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DET TEKNISK-NATURVITENSKAPELIGE FAKULTET

MASTEROPPGAVE

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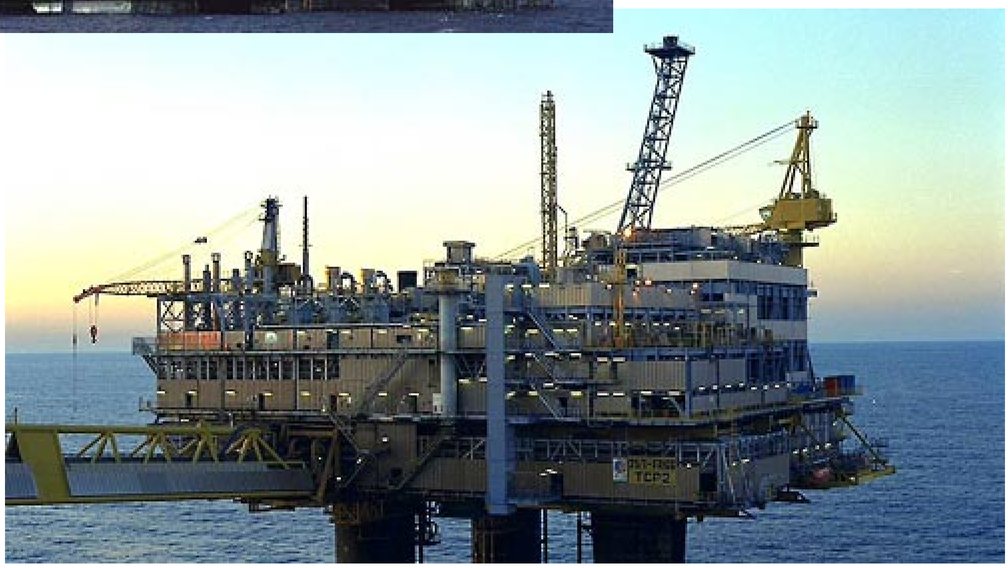
Master Thesis

Structural analysis for heavy lift removal of offshore module



1. PREFACE

This thesis is my final work in order to achieve my Master degree in structural engineering. For the last two years I have been a full time student at the University in Stavanger (UiS) following the Mechanical and Structural Engineering and Materials science- Master's Degree Programme. Prior to my study at UiS I completed a Bachelor program in civil engineering at the Bergen University College.

During the summer months of 2008 I had a job at Aker Solutions in Stavanger. During this period I performed a small modification and installation analysis of an offshore module and found the work very interesting. When I performed this work, I got introduced to some of the engineers which had performed the structural engineering for the heavy lift operations performed in the Frigg cessation project. I found this topic very interesting and in collaboration with UiS and Aker Solutions we prepared a subject for my master thesis.

The subject we chose was to investigate the feasibility of a new lifting arrangement on an old offshore module. To perform the global structural analysis I chose to use the Sesam software package developed by Det Norske Veritas. The Sesam finite element software was unknown to me prior to my work with this thesis. As I am quite interested in the world of finite element analysis (FEA) I found this as a great opportunity to achieve knowledge of using advanced and extensive FEA software together with the work of my master thesis.

As the offshore industry is quite new to me, Aker Solutions invited me to a one day introduction course in heavy lifting operations and even arranged a guided tour on the world’s second largest semi submergible crane vessel, Saipem 7000. When it comes to the understanding of the procedure of heavy lift removal, this has been of great advantage for me when working with this paper. I am grateful to Aker solutions for also providing me with computer, software and work station during my work with this thesis.

I will use the opportunity to express my gratitude to all the people who in any way has contributed to this thesis. Especially to my supervisor at UiS Ove Mikkelsen for constructive feedback during my work who has been invaluable to me, the leader of the structural analysis specialist group in Aker Solutions Stavanger, Viktor Nilsen-Nygaard for suggesting and defining the problem to be addressed and comments to my work, super user of the Sesam system at Aker Solutions, Eirik Engevik for introducing me to the Sesam system and providing the information required to run my analysis in Sesam, and a thank to the rest of the engineers in the structural analysis group at Aker Solutions for useful theoretical discussions.
I will also thank my family for their patience during my work with this thesis.

It is my intention that the content and results of this thesis is interesting and useful for the reader.

Stavanger 10.06.2009

Amund Lundqvist

2. ABSTRACT

This report presents a study of the structural analysis for removal operation of the Frigg TCP2 M32 Module with a new lifting arrangement situated at the top of the M32 Module.

During the removal of the M32 from the Frigg TCP2 platform performed in 2005 a planned delay to the lifting operations was required, due to installation and welding of the M32 module lifting points at the bottom frame of the module. The intention of this study is to investigate if the interruption could have been avoided. This is done by performing structural analysis and verification of the M32 Module and the feasibility of installing padeyes at the top of the M32 Module. Global and local analysis covers the ultimate limit state and is carried out in accordance with prevailing design rules and standards.

The global analyses are performed by using the Sesam software package and local analysis are performed by a combination of finite element analysis, analytical stress analysis and code checks.

The lifting operation is defined as a heavy lift operation. Data from the Saipem S7000 semi-submergible crane vessel is used for defining load input for lifting and transportation of the M32 module. In this study the lifting arrangement is defined as a single crane lift with 3 loose spreader bars.

The first global analysis showed failure of columns connected to the lifting points. To maintain the structural integrity of the module during lifting, these columns were reinforced by adding reinforcement plates to the failing structural elements.

After that the reinforcements for the lifting operation are made the transportation condition is the governing condition for the global analysis of the M32 module, however it does not have a significant effect on the analysis result for the transportation condition, if the padeyes are top or bottom mounted.

Analysis of the padeyes was performed as an analytical stress and showed that the padeye design has the sufficient strength to carry the lifting load.

The joints in the module are analyzed and found to have the required strength to withstand all forces during lifting and transport of the module.

Based on the analysis and considerations performed in this report, I consider it possible to perform the lift of the M32 module with a lifting arrangement situated at the top of the module.

I consider all collected data and sources used in this thesis accurate and reliable. If errors of any kind occur I can assure that this is not of my intention as my aim is to present the results as accurate and realistic as possible. If however any inaccuracies have occurred it is my hope that these are minor and do not effect the final conclusion of this thesis.

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APPENDIX

3. INTRODUCTION

3.1. General

By execution of cessation projects of the early North Sea offshore installations, new challenges in lifting techniques and lifting arrangements have appeared.

In collaboration with the University in Stavanger and the Structural Analysis Group in Aker Solutions, we have found that the M32 module situated on the Frigg TCP2 platform is a well suited module for such a study. This is a rather heavy module (about 1000 tonnes), where the original lifting points for installation was placed at the bottom of the module, and removed after set down. A planned delay to the lifting operations was required in 2005, due to installation and welding of the M32 module lifting points. The intention of this study is therefore to investigate if the interruption could have been avoided.

For removal of this module it would be most cost-, and time-effective to preinstall the lifting padeyes before the lifting operations of any module starts. This would make it possible for the lifting vessel to operate continuously.

It is however not possible to pre-install lifting points on the bottom frame before the lifting operations start, due to the adjacent modules. An option is to locate the lifting points at the top of the module. Due to possible inaccuracies in the centre of gravity of the modules, a top mounted lifting arrangement would also provide better stability of the module during the lifting operation.

The main subject of this thesis is to carry out the structural analysis for heavy lift removal of the Frigg M32 module with a new lifting arrangement situated at the top of the module, and determine the feasibility of the new lifting arrangement and scope of modifications to the module.

It is necessary to verify the main load bearing structure both for the lifting and transportation conditions, and if needed, reinforce the structure to maintain the structural integrity of the module. Local design and analysis of the lifting padeyes is included in the verification.

The analysis will be carried out according with prevailing design rules; DNV Rules, Norsok, Eurocode3/NS3472 and Frigg Design Premises.

The DNV-RP –H102 [7] recommended practice standard requires full structural integrity of the all structures during lifting. This is a safety condition and not to be deviated from.

3.2. Techniques and limitations

For solving the thesis it will be necessary to perform a full verification of the structure with the new lifting arrangement. This will imply collection of load data, create a computer model of the M32 module, run FEA and code check of the FEA results.

For the global analyses of the M32 module I have chosen to use parts of the Sesam FEA software package developed by DNV software. This software was unknown to me prior to this thesis, but information about the benefits of the software for global analysis persuaded me to take the chance of learning a new software to perform the global analysis in this thesis.

To avoid errors when use of FEA software it is in an early phase important to build up an impression of the expected results. This can be done by performing small simplified hand calculations.

If reinforcements are shown to bee needed, the capacity of the different solutions will be calculated theoretically to minimize the time spent on remodelling and FEM analysis.

As my educational direction is in constructions and materials with specialisation in structures, it will be natural to focus my investigations and analysis from a structural point of view. I have chosen to concentrate my investigations from the bottom of the M32 module to the padeyes at the top. In addition to the structural analysis of the M32 module and padeyes, design and calculation of trunnions, slings, spreader bars, bumpers, guides, grillage and seafastening would have to be carried out to have a complete engineering package for the lifting and transportation operation. However these additional steps have a character of production engineering, with standard design, and will not contribute to this thesis case study. Therefore I have chosen not to include this analyse and design elements in this report.

The local analysis of padeyes will be performed with use of analytical hand calculations based on the theory of mechanics of materials. This stress analysis will be carried out for critical points of the padeye using the Von Mises yield criteria [3] Boresi et al. In addition the stress analysis at critical points, the padeye will be checked according to [11] NS3472. To investigate potential stress concentrations in either the pad eye or the connection between padeye and the existing structure I will use the FEA software Abaqus to make a model of the critical detail and use results from the global analysis to apply forces and boundary conditions to the detail.

The joint check is performed using the rules in [5] Eurocode 3 part 1-8, Design of joints and additional stress checks by using the Von Mises yield criteria. The structure consists of a large number of joints. In order to limit the analysis work of the local design a screening of the beam end stresses is performed to find the critical joints in the structure. A full check of these joints will be performed and an acceptable result of the check of these critical joints will imply that joints with similar reinforcement and configuration through out the structure will be of a lower utilization.

3.3. Main characteristics Module M32

Module M32 is situated on the east side on the main deck at the Frigg TCP2. The module is supported on four support points at the main support frame (MSF). The module consists of a simple truss structure with rather heavy load bearing beams in the bottom of the module.
The size of the module is 39m long, 10.6m wide and 15 m high and has an estimated net dry weight of 925 tones.

For additional information about the Frigg field visit [17]
http://www.kulturminne-frigg.no/

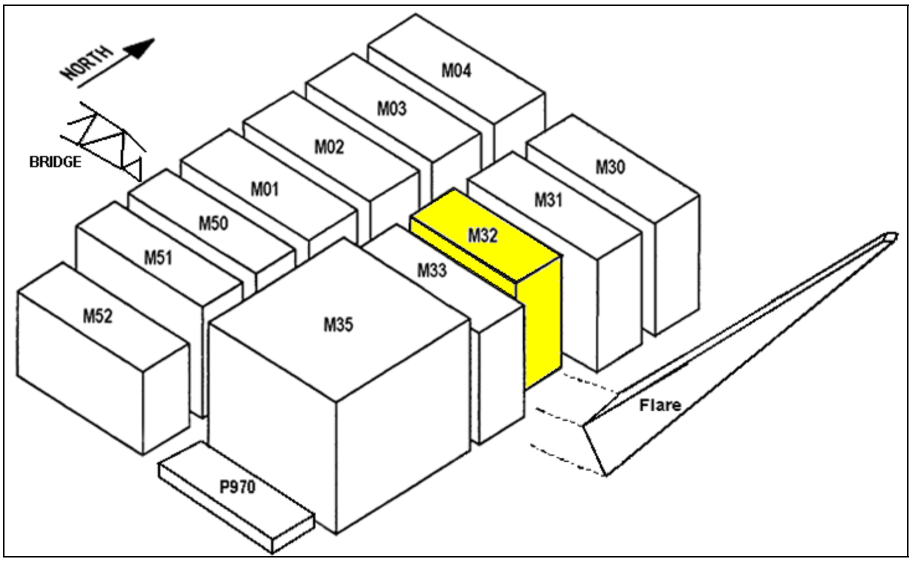


Figure 3-1 Frigg TCP2 Modules

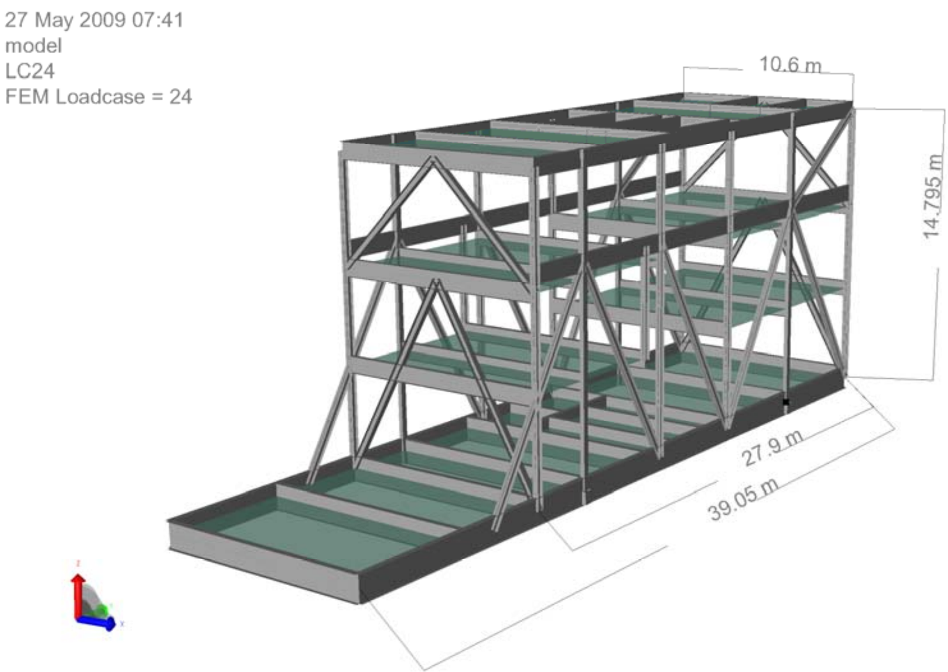
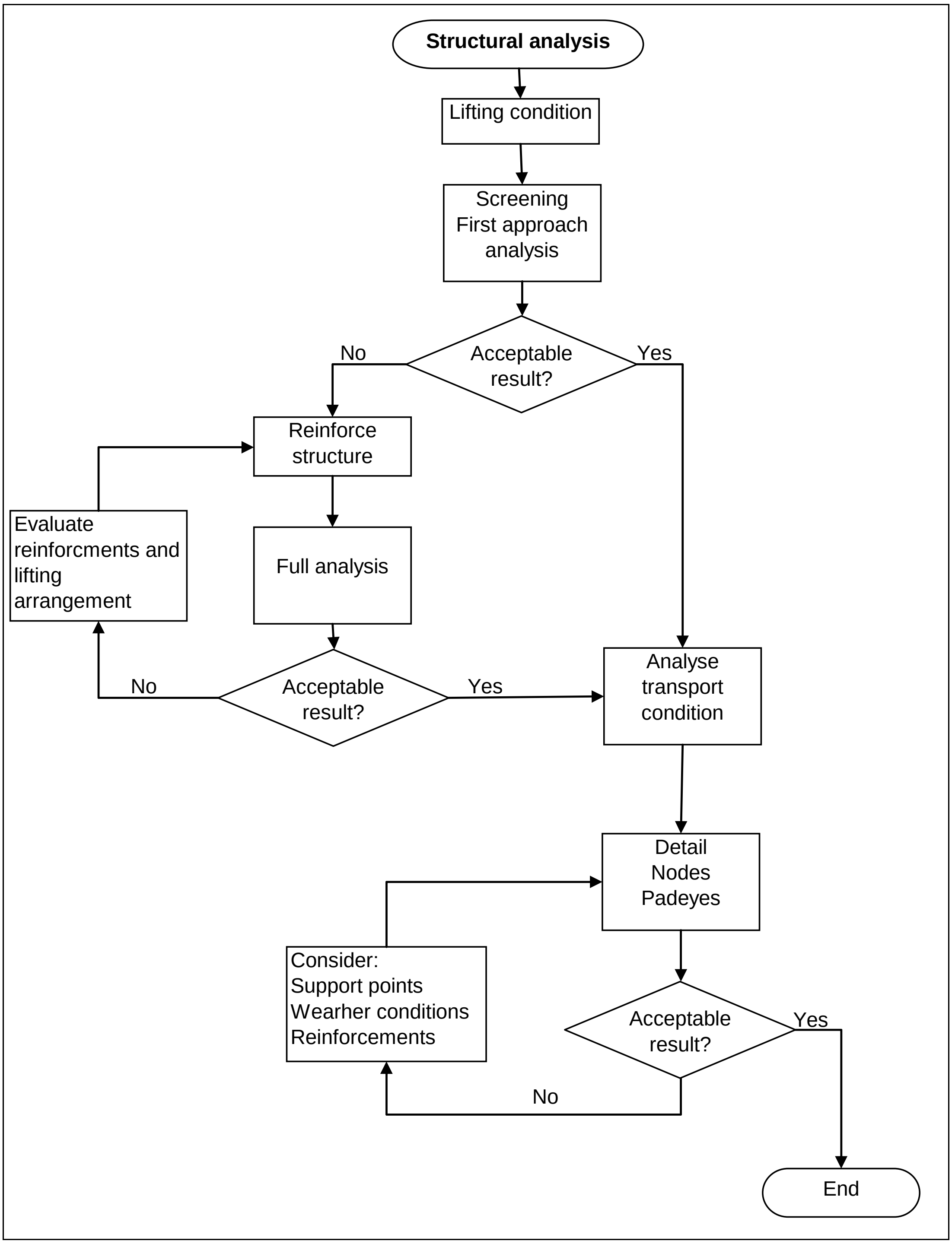


Figure 3-2 Main load bearing steel structure of TCP2 Module M32

3.4. Analysis

The cycle for the analysis procedure is presented in following flow diagram.



3.4.1. Software

For the global structural analysis of the M32 module I have chosen to use the Sesam package developed by DNV Software.
By using the Sesam package this will open up for superelement analysis. This method is time saving when multiple analysis with different boundary conditions are to be carried out.

The parts of the Sesam package used in this thesis are:

- GeniE
  - Pre-processor for modelling beam/shell/plate structures
  - Pre-processor for applying equipment loads and actions
- Presel
  - Superelement and load assembly pre-processor
  - Uses first level super elements created by GeniE to create higher order super elements.
  - Assemblies loads/actions from GeniE and creates load combinations.
- Setsra
  - Solves the Finite Element equations.
- Prepost
  - Conversion of Finite Element model, loads and results into postprosessor database formats.
- Framework
  - Code check unit and post processor for the finite element analysis
- Xtract
  - Is a post-processor for presentation of results from static structural analysis.

Investigation of stress concentrations related to the local analysis is performed using the Abaqus software. The FE model is made by a multi part model with described constraints between the different parts providing a realistic assembly. The Abaqus analysis has been performed as static linear analysis.

For theoretical calculations I have chosen to use the Mathcad software developed by [18] PTC software. This is a mathematical spreadsheet with integrated word processor. This is a very powerful tool which provides the user to present the calculations with mathematical signs and fill in text in the same spreadsheet. The Mathcad software is able to perform both algebraic and numerical calculations. The disadvantage with Mathcad is the ability to handle large amount of input data. For this purpose I consider Microsoft excel as a stronger software.

3.5. Regulations, Specifications, Design Codes and References

References

[1] Aker Solutions (2006): GEN-AKOPS-N-001 Structural design premises – Removal of topsides rev. 3. Aker Solutions. Stavanger.
[2] Aker Solutions (2006): TCP2T-AKOPS-N-001 Structural design brief – Removal of topsides rev.3. Aker Solutions. Stavanger.
[3] Boresi and Schmidt (2003): Advanced mechanics of materials 6th edition. Wiley & sons. USA.
[4] British standards institution (2005): Eurocode 3 part 1-1 Design of steel structures - General rules for buildings, BS EN 1993-1-1, British standards institution (BSi).
[5] British standards institution (2005): Eurocode 3 part1-8 Design of steel structures - Design of joints, BS EN 1993-1-8, (BSi).
[6] Cook, Malkus, Plesha and Witt (2002): Concepts and applications of finite element analysis 4th edition. Wiley & sons. USA.
[7] Det Norske Veritas (2004): DNV-RP-102 Marine operations during removal of offshore installations. Det Norske Veritas, Høvik.
[8] Det Norske Veritas (2007): DNV-RP-C205 Environmental conditions and environmental loads. Det Norske Veritas, Høvik.
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[11] Norsk Standardiseringsforbund (2001): NS3472 Steel structures Design rules 3. Edition. Norsk Standardiseringsforbund, Oslo. (in Norwegian)
[12] Saipem (2006): GEN-SUKL-DBF-005 Revised criteria for S7000 - Seafastening and transportation rev. 2. Saipem. UK.
[13] Saipem (2002): CRI-SUK-ENGI-12 Company engineering criteria Design of lifting points. Saipem. UK
[14] Saipem (2006): GEN-SUKL-REP-0011 S7000 Motions for modules on S7000 deck
[15] Standards Norway (2007): NORSOK N-003 Actions and action effects 2. Edition. Standards Norway, Lysaker
[16] Standards Norway (2004): NORSOK N-004 Design of steel structures rev. 2. Standards Norway, Lysaker

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[17] http://www.vanbeest.nl/public/files/catalogue/en/Chapter01_Shackles.pdf Heavy duty shackles
[18] http://www.kulturminne-frigg.no/ Public Frigg oilfield information site
[19] http://www.ptc.com/ Mathcad software developer home page

3.6. Abbreviations

ALS	Accidental limit state
AOP	Aker Offshore Partner
BE	Best estimate
BSi	British standard institute
COG	Centre of gravity
DAF	Dynamic amplification factor
DNV	Det Norske Veritas
FE	Finite Element
FEA	Finite Element Analysis
Hs	Significant wave height
LC	Load case
LLC	Local load case
MaxW	Maximum weight
MinW	Minimum weight
MSF	Main steel frame
NDT	Non destructive testing
NS	Norsk Standard
SLS	Serviceability limit state
SSCV	Semi submergible crane vessel
UF	Utilization factor
UiS	University in Stavanger
ULS	Ultimate limit state
WFC	Weight contingency factor

4. DESIGN BASIS

4.1. General

The rules and specifications used in this thesis are based on known and published standards and regulations from Det Norske Veritas [7], [8] and [9]. Norwegian Standards [11] and Eurocode [4] and [5]. In addition to these public standards, in-house documents prepared by Aker Solutions, Total E&P Norge and Saipem UK have been used. In the Frigg cessation project a common design agreement between the Frigg field operating company Total E&P Norge, the lifting contractor, Saipem and the engineering and installation contractor Aker Solutions was prepared. This document is the [1] Strucutral design premises - Removal of topsides. When preparing this document a large effort was made to cover interfaces between existing rules and the new requirements for removal phases of offshore installations. The Structural design premises can be find on the attached CD.

The design is in general based on the limit state design method. Relevant limit states for the removal operations are Ultimate Limit State (ULS), Serviceability Limit State (SLS), Accidental Limit State (ALS) and Fatigue Limit State (FLS). [1] Structural design premises, chapter 3.3.

In general a material factor (γ_m) of 1.15 is applied for the ULS condition.

4.2. About the presentation of results

Results from analyses are represented as utilisation factors (UF) where UF denotes the actual utilisation compared with the allowed stress limit for in the condition checked against. When performing structural verification by use of the von Mises Yield criteria the utilisation factor is calculated as $UF = \dfrac{\sigma_{mises}}{\dfrac{f_y}{\gamma_m}}$, f_y = material yield strength

To provide faster code checking of beams and members under axial force and bending, the conservative check in [11] NS3472, 12.2.6 is used. This is a linear summation of the utilisation ratios. Members which not pass this test are being further investigated using the more accurate rules in [11] NS3472.
In the case of using the conservative formula the UF becomes:

$$UF = \frac{N_{Ed}}{N_{Rd}} + \frac{M_{y,Ed}}{M_{y,Rd}} + \frac{M_{z,Ed}}{M_{z,Rd}}$$

Where: N_{Ed}, $M_{y,Ed}$ and $M_{z,Ed}$ denotes the design axial force and bending moments
N_{Rd}, $M_{y,Rd}$ and $M_{z,Rd}$ denotes the design resistance values for axial force and bending moments.

For the calculations performed in this report the maximum allowable utilisation factor is 1.0.

5. GEOMETRY AND PROPERTIES

5.1. *Coordinate system*

The global coordinate system of the M32 Module is chosen with the x-axis running in the platform North direction, the y-axis is pointing West and the z-axis upwards. For larger analysis with several super elements the selection of global coordinate system and the positioning of the super elements in the global coordinate system are essential. Since this analysis only contains of one superelement, and to provide fast modelling from module drawings, the point most eastern and southern of the M32 module is set to (0, 0, 0). Since the load data of the M32 Module is given in the global coordinate system of the Frigg TCP2 platform, and for COG check of the computer model, a coordinate system transformation sheet has been made.

5.2. *Units*

The GeniE input units are set to m, tonnes, kN, and Celsius.
The Framework and Xtract output units are set to m and MN. Stress output will then be in MPa.

5.3. *Structural modelling*

The Genie computer model is made according to the drawings found in the Total E&P Norge Frigg cessation database. The computer model consists of the main, load bearing structure of the M32 module, and shear plates representing the shear stiffness of the plate flooring in the module. The main steel modelled, is considered as the critical structure for the removal operation.

The model consists of a wireframe with joints and beams. For every beam end there is 6 degrees of freedom. The Sesam software package is intelligent in a way such that there is no need creating nodes where two beams intersect in the same plane.

Appendix A shows members and joint names of the computer model.

