+01  1.60000000E+01  1.50000000E+01  0.00000000E+00
         1.30000000E+01  1.40000000E+01
GELMNT1  1.70000000E+01  1.70000000E+01  1.50000000E+01  0.00000000E+00
         1.10000000E+01  8.00000000E+00
GELMNT1  1.80000000E+01  1.80000000E+01  1.50000000E+01  0.00000000E+00
         1.10000000E+01  9.00000000E+00
GELMNT1  1.90000000E+01  1.90000000E+01  1.50000000E+01  0.00000000E+00
         1.20000000E+01  9.00000000E+00
GELMNT1  2.00000000E+01  2.00000000E+01  1.50000000E+01  0.00000000E+00
         1.20000000E+01  1.00000000E+01
GELMNT1  2.10000000E+01  2.10000000E+01  1.50000000E+01  0.00000000E+00
         1.10000000E+01  1.20000000E+01
GELMNT1  2.20000000E+01  2.20000000E+01  1.50000000E+01  0.00000000E+00
         1.20000000E+01  1.50000000E+01
GELMNT1  2.30000000E+01  2.30000000E+01  1.50000000E+01  0.00000000E+00
         1.60000000E+01  1.10000000E+01
GELMNT1  2.40000000E+01  2.40000000E+01  1.50000000E+01  0.00000000E+00
         1.70000000E+01  1.20000000E+01
GELMNT1  2.50000000E+01  2.50000000E+01  1.50000000E+01  0.00000000E+00
         6.00000000E+00  1.80000000E+01
GELMNT1  2.60000000E+01  2.60000000E+01  1.50000000E+01  0.00000000E+00
         7.00000000E+00  1.90000000E+01
GELMNT1  2.70000000E+01  2.70000000E+01  1.50000000E+01  0.00000000E+00
         1.80000000E+01  8.00000000E+00
GELMNT1  2.80000000E+01  2.80000000E+01  1.50000000E+01  0.00000000E+00
         1.80000000E+01  9.00000000E+00
GELMNT1  2.90000000E+01  2.90000000E+01  1.50000000E+01  0.00000000E+00
         1.90000000E+01  9.00000000E+00
GELMNT1  3.00000000E+01  3.00000000E+01  1.50000000E+01  0.00000000E+00
         1.90000000E+01  1.00000000E+01
GELMNT1  3.10000000E+01  3.10000000E+01  1.50000000E+01  0.00000000E+00
         1.80000000E+01  1.60000000E+01
GELMNT1  3.20000000E+01  3.20000000E+01  1.50000000E+01  0.00000000E+00
         1.90000000E+01  1.70000000E+01
GELMNT1  3.30000000E+01  3.30000000E+01  1.50000000E+01  0.00000000E+00
         1.80000000E+01  1.90000000E+01
GELMNT1  3.40000000E+01  3.40000000E+01  1.50000000E+01  0.00000000E+00
         1.90000000E+01  2.00000000E+01
GELREF1  1.00000000E+00  1.00000000E+00  1.00000000E+00  0.00000000E+00
         0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
         1.00000000E+00  0.00000000E+00  0.00000000E+00  1.00000000E+00
```

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GELREF1    2.00000000E+00  1.00000000E+00  1.00000000E+00  0.00000000E+00
           0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
           1.00000000E+00  0.00000000E+00  0.00000000E+00  1.00000000E+00
GELREF1    3.00000000E+00  1.00000000E+00  1.00000000E+00  0.00000000E+00
           0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
           2.00000000E+00  0.00000000E+00  0.00000000E+00  2.00000000E+00
GELREF1    4.00000000E+00  1.00000000E+00  1.00000000E+00  0.00000000E+00
           0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
           2.00000000E+00  0.00000000E+00  0.00000000E+00  2.00000000E+00
GELREF1    5.00000000E+00  1.00000000E+00  1.00000000E+00  0.00000000E+00
           0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
           2.00000000E+00  0.00000000E+00  0.00000000E+00  2.00000000E+00
GELREF1    6.00000000E+00  1.00000000E+00  1.00000000E+00  0.00000000E+00
           0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
           2.00000000E+00  0.00000000E+00  0.00000000E+00  2.00000000E+00
GELREF1    7.00000000E+00  1.00000000E+00  1.00000000E+00  0.00000000E+00
           0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
           2.00000000E+00  0.00000000E+00  0.00000000E+00  3.00000000E+00
GELREF1    8.00000000E+00  1.00000000E+00  1.00000000E+00  0.00000000E+00
           0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
           3.00000000E+00  0.00000000E+00  0.00000000E+00  4.00000000E+00
GELREF1    9.00000000E+00  1.00000000E+00  1.00000000E+00  0.00000000E+00
           0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
           2.00000000E+00  0.00000000E+00  0.00000000E+00  2.00000000E+00
GELREF1    1.00000000E+01  1.00000000E+00  1.00000000E+00  0.00000000E+00
           0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
           3.00000000E+00  0.00000000E+00  0.00000000E+00  5.00000000E+00
GELREF1    1.10000000E+01  1.00000000E+00  1.00000000E+00  0.00000000E+00
           0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
           2.00000000E+00  0.00000000E+00  0.00000000E+00  2.00000000E+00
GELREF1    1.20000000E+01  1.00000000E+00  1.00000000E+00  0.00000000E+00
           0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
           2.00000000E+00  0.00000000E+00  0.00000000E+00  2.00000000E+00
GELREF1    1.30000000E+01  1.00000000E+00  1.00000000E+00  0.00000000E+00
           0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
           4.00000000E+00  0.00000000E+00  0.00000000E+00  1.00000000E+00
GELREF1    1.40000000E+01  1.00000000E+00  1.00000000E+00  0.00000000E+00
           0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
           4.00000000E+00  0.00000000E+00  0.00000000E+00  1.00000000E+00
GELREF1    1.50000000E+01  1.00000000E+00  1.00000000E+00  0.00000000E+00
           0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
           4.00000000E+00  0.00000000E+00  0.00000000E+00  1.00000000E+00
GELREF1    1.60000000E+01  1.00000000E+00  1.00000000E+00  0.00000000E+00
           0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
           4.00000000E+00  0.00000000E+00  0.00000000E+00  1.00000000E+00
GELREF1    1.70000000E+01  1.00000000E+00  1.00000000E+00  0.00000000E+00
           0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
           2.00000000E+00  0.00000000E+00  0.00000000E+00  6.00000000E+00
GELREF1    1.80000000E+01  1.00000000E+00  1.00000000E+00  0.00000000E+00
           0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
           3.00000000E+00  0.00000000E+00  0.00000000E+00  7.00000000E+00
GELREF1    1.90000000E+01  1.00000000E+00  1.00000000E+00  0.00000000E+00
           0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
           2.00000000E+00  0.00000000E+00  0.00000000E+00  2.00000000E+00
GELREF1    2.00000000E+01  1.00000000E+00  1.00000000E+00  0.00000000E+00
           0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
           3.00000000E+00  0.00000000E+00  0.00000000E+00  8.00000000E+00
GELREF1    2.10000000E+01  1.00000000E+00  1.00000000E+00  0.00000000E+00
           0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
           1.00000000E+00  0.00000000E+00  0.00000000E+00  1.00000000E+00
GELREF1    2.20000000E+01  1.00000000E+00  1.00000000E+00  0.00000000E+00
           0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
           1.00000000E+00  0.00000000E+00  0.00000000E+00  1.00000000E+00
GELREF1    2.30000000E+01  1.00000000E+00  1.00000000E+00  0.00000000E+00
           0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
           2.00000000E+00  0.00000000E+00  0.00000000E+00  2.00000000E+00
GELREF1    2.40000000E+01  1.00000000E+00  1.00000000E+00  0.00000000E+00
           0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
```

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          2.00000000E+00  0.00000000E+00  0.00000000E+00  2.00000000E+00
GELREF1   2.50000000E+01  1.00000000E+00  1.00000000E+00  0.00000000E+00
          0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
          2.00000000E+00  0.00000000E+00  0.00000000E+00  2.00000000E+00
GELREF1   2.60000000E+01  1.00000000E+00  1.00000000E+00  0.00000000E+00
          0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
          2.00000000E+00  0.00000000E+00  0.00000000E+00  2.00000000E+00
GELREF1   2.70000000E+01  1.00000000E+00  1.00000000E+00  0.00000000E+00
          0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
          2.00000000E+00  0.00000000E+00  0.00000000E+00  9.00000000E+00
GELREF1   2.80000000E+01  1.00000000E+00  1.00000000E+00  0.00000000E+00
          0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
          3.00000000E+00  0.00000000E+00  0.00000000E+00  1.00000000E+01
GELREF1   2.90000000E+01  1.00000000E+00  1.00000000E+00  0.00000000E+00
          0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
          2.00000000E+00  0.00000000E+00  0.00000000E+00  2.00000000E+00
GELREF1   3.00000000E+01  1.00000000E+00  1.00000000E+00  0.00000000E+00
          0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
          3.00000000E+00  0.00000000E+00  0.00000000E+00  1.10000000E+01
GELREF1   3.10000000E+01  1.00000000E+00  1.00000000E+00  0.00000000E+00
          0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
          2.00000000E+00  0.00000000E+00  0.00000000E+00  2.00000000E+00
GELREF1   3.20000000E+01  1.00000000E+00  1.00000000E+00  0.00000000E+00
          0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
          2.00000000E+00  0.00000000E+00  0.00000000E+00  2.00000000E+00
GELREF1   3.30000000E+01  1.00000000E+00  1.00000000E+00  0.00000000E+00
          0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
          1.00000000E+00  0.00000000E+00  0.00000000E+00  1.00000000E+00
GELREF1   3.40000000E+01  1.00000000E+00  1.00000000E+00  0.00000000E+00
          0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
          1.00000000E+00  0.00000000E+00  0.00000000E+00  1.00000000E+00
TDSETNAM  4.00000000E+00  1.00000000E+00  1.05000000E+02  0.00000000E+00
        ESET1
GSETMEMB  8.00000000E+00  1.00000000E+00  1.00000000E+00  1.00000000E+00
          0.00000000E+00  1.00000000E+00  1.10000000E+01  1.80000000E+01
GSETMEMB  3.90000000E+01  1.00000000E+00  1.00000000E+00  2.00000000E+00
          0.00000000E+00  1.00000000E+00  2.00000000E+00  3.00000000E+00
          4.00000000E+00  5.00000000E+00  6.00000000E+00  7.00000000E+00
          8.00000000E+00  9.00000000E+00  1.00000000E+01  1.10000000E+01
          1.20000000E+01  1.30000000E+01  1.40000000E+01  1.50000000E+01
          1.60000000E+01  1.70000000E+01  1.80000000E+01  1.90000000E+01
          2.00000000E+01  2.10000000E+01  2.20000000E+01  2.30000000E+01
          2.40000000E+01  2.50000000E+01  2.60000000E+01  2.70000000E+01
          2.80000000E+01  2.90000000E+01  3.00000000E+01  3.10000000E+01
          3.20000000E+01  3.30000000E+01  3.40000000E+01
TDLOAD    4.00000000E+00  2.00000000E+00  1.07000000E+02  0.00000000E+00
        GRAVITY
TDLOAD    4.00000000E+00  7.00000000E+00  1.08000000E+02  0.00000000E+00
        FEDEM_FX
TDLOAD    4.00000000E+00  8.00000000E+00  1.08000000E+02  0.00000000E+00
        FEDEM_MX
TDLOAD    4.00000000E+00  9.00000000E+00  1.08000000E+02  0.00000000E+00
        FEDEM_MY
TDLOAD    4.00000000E+00  1.00000000E+01  1.08000000E+02  0.00000000E+00
        FEDEM_FY
TDLOAD    4.00000000E+00  1.10000000E+01  1.08000000E+02  0.00000000E+00
        VEKT_TAA
TDLOAD    4.00000000E+00  1.20000000E+01  1.04000000E+02  0.00000000E+00
        WLC1
TDLOAD    4.00000000E+00  1.30000000E+01  1.04000000E+02  0.00000000E+00
        WLC2
TDLOAD    4.00000000E+00  1.40000000E+01  1.04000000E+02  0.00000000E+00
        WLC3
TDLOAD    4.00000000E+00  1.50000000E+01  1.04000000E+02  0.00000000E+00
        WLC4
TDLOAD    4.00000000E+00  1.60000000E+01  1.04000000E+02  0.00000000E+00
        WLC5
TDLOAD    4.00000000E+00  1.70000000E+01  1.04000000E+02  0.00000000E+00
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        WLC6
TDLOAD    4.00000000E+00  1.80000000E+01  1.04000000E+02  0.00000000E+00
        WLC7
TDLOAD    4.00000000E+00  1.90000000E+01  1.04000000E+02  0.00000000E+00
        WLC8
BGRAV     2.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
          0.00000000E+00  0.00000000E+00 -9.80665016E+00
BNLOAD    7.00000000E+00  1.00000000E+00  0.00000000E+00  0.00000000E+00
          1.40000000E+01  6.00000000E+00 -3.97000000E+05  0.00000000E+00
          0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
BNLOAD    8.00000000E+00  1.00000000E+00  0.00000000E+00  0.00000000E+00
          1.40000000E+01  6.00000000E+00  0.00000000E+00  0.00000000E+00
          0.00000000E+00 -1.43000000E+07  0.00000000E+00  0.00000000E+00
BNLOAD    9.00000000E+00  1.00000000E+00  0.00000000E+00  0.00000000E+00
          1.40000000E+01  6.00000000E+00  0.00000000E+00  0.00000000E+00
          0.00000000E+00  0.00000000E+00 -2.71000000E+07  0.00000000E+00
BNLOAD    1.00000000E+01  1.00000000E+00  0.00000000E+00  0.00000000E+00
          1.40000000E+01  6.00000000E+00  0.00000000E+00  1.45000000E+05
          0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
BNLOAD    1.10000000E+01  1.00000000E+00  0.00000000E+00  0.00000000E+00
          1.40000000E+01  6.00000000E+00  0.00000000E+00  0.00000000E+00
         -6.86465500E+06  0.00000000E+00  0.00000000E+00  0.00000000E+00
IEND                0.00            0.00            0.00            0.00
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Vedlegg 2 – Egenfrekvensanalyse/strukturfrekvensanalyse i Sesam GeniE

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                               **               Superelement Structural Analysis
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*******************************************************************


                                              Marketing and Support by DNV
```

```
Software



               Program id   : 8.4-01
Computer         : 586
               Release date : 20-NOV-2008
Impl. update     :
               Access time  : 01-JUN-2012 19:04:14
Operating system : Win NT 5.2 [3790]
               User id      : ofsbilil
CPU id           : 1975103069

Installation     : , NOS295


               Copyright DET NORSKE VERITAS AS, P.O.Box 300, N-1322 Hovik,
Norway


               Library     Version    Impl.Upd   Release date
               ELLIB       1.9-07                20-NOV-2008
               SIFTOOL     8.3-05                20-NOV-2008
               NORSAM      8.4-01                20-NOV-2008
               MFR         8.3-05                20-NOV-2008
               PRIMAS      5.3-04                20-NOV-2008
               AUXLIB      8.2-02                20-NOV-2008
               SESTRA_PRLL 8.1-02                20-NOV-2008

               Run identification   :





 DATE: 01-JUN-2012 TIME: 19:04:29   ***************  SESTRA  ***************
                                        PAGE:     1

                                    DATA GENERATION MODULE

                                    SUB PAGE:     1

  PRINTOUT OF DATA GIVEN AS DIRECT INPUT TO SESTRA



   HEAD

   COMM

   COMM    Created by: GeniE  V5.3-10  14-Apr-2011

   COMM

   COMM    Date : 01-Jun-2012   Time : 18:04:12   User : ofsbilil

   COMM

   COMM  CHCK ANTP MSUM MOLO STIF RTOP LBCK      PILE CSING     SIGM

   CMAS    0.    2.    1.    0.    0.    0.    0.    0.    0.  0.00E+00  0.00E+00
0.00E+00
   COMM
```

```
   COMM                 WCOR

   ELOP     0.    0.    0.    1.    0.    0.    0.    0.    0.  0.00E+00  0.00E+00
0.00E+00
   COMM

   COMM  ITYP

   ITOP     1.    0.    0.    0.    0.    0.    0.    0.    0.  0.00E+00  0.00E+00
0.00E+00
   COMM

   COMM  PREFIX

   INAM  20120601_180329_

   COMM

   COMM  PREFIX FORMAT

   LNAM  20120601_180329_ UNFORMATTED

   COMM

   COMM  PREFIX FORMAT

   RNAM  20120601_180329_ NORSAM

   COMM

   COMM  SEL1 SEL2 SEL3 SEL4 SEL5 SEL6 SEL7 SEL8

   RSEL     1.    0.    0.    0.    0.    0.    1.    0.    0.  0.00E+00  0.00E+00
0.00E+00
   COMM

   COMM  RTRA

   RETR     3.    0.    0.    0.    0.    0.    0.    0.    0.  0.00E+00  0.00E+00
0.00E+00
   COMM

   COMM  ENR

   EIGL    10.    0.    0.    0.    0.    0.    0.    0.    0.  0.00E+00  0.00E+00
0.00E+00
   COMM

   COMM  SELT

   IDTY     1.

   COMM

   COMM  IMAS IDAM ISST

   DYMA     1.    0.    0.    0.    0.    0.    0.    0.    0.  0.00E+00  0.00E+00
0.00E+00
   Z

 DATE: 01-JUN-2012 TIME: 19:04:34   ***************  SESTRA  ***************
                                        PAGE:     2


                                     DATA GENERATION MODULE
```

```
  INTERPRETATION OF ANALYSIS CONTROL DATA



      Type of Analysis :

         Eigenvalue Solution by Lanczos Method

         Retracking


      Input from CMAS Command :

         ANTYP = 2   Dynamic Analysis

         MSUM  > 0   Calculation of Sum of Masses and Centroid

         The singularity constant for membrane and shell elements

         CSING =  1.0000E-08

         Lowest accepted condition number in reduction

         EPSSOL=  1.1102E-14


      Input from EIGL Command :

         Specification of eigenvalues to be calculated:

            ENR   =    10  eigenvalues are demanded.

            MAXO    50     Maximum number of iterations.

            NBLO     2     Block size.

            NFIG     5     No. of digits of accuracy.

         IU    =     0  The stiffness matrix is triangularised.

            PRIN     0     Print of eigenvalues.


      Input from RSEL Command :

         Data types selected for storing on Results File :

          - Input Interface File Records,

          - mode shapes,  sequence:

               all nodes for the first resultcase, all nodes for the second
resultcase, etc.

         (Can be redefined by RSEL for selected superelements, see below.)
```

```
         Storing is done for superelements specified in RETR command.

 DATE: 01-JUN-2012 TIME: 19:04:38   ***************  SESTRA  ***************
                                        PAGE:     3

                                    DATA GENERATION MODULE

                                    SUB PAGE:     3

  INPUT INTERFACE FILES :




     20120601_180329_T1.FEM

         DATE:     01-Jun-2012         TIME:          18:03:31
         PROGRAM:  SESAM GeniE         VERSION:       V5.3-10 14-Apr-2011
         COMPUTER: X86 Windows         INSTALLATION:
         USER:     ofsbilil            ACCOUNT:

         DATE:     01-Jun-2012         TIME:          18:03:31
         PROGRAM:  SESAM Gamesha       VERSION:       R5.0-3 14-Apr-2011
         COMPUTER: X86 Windows         INSTALLATION:
         USER:     ofsbilil            ACCOUNT:

 DATE: 01-JUN-2012 TIME: 19:04:41   ***************  SESTRA  ***************
                                        PAGE:     4

                                    DATAGENERATION - SUPERELEMENT TYPE     1

                                    SUB PAGE:     4





  INTERPRETATION OF ANALYSIS CONTROL DATA

          FOR SUPERELEMENT TYPE     1  ON LEVEL  1



      Input from DYMA Command :


         IMAS  =     1  Consistent mass matrices from the subelements are
demanded.




      *** SUMMARY OF DATA FROM INPUT AND LOAD INTERFACE FILES ***

               FOR SUPERELEMENT TYPE       1  ON LEVEL  1
```

```
    The superelement has


          43  subelements
          29  nodes
          18  specified (fixed) degrees of freedom
         156  internal (free) degrees of freedom
        totally
         174  degrees of freedom

          11  loadcases



    The following kinds of loads are given:
          node loads
          gravitational load


    The following basic elements are given:
          43  2 node beam elements         BEAS


 DATE: 01-JUN-2012 TIME: 19:04:48   ***************  SESTRA  ***************
                                        PAGE:     5

                                    DATAGENERATION - SUPERELEMENT TYPE     1

                                    SUB PAGE:     5

    *** SUM OF LOADS AND MOMENTS FOR SUPERELEMENT TYPE     1  ON LEVEL  1  ***


   X-LOAD = SUM OF GIVEN LOADS IN GLOBAL X-DIRECTION
   Y-LOAD = SUM OF GIVEN LOADS IN GLOBAL Y-DIRECTION
   Z-LOAD = SUM OF GIVEN LOADS IN GLOBAL Z-DIRECTION
   X-MOM  = SUM OF LOCAL MOMENTS ABOUT GLOBAL X-AXIS
   Y-MOM  = SUM OF LOCAL MOMENTS ABOUT GLOBAL Y-AXIS
   Z-MOM  = SUM OF LOCAL MOMENTS ABOUT GLOBAL Z-AXIS
   X-RMOM = SUM OF MOMENTS ABOUT GLOBAL X-AXIS FROM GIVEN LOADS AND MOMENTS
```

```
     Y-RMOM = SUM OF MOMENTS ABOUT GLOBAL Y-AXIS FROM GIVEN LOADS AND MOMENTS

     Z-RMOM = SUM OF MOMENTS ABOUT GLOBAL Z-AXIS FROM GIVEN LOADS AND MOMENTS


      LOADCASE    X-LOAD      Y-LOAD      Z-LOAD      X-MOM       Y-MOM
Z-MOM      X-RMOM      Y-RMOM      Z-RMOM
           1  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
           2  0.0000E+00  5.8208E-11 -2.1897E+07  0.0000E+00  0.0000E+00
0.0000E+00  1.9893E+07  2.3011E-02  0.0000E+00
           3  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
           4  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
           5  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
           6  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
           7  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
           8  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
           9  0.0000E+00  0.0000E+00 -3.4335E+06  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
          10  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00 -9.5400E+05
0.0000E+00  0.0000E+00 -9.5400E+05  0.0000E+00
          11  0.0000E+00 -1.4500E+05  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  1.9307E+07  0.0000E+00  0.0000E+00

 DATE: 01-JUN-2012 TIME: 19:04:51   ***************  SESTRA  ***************
                                        PAGE:     6

                                    DATAGENERATION - SUPERELEMENT TYPE     1


                                    SUB PAGE:     6


      *** SUM OF MASSES AND CENTROID FOR SUPERELEMENT TYPE     1  ON LEVEL  1
***



   MASS MATRIX IN GLOBAL COORDINATE SYSTEM (OF THE SUPERELEMENT):

   ---------------------------------------

   2.23290E+06   -4.54747E-13    0.00000E+00    8.18545E-12    5.86600E+07
2.02857E+06
  -4.54747E-13    2.23290E+06   -1.93268E-11   -5.86600E+07   -8.18545E-12
2.34643E-03
   0.00000E+00   -1.93268E-11    2.23290E+06   -2.02857E+06   -2.34643E-03
3.23117E-27
   8.18545E-12   -5.86600E+07   -2.02857E+06    3.42854E+09   -1.62601E-02
-3.98088E-02
   5.86600E+07   -8.18545E-12   -2.34643E-03   -1.62601E-02    3.42791E+09
2.09275E+07
   2.02857E+06    2.34643E-03    3.23117E-27   -3.98088E-02    2.09275E+07
2.09182E+08



   COORDINATES OF CENTROID:
```

```
   ------------------------

   1.0508E-09    -9.0849E-01     2.6271E+01



   MASS MATRIX AT CENTROID:

   ------------------------

   2.23290E+06   -4.54747E-13    0.00000E+00   -3.76111E-12   -1.49012E-08
-6.98492E-10
  -4.54747E-13    2.23290E+06   -1.93268E-11    0.00000E+00    3.76111E-12
4.00384E-10
   0.00000E+00   -1.93268E-11    2.23290E+06   -2.32831E-10    4.00384E-10
2.03094E-20
  -3.76111E-12    0.00000E+00   -2.32831E-10    1.88565E+09   -1.83918E-02
2.18337E-02
  -1.49012E-08    3.76111E-12    4.00384E-10   -1.83918E-02    1.88686E+09
-3.23646E+07
  -6.98492E-10    4.00384E-10    2.03094E-20    2.18337E-02   -3.23646E+07
2.07339E+08

  *** Estimated size of stiffness matrix for superelement       1:       15876
variables


  *** Estimate of total size of stiffness matrices for new superelements:
  15876 variables

 DATE: 01-JUN-2012 TIME: 19:04:54   ***************  SESTRA  ***************
                                        PAGE:     7

                                    REDUCTION MODULE - SUPERELEMENT TYPE    1

                                    SUB PAGE:     1






                                     - STIFFNESS MATRICES ALLOCATED
 -

                                     - CONSISTENT MASS MATRICES ALLOCATED
 -

                                     - LOAD MATRICES ALLOCATED
 -

                                     - STIFFNESS MERGE PERFORMED
 -

                                     - MASS MERGE PERFORMED
 -

                                     - LOAD MERGE PERFORMED
 -

 DATE: 01-JUN-2012 TIME: 19:04:59   ***************  SESTRA  ***************
```

```
                                                   PAGE:     8

                                                    DYNAMIC ANALYSIS OF STRUCTURE

                                               SUB PAGE:     1









                                         - EIGENVALUEPROBLEM SOLVED BY LANCZOS METHOD

 DATE: 01-JUN-2012 TIME: 19:05:01   ***************  SESTRA  ***************
                                                   PAGE:     9

                                                    DYNAMIC ANALYSIS OF STRUCTURE

                                               SUB PAGE:     2

                                                             ***************************

                                                             *                         *

                                                             *  E I G E N V A L U E S  *

                                                             *                         *

                                                             *  F R E Q U E N C I E S  *

                                                             *                         *

                                                             ***************************



                                                             ALL EIGENVALUES BEING CAL-

                                                             CULATED ARE PRINTED TOGE-

                                                             THER WITH THE CORRESPONDING

                                                             FREQUENCIES AND PERIODS.

                                                             FREQ = SQRT(EIGENV)/(2.*PI)

                                                             PERI = 1./FREQ
```

```
+-------------------+---------------------------------------+-------------------
---------+----------------------------+
  I                 I                                       I
          I                            I
  I       NO.       I        EIGENVALUE  UNIT: (SEC)-2      I   FREQUENCY
UNIT: HERTZ   I      PERIOD  UNIT: SEC      I
  I                 I                                       I
          I                            I

+-------------------+---------------------------------------+-------------------
---------+----------------------------+
  I                 I                                       I
          I                            I
  I        1        I             0.2402938E+02             I              0.780
          I          1.28177           I
  I        2        I             0.2448558E+02             I              0.788
          I          1.26977           I
  I        3        I             0.3099414E+03             I              2.802
          I          0.35689           I
  I        4        I             0.3198494E+03             I              2.846
          I          0.35132           I
  I        5        I             0.6561894E+03             I              4.077
          I          0.24528           I
  I        6        I             0.1464939E+04             I              6.092
          I          0.16416           I
  I        7        I             0.1564302E+04             I              6.295
          I          0.15886           I
  I        8        I             0.2623088E+04             I              8.151
          I          0.12268           I
  I        9        I             0.2683172E+04             I              8.244
          I          0.12130           I
  I       10        I             0.4008218E+04             I             10.076
          I          0.09924           I
  I                 I                                       I
          I                            I

+-------------------+---------------------------------------+-------------------
---------+----------------------------+

 DATE: 01-JUN-2012 TIME: 19:05:07   ***************  SESTRA  ***************
                                        PAGE:    10

                                         DYNAMIC ANALYSIS OF STRUCTURE


                                    SUB PAGE:     3


      Results file name: 20120601_180329_R1.SIN


      Load sum is missing



 SUPERELEMENT TYPE:     1 ACTUAL ELEMENT:     1

 HAS BEEN STORED ON RESULT FILE


  TOTAL TIME CONSUMED IN SESTRA                      CPU TIME:      2.09  CLOCK
TIME:     61.75  CHANNEL TIME:      0.47
```

Vedlegg 3 – Analyse 1, lineær strukturanalyse og hydrodynamisk analyse, fra Sesam GeniE

```
1



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                               **               Superelement Structural Analysis
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                                              Marketing and Support by DNV
```

```
Software



               Program id   : 8.4-01
Computer         : 586
               Release date : 20-NOV-2008
Impl. update     :
               Access time  : 08-JUN-2012 02:55:28
Operating system : Win NT 5.2 [3790]
               User id      : ofsbilil
CPU id           : 1975101804

Installation     : , NOS294


               Copyright DET NORSKE VERITAS AS, P.O.Box 300, N-1322 Hovik,
Norway


               Library     Version    Impl.Upd   Release date
               ELLIB       1.9-07                20-NOV-2008
               SIFTOOL     8.3-05                20-NOV-2008
               NORSAM      8.4-01                20-NOV-2008
               MFR         8.3-05                20-NOV-2008
               PRIMAS      5.3-04                20-NOV-2008
               AUXLIB      8.2-02                20-NOV-2008
               SESTRA_PRLL 8.1-02                20-NOV-2008

               Run identification   :




 DATE: 08-JUN-2012 TIME: 02:55:45   ***************  SESTRA  ***************
                                        PAGE:     1

                                    DATA GENERATION MODULE

                                    SUB PAGE:     1

  PRINTOUT OF DATA GIVEN AS DIRECT INPUT TO SESTRA



   HEAD

   COMM

   COMM    Created by: GeniE  V5.3-10  14-Apr-2011

   COMM

   COMM    Date : 08-Jun-2012   Time : 01:55:26   User : ofsbilil

   COMM

   COMM  CHCK ANTP MSUM MOLO STIF RTOP LBCK      PILE CSING     SIGM

   CMAS    0.   1.   1.   0.   0.   0.   0.   0.   0.  0.00E+00  0.00E+00
0.00E+00
   COMM
```

```
   COMM            ORDR                          CACH MFRWORK

   SOLM     0.    0.    0.    0.    0.    0.    0.    0.    0.  0.00E+00  0.00E+00
0.00E+00
   COMM

   COMM                 WCOR

   ELOP     0.    0.    0.    1.    0.    0.    0.    0.    0.  0.00E+00  0.00E+00
0.00E+00
   COMM

   COMM  ITYP

   ITOP     1.    0.    0.    0.    0.    0.    0.    0.    0.  0.00E+00  0.00E+00
0.00E+00
   COMM

   COMM  PREFIX

   INAM  20120608_015205_

   COMM

   COMM  PREFIX FORMAT

   LNAM  20120608_015205_ UNFORMATTED

   COMM

   COMM  PREFIX FORMAT

   RNAM  20120608_015205_ NORSAM

   COMM

   COMM  SEL1 SEL2 SEL3 SEL4 SEL5 SEL6 SEL7 SEL8

   RSEL     1.    0.    0.    0.    0.    0.    1.    0.    0.  0.00E+00  0.00E+00
0.00E+00
   COMM

   COMM  RTRA

   RETR     3.    0.    0.    0.    0.    0.    0.    0.    0.  0.00E+00  0.00E+00
0.00E+00
   Z


  PRINTOUT OF DATA GIVEN IN THE FILE 20120608_015205_S1.FEM


   LOHI     1.    0.   12.    1.    1.    0.    0.    0.    1.  0.10E+01  0.00E+00
0.00E+00
   SEAS     1.  0.00E+00  0.10E+01  0.70E+01  0.10E+01  0.27E+03  0.18E+02
0.14E+02
            0.  0.45E+02  0.10E+01 -0.57E-11  0.00E+00  0.00E+00  0.00E+00
0.00E+00
   TILO     1.  0.00E+00  0.10E+01 -0.79E+00 -0.79E+00  0.00E+00  0.00E+00
0.00E+00
   LCOM     1.  0.00E+00  0.10E+01  0.12E+02  0.13E+02  0.00E+00  0.00E+00
0.00E+00
   LOHI     2.    0.   12.    2.    2.    0.    0.    0.    2.  0.20E+01  0.00E+00
0.00E+00
   SEAS     2.  0.00E+00  0.10E+01  0.70E+01  0.10E+01  0.18E+03  0.18E+02
0.14E+02
            0.  0.45E+02  0.10E+01 -0.57E-11  0.00E+00  0.00E+00  0.00E+00
0.00E+00
```

```
   TILO    2.  0.00E+00  0.10E+01 -0.12E+01 -0.79E+00  0.00E+00  0.00E+00
0.00E+00
   LCOM    2.  0.00E+00  0.10E+01  0.14E+02  0.15E+02  0.00E+00  0.00E+00
0.00E+00
   LOHI    3.   0.  12.   3.   3.   0.   0.   0.   3.  0.30E+01  0.00E+00
0.00E+00
   SEAS    3.  0.00E+00  0.10E+01  0.70E+01  0.10E+01  0.90E+02  0.18E+02
0.14E+02
           0.  0.45E+02  0.10E+01 -0.57E-11  0.00E+00  0.00E+00  0.00E+00
0.00E+00
   TILO    3.  0.00E+00  0.10E+01 -0.12E+01 -0.79E+00  0.00E+00  0.00E+00
0.00E+00
   LCOM    3.  0.00E+00  0.10E+01  0.16E+02  0.17E+02  0.00E+00  0.00E+00
0.00E+00

 DATE: 08-JUN-2012 TIME: 02:55:50   ***************  SESTRA  ***************
                                        PAGE:     2


                                    DATA GENERATION MODULE


                                    SUB PAGE:     2


  PRINTOUT OF DATA GIVEN AS DIRECT INPUT TO SESTRA



   LOHI    4.   0.  12.   4.   4.   0.   0.   0.   4.  0.40E+01  0.00E+00
0.00E+00
   SEAS    4.  0.00E+00  0.10E+01  0.70E+01  0.10E+01  0.00E+00  0.18E+02
0.14E+02
           0.  0.45E+02  0.10E+01 -0.57E-11  0.00E+00  0.00E+00  0.00E+00
0.00E+00
   TILO    4.  0.00E+00  0.10E+01 -0.12E+01 -0.79E+00  0.00E+00  0.00E+00
0.00E+00
   LCOM    4.  0.00E+00  0.10E+01  0.18E+02  0.19E+02  0.00E+00  0.00E+00
0.00E+00
   WIND    1.  0.25E+02  0.27E+03  0.32E+00  0.10E+02  0.70E+00  0.00E+00
0.10E+01
           0.  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00
   WIND    2.  0.25E+02  0.18E+03  0.32E+00  0.10E+02  0.70E+00  0.00E+00
0.10E+01
           0.  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00
   WIND    3.  0.25E+02  0.90E+02  0.32E+00  0.10E+02  0.70E+00  0.00E+00
0.10E+01
           0.  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00
   WIND    4.  0.25E+02  0.00E+00  0.32E+00  0.10E+02  0.70E+00  0.00E+00
0.10E+01
           0.  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00

 DATE: 08-JUN-2012 TIME: 02:55:51   ***************  SESTRA  ***************
                                        PAGE:     3


                                    DATA GENERATION MODULE


                                    SUB PAGE:     3
  INTERPRETATION OF ANALYSIS CONTROL DATA
```

```
      Type of Analysis :

         Reduction

         Multifront Solver is used

         Retracking


      Input from CMAS Command :

         ANTYP = 1   Static Analysis

         MSUM  > 0   Calculation of Sum of Masses and Centroid

         The singularity constant for membrane and shell elements

         CSING =  1.0000E-08

         Lowest accepted condition number in reduction

         EPSSOL=  1.1102E-14


      Input from RSEL Command :

         Data types selected for storing on Results File :

          - Input Interface File Records,

          - displacements,  sequence:

               all nodes for the first resultcase, all nodes for the second
resultcase, etc.
          - forces and moments for beam, spring and layered shell elements,
sequence:
               all elements for the first resultcase, all elements for the
second resultcase, etc.
          - stresses (not for beam or spring elements),  sequence:

               all elements for the first resultcase, all elements for the
second resultcase, etc.

         (Can be redefined by RSEL for selected superelements, see below.)

         Storing is done for superelements specified in RETR command.

 DATE: 08-JUN-2012 TIME: 02:55:55   ***************  SESTRA  ***************
                                        PAGE:     4

                                    DATA GENERATION MODULE

                                    SUB PAGE:     4

  INPUT INTERFACE FILES :
```

```
    20120608_015205_T1.FEM

    20120608_015205_L1.FEM

        DATE:     08-Jun-2012         TIME:          01:52:06
        PROGRAM:  SESAM GeniE         VERSION:       V5.3-10 14-Apr-2011
        COMPUTER: X86 Windows         INSTALLATION:
        USER:     ofsbilil            ACCOUNT:

        DATE:     08-Jun-2012         TIME:          01:52:06
        PROGRAM:  SESAM Gamesha       VERSION:       R5.0-3 14-Apr-2011
        COMPUTER: X86 Windows         INSTALLATION:
        USER:     ofsbilil            ACCOUNT:

        DATE:     08-JUN-2012         TIME:         01:53:12
        PROGRAM:  SESAM WAJAC         VERSION:      5.9-02 28-FEB-2007
        COMPUTER: 586 WIN NT 5.2 [3790INSTALLATION: , NOS294
        USER:     OFSBILIL            ACCOUNT:

 DATE: 08-JUN-2012 TIME: 02:55:59   ***************  SESTRA  ***************
                                        PAGE:     5

                                    DATAGENERATION - SUPERELEMENT TYPE     1

                                    SUB PAGE:     5



     *** SUMMARY OF DATA FROM INPUT AND LOAD INTERFACE FILES ***
              FOR SUPERELEMENT TYPE       1  ON LEVEL  1

     The superelement has


           34  subelements
           20  nodes
           18  specified (fixed) degrees of freedom
          102  internal (free) degrees of freedom
         totally
          120  degrees of freedom


           19  loadcases
```

```
    The following kinds of loads are given:

          node loads

          line or point loads for 2 node beams

          gravitational load


    The following basic elements are given:

          34  2 node beam elements         BEAS


 DATE: 08-JUN-2012 TIME: 02:56:06   ***************  SESTRA  ***************
                                        PAGE:     6

                                    DATAGENERATION - SUPERELEMENT TYPE     1

                                    SUB PAGE:     6

    *** SUM OF LOADS AND MOMENTS FOR SUPERELEMENT TYPE     1  ON LEVEL  1  ***


   X-LOAD = SUM OF GIVEN LOADS IN GLOBAL X-DIRECTION

   Y-LOAD = SUM OF GIVEN LOADS IN GLOBAL Y-DIRECTION

   Z-LOAD = SUM OF GIVEN LOADS IN GLOBAL Z-DIRECTION

   X-MOM  = SUM OF LOCAL MOMENTS ABOUT GLOBAL X-AXIS

   Y-MOM  = SUM OF LOCAL MOMENTS ABOUT GLOBAL Y-AXIS

   Z-MOM  = SUM OF LOCAL MOMENTS ABOUT GLOBAL Z-AXIS

   X-RMOM = SUM OF MOMENTS ABOUT GLOBAL X-AXIS FROM GIVEN LOADS AND MOMENTS

   Y-RMOM = SUM OF MOMENTS ABOUT GLOBAL Y-AXIS FROM GIVEN LOADS AND MOMENTS

   Z-RMOM = SUM OF MOMENTS ABOUT GLOBAL Z-AXIS FROM GIVEN LOADS AND MOMENTS


    LOADCASE    X-LOAD      Y-LOAD      Z-LOAD      X-MOM       Y-MOM
Z-MOM       X-RMOM      Y-RMOM      Z-RMOM
           1  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
           2  0.0000E+00  5.8208E-11 -1.9673E+07  0.0000E+00  0.0000E+00
0.0000E+00  1.9893E+07  2.3011E-02  0.0000E+00
           3  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
           4  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
           5  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
           6  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
           7 -3.9700E+05  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00 -2.5865E+07  0.0000E+00
```

```
          8  0.0000E+00  0.0000E+00  0.0000E+00 -1.4300E+07  0.0000E+00
0.0000E+00 -1.4300E+07  0.0000E+00  0.0000E+00
          9  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00 -2.7100E+07
0.0000E+00  0.0000E+00 -2.7100E+07  0.0000E+00
         10  0.0000E+00  1.4500E+05  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00 -9.4468E+06  0.0000E+00  0.0000E+00
         11  0.0000E+00  0.0000E+00 -6.8647E+06  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
         12  3.9946E-02 -9.5816E+06  2.1933E+06 -1.0101E+05 -4.7655E-03
1.1548E-03  2.3229E+08  1.4183E+00 -5.3479E-01
         13  3.9946E-02 -9.5816E+06  2.1933E+06 -1.0101E+05 -4.7655E-03
1.1548E-03  2.3229E+08  1.4183E+00 -5.3479E-01
         14 -9.7955E+06  5.1316E+04  2.1410E+06  1.2797E+04  2.9594E+05
-5.0590E+04 -2.6782E+06 -2.3021E+08 -4.3855E+06
         15 -9.7309E+06  1.1116E+05  1.9395E+06  2.0234E+04  1.0190E+05
-5.4071E+04 -3.3023E+06 -2.3665E+08 -3.7146E+06
         16 -4.3083E-01  9.6754E+06  1.9242E+06  2.7635E+05  6.6428E-03
7.6226E-03 -2.3031E+08 -9.3210E+00 -1.4817E+00
         17 -4.1039E-01  9.4976E+06  1.7001E+06  9.8096E+04 -3.4427E-03
2.0667E-02 -2.3502E+08 -9.8551E+00 -3.5200E-01
         18  9.7955E+06  5.1316E+04  2.1410E+06  1.2797E+04 -2.9594E+05
5.0590E+04 -2.6783E+06  2.3021E+08  4.3855E+06
         19  9.7309E+06  1.1116E+05  1.9395E+06  2.0234E+04 -1.0190E+05
5.4071E+04 -3.3023E+06  2.3665E+08  3.7146E+06

 DATE: 08-JUN-2012 TIME: 02:56:09   ***************  SESTRA  ***************
                                        PAGE:     7

                                    DATAGENERATION - SUPERELEMENT TYPE     1

                                    SUB PAGE:     7

      *** SUM OF MASSES AND CENTROID FOR SUPERELEMENT TYPE     1  ON LEVEL  1
***



   MASS MATRIX IN GLOBAL COORDINATE SYSTEM (OF THE SUPERELEMENT):

   ---------------------------------------

   2.00613E+06    0.00000E+00    0.00000E+00    0.00000E+00    3.73172E+07
2.02857E+06
   0.00000E+00    2.00613E+06    0.00000E+00   -3.73172E+07    0.00000E+00
2.34643E-03
   0.00000E+00    0.00000E+00    2.00613E+06   -2.02857E+06   -2.34643E-03
0.00000E+00
   0.00000E+00   -3.73172E+07   -2.02857E+06    1.40838E+09   -1.62601E-02
-3.98088E-02
   3.73172E+07    0.00000E+00   -2.34643E-03   -1.62601E-02    1.40843E+09
1.83478E+07
   2.02857E+06    2.34643E-03    0.00000E+00   -3.98088E-02    1.83478E+07
2.57899E+08



   COORDINATES OF CENTROID:

   ------------------------

   1.1696E-09    -1.0112E+00     1.8602E+01
```

```
   MASS MATRIX AT CENTROID:

   ------------------------

   2.00613E+06    0.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00
0.00000E+00
   0.00000E+00    2.00613E+06    0.00000E+00    0.00000E+00    0.00000E+00
0.00000E+00
   0.00000E+00    0.00000E+00    2.00613E+06    0.00000E+00    0.00000E+00
0.00000E+00
   0.00000E+00    0.00000E+00    0.00000E+00    7.12173E+08   -1.86327E-02
3.83846E-03
   0.00000E+00    0.00000E+00    0.00000E+00   -1.86327E-02    7.14275E+08
-1.93867E+07
   0.00000E+00    0.00000E+00    0.00000E+00    3.83846E-03   -1.93867E+07
2.55848E+08

  *** Estimated size of stiffness matrix for superelement       1:        1404
variables

 DATE: 08-JUN-2012 TIME: 02:56:11   ***************  SESTRA  ***************
                                        PAGE:     8

                                    DATAGENERATION - SUPERELEMENT TYPE     1

                                    SUB PAGE:     8

      *** CONNECTION BETWEEN LOADCASE AND RESULTCASE NUMBERS ***


  TOP LEVEL EXT.RESULT  INDEX    TIME       WAVE DIR.   WAVE HEIGHT    WATER

  LOADCASE  IDENT.NO.                         (RAD)                    DEPTH

        1         1

        2         2

        3         3

        4         4

        5         5

        6         6

        7         7

        8         8

        9         9

       10        10

       11        11

       12        12         1   -7.944E-01    4.712E+00    1.750E+01    4.500E+01

       13        12         2   -7.944E-01    4.712E+00    1.750E+01    4.500E+01

       14        13         1   -1.192E+00    3.142E+00    1.750E+01    4.500E+01

       15        13         2   -7.944E-01    3.142E+00    1.750E+01    4.500E+01
```

```
      16         14        1   -1.192E+00    1.571E+00    1.750E+01    4.500E+01

      17         14        2   -7.944E-01    1.571E+00    1.750E+01    4.500E+01

      18         15        1   -1.192E+00    0.000E+00    1.750E+01    4.500E+01

      19         15        2   -7.944E-01    0.000E+00    1.750E+01    4.500E+01


  *** Estimate of total size of stiffness matrices for new superelements:
   1404 variables

 DATE: 08-JUN-2012 TIME: 02:56:15   ***************  SESTRA  ***************
                                        PAGE:     9

                                    REDUCTION MODULE - SUPERELEMENT TYPE    1

                                    SUB PAGE:     1




                                     - STIFFNESS FACTORIZATION PERFORMED BY
MULTIFRONT EQUATION SOLVER -

                                     - LOAD SUBSTITUTION PERFORMED BY
MULTIFRONT EQUATION SOLVER -

 DATE: 08-JUN-2012 TIME: 02:56:22   ***************  SESTRA  ***************
                                        PAGE:    10

                                          STATIC ANALYSIS OF STRUCTURE

                                    SUB PAGE:     1


      Results file name: 20120608_015205_R1.SIN


 DATE: 08-JUN-2012 TIME: 02:56:27   ***************  SESTRA  ***************
                                        PAGE:    11

                                    RETRACKING MODULE - SUPERELEMENT TYPE    1

                                    THE STRUCTURE
                                    SUB PAGE:     2

  REACTION FORCES IN NODES WITH SPECIFIED (FIXED) DEGREES OF FREEDOM.

  NODES MARKED WITH AN ASTERISK (*) TO THE RIGHT HAVE A LOCAL COORDINATE SYSTEM.

  ******************************************************************************
```

```
 LOADCASE (INDEX) NODE NO.       X             Y             Z           RX
      RY            RZ

       1              1   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
 0.00000E+00   0.00000E+00
                     11   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
 0.00000E+00   0.00000E+00
                     18   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
 0.00000E+00   0.00000E+00

       2              1   2.71266E+06   1.86475E+06   6.29621E+06   3.00441E+06
-4.73983E+06  -3.00595E+03
                     11   4.87356E-04  -3.72951E+06   7.08101E+06  -5.44973E+06
 1.78674E-03   1.15865E-03
                     18  -2.71266E+06   1.86475E+06   6.29621E+06   3.00441E+06
 4.73983E+06   3.00595E+03

       3              1   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
 0.00000E+00   0.00000E+00
                     11   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
 0.00000E+00   0.00000E+00
                     18   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
 0.00000E+00   0.00000E+00

       4              1   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
 0.00000E+00   0.00000E+00
                     11   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
 0.00000E+00   0.00000E+00
                     18   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
 0.00000E+00   0.00000E+00

       5              1   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
 0.00000E+00   0.00000E+00
                     11   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
 0.00000E+00   0.00000E+00
                     18   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
 0.00000E+00   0.00000E+00

       6              1   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
 0.00000E+00   0.00000E+00
                     11   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
 0.00000E+00   0.00000E+00
                     18   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
 0.00000E+00   0.00000E+00

       7              1   1.97950E+05   1.36535E+05   8.44103E+05   8.66025E+03
 1.69167E+05   4.08670E+04
                     11   1.10014E+03   9.96996E-05  -5.97851E-06  -2.31262E-05
 2.03113E+05  -8.22418E+04
                     18   1.97950E+05  -1.36535E+05  -8.44103E+05  -8.66025E+03
 1.69167E+05   4.08670E+04

       8              1  -4.03757E+03   8.70713E+02  -2.72298E+05   5.10408E+04
-1.05417E+04   4.32712E+04
                     11   6.78053E-06  -1.74143E+03   5.44596E+05   4.88968E+04
 7.20348E-05  -3.44726E-05
                     18   4.03757E+03   8.70713E+02  -2.72298E+05   5.10408E+04
 1.05417E+04  -4.32712E+04

       9              1   5.24281E+03   9.13586E+03   8.90578E+05  -1.39011E+04
 1.35024E+05   7.26074E+04
                     11  -1.04856E+04   1.58580E-04  -9.06968E-06  -3.50920E-05
 1.12622E+05  -1.43564E+05
                     18   5.24281E+03  -9.13586E+03  -8.90578E+05   1.39011E+04
 1.35024E+05   7.26074E+04
```

```
     10              1  -4.13915E+04  -2.93000E+04  -1.78829E+05   5.53510E+04
 2.53319E+03   1.63699E+04
                    11   3.14234E-06  -8.64000E+04   3.57659E+05   4.37980E+04
 3.06999E-05  -1.45349E-05
                    18   4.13915E+04  -2.93000E+04  -1.78829E+05   5.53510E+04
-2.53319E+03  -1.63699E+04

     11              1   1.53517E+06   1.06519E+06   2.05861E+06   2.37915E+05
-3.40449E+05   6.09194E+03
                    11   3.43806E-05  -2.13038E+06   2.74744E+06  -5.27121E+05
 5.37930E-05   9.46746E-04
                    18  -1.53517E+06   1.06519E+06   2.05861E+06   2.37915E+05
 3.40449E+05  -6.09194E+03

     12    1         1   1.39041E+06   1.82520E+06   3.63908E+06  -3.63899E+06
 1.84604E+05   2.17946E+06
                    11  -1.50574E-02   5.93124E+06  -9.47141E+06  -1.72614E+06
-8.58355E-02  -2.01246E-02
                    18  -1.39041E+06   1.82520E+06   3.63908E+06  -3.63899E+06
-1.84604E+05  -2.17946E+06

DATE: 08-JUN-2012 TIME: 02:56:29   ***************  SESTRA  ***************
                                       PAGE:    12

                                   RETRACKING MODULE - SUPERELEMENT TYPE    1

                                   THE STRUCTURE
                                   SUB PAGE:     3


 REACTION FORCES IN NODES WITH SPECIFIED (FIXED) DEGREES OF FREEDOM.

 NODES MARKED WITH AN ASTERISK (*) TO THE RIGHT HAVE A LOCAL COORDINATE SYSTEM.

 ******************************************************************************



 LOADCASE (INDEX) NODE NO.      X             Y             Z            RX
      RY            RZ

     12    2         1   1.39041E+06   1.82520E+06   3.63908E+06  -3.63899E+06
 1.84604E+05   2.17946E+06
                    11  -1.50574E-02   5.93124E+06  -9.47141E+06  -1.72614E+06
-8.58355E-02  -2.01246E-02
                    18  -1.39041E+06   1.82520E+06   3.63908E+06  -3.63899E+06
-1.84604E+05  -2.17946E+06

     13    1         1   3.79116E+06   2.08765E+06   6.62817E+06   3.47132E+05
 3.91315E+06  -1.29002E+06
                    11   8.13330E+05   8.44025E+05  -7.51388E+05   6.37544E+05
 3.83146E+06   2.36705E+06
                    18   5.19098E+06  -2.98299E+06  -8.01778E+06  -1.03151E+06
 2.77573E+06  -1.28370E+06

     13    2         1   3.79617E+06   2.07942E+06   6.89011E+06   3.08819E+05
 3.96232E+06  -1.30744E+06
                    11   8.21779E+05   7.90186E+05  -6.48252E+05   6.43526E+05
 3.93122E+06   2.32222E+06
                    18   5.11297E+06  -2.98076E+06  -8.18141E+06  -9.61451E+05
 2.68428E+06  -1.15894E+06

     14    1         1  -2.74852E+06  -2.69853E+06  -4.83955E+06   2.88789E+06
 9.50642E+05  -2.21439E+06
                    11   1.71407E-02  -4.27836E+06   7.75494E+06   3.06117E+06
 1.21000E-02   1.11212E-01
                    18   2.74852E+06  -2.69853E+06  -4.83955E+06   2.88789E+06
```

```
 -9.50642E+05   2.21439E+06

       14    2          1  -2.70488E+06  -2.62169E+06  -4.86388E+06   2.83995E+06
  9.42010E+05  -2.06023E+06
                       11   2.57342E-02  -4.25417E+06   8.02767E+06   3.10720E+06
  7.23847E-02   1.19649E-01
                       18   2.70488E+06  -2.62169E+06  -4.86388E+06   2.83995E+06
 -9.42009E+05   2.06023E+06

       15    1          1  -5.19098E+06  -2.98299E+06  -8.01778E+06  -1.03151E+06
 -2.77573E+06   1.28370E+06
                       11  -8.13330E+05   8.44025E+05  -7.51387E+05   6.37544E+05
 -3.83146E+06  -2.36705E+06
                       18  -3.79116E+06   2.08765E+06   6.62817E+06   3.47133E+05
 -3.91315E+06   1.29002E+06

       15    2          1  -5.11297E+06  -2.98076E+06  -8.18141E+06  -9.61451E+05
 -2.68428E+06   1.15894E+06
                       11  -8.21779E+05   7.90185E+05  -6.48252E+05   6.43527E+05
 -3.93122E+06  -2.32222E+06
                       18  -3.79617E+06   2.07942E+06   6.89011E+06   3.08819E+05
 -3.96232E+06   1.30744E+06

 DATE: 08-JUN-2012 TIME: 02:56:30   ***************  SESTRA  ***************
                                        PAGE:    13


                                    RETRACKING MODULE - SUPERELEMENT TYPE    1

                                    THE STRUCTURE
                                    SUB PAGE:     4


  SUM OF REACTION FORCES FROM SPECIFIED DEGREES OF FREEDOM.

  THE FORCES AND MOMENTS ARE REFFERED TO THE COORDINATE SYSTEM OF THE ACTUAL
SUPERELEMENT.

********************************************************************************
********


  LOADCASE (INDEX)         X              Y              Z             RX
RY            RZ

       1            0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
0.0000E+00    0.0000E+00
       2            4.6566E-10    6.9849E-10    1.9673E+07   -1.9893E+07
-2.3011E-02   -2.1246E-09
       3            0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
0.0000E+00    0.0000E+00
       4            0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
0.0000E+00    0.0000E+00
       5            0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
0.0000E+00    0.0000E+00
       6            0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
0.0000E+00    0.0000E+00
       7            3.9700E+05    1.4552E-10   -1.1642E-10    0.0000E+00
2.5865E+07    8.6147E-09
       8           -9.9590E-11    3.3415E-09   -1.7462E-10    1.4300E+07
-1.8626E-09   -4.3692E-09
       9           -4.9695E-09    1.1460E-10   -1.1642E-10    1.8626E-09
2.7100E+07    6.6138E-09
      10           -1.0186E-10   -1.4500E+05    0.0000E+00    9.4468E+06
-1.8626E-09   -3.5543E-09
      11            0.0000E+00    2.3283E-10    6.8647E+06   -1.4901E-08
-7.4506E-09   -3.4925E-09
      12    1      -3.9946E-02    9.5816E+06   -2.1933E+06   -2.3229E+08
```

```
-1.4183E+00    5.3479E-01
       12    2      -3.9946E-02    9.5816E+06   -2.1933E+06   -2.3229E+08
-1.4183E+00    5.3479E-01
       13    1       9.7955E+06   -5.1316E+04   -2.1410E+06    2.6782E+06
2.3021E+08    4.3855E+06
       13    2       9.7309E+06   -1.1116E+05   -1.9395E+06    3.3023E+06
2.3665E+08    3.7146E+06
       14    1       4.3083E-01   -9.6754E+06   -1.9242E+06    2.3031E+08
9.3210E+00    1.4817E+00
       14    2       4.1039E-01   -9.4976E+06   -1.7001E+06    2.3502E+08
9.8551E+00    3.5200E-01
       15    1      -9.7955E+06   -5.1316E+04   -2.1410E+06    2.6783E+06
-2.3021E+08   -4.3855E+06
       15    2      -9.7309E+06   -1.1116E+05   -1.9395E+06    3.3023E+06
-2.3665E+08   -3.7146E+06


 SUPERELEMENT TYPE:     1 ACTUAL ELEMENT:     1

 HAS BEEN STORED ON RESULT FILE


 DATE: 08-JUN-2012 TIME: 02:56:37   ***************  SESTRA  ***************
                                        PAGE:    14

                                        RETRACKING MODULE - GLOBAL DATA

                                    SUB PAGE:     1

  SUM OF GLOBAL LOADS AND MOMENTS

  *******************************



  LOADCASE (INDEX)        X             Y             Z             RX
RY            RZ

        1            0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
0.0000E+00    0.0000E+00
        2            0.0000E+00    5.8208E-11   -1.9673E+07    1.9893E+07
2.3011E-02    0.0000E+00
        3            0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
0.0000E+00    0.0000E+00
        4            0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
0.0000E+00    0.0000E+00
        5            0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
0.0000E+00    0.0000E+00
        6            0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
0.0000E+00    0.0000E+00
        7           -3.9700E+05    0.0000E+00    0.0000E+00    0.0000E+00
-2.5865E+07    0.0000E+00
        8            0.0000E+00    0.0000E+00    0.0000E+00   -1.4300E+07
0.0000E+00    0.0000E+00
        9            0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
-2.7100E+07    0.0000E+00
       10            0.0000E+00    1.4500E+05    0.0000E+00   -9.4468E+06
0.0000E+00    0.0000E+00
       11            0.0000E+00    0.0000E+00   -6.8647E+06    0.0000E+00
0.0000E+00    0.0000E+00
       12    1       3.9946E-02   -9.5816E+06    2.1933E+06    2.3229E+08
1.4183E+00   -5.3479E-01
```

```
       12    2       3.9946E-02   -9.5816E+06    2.1933E+06    2.3229E+08
1.4183E+00   -5.3479E-01
       13    1      -9.7955E+06    5.1316E+04    2.1410E+06   -2.6782E+06
-2.3021E+08   -4.3855E+06
       13    2      -9.7309E+06    1.1116E+05    1.9395E+06   -3.3023E+06
-2.3665E+08   -3.7146E+06
       14    1      -4.3083E-01    9.6754E+06    1.9242E+06   -2.3031E+08
-9.3210E+00   -1.4817E+00
       14    2      -4.1039E-01    9.4976E+06    1.7001E+06   -2.3502E+08
-9.8551E+00   -3.5200E-01
       15    1       9.7955E+06    5.1316E+04    2.1410E+06   -2.6783E+06
2.3021E+08    4.3855E+06
       15    2       9.7309E+06    1.1116E+05    1.9395E+06   -3.3023E+06
2.3665E+08    3.7146E+06

 DATE: 08-JUN-2012 TIME: 02:56:38   ****************  SESTRA  ***************
                                        PAGE:    15


                                        RETRACKING MODULE - GLOBAL DATA


                                    SUB PAGE:     2


  SUM OF REACTION FORCES AND MOMENTS

  **********************************

  GIVEN IN THE GLOBAL COORDINATE SYSTEM OF THE TOP LEVEL SUPERELEMENT



  LOADCASE (INDEX)        X             Y             Z             RX
RY            RZ

        1            0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
0.0000E+00    0.0000E+00
        2            4.6566E-10    6.9849E-10    1.9673E+07   -1.9893E+07
-2.3011E-02   -2.1246E-09
        3            0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
0.0000E+00    0.0000E+00
        4            0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
0.0000E+00    0.0000E+00
        5            0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
0.0000E+00    0.0000E+00
        6            0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
0.0000E+00    0.0000E+00
        7            3.9700E+05    1.4552E-10   -1.1642E-10    0.0000E+00
2.5865E+07    8.6147E-09
        8           -9.9590E-11    3.3415E-09   -1.7462E-10    1.4300E+07
-1.8626E-09   -4.3692E-09
        9           -4.9695E-09    1.1460E-10   -1.1642E-10    1.8626E-09
2.7100E+07    6.6138E-09
       10           -1.0186E-10   -1.4500E+05    0.0000E+00    9.4468E+06
-1.8626E-09   -3.5543E-09
       11            0.0000E+00    2.3283E-10    6.8647E+06   -1.4901E-08
-7.4506E-09   -3.4925E-09
       12    1      -3.9946E-02    9.5816E+06   -2.1933E+06   -2.3229E+08
-1.4183E+00    5.3479E-01
       12    2      -3.9946E-02    9.5816E+06   -2.1933E+06   -2.3229E+08
-1.4183E+00    5.3479E-01
       13    1       9.7955E+06   -5.1316E+04   -2.1410E+06    2.6782E+06
2.3021E+08    4.3855E+06
       13    2       9.7309E+06   -1.1116E+05   -1.9395E+06    3.3023E+06
2.3665E+08    3.7146E+06
       14    1       4.3083E-01   -9.6754E+06   -1.9242E+06    2.3031E+08
9.3210E+00    1.4817E+00
```

```
       14    2       4.1039E-01   -9.4976E+06   -1.7001E+06    2.3502E+08
9.8551E+00    3.5200E-01
       15    1      -9.7955E+06   -5.1316E+04   -2.1410E+06    2.6783E+06
-2.3021E+08   -4.3855E+06
       15    2      -9.7309E+06   -1.1116E+05   -1.9395E+06    3.3023E+06
-2.3665E+08   -3.7146E+06

 DATE: 08-JUN-2012 TIME: 02:56:40   ***************  SESTRA  ***************
                                               PAGE:    16


                                               RETRACKING MODULE - GLOBAL DATA


                                           SUB PAGE:     3


  DIFFERENCES BETWEEN SUMMED LOADS AND REACTION FORCES

  ****************************************************

  LARGER THAN   0.00E+00 FOR TRANSLATIONAL COMPONENTS AND LARGER THAN   0.00E+00
FOR ROTATIONAL COMPONENTS


  LOADCASE (INDEX)        X             Y             Z             RX
RY            RZ

        2            4.6566E-10    7.5670E-10    2.9802E-08    0.0000E+00
-2.6077E-08   -2.1246E-09
        7           -1.9209E-09    1.4552E-10   -1.1642E-10    0.0000E+00
-6.3330E-08    8.6147E-09
        8           -9.9590E-11    3.3415E-09   -1.7462E-10   -1.3784E-07
-1.8626E-09   -4.3692E-09
        9           -4.9695E-09    1.1460E-10   -1.1642E-10    1.8626E-09
-2.0117E-07    6.6138E-09
       10           -1.0186E-10    1.1350E-09    0.0000E+00   -3.7253E-08
-1.8626E-09   -3.5543E-09
       11            0.0000E+00    2.3283E-10    9.3132E-09   -1.4901E-08
-7.4506E-09   -3.4925E-09
       12    1       3.7253E-09   -1.6764E-08    9.3132E-10    5.9605E-07
6.7055E-08    1.1362E-07
       12    2       3.7253E-09   -1.6764E-08    9.3132E-10    5.9605E-07
6.7055E-08    1.1362E-07
       13    1       3.7253E-09    5.5879E-09   -9.3132E-10   -1.1083E-07
2.9802E-08    9.4995E-08
       13    2       1.8626E-09    5.1223E-09    2.7940E-09   -1.1642E-07
-2.0862E-07    8.0094E-08
       14    1      -4.3074E-09    1.8626E-08   -1.3970E-09   -4.7684E-07
-6.8918E-08   -1.3411E-07
       14    2      -4.3074E-09    9.3132E-09    4.6566E-10   -4.4703E-07
-6.1467E-08   -1.2573E-07
       15    1       0.0000E+00   -7.2177E-09    0.0000E+00    7.4506E-08
0.0000E+00   -8.9407E-08
       15    2      -1.8626E-09   -6.7521E-09    1.8626E-09    5.8673E-08
1.7881E-07   -9.0804E-08

  TOTAL TIME CONSUMED IN SESTRA                    CPU TIME:      0.91  CLOCK
TIME:     71.93  CHANNEL TIME:      0.22
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```
Software



               Program id   : 5.9-02
Computer         : 586
               Release date : 28-FEB-2007
Impl. update     :
               Access time  : 08-JUN-2012 01:52:36
Operating system : Win NT 5.2 [3790]
               User id      : ofsbilil
CPU id           : 1975101804

Installation     : , NOS294


               Copyright DET NORSKE VERITAS AS, P.O.Box 300, N-1322 Hovik,
Norway


1DATE: 08-JUN-2012 TIME: 01:52:38   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :     1

 LIMITATIONS IN THIS VERSION OF WAJAC :
 --------------------------------------

    MAXIMUM SIZE OF ONE SUPERELEMENT
    -  NUMBER OF NODES          :     20000
    -  NUMBER OF BASIC ELEMENTS :     20000


    MAXIMUM NUMBER OF LOADCASES
    -  DISCRETE WAVE            :     10000
    -  FREQUENCY DOMAIN         :       960
          ( MAX. FREQUENCIES :        60 )
    -  TIME DOMAIN SIMULATION   :      8192


    MAXIMUM NUMBER INPUT CARDS
    -  CARD TYPE SELI           :       100
    -  CARD TYPE ELIM           :     20000
    -  CARD TYPE FLOO           :     20000
    -  CARD TYPE LEG            :        50
    -  CARD TYPE SPEC           :     20000
    -  CARD TYPE CDIR           :     20000
    -  CARD TYPE MPRT           :     20000

 SIZE OF COMMON SCRATCH ARRAYS :
 --------------------------------

 /IWORK/ IWORK(  20000) /WORK/ WORK( 500000 )
 /IWORK4/ IARR(  60000) /WORK4/ ARR(  60120)
 TOTAL SIZE: /IWORK4/= 140068 /WORK4/= 231781

1DATE: 08-JUN-2012 TIME: 01:52:38   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :     2



 W A J A C   I N P U T   P R O C E S S O R :


               *** DATA SET WAJAC ***


               CARD NO   2    TITL      Wajac run name :
Analysis5_Stokes5.step(2)
```

```
               CARD NO   3    C

               CARD NO   4    C                                           PREFIX

               CARD NO   5    FMOD      20120608_015205_

               CARD NO   6    C

               CARD NO   7    C                                           PREFIX
       FORM
               CARD NO   8    FWAVE     20120608_015205_

               CARD NO   9    C

               CARD NO  10    C              UNITS   GRAVITY       RHO      VISC
   RHOAIR   VISCAIR
               CARD NO  11    CONS              1.   9.80665     1025. 1.19e-006
    1.226  1.462e-5
               CARD NO  12    C

               CARD NO  13    C               OPT1      OPT2      OPT3      OPT4
     OPT5      OPT6      OPT7
               CARD NO  14    OPTI              0.        0.        0.        0.
       0.        0.        0.
               CARD NO  15                      0.

               CARD NO  16    C

               CARD NO  17    C                       ILFSAV    ISETOP

               CARD NO  18    MODE                        1.        1.

               CARD NO  19    C

               CARD NO  20    C                 LN

               CARD NO  21    LONO             12.

               CARD NO  22    C         *************************** GEOM Section
*****************************
               *** END OF DATA SET  22 CARDS READ ***


               *** DATA SET GEOM ***


               CARD NO  24    C

               CARD NO  25    C                  Z

               CARD NO  26    MUDP      -5.651e-12

               CARD NO  27    C         *************************** HYDR Section
*****************************
               *** END OF DATA SET   5 CARDS READ ***


               *** DATA SET HYDR ***


               CARD NO  29    C

               CARD NO  30    C               TYPE

               CARD NO  31    CPRI      FEM
```

```
               CARD NO  32    CPRI      SPEC

               CARD NO  33    CPRI      CDIR

               CARD NO  34    C

               CARD NO  35    C              ADMAS      DAMP

               CARD NO  36    MASS              0.        0.

               CARD NO  37    C

               CARD NO  38    C         MarineGrowthZLevel1 ( Marine Growth as
function of Z-level property )
               CARD NO  39    C

1DATE: 08-JUN-2012 TIME: 01:52:38   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :     3

               CARD NO  40    C                 Z1        Z2     HMGRW    HROUGH
      OPT IMEM GRWF
               CARD NO  41    MGRW             -1.       45.       0.1        0.
       0.   1.   0.
               CARD NO  42    MGRW             -1.5.6488e-12       0.1        0.
       0.   1.   0.
               CARD NO  43    C

               CARD NO  44    C                 M1        M2       INC STYP  IDX
IMEM
               CARD NO  45    MEMGRW            1.       34.        1.   1.   1.
  1.
               CARD NO  46    C

               CARD NO  47    C         AirDragConstant1 ( Air Drag Coefficients
property )
               CARD NO  48    C

               CARD NO  49    C                 M1        M2       INC STYP  IDX
 CDX       CDZ
               CARD NO  50    CDWN              1.       34.        1.   1.   1.
 1.2       1.2
               CARD NO  51    C         *************************** LOAD Section
*****************************
               *** END OF DATA SET  24 CARDS READ ***



               *** DATA SET LOAD ***


               CARD NO  53    C

               CARD NO  54    C          ISEA THEO    HEIGHT    PERIOD       PHI0
       T0      STEP     NSTEP
               CARD NO  55    SEA          1.  5.0      17.5      14.3       -60.
       0.       10.      -36.
               CARD NO  56    SEA          2.  5.0      17.5      14.3       -60.
       0.       10.      -36.
               CARD NO  57    SEA          3.  5.0      17.5      14.3       -60.
       0.       10.      -36.
               CARD NO  58    SEA          4.  5.0      17.5      14.3       -60.
       0.       10.      -36.
               CARD NO  59    C

               CARD NO  60    C          ISEA BETA WKFA CTNO CBFA CSTR LOAD DLOA
 WID WIME
               CARD NO  61    SEAOPT       1. 270.    1.   1.   1.  -1.   0.   1.
  1.   0.
```

```
               CARD NO  62    SEAOPT       2. 180.   1.   1.   1.  -1.   0.   1.
  2.   0.
               CARD NO  63    SEAOPT       3.  90.   1.   1.   1.  -1.   0.   1.
  3.   0.
               CARD NO  64    SEAOPT       4.   0.   1.   1.   1.  -1.   0.   1.
  4.   0.
               CARD NO  65    C

               CARD NO  66    C         WindProfileRelDir4 (  Wind profile
property )
               CARD NO  67    C

               CARD NO  68    C      WID       VEL     ANGLE     GUSTF        H0
     HEXP PRAT IFRM
               CARD NO  69    WIND    1.        25.       270.     0.315       10.
      0.7   0.   0.
               CARD NO  70    C

               CARD NO  71    C         WindProfileRelDir3 (  Wind profile
property )
               CARD NO  72    C

               CARD NO  73    C      WID       VEL     ANGLE     GUSTF        H0
     HEXP PRAT IFRM
               CARD NO  74    WIND    2.        25.       180.     0.315       10.
      0.7   0.   0.
               CARD NO  75    C

               CARD NO  76    C         WindProfileRelDir2 (  Wind profile
property )
               CARD NO  77    C

               CARD NO  78    C      WID       VEL     ANGLE     GUSTF        H0
     HEXP PRAT IFRM
               CARD NO  79    WIND    3.        25.        90.     0.315       10.
      0.7   0.   0.
               CARD NO  80    C

               CARD NO  81    C         WindProfileRelDir1 (  Wind profile
property )
               CARD NO  82    C

               CARD NO  83    C      WID       VEL     ANGLE     GUSTF        H0
     HEXP PRAT IFRM
               CARD NO  84    WIND    4.        25.         0.     0.315       10.
      0.7   0.   0.
               CARD NO  85    C

               CARD NO  86    C         CurrentProfile1 (  Current profile
property )
               CARD NO  87    C

               CARD NO  88    C     CTNO                                        Z
        V     THETA       OPT
               CARD NO  89    CRNT    1.                               5.6488e-12
      0.5                  1.
               CARD NO  90                                                    45.
      1.1
               CARD NO  91                                                  65.15
      1.1
1DATE: 08-JUN-2012 TIME: 01:52:38   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :     4

               CARD NO  92    C

               CARD NO  93    C              DEPTH

               CARD NO  94    DPTH            45.
```

```
            CARD NO  95    C

            CARD NO  96    C                  X         Y         Z

            CARD NO  97    MOMT              0.        0.        0.


            *** END OF DATA SET  46 CARDS READ ***


       ***** END OF DATA INPUT   98 CARDS READ *****
1DATE: 08-JUN-2012 TIME: 01:52:38   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                       PAGE :     5


********************************************************************************
************
 *
          *
 *          Wajac run name : Analysis5_Stokes5.step(2)
          *
 *
          *

********************************************************************************
************




 S U M M A R Y   O F   I N P U T   S P E C I F I C A T I O N S :


 PROGRAM EXECUTION:
 ------------------

    THE PROGRAM IS USED IN INTERFACE MODE WITH PARAMETERS:

    IGFSAV=0   ILFSAV=1   ISETOP=  1


 FILE USEAGE:
 ------------

    THE NAME WHICH WILL BE USED FOR THE DEFAULT PART OF
          THE INTERFACE FILE NAMES IS: 20120608_015205_

    GEOMETRY WILL BE STORED ON TEMPORARY FILES DURING EXECUTION.

    THE LOADS WILL BE SAVED ON ONE FILE FOR EACH SUPERELEMENT TYPE

    THE NAME WHICH WILL BE USED FOR THE DEFAULT PART OF
          THE LOAD FILE NAMES IS: 20120608_015205_



 UNITS:
 ------

    THE UNITS ARE USER DEFINED:

    GRAVITY                   = 9.8067E+00
    WATER SPECIFIC MASS       = 1.0250E+03
    WATER KINEMATIC VISCOSITY = 1.1900E-06
    AIR SPECIFIC MASS         = 1.2260E+00
    AIR KINEMATIC VISCOSITY   = 1.4620E-05
```

```
 INITIAL LOADCASE NUMBER ON THE LOAD FILES :
 ------------------------------------------

    IS USER DEFINED =      12 FOR ALL SUPERELEMENT TYPES


 SPECIAL OPTIONS INTENDED FOR COMPARATIVE STUDIES:
--------------------------------------------------


1DATE: 08-JUN-2012 TIME: 01:52:38   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                             PAGE :     6



 LEG PERMABILITY FACTORS:
 ------------------------

    DEFAULT VALUES FOR CPERM IS USED.
    ALL LEGS ARE ASSUMED TO HAVE FULL BUOYANCY.


 MUDPLANE ELEVATION:
 -------------------

    THE MUDPLANE ELEVATION IS SET TO -.5651E-11 IN THE STRUCTURE COORDINATE
SYSTEM.


 HYDRODYNAMIC COEFFICIENTS:
 --------------------------

    *** WARNING: HYDRODYNAMIC COEFFICIENTS HAVE NOT BEEN SPECIFIED BY THE WAJAC
ANALYSIS
        CONTROL DATA. ENSURE THAT THE COEFFICIENTS ARE SPECIFIED ON THE SESAM
INTERFACE FILE ***


 MARINE GROWTH:
 --------------

    MARINE GROWTH AND ROUGHNESS IS SPECIFIED IN THE FOLLOWING DEPTH RANGES:
    (Z1=-1.0 MEANS LINEAR VARYING MARINE GROWTH
     AND ROUGHNESS BETWEEN LEVELS GIVEN BY Z2)

    BETWEEN ELEVATIONS     Z1   AND   Z2          HMGRW      HROUGH    INFLG
IMEM   GRWFAC

                         -1.000       0.000       0.100       0.000     0
 1    0.0000
                         -1.000      45.000       0.100       0.000     0
 1    0.0000

    MARINE GROWTH IS NOT INCLUDED IN INERTIA FORCE CALCULATION.
1DATE: 08-JUN-2012 TIME: 01:52:38   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                             PAGE :     7



 MARINE GROWTH BY MEMBERS:
 -------------------------

    INDIVIDUAL MARINE GROWTH AND ROUGHNESS ARE SPECIFIED FOR THE FOLLOWING
MEMBERS:


                              BY       OF      AND ACTUAL
```

```
    MEMBER  THROUGH  MEMBER  STEP SUP.ELEMENT SUP.ELEMENT    IMEM
    ( OR SETNAME )            OF      TYPE       INDEX

        1           34        1        1          1           1



 MEMBERS WITH SPECIAL HYDRODYNAMIC PROPERTIES:
 ---------------------------------------------

    NO MEMBERS HAVE BEEN DEFINED AS SPECIAL.


 MEMBERS WITH DIRECTIONAL HYDRODYNAMIC COEFFICIENTS:
 ---------------------------------------------------

    NO MEMBERS HAVE DIRECTIONAL HYDRODYNAMIC COEFFICIENTS.


 PRIORITY OF SPECIFIED HYDRODYNAMIC COEFFICIENTS (1 IS HIGHEST):
 ---------------------------------------------------------------

    SPECIFICATION WITH HIGHER PRIORITY WILL SUPERSEDE ANY OTHER COEFFICIENTS
SPECIFIED.

    THE PRIORITY HIERARCHY IS MODIFED.

    OPTION FOR SPECIFICATION     CPRI-TYPE     PRIORITY     GIVEN ON WAJAC INPUT
FILE
    ------------------------     ---------     --------
-------------------------
    API                          API                6       NO
    VERTICAL POSITION            COEF               5       NO
    DIAMETER                     FUNC               4       NO
    KC. NUMBER                   FUNC               4       NO
    RN. NUMBER                   FUNC               4       NO
    INPUT INTERFACE FILE         FEM                3       ---
    INDIVIDUAL                   SPEC               2       NO
    DIRECTIONAL                  CDIR               1       NO


 TRANSFER OF ADDED MASS AND/OR DAMPING FOR DYNAMIC STRUCTURAL ANALYSIS :
 -----------------------------------------------------------------------

    CALCULATED ADDED MASS IS  N O T  TRANSFERRED

    CALCULATED DAMPING IS  N O T  TRANSFERRED

1DATE: 08-JUN-2012 TIME: 01:52:38   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :     8



 AIR DRAG COEFFICIENTS:
 -----------------------

 *** WARNING: DIRECTIONAL DEPENDENT COEFFICIENTS GIVEN THROUGH THE WAJAC
ANALYSIS CONTROL DATA, MUST BE
              SPECIFIED RELATIVE TO THE AXES OF THE MEMBER LOCAL COORDINATE
SYSTEM USED IN WAJAC. THIS
              COORDINATE SYSTEM IS NOT NECESSARILY CORRESPONDING TO THE ONE
DEFINED IN THE PREPROCESSOR
              HAVING CREATED THE MODEL.

              THE RELATION BETWEEN THE LOCAL COORDINATE SYSTEM IN WAJAC AND THE
LOCAL COORDINATE SYSTEM
              IN THE SESAM PREPROCESSORS IS:
```

```
                 WAJAC         PREPROCESSOR
                 -----         ------------
                   x              -y
                   y               x
                   z               z

    THE FOLLOWING MEMBERS HAVE BEEN DEFINED WITH AIR DRAG COEFFICIENTS:
    (VALUE -1.000 MEANS ORIGINAL VALUE RETAINED)

                                 BY       OF      AND ACTUAL
    MEMBER  THROUGH  MEMBER  STEP SUP.ELEMENT SUP.ELEMENT      CDX
CDZ
    ( OR SETNAME )            OF      TYPE       INDEX

        1           34        1        1          1          1.200
1.200


 MOMENT REFERENCE POINT:
 -----------------------

    THE MOMENT REFERENCE POINT COORDINATES HAVE BEEN SPECIFIED AS:

    XM=       0.000   YM=       0.000   ZM=       0.000


 MEMBER SEGMENTATION:
 --------------------

    THE DEFAULT VALUE SEG=1.0 IS USED FOR THE MEMBER SEGMENTATION COEFFICIENT.


 SEGMENTATION BY REFERENCE TO MEMBERS:
 -------------------------------------

    INDIVIDUAL SEGMENTATION IS NOT SPECIFIED FOR ANY MEMBERS.


 WATER DEPTH SPECIFICATION:
 --------------------------

    THE WATER DEPTH HAS BEEN SPECIFIED TO:

    DEPTH=      45.000
1DATE: 08-JUN-2012 TIME: 01:52:38   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                        PAGE :     9


 CURRENT SPECIFICATION:
 ----------------------

    CURRENT IS SPECIFIED BY THE FOLLOWING TABLE(S):

    TABLE NO.  1
+                          Z            V       (THE CURRENT IS RUNNING WITH
THE WAVE)

                        0.000       0.500
                       45.000       1.100
                       65.150       1.100
1DATE: 08-JUN-2012 TIME: 01:52:38   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                        PAGE :    10
```

```
 DETERMINISTIC SEASTATES DEFINITION:
 -----------------------------------


    THE FOLLOWING SEASTATES WILL BE ANALYSED:

      SEA-     WAVE       WAVE       WAVE      PHASE   INITIAL      PHASE/TIME
 NUMBER    WAVE        WAVE        WAVE   DESIGN
      STATE   THEORY      HEIGHT     PERIOD     /TIME   PHASE/TIME   INCREMENTS
OF STEPS  HEADING     KINEMATICS   BUOY   LOADS
      NO.
                       FACTOR      FLAG
      -----  --------    ---------  ---------  ------  -----------  -----------
--------- ----------  -----------  -----  -------

        1    STOKES  5   17.50      14.30      PHASE  -60.00        10.00
   36.    270.0       1.000        0        1
        2    STOKES  5   17.50      14.30      PHASE  -60.00        10.00
   36.    180.0       1.000        0        1
        3    STOKES  5   17.50      14.30      PHASE  -60.00        10.00
   36.    90.00       1.000        0        1
        4    STOKES  5   17.50      14.30      PHASE  -60.00        10.00
   36.       0.0000   1.000        0        1


      SEA-    CURRENT  CURRENT      CURRENT    WIND    WIND LOAD
      STATE   TAB.NO   BLOCKAGE     STRETCH    INDEX   CALC.METH
      NO.
      -----   -------  -----------  ---------  ------  ---------

        1        1     1.000           -1         1        0
        2        1     1.000           -1         2        0
        3        1     1.000           -1         3        0
        4        1     1.000           -1         4        0

 WIND SPECIFICATION:
 --------------------

      WIND     MEAN       WIND      GUST      MEAN      HEIGHT     MEAN      WIND
    PROFILE    WIND      ANGLE     FACTOR   VELOCITY  EXPONENT   PERIOD   PROFILE
     INDEX   VELOCITY                         LEVEL               RATIO   FORMULA

       1      25.000   270.000     0.315    10.000     0.700     -----        0
       2      25.000   180.000     0.315    10.000     0.700     -----        0
       3      25.000    90.000     0.315    10.000     0.700     -----        0
       4      25.000     0.000     0.315    10.000     0.700     -----        0

    AIR DRAG COEFFICIENTS HAVE NOT BEEN SPECIFIED AS FUNCTION OF REYNOLDS
NUMBER.
    THE DEFAULT FUNCTION WILL BEE USED IF THE COEFFICIENTS NOT ARE SPECIFIED BY
THE CDWN COMMAND


 D A T A C H E C K I N G   F I N I S H E D
       Siftool    version 8.3-02   18-JAN-2007


 NAMES OF INPUT INTERFACE FILES READ:
 ------------------------------------


 Direct file opened: ofsbilil6832R1.SIN
 (IUINP,NWS,IUIDNT,MXPHYS,STATUS) :          10      1024     3
 0   SCRATCH
 File is native
     MD-FILE    1 OPENED ON UNIT  10 WITH INDEX   1 MAX LENGTH=     2147483640
WORDS AND BLOCKSIZE=  1024
```

```
              NAME   R1.SIN




              STATUS SCRATCH
     MD-FILE    1 ALLOCATION ACCOUNT OPENED

 20120608_015205_T1.FEM

         DATE:     08-Jun-2012         TIME:          01:52:06

         PROGRAM:  SESAM GeniE         VERSION:       V5.3-10 14-Apr-2011

         COMPUTER: X86 Windows         INSTALLATION:

         USER:     ofsbilil            ACCOUNT:

         DATE:     08-Jun-2012         TIME:          01:52:06

         PROGRAM:  SESAM Gamesha       VERSION:       R5.0-3 14-Apr-2011

         COMPUTER: X86 Windows         INSTALLATION:

         USER:     ofsbilil            ACCOUNT:

1DATE: 08-JUN-2012 TIME: 01:52:38   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :    11



*******************************************
                                           *   W A T E R   D E P T H :
45.000   *
*******************************************


 D E T E R M I N I S T I C   W A V E   C H A R A C T E R I S T I C S :



                 WAVE      WAVE                           DEPTH TO    WAVE HEIGHT
TO    WAVE       WAVE       HALF WAVE   HALF WAVE
 WAVE   WAVE     PERIOD   PERIOD     WAVE        WAVE      WAVE LENGTH    WAVE
LENGTH     CREST       TROUGH       DURATION    DURATION
  NO   THEORY    ACTUAL  APPARENT  HEIGHT      LENGTH       RATIO          RATIO
    ELEVATION   ELEVATION     CREST        TROUGH

   1 STOKES 5TH   14.30            17.50       270.4      0.1664
0.6472E-01   55.93       38.42       6.000        8.300
1DATE: 08-JUN-2012 TIME: 01:52:38   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :    12


 W A V E / C U R R E N T   L O A D I N G :


 STRUCTURE LOADS:
 ----------------
```

```
 SUPERELEMENT TYPE  :         1

    THE HIGHEST LOAD CASE NUMBER ON THE FEM INTERFACE FILE IS :        19
    THE INITIAL LOAD CASE NUMBER ON THE LOAD FILE IS          :        12


 *** WARNING *** LOADCASE NUMBERS WILL OVERLAP ON THE FEM INTERFACE FILE AND THE
LOAD FILE




 SUPERELEMENT TYPE NO   1   INDEX  1  (  34 BASIC ELEMENTS,  34 MEMBERS AND   20
NODES,  1 ACTUAL SUPERELEMENTS OF THAT TYPE )
1DATE: 08-JUN-2012 TIME: 01:52:38   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                               PAGE :    13


 T O T A L   L O A D   S U M M A R Y :


    SEASTATE NO   1

       STEP    PHASE      LX             LY             LZ             MX
     MY             MZ
       ----    -----      ----------     ----------     ----------
----------     ----------     ----------

          1    -60.0      1.7939E-02    -7.4578E+06     2.7134E+06
1.5176E+08     1.7188E-01     2.0938E+00
          2    -50.0      7.2959E-02    -8.3252E+06     2.6324E+06
1.7776E+08     1.4531E+00     8.7500E-01
          3    -40.0      8.1129E-02    -9.0798E+06     2.5183E+06
2.0331E+08     1.8281E+00    -9.0625E-01
          4    -30.0      1.2053E-01    -9.5620E+06     2.3701E+06
2.2351E+08     8.2812E-01    -6.8750E-01
          5    -20.0      1.0517E-01    -9.5816E+06     2.1933E+06
2.3120E+08     3.3359E+00     5.3125E-01
          6    -10.0     -4.0768E-03    -8.9597E+06     1.9988E+06
2.1867E+08     2.9609E+00    -8.7500E-01
          7      0.0      8.5717E-02    -7.6221E+06     1.8030E+06
1.8224E+08     2.5156E+00    -1.7500E+00
          8     10.0      5.0299E-02    -5.6710E+06     1.6265E+06
1.2617E+08     2.0156E+00     2.8125E-01
          9     20.0      4.5918E-02    -3.3750E+06     1.4916E+06
6.2003E+07    -1.6406E-01     6.2500E-02
         10     30.0     -5.5215E-03    -1.0617E+06     1.4175E+06
2.6353E+06    -1.0938E-01    -4.6875E-01
         11     40.0     -4.7078E-02     1.0008E+06     1.4150E+06
-4.3664E+07    -6.7188E-01    -4.6875E-01
         12     50.0     -2.2766E-02     2.6549E+06     1.4837E+06
-7.4643E+07    -9.2969E-01    -1.7188E-01
         13     60.0     -3.5286E-02     3.8385E+06     1.6118E+06
-9.1838E+07    -8.0469E-01     1.5894E-01
         14     70.0     -4.7697E-02     4.5590E+06     1.7788E+06
-9.8301E+07    -1.1797E+00     1.7188E-01
         15     80.0      6.4618E-03     4.8590E+06     1.9599E+06
-9.6978E+07    -9.9219E-01     5.1562E-01
         16     90.0     -2.5121E-02     4.8163E+06     2.1318E+06
-9.0458E+07    -8.3594E-01     2.3438E-01
         17    100.0      1.7713E-02     4.5178E+06     2.2739E+06
-8.0919E+07    -9.2969E-01     2.9688E-01
         18    110.0     -9.5847E-03     4.1087E+06     2.3746E+06
-7.1290E+07    -3.9844E-01     1.0781E+00
         19    120.0      4.1331E-02     3.6924E+06     2.4352E+06
-6.2555E+07    -1.7969E-01    -5.4688E-01
```

```
         20    130.0     -6.4044E-02     3.3172E+06     2.4694E+06
-5.4901E+07    -4.2969E-01    -6.2500E-01
         21    140.0     -5.2260E-02     2.9703E+06     2.4922E+06
-4.8084E+07     7.8125E-03    -3.9062E-01
         22    150.0      5.3109E-04     2.6295E+06     2.5139E+06
-4.1726E+07    -2.4219E-01     3.7500E-01
         23    160.0     -5.7997E-02     2.2706E+06     2.5398E+06
-3.5431E+07     1.6406E-01     7.8125E-01
         24    170.0      2.6411E-03     1.8724E+06     2.5725E+06
-2.8843E+07    -4.2969E-01     4.6875E-02
         25    180.0      1.5465E-02     1.4179E+06     2.6130E+06
-2.1665E+07     1.0156E-01     1.5625E-02
         26    190.0     -2.6351E-02     8.9490E+05     2.6604E+06
-1.3638E+07     1.3281E-01     1.6406E-01
         27    200.0     -1.8556E-02     2.9688E+05     2.7124E+06
-4.5660E+06     1.9531E-01    -1.1719E-01
         28    210.0      7.8465E-03    -3.7640E+05     2.7650E+06
5.6897E+06     6.6406E-01     1.4844E-01
         29    220.0      1.4521E-02    -1.1173E+06     2.8131E+06
1.7189E+07     6.0156E-01    -1.2695E-01
         30    230.0      1.5863E-02    -1.9090E+06     2.8511E+06
2.9899E+07    -4.2969E-01     3.4961E-01
         31    240.0      6.2494E-04    -2.7243E+06     2.8735E+06
4.3676E+07     6.9531E-01     1.0938E-01
         32    250.0     -2.6335E-02    -3.5334E+06     2.8772E+06
5.8301E+07    -8.5938E-02    -2.1875E-01
         33    260.0     -1.8173E-02    -4.3055E+06     2.8630E+06
7.3403E+07     4.4531E-01    -7.8125E-02
         34    270.0      1.7261E-02    -5.0328E+06     2.8379E+06
8.9068E+07     1.3281E-01    -1.7188E-01
         35    280.0      9.6314E-03    -5.7784E+06     2.8070E+06
1.0701E+08     3.2578E+00     2.3438E-01
         36    290.0      4.1097E-02    -6.5890E+06     2.7687E+06
1.2788E+08     1.9531E+00    -6.2500E-01

       MAXIMUM BASE SHEAR         = 9.5816E+06  AT PHASE =  -20.0

       MAXIMUM OVERTURNING MOMENT = 2.3120E+08  AT PHASE =  -20.0


    SEASTATE NO   2

       STEP    PHASE      LX             LY             LZ             MX
     MY             MZ
       ----    -----      ----------     ----------     ----------
----------     ----------     ----------

          1    -60.0     -7.7511E+06    -7.6168E+04     2.5987E+06
-1.5743E+06    -1.5870E+08    -5.4430E+06
          2    -50.0     -8.6282E+06    -4.4900E+04     2.4787E+06
-1.8010E+06    -1.8466E+08    -5.3079E+06
1DATE: 08-JUN-2012 TIME: 01:52:38   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                       PAGE :    14

          3    -40.0     -9.3645E+06    -1.9158E+03     2.3246E+06
-2.1627E+06    -2.0979E+08    -4.9719E+06
          4    -30.0     -9.7955E+06     5.1316E+04     2.1410E+06
-2.6615E+06    -2.2915E+08    -4.4530E+06
          5    -20.0     -9.7309E+06     1.1116E+05     1.9395E+06
-3.2757E+06    -2.3556E+08    -3.7869E+06
          6    -10.0     -8.9984E+06     1.7200E+05     1.7373E+06
-3.9518E+06    -2.2141E+08    -3.0215E+06
          7      0.0     -7.5359E+06     2.2698E+05     1.5544E+06
-4.6032E+06    -1.8316E+08    -2.2074E+06
          8     10.0     -5.4618E+06     2.6909E+05     1.4116E+06
-5.1303E+06    -1.2530E+08    -1.3895E+06
          9     20.0     -3.0614E+06     2.9249E+05     1.3271E+06
-5.4452E+06    -5.9635E+07    -6.0116E+05
```

```
         10     30.0    -6.7715E+05     2.9368E+05     1.3126E+06
-5.4953E+06     7.4188E+05     1.3664E+05
         11     40.0     1.4141E+06     2.7227E+05     1.3711E+06
-5.2802E+06     4.7427E+07     8.1234E+05
         12     50.0     3.0528E+06     2.3110E+05     1.4949E+06
-4.8457E+06     7.8149E+07     1.4183E+06
         13     60.0     4.1821E+06     1.7569E+05     1.6660E+06
-4.2670E+06     9.4532E+07     1.9459E+06
         14     70.0     4.8204E+06     1.1306E+05     1.8602E+06
-3.6309E+06     9.9796E+07     2.3837E+06
         15     80.0     5.0244E+06     5.0621E+04     2.0515E+06
-3.0215E+06     9.7105E+07     2.7285E+06
         16     90.0     4.8891E+06    -2.4574E+03     2.2184E+06
-2.5213E+06     8.9264E+07     3.1309E+06
         17    100.0     4.5226E+06    -3.8223E+04     2.3457E+06
-2.1842E+06     7.8668E+07     3.5934E+06
         18    110.0     4.0991E+06    -5.6268E+04     2.4309E+06
-2.0269E+06     6.8510E+07     3.7186E+06
         19    120.0     3.6947E+06    -6.4016E+04     2.4850E+06
-1.9974E+06     5.9661E+07     3.4340E+06
         20    130.0     3.3246E+06    -6.8622E+04     2.5207E+06
-2.0236E+06     5.1986E+07     3.0104E+06
         21    140.0     2.9762E+06    -7.3380E+04     2.5486E+06
-2.0484E+06     4.5136E+07     2.5590E+06
         22    150.0     2.6247E+06    -7.9940E+04     2.5756E+06
-2.0403E+06     3.8650E+07     2.0940E+06
         23    160.0     2.2462E+06    -8.8887E+04     2.6051E+06
-1.9879E+06     3.2116E+07     1.6175E+06
         24    170.0     1.8209E+06    -1.0004E+05     2.6386E+06
-1.8942E+06     2.5185E+07     1.1260E+06
         25    180.0     1.3334E+06    -1.1271E+05     2.6763E+06
-1.7718E+06     1.7575E+07     6.1585E+05
         26    190.0     7.7377E+05    -1.2592E+05     2.7170E+06
-1.6382E+06     9.0562E+06     8.6547E+04
         27    200.0     1.3807E+05    -1.3837E+05     2.7584E+06
-1.5122E+06    -5.3271E+05    -4.5708E+05
         28    210.0    -5.7058E+05    -1.4855E+05     2.7969E+06
-1.4121E+06    -1.1285E+07    -1.0037E+06
         29    220.0    -1.3405E+06    -1.5479E+05     2.8280E+06
-1.3522E+06    -2.3208E+07    -1.5359E+06
         30    230.0    -2.1505E+06    -1.5554E+05     2.8468E+06
-1.3401E+06    -3.6218E+07    -2.0339E+06
         31    240.0    -2.9692E+06    -1.4977E+05     2.8506E+06
-1.3716E+06    -5.0138E+07    -2.4823E+06
         32    250.0    -3.7639E+06    -1.3781E+05     2.8394E+06
-1.4237E+06    -6.4733E+07    -2.9552E+06
         33    260.0    -4.5112E+06    -1.2407E+05     2.8165E+06
-1.4591E+06    -7.9698E+07    -3.6827E+06
         34    270.0    -5.2287E+06    -1.1405E+05     2.7864E+06
-1.4548E+06    -9.5320E+07    -4.5510E+06
         35    280.0    -6.0073E+06    -1.0690E+05     2.7458E+06
-1.4412E+06    -1.1350E+08    -5.1257E+06
         36    290.0    -6.8544E+06    -9.6148E+04     2.6857E+06
-1.4643E+06    -1.3464E+08    -5.3792E+06

       MAXIMUM BASE SHEAR         = 9.7956E+06  AT PHASE =  -30.0

       MAXIMUM OVERTURNING MOMENT = 2.3558E+08  AT PHASE =  -20.0


    SEASTATE NO   3

       STEP    PHASE      LX             LY             LZ             MX
     MY             MZ
       ----    -----      ----------     ----------     ----------
----------     ----------     ----------

          1    -60.0    -3.4791E-01     7.8370E+06     2.4857E+06
```

```
-1.6240E+08    -7.3281E+00   -1.5625E+00
          2    -50.0     -4.1927E-01     8.6735E+06     2.3308E+06
-1.8755E+08    -7.7109E+00     2.8125E-01
          3    -40.0     -4.1207E-01     9.3403E+06     2.1401E+06
-2.1147E+08    -8.7734E+00   -2.3125E+00
          4    -30.0     -3.3393E-01     9.6754E+06     1.9242E+06
-2.2927E+08    -9.7734E+00   -4.3750E-01
          5    -20.0     -4.2691E-01     9.4976E+06     1.7001E+06
-2.3393E+08    -9.4531E+00   -6.2500E-01
          6    -10.0     -3.8628E-01     8.6480E+06     1.4902E+06
-2.1804E+08    -1.0453E+01   -2.6250E+00
          7      0.0     -3.5276E-01     7.0816E+06     1.3189E+06
-1.7832E+08    -8.8281E+00   -2.2188E+00
          8     10.0     -2.3669E-01     4.9327E+06     1.2079E+06
-1.1948E+08    -5.5000E+00   -2.5625E+00
          9     20.0     -1.3013E-01     2.4993E+06     1.1716E+06
-5.3497E+07    -2.6797E+00   -2.0469E+00
         10     30.0     -5.5360E-02     1.2982E+05     1.2152E+06
6.4777E+06    -5.4688E-02    -5.7617E-01
         11     40.0      8.8408E-02    -1.9002E+06     1.3333E+06
5.2092E+07     1.4531E+00    -4.9219E-01
         12     50.0      1.5690E-01    -3.4398E+06     1.5107E+06
8.1227E+07     3.0156E+00     5.9375E-01
         13     60.0      1.3877E-01    -4.4464E+06     1.7237E+06
9.5735E+07     4.2422E+00     2.6562E-01
         14     70.0      1.7068E-01    -4.9560E+06     1.9429E+06
9.9116E+07     3.8984E+00     8.2812E-01
1DATE: 08-JUN-2012 TIME: 01:52:38   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :    15

         15     80.0      2.4096E-01    -5.0405E+06     2.1417E+06
9.4766E+07     4.1484E+00     8.1250E-01
         16     90.0      2.0142E-01    -4.8099E+06     2.2990E+06
8.5655E+07     4.6797E+00     1.4844E+00
         17    100.0      1.2682E-01    -4.4122E+06     2.4097E+06
7.4440E+07     2.1719E+00     3.4375E-01
         18    110.0      1.8125E-01    -3.9915E+06     2.4818E+06
6.4085E+07     2.8281E+00     9.8438E-01
         19    120.0      1.4979E-01    -3.5952E+06     2.5307E+06
5.5194E+07     2.0469E+00     1.0156E+00
         20    130.0      1.8472E-01    -3.2267E+06     2.5674E+06
4.7493E+07     3.0469E+00     1.7188E+00
         21    140.0      1.2777E-01    -2.8722E+06     2.5994E+06
4.0570E+07     2.6406E+00     2.6562E-01
         22    150.0      1.0780E-01    -2.5075E+06     2.6308E+06
3.3945E+07     1.0469E+00     3.1250E-02
         23    160.0      1.0330E-01    -2.1107E+06     2.6636E+06
2.7211E+07     2.8594E+00     8.7500E-01
         24    170.0      8.9814E-02    -1.6642E+06     2.6980E+06
2.0043E+07     1.4062E-01     3.2812E-01
         25    180.0      5.9538E-02    -1.1553E+06     2.7333E+06
1.2193E+07     1.2891E+00    -1.9141E-01
         26    190.0      6.2283E-02    -5.7642E+05     2.7677E+06
3.4640E+06     4.7656E-01     1.3691E+00
         27    200.0      1.7027E-02     7.3602E+04     2.7985E+06
-6.2711E+06     5.3906E-01     6.2500E-02
         28    210.0     -3.6137E-02     7.8885E+05     2.8225E+06
-1.7070E+07    -1.4844E-01   -4.0625E-01
         29    220.0     -6.5877E-02     1.5547E+06     2.8356E+06
-2.8905E+07    -1.2500E+00   -3.8281E-01
         30    230.0     -9.0638E-02     2.3470E+06     2.8345E+06
-4.1665E+07    -9.0625E-01   -2.8125E-01
         31    240.0     -1.2688E-01     3.1338E+06     2.8196E+06
-5.5202E+07    -1.6875E+00   -2.0312E-01
         32    250.0     -1.4714E-01     3.8793E+06     2.7958E+06
-6.9330E+07    -2.6016E+00   -1.5156E+00
         33    260.0     -1.7913E-01     4.5904E+06     2.7683E+06
-8.4013E+07    -3.3828E+00   -1.5312E+00
```

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         34    270.0     -1.8791E-01     5.3105E+06     2.7338E+06
-9.9621E+07    -4.2891E+00    -9.0625E-01
         35    280.0     -3.2972E-01     6.1022E+06     2.6822E+06
-1.1780E+08    -5.3281E+00    -6.8750E-01
         36    290.0     -4.0133E-01     6.9545E+06     2.6018E+06
-1.3878E+08    -5.5781E+00    -1.1875E+00

       MAXIMUM BASE SHEAR         = 9.6754E+06  AT PHASE =  -30.0

       MAXIMUM OVERTURNING MOMENT = 2.3393E+08  AT PHASE =  -20.0


    SEASTATE NO   4

       STEP    PHASE      LX             LY             LZ             MX
     MY             MZ
       ----    -----      ----------     ----------     ----------
----------     ----------     ----------

          1    -60.0      7.7511E+06    -7.6167E+04     2.5987E+06
-1.5743E+06     1.5870E+08     5.4430E+06
          2    -50.0      8.6282E+06    -4.4900E+04     2.4787E+06
-1.8010E+06     1.8466E+08     5.3079E+06
          3    -40.0      9.3645E+06    -1.9150E+03     2.3246E+06
-2.1627E+06     2.0979E+08     4.9719E+06
          4    -30.0      9.7955E+06     5.1316E+04     2.1410E+06
-2.6615E+06     2.2915E+08     4.4530E+06
          5    -20.0      9.7309E+06     1.1116E+05     1.9395E+06
-3.2758E+06     2.3556E+08     3.7869E+06
          6    -10.0      8.9984E+06     1.7200E+05     1.7373E+06
-3.9519E+06     2.2141E+08     3.0215E+06
          7      0.0      7.5359E+06     2.2698E+05     1.5544E+06
-4.6032E+06     1.8316E+08     2.2074E+06
          8     10.0      5.4618E+06     2.6909E+05     1.4116E+06
-5.1303E+06     1.2530E+08     1.3895E+06
          9     20.0      3.0614E+06     2.9249E+05     1.3271E+06
-5.4452E+06     5.9635E+07     6.0116E+05
         10     30.0      6.7715E+05     2.9368E+05     1.3126E+06
-5.4953E+06    -7.4188E+05    -1.3664E+05
         11     40.0     -1.4141E+06     2.7227E+05     1.3711E+06
-5.2801E+06    -4.7427E+07    -8.1234E+05
         12     50.0     -3.0528E+06     2.3110E+05     1.4949E+06
-4.8457E+06    -7.8149E+07    -1.4183E+06
         13     60.0     -4.1821E+06     1.7569E+05     1.6660E+06
-4.2670E+06    -9.4532E+07    -1.9459E+06
         14     70.0     -4.8204E+06     1.1306E+05     1.8602E+06
-3.6309E+06    -9.9796E+07    -2.3837E+06
         15     80.0     -5.0244E+06     5.0620E+04     2.0515E+06
-3.0215E+06    -9.7105E+07    -2.7285E+06
         16     90.0     -4.8891E+06    -2.4579E+03     2.2184E+06
-2.5213E+06    -8.9264E+07    -3.1309E+06
         17    100.0     -4.5226E+06    -3.8223E+04     2.3457E+06
-2.1842E+06    -7.8668E+07    -3.5934E+06
         18    110.0     -4.0991E+06    -5.6268E+04     2.4309E+06
-2.0269E+06    -6.8510E+07    -3.7186E+06
         19    120.0     -3.6947E+06    -6.4016E+04     2.4850E+06
-1.9974E+06    -5.9661E+07    -3.4340E+06
         20    130.0     -3.3246E+06    -6.8622E+04     2.5207E+06
-2.0236E+06    -5.1986E+07    -3.0104E+06
         21    140.0     -2.9762E+06    -7.3380E+04     2.5486E+06
-2.0484E+06    -4.5136E+07    -2.5590E+06
         22    150.0     -2.6247E+06    -7.9941E+04     2.5756E+06
-2.0403E+06    -3.8650E+07    -2.0940E+06
         23    160.0     -2.2462E+06    -8.8887E+04     2.6051E+06
-1.9879E+06    -3.2116E+07    -1.6175E+06
         24    170.0     -1.8209E+06    -1.0004E+05     2.6386E+06
-1.8942E+06    -2.5185E+07    -1.1260E+06
         25    180.0     -1.3334E+06    -1.1271E+05     2.6763E+06
```

```
-1.7718E+06    -1.7575E+07    -6.1585E+05
         26    190.0     -7.7377E+05    -1.2592E+05     2.7170E+06
-1.6382E+06    -9.0562E+06    -8.6547E+04
1DATE: 08-JUN-2012 TIME: 01:52:38   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                             PAGE :    16

         27    200.0     -1.3807E+05    -1.3837E+05     2.7584E+06
-1.5122E+06     5.3271E+05     4.5708E+05
         28    210.0      5.7058E+05    -1.4855E+05     2.7969E+06
-1.4121E+06     1.1285E+07     1.0037E+06
         29    220.0      1.3405E+06    -1.5479E+05     2.8280E+06
-1.3522E+06     2.3208E+07     1.5359E+06
         30    230.0      2.1505E+06    -1.5554E+05     2.8468E+06
-1.3401E+06     3.6218E+07     2.0339E+06
         31    240.0      2.9692E+06    -1.4977E+05     2.8506E+06
-1.3716E+06     5.0138E+07     2.4823E+06
         32    250.0      3.7639E+06    -1.3781E+05     2.8394E+06
-1.4237E+06     6.4733E+07     2.9552E+06
         33    260.0      4.5112E+06    -1.2407E+05     2.8165E+06
-1.4591E+06     7.9698E+07     3.6827E+06
         34    270.0      5.2287E+06    -1.1405E+05     2.7864E+06
-1.4548E+06     9.5320E+07     4.5510E+06
         35    280.0      6.0073E+06    -1.0690E+05     2.7458E+06
-1.4412E+06     1.1350E+08     5.1257E+06
         36    290.0      6.8544E+06    -9.6147E+04     2.6857E+06
-1.4643E+06     1.3464E+08     5.3792E+06

       MAXIMUM BASE SHEAR         = 9.7956E+06  AT PHASE =  -30.0

       MAXIMUM OVERTURNING MOMENT = 2.3558E+08  AT PHASE =  -20.0


    SUMMARY OF MAXIMUM BASE SHEAR AND OVERTURNING MOMENT:

       SEASTATE     MAXIMUM        MAXIMUM
       NO.          BASE SHEAR     OVERTURNING MOMENT
       --------     ----------     ------------------

          1         9.5816E+06     2.3120E+08
          2         9.7956E+06     2.3558E+08
          3         9.6754E+06     2.3393E+08
          4         9.7956E+06     2.3558E+08


 C E N T R E   O F   B U O Y A N C Y :

   X=-6.3938E-08   Y=-1.1268E+00   Z= 1.4430E+01
1DATE: 08-JUN-2012 TIME: 01:52:38   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                             PAGE :    17

 SUMMARY OF ADMINISTRATIVE DATA TRANSFERRED TO STRUCTURAL ANALYSIS PROGRAM :
 ----------------------------------------------------------------------------



--------------------------------------------------------------------------------
-----------------------------------------------
 : SEASTATE  /   : WAVE     : WAVE     : WAVE     : WATER    : MUDPLANE :  WIND
  : GUST WIND: TIME STEPS                        :
 : IDENTIFICATION: DIRECTION: HEIGHT   : PERIOD   : DEPTH    : ELEVATION:
PROFILE : INDUCED  : LOAD CASE NUMBERS              :
 : NUMBER        :          :          :          :          :          :  INDEX
  : FATIGUE  :                                   :

--------------------------------------------------------------------------------
-----------------------------------------------
 :               :          :          :          :          :          :      1
```

```
  :  NO      :          :          :          :
 :    1  /    1  : 270.0    : 17.50    : 14.30    : 45.00    :-.5651E-11:
  :          :          :          :          :
 :               :          :          :          :          :          :
  :          :    -0.794:    -0.794:
 :               :          :          :          :          :          :
  :          :       12.:       13.:

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-----------------------------------------------
 :               :          :          :          :          :          :      2
  :  NO      :          :          :          :
 :    2  /    2  : 180.0    : 17.50    : 14.30    : 45.00    :-.5651E-11:
  :          :          :          :          :
 :               :          :          :          :          :          :
  :          :    -1.192:    -0.794:
 :               :          :          :          :          :          :
  :          :       14.:       15.:

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-----------------------------------------------
 :               :          :          :          :          :          :      3
  :  NO      :          :          :          :
 :    3  /    3  : 90.00    : 17.50    : 14.30    : 45.00    :-.5651E-11:
  :          :          :          :          :
 :               :          :          :          :          :          :
  :          :    -1.192:    -0.794:
 :               :          :          :          :          :          :
  :          :       16.:       17.:

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 :               :          :          :          :          :          :      4
  :  NO      :          :          :          :
 :    4  /    4  :    0.0000: 17.50    : 14.30    : 45.00    :-.5651E-11:
  :          :          :          :          :
 :               :          :          :          :          :          :
  :          :    -1.192:    -0.794:
 :               :          :          :          :          :          :
  :          :       18.:       19.:



--------------------------------------------------------------------------------
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 :    WIND     MEAN      WIND      GUST      MEAN     HEIGHT     MEAN    LENGTH
     WIND  :
 :  PROFILE    WIND     ANGLE     FACTOR   VELOCITY  EXPONENT   PERIOD   SCALE
   PROFILE :
 :   INDEX   VELOCITY                       LEVEL               RATIO    FACTOR
   FORMULA :

--------------------------------------------------------------------------------
------------
 :     1      25.000   270.000     0.315    10.000     0.700     -----    1.00
       0   :
 :     2      25.000   180.000     0.315    10.000     0.700     -----    1.00
       0   :
 :     3      25.000    90.000     0.315    10.000     0.700     -----    1.00
       0   :
 :     4      25.000     0.000     0.315    10.000     0.700     -----    1.00
       0   :


 CPU TIME CONSUMPTION: 0.1900
```

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P R O G R A M   N O R M A L   E N D
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Vedlegg 4 – Analyse 2, lineær strukturanalyse og hydrodynamisk analyse, fra Sesam GeniE

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1





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**   **    **    **




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               **
                               **               Superelement Structural Analysis
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                                              Marketing and Support by DNV
```

```
Software



               Program id   : 8.4-01
Computer         : 586
               Release date : 20-NOV-2008
Impl. update     :
               Access time  : 01-JUN-2012 18:19:15
Operating system : Win NT 5.2 [3790]
               User id      : ofsbilil
CPU id           : 1975103069

Installation     : , NOS295


               Copyright DET NORSKE VERITAS AS, P.O.Box 300, N-1322 Hovik,
Norway


               Library     Version    Impl.Upd   Release date
               ELLIB       1.9-07                20-NOV-2008
               SIFTOOL     8.3-05                20-NOV-2008
               NORSAM      8.4-01                20-NOV-2008
               MFR         8.3-05                20-NOV-2008
               PRIMAS      5.3-04                20-NOV-2008
               AUXLIB      8.2-02                20-NOV-2008
               SESTRA_PRLL 8.1-02                20-NOV-2008

               Run identification   :




 DATE: 01-JUN-2012 TIME: 18:19:31   ***************  SESTRA  ***************
                                        PAGE:     1

                                    DATA GENERATION MODULE

                                    SUB PAGE:     1

  PRINTOUT OF DATA GIVEN AS DIRECT INPUT TO SESTRA



   HEAD

   COMM

   COMM    Created by: GeniE  V5.3-10  14-Apr-2011

   COMM

   COMM    Date : 01-Jun-2012   Time : 17:19:13   User : ofsbilil

   COMM

   COMM  CHCK ANTP MSUM MOLO STIF RTOP LBCK      PILE CSING     SIGM

   CMAS    0.    1.    1.    0.    0.    0.    0.    0.    0.  0.00E+00  0.00E+00
0.00E+00
   COMM
```

```
   COMM            ORDR                                CACH MFRWORK

   SOLM    0.   0.   0.   0.   0.   0.   0.   0.   0.  0.00E+00  0.00E+00
0.00E+00
   COMM

   COMM                 WCOR

   ELOP    0.   0.   0.   1.   0.   0.   0.   0.   0.  0.00E+00  0.00E+00
0.00E+00
   COMM

   COMM  ITYP

   ITOP    1.   0.   0.   0.   0.   0.   0.   0.   0.  0.00E+00  0.00E+00
0.00E+00
   COMM

   COMM  PREFIX

   INAM  20120601_171510_

   COMM

   COMM  PREFIX FORMAT

   LNAM  20120601_171510_ UNFORMATTED

   COMM

   COMM  PREFIX FORMAT

   RNAM  20120601_171510_ NORSAM

   COMM

   COMM  SEL1 SEL2 SEL3 SEL4 SEL5 SEL6 SEL7 SEL8

   RSEL    1.   0.   0.   0.   0.   0.   1.   0.   0.  0.00E+00  0.00E+00
0.00E+00
   COMM

   COMM  RTRA

   RETR    3.   0.   0.   0.   0.   0.   0.   0.   0.  0.00E+00  0.00E+00
0.00E+00
   Z


  PRINTOUT OF DATA GIVEN IN THE FILE 20120601_171510_S1.FEM


   LOHI    1.   0.  12.   1.   1.   0.   0.   0.   1.  0.10E+01  0.00E+00
0.00E+00
   SEAS    1.  0.00E+00  0.10E+01  0.70E+01  0.10E+01  0.27E+03  0.18E+02
0.14E+02
           0.  0.45E+02  0.10E+01 -0.57E-11  0.00E+00  0.00E+00  0.00E+00
0.00E+00
   TILO    1.  0.00E+00  0.10E+01 -0.79E+00 -0.79E+00  0.00E+00  0.00E+00
0.00E+00
   LCOM    1.  0.00E+00  0.10E+01  0.12E+02  0.13E+02  0.00E+00  0.00E+00
0.00E+00
   LOHI    2.   0.  12.   2.   2.   0.   0.   0.   2.  0.20E+01  0.00E+00
0.00E+00
   SEAS    2.  0.00E+00  0.10E+01  0.70E+01  0.10E+01  0.18E+03  0.18E+02
0.14E+02
           0.  0.45E+02  0.10E+01 -0.57E-11  0.00E+00  0.00E+00  0.00E+00
0.00E+00
```

```
   TILO     2.  0.00E+00  0.10E+01 -0.12E+01 -0.79E+00  0.00E+00  0.00E+00
0.00E+00
   LCOM     2.  0.00E+00  0.10E+01  0.14E+02  0.15E+02  0.00E+00  0.00E+00
0.00E+00
   LOHI     3.   0.  12.   3.   3.   0.   0.   0.   3.  0.30E+01  0.00E+00
0.00E+00
   SEAS     3.  0.00E+00  0.10E+01  0.70E+01  0.10E+01  0.90E+02  0.18E+02
0.14E+02
            0.  0.45E+02  0.10E+01 -0.57E-11  0.00E+00  0.00E+00  0.00E+00
0.00E+00
   TILO     3.  0.00E+00  0.10E+01 -0.12E+01 -0.79E+00  0.00E+00  0.00E+00
0.00E+00
   LCOM     3.  0.00E+00  0.10E+01  0.16E+02  0.17E+02  0.00E+00  0.00E+00
0.00E+00

 DATE: 01-JUN-2012 TIME: 18:19:36   ***************  SESTRA  ***************
                                        PAGE:     2


                                    DATA GENERATION MODULE


                                    SUB PAGE:     2


  PRINTOUT OF DATA GIVEN AS DIRECT INPUT TO SESTRA



   LOHI     4.   0.  12.   4.   4.   0.   0.   0.   4.  0.40E+01  0.00E+00
0.00E+00
   SEAS     4.  0.00E+00  0.10E+01  0.70E+01  0.10E+01  0.00E+00  0.18E+02
0.14E+02
            0.  0.45E+02  0.10E+01 -0.57E-11  0.00E+00  0.00E+00  0.00E+00
0.00E+00
   TILO     4.  0.00E+00  0.10E+01 -0.12E+01 -0.79E+00  0.00E+00  0.00E+00
0.00E+00
   LCOM     4.  0.00E+00  0.10E+01  0.18E+02  0.19E+02  0.00E+00  0.00E+00
0.00E+00
   WIND     1.  0.25E+02  0.27E+03  0.32E+00  0.10E+02  0.70E+00  0.00E+00
0.10E+01
            0.  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00
   WIND     2.  0.25E+02  0.18E+03  0.32E+00  0.10E+02  0.70E+00  0.00E+00
0.10E+01
            0.  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00
   WIND     3.  0.25E+02  0.90E+02  0.32E+00  0.10E+02  0.70E+00  0.00E+00
0.10E+01
            0.  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00
   WIND     4.  0.25E+02  0.00E+00  0.32E+00  0.10E+02  0.70E+00  0.00E+00
0.10E+01
            0.  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00

 DATE: 01-JUN-2012 TIME: 18:19:38   ***************  SESTRA  ***************
                                        PAGE:     3


                                    DATA GENERATION MODULE


                                    SUB PAGE:     3
  INTERPRETATION OF ANALYSIS CONTROL DATA
```

```
      Type of Analysis :

         Reduction

         Multifront Solver is used

         Retracking


      Input from CMAS Command :

         ANTYP = 1   Static Analysis

         MSUM  > 0   Calculation of Sum of Masses and Centroid

         The singularity constant for membrane and shell elements

         CSING =  1.0000E-08

         Lowest accepted condition number in reduction

         EPSSOL=  1.1102E-14


      Input from RSEL Command :

         Data types selected for storing on Results File :

          - Input Interface File Records,

          - displacements,  sequence:

               all nodes for the first resultcase, all nodes for the second
resultcase, etc.
          - forces and moments for beam, spring and layered shell elements,
sequence:
               all elements for the first resultcase, all elements for the
second resultcase, etc.
          - stresses (not for beam or spring elements),  sequence:

               all elements for the first resultcase, all elements for the
second resultcase, etc.

         (Can be redefined by RSEL for selected superelements, see below.)

         Storing is done for superelements specified in RETR command.

 DATE: 01-JUN-2012 TIME: 18:19:41   ***************  SESTRA  ***************
                                        PAGE:     4

                                    DATA GENERATION MODULE

                                    SUB PAGE:     4

  INPUT INTERFACE FILES :
```

```
20120601_171510_T1.FEM

20120601_171510_L1.FEM

    DATE:     01-Jun-2012         TIME:          17:15:10
    PROGRAM:  SESAM GeniE         VERSION:       V5.3-10 14-Apr-2011
    COMPUTER: X86 Windows         INSTALLATION:
    USER:     ofsbilil            ACCOUNT:

    DATE:     01-Jun-2012         TIME:          17:15:10
    PROGRAM:  SESAM Gamesha       VERSION:       R5.0-3 14-Apr-2011
    COMPUTER: X86 Windows         INSTALLATION:
    USER:     ofsbilil            ACCOUNT:

    DATE:     01-JUN-2012         TIME:         17:16:39
    PROGRAM:  SESAM WAJAC         VERSION:      5.9-02 28-FEB-2007
    COMPUTER: 586 WIN NT 5.2 [3790INSTALLATION: , NOS295
    USER:     OFSBILIL            ACCOUNT:

 DATE: 01-JUN-2012 TIME: 18:19:46   ***************  SESTRA  ***************
                                        PAGE:     5

                                    DATAGENERATION - SUPERELEMENT TYPE     1

                                    SUB PAGE:     5



     *** SUMMARY OF DATA FROM INPUT AND LOAD INTERFACE FILES ***
              FOR SUPERELEMENT TYPE       1  ON LEVEL  1

     The superelement has


           43  subelements
           29  nodes
           18  specified (fixed) degrees of freedom
          156  internal (free) degrees of freedom
         totally
          174  degrees of freedom


           19  loadcases
```

```
      The following kinds of loads are given:

            node loads

            line or point loads for 2 node beams

            gravitational load


      The following basic elements are given:

            43  2 node beam elements         BEAS


 DATE: 01-JUN-2012 TIME: 18:19:56   ***************  SESTRA  ***************
                                        PAGE:     6

                                    DATAGENERATION - SUPERELEMENT TYPE     1

                                    SUB PAGE:     6

      *** SUM OF LOADS AND MOMENTS FOR SUPERELEMENT TYPE     1  ON LEVEL  1  ***


     X-LOAD = SUM OF GIVEN LOADS IN GLOBAL X-DIRECTION

     Y-LOAD = SUM OF GIVEN LOADS IN GLOBAL Y-DIRECTION

     Z-LOAD = SUM OF GIVEN LOADS IN GLOBAL Z-DIRECTION

     X-MOM  = SUM OF LOCAL MOMENTS ABOUT GLOBAL X-AXIS

     Y-MOM  = SUM OF LOCAL MOMENTS ABOUT GLOBAL Y-AXIS

     Z-MOM  = SUM OF LOCAL MOMENTS ABOUT GLOBAL Z-AXIS

     X-RMOM = SUM OF MOMENTS ABOUT GLOBAL X-AXIS FROM GIVEN LOADS AND MOMENTS

     Y-RMOM = SUM OF MOMENTS ABOUT GLOBAL Y-AXIS FROM GIVEN LOADS AND MOMENTS

     Z-RMOM = SUM OF MOMENTS ABOUT GLOBAL Z-AXIS FROM GIVEN LOADS AND MOMENTS


      LOADCASE    X-LOAD       Y-LOAD       Z-LOAD       X-MOM        Y-MOM
Z-MOM        X-RMOM       Y-RMOM       Z-RMOM
           1  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
           2  0.0000E+00  5.8208E-11 -2.1897E+07  0.0000E+00  0.0000E+00
0.0000E+00  1.9893E+07  2.3011E-02  0.0000E+00
           3  0.0000E+00 -2.1182E+04  0.0000E+00 -1.0591E+03  0.0000E+00
0.0000E+00  1.8868E+06  0.0000E+00  0.0000E+00
           4  0.0000E+00  2.1182E+04  0.0000E+00  1.0591E+03  0.0000E+00
0.0000E+00 -1.8868E+06  0.0000E+00  0.0000E+00
           5 -2.1182E+04  0.0000E+00  0.0000E+00  0.0000E+00  1.0591E+03
0.0000E+00  0.0000E+00 -1.8868E+06  0.0000E+00
           6  2.1182E+04  0.0000E+00  0.0000E+00  0.0000E+00 -1.0591E+03
0.0000E+00  0.0000E+00  1.8868E+06  0.0000E+00
           7  3.9700E+05  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  5.2861E+07  0.0000E+00
```

```
           8  0.0000E+00  0.0000E+00  0.0000E+00  4.4400E+06  0.0000E+00
0.0000E+00  4.4400E+06  0.0000E+00  0.0000E+00
           9  0.0000E+00  0.0000E+00 -3.4335E+06  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
          10  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00 -9.5400E+05
0.0000E+00  0.0000E+00 -9.5400E+05  0.0000E+00
          11  0.0000E+00 -1.4500E+05  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  1.9307E+07  0.0000E+00  0.0000E+00
          12  1.0570E-01 -9.7076E+06  2.1858E+06 -1.0573E+05 -5.5806E-03
-9.1995E-03  2.4922E+08  2.8746E+00  7.2630E-01
          13  1.0570E-01 -9.7076E+06  2.1858E+06 -1.0573E+05 -5.5806E-03
-9.1995E-03  2.4922E+08  2.8746E+00  7.2630E-01
          14 -9.9288E+06  5.3514E+04  2.1340E+06  1.3047E+04  3.0135E+05
-5.0936E+04 -2.7019E+06 -2.4734E+08 -4.3462E+06
          15 -9.8528E+06  1.1315E+05  1.9330E+06  2.0497E+04  1.0705E+05
-5.4298E+04 -3.3246E+06 -2.5352E+08 -3.6731E+06
          16 -4.3516E-01  9.8065E+06  1.9177E+06  2.8220E+05  1.6183E-02
1.7360E-03 -2.4740E+08 -1.0917E+01 -8.9130E-01
          17 -4.5139E-01  9.6177E+06  1.6945E+06  1.0364E+05  1.3199E-02
1.6972E-02 -2.5186E+08 -1.1343E+01 -1.8371E+00
          18  9.9288E+06  5.3515E+04  2.1340E+06  1.3047E+04 -3.0135E+05
5.0936E+04 -2.7020E+06  2.4734E+08  4.3462E+06
          19  9.8528E+06  1.1315E+05  1.9330E+06  2.0497E+04 -1.0705E+05
5.4298E+04 -3.3247E+06  2.5352E+08  3.6731E+06

 DATE: 01-JUN-2012 TIME: 18:20:00   ***************  SESTRA  ***************
                                        PAGE:     7

                                    DATAGENERATION - SUPERELEMENT TYPE     1

                                    SUB PAGE:     7

      *** SUM OF MASSES AND CENTROID FOR SUPERELEMENT TYPE     1  ON LEVEL  1
***



   MASS MATRIX IN GLOBAL COORDINATE SYSTEM (OF THE SUPERELEMENT):

   ---------------------------------------

   2.23290E+06    0.00000E+00    0.00000E+00    0.00000E+00    5.86600E+07
2.02857E+06
   0.00000E+00    2.23290E+06    0.00000E+00   -5.86600E+07    0.00000E+00
2.34643E-03
   0.00000E+00    0.00000E+00    2.23290E+06   -2.02857E+06   -2.34643E-03
0.00000E+00
   0.00000E+00   -5.86600E+07   -2.02857E+06    3.51039E+09   -1.62601E-02
-3.98088E-02
   5.86600E+07    0.00000E+00   -2.34643E-03   -1.62601E-02    3.51044E+09
1.83478E+07
   2.02857E+06    2.34643E-03    0.00000E+00   -3.98088E-02    1.83478E+07
2.57902E+08



   COORDINATES OF CENTROID:

   ------------------------

   1.0508E-09    -9.0849E-01     2.6271E+01
```

```
   MASS MATRIX AT CENTROID:

   ------------------------

   2.23290E+06    0.00000E+00    0.00000E+00    0.00000E+00   -7.45058E-09
-2.32831E-10
   0.00000E+00    2.23290E+06    0.00000E+00    7.45058E-09    0.00000E+00
0.00000E+00
   0.00000E+00    0.00000E+00    2.23290E+06    2.32831E-10    0.00000E+00
0.00000E+00
   0.00000E+00    7.45058E-09    2.32831E-10    1.96751E+09   -1.83918E-02
2.18337E-02
  -7.45058E-09    0.00000E+00    0.00000E+00   -1.83918E-02    1.96940E+09
-3.49443E+07
  -2.32831E-10    0.00000E+00    0.00000E+00    2.18337E-02   -3.49443E+07
2.56059E+08

  *** Estimated size of stiffness matrix for superelement       1:        2052
variables

 DATE: 01-JUN-2012 TIME: 18:20:02   ***************  SESTRA  ***************
                                        PAGE:     8

                                    DATAGENERATION - SUPERELEMENT TYPE     1


                                    SUB PAGE:     8


      *** CONNECTION BETWEEN LOADCASE AND RESULTCASE NUMBERS ***



  TOP LEVEL EXT.RESULT  INDEX    TIME        WAVE DIR.   WAVE HEIGHT    WATER

  LOADCASE  IDENT.NO.                          (RAD)                    DEPTH

        1          1

        2          2

        3          3

        4          4

        5          5

        6          6

        7          7

        8          8

        9          9

       10         10

       11         11

       12         12        1   -7.889E-01    4.712E+00    1.750E+01    4.500E+01

       13         12        2   -7.889E-01    4.712E+00    1.750E+01    4.500E+01

       14         13        1   -1.183E+00    3.142E+00    1.750E+01    4.500E+01

       15         13        2   -7.889E-01    3.142E+00    1.750E+01    4.500E+01
```

```
        16         14        1   -1.183E+00    1.571E+00    1.750E+01    4.500E+01

        17         14        2   -7.889E-01    1.571E+00    1.750E+01    4.500E+01

        18         15        1   -1.183E+00    0.000E+00    1.750E+01    4.500E+01

        19         15        2   -7.889E-01    0.000E+00    1.750E+01    4.500E+01


  *** Estimate of total size of stiffness matrices for new superelements:
   2052 variables

 DATE: 01-JUN-2012 TIME: 18:20:06   ***************  SESTRA  ***************
                                        PAGE:     9

                                    REDUCTION MODULE - SUPERELEMENT TYPE    1

                                    SUB PAGE:     1






                                     - STIFFNESS FACTORIZATION PERFORMED BY
MULTIFRONT EQUATION SOLVER -

                                     - LOAD SUBSTITUTION PERFORMED BY
MULTIFRONT EQUATION SOLVER -

 DATE: 01-JUN-2012 TIME: 18:20:14   ***************  SESTRA  ***************
                                        PAGE:    10

                                          STATIC ANALYSIS OF STRUCTURE

                                    SUB PAGE:     1


      Results file name: 20120601_171510_R1.SIN


 DATE: 01-JUN-2012 TIME: 18:20:19   ***************  SESTRA  ***************
                                        PAGE:    11

                                    RETRACKING MODULE - SUPERELEMENT TYPE    1

                                    THE STRUCTURE
                                    SUB PAGE:     2

  REACTION FORCES IN NODES WITH SPECIFIED (FIXED) DEGREES OF FREEDOM.

  NODES MARKED WITH AN ASTERISK (*) TO THE RIGHT HAVE A LOCAL COORDINATE SYSTEM.

  ******************************************************************************
```

```
 LOADCASE (INDEX) NODE NO.      X             Y             Z            RX
      RY            RZ

       1              1   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
 0.00000E+00   0.00000E+00
                     11   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
 0.00000E+00   0.00000E+00
                     27   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
 0.00000E+00   0.00000E+00

       2              1   3.20999E+06   2.20983E+06   6.96311E+06   3.08149E+06
-4.85012E+06  -1.03241E+03
                     11   4.98494E-04  -4.41966E+06   7.97106E+06  -5.62050E+06
 1.80417E-03   1.46536E-03
                     27  -3.20999E+06   2.20983E+06   6.96311E+06   3.08149E+06
 4.85012E+06   1.03241E+03

       3              1   6.18980E+03   4.24945E+03   3.57746E+04  -9.89487E+03
 3.53162E+00  -3.92493E+03
                     11  -6.99353E-07   1.26835E+04  -7.15493E+04  -8.13116E+03
-7.03772E-06   3.34505E-06
                     27  -6.18980E+03   4.24945E+03   3.57746E+04  -9.89487E+03
-3.53163E+00   3.92493E+03

       4              1  -6.18980E+03  -4.24945E+03  -3.57746E+04   9.89487E+03
-3.53162E+00   3.92493E+03
                     11   6.99353E-07  -1.26835E+04   7.15493E+04   8.13116E+03
 7.03772E-06  -3.34505E-06
                     27   6.18980E+03  -4.24945E+03  -3.57746E+04   9.89487E+03
 3.53163E+00  -3.92493E+03

       5              1   1.06599E+04   7.45585E+03   6.16927E+04   2.02118E+02
 1.15512E+04   3.53832E+03
                     11  -1.37390E+02   8.28516E-06  -4.88599E-07  -1.89017E-06
 1.29435E+04  -7.07286E+03
                     27   1.06599E+04  -7.45585E+03  -6.16927E+04  -2.02118E+02
 1.15512E+04   3.53832E+03

       6              1  -1.06599E+04  -7.45585E+03  -6.16927E+04  -2.02118E+02
-1.15512E+04  -3.53832E+03
                     11   1.37390E+02  -8.28516E-06   4.88599E-07   1.89017E-06
-1.29435E+04   7.07286E+03
                     27  -1.06599E+04   7.45585E+03   6.16927E+04   2.02118E+02
-1.15512E+04  -3.53832E+03

       7              1  -2.03173E+05  -1.45636E+05  -1.73126E+06   5.18752E+03
-3.03673E+05  -1.13196E+05
                     11   9.34525E+03  -2.57671E-04   1.50134E-05   5.80835E-05
-3.15303E+05   2.25254E+05
                     27  -2.03173E+05   1.45636E+05   1.73126E+06  -5.18752E+03
-3.03673E+05  -1.13196E+05

       8              1   1.25362E+03  -2.70347E+02   8.45457E+04  -1.58476E+04
 3.27308E+03  -1.34353E+04
                     11  -2.10528E-06   5.40694E+02  -1.69091E+05  -1.51820E+04
-2.23660E-05   1.07034E-05
                     27  -1.25362E+03  -2.70347E+02   8.45457E+04  -1.58476E+04
-3.27308E+03   1.34353E+04

       9              1   7.67848E+05   5.32777E+05   1.02966E+06   1.18998E+05
-1.70283E+05   3.04701E+03
                     11   1.71962E-05  -1.06555E+06   1.37419E+06  -2.63651E+05
 2.69057E-05   4.73535E-04
                     27  -7.67848E+05   5.32777E+05   1.02966E+06   1.18998E+05
 1.70283E+05  -3.04701E+03
```

```
     10              1   1.84563E+02   3.21609E+02   3.13510E+04  -4.89360E+02
 4.75326E+03   2.55599E+03
                    11  -3.69125E+02   5.58248E-06  -3.19279E-07  -1.23534E-06
 3.96464E+03  -5.05386E+03
                    27   1.84563E+02  -3.21609E+02  -3.13510E+04   4.89360E+02
 4.75326E+03   2.55599E+03

     11              1   4.41754E+04   2.86996E+04   3.66582E+05  -9.05442E+04
 4.73540E+03  -4.62058E+04
                    11  -7.81759E-06   8.76008E+04  -7.33164E+05  -7.75129E+04
-8.03687E-05   3.83041E-05
                    27  -4.41754E+04   2.86996E+04   3.66582E+05  -9.05442E+04
-4.73540E+03   4.62058E+04

     12    1         1   1.43430E+06   1.84902E+06   3.96324E+06  -3.71164E+06
 1.87980E+05   2.12395E+06
                    11  -6.26903E-03   6.00952E+06  -1.01123E+07  -1.78471E+06
-1.69012E-02  -2.89606E-02
                    27  -1.43430E+06   1.84902E+06   3.96324E+06  -3.71164E+06
-1.87980E+05  -2.12395E+06

DATE: 01-JUN-2012 TIME: 18:20:22   ***************  SESTRA  ***************
                                       PAGE:    12

                                   RETRACKING MODULE - SUPERELEMENT TYPE    1

                                   THE STRUCTURE
                                   SUB PAGE:     3


 REACTION FORCES IN NODES WITH SPECIFIED (FIXED) DEGREES OF FREEDOM.

 NODES MARKED WITH AN ASTERISK (*) TO THE RIGHT HAVE A LOCAL COORDINATE SYSTEM.

 ******************************************************************************



 LOADCASE (INDEX) NODE NO.      X             Y             Z             RX
      RY            RZ

     12    2         1   1.43430E+06   1.84902E+06   3.96324E+06  -3.71164E+06
 1.87980E+05   2.12395E+06
                    11  -6.26903E-03   6.00952E+06  -1.01123E+07  -1.78471E+06
-1.69012E-02  -2.89606E-02
                    27  -1.43430E+06   1.84902E+06   3.96324E+06  -3.71164E+06
-1.87980E+05  -2.12395E+06

     13    1         1   3.86319E+06   2.14161E+06   7.19136E+06   3.44301E+05
 4.00578E+06  -1.24747E+06
                    11   8.06001E+05   8.41679E+05  -7.47741E+05   6.37733E+05
 3.93238E+06   2.27869E+06
                    27   5.25958E+06  -3.03680E+06  -8.57766E+06  -1.02753E+06
 2.86361E+06  -1.23614E+06

     13    2         1   3.86300E+06   2.13060E+06   7.44507E+06   3.05353E+05
 4.05080E+06  -1.26292E+06
                    11   8.13229E+05   7.87914E+05  -6.44826E+05   6.43715E+05
 4.02703E+06   2.23032E+06
                    27   5.17652E+06  -3.03166E+06  -8.73326E+06  -9.56942E+05
 2.76852E+06  -1.10995E+06

     14    1         1  -2.79198E+06  -2.72088E+06  -5.16248E+06   2.96049E+06
 9.47397E+05  -2.15565E+06
                    11   1.80428E-02  -4.36472E+06   8.40728E+06   3.12592E+06
 5.29231E-02   9.38878E-02
                    27   2.79198E+06  -2.72088E+06  -5.16248E+06   2.96049E+06
```

```
 -9.47397E+05   2.15565E+06

      14    2          1  -2.74608E+06  -2.64149E+06  -5.18249E+06   2.90870E+06
  9.38322E+05  -1.99882E+06
                      11   1.63035E-02  -4.33475E+06   8.67050E+06   3.16885E+06
  3.19738E-02   9.13260E-02
                      27   2.74608E+06  -2.64149E+06  -5.18249E+06   2.90870E+06
 -9.38321E+05   1.99882E+06

      15    1          1  -5.25958E+06  -3.03680E+06  -8.57766E+06  -1.02753E+06
 -2.86361E+06   1.23614E+06
                      11  -8.06001E+05   8.41679E+05  -7.47741E+05   6.37733E+05
 -3.93238E+06  -2.27869E+06
                      27  -3.86319E+06   2.14161E+06   7.19136E+06   3.44302E+05
 -4.00578E+06   1.24747E+06

      15    2          1  -5.17652E+06  -3.03166E+06  -8.73326E+06  -9.56942E+05
 -2.76852E+06   1.10995E+06
                      11  -8.13229E+05   7.87914E+05  -6.44826E+05   6.43715E+05
 -4.02703E+06  -2.23032E+06
                      27  -3.86300E+06   2.13060E+06   7.44507E+06   3.05353E+05
 -4.05080E+06   1.26292E+06

 DATE: 01-JUN-2012 TIME: 18:20:23   ***************  SESTRA  ***************
                                        PAGE:    13


                                    RETRACKING MODULE - SUPERELEMENT TYPE    1

                                    THE STRUCTURE
                                    SUB PAGE:     4


  SUM OF REACTION FORCES FROM SPECIFIED DEGREES OF FREEDOM.

  THE FORCES AND MOMENTS ARE REFFERED TO THE COORDINATE SYSTEM OF THE ACTUAL
SUPERELEMENT.

********************************************************************************
********


  LOADCASE (INDEX)        X             Y             Z            RX
RY            RZ

       1           0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
0.0000E+00    0.0000E+00
       2           4.6566E-10    0.0000E+00    2.1897E+07   -1.9893E+07
-2.3011E-02    5.2096E-09
       3           1.7280E-11    2.1182E+04    4.3656E-11   -1.8868E+06
3.4925E-10    6.7075E-10
       4          -1.7280E-11   -2.1182E+04   -4.3656E-11    1.8868E+06
-3.4925E-10   -6.7075E-10
       5           2.1182E+04    1.1823E-11    7.2760E-12   -2.3283E-10
1.8868E+06    6.7848E-10
       6          -2.1182E+04   -1.1823E-11   -7.2760E-12    2.3283E-10
-1.8868E+06   -6.7848E-10
       7          -3.9700E+05   -2.0373E-10    2.3283E-10   -3.7253E-09
-5.2861E+07   -1.3941E-08
       8           3.7289E-11   -1.5411E-07    5.8208E-11   -4.4400E+06
9.3132E-10    1.4115E-09
       9           1.1642E-10    6.9849E-10    3.4335E+06   -4.8429E-08
3.7253E-09    3.9472E-10
      10          -3.3379E-08    2.3874E-12   -3.6380E-12    0.0000E+00
9.5400E+05    2.2101E-10
      11           1.6735E-10    1.4500E+05    4.0745E-10   -1.9307E+07
2.7940E-09    6.5811E-09
      12    1     -1.0570E-01    9.7076E+06   -2.1858E+06   -2.4922E+08
```

```
-2.8746E+00   -7.2630E-01
       12    2      -1.0570E-01    9.7076E+06   -2.1858E+06   -2.4922E+08
-2.8746E+00   -7.2630E-01
       13    1       9.9288E+06   -5.3514E+04   -2.1340E+06    2.7019E+06
2.4734E+08    4.3462E+06
       13    2       9.8528E+06   -1.1315E+05   -1.9330E+06    3.3246E+06
2.5352E+08    3.6731E+06
       14    1       4.3516E-01   -9.8065E+06   -1.9177E+06    2.4740E+08
1.0917E+01    8.9130E-01
       14    2       4.5139E-01   -9.6177E+06   -1.6945E+06    2.5186E+08
1.1343E+01    1.8371E+00
       15    1      -9.9288E+06   -5.3515E+04   -2.1340E+06    2.7020E+06
-2.4734E+08   -4.3462E+06
       15    2      -9.8528E+06   -1.1315E+05   -1.9330E+06    3.3247E+06
-2.5352E+08   -3.6731E+06


 SUPERELEMENT TYPE:     1 ACTUAL ELEMENT:     1

 HAS BEEN STORED ON RESULT FILE


 DATE: 01-JUN-2012 TIME: 18:20:29   ***************  SESTRA  ***************
                                        PAGE:    14

                                        RETRACKING MODULE - GLOBAL DATA

                                    SUB PAGE:     1

  SUM OF GLOBAL LOADS AND MOMENTS

  *******************************




  LOADCASE (INDEX)        X              Y              Z             RX
RY            RZ

        1            0.0000E+00     0.0000E+00     0.0000E+00     0.0000E+00
0.0000E+00    0.0000E+00
        2            0.0000E+00     5.8208E-11    -2.1897E+07     1.9893E+07
2.3011E-02    0.0000E+00
        3            0.0000E+00    -2.1182E+04     0.0000E+00     1.8868E+06
0.0000E+00    0.0000E+00
        4            0.0000E+00     2.1182E+04     0.0000E+00    -1.8868E+06
0.0000E+00    0.0000E+00
        5           -2.1182E+04     0.0000E+00     0.0000E+00     0.0000E+00
-1.8868E+06    0.0000E+00
        6            2.1182E+04     0.0000E+00     0.0000E+00     0.0000E+00
1.8868E+06    0.0000E+00
        7            3.9700E+05     0.0000E+00     0.0000E+00     0.0000E+00
5.2861E+07    0.0000E+00
        8            0.0000E+00     0.0000E+00     0.0000E+00     4.4400E+06
0.0000E+00    0.0000E+00
        9            0.0000E+00     0.0000E+00    -3.4335E+06     0.0000E+00
0.0000E+00    0.0000E+00
       10            0.0000E+00     0.0000E+00     0.0000E+00     0.0000E+00
-9.5400E+05    0.0000E+00
       11            0.0000E+00    -1.4500E+05     0.0000E+00     1.9307E+07
0.0000E+00    0.0000E+00
       12    1       1.0570E-01    -9.7076E+06     2.1858E+06     2.4922E+08
2.8746E+00    7.2630E-01
```

```
       12    2       1.0570E-01   -9.7076E+06    2.1858E+06    2.4922E+08
2.8746E+00    7.2630E-01
       13    1      -9.9288E+06    5.3514E+04    2.1340E+06   -2.7019E+06
-2.4734E+08   -4.3462E+06
       13    2      -9.8528E+06    1.1315E+05    1.9330E+06   -3.3246E+06
-2.5352E+08   -3.6731E+06
       14    1      -4.3516E-01    9.8065E+06    1.9177E+06   -2.4740E+08
-1.0917E+01   -8.9130E-01
       14    2      -4.5139E-01    9.6177E+06    1.6945E+06   -2.5186E+08
-1.1343E+01   -1.8371E+00
       15    1       9.9288E+06    5.3515E+04    2.1340E+06   -2.7020E+06
2.4734E+08    4.3462E+06
       15    2       9.8528E+06    1.1315E+05    1.9330E+06   -3.3247E+06
2.5352E+08    3.6731E+06

 DATE: 01-JUN-2012 TIME: 18:20:30   ***************  SESTRA  ***************
                                                PAGE:    15


                                                RETRACKING MODULE - GLOBAL DATA


                                            SUB PAGE:     2


  SUM OF REACTION FORCES AND MOMENTS

  **********************************

  GIVEN IN THE GLOBAL COORDINATE SYSTEM OF THE TOP LEVEL SUPERELEMENT



  LOADCASE (INDEX)        X              Y              Z             RX
RY            RZ

        1            0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
0.0000E+00    0.0000E+00
        2            4.6566E-10    0.0000E+00    2.1897E+07   -1.9893E+07
-2.3011E-02    5.2096E-09
        3            1.7280E-11    2.1182E+04    4.3656E-11   -1.8868E+06
3.4925E-10    6.7075E-10
        4           -1.7280E-11   -2.1182E+04   -4.3656E-11    1.8868E+06
-3.4925E-10   -6.7075E-10
        5            2.1182E+04    1.1823E-11    7.2760E-12   -2.3283E-10
1.8868E+06    6.7848E-10
        6           -2.1182E+04   -1.1823E-11   -7.2760E-12    2.3283E-10
-1.8868E+06   -6.7848E-10
        7           -3.9700E+05   -2.0373E-10    2.3283E-10   -3.7253E-09
-5.2861E+07   -1.3941E-08
        8            3.7289E-11   -1.5411E-07    5.8208E-11   -4.4400E+06
9.3132E-10    1.4115E-09
        9            1.1642E-10    6.9849E-10    3.4335E+06   -4.8429E-08
3.7253E-09    3.9472E-10
       10           -3.3379E-08    2.3874E-12   -3.6380E-12    0.0000E+00
9.5400E+05    2.2101E-10
       11            1.6735E-10    1.4500E+05    4.0745E-10   -1.9307E+07
2.7940E-09    6.5811E-09
       12    1      -1.0570E-01    9.7076E+06   -2.1858E+06   -2.4922E+08
-2.8746E+00   -7.2630E-01
       12    2      -1.0570E-01    9.7076E+06   -2.1858E+06   -2.4922E+08
-2.8746E+00   -7.2630E-01
       13    1       9.9288E+06   -5.3514E+04   -2.1340E+06    2.7019E+06
2.4734E+08    4.3462E+06
       13    2       9.8528E+06   -1.1315E+05   -1.9330E+06    3.3246E+06
2.5352E+08    3.6731E+06
       14    1       4.3516E-01   -9.8065E+06   -1.9177E+06    2.4740E+08
1.0917E+01    8.9130E-01
```

```
       14    2       4.5139E-01   -9.6177E+06   -1.6945E+06    2.5186E+08
1.1343E+01    1.8371E+00
       15    1      -9.9288E+06   -5.3515E+04   -2.1340E+06    2.7020E+06
-2.4734E+08   -4.3462E+06
       15    2      -9.8528E+06   -1.1315E+05   -1.9330E+06    3.3247E+06
-2.5352E+08   -3.6731E+06

 DATE: 01-JUN-2012 TIME: 18:20:31   ***************  SESTRA  ***************
                                        PAGE:    16


                                        RETRACKING MODULE - GLOBAL DATA


                                    SUB PAGE:     3


  DIFFERENCES BETWEEN SUMMED LOADS AND REACTION FORCES

  *****************************************************

  LARGER THAN   0.00E+00 FOR TRANSLATIONAL COMPONENTS AND LARGER THAN   0.00E+00
FOR ROTATIONAL COMPONENTS


  LOADCASE (INDEX)        X             Y             Z            RX
RY            RZ

        2            4.6566E-10    5.8208E-11   -9.3132E-08    1.2666E-07
1.8626E-08    5.2096E-09
        3            1.7280E-11   -1.9772E-08    4.3656E-11    2.2710E-06
3.4925E-10    6.7075E-10
        4           -1.7280E-11    1.9772E-08   -4.3656E-11   -2.2710E-06
-3.4925E-10   -6.7075E-10
        5           -2.0187E-08    1.1823E-11    7.2760E-12   -2.3283E-10
-2.3129E-06    6.7848E-10
        6            2.0187E-08   -1.1823E-11   -7.2760E-12    2.3283E-10
2.3129E-06   -6.7848E-10
        7            8.7137E-07   -2.0373E-10    2.3283E-10   -3.7253E-09
1.0307E-04   -1.3941E-08
        8            3.7289E-11   -1.5411E-07    5.8208E-11    1.9020E-05
9.3132E-10    1.4115E-09
        9            1.1642E-10    6.9849E-10   -2.6543E-08   -4.8429E-08
3.7253E-09    3.9472E-10
       10           -3.3379E-08    2.3874E-12   -3.6380E-12    0.0000E+00
-4.1123E-06    2.2101E-10
       11            1.6735E-10   -3.1368E-07    4.0745E-10    3.7197E-05
2.7940E-09    6.5811E-09
       12    1       3.9581E-09   -6.7055E-07    7.4506E-09    7.2688E-05
5.5879E-08    1.1502E-07
       12    2       3.9581E-09   -6.7055E-07    7.4506E-09    7.2688E-05
5.5879E-08    1.1502E-07
       13    1      -6.5379E-07    6.4028E-09   -4.6566E-10   -1.1176E-07
-7.0989E-05    9.9652E-08
       13    2      -7.0222E-07    5.7044E-09    3.0268E-09   -1.3877E-07
-7.6383E-05    1.1735E-07
       14    1      -4.4238E-09    6.1654E-07   -4.1910E-09   -6.6936E-05
-9.3132E-08   -1.3784E-07
       14    2      -3.6089E-09    6.6683E-07   -2.3283E-09   -7.2420E-05
-3.7253E-08   -1.2573E-07
       15    1       6.5379E-07   -7.2177E-09    2.7940E-09    6.7987E-08
7.0989E-05   -1.0245E-07
       15    2       7.0035E-07   -5.0059E-09    2.7940E-09    6.5193E-09
7.6324E-05   -1.3271E-07

  TOTAL TIME CONSUMED IN SESTRA                           CPU TIME:      1.05  CLOCK
TIME:     80.25  CHANNEL TIME:      0.31
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1





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Software



               Program id   : 5.9-02
Computer         : 586
               Release date : 28-FEB-2007
Impl. update     :
               Access time  : 01-JUN-2012 17:15:59
Operating system : Win NT 5.2 [3790]
               User id      : ofsbilil
CPU id           : 1975103069

Installation     : , NOS295


               Copyright DET NORSKE VERITAS AS, P.O.Box 300, N-1322 Hovik,
Norway


1DATE: 01-JUN-2012 TIME: 17:16:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :     1

 LIMITATIONS IN THIS VERSION OF WAJAC :
 --------------------------------------

    MAXIMUM SIZE OF ONE SUPERELEMENT
    -  NUMBER OF NODES          :     20000
    -  NUMBER OF BASIC ELEMENTS :     20000


    MAXIMUM NUMBER OF LOADCASES
    -  DISCRETE WAVE            :     10000
    -  FREQUENCY DOMAIN         :       960
          ( MAX. FREQUENCIES :        60 )
    -  TIME DOMAIN SIMULATION   :      8192


    MAXIMUM NUMBER INPUT CARDS
    -  CARD TYPE SELI           :       100
    -  CARD TYPE ELIM           :     20000
    -  CARD TYPE FLOO           :     20000
    -  CARD TYPE LEG            :        50
    -  CARD TYPE SPEC           :     20000
    -  CARD TYPE CDIR           :     20000
    -  CARD TYPE MPRT           :     20000


 SIZE OF COMMON SCRATCH ARRAYS :
 --------------------------------

 /IWORK/ IWORK(  20000) /WORK/ WORK( 500000 )
 /IWORK4/ IARR(  60000) /WORK4/ ARR(  60120)
 TOTAL SIZE: /IWORK4/= 140068 /WORK4/= 231781

1DATE: 01-JUN-2012 TIME: 17:16:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :     2



 W A J A C   I N P U T   P R O C E S S O R :



               *** DATA SET WAJAC ***



               CARD NO   2    TITL      Wajac run name :
Analysis5_Stokes5.step(2)
```

```
               CARD NO   3    C

               CARD NO   4    C                                           PREFIX

               CARD NO   5    FMOD      20120601_171510_

               CARD NO   6    C

               CARD NO   7    C                                           PREFIX
       FORM
               CARD NO   8    FWAVE     20120601_171510_

               CARD NO   9    C

               CARD NO  10    C                UNITS   GRAVITY       RHO      VISC
   RHOAIR   VISCAIR
               CARD NO  11    CONS                1.   9.80665     1025. 1.19e-006
    1.226  1.462e-5
               CARD NO  12    C

               CARD NO  13    C                 OPT1      OPT2      OPT3      OPT4
     OPT5      OPT6      OPT7
               CARD NO  14    OPTI                0.        0.        0.        0.
       0.        0.        0.
               CARD NO  15                        0.

               CARD NO  16    C

               CARD NO  17    C                         ILFSAV    ISETOP

               CARD NO  18    MODE                          1.        1.

               CARD NO  19    C

               CARD NO  20    C                   LN

               CARD NO  21    LONO               12.

               CARD NO  22    C         *************************** GEOM Section
*****************************
               *** END OF DATA SET  22 CARDS READ ***


               *** DATA SET GEOM ***


               CARD NO  24    C

               CARD NO  25    C                    Z

               CARD NO  26    MUDP      -5.651e-12

               CARD NO  27    C         *************************** HYDR Section
*****************************
               *** END OF DATA SET   5 CARDS READ ***


               *** DATA SET HYDR ***


               CARD NO  29    C

               CARD NO  30    C                 TYPE

               CARD NO  31    CPRI      FEM
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               CARD NO  32    CPRI      SPEC

               CARD NO  33    CPRI      CDIR

               CARD NO  34    C

               CARD NO  35    C              ADMAS      DAMP

               CARD NO  36    MASS              0.         0.

               CARD NO  37    C

               CARD NO  38    C         MarineGrowthZLevel1 ( Marine Growth as
function of Z-level property )
               CARD NO  39    C

1DATE: 01-JUN-2012 TIME: 17:16:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                       PAGE :     3

               CARD NO  40    C                 Z1         Z2      HMGRW    HROUGH
      OPT IMEM GRWF
               CARD NO  41    MGRW             -1.        45.        0.1        0.
       0.   1.   0.
               CARD NO  42    MGRW             -1.5.6488e-12        0.1        0.
       0.   1.   0.
               CARD NO  43    C

               CARD NO  44    C                 M1         M2        INC STYP  IDX
IMEM
               CARD NO  45    MEMGRW            1.        16.         1.   1.   1.
  1.
               CARD NO  46    MEMGRW           26.        43.         1.   1.   1.
  1.
               CARD NO  47    C

               CARD NO  48    C         AirDragConstant1 ( Air Drag Coefficients
property )
               CARD NO  49    C

               CARD NO  50    C                 M1         M2        INC STYP  IDX
 CDX       CDZ
               CARD NO  51    CDWN              1.        43.         1.   1.   1.
 1.2       1.2
               CARD NO  52    C         *************************** LOAD Section
*****************************
               *** END OF DATA SET  25 CARDS READ ***


               *** DATA SET LOAD ***


               CARD NO  54    C

               CARD NO  55    C          ISEA THEO    HEIGHT    PERIOD       PHIO
       T0      STEP     NSTEP
               CARD NO  56    SEA           1.  5.0      17.5      14.2      -60.
       0.       10.      -36.
               CARD NO  57    SEA           2.  5.0      17.5      14.2      -60.
       0.       10.      -36.
               CARD NO  58    SEA           3.  5.0      17.5      14.2      -60.
       0.       10.      -36.
               CARD NO  59    SEA           4.  5.0      17.5      14.2      -60.
       0.       10.      -36.
               CARD NO  60    C

               CARD NO  61    C          ISEA BETA WKFA CTNO CBFA CSTR LOAD DLOA
 WID WIME
```

```
               CARD NO  62    SEAOPT       1. 270.   1.   1.   1.  -1.   0.   1.
  1.   0.
               CARD NO  63    SEAOPT       2. 180.   1.   1.   1.  -1.   0.   1.
  2.   0.
               CARD NO  64    SEAOPT       3.  90.   1.   1.   1.  -1.   0.   1.
  3.   0.
               CARD NO  65    SEAOPT       4.   0.   1.   1.   1.  -1.   0.   1.
  4.   0.
               CARD NO  66    C

               CARD NO  67    C         WindProfileRelDir4 (  Wind profile
property )
               CARD NO  68    C

               CARD NO  69    C      WID        VEL      ANGLE      GUSTF         H0
     HEXP PRAT IFRM
               CARD NO  70    WIND    1.        25.       270.      0.315        10.
      0.7   0.   0.
               CARD NO  71    C

               CARD NO  72    C         WindProfileRelDir3 (  Wind profile
property )
               CARD NO  73    C

               CARD NO  74    C      WID        VEL      ANGLE      GUSTF         H0
     HEXP PRAT IFRM
               CARD NO  75    WIND    2.        25.       180.      0.315        10.
      0.7   0.   0.
               CARD NO  76    C

               CARD NO  77    C         WindProfileRelDir2 (  Wind profile
property )
               CARD NO  78    C

               CARD NO  79    C      WID        VEL      ANGLE      GUSTF         H0
     HEXP PRAT IFRM
               CARD NO  80    WIND    3.        25.        90.      0.315        10.
      0.7   0.   0.
               CARD NO  81    C

               CARD NO  82    C         WindProfileRelDir1 (  Wind profile
property )
               CARD NO  83    C

               CARD NO  84    C      WID        VEL      ANGLE      GUSTF         H0
     HEXP PRAT IFRM
               CARD NO  85    WIND    4.        25.         0.      0.315        10.
      0.7   0.   0.
               CARD NO  86    C

               CARD NO  87    C         CurrentProfile1 (  Current profile
property )
               CARD NO  88    C

               CARD NO  89    C     CTNO                                           Z
        V      THETA        OPT
               CARD NO  90    CRNT    1.                                 5.6488e-12
      0.5                    1.
               CARD NO  91                                                      45.
      1.1
1DATE: 01-JUN-2012 TIME: 17:16:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :     4

               CARD NO  92                                                   65.15
      1.1
               CARD NO  93    C

               CARD NO  94    C              DEPTH
```

```
               CARD NO  95    DPTH             45.

               CARD NO  96    C

               CARD NO  97    C                  X         Y         Z

               CARD NO  98    MOMT              0.        0.        0.

               *** END OF DATA SET  46 CARDS READ ***

          ***** END OF DATA INPUT   99 CARDS READ *****
1DATE: 01-JUN-2012 TIME: 17:16:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :     5


********************************************************************************
************
 *
          *
 *          Wajac run name : Analysis5_Stokes5.step(2)
          *
 *
          *

********************************************************************************
************



 S U M M A R Y   O F   I N P U T   S P E C I F I C A T I O N S :


 PROGRAM EXECUTION:
 ------------------

    THE PROGRAM IS USED IN INTERFACE MODE WITH PARAMETERS:

    IGFSAV=0   ILFSAV=1   ISETOP=  1


 FILE USEAGE:
 ------------

    THE NAME WHICH WILL BE USED FOR THE DEFAULT PART OF
          THE INTERFACE FILE NAMES IS: 20120601_171510_

    GEOMETRY WILL BE STORED ON TEMPORARY FILES DURING EXECUTION.

    THE LOADS WILL BE SAVED ON ONE FILE FOR EACH SUPERELEMENT TYPE

    THE NAME WHICH WILL BE USED FOR THE DEFAULT PART OF
          THE LOAD FILE NAMES IS: 20120601_171510_



 UNITS:
 ------

    THE UNITS ARE USER DEFINED:

    GRAVITY                   = 9.8067E+00
    WATER SPECIFIC MASS       = 1.0250E+03
    WATER KINEMATIC VISCOSITY = 1.1900E-06
```

```
    AIR SPECIFIC MASS          = 1.2260E+00
    AIR KINEMATIC VISCOSITY    = 1.4620E-05

 INITIAL LOADCASE NUMBER ON THE LOAD FILES :
 ------------------------------------------

    IS USER DEFINED =      12 FOR ALL SUPERELEMENT TYPES


 SPECIAL OPTIONS INTENDED FOR COMPARATIVE STUDIES:
--------------------------------------------------


1DATE: 01-JUN-2012 TIME: 17:16:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                       PAGE :     6



 LEG PERMABILITY FACTORS:
 ------------------------

    DEFAULT VALUES FOR CPERM IS USED.
    ALL LEGS ARE ASSUMED TO HAVE FULL BUOYANCY.


 MUDPLANE ELEVATION:
 -------------------

    THE MUDPLANE ELEVATION IS SET TO -.5651E-11 IN THE STRUCTURE COORDINATE
SYSTEM.


 HYDRODYNAMIC COEFFICIENTS:
 --------------------------

    *** WARNING: HYDRODYNAMIC COEFFICIENTS HAVE NOT BEEN SPECIFIED BY THE WAJAC
ANALYSIS
        CONTROL DATA. ENSURE THAT THE COEFFICIENTS ARE SPECIFIED ON THE SESAM
INTERFACE FILE ***


 MARINE GROWTH:
 --------------

    MARINE GROWTH AND ROUGHNESS IS SPECIFIED IN THE FOLLOWING DEPTH RANGES:
    (Z1=-1.0 MEANS LINEAR VARYING MARINE GROWTH
     AND ROUGHNESS BETWEEN LEVELS GIVEN BY Z2)

    BETWEEN ELEVATIONS     Z1   AND   Z2          HMGRW      HROUGH    INFLG
IMEM   GRWFAC

                         -1.000       0.000       0.100       0.000     0
 1    0.0000
                         -1.000      45.000       0.100       0.000     0
 1    0.0000

    MARINE GROWTH IS NOT INCLUDED IN INERTIA FORCE CALCULATION.
1DATE: 01-JUN-2012 TIME: 17:16:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                       PAGE :     7



 MARINE GROWTH BY MEMBERS:
 -------------------------

    INDIVIDUAL MARINE GROWTH AND ROUGHNESS ARE SPECIFIED FOR THE FOLLOWING
MEMBERS:
```

```
                              BY       OF      AND ACTUAL
    MEMBER  THROUGH  MEMBER  STEP SUP.ELEMENT SUP.ELEMENT    IMEM
    ( OR SETNAME )            OF      TYPE       INDEX

        1            16         1        1          1           1
       26            43         1        1          1           1


 MEMBERS WITH SPECIAL HYDRODYNAMIC PROPERTIES:
 ---------------------------------------------

    NO MEMBERS HAVE BEEN DEFINED AS SPECIAL.


 MEMBERS WITH DIRECTIONAL HYDRODYNAMIC COEFFICIENTS:
 ---------------------------------------------------

    NO MEMBERS HAVE DIRECTIONAL HYDRODYNAMIC COEFFICIENTS.


 PRIORITY OF SPECIFIED HYDRODYNAMIC COEFFICIENTS (1 IS HIGHEST):
 ---------------------------------------------------------------

    SPECIFICATION WITH HIGHER PRIORITY WILL SUPERSEDE ANY OTHER COEFFICIENTS 
SPECIFIED.

    THE PRIORITY HIERARCHY IS MODIFED.

    OPTION FOR SPECIFICATION     CPRI-TYPE     PRIORITY     GIVEN ON WAJAC INPUT 
FILE
    ------------------------     ---------     --------     
-------------------------
    API                          API                6       NO
    VERTICAL POSITION            COEF               5       NO
    DIAMETER                     FUNC               4       NO
    KC. NUMBER                   FUNC               4       NO
    RN. NUMBER                   FUNC               4       NO
    INPUT INTERFACE FILE         FEM                3       ---
    INDIVIDUAL                   SPEC               2       NO
    DIRECTIONAL                  CDIR               1       NO


 TRANSFER OF ADDED MASS AND/OR DAMPING FOR DYNAMIC STRUCTURAL ANALYSIS :
 -----------------------------------------------------------------------

    CALCULATED ADDED MASS IS  N O T  TRANSFERRED

    CALCULATED DAMPING IS  N O T  TRANSFERRED

1DATE: 01-JUN-2012 TIME: 17:16:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :     8


 AIR DRAG COEFFICIENTS:
 ----------------------

 *** WARNING: DIRECTIONAL DEPENDENT COEFFICIENTS GIVEN THROUGH THE WAJAC 
ANALYSIS CONTROL DATA, MUST BE
              SPECIFIED RELATIVE TO THE AXES OF THE MEMBER LOCAL COORDINATE 
SYSTEM USED IN WAJAC. THIS
              COORDINATE SYSTEM IS NOT NECESSARILY CORRESPONDING TO THE ONE 
DEFINED IN THE PREPROCESSOR
              HAVING CREATED THE MODEL.

              THE RELATION BETWEEN THE LOCAL COORDINATE SYSTEM IN WAJAC AND THE
```

```
LOCAL COORDINATE SYSTEM
              IN THE SESAM PREPROCESSORS IS:

                 WAJAC         PREPROCESSOR
                 -----         ------------
                   x               -y
                   y                x
                   z                z

    THE FOLLOWING MEMBERS HAVE BEEN DEFINED WITH AIR DRAG COEFFICIENTS:
    (VALUE -1.000 MEANS ORIGINAL VALUE RETAINED)

                              BY       OF      AND ACTUAL
    MEMBER  THROUGH  MEMBER  STEP SUP.ELEMENT SUP.ELEMENT      CDX
CDZ
    ( OR SETNAME )            OF      TYPE       INDEX

        1            43        1        1          1          1.200
1.200


 MOMENT REFERENCE POINT:
 -----------------------

    THE MOMENT REFERENCE POINT COORDINATES HAVE BEEN SPECIFIED AS:

    XM=       0.000   YM=       0.000   ZM=       0.000


 MEMBER SEGMENTATION:
 --------------------

    THE DEFAULT VALUE SEG=1.0 IS USED FOR THE MEMBER SEGMENTATION COEFFICIENT.


 SEGMENTATION BY REFERENCE TO MEMBERS:
 -------------------------------------

    INDIVIDUAL SEGMENTATION IS NOT SPECIFIED FOR ANY MEMBERS.


 WATER DEPTH SPECIFICATION:
 --------------------------

    THE WATER DEPTH HAS BEEN SPECIFIED TO:

    DEPTH=      45.000
1DATE: 01-JUN-2012 TIME: 17:16:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :     9


 CURRENT SPECIFICATION:
 ----------------------

    CURRENT IS SPECIFIED BY THE FOLLOWING TABLE(S):

    TABLE NO.  1
+                           Z            V       (THE CURRENT IS RUNNING WITH
THE WAVE)

                          0.000       0.500
                         45.000       1.100
                         65.150       1.100
1DATE: 01-JUN-2012 TIME: 17:16:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :    10
```

```
 DETERMINISTIC SEASTATES DEFINITION:
 -----------------------------------


    THE FOLLOWING SEASTATES WILL BE ANALYSED:

      SEA-     WAVE       WAVE       WAVE      PHASE   INITIAL      PHASE/TIME
 NUMBER    WAVE        WAVE        WAVE   DESIGN
      STATE   THEORY     HEIGHT     PERIOD     /TIME   PHASE/TIME   INCREMENTS
OF STEPS  HEADING     KINEMATICS   BUOY   LOADS
      NO.
                        FACTOR      FLAG
      -----  --------   ---------  ---------  ------  -----------  -----------
--------- ----------  -----------  -----  -------

        1    STOKES  5   17.50      14.20      PHASE  -60.00        10.00
   36.    270.0       1.000        0        1
        2    STOKES  5   17.50      14.20      PHASE  -60.00        10.00
   36.    180.0       1.000        0        1
        3    STOKES  5   17.50      14.20      PHASE  -60.00        10.00
   36.    90.00       1.000        0        1
        4    STOKES  5   17.50      14.20      PHASE  -60.00        10.00
   36.       0.0000   1.000        0        1


      SEA-    CURRENT  CURRENT      CURRENT    WIND    WIND LOAD
      STATE   TAB.NO   BLOCKAGE     STRETCH    INDEX   CALC.METH
      NO.
      -----   -------  -----------  ---------  ------  ---------

        1        1     1.000           -1         1        0
        2        1     1.000           -1         2        0
        3        1     1.000           -1         3        0
        4        1     1.000           -1         4        0


 WIND SPECIFICATION:
 --------------------

      WIND     MEAN      WIND      GUST      MEAN     HEIGHT     MEAN      WIND
    PROFILE    WIND      ANGLE     FACTOR   VELOCITY  EXPONENT   PERIOD   PROFILE
     INDEX   VELOCITY                        LEVEL               RATIO    FORMULA

       1      25.000   270.000    0.315    10.000     0.700     -----        0
       2      25.000   180.000    0.315    10.000     0.700     -----        0
       3      25.000    90.000    0.315    10.000     0.700     -----        0
       4      25.000     0.000    0.315    10.000     0.700     -----        0

    AIR DRAG COEFFICIENTS HAVE NOT BEEN SPECIFIED AS FUNCTION OF REYNOLDS
NUMBER.
    THE DEFAULT FUNCTION WILL BEE USED IF THE COEFFICIENTS NOT ARE SPECIFIED BY
THE CDWN COMMAND


 D A T A C H E C K I N G   F I N I S H E D
       Siftool    version 8.3-02   18-JAN-2007


 NAMES OF INPUT INTERFACE FILES READ:
 ------------------------------------


 Direct file opened: ofsbilil4132R1.SIN
 (IUINP,NWS,IUIDNT,MXPHYS,STATUS) :          10      1024     3
 0   SCRATCH
```

```
 File is native
     MD-FILE    1 OPENED ON UNIT  10 WITH INDEX   1 MAX LENGTH=     2147483640
WORDS AND BLOCKSIZE=  1024
                  NAME   R1.SIN




                  STATUS SCRATCH
     MD-FILE    1 ALLOCATION ACCOUNT OPENED

 20120601_171510_T1.FEM

         DATE:     01-Jun-2012         TIME:          17:15:10

         PROGRAM:  SESAM GeniE         VERSION:       V5.3-10 14-Apr-2011

         COMPUTER: X86 Windows         INSTALLATION:

         USER:     ofsbilil            ACCOUNT:

         DATE:     01-Jun-2012         TIME:          17:15:10

         PROGRAM:  SESAM Gamesha       VERSION:       R5.0-3 14-Apr-2011

         COMPUTER: X86 Windows         INSTALLATION:

         USER:     ofsbilil            ACCOUNT:

1DATE: 01-JUN-2012 TIME: 17:16:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                       PAGE :    11



*******************************************
                                           *   W A T E R   D E P T H :
45.000   *

*******************************************


 D E T E R M I N I S T I C   W A V E   C H A R A C T E R I S T I C S :



                 WAVE      WAVE                           DEPTH TO    WAVE HEIGHT
TO     WAVE      WAVE       HALF WAVE   HALF WAVE
 WAVE    WAVE      PERIOD   PERIOD     WAVE        WAVE      WAVE LENGTH     WAVE
LENGTH     CREST       TROUGH       DURATION    DURATION
  NO   THEORY     ACTUAL  APPARENT  HEIGHT      LENGTH       RATIO          RATIO
    ELEVATION   ELEVATION     CREST       TROUGH

   1 STOKES 5TH   14.20            17.50       267.9      0.1680
0.6532E-01   55.91       38.41       5.964       8.236
1DATE: 01-JUN-2012 TIME: 17:16:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                       PAGE :    12


 W A V E / C U R R E N T   L O A D I N G :
```

```
 STRUCTURE LOADS:
 ----------------


 SUPERELEMENT TYPE  :         1

    THE HIGHEST LOAD CASE NUMBER ON THE FEM INTERFACE FILE IS :        19
    THE INITIAL LOAD CASE NUMBER ON THE LOAD FILE IS          :        12


 *** WARNING *** LOADCASE NUMBERS WILL OVERLAP ON THE FEM INTERFACE FILE AND THE
LOAD FILE




 SUPERELEMENT TYPE NO   1   INDEX  1  (  43 BASIC ELEMENTS,  43 MEMBERS AND   29
NODES,  1 ACTUAL SUPERELEMENTS OF THAT TYPE )
1DATE: 01-JUN-2012 TIME: 17:16:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                       PAGE :    13


 T O T A L   L O A D   S U M M A R Y :


    SEASTATE NO   1

       STEP    PHASE      LX             LY             LZ             MX
     MY             MZ
       ----    -----      ----------     ----------     ----------
----------     ----------     ----------

          1    -60.0     -5.4979E-03    -7.6316E+06     2.7094E+06
1.6951E+08     1.9219E+00     1.5625E+00
          2    -50.0     -5.1703E-03    -8.4879E+06     2.6267E+06
1.9536E+08     1.0156E+00     3.7500E-01
          3    -40.0      1.5924E-01    -9.2301E+06     2.5114E+06
2.2072E+08     1.8359E+00     3.7500E-01
          4    -30.0      1.4395E-01    -9.6994E+06     2.3627E+06
2.4068E+08     3.8281E+00     1.5625E-01
          5    -20.0     -2.7668E-02    -9.7076E+06     2.1858E+06
2.4812E+08     2.3906E+00     2.2188E+00
          6    -10.0      1.1521E-02    -9.0788E+06     1.9919E+06
2.3542E+08     2.7031E+00     5.0000E-01
          7      0.0      3.8813E-02    -7.7403E+06     1.7969E+06
1.9895E+08     2.3906E+00     0.0000E+00
          8     10.0     -3.1760E-02    -5.7933E+06     1.6212E+06
1.4290E+08     9.5312E-01     6.8750E-01
          9     20.0      3.0270E-02    -3.5054E+06     1.4869E+06
7.8835E+07     8.3594E-01     2.8125E-01
         10     30.0      4.5244E-02    -1.2014E+06     1.4128E+06
1.9556E+07     2.6562E-01    -3.4375E-01
         11     40.0     -1.2174E-02     8.5344E+05     1.4098E+06
-2.6711E+07    -6.7969E-01    -1.5625E-02
         12     50.0     -2.2767E-02     2.5028E+06     1.4777E+06
-5.7702E+07    -1.3672E+00     1.5625E-01
         13     60.0     -6.4579E-02     3.6854E+06     1.6049E+06
-7.4958E+07    -8.0469E-01    -1.2615E+00
         14     70.0     -5.5504E-02     4.4084E+06     1.7713E+06
-8.1513E+07    -1.2422E+00    -7.3438E-01
         15     80.0      6.4667E-03     4.7133E+06     1.9525E+06
-8.0269E+07    -4.9219E-01     3.1250E-02
         16     90.0      1.7849E-02     4.6765E+06     2.1254E+06
-7.3822E+07    -6.1719E-01    -3.2812E-01
         17    100.0      2.9428E-02     4.3837E+06     2.2692E+06
-6.4339E+07    -5.8594E-01    -1.2969E+00
         18    110.0     -5.6874E-03     3.9766E+06     2.3724E+06
```

```
-5.4681E+07    -5.5469E-01   -5.4688E-01
         19    120.0     -5.5532E-03     3.5591E+06     2.4357E+06
-4.5912E+07    -6.7969E-01   -6.7188E-01
         20    130.0     -2.1083E-02     3.1806E+06     2.4722E+06
-3.8193E+07     7.8125E-03   -4.8438E-01
         21    140.0     -5.3913E-03     2.8293E+06     2.4968E+06
-3.1294E+07    -3.9844E-01     6.8750E-01
         22    150.0     -3.6583E-02     2.4833E+06     2.5200E+06
-2.4845E+07    -1.7969E-01   -5.7812E-01
         23    160.0     -3.3128E-03     2.1188E+06     2.5471E+06
-1.8455E+07    -5.4688E-02     6.2500E-01
         24    170.0     -3.0564E-02     1.7147E+06     2.5808E+06
-1.1770E+07     1.6406E-01   -5.3125E-01
         25    180.0     -8.9489E-03     1.2541E+06     2.6219E+06
-4.4891E+06     1.3281E-01   -3.1250E-02
         26    190.0      3.9237E-03     7.2493E+05     2.6699E+06
3.6415E+06     7.8125E-03     3.9062E-01
         27    200.0     -7.3219E-03     1.2078E+05     2.7221E+06
1.2821E+07    -1.4844E-01    -6.2500E-01
         28    210.0      1.7129E-02    -5.5822E+05     2.7746E+06
2.3184E+07     6.0156E-01     1.1328E-01
         29    220.0      1.3552E-02    -1.3041E+06     2.8221E+06
3.4787E+07     3.2031E-01    -3.0273E-02
         30    230.0     -9.5189E-03    -2.0995E+06     2.8590E+06
4.7591E+07    -1.2109E+00    -3.1641E-01
         31    240.0      4.5404E-03    -2.9168E+06     2.8801E+06
6.1444E+07     2.8906E-01     3.5156E-01
         32    250.0      1.0183E-03    -3.7266E+06     2.8822E+06
7.6122E+07     1.3203E+00     9.6875E-01
         33    260.0     -1.8164E-02    -4.4979E+06     2.8663E+06
9.1265E+07    -2.1094E-01     2.9688E-01
         34    270.0      1.6426E-03    -5.2235E+06     2.8395E+06
1.0694E+08     6.9531E-01     3.9062E-01
         35    280.0      6.0418E-02    -5.9662E+06     2.8068E+06
1.2489E+08     1.1641E+00    -1.5625E-02
         36    290.0      1.7663E-02    -6.7714E+06     2.7666E+06
1.4573E+08     2.1719E+00     4.6875E-01

       MAXIMUM BASE SHEAR         = 9.7076E+06  AT PHASE =  -20.0

       MAXIMUM OVERTURNING MOMENT = 2.4812E+08  AT PHASE =  -20.0


    SEASTATE NO   2

       STEP    PHASE      LX             LY             LZ             MX
     MY             MZ
       ----    -----      ----------     ----------     ----------
----------     ----------     ----------

          1    -60.0     -7.9232E+06    -7.4628E+04     2.5939E+06
-1.5873E+06    -1.7642E+08   -5.4282E+06
          2    -50.0     -8.7882E+06    -4.2941E+04     2.4727E+06
-1.8195E+06    -2.0221E+08   -5.2830E+06
1DATE: 01-JUN-2012 TIME: 17:16:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :    14

          3    -40.0     -9.5113E+06     2.7500E+02     2.3178E+06
-2.1849E+06    -2.2715E+08   -4.9387E+06
          4    -30.0     -9.9288E+06     5.3514E+04     2.1340E+06
-2.6849E+06    -2.4626E+08   -4.4142E+06
          5    -20.0     -9.8528E+06     1.1315E+05     1.9330E+06
-3.2978E+06    -2.5242E+08   -3.7457E+06
          6    -10.0     -9.1138E+06     1.7363E+05     1.7316E+06
-3.9702E+06    -2.3810E+08   -2.9811E+06
          7      0.0     -7.6512E+06     2.2820E+05     1.5496E+06
-4.6166E+06    -1.9982E+08   -2.1707E+06
          8     10.0     -5.5820E+06     2.6996E+05     1.4076E+06
```

```
-5.1391E+06    -1.4200E+08    -1.3585E+06
          9     20.0     -3.1905E+06     2.9316E+05     1.3234E+06
-5.4512E+06    -7.6442E+07    -5.7749E+05
         10     30.0     -8.1574E+05     2.9434E+05     1.3086E+06
-5.5010E+06    -1.6158E+07     1.5227E+05
         11     40.0      1.2679E+06     2.7311E+05     1.3663E+06
-5.2878E+06     3.0496E+07     8.1994E+05
         12     50.0      2.9021E+06     2.3225E+05     1.4890E+06
-4.8564E+06     6.1236E+07     1.4187E+06
         13     60.0      4.0309E+06     1.7714E+05     1.6593E+06
-4.2807E+06     7.7687E+07     1.9406E+06
         14     70.0      4.6723E+06     1.1468E+05     1.8531E+06
-3.6462E+06     8.3049E+07     2.3752E+06
         15     80.0      4.8812E+06     5.2209E+04     2.0447E+06
-3.0362E+06     8.0439E+07     2.7193E+06
         16     90.0      4.7516E+06    -1.1864E+03     2.2129E+06
-2.5326E+06     7.2665E+07     3.1228E+06
         17    100.0      4.3898E+06    -3.7588E+04     2.3422E+06
-2.1891E+06     6.2112E+07     3.5891E+06
         18    110.0      3.9664E+06    -5.6375E+04     2.4297E+06
-2.0243E+06     5.1904E+07     3.7263E+06
         19    120.0      3.5606E+06    -6.4737E+04     2.4861E+06
-1.9882E+06     4.3008E+07     3.4499E+06
         20    130.0      3.1868E+06    -6.9799E+04     2.5239E+06
-2.0102E+06     3.5257E+07     3.0249E+06
         21    140.0      2.8336E+06    -7.4911E+04     2.5536E+06
-2.0327E+06     2.8319E+07     2.5696E+06
         22    150.0      2.4767E+06    -8.1748E+04     2.5820E+06
-2.0235E+06     2.1738E+07     2.0993E+06
         23    160.0      2.0923E+06    -9.0918E+04     2.6127E+06
-1.9702E+06     1.5104E+07     1.6168E+06
         24    170.0      1.6607E+06    -1.0224E+05     2.6471E+06
-1.8757E+06     8.0706E+06     1.1194E+06
         25    180.0      1.1668E+06    -1.1505E+05     2.6854E+06
-1.7527E+06     3.5317E+05     6.0394E+05
         26    190.0      6.0062E+05    -1.2831E+05     2.7265E+06
-1.6186E+06    -8.2738E+06     7.0440E+04
         27    200.0     -4.1403E+04    -1.4073E+05     2.7680E+06
-1.4928E+06    -1.7973E+07    -4.7586E+05
         28    210.0     -7.5578E+05    -1.5076E+05     2.8061E+06
-1.3937E+06    -2.8832E+07    -1.0233E+06
         29    220.0     -1.5304E+06    -1.5673E+05     2.8364E+06
-1.3358E+06    -4.0857E+07    -1.5545E+06
         30    230.0     -2.3436E+06    -1.5712E+05     2.8541E+06
-1.3261E+06    -5.3955E+07    -2.0500E+06
         31    240.0     -3.1637E+06    -1.5092E+05     2.8564E+06
-1.3599E+06    -6.7943E+07    -2.4948E+06
         32    250.0     -3.9582E+06    -1.3858E+05     2.8437E+06
-1.4135E+06    -8.2582E+07    -2.9705E+06
         33    260.0     -4.7043E+06    -1.2453E+05     2.8192E+06
-1.4508E+06    -9.7581E+07    -3.7023E+06
         34    270.0     -5.4200E+06    -1.1417E+05     2.7873E+06
-1.4496E+06    -1.1321E+08    -4.5652E+06
         35    280.0     -6.1953E+06    -1.0650E+05     2.7448E+06
-1.4414E+06    -1.3139E+08    -5.1311E+06
         36    290.0     -7.0361E+06    -9.5152E+04     2.6828E+06
-1.4710E+06    -1.5248E+08    -5.3749E+06

       MAXIMUM BASE SHEAR         = 9.9289E+06  AT PHASE =  -30.0

       MAXIMUM OVERTURNING MOMENT = 2.5244E+08  AT PHASE =  -20.0


    SEASTATE NO   3

       STEP    PHASE      LX             LY             LZ             MX
     MY             MZ
       ----    -----      ----------     ----------     ----------
```

```
----------     ----------     ----------

          1     -60.0      -3.0882E-01      8.0073E+06      2.4804E+06
-1.8009E+08    -6.8203E+00    -8.4375E-01
          2     -50.0      -3.8797E-01      8.8313E+06      2.3244E+06
-2.0506E+08    -7.3984E+00    -1.7812E+00
          3     -40.0      -3.3386E-01      9.4846E+06      2.1333E+06
-2.2879E+08    -9.4609E+00    -4.3750E-01
          4     -30.0      -4.5882E-01      9.8065E+06      1.9177E+06
-2.4635E+08    -1.1648E+01     5.0000E-01
          5     -20.0      -4.2677E-01      9.6177E+06      1.6945E+06
-2.5076E+08    -1.0953E+01    -2.1875E+00
          6     -10.0      -4.6036E-01      8.7627E+06      1.4857E+06
-2.3471E+08    -9.5156E+00    -2.8438E+00
          7       0.0      -3.2919E-01      7.1968E+06      1.3155E+06
-1.9497E+08    -8.3281E+00    -1.6875E+00
          8      10.0      -2.5025E-01      5.0534E+06      1.2052E+06
-1.3618E+08    -5.9453E+00    -1.1250E+00
          9      20.0      -1.5836E-01      2.6290E+06      1.1690E+06
-7.0306E+07    -3.8750E+00    -9.5312E-01
         10      30.0      -6.9458E-02      2.6882E+05      1.2120E+06
-1.0419E+07    -5.5469E-01    -1.0293E+00
         11      40.0       1.2276E-02     -1.7542E+06      1.3290E+06
3.5173E+07     1.7109E+00    -1.3906E+00
         12      50.0       1.7060E-01     -3.2902E+06      1.5053E+06
6.4337E+07     3.5781E+00    -5.7812E-01
         13      60.0       1.9738E-01     -4.2969E+06      1.7174E+06
7.8922E+07     4.4922E+00    -1.2031E+00
         14      70.0       2.0194E-01     -4.8099E+06      1.9363E+06
8.2405E+07     4.3984E+00     2.1719E+00
1DATE: 01-JUN-2012 TIME: 17:16:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                               PAGE :    15

         15      80.0       2.3708E-01     -4.8992E+06      2.1357E+06
7.8132E+07     3.3672E+00     7.8125E-02
         16      90.0       1.5066E-01     -4.6736E+06      2.2945E+06
6.9079E+07     5.0859E+00     6.0938E-01
         17     100.0       1.7763E-01     -4.2793E+06      2.4072E+06
5.7891E+07     3.8906E+00     1.0938E-01
         18     110.0       1.3830E-01     -3.8580E+06      2.4816E+06
4.7472E+07     1.9219E+00     4.2188E-01
         19     120.0       1.7324E-01     -3.4599E+06      2.5325E+06
3.8524E+07     1.5156E+00    -4.0625E-01
         20     130.0       1.7301E-01     -3.0874E+06      2.5711E+06
3.0738E+07     4.0156E+00     8.4375E-01
         21     140.0       1.0433E-01     -2.7279E+06      2.6047E+06
2.3722E+07     1.6094E+00     1.4062E-01
         22     150.0       1.1365E-01     -2.3575E+06      2.6375E+06
1.6997E+07     6.0938E-01     9.2188E-01
         23     160.0       1.2671E-01     -1.9546E+06      2.6714E+06
1.0159E+07     1.5156E+00     5.9375E-01
         24     170.0       6.6343E-02     -1.5016E+06      2.7067E+06
2.8854E+06     8.5938E-01     1.7188E-01
         25     180.0       6.9257E-02     -9.8598E+05      2.7425E+06
-5.0745E+06     3.2031E-01     3.5156E-01
         26     190.0       3.4272E-02     -4.0052E+05      2.7771E+06
-1.3912E+07     6.9531E-01    -1.9531E-02
         27     200.0       1.2567E-02      2.5576E+05      2.8078E+06
-2.3756E+07     6.9531E-01     3.9062E-03
         28     210.0       4.0941E-02      9.7648E+05      2.8312E+06
-3.4658E+07     1.0000E+00     4.5312E-01
         29     220.0      -6.9853E-02      1.7465E+06      2.8433E+06
-4.6587E+07    -3.4375E-01    -6.8750E-01
         30     230.0      -8.6794E-02      2.5414E+06      2.8409E+06
-5.9426E+07    -2.2188E+00     8.5938E-01
         31     240.0      -1.4647E-01      3.3289E+06      2.8246E+06
-7.3025E+07    -2.6875E+00    -4.2188E-01
         32     250.0      -1.7452E-01      4.0732E+06      2.7994E+06
```

```
-8.7189E+07    -3.2266E+00     3.1250E-01
         33    260.0     -1.7916E-01     4.7838E+06     2.7704E+06
-1.0191E+08    -4.3828E+00    -2.0938E+00
         34    270.0     -1.2935E-01     5.5020E+06     2.7340E+06
-1.1752E+08    -4.7578E+00    -9.6875E-01
         35    280.0     -2.8286E-01     6.2898E+06     2.6804E+06
-1.3568E+08    -5.6328E+00    -6.2500E-01
         36    290.0     -3.3102E-01     7.1352E+06     2.5981E+06
-1.5660E+08    -5.4531E+00     1.0000E+00

       MAXIMUM BASE SHEAR         = 9.8065E+06  AT PHASE =  -30.0

       MAXIMUM OVERTURNING MOMENT = 2.5076E+08  AT PHASE =  -20.0


    SEASTATE NO   4

       STEP    PHASE      LX              LY              LZ              MX
     MY              MZ
       ----    -----      ----------      ----------      ----------
----------     ----------     ----------

          1    -60.0      7.9232E+06    -7.4628E+04      2.5939E+06
-1.5873E+06     1.7642E+08     5.4282E+06
          2    -50.0      8.7882E+06    -4.2940E+04      2.4727E+06
-1.8195E+06     2.0221E+08     5.2830E+06
          3    -40.0      9.5113E+06     2.7582E+02      2.3178E+06
-2.1849E+06     2.2715E+08     4.9387E+06
          4    -30.0      9.9288E+06     5.3515E+04      2.1340E+06
-2.6849E+06     2.4626E+08     4.4142E+06
          5    -20.0      9.8528E+06     1.1315E+05      1.9330E+06
-3.2978E+06     2.5242E+08     3.7457E+06
          6    -10.0      9.1138E+06     1.7364E+05      1.7316E+06
-3.9702E+06     2.3810E+08     2.9811E+06
          7      0.0      7.6512E+06     2.2820E+05      1.5496E+06
-4.6166E+06     1.9982E+08     2.1707E+06
          8     10.0      5.5820E+06     2.6996E+05      1.4076E+06
-5.1391E+06     1.4200E+08     1.3585E+06
          9     20.0      3.1905E+06     2.9316E+05      1.3234E+06
-5.4512E+06     7.6442E+07     5.7749E+05
         10     30.0      8.1574E+05     2.9434E+05      1.3086E+06
-5.5010E+06     1.6158E+07    -1.5227E+05
         11     40.0     -1.2679E+06     2.7311E+05      1.3663E+06
-5.2878E+06    -3.0496E+07    -8.1994E+05
         12     50.0     -2.9021E+06     2.3225E+05      1.4890E+06
-4.8564E+06    -6.1236E+07    -1.4187E+06
         13     60.0     -4.0309E+06     1.7713E+05      1.6593E+06
-4.2807E+06    -7.7687E+07    -1.9406E+06
         14     70.0     -4.6723E+06     1.1468E+05      1.8531E+06
-3.6462E+06    -8.3049E+07    -2.3752E+06
         15     80.0     -4.8812E+06     5.2209E+04      2.0447E+06
-3.0362E+06    -8.0439E+07    -2.7193E+06
         16     90.0     -4.7516E+06    -1.1868E+03      2.2129E+06
-2.5326E+06    -7.2665E+07    -3.1228E+06
         17    100.0     -4.3898E+06    -3.7588E+04      2.3422E+06
-2.1891E+06    -6.2112E+07    -3.5891E+06
         18    110.0     -3.9664E+06    -5.6375E+04      2.4297E+06
-2.0243E+06    -5.1904E+07    -3.7263E+06
         19    120.0     -3.5606E+06    -6.4737E+04      2.4861E+06
-1.9882E+06    -4.3008E+07    -3.4499E+06
         20    130.0     -3.1868E+06    -6.9799E+04      2.5239E+06
-2.0102E+06    -3.5257E+07    -3.0249E+06
         21    140.0     -2.8336E+06    -7.4911E+04      2.5536E+06
-2.0327E+06    -2.8319E+07    -2.5696E+06
         22    150.0     -2.4767E+06    -8.1748E+04      2.5820E+06
-2.0235E+06    -2.1738E+07    -2.0993E+06
         23    160.0     -2.0923E+06    -9.0918E+04      2.6127E+06
-1.9702E+06    -1.5104E+07    -1.6168E+06
```

```
         24    170.0     -1.6607E+06    -1.0225E+05     2.6471E+06
-1.8757E+06    -8.0706E+06    -1.1194E+06
         25    180.0     -1.1668E+06    -1.1505E+05     2.6854E+06
-1.7527E+06    -3.5317E+05    -6.0394E+05
         26    190.0     -6.0062E+05    -1.2831E+05     2.7265E+06
-1.6186E+06     8.2738E+06    -7.0438E+04
1DATE: 01-JUN-2012 TIME: 17:16:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                           PAGE :    16

         27    200.0      4.1403E+04    -1.4073E+05     2.7680E+06
-1.4928E+06     1.7973E+07     4.7586E+05
         28    210.0      7.5578E+05    -1.5076E+05     2.8061E+06
-1.3937E+06     2.8832E+07     1.0233E+06
         29    220.0      1.5304E+06    -1.5673E+05     2.8364E+06
-1.3358E+06     4.0857E+07     1.5545E+06
         30    230.0      2.3436E+06    -1.5712E+05     2.8541E+06
-1.3261E+06     5.3955E+07     2.0500E+06
         31    240.0      3.1637E+06    -1.5092E+05     2.8564E+06
-1.3599E+06     6.7943E+07     2.4948E+06
         32    250.0      3.9582E+06    -1.3858E+05     2.8437E+06
-1.4135E+06     8.2582E+07     2.9705E+06
         33    260.0      4.7043E+06    -1.2453E+05     2.8192E+06
-1.4508E+06     9.7581E+07     3.7023E+06
         34    270.0      5.4200E+06    -1.1417E+05     2.7873E+06
-1.4496E+06     1.1321E+08     4.5652E+06
         35    280.0      6.1953E+06    -1.0650E+05     2.7448E+06
-1.4414E+06     1.3139E+08     5.1311E+06
         36    290.0      7.0361E+06    -9.5151E+04     2.6828E+06
-1.4710E+06     1.5248E+08     5.3749E+06

       MAXIMUM BASE SHEAR         = 9.9289E+06  AT PHASE =  -30.0

       MAXIMUM OVERTURNING MOMENT = 2.5244E+08  AT PHASE =  -20.0


    SUMMARY OF MAXIMUM BASE SHEAR AND OVERTURNING MOMENT:

       SEASTATE     MAXIMUM        MAXIMUM
       NO.          BASE SHEAR     OVERTURNING MOMENT
       --------     ----------     ------------------

          1         9.7076E+06     2.4812E+08
          2         9.9289E+06     2.5244E+08
          3         9.8065E+06     2.5076E+08
          4         9.9289E+06     2.5244E+08


 C E N T R E   O F   B U O Y A N C Y :

   X=-6.3938E-08   Y=-1.1268E+00   Z= 1.4430E+01
1DATE: 01-JUN-2012 TIME: 17:16:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                           PAGE :    17


 SUMMARY OF ADMINISTRATIVE DATA TRANSFERRED TO STRUCTURAL ANALYSIS PROGRAM :
 ---------------------------------------------------------------------------



--------------------------------------------------------------------------------
-----------------------------------------------
 : SEASTATE  /   : WAVE     : WAVE     : WAVE     : WATER    : MUDPLANE :  WIND
  : GUST WIND: TIME STEPS                       :
 : IDENTIFICATION: DIRECTION: HEIGHT   : PERIOD   : DEPTH    : ELEVATION:
PROFILE : INDUCED  : LOAD CASE NUMBERS             :
 : NUMBER        :          :          :          :          :          :  INDEX
  : FATIGUE  :                                  :
```

```
--------------------------------------------------------------------------------
-----------------------------------------------
 :               :          :          :          :          :          :      1
  :  NO      :          :          :          :
 :    1  /    1  : 270.0    : 17.50    : 14.20    : 45.00    :-.5651E-11:
  :          :          :          :          :
 :               :          :          :          :          :          :
  :          :    -0.789:    -0.789:
 :               :          :          :          :          :          :
  :          :       12.:       13.:

--------------------------------------------------------------------------------
-----------------------------------------------
 :               :          :          :          :          :          :      2
  :  NO      :          :          :          :
 :    2  /    2  : 180.0    : 17.50    : 14.20    : 45.00    :-.5651E-11:
  :          :          :          :          :
 :               :          :          :          :          :          :
  :          :    -1.183:    -0.789:
 :               :          :          :          :          :          :
  :          :       14.:       15.:

--------------------------------------------------------------------------------
-----------------------------------------------
 :               :          :          :          :          :          :      3
  :  NO      :          :          :          :
 :    3  /    3  : 90.00    : 17.50    : 14.20    : 45.00    :-.5651E-11:
  :          :          :          :          :
 :               :          :          :          :          :          :
  :          :    -1.183:    -0.789:
 :               :          :          :          :          :          :
  :          :       16.:       17.:

--------------------------------------------------------------------------------
-----------------------------------------------
 :               :          :          :          :          :          :      4
  :  NO      :          :          :          :
 :    4  /    4  :    0.0000: 17.50    : 14.20    : 45.00    :-.5651E-11:
  :          :          :          :          :
 :               :          :          :          :          :          :
  :          :    -1.183:    -0.789:
 :               :          :          :          :          :          :
  :          :       18.:       19.:



--------------------------------------------------------------------------------
------------
 :    WIND     MEAN      WIND      GUST      MEAN     HEIGHT     MEAN    LENGTH
     WIND  :
 :  PROFILE    WIND     ANGLE     FACTOR   VELOCITY  EXPONENT    PERIOD   SCALE
   PROFILE :
 :   INDEX   VELOCITY                       LEVEL                RATIO    FACTOR
   FORMULA :

--------------------------------------------------------------------------------
------------
 :     1      25.000   270.000     0.315    10.000     0.700     -----    1.00
       0   :
 :     2      25.000   180.000     0.315    10.000     0.700     -----    1.00
       0   :
 :     3      25.000    90.000     0.315    10.000     0.700     -----    1.00
       0   :
 :     4      25.000     0.000     0.315    10.000     0.700     -----    1.00
       0   :
```