The analysis procedure is further discussed in the Global analysis setup chapter

5.4. Cross sections

The M32 Module consists both of welded I-Sections and standard HEB and RHS sections.
The bottom frame consists of welded I – Sections 1210 mm x 300 mm.
The figure below displays the cross sections of the M32 Module

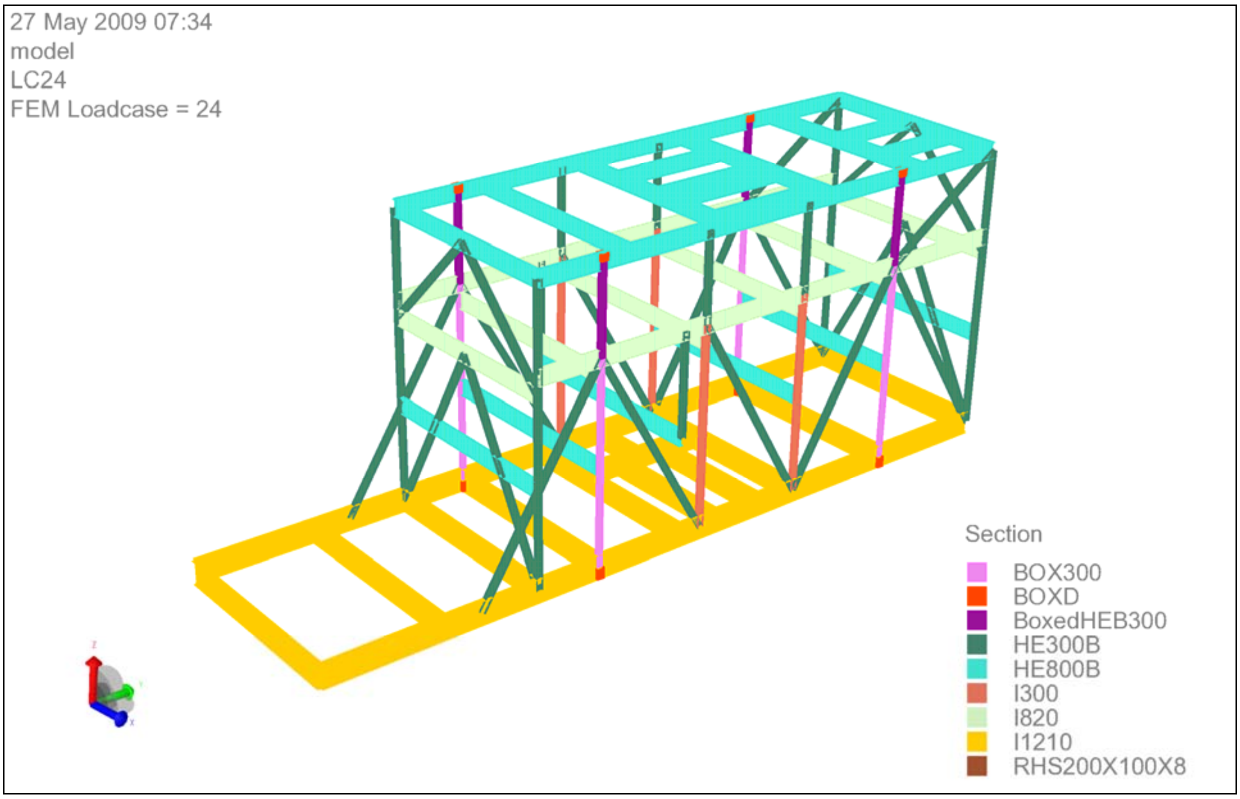


Figure 5-1 M32 Cross sections

Member	Description	Height [mm]	Width [mm]	t.flange [mm]	t.web [mm]
Box sections					
BOX300	Welded channel	300	220	40	40
BOXD	Support dummy members	400	400	100	100
Boxed HE300B	Reinforced HE300B equivalent section	300	300	19	16
RHS200x 100x8	Chanel section	200	100	8	8
I - Sections					
HE300B	Hot rolled	300	300	19	11
HE800B	Hot rolled	800	300	33	17.5
I300	Welded	300	300	16	40
I820	Welded	820	300	16	20
I1210	Welded	1210	300	16	25

Table 5-1 Genie cross sections

5.5. Member local axis

The strong axis for bending is rotation about the y – axis, the weak axis is rotation about the z – axis and the x – axis is pointing in the member length direction. The figure below shows local axis for an I – section and a RHS – section.

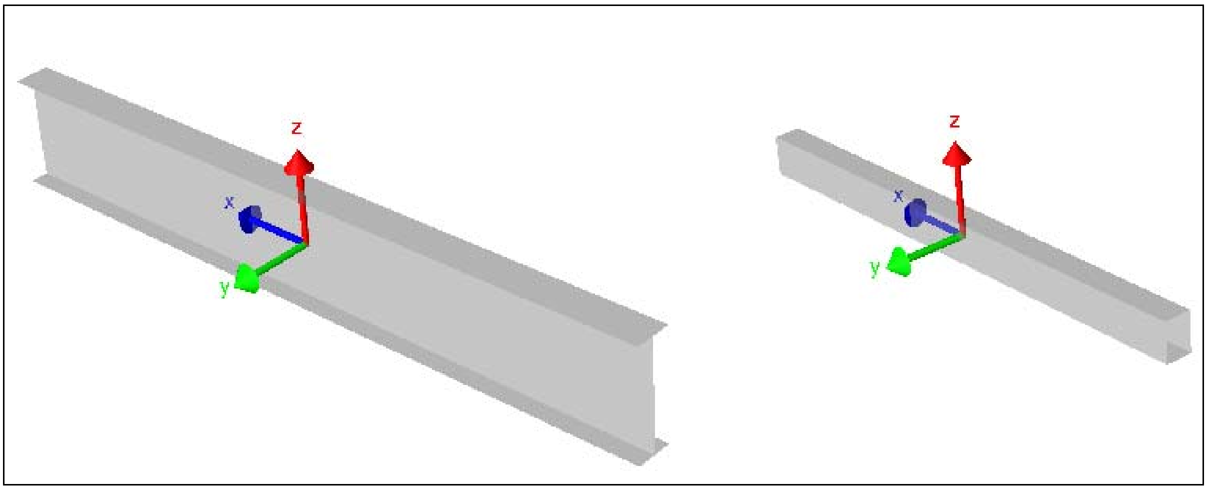


Figure 5-2 Member local axis of I - and box - sections

5.6. Material

The materials used in the computer model is represented in the table below

Material	Yield strength [MPa]	Density [kg/m^3]	Young's Modulus [MPa]	Poisson's ratio	Thermal expansion Coefficient [$^{\circ}C^{-1}$]	Axial reduction
ST355	355	7.85E3	210000	0.3	1.2E-5	
DST355	355	0.000	210000	0.3	1.2E-5	
Shear	0	7.85E-7	210000	0.3	0	100

ST355 denotes the structural steel material used at the M32 module.

DST355 denotes material used for dummy elements offsetting support points and for equipment supports providing a more accurate load distribution.

Shear denotes the material used for the shear elements representing the shear stiffness of the floor plates in the module. To avoid some bending and axial stresses to be taken of the floor plates the axial components in the constitutive matrix are reduced by a factor: $\frac{1}{100} = 0.01$. The axial reduction of 100 provides a small enough factor to remove the unwanted plate effects and large enough to be handled by the FE software. The constitutive matrix [E] representing the elasticity matrix of the plane stress condition of the shear material is: $E = \frac{E}{1-\nu^2}\begin{bmatrix} \frac{1}{100} & \frac{\nu}{100} & 0 \\ \frac{\nu}{100} & \frac{1}{100} & 0 \\ 0 & 0 & \frac{1-\nu}{2} \end{bmatrix}$

Where ν denotes Poisson's ratio.
Ref[6] Cook et al. 2002

5.7. Code check parameters

The code used for code checking in Framework is Eurocode 3/NS3472.
The material factor used is 1.15 according to [1] Structural design premises
The failure criterion for the Von Mises check is yield at the outermost fibre in the cross section. To use the Sesam Framework code check with differentiating between the different section classes, and use the plastic capacity of class one and two beams, the Von Mises check has to be turned off.

The buckling factor is in general set to 0.8 around both the z- and y-axis of the cross section. The buckling factor of 0.8 is used to cover the partial fixation of the welded joints, this factor is considered conservative. For members and columns running over several nodes the buckling length is set from the first to the last node. For different buckling lengths around the z- and y-axis a node to node buckling length is used and the differentiation is covered by scaling the buckling factor for the axis with the longest buckling length. For beams and columns with high utilization factor (UF) the buckling factor is calculated according to NS3472 B 12.3.2.This calculation results shows also that the general factor of buckling factor 0.8 is conservative.

The calculations of buckling factors are displayed in appendix C.2

5.8. Lifting arrangement

Due to the weight of the structure, the lifting arrangement is designed in such a way that the sling loads acting on the module lifting points are vertical. This is done to avoid compression forces in the structure. The compressive loads in the single hook lifting arrangement are taken by the 3 spreader bars shown in figure 5-3.

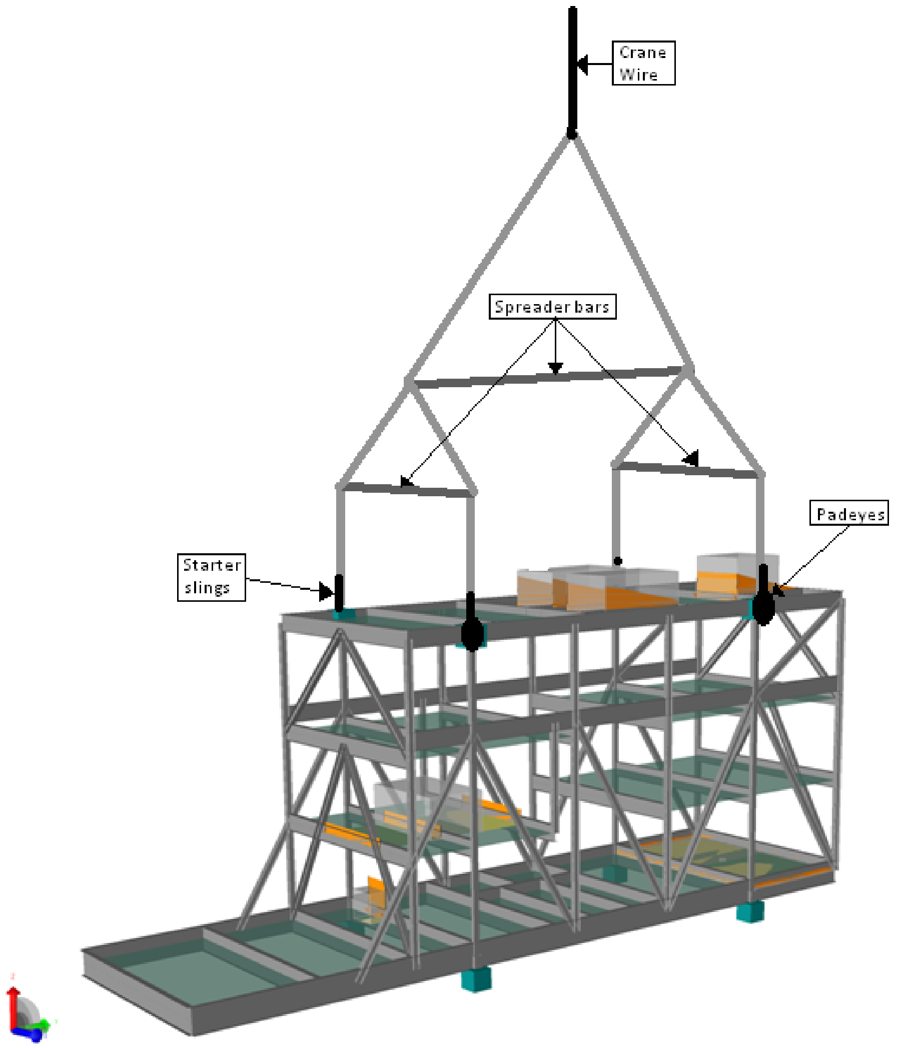


Figure 5-3 Lifting arrangement

When performing the lift I have chosen to use starter slings. This implies that only padeyes, shackles and starter slings need to be installed to the module prior to the lifting.

6. ACTIONS

The analysis of the steel structure of the M32 Module at the TCP2 Frigg platform was carried out as a static analysis with dynamic load effects added as a dynamic amplification factor (DAF) to the static loads and actions.

To provide realistic values of crane vessel actions Saipem S7000 SSCV is chosen to carry out the lifting from the platform and transportation of the module on deck to demolition site. Values for maximum Hs and appurtenant vessel accelerations for transportation condition is given in [14] Motions and accelerations on S7000 deck.

6.1. Basis

The loads are applied to the structure at the lowest superelement level and combined at higher super element levels.

The following table shows GeniE load cases for superelement level one.

LLC	Load case description	Direction
1	Self generated load	(-z)
2	Structural Loads to match weight database	(-z)
3	Mechanical, electrical and Piping	(-z)
4	Heavy equipment	(-z)
11	Wind from South	(x)
13	Wind from North	(-x)
12	Wind from East	(y)
14	Wind from West	(-y)
101	Self generated load	(x)
102	Structural Loads to match weight database	(x)
103	Mechanical, electrical and Piping	(x)
104	Heavy equipment	(x)
201	Self generated load	(y)
202	Structural Loads to match weight database	(y)
203	Mechanical, electrical and Piping	(y)
204	Heavy equipment	(y)

Table 6-1 Local load cases

6.1.1. Structural and Equipment loads

According to [1] Structural design premises, equipment loads over 10 tonnes shall be included in the model with its actual COG coordinates. Other objects such as piping and smaller equipment shall be uniformly distributed over the decks.

The Frigg field operating company,Total E&P Norge has made a web page where all the load data, drawings and pictures are stored and available. Every load item is listed with belonging COG. The load lists is on a detail level which is not suited for use in computer analysis. The loads where sorted after COG z value and equipments with weight below 10 tones where added as distributed loads on each deck.

	Range [m]	
Lower deck	109.1	111.8
Substation deck	111.8	116.8
Contol room deck	116.8	121.4
Upper deck	121.4	

Table 6-2 Range of COG z – values in global TCP2 coordinates

Lower deck:	Load [Tonnes]
Structural	
Secondary steel	49.02
Flooring	7.27
Walls	41.50
Outfitting	26.25
Paint	4.65
Outside areas	6.34
Arcitectural	2.55
Piping	2.30
Electrical	27.67

Control room deck	Load [Tonnes]
Structural	
Secondary steel	0.00
Flooring	5.19
Walls	41.50
Outfitting	26.25
Paint	4.65
Supports	21.80
Piping	0.98
Electrical	38.99

Substation deck	Load [Tonnes]
Structural	
Secondary steel	8.11
Flooring	5.19
Walls	41.50
Outfitting	26.25
Paint	4.65
Supports	1.30
Piping	8.32
Electrical	34.80
	27.67
	6.80
Telecom Fire and s	3.87
HVAC	1.50
Instruments	7.31

Upper deck	Load [Tonnes]
Structural	
Secondary steel	13.86
Flooring	5.19
Walls	
Paint	4.65
Supports	38.40
Arcitectural	7.53
Piping	48.18
Piping supports	11.79
Electrical	
HVAC	4.52
Instruments	1.20
Mechanical	8.26

Table 6-3 Distributed loads in tonnes

Amund Lundqvist

	Load [tonnes]	x	y	z
Electrical		-46.50	8.05	-109.06
Feedbrakers	14.35	5.66	15.49	6.70
El_eq	4.78	2.47	14.38	1.00
GEN_ASSY_TRANSFOREMER1	2.59	7.73	34.53	1.00
GEN_ASSY_TRANSFOREMER2	2.59	2.63	34.53	1.00
GEN_ASSY_TRANSFOREMER3	5.00	7.73	37.13	1.00
GEN_ASSY_TRANSFOREMER4	5.00	2.63	34.13	1.00
Mechanical				
Skid A	20.60	4.36	25.97	15.97
Skid B	18.82	8.27	25.73	15.96
Fuel gas heater	22.38	6.35	35.40	14.94
Sum heavy equipment	61.80	tonnes		
Structural				
Crane	14.41			

Table 6-4 Equipment boxes loads in tonnes

Table 4 - 4 shows that there are four equipment boxes with weights less than 10 tonnes. The reason that these equipment boxes have been modelled separately is that they together make a significant contribution to the accuracy of the COG of the computer model.

6.1.2. Live loads

For lifting and transport of the M32 module the Live loads are considered as zero.

6.1.3. Environmental loads

Since the lifting vessel has an operating wave height limit of 3 m, the environmental loads for the lifting operation are considered very small and therefore covered by the dynamic amplification factor (DAF).
For transport condition, wind and wave loads have to be applied. The lifting and transport actions are defined as weather restricted operations. For lifting the weather restriction given in [12] Revised criteria for S7000 - seafastening and transport is 3m Hs. For transportation, the max Hs is set to 8m and the wind restriction window is set for the spring and summer months, Mai - Aug. For the wind actions the return period used is 1 year, with gust wind duration of 3 s
The wind force is calculated according to [8] DNV – Environmental conditions and environmental loads
The calculations are displayed in appendix B.2.
The module accelerations used is given in [14] Motions for modules on S7000 deck and presented in the following

Worst case acceleratoions 10m above deck				
	S7000	M32	[m/s^2]	factor*g
Surge	x	y	2.153	0.219
Sway	y	x	2.725	0.278
Heave	z	z	1.998	0.204

Table 6-5 Worst case accelerations at Saipem S7000 deck.

The accelerations due to roll and pitch motions are included in the surge, sway and heave acceleration components presented in table 6-5.

6.1.4. Deformation loads

When setting the M32 module down on the S7000 deck vertical inaccuracies in the level of the support frame for transport, called grillage, can appear. This inaccuracy can lead to a small rotation of the module causing additional stresses in the structure. To remove large grillage inaccuracies thin shimming plates is applied between the module and the grillage. However the vertical inaccuracies will never completely be removed. To account for this vertical deformation, short beam elements are modelled between the structure and support points. The element causing the largest stresses in the structure are applied a temperature load elongating the element and simulating the vertical grillage and shimming inaccuracy. According to [1] Structural design premises the inaccuracy tolerance for uneven shimming and grillage deflections is set to 5 mm for the transportation condition.

6.2. Modelling

6.2.1. Structural and equipment loads

All structural and equipment loads both equipment over 10 tonnes, and uniformly distributed loads is added to the computer model as equipment boxes. This enables fast modelling and realistic load distribution. Equipment boxes are a Genie built in tool for adding loads as equipments with a footprint to the FEM model. The load unit for these items are mass, when analysis is carried out an acceleration field is set transforming the mass to loads with a specified direction.

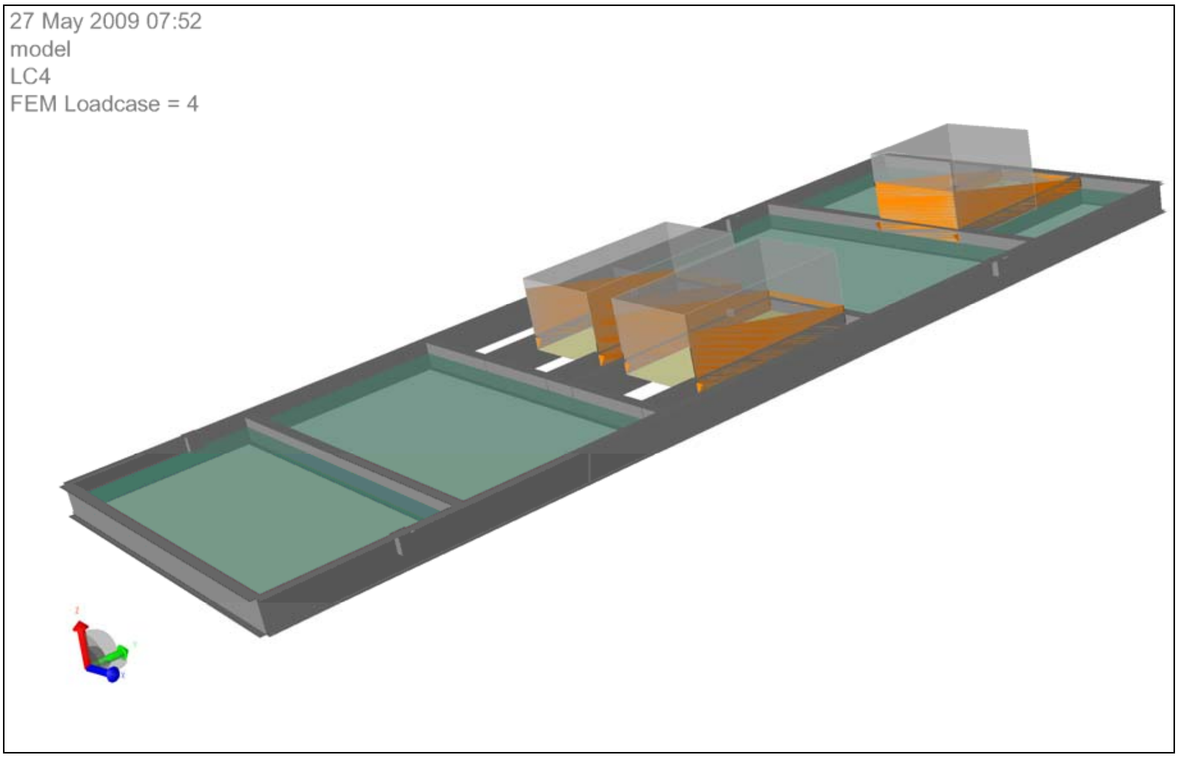


Figure 6-1 Principle of load distribution useing equipment boxes

The deck stringers are running in the global y – direction, therefore the distributed loads are applied on beams running in the global x – direction supporting the stringers.

6.2.2. Environmental loads

The wind loads for the transport condition are applied to the structure as line loads. The height each line load covers is the sum of the half distances between each load. The shape factors for the module are found in [8] DNV – Environmental conditions and environmental loads and are set to 0.7 at the pressure side and 0.5 at the suction side of the M32 Module.

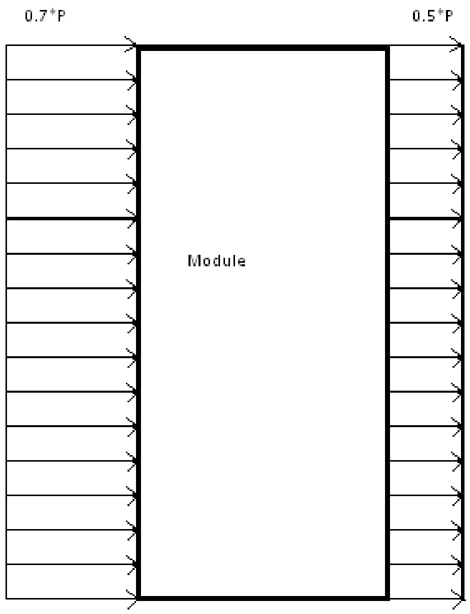


Figure 6-2 Wind pressure distribution on M32 Module

For the wave accelerations worst case of positioning on the S7000 deck has been used to determine the acceleration values. Accelerations are given in the following table, given as a factor times g (9.81m/s^2). The calculation is carried out with the module placed in the unfavourable direction i.e. the module x direction is pointing in the longitudinal direction of the crane vessel.

6.3. Deformation Loads

The deformation load is applied to the support point creating the largest stresses in the structure. To simulate the deflections temperature loads is applied to the dummy member between the support point and the centre of the I1210 beam.

The length increase of the beam segment is given by:

$$\Delta l = k \cdot l \cdot \Delta T$$

Where Thermal expansion factor k =1.2E-5
Sub length = l
ΔT = Temperature difference

6.4. Load sums

Table below show the sum of loads and actions applied to the structure.

Structural and Equipment loads

Structural	[tonnes]
Modeled	184.00
Applied	397.95
Arcitectural	10.08
Mechanical	61.80
Piping	71.56
Electrical	196.88
Sum	922.26

Environmental loads

Wind Loads [kN]

Wind from	Raw	Pressure	Suction	Total
South	202.89	142.02	101.44	243.47
South/East	197.94	138.56	98.97	237.53
East	77.08	53.96	38.54	92.50
North east	197.94	138.56	98.97	237.53
North	202.89	142.02	101.44	243.47
North/west	197.94	138.56	98.97	237.53
West	77.08	53.96	38.54	92.50
South/West	197.94	138.56	98.97	237.53

Waves

Accelerations on S7000

Worst case 10m above deck				
	S7000	M32	[m/s^2]	factor*g
Surge	x	y	2.15	0.22
Sway	y	x	2.73	0.28
Heave	z	z	2.00	0.20
			g = 9.81m/s^2	

Table 6-6 Sum of loads and actions applied to the structure

7. GLOBAL ANALYSIS SETUP

7.1. Software procedure

The analysis is performed with the Sesam components described in 3.4.1 and the following procedures are performed in each program.

- GeniE
  - Properties assignment
  - Structure modelling
  - Defining loads and actions
  - Adding loads and actions to the structure
  - Defining superelement nodes for transport and lift condition
  - Creating FEM file for first level super element level 1
- Presel
  - Superelement assembly
    - Level 2
    - Tope level
  - Load combinations superelement 100 and 200
- Sestra
  - Run Static analysis
  - Top level super elements
- Prepost
  - Conversion of Finite Element model, loads and results into postprosessor database formats. Includes results with different boundary conditions to run a single Framework run.
- Framework
  - Generate code check according to eurocode3/NS3472
  - Generate UF list
  - Generate UF figures
- Xtract
  - Displays deformed shapes
  - Display stress counter plot of the finite elements

The complete set of analysis and output files are at the attached compact disc.

7.2. Super elements and boundary conditions

When generating the finite element file from Genie, the nodes chosen to be added boundary conditions was set as super element nodes. The super element nodes can either be used to assign boundary conditions or to define constraints between different super elements. For instance when analysing the grillage structure the module and all defined loads can be applied to the grillage structure by connecting the module super element to matching super element nodes at the grillage structure. This requires that the module and grillage is modelled in the same coordinate system. The super element assembly is performed by the Sesam component Presel. In Presel there was generated to different super elements for the lifting and transportation condition. For lifting the super element was named 200 and transportation super element 100. The super element numbering is chosen to simplify the result coupling in Prepost where results from superelement 200 containing 4 load cases are added to the super element 100 containing 96 load cases. The figure below shows the superelement nodes defined to add boundary conditions for lifting and transportation condition.

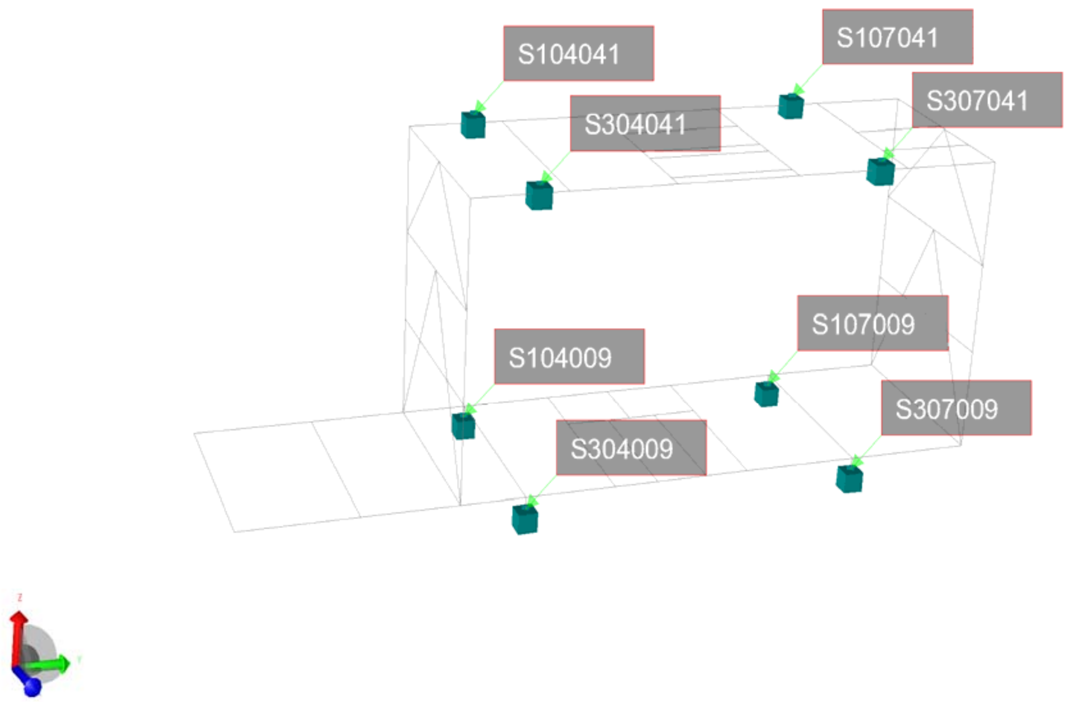


Figure 7-1 Module outline with superelement nodes

7.2.1. Lift condition

The boundary conditions are based on the lifting arrangement with vertical slings described in chapter 3.7.
When lifting the module the connection between the module and the lifting arrangement is done by shackles and starter slings. This connection does not transfer any moment from the module to the lifting arrangement.
To prevent rigid body motions when carrying out the FEM analysis the boundary conditions is made of a 3 – 2 – 1 – 1 pinned support system, the numbers notes the degrees of freedom in x-, z, and y – direction (d.o.f) at the support points.