```
CPU TIME CONSUMPTION: 0.4600


P R O G R A M   N O R M A L   E N D
```

Vedlegg 5 – “Carbon Trust, Draft, OWA OFFSHORE WIND FARM FOUNDATIONS UK Round 3, Design Basis. Version 2, November 2009”

DRAFT

OWA OFFSHORE WIND FARM FOUNDATIONS
UK Round 3

Design Basis. Version 2

November 2009

Date:	November 3, 2009
Prepared:	Stine Rosbjerg, Helge Gravesen
Checked:	Søren Sørensen
Approved:	

TABLE OF CONTENTS PAGE

1 EXECUTIVE SUMMARY

The present design Basis, Version 2, Includes general design principles and specific code interpretations. The metocean conditions were originally roughly estimated values based mainly on a rough hindcast study. 10 years of hourly hindcast data from DHI do now found the basis for Area 3, 4 and 5. The soil data are available data published by British Geological Survey.

Estimated design forces for a typical 3.6-5 MW turbine (with emphasis to the 5 MW alternative) have been estimated for two typical metocean conditions (see Table 4.1) and three different water depth (35 m, 45m and 55 m):

1) Average wind condition + H_s = 7.5 m
2) Exposed wind condition + H_s = 9.4 m

Accordingly, the extreme wave regime is reduced compared to the initial estimate.

The forces have been estimated for 4 different typical structures:

1) Cone gravity structure (Gifford/Freysinnet/BMT)
2) 7 m monopile (Ballast-Nedam and MBD)
3) Keystone battered jacket
4) Tripod on suction piles (SPT)
5) Jack-up (OWPSE/Titan)

Further, the Design Basis Version 2 includes additional information on

1) Simplified design soil profiles including design parameters
2) Acceptable loads during installation in case nacelle or nacelle/rotor is installed integrated to the foundation
3) Loads to platforms
4) Scour

2 INTRODUCTION

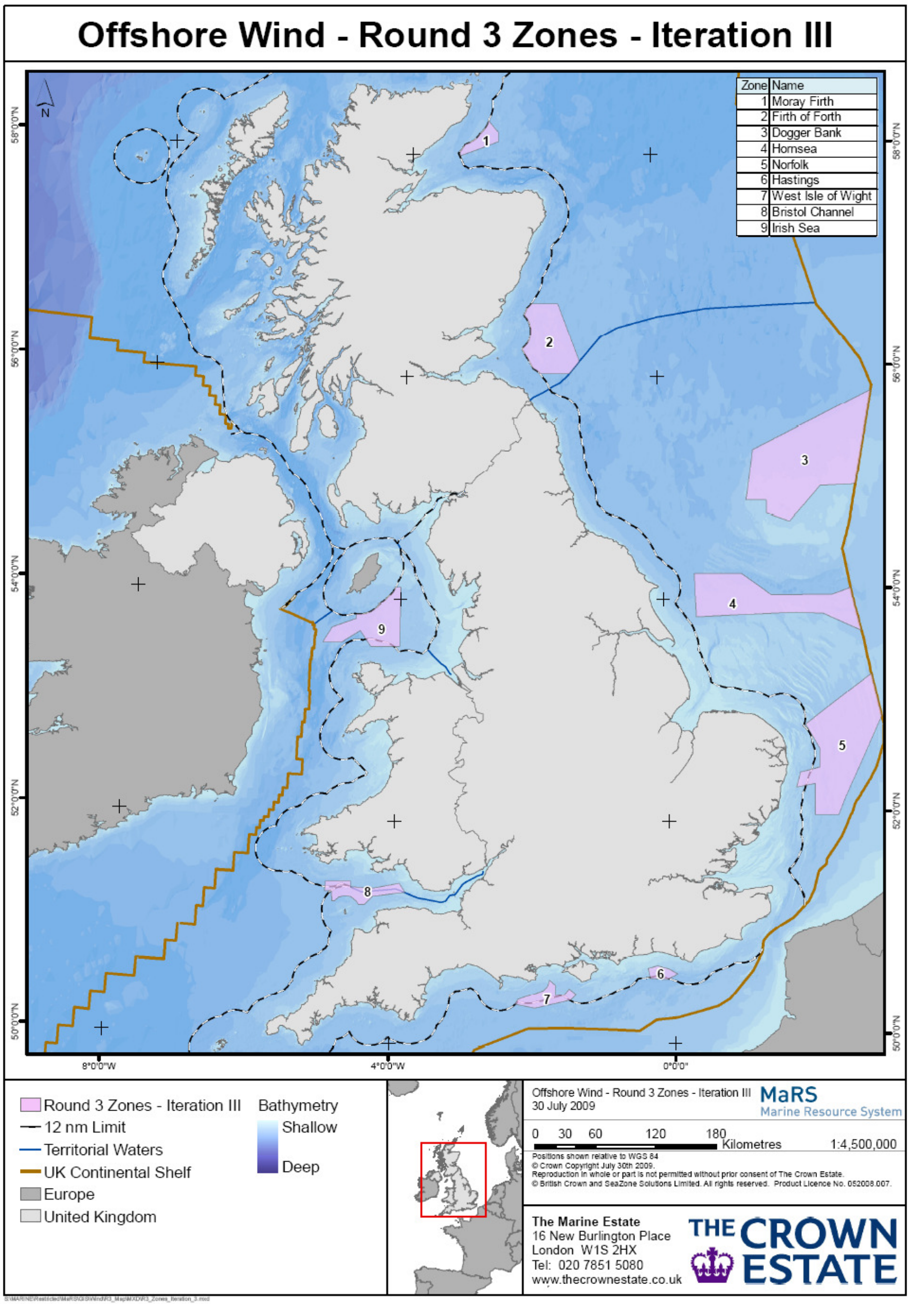


Figure 2.1 Round 3 areas

This document is a combined site assessment/design basis for the 9 Round 3 areas.

With the large areas in mind the description will be rather rough with respect to Metocean and Soil conditions. Also the design parameters represent rough estimates.

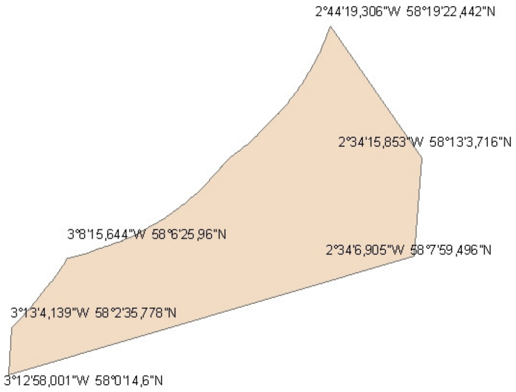
The document has been prepared for the conceptual design only.

3 BASE DESIGN

In the following a rough base design of the UK Round 3 areas for offshore wind farm is presented. The base design is based upon presently available sources.

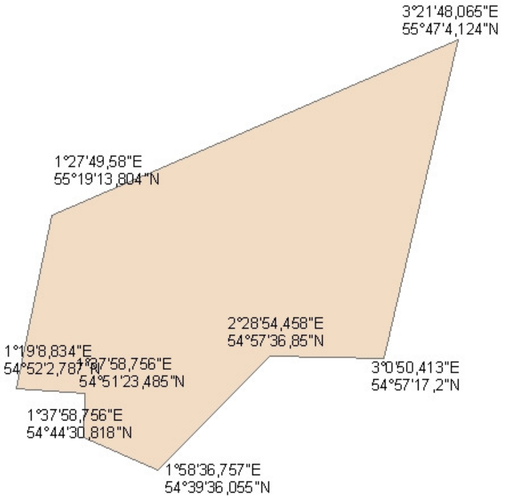
3.1 The sites

In Figure the corner points of the Round 3 areas are shown. The corner points are approximately since the coordinates are extracted from ArcMAP by marking the corner points manually.

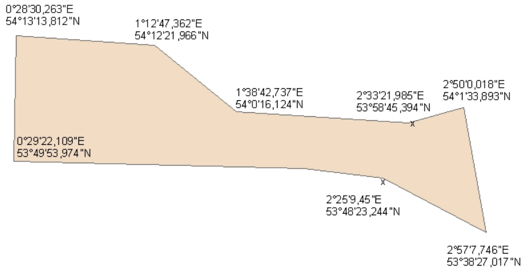


Area 1 Morath Firth

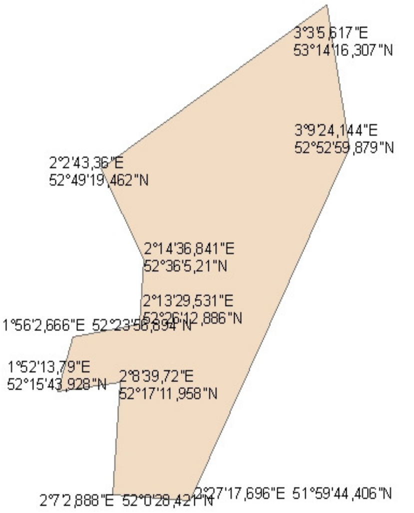
Area 2 Firth of Forth



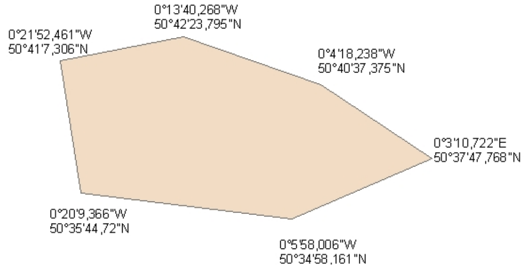
Area 3 Dogger Bank



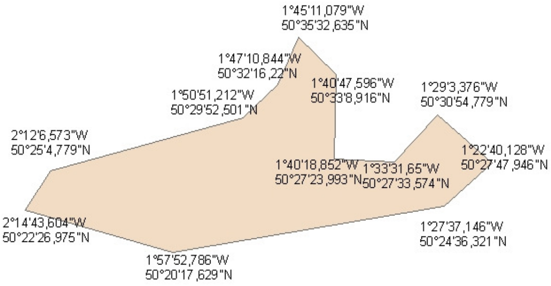
Area 4 Hornsea



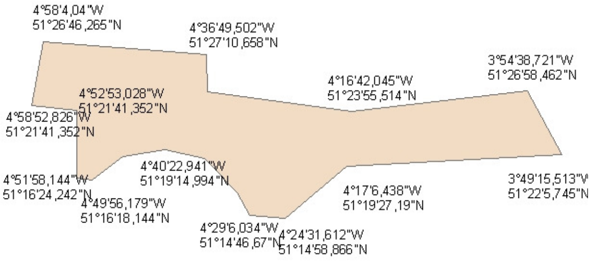
Area 5 Norfolk



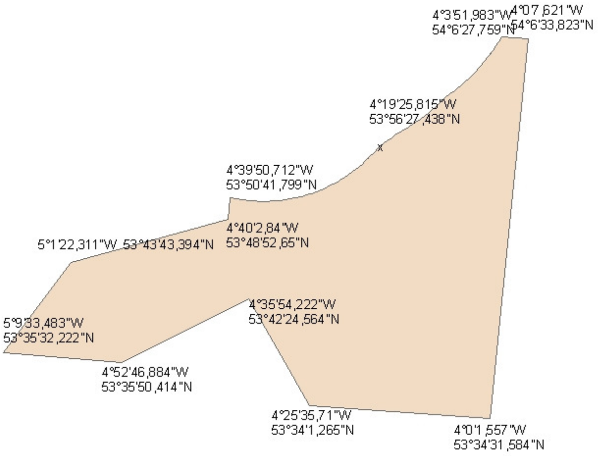
Area 6 Hastings



Area 7 West Isle of Wight



Area 8 Bristol Channel



Area 9 Irish Sea

Figur 3.1 Round 3 areas. Coordinates for corner points in WGS84 .

3.2 Turbines

The Foundation Concept study will consider turbines in the size of 3.6 – 5.0 MW.

Turbines of 3.6 to 5MW typically have rotor diameter that are in the range of 106–126 meters and hub height in the range of 76–86 meters from platform level

3.3 Foundations

In a conceptual design different foundations will be evaluated with regard to economy, installation, maintenance and risk aspects.

4 METOCEAN CONDITIONS

4.1 Wind

Wind shear:
The wind shear exponent factor is 0.11, and thus the wind shear is calculated as:

$V(h) = V_{ref} \times (h/h_{ref})^{0.11}$

Park turbulence
The turbulence in the wind farm is estimated on basis of the turbulence in the free wind, the wake effects and the increased turbulence due to the wind turbine structures.k.

The following resulting values of turbulence presented in table 4.3 can be used for the conceptual design.

Table 4.1: Design park turbulence intensity at hub height

Wind speed	Park Turbulence intensity		
$U_{10\ min}$	Free + Park	STD	Design
5 m/s	13.7%	5.5%	20.7%
7 m/s	12.0%	4.8%	18.1%
10 m/s	11.1%	4.4%	16.8%
15 m/s	10.4%	4.2%	15.7%
25 m/s	10.3%	2.4%	13.4%
45-50 m/s			12.0%

4.2 Extreme wind

Estimates of 50-year return omnidirectional hourly-mean wind speeds at 10 m above still water level are determined in reference /14/. The results are listed in Table 4.1.

4.3 Design wave heights and crest elevation

Design wave heights and crest elevation have been estimated by simplified model analyses and review of the available measurements from the area.

Maximum wave height has been determined on the basis of IEC 61.400-3 Annex C (Battjes & Groenendijk) assuming a maximum sea bed slope of 1 %.

The wave steepness and associated wave period for extreme waves have been assessed on the basis of average wave steepness for the largest measured/modelled waves.

The maximum wave height is found for a return period of 3 hours. The associated crest elevation has been determined for H_{max} and $T(H_{max}) = T_p$ by means of stream function calculation.

The design wave parameters are shown in Table 4.1.

4.1 Initial metocean design data based on the Offshore Technology Report 2001/010. *Exposed wind/weather climate **Average wind/weather climate.

	Wind			Tidal					Waves								
									3h/50y	3h/1y	3h/50y, 30m+0.75TR			3h/50y,60m+0.75TR		
Area	$U_{10m,1h,50\,y}$	$U_{100m,1h,50y}$	$U_{100m,3s,50y}$	TR= HAT-LAT/ MSL(rel LAT)	0.75TR	Avg. Spring current	Max. spring current	Splash Zone Upper/ Lower rel. MSL	Hs/Tp	Hs/Tp	Hmax	Crest η_{max}/u_{max}	Run-up R_{max} (rel LAT)	Hmax	Crest η_{max}/u_{max}	Run-up R_{max} (rel LAT)
	m/s	m/s	m/s	m	m	m/s	m/s	M	m/s	m/s	m	m/ m/s	m	m	m/ m/s	m
1*	37.0	48.5	61.0	3.5/ 1.75	2.6	0.4	0.61	7.3/ -5.4	12.0/ 14.8	9.2/ 13.0	18.6	13.7/ 10.3	35.9	22.4	13.4/ 7.3	25.9
2	35.0	45.5	57.0	4.0 2.0	3.0	0.6	0.86	6.3/ -4.9	10.3/ 14.0	7.2/ 11.8	16.8	11.7/ 8.6	27.6	19.1	11.1/ 6.3	20.6
3*	37.0	48.5	61.0	2.5 1.25	1.9	0.4	0.55	6.7/ -4.9	13.0/ 15.3	9.1/ 12.8	19.7	15.0/ 12.0	44.4	24.4	14.7/ 8.3	30.3
4	36.0	47.0	58.0	4.0 2.0	3.0	0.9	1.20	6.6/ -5.0	10.9/ 13.9	7.6/ 11.6	17.5	12.6/ 9.5	31.7	20.3	11.8/ 6.7	22.4
5**	34.0	44.0	55.0	2.0 1.0	1.5	1.2	1.54	4.4/ -3.2	7.9/ 11.7	5.6/ 9.8	14.0	9.0/ 6.8	19.3	14.5	8.5/ 5.2	15.2
6	32.0	41.0	51.0	7.5 3.75	5.6	1.3	1.60	6.7/ -5.7	7.0/ 8.0	4.9/ 8.0	13.0	8.1/ 8.1	21.8	13.0	7.7/ 8.0	21.0
7**	34.0	44.0	55.0	4.0 2.0	3.0	1.5	1.89	5.4/ -4.2	7.7/ 8.0	5.6	14.3	9.1/ 9.7	28.2	14.7	8.7/ 8.5	23.7
8	36.0	47.0	58.0	9.0 4.5	6.8	1.6	2.26	9.8/ -8.1	12.0/ 15.6	8.9/ 13.5	19.3	13.3/ 9.0	30.8	22.4	13.2/ 6.9	24.6
9*	36.0	47.0	58.0	7.0 3.5	5.3	1.2	1.76	6.7/ -5.6	7.5/ 11.1	5.3/ 9.3	14.0	8.7/ 6.7	18.7	14.0	7.9/ 5.2	14.4

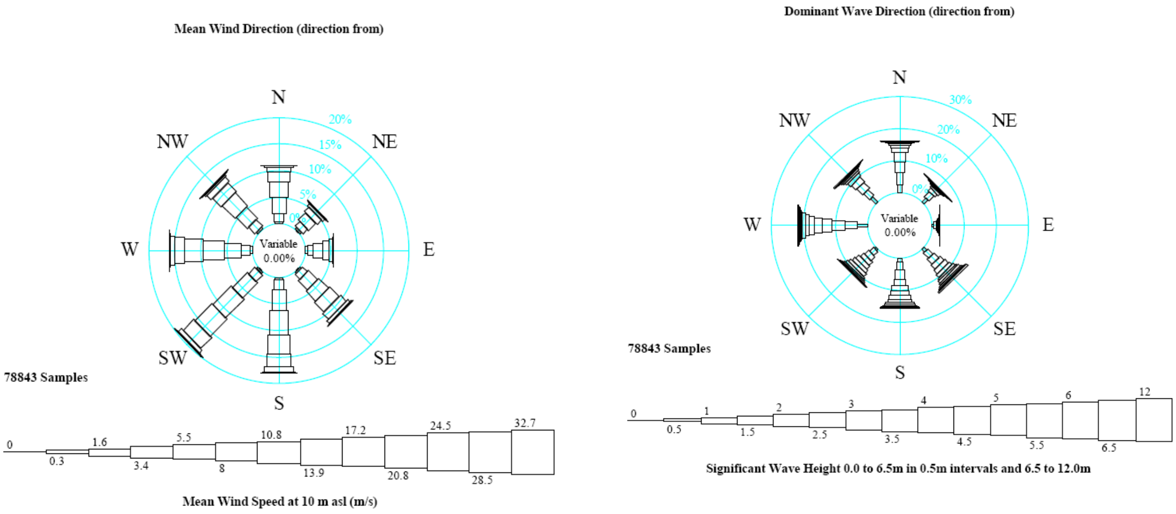
A current speed as shown in Table 4.1 has been used.

The water level of LAT is used for the extreme wave height calculation.

4.4 Wind and wave roses

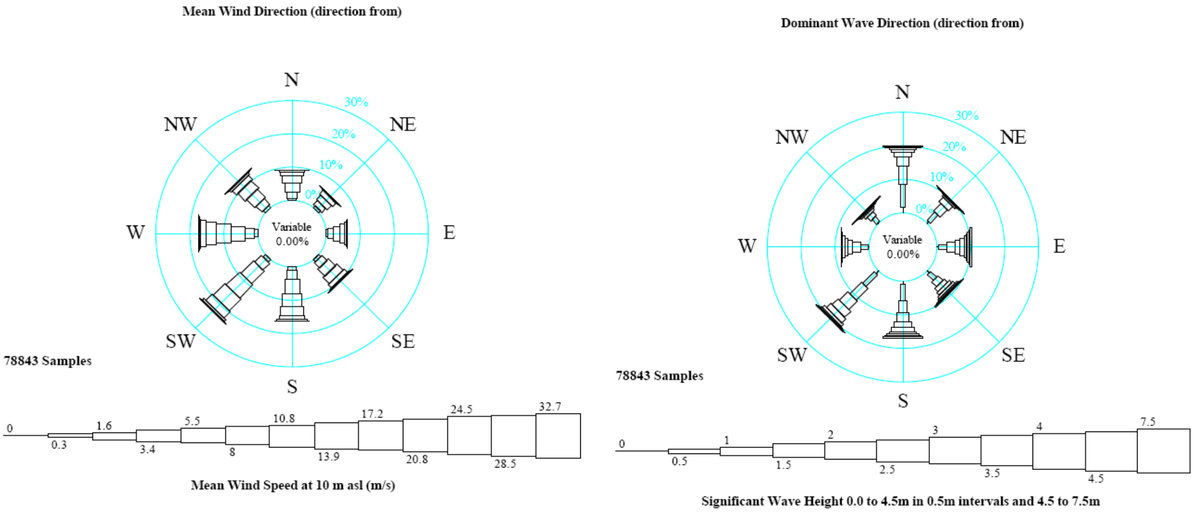
Wind and wave roses for all wind turbine areas are illustrated below. Area 6 and 7 are located near the same extraction point. The data are from reference /11/.

14651



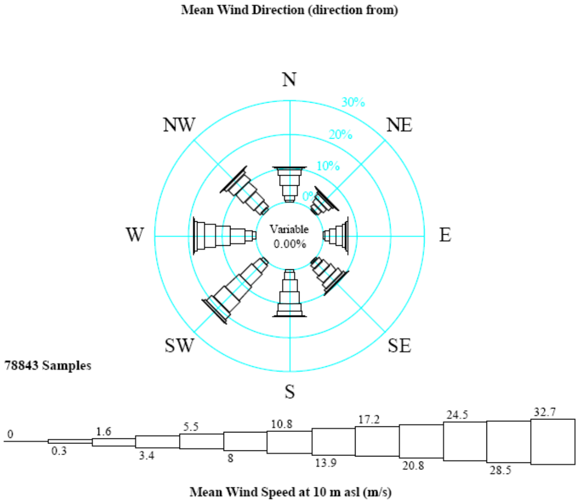
Area 1

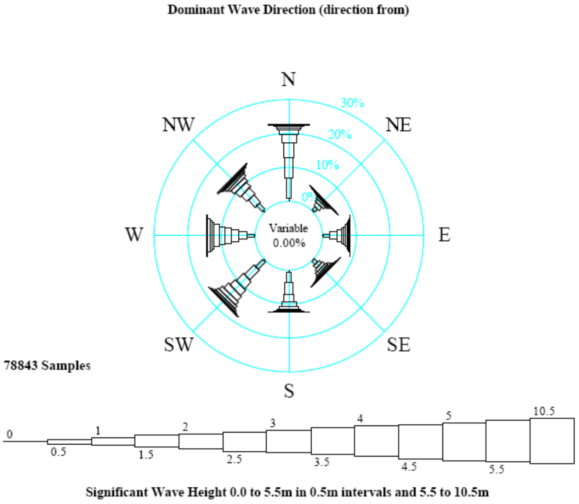
15194



Area 2

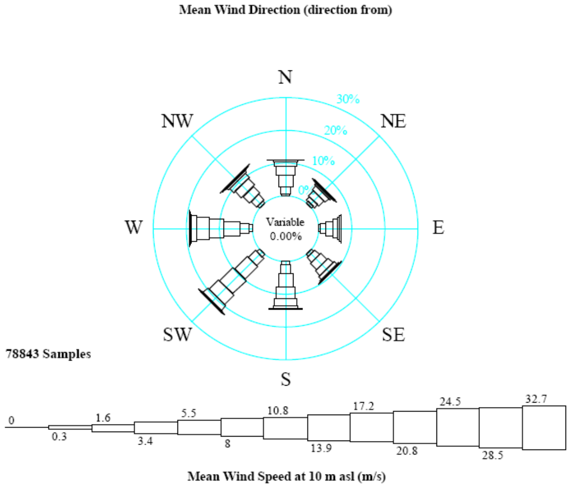
15143

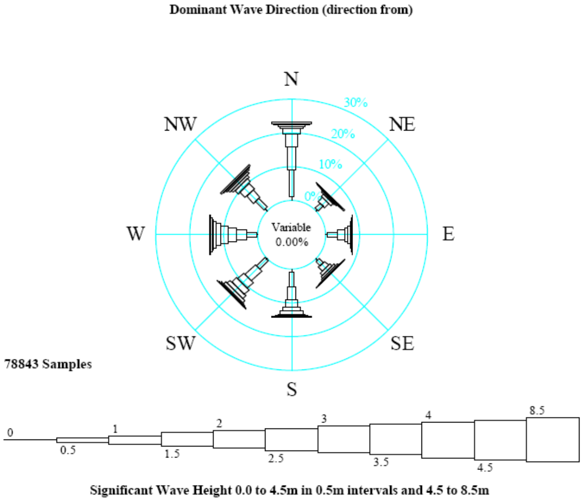




Area 3

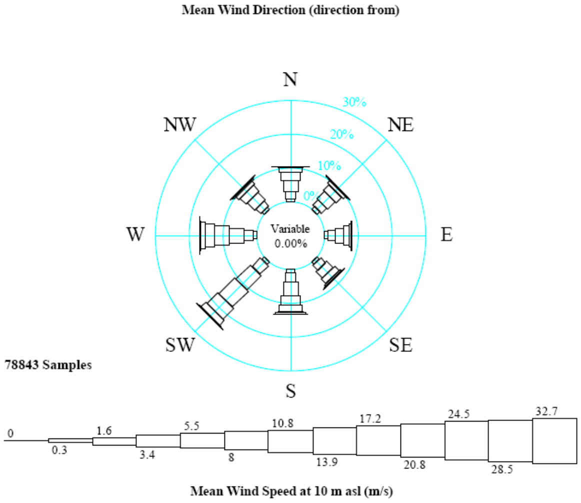
15447

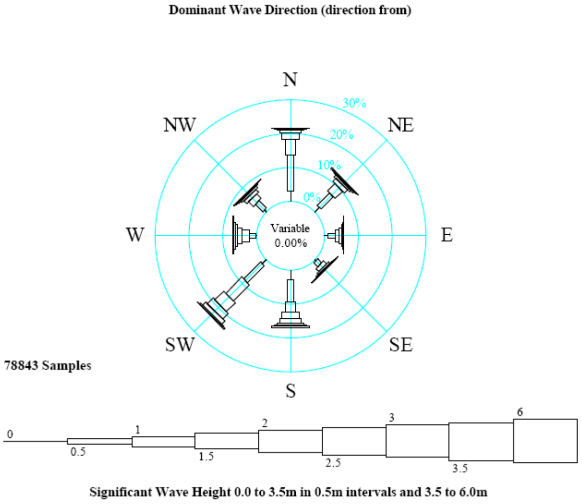




Area 4

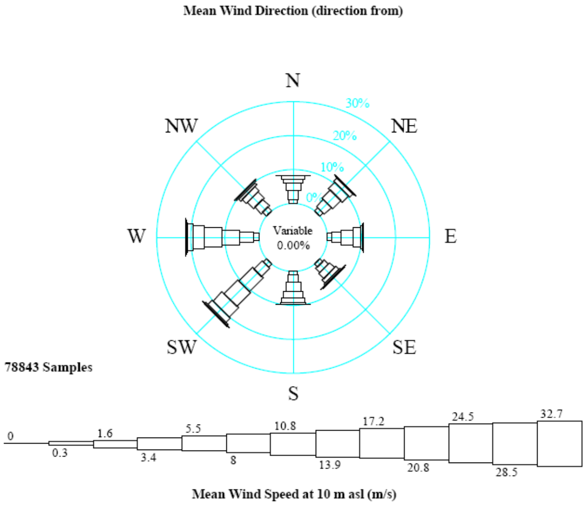
15697

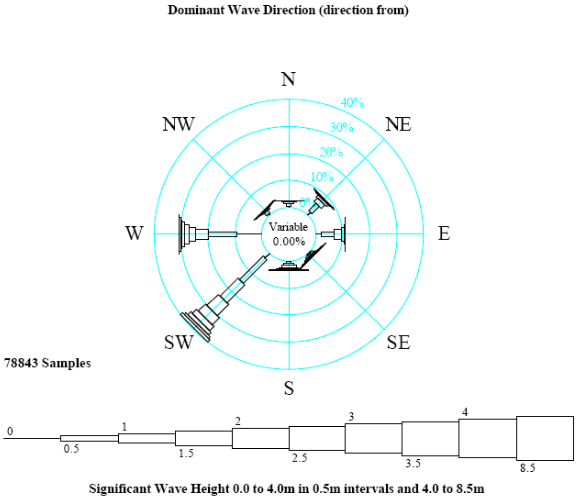




Area 5

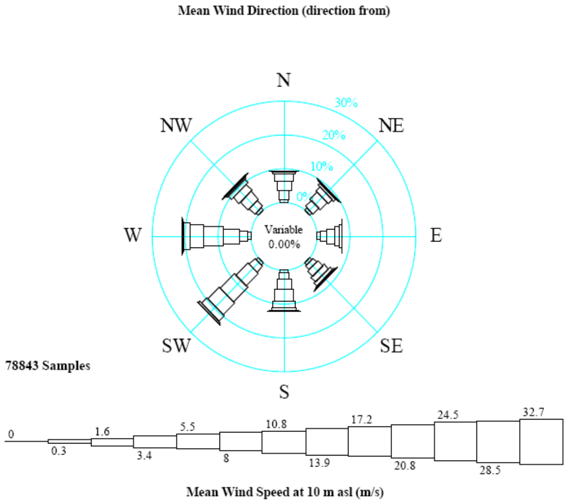
16357

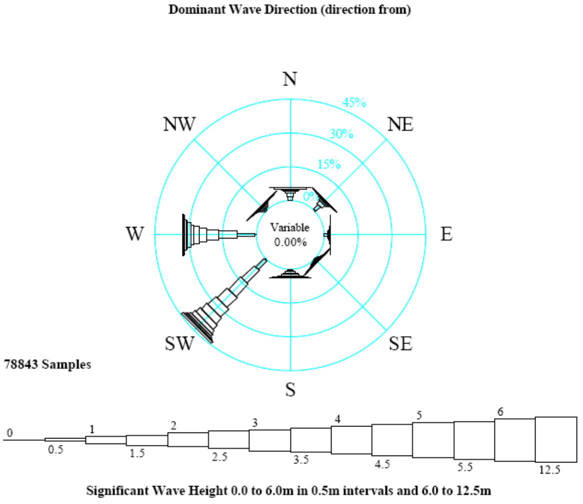




Area 6 and 7

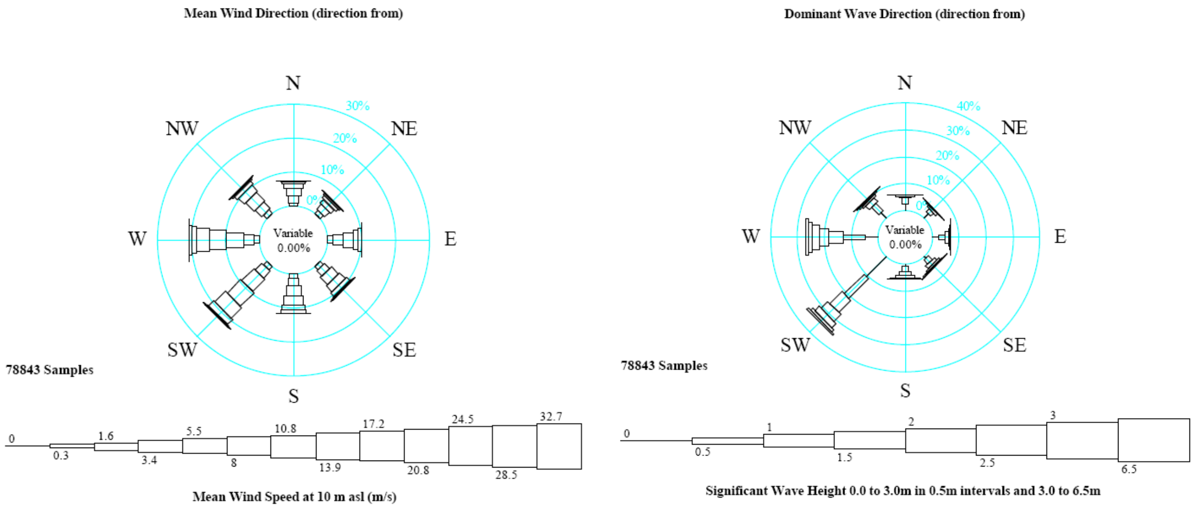
16462





Area 8

15920



Area 9
Figure 4.1 Wind direction and speed.

4.5 Wave steepness and spectrum

The wave steepness is based on: Sop = $H_s/L_o(T_p)$ and varies between 0.034 – 0.047

The used wave spectrum is the Jonswap spectrum with $\gamma = 3.3$.

4.6 Swells

Not analysed. Analyses will be based on wave spectra data from annexes in /14/.

4.7 Breaking waves

Plunging breaking waves are not expected.

4.8 Correlation wind – waves

Not analysed. Analyses will be based on wind and wave frequency distributions in Appendix 3 to Ref. /14/.

4.9 Water Level conditions

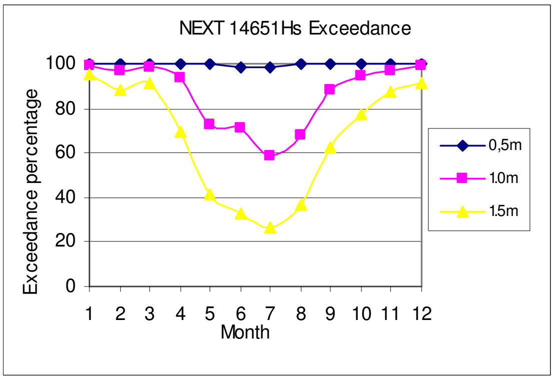
Highest astronomical tide (HAT), lowest astronomical tide (LAT) and storm surge level relative to mean sea level are listed in Table 4.2. See reference /14/.

Table 4.2 Water level conditions.

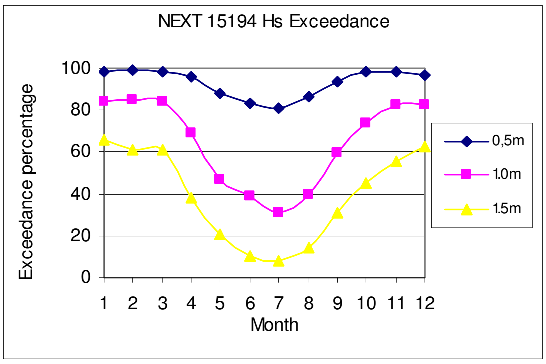
	HAT rel. MSL	LAT rel. MSL	Storm surge
Area	m	m	m
1	1.75	1.75	1.25
2	2.00	2.00	1.50
3	1.25	1.25	1.85
4	2.00	2.00	2.00
5	1.00	1.00	2.25
6	3.75	3.75	1.50
7	2.00	2.00	1.50
8	4.50	4.50	1.50
9	3.50	3.50	1.75

4.10 Operational waves

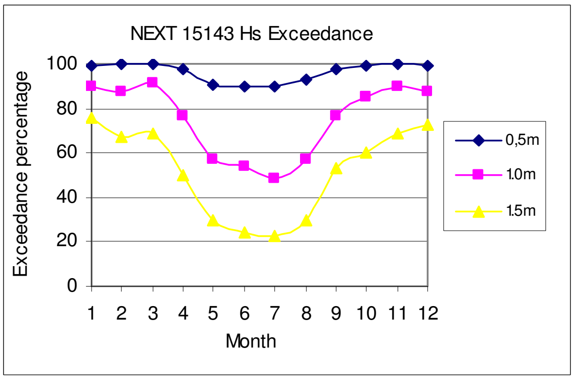
The exceedance percentage per month is described for $H_s > 0.5$m, $H_s > 1$m, and $H_s > 1.5$m:



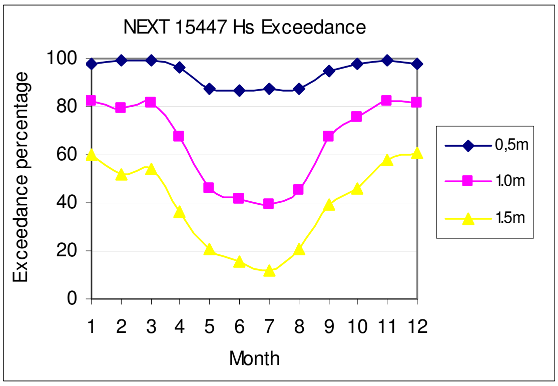
Area 1



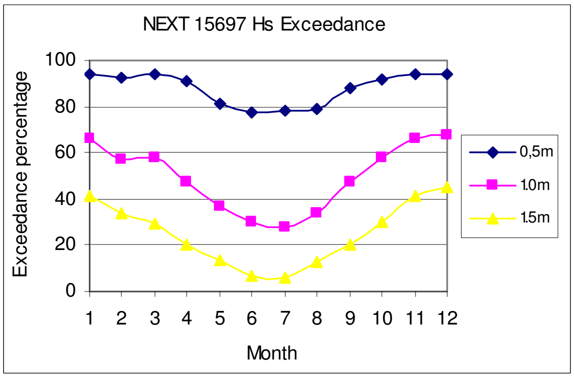
Area 2



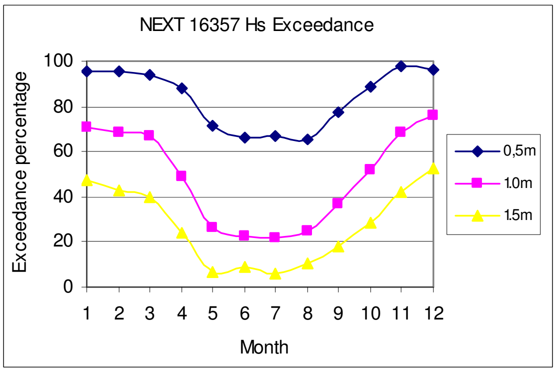
Area 3



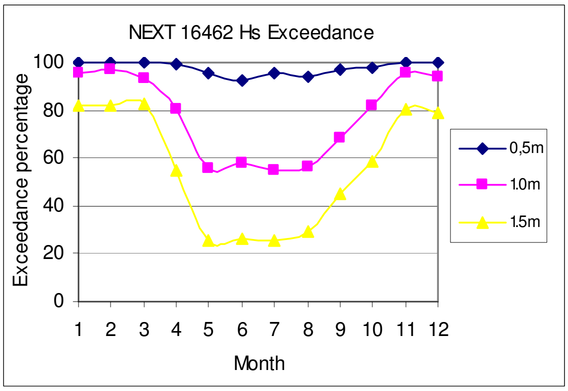
Area 4



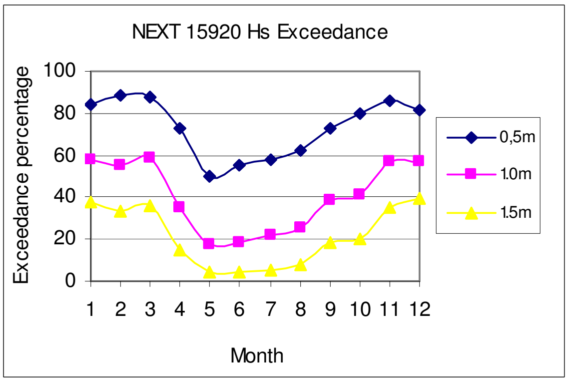
Area 5



Area 6



Area 8



Area 9

Figure 4.2 Exceedance of H_s per month. Area 7 is slightly more exposed than area 6.

4.11 Splash Zone

The splash-zone shall be taken between levels:

Upper limit
$SZ_U = U_1 + U_2$
U_1 = crest of $H_{s,1y}$ = approx. 0.60 $H_{s,1y}$
U_2 = HAT

Lower limit
$SZ_L = L_1 + L_2$
L_1 = trough of $H_{s,1y}$ = approx. 0.40 $H_{s,1y}$

L_2 = LAT

The results are given in Table 4.1.

4.12 Current speeds

Spring tidal amplitudes and spring tidal current speeds are obtained from /1/. The water level of 0.75(LAT+HAT) is used for the extreme wave height calculation where HAT is Highest astronomical Tide and LAT is Lowest astronomical Tide. The results are listed in Table 4.1.

4.13 Marine growth

The marine growth is presented in Table 4.4.

Table 4.4 Marine growth thickness

Depth below MSL [m]	Marine growth thickness [mm]
0 to 25	50
25 -	90

4.14 Water depth

Water level versus areas and risk for excessive slopes are listed in table Table 4.3

Table 4.3 Water depth, occurence of sand waves, risk of excessive slopes determined from sea charts and reference /14/.

Area	<30m	30-40	40-50	50-60	>60	Total	Sand waves	Excessive slopes
Unit	%/km^2	%/km^2	%/km^2	%/km^2	%/km^2	km^2		-
1	0	15/ 78	75/ 390	10/ 52	0	520	No sign	No risk
2	0	4/ 115	46/ 1320	46/ 1320	4/ 115	2870	Sand waves	No risk
3	45/ 3825	40/ 3400	10/ 850	5/ 425	0	8500	Probably at the western border	No risk
4	5/ 238	70/ 3325	10/ 475	10/ 475	5/ 238	4750	Sand waves	Possibility
5	3/ 177	50/ 2950	44/ 2596	2/ 118	1/ 59	5900	Sand waves	No risk
6	25/ 68	25/ 68	25/ 68	25/ 68	0	270	Sand waves	No risk
7	0	70/ 511	30/ 319	0	1/ 7	730	Smaller area with sand waves	No risk
8	1/ 10	50/ 480	20/ 192	28/ 269	1/ 10	960	Sand waves, heights up to 20 m.	No risk
9	0	29/ 624	50/ 1075	20/ 430	1/ 22	2150	Sand waves, heights up to 20 m.	No risk
Total km^2	4317	11550	7185	3157	450	26650	-	-
Total %	16	43	27	12	2	100	-	-

4.15 Updated Metocean Design Conditions (DHI data)

This chapter summarises the model data analysis results that Grontmij | Carl Bro has performed in /21/ which contains model data analysis based on the DHI hindcast model data between 1998 and 2007 for area 3 Dogger Bank, 4 Hornsea and 5 Norfolk. The note include also directional scatter diagrams, which may be used for structures sensitive to the directional wave distribution.

The main difference between the analysis of the DHI model data and the Offshore Technology Report 2001/010 data is that the DHI data analysis are based on water depths of 35 m, 45 m, and 55 m (in comparison the Offshore Technology Report 2001/010 model data analysis is based on respectively 30 m and 60 m water depths). Furthermore the extreme significant wave heights determined from the DHI data differs from the wave heights determined from the Offshore Technology Report 2001/010 model data ($H_s = 9.4$ m instead of $H_s = 13$ m for area 3 and $H_s = 7.5$ m instead of $H_s = 8$ m for area 5). This is also the case with the associated wave steepnesses.

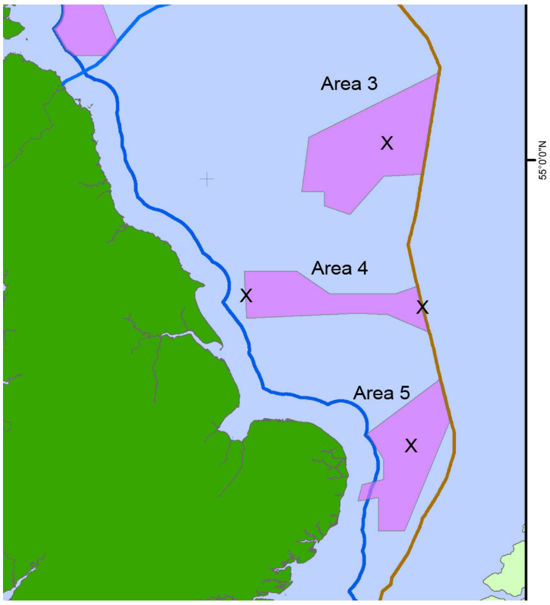


Figure 4.3 DHI model data extraction points (black crosses).

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Table 4.4 Main metocean design data. Wave data are based on DHI model data. *Exposed wind/weather climate **Average wind/weather climate.

	Wind			Tidal					Waves														
										3h/50y	3h/1y	3h/50y, h = 35m				3h/50y,h = 45m				3h/50y, h = 55m			
Area	$U_{10m,1h,50\,y}$	$U_{100m,1h,50y}$	$U_{100m,3s,50y}$	TR=HAT-LAT/MSL(rel LAT)	0.75TR	Avg. Spring current	Max. spring current	Splash Zone Upper/Lower rel MSL	Wave steep-ness	Hs/Tp	Hs/Tp	H_{max}	Crest ηmax/ umax	Run-up Rmax (rel LAT)	h_{LAT}	H_{max}	Crest ηmax/ umax	Run-up Rmax (rel LAT)	h_{LAT}	H_{max}	Crest ηmax/ umax	Run-up Rmax (rel LAT)	h_{LAT}
	m/s	m/s	m/s	M	M	m/s	m/s	M	s	m/s	m/s	m	m/ m/s	m	M	m	m/ m/s	m	m	m	m/ m/s	m	m
3*	37	48.5	61	2.5 1.25	1.9	0.4	0.55	6.7 -4.9	0.030	9.4 14.2	7.8 12.9	16.2	11.6 7.5	24.1	33.1	17.5	11.49 6.59	21.8	43.1	17.5	9.8 5.1	16.5	53.1
4 East	36	47	58	4 2	3	0.9	1.2	6.6 -5	0.040	8.2 11.5	7.1 10.7	15.0	10.0 6.7	20.2	32	15.2	9.22 5.52	16.7	42.0	15.2	8.7 4.77	14.6	52.0
4 West	36	47	58	4 2	3	0.9	1.2	6.6 -5	0.035	8.5 12.5	6.7 11.1	15.3	10.4 6.9	21.1	32	15.7	9.86 5.72	17.8	42.0	15.7	8.97 4.79	15.0	52.0
5**	34	44	55	2 1	1.5	1.2	1.54	4.4 -3.2	0.045	7.5 10.3	6 9.2	14.0	9.0 6.1	17.6	33.5	14.0	8.3 5.1	14.7	43.5	14.0	8.01 4.54	13.4	53.5

4.16 Updated Operational waves

The exceedance percentage per month is described for H_s > 0.5m, 1m, 1.5m, 2 m and 2.5 m:

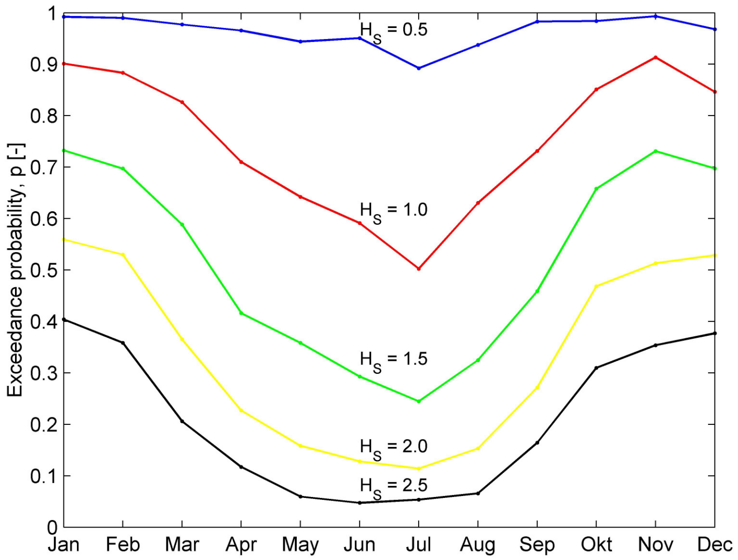


Figure 4.4 Operational waves Area 3

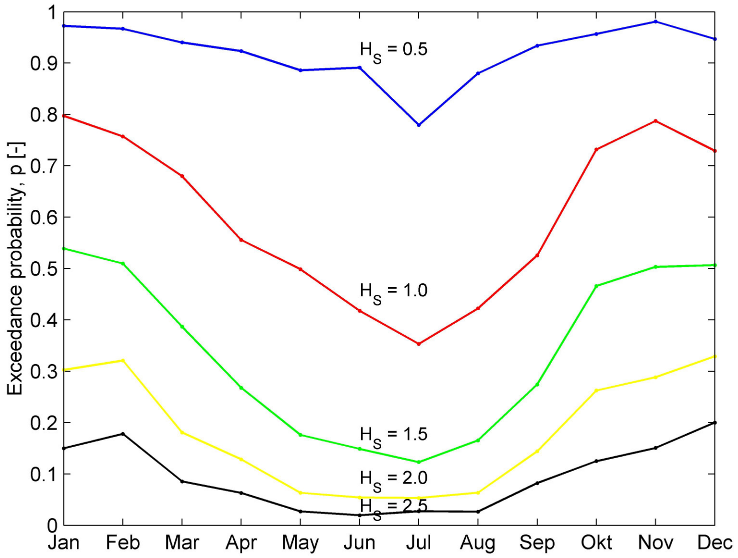


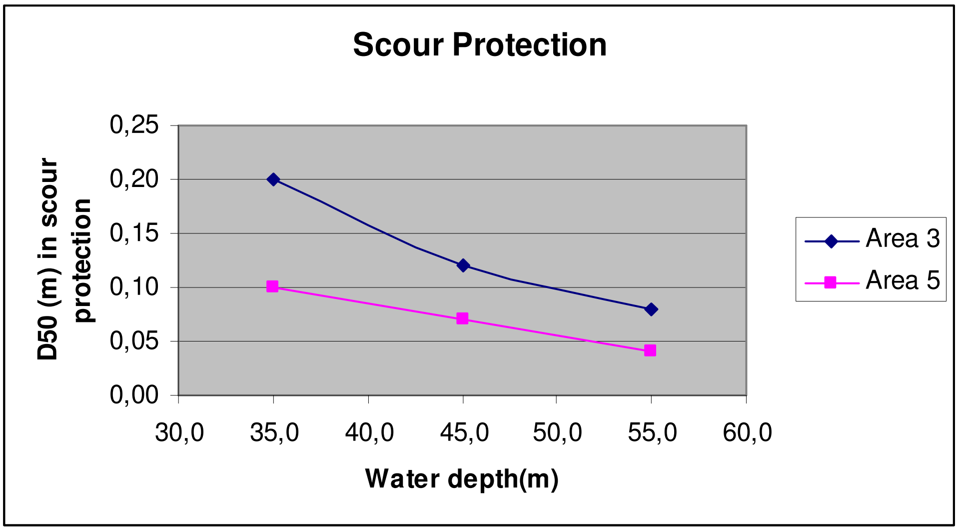
Figure 4.5 Operational waves Area 5

4.17 Sea bed stability

Preliminary estimates are given in chapter 5.

4.18 Scour

A rough scour analysis indicate that coarse gravel is sufficient for scour protection:



Figur 4.6 Estimate of Required stones in scour protection

In case no scour protection is provided the typical scour depth will not exceed 2.5 m. Tunnnel erosion in connection with horizontal members placed close to sea bed shall be avoided.

The required amount of scour protection can be estimated to be 3-5 m^3/m along diameter of structure.

4.19 General environmental data

A number of relevant environmental data are presented in the following.

Air density normal	1.24 kg/m^3
Air density extreme	1.28 kg/m^3
Sea water density	1 010 kg/m^3
Design air temperatures	–10°C < Tair,design < 35°C
Extreme air temperature /14/	–10°C < Tair,extreme < 26°C
Design sea temperature /14/	–2°C < Tsea,design < 24°C
The frequency of lightning striking ground (sea)	Ng = 0.5–1 per km^2 per year
Relative humidity	95%
Salinity of seawater /14/	35 ‰
Design solar radiation intensity	1 000 W/m^2

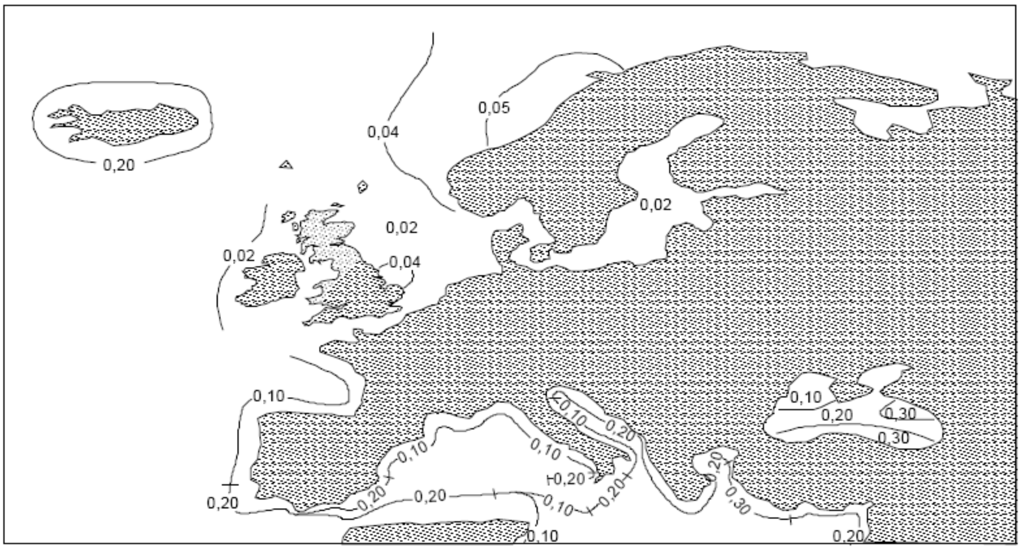
The atmospheric content of mechanical particles is equivalent of a non-polluted inland atmosphere (see IEC 60721-2-1).

4.20 Seismic conditions

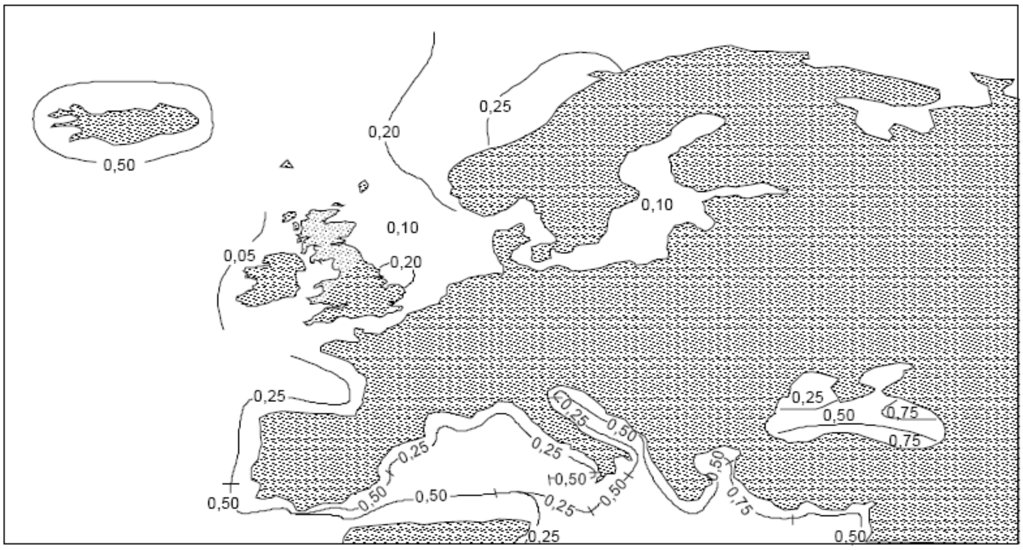
Reference /19/ provides the background for seismic conditions. Seismic conditions vary widely around the world, and the design criteria depend primarily on observations of historical seismic events together with consideration of seismotectonics. In many cases site-specific seismic hazard assessments will be required to complete the design or assessment of a structure.
Part of ISO 19901 (reference /19/) is intended to provide general seismic design procedures for different types of offshore structures, and a framework for the derivation of seismic design criteria.

Where a simplified design approach is allowed, worldwide offshore maps showing the intensity of ground shaking corresponding to a return period of 1 000 years can be applied. These maps may be used with corresponding scale factors to determine appropriate seismic actions for the design of a structure.

Regional information on expected seismic accelerations for offshore areas is provided in Figure 4.7.



a) 1,0 s oscillator periods



b) 0,2 s oscillator periods

Figure 4.7 5 % damped spectral response for offshore Europe. /19/

5 SOIL CONDITIONS

5.1 Geology of the areas

The geology within area 1 is described and illustrated with figures, while the rest of the areas are described in words. Area 1 serves as an example.

In the technical background report ‘Soil design conditions’ reference /18/ all of the areas are described by geological illustrations. The geological descriptions are mainly based on reference /16/ and /17/.

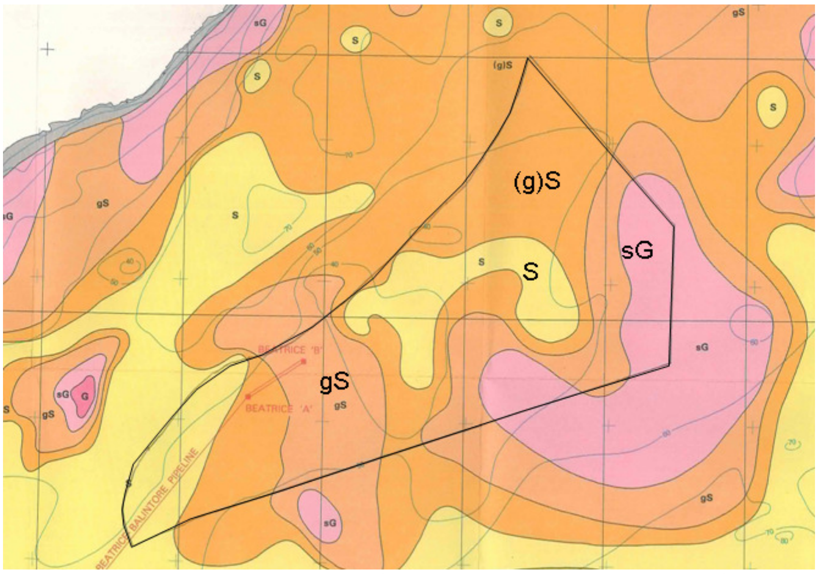
5.1.1 Area 1 (including geological illustrations)

Holocene marine materials and recent mobile materials

Holocene unconsolidated sea-bed sediments are present with a thickness of one to just above two metres. The sediments categorise mainly as slightly gravely to gravely sand with parts of sand and sandy gravel (see Figur 5.1).

Present sediment input from land is small and most sea bed sediments are reworked from older, particularly Pleistocene deposits.

The gravels in the area may have very high shell content, and the gravels are reported to have a carbonate content between 80 and100%.



Figur 5.1 Sea bed sediments. Area 1. S: Sand; (g)S: Slightly gravely sand; gS: Gravely sand; sG: Sandy gravel; G: Gravel. /1/

<u>Quaternary sediments</u>

The Quaternary sediments have a thickness of about 10-20 m, but in a circular area close to the north western border the thickness varies from 20 m to less than 40 m (see Figure 5.2).

The Pleistocene deposits vary from late glacial very soft mud to probably glacial compact clays with scattered pebbles (till). The soft mud occurs in the upper part of the Pleistocene deposits and are generally less than 10 m thick (see Figure 5.3).

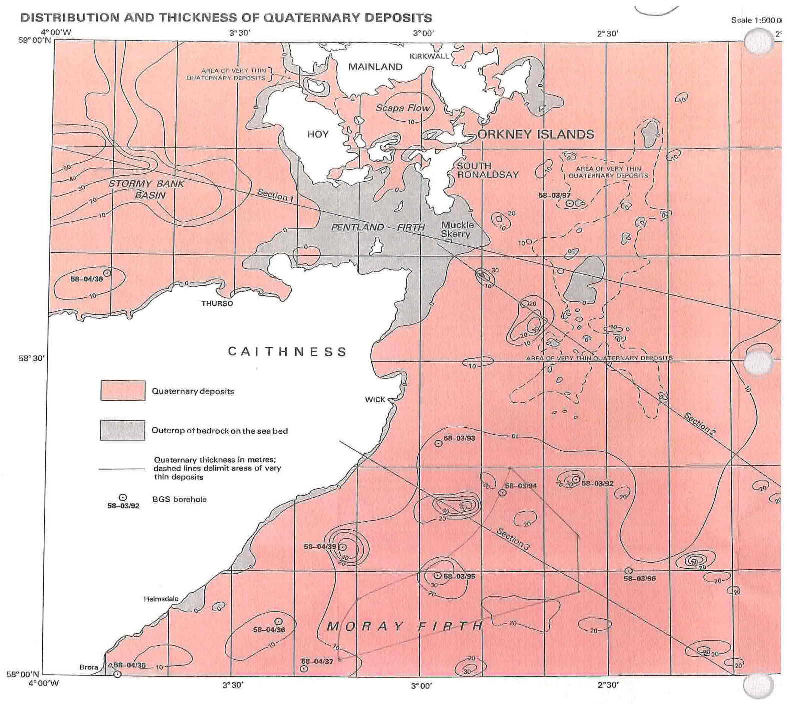


Figure 5.2 Thickness of Quaternary sediments, area 1. /1/

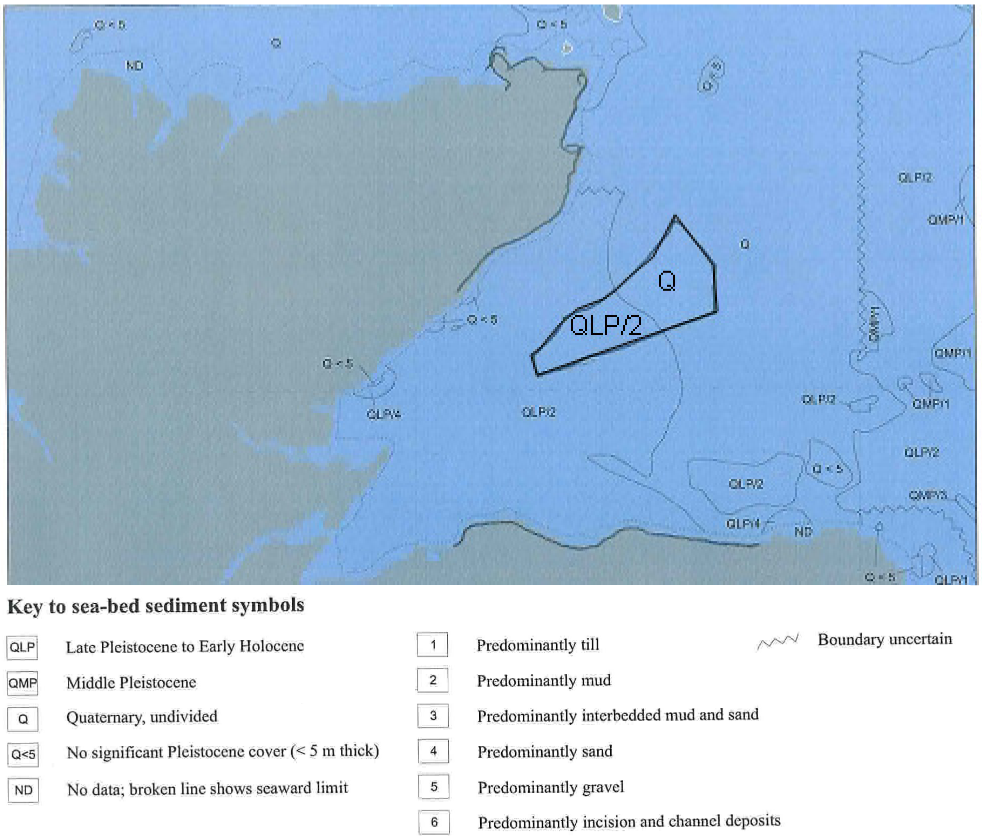


Figure 5.3 Pleistocene deposits, area 1. /2/

Pre-quaternary sediments

The pre-quaternary sediments are entirely represented by Lower Cretaceous deposits with a thickness of several hundred metres to more than a kilometre (Figure 5.4). They are described as argillaceous shale, siltstone, calcareous sandstone and thin limestone. The area is crossed by big fracture zones.

Figure 5.4 Pre-quaternary deposits. kl: Lower Cretaceous; Fz: Fracture zone. Area 1. /1/

5.1.2 Area 2

Holocene marine materials and recent mobile materials

The sea bed is mainly covered by slightly gravelly to gravelly sand, sand, minor parts of sandy gravel and a few spots of muddy sand. These sediments have a general thickness of about 0.0 – 0.5 m. The sea bed is dominated by areas of sediment transport parallel to the dominant tidal currents. Sand waves, which can move several metres a year, are reported in the southern part.

Quaternary sediments

The Holocene deposits are underlain by Pleistocene or Late Pleistocene to Early Holocene sediments. Sediments of the Marr Bank Formation represent the topmost Pleistocene deposits in the greater part of the western area and the Wee Bankie Formation dominates the eastern part. Upon these formations sediments of the Forth Formation are scattered as blanket spreads or infill of earlier channels, especially in the eastern part.

Sediments of the Forth Formation are described as fluviomarine *sand*, fine grained, well to poorly sorted, soft to firm, olive to grey brown, with lithic pebbles, shell and shell fragments in variable amounts and a maximum thickness of 95 m.

Marr Bank Formation is characterised by glaciomarine *sand*, fine grained, poor to well sorted, soft to firm, grey to red brown, with abundant lithic granules and pebbles. Locally silty to muddy, with a thickness of 10-25 m.

Sediments of the Wee Bankie formation are described as *boulder clay* (basal *till*), hard, dark grey to red brown, gravelly, angular to rounded clasts, with thin interbeds of sand and pebbly sand. The thickness is generally less than 20 m but locally exceeds 40 m.

Total thickness of the Quaternary deposits is about 10-25 m with a few infill of 30-80 m.

Pre-quaternary sediments
Pre-quaternary deposits are mainly represented by sediments of the Triassic Group. Deposits of the Zechstein Group are seen along the south western border together with a patch of carboniferous deposits.

Sediments of the Triassic Group are described as red *sandstones*, *siltstones*, *mudstones*, and *marls*, with sporadic thin bands of *gypsum* and disseminated pseudomorphs after *halite*.

The Zechstein Group is characterised by grey argillaceous *limestone*, *anhydrite*, *halite* and *polyhalite*.

Halite, gypsum and anhydrite can be dissolved while buried underground, causing the disturbance and collapse of overlying beds.

The carboniferous deposits are described as *mudstone*, *sandstone*, *limeston*e, *shale* and occasionally with *coal seams*.

5.1.3 Area 3

5.1.4 Holocene marine materials and recent mobile materials

The sea bed is mainly covered by slightly gravely sand, sand and in two areas at the western border by sandy gravel to gravel.

Holocene sediments cover the entire area, are generally less than 1 m thick and often in the range of 0.1 m – 0.2 m. In the south eastern part sediments reach a thickness of 5-20 m. Maximum thickness of 15-30 m in the linear depressions (channel infill) have been reported.

Most part of area 3, found on the Dogger and Silver Well maps, shows Holocene sediments of the Terchellingebank Member, which probably also dominate the rest of area 3. These sediments are described as fine to medium *sand* with shell remains of an open marine to near shore mollusc fauna.

Grey, muddy, shelly *sand* interbedded with clay and containing *peaty organic detritus* or *peat* (Elbow formation) is found in scattered patches in the south eastern part of the area.

The thin and mobile Holocene sediment cover is reported to form low amplitude bed forms and at the western border bed forms standing as much as 5 m above the surrounding sea bed have been observed. Just outside the area, close to the western border, tidal sand ridges related to earlier sea level and recent mobile, linear sand banks are reported to stand as much as 25 m above the surrounding sea bed.

Quaternary sediments

The Holocene deposits are underlain by Pleistocene or Late Pleistocene to Early Holocene sediments. Sediments of the Dogger Bank Formation almost represent the entire topmost Pleistocene deposits of the area. Small areas of the Botney Cut Formation and the Yarmouth Roads Formation are present at the northern border.

Sediments of the Dogger Bank formation are described as proglacial deposits, partly glaciomarine and partly glaciolacustrine. They are represented by greyish, stiff to very stiff, waterlaid *clays* with silt laminae, scattered pebbles and layers of rippled fine to very fine sands. Channelled, horizontal bedding is locally present, and towards the north western border large channels interpreted as ice marginal features, become increasingly well developed. The clays filling these channels are lithologically identical to other clays of the Dogger Bank Formation, but are differentiated as the Volans Member.

The formation is about 40 m thick, locally up to 60 m thick in the filled in channels.

The lower part of the Botney Cut formation is represented by firm to stiff reddish brown *diamicton* with interbedded sand and the upper by a soft, grey and greyish brown, slightly sandy and pebbly *mud*. The filled valleys can be as much as 200 m deep.

The Yarmouth Roads formation at the northern border consists of compact *sands* with abundant *organic matter* and *stiff*, dark grey marine *clays*. It is about 150-200 m thick.

Pre-quaternary sediments
The pre-quaternary deposits are covered by Quaternary sediments with thickness of more than 100 m and in general by several 100 meters.

The topmost Pre-quaternary deposits of the northern part are represented by Pliocene *clays* with some *sand/sandstone, limestone* and *lignite*. In the central part Oligocene to Miocene *clays* and *mudstones* with thin beds of limestone are present, and in the southern part Palaeogene to Eocene deposits of silty *clays* and silty *mudstones are observed*.

5.1.5 Area 4

Holocene marine materials and recent mobile materials
The sea bed is mainly covered by *sand* and *slightly gravelly to gravelly sand*, but at the southern border and in the eastern part areas of *sandy gravel* are also present. In the eastern part two elongated areas with *muddy very fine sands* or *very soft mud* fill in glacial formed valleys reaching a thickness of about 20 m.

The Holocene sediments cover the entire area and apart from the eastern filled in valleys they almost exclusively rest upon glacial till deposits. The Holocene sediments have a general thickness of 1-3 m.

In the western part large areas with abundant migrating sand waves with amplitudes up to 8 m are observed. In the same area mobile linear sandbanks can reach up to 25 m in thickness.

Quaternary sediments

The Holocene sediments are underlain by Pleistocene deposits. Sediments of the Boulder Bank Formation almost represent the entire topmost Pleistocene deposits of the area. Smaller areas of the Botney Cut Formation, Eem Formation and Yarmouth Roads Formation are present in the eastern part. A few smaller areas of mostly Mesozoic deposits are present at the western border, where the Quaternary deposits are rather thin.

Sediments of the Boulder Bank Formation are described as a glacial, blanket *till* deposit. In general it comprises a firm to stiff clay which may be sandy, silty, calcareous or non calcareous. It is generally rather homogeneous clay. The thickness is reported to vary between less than 2 m to about 20 m, thinning to the west.

The sediments of the Boetny Cut Formation were deposited in up to 80 m deep valleys formed during glacial time. The lower unit is described as gravelly coarse *sand*, 15 m thick and the upper as very soft slightly sandy *mud*, 35 m thick and of glaciolacustrine origin. Areas of acoustic blankning in seismic profiles indicate that the sediments are locally gas-charged.

The Eem Formation consists of very fine to medium grained, slightly gravelly, shelly marine *sands*.

In the eastern part the above mentioned deposits are mostly underlain by the up to 150 m thick sands with interbedded silty *clay* of the Yarmouth Formation, which may include reworked *peat*. Channel fill of the Swarta Bank Formation, generally between 100 to 250 m thick, is also covered by the above mentioned deposits in some areas, especially in the eastern part. The lower part of these sediments consists of poorly sorted, gravelly coarse *sands* and the upper part of glaciolacustrine *clays* with silty laminae and bands of sand and silt.

The thickness of the Quaternary deposits varies from 0 m at the western border to about 300 m in the eastern part.

Pre-quaternary sediments
In the eastern part the topmost Pre-quaternary deposits generally are covered by more than 100 m of quaternary sediments. The Quaternary deposits thin towards the western border where they are missing in some places.

The eastern part is dominated by Eocene marine *clays* with smaller areas of Oligocene to Pliocene marine sediments and Upper Cretaceous white *chalky limestones* .
The Western part is characterised by Upper Cretaceous white *chalky limestones* of the Chalk Group and a variety of Jurassic deposits such as *shales*, *sandstones*, *mudstones* and *siltstones* with beds of evaporitic *anhydrite* and *halite* together with some *dolomite*. Smaller areas with Lower Cretaceous marine calcareous *mudstones* and *chalky limestones* are also present.

Jurassic and Cretaceous deposits generally are much thicker than 100 m and are in three areas penetrated by Permian *salt diapers*.

5.1.6 Area 5

Holocene marine materials and recent mobile materials

The sea bed is mainly covered by slightly gravely to gravely sand, areas of sand, minor parts of sandy gravel and a few areas with muddy sand to muddy gravel.

The Holocene has a maximum thickness of 25 m in tidal sand ridges in the north-west, and sediment thickness is particular variable in the fields of mobile sand waves. In these areas, the Holocene therefore has been measured from the top of underlying Pleistocene sediments to sand wave base and represents an estimate of the minimum thickness of superficial deposits. Between the areas with sand waves the Holocene cover is rather thin.

The sand waves have heights from 2-12 m. In the northern part they are underlain by fine to very fine grained muddy sands with interbedded clay of the Holocene Elbow Formation, covering a discontinuous peat bed up to 1 m thick.

Quaternary sediments

The Holocene deposits are underlain by Pleistocene sediments. Sediments of the Brown Bank Formation represent the topmost Pleistocene deposits in the greater part of the area. These sediments are generally described as brackish-marine, grey-brown, silty clays, extensively bioturbated and locally cryoturbated (disturbed by frost), with thin interbeds of shelly gravely sand towards the base. In the east these sediments pass upwards into lagunal or lacustrine laminated clays. Fluviatile silts and finely laminated clays, filling channels up to 20 m deep, are seen in the southern part. The thickness of the formation is generally about 5-10 m, but in a cross section of the area it is about 15-25 m. The formation thins towards its southern and western boarders. In the eastern part areas of acoustic blanking on seismic records, attributed to the effect of gas-charged sediments are seen.

The Brown Bank Formation is underlain by the up to 100 m thick deposits of the Yarmouth Roads Formation. The formation is characterised by fine- or medium-grained non calcareous sands, with variable clay lamination and sometimes deposited in poorly defined channels. There may be local intercalations of reworked peat. The formation represents the topmost Pleistocene deposits in the southern area, where marine coarse- to more or less muddy and fine- grained sands, silts and clays of Lower Pleistocene also top the Pleistocene deposits.

In the north western part fine- to medium- grained shelly marine sands with laminae and interbeds of silty clay of the Eem Formation represent the topmost Pleistocene deposits. It is up to 30 m thick. The same area shows longitudinal deposits of fine-grained, wind blown periglacial sands of the Twente Formation, most of which is less than 1 m thick.

Pre-quaternary sediments

The Pre-quaternary deposits are covered by Quaternary sediments with a thickness of more than 100 m in most of the area. Only in the most southern part the thickness is between 0-100 m. Here the topmost Pre-quaternary is dominated by shelly, fine-grained marine sands of the Red Crag Formation, with a reported maximum thickness of 70 m. The topmost Pre-quaternary deposits in the rest of the area are dominated by Eocene marine clays.

5.1.7 Area 6

The zone 6 – Hastings – is located in the economical zone of United Kingdom just inside the limit of territorial waters 12 nautical miles from the coast line in the English Channel south of Brighton and around 50 km east of Isle of Wight.

In the west-eastern direction it extends about 30 km, and in the north-southern direction it extends 15 km approximately, covering a total area of approximately 270 km^2.

According to available sea charts the water depths in the area are generally between 22 and 59 m – measured at lowest astronomical tide (LAT). With a variation from LAT to Highest Astronomical Tide (HAT) due to the tide of 7.5 m the water depths will have a maximum twice a month in the range of 30 m approximately to almost 70 m.

As a rough estimate 30 % of the total area has 30 m water depth or less, 40 % has a water depth between 30 and 50 m, and 30 % has a water depth extending 50 m (With reference to LAT).

The site can be described as extremely demanding due the unsheltered location at high water depths heavily exposed to waves and wind.

The predominant directions of waves and wind are SW to WSW giving the waves a free run from the Atlantic entering into the English Channel.

In table 8.1 below, the corner points of the wind farm area are shown. According to “Crown Estate” the coordinates can be subject to revision.

Soil conditions

Data in the area are scarce since the area is situated outside the Sussex Sea fisheries District Boundary and inside the gravel dredging zones. Both areas are investigated and data are available regarding sea bed conditions. However no deeper data are readily available.

Based upon the structure of the sea bed top layers and the morphology of sandy areas, the wind farm area is not expected to be stabile in the wind farm’s lifetime. This is mainly due to migrating sand waves on the sea bed. The height of these sand waves is unknown, but there are indications that the height is several meters, maybe as much as 5 m or even higher.

According to the British geological Survey, minor work has been conducted in 1976 and again around 2005. These data are not available for this study since ordered materials did not arrive on time.

The following is based on the present available data.

Geology of the area

The geology consists of cretaceous sedimentary bedrock overlain by sand and gravel. The sea bed is dominated by sand and gravel with strongly movable top layers.

The geology in the area can be subdivided into 3 units:

- Holocene marine sediments and recent mobile materials

- Quaternary sediments
- Pre-quaternary sediments

Holocene marine materials and recent mobile materials
Holocene marine sediments are present with a thickness up to 20 m, but over large areas especially towards north less than 0.5 m occurs. The sediments are categorised as sands.

The thin layers of marine materials consist of relict materials too coarse to be mobilised by the tidal currents. Much of this is believed to be flint shingles. On top of these materials are extensive areas of sand waves. In the below, the sediment types are described. The sea bed map describes the sea bed character and gives some indications of the occurrence of sand waves.

The mobile recent sediments consist of well rounded medium to coarse grained sand, mainly placed in sand waves. These units are abundant in the area. Height of the sand waves is described by the British Geological Survey having maximum amplitude up to 15 m in the eastern part of the area. The amplitude is diminishing with water depth and maximum tidal streams, i.e. towards north.

The movement of the sand waves is indicated to be up to 60 m/year. The distance between the sand waves is indicated to be around 200 to 480 m. Movement of the sand waves is to the east.

Quaternary sediments
Quaternary sediments are found mainly in the paleo-valleys in the pre-quaternary sediments. These materials are normally a complex layering of sand, silt, clay and gravel. Organic beds can be present. The occurrence of these materials can be seen.

The thickness of these sediments is highly variable and can be as much as 30 m.

Pre-quaternary sediments
In the northern part of the area, the pre-quaternary deposits consist of Eocene (Ypresian) clays, belonging to the Wittering Formation. The clays are interpreted as a marginal marine deposit described as organic rich clays and laminated clays with autochthonous lignite layers. Weak sandstone layers is described within this formation. There is described pipe clay beds in the formation indicating low activity clays.

In the southern part of the area Eocene (Lutetian) sands, silts and clays of the Marsh Farm Formation occur. Possibly Earney Sand Formation is found between the two Eocene formations.

The thickness of the Tertiary deposits is in general more than 100 m.
In the eastern part of the area the Pre-quaternary sediment is an upper cretaceous limestone. Here the materials are mainly ISRM rock grade R1.
On the basis of photographs the maximum thickness of flint in the limestone is estimated to 30 cm.

The thickness of the upper Cretaceous material is more than 100 m.
The pre-quaternary deposits are folded in a gentle syncline from Shoreham to just offshore from Beachy Head.

During glacial times sea level was much lower than today. During these low stands, erosion occurred leading to the formation of paleo-valleys more or less Perpendicular to the coast line. The maximum depth of these valleys was determined by the sea level, which was app. 50 m below present day sea level.

When an area such as this is submerged by the sea, the bedrock will tend to be eroded strongly until a hard surface is reached. In this instance, the rise of sea level at the entrance to Holocene was rapid and it is not believed that mayor hard grounds were developed, but unlithified silts and sands were eroded away.

5.1.8 Area 7

Holocene marine materials and recent mobile materials
Holocene unconsolidated sea-bed sediments occur in layers with a thickness of only 0.0 – 0.5 m and areas of sediment free bedrock are also present.

The sediments are coarse winnowed deposits, lag deposits, dominated by sandy gravel and gravel which probably consist of pebbles of flint, chalk, sandstone, limestone and ironstone, derived from underlying bedrock.

In a greater part of the area longitudinal gravel furrows have formed in the gravel layer, parallel to the direction of tidal current.

A smaller area with sand waves is present in the northern part of the area. Sand waves can move several metres a year.

Quaternary sediments
The Pleistocene ice sheet did not cross the area, and quaternary deposits are limited to non-glacial infill of former valleys eroded during periods of lower sea level during glacial time. The maximum depth of these valleys was determined by sea level which was app. 50 m below present sea level.

Such infill are normally a complex layering of sand, silt, clay and gravel. Organic beds may be present.

Pre-quaternary sediments
In the northern part of the area the pre-quaternary deposits chiefly consist of Lower Gretaceous (Aptian to Albian) sands and sandstones of various grades interbedded in part with clay, siltstones, mudstones, ironstones and limestones of mainly marine derivation. Plant debris and chert horizons have been described in a few of the deposits. The sediments are classed with the Lower Greensand and Selborne Groups and have a thickness of about 60 m in the area.

In the southern part of the area the pre-quaternary deposits chiefly consist of Upper Cretaceous (Cenomanian) clayey ('marly') chalk without flint, classed with the Grey Chalk Subgroup, covering the above mentioned deposits. The deposits in the southern part can reach a thickness of about 40 m. The lower part consists of soft, marly chalk and a hard limestone arranged in couplets, with intercalations of weakly cemented sandstone. The upper part mostly consists of firm, blocky chalk with a lower part characterised by rhythmic alternations of marls and marly chalks with firm chalk.

Well developed hardgrounds do occur and the deposits may be topped by a generally hard nodular chalk with flint layers.

5.1.9 Area 8

Holocene marine materials and recent mobile materials
Holocene unconsolidated sea bed sediments are present with a thickness up to 20 m in the central part of the area. The sea bed sediments in the western part are dominated by slightly gravelly to gravelly sand with sandy gravel in some places. In the eastern part sandy gravel to gravel and areas of muddy sandy gravel are the dominating sediments. Areas with outcrop of bedrock are also present in the eastern part. Most of the central area is covered by sand waves with heights up to 20 m, though more commonly heights are 12-14 m and the distance between them varies on average from 1-1.5 km. The sand waves are more or less perpendicular to the principal ebb and flood currents and the crest length ranges from 1-7 km /6/.

In the western part the sediment cover is generally thin (0-0.5 m) and dominated by sand, covering bedrock. Areas covered by muddy sand with an aggregated sediment thickness up to 5 m are observed.

The eastern part is covered by a thin layer (0-0.5 m) of gravel and muddy gravel, which covers the bedrock in large parts of the area. Areas covered by muddy gravel with an aggregated thickness up to 5 m are also present.

In areas with a thin sediment cover and strong currents one might expect a layer of coarse sediment closest to the more or less barren bedrock.

Sand waves are normally mobile and can move up to several metres a year. But the number, position and heights of the large sand waves in the area seam not to have changed significantly in the period from 1977 to 2003, /6/. Only the top metre of the sand waves is apparently mobile. If however there is a significant change in strength and/or direction of the prevailing current the sand waves must move.

Quaternary sediments
The last major ice sheet did not cover the area, but it might have been crossed by earlier Pleistocene ice sheets. Only at the western border of the area sediments are resting on till deposits. Therefore the Holocene sediments in the area probably rest on older bedrocks of Mesozoic age, or at least deposits older than the latest major ice sheet.

Pre-quaternary sediments

In the northern part of the area the pre-quaternary sediments consist of Triassic red mudstones and siltstones with rare sandstones and with a thickness about 200 m. Anhydrite and gypsum veins are present. A thick salt sequence in the Triassic deposits has been reported in a borehole about 30 km west of the area.

Lower Cretaceous deposits of varicoloured clays and sandstones with brecciated lignites and rootlet beds is encountered south of the Triassic area. The deposits have a thickness in the range of a few metres to 400 m.

Most of the area shows Upper Jurassic deposits of grey mudstone with limestones towards the top and sandstones in the middle section. The eastern part of the area is however dominated by Lower Jurassic deposits of grey calcareous mudstone and limestones. Thin sandstones are observed in the middle part of these deposits and limestone / mudstone rhythms in the lower. The thickness of the Jurassic deposits is in the range of about 150 m to more than a kilometre.

At the southern border of the area clays with lignits of Oligocene age are observed.

5.1.10 Area 9

Holocene marine materials and recent mobile materials
Holocene unconsolidated sea bed sediments are present as sand waves and sand carpets with a thickness up to 20 m in the most westerly part of the area. The remaining part is dominated by rather thin and coarse lag deposits, ranging from gravely sand over sandy gravel to gravel. The lag deposits are often topped by a thin and movable sand layer. The underlying geology consists of Quaternary deposits, which can be seen at some barren areas of the sea floor.

The medium to coarse grained sand waves are described by the British Geological Survey as having heights from 2 to 20 m. Sand waves can move several metres a year.

Quaternary sediments
According to British Geological Survey the thickness of the Quaternary deposits lies in the interval 0-50 m. The Pleistocene sediments are almost entirely made up of till deposits, occasionally with lacustrine sediments. In the eastern part the till is described as 5-15 m thick and up to 25 m thick in isolated pockets. A drilling from the western part shows about 40 m of drift deposits. The till is generally dominated by gravel lenses in the upper parts. A few areas with predominantly Pleistocene mud and sand deposits are present.

Pre-quaternary sediments
About fifteen boreholes scattered over the area and geological maps of solid rock show till-/ drift - deposits covering mainly Carboniferous mudstone, siltstone, occasionally sandstone and black shale.

Permian – Triassic mudstone, sandstone, and in one borehole gypsiferous marl are seen at the western border and in the northern part of the area.

A minor area with Lower Palaeozoic deposits is present at the southern border.

6 INTRODUCTION TO DESIGN BASIS

The design basis in the present version is to be used by the foundation designer in connection with the conceptual design for OWA wind turbine foundations for Round 3 areas around UK.

The foundation designer may choose to comply fully or partly with the design basis.

Deviations shall be stated in details. Proposed deviations from the Design Basis shall be discussed and agreed with TDC.

The design basis applies for foundation concepts that include:

- Concrete Gravity Base Structure (GBS)
- Steel monopile (piled structure)
- Jacket structure (piled structure)
- Concrete or steel tripod (piled structure)

Some of the specifications are only relevant for one or more of the foundation types. This is indicated by the leading text of either

- GBS
- Monopile (piled structure)
- Jacket (piled structure)
- Tripod (piled structure)

In certain cases common specifications for both monopile, jacket and tripod are given under the term Piled Structures.

The design basis includes a level of detail sufficient for the following:

- Conceptual design of foundation
- Conceptual design of appurtenances
- Specification of materials
- Specification of safety levels

The level of safety shall match the level presently achieved for land based wind farms. This shall be accomplished by using the codes specified in sub-clause 6.1.1. All demands, requirements and prerequisites shall be met when designing the foundations including any temporary structures and designs such as lifting points etc.

6.1 Design principles

6.1.1 Codes and standards

The Design Basis is based on IEC 61400-3 and DNV-OS-J101 Design of Offshore Wind Turbine Structures/GL Guideline for certification of offshore wind turbines.

The overall hierarchy of the documents is given below and shall be governing for the design. All documents shall be used in the latest edition unless stated otherwise in the Design Basis.

Regarding Steel structures:

- Design Basis for Foundations (this document).
- IEC 61400-3: Design requirements for Offshore Wind Turbines.
- DNV-OS-J101: “Design of Offshore Wind Turbine Structures”, 2007 or GL Guideline for certification of offshore wind turbines (latest version).
- EuroCode no. 3: “Design of Steel structures”

Regarding Concrete structures:

- Design Basis for Foundations (this document)
- EC 61400-3: Design requirements for Offshore Wind Turbines
- DNV-OS-J101: “Design of Offshore Wind Turbine Structures”, 2007 or GL Guideline for certification of offshore wind turbines (latest version)
- DNV-OS-C502: “Offshore concrete Structures”, July 2004
- EuroCode no. 2: “Design of Concrete structures” 1992-1-1

In case of conflict between the requirements, the above ranking shall be used.

6.2 General design conditions

The design of the foundations shall ensure a lifetime of 25 years in every aspect without planned replacement. The choice of structure, materials, operation and inspection programme shall be made accordingly.

Fatigue loads are to be based on repetition over 25 years.

Climate loads such as wind, waves etc. shall be determined based on a recurrence period of 50 years.

The safety of the foundation design should usually be implemented according to the partial safety factor method. In case the design is based on a recognised offshore standard like /3/ using different principles it should be verified that the same target safety is obtained.

7 CO-ORDINATE SYSTEM

All references shall be made according to the co-ordinate system presented in Figure 7.1 below. Origin (0, 0, 0) is located in the centre of the turbine tower at level +0.0 relative to LAT). Interface between foundation and tower is found at level LAT + 20 m.

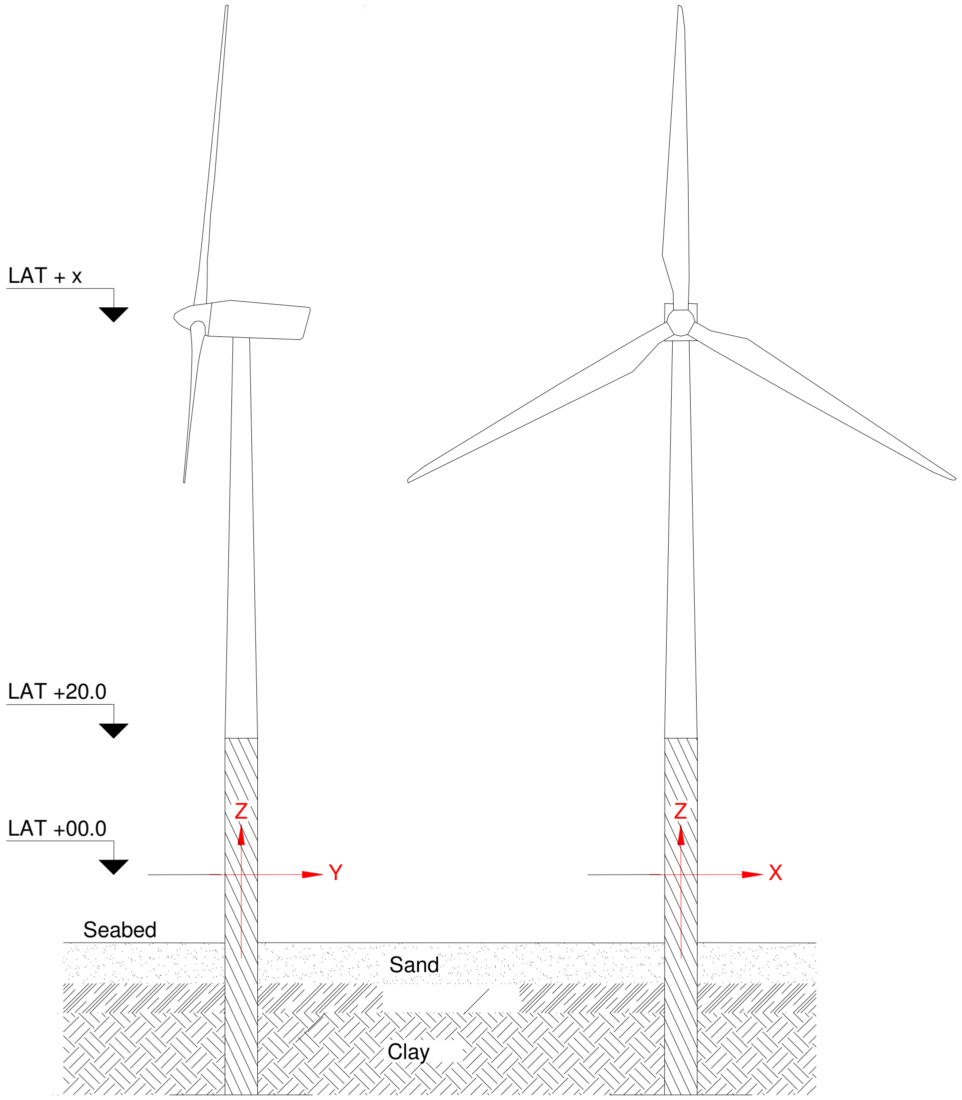


Figure 7.1 Reference co-ordinate system

8 WIND TURBINE

8.1 Wind Turbine layout

For the concept design two turbine sizes shall be investigated: 3.6 MW and 5 MW.

Table 8.1 presents the main parameters for the reference wind turbines and towers. The wind turbine is pitch and frequency regulated. Clearance to the blade tip at MSL is 23 m. Foundation loads in the Design Basis are based on the reference turbines.

Table 8.1 Initial Reference turbines

Turbine size	3.6 MW	5 MW
Output power	3.6 MW	5 MW
Rotor diameter	106 m	126 m
Foundation – tower interface level rel. LAT	20 m	20 m
Hub height above foundation interface = x	72.5 m	82.5 m
Nacelle mass incl. Rotor	220 tons	410 tons
Tower top diameter/wall thickness	3.5 m/15 mm	4.5 m/20 mm
Tower bottom diameter/wall thickness	4.5 m/30 mm	6.0 m/35 mm
Tower mass	220 tons	300 tons

During the study it became apparent that the specified tower was rather soft requiring unreasonable stiffness to the foundation. Therefore it is also allowable to apply the design data in Table 8.2.

Table 8.2 Updated Reference turbines

Turbine size	3.6 MW	5 MW
Output power	3.6 MW	5 MW
Rotor diameter	106 m	126 m
Foundation – tower interface level rel. LAT	20 m	20 m
Hub height above foundation interface = x	67.5 m	77.5m
Nacelle mass incl. Rotor	220 tons	410 tons
Tower top diameter/wall thickness	3.5 m/15 mm	4.5 m/20 mm
Tower bottom diameter/wall thickness	4.5 m/40 mm	6.0 m/45 mm
Tower mass	190 tons	300 tons

9 COMBINED LOADS

Combined loads have been found according DNV-OS-J101 for load cases in four categories:

ULS	Ultimate Limit State analyses
ALS	Accidental Limit State analysis
SLS	Serviceability Limit State Analyses including natural frequency analysis
FLS	Fatigue Limit State Analysis including pile driveability

The above load cases have been investigated for the present structure. The result is summarized in three situations in the Design Basis:

ULS loads
ALS loads
FLS loads

GBS: Loads for calculation of crack width are found in sub-clause 10.7.

9.1 Load factors

Load factors according: IEC 61400-3 are used, as follows:

Environmental ULS load:	1.35
Environmental ULS load (abnormal wind load):	1.10
Environmental ALS load:	1.10
Environmental FLS load:	1.00
Gravity Load (using conservative estimates)	1.00

The governing load for the foundation will be environmental load from wind, wave and currents.

The ULS load factor for waves may be reconsidered when the final foundation has been selected.

In the following design loads are specified – load factors are applied where applicable.

9.1.1 Foundation groups

The Present version of Design Basis only include estimates of Design Forces for 2 water depths (30 m and 60 m) and only for three structures (cone gravity structure, monopile, jacket)

9.2 Turbine loads

Table 9.1 Turbine loads

Turbine design loads		Wind/wave climate	Vertical load	Extreme loads		Fatigue loads M = (4-5) N: 1 x 10^7		
Tower bottom	Level rel LAT[m]		[MN]	F_ex [MN]	M_ex [MNm]	F_eq [MN]	M_eq [MNm]	T_eq* [MNm]
3.6 MW	20	Average	4.4	1.42	89.9	0.35	19.2	3.5
5.0 MW	20	Average	7.1	2.03	150.0	0.49	28.1	5.1

* Preliminary estimate: 0.18 M_eq

Table 9.2 Special design loads at 20 m acc. LAT

Special design cases	Torsion correlated with M_ex	Torsion alone correlated to 0.7 M_ex	Crack and settling forces at tower bottom	
	T_ex [MNm]	T_alone [MNm]	F_cr [MN]	M_cr [MNm]
3.6 MW	5.6	13	0.7	42
5.0 MW	7.9	18	1.0	70

The crack loads are found according the DNV-OS-J101 standard.
Above Table 9.1 and 9.2 relates to average wind conditions (Round 3 area 2 and 4-9). For exposed wind conditions (Round 3 area 1 and 3) the wind loads in Table 9.1 and 9.2 shall be increased with 15 %.

The turbine loads (incl. load case extreme operating gust) shall be reviewed.

9.3 Combined loads

In the present version estimated loads for a 5 MW turbine on 30m and 60 m water depth exposed to Hs = 7.5 m (+ average wind conditions) and Hs = 9.4m (+ exposed wind conditions) have been roughly estimated for various foundation structures in Annex 1. The estimates has been based on non-linear wave kinematics modelled by the Boussinesq wave model and a simplified wave load model based on differential wave pressure and conventional drag force estimates for 4 selected structures resulting in non-linear force/moment time series. Maximum wave loads are checked by Stream function wave kinematics. Combined wind and wave loads have been estimated by a simplified empirical composition rule verified for a 3.6 M turbine. Dynamic interaction between wind and waves are estimated based on experiences from previous simulation on FLEX 5. For details reference is made to the note Summary of loads to selected structures [22]. The loads shall be considered as preliminary estimates applied for the Conceptual Design.

The extreme combined loads are been calculated on the basis of an assumed quadrautic composition rule:

$$F_{x,\max} = F_{x,mean,wind} + ((F_{x,\max,wind} - F_{x,mean,wind})^2 + F_{x,\max,waves}{}^2)^{0.5}$$

$$M_{y,\max} = M_{y,mean,wind} + ((M_{y,\max,wind} - M_{y,mean,wind})^2 + M_{y,\max,waves}{}^2)^{0.5}$$

Adding partial coefficients to the wind and wave force fluctuations, the quadratic composition that will be applied is given by:

$$F_{x,\max} = \gamma_{waves} \cdot F_{x,mean,wind} + ((\gamma_{wind} \cdot (F_{x,\max,wind} - F_{x,mean,wind}))^2 + (\gamma_{waves} \cdot F_{x,\max,waves})^2)^{0.5}$$

$$M_{y,\max} = \gamma_{waves} \cdot M_{y,mean,wind} + ((\gamma_{wind} \cdot (M_{y,\max,wind} - M_{y,mean,wind}))^2 + (\gamma_{waves} \cdot M_{y,\max,waves})^2)^{0.5}$$

For fatique a quadrautic composition rule is also assumed. But in addition a dynamic correction factor should be known:

$FE = DFE \cdot \left(FE_{wind}^2 + FE_{waves}^2\right)^{0.5}$ and $ME = DME \cdot \left(ME_{wind}^2 + ME_{waves}^2\right)^{0.5}$

The dynamic amplification factors should be determined on the basis of FLEX5 simulation. The following estimates is been used for Conceptual Design:

Table 9.3 Assumed dynamic amplification factors

Structure	DFE	DME
Monopile Jack-up	1.10	1.10
Tripod	1.06	1.06
Jacket	1.05	1.05
GBS (cone)	1.03	1.03

9.4 Ship impact loads

The foundation and boat landing arrangement will be dimensioned for ship impact from service vessels and alike.

9.4.1 Ship impact ALS (Accidental Limit State)

The foundations shall be able to withstand impact from vessels with a shock energy of 500 kJ and a static equivalent force of 4.9 MN at the boat landing area between mean sea level (0 m MSL) and level + 5 m MSL (acc. the design). This corresponds to a vessel with a displacement of approximately 160 ton hitting a soft fender with a maximum deformation of 0.2 m with a velocity of 2.0 m/s hitting broadside or from bow/stern direction.

The load area is assumed to be: A = 0.2 m × 0.2 m.

9.4.2 Ship Impact ULS (Ultimate Limit State)

The lower part of the boat landing shall be designed to withstand bow impact from vessels with a shock energy of 30 kJ and a static equivalent force of 300 kN between level (0 m MSL) and level + 5 m MSL (acc. the design). This corresponds to a vessel with a displacement of approximately 160 ton hitting a soft fender with a maximum deformation of 0.2 m with a velocity of 0.5 m/s hitting broadside or from bow/stern direction.

The load area is assumed to be: $A = 0.1 \text{ m} \times 0.1 \text{ m}$.

Further, the boat landing shall be designed for combined load of trusters from a 160 tons boat plus quasistastic load from the maximum wave and current loads for H_s = 1.5 m and U_c = 1 m/s

9.5 Loads to Nacelle and Rotor Installed Simultaneously with the Foundation

Transport:

The general load limitation to turbine component during transport is 0.5 g

Various turbine producers have estimated the allowed maximum acceleration for at turbine installed on the foundation during installation: 0.2g to 0.5 g. Floating concepts should describe consequences in terms of that both the upper and lower boundary is been specified (sensitivity study). The tower stresses have to be within acceptable limits and it cannot be ruled out that standard towers need to be strengthened.

It should further be described if slight yawing of turbine and rotation of rotor will be possible during installation to maintain efficient lubrication.

Deviation tilting: Maximum 2 degrees permanent and 5 degrees for maximum 1 minute.

Deviation rolling: Maximum 5 degrees permanently

Operation:

Loads during operation from floating turbine may require development of a special controller unit. The order of magnitude of allowable roll/pitch of nacelle during operation is estimated to 2-3 degrees. Maximum loads during operation from floating foundation to nacelle should be less than 0.1 g.

10 OTHER DESIGN CRITERIA

10.1 Natural frequency for bottom fixed structures

The stiffness of the foundation shall be sufficient to give a first natural frequency for the whole wind turbine structure and bottom-fixed foundation including soil stiffness if the following range:

Allowable frequency ranges:

First mode: For 3.6 MW the allowable system frequency band is 0.275 - 0.31 Hz
Due to risk of interaction with 1P the following frequency band is prohibited: 0.18 - 0.275 Hz
Due to risk of interaction with 3P the following frequency range is prohibited: 0.31 - 0.94 Hz.

First mode: For 5.0 MW the allowable system frequency band is 0.26-0.29 Hz
Due to risk of interaction with 1P the following frequency band is prohibited: 0.15-0.26 Hz
Due to risk of interaction with 3P the following frequency range is prohibited: 0.29-0.79 Hz.

It is allowable to apply a softer/longer tower than specified in the present document. Linear distribution of the tower diameter and material thickness shall be used.

The properties to be used for the turbine structure are found in sub-clause 8.1.

Linear distribution of the tower diameter and material thickness shall be used.

10.2 Allowed settlement

GBS: Maximum allowable tilt of the GBS foundation is 0.50°.

Monopile, tripods and jackets: Maximum allowable tilt of the mono-pile foundation is 0.25°.

10.3 Corrosion

Corrosion allowance shall be included in the design.

10.4 Material coefficient

According to EuroCode no. 2: “Design of concrete structures”, 1992-1-1 the safety factor materials are according to Table 10.1.

Table 10.1 Material safety factors for concrete structures

	ULS	FLS and ALS
Concrete	1.50	1.50
Reinforcement	1.15	1.15

10.5 Stiffness parameters

The elasticity modulus is as the initial elasticity modulus according EuroCode 2 and is used without safety factor.

The foundation stiffness shall for concrete structures be calculated for the cracked structure.

10.6 Pre stressing of anchor bolts.

Loads from pre-stressing of the anchor bolts shall be taken into account.

10.7 Crack width for concrete

Crack width shall not exceed the figures in Table 10.2.

Crack width shall be calculated according to DNV-OS-J101 for operational loads as stated in sub-clause 7.1.

The Elasticity modulus of the concrete shall be found according to DNV-OS-J101.

The load for the first crack is found using the lower characteristic tensile strength (EuroCode 2 clause 3.1.2.3).

Table 10.2 Allowable crack width

Level acc. LAT [m]	Crack width [mm]
Above 11	0.2
11 – (–4.0)	0.1
(-4.0 – (–15.0)	0.2
Below level (–15)	0.3

10.8 Fatigue for steel

The fatigue life shall be calculated according to Palmgren-Miner cumulative damage law. The allowable damage ratios are presented in
Table **10.3**.

Table 10.3 Allowable Palmgren-Miner damage sum

Level acc. LAT [m]	PM sum
Above 11	1.0
11 – 0	0.5
Below 0	0.3

The use of Wöhler-curves shall be in accordance with the safety system for which they are valid. If Wöhler curves from DNV-OS-J101 / DNV-OS-C502 are used, the material parameter 1.15 shall be used.

11 SECONDARY CONSTRUCTIONS

11.1 Loads – boat landing

Loads from vessels should be according sub-clause 9.4.

11.2 Loads – wave loads to appurtenances

Design should include appropriate account to slamming forces and include both extreme loads and fatigue loads.

11.2.1 Run-up
The maximum run-up height is estimated in Table 4.1

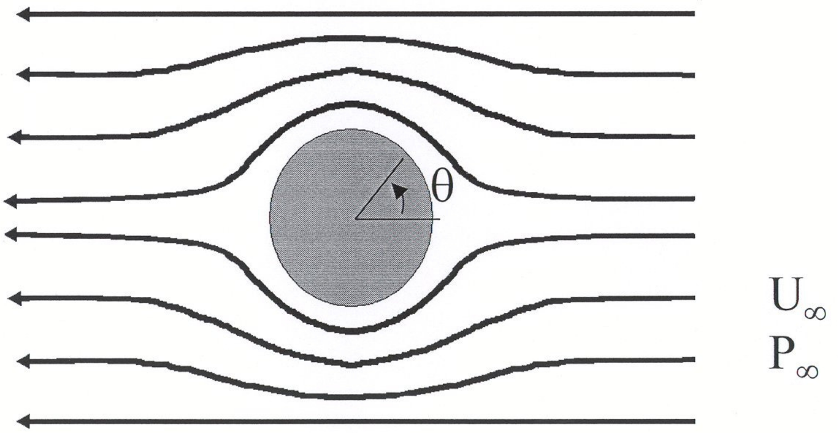
11.2.2 Vertical velocity for vertical structures
The vertical design velocity in a certain elevation (h) may be determined from:

$U = (2\ g\ (R_{max} - h))^{0.5}$
where g = gravitational acceleration

11.2.3 Horizontal velocity for vertical structures
The flow around a cylinder derived from potential flow theory is sketched on Figure 11.1.

The maximum flow velocity around the cylinder is twice the free-stream velocity. In reality the flow is not exactly a potential flow, but is governed by the particle velocity generated by the waves.

The boat landing is in reality not placed at the monopile surface, but never the less the maximum load on the boat landing elements are calculated based on a estimated velocity of two times the velocity found with no monopile structure involved ($u_{max} = U_\infty = 6.0$ m/s).



$$U(\theta) = 2 \cdot U_\infty \cdot \sin(\theta)$$

Figure 11.1 Potential flow velocity around a cylinder/monopile. (P_∞ = pressure without influence of structure)

11.3 Extreme horizontal wave loads.

Forces on the main structure are calculated on basis of stream function calculations.

Stream function theory describes velocity field for $U= U_{max}$ at crest elevation (see Table 4.1)

Account to distance from main cylinder on horizontal velocities is estimated as follows relative to a distance x from the cylinder with diameter D:

$U/U_{max} = (2x/D)^2 -2(2x/D) +2$ for $x<D/2$
$U/U_{max} = 1$ for $x \geq D/2$

This estimate is valid for structures placed 90° relative to the incident wave direction, where the structure amplifies the wave velocity most (up to a 2 factor).

Forces on the Appurtenances are calculated (as drag forces) on basis following formulae (the form factor is equal to 1):

$F = 0.5\ \rho\ U^2\ A$

11.4 Slamming force (vertical)

The extreme vertical design forces (slamming force) from the waves are estimated as follows:

A structure in elevation h (above MSL) is considered.

The maximum vertical velocity is estimated from $U_{wave,vert.} = (2\ g\ (R_{max} – h))^{0.5}$ where g = acceleration of gravity = 9.81 m/s^2, and R_{max} = Maximum run-up (1/50 years) (above MSL).

Slamming force $F_{sl}= 0.5\ \rho\ C_s\ A\ U_{wave,vert.}^2$
where ρ = water density, C_s = slamming coefficient and A = area considered.

Slamming coefficients:

Cylindrical structures:	C_s = minimum 3.
Triangular and rectangular structures:	C_s =minimum 6.
Horizontal platform (load area of 0.5 m^2):	$C_s = 10$
Horizontal platform (average load):	$C_s = 1.5$
Cone platform (load area of 0.5 m^2):	$C_s = 6$
Cone platform (average load):	$C_s = 1.2$

11.5 Fatigue loads

Procedure for fatigue loads to appurtenances:

To be included later in conceptual design if appropriate.

Section 11.6-11.15 includes typical design loads applied to secondary structures on a monopile project. The actual applied design loads may differ depending upon the support structure been applied.

11.6 Loads to Access Platform

The following is an example of typical design loads been applied to an access platform:
Inner gangway: Distributed: 5 kPa. Concentrated (0.2m x0.2 m): 2.5 kN
David Crane laydown area: 20 kPa. Concentrated (0.2m x0.2 m): 100kN
Demountable platforms: 500 KN + dynamic amplification over an area of 2 m x 3 m anywhere on platform

11.7 Loads to Intermediate Rest Platform

The following is an example of typical design loads been applied to an intermediate rest platform:
Distributed: 3 kPa. Concentrated (0.2m x0.2 m): 1.5 kN

11.8 Loads to Boat Landing Ladders

Boat landing ladder rungs: Load of 2.5 kN (in any direction)
Support structure: 15 kN (in any direction) applied on each of the stringers.

11.9 Loads to Other Ladders

Ladder rungs: Load of 1.5 kN (in any direction)
Support structure: 4 kN (in any direction) applied on each of the stringers.

11.10 I-tubes

The I-tubes and bell-mouth:
Vertical pull load from cable at top of I-tube: 100 kN
Minimum bending radius: 2 m
Cable mass in air: 31 kg/m
Cable mass in sea water: 18 kg/m

11.11 Loads to Hand Railings

Loads in all directions: 1 KN/m

11.12 Davit Crane Reactions

Design load is 10 KN at Sea State 3 with a lever arm of 2.2 m

11.13 Internal Transition Piece Structure

Upper gangway: Distributed: 3 kPa. Concentrated (0.2m x0.2 m): 1.5 kN
Upper deck: Distributed: 2 kPa. Concentrated (0.2m x0.2 m): 1.5 kN
Switch gear: 7 kN on 1.2 m^2 at centre of deck

Cable winch rack: 3 reaction points for Cable winch rack shall support cable pull of 100 kN + weight of rack

11.14 Lower Airtight Platform Deck

Distributed: 3 kPa.
Concentrated: Weight of J-tubes, cables and cable hang-off
Pressure loads from water level variations

11.15 Lower Gangway

Distributed: 3 kPa.
Concentrated (0.2m x0.2 m): 1.5 kN

12 GEOTECHNICAL DESIGN

12.1 General

The geotechnical design shall be performed in accordance with DNV-OS-J101 ref. [1] or GL Guidelines ref. [9].

It is the task and the responsibility of the Contractor to analyse and interpret all available geotechnical information and reports from surveys, site investigations, laboratory testing etc. included as annexes.

In order to ease the tender process, an interpretation has been carried out by the Employer and summarized in the Site Assessment and the following clauses.

12.2 ULS Analyses

The partial coefficients for soil parameters and resistance parameters shall be:

ULS Plastic

Angle of Internal Friction	1.2
Undrained Shear Strength	1.3
Pile Axial Bearing Capacity	1.3

12.3 SLS Analysis, ALS Analysis and FLS Analysis

Characteristic soil parameters shall be used in the ALS, SLS analysis, natural frequency analysis, fatigue analyses and the pile driveability study. The partial coefficients shall be taken as unity.

12.4 Undrained Shear Strength Parameters from Cone Tip Resistance

The in situ measured cone penetration tests shall be compared with the undrained triaxial tests from the borings in order to determine the relationship between the cone resistance and the undrained shear strength, i.e. the N_k value. This relationship, expressed by the N_k value, has then been used to determine undrained shear strengths from the CPT tests in clays.

The undrained shear strength, c_u can be expressed by the following formula:

$$c_u = \frac{q_c - \sigma}{N_k}$$

where

q_c is the net cone tip resistance
σ is the total overburden pressure
N_k is the cone factor

12.5 Friction Angle from the Cone Tip Resistance

The interpretation of the angle of internal friction in sand can be carried out by the method described in ref. [7]. A relationship between the peak secant friction angle and the relative density for different grain-size characteristics is given in ref. [7].

The friction angle shown in Figure 12.1 appears to an effective overburden stress of 150 kPa. If the overburden stress is higher than 150 kP and less than 300 kPa, the friction angle shall be reduced by 1 degree.

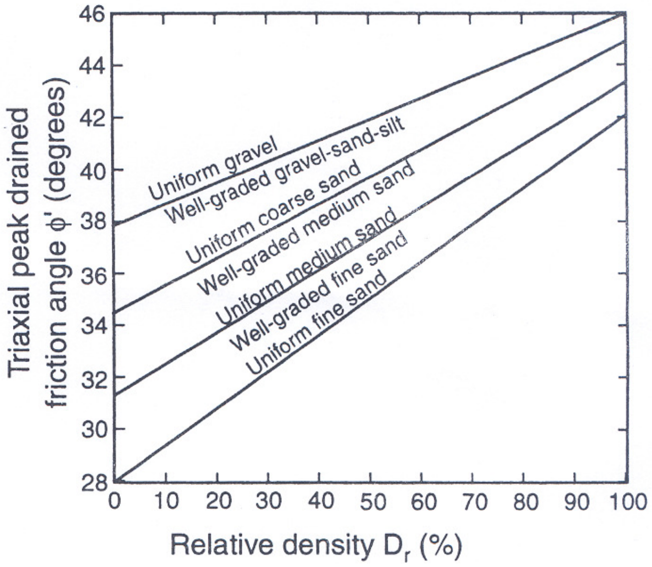


Figure 12.1 Relationship between the friction angle and the relative density, ref. [7].

Baldim et al. 1986 ref. [4] recommended the following formula to estimate the relative density of normally and over consolidated sands based on the cone tip resistance:

$$D_r = \frac{1}{2.61}\ln\left[\frac{q_c}{181\cdot(\sigma'_m)^{0.55}}\right]$$

where

D_r is the relative density
q_c is the cone tip resistance
σ'_m is the effective vertical stress

The correlations based on the above formula and the soil constants are shown in Figure 12.2.

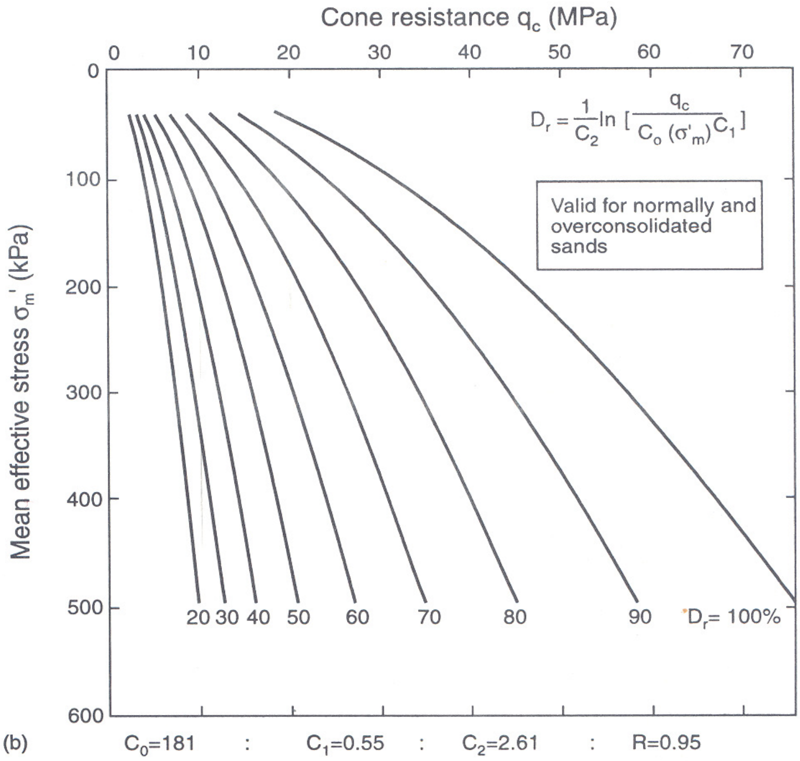


Figure 12.2 Relationship between cone tip resistance, vertical stresses and relative density, ref. [4]

These two relationships can be combined to a relationship between the angle of internal friction and the cone tip resistance. The relation is depicted in Figure 12.3 for fine sand.

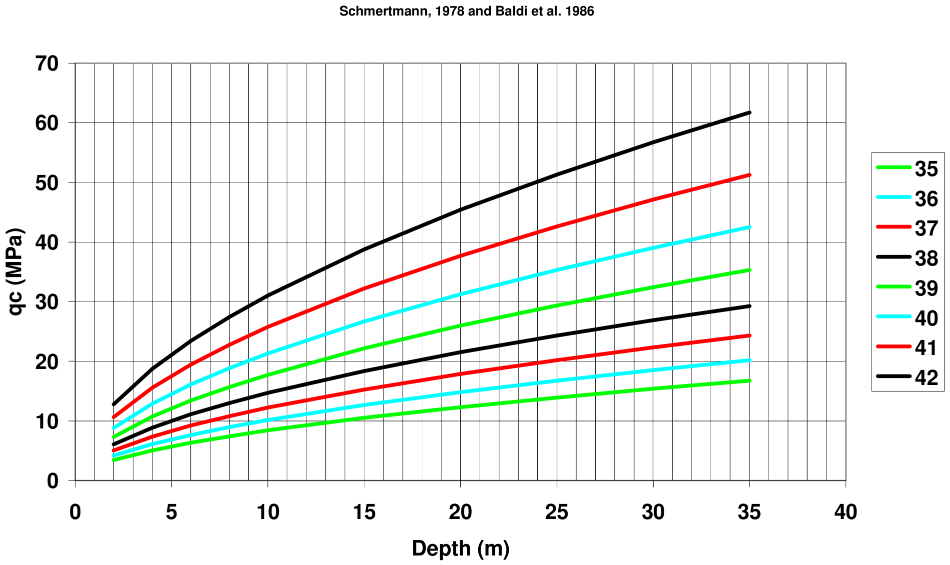


Figure 12.3 Evaluation of Angle of Internal Friction in Fine Uniform Sand

The correlation given in Figure 12.3 shall be used to interpret the angle of internal friction for the sand deposits. The friction angle will be limited to 42°.

This approach appears rational and conservative. The curves are implemented on all the CPT's.

12.6 Dynamic Soil Spring Stiffness

The initial, small strain modulus is denoted G_o. In Figure 12.4 the G_0/q_c is depicted for uncemented quartz sand.

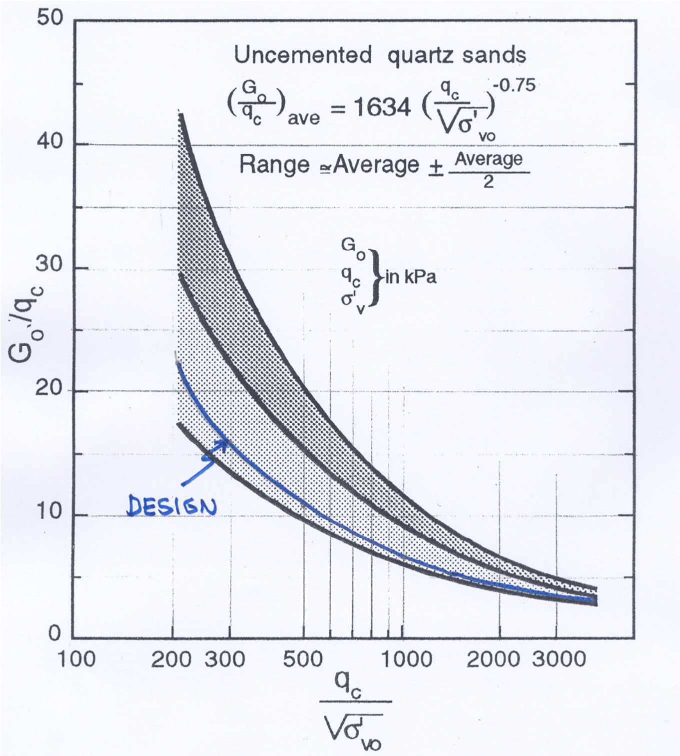


Figure 12.4 Gmax/qc, ref. [5]

The design value can be taken as:

$$\frac{G_o}{q_c} = 1200 \cdot \left[\frac{q_c}{\sqrt{\sigma'}}\right]^{-0.75}$$

where

G_o is the small strain shear modulus
q_c is the cone tip resistance
σ' is the effective vertical stress
Valid for relative deformation $\varepsilon \leq 10^{-3}$ %

For clay deposits the initial small strain modulus can be taken as:

$$G_o = 1000 \cdot c_u \text{ for } \varepsilon < 10^{-3} \quad \%$$

Where c_u is the undrained shear strength.

12.7 Risk of Liquefaction due to Cyclic Loading

The cyclic liquefaction resistance shall be evaluated for silty fine sand with a low relative density.

Risk of liquefaction is a severe risk to gravity structures. The possibility of wind and wave producing liquefaction in the foundation sands is similar in some respects to the problem of earthquake-induced liquefaction. Both cases involve cyclic shear stresses induced on horizontal planes. For further information and details on this subject see Lee et al ref. [5]. The NAVFAQ DM-7.3 approach can be used as an initial evaluation method.

For piled foundation including monopiles the loose silty sand will liquefy for lateral loading. In the design of monopiles, the soil deposits above the bottom of the loose silty sand shall be ignored.

13 MONOPILE: GEOTECHNICAL PARAMETERS

The present section include general design principles also valid for other plied structures like jackets and tripods.

13.1 Soil-Structure Interaction

Generally, non-linear behaviour of the interaction between soil and monopole, laterally and axially, shall be taken into account in the entire analyses.

The length of the soil plug inside the monopile is taken as 0.9 times the length of the pile embedded in the soil due to compaction of the soil during pile driving.

13.2 Soil Curves

13.2.1 Axial Bearing Capacity, t-z and Q-W Curves

The unit skin friction and the tip resistance shall be calculated in accordance with the DNV-approach using the characteristic soil parameters.

Cyclic t-z curves in accordance with DNV shall be used Ref. [1] DNV:

The tip load-displacement curves, Q-W shall be taken as Ref. [4] API:

Table 13.1 Tip load displacement. W is axial tip deflection (mm), D is pile diameter (mm) Q is mobilized end bearing capacity (kN), Q_p is total end bearing capacity (kN)

W/D	Q/Q_P
0.002	0.25
0.013	0.50
0.042	0.75
0.073	0.90
0.1	1.00

13.2.2 Lateral Bearing Capacity, ULS Elastic Analyses, p-y Curves

The lateral bearing capacity shall be based on p-y data developed by the DNV-approach.

For clay the first point on multi-linearly curves shall be taken as $y/y_c = 0.1$ and $p/p_u = 0.23$ in order to get a better model for small strain behaviour. The approach is in line with the ISO approaches, ref. [3] as shown on Figure 13.1

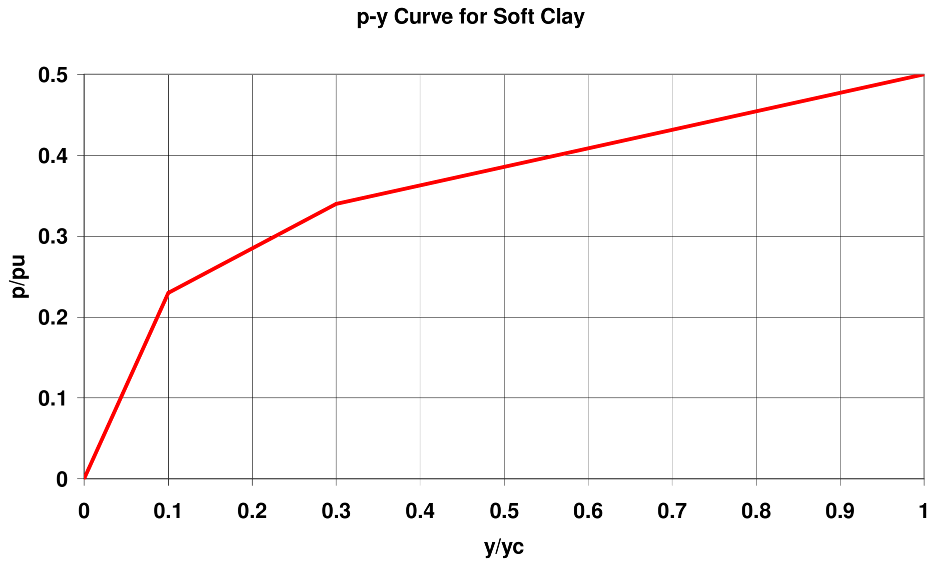


Figure 13.1 p-y curves for clay, ref [3]

y_c is calculated as:

$$y_c = 2.5 \cdot \varepsilon_{50} \cdot D$$

ε_{50} is strain which occurs at one-half the maximum stress on laboratory undrained compression tests and D is the pile diameter.

The ε_{50}value for clay can be taken according to Table 13.2.

Table 13.2 Representative values for ε50 for unified criteria, ref. [3]

c_u [kPa]	ε_{50}
12–25	0.02
25–50	0.01
50–100	0.007
100–200	0.005
200–400	0.004

The p-y curves specified for cyclic loading conditions shall be applied for representation of the lateral support.

13.2.3 Lateral and Axial Bearing, Fatigue Analysis, Spring Constant

The lateral and axial bearing capacity in the fatigue analysis shall be modelled as spring constants.

The soil pile interaction relationship is normally a smooth curve. The spring constants used in the linear analysis shall be taken as the initial slope of the smooth curve.

13.3 Minimum Wall Thickness

For piles that are to be installed by driving and hard driving (200 blows per 0.25 m) is anticipated, the minimum wall thickness used should not be less than, ref. [4] API:

$$t = 6.35 + \frac{D}{100}$$

where

t is the wall thickness of the pile
D is the outside diameter of the pile

13.4 FLS – Driveability and Fatigue Analysis

The driveability studies and driving fatigue analyses shall be carried out for the piles. The upper bound of the cone tip resistances shall be used.

The driveability and fatigue study shall be performed to investigate if the piles can be driven safely to the target penetration and to ensure that the fatigue damage, which can occur during driving is acceptable.

13.4.1 Driveability Study

The driveability study shall be performed using a dynamic analysis, which is fully capable of representing the stress wave propagation (inclusive reflection) through the pile. All sections in the pile shall be modelled. The analysis shall include a detailed model of the hammer.

13.4.2 Pile Driving Fatigue

The installation induced partial fatigue damage shall be calculated by applying the following procedure:

Each pile is divided into a number of elements during the driveability analysis in order to specify maximum and minimum stress for each element at each depth analysed and for each stroke. The stress range is calculated from these stresses.

The accumulated damage for each element is calculated by adding the damages down to the actual driving depth.

14 GBS: GEOTECHNICAL PARAMETERS

14.1 Vertical Bearing Capacity

The vertical bearing capacity analysis shall be carried out for the extreme design loading and ULS condition in accordance with DNV approach, ref. [1] or GL approach, ref. [10].

14.2 Sliding

Horizontal forces to be used for check of sliding failure shall be determined taking into account the combined action of horizontal force and torsional moment. The method is described in DNV.

The sliding resistance of the gravity base shall be determined according to DNV rules assuming that the strength parameters for intact soil apply.

In case that the foundations are excavated into cohesive soils, the weakening of the thin upper zone shall be taken into consideration.

14.3 Skirt Penetration Analyses

The skirt penetration resistance shall be calculated based on cone tip resistance in accordance with DNV.

14.4 Soil Reactions

Installation load case and permanent load case shall be analysed.

14.4.1 Installation load case

For the installation case, the load case cover the period from first seabed contact until the under-base grouting operation has been completed and the grout has cured.

14.4.2 Permanent load case

During the extreme event it is expected that the vertical loads on the skirts will tend to go over to the base.

If settlement takes place after the extreme event the loads will tend to go back from the base to the skirts. Therefore the following two assumptions shall be used for the analysis of the foundation base:

1) All permanent loads are carried as a uniform vertical stress against the grout.
2) The skirts carry all the permanent vertical loads as skin friction.

14.4.3 ULS load case.

The soil reaction on the contact face of the base slab shall be assumed to be distributed according to the one assumption, out of the two described below, which gives the most severe loading on the base slap.

- Uniform distribution over an effective foundation area
- Distributed contact pressure, calculated according to the theory of elasticity.

14.5 Settlements

For SLS design conditions, analyses of settlements and displacements shall be investigated in accordance with DNV/GL.