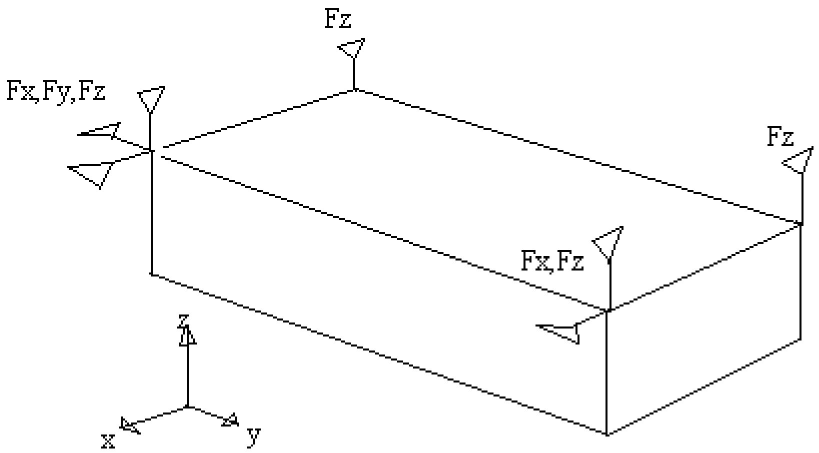


Figure 7-2 schematic boundary conditions for lifting

The super element nodes used for to apply the boundary conditions for the lifting condition are:
S(104041)
S(304041)
S(107041)
S(317041)

7.2.2. Transportation condition

The support points for the transport condition is chosen as the same as for the in-place condition for the M32 Module. To prevent large constraint forces in the structure during transportation, a 3 – 2 – 2 – 1 pinned support system is chosen. The seafastening has to be design to fit the selected boundary conditions.

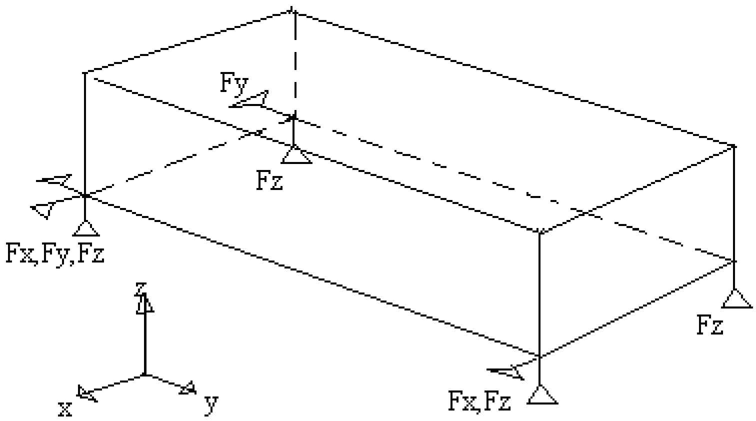


Figure 7-3 schematic boundary conditions for transportation

The super element nodes used to apply the boundary conditions for the transportation condition are:

S(104009)
S(304009)
S(107009)
S(317009)

7.3. Action combinations

In Presel the actions are combined in two levels, the first level 10 adds the load cases from GeniE to the super element. In top level xxx the n level assembly is combined to the final load cases. For lifting condition the top level super element is 200 and for transportation the top level super element is 100.

The different action combinations used at top level for both transportation and lifting is; SLS, ULS-a and ULS-b

Neg Z-dir	1.00
Neg Z-dir Heave	2.00
X (waves from S)	3.00
Y(waves from E)	4.00
Min Load	
Z	5.00
Z Heave	6.00
X (waves from S)	7.00
Y(waves from E)	8.00

7.3.1. Lift condition

For the lift condition ULS-a is the governing load combination. Additional load factor is presented in Table 7-1. With reference to [1] Structural design premises.

Weight contingency factor	1,10
CIF CoG inaccuracy factor:	1,02
CoG factor (xy plane)	1,14
Skew load factor	1,00
DAF	1,10
ULS-a	1,20
Consequence factor (CF)	
Non-lift members, no consequence	1,00
Lift members, reduced consequence	1,15
Consequence factor, Lift members	1,30

Consequence factors DNV-RP-H102 Chapter 3.1.4 table 3.2

Load Case (LC)		
LC	CF	Total LF
101	1,00	1,00
102	1,00	1,68
103	1,15	1,93
104	1,30	2,19

Table 7-2 Load factors and top level load cases ULS-a

7.3.2. Transportation condition

Load combinations for transportation condition are presented in the following table.

General load factors

Weight contingency factor		1.10
CIF CoG inaccuracy factor:		1.02
CoG factor z-direction		1.14
CoG factor x-direction		1.13
CoG factor y-direction		1.10
Wave acceleration *g		
	z	0.20
	x	0.28
	y	0.22

Multiplyed direction- and contingency factors

	Max load			Min Load		
	z	x	y	z	x	y
Struct. Eq. Loads	1.27			0.79		
Environmental loads	0.26	0.35	0.27	0.16	0.22	0.18

Table 7-3 Load combination factors transport condition

	Max. Load			Min. Load		
Wind/Waves from	SLS	ULS-a	ULS-b	SLS	ULS-a	ULS-b
South +	1	17	33	49	65	81
-	2	18	34	50	66	82
South/East +	3	19	35	51	67	83
-	4	20	36	52	68	84
East +	5	21	37	53	69	85
-	6	22	38	54	70	86
North/East +	7	23	39	55	71	87
-	8	24	40	56	72	88
North +	9	25	41	57	73	89
-	10	26	42	58	74	90
North/West +	11	27	43	59	75	91
-	12	28	44	60	76	92
West +	13	29	45	61	77	93
-	14	30	46	62	78	94
South/West +	15	31	47	63	79	95
-	16	32	48	64	80	96

Table 7-4 Top level load cases transportation condition

The max and min loads are, according to the [1] Structural design premises, calculated as:

$$W_{\max} = dryweight \cdot WCF$$

$$W_{\min} = \frac{dryweight}{WCF}$$

8. GLOBAL ANALYSIS RESULTS NO REINFORCEMENTS

The first global analysis was performed as a conservative screening analysis. The main goal of this analysis was to detect possible structural failures of the module for the different conditions.

8.1. Code check results

8.1.1. Lift condition

The Framework code check showed failure of critical columns connected to the padeyes. The Framework output results gave huge and misleading utilization factors. This can be explained by investigating the interaction formulas in Eurocode3 6.2.9. The moment reduction factor is dependent on the occurring axial force. When the axial force approaches the failure limit, the moment reduction factor approaches zero and the reduced moment capacity approaches zero. Finally the UF factor will be infinite. This is showed symbolically by using the formulas in [4] Eurocode3 part 1-1 6.2.9.1

Eurocode3 6.2.9.1

$$n = \frac{N}{N_d} \qquad M_d = f_d \cdot W_{py}$$

$$a = \frac{A - 2 \cdot b \cdot t}{A}$$

$$m_y = \frac{1 - n}{1 - 0.5 \cdot a} \qquad M_{nd} = m_y \cdot M_d$$

Framework UF: $UF = \frac{M}{M_{nd}} + \frac{N}{N_d}$

From the equations we can see that when $n = \lim_{N \to N_d} \frac{N}{N_d} = 1$

Further $m_y = \lim_{n \to 1} \frac{1 - n}{1 - 0.5 \cdot a} = 0$

Then $M_{nd} = \lim_{m_y \to 0} m_y \cdot M_d = 0$

And finally the error accures: $UF = \lim_{M_{nd} \to 0} \left(\frac{M}{M_{nd}} + \frac{N}{N_d} \right) = \infty$

By rearrangeing the formula a more precise UF will be :

$$UF = \frac{N}{N_d} + \frac{M}{M_d} \cdot (1 - 0.5 \cdot a)$$

By turning the plastic capacity control off and use the conservative capacity valid for section class 3, $m_y + m_z + n \leq 1$.The error form [4] is removed and the results can be used as guiding values for further calculations.

The reserve capacity for moment can be calculated as $\frac{W_p}{W_e}$ for HE300B this factor is 1.10. This implies that HE300B beams with conservative UF near or above 1.1 have to be reinforced.

Results for the critical beams from the conservative Framework check is presented in the following table.

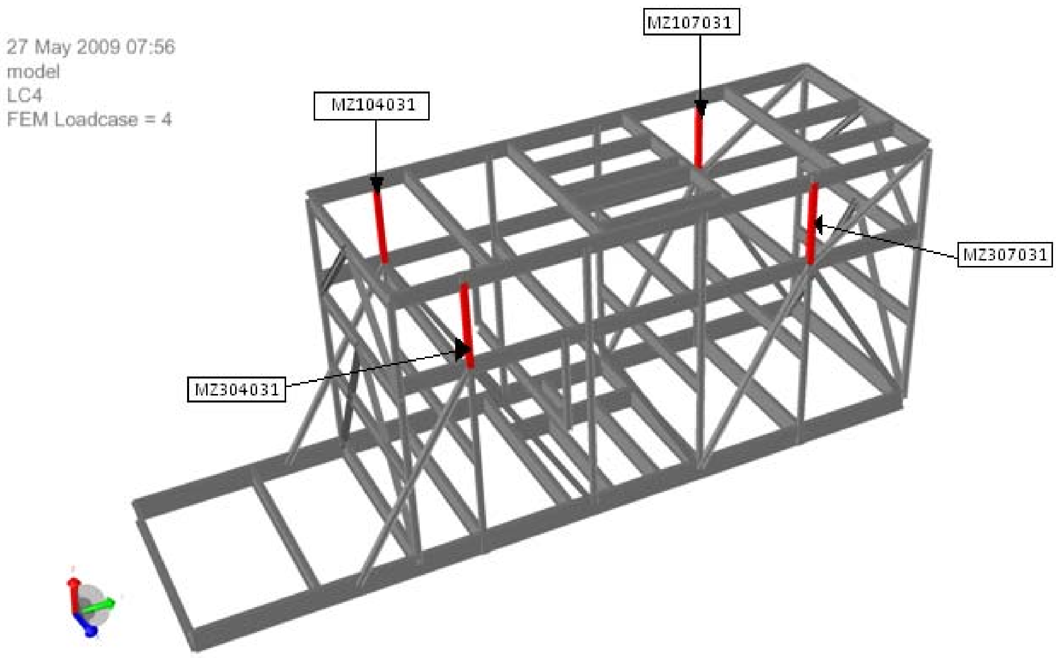


Figure 8-1 Failing members

Member	Type	Outcome	UsfTot	UsfAx
	SctNam			UsfMy
				UsfMz
MZ104030	I	*Fa M+Ax	1.123	0.915
	HE300B			0.044
				0.164
MZ107030	I	*Fa M+Ax	1.316	0.968
	HE300B			0.149
				0.199
MZ304030	I	*Fa M+Ax	1.089	0.922
	HE300B			0.035
				0.127
MZ307030	I	*Fa M+Ax	1.350	0.993
	HE300B			0.155
				0.201

Table 8-1 Conservative utilization factors failing members

8.1.2. Transportation condition

Since four members fail for the lifting condition, it will be necessary to reinforce these members to maintain the structural integrity of the module. The transport condition is analysed in the final analysis with the reinforcements for lifting installed and the extra weight implemented.

8.2. Analysis consequences

8.2.1. Structural reinforcements

It will be necessary to design reinforcements in order to prevent the members shown in table 8-1 from failure.

The reinforcements can be made in different ways, either reinforce the failing members or add additional members to redistribute the stresses in the structure. I have chosen t o investigate two different reinforcement methods. Both these methods can easily be adapted to other structures/modules where top mounted pad eyes leads to large tension forces in the structure.

Method A

Since the governing force for the failing members is axial force it is possible to use tension rods to redistribute the tension forces in the structure. This can be mad by using massive circular steel rods and pinned connections to the existing structure. A sketch of such a rod and the reinforced structure is shown below.

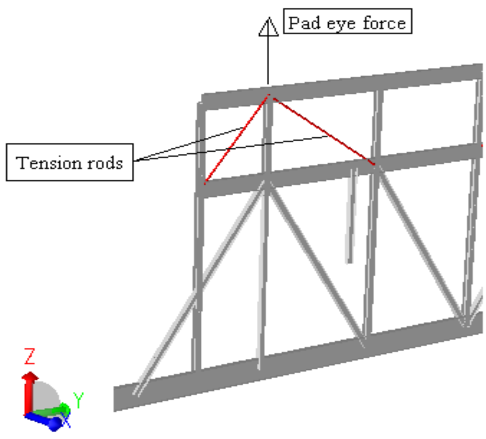


Figure 8-2 Reinforcement method A

Method B

It will also be possible to reinforce the failing members by adding additional webs to the HE300B profile. This reinforcements increase both the tension and bending capacity of the columns.

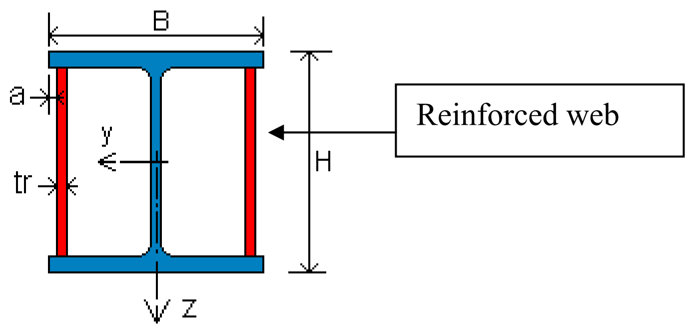


Figure 8-3 Sketch of boxed HEB profile.

8.2.2. Feasibility of suggested solutions

To decide which reinforcement method that will be best suited, small calculations of the additional capacity have been carried out. Further an evaluation of the capacity, cost and installation time led to the choice of which method to use.

Since the governing load direction for the failing members is axial force, only the additional capacity for tension has been calculated. The calculations are shown in Appendix C.4.

The main subjects investigated are

- Additional capacity
- Additional steel weight pr. Capacity %

From the calculations in Appendix C.4 the result is that will take three times as much steel to increase the capacity with 1% using Method A compared to Method B. Hence Method B is selected, although this method needs more welding for installation. In the computer model the reinforced cross section in for the global analysis only consists of the beam flanges and reinforcement plates. This was done to make a sufficient code check of the reinforced members, and cover for the stress concentration in the web as a result of the load transfer from the padeye to the column. This is further described in chapter 11.

The section reinforcement plates chosen are 16mm thick.

Method A can be considered if the joint forces get to high.

9. GLOBAL REANALYSIS

For the reanalysis a similar analysis setup as for the first analysis is used. In this analysis the transportation condition is covered and the transportation analysis is performed with the modified model. Boundary conditions and load combinations for the lifting condition is described in chapter 5.

10. FINAL GLOBAL ANALYSIS RESULTS

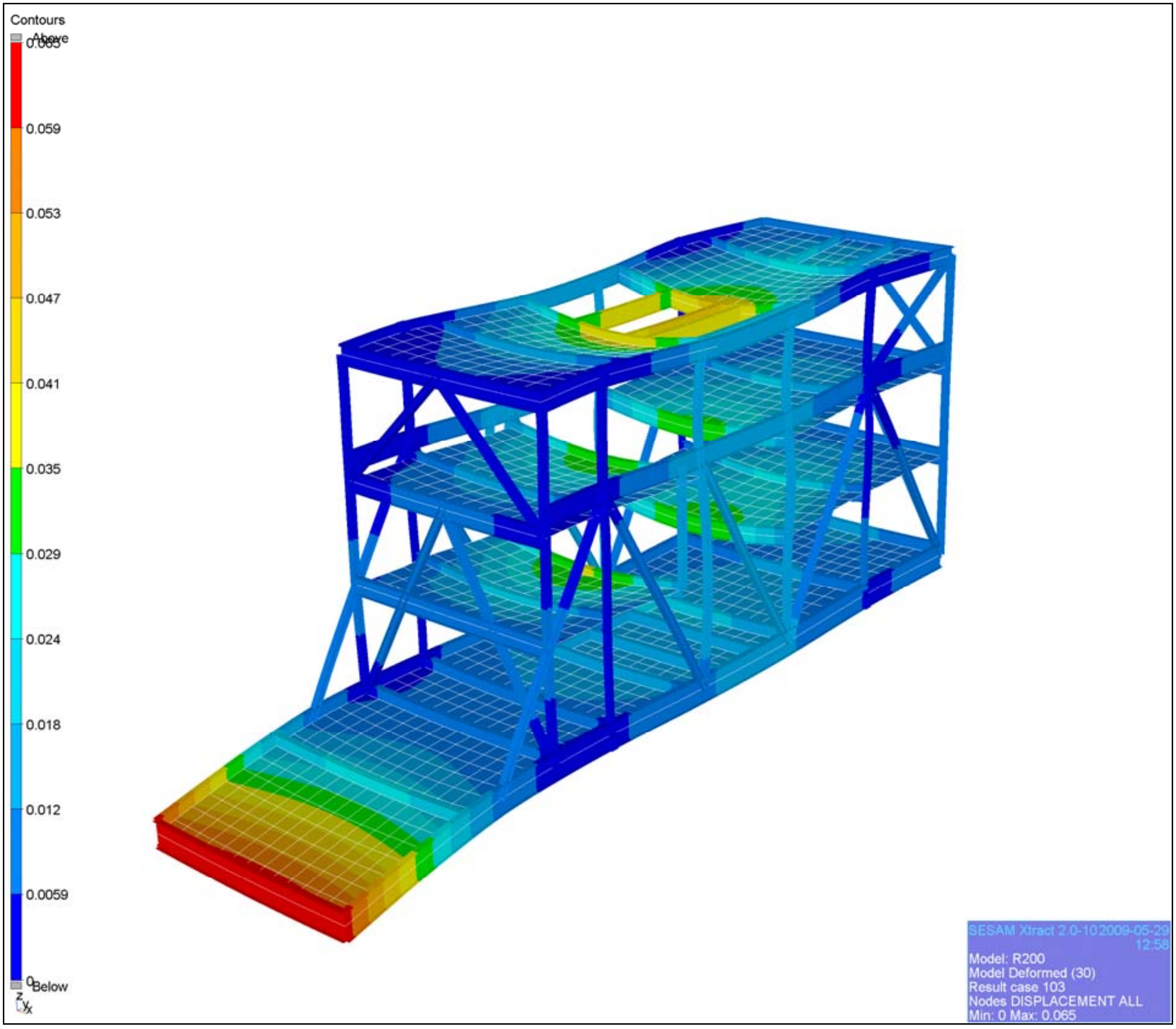


Figure 10-1 Deformed shape for governing lift load combination

Span checked for vertical deformation = 14.55m

$$\frac{L}{200} = \frac{14.55m}{200} = 0.073m > 0.061m$$

The maximum deformation for lift condition is acceptable.

10.1. Code check results

Utilization factors for worst case condition for the final analysis run are presented in the following tables.

10.1.1. Lift condition

Results from Framework load case 104 with reinforced members are presented in the following table.

Member	Type	Outcome	UsfTot	UsfAx
	SctNam			UsfMy
				UsfMz
MZ104031	BOX	AxLd	0.678	0.678
	BOXEDHEB			0.000
				0.000
MZ107031	BOX	AxLd	0.710	0.710
	BOXEDHEB			0.000
				0.000
MZ304031	BOX	AxLd	0.682	0.682
	BOXEDHEB			0.000
				0.000
MZ307031	BOX	AxLd	0.728	0.728
	BOXEDHEB			0.000
				0.000

Table 10-1 Framework results LC 104, UF above 0.6

10.1.2. Transportation condition

For transport condition the analysis results showed no need for reinforcements. Utilizations above 0.8 from framework are presented in the following table.

Member	LoadCase	Type	Joint/Po	Outcome	UsfTot	UsfAx
		SctNam	EleNum			UsfMy
						UsfMz
MY104010	43	I	0.4	Stab	0.978	0.269
		I1210	1520			0.648
						0.061
MZ307010	33	BOX	0.5	StaL	0.96	0.544
		BOX300	2423			0.065
						0.351
MF305031	37	I	0.5	StaL	0.921	0.853
		HE300B	2351			0.039
						0.029
MY306010	35	I	0.5	Stab	0.892	0.29
		I1210	2404			0.567
						0.035
MF107031	34	I	0.46	StaL	0.868	0.58
		HE300B	1702			0.181
						0.106

Table 10-2 Framework results transportation condition, UF above 0.8

10.2. Reaction forces

Table 10-3 shows the reaction forces from the structural and equipment loads, and deviation between the web database loads and the applied bulk loads.

Struct and Eq.	1696.000			2.153
101	1801.000			2.317
	1981.000	0.000		2.167
	2083.000	0.000	0.000	2.414

Sum	9.051	[MN]
Web database	9.062	[MN]
Diff	0.010	[MN]
	1.054	[tonnes]

Table 10-4 Reaction forces

The difference in bulk loads can be explained by that the old padeyes are included in the weight database. The new top mounted pad eyes are considered not to have any major effect on the analysis result and are therefore not included in the global analysis model.

10.2.1.Lift condition

Table 10-5 shows reaction forces for lifting condition with Consequence factor 1.30 and total load factor 2.32. These results will be used for load input in the local design of pad eyes.

Struct and Eq.	1696.000			4.996
104	1801.000			5.378
	1981.000	0.000		5.030
	2083.000	0.000	0.000	5.604

Table 10-6 reaction forces lift, consequence factor 1.3

10.2.2.Transportation condition

LOADCASE	NODE NO	X	Y	Z
ALL	1775	1.91	1.48	5.08
	1881	2.06	0.00	4.22
	2062	0.00	0.00	4.86
	2165	0.00	1.46	5.50

Table 10-7 largest reaction forces for transportation

11. LOCAL ANALYSIS PADEYES

This chapter covers the local design and analysis of the padeye and local check of the single critical column whom the lift force are transferred to.

11.1. Design

The padeyes for lifting of the M32 Module is designed to sustain actions of the heaviest loaded support point for lifting. The magnitude of this lift force is 5.6MN and is generated from the Sesam analysis shown in table 10 – 6.

The geometry of the padeye is designed according to [13] Company engineering criteria Design of lifting points, and the shackle designed for is P-6036 Green Pin shackles [17].

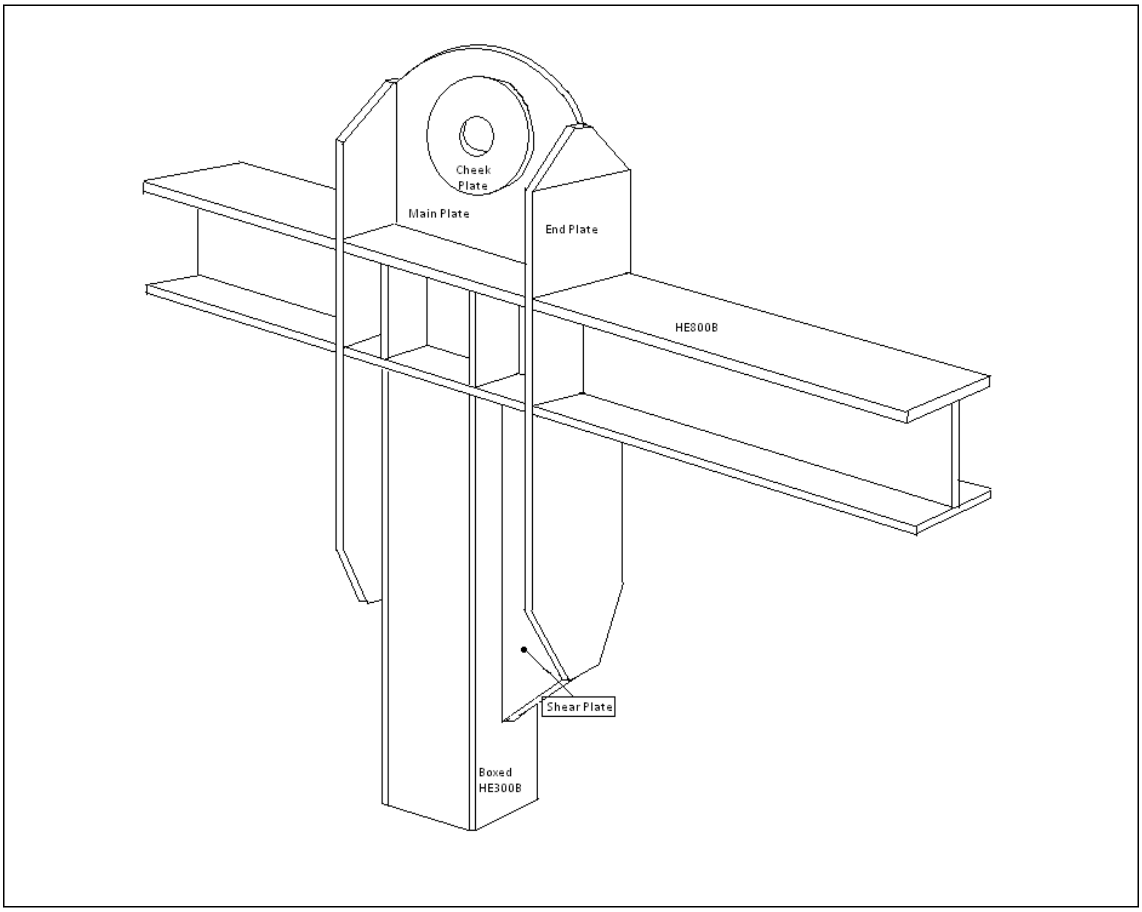


Figure 11-1 Isometric sketch installed padeye

Since there is no backing beam at the point where the padeyes are to be placed, the padeye is placed in the length direction of the M32 Module. By using this configuration the flanges of the top beam has to be cut and the pad eye end plates be elongated through these beams and down to the reinforced column between the upper deck and the control room deck. The forces from the padeye end plates are transferred to the boxed HE300B column via shear plates.

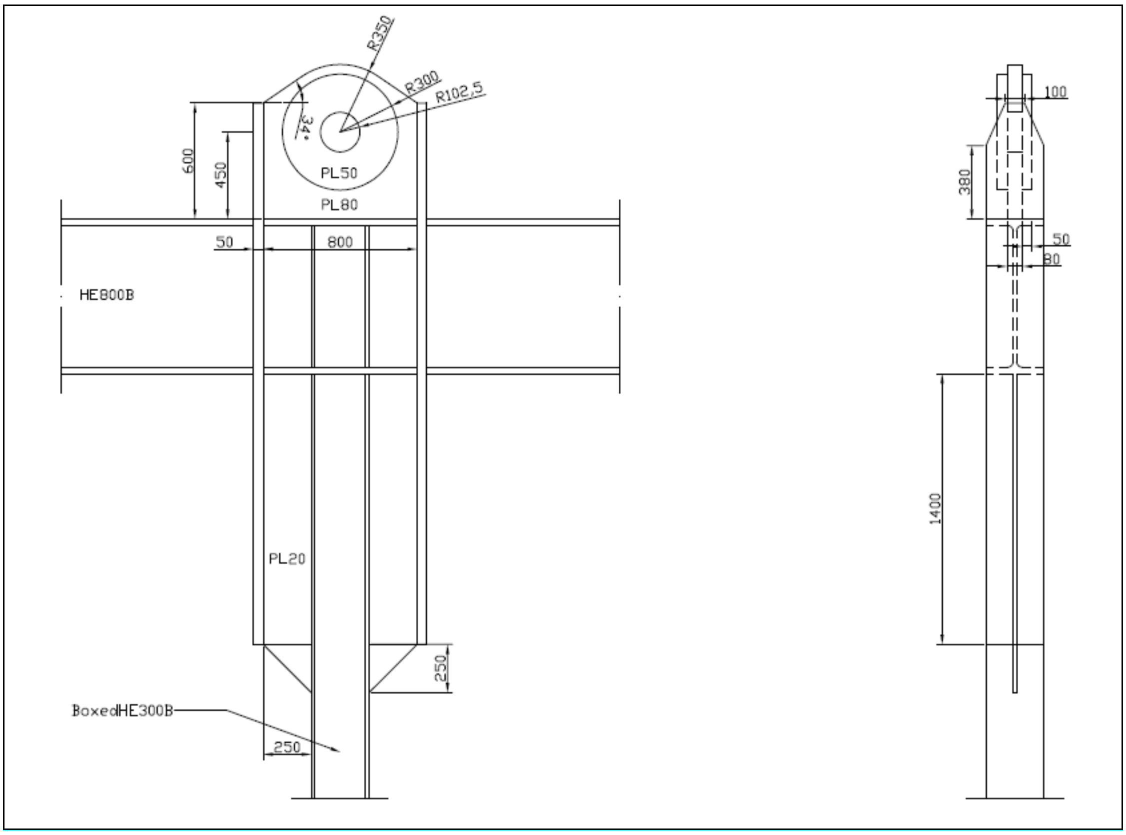


Figure 11-2 Padeye drawing with existing structure

11.2. Stress analysis

To verify the structural integrity of the padeye, the padeye is checked for tear out stress and pinhole bearing stress according to [11] NS3472 12.5.3.3 and 12.5.2.2. In addition to this check, stresses at the outermost fibre at critical points in the ground material of the padeye, are calculated according to the Von Mises yield criteria. The criterion for pin hole bearing stress in [11]NS3472 allows a certain yield deformation for the pin hole, so the Von Mises yield check is done at the outside the yield zone. The assumptions of boundary condition for the analytical stresses analysis from lift force and lateral forces are made in a conservative manner.

For the single critical column a FE computer model where made using the Abaqus software. This was mainly done to get an overview of the stress intensities at the lower end of the shear plate. The FEA and results are described in chapter 9.3. To include effects of the bending moments from the global structure deformation the final stresses in the column is calculated analytically using the results from the Sesam and Abaqus computer analysis.

11.3. Loads

In addition to the vertical force of 5.6MN, lateral forces in the horizontal crosswise and lengthwise direction are applied.

The crosswise lateral force consists of a 2 deg tilt + 0.5 deg installation inaccuracy.
The load criteria for the padeye loads is given in [1] Structural design premises 6.2
Calculated as % of the vertical force:

F – Vertical force
F_l – Lateral force

$$\sin(2.5^{\circ}) = \frac{F_l}{F}$$

$$F_l = F \cdot \sin(2.5^{\circ}) = 4.3\% \cdot F \approx 4\% \cdot F$$

Lengthwise lateral force consists only of 2 deg tilt

$$F_l = F \cdot \sin(2^{\circ}) = 3.5\% \cdot F$$

Force	Magnitude
Lift force	5.600MN
Lateral force in x - direction	0.224MN
Lateral force in y - direction	0.195MN

Table 11-1

11.4. Boundary conditions

For stress calculations due to the effect of the lateral forces acting at the padeye, the boundary conditions were chosen to provide the largest stresses in the selected points of calculation. For stresses at the section horizontal through the centre of the pin hole, the rotation stiffness about the global z – axis of the end plates are chosen to be zero for stress calculations at the centre of the pad eye and infinite stiff for stresses calculated in the base plate near the end plate.

Because of unknown z – quality of the HE800B beam all the vertical lift loads are transferred by the end plates. For stress calculation at the bottom of the pad eye the main plate is considered free and the end plates fully fixed and continuous through the HE800B section.

For the FEA using Abaqus, the bottom of the boxed HE300B section is considered fully fixed and the boundary conditions at the top is set as symmetrical about the z – axis.

FEA boundary conditions in global coordinates:

U = displacement, UR = rotations:

Bottom:
Ux = Uy = Uz = URx = URy = URz = 0

Top:

Ux = Uy = URz = 0
Uz = URx = URy = Free

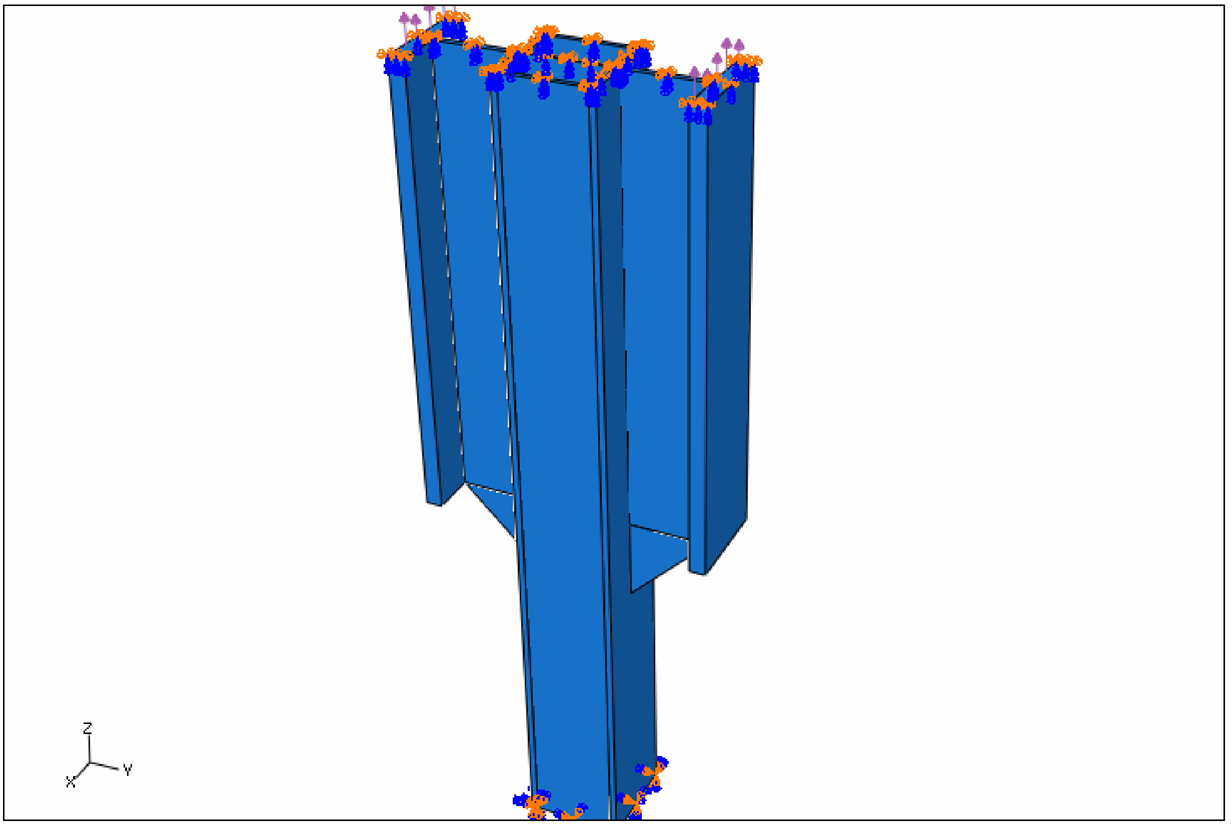


Figure 11-3 Boundary conditions and loading

11.5. *Finite Element Analysis*

The FEA was mainly done to investigate the stress concentrations at the lower end of the shear plate.
This analysis showed that the web of the boxed HE300B reaches yield stress in the section where the shear plate ends when the HE300B section is reinforced with two 10mm plates. As a consequence of this analysis the stress capacity of the web is neglected and only the flanges and the reinforcement plates act as an effective cross section of the BoxedHE300B section. With this assumption of the cross section the reinforcement plates has to be 16mm thick instead of 10 mm as first assumed in the global analysis.

The models was made by using the part assembly tool in Abaqus which provides possibilities to model single parts, and in a later step assembles these and describe constraints between the assembled parts. The constraints were set to surface to surface constraints with full contact between the parts. This constraint choice describes robust welds between the different parts. The weld analysis in chapter 11.6.3 shows that these welds have acceptable utilisation.

A C3D20R element was chosen for mesh of the whole model. This element type is a

20 – Node quadratic brick with reduced integration and is considered to have sufficient accuracy for the purpose of the FEA. The material was set to as steel with a Young’s modulus, E = 210000 MPa, and yield strength $f_d = \frac{355MPa}{1.15} = 308.7MPa$.

The lift loads were applied as uniform loads over the cross section of the padeye end plates, showed in figure 11-3.

Applied out of surface pressure:

$$F = 5.600MN$$

$$A = 2 \cdot 50mm \cdot 300mm = 3.0 \times 10^4 mm^2$$

$$f = \frac{F}{A} = \frac{5.600 \times 10^6 N}{3.0 \times 10^4 mm^2} = 186.67 \frac{N}{mm^2}$$

The Abaqus analysis was performed as a single step static analysis with no second order deformation effects.

11.6. Analysis results

11.6.1.FEA

The figures below indicate axial stresses in the z – direction for the reinforced HE300B column and the connected shear plates and endplates from the padeye the gray area denotes stresses > 308.7 MPa.

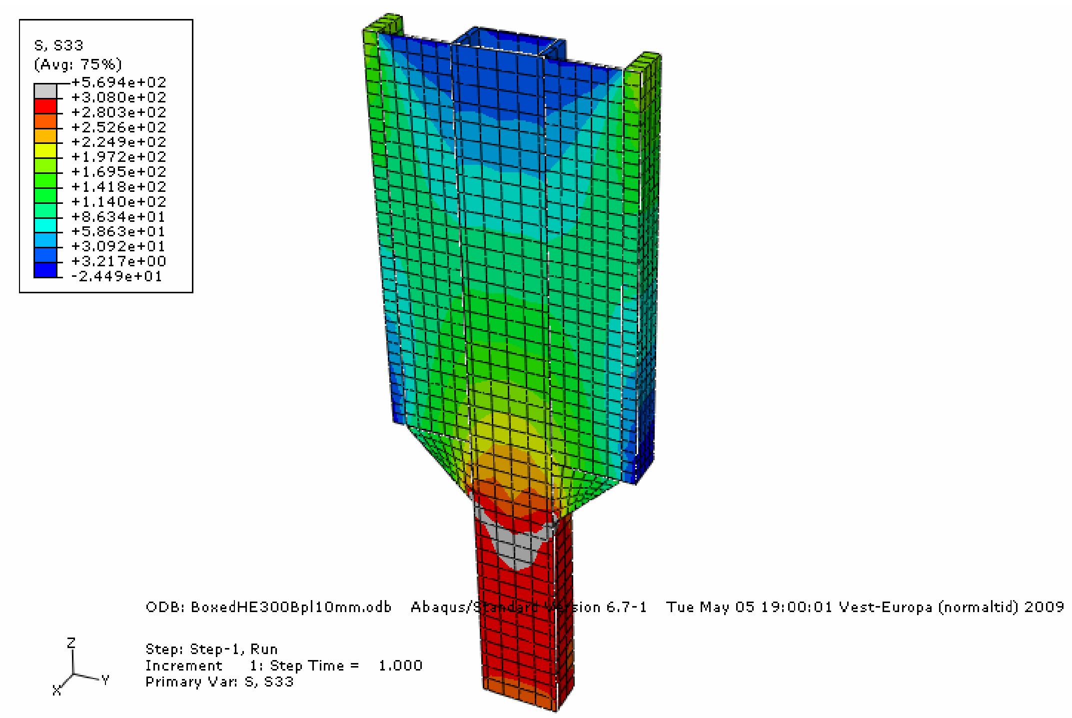


Figure 11-4 Tension stresses with 10mm reinforcement plates, gray area indicates yield.

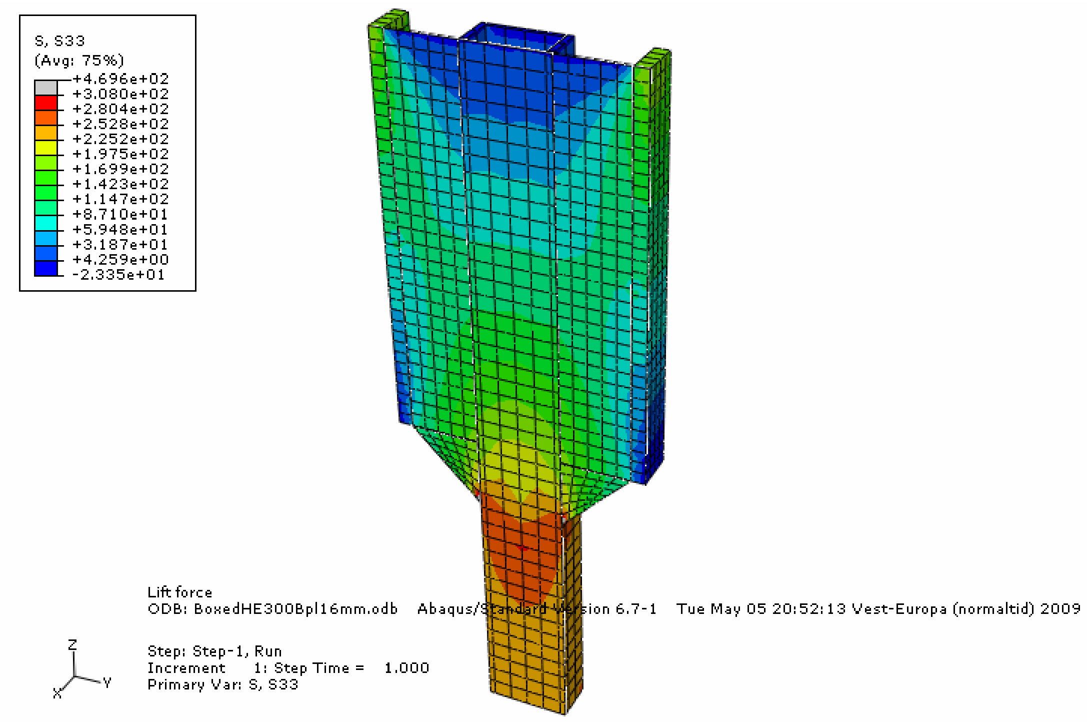


Figure 11-5 Tension stresses with 16mm reinforcement plates

The complete FE model of the critical column is at the attached compact disc.

11.6.2.Analytical calculations

The main part of the structural verification of the design of the padeye and the appurtenant welds were performed with analytical hand calculations based on the rules in NS3472/Eurocode3 and general theory of mechanics of materials [3] Boresi et al., 2003

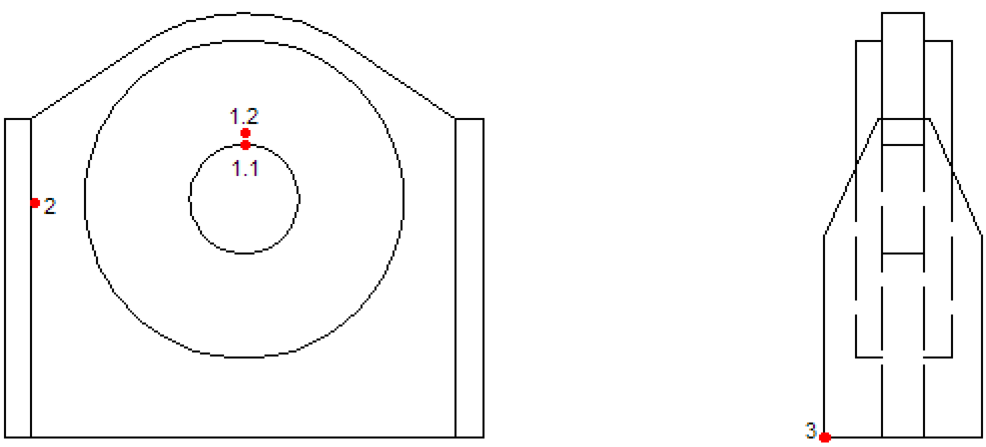


Figure 11-6 Padeye stress control points

From the Sesam Sestra and Framework output file the single critical boxed HE300B column takes 80% of the total lift force.

Reaction Force = 5.6MN
Column tension force = 4.44MN

$$\frac{4.44}{5.6} = 0.8 = 80\%$$

This reduction comes from the force distribution in the joint HE800B to BoxedHE300B column where 20% of the lift force is distributed to the rest of the structure.
The global UF of the boxed HE300B column is 0.73. The assumption of load distribution from the pad eye to the structure is done in a way that the boxed HE300B column can withstand 100% of the lift force. This provides an extra safety for the single critical column in addition to the 1.3 safety factor for single critical columns given in the [1] Structural design premises.

Table below shows UF for the stress control points and mid point and end point of the single critical boxed HE300Bcolumn.

Point/part	UF
1.1	0.78
1.2	0.60
2	0.33
3	0.69
Tear stress	0.21
Pin hole	0.26
Shear Plate	0.92
BoxedHE300B	
mid	0.98
end	0.94

Table 11-2 UF padeye ground material and single critical column.

Calculations of the padeye and critical column are displayed in appendix D.1 and D.2.

11.6.3. Welds

The welds are calculated according to [11] NS3472 12.6
Both method a, and method b in 12.6.2.1 are used, and the stress distribution in the welds are based on a static load case perspective and plastic load distribution in the welds. The different assumptions are specified for each case in the calculations.

The padeye is symmetrical around both global x – and y – axis, i.e. welds are symmetrical as well.

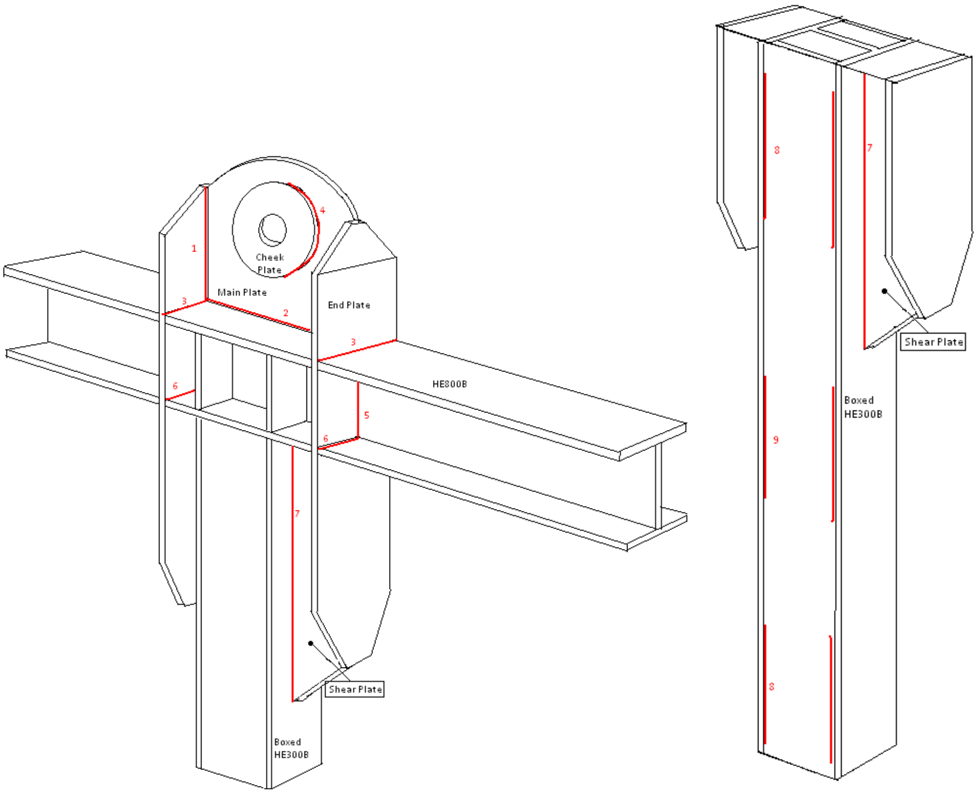


Figure 11-7 Weld numbering padeye and critical column

Table below shows UF for weld 1 – 9 and the different weld sizes

Weld nr.	Weld size		UF
	Part pen	Fillet	
1	10	10	0.73
2	0	4	0.15
3	15	15	0.58
4	10	10	0.39
5	4	4	0.31
6	15	15	0.55
7	10	10	0.46
8	10	10	0.73
9	0	4	0.53

Table 11-3 Weld UF and weld size

Appendix D.3 shows the complete weld calculations.

12. LOCAL ANALYSIS JOINTS

12.1. Basis

Since this is a time-limited project, the local analysis has been performed on selected critical nodes related to the study of the feasibility of a new lifting arrangement on the TCP2 M32 Module. This are nodes where most of the lift forces pass through, and failure or limited reinforcement possibilities of this joints will be crucial for the final conclusion of this thesis.

In lack of field survey reports, detail drawings from the cessation.total database website have been used as basis for the joint design. It is also assumed that the base material is the critical component of the joint. This assumption is made based on experience of robust welds made by structural engineers in Aker Solutions.

NDT (non destructive testing) has to be performed on welds and steel around the joints to verify the structural integrity of the main load bearing welds in the joint.
The figure below shows incoming members marked with red, to critical joint J307031

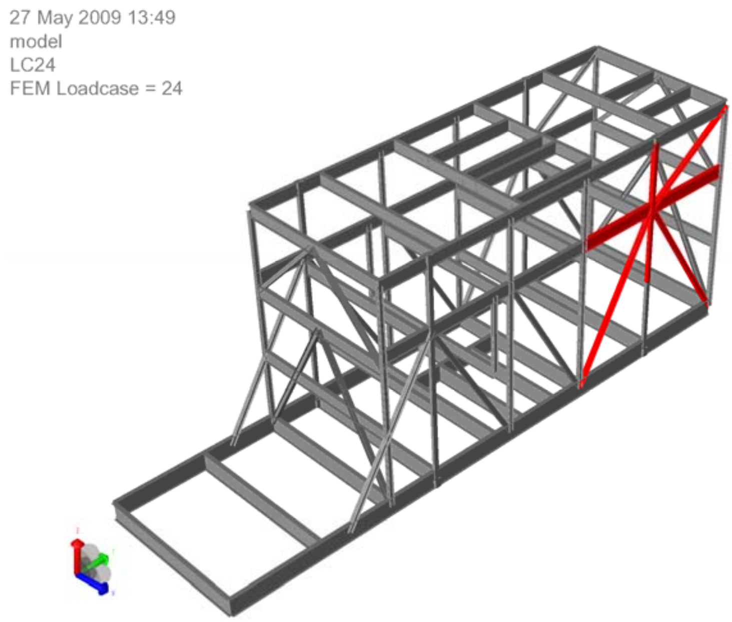


Figure 12-1 Critical joint J107031 with incoming members.

12.2. Beam forces

The Sesam Framework software module is used to sort the beams with highest end stresses and print incoming beam forces on specified joints. From the beam end stresses print, highly stressed joints were selected for further investigation.

This showed as expected the joint connected to the single critical boxed HE300B column reached high stresses for the lifting condition.

The same assumptions of the stress distribution in the single critical boxed HE300B columns are used as in the analysis in chapter 11 e.g. the whole reinforced cross section acts as effective cross section in the lower end of the column. To include this effect an equivalent box cross section where calculated and used in the Sesam to generate stresses in the boxed HE300B column. The equivalent section where calculated such that the real section area, moment of inertia around column y – and z – axis are congruent with the real boxed HE300B section.

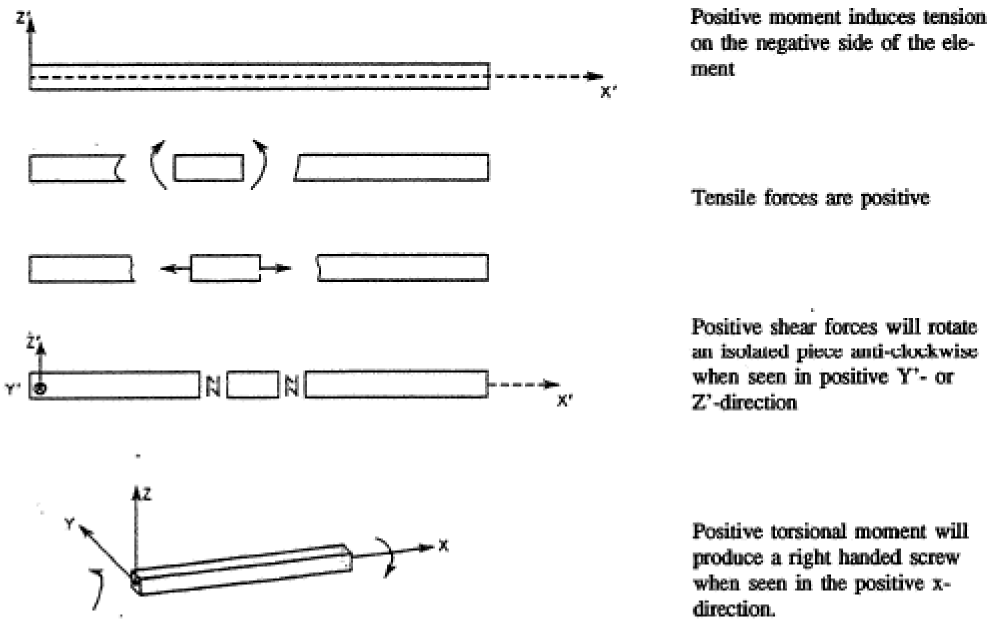


Figure 12-2 Framework sign conventions of a beam element
[10] Sesam theoretical manual Framework

12.3. Joint check

The joints was checked according to [5] Eurocode 3, part 1-8. Table 7.21 and 7.22 is used to calculate chord web stability force and dimensioning brace forces. To include interaction effects between moment and tension/compression formula 7.4 is used.

In the computer model, joints were modelled without brace eccentricities. When checking the shear capacity of horizontal beams in the intersection between columns and braces an analytical approach was used based on the beam forces printed from the Framework output file. The shear forces in the intersection were calculated using static condition of the sum of moments and forces in x - , y - and z – direction to be zero. When calculating the shear stresses in the intersection the moment effects and small shear forces in braces was neglected. The analysis showed low UF for shear in the intersection concluding that the load simplifications did not have any effect on the final conclusion regarding the structural integrity of the joints.

The figure below shows the load assumptions made to calculate shear forces in the gap.

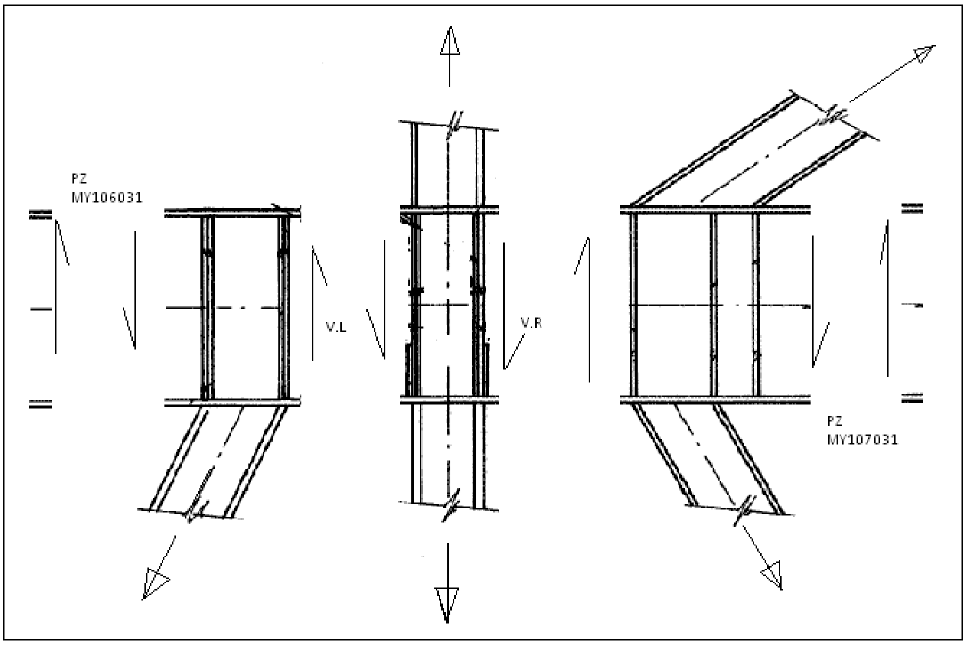


Figure 12-3 shear distribution and force directions in J307031.

12.4. Analysis results

Table below shows analysis results of the local check of the heaviest loaded joints:

J307031

Summary code check Eurocode:

Member	UF Brace	UF Chord
MZ107031	0.87	0.68
ME107031	0.12	0.06
ME106010	0.54	0.50
MF107031	0.36	0.38
MZ107030	0.19	0.38

Summary shear check in gap:

Member	Shear Force	UF shear
	[kN]	
MY106031	1012.36	0.21
MY107031	1586.26	0.32

Table 12-1 Local analysis results J307031

The joint check is shown in appendix E.1

13. OFFSHORE PREPARATIONS

13.1. Temporary reinforcements/offshore preparations

When installing the padeyes it will be necessary to cut away parts of the top and bottom flange this implies that the web of the HE800B needs to carry the entire load while the padeyes are being installed. To verify the capacity of the HE800B web an in place analysis with governing load combinations ULS-a with a load factor of 1.2 where performed.
The utilisation of the web was calculated based on the beam end moments from this analysis. The result of the analytical calculation gave an overall highest utilisation factor for the beams connected to the lifting points of 0.77. These results shows that no temporary reinforcements have to be installed for while installing the padeyes.