15 SIMPLIFIED DESIGN SOIL PROFILES

15.1 Design Soil Profiles

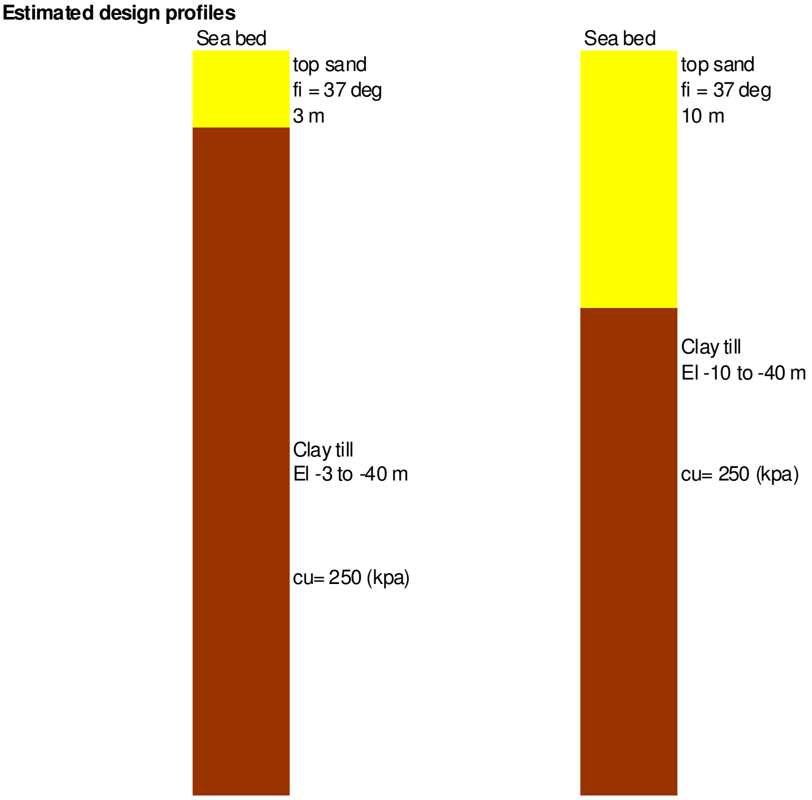


Figure 15.1 Area 3-4

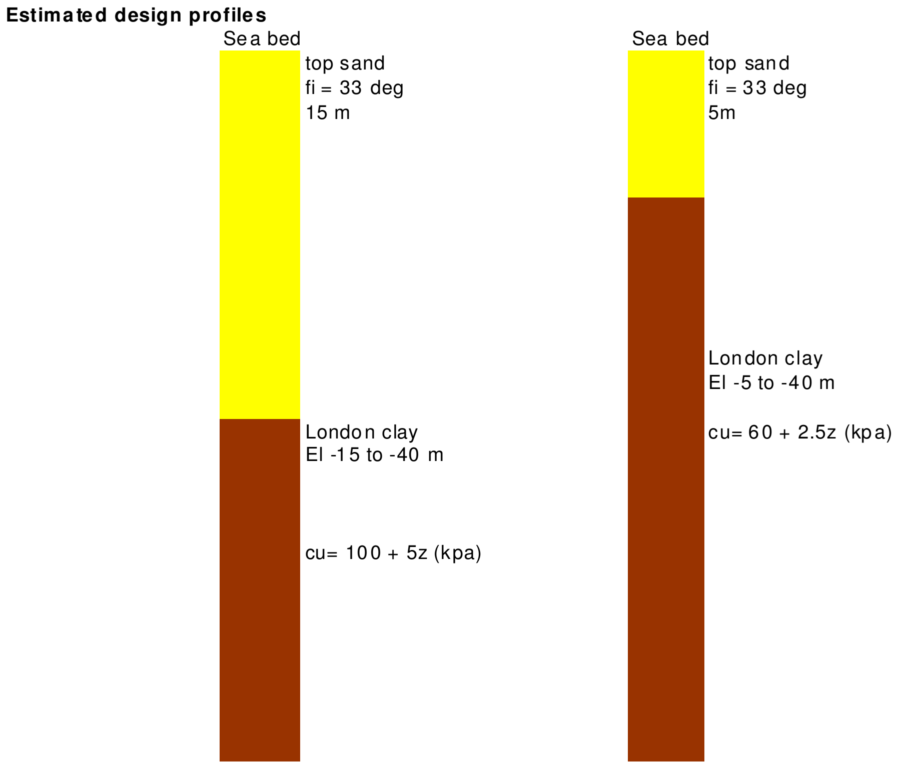


Figure 15.2 Area 5

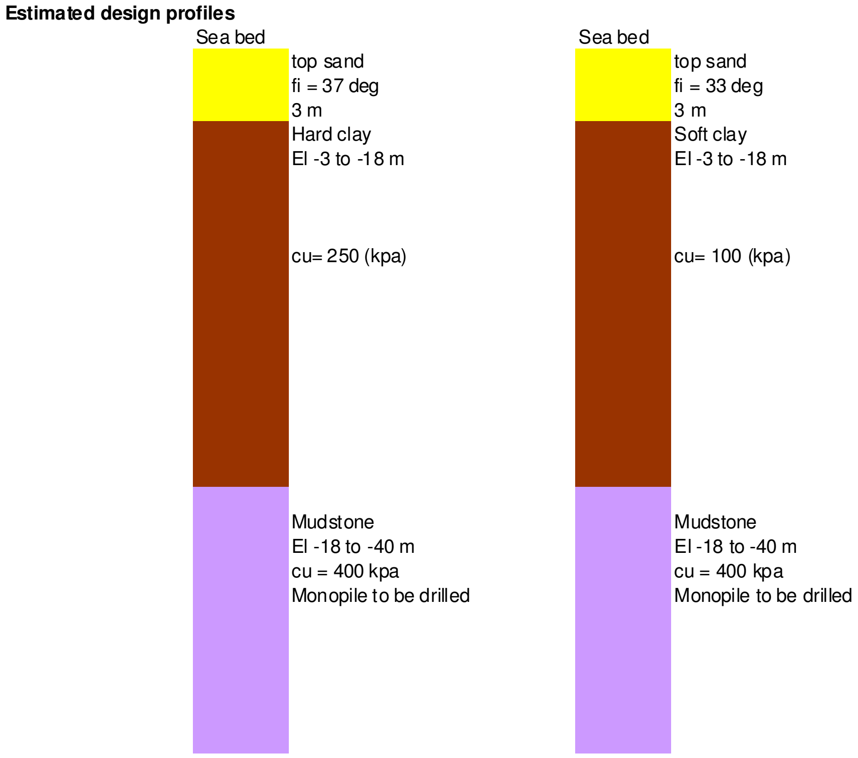


Figure 15.3 Area 9

15.2 Design Soil Parameters

Table 15.4 Design Soil Parameters

Area 3-4

Profile 1

Top layer [m below]	Bottom layer [m below]	Soil type [-]	Effective weight γ' $[kN/m^3]$	Undr.shear strength		Internal friction φ [º]	Cohesion	CPT cone resistance		E_{dyn}	E_{stat}
				top s_u [kPa]	bottom s_u [kPa]		c [kPa]	top q_c [MPa]	bottom q_c [MPa]	$[kN/m^2]$	$[kN/m^2]$
0,0	3,0	medium dense sand	10,0	-	-	37	0	0,00	7,50	69.000	34.500
3,0	40,0	clay Till	10,0	250,0	250,0	-	-	5,00	5,00	188.000	37.600

Profile 2

Top layer [m below]	Bottom layer [m below]	Soil type [-]	Effective weight γ' $[kN/m^3]$	Undr.shear strength		Internal friction φ [º]	Cohesion	CPT cone resistance		E_{dyn}	E_{stat}
				top s_u [kPa]	bottom s_u [kPa]		c [kPa]	top q_c [MPa]	bottom q_c [MPa]	$[kN/m^2]$	$[kN/m^2]$
0,0	2,5	dense sand	10,0	-	-	37	0	0,00	40,00	98.000	49.000
2,5	10,0	dense sand	10,0	-	-	37	0	40,00	40,00	176.000	88.000
10,0	40,0	clay Till	10,0	250,0	250,0	-	-	5,00	5,00	188.000	37.600

Area 5

Profile 1

Top layer [m below]	Bottom layer [m below]	Soil type [-]	Effective weight γ' $[kN/m^3]$	Undr.shear strength		Internal friction φ [º]	Cohesion	CPT cone resistance		E_{dyn}	E_{stat}
				top s_u [kPa]	bottom s_u [kPa]		c [kPa]	top q_c [MPa]	bottom q_c [MPa]	$[kN/m^2]$	$[kN/m^2]$
0,0	2,0	medium dense sand	10,0	-	-	33	0	0,00	2,00	43.000	21.500
2,0	15,0	medium dense sand	10,0	-	-	33	0	20,00	40,00	201.000	100.500
15,0	40,0	London Clay	9,0	175,0	300,0	-	-	3,50	6,00	179.000	35.800

Profile 2

Top layer [m below]	Bottom layer [m below]	Soil type [-]	Effective weight γ' $[kN/m^3]$	Undr.shear strength		Internal friction φ [º]	Cohesion	CPT cone resistance		E_{dyn}	E_{stat}
				top s_u [kPa]	bottom s_u [kPa]		c [kPa]	top q_c [MPa]	bottom q_c [MPa]	$[kN/m^2]$	$[kN/m^2]$
0,0	5,0	medium dense sand	10,0	-	-	33	0	0,00	8,00	85.000	42.500
5,0	40,0	London Clay	9,0	72,5	162,0	-	-	1,45	3,24	88.000	17.600

Area 9

Profile 1

Top layer [m below]	Bottom layer [m below]	Soil type [-]	Effective weight γ' $[kN/m^3]$	Undr.shear strength		Internal friction φ [º]	Cohesion	CPT cone resistance		E_{dyn}	E_{stat}
				top s_u [kPa]	bottom s_u [kPa]		c [kPa]	top q_c [MPa]	bottom q_c [MPa]	$[kN/m^2]$	$[kN/m^2]$
0,0	3,0	dense sand	10,0	-	-	37	0	0,00	7,50	69.000	34.500
3,0	18,0	Hard Clay	10,0	250	250	-	-	5,00	5,00	188.000	37.600

Profile 2

Top layer [m below]	Bottom layer [m below]	Soil type [-]	Effective weight γ' $[kN/m^3]$	Undr.shear strength		Internal friction φ [º]	Cohesion	CPT cone resistance		E_{dyn}	E_{stat}
				top s_u [kPa]	bottom s_u [kPa]		c [kPa]	top q_c [MPa]	bottom q_c [MPa]	$[kN/m^2]$	$[kN/m^2]$
0,0	3,0	medium dense sand	10,0	-	-	33	0	0,00	5,00	62.313	31.157
3,0	18,0	stiff clay	10,0	100	100	-	-	2,00	2,00	75.000	15.000

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ANNEX 1 DESIGN LOADS TO VARIOUS CONCEPTS

A.1 SPT

A.2 Monopile 7 m (Ballast-Nedam)

A.3 Keystone

A.4 OWPSE/Titan

A.5 Gifford/Freyssinet/BMT

Vedlegg 6 – “Technical Report, NREL/TP-500-38060, February 2009, Defenition of a 5-MW Reference Wind Turbine for Offshore System Development; J.Jonkman, S.Butterfield, W. Musial, and G. Scott”

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Office of Energy Efficiency & Renewable Energy
Innovation for Our Energy Future

Definition of a 5-MW Reference Wind Turbine for Offshore System Development

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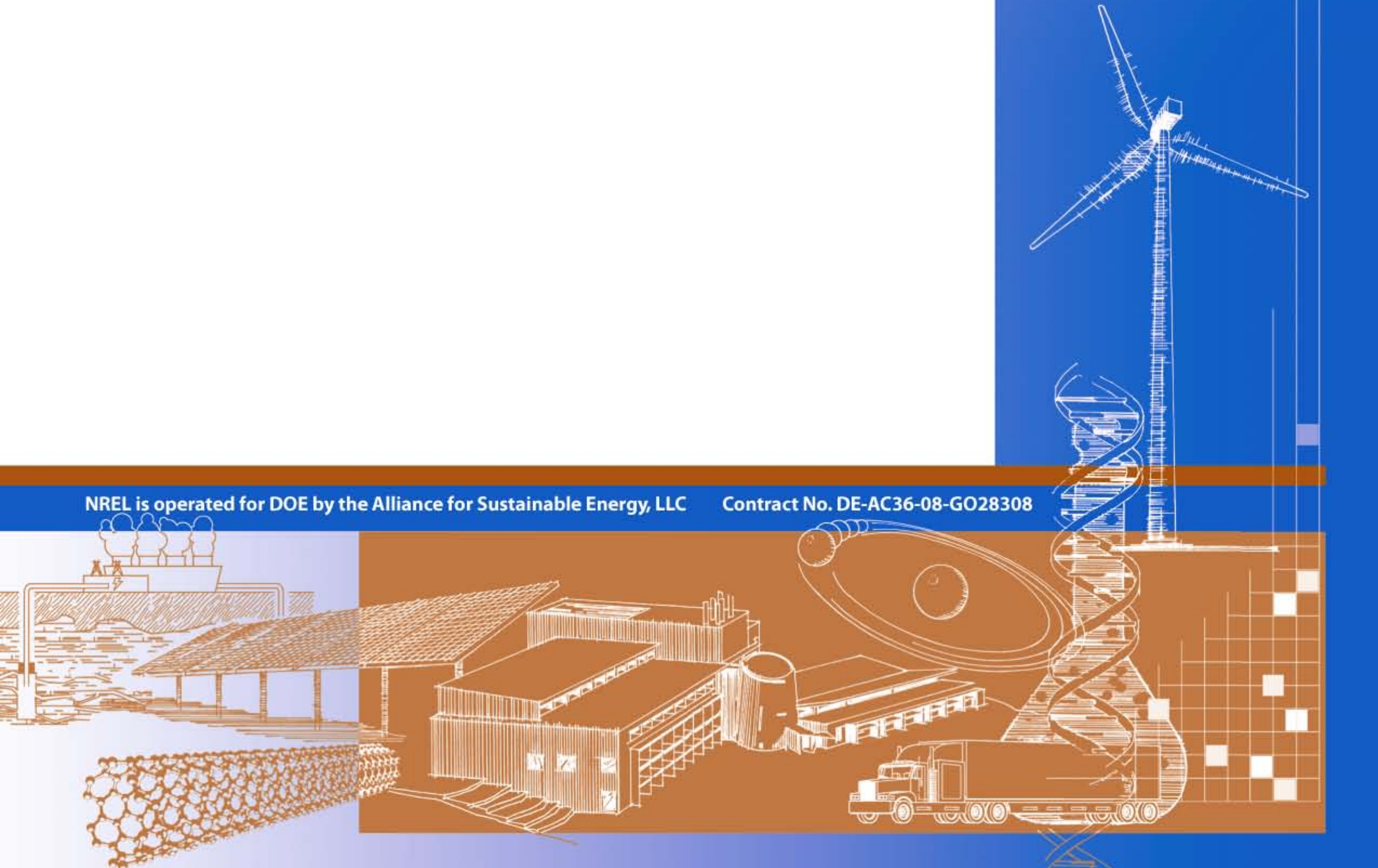
Technical Report
NREL/TP-500-38060
February 2009



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Definition of a 5-MW Reference Wind Turbine for Offshore System Development

Technical Report
NREL/TP-500-38060
February 2009

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Prepared under Task No. WER5.3301

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Acronyms and Abbreviations

ADAMS® = Automatic Dynamic Analysis of Mechanical Systems
A2AD = ADAMS-to-AeroDyn

BEM = blade-element / momentum

CM = center of mass

DLL = dynamic link library
DOE = U.S. Department of Energy
DOF = degree of freedom
DOWEC = Dutch Offshore Wind Energy Converter project
DU = Delft University

ECN = Energy Research Center of the Netherlands
equiripple = equalized-ripple

FAST = Fatigue, Aerodynamics, Structures, and Turbulence

GE = General Electric

IEA = International Energy Agency

MSL = mean sea level

NACA = National Advisory Committee for Aeronautics
NREL = National Renewable Energy Laboratory
NWTC = National Wind Technology Center

OCS = offshore continental shelf
OC3 = Offshore Code Comparison Collaborative

PI = proportional-integral
PID = proportional-integral-derivative

RECOFF = Recommendations for Design of Offshore Wind Turbines project

WindPACT= Wind Partnerships for Advanced Component Technology project
w.r.t. = with respect to

Nomenclature

A_d = discrete-time state matrix

B_d = discrete-time input matrix

C_d = discrete-time output state matrix

C_φ = effective damping in the equation of motion for the rotor-speed error

D_d = discrete-time input transmission matrix

f_c = corner frequency

GK = gain-correction factor

$I_{Drivetrain}$ = drivetrain inertia cast to the low-speed shaft

I_{Gen} = generator inertia relative to the high-speed shaft

I_{Rotor} = rotor inertia

K_D = blade-pitch controller derivative gain

K_I = blade-pitch controller integral gain

K_P = blade-pitch controller proportional gain

K_φ = effective stiffness in the equation of motion for the rotor-speed error

M_φ = effective inertia (mass) in the equation of motion for the rotor-speed error

n = discrete-time-step counter

N_{Gear} = high-speed to low-speed gearbox ratio

P = mechanical power

P_0 = rated mechanical power

$\partial P/\partial\theta$ = sensitivity of the aerodynamic power to the rotor-collective blade-pitch angle

t = simulation time

T_{Aero} = aerodynamic torque in the low-speed shaft

T_{Gen} = generator torque in the high-speed shaft

T_s = discrete-time step

u = unfiltered generator speed

x = for the control-measurement filter, the filter state

x,y,z = set of orthogonal axes making up a reference-frame coordinate system

y = for the control-measurement filter, the filtered generator speed

α = low-pass filter coefficient

$\Delta\theta$ = small perturbation of the blade-pitch angles about their operating point

$\Delta\Omega$ = small perturbation of the low-speed shaft rotational speed about the rated speed

$\Delta\dot{\Omega}$ = low-speed shaft rotational acceleration

ζ_φ = damping ratio of the response associated with the equation of motion for the rotor-speed error

θ = full-span rotor-collective blade-pitch angle

θ_K = rotor-collective blade-pitch angle at which the pitch sensitivity has doubled from its value at the rated operating point

π = the ratio of a circle's circumference to its diameter

φ = the integral of $\dot{\varphi}$ with respect to time

$\dot{\varphi}$ = small perturbation of the low-speed shaft rotational speed about the rated speed

$\ddot{\varphi}$ = low-speed shaft rotational acceleration

Ω = low-speed shaft rotational speed

Ω_0 = rated low-speed shaft rotational speed

$\omega_{\varphi n}$ = natural frequency of the response associated with the equation of motion for the rotor-speed error

Executive Summary

To support concept studies aimed at assessing offshore wind technology, we developed the specifications of a representative utility-scale multimegawatt turbine now known as the "NREL offshore 5-MW baseline wind turbine." This wind turbine is a conventional three-bladed upwind variable-speed variable blade-pitch-to-feather-controlled turbine. To create the model, we obtained some broad design information from the published documents of turbine manufacturers, with a heavy emphasis on the REpower 5M machine. Because detailed data was unavailable, however, we also used the publicly available properties from the conceptual models in the WindPACT, RECOFF, and DOWEC projects. We then created a composite from these data, extracting the best available and most representative specifications. This report documents the specifications of the NREL offshore 5-MW baseline wind turbine—including the aerodynamic, structural, and control-system properties—and the rationale behind its development. The model has been, and will likely continue to be, used as a reference by research teams throughout the world to standardize baseline offshore wind turbine specifications and to quantify the benefits of advanced land- and sea-based wind energy technologies.

Table of Contents

List of Tables

List of Figures

1 Introduction

The U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory (NREL), through the National Wind Technology Center (NWTC), has sponsored conceptual studies aimed at assessing offshore wind technology suitable in the shallow and deep waters off the U.S. offshore continental shelf (OCS) and other offshore sites worldwide. To obtain useful information from such studies, use of realistic and standardized input data is required. This report documents the turbine specifications of what is now called the "NREL offshore 5-MW baseline wind turbine" and the rationale behind its development. Our objective was to establish the detailed specifications of a large wind turbine that is representative of typical utility-scale land- and sea-based multimegawatt turbines, and suitable for deployment in deep waters.

Before establishing the detailed specifications, however, we had to choose the basic size and power rating of the machine. Because of the large portion of system costs in the support structure of an offshore wind system, we understood from the outset that if a deepwater wind system is to be cost-effective, each individual wind turbine must be rated at 5 MW or higher [23].[1] Ratings considered for the baseline ranged from 5 MW to 20 MW. We decided that the baseline should be 5 MW because it has precedence:

- Feasible floater configurations for offshore wind turbines scoped out by Musial, Butterfield, and Boone [23] were based on the assumption of a 5-MW unit.
- Unpublished DOE offshore cost studies were based on a rotor diameter of 128 m, which is a size representative of a 5- to 6-MW wind turbine.
- The land-based Wind Partnerships for Advanced Component Technology (WindPACT) series of studies, considered wind turbine systems rated up to 5 MW [19,24,29].
- The Recommendations for Design of Offshore Wind Turbines project (known as RECOFF) based its conceptual design calculations on a wind turbine with a 5-MW rating [32].
- The Dutch Offshore Wind Energy Converter (DOWEC) project based its conceptual design calculations on a wind turbine with a 6-MW rating [8,14,17].
- At the time of this writing, the largest wind turbine prototypes in the world—the Multibrid M5000 [5,21,22] and the REpower 5M [18,26,27]—each had a 5-MW rating.

We gathered the publicly available information on the Multibrid M5000 and REpower 5M prototype wind turbines. And because detailed information on these machines was unavailable, we also used the publicly available properties from the conceptual models used in the WindPACT, RECOFF, and DOWEC projects. These models contained much greater detail than was available about the prototypes. We then created a composite from these models, extracting the best available and most representative specifications.

---

[1] A single 5-MW wind turbine can supply enough energy annually to power 1,250 average American homes.

The Multibrid M5000 machine has a significantly higher tip speed than typical onshore wind turbines and a lower tower-top mass than would be expected from scaling laws previously developed in one of the WindPACT studies [29]. In contrast, the REpower 5M machine has properties that are more "expected" and "conventional." For this reason, we decided to use the specifications of the REpower 5M machine as the target specifications[2] for our baseline model.

The wind turbine used in the DOWEC project had a slightly higher rating than the rating of the REpower 5M machine, but many of the other basic properties of the DOWEC turbine matched the REpower 5M machine very well. In fact, the DOWEC turbine matched many of the properties of the REpower 5M machine better than the turbine properties derived for the WindPACT and RECOFF studies.[3] As a result of these similarities, we made the heaviest use of data from the DOWEC study in our development of the NREL offshore 5-MW baseline wind turbine.

The REpower 5M machine has a rotor radius of about 63 m. Wanting the same radius and the lowest reasonable hub height possible to minimize the overturning moment acting on an offshore substructure, we decided that the hub height for the baseline wind turbine should be 90 m. This would give a 15-m air gap between the blade tips at their lowest point when the wind turbine is undeflected and an estimated extreme 50-year individual wave height of 30 m (i.e., 15-m amplitude). The additional gross properties we chose for the NREL 5-MW baseline wind turbine, most of which are identical to those of the REpower 5M, are given in Table 1-1. The (*x*,*y*,*z*) coordinates of the overall center of mass (CM) location of the wind turbine are indicated in a tower-base coordinate system, which originates along the tower centerline at ground or mean

Table 1-1. Gross Properties Chosen for the NREL 5-MW Baseline Wind Turbine

Rating	5 MW
Rotor Orientation, Configuration	Upwind, 3 Blades
Control	Variable Speed, Collective Pitch
Drivetrain	High Speed, Multiple-Stage Gearbox
Rotor, Hub Diameter	126 m, 3 m
Hub Height	90 m
Cut-In, Rated, Cut-Out Wind Speed	3 m/s, 11.4 m/s, 25 m/s
Cut-In, Rated Rotor Speed	6.9 rpm, 12.1 rpm
Rated Tip Speed	80 m/s
Overhang, Shaft Tilt, Precone	5 m, 5º, 2.5º
Rotor Mass	110,000 kg
Nacelle Mass	240,000 kg
Tower Mass	347,460 kg
Coordinate Location of Overall CM	(-0.2 m, 0.0 m, 64.0 m)

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[2] Note that we established the target specifications using information about the REpower 5M machine that was published in January 2005 [26,27]. Some of the information presented in Refs. [26] and [27] disagrees with more recently published information. For example, the published nacelle and rotor masses of the REpower 5M are higher in the more recent publications.

[3] This was probably because the REpower 5M prototype utilized blades provided by LM Glasfiber [18], a company that helped establish the structural properties of the blades used in the DOWEC study.

sea level (MSL). The *x*-axis of this coordinate system is directed nominally downwind, the *y*-axis is directed transverse to the nominal wind direction, and the *z*-axis is directed vertically from the tower base to the yaw bearing.

The actual REpower 5M wind turbine uses blades with built-in prebend as a means of increasing tower clearance without a large rotor overhang. Because many of the available simulation tools and design codes cannot support blades with built-in prebend, we chose a 2.5°-upwind precone in the baseline wind turbine to represent the smaller amount of precone and larger amount of prebend that are built into the actual REpower 5M machine.

The rotor diameter indicated in Table 1-1 ignores the effect of blade precone, which reduces the actual diameter and swept area. The exact rotor diameter in the turbine specifications (assuming that the blades are undeflected) is actually $(126 \text{ m}) \times cos(2.5°) = 125.88$ m and the actual swept area is $(\pi/4) \times (125.88 \text{ m})^2 = 12{,}445.3 \text{ m}^2$.

We present other information about this model as follows:

- The blade structural properties in Section 2
- The blade aerodynamic properties in Section 3
- The hub and nacelle properties in Section 4
- The drivetrain properties in Section 5
- The tower properties in Section 6
- The baseline control system properties in Section 7
- The aero-servo-elastic FAST (Fatigue, Aerodynamics, Structures, and Turbulence) [11] with AeroDyn [16,20] and MSC.ADAMS® (Automatic Dynamic Analysis of Mechanical Systems) with A2AD (ADAMS-to-AeroDyn)[4] [6,15] and AeroDyn models of the wind turbine in Section 8
- The basic responses of the land-based version of the wind turbine, including its full-system natural frequencies and steady-state behavior in Section 9.

Although we summarize much of this information[5] for conciseness and clarity, Section 7 contains a high level of detail about the development of the wind turbine's baseline control system. These details are provided because they are fundamental to the development of more advanced control systems.

The NREL offshore 5-MW baseline wind turbine has been used to establish the reference specifications for a number of research projects supported by the U.S. DOE's Wind & Hydropower Technologies Program [1,2,7,12,28,33,34]. In addition, the integrated European

---

[4] Note that we use the term "ADAMS" to mean "MSC.ADAMS with A2AD" in this work.

[5] Note that some of the turbine properties are presented with a large number (>4) of significant figures. Most of these were carried over from the turbine properties documented in the DOWEC study [8,14,17]—We did not truncate their precision to maintain consistency with the original data source.

Union UpWind research program[6] and the International Energy Agency (IEA) Wind Annex XXIII Subtask 2[7] Offshore Code Comparison Collaboration (OC3) [13,25] have adopted the NREL offshore 5-MW baseline wind turbine as their reference model. The model has been, and will likely continue to be, used as a reference by research teams throughout the world to standardize baseline offshore wind turbine specifications and to quantify the benefits of advanced land- and sea-based wind energy technologies.

---

[6] Web site: http://www.upwind.eu/default.aspx

[7] Web site: http://www.ieawind.org/Annex%20XXIII/Subtask2.html

2 Blade Structural Properties

The NREL offshore 5-MW baseline wind turbine has three blades. We based the distributed blade structural properties of each blade on the structural properties of the 62.6-m-long LM Glasfiber blade used in the DOWEC study (using the data given in Appendix A of Ref. [17]). Because the blades in the DOWEC study were 1.1 m longer than the 61.5-m-long LM Glasfiber blades [18] used on the actual REpower 5M machine, we truncated the 62.6-m blades at 61.5-m span to obtain the structural properties of the NREL 5-MW baseline blades (we found the structural properties at the blade tip by interpolating between the 61.2-m and 61.7-m stations given in Appendix A of Ref. [17]). Table 2-1 lists the resulting properties.

The entries in the first column of Table 2-1, labeled “Radius,” are the spanwise locations along the blade-pitch axis relative to the rotor center (apex). “BlFract” is the fractional distance along the blade-pitch axis from the root (0.0) to the tip (1.0). We located the blade root 1.5 m along the pitch axis from the rotor center, equivalent to half the hub diameter listed in Table 1-1.

“AeroCent” is the name of a FAST input parameter. The FAST code assumes that the blade-pitch axis passes through each airfoil section at 25% chord. By definition, then, the quantity (AeroCent − 0.25) is the fractional distance to the aerodynamic center from the blade-pitch axis along the chordline, positive toward the trailing edge. Thus, at the root (i.e., BlFract = 0.0), AeroCent = 0.25 means that the aerodynamic center lies on the blade-pitch axis [because (0.25 − 0.25) = 0.0], and at the tip (i.e., BlFract = 1.0), AeroCent = 0.125 means that the aerodynamic center lies 0.125 chordlengths toward the leading edge from the blade-pitch axis [because (0.125

Table 2-1. Distributed Blade Structural Properties

Radius (m)	BlFract (-)	AeroCent (-)	StrcTwst (°)	BMassDen (kg/m)	FlpStff (N•m^2)	EdgStff (N•m^2)	GJStff (N•m^2)	EAStff (N)	Alpha (-)	FlpIner (kg•m)	EdgIner (kg•m)	PrecrvRef (m)	PreswpRef (m)	FlpcgOf (m)	EdgcgOf (m)	FlpEAOf (m)	EdgEAOf (m)
1.50	0.00000	0.25000	13.308	678.935	18110.00E+6	18113.60E+6	5564.40E+6	9729.48E+6	0.0	972.86	973.04	0.0	0.0	0.0	0.00017	0.0	0.0
1.70	0.00325	0.25000	13.308	678.935	18110.00E+6	18113.60E+6	5564.40E+6	9729.48E+6	0.0	972.86	973.04	0.0	0.0	0.0	0.00017	0.0	0.0
2.70	0.01951	0.24951	13.308	773.363	19424.90E+6	19558.60E+6	5431.59E+6	10789.50E+6	0.0	1091.52	1066.38	0.0	0.0	0.0	-0.02309	0.0	0.0
3.70	0.03577	0.24510	13.308	740.550	17455.90E+6	19497.80E+6	4993.98E+6	10067.23E+6	0.0	966.09	1047.36	0.0	0.0	0.0	0.00344	0.0	0.0
4.70	0.05203	0.23284	13.308	740.042	15287.40E+6	19788.80E+6	4666.59E+6	9867.78E+6	0.0	873.81	1099.75	0.0	0.0	0.0	0.04345	0.0	0.0
5.70	0.06829	0.22059	13.308	592.496	10782.40E+6	14858.50E+6	3474.71E+6	7607.86E+6	0.0	648.55	873.02	0.0	0.0	0.0	0.05893	0.0	0.0
6.70	0.08455	0.20833	13.308	450.275	7229.72E+6	10220.60E+6	2323.54E+6	5491.26E+6	0.0	456.76	641.49	0.0	0.0	0.0	0.06494	0.0	0.0
7.70	0.10081	0.19608	13.308	424.054	6309.54E+6	9144.70E+6	1907.87E+6	4971.30E+6	0.0	400.53	593.73	0.0	0.0	0.0	0.07718	0.0	0.0
8.70	0.11707	0.18382	13.308	400.638	5528.36E+6	8063.16E+6	1570.36E+6	4493.95E+6	0.0	351.61	547.18	0.0	0.0	0.0	0.08394	0.0	0.0
9.70	0.13335	0.17156	13.308	382.062	4980.06E+6	6884.44E+6	1158.26E+6	4034.80E+6	0.0	316.12	490.84	0.0	0.0	0.0	0.10174	0.0	0.0
10.70	0.14959	0.15931	13.308	399.655	4936.84E+6	7009.18E+6	1002.12E+6	4037.29E+6	0.0	303.60	503.86	0.0	0.0	0.0	0.10758	0.0	0.0
11.70	0.16585	0.14706	13.308	426.321	4691.66E+6	7167.68E+6	855.90E+6	4169.72E+6	0.0	289.24	544.70	0.0	0.0	0.0	0.15829	0.0	0.0
12.70	0.18211	0.13481	13.181	416.820	3949.46E+6	7271.66E+6	672.27E+6	4082.35E+6	0.0	246.57	569.90	0.0	0.0	0.0	0.22235	0.0	0.0
13.70	0.19837	0.12500	12.848	406.186	3386.52E+6	7081.70E+6	547.49E+6	4085.97E+6	0.0	215.91	601.28	0.0	0.0	0.0	0.30756	0.0	0.0
14.70	0.21465	0.12500	12.192	381.420	2933.74E+6	6244.53E+6	448.84E+6	3668.34E+6	0.0	187.11	546.56	0.0	0.0	0.0	0.30386	0.0	0.0
15.70	0.23089	0.12500	11.561	352.822	2568.96E+6	5048.96E+6	335.92E+6	3147.76E+6	0.0	160.84	468.71	0.0	0.0	0.0	0.26519	0.0	0.0
16.70	0.24715	0.12500	11.072	349.477	2388.65E+6	4948.49E+6	311.35E+6	3011.58E+6	0.0	148.56	453.76	0.0	0.0	0.0	0.25941	0.0	0.0
17.70	0.26341	0.12500	10.792	346.538	2271.99E+6	4808.02E+6	291.94E+6	2882.62E+6	0.0	140.30	436.22	0.0	0.0	0.0	0.25007	0.0	0.0
19.70	0.29595	0.12500	10.232	339.333	2050.05E+6	4501.40E+6	261.00E+6	2613.97E+6	0.0	124.61	398.18	0.0	0.0	0.0	0.23155	0.0	0.0
21.70	0.32846	0.12500	9.672	330.004	1828.25E+6	4244.07E+6	228.82E+6	2357.48E+6	0.0	109.42	362.08	0.0	0.0	0.0	0.20382	0.0	0.0
23.70	0.36098	0.12500	9.110	321.990	1588.71E+6	3995.28E+6	200.75E+6	2146.86E+6	0.0	94.36	335.01	0.0	0.0	0.0	0.19934	0.0	0.0
25.70	0.39350	0.12500	8.534	313.820	1361.93E+6	3750.76E+6	174.38E+6	1944.09E+6	0.0	80.24	308.57	0.0	0.0	0.0	0.19323	0.0	0.0
27.70	0.42602	0.12500	7.932	294.734	1102.38E+6	3447.14E+6	144.47E+6	1632.70E+6	0.0	62.67	263.87	0.0	0.0	0.0	0.14994	0.0	0.0
29.70	0.45855	0.12500	7.321	287.120	875.80E+6	3139.07E+6	119.98E+6	1432.40E+6	0.0	49.42	237.06	0.0	0.0	0.0	0.15421	0.0	0.0
31.70	0.49106	0.12500	6.711	263.343	681.30E+6	2734.24E+6	81.19E+6	1168.76E+6	0.0	37.34	196.41	0.0	0.0	0.0	0.13252	0.0	0.0
33.70	0.52358	0.12500	6.122	253.207	534.72E+6	2554.87E+6	69.09E+6	1047.43E+6	0.0	29.14	180.34	0.0	0.0	0.0	0.13313	0.0	0.0
35.70	0.55610	0.12500	5.546	241.666	408.90E+6	2334.03E+6	57.45E+6	922.95E+6	0.0	22.16	162.43	0.0	0.0	0.0	0.14035	0.0	0.0
37.70	0.58862	0.12500	4.971	220.638	314.54E+6	1828.73E+6	45.92E+6	760.82E+6	0.0	17.33	134.83	0.0	0.0	0.0	0.13950	0.0	0.0
39.70	0.62115	0.12500	4.401	200.293	238.63E+6	1584.10E+6	35.98E+6	648.03E+6	0.0	13.30	116.30	0.0	0.0	0.0	0.15134	0.0	0.0
41.70	0.65366	0.12500	3.834	179.404	175.88E+6	1323.36E+6	27.44E+6	539.70E+6	0.0	9.96	97.98	0.0	0.0	0.0	0.17418	0.0	0.0
43.70	0.68618	0.12500	3.332	165.094	126.01E+6	1183.68E+6	20.90E+6	531.15E+6	0.0	7.30	98.93	0.0	0.0	0.0	0.24922	0.0	0.0
45.70	0.71870	0.12500	2.890	154.411	107.26E+6	1020.16E+6	18.54E+6	460.01E+6	0.0	6.22	85.78	0.0	0.0	0.0	0.26022	0.0	0.0
47.70	0.75122	0.12500	2.503	138.935	90.88E+6	797.81E+6	16.28E+6	375.75E+6	0.0	5.19	69.96	0.0	0.0	0.0	0.22554	0.0	0.0
49.70	0.78376	0.12500	2.116	129.555	76.31E+6	709.61E+6	14.53E+6	328.89E+6	0.0	4.36	61.41	0.0	0.0	0.0	0.22795	0.0	0.0
51.70	0.81626	0.12500	1.730	107.264	61.05E+6	518.19E+6	9.07E+6	244.04E+6	0.0	3.36	45.44	0.0	0.0	0.0	0.20600	0.0	0.0
53.70	0.84878	0.12500	1.342	98.776	49.48E+6	454.87E+6	8.06E+6	211.60E+6	0.0	2.75	39.57	0.0	0.0	0.0	0.21662	0.0	0.0
55.70	0.88130	0.12500	0.954	90.248	39.36E+6	395.12E+6	7.08E+6	181.52E+6	0.0	2.21	34.09	0.0	0.0	0.0	0.22784	0.0	0.0
56.70	0.89756	0.12500	0.760	83.001	34.67E+6	353.72E+6	6.09E+6	160.25E+6	0.0	1.93	30.12	0.0	0.0	0.0	0.23124	0.0	0.0
57.70	0.91382	0.12500	0.574	72.906	30.41E+6	304.73E+6	5.75E+6	109.23E+6	0.0	1.69	20.15	0.0	0.0	0.0	0.14826	0.0	0.0
58.70	0.93008	0.12500	0.404	68.772	26.52E+6	281.42E+6	5.33E+6	100.08E+6	0.0	1.49	18.53	0.0	0.0	0.0	0.15346	0.0	0.0
59.20	0.93821	0.12500	0.319	66.264	23.84E+6	261.71E+6	4.94E+6	92.24E+6	0.0	1.34	17.11	0.0	0.0	0.0	0.15382	0.0	0.0
59.70	0.94636	0.12500	0.253	59.340	19.63E+6	158.81E+6	4.24E+6	63.23E+6	0.0	1.10	11.55	0.0	0.0	0.0	0.09470	0.0	0.0
60.20	0.95447	0.12500	0.216	55.914	16.00E+6	137.88E+6	3.66E+6	53.32E+6	0.0	0.89	9.77	0.0	0.0	0.0	0.09018	0.0	0.0
60.70	0.96260	0.12500	0.178	52.484	12.83E+6	118.79E+6	3.13E+6	44.53E+6	0.0	0.71	8.19	0.0	0.0	0.0	0.08561	0.0	0.0
61.20	0.97073	0.12500	0.140	49.114	10.08E+6	101.63E+6	2.64E+6	36.90E+6	0.0	0.56	6.82	0.0	0.0	0.0	0.08035	0.0	0.0
61.70	0.97886	0.12500	0.101	45.818	7.55E+6	85.07E+6	2.17E+6	29.92E+6	0.0	0.42	5.57	0.0	0.0	0.0	0.07096	0.0	0.0
62.20	0.98699	0.12500	0.062	41.669	4.60E+6	64.26E+6	1.58E+6	21.31E+6	0.0	0.25	4.01	0.0	0.0	0.0	0.05424	0.0	0.0
62.70	0.99512	0.12500	0.023	11.453	0.25E+6	6.61E+6	0.25E+6	4.85E+6	0.0	0.04	0.94	0.0	0.0	0.0	0.05387	0.0	0.0
63.00	1.00000	0.12500	0.000	10.319	0.17E+6	5.01E+6	0.19E+6	3.53E+6	0.0	0.02	0.68	0.0	0.0	0.0	0.05181	0.0	0.0

− 0.25) = −0.125].

The flapwise and edgewise section stiffness and inertia values, “FlpStff,” “EdgStff,” “FlpIner,” and “EdgIner” in Table 2-1, are given about the principal structural axes of each cross section as oriented by the structural-twist angle, “StrcTwst.” The values of the structural twist were assumed to be identical to the aerodynamic twist discussed in Section 3.

“GJStff” represents the values of the blade torsion stiffness. Because the DOWEC blade data did not contain extensional stiffness information, we estimated the blade extensional stiffness values—“EAStff” in Table 2-1—to be 10^7 times the average mass moment of inertia at each blade station. This came from a rule of thumb derived from the data available in the WindPACT rotor design study [19], but the exact values are not important because of the low rotational speed of the rotor.

The edgewise CM offset values, “EdgcgOf,” are the distances in meters along the chordline from the blade-pitch axis to the CM of the blade section, positive toward the trailing edge. We neglected the insignificant values of the flapwise CM offsets, “FlpcgOf,” and flapwise and edgewise elastic offsets, “FlpEAOf” and “EdgEAOf,” given in Appendix A of Ref. [17]. Instead, we assumed that they were zero as shown in Table 2-1.

The distributed blade section mass per unit length values, “BMassDen,” given in Table 2-1 are the values documented in Appendix A of Ref. [17]. We increased these by 4.536% in the model to scale the overall (integrated) blade mass to 17,740 kg, which was the nominal mass of the blades in the REpower 5M prototype. In our baseline specifications, the nominal second mass moment of inertia, nominal first mass moment of inertia, and the nominal radial CM location of each blade are 11,776,047 kg•m^2, 363,231 kg•m, and 20.475 m with respect to (w.r.t.) the blade root, respectively.

We specified a structural-damping ratio of 0.477465% critical in all modes of the isolated blade, which corresponds to the 3% logarithmic decrement used in the DOWEC study from page 20 of Ref. [14].

Table 2-2 summarizes the undistributed blade structural properties discussed in this section.

Table 2-2. Undistributed Blade Structural Properties

Length (w.r.t. Root Along Preconed Axis)	61.5 m
Mass Scaling Factor	4.536 %
Overall (Integrated) Mass	17,740 kg
Second Mass Moment of Inertia (w.r.t. Root)	11,776,047 kg•m^2
First Mass Moment of Inertia (w.r.t. Root)	363,231 kg•m
CM Location (w.r.t. Root along Preconed Axis)	20.475 m
Structural-Damping Ratio (All Modes)	0.477465 %

3 Blade Aerodynamic Properties

Similar to the blade structural properties, we based the blade aerodynamic properties of the NREL 5-MW baseline wind turbine on the DOWEC blades (using the data described in Table 1 on page 13 of Ref. [14] and in Appendix A of Ref. [17]). We set the FAST with AeroDyn and ADAMS with AeroDyn models to use 17 blade elements for integration of the aerodynamic and structural forces. To better capture the large structural gradients at the blade root and the large aerodynamic gradients at the blade tip, the 3 inboard and 3 outboard elements are two-thirds the size of the 11 equally spaced midspan elements. Table 3-1 gives the aerodynamic properties at the blade nodes, which are located at the center of the blade elements.

The blade node locations, labeled as "RNodes" in Table 3-1, are directed along the blade-pitch axis from the rotor center (apex) to the blade cross sections. The element lengths, "DRNodes," sum to the total blade length of 61.5 m indicated in Table 2-2. The aerodynamic twist, "AeroTwst," as given in Table 3-1, are offset by −0.09182° from the values provided in Appendix A of Ref. [17] to ensure that the zero-twist reference location is at the blade tip. Integrating the chord distribution along the blade span reveals that the rotor solidity is roughly 5.16%.

As indicated in Table 3-1, we incorporated eight unique airfoil-data tables for the NREL offshore 5-MW baseline wind turbine. The two innermost airfoil tables represent cylinders with drag coefficients of 0.50 (Cylinder1.dat) and 0.35 (Cylinder2.dat) and no lift. We created the remaining six airfoil tables by making corrections for three-dimensional behavior to the two-dimensional airfoil-data coefficients of the six airfoils used in the DOWEC study (as detailed in

Table 3-1. Distributed Blade Aerodynamic Properties

Node (-)	RNodes (m)	AeroTwst (º)	DRNodes (m)	Chord (m)	Airfoil Table (-)
1	2.8667	13.308	2.7333	3.542	Cylinder1.dat
2	5.6000	13.308	2.7333	3.854	Cylinder1.dat
3	8.3333	13.308	2.7333	4.167	Cylinder2.dat
4	11.7500	13.308	4.1000	4.557	DU40_A17.dat
5	15.8500	11.480	4.1000	4.652	DU35_A17.dat
6	19.9500	10.162	4.1000	4.458	DU35_A17.dat
7	24.0500	9.011	4.1000	4.249	DU30_A17.dat
8	28.1500	7.795	4.1000	4.007	DU25_A17.dat
9	32.2500	6.544	4.1000	3.748	DU25_A17.dat
10	36.3500	5.361	4.1000	3.502	DU21_A17.dat
11	40.4500	4.188	4.1000	3.256	DU21_A17.dat
12	44.5500	3.125	4.1000	3.010	NACA64_A17.dat
13	48.6500	2.319	4.1000	2.764	NACA64_A17.dat
14	52.7500	1.526	4.1000	2.518	NACA64_A17.dat
15	56.1667	0.863	2.7333	2.313	NACA64_A17.dat
16	58.9000	0.370	2.7333	2.086	NACA64_A17.dat
17	61.6333	0.106	2.7333	1.419	NACA64_A17.dat

Appendix A of Ref. [14]).[8] In these airfoil tables, "DU" refers to Delft University and "NACA" refers to the National Advisory Committee for Aeronautics. We used AirfoilPrep v2.0 [9] to "tailor" these airfoil data. We first corrected the lift and drag coefficients for rotational stall delay using the Selig and Eggars method for 0° to 90° angles of attack. We then corrected the drag coefficients using the Viterna method for 0° to 90° angles of attack assuming an aspect ratio of 17. Finally, we estimated the Beddoes-Leishman dynamic-stall hysteresis parameters. We made no corrections to the DOWEC-supplied pitching-moment coefficients. The resulting three-dimensionally corrected airfoil-data coefficients are illustrated graphically in Figure 3-1 through Figure 3-6. The numerical values are documented in the AeroDyn airfoil-data input files that make up Appendix B.

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[8] C. Lindenburg of the Energy Research Center of the Netherlands (ECN) provided numerical values for these coefficients.

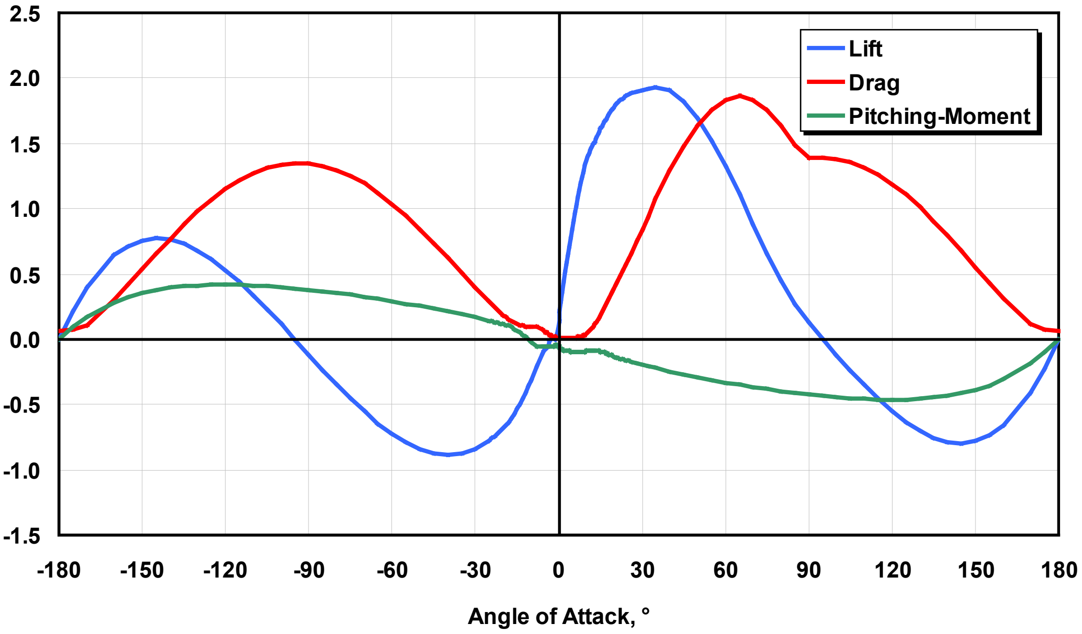

Figure 3-1. Corrected coefficients of the DU40 airfoil

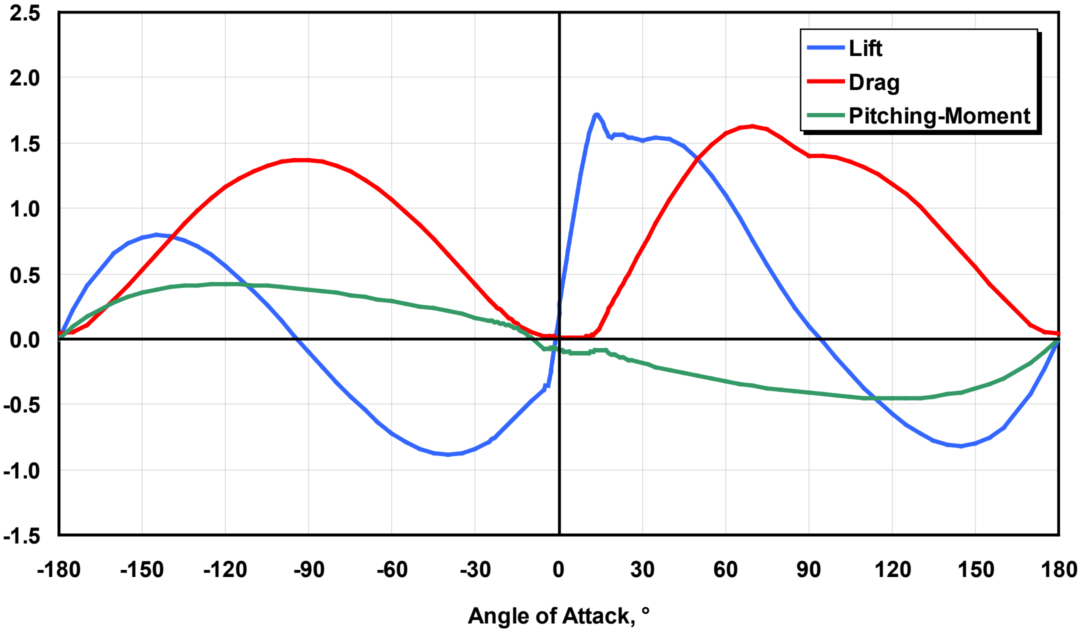

Figure 3-2. Corrected coefficients of the DU35 airfoil

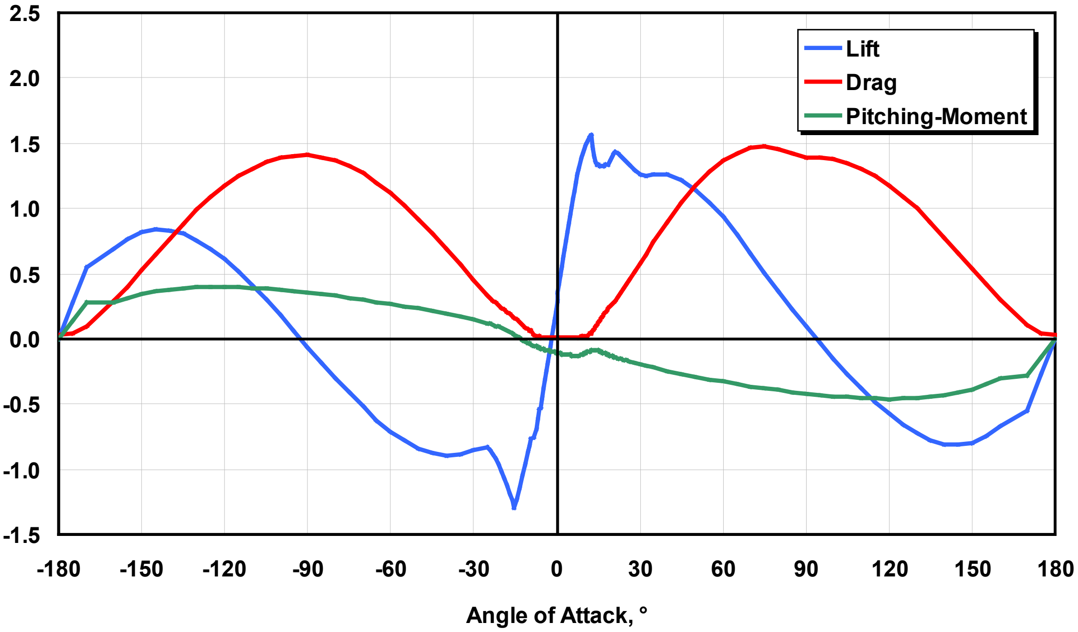

Figure 3-3. Corrected coefficients of the DU30 airfoil

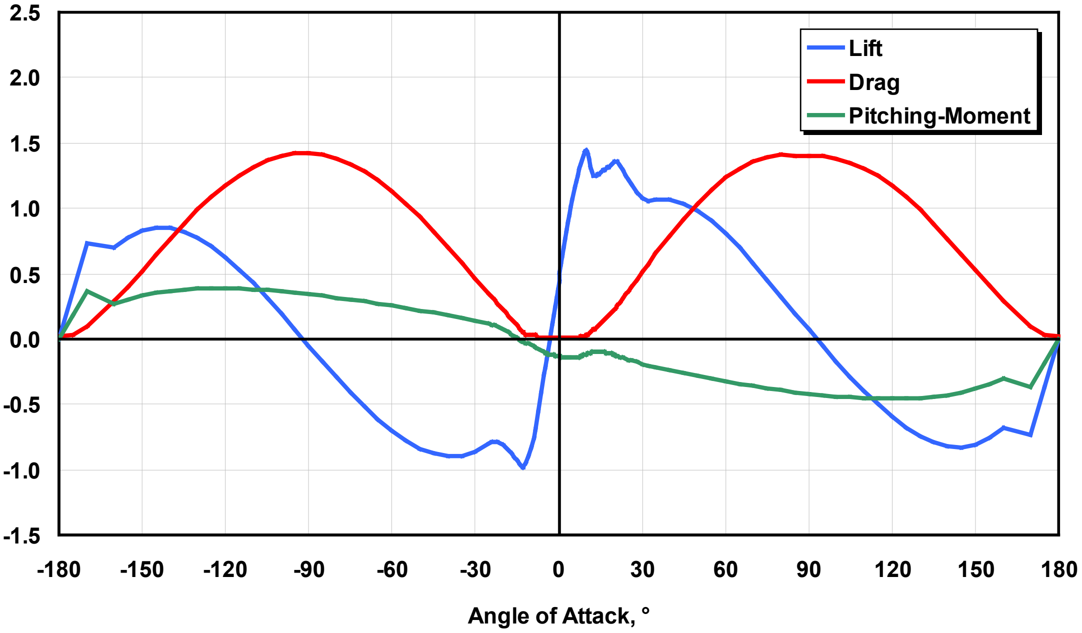

Figure 3-4. Corrected coefficients of the DU25 airfoil

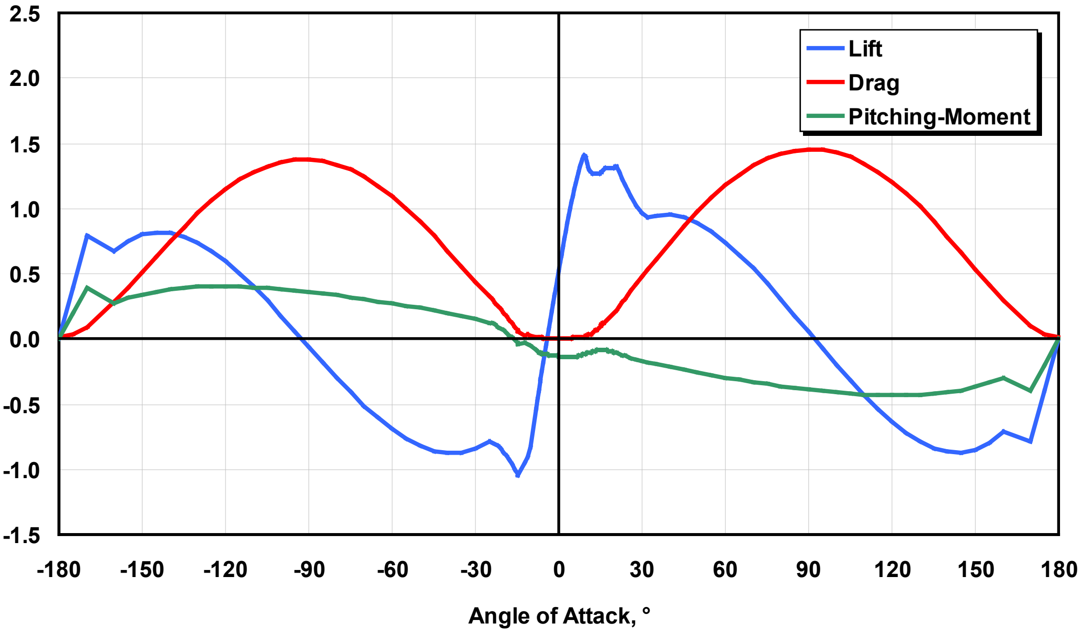

Figure 3-5. Corrected coefficients of the DU21 airfoil

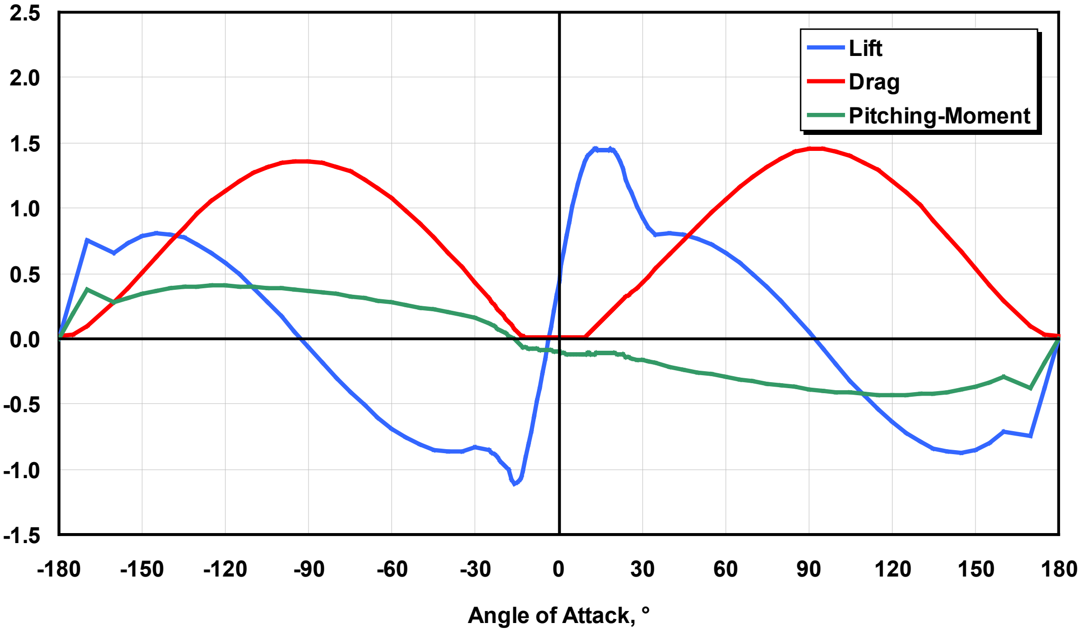

Figure 3-6. Corrected coefficients of the NACA64 airfoil

4 Hub and Nacelle Properties

As indicated in Table 1-1, we located the hub of the NREL 5-MW baseline wind turbine 5 m upwind of the tower centerline at an elevation of 90 m above the ground when the system is undeflected. We also specified the same vertical distance from the tower top to the hub height used by the DOWEC study—that is, 2.4 m (as specified in Table 6 on page 26 of Ref. [14]). Consequently, the elevation of the yaw bearing above ground or MSL is 87.6 m. With a shaft tilt of 5°, this made the distance directed along the shaft from the hub center to the yaw axis 5.01910 m and the vertical distance along the yaw axis from the tower top to the shaft 1.96256 m. The distance directed along the shaft from the hub center to the main bearing was taken to be 1.912 m (from Table 6 on page 26 of Ref. [14]).

We specified the hub mass to be 56,780 kg like in the REpower 5M, and we located its CM at the hub center. The hub inertia about the shaft, taken to be 115,926 kg•m^2, was found by assuming that the hub casting is a thin spherical shell with a radius of 1.75 m (this is 0.25 m longer than the actual hub radius because the nacelle height of the DOWEC turbine was 3.5 m, based on the data in Table 6 on page 26 of Ref. [14]).

We specified the nacelle mass to be 240,000 kg like in the REpower 5M and we located its CM 1.9 m downwind of the yaw axis like in the DOWEC turbine (from Table 7 on page 27 of Ref. [14]) and 1.75 m above the yaw bearing, which was half the height of the DOWEC turbine's nacelle (from Table 6 on page 26 of Ref. [14]). The nacelle inertia about the yaw axis was taken to be 2,607,890 kg•m^2. We chose this to be equivalent to the DOWEC turbine's nacelle inertia about its nacelle CM, but translated to the yaw axis using the parallel-axis theorem with the nacelle mass and downwind distance to the nacelle CM.

We took the nacelle-yaw actuator to have a natural frequency of 3 Hz, which is roughly equivalent to the highest full-system natural frequency in the FAST model (see Section 9), and a damping ratio of 2% critical. This resulted in an equivalent nacelle-yaw-actuator linear-spring constant of 9,028,320,000 N•m/rad and an equivalent nacelle-yaw-actuator linear-damping constant of 19,160,000 N•m/(rad/s). The nominal nacelle-yaw rate was chosen to be the same as that for the DOWEC 6-MW turbine, or 0.3°/s (from page 27 of Ref. [14]).

Table 4-1 summarizes the nacelle and hub properties discussed in this section.

Table 4-1. Nacelle and Hub Properties

Elevation of Yaw Bearing above Ground	87.6	m
Vertical Distance along Yaw Axis from Yaw Bearing to Shaft	1.96256	m
Distance along Shaft from Hub Center to Yaw Axis	5.01910	m
Distance along Shaft from Hub Center to Main Bearing	1.912	m
Hub Mass	56,780	kg
Hub Inertia about Low-Speed Shaft	115,926	kg•m^2
Nacelle Mass	240,000	kg
Nacelle Inertia about Yaw Axis	2,607,890	kg•m^2
Nacelle CM Location Downwind of Yaw Axis	1.9	m
Nacelle CM Location above Yaw Bearing	1.75	m
Equivalent Nacelle-Yaw-Actuator Linear-Spring Constant	9,028,320,000	N•m/rad
Equivalent Nacelle-Yaw-Actuator Linear-Damping Constant	19,160,000	N•m/(rad/s)
Nominal Nacelle-Yaw Rate	0.3	°/s

5 Drivetrain Properties

We specified the NREL 5-MW baseline wind turbine to have the same rated rotor speed (12.1 rpm), rated generator speed (1173.7 rpm), and gearbox ratio (97:1) as the REpower 5M machine. The gearbox was assumed be a typical multiple-stage gearbox but with no frictional losses—a requirement of the preprocessor functionality in FAST for creating ADAMS models [11]. The electrical efficiency of the generator was taken to be 94.4%. This was chosen to be roughly the same as the total mechanical-to-electrical conversion loss used by the DOWEC turbine at rated power—that is, the DOWEC turbine had about 0.35 MW of power loss at about 6.25 MW of aerodynamic power (from Figure 15, page 24 of Ref. [14]). The generator inertia about the high-speed shaft was taken to be 534.116 kg•m^2, which is the same equivalent low-speed shaft generator inertia used in the DOWEC study (i.e., 5,025,500 kg•m^2 from page 36 of Ref. [14]).

The driveshaft was taken to have the same natural frequency as the RECOFF turbine model and a structural-damping ratio—associated with the free-free mode of a drivetrain composed of a rigid generator and rigid rotor—of 5% critical. This resulted in an equivalent driveshaft linear-spring constant of 867,637,000 N•m/rad and a linear-damping constant of 6,215,000 N•m/(rad/s).

The high-speed shaft brake was assumed to have the same ratio of maximum brake torque to maximum generator torque and the same time lag as used in the DOWEC study (from page 29 of Ref. [14]). This resulted in a fully deployed high-speed shaft brake torque of 28,116.2 N•m and a time lag of 0.6 s. This time lag is the amount of time it takes for the brake to fully engage once deployed. The FAST and ADAMS models employ a simple linear ramp from nothing to full braking over the 0.6-s period.

Table 5-1 summarizes the drivetrain properties discussed in this section.

Table 5-1. Drivetrain Properties

Rated Rotor Speed	12.1	rpm
Rated Generator Speed	1173.7	rpm
Gearbox Ratio	97	:1
Electrical Generator Efficiency	94.4	%
Generator Inertia about High-Speed Shaft	534.116	kg•m^2
Equivalent Drive-Shaft Torsional-Spring Constant	867,637,000	N•m/rad
Equivalent Drive-Shaft Torsional-Damping Constant	6,215,000	N•m/(rad/s)
Fully-Deployed High-Speed Shaft Brake Torque	28,116.2	N•m
High-Speed Shaft Brake Time Constant	0.6	s

6 Tower Properties

The properties of the tower for the NREL offshore 5-MW baseline wind turbine will depend on the type support structure used to carry the rotor-nacelle assembly. The type of support structure will, in turn, depend on the installation site, whose properties vary significantly through differences in water depth, soil type, and wind and wave severity. Offshore support-structure types include fixed-bottom monopiles, gravity bases, and space-frames—such as tripods, quadpods, and lattice frames (e.g., "jackets")—and floating structures. This section documents the tower properties for the equivalent land-based version of the NREL 5-MW baseline wind turbine. These properties provide a basis with which to design towers for site-specific offshore support structures. For example, different types of offshore support structures for the NREL 5-MW baseline wind turbine have been designed for—and investigated in—separate phases of the OC3 project [13,25].

We based the distributed properties of the land-based tower for the NREL 5-MW baseline wind turbine on the base diameter (6 m) and thickness (0.027 m), top diameter (3.87 m) and thickness (0.019 m), and effective mechanical steel properties of the tower used in the DOWEC study (as given in Table 9 on page 31 of Ref. [14]). The Young's modulus was taken to be 210 GPa, the shear modulus was taken to be 80.8 GPa, and the effective density of the steel was taken to be 8,500 kg/m^3. The density of 8,500 kg/m^3 was meant to be an increase above steel's typical value of 7,850 kg/m^3 to account for paint, bolts, welds, and flanges that are not accounted for in the tower thickness data. The radius and thickness of the tower were assumed to be linearly tapered from the tower base to tower top. Because the REpower 5M machine had a larger tower-top mass than the DOWEC wind turbine, we scaled up the thickness of the tower relative to the values given earlier in this paragraph to strengthen the tower. We chose an increase of 30% to ensure that the first fore-aft and side-to-side tower frequencies were placed between the one- and three-per-rev frequencies throughout the operational range of the wind turbine in a Campbell diagram. Table 6-1 gives the resulting distributed tower properties.

The entries in the first column, "Elevation," are the vertical locations along the tower centerline relative to the tower base. "HtFract" is the fractional height along the tower centerline from the tower base (0.0) to the tower top (1.0). The rest of columns are similar to those described for the distributed blade properties presented in Table 2-1.

The resulting overall (integrated) tower mass is 347,460 kg and is centered at 38.234 m along the

Table 6-1. Distributed Tower Properties

Elevation (m)	HtFract (-)	TMassDen (kg/m)	TwFAStif (N•m^2)	TwSSStif (N•m^2)	TwGJStif (N•m^2)	TwEAStif (N)	TwFAIner (kg•m)	TwSSIner (kg•m)	TwFAcgOf (m)	TwSScgOf (m)
0.00	0.0	5590.87	614.34E+9	614.34E+9	472.75E+9	138.13E+9	24866.3	24866.3	0.0	0.0
8.76	0.1	5232.43	534.82E+9	534.82E+9	411.56E+9	129.27E+9	21647.5	21647.5	0.0	0.0
17.52	0.2	4885.76	463.27E+9	463.27E+9	356.50E+9	120.71E+9	18751.3	18751.3	0.0	0.0
26.28	0.3	4550.87	399.13E+9	399.13E+9	307.14E+9	112.43E+9	16155.3	16155.3	0.0	0.0
35.04	0.4	4227.75	341.88E+9	341.88E+9	263.09E+9	104.45E+9	13838.1	13838.1	0.0	0.0
43.80	0.5	3916.41	291.01E+9	291.01E+9	223.94E+9	96.76E+9	11779.0	11779.0	0.0	0.0
52.56	0.6	3616.83	246.03E+9	246.03E+9	189.32E+9	89.36E+9	9958.2	9958.2	0.0	0.0
61.32	0.7	3329.03	206.46E+9	206.46E+9	158.87E+9	82.25E+9	8356.6	8356.6	0.0	0.0
70.08	0.8	3053.01	171.85E+9	171.85E+9	132.24E+9	75.43E+9	6955.9	6955.9	0.0	0.0
78.84	0.9	2788.75	141.78E+9	141.78E+9	109.10E+9	68.90E+9	5738.6	5738.6	0.0	0.0
87.60	1.0	2536.27	115.82E+9	115.82E+9	89.13E+9	62.66E+9	4688.0	4688.0	0.0	0.0

tower centerline above the ground. This result follows directly from the overall tower height of 87.6 m.

We specified a structural-damping ratio of 1% critical in all modes of the isolated tower (without the rotor-nacelle assembly mass present), which corresponds to the values used in the DOWEC study (from page 21 of Ref. [14]).

Table 6-2 summarizes the undistributed tower properties discussed in this section.

Table 6-2. Undistributed Tower Properties

Height above Ground	87.6 m
Overall (Integrated) Mass	347,460 kg
CM Location (w.r.t. Ground along Tower Centerline)	38.234 m
Structural-Damping Ratio (All Modes)	1 %

7 Baseline Control System Properties

For the NREL 5-MW baseline wind turbine, we chose a conventional variable-speed, variable blade-pitch-to-feather configuration. In such wind turbines, the conventional approach for controlling power-production operation relies on the design of two basic control systems: a generator-torque controller and a full-span rotor-collective blade-pitch controller. The two control systems are designed to work independently, for the most part, in the below-rated and above-rated wind-speed range, respectively. The goal of the generator-torque controller is to maximize power capture below the rated operation point. The goal of the blade-pitch controller is to regulate generator speed above the rated operation point.

We based the baseline control system for the NREL 5-MW wind turbine on this conventional design approach. We did not establish additional control actions for nonpower-production operations, such as control actions for normal start-up sequences, normal shutdown sequences, and safety and protection functions. Nor did we develop control actions to regulate the nacelle-yaw angle. (The nacelle-yaw control system is generally neglected within aero-servo-elastic simulation because its response is slow enough that it does not generally contribute to large extreme loads or fatigue damage.)

We describe the development of our baseline control system next, including the control-measurement filter (Section 7.1), the generator-torque controller (Section 7.2), the blade-pitch controller (Section 7.3), and the blade-pitch actuator (Section 7.4). Section 7.5 shows how these systems are put together in the overall integrated control system.

7.1 Baseline Control-Measurement Filter

As is typical in utility-scale multimegawatt wind turbines, both the generator-torque and blade-pitch controllers use the generator speed measurement as the sole feedback input. To mitigate high-frequency excitation of the control systems, we filtered the generator speed measurement for both the torque and pitch controllers using a recursive, single-pole low-pass filter with exponential smoothing [30]. The discrete-time recursion (difference) equation for this filter is

$$y[n] = (1-\alpha)u[n] + \alpha y[n-1], \tag{7-1}$$

with

$$\alpha = e^{-2\pi T_s f_c}, \tag{7-2}$$

where y is the filtered generator speed (output measurement), u is the unfiltered generator speed (input), α is the low-pass filter coefficient, n is the discrete-time-step counter, T_s is the discrete time step, and f_c is the corner frequency.

By defining the filter state,

$$x[n] = y[n-1], \tag{7-3a}$$

or

$$x\left[n+1\right]=y\left[n\right], \tag{7-3b}$$

one can derive a discrete-time state-space representation of this filter:

$$\begin{aligned} x\left[n+1\right]&=A_d x\left[n\right]+B_d u\left[n\right]\\ y\left[n\right]&=C_d x\left[n\right]+D_d u\left[n\right] \end{aligned}, \tag{7-4}$$

where $A_d = \alpha$ is the discrete-time state matrix, $B_d = 1-\alpha$ is the discrete-time input matrix, $C_d = \alpha$ is the discrete-time output state matrix, and $D_d = 1-\alpha$ is the discrete-time input transmission matrix.

The state-space representation of Eq. (7-4) is useful for converting the filter into other forms, such as transfer-function form or frequency-response form [31].

We set the corner frequency (the -3 dB point in Figure 7-1) of the low-pass filter to be roughly one-quarter of the blade's first edgewise natural frequency (see Section 9) or 0.25 Hz. For a discrete time step of 0.0125 s, the frequency response of the resulting filter is shown in the Bode plot of Figure 7-1.

We chose the recursive, single-pole filter for its simplicity in implementation and effectiveness

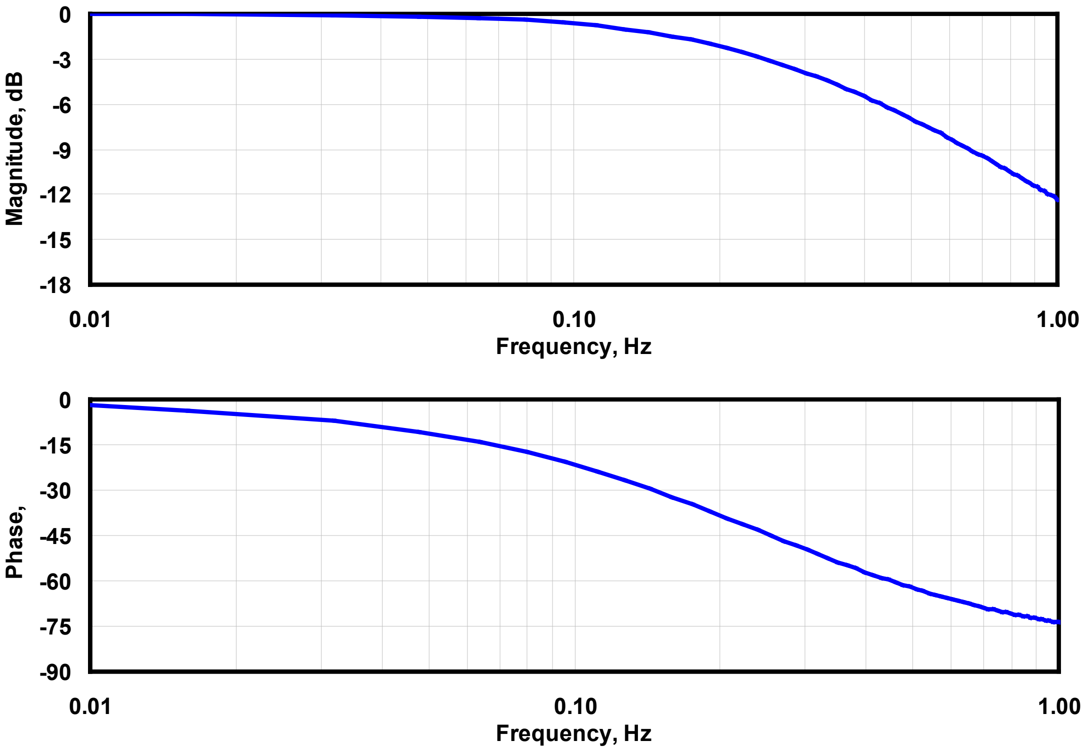

Figure 7-1. Bode plot of generator speed low-pass filter frequency response

in the time domain. The drawbacks to this filter are its gentle roll-off in the stop band (-6 dB/octave) and the magnitude and nonlinearity of its phase lag in the pass band [30]. We considered other linear low-pass filters, such as Butterworth, Chebyshev, Elliptic, and Bessel filters because of their inherent advantages relative to the chosen filter. Like the chosen filter, a Butterworth filter has a frequency response that is flat in the pass band, but the Butterworth filter offers steeper roll-off in the stop band. Chebyshev filters offer even steeper roll-off in the stop band at the expense of equalized-ripple (equiripple) in the pass band (Type 1) or stop band (Type 2), respectively. Elliptic filters offer the steepest roll-off of any linear filter, but have equiripple in both the pass and stop bands. Bessel filters offer the flattest group delay (linear phase lag) in the pass band. We designed and tested examples of each of these other low-pass filter types, considering state-space representations of up to fourth order (four states). None were found to give superior performance in the overall system response, however, so they did not warrant the added complexity of implementation.

7.2 Baseline Generator-Torque Controller

The generator torque is computed as a tabulated function of the filtered generator speed, incorporating five control regions: 1, 1½, 2, 2½, and 3. Region 1 is a control region before cut-in wind speed, where the generator torque is zero and no power is extracted from the wind; instead, the wind is used to accelerate the rotor for start-up. Region 2 is a control region for optimizing power capture. Here, the generator torque is proportional to the square of the filtered generator speed to maintain a constant (optimal) tip-speed ratio. In Region 3, the generator power is held constant so that the generator torque is inversely proportional to the filtered generator speed. Region 1½, a start-up region, is a linear transition between Regions 1 and 2. This region is used to place a lower limit on the generator speed to limit the wind turbine's operational speed range. Region 2½ is a linear transition between Regions 2 and 3 with a torque slope corresponding to the slope of an induction machine. Region 2½ is typically needed (as is the case for my 5-MW turbine) to limit tip speed (and hence noise emissions) at rated power.

We found the peak of the power coefficient as a function of the tip-speed ratio and blade-pitch surface by running FAST with AeroDyn simulations at a number of given rotor speeds and a number of given rotor-collective blade-pitch angles at a fixed wind speed of 8 m/s. From these simulations, we found that the peak power coefficient of 0.482 occurred at a tip-speed ratio of 7.55 and a rotor-collective blade-pitch angle of 0.0˚. With the 97:1 gearbox ratio, this resulted in an optimal constant of proportionality of 0.0255764 N•m/rpm^2 in the Region 2 control law. With the rated generator speed of 1173.7 rpm, rated electric power of 5 MW, and a generator efficiency of 94.4%, the rated mechanical power is 5.296610 MW and the rated generator torque is 43,093.55 N•m. We defined Region 1½ to span the range of generator speeds between 670 rpm and 30% above this value (or 871 rpm). The minimum generator speed of 670 rpm corresponds to the minimum rotor speed of 6.9 rpm used by the actual REpower 5M machine [26]. We took the transitional generator speed between Regions 2½ and 3 to be 99% of the rated generator speed, or 1,161.963 rpm. The generator-slip percentage in Region 2½ was taken to be 10%, in accordance with the value used in the DOWEC study (see page 24 of Ref. [14]). Figure 7-2 shows the resulting generator-torque versus generator speed response curve.

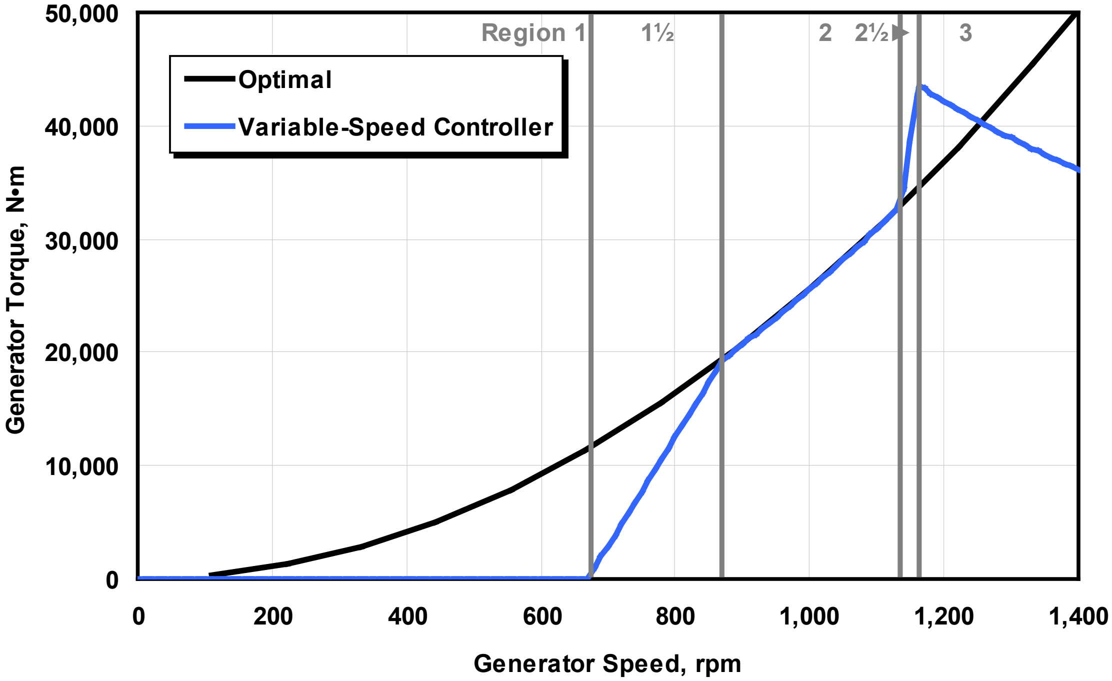

Figure 7-2. Torque-versus-speed response of the variable-speed controller

Because of the high intrinsic structural damping of the drivetrain, we did not need to incorporate a control loop for damping drivetrain torsional vibration in our baseline generator-torque controller.

We did, however, place a conditional statement on the generator-torque controller so that the torque would be computed as if it were in Region 3—regardless of the generator speed—whenever the previous blade-pitch-angle command was 1° or greater. This results in improved output power quality (fewer dips below rated) at the expense of short-term overloading of the generator and the gearbox. To avoid this excessive overloading, we saturated the torque to a maximum of 10% above rated, or 47,402.91 N•m. We also imposed a torque rate limit of 15,000 N•m/s. In Region 3, the blade-pitch control system takes over.

7.3 Baseline Blade-Pitch Controller

In Region 3, the full-span rotor-collective blade-pitch-angle commands are computed using gain-scheduled proportional-integral (PI) control on the speed error between the filtered generator speed and the rated generator speed (1173.7 rpm).

We designed the blade-pitch control system using a simple single-degree-of-freedom (single-DOF) model of the wind turbine. Because the goal of the blade-pitch control system is to regulate the generator speed, this DOF is the angular rotation of the shaft. To compute the required control gains, it is beneficial to examine the equation of motion of this single-DOF system. From a simple free-body diagram of the drivetrain, the equation of motion is

$$T_{Aero} - N_{Gear} T_{Gen} = \left(I_{Rotor} + N_{Gear}^2 I_{Gen} \right) \frac{d}{dt} \left(\Omega_0 + \Delta\Omega \right) = I_{Drivetrain} \Delta\dot{\Omega}, \tag{7-5}$$

where T_{Aero} is the low-speed shaft aerodynamic torque, T_{Gen} is the high-speed shaft generator torque, N_{Gear} is the high-speed to low-speed gearbox ratio, $I_{Drivetrain}$ is the drivetrain inertia cast to the low-speed shaft, I_{Rotor} is the rotor inertia, I_{Gen} is the generator inertia relative to the high-speed shaft, Ω_0 is the rated low-speed shaft rotational speed, $\Delta\Omega$ is the small perturbation of low-speed shaft rotational speed about the rated speed, $\Delta\dot{\Omega}$ is the low-speed shaft rotational acceleration, and t is the simulation time.

Because the generator-torque controller maintains constant generator power in Region 3, the generator torque in Region 3 is inversely proportional to the generator speed (see Figure 7-2), or

$$T_{Gen}\left(N_{Gear}\Omega\right)=\frac{P_0}{N_{Gear}\Omega}, \tag{7-6}$$

where P_0 is the rated mechanical power and Ω is the low-speed shaft rotational speed.

Similarly, assuming negligible variation of aerodynamic torque with rotor speed, the aerodynamic torque in Region 3 is

$$T_{Aero}\left(\theta\right)=\frac{P\left(\theta,\Omega_0\right)}{\Omega_0}, \tag{7-7}$$

where P is the mechanical power and θ is the full-span rotor-collective blade-pitch angle.

Using a first-order Taylor series expansion of Eqs. (7-6) and (7-7), one can see that

$$T_{Gen}\approx\frac{P_0}{N_{Gear}\Omega_0}-\frac{P_0}{N_{Gear}\Omega_0^2}\Delta\Omega \tag{7-8}$$

and

$$T_{Aero}\approx\frac{P_0}{\Omega_0}+\frac{1}{\Omega_0}\left(\frac{\partial P}{\partial\theta}\right)\Delta\theta, \tag{7-9}$$

where $\Delta\theta$ is a small perturbation of the blade-pitch angles about their operating point. With proportional-integral-derivative (PID) control, this is related to the rotor-speed perturbations by

$$\Delta\theta=K_PN_{Gear}\Delta\Omega+K_I\int_0^t N_{Gear}\Delta\Omega dt+K_DN_{Gear}\Delta\dot{\Omega}, \tag{7-10}$$

where K_P, K_I, and K_D are the blade-pitch controller proportional, integral, and derivative gains, respectively.

By setting $\dot{\varphi}=\Delta\Omega$, combining the above expressions, and simplifying, the equation of motion for the rotor-speed error becomes

$$\underbrace{\left[I_{Drivetrain}+\frac{1}{\Omega_0}\left(-\frac{\partial P}{\partial \theta}\right)N_{Gear}K_D\right]}_{M_\varphi}\ddot{\varphi}+\underbrace{\left[\frac{1}{\Omega_0}\left(-\frac{\partial P}{\partial \theta}\right)N_{Gear}K_P-\frac{P_0}{\Omega_0^2}\right]}_{C_\varphi}\dot{\varphi}+\underbrace{\left[\frac{1}{\Omega_0}\left(-\frac{\partial P}{\partial \theta}\right)N_{Gear}K_I\right]}_{K_\varphi}\varphi=0 . \tag{7-11}$$

One can see that the idealized PID-controlled rotor-speed error will respond as a second-order system with the natural frequency, $\omega_{\varphi n}$, and damping ratio, ζ_φ, equal to

$$\omega_{\varphi n}=\sqrt{\frac{K_\varphi}{M_\varphi}} \tag{7-12}$$

and

$$\zeta_\varphi=\frac{C_\varphi}{2\sqrt{K_\varphi M_\varphi}}=\frac{C_\varphi}{2M_\varphi\omega_{\varphi n}} . \tag{7-13}$$

In an active pitch-to-feather wind turbine, the sensitivity of aerodynamic power to the rotor-collective blade-pitch angle, $\partial P/\partial\theta$, is negative in Region 3. With positive control gains, then, the derivative term acts to increase the effective inertia of the drivetrain, the proportional term adds damping, and the integral term adds restoring. Also, because the generator torque drops with increasing speed error (to maintain constant power) in Region 3, one can see that the generator-torque controller introduces a negative damping in the speed error response [indicated by the $-P_0/\Omega_0^2$ term in Eq. (7-11)]. This negative damping must be compensated by the proportional term in the blade-pitch controller.

In the design of the blade-pitch controller, Ref. [10] recommends neglecting the derivative gain, ignoring the negative damping from the generator-torque controller, and aiming for the response characteristics given by $\omega_{\varphi n}$ = 0.6 rad/s and ζ_φ = 0.6 to 0.7. This specification leads to direct expressions for choosing appropriate PI gains once the sensitivity of aerodynamic power to rotor-collective blade pitch, $\partial P/\partial\theta$, is known:

$$K_P=\frac{2I_{Drivetrain}\Omega_0\zeta_\varphi\omega_{\varphi n}}{N_{Gear}\left(-\frac{\partial P}{\partial\theta}\right)} \tag{7-14}$$

and

$$K_I=\frac{I_{Drivetrain}\Omega_0\omega_{\varphi n}^2}{N_{Gear}\left(-\frac{\partial P}{\partial\theta}\right)} . \tag{7-15}$$

The blade-pitch sensitivity, $\partial P/\partial\theta$, is an aerodynamic property of the rotor that depends on the wind speed, rotor speed, and blade-pitch angle. We calculated it for the NREL offshore 5-MW baseline wind turbine by performing a linearization analysis in FAST with AeroDyn at a number of given, steady, and uniform wind speeds; at the rated rotor speed (Ω_0 = 12.1 rpm); and at the corresponding blade-pitch angles that produce the rated mechanical power (P_0 = 5.296610 MW). The linearization analysis involves perturbing the rotor-collective blade-pitch angle at each operating point and measuring the resulting variation in aerodynamic power. Within FAST, the partial derivative is computed using the central-difference-perturbation numerical technique. We created a slightly customized copy of FAST with AeroDyn so that the linearization procedure would invoke the frozen-wake assumption, in which the induced wake velocities are held constant while the blade-pitch angle is perturbed. This gives a more accurate linearization for heavily loaded rotors (i.e., for operating points in Region 3 closest to rated). Table 7-1 presents the results.

Table 7-1. Sensitivity of Aerodynamic Power to Blade Pitch in Region 3

Wind Speed (m/s)	Rotor Speed (rpm)	Pitch Angle (º)	$\partial P/\partial\theta$ (watt/rad)
11.4 - Rated	12.1	0.00	-28.24E+6
12.0	12.1	3.83	-43.73E+6
13.0	12.1	6.60	-51.66E+6
14.0	12.1	8.70	-58.44E+6
15.0	12.1	10.45	-64.44E+6
16.0	12.1	12.06	-70.46E+6
17.0	12.1	13.54	-76.53E+6
18.0	12.1	14.92	-83.94E+6
19.0	12.1	16.23	-90.67E+6
20.0	12.1	17.47	-94.71E+6
21.0	12.1	18.70	-99.04E+6
22.0	12.1	19.94	-105.90E+6
23.0	12.1	21.18	-114.30E+6
24.0	12.1	22.35	-120.20E+6
25.0	12.1	23.47	-125.30E+6

As Table 7-1 shows, the sensitivity of aerodynamic power to rotor-collective blade pitch varies considerably over Region 3, so constant PI gains are not adequate for effective speed control. The pitch sensitivity, though, varies nearly linearly with blade-pitch angle:

$$\frac{\partial P}{\partial \theta} = \left[\frac{\frac{\partial P}{\partial \theta}(\theta = 0)}{\theta_K} \right] \theta + \left[\frac{\partial P}{\partial \theta}(\theta = 0) \right] \tag{7-16a}$$

or

$$\frac{1}{\frac{\partial P}{\partial \theta}} = \frac{1}{\frac{\partial P}{\partial \theta}(\theta = 0)\left(1 + \frac{\theta}{\theta_K} \right)}, \tag{7-16b}$$

where $\frac{\partial P}{\partial \theta}(\theta = 0)$ is the pitch sensitivity at rated and θ_K is the blade-pitch angle at which the pitch sensitivity has doubled from its value at the rated operating point; that is,

$$\frac{\partial P}{\partial \theta}(\theta = \theta_K) = 2\frac{\partial P}{\partial \theta}(\theta = 0). \tag{7-17}$$

On the right-hand side of Eq. (7-16a), the first and second terms in square brackets represent the slope and intercept of the best-fit line, respectively. We computed this regression for the NREL 5-MW baseline wind turbine and present the results in Figure 7-3.

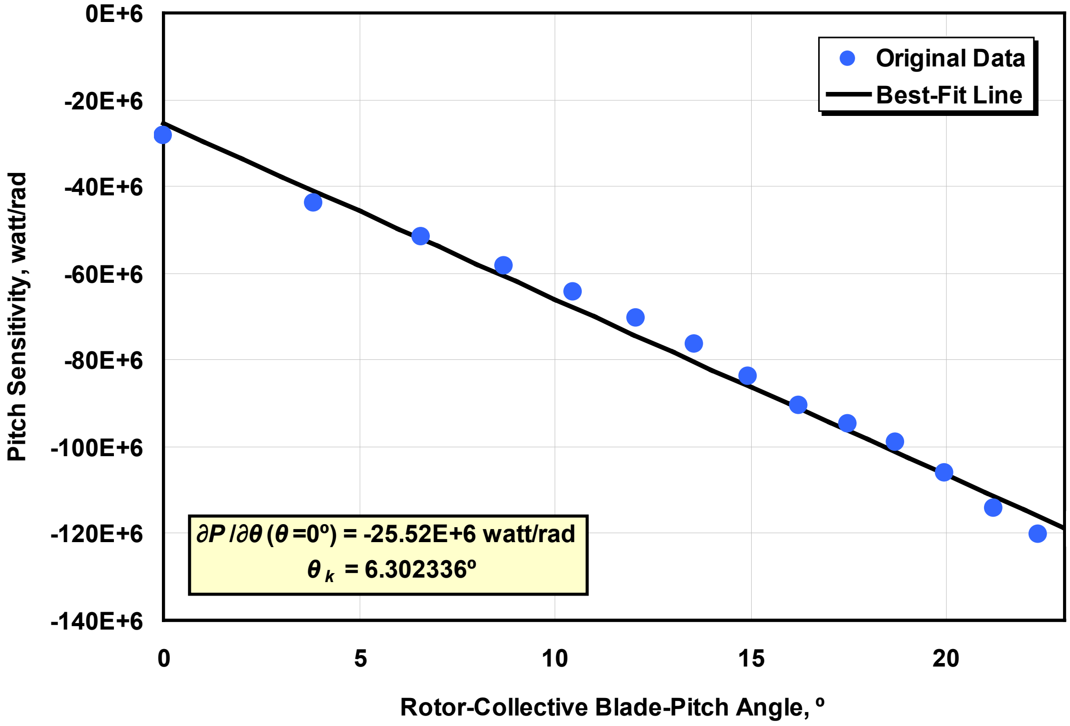

Figure 7-3. Best-fit line of pitch sensitivity in Region 3

The linear relation between pitch sensitivity and blade-pitch angle presents a simple technique for implementing gain scheduling based on blade-pitch angle; that is,

$$K_P(\theta) = \frac{2 I_{Drivetrain} \Omega_0 \zeta_\varphi \omega_{\varphi n}}{N_{Gear}\left[-\frac{\partial P}{\partial \theta}(\theta = 0)\right]} GK(\theta) \tag{7-18}$$

and

$$K_I(\theta)=\frac{I_{Drivetrain}\Omega_0\omega_{\varphi n}^2}{N_{Gear}\left[-\frac{\partial P}{\partial\theta}(\theta=0)\right]}GK(\theta), \tag{7-19}$$

where $GK(\theta)$ is the dimensionless gain-correction factor (from Ref. [10]), which is dependent on the blade-pitch angle:

$$GK(\theta)=\frac{1}{1+\frac{\theta}{\theta_K}}. \tag{7-20}$$

In our implementation of the gain-scheduled PI blade-pitch controller, we used the blade-pitch angle from the previous controller time step to calculate the gain-correction factor at the next time step.

Using the properties for the baseline wind turbine and the recommended response characteristics from Ref. [10], the resulting gains are $K_P(\theta = 0^\circ) = 0.01882681$ s, $K_I(\theta = 0^\circ) = 0.008068634$, and $K_D = 0.0$ s^2. Figure 7-4 presents the gains at other blade-pitch angles, along with the gain-correction factor. We used the upper limit of the recommended damping ratio range, $\zeta_\varphi = 0.7$, to compensate for neglecting negative damping from the generator-torque controller in the determination of K_P.

Unfortunately, the simple gain-scheduling law derived in this section for the proportional and integral gains cannot retain consistent response characteristics (i.e., constant values of $\omega_{\varphi n}$ and

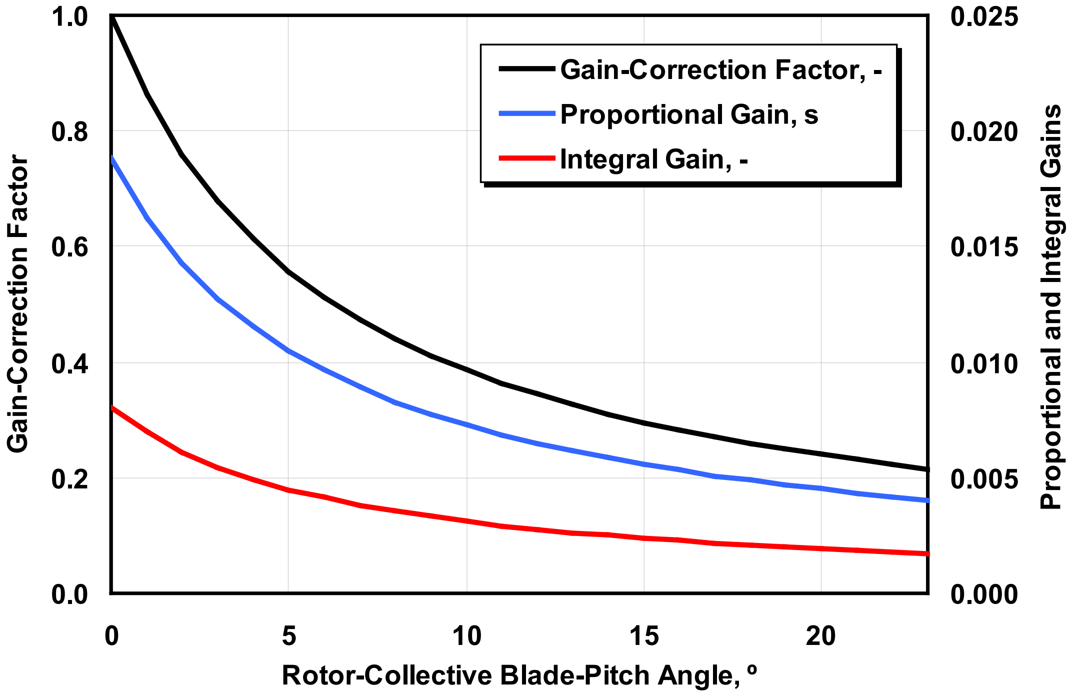

Figure 7-4. Baseline blade-pitch control system gain-scheduling law

ζ_{φ}) across all of Region 3 when applied to the derivative gain. We, nevertheless, considered adding a derivative term by selecting and testing a range of gains, but none were found to give better performance in the overall system response. Instead, the baseline control system uses the gains derived previously in this section (without the derivative term).

We set the blade-pitch rate limit to 8°/s in absolute value. This is speculated to be the blade-pitch rate limit of conventional 5-MW machines based on General Electric (GE) Wind's long-blade test program. We also set the minimum and maximum blade-pitch settings to 0° and 90°, respectively. The lower limit is the set blade pitch for maximizing power in Region 2, as described in Section 7.2. The upper limit is very close to the fully feathered blade pitch for neutral torque. We saturated the integral term in the PI controller between these limits to ensure a fast response in the transitions between Regions 2 and 3.

7.4 Baseline Blade-Pitch Actuator

Because of limitations in the FAST code, the FAST model does not include any blade-pitch actuator dynamic effects. Blade-pitch actuator dynamics are, however, needed in ADAMS. To enable successful comparisons between the FAST and ADAMS response predictions, then, we found it beneficial to reduce the effect of the blade-pitch actuator response in ADAMS. Consequently, we designed the blade-pitch actuator in the ADAMS model with a very high natural frequency of 30 Hz, which is higher than the highest full-system natural frequency in the FAST model (see Section 9), and a damping ratio of 2% critical. This resulted in an equivalent blade-pitch actuator linear-spring constant of 971,350,000 N•m/rad and an equivalent blade-pitch actuator linear-damping constant of 206,000 N•m/(rad/s).

7.5 Summary of Baseline Control System Properties

We implemented the NREL offshore 5-MW wind turbine's baseline control system as an external dynamic link library (DLL) in the style of Garrad Hassan's *BLADED* wind turbine software package [3]. Appendix C contains the source code for this DLL, and Figure 7-5 presents a flowchart of the overall integrated control system calculations. Table 7-2 summarizes the baseline generator-torque and blade-pitch control properties we discussed earlier in this section.

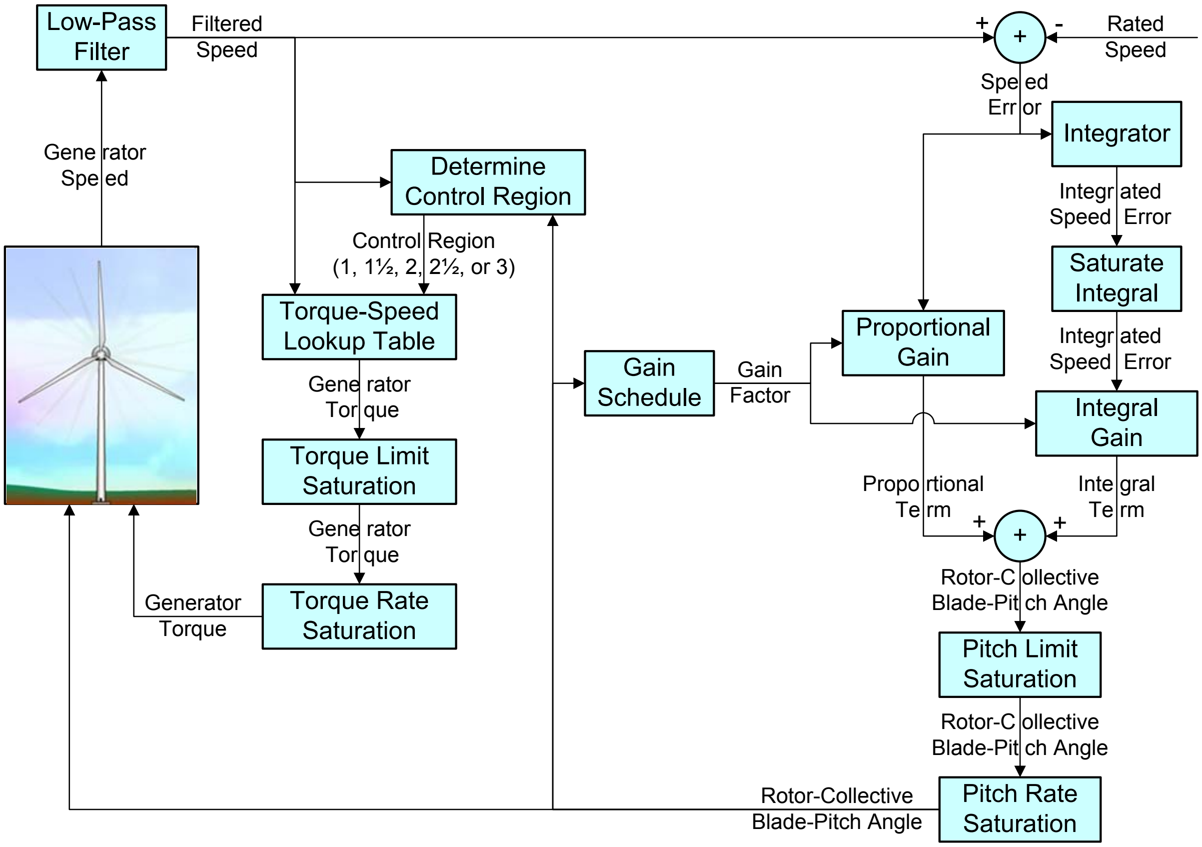

Figure 7-5. Flowchart of the baseline control system

Table 7-2. Baseline Control System Properties

Corner Frequency of Generator-Speed Low-Pass Filter	0.25 Hz
Peak Power Coefficient	0.482
Tip-Speed Ratio at Peak Power Coefficient	7.55
Rotor-Collective Blade-Pitch Angle at Peak Power Coefficient	0.0 º
Generator-Torque Constant in Region 2	0.0255764 N•m/rpm^2
Rated Mechanical Power	5.296610 MW
Rated Generator Torque	43,093.55 N•m
Transitional Generator Speed between Regions 1 and 1½	670 rpm
Transitional Generator Speed between Regions 1½ and 2	871 rpm
Transitional Generator Speed between Regions 2½ and 3	1,161.963 rpm
Generator Slip Percentage in Region 2½	10 %
Minimum Blade Pitch for Ensuring Region 3 Torque	1 º
Maximum Generator Torque	47,402.91 N•m
Maximum Generator Torque Rate	15,000 N•m/s
Proportional Gain at Minimum Blade-Pitch Setting	0.01882681 s
Integral Gain at Minimum Blade-Pitch Setting	0.008068634
Blade-Pitch Angle at which the Rotor Power Has Doubled	6.302336 º
Minimum Blade-Pitch Setting	0 º
Maximum Blade-Pitch Setting	90 º
Maximum Absolute Blade Pitch Rate	8 º/s
Equivalent Blade-Pitch-Actuator Linear-Spring Constant	971,350,000 N•m/rad
Equivalent Blade-Pitch-Actuator Linear-Damping Constant	206,000 N•m/rad/s

8 FAST with AeroDyn and ADAMS with AeroDyn Models

Using the turbine properties described previously in this report, we put together models of the NREL offshore 5-MW baseline wind turbine within FAST [11] with AeroDyn [16,20]. The input files for these models are given in Appendix A and Appendix B, for version (v) 6.10a-jmj of FAST and v12.58 of AeroDyn, respectively. We then generated the higher fidelity ADAMS with AeroDyn models through the preprocessor functionality built into the FAST code.

The input files in Appendix A are for the FAST model of the equivalent land-based version of the NREL 5-MW baseline wind turbine. The input files for other versions of the model, such as those for different support structures, require only a few minor changes. These include changes to input parameters "PtfmModel" and "PtfmFile," which identify the type and properties of the support platform, and modifications to the prescribed mode shapes in the tower input file, "TwrFile."

Although most of the input-parameter specifications in Appendix A and Appendix B are self-explanatory, the specifications of the prescribed mode shapes needed by FAST to characterize the flexibility of the blades and tower deserve a special explanation. The required mode shapes depend on the member's boundary conditions. For the blade modes, we used v2.22 of the Modes program [4] to derive the equivalent polynomial representations of the blade mode shapes needed by FAST. The Modes program calculates the mode shapes of rotating blades, assuming that a blade mode shape is unaffected by its coupling with other system modes of motion. This is a common assumption in wind turbine analysis. For the tower modes, however, there is a great deal of coupling with the rotor motions, and in offshore floating systems, there is coupling with the platform motions as well. To take the former factor into account, we used the linearization functionality of the full-system ADAMS model to obtain the tower modes for the land-based version of the NREL 5-MW baseline wind turbine. In other words, we built an ADAMS model of the wind turbine, enabled all system DOFs, and linearized the model. Then we passed a best-fit polynomial through the resulting tower mode shapes to get the equivalent polynomial representations of the tower mode shapes needed by FAST.

Not including platform motions, the FAST model of the land-based version of the NREL 5-MW baseline wind turbine incorporates 16 DOFs as follows:

- Two flapwise and one edgewise bending-mode DOFs for each of the three blades
- One variable-generator speed DOF and one driveshaft torsional DOF
- One nacelle-yaw-actuator DOF
- Two fore-aft and two side-to-side bending-mode DOFs in the tower.

Not including platform motion, the higher fidelity ADAMS model of the land-based version of the wind turbine incorporates 438 DOFs as follows:

- One hundred and two DOFs in each of the three blades, including flapwise and edgewise shear and bending, torsion, and extension DOFs
- One blade-pitch actuator DOF in each of the three blades

- One variable-generator speed DOF and one driveshaft torsional DOF
- One nacelle-yaw actuator DOF
- One hundred and twenty-six DOFs in the tower, including fore-aft and side-to-side shear and bending, torsion, and extension DOFs.

The support platform motions in, for example, the floating-platform versions of the NREL 5-MW baseline wind turbine add six DOFs per model.

We use a constant time step of 0.0125 s in FAST's fixed-step-size time-integration scheme and a maximum step size of 0.0125 s in ADAMS' variable-step-size time integrator. We have AeroDyn perform aerodynamic calculations every other structural time step (i.e., 0.025 s) to ensure that there are at least 200-azimuth-step computations per revolution at 12 rpm. Data are output at 20 Hz or every fourth structural time step. We made these time steps as large as possible to ensure numerical stability and suitable output resolution across a range of operating conditions.

9 Full-System Natural Frequencies and Steady-State Behavior

To provide a cursory overview of the overall system behavior of the equivalent land-based version of the NREL 5-MW baseline wind turbine, we calculated the full-system natural frequencies and the steady-state response of the system as a function of wind speed.

We obtained the full-system natural frequencies with both the FAST model and the ADAMS model. In FAST, we calculated the natural frequencies by performing an eigenanalysis on the first-order state matrix created from a linearization analysis. In ADAMS, we obtained the frequencies by invoking a "LINEAR/EIGENSOL" command, which linearizes the complete ADAMS model and computes eigendata. To avoid the rigid-body drivetrain mode, the analyses considered the wind turbine in a stationary condition with the high-speed shaft brake engaged. The blades were pitched to their minimum set point (0º), but aerodynamic damping was ignored. Table 9-1 lists results for the first 13 full-system natural frequencies.

Table 9-1. Full-System Natural Frequencies in Hertz

Mode	Description	FAST	ADAMS
1	1st Tower Fore-Aft	0.3240	0.3195
2	1st Tower Side-to-Side	0.3120	0.3164
3	1st Drivetrain Torsion	0.6205	0.6094
4	1st Blade Asymmetric Flapwise Yaw	0.6664	0.6296
5	1st Blade Asymmetric Flapwise Pitch	0.6675	0.6686
6	1st Blade Collective Flap	0.6993	0.7019
7	1st Blade Asymmetric Edgewise Pitch	1.0793	1.0740
8	1st Blade Asymmetric Edgewise Yaw	1.0898	1.0877
9	2nd Blade Asymmetric Flapwise Yaw	1.9337	1.6507
10	2nd Blade Asymmetric Flapwise Pitch	1.9223	1.8558
11	2nd Blade Collective Flap	2.0205	1.9601
12	2nd Tower Fore-Aft	2.9003	2.8590
13	2nd Tower Side-to-Side	2.9361	2.9408

The agreement between FAST and ADAMS is quite good. The biggest differences exist in the predictions of the blades' second asymmetric flapwise yaw and pitch modes. By "yaw" and "pitch" we mean that these blade asymmetric modes couple with the nacelle-yaw and nacelle-pitching motions, respectively. Because of the offsets of the blade section CM from the pitch axis, higher-order modes, and tower-torsion DOFs—which are available in ADAMS, but not in FAST—ADAMS predicts lower natural frequencies in these modes than FAST does.

Bir and Jonkman have published [2] a much more exhaustive eigenanalysis for the NREL 5-MW baseline wind turbine. The referenced publication documents the natural frequencies and damping ratios of the land- and floating-platform versions of the 5-MW turbine across a range of operating conditions.

We obtained the steady-state response of the land-based 5-MW baseline wind turbine by running a series of FAST with AeroDyn simulations at a number of given, steady, and uniform wind speeds. The simulations lengths were long enough to ensure that all transient behavior had died out; we then recorded the steady-state output values. We ran the simulations using the blade-element / momentum (BEM) wake option of AeroDyn and with all available and relevant land-based DOFs enabled. Figure 9-1 shows the results for several output parameters, which are defined as follows:

- "GenSpeed" represents the rotational speed of the generator (high-speed shaft).
- "RotPwr" and "GenPwr" represent the mechanical power within the rotor and the electrical output of the generator, respectively.
- "RotThrust" represents the rotor thrust.
- "RotTorq" represents the mechanical torque in the low-speed shaft.
- "RotSpeed" represents the rotational speed of the rotor (low-speed shaft).
- "BlPitch1" represents the pitch angle of Blade 1.
- "GenTq" represents the electrical torque of the generator.
- "TSR" represents the tip-speed ratio.
- "OoPDefl1" and "IPDefl1" represent the out-of-plane and in-plane tip deflections of Blade 1 relative to the undeflected blade-pitch axis.
- "TTDspFA" and "TTDspSS" represent the fore-aft and side-to-side deflection of the tower top relative to the centerline of the undeflected tower.

As planned, the generator and rotor speeds increase linearly with wind speed in Region 2 to maintain constant tip-speed ratio and optimal wind-power conversion efficiency. Similarly, the generator and rotor powers and generator and rotor torques increase dramatically with wind speed in Region 2, increasing cubically and quadratically, respectively. Above rated, the generator and rotor powers are held constant by regulating to a fixed speed with active blade-pitch control. The out-of-plane tip deflection of the reference blade (Blade 1) reaches a maximum at the rated operating point before dropping again. This response characteristic is the result of the peak in rotor thrust at rated. This peak is typical of variable generator speed variable blade-pitch-to-feather wind turbines because of the transition that occurs in the control system at rated between the active generator-torque and the active blade-pitch control regions. This peak in response is also visible, though less pronounced, in the in-plane tip deflection of the reference blade and the tower-top fore-aft displacement.

Start-up transient behavior is an artifact of computational analysis. To mitigate this behavior, we suggest using the steady-state values of the rotor speed and blade-pitch angles found in Figure 9-1 as initial conditions in simulations.

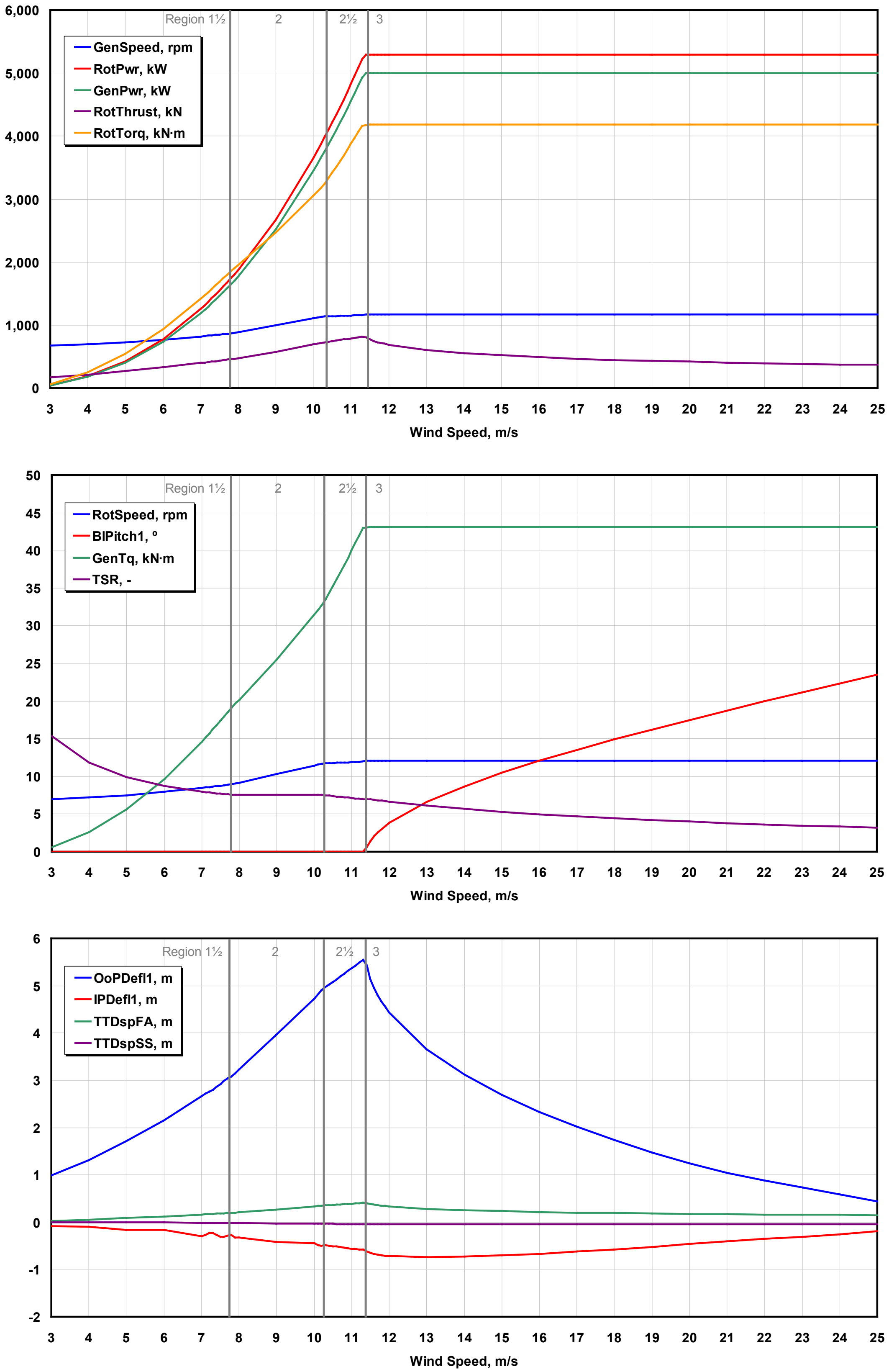

Figure 9-1. Steady-state responses as a function of wind speed

10 Conclusions

To support concept studies aimed at assessing offshore wind technology, we developed the specifications of a representative utility-scale multimegawatt turbine now known as the "NREL offshore 5-MW baseline wind turbine." This wind turbine is a conventional three-bladed upwind variable-speed variable blade-pitch-to-feather-controlled turbine. To create the model, we obtained some broad design information from the published documents of turbine manufacturers, with a heavy emphasis on the REpower 5M machine. Because detailed data was unavailable, however, we also used the publicly available properties from the conceptual models in the WindPACT, RECOFF, and DOWEC projects. We then created a composite from these data, extracting the best available and most representative specifications. This report documented the specifications of the NREL offshore 5-MW baseline wind turbine—including the aerodynamic, structural, and control-system properties—and the rationale behind its development. The model has been, and will likely continue to be, used as a reference by research teams throughout the world to standardize baseline offshore wind turbine specifications and to quantify the benefits of advanced land- and sea-based wind energy technologies.

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Appendix A FAST Input Files

A.1 Primary Input File