These calculations are displayed in appendix F.1.

13.2. Sling laydown area

According to [13] a sling laydown area shall be prepared around each pad eye, either by preparing a laydown platform or remove items at the top of the module. These requirements are specified by the lifting contractor in each specific case based on the configuration of the lifting arrangement, the module situation on the MSF and the crane access. It has not been possible for me to gather the information required in this area. It is my opinion, based on the investigations and analysis made in this report, that the M32 module will have adequate reserve capacity to manage the installation weight of laydown platforms at the top of the module. Removal of items at the top of the module to make space for the laydown area will remove more weight than laydown area design load will introduce, and therefore have a lower total weight than used in this report.

14. SUBJECTS FOR FURTHER INVESTIGATIONS

During the work with this thesis many new subjects whom I would have spent more time on have appeared. However the scope of these subjects is too comprehensive to be dealt with in this thesis. The main subjects that could be interesting to look into are:

- Dynamic response of the module during transportation by using the SESAM software.
- Calculating plastic reserve capacity of padeye.
- Further investigation of stress-concentrations due to load transfer from a shear plate to a beam/column by use of FEA software and analytical calculations.
- Comparing results of node check by use of Eurocode 3 and classical stress analysis or FE analysis.
- Define sling laydown area/design sling lay down platforms.
- Design and verify bumpers and guides

15. CONCLUSION

For reinforcement of HE300B columns I first chose to reinforce the cross section with two 10 mm thick plates this gave an acceptable result in the global analysis. The local analysis of the connection between the padeye and the column showed that reinforcement plates had to be 16 mm thick. If I have chosen a thicker plate in the first global analysis I would have saved the extra time spent on running a new global analysis with changed plate thicknesses after completing the local analysis. In an educational perspective this process taught me a lot when it comes to the relation between global and local analysis.

The analysis and considerations performed in this report show that, from a technical point of view, it will be possible to perform the lift of the M32 module with a lifting arrangement situated at the top of the module. The engineering performed on the early North Sea offshore installations seems to be of a robust character, especially the design of the joint reinforcements. This would be of great advantage for future cessation projects. The robust structure and joint design excludes, to a great extent, fatigue problems when transporting the modules to onshore disposal sites primary at the Norwegian west coast.

It is the operating oil company's call to decide if the costs of installing reinforcements and preparing a module such as the M32 module for a top mounted lifting arrangement, is competitive with using the original lifting points with the associated delay and stand by time for the lifting vessel this will imply. From the analysis and considerations performed in this thesis I have found that the modifications needed to perform a top mounted heavy lift is moderate and will be both cost and time saving. The reduction of lifting vessel stand by time will also benefit the environment by reducing the vessel emissions during the lifting campaign.

I feel that my work with this thesis has given me considerable further knowledge of structural analysis and marine operations. I am certain that the work with this thesis have made me better fit for meeting new challenges as an engineer in the future.