```
--------------------------------------------------------------------------------
------- FAST INPUT FILE --------------------------------------------------------
NREL 5.0 MW Baseline Wind Turbine for Use in Offshore Analysis.
Properties from Dutch Offshore Wind Energy Converter (DOWEC) 6MW Pre-Design (10046_009.pdf) and REpower 5M 5MW (5m_uk.pdf); C
---------------------- SIMULATION CONTROL --------------------------------------
False       Echo        - Echo input data to "echo.out" (flag)
   3        ADAMSPrep   - ADAMS preprocessor mode {1: Run FAST, 2: use FAST as a preprocessor to create an ADAMS model, 3: do
   1        AnalMode    - Analysis mode {1: Run a time-marching simulation, 2: create a periodic linearized model} (switch)
   3        NumBl       - Number of blades (-)
 630.0      TMax        - Total run time (s)
   0.0125   DT          - Integration time step (s)
---------------------- TURBINE CONTROL -----------------------------------------
   0        YCMode      - Yaw control mode {0: none, 1: user-defined from routine UserYawCont, 2: user-defined from Simulink}
9999.9      TYCOn       - Time to enable active yaw control (s) [unused when YCMode=0]
   1        PCMode      - Pitch control mode {0: none, 1: user-defined from routine PitchCntrl, 2: user-defined from Simulink
   0.0      TPCOn       - Time to enable active pitch control (s) [unused when PCMode=0]
   2        VSContrl    - Variable-speed control mode {0: none, 1: simple VS, 2: user-defined from routine UserVSCont, 3: use
9999.9      VS_RtGnSp   - Rated generator speed for simple variable-speed generator control (HSS side) (rpm) [used only when
9999.9      VS_RtTq     - Rated generator torque/constant generator torque in Region 3 for simple variable-speed generator co
9999.9      VS_Rgn2K    - Generator torque constant in Region 2 for simple variable-speed generator control (HSS side) (N-m/r
9999.9      VS_SlPc     - Rated generator slip percentage in Region 2 1/2 for simple variable-speed generator control (%) [us
   2        GenModel    - Generator model {1: simple, 2: Thevenin, 3: user-defined from routine UserGen} (switch) [used only
True        GenTiStr    - Method to start the generator {T: timed using TimGenOn, F: generator speed using SpdGenOn} (flag)
True        GenTiStp    - Method to stop the generator {T: timed using TimGenOf, F: when generator power = 0} (flag)
9999.9      SpdGenOn    - Generator speed to turn on the generator for a startup (HSS speed) (rpm) [used only when GenTiStr=F
   0.0      TimGenOn    - Time to turn on the generator for a startup (s) [used only when GenTiStr=True]
9999.9      TimGenOf    - Time to turn off the generator (s) [used only when GenTiStp=True]
   1        HSSBrMode   - HSS brake model {1: simple, 2: user-defined from routine UserHSSBr} (switch)
9999.9      THSSBrDp    - Time to initiate deployment of the HSS brake (s)
9999.9      TiDynBrk    - Time to initiate deployment of the dynamic generator brake [CURRENTLY IGNORED] (s)
9999.9      TTpBrDp(1)  - Time to initiate deployment of tip brake 1 (s)
9999.9      TTpBrDp(2)  - Time to initiate deployment of tip brake 2 (s)
9999.9      TTpBrDp(3)  - Time to initiate deployment of tip brake 3 (s) [unused for 2 blades]
9999.9      TBDepISp(1) - Deployment-initiation speed for the tip brake on blade 1 (rpm)
9999.9      TBDepISp(2) - Deployment-initiation speed for the tip brake on blade 2 (rpm)
9999.9      TBDepISp(3) - Deployment-initiation speed for the tip brake on blade 3 (rpm) [unused for 2 blades]
9999.9      TYawManS    - Time to start override yaw maneuver and end standard yaw control (s)
   0.3      YawManRat   - Yaw rate (in absolute value) at which override yaw maneuver heads toward final yaw angle (deg/s)
   0.0      NacYawF     - Final yaw angle for override yaw maneuvers (degrees)
9999.9      TPitManS(1) - Time to start override pitch maneuver for blade 1 and end standard pitch control (s)
9999.9      TPitManS(2) - Time to start override pitch maneuver for blade 2 and end standard pitch control (s)
9999.9      TPitManS(3) - Time to start override pitch maneuver for blade 3 and end standard pitch control (s) [unused for 2
   8.0      PitManRat(1)- Pitch rate (in absolute value) at which override pitch maneuver for blade 1 heads toward final pitc
   8.0      PitManRat(2)- Pitch rate (in absolute value) at which override pitch maneuver for blade 2 heads toward final pitc
   8.0      PitManRat(3)- Pitch rate (in absolute value) at which override pitch maneuver for blade 3 heads toward final pitc
   0.0      BlPitch(1)  - Blade 1 initial pitch (degrees)
   0.0      BlPitch(2)  - Blade 2 initial pitch (degrees)
   0.0      BlPitch(3)  - Blade 3 initial pitch (degrees) [unused for 2 blades]
   0.0      BlPitchF(1) - Blade 1 final pitch for override pitch maneuvers (degrees)
   0.0      BlPitchF(2) - Blade 2 final pitch for override pitch maneuvers (degrees)
   0.0      BlPitchF(3) - Blade 3 final pitch for override pitch maneuvers (degrees) [unused for 2 blades]
---------------------- ENVIRONMENTAL CONDITIONS --------------------------------
   9.80665  Gravity     - Gravitational acceleration (m/s^2)
---------------------- FEATURE FLAGS -------------------------------------------
True        FlapDOF1    - First flapwise blade mode DOF (flag)
True        FlapDOF2    - Second flapwise blade mode DOF (flag)
True        EdgeDOF     - First edgewise blade mode DOF (flag)
False       TeetDOF     - Rotor-teeter DOF (flag) [unused for 3 blades]
True        DrTrDOF     - Drivetrain rotational-flexibility DOF (flag)
True        GenDOF      - Generator DOF (flag)
True        YawDOF      - Yaw DOF (flag)
True        TwFADOF1    - First fore-aft tower bending-mode DOF (flag)
True        TwFADOF2    - Second fore-aft tower bending-mode DOF (flag)
True        TwSSDOF1    - First side-to-side tower bending-mode DOF (flag)
True        TwSSDOF2    - Second side-to-side tower bending-mode DOF (flag)
True        CompAero    - Compute aerodynamic forces (flag)
False       CompNoise   - Compute aerodynamic noise (flag)
---------------------- INITIAL CONDITIONS --------------------------------------
   0.0      OoPDefl     - Initial out-of-plane blade-tip displacement (meters)
   0.0      IPDefl      - Initial in-plane blade-tip deflection (meters)
   0.0      TeetDefl    - Initial or fixed teeter angle (degrees) [unused for 3 blades]
   0.0      Azimuth     - Initial azimuth angle for blade 1 (degrees)
  12.1      RotSpeed    - Initial or fixed rotor speed (rpm)
   0.0      NacYaw      - Initial or fixed nacelle-yaw angle (degrees)
   0.0      TTDspFA     - Initial fore-aft tower-top displacement (meters)
   0.0      TTDspSS     - Initial side-to-side tower-top displacement (meters)
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---------------------- TURBINE CONFIGURATION -----------------------------------
  63.0      TipRad      - The distance from the rotor apex to the blade tip (meters)
   1.5      HubRad      - The distance from the rotor apex to the blade root (meters)
   1        PSpnElN     - Number of the innermost blade element which is still part of the pitchable portion of the blade for
   0.0      UndSling    - Undersling length [distance from teeter pin to the rotor apex] (meters) [unused for 3 blades]
   0.0      HubCM       - Distance from rotor apex to hub mass [positive downwind] (meters)
  -5.01910  OverHang    - Distance from yaw axis to rotor apex [3 blades] or teeter pin [2 blades] (meters)
   1.9      NacCMxn     - Downwind distance from the tower-top to the nacelle CM (meters)
   0.0      NacCMyn     - Lateral  distance from the tower-top to the nacelle CM (meters)
   1.75     NacCMzn     - Vertical distance from the tower-top to the nacelle CM (meters)
  87.6      TowerHt     - Height of tower above ground level [onshore] or MSL [offshore] (meters)
   1.96256  Twr2Shft    - Vertical distance from the tower-top to the rotor shaft (meters)
   0.0      TwrRBHt     - Tower rigid base height (meters)
  -5.0      ShftTilt    - Rotor shaft tilt angle (degrees)
   0.0      Delta3      - Delta-3 angle for teetering rotors (degrees) [unused for 3 blades]
  -2.5      PreCone(1)  - Blade 1 cone angle (degrees)
  -2.5      PreCone(2)  - Blade 2 cone angle (degrees)
  -2.5      PreCone(3)  - Blade 3 cone angle (degrees) [unused for 2 blades]
   0.0      AzimB1Up    - Azimuth value to use for I/O when blade 1 points up (degrees)
---------------------- MASS AND INERTIA ----------------------------------------
   0.0      YawBrMass   - Yaw bearing mass (kg)
 240.00E3   NacMass     - Nacelle mass (kg)
  56.78E3   HubMass     - Hub mass (kg)
   0.0      TipMass(1)  - Tip-brake mass, blade 1 (kg)
   0.0      TipMass(2)  - Tip-brake mass, blade 2 (kg)
   0.0      TipMass(3)  - Tip-brake mass, blade 3 (kg) [unused for 2 blades]
2607.89E3   NacYIner    - Nacelle inertia about yaw axis (kg m^2)
 534.116    GenIner     - Generator inertia about HSS (kg m^2)
 115.926E3  HubIner     - Hub inertia about rotor axis [3 blades] or teeter axis [2 blades] (kg m^2)
---------------------- DRIVETRAIN ----------------------------------------------
 100.0      GBoxEff     - Gearbox efficiency (%)
  94.4      GenEff      - Generator efficiency [ignored by the Thevenin and user-defined generator models] (%)
  97.0      GBRatio     - Gearbox ratio (-)
False       GBRevers    - Gearbox reversal {T: if rotor and generator rotate in opposite directions} (flag)
  28.1162E3 HSSBrTqF    - Fully deployed HSS-brake torque (N-m)
   0.6      HSSBrDT     - Time for HSS-brake to reach full deployment once initiated (sec) [used only when HSSBrMode=1]
            DynBrkFi    - File containing a mech-gen-torque vs HSS-speed curve for a dynamic brake [CURRENTLY IGNORED] (quote
 867.637E6  DTTorSpr    - Drivetrain torsional spring (N-m/rad)
   6.215E6  DTTorDmp    - Drivetrain torsional damper (N-m/(rad/s))
---------------------- SIMPLE INDUCTION GENERATOR ------------------------------
9999.9      SIG_SlPc    - Rated generator slip percentage (%) [used only when VSContrl=0 and GenModel=1]
9999.9      SIG_SySp    - Synchronous (zero-torque) generator speed (rpm) [used only when VSContrl=0 and GenModel=1]
9999.9      SIG_RtTq    - Rated torque (N-m) [used only when VSContrl=0 and GenModel=1]
9999.9      SIG_PORt    - Pull-out ratio (Tpullout/Trated) (-) [used only when VSContrl=0 and GenModel=1]
---------------------- THEVENIN-EQUIVALENT INDUCTION GENERATOR -----------------
9999.9      TEC_Freq    - Line frequency [50 or 60] (Hz) [used only when VSContrl=0 and GenModel=2]
9998        TEC_NPol    - Number of poles [even integer > 0] (-) [used only when VSContrl=0 and GenModel=2]
9999.9      TEC_SRes    - Stator resistance (ohms) [used only when VSContrl=0 and GenModel=2]
9999.9      TEC_RRes    - Rotor resistance (ohms) [used only when VSContrl=0 and GenModel=2]
9999.9      TEC_VLL     - Line-to-line RMS voltage (volts) [used only when VSContrl=0 and GenModel=2]
9999.9      TEC_SLR     - Stator leakage reactance (ohms) [used only when VSContrl=0 and GenModel=2]
9999.9      TEC_RLR     - Rotor leakage reactance (ohms) [used only when VSContrl=0 and GenModel=2]
9999.9      TEC_MR      - Magnetizing reactance (ohms) [used only when VSContrl=0 and GenModel=2]
---------------------- PLATFORM ------------------------------------------------
   0        PtfmModel   - Platform model {0: none, 1: onshore, 2: fixed bottom offshore, 3: floating offshore} (switch)
            PtfmFile    - Name of file containing platform properties (quoted string) [unused when PtfmModel=0]
---------------------- TOWER ---------------------------------------------------
  20        TwrNodes    - Number of tower nodes used for analysis (-)
"NRELOffshrBsline5MW_Tower_Onshore.dat"          TwrFile     - Name of file containing tower properties (quoted string)
---------------------- NACELLE-YAW ---------------------------------------------
9028.32E6   YawSpr      - Nacelle-yaw spring constant (N-m/rad)
  19.16E6   YawDamp     - Nacelle-yaw damping constant (N-m/(rad/s))
   0.0      YawNeut     - Neutral yaw position--yaw spring force is zero at this yaw (degrees)
---------------------- FURLING -------------------------------------------------
False       Furling     - Read in additional model properties for furling turbine (flag)
            FurlFile    - Name of file containing furling properties (quoted string) [unused when Furling=False]
---------------------- ROTOR-TEETER --------------------------------------------
   0        TeetMod     - Rotor-teeter spring/damper model {0: none, 1: standard, 2: user-defined from routine UserTeet} (swi
   0.0      TeetDmpP    - Rotor-teeter damper position (degrees) [used only for 2 blades and when TeetMod=1]
   0.0      TeetDmp     - Rotor-teeter damping constant (N-m/(rad/s)) [used only for 2 blades and when TeetMod=1]
   0.0      TeetCDmp    - Rotor-teeter rate-independent Coulomb-damping moment (N-m) [used only for 2 blades and when TeetMod
   0.0      TeetSStP    - Rotor-teeter soft-stop position (degrees) [used only for 2 blades and when TeetMod=1]
   0.0      TeetHStP    - Rotor-teeter hard-stop position (degrees) [used only for 2 blades and when TeetMod=1]
   0.0      TeetSSSp    - Rotor-teeter soft-stop linear-spring constant (N-m/rad) [used only for 2 blades and when TeetMod=1]
   0.0      TeetHSSp    - Rotor-teeter hard-stop linear-spring constant (N-m/rad) [used only for 2 blades and when TeetMod=1]
---------------------- TIP-BRAKE -----------------------------------------------
   0.0      TBDrConN    - Tip-brake drag constant during normal operation, Cd*Area (m^2)
   0.0      TBDrConD    - Tip-brake drag constant during fully-deployed operation, Cd*Area (m^2)
   0.0      TpBrDT      - Time for tip-brake to reach full deployment once released (sec)
---------------------- BLADE ---------------------------------------------------
"NRELOffshrBsline5MW_Blade.dat"                  BldFile(1)  - Name of file containing properties for blade 1 (quoted string)
"NRELOffshrBsline5MW_Blade.dat"                  BldFile(2)  - Name of file containing properties for blade 2 (quoted string)
"NRELOffshrBsline5MW_Blade.dat"                  BldFile(3)  - Name of file containing properties for blade 3 (quoted string)
---------------------- AERODYN -------------------------------------------------
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"NRELOffshrBsline5MW_AeroDyn.ipt"                ADFile      - Name of file containing AeroDyn input parameters (quoted strin
---------------------- NOISE ---------------------------------------------------
            NoiseFile     - Name of file containing aerodynamic noise input parameters (quoted string) [used only when CompNois
---------------------- ADAMS ---------------------------------------------------
"NRELOffshrBsline5MW_ADAMSSpecific.dat"          ADAMSFile   - Name of file containing ADAMS-specific input parameters (quote
---------------------- LINEARIZATION CONTROL -----------------------------------
"NRELOffshrBsline5MW_Linear.dat"                 LinFile     - Name of file containing FAST linearization parameters (quoted
---------------------- OUTPUT --------------------------------------------------
True        SumPrint    - Print summary data to "<RootName>.fsm" (flag)
True        TabDelim    - Generate a tab-delimited tabular output file. (flag)
"ES10.3E2"  OutFmt      - Format used for tabular output except time.  Resulting field should be 10 characters. (quoted strin
  30.0      TStart      - Time to begin tabular output (s)
   4        DecFact     - Decimation factor for tabular output {1: output every time step} (-)
   1.0      SttsTime    - Amount of time between screen status messages (sec)
  -3.09528  NcIMUxn     - Downwind distance from the tower-top to the nacelle IMU (meters)
   0.0      NcIMUyn     - Lateral  distance from the tower-top to the nacelle IMU (meters)
   2.23336  NcIMUzn     - Vertical distance from the tower-top to the nacelle IMU (meters)
   1.912    ShftGagL    - Distance from rotor apex [3 blades] or teeter pin [2 blades] to shaft strain gages [positive for up
   1        NTwGages    - Number of tower nodes that have strain gages for output [0 to 9] (-)
  10        TwrGagNd    - List of tower nodes that have strain gages [1 to TwrNodes] (-) [unused if NTwGages=0]
   1        NBlGages    - Number of blade nodes that have strain gages for output [0 to 9] (-)
   9        BldGagNd    - List of blade nodes that have strain gages [1 to BldNodes] (-) [unused if NBlGages=0]
            OutList     - The next line(s) contains a list of output parameters.  See OutList.txt for a listing of available
"WindVxi  , WindVyi  , WindVzi"                              - Longitudinal, lateral, and vertical wind speeds
"WaveElev"                                                   - Wave elevation at the platform reference point
"Wave1Vxi , Wave1Vyi , Wave1Vzi"                             - Longitudinal, lateral, and vertical wave particle velocities a
"Wave1Axi , Wave1Ayi , Wave1Azi"                             - Longitudinal, lateral, and vertical wave particle acceleration
"GenPwr   , GenTq"                                           - Electrical generator power and torque
"HSSBrTq"                                                    - High-speed shaft brake torque
"BldPitch1, BldPitch2, BldPitch3"                            - Pitch angles for blades 1, 2, and 3
"Azimuth"                                                    - Blade 1 azimuth angle
"RotSpeed , GenSpeed"                                        - Low-speed shaft and high-speed shaft speeds
"NacYaw   , NacYawErr"                                       - Nacelle yaw angle and nacelle yaw error estimate
"OoPDefl1 , IPDefl1  , TwstDefl1"                            - Blade 1 out-of-plane and in-plane deflections and tip twist
"OoPDefl2 , IPDefl2  , TwstDefl2"                            - Blade 2 out-of-plane and in-plane deflections and tip twist
"OoPDefl3 , IPDefl3  , TwstDefl3"                            - Blade 3 out-of-plane and in-plane deflections and tip twist
"TwrClrnc1, TwrClrnc2, TwrClrnc3"                            - Tip-to-tower clearance estimate for blades 1, 2, and 3
"NcIMUTAxs, NcIMUTAys, NcIMUTAzs"                            - Nacelle IMU translational accelerations (absolute) in the nonr
"TTDspFA  , TTDspSS  , TTDspTwst"                            - Tower fore-aft and side-to-side displacements and top twist
"PtfmSurge, PtfmSway , PtfmHeave"                            - Platform translational surge, sway, and heave displacements
"PtfmRoll , PtfmPitch, PtfmYaw"                              - Platform rotational roll, pitch and yaw displacements
"PtfmTAxt , PtfmTAyt , PtfmTAzt"                             - Platform translation accelerations (absolute) in the tower-bas
"RootFxc1 , RootFyc1 , RootFzc1"                             - Out-of-plane shear, in-plane shear, and axial forces at the ro
"RootMxc1 , RootMyc1 , RootMzc1"                             - In-plane bending, out-of-plane bending, and pitching moments a
"RootFxc2 , RootFyc2 , RootFzc2"                             - Out-of-plane shear, in-plane shear, and axial forces at the ro
"RootMxc2 , RootMyc2 , RootMzc2"                             - In-plane bending, out-of-plane bending, and pitching moments a
"RootFxc3 , RootFyc3 , RootFzc3"                             - Out-of-plane shear, in-plane shear, and axial forces at the ro
"RootMxc3 , RootMyc3 , RootMzc3"                             - In-plane bending, out-of-plane bending, and pitching moments a
"Spn1MLxb1, Spn1MLyb1, Spn1MLzb1"                            - Blade 1 local edgewise bending, flapwise bending, and pitching
"Spn1MLxb2, Spn1MLyb2, Spn1MLzb2"                            - Blade 2 local edgewise bending, flapwise bending, and pitching
"Spn1MLxb3, Spn1MLyb3, Spn1MLzb3"                            - Blade 3 local edgewise bending, flapwise bending, and pitching
"RotThrust, LSSGagFya, LSSGagFza"                            - Rotor thrust and low-speed shaft 0- and 90-rotating shear forc
"RotTorq  , LSSGagMya, LSSGagMza"                            - Rotor torque and low-speed shaft 0- and 90-rotating bending mo
"YawBrFxp , YawBrFyp , YawBrFzp"                             - Fore-aft shear, side-to-side shear, and vertical forces at the
"YawBrMxp , YawBrMyp , YawBrMzp"                             - Side-to-side bending, fore-aft bending, and yaw moments at the
"TwrBsFxt , TwrBsFyt , TwrBsFzt"                             - Fore-aft shear, side-to-side shear, and vertical forces at the
"TwrBsMxt , TwrBsMyt , TwrBsMzt"                             - Side-to-side bending, fore-aft bending, and yaw moments at the
"TwHt1MLxt, TwHt1MLyt, TwHt1MLzt"                            - Local side-to-side bending, fore-aft bending, and yaw moments
"Fair1Ten , Fair1Ang , Anch1Ten , Anch1Ang"                  - Line 1 fairlead and anchor effective tensions and vertical ang
"Fair2Ten , Fair2Ang , Anch2Ten , Anch2Ang"                  - Line 2 fairlead and anchor effective tensions and vertical ang
"Fair3Ten , Fair3Ang , Anch3Ten , Anch3Ang"                  - Line 3 fairlead and anchor effective tensions and vertical ang
"Fair4Ten , Fair4Ang , Anch4Ten , Anch4Ang"                  - Line 4 fairlead and anchor effective tensions and vertical ang
"Fair5Ten , Fair5Ang , Anch5Ten , Anch5Ang"                  - Line 5 fairlead and anchor effective tensions and vertical ang
"Fair6Ten , Fair6Ang , Anch6Ten , Anch6Ang"                  - Line 6 fairlead and anchor effective tensions and vertical ang
"Fair7Ten , Fair7Ang , Anch7Ten , Anch7Ang"                  - Line 7 fairlead and anchor effective tensions and vertical ang
"Fair8Ten , Fair8Ang , Anch8Ten , Anch8Ang"                  - Line 8 fairlead and anchor effective tensions and vertical ang
"TipSpdRat, RotCp    , RotCt    , RotCq"                     - Rotor tip speed ratio and power, thrust, and torque coefficien
END of FAST input file (the word "END" must appear in the first 3 columns of this last line).
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A.2 Blade Input File – NRELOffshrBsline5MW_Blade.dat

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---------------------- FAST INDIVIDUAL BLADE FILE ------------------------------
NREL 5.0 MW offshore baseline blade input properties.
---------------------- BLADE PARAMETERS ----------------------------------------
  49        NBlInpSt    - Number of blade input stations (-)
False       CalcBMode   - Calculate blade mode shapes internally {T: ignore mode shapes from below, F: use mode shapes from b
   0.477465 BldFlDmp(1) - Blade flap mode #1 structural damping in percent of critical (%)
   0.477465 BldFlDmp(2) - Blade flap mode #2 structural damping in percent of critical (%)
   0.477465 BldEdDmp(1) - Blade edge mode #1 structural damping in percent of critical (%)
---------------------- BLADE ADJUSTMENT FACTORS --------------------------------
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```
   1.0      FlStTunr(1) - Blade flapwise modal stiffness tuner, 1st mode (-)
   1.0      FlStTunr(2) - Blade flapwise modal stiffness tuner, 2nd mode (-)
   1.04536  AdjBlMs     - Factor to adjust blade mass density (-)
   1.0      AdjFlSt     - Factor to adjust blade flap stiffness (-)
   1.0      AdjEdSt     - Factor to adjust blade edge stiffness (-)
---------------------- DISTRIBUTED BLADE PROPERTIES ----------------------------
BlFract  AeroCent  StrcTwst  BMassDen  FlpStff     EdgStff     GJStff     EAStff      Alpha  FlpIner  EdgIner  PrecrvRef  Pre
(-)      (-)       (deg)     (kg/m)    (Nm^2)      (Nm^2)      (Nm^2)     (N)         (-)    (kg m)   (kg m)   (m)        (m)
0.00000  0.25000   13.308    678.935   18110.00E6  18113.60E6  5564.40E6   9729.48E6  0.0     972.86   973.04  0.0        0.0
0.00325  0.25000   13.308    678.935   18110.00E6  18113.60E6  5564.40E6   9729.48E6  0.0     972.86   973.04  0.0        0.0
0.01951  0.24951   13.308    773.363   19424.90E6  19558.60E6  5431.59E6  10789.50E6  0.0    1091.52  1066.38  0.0        0.0
0.03577  0.24510   13.308    740.550   17455.90E6  19497.80E6  4993.98E6  10067.23E6  0.0     966.09  1047.36  0.0        0.0
0.05203  0.23284   13.308    740.042   15287.40E6  19788.80E6  4666.59E6   9867.78E6  0.0     873.81  1099.75  0.0        0.0
0.06829  0.22059   13.308    592.496   10782.40E6  14858.50E6  3474.71E6   7607.86E6  0.0     648.55   873.02  0.0        0.0
0.08455  0.20833   13.308    450.275    7229.72E6  10220.60E6  2323.54E6   5491.26E6  0.0     456.76   641.49  0.0        0.0
0.10081  0.19608   13.308    424.054    6309.54E6   9144.70E6  1907.87E6   4971.30E6  0.0     400.53   593.73  0.0        0.0
0.11707  0.18382   13.308    400.638    5528.36E6   8063.16E6  1570.36E6   4493.95E6  0.0     351.61   547.18  0.0        0.0
0.13335  0.17156   13.308    382.062    4980.06E6   6884.44E6  1158.26E6   4034.80E6  0.0     316.12   490.84  0.0        0.0
0.14959  0.15931   13.308    399.655    4936.84E6   7009.18E6  1002.12E6   4037.29E6  0.0     303.60   503.86  0.0        0.0
0.16585  0.14706   13.308    426.321    4691.66E6   7167.68E6   855.90E6   4169.72E6  0.0     289.24   544.70  0.0        0.0
0.18211  0.13481   13.181    416.820    3949.46E6   7271.66E6   672.27E6   4082.35E6  0.0     246.57   569.90  0.0        0.0
0.19837  0.12500   12.848    406.186    3386.52E6   7081.70E6   547.49E6   4085.97E6  0.0     215.91   601.28  0.0        0.0
0.21465  0.12500   12.192    381.420    2933.74E6   6244.53E6   448.84E6   3668.34E6  0.0     187.11   546.56  0.0        0.0
0.23089  0.12500   11.561    352.822    2568.96E6   5048.96E6   335.92E6   3147.76E6  0.0     160.84   468.71  0.0        0.0
0.24715  0.12500   11.072    349.477    2388.65E6   4948.49E6   311.35E6   3011.58E6  0.0     148.56   453.76  0.0        0.0
0.26341  0.12500   10.792    346.538    2271.99E6   4808.02E6   291.94E6   2882.62E6  0.0     140.30   436.22  0.0        0.0
0.29595  0.12500   10.232    339.333    2050.05E6   4501.40E6   261.00E6   2613.97E6  0.0     124.61   398.18  0.0        0.0
0.32846  0.12500    9.672    330.004    1828.25E6   4244.07E6   228.82E6   2357.48E6  0.0     109.42   362.08  0.0        0.0
0.36098  0.12500    9.110    321.990    1588.71E6   3995.28E6   200.75E6   2146.86E6  0.0      94.36   335.01  0.0        0.0
0.39350  0.12500    8.534    313.820    1361.93E6   3750.76E6   174.38E6   1944.09E6  0.0      80.24   308.57  0.0        0.0
0.42602  0.12500    7.932    294.734    1102.38E6   3447.14E6   144.47E6   1632.70E6  0.0      62.67   263.87  0.0        0.0
0.45855  0.12500    7.321    287.120     875.80E6   3139.07E6   119.98E6   1432.40E6  0.0      49.42   237.06  0.0        0.0
0.49106  0.12500    6.711    263.343     681.30E6   2734.24E6    81.19E6   1168.76E6  0.0      37.34   196.41  0.0        0.0
0.52358  0.12500    6.122    253.207     534.72E6   2554.87E6    69.09E6   1047.43E6  0.0      29.14   180.34  0.0        0.0
0.55610  0.12500    5.546    241.666     408.90E6   2334.03E6    57.45E6    922.95E6  0.0      22.16   162.43  0.0        0.0
0.58862  0.12500    4.971    220.638     314.54E6   1828.73E6    45.92E6    760.82E6  0.0      17.33   134.83  0.0        0.0
0.62115  0.12500    4.401    200.293     238.63E6   1584.10E6    35.98E6    648.03E6  0.0      13.30   116.30  0.0        0.0
0.65366  0.12500    3.834    179.404     175.88E6   1323.36E6    27.44E6    539.70E6  0.0       9.96    97.98  0.0        0.0
0.68618  0.12500    3.332    165.094     126.01E6   1183.68E6    20.90E6    531.15E6  0.0       7.30    98.93  0.0        0.0
0.71870  0.12500    2.890    154.411     107.26E6   1020.16E6    18.54E6    460.01E6  0.0       6.22    85.78  0.0        0.0
0.75122  0.12500    2.503    138.935      90.88E6    797.81E6    16.28E6    375.75E6  0.0       5.19    69.96  0.0        0.0
0.78376  0.12500    2.116    129.555      76.31E6    709.61E6    14.53E6    328.89E6  0.0       4.36    61.41  0.0        0.0
0.81626  0.12500    1.730    107.264      61.05E6    518.19E6     9.07E6    244.04E6  0.0       3.36    45.44  0.0        0.0
0.84878  0.12500    1.342     98.776      49.48E6    454.87E6     8.06E6    211.60E6  0.0       2.75    39.57  0.0        0.0
0.88130  0.12500    0.954     90.248      39.36E6    395.12E6     7.08E6    181.52E6  0.0       2.21    34.09  0.0        0.0
0.89756  0.12500    0.760     83.001      34.67E6    353.72E6     6.09E6    160.25E6  0.0       1.93    30.12  0.0        0.0
0.91382  0.12500    0.574     72.906      30.41E6    304.73E6     5.75E6    109.23E6  0.0       1.69    20.15  0.0        0.0
0.93008  0.12500    0.404     68.772      26.52E6    281.42E6     5.33E6    100.08E6  0.0       1.49    18.53  0.0        0.0
0.93821  0.12500    0.319     66.264      23.84E6    261.71E6     4.94E6     92.24E6  0.0       1.34    17.11  0.0        0.0
0.94636  0.12500    0.253     59.340      19.63E6    158.81E6     4.24E6     63.23E6  0.0       1.10    11.55  0.0        0.0
0.95447  0.12500    0.216     55.914      16.00E6    137.88E6     3.66E6     53.32E6  0.0       0.89     9.77  0.0        0.0
0.96260  0.12500    0.178     52.484      12.83E6    118.79E6     3.13E6     44.53E6  0.0       0.71     8.19  0.0        0.0
0.97073  0.12500    0.140     49.114      10.08E6    101.63E6     2.64E6     36.90E6  0.0       0.56     6.82  0.0        0.0
0.97886  0.12500    0.101     45.818       7.55E6     85.07E6     2.17E6     29.92E6  0.0       0.42     5.57  0.0        0.0
0.98699  0.12500    0.062     41.669       4.60E6     64.26E6     1.58E6     21.31E6  0.0       0.25     4.01  0.0        0.0
0.99512  0.12500    0.023     11.453       0.25E6      6.61E6     0.25E6      4.85E6  0.0       0.04     0.94  0.0        0.0
1.00000  0.12500    0.000     10.319       0.17E6      5.01E6     0.19E6      3.53E6  0.0       0.02     0.68  0.0        0.0
---------------------- BLADE MODE SHAPES ---------------------------------------
   0.0622   BldFl1Sh(2) - Flap mode 1, coeff of x^2
   1.7254   BldFl1Sh(3) -            , coeff of x^3
  -3.2452   BldFl1Sh(4) -            , coeff of x^4
   4.7131   BldFl1Sh(5) -            , coeff of x^5
  -2.2555   BldFl1Sh(6) -            , coeff of x^6
  -0.5809   BldFl2Sh(2) - Flap mode 2, coeff of x^2
   1.2067   BldFl2Sh(3) -            , coeff of x^3
 -15.5349   BldFl2Sh(4) -            , coeff of x^4
  29.7347   BldFl2Sh(5) -            , coeff of x^5
 -13.8255   BldFl2Sh(6) -            , coeff of x^6
   0.3627   BldEdgSh(2) - Edge mode 1, coeff of x^2
   2.5337   BldEdgSh(3) -            , coeff of x^3
  -3.5772   BldEdgSh(4) -            , coeff of x^4
   2.3760   BldEdgSh(5) -            , coeff of x^5
  -0.6952   BldEdgSh(6) -            , coeff of x^6
```

A.3 Tower Input File – NRELOffshrBsline5MW_Tower_Onshore.dat

```
--------------------------------------------------------------------------------
---------------------- FAST TOWER FILE -----------------------------------------
NREL 5.0 MW offshore baseline tower input properties.
---------------------- TOWER PARAMETERS ----------------------------------------
  11        NTwInpSt    - Number of input stations to specify tower geometry
False       CalcTMode   - Calculate tower mode shapes internally {T: ignore mode shapes from below, F: use mode shapes from b
```

```
   1.0      TwrFADmp(1) - Tower 1st fore-aft mode structural damping ratio (%)
   1.0      TwrFADmp(2) - Tower 2nd fore-aft mode structural damping ratio (%)
   1.0      TwrSSDmp(1) - Tower 1st side-to-side mode structural damping ratio (%)
   1.0      TwrSSDmp(2) - Tower 2nd side-to-side mode structural damping ratio (%)
---------------------- TOWER ADJUSTMUNT FACTORS --------------------------------
   1.0      FAStTunr(1) - Tower fore-aft modal stiffness tuner, 1st mode (-)
   1.0      FAStTunr(2) - Tower fore-aft modal stiffness tuner, 2nd mode (-)
   1.0      SSStTunr(1) - Tower side-to-side stiffness tuner, 1st mode (-)
   1.0      SSStTunr(2) - Tower side-to-side stiffness tuner, 2nd mode (-)
   1.0      AdjTwMa     - Factor to adjust tower mass density (-)
   1.0      AdjFASt     - Factor to adjust tower fore-aft stiffness (-)
   1.0      AdjSSSt     - Factor to adjust tower side-to-side stiffness (-)
---------------------- DISTRIBUTED TOWER PROPERTIES ----------------------------
HtFract  TMassDen  TwFAStif   TwSSStif   TwGJStif   TwEAStif   TwFAIner  TwSSIner  TwFAcgOf  TwSScgOf
(-)      (kg/m)    (Nm^2)     (Nm^2)     (Nm^2)     (N)        (kg m)    (kg m)    (m)       (m)
0.0      5590.87   614.343E9  614.343E9  472.751E9  138.127E9  24866.3   24866.3   0.0       0.0
0.1      5232.43   534.821E9  534.821E9  411.558E9  129.272E9  21647.5   21647.5   0.0       0.0
0.2      4885.76   463.267E9  463.267E9  356.495E9  120.707E9  18751.3   18751.3   0.0       0.0
0.3      4550.87   399.131E9  399.131E9  307.141E9  112.433E9  16155.3   16155.3   0.0       0.0
0.4      4227.75   341.883E9  341.883E9  263.087E9  104.450E9  13838.1   13838.1   0.0       0.0
0.5      3916.41   291.011E9  291.011E9  223.940E9   96.758E9  11779.0   11779.0   0.0       0.0
0.6      3616.83   246.027E9  246.027E9  189.323E9   89.357E9   9958.2    9958.2   0.0       0.0
0.7      3329.03   206.457E9  206.457E9  158.874E9   82.247E9   8356.6    8356.6   0.0       0.0
0.8      3053.01   171.851E9  171.851E9  132.244E9   75.427E9   6955.9    6955.9   0.0       0.0
0.9      2788.75   141.776E9  141.776E9  109.100E9   68.899E9   5738.6    5738.6   0.0       0.0
1.0      2536.27   115.820E9  115.820E9   89.126E9   62.661E9   4688.0    4688.0   0.0       0.0
---------------------- TOWER FORE-AFT MODE SHAPES ------------------------------
   0.7004   TwFAM1Sh(2) - Mode 1, coefficient of x^2 term
   2.1963   TwFAM1Sh(3) -       , coefficient of x^3 term
  -5.6202   TwFAM1Sh(4) -       , coefficient of x^4 term
   6.2275   TwFAM1Sh(5) -       , coefficient of x^5 term
  -2.5040   TwFAM1Sh(6) -       , coefficient of x^6 term
 -70.5319   TwFAM2Sh(2) - Mode 2, coefficient of x^2 term
 -63.7623   TwFAM2Sh(3) -       , coefficient of x^3 term
 289.7369   TwFAM2Sh(4) -       , coefficient of x^4 term
-176.5134   TwFAM2Sh(5) -       , coefficient of x^5 term
  22.0706   TwFAM2Sh(6) -       , coefficient of x^6 term
---------------------- TOWER SIDE-TO-SIDE MODE SHAPES --------------------------
   1.3850   TwSSM1Sh(2) - Mode 1, coefficient of x^2 term
  -1.7684   TwSSM1Sh(3) -       , coefficient of x^3 term
   3.0871   TwSSM1Sh(4) -       , coefficient of x^4 term
  -2.2395   TwSSM1Sh(5) -       , coefficient of x^5 term
   0.5357   TwSSM1Sh(6) -       , coefficient of x^6 term
-121.2097   TwSSM2Sh(2) - Mode 2, coefficient of x^2 term
 184.4151   TwSSM2Sh(3) -       , coefficient of x^3 term
-224.9037   TwSSM2Sh(4) -       , coefficient of x^4 term
 298.5360   TwSSM2Sh(5) -       , coefficient of x^5 term
-135.8377   TwSSM2Sh(6) -       , coefficient of x^6 term
```

A.4 ADAMS Input File – NRELOffshrBsline5MW_ADAMSSpecific.dat

```
--------------------------------------------------------------------------------
---------------------- FAST 2 ADAMS PREPROCESSOR, ADAMS-SPECIFIC DATA FILE -----
NREL 5.0 MW offshore baseline ADAMS-specific input properties.
---------------------- FEATURE FLAGS -------------------------------------------
True        SaveGrphcs  - Save GRAPHICS output (flag)
False       MakeLINacf  - Make an ADAMS/LINEAR control / command file (flag)
---------------------- DAMPING PARAMETERS --------------------------------------
   0.01     CRatioTGJ   - Ratio of damping to stiffness for the tower torsion     deflection  (-)
   0.01     CRatioTEA   - Ratio of damping to stiffness for the tower extensional deflection  (-)
   0.01     CRatioBGJ   - Ratio of damping to stiffness for the blade torsion     deflections (-)
   0.01     CRatioBEA   - Ratio of damping to stiffness for the blade extensional deflections (-)
---------------------- BLADE PITCH ACTUATOR PARAMETERS -------------------------
 971.350E6  BPActrSpr   - Blade pitch actuator spring stiffness constant (N-m/rad)
   0.206E6  BPActrDmp   - Blade pitch actuator damping          constant (N-m/(rad/s))
---------------------- GRAPHICS PARAMETERS -------------------------------------
  20        NSides      - Number of sides used in GRAPHICS CYLINDER and FRUSTUM statements (-)
   3.000    TwrBaseRad  - Tower base radius used for linearly tapered tower GRAPHICS CYLINDERs (m)
   1.935    TwrTopRad   - Tower top  radius used for linearly tapered tower GRAPHICS CYLINDERs (m)
   7.0      NacLength   - Length of nacelle used for the nacelle GRAPHICS (m)
   1.75     NacRadBot   - Bottom (opposite rotor) radius of nacelle FRUSTUM used for the nacelle GRAPHICS (m)
   1.75     NacRadTop   - Top    (rotor end)      radius of nacelle FRUSTUM used for the nacelle GRAPHICS (m)
   1.0      GBoxLength  - Length, width, and height of the gearbox BOX for gearbox GRAPHICS (m)
   2.39     GenLength   - Length of the generator CYLINDER used for generator GRAPHICS (m)
   1.195    HSSLength   - Length of the high-speed shaft CYLINDER used for HSS GRAPHICS (m)
   4.78     LSSLength   - Length of the low-speed shaft CYLINDER used for LSS GRAPHICS (m)
   0.75     GenRad      - Radius of the generator CYLINDER used for generator GRAPHICS (m)
   0.2      HSSRad      - Radius of the high-speed shaft CYLINDER used for HSS GRAPHICS (m)
   0.4      LSSRad      - Radius of the low -speed shaft CYLINDER used for LSS GRAPHICS (m)
   0.875    HubCylRad   - Radius of hub CYLINDER used for hub GRAPHICS (m)
   0.18     ThkOvrChrd  - Ratio of blade thickness to blade chord used for blade element BOX GRAPHICS (-)
   0.0      BoomRad     - Radius of the tail boom CYLINDER used for tail boom GRAPHICS (m)
```

A.5 Linearization Input File – NRELOffshrBsline5MW_Linear.dat

```
--------------------------------------------------------------------------------
---------------------- FAST LINEARIZATION CONTROL FILE -------------------------
NREL 5.0 MW offshore baseline linearization input properties.
---------------------- PERIODIC STEADY STATE SOLUTION --------------------------
True        CalcStdy    - Calculate periodic steady state condition {False: linearize about initial conditions} (flag)
   3        TrimCase    - Trim case {1: find nacelle yaw, 2: find generator torque, 3: find collective blade pitch} (switch)
   0.0001   DispTol     - Convergence tolerance for the 2-norm of displacements in the periodic steady state calculation (rad
   0.0010   VelTol      - Convergence tolerance for the 2-norm of velocities    in the periodic steady state calculation (rad
---------------------- MODEL LINEARIZATION -------------------------------------
  36        NAzimStep   - Number of equally-spaced azimuth steps in periodic linearized model (-)
   1        MdlOrder    - Order of output linearized model {1: 1st order A, B, Bd, C, D, Dd; 2: 2nd order M, C, K, F, Fd, Vel
---------------------- INPUTS AND DISTURBANCES ---------------------------------
   0        NInputs     - Number of control inputs [0 (none) or 1 to 4+NumBl] (-)
            CntrlInpt   - List   of control inputs [1 to NInputs] {1: nacelle yaw angle, 2: nacelle yaw rate, 3: generator to
   0        NDisturbs   - Number of wind disturbances [0 (none) or 1 to 7] (-)
            Disturbnc   - List   of input wind disturbances [1 to NDisturbs] {1: horizontal hub-height wind speed, 2: horizon
```

Appendix B AeroDyn Input Files

B.1 Primary Input File – NRELOffshrBsline5MW_AeroDyn.ipt

```
NREL 5.0 MW offshore baseline aerodynamic input properties; Compatible with AeroDyn v12.58.
SI          SysUnits    - System of units used for input and output [must be SI for FAST] (unquoted string)
BEDDOES     StallMod    - Dynamic stall included [BEDDOES or STEADY] (unquoted string)
USE_CM      UseCm       - Use aerodynamic pitching moment model? [USE_CM or NO_CM] (unquoted string)
EQUIL       InfModel    - Inflow model [DYNIN or EQUIL] (unquoted string)
WAKE        IndModel    - Induction-factor model [NONE or WAKE or SWIRL] (unquoted string)
   0.005    AToler      - Induction-factor tolerance (convergence criteria) (-)
PRANDtl     TLModel     - Tip-loss model (EQUIL only) [PRANDtl, GTECH, or NONE] (unquoted string)
PRANDtl     HLModel     - Hub-loss model (EQUIL only) [PRANdtl or NONE] (unquoted string)
"WindData\90m_12mps"                             WindFile    - Name of file containing wind data (quoted string)
  90.0      HH          - Wind reference (hub) height [TowerHt+Twr2Shft+OverHang*SIN(ShftTilt)] (m)
   0.0      TwrShad     - Tower-shadow velocity deficit (-)
9999.9      ShadHWid    - Tower-shadow half width (m)
9999.9      T_Shad_Refpt- Tower-shadow reference point (m)
   1.225    AirDens     - Air density (kg/m^3)
   1.464E-5 KinVisc     - Kinematic air viscosity [CURRENTLY IGNORED] (m^2/sec)
   0.02479  DTAero      - Time interval for aerodynamic calculations (sec)
   8        NumFoil     - Number of airfoil files (-)
"AeroData\Cylinder1.dat"                         FoilNm      - Names of the airfoil files [NumFoil lines] (quoted strings)
"AeroData\Cylinder2.dat"
"AeroData\DU40_A17.dat"
"AeroData\DU35_A17.dat"
"AeroData\DU30_A17.dat"
"AeroData\DU25_A17.dat"
"AeroData\DU21_A17.dat"
"AeroData\NACA64_A17.dat"
  17        BldNodes    - Number of blade nodes used for analysis (-)
RNodes   AeroTwst  DRNodes  Chord  NFoil  PrnElm
 2.8667  13.308    2.7333   3.542  1      NOPRINT
 5.6000  13.308    2.7333   3.854  1      NOPRINT
 8.3333  13.308    2.7333   4.167  2      NOPRINT
11.7500  13.308    4.1000   4.557  3      NOPRINT
15.8500  11.480    4.1000   4.652  4      NOPRINT
19.9500  10.162    4.1000   4.458  4      NOPRINT
24.0500   9.011    4.1000   4.249  5      NOPRINT
28.1500   7.795    4.1000   4.007  6      NOPRINT
32.2500   6.544    4.1000   3.748  6      NOPRINT
36.3500   5.361    4.1000   3.502  7      NOPRINT
40.4500   4.188    4.1000   3.256  7      NOPRINT
44.5500   3.125    4.1000   3.010  8      NOPRINT
48.6500   2.319    4.1000   2.764  8      NOPRINT
52.7500   1.526    4.1000   2.518  8      NOPRINT
56.1667   0.863    2.7333   2.313  8      NOPRINT
58.9000   0.370    2.7333   2.086  8      NOPRINT
61.6333   0.106    2.7333   1.419  8      NOPRINT
```

B.2 Airfoil-Data Input File – Cylinder1.dat

```
Round root section with a Cd of 0.50
Made by Jason Jonkman
   1        Number of airfoil tables in this file
   0.0      Table ID parameter
   0.0      Stall angle (deg)
   0.0      No longer used, enter zero
   0.0      No longer used, enter zero
   0.0      No longer used, enter zero
   0.0      Zero Cn angle of attack (deg)
   0.0      Cn slope for zero lift (dimensionless)
   0.0      Cn extrapolated to value at positive stall angle of attack
   0.0      Cn at stall value for negative angle of attack
   0.0      Angle of attack for minimum CD (deg)
   0.50     Minimum CD value
-180.00    0.000   0.5000   0.000
   0.00    0.000   0.5000   0.000
 180.00    0.000   0.5000   0.000
```

B.3 Airfoil-Data Input File – Cylinder2.dat

```
Round root section with a Cd of 0.35
Made by Jason Jonkman
   1        Number of airfoil tables in this file
```

```
   0.0      Table ID parameter
   0.0      Stall angle (deg)
   0.0      No longer used, enter zero
   0.0      No longer used, enter zero
   0.0      No longer used, enter zero
   0.0      Zero Cn angle of attack (deg)
   0.0      Cn slope for zero lift (dimensionless)
   0.0      Cn extrapolated to value at positive stall angle of attack
   0.0      Cn at stall value for negative angle of attack
   0.0      Angle of attack for minimum CD (deg)
   0.35     Minimum CD value
-180.00    0.000   0.3500   0.000
   0.00    0.000   0.3500   0.000
 180.00    0.000   0.3500   0.000
```

B.4 Airfoil-Data Input File – DU40_A17.dat

```
DU40 airfoil with an aspect ratio of 17.  Original -180 to 180deg Cl, Cd, and Cm versus AOA data taken from Appendix A of DOW
Cl and Cd values corrected for rotational stall delay and Cd values corrected using the Viterna method for 0 to 90deg AOA by
   1        Number of airfoil tables in this file
   0.0      Table ID parameter
   9.00     Stall angle (deg)
   0.0      No longer used, enter zero
   0.0      No longer used, enter zero
   0.0      No longer used, enter zero
  -1.3430   Zero Cn angle of attack (deg)
   7.4888   Cn slope for zero lift (dimensionless)
   1.3519   Cn extrapolated to value at positive stall angle of attack
  -0.3226   Cn at stall value for negative angle of attack
   0.00     Angle of attack for minimum CD (deg)
   0.0113   Minimum CD value
-180.00    0.000   0.0602   0.0000
-175.00    0.218   0.0699   0.0934
-170.00    0.397   0.1107   0.1697
-160.00    0.642   0.3045   0.2813
-155.00    0.715   0.4179   0.3208
-150.00    0.757   0.5355   0.3516
-145.00    0.772   0.6535   0.3752
-140.00    0.762   0.7685   0.3926
-135.00    0.731   0.8777   0.4048
-130.00    0.680   0.9788   0.4126
-125.00    0.613   1.0700   0.4166
-120.00    0.532   1.1499   0.4176
-115.00    0.439   1.2174   0.4158
-110.00    0.337   1.2716   0.4117
-105.00    0.228   1.3118   0.4057
-100.00    0.114   1.3378   0.3979
 -95.00   -0.002   1.3492   0.3887
 -90.00   -0.120   1.3460   0.3781
 -85.00   -0.236   1.3283   0.3663
 -80.00   -0.349   1.2964   0.3534
 -75.00   -0.456   1.2507   0.3394
 -70.00   -0.557   1.1918   0.3244
 -65.00   -0.647   1.1204   0.3084
 -60.00   -0.727   1.0376   0.2914
 -55.00   -0.792   0.9446   0.2733
 -50.00   -0.842   0.8429   0.2543
 -45.00   -0.874   0.7345   0.2342
 -40.00   -0.886   0.6215   0.2129
 -35.00   -0.875   0.5067   0.1906
 -30.00   -0.839   0.3932   0.1670
 -25.00   -0.777   0.2849   0.1422
 -24.00   -0.761   0.2642   0.1371
 -23.00   -0.744   0.2440   0.1320
 -22.00   -0.725   0.2242   0.1268
 -21.00   -0.706   0.2049   0.1215
 -20.00   -0.685   0.1861   0.1162
 -19.00   -0.662   0.1687   0.1097
 -18.00   -0.635   0.1533   0.1012
 -17.00   -0.605   0.1398   0.0907
 -16.00   -0.571   0.1281   0.0784
 -15.00   -0.534   0.1183   0.0646
 -14.00   -0.494   0.1101   0.0494
 -13.00   -0.452   0.1036   0.0330
 -12.00   -0.407   0.0986   0.0156
 -11.00   -0.360   0.0951  -0.0026
 -10.00   -0.311   0.0931  -0.0213
  -8.00   -0.208   0.0930  -0.0600
  -6.00   -0.111   0.0689  -0.0500
  -5.50   -0.090   0.0614  -0.0516
  -5.00   -0.072   0.0547  -0.0532
  -4.50   -0.065   0.0480  -0.0538
```

```
  -4.00   -0.054  0.0411  -0.0544
  -3.50   -0.017  0.0349  -0.0554
  -3.00    0.003  0.0299  -0.0558
  -2.50    0.014  0.0255  -0.0555
  -2.00    0.009  0.0198  -0.0534
  -1.50    0.004  0.0164  -0.0442
  -1.00    0.036  0.0147  -0.0469
  -0.50    0.073  0.0137  -0.0522
   0.00    0.137  0.0113  -0.0573
   0.50    0.213  0.0114  -0.0644
   1.00    0.292  0.0118  -0.0718
   1.50    0.369  0.0122  -0.0783
   2.00    0.444  0.0124  -0.0835
   2.50    0.514  0.0124  -0.0866
   3.00    0.580  0.0123  -0.0887
   3.50    0.645  0.0120  -0.0900
   4.00    0.710  0.0119  -0.0914
   4.50    0.776  0.0122  -0.0933
   5.00    0.841  0.0125  -0.0947
   5.50    0.904  0.0129  -0.0957
   6.00    0.967  0.0135  -0.0967
   6.50    1.027  0.0144  -0.0973
   7.00    1.084  0.0158  -0.0972
   7.50    1.140  0.0174  -0.0972
   8.00    1.193  0.0198  -0.0968
   8.50    1.242  0.0231  -0.0958
   9.00    1.287  0.0275  -0.0948
   9.50    1.333  0.0323  -0.0942
  10.00    1.368  0.0393  -0.0926
  10.50    1.400  0.0475  -0.0908
  11.00    1.425  0.0580  -0.0890
  11.50    1.449  0.0691  -0.0877
  12.00    1.473  0.0816  -0.0870
  12.50    1.494  0.0973  -0.0870
  13.00    1.513  0.1129  -0.0876
  13.50    1.538  0.1288  -0.0886
  14.50    1.587  0.1650  -0.0917
  15.00    1.614  0.1845  -0.0939
  15.50    1.631  0.2052  -0.0966
  16.00    1.649  0.2250  -0.0996
  16.50    1.666  0.2467  -0.1031
  17.00    1.681  0.2684  -0.1069
  17.50    1.699  0.2900  -0.1110
  18.00    1.719  0.3121  -0.1157
  19.00    1.751  0.3554  -0.1242
  19.50    1.767  0.3783  -0.1291
  20.50    1.798  0.4212  -0.1384
  21.00    1.810  0.4415  -0.1416
  22.00    1.830  0.4830  -0.1479
  23.00    1.847  0.5257  -0.1542
  24.00    1.861  0.5694  -0.1603
  25.00    1.872  0.6141  -0.1664
  26.00    1.881  0.6593  -0.1724
  28.00    1.894  0.7513  -0.1841
  30.00    1.904  0.8441  -0.1954
  32.00    1.915  0.9364  -0.2063
  35.00    1.929  1.0722  -0.2220
  40.00    1.903  1.2873  -0.2468
  45.00    1.820  1.4796  -0.2701
  50.00    1.690  1.6401  -0.2921
  55.00    1.522  1.7609  -0.3127
  60.00    1.323  1.8360  -0.3321
  65.00    1.106  1.8614  -0.3502
  70.00    0.880  1.8347  -0.3672
  75.00    0.658  1.7567  -0.3830
  80.00    0.449  1.6334  -0.3977
  85.00    0.267  1.4847  -0.4112
  90.00    0.124  1.3879  -0.4234
  95.00    0.002  1.3912  -0.4343
 100.00   -0.118  1.3795  -0.4437
 105.00   -0.235  1.3528  -0.4514
 110.00   -0.348  1.3114  -0.4573
 115.00   -0.453  1.2557  -0.4610
 120.00   -0.549  1.1864  -0.4623
 125.00   -0.633  1.1041  -0.4606
 130.00   -0.702  1.0102  -0.4554
 135.00   -0.754  0.9060  -0.4462
 140.00   -0.787  0.7935  -0.4323
 145.00   -0.797  0.6750  -0.4127
 150.00   -0.782  0.5532  -0.3863
 155.00   -0.739  0.4318  -0.3521
 160.00   -0.664  0.3147  -0.3085
 170.00   -0.410  0.1144  -0.1858
 175.00   -0.226  0.0702  -0.1022
```

```
 180.00    0.000   0.0602   0.0000
```

B.5 Airfoil-Data Input File – DU35_A17.dat

```
DU35 airfoil with an aspect ratio of 17.  Original -180 to 180deg Cl, Cd, and Cm versus AOA data taken from Appendix A of DOW
Cl and Cd values corrected for rotational stall delay and Cd values corrected using the Viterna method for 0 to 90deg AOA by
   1        Number of airfoil tables in this file
   0.0      Table ID parameter
  11.50     Stall angle (deg)
   0.0      No longer used, enter zero
   0.0      No longer used, enter zero
   0.0      No longer used, enter zero
  -1.8330   Zero Cn angle of attack (deg)
   7.1838   Cn slope for zero lift (dimensionless)
   1.6717   Cn extrapolated to value at positive stall angle of attack
  -0.3075   Cn at stall value for negative angle of attack
   0.00     Angle of attack for minimum CD (deg)
   0.0094   Minimum CD value
-180.00    0.000   0.0407   0.0000
-175.00    0.223   0.0507   0.0937
-170.00    0.405   0.1055   0.1702
-160.00    0.658   0.2982   0.2819
-155.00    0.733   0.4121   0.3213
-150.00    0.778   0.5308   0.3520
-145.00    0.795   0.6503   0.3754
-140.00    0.787   0.7672   0.3926
-135.00    0.757   0.8785   0.4046
-130.00    0.708   0.9819   0.4121
-125.00    0.641   1.0756   0.4160
-120.00    0.560   1.1580   0.4167
-115.00    0.467   1.2280   0.4146
-110.00    0.365   1.2847   0.4104
-105.00    0.255   1.3274   0.4041
-100.00    0.139   1.3557   0.3961
 -95.00    0.021   1.3692   0.3867
 -90.00   -0.098   1.3680   0.3759
 -85.00   -0.216   1.3521   0.3639
 -80.00   -0.331   1.3218   0.3508
 -75.00   -0.441   1.2773   0.3367
 -70.00   -0.544   1.2193   0.3216
 -65.00   -0.638   1.1486   0.3054
 -60.00   -0.720   1.0660   0.2884
 -55.00   -0.788   0.9728   0.2703
 -50.00   -0.840   0.8705   0.2512
 -45.00   -0.875   0.7611   0.2311
 -40.00   -0.889   0.6466   0.2099
 -35.00   -0.880   0.5299   0.1876
 -30.00   -0.846   0.4141   0.1641
 -25.00   -0.784   0.3030   0.1396
 -24.00   -0.768   0.2817   0.1345
 -23.00   -0.751   0.2608   0.1294
 -22.00   -0.733   0.2404   0.1243
 -21.00   -0.714   0.2205   0.1191
 -20.00   -0.693   0.2011   0.1139
 -19.00   -0.671   0.1822   0.1086
 -18.00   -0.648   0.1640   0.1032
 -17.00   -0.624   0.1465   0.0975
 -16.00   -0.601   0.1300   0.0898
 -15.00   -0.579   0.1145   0.0799
 -14.00   -0.559   0.1000   0.0682
 -13.00   -0.539   0.0867   0.0547
 -12.00   -0.519   0.0744   0.0397
 -11.00   -0.499   0.0633   0.0234
 -10.00   -0.480   0.0534   0.0060
  -5.54   -0.385   0.0245  -0.0800
  -5.04   -0.359   0.0225  -0.0800
  -4.54   -0.360   0.0196  -0.0800
  -4.04   -0.355   0.0174  -0.0800
  -3.54   -0.307   0.0162  -0.0800
  -3.04   -0.246   0.0144  -0.0800
  -3.00   -0.240   0.0240  -0.0623
  -2.50   -0.163   0.0188  -0.0674
  -2.00   -0.091   0.0160  -0.0712
  -1.50   -0.019   0.0137  -0.0746
  -1.00    0.052   0.0118  -0.0778
  -0.50    0.121   0.0104  -0.0806
   0.00    0.196   0.0094  -0.0831
   0.50    0.265   0.0096  -0.0863
   1.00    0.335   0.0098  -0.0895
   1.50    0.404   0.0099  -0.0924
   2.00    0.472   0.0100  -0.0949
   2.50    0.540   0.0102  -0.0973
```

```
   3.00    0.608   0.0103  -0.0996
   3.50    0.674   0.0104  -0.1016
   4.00    0.742   0.0105  -0.1037
   4.50    0.809   0.0107  -0.1057
   5.00    0.875   0.0108  -0.1076
   5.50    0.941   0.0109  -0.1094
   6.00    1.007   0.0110  -0.1109
   6.50    1.071   0.0113  -0.1118
   7.00    1.134   0.0115  -0.1127
   7.50    1.198   0.0117  -0.1138
   8.00    1.260   0.0120  -0.1144
   8.50    1.318   0.0126  -0.1137
   9.00    1.368   0.0133  -0.1112
   9.50    1.422   0.0143  -0.1100
  10.00    1.475   0.0156  -0.1086
  10.50    1.523   0.0174  -0.1064
  11.00    1.570   0.0194  -0.1044
  11.50    1.609   0.0227  -0.1013
  12.00    1.642   0.0269  -0.0980
  12.50    1.675   0.0319  -0.0953
  13.00    1.700   0.0398  -0.0925
  13.50    1.717   0.0488  -0.0896
  14.00    1.712   0.0614  -0.0864
  14.50    1.703   0.0786  -0.0840
  15.50    1.671   0.1173  -0.0830
  16.00    1.649   0.1377  -0.0848
  16.50    1.621   0.1600  -0.0880
  17.00    1.598   0.1814  -0.0926
  17.50    1.571   0.2042  -0.0984
  18.00    1.549   0.2316  -0.1052
  19.00    1.544   0.2719  -0.1158
  19.50    1.549   0.2906  -0.1213
  20.00    1.565   0.3085  -0.1248
  21.00    1.565   0.3447  -0.1317
  22.00    1.563   0.3820  -0.1385
  23.00    1.558   0.4203  -0.1452
  24.00    1.552   0.4593  -0.1518
  25.00    1.546   0.4988  -0.1583
  26.00    1.539   0.5387  -0.1647
  28.00    1.527   0.6187  -0.1770
  30.00    1.522   0.6978  -0.1886
  32.00    1.529   0.7747  -0.1994
  35.00    1.544   0.8869  -0.2148
  40.00    1.529   1.0671  -0.2392
  45.00    1.471   1.2319  -0.2622
  50.00    1.376   1.3747  -0.2839
  55.00    1.249   1.4899  -0.3043
  60.00    1.097   1.5728  -0.3236
  65.00    0.928   1.6202  -0.3417
  70.00    0.750   1.6302  -0.3586
  75.00    0.570   1.6031  -0.3745
  80.00    0.396   1.5423  -0.3892
  85.00    0.237   1.4598  -0.4028
  90.00    0.101   1.4041  -0.4151
  95.00   -0.022   1.4053  -0.4261
 100.00   -0.143   1.3914  -0.4357
 105.00   -0.261   1.3625  -0.4437
 110.00   -0.374   1.3188  -0.4498
 115.00   -0.480   1.2608  -0.4538
 120.00   -0.575   1.1891  -0.4553
 125.00   -0.659   1.1046  -0.4540
 130.00   -0.727   1.0086  -0.4492
 135.00   -0.778   0.9025  -0.4405
 140.00   -0.809   0.7883  -0.4270
 145.00   -0.818   0.6684  -0.4078
 150.00   -0.800   0.5457  -0.3821
 155.00   -0.754   0.4236  -0.3484
 160.00   -0.677   0.3066  -0.3054
 170.00   -0.417   0.1085  -0.1842
 175.00   -0.229   0.0510  -0.1013
 180.00    0.000   0.0407   0.0000
```

B.6 Airfoil-Data Input File – DU30_A17.dat

```
DU30 airfoil with an aspect ratio of 17.  Original -180 to 180deg Cl, Cd, and Cm versus AOA data taken from Appendix A of DOW
Cl and Cd values corrected for rotational stall delay and Cd values corrected using the Viterna method for 0 to 90deg AOA by
   1        Number of airfoil tables in this file
   0.0      Table ID parameter
   9.00     Stall angle (deg)
   0.0      No longer used, enter zero
   0.0      No longer used, enter zero
   0.0      No longer used, enter zero
```