APPENDIX

A. GEOMETRY

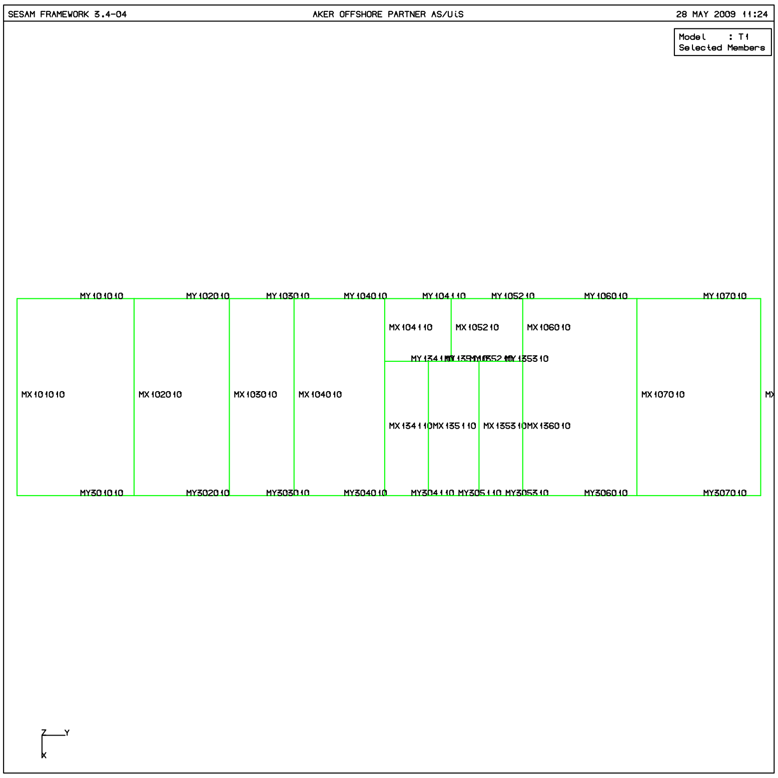


Figure A-1 Members lower deck

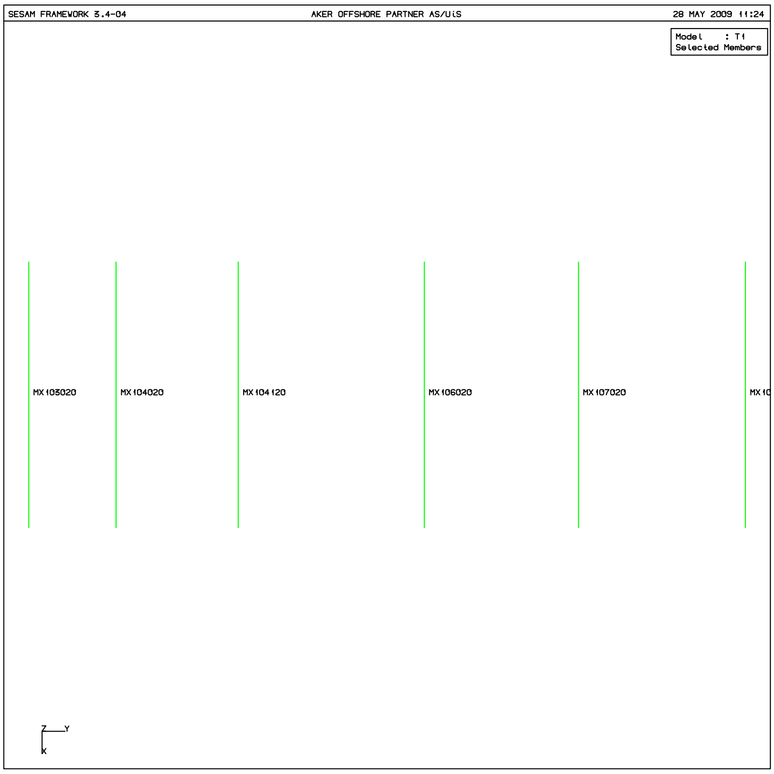


Figure A-2 Members substation deck

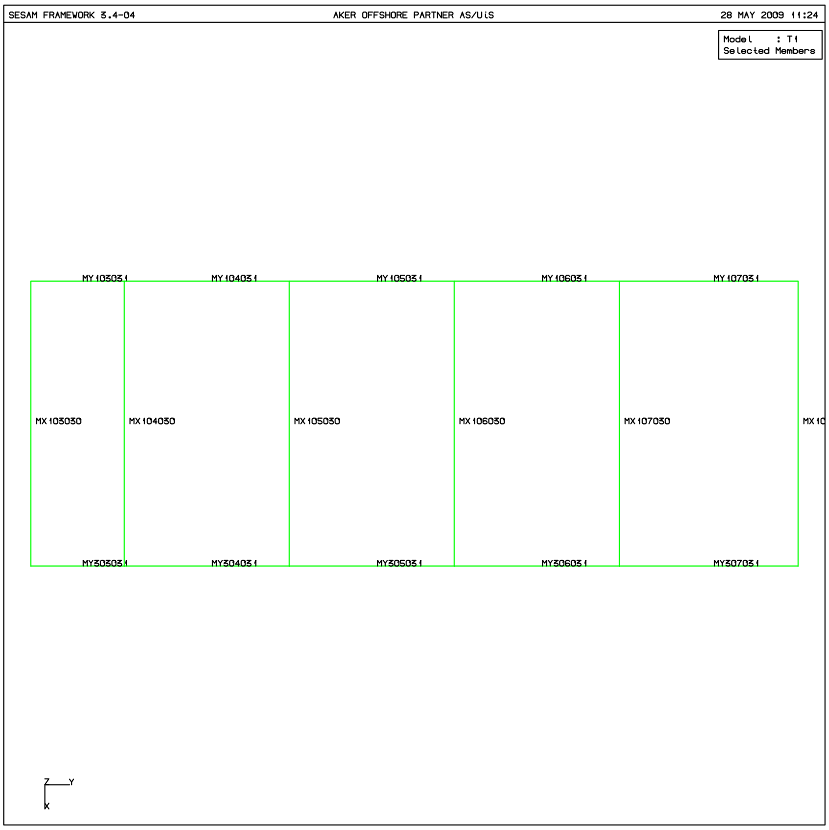


Figure A-3 Members control room deck

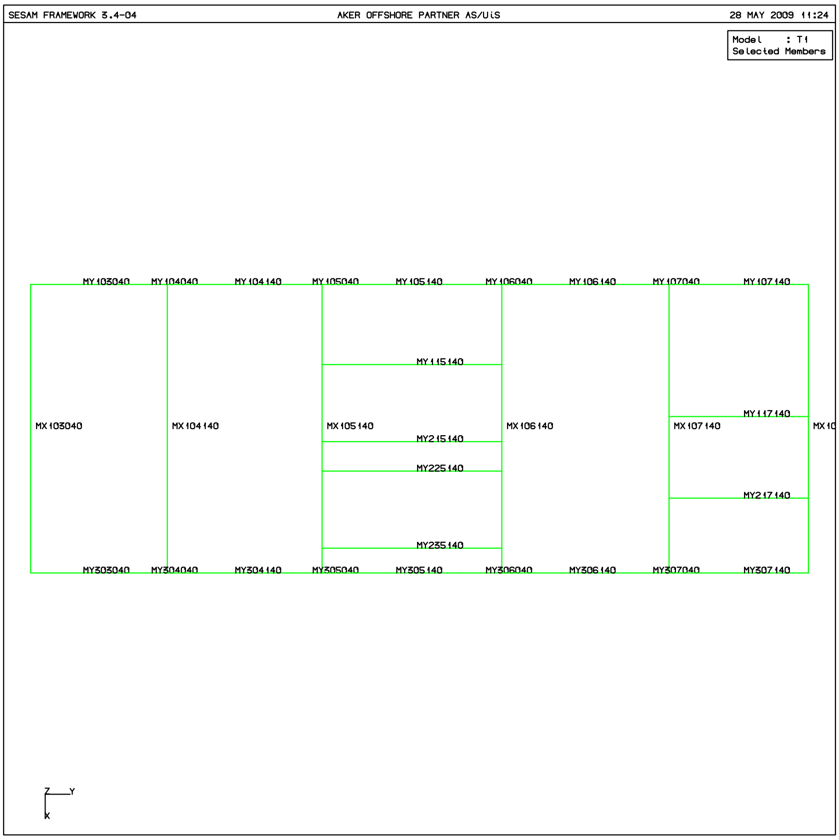


Figure A-4 Members upper deck

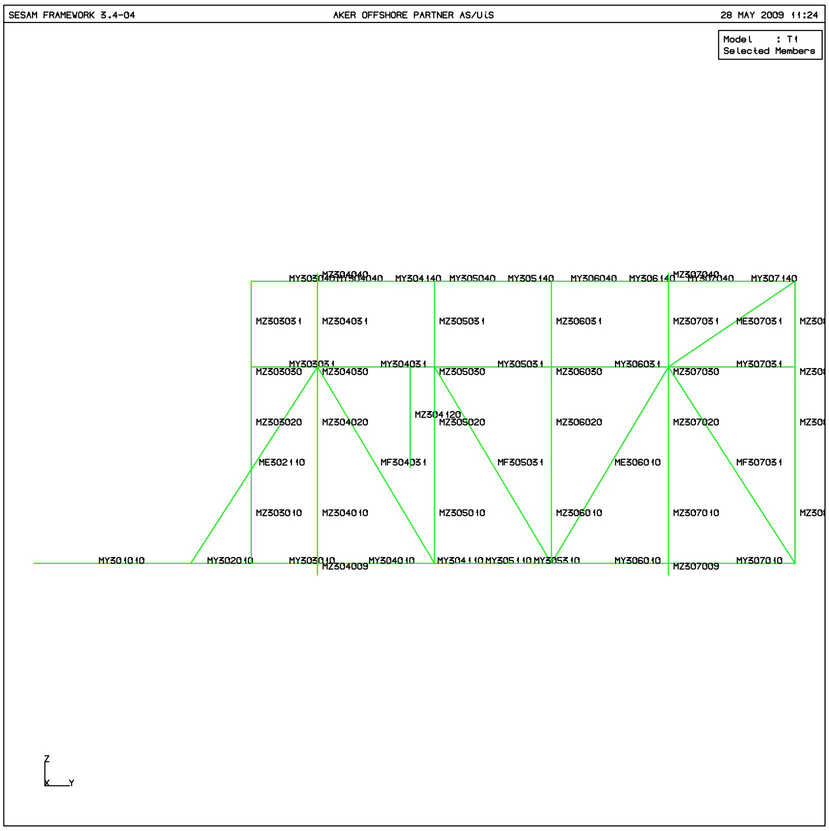


Figure A-5 Members truss North

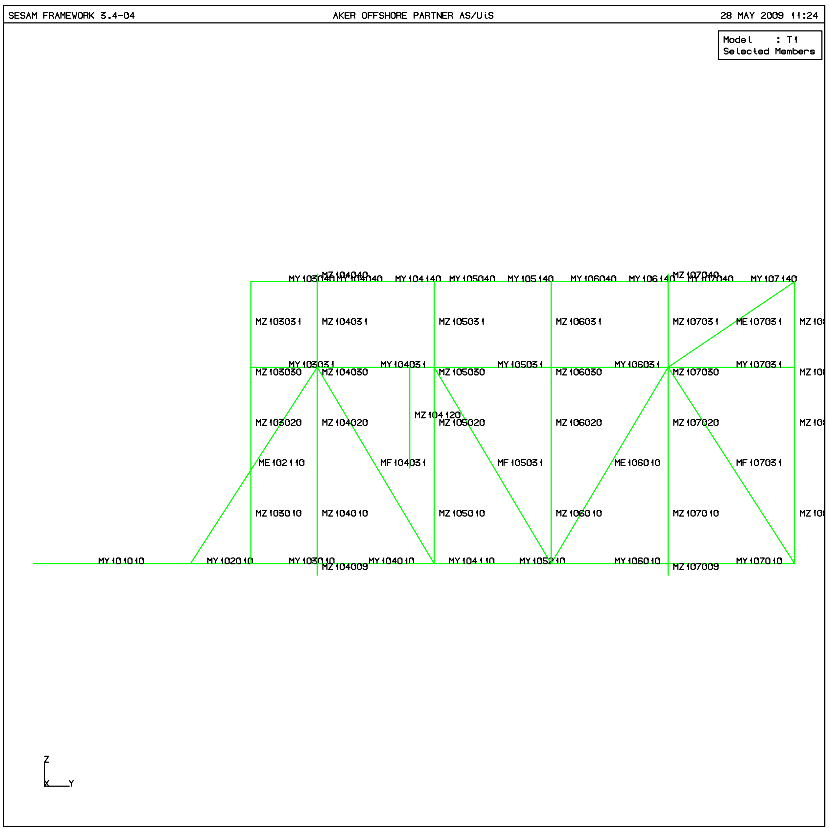


Figure A-6 Members truss South

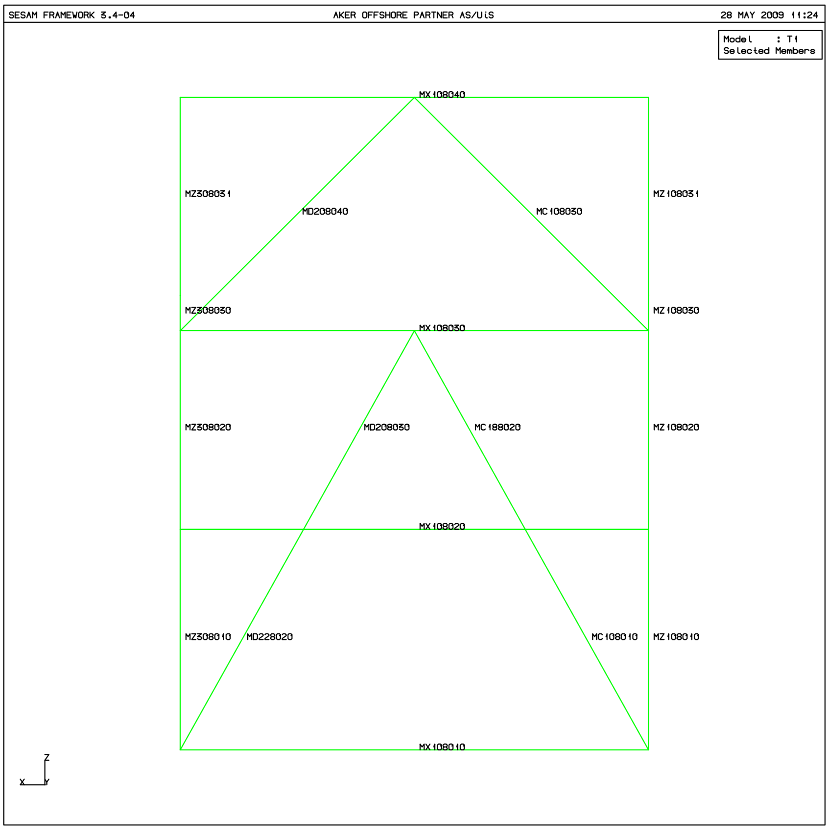


Figure A-7 Members truss West

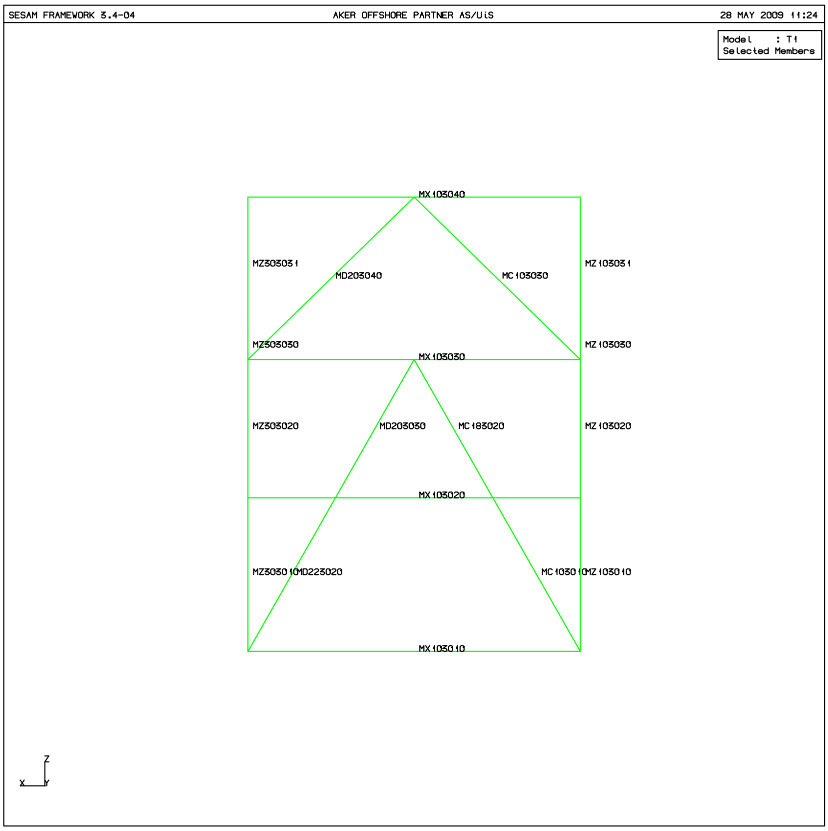


Figure A-8 Members truss East

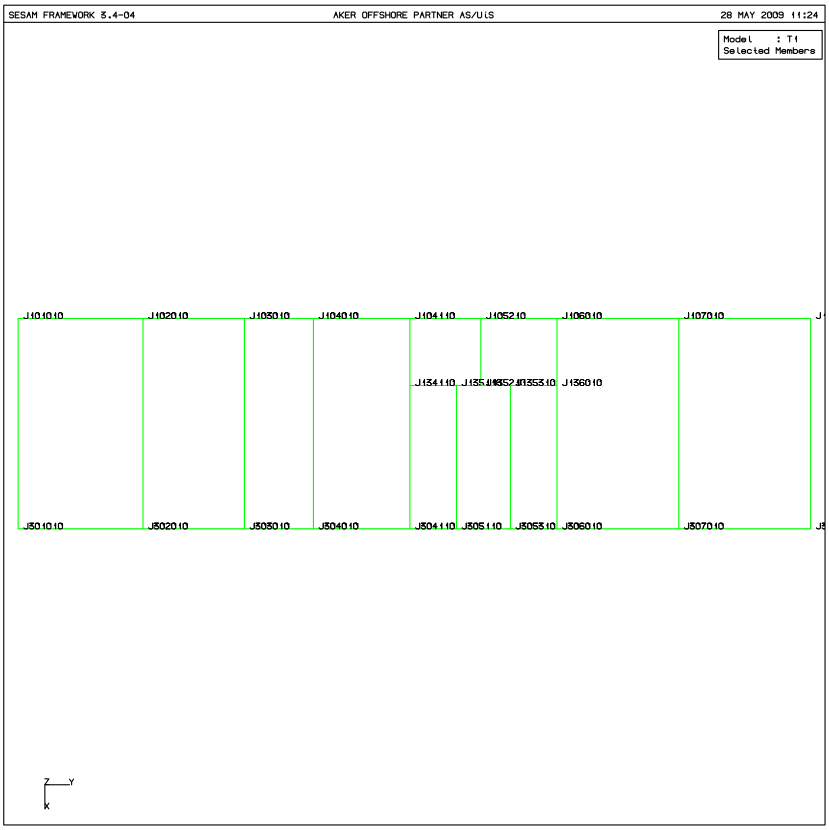


Figure A-9 Joints lower deck

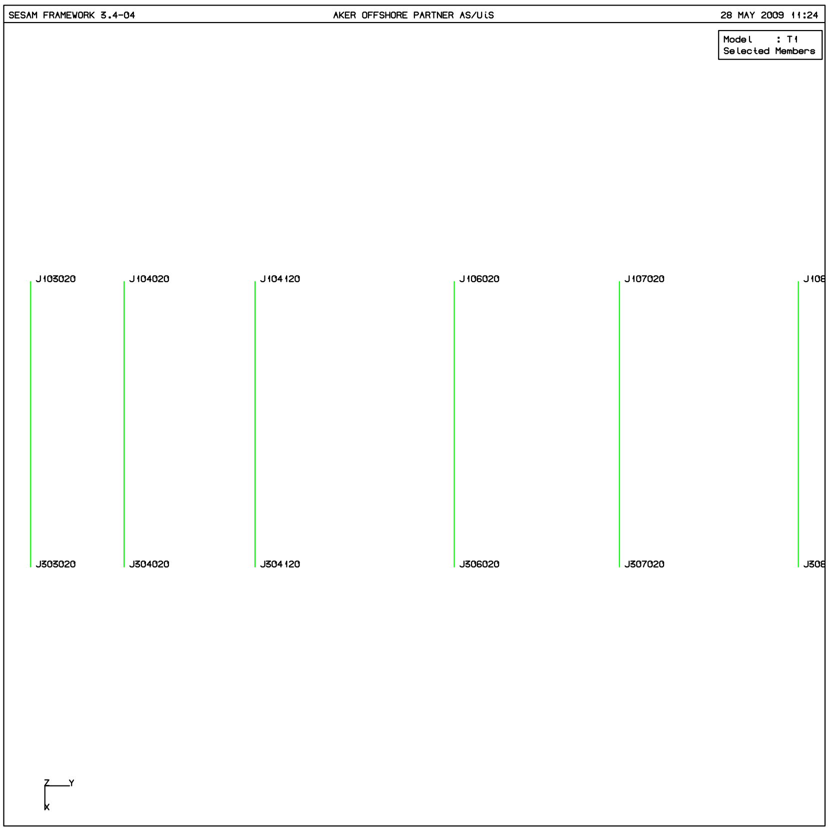


Figure A-10 Joints substation deck

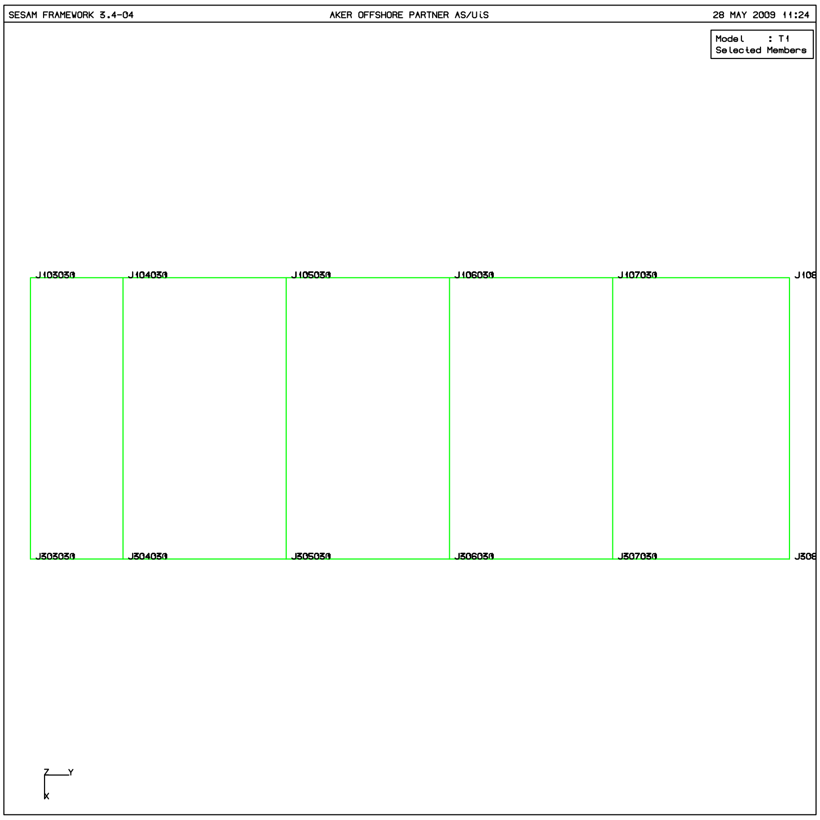


Figure A-11 Joints control room deck

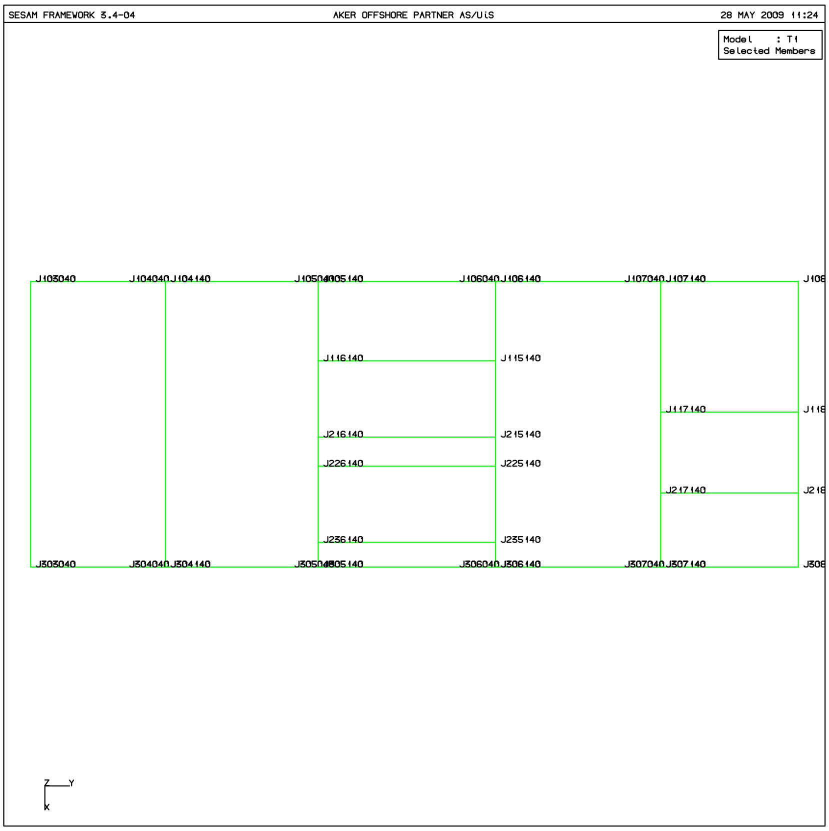


Figure A-12 Joints upper deck

Amund Lundqvist

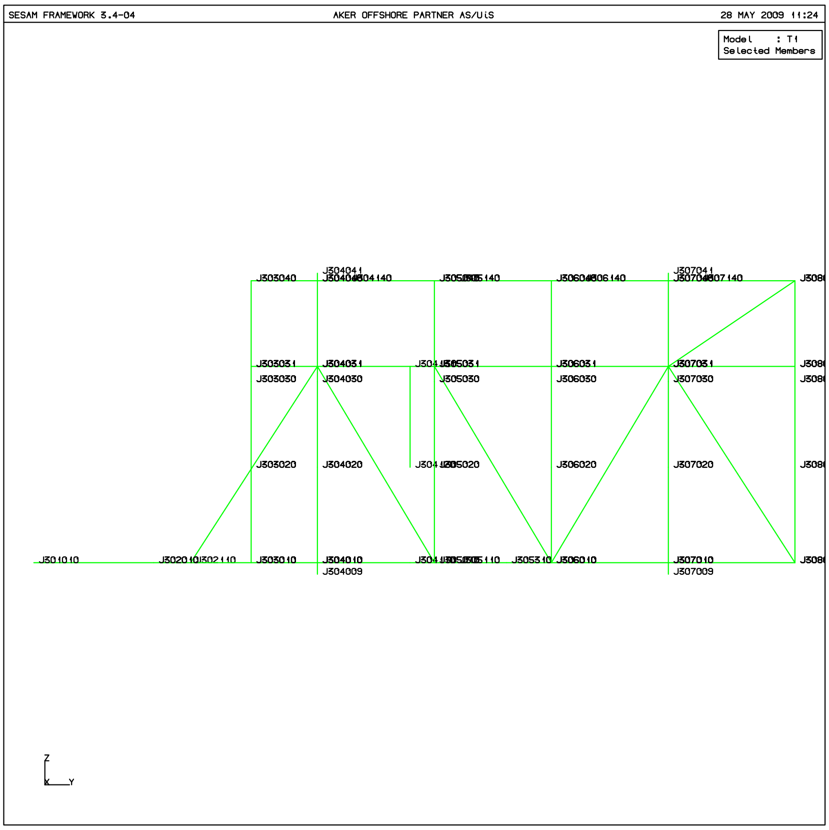


Figure A-13 Joints truss North

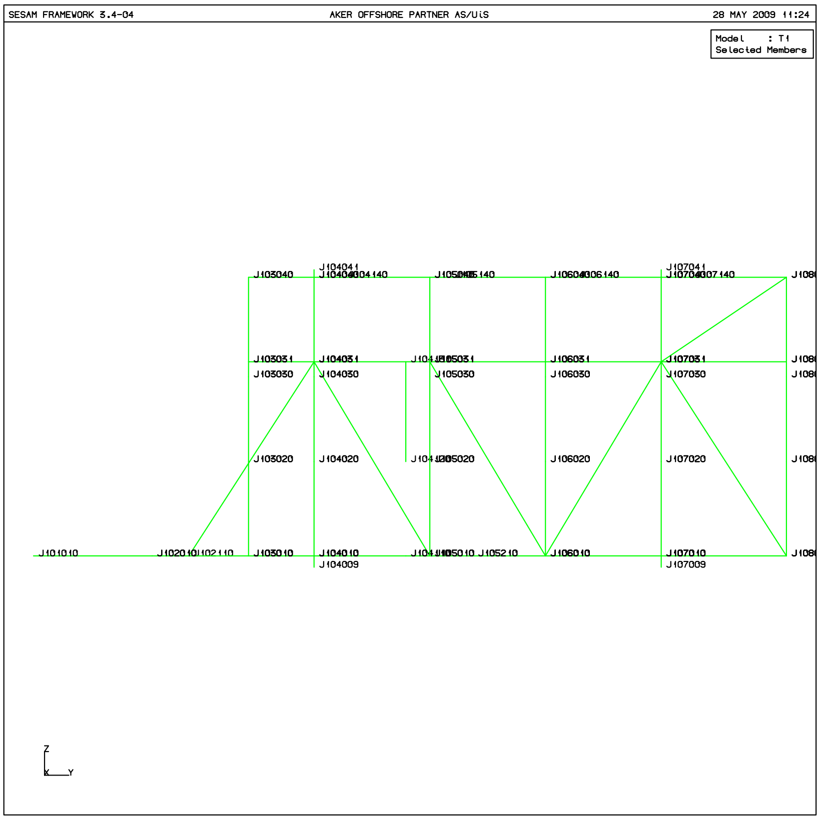


Figure A-14 Joints truss South

Amund Lundqvist

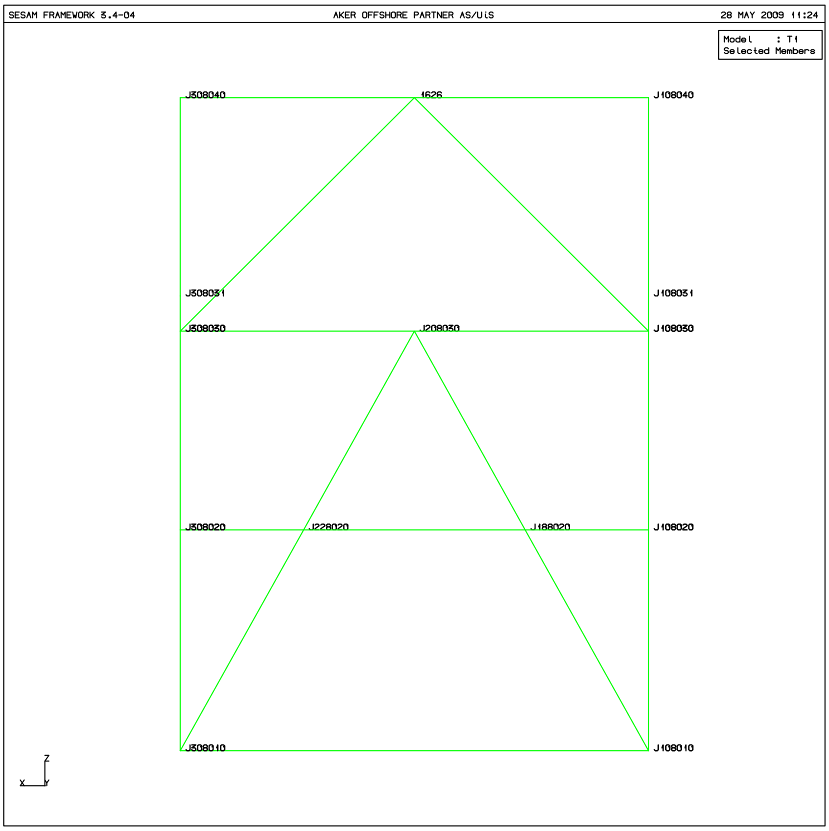


Figure A-15 Joints truss West

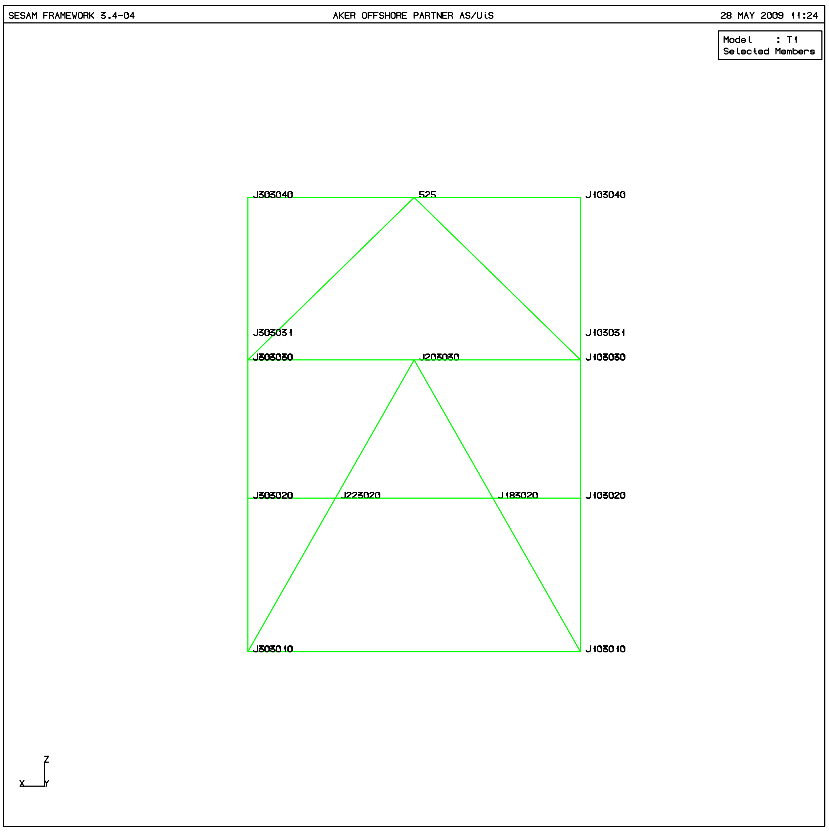


Figure A-16 Joints truss East

B. ACTIONS

I. Structural and equipment loads

Distributed loads

Lower deck:	Load [Tonnes]
Structural	
Secondary steel	49.02
Flooring	7.27
Walls	41.50
Outfitting	26.25
Paint	4.65
Outside areas	6.34
Arcitectural	2.55
Piping	2.30
Electrical	27.67

Control room deck	Load [Tonnes]
Structural	
Secondary steel	0.00
Flooring	5.19
Walls	41.50
Outfitting	26.25
Paint	4.65
Supports	21.80
Piping	0.98
Electrical	38.99

Substation deck	Load [Tonnes]
Structural	
Secondary steel	8.11
Flooring	5.19
Walls	41.50
Outfitting	26.25
Paint	4.65
Supports	1.30
Piping	8.32
Electrical	34.80
	27.67
	6.80
Telecom Fire and s	3.87
HVAC	1.50

Upper deck	Load [Tonnes]
Structural	
Secondary steel	13.86
Flooring	5.19
Walls	
Paint	4.65
Supports	38.40
Arcitectural	7.53
Piping	48.18
Piping supports	11.79
Electrical	
HVAC	4.52
Instruments	1.20
Mechanical	8.26

Table B-1 Web database loads, distributed deck loads

II. Environmental loads

WIND CALCULATIONS

According to DNV, Classification Notes No 30.5

Insert table 4-1 Design Prem.

Reference wind speed: $U_0 := 19.9\frac{m}{s}$ $\rho := 1.225\frac{kg}{m^3}$

Reference height and time: $z_r := 10m$ $t_r := 600s$ (10 min. average)

Elevation main deck Saipem S7000 $z_s := 16m$

$t := 3s$ (3 second gust)

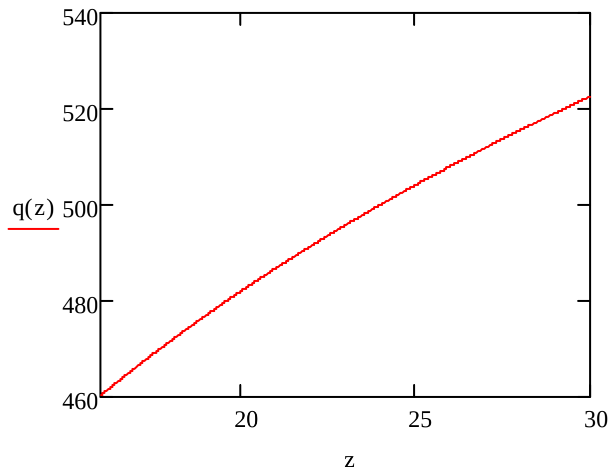
Average Wind Speed:

$$U(z) = U_0 \cdot \left(1 + 0.137 \cdot \ln\left(\frac{z}{z_r}\right) - 0.047 \ln\left(\frac{t}{t_r}\right)\right)$$

Shape factor: $C_r := 1.1$ (From table 5.5,Classification Notes No 30.5)

Wind pressure:

$$q(z) := \left(\frac{1}{2}\right) \cdot \rho \cdot \left[U_0 \cdot \left(1 + 0.137 \cdot \ln\left(\frac{z}{z_r}\right) - 0.047 \ln\left(\frac{t}{t_r}\right)\right)\right]^2 \cdot C_r$$



Wind elevations (zero at S700 deck)

Lower deck $z_{LoD} := 0m$

Control room deck $z_{CrD} := 10.35m$

Upper deck $z_{UpD} := 14.795m$

Load field heights

Lower deck $h_{LoD} := \frac{z_{CrD}}{2} = 5.175m$

Control room deck $h_{CrD} := \frac{z_{CrD}}{2} + \frac{z_{UpD} - z_{CrD}}{2} = 7.397m$

Upper deck $h_{UpD} := \frac{z_{UpD} - z_{CrD}}{2} + 3.7m = 5.923m$

Average height of items at upper deck 3.7m

Line loads q

$$q_{LoD} := h_{LoD} \cdot q\left(\frac{h_{LoD}}{2}\right) = 1.563 \cdot \frac{kN}{m}$$

$$q_{CrD} := h_{CrD} \cdot q\left(h_{LoD} + \frac{h_{CrD}}{2}\right) = 2.999 \cdot \frac{kN}{m}$$

$$q_{UpD} := h_{UpD} \cdot q\left(h_{LoD} + h_{CrD} + \frac{h_{UpD}}{2}\right) = 2.709 \cdot \frac{kN}{m}$$

III. Load sums

Loadlist to genie.xls \load sums

Structural and Equipment loads

Structural	[tonnes]
Modeled	184.00
Applied	397.95
Arcitectural	10.08
Mechanical	61.80
Piping	71.56
Electrical	196.88

Sum	922.26

Environmental loads

Wind Loads [kN]

Wind from	Raw	Pressure	Suction	Total
South	202.89	142.02	101.44	243.47
South/East	197.94	138.56	98.97	237.53
East	77.08	53.96	38.54	92.50
North east	197.94	138.56	98.97	237.53
North	202.89	142.02	101.44	243.47
North/west	197.94	138.56	98.97	237.53
West	77.08	53.96	38.54	92.50
South/West	197.94	138.56	98.97	237.53

Waves

Accelerations on S7000

Worst case 10m above deck				
	S7000	M32	[m/s^2]	factor*g
Surge	x	y	2.15	0.22
Sway	y	x	2.73	0.28
Heave	z	z	2.00	0.20

g = 9.81m/s^2

Table B-2 Load sums

C. GLOBAL ANALYSIS

I. COG envelope

COG Envelope and inaccuracy factor

COG
(x and y coordinates)

Input

Centre Of Gravity $COG := (5.366\ \ 23.959\ \ 7.418)\cdot m$

Size of module: $MSize := (10.6\ \ 27.9\ \ 14.5)\cdot m$

Coordiantes of footings nearest COG $F1 := (10.600\ \ 32.55\ \ 0)\cdot m$ P307040

Calculations

COG Envlope
Design premisis 2.3

$$COGE(MSize) := 0.05\cdot MSize$$

Size COG Envelope $COGE(MSize) = (0.53\ \ 1.395\ \ 0.725)\,m$

$$(a\ \ b\ \ c) := COG - F1 = (-5.234\ \ -8.591\ \ 7.418)\,m$$

$$(\Delta x\ \ \Delta y\ \ \Delta z) := \frac{COGE(MSize)}{2} = (0.265\ \ 0.697\ \ 0.363)\,m$$

where a and b are the distances to the nearest footings in X- and Y - direction respectively and the size of the envelope in X- and Y- direction is $2\cdot\Delta x$ and $2\cdot\Delta y$

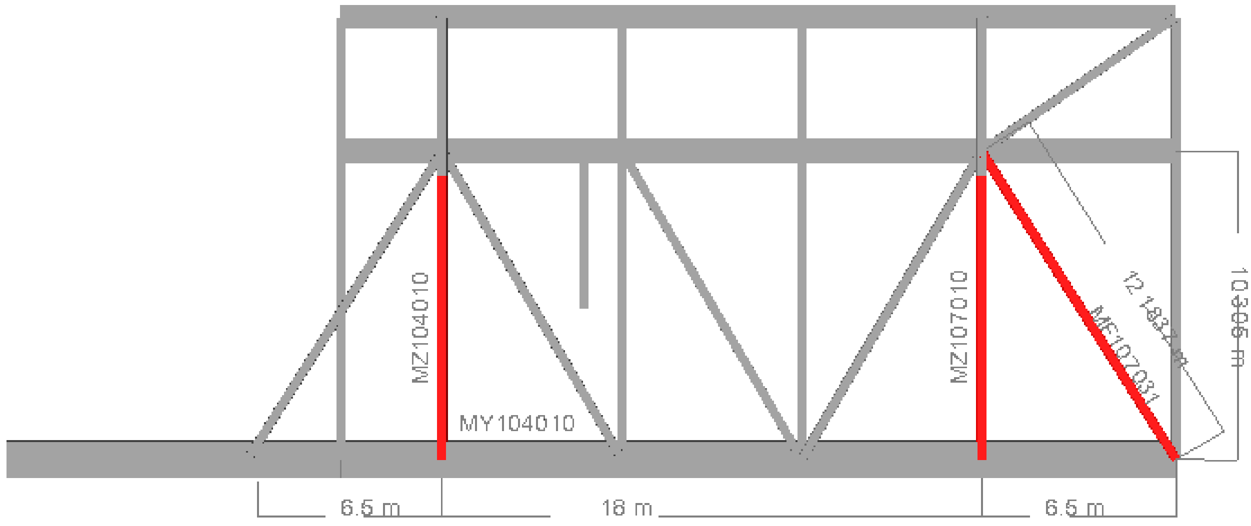
COG Shift factor

$$f_{cogz} := \frac{|a| + \Delta x}{|a|}\cdot\frac{|b| + \Delta y}{|b|}$$ $f_{cogz} = 1.136$

$$f_{cogx} := \frac{|b| + \Delta y}{|b|}\cdot\frac{|c| + \Delta z}{|c|}$$ $f_{cogx} = 1.134$

$$f_{cogy} := \frac{|a| + \Delta x}{|a|}\cdot\frac{|c| + \Delta z}{|c|}$$ $f_{cogy} = 1.102$

II. Buckling factors



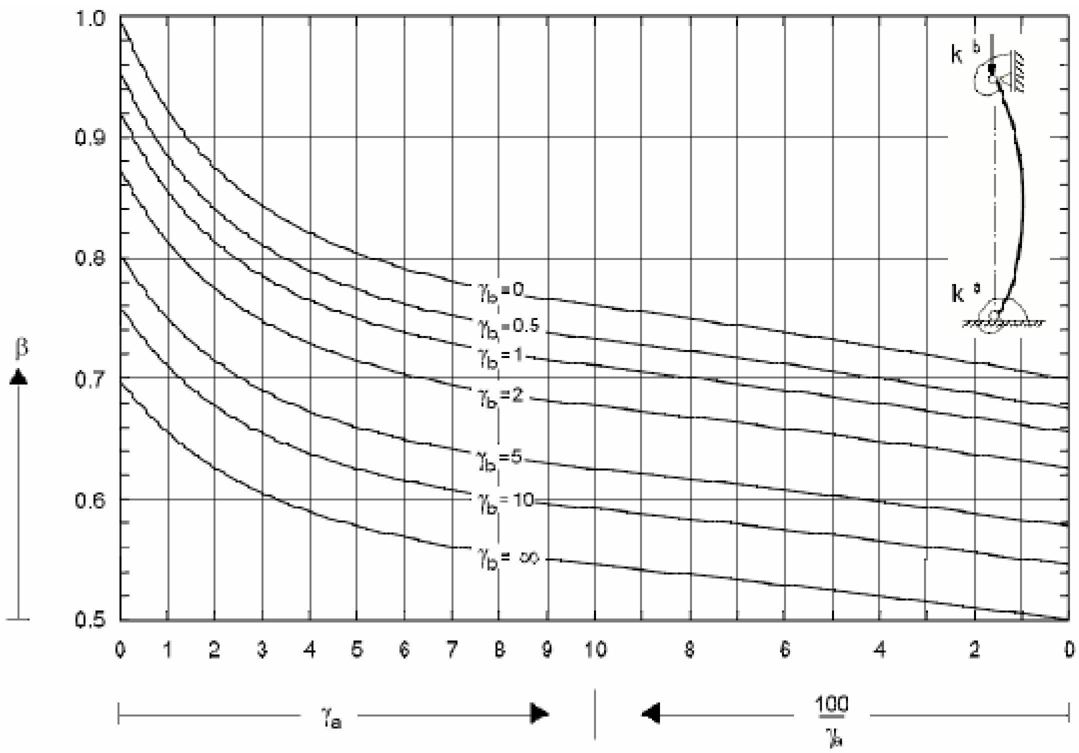
$E := 2.10 \cdot 10^5 \, MPa$

Bucklyng about y-axis

Member properties

$I_{yI1210} := 7.384 \cdot 10^9 \, mm^4$ $I_{yBOX300} := 3.708 \cdot 10^8 \, mm^4$

$I_{yI820} := 2.553 \cdot 10^9 \, mm^4$ $I_{yHE300B} := 1.826 \cdot 10^8 \, mm^4$



Buckling factors for BOX300Columns

$$k_\phi = \frac{2E \cdot I}{L_b} \qquad \gamma = \frac{k_\phi \cdot L_s}{E \cdot I_s}$$

Lower end a

$$k_{\phi a} := \frac{2 \cdot E \cdot I_{yI1210}}{6.5m} + \frac{2 \cdot E \cdot I_{yI1210}}{18m} = 6.494 \times 10^{11} \cdot N \cdot mm$$

$$\gamma_a := \frac{k_{\phi a} \cdot 10.31m}{E \cdot I_{yBOX300}} = 85.985 \qquad \frac{100}{\gamma_a} = 1.163$$

Upper end b

$$k_{\phi b} := \frac{2 \cdot E \cdot I_{yI820}}{6.5m} + \frac{2 \cdot E \cdot I_{yI820}}{18m} = 2.245 \times 10^{11} \cdot N \cdot mm$$

$$\gamma_b := \frac{k_{\phi b} \cdot 10.31m}{E \cdot I_{yBOX300}} \qquad \gamma_b = 29.729$$

Figure 4.4 $\beta = 0.54$

Braces (MF107031)

Lower end a

$$k_{\phi a} := \frac{2 \cdot E \cdot I_{yI1210}}{6.5m} = 4.771 \times 10^{11} \cdot N \cdot mm$$

$$\gamma_a := \frac{k_{\phi a} \cdot 12.18m}{E \cdot I_{yHE300B}} = 151.55 \qquad \frac{100}{\gamma_a} = 0.66$$

Upper end b

$$k_{\phi b} := \frac{2 \cdot E \cdot I_{yI820}}{6.5m} + \frac{2 \cdot E \cdot I_{yI820}}{18m} = 2.245 \times 10^{11} \cdot N \cdot mm$$

$$\gamma_b := \frac{k_{\phi b} \cdot 12.18m}{E \cdot I_{yHE300B}} \qquad \gamma_b = 71.319$$

Figure 4.4 $\beta = 0.52$

Main beams between transportation support points

Buckling length $L := 18m$

$L_a := 6.5m$ $L_b := L_a$

End a

$$k_{\phi a} := \frac{2 \cdot E \cdot I_{yI1210}}{L_a} = 4.771 \times 10^{11} \cdot N \cdot mm$$

$$\gamma_a := \frac{k_{\phi a} \cdot L}{E \cdot I_{yI1210}} = 5.538 \qquad \frac{100}{\gamma_a} = 18.056$$

End b

$$k_{\phi b} := \frac{2 \cdot E \cdot I_{yI1210}}{L_b} = 4.771 \times 10^{11} \cdot N \cdot mm$$

$$\gamma_b := \frac{k_{\phi b} \cdot L}{E \cdot I_{yI1210}} \qquad \gamma_b = 5.538$$

Figure 4.4

$\beta = 0.66$

III. Load combinations

Weight contingency factor	1.10
Weight Inaccuracy factor	1.00
CIF CoG inaccuracy factor:	1.02
CoG factor (xy plane)	1.14
Skew load factor	1.00
DAF	1.10
ULS-a	1.20
Consequence factor (CF)	
Non-lift members, no consequence	1.00
Lift members, reduced consequence	1.15
Consequence factor, Lift members	1.30

Consequence factors DNV-RP-H102 Chapter 3.1.4 table 3.2

Load Case (LC)		
LC	CF	Total LF
101	1.00	1.00
102	1.00	1.68
103	1.15	1.93
104	1.30	2.19

Table C-1 Load combinations lifting condition

Amund Lundqvist

Intermediate level 50

General load factors

Weight contingency factor		1.10
CIF CoG inaccuracy factor:		1.02
CoG factor z-direction		1.14
CoG factor x-direction		1.13
CoG factor y-direction		1.10
Wave acceleration *g		
	z	0.20
	x	0.28
	y	0.22

Multiplyed direction- and contingency factors

	Max load			Min Load		
	z	x	y	z	x	y
Struct. Eq. Loads	1.27			0.79		
Environmental loads	0.26	0.35	0.27	0.16	0.22	0.18

Intermediate level load cases:

Max Load	llc
Neg Z-dir	1.00
Neg Z-dir Heave	2.00
X (waves from S)	3.00
Y(waves from E)	4.00
Min Load	
Z	5.00
Z Heave	6.00
X (waves from S)	7.00
Y(waves from E)	8.00
Wind Loads	
Wind from South	11.00
Wind from North	13.00
Wind from East	12.00
Wind from West	14.00
Deformation Loads	21.00

Table C-2 Intermediate level load combinations transportation condition, superelement 50

Top level 100 SLS/ULS

SLS		
	Permanent	1.00
	Environmental	1.00
ULS-a		
	Permanent	1.20
	Environmental	0.70
ULS-b		
	Permanent	1.00
	Environmental	1.15

Top Level

Direction combinations

	Max. Load			Min. Load		
Wind/Waves from	SLS	ULS-a	ULS-b	SLS	ULS-a	ULS-b
South +	1	17	33	49	65	81
-	2	18	34	50	66	82
South/East +	3	19	35	51	67	83
-	4	20	36	52	68	84
East +	5	21	37	53	69	85
-	6	22	38	54	70	86
North/East +	7	23	39	55	71	87
-	8	24	40	56	72	88
North +	9	25	41	57	73	89
-	10	26	42	58	74	90
North/West +	11	27	43	59	75	91
-	12	28	44	60	76	92
West +	13	29	45	61	77	93
-	14	30	46	62	78	94
South/West +	15	31	47	63	79	95
-	16	32	48	64	80	96

Table C-3 Top level load combinations transport condition superelement 100

IV. Reinforcement solutions

Solutions for reinforcement of failing columns in transport condition

General properties

Steel density: $\rho_s := 7850\frac{kg}{m^3}$

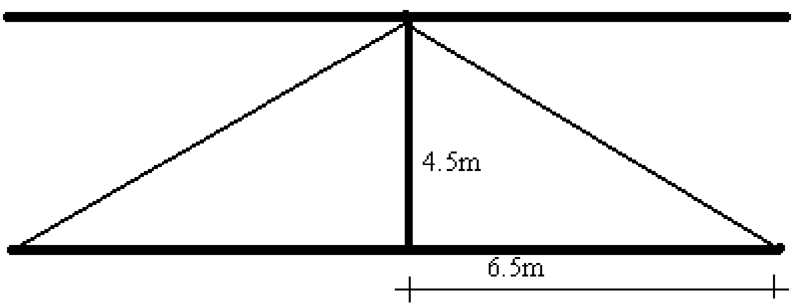
Dimensioning stress $f_d := \frac{355MPa}{1.15} = 308.696MPa$

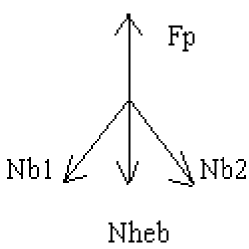
Method A.