```
  -2.3220   Zero Cn angle of attack (deg)
   7.3326   Cn slope for zero lift (dimensionless)
   1.4490   Cn extrapolated to value at positive stall angle of attack
  -0.6138   Cn at stall value for negative angle of attack
   0.00     Angle of attack for minimum CD (deg)
   0.0087   Minimum CD value
-180.00    0.000   0.0267   0.0000
-175.00    0.274   0.0370   0.1379
-170.00    0.547   0.0968   0.2778
-160.00    0.685   0.2876   0.2740
-155.00    0.766   0.4025   0.3118
-150.00    0.816   0.5232   0.3411
-145.00    0.836   0.6454   0.3631
-140.00    0.832   0.7656   0.3791
-135.00    0.804   0.8807   0.3899
-130.00    0.756   0.9882   0.3965
-125.00    0.690   1.0861   0.3994
-120.00    0.609   1.1730   0.3992
-115.00    0.515   1.2474   0.3964
-110.00    0.411   1.3084   0.3915
-105.00    0.300   1.3552   0.3846
-100.00    0.182   1.3875   0.3761
 -95.00    0.061   1.4048   0.3663
 -90.00   -0.061   1.4070   0.3551
 -85.00   -0.183   1.3941   0.3428
 -80.00   -0.302   1.3664   0.3295
 -75.00   -0.416   1.3240   0.3153
 -70.00   -0.523   1.2676   0.3001
 -65.00   -0.622   1.1978   0.2841
 -60.00   -0.708   1.1156   0.2672
 -55.00   -0.781   1.0220   0.2494
 -50.00   -0.838   0.9187   0.2308
 -45.00   -0.877   0.8074   0.2113
 -40.00   -0.895   0.6904   0.1909
 -35.00   -0.889   0.5703   0.1696
 -30.00   -0.858   0.4503   0.1475
 -25.00   -0.832   0.3357   0.1224
 -24.00   -0.852   0.3147   0.1156
 -23.00   -0.882   0.2946   0.1081
 -22.00   -0.919   0.2752   0.1000
 -21.00   -0.963   0.2566   0.0914
 -20.00   -1.013   0.2388   0.0823
 -19.00   -1.067   0.2218   0.0728
 -18.00   -1.125   0.2056   0.0631
 -17.00   -1.185   0.1901   0.0531
 -16.00   -1.245   0.1754   0.0430
 -15.25   -1.290   0.1649   0.0353
 -14.24   -1.229   0.1461   0.0240
 -13.24   -1.148   0.1263   0.0100
 -12.22   -1.052   0.1051  -0.0090
 -11.22   -0.965   0.0886  -0.0230
 -10.19   -0.867   0.0740  -0.0336
  -9.70   -0.822   0.0684  -0.0375
  -9.18   -0.769   0.0605  -0.0440
  -8.18   -0.756   0.0270  -0.0578
  -7.19   -0.690   0.0180  -0.0590
  -6.65   -0.616   0.0166  -0.0633
  -6.13   -0.542   0.0152  -0.0674
  -6.00   -0.525   0.0117  -0.0732
  -5.50   -0.451   0.0105  -0.0766
  -5.00   -0.382   0.0097  -0.0797
  -4.50   -0.314   0.0092  -0.0825
  -4.00   -0.251   0.0091  -0.0853
  -3.50   -0.189   0.0089  -0.0884
  -3.00   -0.120   0.0089  -0.0914
  -2.50   -0.051   0.0088  -0.0942
  -2.00    0.017   0.0088  -0.0969
  -1.50    0.085   0.0088  -0.0994
  -1.00    0.152   0.0088  -0.1018
  -0.50    0.219   0.0088  -0.1041
   0.00    0.288   0.0087  -0.1062
   0.50    0.354   0.0087  -0.1086
   1.00    0.421   0.0088  -0.1107
   1.50    0.487   0.0089  -0.1129
   2.00    0.554   0.0090  -0.1149
   2.50    0.619   0.0091  -0.1168
   3.00    0.685   0.0092  -0.1185
   3.50    0.749   0.0093  -0.1201
   4.00    0.815   0.0095  -0.1218
   4.50    0.879   0.0096  -0.1233
   5.00    0.944   0.0097  -0.1248
   5.50    1.008   0.0099  -0.1260
   6.00    1.072   0.0101  -0.1270
   6.50    1.135   0.0103  -0.1280
```

```
   7.00    1.197   0.0107  -0.1287
   7.50    1.256   0.0112  -0.1289
   8.00    1.305   0.0125  -0.1270
   9.00    1.390   0.0155  -0.1207
   9.50    1.424   0.0171  -0.1158
  10.00    1.458   0.0192  -0.1116
  10.50    1.488   0.0219  -0.1073
  11.00    1.512   0.0255  -0.1029
  11.50    1.533   0.0307  -0.0983
  12.00    1.549   0.0370  -0.0949
  12.50    1.558   0.0452  -0.0921
  13.00    1.470   0.0630  -0.0899
  13.50    1.398   0.0784  -0.0885
  14.00    1.354   0.0931  -0.0885
  14.50    1.336   0.1081  -0.0902
  15.00    1.333   0.1239  -0.0928
  15.50    1.326   0.1415  -0.0963
  16.00    1.329   0.1592  -0.1006
  16.50    1.326   0.1743  -0.1042
  17.00    1.321   0.1903  -0.1084
  17.50    1.331   0.2044  -0.1125
  18.00    1.333   0.2186  -0.1169
  18.50    1.340   0.2324  -0.1215
  19.00    1.362   0.2455  -0.1263
  19.50    1.382   0.2584  -0.1313
  20.00    1.398   0.2689  -0.1352
  20.50    1.426   0.2814  -0.1406
  21.00    1.437   0.2943  -0.1462
  22.00    1.418   0.3246  -0.1516
  23.00    1.397   0.3557  -0.1570
  24.00    1.376   0.3875  -0.1623
  25.00    1.354   0.4198  -0.1676
  26.00    1.332   0.4524  -0.1728
  28.00    1.293   0.5183  -0.1832
  30.00    1.265   0.5843  -0.1935
  32.00    1.253   0.6492  -0.2039
  35.00    1.264   0.7438  -0.2193
  40.00    1.258   0.8970  -0.2440
  45.00    1.217   1.0402  -0.2672
  50.00    1.146   1.1686  -0.2891
  55.00    1.049   1.2779  -0.3097
  60.00    0.932   1.3647  -0.3290
  65.00    0.799   1.4267  -0.3471
  70.00    0.657   1.4621  -0.3641
  75.00    0.509   1.4708  -0.3799
  80.00    0.362   1.4544  -0.3946
  85.00    0.221   1.4196  -0.4081
  90.00    0.092   1.3938  -0.4204
  95.00   -0.030   1.3943  -0.4313
 100.00   -0.150   1.3798  -0.4408
 105.00   -0.267   1.3504  -0.4486
 110.00   -0.379   1.3063  -0.4546
 115.00   -0.483   1.2481  -0.4584
 120.00   -0.578   1.1763  -0.4597
 125.00   -0.660   1.0919  -0.4582
 130.00   -0.727   0.9962  -0.4532
 135.00   -0.777   0.8906  -0.4441
 140.00   -0.807   0.7771  -0.4303
 145.00   -0.815   0.6581  -0.4109
 150.00   -0.797   0.5364  -0.3848
 155.00   -0.750   0.4157  -0.3508
 160.00   -0.673   0.3000  -0.3074
 170.00   -0.547   0.1051  -0.2786
 175.00   -0.274   0.0388  -0.1380
 180.00    0.000   0.0267   0.0000
```

B.7 Airfoil-Data Input File – DU25_A17.dat

```
DU25 airfoil with an aspect ratio of 17.  Original -180 to 180deg Cl, Cd, and Cm versus AOA data taken from Appendix A of DOW
Cl and Cd values corrected for rotational stall delay and Cd values corrected using the Viterna method for 0 to 90deg AOA by
   1        Number of airfoil tables in this file
   0.0      Table ID parameter
   8.50     Stall angle (deg)
   0.0      No longer used, enter zero
   0.0      No longer used, enter zero
   0.0      No longer used, enter zero
  -4.2422   Zero Cn angle of attack (deg)
   6.4462   Cn slope for zero lift (dimensionless)
   1.4336   Cn extrapolated to value at positive stall angle of attack
  -0.6873   Cn at stall value for negative angle of attack
   0.00     Angle of attack for minimum CD (deg)
   0.0065   Minimum CD value
```

```
-180.00    0.000   0.0202   0.0000
-175.00    0.368   0.0324   0.1845
-170.00    0.735   0.0943   0.3701
-160.00    0.695   0.2848   0.2679
-155.00    0.777   0.4001   0.3046
-150.00    0.828   0.5215   0.3329
-145.00    0.850   0.6447   0.3540
-140.00    0.846   0.7660   0.3693
-135.00    0.818   0.8823   0.3794
-130.00    0.771   0.9911   0.3854
-125.00    0.705   1.0905   0.3878
-120.00    0.624   1.1787   0.3872
-115.00    0.530   1.2545   0.3841
-110.00    0.426   1.3168   0.3788
-105.00    0.314   1.3650   0.3716
-100.00    0.195   1.3984   0.3629
 -95.00    0.073   1.4169   0.3529
 -90.00   -0.050   1.4201   0.3416
 -85.00   -0.173   1.4081   0.3292
 -80.00   -0.294   1.3811   0.3159
 -75.00   -0.409   1.3394   0.3017
 -70.00   -0.518   1.2833   0.2866
 -65.00   -0.617   1.2138   0.2707
 -60.00   -0.706   1.1315   0.2539
 -55.00   -0.780   1.0378   0.2364
 -50.00   -0.839   0.9341   0.2181
 -45.00   -0.879   0.8221   0.1991
 -40.00   -0.898   0.7042   0.1792
 -35.00   -0.893   0.5829   0.1587
 -30.00   -0.862   0.4616   0.1374
 -25.00   -0.803   0.3441   0.1154
 -24.00   -0.792   0.3209   0.1101
 -23.00   -0.789   0.2972   0.1031
 -22.00   -0.792   0.2730   0.0947
 -21.00   -0.801   0.2485   0.0849
 -20.00   -0.815   0.2237   0.0739
 -19.00   -0.833   0.1990   0.0618
 -18.00   -0.854   0.1743   0.0488
 -17.00   -0.879   0.1498   0.0351
 -16.00   -0.905   0.1256   0.0208
 -15.00   -0.932   0.1020   0.0060
 -14.00   -0.959   0.0789  -0.0091
 -13.00   -0.985   0.0567  -0.0243
 -13.00   -0.985   0.0567  -0.0243
 -12.01   -0.953   0.0271  -0.0349
 -11.00   -0.900   0.0303  -0.0361
  -9.98   -0.827   0.0287  -0.0464
  -8.98   -0.753   0.0271  -0.0534
  -8.47   -0.691   0.0264  -0.0650
  -7.45   -0.555   0.0114  -0.0782
  -6.42   -0.413   0.0094  -0.0904
  -5.40   -0.271   0.0086  -0.1006
  -5.00   -0.220   0.0073  -0.1107
  -4.50   -0.152   0.0071  -0.1135
  -4.00   -0.084   0.0070  -0.1162
  -3.50   -0.018   0.0069  -0.1186
  -3.00    0.049   0.0068  -0.1209
  -2.50    0.115   0.0068  -0.1231
  -2.00    0.181   0.0068  -0.1252
  -1.50    0.247   0.0067  -0.1272
  -1.00    0.312   0.0067  -0.1293
  -0.50    0.377   0.0067  -0.1311
   0.00    0.444   0.0065  -0.1330
   0.50    0.508   0.0065  -0.1347
   1.00    0.573   0.0066  -0.1364
   1.50    0.636   0.0067  -0.1380
   2.00    0.701   0.0068  -0.1396
   2.50    0.765   0.0069  -0.1411
   3.00    0.827   0.0070  -0.1424
   3.50    0.890   0.0071  -0.1437
   4.00    0.952   0.0073  -0.1448
   4.50    1.013   0.0076  -0.1456
   5.00    1.062   0.0079  -0.1445
   6.00    1.161   0.0099  -0.1419
   6.50    1.208   0.0117  -0.1403
   7.00    1.254   0.0132  -0.1382
   7.50    1.301   0.0143  -0.1362
   8.00    1.336   0.0153  -0.1320
   8.50    1.369   0.0165  -0.1276
   9.00    1.400   0.0181  -0.1234
   9.50    1.428   0.0211  -0.1193
  10.00    1.442   0.0262  -0.1152
  10.50    1.427   0.0336  -0.1115
  11.00    1.374   0.0420  -0.1081
```

```
  11.50    1.316   0.0515  -0.1052
  12.00    1.277   0.0601  -0.1026
  12.50    1.250   0.0693  -0.1000
  13.00    1.246   0.0785  -0.0980
  13.50    1.247   0.0888  -0.0969
  14.00    1.256   0.1000  -0.0968
  14.50    1.260   0.1108  -0.0973
  15.00    1.271   0.1219  -0.0981
  15.50    1.281   0.1325  -0.0992
  16.00    1.289   0.1433  -0.1006
  16.50    1.294   0.1541  -0.1023
  17.00    1.304   0.1649  -0.1042
  17.50    1.309   0.1754  -0.1064
  18.00    1.315   0.1845  -0.1082
  18.50    1.320   0.1953  -0.1110
  19.00    1.330   0.2061  -0.1143
  19.50    1.343   0.2170  -0.1179
  20.00    1.354   0.2280  -0.1219
  20.50    1.359   0.2390  -0.1261
  21.00    1.360   0.2536  -0.1303
  22.00    1.325   0.2814  -0.1375
  23.00    1.288   0.3098  -0.1446
  24.00    1.251   0.3386  -0.1515
  25.00    1.215   0.3678  -0.1584
  26.00    1.181   0.3972  -0.1651
  28.00    1.120   0.4563  -0.1781
  30.00    1.076   0.5149  -0.1904
  32.00    1.056   0.5720  -0.2017
  35.00    1.066   0.6548  -0.2173
  40.00    1.064   0.7901  -0.2418
  45.00    1.035   0.9190  -0.2650
  50.00    0.980   1.0378  -0.2867
  55.00    0.904   1.1434  -0.3072
  60.00    0.810   1.2333  -0.3265
  65.00    0.702   1.3055  -0.3446
  70.00    0.582   1.3587  -0.3616
  75.00    0.456   1.3922  -0.3775
  80.00    0.326   1.4063  -0.3921
  85.00    0.197   1.4042  -0.4057
  90.00    0.072   1.3985  -0.4180
  95.00   -0.050   1.3973  -0.4289
 100.00   -0.170   1.3810  -0.4385
 105.00   -0.287   1.3498  -0.4464
 110.00   -0.399   1.3041  -0.4524
 115.00   -0.502   1.2442  -0.4563
 120.00   -0.596   1.1709  -0.4577
 125.00   -0.677   1.0852  -0.4563
 130.00   -0.743   0.9883  -0.4514
 135.00   -0.792   0.8818  -0.4425
 140.00   -0.821   0.7676  -0.4288
 145.00   -0.826   0.6481  -0.4095
 150.00   -0.806   0.5264  -0.3836
 155.00   -0.758   0.4060  -0.3497
 160.00   -0.679   0.2912  -0.3065
 170.00   -0.735   0.0995  -0.3706
 175.00   -0.368   0.0356  -0.1846
 180.00    0.000   0.0202   0.0000
```

B.8 Airfoil-Data Input File – DU21_A17.dat

```
DU21 airfoil with an aspect ratio of 17.  Original -180 to 180deg Cl, Cd, and Cm versus AOA data taken from Appendix A of DOW
Cl and Cd values corrected for rotational stall delay and Cd values corrected using the Viterna method for 0 to 90deg AOA by
   1        Number of airfoil tables in this file
   0.0      Table ID parameter
   8.00     Stall angle (deg)
   0.0      No longer used, enter zero
   0.0      No longer used, enter zero
   0.0      No longer used, enter zero
  -5.0609   Zero Cn angle of attack (deg)
   6.2047   Cn slope for zero lift (dimensionless)
   1.4144   Cn extrapolated to value at positive stall angle of attack
  -0.5324   Cn at stall value for negative angle of attack
  -1.50     Angle of attack for minimum CD (deg)
   0.0057   Minimum CD value
-180.00    0.000   0.0185   0.0000
-175.00    0.394   0.0332   0.1978
-170.00    0.788   0.0945   0.3963
-160.00    0.670   0.2809   0.2738
-155.00    0.749   0.3932   0.3118
-150.00    0.797   0.5112   0.3413
-145.00    0.818   0.6309   0.3636
-140.00    0.813   0.7485   0.3799
```

```
-135.00    0.786   0.8612   0.3911
-130.00    0.739   0.9665   0.3980
-125.00    0.675   1.0625   0.4012
-120.00    0.596   1.1476   0.4014
-115.00    0.505   1.2206   0.3990
-110.00    0.403   1.2805   0.3943
-105.00    0.294   1.3265   0.3878
-100.00    0.179   1.3582   0.3796
 -95.00    0.060   1.3752   0.3700
 -90.00   -0.060   1.3774   0.3591
 -85.00   -0.179   1.3648   0.3471
 -80.00   -0.295   1.3376   0.3340
 -75.00   -0.407   1.2962   0.3199
 -70.00   -0.512   1.2409   0.3049
 -65.00   -0.608   1.1725   0.2890
 -60.00   -0.693   1.0919   0.2722
 -55.00   -0.764   1.0002   0.2545
 -50.00   -0.820   0.8990   0.2359
 -45.00   -0.857   0.7900   0.2163
 -40.00   -0.875   0.6754   0.1958
 -35.00   -0.869   0.5579   0.1744
 -30.00   -0.838   0.4405   0.1520
 -25.00   -0.791   0.3256   0.1262
 -24.00   -0.794   0.3013   0.1170
 -23.00   -0.805   0.2762   0.1059
 -22.00   -0.821   0.2506   0.0931
 -21.00   -0.843   0.2246   0.0788
 -20.00   -0.869   0.1983   0.0631
 -19.00   -0.899   0.1720   0.0464
 -18.00   -0.931   0.1457   0.0286
 -17.00   -0.964   0.1197   0.0102
 -16.00   -0.999   0.0940  -0.0088
 -15.00   -1.033   0.0689  -0.0281
 -14.50   -1.050   0.0567  -0.0378
 -12.01   -0.953   0.0271  -0.0349
 -11.00   -0.900   0.0303  -0.0361
  -9.98   -0.827   0.0287  -0.0464
  -8.12   -0.536   0.0124  -0.0821
  -7.62   -0.467   0.0109  -0.0924
  -7.11   -0.393   0.0092  -0.1015
  -6.60   -0.323   0.0083  -0.1073
  -6.50   -0.311   0.0089  -0.1083
  -6.00   -0.245   0.0082  -0.1112
  -5.50   -0.178   0.0074  -0.1146
  -5.00   -0.113   0.0069  -0.1172
  -4.50   -0.048   0.0065  -0.1194
  -4.00    0.016   0.0063  -0.1213
  -3.50    0.080   0.0061  -0.1232
  -3.00    0.145   0.0058  -0.1252
  -2.50    0.208   0.0057  -0.1268
  -2.00    0.270   0.0057  -0.1282
  -1.50    0.333   0.0057  -0.1297
  -1.00    0.396   0.0057  -0.1310
  -0.50    0.458   0.0057  -0.1324
   0.00    0.521   0.0057  -0.1337
   0.50    0.583   0.0057  -0.1350
   1.00    0.645   0.0058  -0.1363
   1.50    0.706   0.0058  -0.1374
   2.00    0.768   0.0059  -0.1385
   2.50    0.828   0.0061  -0.1395
   3.00    0.888   0.0063  -0.1403
   3.50    0.948   0.0066  -0.1406
   4.00    0.996   0.0071  -0.1398
   4.50    1.046   0.0079  -0.1390
   5.00    1.095   0.0090  -0.1378
   5.50    1.145   0.0103  -0.1369
   6.00    1.192   0.0113  -0.1353
   6.50    1.239   0.0122  -0.1338
   7.00    1.283   0.0131  -0.1317
   7.50    1.324   0.0139  -0.1291
   8.00    1.358   0.0147  -0.1249
   8.50    1.385   0.0158  -0.1213
   9.00    1.403   0.0181  -0.1177
   9.50    1.401   0.0211  -0.1142
  10.00    1.358   0.0255  -0.1103
  10.50    1.313   0.0301  -0.1066
  11.00    1.287   0.0347  -0.1032
  11.50    1.274   0.0401  -0.1002
  12.00    1.272   0.0468  -0.0971
  12.50    1.273   0.0545  -0.0940
  13.00    1.273   0.0633  -0.0909
  13.50    1.273   0.0722  -0.0883
  14.00    1.272   0.0806  -0.0865
  14.50    1.273   0.0900  -0.0854
```

```
  15.00    1.275   0.0987  -0.0849
  15.50    1.281   0.1075  -0.0847
  16.00    1.284   0.1170  -0.0850
  16.50    1.296   0.1270  -0.0858
  17.00    1.306   0.1368  -0.0869
  17.50    1.308   0.1464  -0.0883
  18.00    1.308   0.1562  -0.0901
  18.50    1.308   0.1664  -0.0922
  19.00    1.308   0.1770  -0.0949
  19.50    1.307   0.1878  -0.0980
  20.00    1.311   0.1987  -0.1017
  20.50    1.325   0.2100  -0.1059
  21.00    1.324   0.2214  -0.1105
  22.00    1.277   0.2499  -0.1172
  23.00    1.229   0.2786  -0.1239
  24.00    1.182   0.3077  -0.1305
  25.00    1.136   0.3371  -0.1370
  26.00    1.093   0.3664  -0.1433
  28.00    1.017   0.4246  -0.1556
  30.00    0.962   0.4813  -0.1671
  32.00    0.937   0.5356  -0.1778
  35.00    0.947   0.6127  -0.1923
  40.00    0.950   0.7396  -0.2154
  45.00    0.928   0.8623  -0.2374
  50.00    0.884   0.9781  -0.2583
  55.00    0.821   1.0846  -0.2782
  60.00    0.740   1.1796  -0.2971
  65.00    0.646   1.2617  -0.3149
  70.00    0.540   1.3297  -0.3318
  75.00    0.425   1.3827  -0.3476
  80.00    0.304   1.4202  -0.3625
  85.00    0.179   1.4423  -0.3763
  90.00    0.053   1.4512  -0.3890
  95.00   -0.073   1.4480  -0.4004
 100.00   -0.198   1.4294  -0.4105
 105.00   -0.319   1.3954  -0.4191
 110.00   -0.434   1.3464  -0.4260
 115.00   -0.541   1.2829  -0.4308
 120.00   -0.637   1.2057  -0.4333
 125.00   -0.720   1.1157  -0.4330
 130.00   -0.787   1.0144  -0.4294
 135.00   -0.836   0.9033  -0.4219
 140.00   -0.864   0.7845  -0.4098
 145.00   -0.869   0.6605  -0.3922
 150.00   -0.847   0.5346  -0.3682
 155.00   -0.795   0.4103  -0.3364
 160.00   -0.711   0.2922  -0.2954
 170.00   -0.788   0.0969  -0.3966
 175.00   -0.394   0.0334  -0.1978
 180.00    0.000   0.0185   0.0000
```

B.9 Airfoil-Data Input File – NACA64_A17.dat

```
NACA64 airfoil with an aspect ratio of 17.  Original -180 to 180deg Cl, Cd, and Cm versus AOA data taken from Appendix A of D
Cl and Cd values corrected for rotational stall delay and Cd values corrected using the Viterna method for 0 to 90deg AOA by
   1        Number of airfoil tables in this file
   0.0      Table ID parameter
   9.00     Stall angle (deg)
   0.0      No longer used, enter zero
   0.0      No longer used, enter zero
   0.0      No longer used, enter zero
  -4.4320   Zero Cn angle of attack (deg)
   6.0031   Cn slope for zero lift (dimensionless)
   1.4073   Cn extrapolated to value at positive stall angle of attack
  -0.7945   Cn at stall value for negative angle of attack
  -1.00     Angle of attack for minimum CD (deg)
   0.0052   Minimum CD value
-180.00    0.000   0.0198   0.0000
-175.00    0.374   0.0341   0.1880
-170.00    0.749   0.0955   0.3770
-160.00    0.659   0.2807   0.2747
-155.00    0.736   0.3919   0.3130
-150.00    0.783   0.5086   0.3428
-145.00    0.803   0.6267   0.3654
-140.00    0.798   0.7427   0.3820
-135.00    0.771   0.8537   0.3935
-130.00    0.724   0.9574   0.4007
-125.00    0.660   1.0519   0.4042
-120.00    0.581   1.1355   0.4047
-115.00    0.491   1.2070   0.4025
-110.00    0.390   1.2656   0.3981
-105.00    0.282   1.3104   0.3918
```

```
-100.00    0.169   1.3410   0.3838
 -95.00    0.052   1.3572   0.3743
 -90.00   -0.067   1.3587   0.3636
 -85.00   -0.184   1.3456   0.3517
 -80.00   -0.299   1.3181   0.3388
 -75.00   -0.409   1.2765   0.3248
 -70.00   -0.512   1.2212   0.3099
 -65.00   -0.606   1.1532   0.2940
 -60.00   -0.689   1.0731   0.2772
 -55.00   -0.759   0.9822   0.2595
 -50.00   -0.814   0.8820   0.2409
 -45.00   -0.850   0.7742   0.2212
 -40.00   -0.866   0.6610   0.2006
 -35.00   -0.860   0.5451   0.1789
 -30.00   -0.829   0.4295   0.1563
 -25.00   -0.853   0.3071   0.1156
 -24.00   -0.870   0.2814   0.1040
 -23.00   -0.890   0.2556   0.0916
 -22.00   -0.911   0.2297   0.0785
 -21.00   -0.934   0.2040   0.0649
 -20.00   -0.958   0.1785   0.0508
 -19.00   -0.982   0.1534   0.0364
 -18.00   -1.005   0.1288   0.0218
 -17.00   -1.082   0.1037   0.0129
 -16.00   -1.113   0.0786  -0.0028
 -15.00   -1.105   0.0535  -0.0251
 -14.00   -1.078   0.0283  -0.0419
 -13.50   -1.053   0.0158  -0.0521
 -13.00   -1.015   0.0151  -0.0610
 -12.00   -0.904   0.0134  -0.0707
 -11.00   -0.807   0.0121  -0.0722
 -10.00   -0.711   0.0111  -0.0734
  -9.00   -0.595   0.0099  -0.0772
  -8.00   -0.478   0.0091  -0.0807
  -7.00   -0.375   0.0086  -0.0825
  -6.00   -0.264   0.0082  -0.0832
  -5.00   -0.151   0.0079  -0.0841
  -4.00   -0.017   0.0072  -0.0869
  -3.00    0.088   0.0064  -0.0912
  -2.00    0.213   0.0054  -0.0946
  -1.00    0.328   0.0052  -0.0971
   0.00    0.442   0.0052  -0.1014
   1.00    0.556   0.0052  -0.1076
   2.00    0.670   0.0053  -0.1126
   3.00    0.784   0.0053  -0.1157
   4.00    0.898   0.0054  -0.1199
   5.00    1.011   0.0058  -0.1240
   6.00    1.103   0.0091  -0.1234
   7.00    1.181   0.0113  -0.1184
   8.00    1.257   0.0124  -0.1163
   8.50    1.293   0.0130  -0.1163
   9.00    1.326   0.0136  -0.1160
   9.50    1.356   0.0143  -0.1154
  10.00    1.382   0.0150  -0.1149
  10.50    1.400   0.0267  -0.1145
  11.00    1.415   0.0383  -0.1143
  11.50    1.425   0.0498  -0.1147
  12.00    1.434   0.0613  -0.1158
  12.50    1.443   0.0727  -0.1165
  13.00    1.451   0.0841  -0.1153
  13.50    1.453   0.0954  -0.1131
  14.00    1.448   0.1065  -0.1112
  14.50    1.444   0.1176  -0.1101
  15.00    1.445   0.1287  -0.1103
  15.50    1.447   0.1398  -0.1109
  16.00    1.448   0.1509  -0.1114
  16.50    1.444   0.1619  -0.1111
  17.00    1.438   0.1728  -0.1097
  17.50    1.439   0.1837  -0.1079
  18.00    1.448   0.1947  -0.1080
  18.50    1.452   0.2057  -0.1090
  19.00    1.448   0.2165  -0.1086
  19.50    1.438   0.2272  -0.1077
  20.00    1.428   0.2379  -0.1099
  21.00    1.401   0.2590  -0.1169
  22.00    1.359   0.2799  -0.1190
  23.00    1.300   0.3004  -0.1235
  24.00    1.220   0.3204  -0.1393
  25.00    1.168   0.3377  -0.1440
  26.00    1.116   0.3554  -0.1486
  28.00    1.015   0.3916  -0.1577
  30.00    0.926   0.4294  -0.1668
  32.00    0.855   0.4690  -0.1759
  35.00    0.800   0.5324  -0.1897
```

```
  40.00    0.804   0.6452  -0.2126
  45.00    0.793   0.7573  -0.2344
  50.00    0.763   0.8664  -0.2553
  55.00    0.717   0.9708  -0.2751
  60.00    0.656   1.0693  -0.2939
  65.00    0.582   1.1606  -0.3117
  70.00    0.495   1.2438  -0.3285
  75.00    0.398   1.3178  -0.3444
  80.00    0.291   1.3809  -0.3593
  85.00    0.176   1.4304  -0.3731
  90.00    0.053   1.4565  -0.3858
  95.00   -0.074   1.4533  -0.3973
 100.00   -0.199   1.4345  -0.4075
 105.00   -0.321   1.4004  -0.4162
 110.00   -0.436   1.3512  -0.4231
 115.00   -0.543   1.2874  -0.4280
 120.00   -0.640   1.2099  -0.4306
 125.00   -0.723   1.1196  -0.4304
 130.00   -0.790   1.0179  -0.4270
 135.00   -0.840   0.9064  -0.4196
 140.00   -0.868   0.7871  -0.4077
 145.00   -0.872   0.6627  -0.3903
 150.00   -0.850   0.5363  -0.3665
 155.00   -0.798   0.4116  -0.3349
 160.00   -0.714   0.2931  -0.2942
 170.00   -0.749   0.0971  -0.3771
 175.00   -0.374   0.0334  -0.1879
 180.00    0.000   0.0198   0.0000
```

Appendix C Source Code for the Control System DLL

```
!=======================================================================
SUBROUTINE DISCON ( avrSWAP, aviFAIL, accINFILE, avcOUTNAME, avcMSG )
!DEC$ ATTRIBUTES DLLEXPORT, ALIAS:'DISCON' :: DISCON


   ! This Bladed-style DLL controller is used to implement a variable-speed
   ! generator-torque controller and PI collective blade pitch controller for
   ! the NREL Offshore 5MW baseline wind turbine.  This routine was written by
   ! J. Jonkman of NREL/NWTC for use in the IEA Annex XXIII OC3 studies.


IMPLICIT                        NONE


   ! Passed Variables:

REAL(4),    INTENT(INOUT)    :: avrSWAP   (*)                                   ! The swap array, used to pass data to, and r

INTEGER(4), INTENT(  OUT)    :: aviFAIL                                         ! A flag used to indicate the success of this

INTEGER(1), INTENT(IN   )    :: accINFILE (*)                                   ! The address of the first record of an array
INTEGER(1), INTENT(  OUT)    :: avcMSG    (*)                                   ! The address of the first record of an array
INTEGER(1), INTENT(IN   )    :: avcOUTNAME(*)                                   ! The address of the first record of an array


   ! Local Variables:

REAL(4)                      :: Alpha                                           ! Current coefficient in the recursive, singl
REAL(4)                      :: BlPitch   (3)                                   ! Current values of the blade pitch angles, r
REAL(4)                      :: ElapTime                                        ! Elapsed time since the last call to the con
REAL(4), PARAMETER           :: CornerFreq    =       1.570796                  ! Corner frequency (-3dB point) in the recurs
REAL(4)                      :: GenSpeed                                        ! Current  HSS (generator) speed, rad/s.
REAL(4), SAVE                :: GenSpeedF                                       ! Filtered HSS (generator) speed, rad/s.
REAL(4)                      :: GenTrq                                          ! Electrical generator torque, N-m.
REAL(4)                      :: GK                                              ! Current value of the gain correction factor
REAL(4)                      :: HorWindV                                        ! Horizontal hub-heigh wind speed, m/s.
REAL(4), SAVE                :: IntSpdErr                                       ! Current integral of speed error w.r.t. time
REAL(4), SAVE                :: LastGenTrq                                      ! Commanded electrical generator torque the l
REAL(4), SAVE                :: LastTime                                        ! Last time this DLL was called, sec.
REAL(4), SAVE                :: LastTimePC                                      ! Last time the pitch  controller was called,
REAL(4), SAVE                :: LastTimeVS                                      ! Last time the torque controller was called,
REAL(4), PARAMETER           :: OnePlusEps    = 1.0 + EPSILON(OnePlusEps)       ! The number slighty greater than unity in si
REAL(4), PARAMETER           :: PC_DT         =       0.00125                   ! Communication interval for pitch  controlle
REAL(4), PARAMETER           :: PC_KI         =       0.008068634               ! Integral gain for pitch controller at rated
REAL(4), PARAMETER           :: PC_KK         =       0.1099965                 ! Pitch angle were the the derivative of the
REAL(4), PARAMETER           :: PC_KP         =       0.01882681                ! Proportional gain for pitch controller at r
REAL(4), PARAMETER           :: PC_MaxPit     =       1.570796                  ! Maximum pitch setting in pitch controller,
REAL(4), PARAMETER           :: PC_MaxRat     =       0.1396263                 ! Maximum pitch  rate (in absolute value) in
REAL(4), PARAMETER           :: PC_MinPit     =       0.0                       ! Minimum pitch setting in pitch controller,
REAL(4), PARAMETER           :: PC_RefSpd     =     122.9096                    ! Desired (reference) HSS speed for pitch con
REAL(4), SAVE                :: PitCom    (3)                                   ! Commanded pitch of each blade the last time
REAL(4)                      :: PitComI                                         ! Integral term of command pitch, rad.
REAL(4)                      :: PitComP                                         ! Proportional term of command pitch, rad.
REAL(4)                      :: PitComT                                         ! Total command pitch based on the sum of the
REAL(4)                      :: PitRate   (3)                                   ! Pitch rates of each blade based on the curr
REAL(4), PARAMETER           :: R2D           =      57.295780                  ! Factor to convert radians to degrees.
REAL(4), PARAMETER           :: RPS2RPM       =       9.5492966                 ! Factor to convert radians per second to rev
REAL(4)                      :: SpdErr                                          ! Current speed error, rad/s.
REAL(4)                      :: Time                                            ! Current simulation time, sec.
REAL(4)                      :: TrqRate                                         ! Torque rate based on the current and last t
REAL(4), PARAMETER           :: VS_CtInSp     =      70.16224                   ! Transitional generator speed (HSS side) bet
REAL(4), PARAMETER           :: VS_DT         =       0.00125                   ! Communication interval for torque controlle
REAL(4), PARAMETER           :: VS_MaxRat     =   15000.0                       ! Maximum torque rate (in absolute value) in
REAL(4), PARAMETER           :: VS_MaxTq      =   47402.91                      ! Maximum generator torque in Region 3 (HSS s
REAL(4), PARAMETER           :: VS_Rgn2K      =       2.332287                  ! Generator torque constant in Region 2 (HSS
REAL(4), PARAMETER           :: VS_Rgn2Sp     =      91.21091                   ! Transitional generator speed (HSS side) bet
REAL(4), PARAMETER           :: VS_Rgn3MP     =       0.01745329                ! Minimum pitch angle at which the torque is
REAL(4), PARAMETER           :: VS_RtGnSp     =     121.6805                    ! Rated generator speed (HSS side), rad/s. --
REAL(4), PARAMETER           :: VS_RtPwr      = 5296610.0                       ! Rated generator generator power in Region 3
REAL(4), SAVE                :: VS_Slope15                                      ! Torque/speed slope of region 1 1/2 cut-in t
REAL(4), SAVE                :: VS_Slope25                                      ! Torque/speed slope of region 2 1/2 inductio
REAL(4), PARAMETER           :: VS_SlPc       =      10.0                       ! Rated generator slip percentage in Region 2
REAL(4), SAVE                :: VS_SySp                                         ! Synchronous speed of region 2 1/2 induction
REAL(4), SAVE                :: VS_TrGnSp                                       ! Transitional generator speed (HSS side) bet

INTEGER(4)                   :: I                                               ! Generic index.
INTEGER(4)                   :: iStatus                                         ! A status flag set by the simulation as foll
INTEGER(4)                   :: K                                               ! Loops through blades.
INTEGER(4)                   :: NumBl                                           ! Number of blades, (-).
```

```
INTEGER(4), PARAMETER        :: UnDb          = 85                              ! I/O unit for the debugging information

INTEGER(1)                   :: iInFile   ( 256)                                ! CHARACTER string cInFile  stored as a 1-byt
INTEGER(1)                   :: iMessage  ( 256)                                ! CHARACTER string cMessage stored as a 1-byt
INTEGER(1), SAVE             :: iOutName  (1024)                                ! CHARACTER string cOutName stored as a 1-byt

LOGICAL(1), PARAMETER        :: PC_DbgOut     = .FALSE.                         ! Flag to indicate whether to output debuggin

CHARACTER( 256)              :: cInFile                                         ! CHARACTER string giving the name of the par
CHARACTER( 256)              :: cMessage                                        ! CHARACTER string giving a message that will
CHARACTER(1024), SAVE        :: cOutName                                        ! CHARACTER string giving the simulation run
CHARACTER(   1), PARAMETER   :: Tab           = CHAR( 9 )                       ! The tab character.
CHARACTER(  25), PARAMETER   :: FmtDat    = "(F8.3,99('"//Tab//"',ES10.3E2,:))" ! The format of the debugging data


   ! Set EQUIVALENCE relationships between INTEGER(1) byte arrays and CHARACTER strings:

EQUIVALENCE (iInFile , cInFile )
EQUIVALENCE (iMessage, cMessage)
EQUIVALENCE (iOutName, cOutName)




   ! Load variables from calling program (See Appendix A of Bladed User's Guide):

iStatus      = NINT( avrSWAP( 1) )
NumBl        = NINT( avrSWAP(61) )

BlPitch  (1) =       avrSWAP( 4)
BlPitch  (2) =       avrSWAP(33)
BlPitch  (3) =       avrSWAP(34)
GenSpeed     =       avrSWAP(20)
HorWindV     =       avrSWAP(27)
Time         =       avrSWAP( 2)



   ! Initialize aviFAIL to 0:

aviFAIL      = 0



   ! Read any External Controller Parameters specified in the User Interface
   !   and initialize variables:

IF ( iStatus == 0 )  THEN  ! .TRUE. if were on the first call to the DLL


   ! Convert byte arrays to CHARACTER strings, for convenience:

   DO I = 1,MIN(  256, NINT( avrSWAP(50) ) )
      iInFile (I) = accINFILE (I)   ! Sets cInfile  by EQUIVALENCE
   ENDDO
   DO I = 1,MIN( 1024, NINT( avrSWAP(51) ) )
      iOutName(I) = avcOUTNAME(I)   ! Sets cOutName by EQUIVALENCE
   ENDDO


   ! Inform users that we are using this user-defined routine:

   aviFAIL  = 1
   cMessage = 'Running with torque and pitch control of the NREL offshore '// &
              '5MW baseline wind turbine from DISCON.dll as written by J. '// &
              'Jonkman of NREL/NWTC for use in the IEA Annex XXIII OC3 '   // &
              'studies.'


   ! Determine some torque control parameters not specified directly:

   VS_SySp    = VS_RtGnSp/( 1.0 +  0.01*VS_SlPc )
   VS_Slope15 = ( VS_Rgn2K*VS_Rgn2Sp*VS_Rgn2Sp )/( VS_Rgn2Sp - VS_CtInSp )
   VS_Slope25 = ( VS_RtPwr/VS_RtGnSp           )/( VS_RtGnSp - VS_SySp   )
   IF ( VS_Rgn2K == 0.0 )  THEN  ! .TRUE. if the Region 2 torque is flat, and thus, the denominator in the ELSE condition is
      VS_TrGnSp = VS_SySp
   ELSE                          ! .TRUE. if the Region 2 torque is quadratic with speed
      VS_TrGnSp = ( VS_Slope25 - SQRT( VS_Slope25*( VS_Slope25 - 4.0*VS_Rgn2K*VS_SySp ) ) )/( 2.0*VS_Rgn2K )
   ENDIF


   ! Check validity of input parameters:

   IF ( CornerFreq <= 0.0 )  THEN
      aviFAIL  = -1
```

```
   cMessage = 'CornerFreq must be greater than zero.'
ENDIF

IF ( VS_DT     <= 0.0 )  THEN
   aviFAIL  = -1
   cMessage = 'VS_DT must be greater than zero.'
ENDIF

IF ( VS_CtInSp <  0.0 )  THEN
   aviFAIL  = -1
   cMessage = 'VS_CtInSp must not be negative.'
ENDIF

IF ( VS_Rgn2Sp <= VS_CtInSp )  THEN
   aviFAIL  = -1
   cMessage = 'VS_Rgn2Sp must be greater than VS_CtInSp.'
ENDIF

IF ( VS_TrGnSp <  VS_Rgn2Sp )  THEN
   aviFAIL  = -1
   cMessage = 'VS_TrGnSp must not be less than VS_Rgn2Sp.'
ENDIF

IF ( VS_SlPc   <= 0.0 )  THEN
   aviFAIL  = -1
   cMessage = 'VS_SlPc must be greater than zero.'
ENDIF

IF ( VS_MaxRat <= 0.0 )  THEN
   aviFAIL  =  -1
   cMessage = 'VS_MaxRat must be greater than zero.'
ENDIF

IF ( VS_RtPwr  <  0.0 )  THEN
   aviFAIL  = -1
   cMessage = 'VS_RtPwr must not be negative.'
ENDIF

IF ( VS_Rgn2K  <  0.0 )  THEN
   aviFAIL  = -1
   cMessage = 'VS_Rgn2K must not be negative.'
ENDIF

IF ( VS_Rgn2K*VS_RtGnSp*VS_RtGnSp > VS_RtPwr/VS_RtGnSp )  THEN
   aviFAIL  = -1
   cMessage = 'VS_Rgn2K*VS_RtGnSp^2 must not be greater than VS_RtPwr/VS_RtGnSp.'
ENDIF

IF ( VS_MaxTq                     < VS_RtPwr/VS_RtGnSp )  THEN
   aviFAIL  = -1
   cMessage = 'VS_RtPwr/VS_RtGnSp must not be greater than VS_MaxTq.'
ENDIF

IF ( PC_DT     <= 0.0 )  THEN
   aviFAIL  = -1
   cMessage = 'PC_DT must be greater than zero.'
ENDIF

IF ( PC_KI     <= 0.0 )  THEN
   aviFAIL  = -1
   cMessage = 'PC_KI must be greater than zero.'
ENDIF

IF ( PC_KK     <= 0.0 )  THEN
   aviFAIL  = -1
   cMessage = 'PC_KK must be greater than zero.'
ENDIF

IF ( PC_RefSpd <= 0.0 )  THEN
   aviFAIL  = -1
   cMessage = 'PC_RefSpd must be greater than zero.'
ENDIF

IF ( PC_MaxRat <= 0.0 )  THEN
   aviFAIL  = -1
   cMessage = 'PC_MaxRat must be greater than zero.'
ENDIF

IF ( PC_MinPit >= PC_MaxPit )  THEN
   aviFAIL  = -1
   cMessage = 'PC_MinPit must be less than PC_MaxPit.'
ENDIF


! If we're debugging the pitch controller, open the debug file and write the
```

```fortran
   !   header:

   IF ( PC_DbgOut )  THEN

      OPEN ( UnDb, FILE=TRIM( cOutName )//'.dbg', STATUS='REPLACE' )

      WRITE (UnDb,'(/////)')
      WRITE (UnDb,'(A)')  'Time '//Tab//'ElapTime'//Tab//'HorWindV'//Tab//'GenSpeed'//Tab//'GenSpeedF'//Tab//'RelSpdErr'//Tab
                          'SpdErr '//Tab//'IntSpdErr'//Tab//'GK '//Tab//'PitComP'//Tab//'PitComI'//Tab//'PitComT'//Tab//
                          'PitRate1'//Tab//'PitCom1'
      WRITE (UnDb,'(A)')  '(sec)'//Tab//'(sec)   '//Tab//'(m/sec) '//Tab//'(rpm)   '//Tab//'(rpm)    '//Tab//'(%)      '//Tab
                          '(rad/s)'//Tab//'(rad)    '//Tab//'(-)'//Tab//'(deg)  '//Tab//'(deg)  '//Tab//'(deg)  '//Tab//
                          '(deg/s) '//Tab//'(deg)  '

   ENDIF


   ! Initialize the SAVEd variables:
   ! NOTE: LastGenTrq, though SAVEd, is initialized in the torque controller
   !       below for simplicity, not here.

   GenSpeedF  = GenSpeed                        ! This will ensure that generator speed filter will use the initial value of
   PitCom     = BlPitch                         ! This will ensure that the variable speed controller picks the correct contr
   GK         = 1.0/( 1.0 + PitCom(1)/PC_KK )   ! This will ensure that the pitch angle is unchanged if the initial SpdErr is
   IntSpdErr  = PitCom(1)/( GK*PC_KI )          ! This will ensure that the pitch angle is unchanged if the initial SpdErr is

   LastTime   = Time                            ! This will ensure that generator speed filter will use the initial value of
   LastTimePC = Time - PC_DT                    ! This will ensure that the pitch  controller is called on the first pass
   LastTimeVS = Time - VS_DT                    ! This will ensure that the torque controller is called on the first pass


ENDIF



   ! Main control calculations:

IF ( ( iStatus >= 0 ) .AND. ( aviFAIL >= 0 ) )  THEN  ! Only compute control calculations if no error has occured and we are



   ! Abort if the user has not requested a pitch angle actuator (See Appendix A
   !   of Bladed User's Guide):

   IF ( NINT(avrSWAP(10)) /= 0 )  THEN ! .TRUE. if a pitch angle actuator hasn't been requested
      aviFAIL  = -1
      cMessage = 'Pitch angle actuator not requested.'
   ENDIF


   ! Set unused outputs to zero (See Appendix A of Bladed User's Guide):

   avrSWAP(36) = 0.0 ! Shaft brake status: 0=off
   avrSWAP(41) = 0.0 ! Demanded yaw actuator torque
   avrSWAP(46) = 0.0 ! Demanded pitch rate (Collective pitch)
   avrSWAP(48) = 0.0 ! Demanded nacelle yaw rate
   avrSWAP(65) = 0.0 ! Number of variables returned for logging
   avrSWAP(72) = 0.0 ! Generator startup resistance
   avrSWAP(79) = 0.0 ! Request for loads: 0=none
   avrSWAP(80) = 0.0 ! Variable slip current status
   avrSWAP(81) = 0.0 ! Variable slip current demand


!=======================================================================


   ! Filter the HSS (generator) speed measurement:
   ! NOTE: This is a very simple recursive, single-pole, low-pass filter with
   !       exponential smoothing.

   ! Update the coefficient in the recursive formula based on the elapsed time
   !   since the last call to the controller:

   Alpha     = EXP( ( LastTime - Time )*CornerFreq )


   ! Apply the filter:

   GenSpeedF = ( 1.0 - Alpha )*GenSpeed + Alpha*GenSpeedF


!=======================================================================


   ! Variable-speed torque control:
```

```
   ! Compute the elapsed time since the last call to the controller:

   ElapTime = Time - LastTimeVS


   ! Only perform the control calculations if the elapsed time is greater than
   !   or equal to the communication interval of the torque controller:
   ! NOTE: Time is scaled by OnePlusEps to ensure that the contoller is called
   !       at every time step when VS_DT = DT, even in the presence of
   !       numerical precision errors.

   IF ( ( Time*OnePlusEps - LastTimeVS ) >= VS_DT )  THEN


   ! Compute the generator torque, which depends on which region we are in:

      IF ( (   GenSpeedF >= VS_RtGnSp ) .OR. (  PitCom(1) >= VS_Rgn3MP ) )  THEN ! We are in region 3 - power is constant
         GenTrq = VS_RtPwr/GenSpeedF
      ELSEIF ( GenSpeedF <= VS_CtInSp )  THEN                                    ! We are in region 1 - torque is zero
         GenTrq = 0.0
      ELSEIF ( GenSpeedF <  VS_Rgn2Sp )  THEN                                    ! We are in region 1 1/2 - linear ramp in to
         GenTrq = VS_Slope15*( GenSpeedF - VS_CtInSp )
      ELSEIF ( GenSpeedF <  VS_TrGnSp )  THEN                                    ! We are in region 2 - optimal torque is pro
         GenTrq = VS_Rgn2K*GenSpeedF*GenSpeedF
      ELSE                                                                       ! We are in region 2 1/2 - simple induction
         GenTrq = VS_Slope25*( GenSpeedF - VS_SySp   )
      ENDIF


   ! Saturate the commanded torque using the maximum torque limit:

      GenTrq  = MIN( GenTrq                    , VS_MaxTq  )   ! Saturate the command using the maximum torque limit


   ! Saturate the commanded torque using the torque rate limit:

      IF ( iStatus == 0 )  LastGenTrq = GenTrq                 ! Initialize the value of LastGenTrq on the first pass only
      TrqRate = ( GenTrq - LastGenTrq )/ElapTime               ! Torque rate (unsaturated)
      TrqRate = MIN( MAX( TrqRate, -VS_MaxRat ), VS_MaxRat )   ! Saturate the torque rate using its maximum absolute value
      GenTrq  = LastGenTrq + TrqRate*ElapTime                  ! Saturate the command using the torque rate limit


   ! Reset the values of LastTimeVS and LastGenTrq to the current values:

      LastTimeVS = Time
      LastGenTrq = GenTrq


   ENDIF


   ! Set the generator contactor status, avrSWAP(35), to main (high speed)
   !   variable-speed generator, the torque override to yes, and command the
   !   generator torque (See Appendix A of Bladed User's Guide):

   avrSWAP(35) = 1.0          ! Generator contactor status: 1=main (high speed) variable-speed generator
   avrSWAP(56) = 0.0          ! Torque override: 0=yes
   avrSWAP(47) = LastGenTrq   ! Demanded generator torque


!=======================================================================


   ! Pitch control:

   ! Compute the elapsed time since the last call to the controller:

   ElapTime = Time - LastTimePC


   ! Only perform the control calculations if the elapsed time is greater than
   !   or equal to the communication interval of the pitch controller:
   ! NOTE: Time is scaled by OnePlusEps to ensure that the contoller is called
   !       at every time step when PC_DT = DT, even in the presence of
   !       numerical precision errors.

   IF ( ( Time*OnePlusEps - LastTimePC ) >= PC_DT )  THEN


   ! Compute the gain scheduling correction factor based on the previously
   !   commanded pitch angle for blade 1:

      GK = 1.0/( 1.0 + PitCom(1)/PC_KK )
```

```
   ! Compute the current speed error and its integral w.r.t. time; saturate the
   !   integral term using the pitch angle limits:

      SpdErr    = GenSpeedF - PC_RefSpd                                 ! Current speed error
      IntSpdErr = IntSpdErr + SpdErr*ElapTime                           ! Current integral of speed error w.r.t. time
      IntSpdErr = MIN( MAX( IntSpdErr, PC_MinPit/( GK*PC_KI ) ), &
                                       PC_MaxPit/( GK*PC_KI )      )    ! Saturate the integral term using the pitch angle li


   ! Compute the pitch commands associated with the proportional and integral
   !   gains:

      PitComP   = GK*PC_KP*   SpdErr                                    ! Proportional term
      PitComI   = GK*PC_KI*IntSpdErr                                    ! Integral term (saturated)


   ! Superimpose the individual commands to get the total pitch command;
   !   saturate the overall command using the pitch angle limits:

      PitComT   = PitComP + PitComI                                     ! Overall command (unsaturated)
      PitComT   = MIN( MAX( PitComT, PC_MinPit ), PC_MaxPit )           ! Saturate the overall command using the pitch angle


   ! Saturate the overall commanded pitch using the pitch rate limit:
   ! NOTE: Since the current pitch angle may be different for each blade
   !       (depending on the type of actuator implemented in the structural
   !       dynamics model), this pitch rate limit calculation and the
   !       resulting overall pitch angle command may be different for each
   !       blade.

      DO K = 1,NumBl ! Loop through all blades

         PitRate(K) = ( PitComT - BlPitch(K) )/ElapTime                 ! Pitch rate of blade K (unsaturated)
         PitRate(K) = MIN( MAX( PitRate(K), -PC_MaxRat ), PC_MaxRat )   ! Saturate the pitch rate of blade K using its maximu
         PitCom (K) = BlPitch(K) + PitRate(K)*ElapTime                  ! Saturate the overall command of blade K using the p

      ENDDO          ! K - all blades


   ! Reset the value of LastTimePC to the current value:

      LastTimePC = Time


   ! Output debugging information if requested:

      IF ( PC_DbgOut )  WRITE (UnDb,FmtDat)  Time, ElapTime, HorWindV, GenSpeed*RPS2RPM, GenSpeedF*RPS2RPM,           &
                                             100.0*SpdErr/PC_RefSpd, SpdErr, IntSpdErr, GK, PitComP*R2D, PitComI*R2D, &
                                             PitComT*R2D, PitRate(1)*R2D, PitCom(1)*R2D


   ENDIF


   ! Set the pitch override to yes and command the pitch demanded from the last
   !   call to the controller (See Appendix A of Bladed User's Guide):

   avrSWAP(55) = 0.0       ! Pitch override: 0=yes

   avrSWAP(42) = PitCom(1) ! Use the command angles of all blades if using individual pitch
   avrSWAP(43) = PitCom(2) ! "
   avrSWAP(44) = PitCom(3) ! "

   avrSWAP(45) = PitCom(1) ! Use the command angle of blade 1 if using collective pitch


!=======================================================================


   ! Reset the value of LastTime to the current value:

   LastTime = Time


ENDIF


   ! Convert CHARACTER string to byte array for the return message:

DO I = 1,MIN(  256, NINT( avrSWAP(49) ) )
   avcMSG(I) = iMessage(I) ! Same as cMessage by EQUIVALENCE
ENDDO
```

```
RETURN
END SUBROUTINE DISCON
!=======================================================================
```

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14. **ABSTRACT** *(Maximum 200 Words)*

This report describes a three-bladed, upwind, variable-speed, variable blade-pitch-to-feather-controlled multimegawatt wind turbine model developed by NREL to support concept studies aimed at assessing offshore wind technology.

15. **SUBJECT TERMS**

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Vedlegg 7 – “Description of a basic model of the “UpWind reference jacket” for code comparison in the OC4 project under IEA Wind Annex XXX”

Description of a basic model of the "UpWind reference jacket" for code comparison in the OC4 project under IEA Wind Annex XXX

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Acknowledgements

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1. Introduction

This document describes the jacket support structure model to be used in phase I of the OC4 project. The jacket was originally designed by RAMBØLL A/S (cf. Vemula et al. (2010)) in the UpWind project. The turbine which is to be used with this jacket structure is the well known "NREL 5-MW baseline turbine" as described by Jonkman et al. (2009).

The support structure model is described in the following, no further information concerning structural properties is necessary to run the simulations in the course of this project (the interested reader may find further details on the jacket and the design process in Vemula et al. (2010)). For the turbine model, i.e. the rotor nacelle assembly (RNA) as the tower is mentioned as part of the support structure in the following, it is referred to Jonkman et al. (2009). There is one difference compared to the description in Jonkman et al. (2009): The hub height of the turbine is shifted from 90 m to 90.55 m with the jacket due to a shifted tower top elevation.

~~hub height OC3=90 m~~ hub height OC4=90.55 m

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[1] `www.upwind.eu`; July, 2010

[2] `http://www.ieawind.org/Task_30/Task30_Public.html`; July, 2010

The term offshore wind turbine (OWT) denotes the system as a whole (RNA and support structure) in this document. All properties given in the appendix may be found in "UpWind Jacket Model - Nodes and Members.xls" as well.

2. General properties of the jacket structure as defined in UpWind

This section is meant to give a general overview of the *jacket structure* as it was designed by RAMBØLL A/S for the UpWind project. A detailed description of the *numerical model* of this structure for code comparison in OC4 is given in section 3.

The support structure described herein is designed for the 5-MW baseline turbine at the UpWind deep water reference site (cf. Fischer et al. (2010)) in 50 m of water. The four legged jacket has four levels of X-braces, accordingly mud braces and four central piles with a penetration depth of 45 m being grouted to the jacket legs. The transition piece (TP) between jacket and tower is a block of concrete that is penetrated by the upper parts of the four jacket legs. The total height of the jacket from mudline including the TP and excluding the tower is 70.15 m. The conical tower has a total length of 68 m leading to a realistic hub height over the mean sea level (MSL) of 90.55 m. Figure 1 shows the complete support structure.

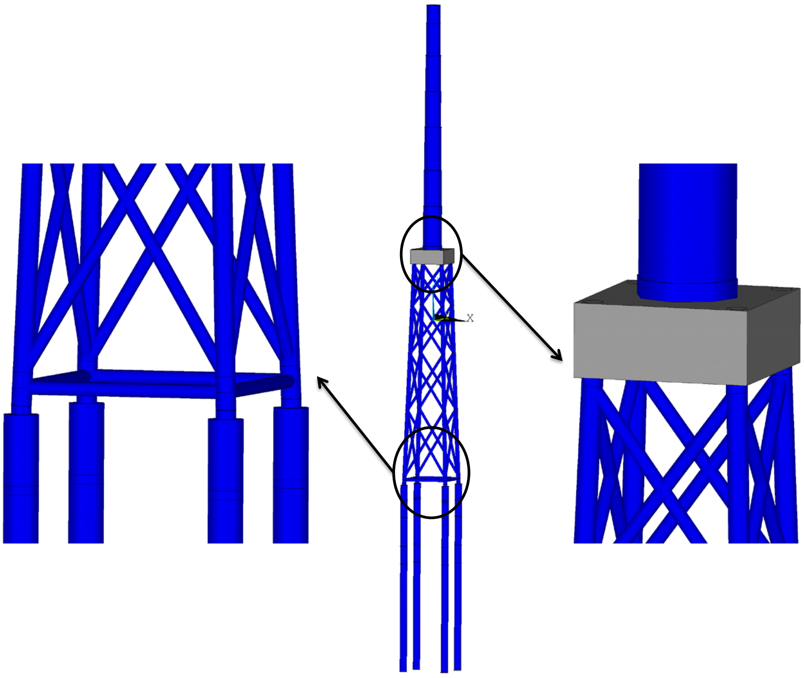

Figure 1: *Jacket with tower and piles (middle),concrete TP (right) and pile heads in detail (left).*

The jacket design includes joint cans, especially around the X-joints to match the code check requirements. Appurtenances, such as anodes, J-tubes and boat landing for example lead to supplementary masses of about 346 t.

3. Description of the support structure model for the OC4 project

In this section, a basic numerical model of the jacket support structure carrying the NREL 5-MW baseline RNA for the aero-hydro-servo-elastic simulation in the OC4 project is described. This model is meant to be a common starting point. Further refinements may be realized in the course of the project. The assumed steel properties Density, Young's Modulus and Poisson's ratio are as follows for the whole structural model:

$$\rho_s = 7850\,\mathrm{kg/m^3} \qquad E_s = 2.1E11\,\mathrm{N/m^2} \qquad \nu_s = 0.3$$

The critical structural-damping ratio ζ_s (and the corresponding logarithmic decrement δ_s) for all modes of the support structure (without the rotor-nacelle assembly mass present)is defined as follows:

$$\zeta_s = 1\,\% \qquad \delta_s = 6\,\%$$

This corresponds to the values defined by Kooijman et al. (2003) that were used in Jonkman et al. (2009) for the steel tower.

Node coordinates and member properties are given in Appendix A and in "UpWind Jacket Model - Nodes and Members.xls" for the jacket including the pile sections above mudline. For the grout connection between piles and legs, for the TP and for the tower, the properties are *not* included in the appendix and in "UpWind Jacket Model - Nodes and Members.xls" as these might be modeled differently in different simulation systems. For those parts, all necessary assumptions for a proper modeling are given in sections 3.3, section 3.4 and section 3.5 respectively. Section 3.7 provides supplementary information necessary for modeling and simulating the jacket properly.

3.1. Coordinate systems and definitions for joint and member identification

The x-axis of the global Cartesian coordinate system points downwind with respect to the main wind direction, the z-axis points upwards, the y-axis forms a right hand system. The origin lies at the mean sea level (MSL) in the centerline of the tower. Mean wind and wave directions are aligned and the jacket is positioned with its sides (top view) parallel to the x and y axis respectively.

The definitions described in Table 1 enable the project partners to clearly identify jacket members, joints and positions.

Figure 2 illustrates the global coordinates, the mean wind and wave directions and the definitions given in Table 1. As an example Joint *K2L1* identifies the double K-Joint at the middle K-joint level ($z = -8.922\,\mathrm{m}$) being part of leg 1. These definitions allow for the clear identification of braces as well, here, the information about the side must be included. As this becomes difficult to manage, the 64 braces are numbered top-down, from leg 1 to leg 4 with increasing leg number (counter clockwise for top view) as indicated in Figure 2 as well (bottom right) additionally.

The local member coordinate systems are defined as follows: The origin of each coordinate system lies between the two nodes in the center of the member. The local x-axis points from the node with the lower number to the node with the higher number along the member axis (cf. node numbering given in Appendix A). The local z-axis is perpendicular to a plane defined by the global x-axis and the member axis. There is one exception of this definition: With a member axis parallel to the global x-axis, this plane definition is impossible. In this case, the local z-axis is parallel to the global y-axis. The local y-axis is defined to form a right handed coordinate system.

Table 1: Description for identification of jacket joints, members and positions

Description	Name	Position
jacket leg 1	L1	$x > 0; y > 0$
jacket leg 2	L2	$x < 0; y > 0$
jacket leg 3	L3	$x < 0; y < 0$
jacket leg 4	L4	$x > 0; y < 0$
jacket side 1	S1	leg 1 to leg 2
jacket side 2	S2	leg 2 to leg 3
jacket side 3	S3	leg 3 to leg 4
jacket side 4	S4	leg 4 to leg 1
intersection level at upper Y-Joints	YUp	z=15.615 m
intersection level at highest X-Joints	X1	z=10.262 m
intersection level at 2nd X-Joints	X2	z=-1.958 m
intersection level at 3rd X-Joints	X3	z=-16.371 m
intersection level at 4th X-Joints	X4	z=-33.373 m
intersection level at highest K-Joints	K1	z=4.378 m
intersection level at middle K-Joints	K2	z=-8.922 m
intersection level at lower K-Joints	K3	z=-24.614 m
intersection level at lower Y-Joints	YBottom	z=-43.127 m
intersection level at mud brace	mud brace	z=-44.001 m

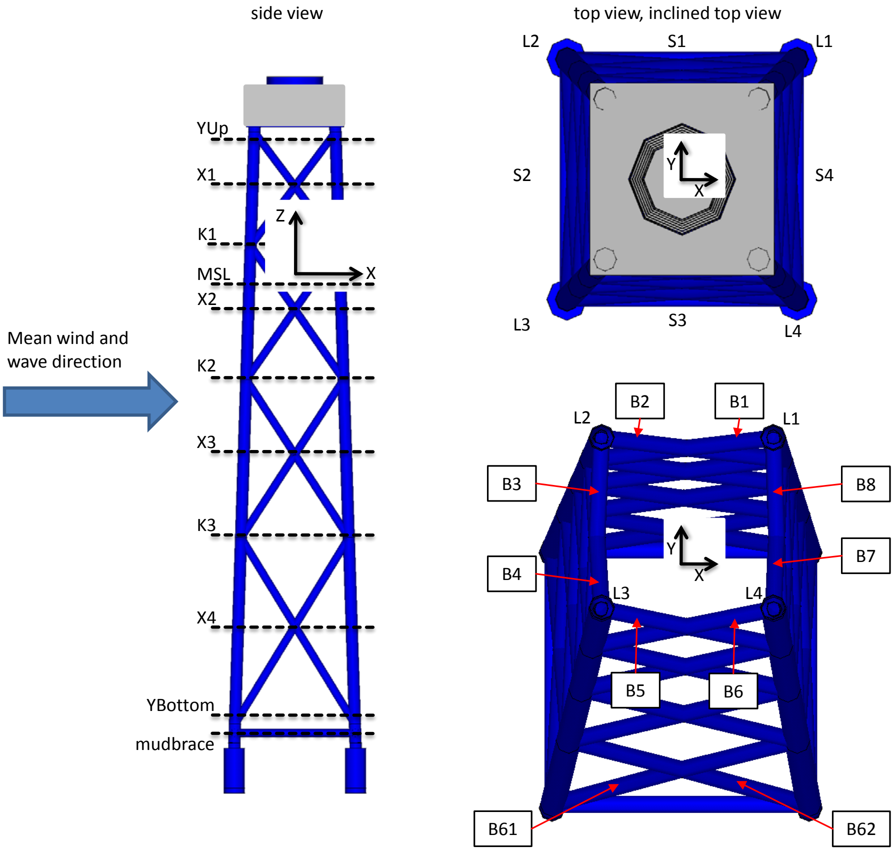

Figure 2: *Global coordinate system, mean sea level (MSL), mean wind- and wave directions and definitions given in Table 1 (left). Jacket top view (upper, right) and inclined top view (lower, right) to clarify Joint, leg and brace naming conventions.*

3.2. Jacket primary steel

Nodes, members and properties of the jacket model defined in the global Cartesian system as described in section 3.1 are given in Appendix A and in "UpWind Jacket Model - Nodes and Members.xls" (cf. Figure 3).

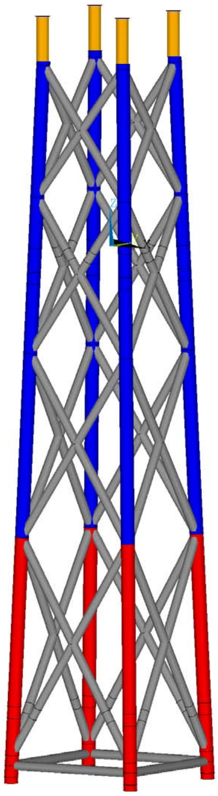

Figure 3: *Jacket as described in Appendix A and in "UpWind Jacket Model - Nodes and Members.xls". Member properties displayed as given in Table 2.*

The properties of the tubular members are shown as described in Table 2. The table gives the property set number describing the geometry of the component, the name of each of those components, its color in Figure 3 and the properties outer diameter and wall thickness.

Table 2: Properties of jacket members

property set	component	color in Figure 3	outer diameter [m]	thickness [mm]
1	x- and mud braces	grey	0.8	20
2	leg at lowest level	red	1.2	50
3	leg 2nd to 4th level	blue	1.2	35
4	leg crossing TP	orange	1.2	40
5	pile	not shown	2.082	60

3.3. Grouted connection between piles and jacket legs

In this basic model, the structure is cantilevered at mudline. Meaning that all six degrees of freedom are set to zero at those positions. Therefore only the part of the piles over mudline is included in the model. These parts are mentioned as part of the jacket in the following. They consist basically of two tubular members, the pile and the jacket leg that are connected with a grout material at each jacket corner. Figure 4 shows this part of the structure in detail.

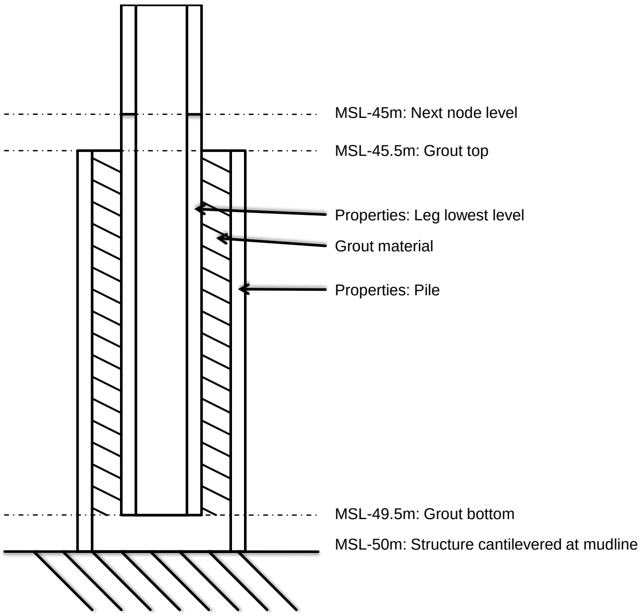

Figure 4: *Grouted leg pile connection in basic model. The coordinates are given with respect to MSL and the properties of the steel members are defined in Table 2. The density of the grout material is* $\rho_G = 2000\,\text{kg}/\text{m}^3$

As described in this figure in global coordinates (cf. section 3.1), mudline lies at $z = -50\,\text{m}$. The bottom of the grouted connection at $z = -49.5\,\text{m}$ and the upper end of the grout lies at $z = -45.5\,\text{m}$. At z=-45 m the next level of structural nodes is found as defined in Appendix A and in "UpWind Jacket Model - Nodes and Members.xls" at $z = -45\,\text{m}$. The properties of the leg at lowest level and the pile are given in Table 2.

The density of the grout material between the two steel parts is $\rho_G = 2000\,\text{kg}/\text{m}^3$. As the stiffness of the two steel members together with the grout material is very high, the grouted volume from MSL-49.5 m to MSL-45 m (pile and leg and grout) is assumed to be rigid in the model.

3.4. Transition piece

The model includes a TP defined as follows: A rigid concrete block with a mass of 666 t and a size of 4 x 9.6 x 9.6 m is positioned on top of the jacket with its center in the centerline of the tower as shown in Figure 5. The four supplementary vertical steel members, that are grouted into the concrete, are parts of the jacket legs and therefore mentioned as part of the jacket in the context of this project. At $z = 15.651\,\text{m}$ the legs and the braces at the highest level (cf.Table 1; YUp) intersect and the lower end of the TP lies at $z = 16.15\,\text{m}$. The upper end of the TP and therefore the connection to the tower lies at $z = 20.15\,\text{m}$. The following member from $z = 20.15\,\text{m}$ to $z = 21.15\,\text{m}$ is mentioned as part of the tower.

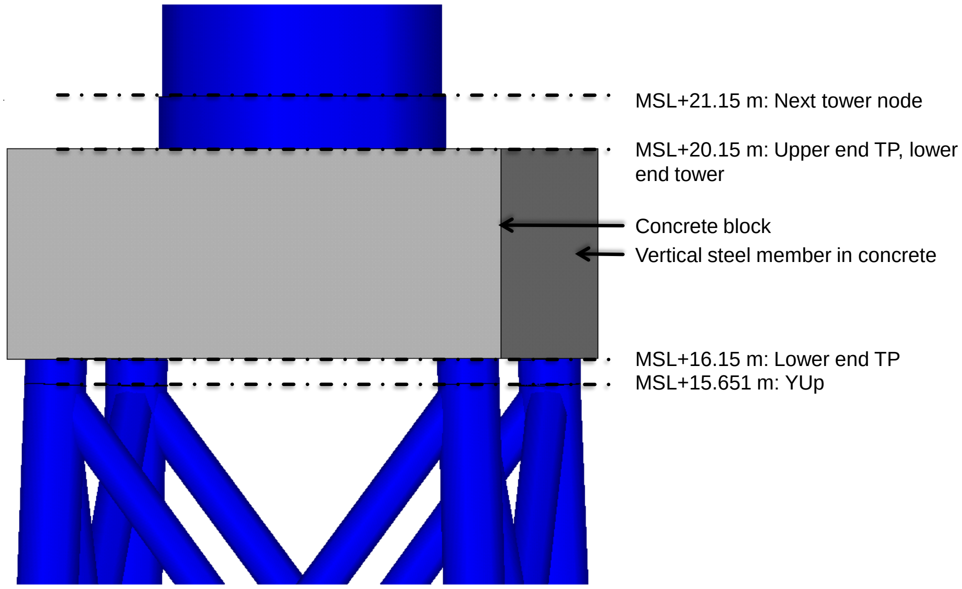

Figure 5: *TP in basic model. The coordinates are given with respect to MSL. The properties of the vertical steel members are given in Table 2.*

3.5. Tower

As described in Figure 5, the connection between TP and tower lies at MSL+ 20.15 m. The diameter of the conical tower is decreasing with height, the wall thickness as well. Only in the very upper part of the tower the thickness is re-increased. The tower properties are given in terms of values at cross sections herein. In Table 3, the z-coordinate in the global coordinate system (with respect to MSL), and the properties outer diameter and thickness are provided. Three point masses representing flanges, bolts and equipment installed in the tower are included in the model. The masses are positioned at the vertical tower centerline, the height coordinates and the masses are given in Table 3 as well.

Table 3: Tower cross sectional properties: Z-coordinate with respect to MSL, outer Diameter, thickness and point masses representing masses of flanges bolts and installed equipment

global height z [m]	outer diameter [m]	thickness [mm]	point mass [t]
20.15	5.600	32	1.9
21.15	5.577	32	No
32.15	5.318	30	No
42.15	5.082	28	No
54.15	4.800	24	1.4
64.15	4.565	22	No
74.15	4.329	20	No
83.15	4.118	30	No
88.15	4.000	30	1.0

3.6. Connection to the Rotor Nacelle Assembly

The RNA as defined in Jonkman et al. (2009) and the support structure as described herein include all properties of the OWT to be used in this project. The highest tower node defined in Table 3 represents the yaw bearing.

The elevation of the yaw bearing given in Jonkman et al. (2009) (p.13, Table 4-1) is $z = 87.6\,\text{m}$ above MSL and the corresponding value defined herein is $z = 88.15\,\text{m}$ over MSL. As all other distances provided by Jonkman are kept the same, the hub height of the OC4 model is $z = 90.55\,\text{m}$ and *not* $z = 90\,\text{m}$. Figure 6 shows the RNA to be used here based on the description in Jonkman et al. (2009) (values from Table 1-1 on page 2 and Table 4-1 on page 13 included). The elevation of the yaw bearing in the global coordinate system (the only value that has been modified) is marked in red. If there is a supplementary member to be defined in certain simulation systems to connect the tower top to the RNA, this should be modeled rigid and massless.

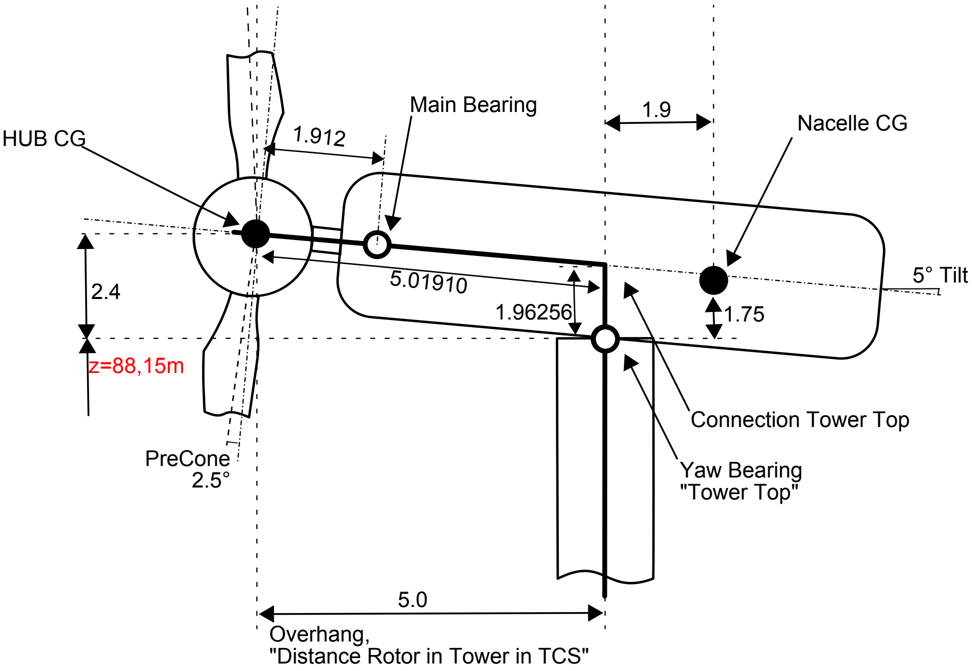

Figure 6: *RNA to be used in this project based on the definitions given in Jonkman et al. (2009). Only the yaw bearing elevation (red) was changed from* $z = 87.6\,\text{m}$ *to* $z = 88.15\,\text{m}$. *This leads to a modified hub height.*

3.7. Marine Growth, appurtenances, free flooded members

As **marine growth** may influence the loads and the dynamic behavior, namely the eigenstates of a jacket structure significantly, it is included in the model described herein as recommended by the respective guidelines (cf. e.g. DNV (2004)) and given by Fischer and Kuehn (2009). Table 4 shows the depth range with respect to MSL to apply marine growth, its thickness and density. **Appurtenances** on the jacket structure such as boat landings, J-tubes, anodes, cables, ladders etc. are not included in the model. The legs of the jacket structure are assumed to be **free flooded** by sea water with a density of $\rho_w = 1025\,\text{kg/m}^3$, the braces are not.

Table 4: Marine growth in the jacket model

Depth range:	$-40\,\text{m} \leq z_g \leq -2\,\text{m}$
Thickness:	$t_g = 100\,\text{mm}$
Density:	$\rho_g = 1100\,\text{kg/m}^3$

References

DNV (2004). DNV-OS-J101: Design of offshore wind turbine structures. Det Norske Veritas.

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Jonkman, J., Butterfield, S., Musial, W., and Scott, G. (2009). Definition of a 5-MW Reference Wind Turbine for Offshore System Development. Technical Report NREL/TP-500-38060, National Renewable Energy Laboratory (NREL).

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Vemula, N. K., DeVries, W., Fischer, T., Cordle, A., and Schmidt, B. (2010). Design solution for the upwind reference offshore support structure. Upwind deliverable D4.2.6 (WP4: Offshore foundations and support structures), Rambøll Wind Energy. (to be published).

A. Node coordinates, property sets and members of the jacket structure

For the grout connection between piles and legs, for the TP and for the tower, the properties are *not* included in this appendix and in "UpWind Jacket Model - Nodes and Members.xls" as these might be modeled differently in different simulation systems. For those parts, all necessary assumptions for a proper modeling are given in sections 3.3, section 3.4 and section 3.5 respectively.

```
Jacket as given in "UpWind Jacket Model - Nodes and Members.xls"

Nodes

node   x [m]   y [m]   z [m]
   1  6.000  6.000 -45.500
   2  6.000  6.000 -45.000
   3  5.967  5.967 -44.001
   4  5.939  5.939 -43.127
   5  5.333  5.333 -24.614
   6 -6.000  6.000 -45.500
   7 -6.000  6.000 -45.000
   8 -5.967  5.967 -44.001
   9 -5.939  5.939 -43.127
  10 -5.333  5.333 -24.614
  11 -6.000 -6.000 -45.500
  12 -6.000 -6.000 -45.000
  13 -5.967 -5.967 -44.001
  14 -5.939 -5.939 -43.127
  15 -5.333 -5.333 -24.614
  16  6.000 -6.000 -45.500
  17  6.000 -6.000 -45.000
  18  5.967 -5.967 -44.001
  19  5.939 -5.939 -43.127
  20  5.333 -5.333 -24.614
  21  4.820  4.820  -8.922
  22  4.385  4.385   4.378
  23  4.016  4.016  15.651
  24  4.000  4.000  16.150
  25 -4.820  4.820  -8.922
  26 -4.385  4.385   4.378
  27 -4.016  4.016  15.651
  28 -4.000  4.000  16.150
  29 -4.820 -4.820  -8.922
  30 -4.385 -4.385   4.378
  31 -4.016 -4.016  15.651
  32 -4.000 -4.000  16.150
  33  4.820 -4.820  -8.922
  34  4.385 -4.385   4.378
  35  4.016 -4.016  15.651
  36  4.000 -4.000  16.150
  41  5.620  0.000 -33.373
  42 -5.620  0.000 -33.373
  43  0.000  5.620 -33.373
```

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  44  0.000 -5.620 -33.373
  45  5.064  0.000 -16.371
  46 -5.064  0.000 -16.371
  47  0.000  5.064 -16.371
  48  0.000 -5.064 -16.371
  49  4.592  0.000  -1.958
  50 -4.592  0.000  -1.958
  51  0.000  4.592  -1.958
  52  0.000 -4.592  -1.958
  53  4.193  0.000  10.262
  54 -4.193  0.000  10.262
  55  0.000  4.193  10.262
  56  0.000 -4.193  10.262
  57  4.000  4.000  20.150
  58 -4.000  4.000  20.150
  59  4.000 -4.000  20.150
  60 -4.000 -4.000  20.150


member properties

property_Set D_out [m] thick [m]
1             0.80000     0.20000E-01
2             1.2000      0.50000E-01
3             1.2000      0.35000E-01
4             1.2000      0.40000E-01

members

member_no      node_1 node_2  Property_Set
       1          1     2       2
       2          2     3       2
       3          3     4       2
       4          4     5       2
       5          6     7       2
       6          7     8       2
       7          8     9       2
       8          9    10       2
       9         11    12       2
      10         12    13       2
      11         13    14       2
      12         14    15       2
      13         16    17       2
      14         17    18       2
      15         18    19       2
      16         19    20       2
      17          5    21       3
      18         21    22       3
      19         22    23       3
      20         23    24       3
      21         10    25       3
```

```
22         25    26       3
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24         27    28       3
25         15    29       3
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29         20    33       3
30         33    34       3
31         34    35       3
32         35    36       3
37          3     8       1
38          8    13       1
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40         18     3       1
41          4    41       1
42         41    20       1
43         19    41       1
44         41     5       1
45          9    42       1
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47         14    42       1
48         42    10       1
49          4    43       1
50         43    10       1
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72         48    33       1
73         21    49       1
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75         33    49       1
76         49    22       1
```

```
  77          25    50        1
  78          50    30        1
  79          29    50        1
  80          50    26        1
  81          21    51        1
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  84          51    22        1
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  86          52    30        1
  87          29    52        1
  88          52    34        1
  89          22    53        1
  90          53    35        1
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  92          53    23        1
  93          26    54        1
  94          54    31        1
  95          30    54        1
  96          54    27        1
  97          22    55        1
  98          55    27        1
  99          26    55        1
 100          55    23        1
 101          34    56        1
 102          56    31        1
 103          30    56        1
 104          56    35        1
 105          24    57        4
 106          28    58        4
 107          32    60        4
 108          36    59        4
```

Vedlegg 8 – ”Marine technology/Environmental Loads, Wind Load on Strutures, Part 1, Jasna Jakobsen

Marine technology/Environmental Loads

Part 1

WIND LOAD ON STRUCTURES

Jasna B. Jakobsen

Content:

1. Mean and fluctuating wind velocity and their statistical properties.
2. Mean wind load. Force coefficients.
3. Wind load due to turbulence.
4. Vortex-induced wind forces and response.
5. Wind loads on wind turbines.

Literature:

Books:

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4. *Wind Engineering, Lecture Notes 1 & 2,* Erik Hjorth-Hansen, NTNU, 1988&1989.

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.

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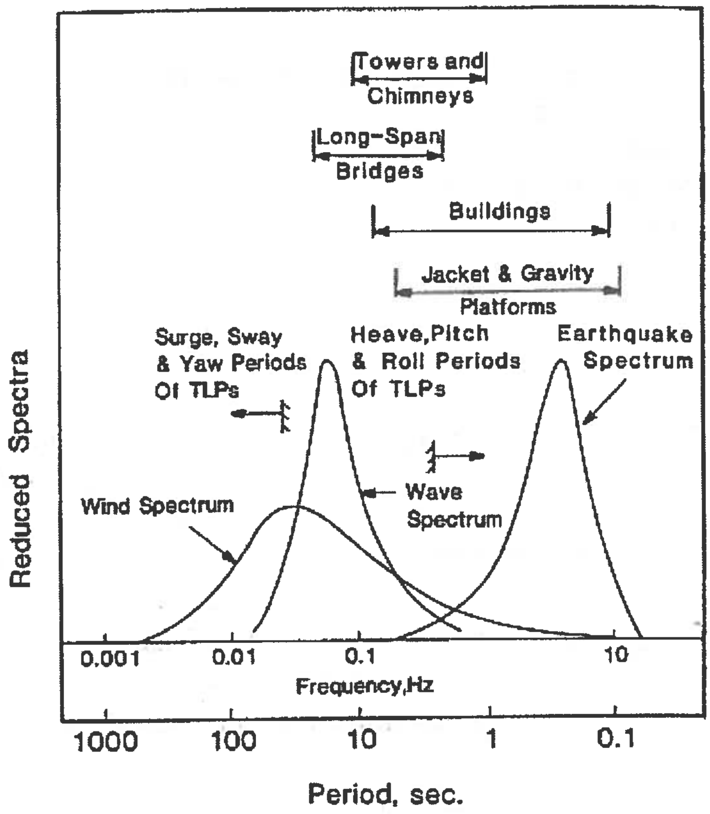
P1. Wind loads on offshore structures, Kareem, A., in Wind Effects on Buildings and Structures, Riera & Davenport (eds.). Balkema, 1998.

Tutorial work

There will be one tutorial based on the recorded wind velocity data.

1. Introduction.

Motivation for studying wind and wind effects on structures:



Example:
Eigen-periods for Hywind wind turbine
Tower pitch ~ 25 sec
Tower surge ~ 120 sec

Spectral descriptions of wind, waves and earthquakes, from [P1]

Many flexible structures (offshore structures, long span bridges, towers, tall buildings etc.) have their natural frequencies in the range where there is considerable "energy" in wind.

The power spectral density shown in the figure above (PSD) of e.g. wind velocity *u* (so-called along-wind turbulence component), $S_u(f)$, is proportional to the square amplitude of a harmonic component in the Fourier series representation of fluctuating wind speed *u(t):*

$u(t) = \sum_i U_i \cos(2\pi f_i t + \phi_i)$ and

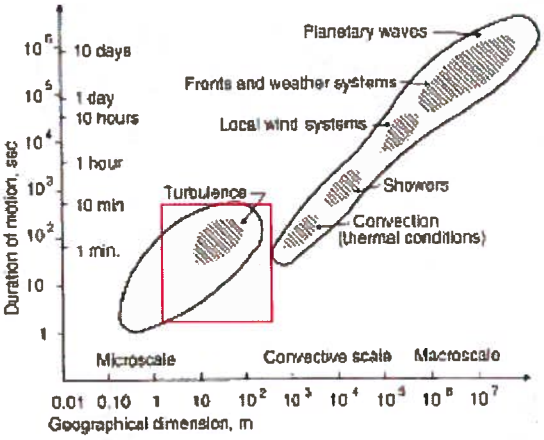
$S_u(f_i)\Delta f = \frac{U_i^2}{2}$, where Δf is a small interval along the frequency axis, f_i is a discrete frequency and ϕ_i the associated phase. The left hand side of the equation is the area of a thin rectangular under the spectral curve.

"Reduced spectra", in the above figure, is given as a product between frequency f and PSD S(f), in order to ease the comparison between different spectra.

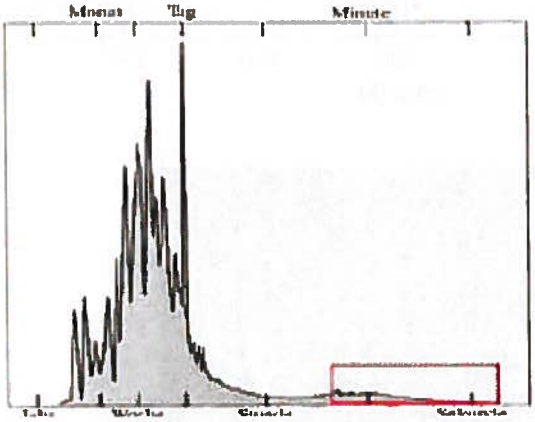
Wind climate:

- Microscale: turbulence - vortices of air in range of few meters and lifetime of some minutes.
- Convection: local weather systems.
- Macroscale: planetary waves, lifetime of several days.

The different time- and space-scales are illustrated in the figures below:



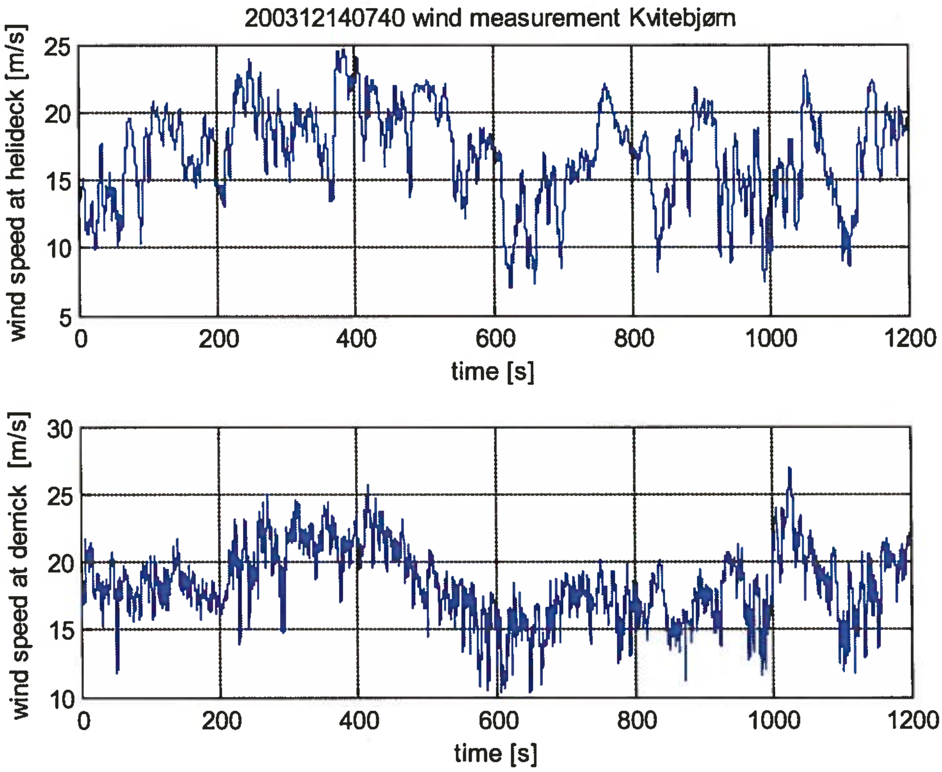
Time- and space scales for different air motions in the atmosphere, from [1]



From: M. Courtney, I. Troen: Wind spectrum for one year of continous 8 Hz measurements. pp 301-304, 9th symposium on Turbulence and diffusion, Denmark 1990.

The figure above shows the distribution of the energy in the natural wind over different time-scales. Most part of the energy is concentrated at longer scales/ large systems. This part of the spectrum is relevant for the energy potential of wind turbines. In short term, small scale turbulence (red rectangle) is important for establishing the short term peak loads for structural design as well as possible turbulence-induced dynamic response of a structure.

An example of a 20 minutes long record of wind speed from Kvitebjørn platform is given in the figure below. The data are recorded at helideck (52.m above sea) and at derrick (110 m above sea). The records illustrate well the short term variation in wind speed, i.e. turbulence. In this particular case, turbulence is somewhat higher than in natural wind, because the wind direction (more or less from the West) was such that the measurements were affected by the presence of the platform itself.



Kvitebjørn platform, water depth 190 m,
from http://www.oilrig-photos.com/picture/number165.asp

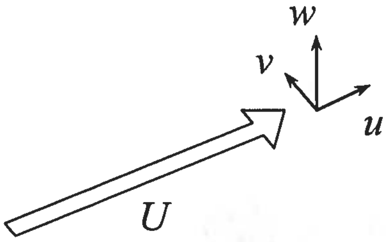
STATISTICAL DESCRIPTION OF WIND

Wind flow is *turbulent* as a result of the (shear) flow passage over a rough surface. Another cause of turbulence may be buoyancy (air "boiling" over a heated ground surface).

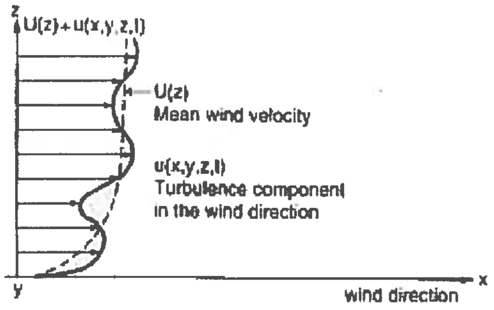
Turbulent flow is a *3-dimensional flow*. It varies in a complex, random way both in space and time. Therefore it must be described in statistical terms.

In short term, usually over 10 minutes period (or up to 1 hour), the instantaneous velocity is described as a sum of mean velocity and a fluctuating (turbulent) component. In the Cartesian coordinate system, with x-axis along the direction of the mean wind, the wind velocity components are:

In the direction along the wind:	$U(z)+u(x,y,z,t)$
In the direction across the wind, sideways :	$v(x,y,z,t)$
In the direction across the wind, "vertically":	$w(x,y,z,t)$.

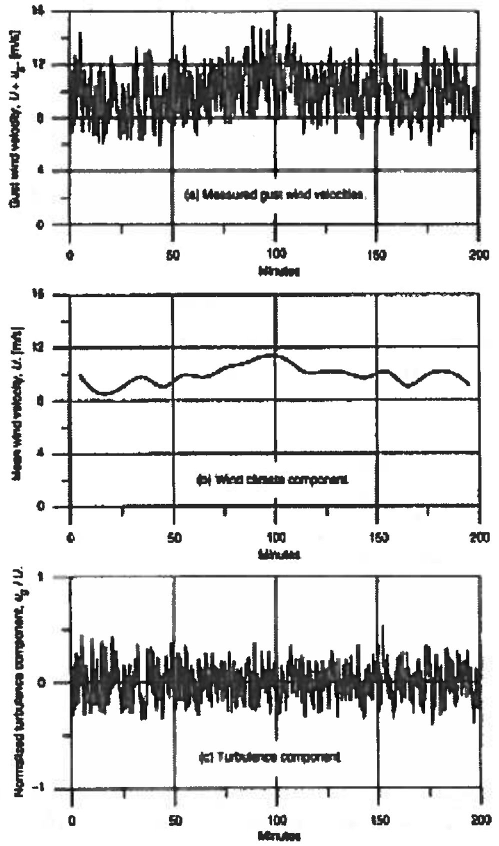


The mean(expected) wind velocity is considered to be equal to its time average, i.e. the wind velocity is treated as an ergodic process. In short terms, $U(z)$ varies only with height above the ground z, while the fluctuating components are assumed to be stationary, stochastic functions of position and time, with a zero mean value. The figure bellow shows the separation of the total along wind velocity into a mean and fluctuating, turbulent part.



Instantaneous wind velocity along the mean wind direction: Dashed line: mean wind profile, constant over e.g. 10 minutes, Solid line: instantaneous wind velocity (changing with time t).
from [1]

The following figure illustrates the decomposition of the total along wind velocity at one measurement station (averaged at 10s) into the mean and fluctuating part. It shows that, over the observation period of 200 minutes and in long term in general, the mean wind speed is also a random process.



from [1]

The gust wind velocity $U + u_g$ is separated into a wind climate component U and a turbulence component u_g. The wind climate component U is the 10 minute mean wind velocity and the turbulence component u_g is here calculated using an average time of 10 s, i.e. $u_g = u_m(T = 10\ s, t_1) - u_m(T = 600\ s, t_1)$ in equation (2.1.1). The measurements shown are the Lammefjord data also used in Figure 2.2. The wind velocities used in this figure were supplied by Risø National Laboratory, Denmark.

2. 1 Mean wind profile

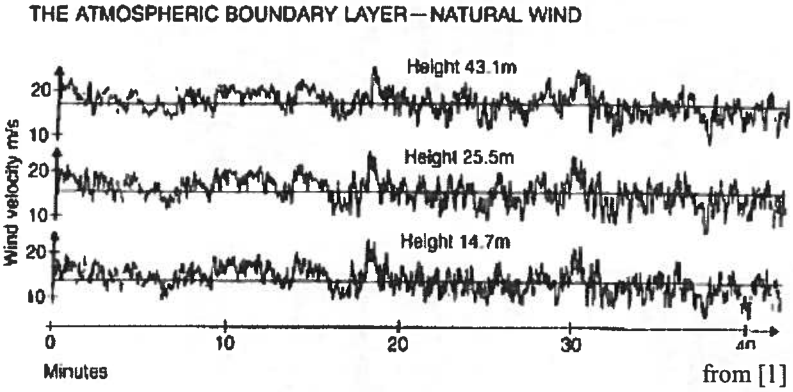
2.1.1 Logarithmic profile

For design purposes, mean wind speed on a structure at a certain location is given as *reference wind speed* in the area, adjusted for the possible effects of:

- Wind direction
- Seasonal variation
- Annual probability of being exceeded
- Height above the sea level
- Height above the ground
- Terrain roughness
- Local topographical effects.

In NS-EN 1991-1-4, *reference wind speed* is defined as the 10 minutes mean wind speed at the 10 m above the ground (at sea level) of the terrain of roughness category II (i.e. roughness length z_0=0.05m), with the annual probability of being exceeded of p=0.02, see next figure:

The variation of mean wind speed with height z can be observed in the figure bellow:



from [1]

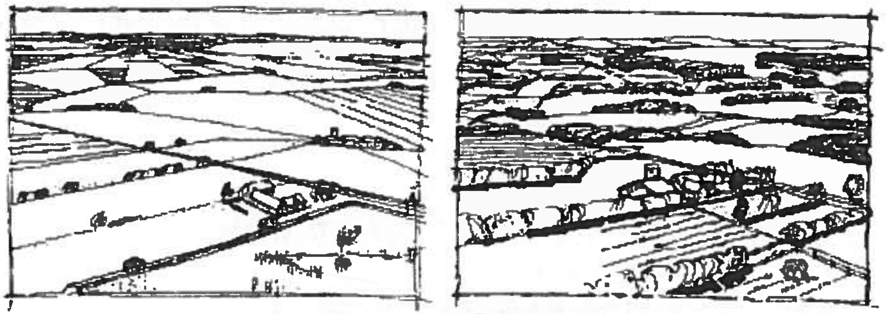
Wind velocities measured at Stigsnæs, Denmark, at three different heights (afte Sigbjörnsson (1974)). The differences of mean wind velocities should be noticec (Reproduced by permission of R. Sigbjörnsson). from [1]

[5] gives a location dependent wind speed as a product of the reference wind speed defined above, a terrain shape factor $c_0(z)$ (typically set equal to 1) and a roughness factor $c_r(z)$. The factor gives the variation of the wind "profile" with height z is given ([4a]) by a logarithmic function, governed by the terrain roughness through a factor k_T and a roughness length z_0:

$$c_r(z) = \begin{cases} k_r \ln(z/z_0) & z_{\min} \le z \le 200m \\ c_r(z_{\min}) & z < z_{\min} \end{cases}$$

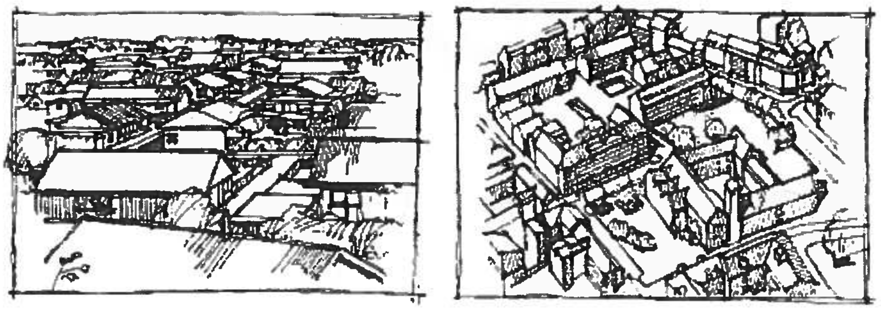
The parameters in the equation are given in the table:

Terrain category	k_r	z_0 [m]	z_{min} [m] EN 1991-4	z_{min} [m] Nat Annex
0) Sea or costal area exposed to the open sea	0.155	0.003	1	2
I) Rough open sea, lakes with at least 5 km fetch upwind and smooth flat country without obstacles	0.17	0.01	1	2
II) Farmland with boundary hedges, occasional small farm structures, houses and trees	0.19	0.05	2	4
III) Suburban or industrial areas and permanent forests	0.22	0.3	5	8
IV) Urban areas in wich at least 15% of the surface is covered with buildings and their average height exceeds 15 m	0.24	1	10	16



a) Terrengkategori I

b) Terrengkategori II



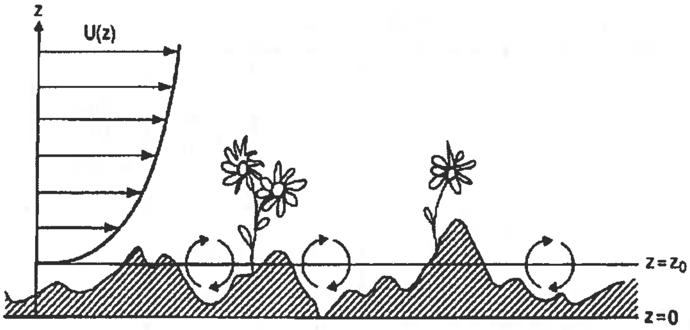
c) Terrengkategori III

d) Terrengkategori IV

Figur 1 – Eksempel på terrengkategoriene I - IV

The different type of terrains can be seen in the figure above.

The z_0 parameter above represents an average roughness size:



Surface roughness z_0, from [1].

The logarithmic function for the mean wind profile stems from the boundary layer theory. If velocity and pressure decomposition into a mean and a time-varying part is applied in the Navier-Stokes equation and the expected value found, the so-called *Reynolds momentum equation* emerges:

$$\frac{\partial \overline{U}_i}{\partial t} + \overline{U}_k \frac{\partial \overline{U}_i}{\partial x_k} = -\frac{1}{\rho}\frac{\partial \overline{p}}{\partial x_i} - \frac{\partial E[u_i u_k]}{\partial x_k}$$

The contribution of the turbulent motion to the mean stress tensor is:

$$\tau_{ij} = -\rho E[u_i u_j]$$

where τ_{ij} is the so-called the Reynolds stress tensor.
The off-diagonal elements are shear stresses which play a dominant role in momentum transfer by turbulent motion.

The **shear velocity, u_*,** is often used as a characteristic variable for turbulent flow. It is based on the Reynolds shear stress and defined as:

$$u_* = \sqrt{\frac{\tau_{xz}}{\rho}}$$

The shear frictional velocity can also be related to the local mean wind speed through the dimensionless surface drag coefficient, *k*.

In strong winds, the assumptions for derivation of the logarithmic profile are:

- Sufficient mixing of air
- Thermally neutral conditions
- Effects of roughness are predominant
- Shear force (Reynolds stress) increases from zero at the gradient height to a maximum at the zero-displacement height

This leads to the following:

$$\frac{d\overline{U}}{dz} \text{ is a function of } (z, \rho_a \tau_0)$$

$$\frac{d\overline{U}}{dz} = \text{constant} \cdot \frac{u_*}{z}$$

τ_0 - surface shear stress
ρ_a - air density
u_* = friction velocity = $\sqrt{(\tau_0/\rho_a)}$
z_0- roughness length

Integrating with respect to z gives:

$$\overline{U} = (1/k) \cdot u_* \ln(z) + \text{constant}$$

or $$\overline{U}(z) = \frac{u_*}{k} \ln(z/z_0)$$

k is von Karman's constant, 0.4 for all surfaces

The expression can be re-written as $U_{ref} \ln(z/z_0)$, for example:

$$\overline{U}(z) = U_{bas} k_r \ln(z/z_0)$$

U_{bas} = reference wind speed , in EN 1991-1-4:2005 defined as the 10 minutes mean wind speed at the 10 m above the ground (at sea level) of the terrain of roughness category II (i.e. roughness length z_0=0.05m), with the annual probability of being exceeded of p=0.02,
k_r = terrain roughness coefficient.

Product $k_r \ln(z/z_0)$ is the terrain roughness factor.

The parameters in the equations above can also be related to the so-called surface drag coefficient κ, i.e. a non-dimensional shear stress:

$$\kappa = \frac{\tau_{xy}}{\rho \overline{U}_{10}^2} = \frac{u_*^2}{\overline{U}_{10}^2}$$

Bu expressing the mean wind speed at 10 m height from the logarithmic law, we obtain a connection between the surface drag coefficient κ and the roughness length z_0:

$$\kappa = \left[\frac{k}{\log_e \left(\frac{10}{z_o} \right)} \right]^2$$

Where is von Karman's constant, 0.4 for all surfaces.

2.1.2 Power law profile

Alternatively the empirically established "power law" is used for describing the mean wind profile:

$$\overline{U}(z) = \overline{U}_{ref} \left(\frac{z}{z_{ref}} \right)^{\alpha} = \overline{U}_{10} \left(\frac{z}{10} \right)^{\alpha}$$

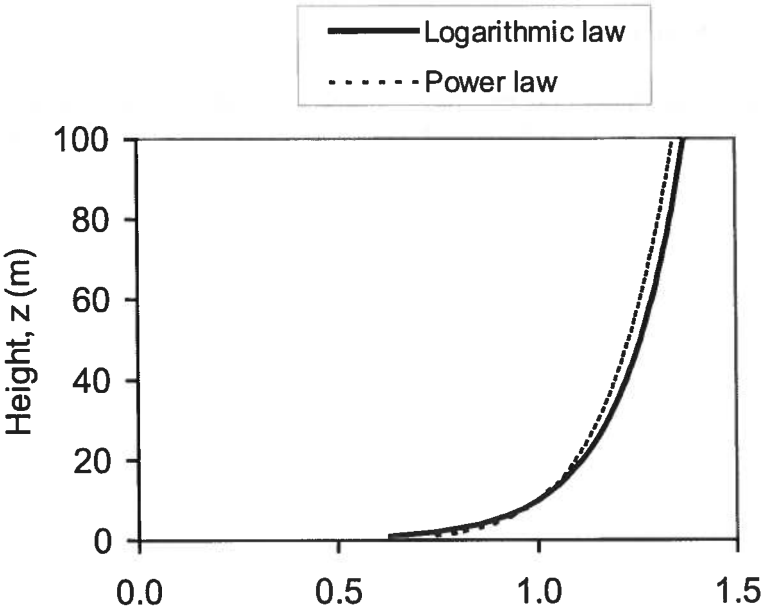
where the power coefficient α changes with terrain roughness and height range:

$$\alpha \cong \left(\frac{1}{\log_e (z_{ref} / z_0)} \right)$$

$z_{ref} =$ reference height, for instance 10 m.

An example of the comparison between the logarithmic and the exponential mean wind profiles is shown below for $z_o = 0.02$ m $\alpha = 0.128$ $z_{ref} = 50$ metres.

:



In structural engineering one will design for the extreme mean wind speed and the extreme peak / gust wind speed (see the next lecture) at the specific location of the structure.

On the other hand the wind turbines are produced in series and are documented to withstand different reference (i.e. extreme) wind speeds according to the classification. In EN 61400-1:2009 [8] and EN 61400-3:2009 [9], wind turbines are divided into four different classes depending on the conditions they are designed to operate in:

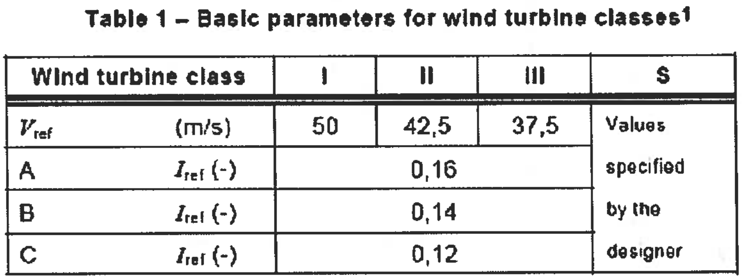


Table 1 – Basic parameters for wind turbine classes[1]

Wind turbine class		I	II	III	S
V_{ref}	(m/s)	50	42,5	37,5	Values specified by the designer
A	I_{ref} (-)	0,16			
B	I_{ref} (-)	0,14			
C	I_{ref} (-)	0,12			

The reference wind speed is 10 minutes mean value at the hub height, with the annual probability of exceedence of 0.02, and turbulence intensities are given in the figure below. Iref values are turbulence intensities, see next lecture

Variation in mean speed with height is covered by a power law:

$$U(z) = U_{hub}\left(\frac{z}{z_{hub}}\right)^{\alpha},$$

For "normal wind conditions" α is set to α=0.2, and α=0.11 for extreme wind condition.

For offshore wind turbines, the wind profile is defined with a power coefficient α=0.14, which better represents the wind conditions over the sea surface.

2.1.3 Wind characteristics over ocean

Over the ocean, the surface drag coefficient (κ) and the roughness length (z_o) increase with mean wind speed as the wave height varies with wind speed. Charnok (1955) relation gives:

$$z_o = \frac{a u_*^2}{g} = \frac{a \kappa \overline{U}_{10}^{\,2}}{g}$$

Where g is gravitational constant (9.81 m/s^2) and a empirical constant, between 0.01 and 0.02

Substituting:

$$\kappa = \left[\frac{k}{\log_e\left(\frac{10}{z_o}\right)} \right]^2$$

we obtain an implicit relationship between the roughness length and the mean wind speed. Assuming a = 0.0144 (Garratt) ; k =0.41, we obtain following connection between the wind speed and the surface roughness:

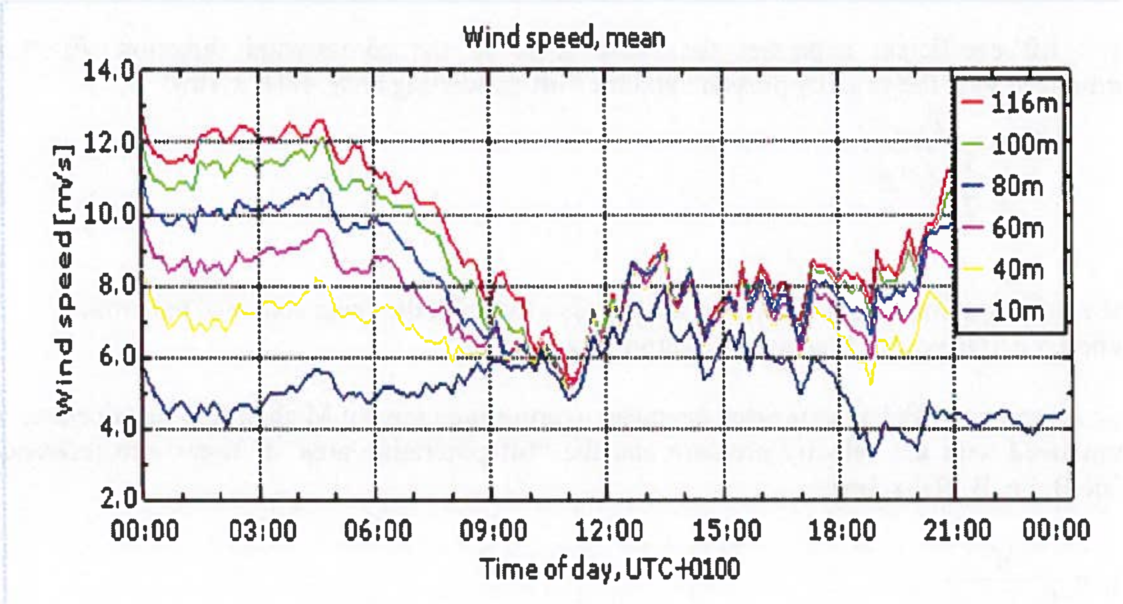
$\overline{U}_{10}$ (m/s)	**Roughness Length (mm)**
10	0.21
15	0.59
20	1.22
25	2.17
30	3.51

NORSOK N-003 defines the so-called characteristic wind velocity as mean wind velocity at a certain height with design wind velocity with the annual probability of exceedence of 0.01. The wind profile refers to a 1 hour mean wind speed at 10 m height, and a direct calculation of the characteristic wind speeds for other heights and durations is provided, see Eq. (6) to (8) in the document ([6]) on It's learning. The mean wind speed for other time-windows than 1 hour depends on the turbulence intensity. The variation of mean wind speed with height follows a logarithmic law.

2.1.4 Effect of atmospheric stability on mean wind profile

The mean wind profile described above assumes a so-called neutral atmosphere. Different pressure and temperature gradients with height can cause different stability conditions. An example of such an effect on the wind profile is shown in the figure below:

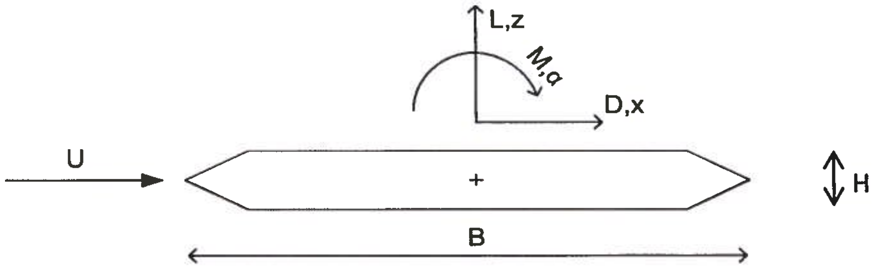
Met-mast measurements, Høvsøre



from http://veaonline.risoe.dk

2. 2 Mean force coefficients and mean wind loads

Experimentally obtained (mean) wind forces on different objects/cross sections are commonly expressed in terms of non-dimensional force coefficients, which depend on the shape of the cross-section and in some cases also on Reynolds number.



Men wind forces: Sketch by Ove Mikkelsen, UiS

C_D : drag coefficient expresses the static force in the along-wind direction, $F_D \equiv D$ normalized with the velocity pressure and the cross-sectional height H, i.e. the wind exposed area Hx1m:

$$C_D = \frac{F_D}{\frac{1}{2}\rho U^2 H} \qquad \text{Alternatively:} \quad C_D = \frac{F_D}{\frac{1}{2}\rho U^2 B}.$$

Similarly,

C_L : lift coefficient expresses the mean force in the across-wind direction, $F_L \equiv L$ normalized with the velocity pressure and the "lift-generating area" B (B x 1m).

$$C_L = \frac{F_L}{\frac{1}{2}\rho U^2 B}.$$

The resulting aerodynamic load does not necessarily act at the shear center of the cross-section, i.e. it may also generate an overturning moment.

C_M : moment coefficient expresses the mean overturning moment M about the shear centre, L normalized with the velocity pressure and the "lift-generating area" B times arm reference value B, i.e. B^2 (B^2 x 1m).

$$C_M = \frac{M}{\frac{1}{2}\rho U^2 B^2}.$$

Force coefficients are typically obtained either by direct force measurements are by integrating the surface pressures, i.e. surface pressure coefficients C_p, where

$C_p = \frac{p - p_o}{\frac{1}{2}\rho U^2}$, are local pressure referenced to the static pressure and normalized by the velocity pressure.

Example: Mean force coefficients of the Hardanger suspension bridge box-girder

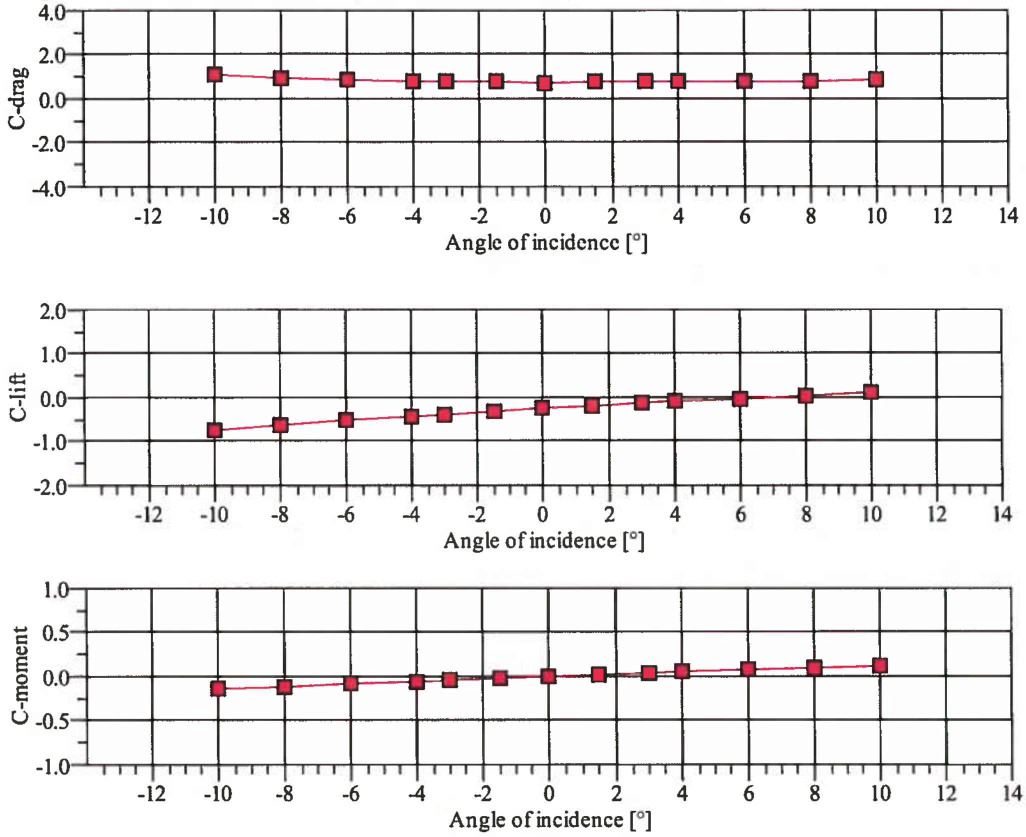
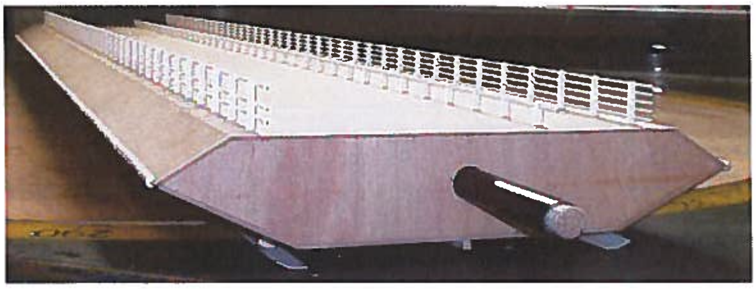


Figure A.3. Cycle path downstream, optimal vortex mitigation devices included.



From: **The Hardanger bridge: Static and dynamic wind tunnel tests with a section model,** Hansen S.O., Lolesgaard M., Rex, S., Jakobsen, J.B . and Hjorth-Hansen., E., Svend Ole Hansen ApS, 2006 and rev. 2009.

Suspension bridge with the main span 1310 m

Mean drag force (per unit length) on the bridge girder at 0° of attack:

Mean wind speed: ref NS-EN 1991-1-4:

U_b=26 m/s. (10 min average, p=0.02 at z=10m, terrain cat. II, i.e. z_0=0.05m). Other factors set equal to 1.

For wind acting normal to the bridge terrain, cat. I is assumed → : k_r=0.17, z_0=0.01m.

Mean wind speed at the bridge girder elevation z=62 m:

$$U(z) = U_b k_r \ln(\frac{z}{z_0}) = 26\frac{m}{s}\ln(\frac{62.0m}{0.01m}) = 38.6\frac{m}{s}$$

Mean drag force (per unit length) on the bridge girder at 0° of attack:
Bridge girder height H=3.3m and drag coefficient app. 0.8.

$$F_D = \frac{1}{2}\rho U^2 C_D H = \frac{1}{2}1.25\frac{kg}{m^3}38.6^2\frac{m^2}{s^2}0.8\cdot 3.3m \approx 2.5\frac{kN}{m}$$

Vedlegg 9 – Egenfrekvensanalyse/strukturfrekvensanalyse av alternativt design; Sesam GeniE

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Software



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Computer         : 586
               Release date : 20-NOV-2008
Impl. update     :
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Operating system : Win NT 5.2 [3790]
               User id      : ofsbilil
CPU id           : 1975103069

Installation     : , NOS295


               Copyright DET NORSKE VERITAS AS, P.O.Box 300, N-1322 Hovik,
Norway


               Library     Version    Impl.Upd   Release date
               ELLIB       1.9-07                20-NOV-2008
               SIFTOOL     8.3-05                20-NOV-2008
               NORSAM      8.4-01                20-NOV-2008
               MFR         8.3-05                20-NOV-2008
               PRIMAS      5.3-04                20-NOV-2008
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 DATE: 01-JUN-2012 TIME: 10:40:39   ***************  SESTRA  ***************
                                        PAGE:     1

                                    DATA GENERATION MODULE

                                    SUB PAGE:     1

  PRINTOUT OF DATA GIVEN AS DIRECT INPUT TO SESTRA



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   COMM    Date : 01-Jun-2012   Time : 09:40:14   User : ofsbilil

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0.00E+00
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0.00E+00
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   COMM  ITYP

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0.00E+00
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   COMM  PREFIX FORMAT

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 DATE: 01-JUN-2012 TIME: 10:40:45   ***************  SESTRA  ***************
                                        PAGE:     2


                                    DATA GENERATION MODULE
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  INTERPRETATION OF ANALYSIS CONTROL DATA




      Type of Analysis :

         Eigenvalue Solution by Lanczos Method

         Retracking


      Input from CMAS Command :

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         The singularity constant for membrane and shell elements

         CSING =  1.0000E-08

         Lowest accepted condition number in reduction

         EPSSOL=  1.1102E-14


      Input from EIGL Command :

         Specification of eigenvalues to be calculated:

            ENR   =    10  eigenvalues are demanded.

            MAXO    50     Maximum number of iterations.

            NBLO     2     Block size.

            NFIG     5     No. of digits of accuracy.

         IU    =     0  The stiffness matrix is triangularised.

            PRIN     0     Print of eigenvalues.


      Input from RSEL Command :

         Data types selected for storing on Results File :

          - Input Interface File Records,

          - mode shapes,  sequence:

               all nodes for the first resultcase, all nodes for the second
resultcase, etc.

         (Can be redefined by RSEL for selected superelements, see below.)
```

```
        Storing is done for superelements specified in RETR command.

 DATE: 01-JUN-2012 TIME: 10:40:50   ***************  SESTRA  ***************
                                        PAGE:     3

                                    DATA GENERATION MODULE

                                    SUB PAGE:     3

  INPUT INTERFACE FILES :



     20120601_093927_T1.FEM

         DATE:     01-Jun-2012         TIME:          09:39:29
         PROGRAM:  SESAM GeniE         VERSION:       V5.3-10 14-Apr-2011
         COMPUTER: X86 Windows         INSTALLATION:
         USER:     ofsbilil            ACCOUNT:

         DATE:     01-Jun-2012         TIME:          09:39:29
         PROGRAM:  SESAM Gamesha       VERSION:       R5.0-3 14-Apr-2011
         COMPUTER: X86 Windows         INSTALLATION:
         USER:     ofsbilil            ACCOUNT:

 DATE: 01-JUN-2012 TIME: 10:40:54   ***************  SESTRA  ***************
                                        PAGE:     4

                                    DATAGENERATION - SUPERELEMENT TYPE     1

                                    SUB PAGE:     4




  INTERPRETATION OF ANALYSIS CONTROL DATA

          FOR SUPERELEMENT TYPE     1  ON LEVEL  1


      Input from DYMA Command :


         IMAS  =     1  Consistent mass matrices from the subelements are
demanded.



      *** SUMMARY OF DATA FROM INPUT AND LOAD INTERFACE FILES ***

               FOR SUPERELEMENT TYPE       1  ON LEVEL  1
```

```
     The superelement has


            51  subelements
            34  nodes
            18  specified (fixed) degrees of freedom
           186  internal (free) degrees of freedom
          totally
           204  degrees of freedom

            11  loadcases




     The following kinds of loads are given:
            node loads
            gravitational load


     The following basic elements are given:
            51  2 node beam elements         BEAS


 DATE: 01-JUN-2012 TIME: 10:41:03   ***************  SESTRA  ***************
                                            PAGE:     5

                                        DATAGENERATION - SUPERELEMENT TYPE     1

                                        SUB PAGE:     5

     *** SUM OF LOADS AND MOMENTS FOR SUPERELEMENT TYPE     1  ON LEVEL  1  ***


    X-LOAD = SUM OF GIVEN LOADS IN GLOBAL X-DIRECTION
    Y-LOAD = SUM OF GIVEN LOADS IN GLOBAL Y-DIRECTION
    Z-LOAD = SUM OF GIVEN LOADS IN GLOBAL Z-DIRECTION
    X-MOM  = SUM OF LOCAL MOMENTS ABOUT GLOBAL X-AXIS
    Y-MOM  = SUM OF LOCAL MOMENTS ABOUT GLOBAL Y-AXIS
    Z-MOM  = SUM OF LOCAL MOMENTS ABOUT GLOBAL Z-AXIS
    X-RMOM = SUM OF MOMENTS ABOUT GLOBAL X-AXIS FROM GIVEN LOADS AND MOMENTS
```

```
     Y-RMOM = SUM OF MOMENTS ABOUT GLOBAL Y-AXIS FROM GIVEN LOADS AND MOMENTS

     Z-RMOM = SUM OF MOMENTS ABOUT GLOBAL Z-AXIS FROM GIVEN LOADS AND MOMENTS



      LOADCASE    X-LOAD       Y-LOAD       Z-LOAD       X-MOM        Y-MOM
Z-MOM       X-RMOM       Y-RMOM       Z-RMOM
           1  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
           2  0.0000E+00  4.4383E-10 -2.2931E+07  0.0000E+00  0.0000E+00
0.0000E+00  1.9440E+07  5.3362E-04  0.0000E+00
           3  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
           4  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
           5  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
           6  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
           7  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
           8  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
           9  0.0000E+00  0.0000E+00 -3.4335E+06  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
          10  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00 -9.5400E+05
0.0000E+00  0.0000E+00 -9.5400E+05  0.0000E+00
          11  0.0000E+00 -1.4500E+05  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  1.9307E+07  0.0000E+00  0.0000E+00

 DATE: 01-JUN-2012 TIME: 10:41:05    ***************  SESTRA  ***************
                                         PAGE:     6

                                     DATAGENERATION - SUPERELEMENT TYPE     1

                                     SUB PAGE:     6

      *** SUM OF MASSES AND CENTROID FOR SUPERELEMENT TYPE     1  ON LEVEL  1
***



   MASS MATRIX IN GLOBAL COORDINATE SYSTEM (OF THE SUPERELEMENT):

   ---------------------------------------

   2.33826E+06    7.95808E-13    0.00000E+00    1.03398E-25    8.12642E+07
1.98237E+06
   7.95808E-13    2.33826E+06   -5.28644E-11   -8.12642E+07    0.00000E+00
5.44135E-05
   0.00000E+00   -5.28644E-11    2.33826E+06   -1.98237E+06   -5.44135E-05
0.00000E+00
   1.03398E-25   -8.12642E+07   -1.98237E+06    4.68283E+09   -3.77082E-04
1.02445E-08
   8.12642E+07    0.00000E+00   -5.44135E-05   -3.77082E-04    4.68092E+09
3.90656E+07
   1.98237E+06    5.44135E-05    0.00000E+00    1.02445E-08    3.90656E+07
2.49524E+08



   COORDINATES OF CENTROID:
```

```
   ------------------------

   2.3271E-11    -8.4780E-01     3.4754E+01



   MASS MATRIX AT CENTROID:

   ------------------------

   2.33826E+06    7.95808E-13    0.00000E+00    2.76576E-11    0.00000E+00
2.32831E-10
   7.95808E-13    2.33826E+06   -5.28644E-11    0.00000E+00   -2.76576E-11
2.87665E-11
   0.00000E+00   -5.28644E-11    2.33826E+06    0.00000E+00    2.87665E-11
1.23020E-21
   2.76576E-11    0.00000E+00    0.00000E+00    1.85689E+09   -4.23215E-04
1.89110E-03
   0.00000E+00   -2.76576E-11    2.87665E-11   -4.23215E-04    1.85666E+09
-2.98298E+07
   2.32831E-10    2.87665E-11    1.23020E-21    1.89110E-03   -2.98298E+07
2.47843E+08

  *** Estimated size of stiffness matrix for superelement       1:       20628
variables


  *** Estimate of total size of stiffness matrices for new superelements:
  20628 variables

 DATE: 01-JUN-2012 TIME: 10:41:10   ***************  SESTRA  ***************
                                        PAGE:     7

                                    REDUCTION MODULE - SUPERELEMENT TYPE    1

                                    SUB PAGE:     1






                                     - STIFFNESS MATRICES ALLOCATED
 -

                                     - CONSISTENT MASS MATRICES ALLOCATED
 -

                                     - LOAD MATRICES ALLOCATED
 -

                                     - STIFFNESS MERGE PERFORMED
 -

                                     - MASS MERGE PERFORMED
 -

                                     - LOAD MERGE PERFORMED
 -

 DATE: 01-JUN-2012 TIME: 10:41:15   ***************  SESTRA  ***************
```

```
                                        PAGE:     8

                                         DYNAMIC ANALYSIS OF STRUCTURE

                                    SUB PAGE:     1









                               - EIGENVALUEPROBLEM SOLVED BY LANCZOS METHOD

 DATE: 01-JUN-2012 TIME: 10:41:18   ***************  SESTRA  ***************
                                        PAGE:     9

                                         DYNAMIC ANALYSIS OF STRUCTURE

                                    SUB PAGE:     2

                                                  ***************************

                                                  *                         *

                                                  *  E I G E N V A L U E S  *

                                                  *                         *

                                                  *  F R E Q U E N C I E S  *

                                                  *                         *

                                                  ***************************



                                                  ALL EIGENVALUES BEING CAL-

                                                  CULATED ARE PRINTED TOGE-

                                                  THER WITH THE CORRESPONDING

                                                  FREQUENCIES AND PERIODS.

                                                  FREQ = SQRT(EIGENV)/(2.*PI)

                                                  PERI = 1./FREQ
```

```
+-------------------+---------------------------------------+-------------------
---------+----------------------------+
  I                 I                                       I
         I                            I
  I       NO.       I      EIGENVALUE  UNIT: (SEC)-2        I   FREQUENCY
UNIT: HERTZ   I     PERIOD  UNIT: SEC      I
  I                 I                                       I
         I                            I

+-------------------+---------------------------------------+-------------------
---------+----------------------------+
  I                 I                                       I
         I                            I
  I       1         I          0.5515313E+02                I             1.182
         I          0.84605           I
  I       2         I          0.5587415E+02                I             1.190
         I          0.84057           I
  I       3         I          0.1609835E+03                I             2.019
         I          0.49521           I
  I       4         I          0.1638656E+03                I             2.037
         I          0.49084           I
  I       5         I          0.3654462E+03                I             3.043
         I          0.32868           I
  I       6         I          0.1276392E+04                I             5.686
         I          0.17587           I
  I       7         I          0.1291590E+04                I             5.720
         I          0.17483           I
  I       8         I          0.2370789E+04                I             7.749
         I          0.12904           I
  I       9         I          0.2533360E+04                I             8.011
         I          0.12483           I
  I      10         I          0.2624070E+04                I             8.153
         I          0.12266           I
  I                 I                                       I
         I                            I

+-------------------+---------------------------------------+-------------------
---------+----------------------------+

 DATE: 01-JUN-2012 TIME: 10:41:23   ***************  SESTRA  ***************
                                        PAGE:    10

                                         DYNAMIC ANALYSIS OF STRUCTURE

                                    SUB PAGE:     3


      Results file name: 20120601_093927_R1.SIN


      Load sum is missing



 SUPERELEMENT TYPE:     1 ACTUAL ELEMENT:     1

 HAS BEEN STORED ON RESULT FILE


  TOTAL TIME CONSUMED IN SESTRA                   CPU TIME:      3.22  CLOCK
TIME:     74.67  CHANNEL TIME:      0.92
```

Vedlegg 10 – Analyse 1, lineær strukturanalyse og hydrodynamisk analyse, alternativt design, fra Sesam GeniE

```
1



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                               **               Superelement Structural Analysis
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                                              Marketing and Support by DNV
```

```
Software



                Program id   : 8.4-01
Computer          : 586
                Release date : 20-NOV-2008
Impl. update      :
                Access time  : 04-JUN-2012 15:08:21
Operating system : Win NT 5.1 [2600]
                User id      : ofsbilil
CPU id            : 1016725624

Installation      : , NOWFKYLW4J


                Copyright DET NORSKE VERITAS AS, P.O.Box 300, N-1322 Hovik,
Norway


                Library     Version    Impl.Upd   Release date
                ELLIB       1.9-07                20-NOV-2008
                SIFTOOL     8.3-05                20-NOV-2008
                NORSAM      8.4-01                20-NOV-2008
                MFR         8.3-05                20-NOV-2008
                PRIMAS      5.3-04                20-NOV-2008
                AUXLIB      8.2-02                20-NOV-2008
                SESTRA_PRLL 8.1-02                20-NOV-2008

                Run identification   :




 DATE: 04-JUN-2012 TIME: 15:08:37   ***************  SESTRA  ***************
                                        PAGE:     1

                                    DATA GENERATION MODULE

                                    SUB PAGE:     1


  PRINTOUT OF DATA GIVEN AS DIRECT INPUT TO SESTRA



   HEAD

   COMM

   COMM    Created by: GeniE  V5.3-10  14-Apr-2011

   COMM

   COMM    Date : 04-Jun-2012   Time : 15:08:21   User : ofsbilil

   COMM

   COMM  CHCK ANTP MSUM MOLO STIF RTOP LBCK      PILE CSING     SIGM

   CMAS    0.   1.   1.   0.   0.   0.   0.   0.   0.  0.00E+00  0.00E+00
0.00E+00
   COMM
```

```
   COMM            ORDR                               CACH MFRWORK

   SOLM    0.    0.    0.    0.    0.    0.    0.    0.    0.  0.00E+00  0.00E+00
0.00E+00
   COMM

   COMM                 WCOR

   ELOP    0.    0.    0.    1.    0.    0.    0.    0.    0.  0.00E+00  0.00E+00
0.00E+00
   COMM

   COMM  ITYP

   ITOP    1.    0.    0.    0.    0.    0.    0.    0.    0.  0.00E+00  0.00E+00
0.00E+00
   COMM

   COMM  PREFIX

   INAM  20120604_150750_

   COMM

   COMM  PREFIX FORMAT

   LNAM  20120604_150750_ UNFORMATTED

   COMM

   COMM  PREFIX FORMAT

   RNAM  20120604_150750_ NORSAM

   COMM

   COMM  SEL1 SEL2 SEL3 SEL4 SEL5 SEL6 SEL7 SEL8

   RSEL    1.    0.    0.    0.    0.    0.    1.    0.    0.  0.00E+00  0.00E+00
0.00E+00
   COMM

   COMM  RTRA

   RETR    3.    0.    0.    0.    0.    0.    0.    0.    0.  0.00E+00  0.00E+00
0.00E+00
   Z


  PRINTOUT OF DATA GIVEN IN THE FILE 20120604_150750_S1.FEM


   LOHI    1.    0.   12.    1.    1.    0.    0.    0.    1.  0.10E+01  0.00E+00
0.00E+00
   SEAS    1.  0.00E+00  0.10E+01  0.70E+01  0.10E+01  0.27E+03  0.18E+02
0.14E+02
           0.  0.45E+02  0.10E+01 -0.57E-11  0.00E+00  0.00E+00  0.00E+00
0.00E+00
   TILO    1.  0.00E+00  0.10E+01 -0.79E+00 -0.79E+00  0.00E+00  0.00E+00
0.00E+00
   LCOM    1.  0.00E+00  0.10E+01  0.12E+02  0.13E+02  0.00E+00  0.00E+00
0.00E+00
   LOHI    2.    0.   12.    2.    2.    0.    0.    0.    2.  0.20E+01  0.00E+00
0.00E+00
   SEAS    2.  0.00E+00  0.10E+01  0.70E+01  0.10E+01  0.18E+03  0.18E+02
0.14E+02
           0.  0.45E+02  0.10E+01 -0.57E-11  0.00E+00  0.00E+00  0.00E+00
0.00E+00
```

```
   TILO     2.  0.00E+00  0.10E+01 -0.79E+00 -0.79E+00  0.00E+00  0.00E+00
0.00E+00
   LCOM     2.  0.00E+00  0.10E+01  0.14E+02  0.15E+02  0.00E+00  0.00E+00
0.00E+00
   LOHI     3.   0.  12.   3.   3.   0.   0.   0.   3.  0.30E+01  0.00E+00
0.00E+00
   SEAS     3.  0.00E+00  0.10E+01  0.70E+01  0.10E+01  0.90E+02  0.18E+02
0.14E+02
            0.  0.45E+02  0.10E+01 -0.57E-11  0.00E+00  0.00E+00  0.00E+00
0.00E+00
   TILO     3.  0.00E+00  0.10E+01 -0.79E+00 -0.79E+00  0.00E+00  0.00E+00
0.00E+00
   LCOM     3.  0.00E+00  0.10E+01  0.16E+02  0.17E+02  0.00E+00  0.00E+00
0.00E+00

 DATE: 04-JUN-2012 TIME: 15:08:37   ***************  SESTRA  ***************
                                        PAGE:     2

                                    DATA GENERATION MODULE

                                    SUB PAGE:     2

  PRINTOUT OF DATA GIVEN AS DIRECT INPUT TO SESTRA


   LOHI     4.   0.  12.   4.   4.   0.   0.   0.   4.  0.40E+01  0.00E+00
0.00E+00
   SEAS     4.  0.00E+00  0.10E+01  0.70E+01  0.10E+01  0.00E+00  0.18E+02
0.14E+02
            0.  0.45E+02  0.10E+01 -0.57E-11  0.00E+00  0.00E+00  0.00E+00
0.00E+00
   TILO     4.  0.00E+00  0.10E+01 -0.79E+00 -0.79E+00  0.00E+00  0.00E+00
0.00E+00
   LCOM     4.  0.00E+00  0.10E+01  0.18E+02  0.19E+02  0.00E+00  0.00E+00
0.00E+00
   WIND     1.  0.25E+02  0.27E+03  0.32E+00  0.10E+02  0.70E+00  0.00E+00
0.10E+01
            0.  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00
   WIND     2.  0.25E+02  0.18E+03  0.32E+00  0.10E+02  0.70E+00  0.00E+00
0.10E+01
            0.  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00
   WIND     3.  0.25E+02  0.90E+02  0.32E+00  0.10E+02  0.70E+00  0.00E+00
0.10E+01
            0.  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00
   WIND     4.  0.25E+02  0.00E+00  0.32E+00  0.10E+02  0.70E+00  0.00E+00
0.10E+01
            0.  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00

 DATE: 04-JUN-2012 TIME: 15:08:37   ***************  SESTRA  ***************
                                        PAGE:     3

                                    DATA GENERATION MODULE

                                    SUB PAGE:     3
  INTERPRETATION OF ANALYSIS CONTROL DATA
```

```
      Type of Analysis :

         Reduction

         Multifront Solver is used

         Retracking


      Input from CMAS Command :

         ANTYP = 1   Static Analysis

         MSUM  > 0   Calculation of Sum of Masses and Centroid

         The singularity constant for membrane and shell elements

         CSING =  1.0000E-08

         Lowest accepted condition number in reduction

         EPSSOL=  1.1102E-14


      Input from RSEL Command :

         Data types selected for storing on Results File :

          - Input Interface File Records,

          - displacements,  sequence:

               all nodes for the first resultcase, all nodes for the second
resultcase, etc.
          - forces and moments for beam, spring and layered shell elements,
sequence:
               all elements for the first resultcase, all elements for the
second resultcase, etc.
          - stresses (not for beam or spring elements),  sequence:

               all elements for the first resultcase, all elements for the
second resultcase, etc.

         (Can be redefined by RSEL for selected superelements, see below.)

         Storing is done for superelements specified in RETR command.

 DATE: 04-JUN-2012 TIME: 15:08:37   ***************  SESTRA  ***************
                                        PAGE:     4

                                    DATA GENERATION MODULE

                                    SUB PAGE:     4

  INPUT INTERFACE FILES :
```

```
20120604_150750_T1.FEM

20120604_150750_L1.FEM

    DATE:     04-Jun-2012         TIME:          15:07:51
    PROGRAM:  SESAM GeniE         VERSION:       V5.3-10 14-Apr-2011
    COMPUTER: X86 Windows         INSTALLATION:
    USER:     ofsbilil            ACCOUNT:

    DATE:     04-Jun-2012         TIME:          15:07:51
    PROGRAM:  SESAM Gamesha       VERSION:       R5.0-3 14-Apr-2011
    COMPUTER: X86 Windows         INSTALLATION:
    USER:     ofsbilil            ACCOUNT:

    DATE:     04-JUN-2012         TIME:         15:08:20
    PROGRAM:  SESAM WAJAC         VERSION:      5.9-02 28-FEB-2007
    COMPUTER: 586 WIN NT 5.1 [2600INSTALLATION: , NOWFKYLW4J
    USER:     OFSBILIL            ACCOUNT:


 DATE: 04-JUN-2012 TIME: 15:08:37   ***************  SESTRA  ***************
                                        PAGE:     5

                                    DATAGENERATION - SUPERELEMENT TYPE     1

                                    SUB PAGE:     5




     *** SUMMARY OF DATA FROM INPUT AND LOAD INTERFACE FILES ***

              FOR SUPERELEMENT TYPE       1  ON LEVEL  1

     The superelement has


           42  subelements

           26  nodes

           18  specified (fixed) degrees of freedom

          138  internal (free) degrees of freedom

         totally

          156  degrees of freedom


           19  loadcases
```

```
      The following kinds of loads are given:

            node loads

            line or point loads for 2 node beams

            gravitational load


      The following basic elements are given:

            42  2 node beam elements         BEAS



 DATE: 04-JUN-2012 TIME: 15:08:37   ***************  SESTRA  ***************
                                        PAGE:     6

                                    DATAGENERATION - SUPERELEMENT TYPE     1

                                    SUB PAGE:     6

      *** SUM OF LOADS AND MOMENTS FOR SUPERELEMENT TYPE     1  ON LEVEL  1  ***


     X-LOAD = SUM OF GIVEN LOADS IN GLOBAL X-DIRECTION

     Y-LOAD = SUM OF GIVEN LOADS IN GLOBAL Y-DIRECTION

     Z-LOAD = SUM OF GIVEN LOADS IN GLOBAL Z-DIRECTION

     X-MOM  = SUM OF LOCAL MOMENTS ABOUT GLOBAL X-AXIS

     Y-MOM  = SUM OF LOCAL MOMENTS ABOUT GLOBAL Y-AXIS

     Z-MOM  = SUM OF LOCAL MOMENTS ABOUT GLOBAL Z-AXIS

     X-RMOM = SUM OF MOMENTS ABOUT GLOBAL X-AXIS FROM GIVEN LOADS AND MOMENTS

     Y-RMOM = SUM OF MOMENTS ABOUT GLOBAL Y-AXIS FROM GIVEN LOADS AND MOMENTS

     Z-RMOM = SUM OF MOMENTS ABOUT GLOBAL Z-AXIS FROM GIVEN LOADS AND MOMENTS


      LOADCASE    X-LOAD      Y-LOAD      Z-LOAD       X-MOM       Y-MOM
Z-MOM       X-RMOM      Y-RMOM      Z-RMOM
           1  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
           2  0.0000E+00  1.2369E-10 -2.0778E+07  0.0000E+00  0.0000E+00
0.0000E+00  1.9895E+07  5.3361E-04 -5.1699E-26
           3  0.0000E+00 -4.8420E+03  0.0000E+00 -1.0591E+03  0.0000E+00
0.0000E+00  2.6668E+05  0.0000E+00  0.0000E+00
           4  0.0000E+00  4.8420E+03  0.0000E+00  1.0591E+03  0.0000E+00
0.0000E+00 -2.6668E+05  0.0000E+00  0.0000E+00
           5 -4.8420E+03  0.0000E+00  0.0000E+00  0.0000E+00  1.0591E+03
0.0000E+00  0.0000E+00 -2.6668E+05  0.0000E+00
           6  4.8420E+03  0.0000E+00  0.0000E+00  0.0000E+00 -1.0591E+03
0.0000E+00  0.0000E+00  2.6668E+05  0.0000E+00
           7 -3.9700E+05  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00 -2.5865E+07  0.0000E+00
```

```
           8  0.0000E+00  0.0000E+00  0.0000E+00 -1.4300E+07  0.0000E+00
0.0000E+00 -1.4300E+07  0.0000E+00  0.0000E+00
           9  0.0000E+00  0.0000E+00 -6.8670E+06  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
          10  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00 -2.7100E+07
0.0000E+00  0.0000E+00 -2.7100E+07  0.0000E+00
          11  0.0000E+00  1.4500E+05  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00 -9.4468E+06  0.0000E+00  0.0000E+00
          12  2.0785E-01 -1.5473E+07  2.4483E+06  3.3757E+06  9.9251E-02
-3.1927E-02  4.6121E+08  6.0868E+00 -2.5057E+03
          13  2.0785E-01 -1.5473E+07  2.4483E+06  3.3757E+06  9.9251E-02
-3.1927E-02  4.6121E+08  6.0868E+00 -2.5057E+03
          14 -1.5634E+07  8.4298E+04  1.9964E+06  6.6779E+03 -3.2505E+06
1.6296E+04 -4.3385E+06 -4.6729E+08 -9.6747E+06
          15 -1.5634E+07  8.4298E+04  1.9964E+06  6.6779E+03 -3.2505E+06
1.6296E+04 -4.3385E+06 -4.6729E+08 -9.6747E+06
          16 -6.5153E-01  1.5515E+07  1.5705E+06 -3.1479E+06 -2.2409E-02
6.1712E-02 -4.6737E+08 -1.9222E+01  2.6841E+03
          17 -6.5153E-01  1.5515E+07  1.5705E+06 -3.1479E+06 -2.2409E-02
6.1712E-02 -4.6737E+08 -1.9222E+01  2.6841E+03
          18  1.5634E+07  8.4299E+04  1.9964E+06  6.6777E+03  3.2506E+06
-1.6296E+04 -4.3385E+06  4.6729E+08  9.6746E+06
          19  1.5634E+07  8.4299E+04  1.9964E+06  6.6777E+03  3.2506E+06
-1.6296E+04 -4.3385E+06  4.6729E+08  9.6746E+06

 DATE: 04-JUN-2012 TIME: 15:08:37   ***************  SESTRA  ***************
                                        PAGE:     7

                                    DATAGENERATION - SUPERELEMENT TYPE     1


                                    SUB PAGE:     7


      *** SUM OF MASSES AND CENTROID FOR SUPERELEMENT TYPE     1  ON LEVEL  1
***



   MASS MATRIX IN GLOBAL COORDINATE SYSTEM (OF THE SUPERELEMENT):

   ---------------------------------------

   2.11878E+06    0.00000E+00    0.00000E+00    0.00000E+00    5.76574E+07
2.02869E+06
   0.00000E+00    2.11878E+06    0.00000E+00   -5.76574E+07    0.00000E+00
5.44135E-05
   0.00000E+00    0.00000E+00    2.11878E+06   -2.02869E+06   -5.44135E-05
0.00000E+00
   0.00000E+00   -5.76574E+07   -2.02869E+06    2.66680E+09   -3.77063E-04
0.00000E+00
   5.76574E+07    0.00000E+00   -5.44135E-05   -3.77063E-04    2.66491E+09
2.98574E+07
   2.02869E+06    5.44135E-05    0.00000E+00    0.00000E+00    2.98574E+07
3.25716E+08



   COORDINATES OF CENTROID:

   ------------------------

   2.5681E-11    -9.5748E-01     2.7213E+01
```

```
   MASS MATRIX AT CENTROID:

   ------------------------

   2.11878E+06    0.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00
0.00000E+00
   0.00000E+00    2.11878E+06    0.00000E+00    0.00000E+00    0.00000E+00
-6.77626E-21
   0.00000E+00    0.00000E+00    2.11878E+06    0.00000E+00    6.77626E-21
0.00000E+00
   0.00000E+00    0.00000E+00    0.00000E+00    1.09585E+09   -4.29163E-04
1.48073E-03
   0.00000E+00    0.00000E+00    6.77626E-21   -4.29163E-04    1.09591E+09
-2.53482E+07
   0.00000E+00   -6.77626E-21    0.00000E+00    1.48073E-03   -2.53482E+07
3.23774E+08

  *** Estimated size of stiffness matrix for superelement       1:        2124
variables

 DATE: 04-JUN-2012 TIME: 15:08:37   ***************  SESTRA  ***************
                                               PAGE:     8

                                           DATAGENERATION - SUPERELEMENT TYPE     1

                                           SUB PAGE:     8

      *** CONNECTION BETWEEN LOADCASE AND RESULTCASE NUMBERS ***


  TOP LEVEL EXT.RESULT  INDEX    TIME       WAVE DIR.   WAVE HEIGHT    WATER

  LOADCASE  IDENT.NO.                         (RAD)                    DEPTH

        1         1

        2         2

        3         3

        4         4

        5         5

        6         6

        7         7

        8         8

        9         9

       10        10

       11        11

       12        12         1   -7.889E-01    4.712E+00    1.750E+01    4.500E+01

       13        12         2   -7.889E-01    4.712E+00    1.750E+01    4.500E+01

       14        13         1   -7.889E-01    3.142E+00    1.750E+01    4.500E+01

       15        13         2   -7.889E-01    3.142E+00    1.750E+01    4.500E+01
```

```
      16         14       1   -7.889E-01    1.571E+00    1.750E+01    4.500E+01
      17         14       2   -7.889E-01    1.571E+00    1.750E+01    4.500E+01
      18         15       1   -7.889E-01    0.000E+00    1.750E+01    4.500E+01
      19         15       2   -7.889E-01    0.000E+00    1.750E+01    4.500E+01


   *** Estimate of total size of stiffness matrices for new superelements:
    2124 variables

 DATE: 04-JUN-2012 TIME: 15:08:37   ***************  SESTRA  ***************
                                        PAGE:     9

                                    REDUCTION MODULE - SUPERELEMENT TYPE    1

                                    SUB PAGE:     1




                                     - STIFFNESS FACTORIZATION PERFORMED BY
MULTIFRONT EQUATION SOLVER -

                                     - LOAD SUBSTITUTION PERFORMED BY
MULTIFRONT EQUATION SOLVER -

 DATE: 04-JUN-2012 TIME: 15:08:38   ***************  SESTRA  ***************
                                        PAGE:    10

                                          STATIC ANALYSIS OF STRUCTURE

                                    SUB PAGE:     1


      Results file name: 20120604_150750_R1.SIN


 DATE: 04-JUN-2012 TIME: 15:08:38   ***************  SESTRA  ***************
                                        PAGE:    11

                                    RETRACKING MODULE - SUPERELEMENT TYPE    1

                                    THE STRUCTURE
                                    SUB PAGE:     2

   REACTION FORCES IN NODES WITH SPECIFIED (FIXED) DEGREES OF FREEDOM.

   NODES MARKED WITH AN ASTERISK (*) TO THE RIGHT HAVE A LOCAL COORDINATE SYSTEM.

   ******************************************************************************
```

```
 LOADCASE (INDEX) NODE NO.      X             Y             Z             RX
      RY            RZ

       1              1   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
 0.00000E+00   0.00000E+00
                     15   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
 0.00000E+00   0.00000E+00
                     24   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
 0.00000E+00   0.00000E+00

       2              1   1.78164E+06   1.23558E+06   6.62961E+06   8.98964E+05
-1.32010E+06  -1.43644E+04
                     15  -5.05734E-11  -2.47115E+06   7.51896E+06  -1.13907E+06
-2.66806E-04  -1.46032E-10
                     24  -1.78164E+06   1.23558E+06   6.62961E+06   8.98964E+05
 1.32010E+06   1.43644E+04

       3              1  -1.64138E+02   1.71310E+03   3.68244E+03  -2.35459E+04
 3.25635E+03  -1.28044E+03
                     15  -7.77450E-12   1.41585E+03  -7.36489E+03  -2.82386E+04
-9.85440E-11   2.02566E-11
                     24   1.64138E+02   1.71310E+03   3.68244E+03  -2.35459E+04
-3.25635E+03   1.28044E+03

       4              1   1.64138E+02  -1.71310E+03  -3.68244E+03   2.35459E+04
-3.25635E+03   1.28044E+03
                     15   7.77450E-12  -1.41585E+03   7.36489E+03   2.82386E+04
 9.85440E-11  -2.02566E-11
                     24  -1.64138E+02  -1.71310E+03  -3.68244E+03   2.35459E+04
 3.25635E+03  -1.28044E+03

       5              1   1.43966E+03  -4.82095E+01   6.37460E+03  -5.49936E+03
 2.61883E+04   6.61252E+02
                     15   1.96273E+03  -1.79949E-12   1.80375E-12   2.10108E-11
 2.30611E+04  -2.08833E+03
                     24   1.43966E+03   4.82095E+01  -6.37460E+03   5.49936E+03
 2.61883E+04   6.61252E+02

       6              1  -1.43966E+03   4.82095E+01  -6.37460E+03   5.49936E+03
-2.61883E+04  -6.61252E+02
                     15  -1.96273E+03   1.79949E-12  -1.80375E-12  -2.10108E-11
-2.30611E+04   2.08833E+03
                     24  -1.43966E+03  -4.82095E+01   6.37460E+03  -5.49936E+03
-2.61883E+04  -6.61252E+02

       7              1   9.99579E+04  -3.57423E+04   6.08924E+05  -5.57954E+05
 2.63964E+06   7.21662E+04
                     15   1.97084E+05  -1.54106E-10   1.79853E-10   2.12034E-09
 2.31754E+06  -2.21345E+05
                     24   9.99579E+04   3.57423E+04  -6.08924E+05   5.57954E+05
 2.63964E+06   7.21662E+04

       8              1   1.02259E+05  -5.13864E+04  -1.77233E+05   1.58625E+06
-2.32984E+05   1.11651E+05
                     15   5.58535E-10   1.02773E+05   3.54466E+05   1.91821E+06
 7.02823E-09  -1.34808E-09
                     24  -1.02259E+05  -5.13864E+04  -1.77233E+05   1.58625E+06
 2.32984E+05  -1.11651E+05

       9              1   1.41249E+06   9.84570E+05   2.06196E+06  -3.06364E+05
 4.17050E+05   1.83827E+03
                     15  -7.05032E-11  -1.96914E+06   2.74309E+06   6.98835E+05
-9.21494E-10   4.94834E-11
                     24  -1.41249E+06   9.84570E+05   2.06196E+06  -3.06364E+05
-4.17050E+05  -1.83827E+03
```

```
      10              1  -1.22499E+05  -2.15386E+05   5.84514E+05  -7.25377E+05
 3.33655E+06   1.21618E+05
                     15   2.44998E+05  -2.49936E-10   2.50070E-10   2.45591E-09
 2.89148E+06  -3.39602E+05
                     24  -1.22499E+05   2.15386E+05  -5.84514E+05   7.25377E+05
 3.33655E+06   1.21618E+05

      11              1   1.53620E+04  -5.65500E+04  -1.28380E+05   8.67154E+05
-1.21316E+05   4.97501E+04
                     15   2.80584E-10  -3.19000E+04   2.56761E+05   1.04160E+06
 3.54928E-09  -7.14862E-10
                     24  -1.53620E+04  -5.65500E+04  -1.28380E+05   8.67154E+05
 1.21316E+05  -4.97501E+04

      12     1        1   1.17448E+06   4.28216E+06   5.24942E+06  -4.97690E+07
 1.03177E+06   1.70090E+06
                     15  -3.87086E+01   6.90857E+06  -1.29471E+07  -5.07328E+07
-4.53114E+02   8.69699E+01
                     24  -1.17444E+06   4.28225E+06   5.24942E+06  -4.97699E+07
-1.03127E+06  -1.70072E+06

DATE: 04-JUN-2012 TIME: 15:08:38   ***************  SESTRA  ***************
                                        PAGE:    12

                                    RETRACKING MODULE - SUPERELEMENT TYPE    1

                                    THE STRUCTURE
                                    SUB PAGE:     3


 REACTION FORCES IN NODES WITH SPECIFIED (FIXED) DEGREES OF FREEDOM.

 NODES MARKED WITH AN ASTERISK (*) TO THE RIGHT HAVE A LOCAL COORDINATE SYSTEM.

 *******************************************************************************



 LOADCASE (INDEX) NODE NO.      X             Y             Z            RX
      RY            RZ

      12     2        1   1.17448E+06   4.28216E+06   5.24942E+06  -4.97690E+07
 1.03177E+06   1.70090E+06
                     15  -3.87086E+01   6.90857E+06  -1.29471E+07  -5.07328E+07
-4.53114E+02   8.69699E+01
                     24  -1.17444E+06   4.28225E+06   5.24942E+06  -4.97699E+07
-1.03127E+06  -1.70072E+06

      13     1        1   5.63119E+06   1.60638E+06   9.74931E+06  -2.45434E+06
 5.15659E+07  -1.19680E+06
                     15   3.68491E+06   4.34029E+05  -6.60692E+05   3.63022E+05
 5.20754E+07   1.23174E+06
                     24   6.31766E+06  -2.12471E+06  -1.10850E+07   2.85132E+06
 5.11301E+07  -1.10419E+06

      13     2        1   5.63119E+06   1.60638E+06   9.74931E+06  -2.45434E+06
 5.15659E+07  -1.19680E+06
                     15   3.68491E+06   4.34029E+05  -6.60692E+05   3.63022E+05
 5.20754E+07   1.23174E+06
                     24   6.31766E+06  -2.12471E+06  -1.10850E+07   2.85132E+06
 5.11301E+07  -1.10419E+06

      14     1        1  -1.90292E+06  -4.73414E+06  -6.56453E+06   4.97132E+07
-7.86240E+05  -1.67558E+06
                     15   4.16077E+01  -6.04694E+06   1.15585E+07   5.13242E+07
 4.87592E+02  -9.33601E+01
                     24   1.90288E+06  -4.73422E+06  -6.56453E+06   4.97143E+07
```

```
  7.85697E+05   1.67538E+06

       14    2          1  -1.90292E+06  -4.73414E+06  -6.56453E+06   4.97132E+07
 -7.86240E+05  -1.67558E+06
                       15   4.16077E+01  -6.04694E+06   1.15585E+07   5.13242E+07
  4.87592E+02  -9.33601E+01
                       24   1.90288E+06  -4.73422E+06  -6.56453E+06   4.97143E+07
  7.85697E+05   1.67538E+06

       15    1          1  -6.31765E+06  -2.12471E+06  -1.10850E+07   2.85138E+06
 -5.11299E+07   1.10419E+06
                       15  -3.68491E+06   4.34028E+05  -6.60693E+05   3.62993E+05
 -5.20754E+07  -1.23174E+06
                       24  -5.63119E+06   1.60638E+06   9.74931E+06  -2.45431E+06
 -5.15659E+07   1.19681E+06

       15    2          1  -6.31765E+06  -2.12471E+06  -1.10850E+07   2.85138E+06
 -5.11299E+07   1.10419E+06
                       15  -3.68491E+06   4.34028E+05  -6.60693E+05   3.62993E+05
 -5.20754E+07  -1.23174E+06
                       24  -5.63119E+06   1.60638E+06   9.74931E+06  -2.45431E+06
 -5.15659E+07   1.19681E+06

 DATE: 04-JUN-2012 TIME: 15:08:38   ***************  SESTRA  ***************
                                        PAGE:    13


                                    RETRACKING MODULE - SUPERELEMENT TYPE    1

                                    THE STRUCTURE
                                    SUB PAGE:     4


  SUM OF REACTION FORCES FROM SPECIFIED DEGREES OF FREEDOM.

  THE FORCES AND MOMENTS ARE REFFERED TO THE COORDINATE SYSTEM OF THE ACTUAL
SUPERELEMENT.

********************************************************************************
********


  LOADCASE (INDEX)        X             Y             Z             RX
RY            RZ

       1            0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
0.0000E+00    0.0000E+00
       2           -9.3132E-10    2.7940E-09    2.0778E+07   -1.9895E+07
-5.3351E-04   -1.0536E-08
       3           -9.6634E-13    4.8420E+03   -4.5475E-13   -2.6668E+05
7.2760E-12    4.9477E-10
       4            9.6634E-13   -4.8420E+03    4.5475E-13    2.6668E+05
-7.2760E-12   -4.9477E-10
       5            4.8420E+03   -5.2083E-12    4.5475E-12    4.3656E-11
2.6668E+05    3.1105E-10
       6           -4.8420E+03    5.2083E-12   -4.5475E-12   -4.3656E-11
-2.6668E+05   -3.1105E-10
       7            3.9700E+05   -6.1846E-10    2.3283E-10    8.3819E-09
2.5865E+07    3.1898E-08
       8            2.0373E-10    1.5134E-08   -1.1642E-10    1.4300E+07
1.3970E-09   -3.1665E-08
       9           -2.3283E-10    4.6566E-10    6.8670E+06    3.7253E-09
3.7253E-09   -2.5757E-09
      10           -2.5466E-08   -5.5297E-10    3.4925E-10    1.0245E-08
2.7100E+07    4.4471E-08
      11            3.2742E-11   -1.4500E+05    1.4552E-11    9.4468E+06
-1.1642E-09   -1.6997E-08
      12    1      -2.0785E-01    1.5473E+07   -2.4483E+06   -4.6121E+08
```

```
-6.0868E+00    2.5057E+03
       12    2      -2.0785E-01    1.5473E+07   -2.4483E+06   -4.6121E+08
-6.0868E+00    2.5057E+03
       13    1       1.5634E+07   -8.4298E+04   -1.9964E+06    4.3385E+06
4.6729E+08    9.6747E+06
       13    2       1.5634E+07   -8.4298E+04   -1.9964E+06    4.3385E+06
4.6729E+08    9.6747E+06
       14    1       6.5153E-01   -1.5515E+07   -1.5705E+06    4.6737E+08
1.9222E+01   -2.6841E+03
       14    2       6.5153E-01   -1.5515E+07   -1.5705E+06    4.6737E+08
1.9222E+01   -2.6841E+03
       15    1      -1.5634E+07   -8.4299E+04   -1.9964E+06    4.3385E+06
-4.6729E+08   -9.6746E+06
       15    2      -1.5634E+07   -8.4299E+04   -1.9964E+06    4.3385E+06
-4.6729E+08   -9.6746E+06


 SUPERELEMENT TYPE:     1 ACTUAL ELEMENT:     1

 HAS BEEN STORED ON RESULT FILE


 DATE: 04-JUN-2012 TIME: 15:08:38   ***************  SESTRA  ***************
                                                PAGE:    14

                                                RETRACKING MODULE - GLOBAL DATA

                                            SUB PAGE:     1

  SUM OF GLOBAL LOADS AND MOMENTS

  *******************************




  LOADCASE (INDEX)        X             Y             Z             RX
RY            RZ

        1            0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
0.0000E+00    0.0000E+00
        2            0.0000E+00    1.2369E-10   -2.0778E+07    1.9895E+07
5.3361E-04   -5.1699E-26
        3            0.0000E+00   -4.8420E+03    0.0000E+00    2.6668E+05
0.0000E+00    0.0000E+00
        4            0.0000E+00    4.8420E+03    0.0000E+00   -2.6668E+05
0.0000E+00    0.0000E+00
        5           -4.8420E+03    0.0000E+00    0.0000E+00    0.0000E+00
-2.6668E+05    0.0000E+00
        6            4.8420E+03    0.0000E+00    0.0000E+00    0.0000E+00
2.6668E+05    0.0000E+00
        7           -3.9700E+05    0.0000E+00    0.0000E+00    0.0000E+00
-2.5865E+07    0.0000E+00
        8            0.0000E+00    0.0000E+00    0.0000E+00   -1.4300E+07
0.0000E+00    0.0000E+00
        9            0.0000E+00    0.0000E+00   -6.8670E+06    0.0000E+00
0.0000E+00    0.0000E+00
       10            0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
-2.7100E+07    0.0000E+00
       11            0.0000E+00    1.4500E+05    0.0000E+00   -9.4468E+06
0.0000E+00    0.0000E+00
       12    1       2.0785E-01   -1.5473E+07    2.4483E+06    4.6121E+08
6.0868E+00   -2.5057E+03
```

```
       12    2       2.0785E-01   -1.5473E+07    2.4483E+06    4.6121E+08
6.0868E+00   -2.5057E+03
       13    1      -1.5634E+07    8.4298E+04    1.9964E+06   -4.3385E+06
-4.6729E+08   -9.6747E+06
       13    2      -1.5634E+07    8.4298E+04    1.9964E+06   -4.3385E+06
-4.6729E+08   -9.6747E+06
       14    1      -6.5153E-01    1.5515E+07    1.5705E+06   -4.6737E+08
-1.9222E+01    2.6841E+03
       14    2      -6.5153E-01    1.5515E+07    1.5705E+06   -4.6737E+08
-1.9222E+01    2.6841E+03
       15    1       1.5634E+07    8.4299E+04    1.9964E+06   -4.3385E+06
4.6729E+08    9.6746E+06
       15    2       1.5634E+07    8.4299E+04    1.9964E+06   -4.3385E+06
4.6729E+08    9.6746E+06

 DATE: 04-JUN-2012 TIME: 15:08:38   ***************  SESTRA  ***************
                                               PAGE:    15