Diameter steel rod $d := 75mm$

Cross section area HE300B $A_{heb} := 14.9 \cdot 10^3 mm^2$

Chooses the module geometry with the smallest angle α , for the comparison





$\alpha := \text{atan}\left(\frac{4.5m}{6.5m}\right) = 34.695 deg$

$N_{bd} := \pi \frac{d^2}{4} \cdot f_d = 1.364\times 10^3 \cdot kN$ $N_{bdy} := N_{bd} \cdot \sin(\alpha) = 776.275kN$

Additional capacity: $N_a := 2 \cdot N_{bdy} = 1.553 \times 10^3 \cdot kN$

$$UF_{add} := \frac{A_{heb} \cdot f_d + N_a}{A_{heb} \cdot f_d} = 133.754\%$$

Length braces $L_b := \sqrt{(4.5m)^2 + (6.5m)^2} = 7.906m$

additional steel weight $m_s := \left(\pi \cdot \frac{d^2}{4} \cdot \rho_s \cdot L_b\right) \cdot 2 = 548.343kg$

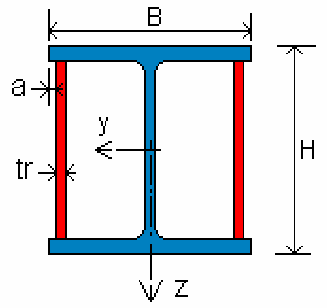
$$\frac{m_s}{UF_{add} - 1} = 16.245 \frac{kg}{\%}$$

Method B

Plate thickness $t := 16mm$

Plate height $h_p := 300mm - 2 \cdot 19mm = 262 \cdot mm$

Length beam $L_b := 4.5m$



Additional axial capacity: $N_p := 2 \cdot (t \cdot h_p) \cdot f_d = 2.588 \times 10^3 \cdot kN$

Axial capacity HE300B $N_b := A_{heb} \cdot f_d + N_p = 7.188 \times 10^3 \cdot kN$

$$UF_{add} := \frac{A_{heb} \cdot f_d + N_p}{A_{heb} \cdot f_d} = 156.268\%$$

Additional steel weight $m_s := (t \cdot h_p \cdot \rho_s \cdot L_b) \cdot 2 = 296.165 kg$

$$\frac{m_s}{UF_{add} - 1} = 5.263 \cdot \frac{kg}{\%}$$

Rest capacity
Conservative elastic NS 3472 12.2.6 $n + m_y + m_z \leq 1.0$

Largest tension force column MZ307031

$N_f := 4.453 MN$

Rest cap for moment: $1 - \frac{N_f}{A_{heb} \cdot f_d + N_p} = 38.047 \cdot \%$

Conclusion:

From these calculations the result is that it takes three times as much steel to increase the capacity with 1% with Method A compared to Method B. Chooses Method B although this method needs more welding for installation.

Method A can be considered if the joint forces get to high.

D. LOCAL ANALYSIS PADEYE AND CRITICAL COLUMN

I. Padeye load

Load calculation pad eye

Max lift force : $F := 5.600 MN$

Pad eye thickness $t_{pl} := 80mm$

Cheek plate thickness $t_c := 50mm$

Total thickness $t := t_{pl} + 2 \cdot t_c = 180 \cdot mm$

Inner diametre $r_i := 105mm$

Uniformly distributed pressure p at upper half of the hole.

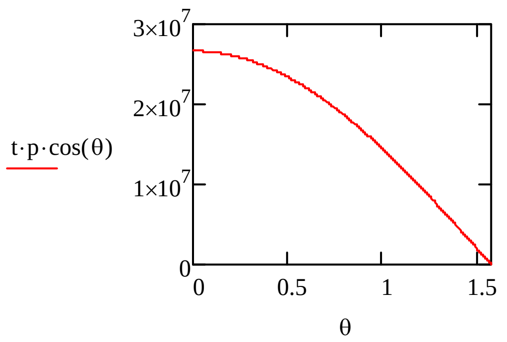
$$\int_0^{\pi} p \, dA = \left(\int_0^{\pi} t \cdot p \cdot r_i \cdot \sin(\theta) \, d\theta \right) = F$$

$$\int_0^{\pi} t \cdot p \cdot r_i \cdot \sin(\theta) \, d\theta = F$$

$$2t \cdot p \cdot r_i = F \qquad p := \frac{F}{2 \cdot t \cdot r_i} = 148.148 MPa$$

Horisontal forces causing horisontal stess at pin hole top:

$$t \, r_i \cdot \int_0^{\frac{\pi}{2}} p \cdot \cos(\theta) \, d\theta = 2.8 \cdot MN$$



Structural design premisis 6.2

Lateral force in crosswise direction (x - direction)

Tilit $2deg$ tilt + $0.5deg$ innstalation inaccuracy $\alpha := 2.5deg$

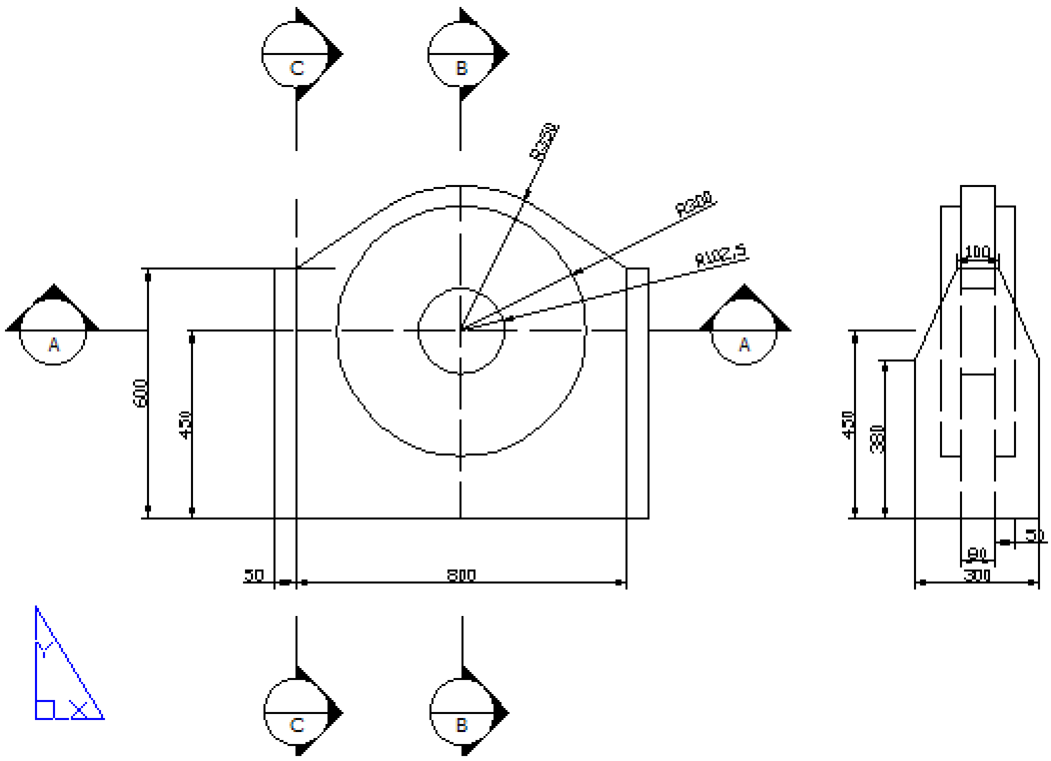
$\sin(\alpha) = \frac{F}{F_{lx}}$ $F_{lx} := 0.04 \cdot F = 224 \cdot kN$ Acting at the shackle bow

Lateral force in lengthwise direction (y - direction)

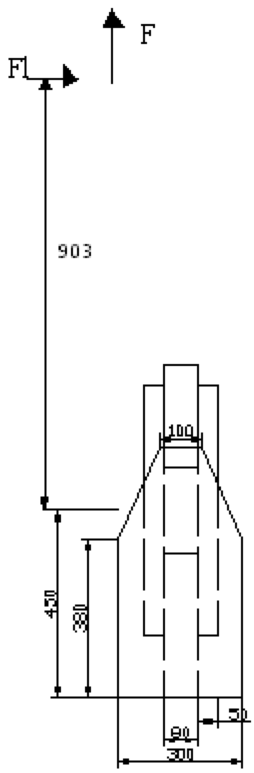
$\sin(2deg) = \frac{F}{F_{ly}}$ $F_{ly} := F \cdot \sin(2deg) = 195.437 kN$

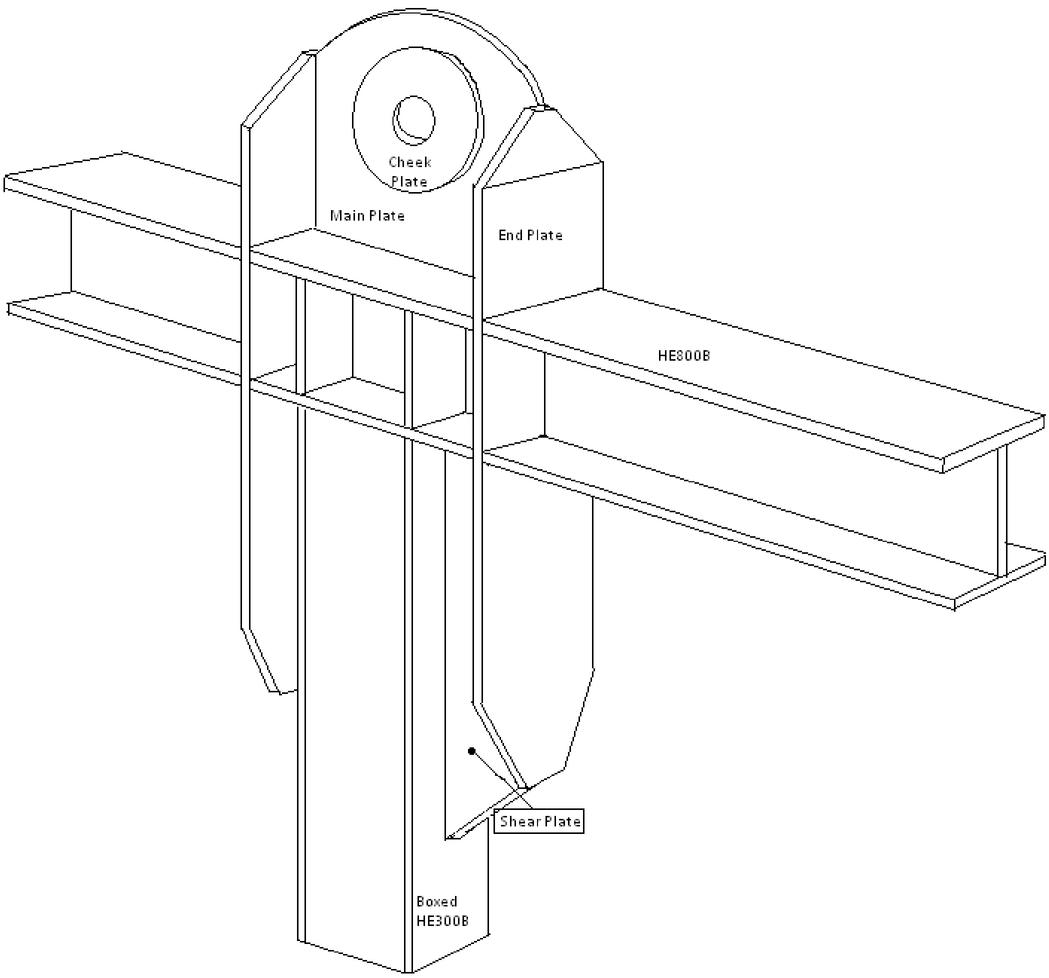
In y - direction the lateral load acts at the pin hole edge since the shackle can rotate about the x - axis.

II. Stress analysis



Action Point Lift force and Lateral force at top of shackle
GreenPin P-6036, 600 tonnes.





Sketch of installed padeye and part of M32 structure.

Design factors and material properties:

$\gamma_m := 1.15$ $\gamma_{m2} := 1.25$

$f_y := 355MPa$ $f_d := \frac{f_y}{\gamma_m} = 308.696MPa$ $f_u := 490MPa$

Geometry

Pad eye base plate:

Plate thickness $t_{pl} := 80mm$

Diametre of top circle $R := 350mm$

Bottom width $l := 800mm$

Heigth to centre of pin hole $h_c := 450mm$

Height section B - B $h_{BB} := 800mm$

Cheek plates $t_c := 50mm$

$r_c := 300mm$

End stiffeners

Height $h_{CC} := 600mm$

Bottom width $l_{es} := 300mm$

Plate thickness $t_{es} := 50mm$

Pin hole $r_i := 105mm$

$d_0 := 2 \cdot r_i$

Pin $r_p := 102.5mm$

$d_p := 2 \cdot r_p$

Forces

Max Lift force (sestra output)
Load factors similar to uls-a with consequence factor $\gamma_c := 1.3$

Dimensioning lift force for local design F: $F := 5.604MN$

Lateral force in global x - direction 4% of the lift force $F_{lx} := 0.04 \cdot F = 224.16kN$

Lateral force in global y - direction 3.5% of the lift force $F_{ly} := 0.035 \cdot F = 196.14kN$

Von Mises yield criteria

$$\sigma_{mises} = \sqrt{\frac{1}{2}\left[\left(\sigma_{xx} - \sigma_{yy}\right)^2 + \left(\sigma_{yy} - \sigma_{zz}\right)^2 + \left(\sigma_{zz} - \sigma_{xx}\right)^2\right] + 3\left(\tau_{xy}^{\;2} + \tau_{yz}^{\;2} + \tau_{xz}^{\;2}\right)}$$

Ground material

Conservative approach for bending around the z – axis, lateral force acting in the centre of the pin hole.

section A - A

Boundary conditions for stress calculations from lateral force about z - axis

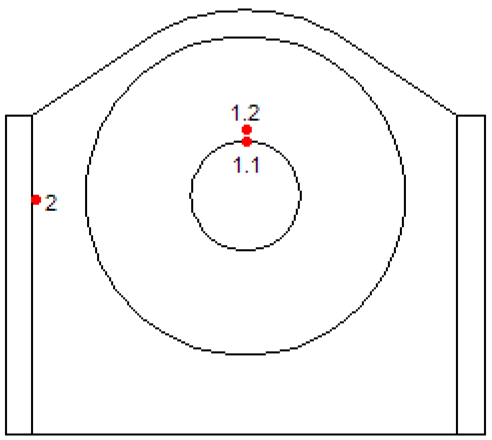
The base plate is partly fixed to the stiffener end plates and fully welded to the bottom beam .

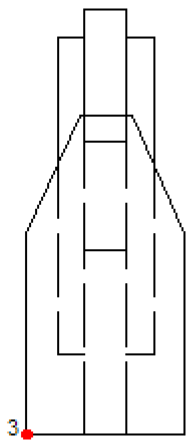
Conservative boundary simplification:

Stress calculations at point 1
Simply supported boundary conditions, the end stiffener plates rotate free.

Stress calculations at point 2
Full fixation of the end stiffener plates, no rotation.

Stress calculations at point 3





Point 1, section B - B

Elastic yield check of the outermost fibre of the pin hole edge.

$r_c = 300\cdot mm$ $r_i = 105\cdot mm$ $t_{pl} = 80\cdot mm$ $t_c = 50\cdot mm$ $l = 800\cdot mm$

$F_{lx} = 0.224\,MN$ $F_{ly} = 0.196\,MN$ $F = 5.604\,MN$

$$M_A := \frac{F_{lx}\cdot l}{4} = 44.832\,kN\cdot m$$

No bending stresses from lateral force in y - direction. Point 1.1 and 1.2 is on the neutral axis for bending from F_{ly}

Section modulus:
Large hole, uses only upper half of the cross section.

$$W_{elA} := \frac{(r_c - r_i)\cdot(t_{pl} + 2\cdot t_c)^2}{6} = 1.053\times 10^6\cdot mm^3$$

$$\sigma_{xxA} := \frac{M_A}{W_{elA}} \qquad \sigma_{xxA} = 42.575\,MPa$$

Stresses from horizontal pin load distribution. Distributed over the cheek plate radius.
Calculated in Padeyload.xmd

$F_x := 2.8MN$

$$\sigma_{xx} := \frac{F_x}{(r_c - r_i)\cdot(t_{pl} + 2\cdot t_c)} = 79.772\,MPa$$

Stress from pin pressure at pin hole.

$$\sigma_{yyA} := \frac{F}{d_p\cdot(t_{pl} + 2\cdot t_c)} = 151.87\,MPa$$

Shear stresses from lateral force are zero at section B - B $\tau_{yz} := 0$

Shear stress in section B - B (conservative)

$$A_s := \left(t_{pl} + 2\cdot t_c\right)\cdot\left(r_c - r_i\right)$$

$$\tau_{xy} := \frac{F}{2\cdot A_s} = 79.829\,MPa$$

Shear stress from lateral force in global x - direction

$$\tau_{yz} := \frac{F_{lx}}{2\cdot A_s} = 3.193\,MPa$$

Von Mises stress at the outer most fibre

$$\sigma_{mises} := \sqrt{\left(\sigma_{xxA} + \sigma_{xx}\right)^2 + \sigma_{yyA}{}^2 + 3\cdot\left(\tau_{xy} + \tau_{yz}\right)^2} = 242.304\,MPa$$

$\sigma_{mises} = 242.304\,MPa$

$$UF_{1.1} := \frac{\sigma_{mises}}{f_d}$$

$UF_{1.1} = 0.785$

NS 3472 12.5.2.2 Allows a certain yield deformation until all pressure from pin acts in the vertical direction.

Stress calculation at a point near the yield zone:
Surface traction $\sigma_{yyA} := 0$

$$\sigma_{mises} := \sqrt{\left(\sigma_{xxA} + \sigma_{xx}\right)^2 + \sigma_{yyA}{}^2 + 3\cdot\tau_{xy}{}^2} = 184.627\,MPa$$

$\sigma_{mises} = 184.627\,MPa$

$$UF_{1.2} := \frac{\sigma_{mises}}{f_d}$$

$UF_{1.2} = 0.598$

The stresses for the pin hole edge is acceptable if the criteria for pin hole bearing stress NS3472 12.5.2.2 is fulfilled.

Point 2, section C - C

$h_{CC} = 600 \cdot mm$ $r_c - r_i = 0.195m$

$M_{CC} := \frac{F_{lx} \cdot l}{8}$ $t_{pl} + 2 \cdot t_c = 0.18m$

$W_{elCC} := \frac{h_{CC} \cdot t_{pl}^2}{6}$

$\sigma_{xx2} := \frac{M_{CC}}{W_{elCC}}$ $\sigma_{xx2} = 35.025 MPa$

The point is at the action line for F_{ly}, no bending stresses from this force

$l = 800 \cdot mm$ $R = 350 \cdot mm$ $r_i = 105 \cdot mm$ $t_c = 50 \cdot mm$

$\sigma_{yy2} := \frac{F}{t_{pl} \cdot (l - 2 \cdot r_i) + t_c \cdot (R - r_i) \cdot 2}$ $\sigma_{yy2} = 7.816 \times 10^7 Pa$

Shear stresses

Shear area $A_s := h_{BB} \cdot t_{pl}$

From lateral force

$\tau_{yz} := \frac{F_{lx}}{2 \cdot A_s}$ $\tau_{yz} = 1.751 \times 10^6 Pa$

From lift force

$\tau_{xy} := \frac{F}{2 \cdot A_s}$ $\tau_{xy} = 4.378 \times 10^7 Pa$

Von Mises stress

$\sigma_{mises2} := \sqrt{\sigma_{xx2}^2 + \sigma_{yy2}^2 - \sigma_{xx2}\sigma_{yy2} + 3\left(\tau_{xy}^2 + \tau_{yz}^2\right)}$

$UF_2 := \frac{\sigma_{mises2}}{f_d}$ $UF_2 = 0.33$

Point 3

Moment effect from lateral force at shackle bow is included in the stress calculation.

$F = 5.604\cdot MN$ $\qquad F_{lx} = 0.224\cdot MN$

$h_c = 450\cdot mm$

height from shackle bow to centre of pin $\qquad h_s := 903mm$

Moment arm from lateral force $\qquad h_l := h_c + h_s = 1.353\times 10^3\cdot mm$

Moment of inertia

End plates ,1

$b_1 := t_{es} = 50\cdot mm$ $\qquad h_1 := l_{es} = 300\cdot mm$ $\qquad A_1 := b_1\cdot h_1 = 1.5\times 10^4\cdot mm^2$ $\qquad y_1 := 0mm$

$$I_1 := \frac{b_1\cdot h_1^{\,3}}{12} = 1.125\times 10^8\cdot mm^4$$

Main plate, 2

$b_2 := l = 800\cdot mm$ $\qquad h_2 := t_{pl} = 80\cdot mm$ $\qquad A_2 := b_2\cdot h_2 = 6.4\times 10^4\cdot mm^2$ $\qquad y_2 := 0$

$$I_2 := \frac{b_2\cdot h_2^{\,3}}{12} = 3.413\times 10^7\cdot mm^4$$

Steiner

$$I_{3y} := \left[I_1 + \left(A_1\cdot y_1^{\,2}\right)\right]\cdot 2 + I_2 + \left(A_2\cdot y_2^{\,2}\right) = 2.591\times 10^8\cdot mm^4$$

$$W_{e3x} := \frac{I_{3y}}{150mm} = 1.728\times 10^6\cdot mm^3$$

$W_{e3z} := 1.628\, 10^7 mm^3$

Moment from lateral force: $\qquad M_{lx} := F_{lx}\cdot h_l = 303.288\,kN\cdot m$

$\qquad M_{ly} := F_{ly}\cdot h_c = 88.263\,kN\cdot m$

Stresses from beam bending transferred through the padeye end plates,
result from Framework output for beam MY306140.:

$\sigma_{zz3} := 159MPa$

Stress calculation

$$\sigma_{yylx} := \frac{M_{lx}}{W_{e3x}} = 175.559\,MPa$$

$$\sigma_{yy3} := \frac{F}{(2\cdot A_1 + A_2)} = 59.617\cdot MPa$$

$$\sigma_{yyly} := \frac{M_{ly}}{W_{e3z}} = 5.422\cdot MPa$$

$$\tau_1 := \frac{F_{lx}}{2\cdot A_1} = 7.472\cdot MPa$$

$$\tau_2 := \frac{F_{ly}}{A_2}$$

$$\sigma_{Myy3} := \sigma_{yy3} + \sigma_{yylx} + \sigma_{yyly}$$

$$\sigma_3 := \sqrt{\sigma_{Myy3}^2 - \sigma_{Myy3}\cdot\sigma_{zz3} + \sigma_{zz3}^2 + 3\cdot\left(\tau_1^2 + \tau_2^2\right)} \qquad \sigma_3 = 212.389\,MPa$$

$$UF_3 := \frac{\sigma_3}{f_d} \qquad UF_3 = 0.688$$

Pin hole bearing stress:

NS 3472 12.5.2.2

$$F_{db} = \frac{1.5 \cdot f_u \cdot d \cdot t}{\gamma_{m2}}$$

$$\sigma_d := \frac{1.5 \cdot f_u}{\gamma_{m2}} \qquad \sigma_d = 588 \cdot MPa$$

$$\sigma_a := \frac{F}{d_p \cdot (t_{pl} + 2 \cdot t_c)} = 151.87 \cdot MPa \qquad \sigma_a = 151.87 \cdot MPa$$

$$UF_{Pinhole} := \frac{\sigma_a}{\sigma_d} \qquad UF_{Pinhole} = 0.258$$

Tear out stress

12.5.3.3

$$\tau_d := \frac{f_y}{\gamma_m \cdot \sqrt{3}} = 178.226 MPa$$

Shear area

$$A_\tau := [[330mm - (R - r_c)] \cdot t_{pl} + r_c \cdot (t_{pl} + 2 \cdot t_c)] \cdot 2 = 1.528 \times 10^5 \cdot mm^2$$

Shear stress:

$$\tau := \frac{F}{A_\tau} \qquad \tau = 36.675 MPa$$

$$UF_{Tear} := \frac{\tau}{\tau_d} \qquad UF_{Tear} = 0.206$$

Shear plate:

Width shear plate: $w_{Shearpl} := \frac{l - 300mm}{2} = 250 \cdot mm$

Thickness end plates: $t_{es} = 50 \cdot mm$

Thickness shear plates
(fits "fork cut" for HE800B web) $t_{Shearpl} := 20mm$

Minimum necessary length of shear plate:

$$308MPa = \sqrt{3 \cdot \left(\frac{3}{2} \cdot \frac{\frac{F}{2}}{t_{Shearpl} \cdot x} \right)^2}$$

$$l_{MinShearpl} := \begin{pmatrix} -1180.9437324333254274 \\ 1180.9437324333254274 \end{pmatrix}$$

Length shear plate: $l_{Shearpl} := 1400mm$

Shear area : $A_{vShearpl} := \frac{2}{3} \cdot \left(l_{Shearpl} \cdot t_{Shearpl} \right) = 1.867 \times 10^4 \cdot mm^2$

$$W_{ElShearpl} := \frac{t_{Shearpl} \cdot l_{Shearpl}^2}{6}$$

$\frac{F}{2} = 2.802 \cdot MN$ $t_{es} = 50 \cdot mm$

Moment $M_{Shearpl} := \frac{F}{2} \cdot \left(w_{Shearpl} + \frac{t_{es}}{2} \right) = 770.55 \, kN \cdot m$

$$\sigma_{mShearpl} := \frac{M_{Shearpl}}{W_{ElShearpl}} = 117.941 \, MPa$$

$$\tau_{Shearpl} := \frac{\frac{F}{2}}{A_{vShearpl}} = 150.107 \, MPa$$

$$\sigma_{misesShearpl} := \sqrt{\sigma_{mShearpl}^2 + 3 \cdot \tau_{Shearpl}^2} = 285.494 \, MPa$$

$$UF_{Shearpl} := \frac{\sigma_{misesShearpl}}{f_d} = 0.925$$

Single critical column BxoedHE300B

From abacus stress intensity analysis, only flanges and reinforcement plates acts as effective cross section.

$t_{fl} := 19mm$ $b_{fl} := 300mm$ $t_w := 11mm$

Reinforcement plates used in first Sesam analysis:

$t_{rpl} := 10mm$ $b_{rpl} := 300mm - 2 \cdot t_{fl}$

$$A_{eff} := 2 \cdot t_{fl} \cdot b_{fl} + 2 \cdot t_{rpl} \cdot b_{rpl} = 1.664 \times 10^4 \cdot mm^2$$

$$\sigma_{ten} := \frac{F}{A_{eff}} = 3.368 \times 10^8 Pa$$

$$UF_{PL10BoxedHE300B} = \frac{\sigma_{ten}}{f_d} = 1.091$$

Failure of column due to local yield of web.