                                               RETRACKING MODULE - GLOBAL DATA

                                           SUB PAGE:     2

  SUM OF REACTION FORCES AND MOMENTS

  **********************************

  GIVEN IN THE GLOBAL COORDINATE SYSTEM OF THE TOP LEVEL SUPERELEMENT



  LOADCASE (INDEX)        X             Y             Z             RX
RY            RZ

        1            0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
0.0000E+00    0.0000E+00
        2           -9.3132E-10    2.7940E-09    2.0778E+07   -1.9895E+07
-5.3351E-04   -1.0536E-08
        3           -9.6634E-13    4.8420E+03   -4.5475E-13   -2.6668E+05
7.2760E-12    4.9477E-10
        4            9.6634E-13   -4.8420E+03    4.5475E-13    2.6668E+05
-7.2760E-12   -4.9477E-10
        5            4.8420E+03   -5.2083E-12    4.5475E-12    4.3656E-11
2.6668E+05    3.1105E-10
        6           -4.8420E+03    5.2083E-12   -4.5475E-12   -4.3656E-11
-2.6668E+05   -3.1105E-10
        7            3.9700E+05   -6.1846E-10    2.3283E-10    8.3819E-09
2.5865E+07    3.1898E-08
        8            2.0373E-10    1.5134E-08   -1.1642E-10    1.4300E+07
1.3970E-09   -3.1665E-08
        9           -2.3283E-10    4.6566E-10    6.8670E+06    3.7253E-09
3.7253E-09   -2.5757E-09
       10           -2.5466E-08   -5.5297E-10    3.4925E-10    1.0245E-08
2.7100E+07    4.4471E-08
       11            3.2742E-11   -1.4500E+05    1.4552E-11    9.4468E+06
-1.1642E-09   -1.6997E-08
       12    1      -2.0785E-01    1.5473E+07   -2.4483E+06   -4.6121E+08
-6.0868E+00    2.5057E+03
       12    2      -2.0785E-01    1.5473E+07   -2.4483E+06   -4.6121E+08
-6.0868E+00    2.5057E+03
       13    1       1.5634E+07   -8.4298E+04   -1.9964E+06    4.3385E+06
4.6729E+08    9.6747E+06
       13    2       1.5634E+07   -8.4298E+04   -1.9964E+06    4.3385E+06
4.6729E+08    9.6747E+06
       14    1       6.5153E-01   -1.5515E+07   -1.5705E+06    4.6737E+08
1.9222E+01   -2.6841E+03
```

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       14    2        6.5153E-01   -1.5515E+07   -1.5705E+06    4.6737E+08
1.9222E+01   -2.6841E+03
       15    1       -1.5634E+07   -8.4299E+04   -1.9964E+06    4.3385E+06
-4.6729E+08   -9.6746E+06
       15    2       -1.5634E+07   -8.4299E+04   -1.9964E+06    4.3385E+06
-4.6729E+08   -9.6746E+06

 DATE: 04-JUN-2012 TIME: 15:08:38   ***************  SESTRA  ***************
                                        PAGE:    16


                                        RETRACKING MODULE - GLOBAL DATA


                                    SUB PAGE:     3


  DIFFERENCES BETWEEN SUMMED LOADS AND REACTION FORCES

  ****************************************************

  LARGER THAN   0.00E+00 FOR TRANSLATIONAL COMPONENTS AND LARGER THAN   0.00E+00
FOR ROTATIONAL COMPONENTS


  LOADCASE (INDEX)        X             Y             Z            RX
RY            RZ

        2            -9.3132E-10    2.9177E-09    7.4506E-09   -3.7253E-09
1.0803E-07   -1.0536E-08
        3            -9.6634E-13   -1.9463E-10   -4.5475E-13    5.8208E-09
7.2760E-12    4.9477E-10
        4             9.6634E-13    1.9463E-10    4.5475E-13   -5.8208E-09
-7.2760E-12   -4.9477E-10
        5            -1.8190E-10   -5.2083E-12    4.5475E-12    4.3656E-11
-5.5879E-09    3.1105E-10
        6             1.8190E-10    5.2083E-12   -4.5475E-12   -4.3656E-11
5.5879E-09   -3.1105E-10
        7            -1.8161E-08   -6.1846E-10    2.3283E-10    8.3819E-09
-5.7369E-07    3.1898E-08
        8             2.0373E-10    1.5134E-08   -1.1642E-10   -4.7684E-07
1.3970E-09   -3.1665E-08
        9            -2.3283E-10    4.6566E-10    1.1176E-08    3.7253E-09
3.7253E-09   -2.5757E-09
       10            -2.5466E-08   -5.5297E-10    3.4925E-10    1.0245E-08
-8.4192E-07    4.4471E-08
       11             3.2742E-11    7.3051E-09    1.4552E-11   -2.2165E-07
-1.1642E-09   -1.6997E-08
       12    1       -3.3760E-09   -5.4389E-07    1.8626E-09    1.5438E-05
-5.9605E-08    1.2796E-06
       12    2       -3.3760E-09   -5.4389E-07    1.8626E-09    1.5438E-05
-5.9605E-08    1.2796E-06
       13    1       -5.5134E-07   -6.7521E-09    1.3039E-08   -9.3132E-09
-1.5259E-05    2.3469E-07
       13    2       -5.5134E-07   -6.7521E-09    1.3039E-08   -9.3132E-09
-1.5259E-05    2.3469E-07
       14    1        1.7462E-09    5.4576E-07   -2.3283E-09   -1.5140E-05
7.4506E-08   -1.4114E-06
       14    2        1.7462E-09    5.4576E-07   -2.3283E-09   -1.5140E-05
7.4506E-08   -1.4114E-06
       15    1        5.4203E-07    1.1525E-08   -7.4506E-09   -2.1048E-07
1.5199E-05   -3.7067E-07
       15    2        5.4203E-07    1.1525E-08   -7.4506E-09   -2.1048E-07
1.5199E-05   -3.7067E-07

  TOTAL TIME CONSUMED IN SESTRA                     CPU TIME:      0.66  CLOCK
TIME:      1.78  CHANNEL TIME:      0.11
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                        Vedlegg 10 wajac uten taarn alt
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                                              Marketing and Support by DNV
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```
Software



               Program id   : 5.9-02
Computer         : 586
               Release date : 28-FEB-2007
Impl. update     :
               Access time  : 04-JUN-2012 15:07:51
Operating system : Win NT 5.1 [2600]
               User id      : ofsbilil
CPU id           : 1016725624

Installation     : , NOWFKYLW4J


               Copyright DET NORSKE VERITAS AS, P.O.Box 300, N-1322 Hovik,
Norway


1DATE: 04-JUN-2012 TIME: 15:08:19   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :     1

 LIMITATIONS IN THIS VERSION OF WAJAC :
 --------------------------------------

    MAXIMUM SIZE OF ONE SUPERELEMENT
    -  NUMBER OF NODES          :     20000
    -  NUMBER OF BASIC ELEMENTS :     20000


    MAXIMUM NUMBER OF LOADCASES
    -  DISCRETE WAVE            :     10000
    -  FREQUENCY DOMAIN         :       960
          ( MAX. FREQUENCIES :        60 )
    -  TIME DOMAIN SIMULATION   :      8192


    MAXIMUM NUMBER INPUT CARDS
    -  CARD TYPE SELI           :       100
    -  CARD TYPE ELIM           :     20000
    -  CARD TYPE FLOO           :     20000
    -  CARD TYPE LEG            :        50
    -  CARD TYPE SPEC           :     20000
    -  CARD TYPE CDIR           :     20000
    -  CARD TYPE MPRT           :     20000

 SIZE OF COMMON SCRATCH ARRAYS :
 --------------------------------

 /IWORK/ IWORK(  20000) /WORK/ WORK( 500000 )
 /IWORK4/ IARR(  60000) /WORK4/ ARR(  60120)
 TOTAL SIZE: /IWORK4/= 140068 /WORK4/= 231781

1DATE: 04-JUN-2012 TIME: 15:08:19   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :     2



 W A J A C   I N P U T   P R O C E S S O R :



               *** DATA SET WAJAC ***



               CARD NO   2    TITL      Wajac run name :
Analysis5_Stokes5.step(2)
```

```
               CARD NO   3    C

               CARD NO   4    C                                           PREFIX

               CARD NO   5    FMOD      20120604_150750_

               CARD NO   6    C

               CARD NO   7    C                                           PREFIX
       FORM
               CARD NO   8    FWAVE     20120604_150750_

               CARD NO   9    C

               CARD NO  10    C              UNITS   GRAVITY       RHO      VISC
   RHOAIR   VISCAIR
               CARD NO  11    CONS              1.   9.80665     1025. 1.19e-006
    1.226  1.462e-5
               CARD NO  12    C

               CARD NO  13    C               OPT1      OPT2      OPT3      OPT4
     OPT5      OPT6      OPT7
               CARD NO  14    OPTI              0.        0.        0.        0.
       0.        0.        0.
               CARD NO  15                      0.

               CARD NO  16    C

               CARD NO  17    C                        ILFSAV    ISETOP

               CARD NO  18    MODE                         1.        1.

               CARD NO  19    C

               CARD NO  20    C                 LN

               CARD NO  21    LONO             12.

               CARD NO  22    C         *************************** GEOM Section
*****************************
               *** END OF DATA SET  22 CARDS READ ***


               *** DATA SET GEOM ***


               CARD NO  24    C

               CARD NO  25    C                  Z

               CARD NO  26    MUDP      -5.651e-12

               CARD NO  27    C         *************************** HYDR Section
*****************************
               *** END OF DATA SET   5 CARDS READ ***


               *** DATA SET HYDR ***


               CARD NO  29    C

               CARD NO  30    C               TYPE

               CARD NO  31    CPRI      FEM
```

```
               CARD NO  32    CPRI      SPEC

               CARD NO  33    CPRI      CDIR

               CARD NO  34    C

               CARD NO  35    C              ADMAS      DAMP

               CARD NO  36    MASS              0.        0.

               CARD NO  37    C

               CARD NO  38    C         MarineGrowthZLevel1 ( Marine Growth as
function of Z-level property )
               CARD NO  39    C

1DATE: 04-JUN-2012 TIME: 15:08:19   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :     3

               CARD NO  40    C                 Z1        Z2     HMGRW    HROUGH
      OPT IMEM GRWF
               CARD NO  41    MGRW             -1.       45.       0.1        0.
       0.   1.   0.
               CARD NO  42    MGRW             -1.5.6488e-12       0.1        0.
       0.   1.   0.
               CARD NO  43    C

               CARD NO  44    C                 M1        M2       INC STYP  IDX
IMEM
               CARD NO  45    MEMGRW            1.       42.        1.   1.   1.
  1.
               CARD NO  46    C

               CARD NO  47    C         AirDragConstant1 ( Air Drag Coefficients
property )
               CARD NO  48    C

               CARD NO  49    C                 M1        M2       INC STYP  IDX
 CDX       CDZ
               CARD NO  50    CDWN              1.       42.        1.   1.   1.
 1.2       1.2
               CARD NO  51    C         *************************** LOAD Section
*****************************
               *** END OF DATA SET  24 CARDS READ ***


               *** DATA SET LOAD ***


               CARD NO  53    C

               CARD NO  54    C          ISEA THEO    HEIGHT    PERIOD      PHI0
       T0      STEP     NSTEP
               CARD NO  55    SEA          1. 5.0       17.5      14.2      -60.
       0.       10.      -36.
               CARD NO  56    SEA          2. 5.0       17.5      14.2      -60.
       0.       10.      -36.
               CARD NO  57    SEA          3. 5.0       17.5      14.2      -60.
       0.       10.      -36.
               CARD NO  58    SEA          4. 5.0       17.5      14.2      -60.
       0.       10.      -36.
               CARD NO  59    C

               CARD NO  60    C          ISEA BETA WKFA CTNO CBFA CSTR LOAD DLOA
 WID WIME
               CARD NO  61    SEAOPT       1. 270.   1.   1.   1.  -1.   0.   1.
  1.   0.
```

```
               CARD NO  62    SEAOPT       2. 180.   1.   1.   1.  -1.   0.   1.
  2.   0.
               CARD NO  63    SEAOPT       3.  90.   1.   1.   1.  -1.   0.   1.
  3.   0.
               CARD NO  64    SEAOPT       4.   0.   1.   1.   1.  -1.   0.   1.
  4.   0.
               CARD NO  65    C

               CARD NO  66    C         WindProfileRelDir4 (  Wind profile
property )
               CARD NO  67    C

               CARD NO  68    C      WID        VEL     ANGLE     GUSTF        H0
     HEXP PRAT IFRM
               CARD NO  69    WIND    1.        25.      270.     0.315       10.
      0.7   0.   0.
               CARD NO  70    C

               CARD NO  71    C         WindProfileRelDir3 (  Wind profile
property )
               CARD NO  72    C

               CARD NO  73    C      WID        VEL     ANGLE     GUSTF        H0
     HEXP PRAT IFRM
               CARD NO  74    WIND    2.        25.      180.     0.315       10.
      0.7   0.   0.
               CARD NO  75    C

               CARD NO  76    C         WindProfileRelDir2 (  Wind profile
property )
               CARD NO  77    C

               CARD NO  78    C      WID        VEL     ANGLE     GUSTF        H0
     HEXP PRAT IFRM
               CARD NO  79    WIND    3.        25.       90.     0.315       10.
      0.7   0.   0.
               CARD NO  80    C

               CARD NO  81    C         WindProfileRelDir1 (  Wind profile
property )
               CARD NO  82    C

               CARD NO  83    C      WID        VEL     ANGLE     GUSTF        H0
     HEXP PRAT IFRM
               CARD NO  84    WIND    4.        25.        0.     0.315       10.
      0.7   0.   0.
               CARD NO  85    C

               CARD NO  86    C         CurrentProfile1 (  Current profile
property )
               CARD NO  87    C

               CARD NO  88    C     CTNO                                        Z
        V     THETA       OPT
               CARD NO  89    CRNT    1.                               5.6488e-12
      0.5                1.
               CARD NO  90                                                    45.
      1.1
               CARD NO  91                                                  65.15
      1.1
1DATE: 04-JUN-2012 TIME: 15:08:19   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                        PAGE :     4

               CARD NO  92    C

               CARD NO  93    C              DEPTH

               CARD NO  94    DPTH              45.
```

```
            CARD NO  95    C

            CARD NO  96    C                  X         Y         Z

            CARD NO  97    MOMT              0.        0.        0.

            *** END OF DATA SET  46 CARDS READ ***

       ***** END OF DATA INPUT   98 CARDS READ *****
1DATE: 04-JUN-2012 TIME: 15:08:19   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :     5


********************************************************************************
************
 *
          *
 *          Wajac run name : Analysis5_Stokes5.step(2)
          *
 *
          *

********************************************************************************
************



 S U M M A R Y   O F   I N P U T   S P E C I F I C A T I O N S :


 PROGRAM EXECUTION:
 ------------------

    THE PROGRAM IS USED IN INTERFACE MODE WITH PARAMETERS:

    IGFSAV=0   ILFSAV=1   ISETOP=  1


 FILE USEAGE:
 ------------

    THE NAME WHICH WILL BE USED FOR THE DEFAULT PART OF
          THE INTERFACE FILE NAMES IS: 20120604_150750_

    GEOMETRY WILL BE STORED ON TEMPORARY FILES DURING EXECUTION.

    THE LOADS WILL BE SAVED ON ONE FILE FOR EACH SUPERELEMENT TYPE

    THE NAME WHICH WILL BE USED FOR THE DEFAULT PART OF
          THE LOAD FILE NAMES IS: 20120604_150750_



 UNITS:
 ------

    THE UNITS ARE USER DEFINED:

    GRAVITY                   = 9.8067E+00
    WATER SPECIFIC MASS       = 1.0250E+03
    WATER KINEMATIC VISCOSITY = 1.1900E-06
    AIR SPECIFIC MASS         = 1.2260E+00
    AIR KINEMATIC VISCOSITY   = 1.4620E-05
```

```
 INITIAL LOADCASE NUMBER ON THE LOAD FILES :
 ------------------------------------------

    IS USER DEFINED =      12 FOR ALL SUPERELEMENT TYPES


 SPECIAL OPTIONS INTENDED FOR COMPARATIVE STUDIES:
--------------------------------------------------


1DATE: 04-JUN-2012 TIME: 15:08:19   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                               PAGE :     6



 LEG PERMABILITY FACTORS:
 ------------------------

    DEFAULT VALUES FOR CPERM IS USED.
    ALL LEGS ARE ASSUMED TO HAVE FULL BUOYANCY.


 MUDPLANE ELEVATION:
 -------------------

    THE MUDPLANE ELEVATION IS SET TO -.5651E-11 IN THE STRUCTURE COORDINATE
SYSTEM.


 HYDRODYNAMIC COEFFICIENTS:
 --------------------------

    *** WARNING: HYDRODYNAMIC COEFFICIENTS HAVE NOT BEEN SPECIFIED BY THE WAJAC
ANALYSIS
        CONTROL DATA. ENSURE THAT THE COEFFICIENTS ARE SPECIFIED ON THE SESAM
INTERFACE FILE ***


 MARINE GROWTH:
 --------------

    MARINE GROWTH AND ROUGHNESS IS SPECIFIED IN THE FOLLOWING DEPTH RANGES:
    (Z1=-1.0 MEANS LINEAR VARYING MARINE GROWTH
     AND ROUGHNESS BETWEEN LEVELS GIVEN BY Z2)

    BETWEEN ELEVATIONS     Z1   AND   Z2          HMGRW      HROUGH    INFLG
IMEM   GRWFAC

                         -1.000       0.000       0.100       0.000     0
 1    0.0000
                         -1.000      45.000       0.100       0.000     0
 1    0.0000

    MARINE GROWTH IS NOT INCLUDED IN INERTIA FORCE CALCULATION.
1DATE: 04-JUN-2012 TIME: 15:08:19   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                               PAGE :     7



 MARINE GROWTH BY MEMBERS:
 -------------------------

    INDIVIDUAL MARINE GROWTH AND ROUGHNESS ARE SPECIFIED FOR THE FOLLOWING
MEMBERS:


                              BY        OF       AND ACTUAL
```

```
    MEMBER  THROUGH  MEMBER  STEP SUP.ELEMENT SUP.ELEMENT    IMEM
    ( OR SETNAME )            OF      TYPE       INDEX

        1            42        1        1          1           1



 MEMBERS WITH SPECIAL HYDRODYNAMIC PROPERTIES:
 ---------------------------------------------

    NO MEMBERS HAVE BEEN DEFINED AS SPECIAL.


 MEMBERS WITH DIRECTIONAL HYDRODYNAMIC COEFFICIENTS:
 ---------------------------------------------------

    NO MEMBERS HAVE DIRECTIONAL HYDRODYNAMIC COEFFICIENTS.


 PRIORITY OF SPECIFIED HYDRODYNAMIC COEFFICIENTS (1 IS HIGHEST):
 ---------------------------------------------------------------

    SPECIFICATION WITH HIGHER PRIORITY WILL SUPERSEDE ANY OTHER COEFFICIENTS
SPECIFIED.

    THE PRIORITY HIERARCHY IS MODIFED.

    OPTION FOR SPECIFICATION     CPRI-TYPE     PRIORITY     GIVEN ON WAJAC INPUT
FILE
    ------------------------     ---------     --------
-------------------------
    API                         API               6       NO
    VERTICAL POSITION           COEF              5       NO
    DIAMETER                    FUNC              4       NO
    KC. NUMBER                  FUNC              4       NO
    RN. NUMBER                  FUNC              4       NO
    INPUT INTERFACE FILE        FEM               3       ---
    INDIVIDUAL                  SPEC              2       NO
    DIRECTIONAL                 CDIR              1       NO


 TRANSFER OF ADDED MASS AND/OR DAMPING FOR DYNAMIC STRUCTURAL ANALYSIS :
 -----------------------------------------------------------------------

    CALCULATED ADDED MASS IS  N O T  TRANSFERRED

    CALCULATED DAMPING IS  N O T  TRANSFERRED

1DATE: 04-JUN-2012 TIME: 15:08:19   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :     8



 AIR DRAG COEFFICIENTS:
 -----------------------

 *** WARNING: DIRECTIONAL DEPENDENT COEFFICIENTS GIVEN THROUGH THE WAJAC
ANALYSIS CONTROL DATA, MUST BE
              SPECIFIED RELATIVE TO THE AXES OF THE MEMBER LOCAL COORDINATE
SYSTEM USED IN WAJAC. THIS
              COORDINATE SYSTEM IS NOT NECESSARILY CORRESPONDING TO THE ONE
DEFINED IN THE PREPROCESSOR
              HAVING CREATED THE MODEL.

              THE RELATION BETWEEN THE LOCAL COORDINATE SYSTEM IN WAJAC AND THE
LOCAL COORDINATE SYSTEM
              IN THE SESAM PREPROCESSORS IS:
```

```
                WAJAC          PREPROCESSOR
                -----          ------------
                  x               -y
                  y                x
                  z                z

    THE FOLLOWING MEMBERS HAVE BEEN DEFINED WITH AIR DRAG COEFFICIENTS:
    (VALUE -1.000 MEANS ORIGINAL VALUE RETAINED)

                                  BY       OF      AND ACTUAL
    MEMBER  THROUGH  MEMBER  STEP SUP.ELEMENT SUP.ELEMENT      CDX
CDZ
    ( OR SETNAME )            OF      TYPE       INDEX

        1           42        1        1          1          1.200
1.200


 MOMENT REFERENCE POINT:
 -----------------------

    THE MOMENT REFERENCE POINT COORDINATES HAVE BEEN SPECIFIED AS:

    XM=       0.000   YM=       0.000   ZM=       0.000


 MEMBER SEGMENTATION:
 --------------------

    THE DEFAULT VALUE SEG=1.0 IS USED FOR THE MEMBER SEGMENTATION COEFFICIENT.


 SEGMENTATION BY REFERENCE TO MEMBERS:
 -------------------------------------

    INDIVIDUAL SEGMENTATION IS NOT SPECIFIED FOR ANY MEMBERS.


 WATER DEPTH SPECIFICATION:
 --------------------------

    THE WATER DEPTH HAS BEEN SPECIFIED TO:

    DEPTH=      45.000
1DATE: 04-JUN-2012 TIME: 15:08:19   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :     9


 CURRENT SPECIFICATION:
 ----------------------

    CURRENT IS SPECIFIED BY THE FOLLOWING TABLE(S):

    TABLE NO.  1
+                            Z            V       (THE CURRENT IS RUNNING WITH
THE WAVE)

                          0.000       0.500
                         45.000       1.100
                         65.150       1.100
1DATE: 04-JUN-2012 TIME: 15:08:19   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :    10
```

```
 DETERMINISTIC SEASTATES DEFINITION:
 -----------------------------------


    THE FOLLOWING SEASTATES WILL BE ANALYSED:

      SEA-      WAVE        WAVE        WAVE       PHASE   INITIAL       PHASE/TIME
 NUMBER    WAVE         WAVE         WAVE   DESIGN
      STATE   THEORY      HEIGHT      PERIOD     /TIME   PHASE/TIME    INCREMENTS
OF STEPS  HEADING     KINEMATICS   BUOY   LOADS
      NO.
                         FACTOR      FLAG
      -----  --------    ---------  ---------  ------  -----------   -----------
--------- ----------  -----------  -----  -------

        1     STOKES  5   17.50      14.20      PHASE  -60.00        10.00
   36.     270.0       1.000        0        1
        2     STOKES  5   17.50      14.20      PHASE  -60.00        10.00
   36.     180.0       1.000        0        1
        3     STOKES  5   17.50      14.20      PHASE  -60.00        10.00
   36.     90.00       1.000        0        1
        4     STOKES  5   17.50      14.20      PHASE  -60.00        10.00
   36.        0.0000   1.000        0        1


      SEA-     CURRENT  CURRENT      CURRENT    WIND    WIND LOAD
      STATE    TAB.NO   BLOCKAGE     STRETCH    INDEX   CALC.METH
      NO.
      -----    -------  -----------  ---------  ------  ---------

        1         1     1.000           -1         1        0
        2         1     1.000           -1         2        0
        3         1     1.000           -1         3        0
        4         1     1.000           -1         4        0


 WIND SPECIFICATION:
 --------------------

      WIND     MEAN      WIND      GUST      MEAN     HEIGHT     MEAN      WIND
    PROFILE    WIND      ANGLE     FACTOR   VELOCITY  EXPONENT   PERIOD   PROFILE
     INDEX   VELOCITY                        LEVEL               RATIO    FORMULA

       1      25.000   270.000    0.315    10.000     0.700     -----       0
       2      25.000   180.000    0.315    10.000     0.700     -----       0
       3      25.000    90.000    0.315    10.000     0.700     -----       0
       4      25.000     0.000    0.315    10.000     0.700     -----       0

    AIR DRAG COEFFICIENTS HAVE NOT BEEN SPECIFIED AS FUNCTION OF REYNOLDS
NUMBER.
    THE DEFAULT FUNCTION WILL BEE USED IF THE COEFFICIENTS NOT ARE SPECIFIED BY
THE CDWN COMMAND


 D A T A C H E C K I N G   F I N I S H E D
       Siftool    version 8.3-02   18-JAN-2007


 NAMES OF INPUT INTERFACE FILES READ:
 ------------------------------------


 Direct file opened: ofsbilil5320R1.SIN
 (IUINP,NWS,IUIDNT,MXPHYS,STATUS) :          10      1024     3
 0   SCRATCH
 File is native
     MD-FILE    1 OPENED ON UNIT  10 WITH INDEX   1 MAX LENGTH=      2147483640
WORDS AND BLOCKSIZE=  1024
```

```
                  NAME   R1.SIN





                  STATUS SCRATCH
     MD-FILE    1 ALLOCATION ACCOUNT OPENED

 20120604_150750_T1.FEM

         DATE:     04-Jun-2012         TIME:          15:07:51

         PROGRAM:  SESAM GeniE         VERSION:       V5.3-10 14-Apr-2011

         COMPUTER: X86 Windows         INSTALLATION:

         USER:     ofsbilil            ACCOUNT:

         DATE:     04-Jun-2012         TIME:          15:07:51

         PROGRAM:  SESAM Gamesha       VERSION:       R5.0-3 14-Apr-2011

         COMPUTER: X86 Windows         INSTALLATION:

         USER:     ofsbilil            ACCOUNT:

1DATE: 04-JUN-2012 TIME: 15:08:19   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :    11



*******************************************
                                           *   W A T E R   D E P T H :
45.000   *
*******************************************


 D E T E R M I N I S T I C   W A V E   C H A R A C T E R I S T I C S :



                 WAVE     WAVE                           DEPTH TO    WAVE HEIGHT
TO    WAVE       WAVE      HALF WAVE   HALF WAVE
 WAVE   WAVE     PERIOD   PERIOD    WAVE       WAVE     WAVE LENGTH    WAVE
LENGTH    CREST      TROUGH      DURATION    DURATION
  NO   THEORY    ACTUAL  APPARENT  HEIGHT     LENGTH       RATIO          RATIO
    ELEVATION   ELEVATION     CREST       TROUGH

   1 STOKES 5TH   14.20            17.50      267.9      0.1680
0.6532E-01   55.91       38.41       5.964       8.236
1DATE: 04-JUN-2012 TIME: 15:08:19   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :    12


 W A V E / C U R R E N T   L O A D I N G :


 STRUCTURE LOADS:
 ----------------
```

```
 SUPERELEMENT TYPE  :         1

    THE HIGHEST LOAD CASE NUMBER ON THE FEM INTERFACE FILE IS :        19
    THE INITIAL LOAD CASE NUMBER ON THE LOAD FILE IS          :        12


 *** WARNING *** LOADCASE NUMBERS WILL OVERLAP ON THE FEM INTERFACE FILE AND THE
LOAD FILE



 SUPERELEMENT TYPE NO   1   INDEX  1  (  42 BASIC ELEMENTS,  42 MEMBERS AND   26
NODES,  1 ACTUAL SUPERELEMENTS OF THAT TYPE )
1DATE: 04-JUN-2012 TIME: 15:08:19   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                              PAGE :    13


 T O T A L   L O A D   S U M M A R Y :


    SEASTATE NO   1

       STEP    PHASE      LX             LY             LZ             MX
     MY             MZ
       ----    -----      ----------     ----------     ----------
----------     ----------     ----------

          1    -60.0      1.1659E-01    -1.0492E+07     2.6406E+06
2.5367E+08     4.9062E+00    -1.0358E+03
          2    -50.0      1.1342E-01    -1.2064E+07     2.6364E+06
3.0746E+08     5.0312E+00    -1.3696E+03
          3    -40.0      4.7712E-02    -1.3611E+07     2.6153E+06
3.6600E+08     8.1250E-01    -1.7530E+03
          4    -30.0      1.3421E-01    -1.4877E+07     2.5533E+06
4.2106E+08     2.6562E+00    -2.1512E+03
          5    -20.0      1.5013E-01    -1.5473E+07     2.4483E+06
4.5678E+08     5.6250E+00    -2.5029E+03
          6    -10.0      6.4120E-02    -1.4976E+07     2.2575E+06
4.5396E+08     1.6562E+00    -2.7446E+03
          7      0.0      3.4279E-02    -1.3119E+07     2.0061E+06
3.9892E+08     5.6250E-01    -2.7979E+03
          8     10.0      9.7674E-02    -1.0025E+07     1.7692E+06
2.9651E+08     3.6562E+00    -2.6321E+03
          9     20.0      9.4174E-02    -6.2201E+06     1.5577E+06
1.7071E+08     4.0000E+00    -2.2360E+03
         10     30.0     -5.1323E-02    -2.3830E+06     1.3996E+06
5.0778E+07     3.0938E+00    -1.6498E+03
         11     40.0      3.2800E-02     9.4212E+05     1.3284E+06
-4.3068E+07    -9.6875E-01    -9.5297E+02
         12     50.0     -3.6194E-02     3.4878E+06     1.3395E+06
-1.0523E+08    -1.1250E+00    -2.4558E+02
         13     60.0     -2.9463E-02     5.2097E+06     1.4038E+06
-1.3961E+08     3.1250E-02     3.6431E+02
         14     70.0     -6.2429E-02     6.1760E+06     1.5077E+06
-1.5267E+08    -1.2812E+00     7.9744E+02
         15     80.0     -5.3912E-02     6.5049E+06     1.6466E+06
-1.5062E+08    -1.8125E+00     1.0159E+03
         16     90.0     -5.4635E-02     6.3610E+06     1.7758E+06
-1.3951E+08    -1.4062E+00     1.0181E+03
         17    100.0     -5.6794E-02     5.8943E+06     1.8920E+06
-1.2352E+08    -1.2812E+00     8.5838E+02
         18    110.0     -4.0919E-02     5.3058E+06     1.9748E+06
-1.0757E+08    -1.5938E+00     5.9569E+02
         19    120.0     -3.6510E-02     4.7251E+06     2.0241E+06
-9.3435E+07    -1.0938E+00     4.2875E+02
```

```
         20    130.0     -2.8251E-02     4.2176E+06     2.0553E+06
-8.1456E+07    -1.2500E-01     3.6300E+02
         21    140.0     -2.0041E-02     3.7615E+06     2.0765E+06
-7.1144E+07    -1.5625E-01     3.3306E+02
         22    150.0     -5.9867E-03     3.3213E+06     2.0966E+06
-6.1702E+07    -6.2500E-02     3.3075E+02
         23    160.0     -1.3401E-02     2.8632E+06     2.1218E+06
-5.2419E+07     1.5625E-01     3.4806E+02
         24    170.0     -4.0301E-02     2.3590E+06     2.1534E+06
-4.2736E+07    -3.7500E-01     3.7838E+02
         25    180.0     -3.1972E-02     1.7859E+06     2.1927E+06
-3.2168E+07     1.5625E-01     4.0988E+02
         26    190.0     -2.2086E-02     1.1272E+06     2.2393E+06
-2.0309E+07     2.8125E-01     4.3903E+02
         27    200.0      1.5751E-03     3.7209E+05     2.2910E+06
-6.8083E+06     1.2500E-01     4.6078E+02
         28    210.0      8.4990E-03    -4.8213E+05     2.3455E+06
8.5937E+06     2.8125E-01     4.6853E+02
         29    220.0      1.8943E-02    -1.4291E+06     2.3992E+06
2.6054E+07     2.1875E-01     4.5305E+02
         30    230.0      4.3245E-03    -2.4507E+06     2.4481E+06
4.5585E+07     2.8125E-01     4.0181E+02
         31    240.0      2.9796E-02    -3.5146E+06     2.4907E+06
6.6973E+07     3.7500E-01     3.0112E+02
         32    250.0      4.2570E-02    -4.5924E+06     2.5209E+06
9.0104E+07     1.5312E+00     1.3828E+02
         33    260.0      8.0661E-02    -5.6516E+06     2.5421E+06
1.1456E+08     1.1562E+00    -8.7688E+01
         34    270.0      4.0461E-02    -6.6852E+06     2.5616E+06
1.4056E+08     5.3125E-01    -3.6419E+02
         35    280.0      1.0160E-01    -7.7849E+06     2.5883E+06
1.7097E+08     1.5938E+00    -5.7775E+02
         36    290.0      7.4881E-02    -9.0526E+06     2.6188E+06
2.0838E+08     1.5938E+00    -7.7294E+02

       MAXIMUM BASE SHEAR          = 1.5473E+07  AT PHASE =  -20.0

       MAXIMUM OVERTURNING MOMENT = 4.5678E+08  AT PHASE =  -20.0


    SEASTATE NO   2

       STEP    PHASE      LX             LY             LZ             MX
     MY            MZ
       ----    -----     ----------     ----------     ----------
----------     ----------     ----------

          1    -60.0     -1.0840E+07    -1.1325E+05     2.4400E+06
4.0564E+05    -2.6441E+08    -9.1480E+06
          2    -50.0     -1.2425E+07    -9.4687E+04     2.3787E+06
1.9728E+05    -3.1835E+08    -9.6290E+06
1DATE: 04-JUN-2012 TIME: 15:08:19   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                             PAGE :    14

          3    -40.0     -1.3947E+07    -5.5037E+04     2.2934E+06
-6.8332E+05    -3.7613E+08    -9.9678E+06
          4    -30.0     -1.5144E+07     4.3118E+03     2.1637E+06
-2.1231E+06    -4.2949E+08    -1.0106E+07
          5    -20.0     -1.5634E+07     8.4298E+04     1.9964E+06
-4.3020E+06    -4.6280E+08    -9.9401E+06
          6    -10.0     -1.5000E+07     1.7454E+05     1.7877E+06
-6.8144E+06    -4.5692E+08    -9.3106E+06
          7      0.0     -1.2987E+07     2.6318E+05     1.5796E+06
-9.3509E+06    -3.9811E+08    -8.1126E+06
          8     10.0     -9.7427E+06     3.3102E+05     1.4105E+06
-1.1174E+07    -2.9218E+08    -6.3997E+06
          9     20.0     -5.8234E+06     3.6544E+05     1.3140E+06
-1.1873E+07    -1.6413E+08    -4.3967E+06
```

```
         10     30.0     -1.9201E+06     3.5967E+05     1.2805E+06
-1.1197E+07    -4.3247E+07    -2.3888E+06
         11     40.0      1.4177E+06     3.2254E+05     1.3093E+06
-9.6654E+06     5.0439E+07    -5.7911E+05
         12     50.0      3.9270E+06     2.6151E+05     1.3805E+06
-7.5801E+06     1.1168E+08     9.5626E+05
         13     60.0      5.5622E+06     1.9115E+05     1.4981E+06
-5.6128E+06     1.4390E+08     2.2058E+06
         14     70.0      6.4146E+06     1.1875E+05     1.6345E+06
-3.8722E+06     1.5439E+08     3.1594E+06
         15     80.0      6.6267E+06     5.0089E+04     1.7726E+06
-2.4397E+06     1.5013E+08     3.8470E+06
         16     90.0      6.3745E+06    -1.3422E+03     1.8970E+06
-1.5894E+06     1.3694E+08     4.4812E+06
         17    100.0      5.8381E+06    -3.2185E+04     1.9879E+06
-1.1633E+06     1.1980E+08     5.1904E+06
         18    110.0      5.2457E+06    -4.4519E+04     2.0470E+06
-1.0858E+06     1.0362E+08     5.4262E+06
         19    120.0      4.6934E+06    -4.6084E+04     2.0888E+06
-1.2458E+06     8.9741E+07     5.0384E+06
         20    130.0      4.2004E+06    -4.6728E+04     2.1168E+06
-1.3962E+06     7.8046E+07     4.4568E+06
         21    140.0      3.7487E+06    -4.9647E+04     2.1397E+06
-1.4827E+06     6.7879E+07     3.8712E+06
         22    150.0      3.3016E+06    -5.5609E+04     2.1639E+06
-1.5025E+06     5.8388E+07     3.2787E+06
         23    160.0      2.8270E+06    -6.4897E+04     2.1908E+06
-1.4338E+06     4.8910E+07     2.6650E+06
         24    170.0      2.2980E+06    -7.6994E+04     2.2215E+06
-1.2863E+06     3.8885E+07     2.0140E+06
         25    180.0      1.6940E+06    -9.0998E+04     2.2565E+06
-1.0796E+06     2.7856E+07     1.3125E+06
         26    190.0      1.0005E+06    -1.0565E+05     2.2953E+06
-8.4540E+05     1.5442E+07     5.5251E+05
         27    200.0      2.0988E+05    -1.1973E+05     2.3364E+06
-6.0760E+05     1.3420E+06    -2.6007E+05
         28    210.0     -6.7749E+05    -1.3164E+05     2.3770E+06
-3.9108E+05    -1.4658E+07    -1.1091E+06
         29    220.0     -1.6510E+06    -1.3957E+05     2.4138E+06
-2.2698E+05    -3.2647E+07    -1.9638E+06
         30    230.0     -2.6878E+06    -1.4157E+05     2.4444E+06
-1.5092E+05    -5.2554E+07    -2.7816E+06
         31    240.0     -3.7526E+06    -1.3697E+05     2.4647E+06
-1.4156E+05    -7.4202E+07    -3.5127E+06
         32    250.0     -4.8130E+06    -1.2688E+05     2.4742E+06
-1.6437E+05    -9.7407E+07    -4.2892E+06
         33    260.0     -5.8446E+06    -1.1528E+05     2.4817E+06
-2.5587E+05    -1.2176E+08    -5.4739E+06
         34    270.0     -6.8777E+06    -1.1134E+05     2.4828E+06
-1.4902E+05    -1.4817E+08    -6.8630E+06
         35    280.0     -8.0353E+06    -1.1412E+05     2.4839E+06
4.4479E+04    -1.7971E+08    -7.8620E+06
         36    290.0     -9.3547E+06    -1.1862E+05     2.4731E+06
3.2150E+05    -2.1810E+08    -8.5581E+06

       MAXIMUM BASE SHEAR         = 1.5634E+07  AT PHASE =  -20.0

       MAXIMUM OVERTURNING MOMENT = 4.6282E+08  AT PHASE =  -20.0


    SEASTATE NO   3

       STEP    PHASE      LX             LY             LZ             MX
     MY             MZ
       ----    -----      ----------     ----------     ----------
----------     ----------     ----------

          1    -60.0     -4.6698E-01     1.1080E+07     2.2582E+06
```

```
-2.7281E+08    -1.1844E+01     2.0710E+03
         2     -50.0     -5.5816E-01     1.2637E+07     2.1357E+06
-3.2612E+08    -1.2656E+01     2.4376E+03
         3     -40.0     -4.8789E-01     1.4096E+07     1.9644E+06
-3.8282E+08    -1.4000E+01     2.7068E+03
         4     -30.0     -5.0580E-01     1.5178E+07     1.7710E+06
-4.3342E+08    -1.6000E+01     2.8011E+03
         5     -20.0     -6.3123E-01     1.5515E+07     1.5705E+06
-4.6286E+08    -2.1094E+01     2.6780E+03
         6     -10.0     -4.9700E-01     1.4719E+07     1.3593E+06
-4.5293E+08    -1.4812E+01     2.3359E+03
         7       0.0     -6.0537E-01     1.2561E+07     1.1711E+06
-3.9100E+08    -1.6781E+01     1.7782E+03
         8      10.0     -4.5102E-01     9.2020E+06     1.0810E+06
-2.8269E+08    -9.9062E+00     1.0996E+03
         9      20.0     -2.2947E-01     5.2111E+06     1.0759E+06
-1.5314E+08    -3.2500E+00     3.8819E+02
        10      30.0     -1.6543E-02     1.2969E+06     1.1358E+06
-3.2267E+07    -4.0625E-01    -2.5220E+02
        11      40.0      4.2178E-02    -1.9858E+06     1.2649E+06
5.9712E+07     1.3438E+00    -7.2741E+02
        12      50.0      1.8581E-01    -4.3869E+06     1.4222E+06
1.1806E+08     3.3438E+00    -9.8888E+02
        13      60.0      2.1035E-01    -5.8842E+06     1.5990E+06
1.4704E+08     6.7500E+00    -1.0336E+03
        14      70.0      2.9156E-01    -6.5912E+06     1.7562E+06
1.5453E+08     5.5625E+00    -8.9850E+02
1DATE: 04-JUN-2012 TIME: 15:08:19   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :    15

        15      80.0      2.5581E-01    -6.6734E+06     1.8952E+06
1.4794E+08     7.5000E+00    -6.5462E+02
        16      90.0      2.5989E-01    -6.3089E+06     2.0007E+06
1.3292E+08     5.3750E+00    -4.4844E+02
        17     100.0      2.2695E-01    -5.7404E+06     2.0694E+06
1.1513E+08     4.3438E+00    -3.7206E+02
        18     110.0      2.4304E-01    -5.1586E+06     2.1132E+06
9.9017E+07     4.8125E+00    -3.3700E+02
        19     120.0      2.1625E-01    -4.6235E+06     2.1445E+06
8.5456E+07     3.8125E+00    -3.3038E+02
        20     130.0      1.5817E-01    -4.1368E+06     2.1692E+06
7.3953E+07     3.3750E+00    -3.4278E+02
        21     140.0      1.2729E-01    -3.6798E+06     2.1950E+06
6.3774E+07     2.4375E+00    -3.7116E+02
        22     150.0      1.3327E-01    -3.2179E+06     2.2218E+06
5.4126E+07     3.7812E+00    -4.0284E+02
        23     160.0      1.0866E-01    -2.7212E+06     2.2507E+06
4.4362E+07     2.7812E+00    -4.3203E+02
        24     170.0      8.8548E-02    -2.1655E+06     2.2819E+06
3.3955E+07     1.0938E+00    -4.5647E+02
        25     180.0      5.4861E-02    -1.5333E+06     2.3146E+06
2.2507E+07     6.5625E-01    -4.6866E+02
        26     190.0      5.0577E-02    -8.1265E+05     2.3479E+06
9.6744E+06     7.1875E-01    -4.5908E+02
        27     200.0     -1.4578E-03     1.4365E+03     2.3792E+06
-4.8097E+06     4.3750E-01    -4.1625E+02
        28     210.0     -3.9914E-02     9.0583E+05     2.4052E+06
-2.1130E+07    -7.8125E-01    -3.2672E+02
        29     220.0     -7.3589E-02     1.8863E+06     2.4244E+06
-3.9305E+07    -1.2812E+00    -1.7788E+02
        30     230.0     -1.2024E-01     2.9180E+06     2.4333E+06
-5.9291E+07    -1.8750E+00     3.6125E+01
        31     240.0     -1.8100E-01     3.9636E+06     2.4309E+06
-8.0894E+07    -3.0625E+00     3.0406E+02
        32     250.0     -2.1650E-01     4.9774E+06     2.4270E+06
-1.0368E+08    -4.6875E+00     5.4488E+02
        33     260.0     -2.0895E-01     5.9851E+06     2.4217E+06
-1.2810E+08    -5.3125E+00     7.2325E+02
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          34    270.0     -2.3881E-01     7.0429E+06     2.4084E+06
-1.5514E+08    -6.4375E+00     9.7125E+02
          35    280.0     -3.6063E-01     8.2371E+06     2.3887E+06
-1.8733E+08    -7.0312E+00     1.2912E+03
          36    290.0     -3.9448E-01     9.5901E+06     2.3359E+06
-2.2649E+08    -1.0562E+01     1.6692E+03

       MAXIMUM BASE SHEAR         = 1.5515E+07  AT PHASE =  -20.0

       MAXIMUM OVERTURNING MOMENT = 4.6286E+08  AT PHASE =  -20.0


    SEASTATE NO   4

       STEP    PHASE      LX             LY             LZ             MX
     MY           MZ
       ----    -----      ----------     ----------     ----------
----------     ----------     ----------

           1    -60.0      1.0840E+07    -1.1325E+05     2.4400E+06
4.0562E+05     2.6441E+08     9.1470E+06
           2    -50.0      1.2425E+07    -9.4686E+04     2.3787E+06
1.9725E+05     3.1835E+08     9.6279E+06
           3    -40.0      1.3946E+07    -5.5036E+04     2.2934E+06
-6.8335E+05     3.7613E+08     9.9669E+06
           4    -30.0      1.5144E+07     4.3130E+03     2.1637E+06
-2.1232E+06     4.2949E+08     1.0105E+07
           5    -20.0      1.5634E+07     8.4300E+04     1.9964E+06
-4.3020E+06     4.6280E+08     9.9400E+06
           6    -10.0      1.5001E+07     1.7454E+05     1.7877E+06
-6.8144E+06     4.5692E+08     9.3110E+06
           7      0.0      1.2987E+07     2.6318E+05     1.5796E+06
-9.3510E+06     3.9811E+08     8.1136E+06
           8     10.0      9.7429E+06     3.3103E+05     1.4105E+06
-1.1174E+07     2.9218E+08     6.4012E+06
           9     20.0      5.8236E+06     3.6544E+05     1.3140E+06
-1.1873E+07     1.6413E+08     4.3985E+06
          10     30.0      1.9202E+06     3.5967E+05     1.2805E+06
-1.1197E+07     4.3247E+07     2.3906E+06
          11     40.0     -1.4175E+06     3.2254E+05     1.3093E+06
-9.6654E+06    -5.0439E+07     5.8071E+05
          12     50.0     -3.9269E+06     2.6151E+05     1.3805E+06
-7.5801E+06    -1.1168E+08    -9.5507E+05
          13     60.0     -5.5621E+06     1.9115E+05     1.4981E+06
-5.6128E+06    -1.4390E+08    -2.2051E+06
          14     70.0     -6.4146E+06     1.1875E+05     1.6345E+06
-3.8722E+06    -1.5439E+08    -3.1593E+06
          15     80.0     -6.6267E+06     5.0088E+04     1.7726E+06
-2.4397E+06    -1.5013E+08    -3.8472E+06
          16     90.0     -6.3745E+06    -1.3427E+03     1.8970E+06
-1.5894E+06    -1.3694E+08    -4.4816E+06
          17    100.0     -5.8382E+06    -3.2185E+04     1.9879E+06
-1.1633E+06    -1.1980E+08    -5.1908E+06
          18    110.0     -5.2458E+06    -4.4519E+04     2.0470E+06
-1.0858E+06    -1.0362E+08    -5.4265E+06
          19    120.0     -4.6934E+06    -4.6084E+04     2.0888E+06
-1.2458E+06    -8.9740E+07    -5.0385E+06
          20    130.0     -4.2004E+06    -4.6729E+04     2.1168E+06
-1.3962E+06    -7.8045E+07    -4.4568E+06
          21    140.0     -3.7487E+06    -4.9647E+04     2.1397E+06
-1.4827E+06    -6.7878E+07    -3.8712E+06
          22    150.0     -3.3016E+06    -5.5610E+04     2.1639E+06
-1.5025E+06    -5.8388E+07    -3.2787E+06
          23    160.0     -2.8270E+06    -6.4897E+04     2.1908E+06
-1.4338E+06    -4.8910E+07    -2.6649E+06
          24    170.0     -2.2980E+06    -7.6994E+04     2.2215E+06
-1.2863E+06    -3.8885E+07    -2.0139E+06
          25    180.0     -1.6940E+06    -9.0998E+04     2.2565E+06
```

```
-1.0796E+06    -2.7856E+07    -1.3124E+06
         26    190.0     -1.0005E+06    -1.0565E+05     2.2953E+06
-8.4540E+05    -1.5442E+07    -5.5250E+05
1DATE: 04-JUN-2012 TIME: 15:08:19   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                                PAGE :    16

         27    200.0     -2.0989E+05    -1.1973E+05     2.3364E+06
-6.0760E+05    -1.3420E+06     2.6001E+05
         28    210.0      6.7748E+05    -1.3164E+05     2.3770E+06
-3.9108E+05     1.4658E+07     1.1089E+06
         29    220.0      1.6510E+06    -1.3957E+05     2.4138E+06
-2.2698E+05     3.2647E+07     1.9635E+06
         30    230.0      2.6877E+06    -1.4157E+05     2.4444E+06
-1.5092E+05     5.2553E+07     2.7812E+06
         31    240.0      3.7526E+06    -1.3697E+05     2.4647E+06
-1.4156E+05     7.4202E+07     3.5121E+06
         32    250.0      4.8129E+06    -1.2688E+05     2.4742E+06
-1.6438E+05     9.7406E+07     4.2886E+06
         33    260.0      5.8445E+06    -1.1528E+05     2.4817E+06
-2.5589E+05     1.2176E+08     5.4733E+06
         34    270.0      6.8777E+06    -1.1133E+05     2.4828E+06
-1.4904E+05     1.4817E+08     6.8623E+06
         35    280.0      8.0352E+06    -1.1412E+05     2.4839E+06
4.4463E+04     1.7971E+08     7.8613E+06
         36    290.0      9.3546E+06    -1.1862E+05     2.4731E+06
3.2148E+05     2.1810E+08     8.5572E+06

       MAXIMUM BASE SHEAR         = 1.5634E+07  AT PHASE =  -20.0

       MAXIMUM OVERTURNING MOMENT = 4.6282E+08  AT PHASE =  -20.0


    SUMMARY OF MAXIMUM BASE SHEAR AND OVERTURNING MOMENT:

       SEASTATE     MAXIMUM        MAXIMUM
       NO.          BASE SHEAR     OVERTURNING MOMENT
       --------     ----------     ------------------

          1         1.5473E+07     4.5678E+08
          2         1.5634E+07     4.6282E+08
          3         1.5515E+07     4.6286E+08
          4         1.5634E+07     4.6282E+08


 C E N T R E   O F   B U O Y A N C Y :

   X=-1.9368E-07   Y=-1.1523E+00   Z= 1.9271E+01
1DATE: 04-JUN-2012 TIME: 15:08:19   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                                PAGE :    17


 SUMMARY OF ADMINISTRATIVE DATA TRANSFERRED TO STRUCTURAL ANALYSIS PROGRAM :
 ---------------------------------------------------------------------------



----------------------------------------------------------------------------------
------------------------------------------------
 : SEASTATE  /   : WAVE     : WAVE     : WAVE     : WATER    : MUDPLANE :  WIND
  : GUST WIND: TIME STEPS                 :
 : IDENTIFICATION: DIRECTION: HEIGHT   : PERIOD   : DEPTH    : ELEVATION:
PROFILE : INDUCED  : LOAD CASE NUMBERS             :
 : NUMBER        :          :          :          :          :          :  INDEX
  : FATIGUE  :                             :

----------------------------------------------------------------------------------
------------------------------------------------
 :               :          :          :          :          :          :      1
```

```
  :  NO      :          :          :          :
 :    1  /    1  : 270.0    : 17.50    : 14.20    : 45.00    :-.5651E-11:
  :          :          :          :          :
 :               :          :          :          :          :          :
  :          :    -0.789:    -0.789:
 :               :          :          :          :          :          :
  :          :        12.:        13.:

--------------------------------------------------------------------------------
--------------------------------------------
 :               :          :          :          :          :          :     2
  :  NO      :          :          :          :
 :    2  /    2  : 180.0    : 17.50    : 14.20    : 45.00    :-.5651E-11:
  :          :          :          :          :
 :               :          :          :          :          :          :
  :          :    -0.789:    -0.789:
 :               :          :          :          :          :          :
  :          :        14.:        15.:

--------------------------------------------------------------------------------
--------------------------------------------
 :               :          :          :          :          :          :     3
  :  NO      :          :          :          :
 :    3  /    3  : 90.00    : 17.50    : 14.20    : 45.00    :-.5651E-11:
  :          :          :          :          :
 :               :          :          :          :          :          :
  :          :    -0.789:    -0.789:
 :               :          :          :          :          :          :
  :          :        16.:        17.:

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--------------------------------------------
 :               :          :          :          :          :          :     4
  :  NO      :          :          :          :
 :    4  /    4  :     0.0000: 17.50    : 14.20    : 45.00    :-.5651E-11:
  :          :          :          :          :
 :               :          :          :          :          :          :
  :          :    -0.789:    -0.789:
 :               :          :          :          :          :          :
  :          :        18.:        19.:



--------------------------------------------------------------------------------
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 :     WIND     MEAN       WIND       GUST       MEAN      HEIGHT      MEAN     LENGTH
    WIND   :
 :  PROFILE     WIND      ANGLE      FACTOR    VELOCITY  EXPONENT    PERIOD    SCALE
   PROFILE :
 :   INDEX    VELOCITY                           LEVEL                RATIO     FACTOR
   FORMULA :

--------------------------------------------------------------------------------
------------
 :      1       25.000   270.000      0.315     10.000      0.700     -----      1.00
      0    :
 :      2       25.000   180.000      0.315     10.000      0.700     -----      1.00
      0    :
 :      3       25.000    90.000      0.315     10.000      0.700     -----      1.00
      0    :
 :      4       25.000     0.000      0.315     10.000      0.700     -----      1.00
      0    :


 CPU TIME CONSUMPTION: 0.2300
```

```
P R O G R A M   N O R M A L   E N D
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Vedlegg 11 – Analyse 2, lineær strukturanalyse og hydrodynamisk analyse , alternativt design, fra Sesam GeniE

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1



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                               **               Superelement Structural Analysis
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                                              Marketing and Support by DNV
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```
Software



               Program id   : 8.4-01
Computer         : 586
               Release date : 20-NOV-2008
Impl. update     :
               Access time  : 01-JUN-2012 17:41:47
Operating system : Win NT 5.2 [3790]
               User id      : ofsbilil
CPU id           : 1975103069

Installation     : , NOS295


               Copyright DET NORSKE VERITAS AS, P.O.Box 300, N-1322 Hovik,
Norway


               Library     Version    Impl.Upd   Release date
               ELLIB       1.9-07                20-NOV-2008
               SIFTOOL     8.3-05                20-NOV-2008
               NORSAM      8.4-01                20-NOV-2008
               MFR         8.3-05                20-NOV-2008
               PRIMAS      5.3-04                20-NOV-2008
               AUXLIB      8.2-02                20-NOV-2008
               SESTRA_PRLL 8.1-02                20-NOV-2008

               Run identification   :




□
 DATE: 01-JUN-2012 TIME: 17:42:04   ***************  SESTRA  ***************
                                        PAGE:     1

                                    DATA GENERATION MODULE

                                    SUB PAGE:     1

  PRINTOUT OF DATA GIVEN AS DIRECT INPUT TO SESTRA



   HEAD

   COMM

   COMM    Created by: GeniE  V5.3-10  14-Apr-2011

   COMM

   COMM    Date : 01-Jun-2012   Time : 16:41:45   User : ofsbilil

   COMM

   COMM  CHCK ANTP MSUM MOLO STIF RTOP LBCK      PILE CSING     SIGM

   CMAS    0.   1.   1.   0.   0.   0.   0.   0.   0.  0.00E+00  0.00E+00
0.00E+00
   COMM
```

```
   COMM            ORDR                           CACH MFRWORK

   SOLM    0.   0.   0.   0.   0.   0.   0.   0.   0.  0.00E+00  0.00E+00
0.00E+00
   COMM

   COMM                 WCOR

   ELOP    0.   0.   0.   1.   0.   0.   0.   0.   0.  0.00E+00  0.00E+00
0.00E+00
   COMM

   COMM  ITYP

   ITOP    1.   0.   0.   0.   0.   0.   0.   0.   0.  0.00E+00  0.00E+00
0.00E+00
   COMM

   COMM  PREFIX

   INAM  20120601_163705_

   COMM

   COMM  PREFIX FORMAT

   LNAM  20120601_163705_ UNFORMATTED

   COMM

   COMM  PREFIX FORMAT

   RNAM  20120601_163705_ NORSAM

   COMM

   COMM  SEL1 SEL2 SEL3 SEL4 SEL5 SEL6 SEL7 SEL8

   RSEL    1.   0.   0.   0.   0.   0.   1.   0.   0.  0.00E+00  0.00E+00
0.00E+00
   COMM

   COMM  RTRA

   RETR    3.   0.   0.   0.   0.   0.   0.   0.   0.  0.00E+00  0.00E+00
0.00E+00
   Z


  PRINTOUT OF DATA GIVEN IN THE FILE 20120601_163705_S1.FEM


   LOHI    1.   0.  12.   1.   1.   0.   0.   0.   1.  0.10E+01  0.00E+00
0.00E+00
   SEAS    1.  0.00E+00  0.10E+01  0.70E+01  0.10E+01  0.27E+03  0.18E+02
0.14E+02
           0.  0.45E+02  0.10E+01 -0.57E-11  0.00E+00  0.00E+00  0.00E+00
0.00E+00
   TILO    1.  0.00E+00  0.10E+01 -0.79E+00 -0.79E+00  0.00E+00  0.00E+00
0.00E+00
   LCOM    1.  0.00E+00  0.10E+01  0.12E+02  0.13E+02  0.00E+00  0.00E+00
0.00E+00
   LOHI    2.   0.  12.   2.   2.   0.   0.   0.   2.  0.20E+01  0.00E+00
0.00E+00
   SEAS    2.  0.00E+00  0.10E+01  0.70E+01  0.10E+01  0.18E+03  0.18E+02
0.14E+02
           0.  0.45E+02  0.10E+01 -0.57E-11  0.00E+00  0.00E+00  0.00E+00
0.00E+00
```

```
   TILO    2.  0.00E+00  0.10E+01 -0.79E+00 -0.79E+00  0.00E+00  0.00E+00
0.00E+00
   LCOM    2.  0.00E+00  0.10E+01  0.14E+02  0.15E+02  0.00E+00  0.00E+00
0.00E+00
   LOHI    3.   0.  12.   3.   3.   0.   0.   0.   3.  0.30E+01  0.00E+00
0.00E+00
   SEAS    3.  0.00E+00  0.10E+01  0.70E+01  0.10E+01  0.90E+02  0.18E+02
0.14E+02
           0.  0.45E+02  0.10E+01 -0.57E-11  0.00E+00  0.00E+00  0.00E+00
0.00E+00
   TILO    3.  0.00E+00  0.10E+01 -0.79E+00 -0.79E+00  0.00E+00  0.00E+00
0.00E+00
   LCOM    3.  0.00E+00  0.10E+01  0.16E+02  0.17E+02  0.00E+00  0.00E+00
0.00E+00

 DATE: 01-JUN-2012 TIME: 17:42:09   ***************  SESTRA  ***************
                                        PAGE:     2

                                    DATA GENERATION MODULE

                                    SUB PAGE:     2

  PRINTOUT OF DATA GIVEN AS DIRECT INPUT TO SESTRA



   LOHI    4.   0.  12.   4.   4.   0.   0.   0.   4.  0.40E+01  0.00E+00
0.00E+00
   SEAS    4.  0.00E+00  0.10E+01  0.70E+01  0.10E+01  0.00E+00  0.18E+02
0.14E+02
           0.  0.45E+02  0.10E+01 -0.57E-11  0.00E+00  0.00E+00  0.00E+00
0.00E+00
   TILO    4.  0.00E+00  0.10E+01 -0.79E+00 -0.79E+00  0.00E+00  0.00E+00
0.00E+00
   LCOM    4.  0.00E+00  0.10E+01  0.18E+02  0.19E+02  0.00E+00  0.00E+00
0.00E+00
   WIND    1.  0.25E+02  0.27E+03  0.32E+00  0.10E+02  0.70E+00  0.00E+00
0.10E+01
           0.  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00
   WIND    2.  0.25E+02  0.18E+03  0.32E+00  0.10E+02  0.70E+00  0.00E+00
0.10E+01
           0.  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00
   WIND    3.  0.25E+02  0.90E+02  0.32E+00  0.10E+02  0.70E+00  0.00E+00
0.10E+01
           0.  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00
   WIND    4.  0.25E+02  0.00E+00  0.32E+00  0.10E+02  0.70E+00  0.00E+00
0.10E+01
           0.  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00

 DATE: 01-JUN-2012 TIME: 17:42:11   ***************  SESTRA  ***************
                                        PAGE:     3

                                    DATA GENERATION MODULE

                                    SUB PAGE:     3
  INTERPRETATION OF ANALYSIS CONTROL DATA
```

```
      Type of Analysis :

         Reduction

         Multifront Solver is used

         Retracking


      Input from CMAS Command :

         ANTYP = 1   Static Analysis

         MSUM  > 0   Calculation of Sum of Masses and Centroid

         The singularity constant for membrane and shell elements

         CSING =  1.0000E-08

         Lowest accepted condition number in reduction

         EPSSOL=  1.1102E-14


      Input from RSEL Command :

         Data types selected for storing on Results File :

          - Input Interface File Records,

          - displacements,  sequence:

               all nodes for the first resultcase, all nodes for the second
resultcase, etc.
          - forces and moments for beam, spring and layered shell elements,
sequence:
               all elements for the first resultcase, all elements for the
second resultcase, etc.
          - stresses (not for beam or spring elements),  sequence:

               all elements for the first resultcase, all elements for the
second resultcase, etc.

         (Can be redefined by RSEL for selected superelements, see below.)

         Storing is done for superelements specified in RETR command.

 DATE: 01-JUN-2012 TIME: 17:42:14   ***************  SESTRA  ***************
                                        PAGE:     4

                                    DATA GENERATION MODULE

                                    SUB PAGE:     4

  INPUT INTERFACE FILES :
```

```
20120601_163705_T1.FEM

20120601_163705_L1.FEM

    DATE:     01-Jun-2012         TIME:          16:37:05
    PROGRAM:  SESAM GeniE         VERSION:       V5.3-10 14-Apr-2011
    COMPUTER: X86 Windows         INSTALLATION:
    USER:     ofsbilil            ACCOUNT:

    DATE:     01-Jun-2012         TIME:          16:37:05
    PROGRAM:  SESAM Gamesha       VERSION:       R5.0-3 14-Apr-2011
    COMPUTER: X86 Windows         INSTALLATION:
    USER:     ofsbilil            ACCOUNT:

    DATE:     01-JUN-2012         TIME:         16:38:41
    PROGRAM:  SESAM WAJAC         VERSION:      5.9-02 28-FEB-2007
    COMPUTER: 586 WIN NT 5.2 [3790INSTALLATION: , NOS295
    USER:     OFSBILIL            ACCOUNT:

 DATE: 01-JUN-2012 TIME: 17:42:19   ***************  SESTRA  ***************
                                        PAGE:     5

                                    DATAGENERATION - SUPERELEMENT TYPE     1

                                    SUB PAGE:     5




     *** SUMMARY OF DATA FROM INPUT AND LOAD INTERFACE FILES ***

              FOR SUPERELEMENT TYPE       1  ON LEVEL  1

     The superelement has


           51  subelements

           34  nodes

           18  specified (fixed) degrees of freedom

          186  internal (free) degrees of freedom

         totally

          204  degrees of freedom


           19  loadcases
```

```
 The following kinds of loads are given:

       node loads

       line or point loads for 2 node beams

       gravitational load


 The following basic elements are given:

       51  2 node beam elements         BEAS


 DATE: 01-JUN-2012 TIME: 17:42:27   ***************  SESTRA  ***************
                                            PAGE:     6

                                        DATAGENERATION - SUPERELEMENT TYPE     1

                                        SUB PAGE:     6

     *** SUM OF LOADS AND MOMENTS FOR SUPERELEMENT TYPE     1  ON LEVEL  1  ***


    X-LOAD = SUM OF GIVEN LOADS IN GLOBAL X-DIRECTION

    Y-LOAD = SUM OF GIVEN LOADS IN GLOBAL Y-DIRECTION

    Z-LOAD = SUM OF GIVEN LOADS IN GLOBAL Z-DIRECTION

    X-MOM  = SUM OF LOCAL MOMENTS ABOUT GLOBAL X-AXIS

    Y-MOM  = SUM OF LOCAL MOMENTS ABOUT GLOBAL Y-AXIS

    Z-MOM  = SUM OF LOCAL MOMENTS ABOUT GLOBAL Z-AXIS

    X-RMOM = SUM OF MOMENTS ABOUT GLOBAL X-AXIS FROM GIVEN LOADS AND MOMENTS

    Y-RMOM = SUM OF MOMENTS ABOUT GLOBAL Y-AXIS FROM GIVEN LOADS AND MOMENTS

    Z-RMOM = SUM OF MOMENTS ABOUT GLOBAL Z-AXIS FROM GIVEN LOADS AND MOMENTS


     LOADCASE    X-LOAD      Y-LOAD      Z-LOAD      X-MOM       Y-MOM
Z-MOM      X-RMOM      Y-RMOM      Z-RMOM
           1  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
           2  0.0000E+00  1.2369E-10 -2.3002E+07  0.0000E+00  0.0000E+00
0.0000E+00  1.9895E+07  5.3361E-04 -5.1699E-26
           3  0.0000E+00 -2.1182E+04  0.0000E+00 -1.0591E+03  0.0000E+00
0.0000E+00  1.8868E+06  0.0000E+00  0.0000E+00
           4  0.0000E+00  2.1182E+04  0.0000E+00  1.0591E+03  0.0000E+00
0.0000E+00 -1.8868E+06  0.0000E+00  0.0000E+00
           5 -2.1182E+04  0.0000E+00  0.0000E+00  0.0000E+00  1.0591E+03
0.0000E+00  0.0000E+00 -1.8868E+06  0.0000E+00
           6  2.1182E+04  0.0000E+00  0.0000E+00  0.0000E+00 -1.0591E+03
0.0000E+00  0.0000E+00  1.8868E+06  0.0000E+00
           7  3.9700E+05  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  5.2861E+07  0.0000E+00
```

```
           8  0.0000E+00  0.0000E+00  0.0000E+00  4.4400E+06  0.0000E+00
0.0000E+00  4.4400E+06  0.0000E+00  0.0000E+00
           9  0.0000E+00  0.0000E+00 -3.4335E+06  0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
          10  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00 -9.5400E+05
0.0000E+00  0.0000E+00 -9.5400E+05  0.0000E+00
          11  0.0000E+00 -1.4500E+05  0.0000E+00  0.0000E+00  0.0000E+00
0.0000E+00  1.9307E+07  0.0000E+00  0.0000E+00
          12  2.0976E-01 -1.5634E+07  2.4483E+06  3.3732E+06  9.9222E-02
-3.1927E-02  4.7840E+08  6.2919E+00 -2.5057E+03
          13  2.0976E-01 -1.5634E+07  2.4483E+06  3.3732E+06  9.9222E-02
-3.1927E-02  4.7840E+08  6.2919E+00 -2.5057E+03
          14 -1.5794E+07  8.4298E+04  1.9964E+06  6.6779E+03 -3.2480E+06
1.6296E+04 -4.3385E+06 -4.8448E+08 -9.6747E+06
          15 -1.5794E+07  8.4298E+04  1.9964E+06  6.6779E+03 -3.2480E+06
1.6296E+04 -4.3385E+06 -4.8448E+08 -9.6747E+06
          16 -6.5855E-01  1.5676E+07  1.5705E+06 -3.1454E+06 -2.2300E-02
6.1712E-02 -4.8457E+08 -1.9973E+01  2.6841E+03
          17 -6.5855E-01  1.5676E+07  1.5705E+06 -3.1454E+06 -2.2300E-02
6.1712E-02 -4.8457E+08 -1.9973E+01  2.6841E+03
          18  1.5794E+07  8.4299E+04  1.9964E+06  6.6777E+03  3.2481E+06
-1.6296E+04 -4.3385E+06  4.8448E+08  9.6746E+06
          19  1.5794E+07  8.4299E+04  1.9964E+06  6.6777E+03  3.2481E+06
-1.6296E+04 -4.3385E+06  4.8448E+08  9.6746E+06

 DATE: 01-JUN-2012 TIME: 17:42:31   ***************  SESTRA  ***************
                                        PAGE:     7

                                    DATAGENERATION - SUPERELEMENT TYPE     1

                                    SUB PAGE:     7

      *** SUM OF MASSES AND CENTROID FOR SUPERELEMENT TYPE     1  ON LEVEL  1
***



   MASS MATRIX IN GLOBAL COORDINATE SYSTEM (OF THE SUPERELEMENT):

   ---------------------------------------

   2.34555E+06    0.00000E+00    0.00000E+00    0.00000E+00    7.90003E+07
2.02869E+06
   0.00000E+00    2.34555E+06    0.00000E+00   -7.90003E+07    0.00000E+00
5.44135E-05
   0.00000E+00    0.00000E+00    2.34555E+06   -2.02869E+06   -5.44135E-05
0.00000E+00
   0.00000E+00   -7.90003E+07   -2.02869E+06    4.76881E+09   -3.77063E-04
0.00000E+00
   7.90003E+07    0.00000E+00   -5.44135E-05   -3.77063E-04    4.76692E+09
2.98574E+07
   2.02869E+06    5.44135E-05    0.00000E+00    0.00000E+00    2.98574E+07
3.25718E+08



   COORDINATES OF CENTROID:

   ------------------------

   2.3199E-11    -8.6491E-01     3.3681E+01
```

```
   MASS MATRIX AT CENTROID:

   ------------------------

   2.34555E+06    0.00000E+00    0.00000E+00    0.00000E+00   -1.49012E-08
0.00000E+00
   0.00000E+00    2.34555E+06    0.00000E+00    1.49012E-08    0.00000E+00
0.00000E+00
   0.00000E+00    0.00000E+00    2.34555E+06    0.00000E+00    0.00000E+00
0.00000E+00
   0.00000E+00    1.49012E-08    0.00000E+00    2.10626E+09   -4.24126E-04
1.83269E-03
  -1.49012E-08    0.00000E+00    0.00000E+00   -4.24126E-04    2.10613E+09
-3.84705E+07
   0.00000E+00    0.00000E+00    0.00000E+00    1.83269E-03   -3.84705E+07
3.23964E+08

  *** Estimated size of stiffness matrix for superelement       1:        2952
variables

 DATE: 01-JUN-2012 TIME: 17:42:33   ***************  SESTRA  ***************
                                                PAGE:     8

                                            DATAGENERATION - SUPERELEMENT TYPE     1

                                            SUB PAGE:     8

      *** CONNECTION BETWEEN LOADCASE AND RESULTCASE NUMBERS ***


  TOP LEVEL EXT.RESULT  INDEX    TIME       WAVE DIR.   WAVE HEIGHT    WATER

  LOADCASE  IDENT.NO.                         (RAD)                    DEPTH

        1          1

        2          2

        3          3

        4          4

        5          5

        6          6

        7          7

        8          8

        9          9

       10         10

       11         11

       12         12        1   -7.889E-01    4.712E+00    1.750E+01    4.500E+01

       13         12        2   -7.889E-01    4.712E+00    1.750E+01    4.500E+01

       14         13        1   -7.889E-01    3.142E+00    1.750E+01    4.500E+01

       15         13        2   -7.889E-01    3.142E+00    1.750E+01    4.500E+01
```

```
     16         14       1   -7.889E-01    1.571E+00    1.750E+01    4.500E+01
     17         14       2   -7.889E-01    1.571E+00    1.750E+01    4.500E+01
     18         15       1   -7.889E-01    0.000E+00    1.750E+01    4.500E+01
     19         15       2   -7.889E-01    0.000E+00    1.750E+01    4.500E+01


  *** Estimate of total size of stiffness matrices for new superelements:
   2952 variables

 DATE: 01-JUN-2012 TIME: 17:42:37   ***************  SESTRA  ***************
                                        PAGE:     9

                                    REDUCTION MODULE - SUPERELEMENT TYPE    1

                                    SUB PAGE:     1




                                     - STIFFNESS FACTORIZATION PERFORMED BY
MULTIFRONT EQUATION SOLVER -

                                     - LOAD SUBSTITUTION PERFORMED BY
MULTIFRONT EQUATION SOLVER -

 DATE: 01-JUN-2012 TIME: 17:42:45   ***************  SESTRA  ***************
                                        PAGE:    10

                                          STATIC ANALYSIS OF STRUCTURE

                                    SUB PAGE:     1


      Results file name: 20120601_163705_R1.SIN


 DATE: 01-JUN-2012 TIME: 17:42:50   ***************  SESTRA  ***************
                                        PAGE:    11

                                    RETRACKING MODULE - SUPERELEMENT TYPE    1

                                    THE STRUCTURE
                                    SUB PAGE:     2

  REACTION FORCES IN NODES WITH SPECIFIED (FIXED) DEGREES OF FREEDOM.

  NODES MARKED WITH AN ASTERISK (*) TO THE RIGHT HAVE A LOCAL COORDINATE SYSTEM.

  ******************************************************************************
```

```
 LOADCASE (INDEX) NODE NO.      X             Y             Z            RX
      RY            RZ

       1              1   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
 0.00000E+00   0.00000E+00
                     15   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
 0.00000E+00   0.00000E+00
                     32   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
 0.00000E+00   0.00000E+00

       2              1   1.68402E+06   1.16387E+06   7.29546E+06   9.27668E+05
-1.42672E+06  -3.27093E+03
                     15  -1.03644E-10  -2.32774E+06   8.41112E+06  -1.26798E+06
-2.66807E-04   4.92589E-11
                     32  -1.68402E+06   1.16387E+06   7.29546E+06   9.27668E+05
 1.42672E+06   3.27093E+03

       3              1   2.52144E+02   5.83004E+03   3.07780E+04  -9.69424E+04
-3.32786E+03  -1.07694E+04
                     15  -5.54682E-11   9.52237E+03  -6.15560E+04  -9.36697E+04
-6.61162E-10   1.13883E-10
                     32  -2.52144E+02   5.83004E+03   3.07780E+04  -9.69424E+04
 3.32786E+03   1.07694E+04

       4              1  -2.52144E+02  -5.83004E+03  -3.07780E+04   9.69424E+04
 3.32786E+03   1.07694E+04
                     15   5.54682E-11  -9.52237E+03   6.15560E+04   9.36697E+04
 6.61162E-10  -1.13883E-10
                     32   2.52144E+02  -5.83004E+03  -3.07780E+04   9.69424E+04
-3.32786E+03  -1.07694E+04

       5              1   7.34623E+03   1.60378E+03   5.29689E+04  -3.58159E+03
 9.36784E+04   5.73673E+03
                     15   6.48999E+03  -1.07617E-11   5.39523E-12   7.22380E-11
 1.10401E+05  -1.48474E+04
                     32   7.34623E+03  -1.60378E+03  -5.29689E+04   3.58159E+03
 9.36784E+04   5.73673E+03

       6              1  -7.34623E+03  -1.60378E+03  -5.29689E+04   3.58159E+03
-9.36784E+04  -5.73673E+03
                     15  -6.48999E+03   1.07617E-11  -5.39523E-12  -7.22380E-11
-1.10401E+05   1.48474E+04
                     32  -7.34623E+03   1.60378E+03   5.29689E+04  -3.58159E+03
-9.36784E+04  -5.73673E+03

       7              1  -1.22404E+05  -2.98847E+03  -1.52521E+06  -3.20712E+04
-2.16407E+06  -1.98693E+05
                     15  -1.52191E+05   4.60717E-10  -3.37254E-10  -3.02979E-09
-2.77618E+06   4.78834E+05
                     32  -1.22404E+05   2.98847E+03   1.52521E+06   3.20712E+04
-2.16407E+06  -1.98693E+05

       8              1  -9.03781E+03  -3.58505E+02   7.87654E+04  -1.29836E+05
-3.31527E+04  -4.02585E+04
                     15  -9.75028E-11   7.17010E+02  -1.57531E+05  -8.75595E+04
-1.17155E-09   1.97254E-10
                     32   9.03781E+03  -3.58505E+02   7.87654E+04  -1.29836E+05
 3.31527E+04   4.02585E+04

       9              1   3.08482E+05   2.14225E+05   1.03122E+06  -2.78425E+04
 4.93287E+04  -1.67761E+03
                     15  -2.02621E-11  -4.28450E+05   1.37106E+06   1.11161E+05
-2.45684E-10   1.46257E-11
                     32  -3.08482E+05   2.14225E+05   1.03122E+06  -2.78425E+04
-4.93287E+04   1.67761E+03
```

```
      10                1  -8.29808E+02  -1.46922E+03   2.90826E+04   5.36841E+03
  2.17801E+04   5.03531E+03
                       15   1.65962E+03  -7.66352E-12   6.99188E-12   4.70066E-11
  3.79618E+04  -1.10291E+04
                       32  -8.29808E+02   1.46922E+03  -2.90826E+04  -5.36841E+03
  2.17801E+04   5.03531E+03

      11                1  -1.12937E+04   3.94156E+04   3.23863E+05  -8.54013E+05
 -7.08310E+04  -1.31054E+05
                       15  -5.47214E-10   6.61687E+04  -6.47727E+05  -7.70289E+05
 -6.35876E-09   1.07546E-09
                       32   1.12937E+04   3.94156E+04   3.23863E+05  -8.54013E+05
  7.08310E+04   1.31054E+05

      12    1           1   1.28074E+06   4.20657E+06   5.87849E+06  -4.46780E+07
  8.35986E+05   8.53719E+05
                       15  -3.97600E+01   7.22046E+06  -1.42053E+07  -4.54233E+07
 -4.43252E+02   6.81698E+01
                       32  -1.28070E+06   4.20665E+06   5.87849E+06  -4.46790E+07
 -8.35483E+05  -8.53576E+05

 DATE: 01-JUN-2012 TIME: 17:42:53   ****************  SESTRA  ***************
                                        PAGE:    12

                                    RETRACKING MODULE - SUPERELEMENT TYPE    1

                                    THE STRUCTURE
                                    SUB PAGE:     3


  REACTION FORCES IN NODES WITH SPECIFIED (FIXED) DEGREES OF FREEDOM.

  NODES MARKED WITH AN ASTERISK (*) TO THE RIGHT HAVE A LOCAL COORDINATE SYSTEM.

  ******************************************************************************



  LOADCASE (INDEX) NODE NO.      X             Y             Z             RX
       RY            RZ

      12    2           1   1.28074E+06   4.20657E+06   5.87849E+06  -4.46780E+07
  8.35986E+05   8.53719E+05
                       15  -3.97600E+01   7.22046E+06  -1.42053E+07  -4.54233E+07
 -4.43252E+02   6.81698E+01
                       32  -1.28070E+06   4.20665E+06   5.87849E+06  -4.46790E+07
 -8.35483E+05  -8.53576E+05

      13    1           1   5.82241E+06   1.83416E+06   1.08476E+07  -2.06113E+06
  4.62638E+07  -5.97742E+05
                       15   3.52249E+06   3.93791E+05  -6.57897E+05   3.62753E+05
  4.68965E+07   3.86803E+05
                       32   6.44956E+06  -2.31225E+06  -1.21860E+07   2.38576E+06
  4.58180E+07  -5.18271E+05

      13    2           1   5.82241E+06   1.83416E+06   1.08476E+07  -2.06113E+06
  4.62638E+07  -5.97742E+05
                       15   3.52249E+06   3.93791E+05  -6.57897E+05   3.62753E+05
  4.68965E+07   3.86803E+05
                       32   6.44956E+06  -2.31225E+06  -1.21860E+07   2.38576E+06
  4.58180E+07  -5.18271E+05

      14    1           1  -1.94777E+06  -4.61731E+06  -7.19461E+06   4.45814E+07
 -5.77587E+05  -8.20427E+05
                       15   4.27345E+01  -6.44128E+06   1.28187E+07   4.60442E+07
  4.76864E+02  -7.31708E+01
                       32   1.94773E+06  -4.61740E+06  -7.19461E+06   4.45824E+07
```

```
  5.77050E+05   8.20274E+05

       14    2          1  -1.94777E+06  -4.61731E+06  -7.19461E+06   4.45814E+07
 -5.77587E+05  -8.20427E+05
                       15   4.27345E+01  -6.44128E+06   1.28187E+07   4.60442E+07
  4.76864E+02  -7.31708E+01
                       32   1.94773E+06  -4.61740E+06  -7.19461E+06   4.45824E+07
  5.77050E+05   8.20274E+05

       15    1          1  -6.44954E+06  -2.31225E+06  -1.21860E+07   2.38582E+06
 -4.58178E+07   5.18278E+05
                       15  -3.52249E+06   3.93792E+05  -6.57898E+05   3.62727E+05
 -4.68965E+07  -3.86803E+05
                       32  -5.82241E+06   1.83415E+06   1.08476E+07  -2.06110E+06
 -4.62638E+07   5.97745E+05

       15    2          1  -6.44954E+06  -2.31225E+06  -1.21860E+07   2.38582E+06
 -4.58178E+07   5.18278E+05
                       15  -3.52249E+06   3.93792E+05  -6.57898E+05   3.62727E+05
 -4.68965E+07  -3.86803E+05
                       32  -5.82241E+06   1.83415E+06   1.08476E+07  -2.06110E+06
 -4.62638E+07   5.97745E+05

 DATE: 01-JUN-2012 TIME: 17:42:54   ***************  SESTRA  ***************
                                        PAGE:    13

                                    RETRACKING MODULE - SUPERELEMENT TYPE    1

                                    THE STRUCTURE
                                    SUB PAGE:     4


  SUM OF REACTION FORCES FROM SPECIFIED DEGREES OF FREEDOM.

  THE FORCES AND MOMENTS ARE REFFERED TO THE COORDINATE SYSTEM OF THE ACTUAL
SUPERELEMENT.

********************************************************************************
********


  LOADCASE (INDEX)        X             Y             Z            RX
RY            RZ

       1            0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
0.0000E+00    0.0000E+00
       2            0.0000E+00    0.0000E+00    2.3002E+07   -1.9895E+07
-5.3346E-04    1.6662E-09
       3            5.0022E-12    2.1182E+04    0.0000E+00   -1.8868E+06
3.4925E-10    3.3178E-09
       4           -5.0022E-12   -2.1182E+04    0.0000E+00    1.8868E+06
-3.4925E-10   -3.3178E-09
       5            2.1182E+04   -2.1600E-11    1.2369E-10   -9.3132E-10
1.8868E+06    1.8917E-09
       6           -2.1182E+04    2.1600E-11   -1.2369E-10    9.3132E-10
-1.8868E+06   -1.8917E-09
       7           -3.9700E+05    9.1904E-10   -2.7940E-09    1.3039E-08
-5.2861E+07   -4.1910E-08
       8            5.4570E-12   -9.8278E-08    2.9104E-11   -4.4400E+06
2.0955E-09    5.3551E-09
       9           -5.8208E-11    2.3283E-10    3.4335E+06   -1.0058E-07
2.0489E-08   -1.3461E-10
      10           -2.1130E-08   -1.2960E-11    6.5484E-11   -4.0745E-10
9.5400E+05    8.2218E-10
      11           -4.0018E-11    1.4500E+05    2.3283E-10   -1.9307E+07
5.5879E-09    2.9802E-08
      12    1      -2.0976E-01    1.5634E+07   -2.4483E+06   -4.7840E+08
```

```
-6.2919E+00    2.5057E+03
       12    2       -2.0976E-01    1.5634E+07   -2.4483E+06   -4.7840E+08
-6.2919E+00    2.5057E+03
       13    1        1.5794E+07   -8.4298E+04   -1.9964E+06    4.3385E+06
4.8448E+08    9.6747E+06
       13    2        1.5794E+07   -8.4298E+04   -1.9964E+06    4.3385E+06
4.8448E+08    9.6747E+06
       14    1        6.5855E-01   -1.5676E+07   -1.5705E+06    4.8457E+08
1.9973E+01   -2.6841E+03
       14    2        6.5855E-01   -1.5676E+07   -1.5705E+06    4.8457E+08
1.9973E+01   -2.6841E+03
       15    1       -1.5794E+07   -8.4299E+04   -1.9964E+06    4.3385E+06
-4.8448E+08   -9.6746E+06
       15    2       -1.5794E+07   -8.4299E+04   -1.9964E+06    4.3385E+06
-4.8448E+08   -9.6746E+06


 SUPERELEMENT TYPE:     1 ACTUAL ELEMENT:     1

 HAS BEEN STORED ON RESULT FILE


 DATE: 01-JUN-2012 TIME: 17:43:00   ***************  SESTRA  ***************
                                                PAGE:    14

                                                RETRACKING MODULE - GLOBAL DATA

                                            SUB PAGE:     1

   SUM OF GLOBAL LOADS AND MOMENTS

   *******************************



   LOADCASE (INDEX)        X              Y              Z             RX
RY            RZ

        1             0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
0.0000E+00    0.0000E+00
        2             0.0000E+00    1.2369E-10   -2.3002E+07    1.9895E+07
5.3361E-04   -5.1699E-26
        3             0.0000E+00   -2.1182E+04    0.0000E+00    1.8868E+06
0.0000E+00    0.0000E+00
        4             0.0000E+00    2.1182E+04    0.0000E+00   -1.8868E+06
0.0000E+00    0.0000E+00
        5            -2.1182E+04    0.0000E+00    0.0000E+00    0.0000E+00
-1.8868E+06    0.0000E+00
        6             2.1182E+04    0.0000E+00    0.0000E+00    0.0000E+00
1.8868E+06    0.0000E+00
        7             3.9700E+05    0.0000E+00    0.0000E+00    0.0000E+00
5.2861E+07    0.0000E+00
        8             0.0000E+00    0.0000E+00    0.0000E+00    4.4400E+06
0.0000E+00    0.0000E+00
        9             0.0000E+00    0.0000E+00   -3.4335E+06    0.0000E+00
0.0000E+00    0.0000E+00
       10             0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
-9.5400E+05    0.0000E+00
       11             0.0000E+00   -1.4500E+05    0.0000E+00    1.9307E+07
0.0000E+00    0.0000E+00
       12    1        2.0976E-01   -1.5634E+07    2.4483E+06    4.7840E+08
6.2919E+00   -2.5057E+03
```

```
       12    2         2.0976E-01   -1.5634E+07    2.4483E+06    4.7840E+08
6.2919E+00   -2.5057E+03
       13    1        -1.5794E+07    8.4298E+04    1.9964E+06   -4.3385E+06
-4.8448E+08   -9.6747E+06
       13    2        -1.5794E+07    8.4298E+04    1.9964E+06   -4.3385E+06
-4.8448E+08   -9.6747E+06
       14    1        -6.5855E-01    1.5676E+07    1.5705E+06   -4.8457E+08
-1.9973E+01    2.6841E+03
       14    2        -6.5855E-01    1.5676E+07    1.5705E+06   -4.8457E+08
-1.9973E+01    2.6841E+03
       15    1         1.5794E+07    8.4299E+04    1.9964E+06   -4.3385E+06
4.8448E+08    9.6746E+06
       15    2         1.5794E+07    8.4299E+04    1.9964E+06   -4.3385E+06
4.8448E+08    9.6746E+06

 DATE: 01-JUN-2012 TIME: 17:43:01   ***************  SESTRA  ***************
                                        PAGE:    15


                                        RETRACKING MODULE - GLOBAL DATA


                                    SUB PAGE:     2


  SUM OF REACTION FORCES AND MOMENTS

  **********************************

  GIVEN IN THE GLOBAL COORDINATE SYSTEM OF THE TOP LEVEL SUPERELEMENT



  LOADCASE (INDEX)        X             Y             Z             RX
RY            RZ

        1              0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
0.0000E+00    0.0000E+00
        2              0.0000E+00    0.0000E+00    2.3002E+07   -1.9895E+07
-5.3346E-04    1.6662E-09
        3              5.0022E-12    2.1182E+04    0.0000E+00   -1.8868E+06
3.4925E-10    3.3178E-09
        4             -5.0022E-12   -2.1182E+04    0.0000E+00    1.8868E+06
-3.4925E-10   -3.3178E-09
        5              2.1182E+04   -2.1600E-11    1.2369E-10   -9.3132E-10
1.8868E+06    1.8917E-09
        6             -2.1182E+04    2.1600E-11   -1.2369E-10    9.3132E-10
-1.8868E+06   -1.8917E-09
        7             -3.9700E+05    9.1904E-10   -2.7940E-09    1.3039E-08
-5.2861E+07   -4.1910E-08
        8              5.4570E-12   -9.8278E-08    2.9104E-11   -4.4400E+06
2.0955E-09    5.3551E-09
        9             -5.8208E-11    2.3283E-10    3.4335E+06   -1.0058E-07
2.0489E-08   -1.3461E-10
       10             -2.1130E-08   -1.2960E-11    6.5484E-11   -4.0745E-10
9.5400E+05    8.2218E-10
       11             -4.0018E-11    1.4500E+05    2.3283E-10   -1.9307E+07
5.5879E-09    2.9802E-08
       12    1        -2.0976E-01    1.5634E+07   -2.4483E+06   -4.7840E+08
-6.2919E+00    2.5057E+03
       12    2        -2.0976E-01    1.5634E+07   -2.4483E+06   -4.7840E+08
-6.2919E+00    2.5057E+03
       13    1         1.5794E+07   -8.4298E+04   -1.9964E+06    4.3385E+06
4.8448E+08    9.6747E+06
       13    2         1.5794E+07   -8.4298E+04   -1.9964E+06    4.3385E+06
4.8448E+08    9.6747E+06
       14    1         6.5855E-01   -1.5676E+07   -1.5705E+06    4.8457E+08
1.9973E+01   -2.6841E+03
```

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       14    2       6.5855E-01   -1.5676E+07   -1.5705E+06    4.8457E+08
1.9973E+01   -2.6841E+03
       15    1      -1.5794E+07   -8.4299E+04   -1.9964E+06    4.3385E+06
-4.8448E+08   -9.6746E+06
       15    2      -1.5794E+07   -8.4299E+04   -1.9964E+06    4.3385E+06
-4.8448E+08   -9.6746E+06

 DATE: 01-JUN-2012 TIME: 17:43:02   ***************  SESTRA  ***************
                                        PAGE:    16


                                        RETRACKING MODULE - GLOBAL DATA


                                    SUB PAGE:     3


  DIFFERENCES BETWEEN SUMMED LOADS AND REACTION FORCES

  ****************************************************

  LARGER THAN   0.00E+00 FOR TRANSLATIONAL COMPONENTS AND LARGER THAN   0.00E+00
FOR ROTATIONAL COMPONENTS


  LOADCASE (INDEX)        X             Y             Z            RX
RY            RZ

        2            0.0000E+00    1.2369E-10   -1.1176E-08   -6.3330E-08
1.5274E-07    1.6662E-09
        3            5.0022E-12   -5.9772E-09    0.0000E+00    8.0513E-07
3.4925E-10    3.3178E-09
        4           -5.0022E-12    5.9772E-09    0.0000E+00   -8.0513E-07
-3.4925E-10   -3.3178E-09
        5           -5.9736E-09   -2.1600E-11    1.2369E-10   -9.3132E-10
-8.1025E-07    1.8917E-09
        6            5.9736E-09    2.1600E-11   -1.2369E-10    9.3132E-10
8.1025E-07   -1.8917E-09
        7            3.8178E-07    9.1904E-10   -2.7940E-09    1.3039E-08
5.1215E-05   -4.1910E-08
        8            5.4570E-12   -9.8278E-08    2.9104E-11    1.3085E-05
2.0955E-09    5.3551E-09
        9           -5.8208E-11    2.3283E-10    2.0489E-08   -1.0058E-07
2.0489E-08   -1.3461E-10
       10           -2.1130E-08   -1.2960E-11    6.5484E-11   -4.0745E-10
-2.8161E-06    8.2218E-10
       11           -4.0018E-11   -1.3903E-07    2.3283E-10    1.8645E-05
5.5879E-09    2.9802E-08
       12    1      -2.3283E-10   -2.3097E-07    7.4506E-09    2.0444E-05
-7.8231E-08    1.1306E-06
       12    2      -2.3283E-10   -2.3097E-07    7.4506E-09    2.0444E-05
-7.8231E-08    1.1306E-06
       13    1      -2.2724E-07   -4.1910E-09    1.3039E-08   -1.6205E-07
-2.0444E-05    3.7625E-07
       13    2      -2.2724E-07   -4.1910E-09    1.3039E-08   -1.6205E-07
-2.0444E-05    3.7625E-07
       14    1      -8.1491E-10    2.1793E-07   -1.2573E-08   -2.0325E-05
2.4214E-08   -1.2624E-06
       14    2      -8.1491E-10    2.1793E-07   -1.2573E-08   -2.0325E-05
2.4214E-08   -1.2624E-06
       15    1       2.2538E-07    5.4715E-09   -1.1176E-08    8.7544E-08
2.0385E-05   -3.4831E-07
       15    2       2.2538E-07    5.4715E-09   -1.1176E-08    8.7544E-08
2.0385E-05   -3.4831E-07

  TOTAL TIME CONSUMED IN SESTRA                    CPU TIME:      0.97  CLOCK
TIME:     81.03  CHANNEL TIME:      0.30
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1





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                                              Marketing and Support by DNV
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Software



               Program id   : 5.9-02
Computer         : 586
               Release date : 28-FEB-2007
Impl. update     :
               Access time  : 01-JUN-2012 16:38:00
Operating system : Win NT 5.2 [3790]
               User id      : ofsbilil
CPU id           : 1975103069

Installation     : , NOS295


               Copyright DET NORSKE VERITAS AS, P.O.Box 300, N-1322 Hovik,
Norway


1DATE: 01-JUN-2012 TIME: 16:38:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :     1

 LIMITATIONS IN THIS VERSION OF WAJAC :
 --------------------------------------

    MAXIMUM SIZE OF ONE SUPERELEMENT
    -  NUMBER OF NODES          :     20000
    -  NUMBER OF BASIC ELEMENTS :     20000


    MAXIMUM NUMBER OF LOADCASES
    -  DISCRETE WAVE            :     10000
    -  FREQUENCY DOMAIN         :       960
          ( MAX. FREQUENCIES :        60 )
    -  TIME DOMAIN SIMULATION   :      8192


    MAXIMUM NUMBER INPUT CARDS
    -  CARD TYPE SELI           :       100
    -  CARD TYPE ELIM           :     20000
    -  CARD TYPE FLOO           :     20000
    -  CARD TYPE LEG            :        50
    -  CARD TYPE SPEC           :     20000
    -  CARD TYPE CDIR           :     20000
    -  CARD TYPE MPRT           :     20000


 SIZE OF COMMON SCRATCH ARRAYS :
 --------------------------------

 /IWORK/ IWORK(  20000) /WORK/ WORK( 500000 )
 /IWORK4/ IARR(  60000) /WORK4/ ARR(  60120)
 TOTAL SIZE: /IWORK4/= 140068 /WORK4/= 231781

1DATE: 01-JUN-2012 TIME: 16:38:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :     2



 W A J A C   I N P U T   P R O C E S S O R :



               *** DATA SET WAJAC ***



               CARD NO   2    TITL      Wajac run name :
Analysis5_Stokes5.step(2)
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```
          CARD NO   3    C

          CARD NO   4    C                                            PREFIX

          CARD NO   5    FMOD      20120601_163705_

          CARD NO   6    C

          CARD NO   7    C                                            PREFIX
      FORM
          CARD NO   8    FWAVE     20120601_163705_

          CARD NO   9    C

          CARD NO  10    C               UNITS   GRAVITY       RHO      VISC
   RHOAIR   VISCAIR
          CARD NO  11    CONS               1.   9.80665     1025. 1.19e-006
    1.226  1.462e-5
          CARD NO  12    C

          CARD NO  13    C                OPT1      OPT2      OPT3      OPT4
    OPT5      OPT6      OPT7
          CARD NO  14    OPTI               0.        0.        0.        0.
      0.        0.        0.
          CARD NO  15                       0.

          CARD NO  16    C

          CARD NO  17    C                        ILFSAV    ISETOP

          CARD NO  18    MODE                         1.        1.

          CARD NO  19    C

          CARD NO  20    C                  LN

          CARD NO  21    LONO              12.

          CARD NO  22    C         *************************** GEOM Section
*****************************
          *** END OF DATA SET  22 CARDS READ ***


          *** DATA SET GEOM ***


          CARD NO  24    C

          CARD NO  25    C                   Z

          CARD NO  26    MUDP      -5.651e-12

          CARD NO  27    C         *************************** HYDR Section
*****************************
          *** END OF DATA SET   5 CARDS READ ***


          *** DATA SET HYDR ***


          CARD NO  29    C

          CARD NO  30    C                TYPE

          CARD NO  31    CPRI      FEM
```

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               CARD NO  32    CPRI      SPEC

               CARD NO  33    CPRI      CDIR

               CARD NO  34    C

               CARD NO  35    C             ADMAS      DAMP

               CARD NO  36    MASS             0.        0.

               CARD NO  37    C

               CARD NO  38    C         MarineGrowthZLevel1 ( Marine Growth as
function of Z-level property )
               CARD NO  39    C

1DATE: 01-JUN-2012 TIME: 16:38:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :     3

               CARD NO  40    C                Z1        Z2     HMGRW    HROUGH
      OPT IMEM GRWF
               CARD NO  41    MGRW            -1.       45.       0.1        0.
       0.   1.   0.
               CARD NO  42    MGRW            -1.5.6488e-12       0.1        0.
       0.   1.   0.
               CARD NO  43    C

               CARD NO  44    C                M1        M2       INC STYP  IDX
IMEM
               CARD NO  45    MEMGRW           1.       20.        1.   1.   1.
  1.
               CARD NO  46    MEMGRW          30.       51.        1.   1.   1.
  1.
               CARD NO  47    C

               CARD NO  48    C         AirDragConstant1 ( Air Drag Coefficients
property )
               CARD NO  49    C

               CARD NO  50    C                M1        M2       INC STYP  IDX
 CDX       CDZ
               CARD NO  51    CDWN             1.       51.        1.   1.   1.
 1.2       1.2
               CARD NO  52    C         *************************** LOAD Section
*****************************
               *** END OF DATA SET  25 CARDS READ ***



               *** DATA SET LOAD ***


               CARD NO  54    C

               CARD NO  55    C          ISEA THEO    HEIGHT    PERIOD      PHIO
       T0      STEP     NSTEP
               CARD NO  56    SEA          1.  5.0      17.5      14.2      -60.
       0.       10.      -36.
               CARD NO  57    SEA          2.  5.0      17.5      14.2      -60.
       0.       10.      -36.
               CARD NO  58    SEA          3.  5.0      17.5      14.2      -60.
       0.       10.      -36.
               CARD NO  59    SEA          4.  5.0      17.5      14.2      -60.
       0.       10.      -36.
               CARD NO  60    C

               CARD NO  61    C          ISEA BETA WKFA CTNO CBFA CSTR LOAD DLOA
 WID WIME
```

```
               CARD NO  62    SEAOPT       1. 270.   1.   1.   1.  -1.   0.   1.
  1.   0.
               CARD NO  63    SEAOPT       2. 180.   1.   1.   1.  -1.   0.   1.
  2.   0.
               CARD NO  64    SEAOPT       3.  90.   1.   1.   1.  -1.   0.   1.
  3.   0.
               CARD NO  65    SEAOPT       4.   0.   1.   1.   1.  -1.   0.   1.
  4.   0.
               CARD NO  66    C

               CARD NO  67    C         WindProfileRelDir4 (  Wind profile
property )
               CARD NO  68    C

               CARD NO  69    C      WID       VEL     ANGLE     GUSTF        H0
     HEXP PRAT IFRM
               CARD NO  70    WIND    1.       25.      270.     0.315       10.
      0.7   0.   0.
               CARD NO  71    C

               CARD NO  72    C         WindProfileRelDir3 (  Wind profile
property )
               CARD NO  73    C

               CARD NO  74    C      WID       VEL     ANGLE     GUSTF        H0
     HEXP PRAT IFRM
               CARD NO  75    WIND    2.       25.      180.     0.315       10.
      0.7   0.   0.
               CARD NO  76    C

               CARD NO  77    C         WindProfileRelDir2 (  Wind profile
property )
               CARD NO  78    C

               CARD NO  79    C      WID       VEL     ANGLE     GUSTF        H0
     HEXP PRAT IFRM
               CARD NO  80    WIND    3.       25.       90.     0.315       10.
      0.7   0.   0.
               CARD NO  81    C

               CARD NO  82    C         WindProfileRelDir1 (  Wind profile
property )
               CARD NO  83    C

               CARD NO  84    C      WID       VEL     ANGLE     GUSTF        H0
     HEXP PRAT IFRM
               CARD NO  85    WIND    4.       25.        0.     0.315       10.
      0.7   0.   0.
               CARD NO  86    C

               CARD NO  87    C         CurrentProfile1 (  Current profile
property )
               CARD NO  88    C

               CARD NO  89    C     CTNO                                       Z
        V     THETA       OPT
               CARD NO  90    CRNT    1.                              5.6488e-12
      0.5                  1.
               CARD NO  91                                                   45.
      1.1
1DATE: 01-JUN-2012 TIME: 16:38:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :     4

               CARD NO  92                                                 65.15
      1.1
               CARD NO  93    C

               CARD NO  94    C              DEPTH
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               CARD NO  95    DPTH            45.

               CARD NO  96    C

               CARD NO  97    C                X         Y         Z

               CARD NO  98    MOMT             0.        0.        0.

               *** END OF DATA SET  46 CARDS READ ***

          ***** END OF DATA INPUT   99 CARDS READ *****
1DATE: 01-JUN-2012 TIME: 16:38:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :     5


********************************************************************************
************
 *
          *
 *          Wajac run name : Analysis5_Stokes5.step(2)
          *
 *
          *

********************************************************************************
************



 S U M M A R Y   O F   I N P U T   S P E C I F I C A T I O N S :


 PROGRAM EXECUTION:
 ------------------

    THE PROGRAM IS USED IN INTERFACE MODE WITH PARAMETERS:

    IGFSAV=0   ILFSAV=1   ISETOP=  1


 FILE USEAGE:
 ------------

    THE NAME WHICH WILL BE USED FOR THE DEFAULT PART OF
          THE INTERFACE FILE NAMES IS: 20120601_163705_

    GEOMETRY WILL BE STORED ON TEMPORARY FILES DURING EXECUTION.

    THE LOADS WILL BE SAVED ON ONE FILE FOR EACH SUPERELEMENT TYPE

    THE NAME WHICH WILL BE USED FOR THE DEFAULT PART OF
          THE LOAD FILE NAMES IS: 20120601_163705_



 UNITS:
 ------

    THE UNITS ARE USER DEFINED:

    GRAVITY                   = 9.8067E+00
    WATER SPECIFIC MASS       = 1.0250E+03
    WATER KINEMATIC VISCOSITY = 1.1900E-06
```

```
    AIR SPECIFIC MASS         = 1.2260E+00
    AIR KINEMATIC VISCOSITY   = 1.4620E-05

 INITIAL LOADCASE NUMBER ON THE LOAD FILES :
 ------------------------------------------

    IS USER DEFINED =      12 FOR ALL SUPERELEMENT TYPES


 SPECIAL OPTIONS INTENDED FOR COMPARATIVE STUDIES:
--------------------------------------------------


1DATE: 01-JUN-2012 TIME: 16:38:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :     6



 LEG PERMABILITY FACTORS:
 ------------------------

    DEFAULT VALUES FOR CPERM IS USED.
    ALL LEGS ARE ASSUMED TO HAVE FULL BUOYANCY.


 MUDPLANE ELEVATION:
 -------------------

    THE MUDPLANE ELEVATION IS SET TO -.5651E-11 IN THE STRUCTURE COORDINATE
SYSTEM.


 HYDRODYNAMIC COEFFICIENTS:
 --------------------------

    *** WARNING: HYDRODYNAMIC COEFFICIENTS HAVE NOT BEEN SPECIFIED BY THE WAJAC
ANALYSIS
        CONTROL DATA. ENSURE THAT THE COEFFICIENTS ARE SPECIFIED ON THE SESAM
INTERFACE FILE ***


 MARINE GROWTH:
 --------------

    MARINE GROWTH AND ROUGHNESS IS SPECIFIED IN THE FOLLOWING DEPTH RANGES:
    (Z1=-1.0 MEANS LINEAR VARYING MARINE GROWTH
     AND ROUGHNESS BETWEEN LEVELS GIVEN BY Z2)

    BETWEEN ELEVATIONS     Z1   AND   Z2          HMGRW      HROUGH    INFLG
IMEM   GRWFAC

                         -1.000       0.000       0.100       0.000     0
 1    0.0000
                         -1.000      45.000       0.100       0.000     0
 1    0.0000

    MARINE GROWTH IS NOT INCLUDED IN INERTIA FORCE CALCULATION.
1DATE: 01-JUN-2012 TIME: 16:38:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :     7



 MARINE GROWTH BY MEMBERS:
 -------------------------

    INDIVIDUAL MARINE GROWTH AND ROUGHNESS ARE SPECIFIED FOR THE FOLLOWING
MEMBERS:
```

```
                          BY       OF      AND ACTUAL
    MEMBER  THROUGH  MEMBER  STEP SUP.ELEMENT SUP.ELEMENT    IMEM
    ( OR SETNAME )            OF      TYPE       INDEX

       1           20        1        1          1           1
      30           51        1        1          1           1


 MEMBERS WITH SPECIAL HYDRODYNAMIC PROPERTIES:
 --------------------------------------------

    NO MEMBERS HAVE BEEN DEFINED AS SPECIAL.


 MEMBERS WITH DIRECTIONAL HYDRODYNAMIC COEFFICIENTS:
 --------------------------------------------------

    NO MEMBERS HAVE DIRECTIONAL HYDRODYNAMIC COEFFICIENTS.


 PRIORITY OF SPECIFIED HYDRODYNAMIC COEFFICIENTS (1 IS HIGHEST):
 --------------------------------------------------------------

    SPECIFICATION WITH HIGHER PRIORITY WILL SUPERSEDE ANY OTHER COEFFICIENTS
SPECIFIED.

    THE PRIORITY HIERARCHY IS MODIFED.

    OPTION FOR SPECIFICATION     CPRI-TYPE     PRIORITY     GIVEN ON WAJAC INPUT
FILE
    ------------------------     ---------     --------
-------------------------
    API                          API               6       NO
    VERTICAL POSITION            COEF              5       NO
    DIAMETER                     FUNC              4       NO
    KC. NUMBER                   FUNC              4       NO
    RN. NUMBER                   FUNC              4       NO
    INPUT INTERFACE FILE         FEM               3       ---
    INDIVIDUAL                   SPEC              2       NO
    DIRECTIONAL                  CDIR              1       NO


 TRANSFER OF ADDED MASS AND/OR DAMPING FOR DYNAMIC STRUCTURAL ANALYSIS :
 ----------------------------------------------------------------------

    CALCULATED ADDED MASS IS  N O T  TRANSFERRED

    CALCULATED DAMPING IS  N O T  TRANSFERRED

1DATE: 01-JUN-2012 TIME: 16:38:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                              PAGE :     8


 AIR DRAG COEFFICIENTS:
 ----------------------

 *** WARNING: DIRECTIONAL DEPENDENT COEFFICIENTS GIVEN THROUGH THE WAJAC
ANALYSIS CONTROL DATA, MUST BE
              SPECIFIED RELATIVE TO THE AXES OF THE MEMBER LOCAL COORDINATE
SYSTEM USED IN WAJAC. THIS
              COORDINATE SYSTEM IS NOT NECESSARILY CORRESPONDING TO THE ONE
DEFINED IN THE PREPROCESSOR
              HAVING CREATED THE MODEL.

              THE RELATION BETWEEN THE LOCAL COORDINATE SYSTEM IN WAJAC AND THE
```

```
LOCAL COORDINATE SYSTEM
              IN THE SESAM PREPROCESSORS IS:

                 WAJAC         PREPROCESSOR
                 -----         ------------
                   x               -y
                   y                x
                   z                z

    THE FOLLOWING MEMBERS HAVE BEEN DEFINED WITH AIR DRAG COEFFICIENTS:
    (VALUE -1.000 MEANS ORIGINAL VALUE RETAINED)

                                BY       OF      AND ACTUAL
    MEMBER  THROUGH  MEMBER  STEP SUP.ELEMENT SUP.ELEMENT      CDX
CDZ
    ( OR SETNAME )            OF      TYPE       INDEX

        1           51        1        1          1         1.200
1.200


 MOMENT REFERENCE POINT:
 -----------------------

    THE MOMENT REFERENCE POINT COORDINATES HAVE BEEN SPECIFIED AS:

    XM=       0.000   YM=       0.000   ZM=       0.000


 MEMBER SEGMENTATION:
 --------------------

    THE DEFAULT VALUE SEG=1.0 IS USED FOR THE MEMBER SEGMENTATION COEFFICIENT.


 SEGMENTATION BY REFERENCE TO MEMBERS:
 -------------------------------------

    INDIVIDUAL SEGMENTATION IS NOT SPECIFIED FOR ANY MEMBERS.


 WATER DEPTH SPECIFICATION:
 --------------------------

    THE WATER DEPTH HAS BEEN SPECIFIED TO:

    DEPTH=      45.000
1DATE: 01-JUN-2012 TIME: 16:38:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                        PAGE :     9


 CURRENT SPECIFICATION:
 ----------------------

    CURRENT IS SPECIFIED BY THE FOLLOWING TABLE(S):

    TABLE NO.  1
+                          Z            V       (THE CURRENT IS RUNNING WITH
THE WAVE)

                         0.000       0.500
                        45.000       1.100
                        65.150       1.100
1DATE: 01-JUN-2012 TIME: 16:38:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                        PAGE :    10
```

```
 DETERMINISTIC SEASTATES DEFINITION:
 -----------------------------------


    THE FOLLOWING SEASTATES WILL BE ANALYSED:

      SEA-     WAVE       WAVE       WAVE      PHASE   INITIAL      PHASE/TIME
 NUMBER    WAVE        WAVE        WAVE   DESIGN
      STATE   THEORY     HEIGHT     PERIOD     /TIME   PHASE/TIME   INCREMENTS
OF STEPS  HEADING     KINEMATICS   BUOY   LOADS
      NO.
                       FACTOR      FLAG
      -----  --------    ---------  ---------  ------  -----------  -----------
--------- ----------  -----------  -----  -------

        1    STOKES  5   17.50      14.20      PHASE  -60.00        10.00
   36.    270.0       1.000        0        1
        2    STOKES  5   17.50      14.20      PHASE  -60.00        10.00
   36.    180.0       1.000        0        1
        3    STOKES  5   17.50      14.20      PHASE  -60.00        10.00
   36.    90.00       1.000        0        1
        4    STOKES  5   17.50      14.20      PHASE  -60.00        10.00
   36.       0.0000   1.000        0        1


      SEA-    CURRENT  CURRENT      CURRENT    WIND    WIND LOAD
      STATE   TAB.NO   BLOCKAGE     STRETCH    INDEX   CALC.METH
      NO.
      -----   -------  -----------  ---------  ------  ---------

        1        1     1.000           -1         1        0
        2        1     1.000           -1         2        0
        3        1     1.000           -1         3        0
        4        1     1.000           -1         4        0


 WIND SPECIFICATION:
 --------------------

      WIND     MEAN       WIND       GUST      MEAN      HEIGHT     MEAN      WIND
    PROFILE    WIND      ANGLE      FACTOR    VELOCITY  EXPONENT   PERIOD    PROFILE
     INDEX   VELOCITY                          LEVEL               RATIO     FORMULA

       1      25.000   270.000     0.315     10.000     0.700      -----       0
       2      25.000   180.000     0.315     10.000     0.700      -----       0
       3      25.000    90.000     0.315     10.000     0.700      -----       0
       4      25.000     0.000     0.315     10.000     0.700      -----       0

    AIR DRAG COEFFICIENTS HAVE NOT BEEN SPECIFIED AS FUNCTION OF REYNOLDS
NUMBER.
    THE DEFAULT FUNCTION WILL BEE USED IF THE COEFFICIENTS NOT ARE SPECIFIED BY
THE CDWN COMMAND


 D A T A C H E C K I N G   F I N I S H E D
       Siftool    version 8.3-02   18-JAN-2007


 NAMES OF INPUT INTERFACE FILES READ:
 ------------------------------------



 Direct file opened: ofsbilil3880R1.SIN
 (IUINP,NWS,IUIDNT,MXPHYS,STATUS) :          10      1024     3
 0   SCRATCH
```

```
 File is native
     MD-FILE    1 OPENED ON UNIT  10 WITH INDEX   1 MAX LENGTH=     2147483640
WORDS AND BLOCKSIZE=  1024
                  NAME   R1.SIN





                  STATUS SCRATCH
     MD-FILE    1 ALLOCATION ACCOUNT OPENED

 20120601_163705_T1.FEM

         DATE:     01-Jun-2012         TIME:          16:37:05

         PROGRAM:  SESAM GeniE         VERSION:       V5.3-10 14-Apr-2011

         COMPUTER: X86 Windows         INSTALLATION:

         USER:     ofsbilil            ACCOUNT:

         DATE:     01-Jun-2012         TIME:          16:37:05

         PROGRAM:  SESAM Gamesha       VERSION:       R5.0-3 14-Apr-2011

         COMPUTER: X86 Windows         INSTALLATION:

         USER:     ofsbilil            ACCOUNT:

1DATE: 01-JUN-2012 TIME: 16:38:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :    11



*******************************************
                                           *   W A T E R   D E P T H :
45.000   *

*******************************************


 D E T E R M I N I S T I C   W A V E   C H A R A C T E R I S T I C S :



                WAVE      WAVE                           DEPTH TO    WAVE HEIGHT
TO    WAVE        WAVE       HALF WAVE   HALF WAVE
 WAVE   WAVE      PERIOD    PERIOD     WAVE        WAVE     WAVE LENGTH    WAVE
LENGTH    CREST       TROUGH       DURATION    DURATION
  NO   THEORY     ACTUAL  APPARENT  HEIGHT      LENGTH       RATIO          RATIO
    ELEVATION   ELEVATION     CREST        TROUGH

   1 STOKES 5TH   14.20            17.50       267.9      0.1680
0.6532E-01   55.91       38.41       5.964       8.236
1DATE: 01-JUN-2012 TIME: 16:38:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :    12


 W A V E / C U R R E N T   L O A D I N G :
```

```
 STRUCTURE LOADS:
 ----------------


 SUPERELEMENT TYPE  :         1

    THE HIGHEST LOAD CASE NUMBER ON THE FEM INTERFACE FILE IS :        19
    THE INITIAL LOAD CASE NUMBER ON THE LOAD FILE IS          :        12


 *** WARNING *** LOADCASE NUMBERS WILL OVERLAP ON THE FEM INTERFACE FILE AND THE
LOAD FILE




 SUPERELEMENT TYPE NO   1   INDEX  1  (  51 BASIC ELEMENTS,  51 MEMBERS AND   34
NODES,  1 ACTUAL SUPERELEMENTS OF THAT TYPE )
1DATE: 01-JUN-2012 TIME: 16:38:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                              PAGE :    13


 T O T A L   L O A D   S U M M A R Y :


    SEASTATE NO   1

       STEP    PHASE      LX             LY             LZ             MX
     MY             MZ
       ----    -----      ----------     ----------     ----------
----------     ----------     ----------

          1    -60.0      1.1659E-01    -1.0653E+07     2.6406E+06
2.7086E+08     4.9062E+00    -1.0358E+03
          2    -50.0      1.1342E-01    -1.2224E+07     2.6364E+06
3.2465E+08     5.0312E+00    -1.3696E+03
          3    -40.0      4.7712E-02    -1.3772E+07     2.6153E+06
3.8319E+08     8.1250E-01    -1.7530E+03
          4    -30.0      1.3421E-01    -1.5038E+07     2.5533E+06
4.3825E+08     2.6562E+00    -2.1512E+03
          5    -20.0      1.5013E-01    -1.5634E+07     2.4483E+06
4.7397E+08     5.6250E+00    -2.5029E+03
          6    -10.0      6.4120E-02    -1.5137E+07     2.2575E+06
4.7115E+08     1.6562E+00    -2.7446E+03
          7      0.0      3.4279E-02    -1.3280E+07     2.0061E+06
4.1611E+08     5.6250E-01    -2.7979E+03
          8     10.0      9.7674E-02    -1.0186E+07     1.7692E+06
3.1370E+08     3.6562E+00    -2.6321E+03
          9     20.0      9.4174E-02    -6.3808E+06     1.5577E+06
1.8790E+08     4.0000E+00    -2.2360E+03
         10     30.0     -5.1323E-02    -2.5436E+06     1.3996E+06
6.7965E+07     3.0938E+00    -1.6498E+03
         11     40.0      3.2800E-02     7.8142E+05     1.3284E+06
-2.5880E+07    -9.6875E-01    -9.5297E+02
         12     50.0     -3.6194E-02     3.3271E+06     1.3395E+06
-8.8043E+07    -1.1250E+00    -2.4558E+02
         13     60.0     -2.9463E-02     5.0490E+06     1.4038E+06
-1.2242E+08     3.1250E-02     3.6431E+02
         14     70.0     -6.2429E-02     6.0153E+06     1.5077E+06
-1.3548E+08    -1.2812E+00     7.9744E+02
         15     80.0     -5.3912E-02     6.3442E+06     1.6466E+06
-1.3343E+08    -1.5625E+00     1.0159E+03
         16     90.0     -5.4635E-02     6.2003E+06     1.7758E+06
-1.2233E+08    -1.4062E+00     1.0181E+03
         17    100.0     -5.6794E-02     5.7336E+06     1.8920E+06
-1.0633E+08    -7.8125E-01     8.5838E+02
         18    110.0     -4.0919E-02     5.1451E+06     1.9748E+06
```

```
-9.0384E+07    -1.3438E+00     5.9569E+02
         19    120.0     -3.6510E-02     4.5644E+06     2.0241E+06
-7.6247E+07    -8.4375E-01     4.2875E+02
         20    130.0     -2.8251E-02     4.0569E+06     2.0553E+06
-6.4268E+07    -1.2500E-01     3.6300E+02
         21    140.0     -2.0041E-02     3.6008E+06     2.0765E+06
-5.3956E+07    -1.5625E-01     3.3306E+02
         22    150.0     -5.9867E-03     3.1606E+06     2.0966E+06
-4.4514E+07    -6.2500E-02     3.3075E+02
         23    160.0     -1.3401E-02     2.7025E+06     2.1218E+06
-3.5231E+07     1.5625E-01     3.4806E+02
         24    170.0     -4.0301E-02     2.1983E+06     2.1534E+06
-2.5548E+07    -3.7500E-01     3.7838E+02
         25    180.0     -3.1972E-02     1.6252E+06     2.1927E+06
-1.4980E+07     1.5625E-01     4.0988E+02
         26    190.0     -2.2086E-02     9.6646E+05     2.2393E+06
-3.1210E+06     2.8125E-01     4.3903E+02
         27    200.0      1.5751E-03     2.1139E+05     2.2910E+06
1.0379E+07     1.2500E-01     4.6078E+02
         28    210.0      8.4990E-03    -6.4283E+05     2.3455E+06
2.5782E+07     2.8125E-01     4.6853E+02
         29    220.0      1.8943E-02    -1.5898E+06     2.3992E+06
4.3242E+07     2.1875E-01     4.5305E+02
         30    230.0      4.3245E-03    -2.6114E+06     2.4481E+06
6.2773E+07     2.8125E-01     4.0181E+02
         31    240.0      2.9796E-02    -3.6753E+06     2.4907E+06
8.4161E+07     3.7500E-01     3.0112E+02
         32    250.0      4.2570E-02    -4.7531E+06     2.5209E+06
1.0729E+08     1.5312E+00     1.3828E+02
         33    260.0      8.0661E-02    -5.8123E+06     2.5421E+06
1.3175E+08     1.1562E+00    -8.7688E+01
         34    270.0      4.0461E-02    -6.8459E+06     2.5616E+06
1.5774E+08     5.3125E-01    -3.6419E+02
         35    280.0      1.0160E-01    -7.9456E+06     2.5883E+06
1.8816E+08     1.5938E+00    -5.7775E+02
         36    290.0      7.4881E-02    -9.2133E+06     2.6188E+06
2.2556E+08     1.5938E+00    -7.7294E+02

       MAXIMUM BASE SHEAR         = 1.5634E+07  AT PHASE =  -20.0

       MAXIMUM OVERTURNING MOMENT = 4.7397E+08  AT PHASE =  -20.0


    SEASTATE NO   2

       STEP    PHASE      LX             LY             LZ             MX
     MY             MZ
       ----    -----      ----------     ----------     ----------
----------     ----------     ----------

          1    -60.0     -1.1001E+07    -1.1325E+05     2.4400E+06
4.0564E+05    -2.8160E+08    -9.1480E+06
          2    -50.0     -1.2585E+07    -9.4687E+04     2.3787E+06
1.9728E+05    -3.3554E+08    -9.6290E+06
1DATE: 01-JUN-2012 TIME: 16:38:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                      PAGE :    14

          3    -40.0     -1.4107E+07    -5.5037E+04     2.2934E+06
-6.8332E+05    -3.9332E+08    -9.9678E+06
          4    -30.0     -1.5305E+07     4.3118E+03     2.1637E+06
-2.1231E+06    -4.4668E+08    -1.0106E+07
          5    -20.0     -1.5794E+07     8.4298E+04     1.9964E+06
-4.3020E+06    -4.7999E+08    -9.9401E+06
          6    -10.0     -1.5161E+07     1.7454E+05     1.7877E+06
-6.8144E+06    -4.7410E+08    -9.3106E+06
          7      0.0     -1.3147E+07     2.6318E+05     1.5796E+06
-9.3509E+06    -4.1530E+08    -8.1126E+06
          8     10.0     -9.9034E+06     3.3102E+05     1.4105E+06
```

```
-1.1174E+07    -3.0937E+08    -6.3997E+06
          9     20.0     -5.9841E+06     3.6544E+05     1.3140E+06
-1.1873E+07    -1.8132E+08    -4.3967E+06
         10     30.0     -2.0808E+06     3.5967E+05     1.2805E+06
-1.1197E+07    -6.0435E+07    -2.3888E+06
         11     40.0      1.2570E+06     3.2254E+05     1.3093E+06
-9.6654E+06     3.3251E+07    -5.7911E+05
         12     50.0      3.7663E+06     2.6151E+05     1.3805E+06
-7.5801E+06     9.4494E+07     9.5626E+05
         13     60.0      5.4015E+06     1.9115E+05     1.4981E+06
-5.6128E+06     1.2672E+08     2.2058E+06
         14     70.0      6.2539E+06     1.1875E+05     1.6345E+06
-3.8722E+06     1.3720E+08     3.1594E+06
         15     80.0      6.4660E+06     5.0089E+04     1.7726E+06
-2.4397E+06     1.3294E+08     3.8470E+06
         16     90.0      6.2138E+06    -1.3422E+03     1.8970E+06
-1.5894E+06     1.1975E+08     4.4812E+06
         17    100.0      5.6774E+06    -3.2185E+04     1.9879E+06
-1.1633E+06     1.0261E+08     5.1904E+06
         18    110.0      5.0850E+06    -4.4519E+04     2.0470E+06
-1.0858E+06     8.6435E+07     5.4262E+06
         19    120.0      4.5327E+06    -4.6084E+04     2.0888E+06
-1.2458E+06     7.2553E+07     5.0384E+06
         20    130.0      4.0397E+06    -4.6728E+04     2.1168E+06
-1.3962E+06     6.0858E+07     4.4568E+06
         21    140.0      3.5880E+06    -4.9647E+04     2.1397E+06
-1.4827E+06     5.0691E+07     3.8712E+06
         22    150.0      3.1409E+06    -5.5609E+04     2.1639E+06
-1.5025E+06     4.1200E+07     3.2787E+06
         23    160.0      2.6663E+06    -6.4897E+04     2.1908E+06
-1.4338E+06     3.1723E+07     2.6650E+06
         24    170.0      2.1373E+06    -7.6994E+04     2.2215E+06
-1.2863E+06     2.1697E+07     2.0140E+06
         25    180.0      1.5333E+06    -9.0998E+04     2.2565E+06
-1.0796E+06     1.0668E+07     1.3125E+06
         26    190.0      8.3984E+05    -1.0565E+05     2.2953E+06
-8.4540E+05    -1.7457E+06     5.5251E+05
         27    200.0      4.9186E+04    -1.1973E+05     2.3364E+06
-6.0759E+05    -1.5846E+07    -2.6007E+05
         28    210.0     -8.3819E+05    -1.3164E+05     2.3770E+06
-3.9108E+05    -3.1846E+07    -1.1091E+06
         29    220.0     -1.8117E+06    -1.3957E+05     2.4138E+06
-2.2698E+05    -4.9835E+07    -1.9638E+06
         30    230.0     -2.8485E+06    -1.4157E+05     2.4444E+06
-1.5092E+05    -6.9741E+07    -2.7816E+06
         31    240.0     -3.9133E+06    -1.3697E+05     2.4647E+06
-1.4156E+05    -9.1390E+07    -3.5127E+06
         32    250.0     -4.9737E+06    -1.2688E+05     2.4742E+06
-1.6437E+05    -1.1459E+08    -4.2892E+06
         33    260.0     -6.0053E+06    -1.1528E+05     2.4817E+06
-2.5587E+05    -1.3895E+08    -5.4739E+06
         34    270.0     -7.0384E+06    -1.1134E+05     2.4828E+06
-1.4902E+05    -1.6536E+08    -6.8630E+06
         35    280.0     -8.1960E+06    -1.1412E+05     2.4839E+06
4.4479E+04    -1.9690E+08    -7.8620E+06
         36    290.0     -9.5154E+06    -1.1862E+05     2.4731E+06
3.2150E+05    -2.3529E+08    -8.5581E+06

       MAXIMUM BASE SHEAR         = 1.5795E+07  AT PHASE =  -20.0

       MAXIMUM OVERTURNING MOMENT = 4.8001E+08  AT PHASE =  -20.0


    SEASTATE NO   3

       STEP    PHASE      LX             LY             LZ             MX
     MY             MZ
       ----    -----      ----------     ----------     ----------
```

```
----------     ----------     ----------

         1     -60.0     -4.6698E-01     1.1241E+07     2.2582E+06
-2.9000E+08    -1.1844E+01     2.0710E+03
         2     -50.0     -5.5816E-01     1.2798E+07     2.1357E+06
-3.4331E+08    -1.2656E+01     2.4376E+03
         3     -40.0     -4.8789E-01     1.4257E+07     1.9644E+06
-4.0001E+08    -1.4000E+01     2.7068E+03
         4     -30.0     -5.0580E-01     1.5339E+07     1.7710E+06
-4.5061E+08    -1.6000E+01     2.8011E+03
         5     -20.0     -6.3123E-01     1.5676E+07     1.5705E+06
-4.8005E+08    -2.1094E+01     2.6780E+03
         6     -10.0     -4.9700E-01     1.4880E+07     1.3593E+06
-4.7012E+08    -1.5562E+01     2.3359E+03
         7       0.0     -6.0537E-01     1.2722E+07     1.1711E+06
-4.0818E+08    -1.6781E+01     1.7782E+03
         8      10.0     -4.6665E-01     9.3627E+06     1.0810E+06
-2.9988E+08    -9.9062E+00     1.0996E+03
         9      20.0     -2.2947E-01     5.3718E+06     1.0759E+06
-1.7033E+08    -3.2500E+00     3.8819E+02
        10      30.0     -1.6543E-02     1.4576E+06     1.1358E+06
-4.9455E+07    -4.0625E-01    -2.5220E+02
        11      40.0      4.2178E-02    -1.8251E+06     1.2649E+06
4.2524E+07     1.3438E+00    -7.2741E+02
        12      50.0      1.8581E-01    -4.2262E+06     1.4222E+06
1.0087E+08     3.3438E+00    -9.8888E+02
        13      60.0      2.1035E-01    -5.7235E+06     1.5990E+06
1.2986E+08     6.7500E+00    -1.0336E+03
        14      70.0      2.9156E-01    -6.4305E+06     1.7562E+06
1.3734E+08     5.5625E+00    -8.9850E+02
1DATE: 01-JUN-2012 TIME: 16:38:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                                   PAGE :    15

        15      80.0      2.5581E-01    -6.5127E+06     1.8952E+06
1.3075E+08     7.5000E+00    -6.5462E+02
        16      90.0      2.5989E-01    -6.1482E+06     2.0007E+06
1.1573E+08     5.3750E+00    -4.4844E+02
        17     100.0      2.2695E-01    -5.5797E+06     2.0694E+06
9.7944E+07     4.3438E+00    -3.7206E+02
        18     110.0      2.4304E-01    -4.9979E+06     2.1132E+06
8.1829E+07     4.8125E+00    -3.3700E+02
        19     120.0      2.1625E-01    -4.4628E+06     2.1445E+06
6.8269E+07     3.8125E+00    -3.3038E+02
        20     130.0      1.5817E-01    -3.9761E+06     2.1692E+06
5.6765E+07     3.3750E+00    -3.4278E+02
        21     140.0      1.2729E-01    -3.5191E+06     2.1950E+06
4.6586E+07     2.4375E+00    -3.7116E+02
        22     150.0      1.3327E-01    -3.0572E+06     2.2218E+06
3.6938E+07     3.7812E+00    -4.0284E+02
        23     160.0      1.0866E-01    -2.5605E+06     2.2507E+06
2.7174E+07     2.7812E+00    -4.3203E+02
        24     170.0      8.8548E-02    -2.0048E+06     2.2819E+06
1.6767E+07     1.0938E+00    -4.5647E+02
        25     180.0      5.4861E-02    -1.3726E+06     2.3146E+06
5.3195E+06     6.5625E-01    -4.6866E+02
        26     190.0      4.4717E-02    -6.5195E+05     2.3479E+06
-7.5134E+06     7.1875E-01    -4.5908E+02
        27     200.0     -1.4578E-03     1.6213E+05     2.3792E+06
-2.1998E+07     4.3750E-01    -4.1625E+02
        28     210.0     -3.9914E-02     1.0665E+06     2.4052E+06
-3.8317E+07    -1.2812E+00    -3.2672E+02
        29     220.0     -7.3589E-02     2.0470E+06     2.4244E+06
-5.6493E+07    -1.7812E+00    -1.7788E+02
        30     230.0     -1.2024E-01     3.0787E+06     2.4333E+06
-7.6479E+07    -2.3750E+00     3.6125E+01
        31     240.0     -1.8100E-01     4.1243E+06     2.4309E+06
-9.8082E+07    -3.8125E+00     3.0406E+02
        32     250.0     -2.1650E-01     5.1381E+06     2.4270E+06
```

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-1.2086E+08    -5.4375E+00     5.4488E+02
         33    260.0    -2.0895E-01     6.1458E+06     2.4217E+06
-1.4529E+08    -5.8125E+00     7.2325E+02
         34    270.0    -2.3881E-01     7.2036E+06     2.4084E+06
-1.7233E+08    -6.9375E+00     9.7125E+02
         35    280.0    -3.6063E-01     8.3978E+06     2.3887E+06
-2.0452E+08    -7.5312E+00     1.2912E+03
         36    290.0    -3.9448E-01     9.7508E+06     2.3359E+06
-2.4368E+08    -1.0562E+01     1.6692E+03

       MAXIMUM BASE SHEAR         = 1.5676E+07  AT PHASE =  -20.0

       MAXIMUM OVERTURNING MOMENT = 4.8005E+08  AT PHASE =  -20.0


    SEASTATE NO   4

       STEP    PHASE      LX             LY             LZ             MX
     MY             MZ
       ----    -----      ----------     ----------     ----------
----------     ----------     ----------


          1    -60.0     1.1000E+07    -1.1325E+05     2.4400E+06
4.0562E+05     2.8160E+08     9.1470E+06
          2    -50.0     1.2585E+07    -9.4686E+04     2.3787E+06
1.9725E+05     3.3554E+08     9.6279E+06
          3    -40.0     1.4107E+07    -5.5036E+04     2.2934E+06
-6.8335E+05     3.9332E+08     9.9669E+06
          4    -30.0     1.5305E+07     4.3130E+03     2.1637E+06
-2.1232E+06     4.4668E+08     1.0105E+07
          5    -20.0     1.5794E+07     8.4300E+04     1.9964E+06
-4.3020E+06     4.7999E+08     9.9400E+06
          6    -10.0     1.5161E+07     1.7454E+05     1.7877E+06
-6.8144E+06     4.7410E+08     9.3110E+06
          7      0.0     1.3148E+07     2.6318E+05     1.5796E+06
-9.3510E+06     4.1530E+08     8.1136E+06
          8     10.0     9.9036E+06     3.3103E+05     1.4105E+06
-1.1174E+07     3.0937E+08     6.4012E+06
          9     20.0     5.9842E+06     3.6544E+05     1.3140E+06
-1.1873E+07     1.8132E+08     4.3985E+06
         10     30.0     2.0809E+06     3.5967E+05     1.2805E+06
-1.1197E+07     6.0435E+07     2.3906E+06
         11     40.0    -1.2568E+06     3.2254E+05     1.3093E+06
-9.6654E+06    -3.3251E+07     5.8071E+05
         12     50.0    -3.7662E+06     2.6151E+05     1.3805E+06
-7.5801E+06    -9.4494E+07    -9.5507E+05
         13     60.0    -5.4014E+06     1.9115E+05     1.4981E+06
-5.6128E+06    -1.2672E+08    -2.2051E+06
         14     70.0    -6.2539E+06     1.1875E+05     1.6345E+06
-3.8722E+06    -1.3720E+08    -3.1593E+06
         15     80.0    -6.4660E+06     5.0088E+04     1.7726E+06
-2.4397E+06    -1.3294E+08    -3.8472E+06
         16     90.0    -6.2138E+06    -1.3427E+03     1.8970E+06
-1.5894E+06    -1.1975E+08    -4.4816E+06
         17    100.0    -5.6775E+06    -3.2185E+04     1.9879E+06
-1.1633E+06    -1.0261E+08    -5.1908E+06
         18    110.0    -5.0851E+06    -4.4519E+04     2.0470E+06
-1.0858E+06    -8.6435E+07    -5.4265E+06
         19    120.0    -4.5327E+06    -4.6084E+04     2.0888E+06
-1.2458E+06    -7.2553E+07    -5.0385E+06
         20    130.0    -4.0397E+06    -4.6729E+04     2.1168E+06
-1.3962E+06    -6.0858E+07    -4.4568E+06
         21    140.0    -3.5880E+06    -4.9647E+04     2.1397E+06
-1.4827E+06    -5.0691E+07    -3.8712E+06
         22    150.0    -3.1409E+06    -5.5610E+04     2.1639E+06
-1.5025E+06    -4.1200E+07    -3.2787E+06
         23    160.0    -2.6663E+06    -6.4897E+04     2.1908E+06
-1.4338E+06    -3.1722E+07    -2.6649E+06
```

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         24    170.0     -2.1373E+06    -7.6994E+04     2.2215E+06
-1.2863E+06    -2.1697E+07    -2.0139E+06
         25    180.0     -1.5333E+06    -9.0998E+04     2.2565E+06
-1.0796E+06    -1.0668E+07    -1.3124E+06
         26    190.0     -8.3984E+05    -1.0565E+05     2.2953E+06
-8.4540E+05     1.7457E+06    -5.5250E+05
1DATE: 01-JUN-2012 TIME: 16:38:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                              PAGE :    16

         27    200.0     -4.9191E+04    -1.1973E+05     2.3364E+06
-6.0760E+05     1.5846E+07     2.6001E+05
         28    210.0      8.3818E+05    -1.3164E+05     2.3770E+06
-3.9108E+05     3.1846E+07     1.1089E+06
         29    220.0      1.8117E+06    -1.3957E+05     2.4138E+06
-2.2698E+05     4.9835E+07     1.9635E+06
         30    230.0      2.8484E+06    -1.4157E+05     2.4444E+06
-1.5092E+05     6.9741E+07     2.7812E+06
         31    240.0      3.9133E+06    -1.3697E+05     2.4647E+06
-1.4156E+05     9.1390E+07     3.5121E+06
         32    250.0      4.9736E+06    -1.2688E+05     2.4742E+06
-1.6438E+05     1.1459E+08     4.2886E+06
         33    260.0      6.0052E+06    -1.1528E+05     2.4817E+06
-2.5589E+05     1.3895E+08     5.4733E+06
         34    270.0      7.0384E+06    -1.1133E+05     2.4828E+06
-1.4904E+05     1.6536E+08     6.8623E+06
         35    280.0      8.1959E+06    -1.1412E+05     2.4839E+06
4.4463E+04     1.9690E+08     7.8613E+06
         36    290.0      9.5153E+06    -1.1862E+05     2.4731E+06
3.2148E+05     2.3529E+08     8.5572E+06

       MAXIMUM BASE SHEAR         = 1.5795E+07  AT PHASE =  -20.0

       MAXIMUM OVERTURNING MOMENT = 4.8001E+08  AT PHASE =  -20.0


    SUMMARY OF MAXIMUM BASE SHEAR AND OVERTURNING MOMENT:

       SEASTATE     MAXIMUM        MAXIMUM
       NO.          BASE SHEAR     OVERTURNING MOMENT
       --------     ----------     ------------------

          1         1.5634E+07     4.7397E+08
          2         1.5795E+07     4.8001E+08
          3         1.5676E+07     4.8005E+08
          4         1.5795E+07     4.8001E+08


 C E N T R E   O F   B U O Y A N C Y :

   X=-1.9368E-07   Y=-1.1523E+00   Z= 1.9271E+01
1DATE: 01-JUN-2012 TIME: 16:38:02   SESAM : WAJAC  VERSION: 5.9-02  28-FEB-2007
                                              PAGE :    17

 SUMMARY OF ADMINISTRATIVE DATA TRANSFERRED TO STRUCTURAL ANALYSIS PROGRAM :
 ---------------------------------------------------------------------------



--------------------------------------------------------------------------------
-----------------------------------------------
 : SEASTATE  /   : WAVE     : WAVE     : WAVE     : WATER    : MUDPLANE :  WIND
  : GUST WIND: TIME STEPS                         :
 : IDENTIFICATION: DIRECTION: HEIGHT   : PERIOD   : DEPTH    : ELEVATION:
PROFILE : INDUCED  : LOAD CASE NUMBERS              :
 : NUMBER        :          :          :          :          :          :  INDEX
  : FATIGUE  :                                    :
```

```
--------------------------------------------------------------------------------
-----------------------------------------------
 :               :          :          :          :          :          :      1
  :  NO      :          :          :          :
 :    1  /    1  : 270.0    : 17.50    : 14.20    : 45.00    :-.5651E-11:
  :          :          :          :          :
 :               :          :          :          :          :          :
  :          :    -0.789:    -0.789:
 :               :          :          :          :          :          :
  :          :       12.:       13.:

--------------------------------------------------------------------------------
-----------------------------------------------
 :               :          :          :          :          :          :      2
  :  NO      :          :          :          :
 :    2  /    2  : 180.0    : 17.50    : 14.20    : 45.00    :-.5651E-11:
  :          :          :          :          :
 :               :          :          :          :          :          :
  :          :    -0.789:    -0.789:
 :               :          :          :          :          :          :
  :          :       14.:       15.:

--------------------------------------------------------------------------------
-----------------------------------------------
 :               :          :          :          :          :          :      3
  :  NO      :          :          :          :
 :    3  /    3  : 90.00    : 17.50    : 14.20    : 45.00    :-.5651E-11:
  :          :          :          :          :
 :               :          :          :          :          :          :
  :          :    -0.789:    -0.789:
 :               :          :          :          :          :          :
  :          :       16.:       17.:

--------------------------------------------------------------------------------
-----------------------------------------------
 :               :          :          :          :          :          :      4
  :  NO      :          :          :          :
 :    4  /    4  :    0.0000: 17.50    : 14.20    : 45.00    :-.5651E-11:
  :          :          :          :          :
 :               :          :          :          :          :          :
  :          :    -0.789:    -0.789:
 :               :          :          :          :          :          :
  :          :       18.:       19.:



--------------------------------------------------------------------------------
------------
 :    WIND     MEAN      WIND      GUST      MEAN     HEIGHT     MEAN    LENGTH
     WIND  :
 :  PROFILE    WIND     ANGLE     FACTOR   VELOCITY  EXPONENT   PERIOD   SCALE
   PROFILE :
 :   INDEX   VELOCITY                       LEVEL                RATIO    FACTOR
   FORMULA :

--------------------------------------------------------------------------------
------------
 :     1      25.000   270.000     0.315    10.000     0.700     -----    1.00
       0   :
 :     2      25.000   180.000     0.315    10.000     0.700     -----    1.00
       0   :
 :     3      25.000    90.000     0.315    10.000     0.700     -----    1.00
       0   :
 :     4      25.000     0.000     0.315    10.000     0.700     -----    1.00
       0   :
```

```
CPU TIME CONSUMPTION: 0.7200


P R O G R A M   N O R M A L   E N D
```