New reinforcement plate:

$t_{rpl} := 16mm$

$$A_{eff} := 2 \cdot t_{fl} \cdot b_{fl} + 2 \cdot t_{rpl} \cdot b_{rpl} = 1.978 \times 10^4 \cdot mm^2$$

Shear area NS3472 12.4.4:

$$A_v := \frac{b_{fl}}{2 \cdot b_{fl}} \cdot A_{eff} = 9.892 \times 10^3 \cdot mm^2$$

Moment of inertia without HE300B web

$W_{ey1} := 1.82 \cdot 10^6 mm^3$ $W_{py1} := 2.15 \cdot 10^6 mm^3$

$W_{ez1} := 1.545 \cdot 10^6 mm^3$ $W_{pz1} := 2.962 \cdot 10^6 mm^3$

Moment of inertia with HE300B web:

$W_{ey2} := 1.932 \cdot 10^6 mm^3$ $W_{py2} := 2.34 \cdot 10^6 mm^3$

$W_{ez2} := 1.545 \cdot 10^6 mm^3$ $W_{pz2} := 1.97 \cdot 10^6 mm^3$

$A_{BoxedHE300B} := A_{eff} + t_w \cdot (b_{fl} - 2 \cdot t_{fl}) = 2.267 \times 10^4 \cdot mm^2$

Moments and shear forces from Sesam Framework output file:

Lift force $F = 5.604 MN$ $V_z := 4.103 \cdot 10^{-2} MN$ $V_y := 2.192 \cdot 10^{-2} MN$

At column midpoint:

$M_{y1} := 1.809 \cdot 10^{-2} MN \cdot m$ $M_{z1} := 3.16 \times 10^{-2} \cdot MN \cdot m$

At column end:

$M_{y2} := 9.245 \cdot 10^{-2} MN \cdot m$ $M_{z2} := 7.762 \cdot 10^{-3} MN \cdot m$

$$\sigma_{ten} := \frac{F}{A_{eff}} = 2.833 \times 10^8 Pa$$

$$\sigma_{my} := \frac{M_{y1}}{W_{ey1}} = 9.94 MPa \qquad \sigma_{mz} := \frac{M_{z1}}{W_{ez1}} = 20.453 MPa$$

$$\tau_1 := \frac{V_z}{A_v} = 4.148 MPa \qquad \tau_2 := \frac{V_y}{A_v} = 2.216 MPa$$

$$\sigma_{Mises} := \sqrt{(\sigma_{my} + \sigma_{mz} + \sigma_{ten})^2 + 3 \cdot (\tau_1^2 + \tau_2^2)} = 313.758 MPa$$

$$UF_{elBoxedHE300B} := \frac{\sigma_{Mises}}{f_d} = 1.016$$

Check according to NS3472:

Section class:

$$\varepsilon := \sqrt{\frac{235MPa}{f_y}} = 0.814$$

Reinforcement plates as web (My):

$d := b_{rpl} = 262 \cdot mm$ $\quad t_w := t_{rpl} = 0.016m$

$\frac{d}{t_w \cdot \varepsilon} = 20.126$ < 33 ε -> Class 1

Reinforcement plates as flange (Mz)

$t_f := t_w \quad b := d$

$\frac{b}{t_f \cdot \varepsilon} = 20.126$ < 33 ε -> Class 1

Section class 1 $\quad \beta_{Wp} := 1$

Shear check NS3472 12.2.7:

$$V_d := \frac{f_y}{\gamma_m \cdot \sqrt{3}} \cdot A_v = 1.763 MN$$

Can neglect the shear stresses effect on the moment if $\frac{V_z + V_y}{V_d} < 0.5$

$\frac{V_z + V_y}{V_d} = 0.036$ Neglecting the effect from the shear force

Conservative check at column mid point:

$n_1 := \frac{F}{A_{eff} \cdot f_d} = 0.918 \quad m_{y1} := \frac{M_{y1}}{W_{py1} \cdot f_d \cdot \beta_{Wp}} = 0.027 \quad m_{z1} := \frac{M_{z1}}{W_{pz1} \cdot f_d \cdot \beta_{Wp}} = 0.035$

$UF_{BoxedHE300B1} := n_1 + m_{y1} + m_{z1} = 0.979$

Conservative check at column end point:
Assume long distance from stress concentration point, whole section of Boxed HE300B acts as effective area.

$$n_2 := \frac{F}{A_{BoxedHE300B} f_d} = 0.801 \qquad m_{y2} := \frac{M_{y2}}{W_{py2} \cdot f_d \cdot \beta_{Wp}} = 0.128 \qquad m_{z2} := \frac{M_{z2}}{W_{pz2} \cdot f_d \cdot \beta_{Wp}} = 0.013$$

$$UF_{BoxedHE300B2} := n_2 + m_{y2} + m_{z2} = 0.942$$

Summary

$UF_{1.1} = 0.785$ $UF_{1.2} = 0.598$ $UF_2 = 0.33$ $UF_3 = 0.688$

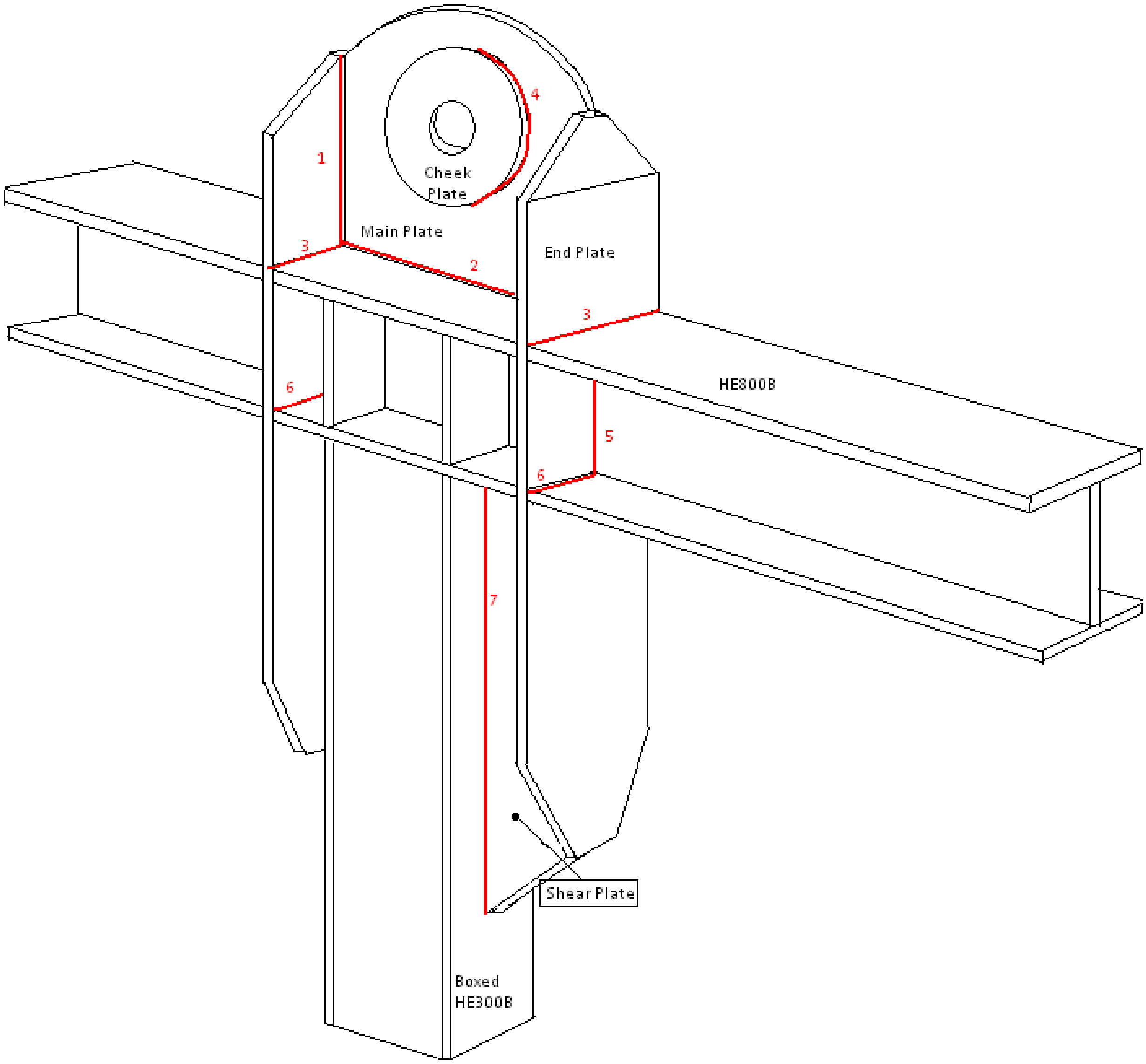
$UF_{Tear} = 0.206$ $UF_{Pinhole} = 0.258$ $UF_{Shearpl} = 0.925$ $UF_{BoxedHE300B1} = 0.979$

$UF_{BoxedHE300B2} = 0.942$

Point/part	UF
1.1	0.78
1.2	0.60
2	0.33
3	0.69
Tear stress	0.21
Pin hole	0.26
Shear Plate	0.92
BoxedHE300B	
mid	0.98
end	0.94

III. Welds

Weld calculations



Design factors and material properties:

$\gamma_m := 1.15$ $\gamma_{m2} := 1.25$

$f_y := 355MPa$ $f_d := \frac{f_y}{\gamma_m} = 308.696MPa$ $f_u := 490MPa$

Geometry

Pad eye base plate:

Plate thickness $t_{pl} := 80mm$

Diameter of top circle $R := 350mm$

Bottom width $l := 800mm$

Height to centre of pin hole $h_c := 450mm$

Height section B - B $h_{BB} := 800mm$

Cheek plates $t_c := 50mm$

$r_c := 300mm$

End stiffeners

Height $h_{CC} := 600mm$

Bottom width $l_{es} := 300mm$

Plate thickness $t_{es} := 50mm$

Pin hole $r_i := 105mm$

$d_0 := 2 \cdot r_i$

Pin $r_p := 102.5mm$

$d_p := 2 \cdot r_p$

Forces

Max Lift force (Sestra output)
Load factors similar to uls-a with consequence factor $\gamma_c := 1.3$
Dimensioning lift force for local design F: $F := 5.604MN$

Lateral force in global x - direction 4% of the lift force $F_{lx} := 0.04 \cdot F = 224.16kN$

Lateral force in global y - direction 3.5% of the lift force $F_{ly} := 0.035 \cdot F = 196.14kN$

Welds to be calculated:

Section C - C, Shear stress from lifting force
Base plate - beam flange, shear forces from F_{ly}
End plate - beam top flange
Cheek plate base plate
End plate - beam web
End plate - beam bottom flange
Shear plate - Endplate/BoxedHE300B
Reinforcement plate - HE300B ends
Reinforcement plate - HE300B mid part

NS 3472 12.6.2.1

Weld stresses:

τ_{pa} = Parallel shear stress
τ_{pe} = Perpendicular shear stress
σ_{pe} = Perpendicular stress

$$\sqrt{\sigma_{pe}^2 + 3\left(\tau_{pa}^2 + \tau_{pe}^2\right)} \le \frac{f_u}{\gamma_{m2} \cdot \beta_w}$$

Tab. 18

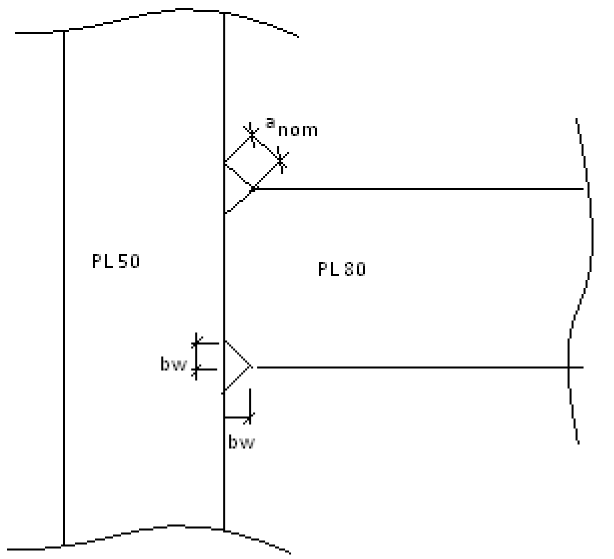
$f_u := 510MPa$ $\beta_w := 0.9$ $f_{ud} := \frac{f_u}{\gamma_{m2} \cdot \beta_w} = 453.333MPa$

1 End plates - Base plate
Section C - C (Symmetric around section B - B

$h_{CC} = 600 \cdot mm$

Two sided weld
Shear force: $F_{ws} := \frac{F}{4}$

Lateral force $F_{wl} := \frac{F_{lx}}{4}$



Part pen weld and fillet weld $b_{w1} := 10mm$

NS3472 12.6.3

$$a_{nom1} := \left[\sqrt{\left(b_{w1}\right)^2 + \left(b_{w1}\right)^2}\right] - 2mm = 12.142mm$$

$$\tau_{pa1} := \frac{F}{4 \cdot a_{nom1} \cdot h_{CC}} = 192.306MPa$$

$$\sigma_{MisesW1} := \sqrt{3 \cdot \tau_{pa1}^{\ 2}} = 333.083MPa$$

$$UF_{W1} := \frac{\sigma_{MisesW1}}{f_{ud}} = 0.735$$

2 Base plate - Top flange

Only shear stresses due to uncertain z - quality of the beam.

$F_{lx} = 224.16kN$ $F_{ly} = 196.14kN$ $l = 0.8m$ $t_{es} = 50 \cdot mm$

4mm fillet weld $b_{w2} := 4mm$ $a_2 := \frac{b_{w2}}{\sqrt{2}}$

$\sigma_{pe2} := \frac{F_{lx} \cdot \sqrt{2}}{2} \cdot \frac{1}{2 \cdot a_2 \cdot l} = 35.025MPa$ $\tau_{pe2} := \sigma_{pe2}$

$\sigma_{MisesW2} := \sqrt{\sigma_{pe2}^2 + 3\tau_{pe2}^2} = 70.05MPa$

$UF_{W2} := \frac{\sigma_{MisesW2}}{f_{ud}} = 0.155$

3 End plate - Top flange

Weld load distribution
Cause of poor z - quality top flange of the HE800 Beam will be cut out and the padeye end plates will be welded to the beam web.

Beam stresses from structural loads, Sesam output

Stresses at the outermost fibre from bending acting as z - stresses in the end plate.
This implies the end plate must be of homogenous steel in all 3 dimensions. (z - quality)

$F_{lx} = 224.16kN$

The moment from the lateral force in x - direction is taken as shear craft couple between weld 3 and 6.

Beam forces:

$MN \cdot m = 1 \times 10^3 \cdot kN \cdot m$

Beam forces, worst case bending and tension member MY306140.

$M_y := 1.378 \cdot 10^3 kN \cdot m$ $N := 50.15kN$ $V := 483.5kN$

Shear forces taken by the beam web.

$t_w := 15mm$ $h_{HE800B} := 800mm$

$A_v := t_w \cdot h_{HE800B} = 1.2 \times 10^4 \cdot mm^2$

Axial stress

$A_{HE800B} := 33.4 \cdot 10^3 mm^2$ $A_{flange} := 300mm \cdot 33mm$

$\frac{N}{A_{HE800B} - A_{flange}} = 2.134MPa$ Stresses in "damaged" cross section is small, neglect able value.

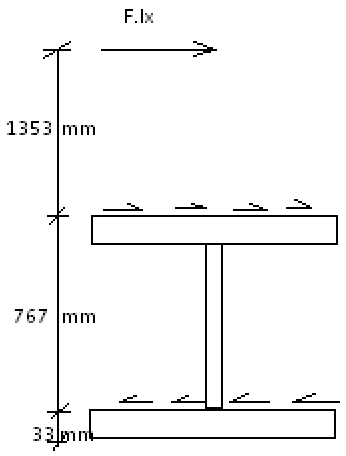
Part pen weld and fillet weld $b_{w3} := 15mm$

NS3472 12.6.3

$a_{nom3} := \left[\sqrt{(b_{w3})^2 + (b_{w3})^2}\right] - 2mm = 19.213mm$

Total length of weld 3 at one end of the padeye $l_{bw3} := 300mm + (300mm - 17.5mm - 2 \cdot 30mm) = 522.5mm$

Force at weld 3 from F_{lx}



Moment around bottom point of HE800B beam:

$F_{lx3} \cdot 800mm - F_{lx} \cdot (1353mm + 800mm) = 0$

$F_{lx3} := \frac{F_{lx} \cdot (1353mm + 800mm)}{800mm} = 603.271kN$

$\tau_{pa3} := \frac{F_{lx3}}{a_{nom3} \cdot l_{bw3}} = 60.093MPa$

Conservative simplification, recalculates the bending moment in the HE800B to a craft couple with the inner arm

$$\frac{h_{HE800B}}{2} = 400 \cdot mm$$

$$F_{Mbeam} := \frac{M_y}{h_{HE800B}} = 1.722 \cdot MN$$

$$\sigma_{pe3} := \frac{F_{Mbeam} \cdot \sqrt{2}}{2 \cdot a_{nom3} \cdot l_{bw3}} = 121.327 MPa \qquad \tau_{pe3} := \sigma_{pe3}$$

$$\sigma_{MisesW3} := \sqrt{\sigma_{pe3}^2 + 3\left(\tau_{pa3}^2 + \tau_{pe3}^2\right)} = 264.036 MPa$$

$$UF_{W3} := \frac{\sigma_{MisesW3}}{f_{ud}} = 0.582$$

Weld 4 Cheek plates - Main plate

Two thirds of the weld around the checck plates are effective.

$F = 5.604 \cdot MN$

$t_c = 50 \cdot mm$ $\qquad t_{pl} = 80 \cdot mm$ $\qquad r_c = 300 \cdot mm$

Part pen weld and fillet weld $b_{w4} := b_{w1} = 10 \cdot mm$ $\qquad a_{nom4} := a_{nom1} = 0.012m$

Weld length: $l_{w4} := 2 \cdot \pi \cdot r_c$

Force in one cheek plate:

$$F_{ch} := \frac{F \cdot t_c}{\left(t_{pl} + 2 \cdot t_c\right)} = 1.557 \cdot MN$$

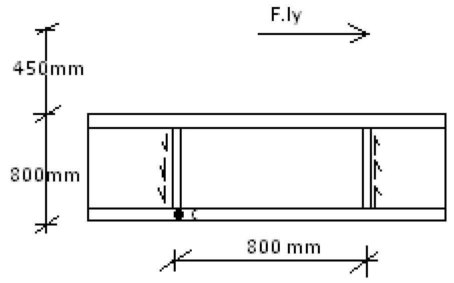
$$\tau_{pa4} := \frac{F_{ch}}{l_{w4} \cdot \frac{2}{3} \cdot a_{nom4}} = 102.021 MPa$$

$$\sigma_{MisesW4} := \sqrt{3 \cdot \left(\tau_{pa4}\right)^2} = 176.706 MPa$$

$$UF_{W4} := \frac{\sigma_{MisesW4}}{f_{ud}} = 0.39$$

Weld 5 End plates - Beam web

Weld 5 takes craft couple from F_{ly}



$h_c = 450\cdot mm$ $h_{HE800B} = 800\cdot mm$ $l = 800\cdot mm$

Moment equilibrium around point c:

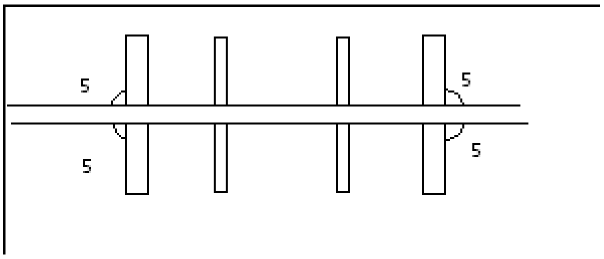
$$F_{ly5}\cdot l - F_{ly}\cdot(h_{HE800B} + h_c) = 0$$

$$F_{ly5} := \frac{F_{ly}\cdot(h_{HE800B} + h_c)}{l} = 306.469\,kN$$

Similar weld as for weld 2: $b_{w5} := b_{w2} = 4\cdot mm$ fillet weld $a_5 := a_2 = 2.828\,mm$

Length of weld (Flange height): $l_{w5} := h_{HE800B} - 2\cdot 30mm - 2\cdot 33mm = 674\cdot mm$

One weld on each end plate on each side of the beam web to provide better access



Section horizontal through the HE800B web showing placing of weld 5

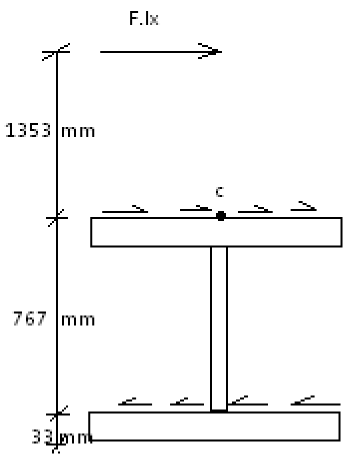
$$\tau_{pa5} := \frac{F_{ly5}}{2a_5 \cdot l_{w5}} = 80.381\text{MPa}$$

$$\sigma_{MisesW5} := \sqrt{3 \cdot \tau_{pa5}^{\ 2}} = 139.223\text{MPa}$$

$$UF_{W5} := \frac{\sigma_{MisesW5}}{f_{ud}} = 0.307$$

Weld 6 End plate - Bottom flange

Force at weld 6 from F_{lx}



Moment around point C:

$$F_{lx6} 767\text{mm} - F_{lx} \cdot (1353\text{mm} + 767\text{mm}) = 0$$

$$F_{lx6} := \frac{F_{lx} \cdot (1353\text{mm} + 767\text{mm})}{767\text{mm}} = 619.582\text{kN}$$

Similar weld as for weld 3

Part pen weld and fillet weld $b_{w6} := b_{w3} = 15 \cdot \text{mm}$ $a_{nom6} := a_{nom3} = 19.213\,\text{mm}$

Length weld 6 $l_{bw6} := 300\text{mm} - 2 \cdot 30\text{mm} - 17.5\text{mm}$

$$\tau_{pa6} := \frac{F_{lx6}}{a_{nom3} \cdot l_{bw6}} = 144.934\text{MPa}$$

$$\sigma_{MisesW6} := \sqrt{3\left(\tau_{pa6}^{2}\right)} = 251.032\,MPa$$

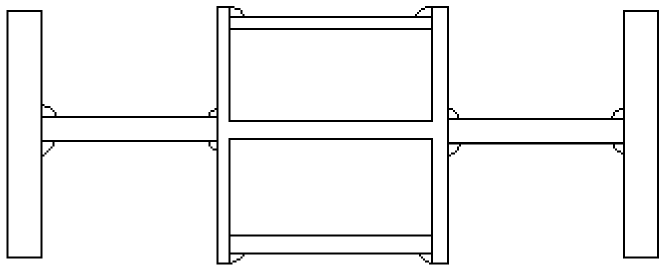
$$UF_{W6} := \frac{\sigma_{MisesW6}}{f_{ud}} = 0.554$$

Weld 7 Shear plate - End plate/BoxedHE300B

Width shear plate: $w_{Shearpl} := \frac{l - 300mm}{2} = 250 \cdot mm$

Thickness end plates: $t_{es} = 50 \cdot mm$

Length shear plate: $l_{Shearpl} := 1400mm$



Section through Boxed HE300B, shear plates and end plates.

Part pen weld and fillet weld $b_{w7} := b_{w1} = 10 \cdot mm$ $a_{nom7} := a_{nom1} = 12.142 \cdot mm$

Simplyfied method NS3472 12.6.2.1 b

$$I_{weld} := \frac{b_{w7} \cdot l_{Shearpl}^{3}}{2} \cdot 2$$

Moment $M_{Shearpl} := \frac{F}{2} \cdot \left(w_{Shearpl} + \frac{t_{es}}{2}\right) = 770.55\,kN \cdot m$

$$\sigma_m := \frac{M_{Shearpl}}{I_{weld}} \cdot \frac{l_{Shearpl}}{2} = 19.657\,MPa$$

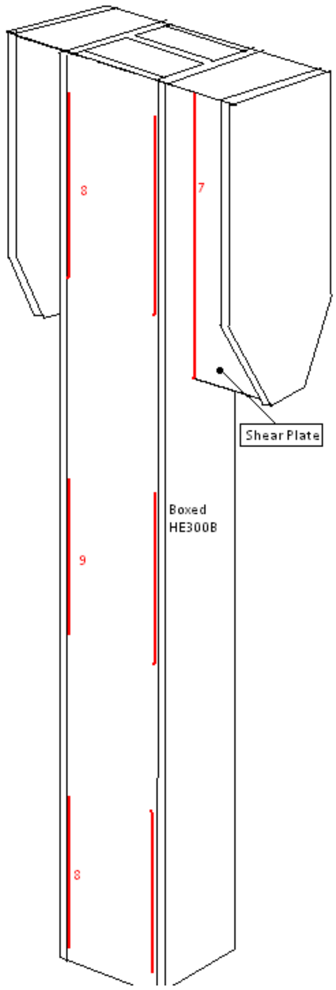
$$\tau := \frac{\frac{F}{2}}{2 \cdot l_{Shearpl} \cdot b_{w7}} = 100.071\,MPa$$

$f_u = 510\,MPa$ $\gamma_{m2} = 1.25$ $\beta_w = 0.9$

$$f_{wd} := \frac{f_u}{\gamma_{m2} \cdot \beta_w \cdot \sqrt{3}} = 261.732\,MPa$$

$$UF_{W7} := \frac{\sigma_m + \tau}{f_{wd}} = 0.457$$

Critical column boxed HE300B



Weld 8 HE300B - PL16 Column ends

$F = 5.604\,MN$

Properties HE300B

$t_f := 19mm$ $t_w := 11mm$ $h := 300mm$ $b := 300mm$

Reinforcement plates:

$t_{rpl} := 16mm$

Width reinforcement plate $w_{rpl} := h - 2\cdot t_f = 262\cdot mm$

Section area:

$A := t_f\cdot b\cdot 2 + t_w\cdot\left(h - 2\cdot t_f\right) + t_{rpl}\cdot w_{rpl} = 1.847\times 10^4\cdot mm^2$

stresses over the cross section proportional with the cross section area.

Forces to be transferred by weld 8 at upper part of the column:

Weld length: $l_{w8} := 1.0m$

Weld equal as weld 1 and 7.

Part pen weld and fillet weld $b_{w8} := b_{w1} = 10 \cdot mm$ $a_{nom8} := a_{nom1} = 12.142 \, mm$

Tension: $F = 5.604 \, MN$

$$F_{weld8} := \frac{\frac{F}{A} \cdot \left(2 \cdot t_{rpl} \cdot w_{rpl}\right)}{4} = 635.812 \, kN$$

Transferred as shear stress in weld

End moments

$M_{y8} := 9.178 \cdot 10^{-2} MN \cdot m$ $M_{z8} := 9.067 \cdot 10^{-2} MN \cdot m$

Craft couple at weld (conservative)

$arm := h - 2 \cdot t_f = 0.262m$

$F_{my} := \frac{M_{y8}}{arm} = 350.305 \, kN$ $F_{mz} := \frac{M_{z8}}{arm} = 346.069 \, kN$

$$\tau_{pa8} := \frac{F_{weld8} + F_{my} + F_{mz}}{a_{nom8} \cdot l_{w8}} = 109.716 \, MPa$$

$$\sigma_{Mises8} := 3 \cdot \sqrt{\tau_{pa8}^2} = 329.148 \, MPa$$

$$UF_{W8} := \frac{\sigma_{Mises8}}{f_{ud}} = 0.726$$

Weld 9 HE300B - PL16 Column mid part

Tension stresses from lift force is distributed over the HE300B flanges and reinforcement plates at the mid parts of the column. The mid part weld need to transfer forces from the moments at the column mid part.

Weld length: $l_{w9} := 700mm$

4 mm fillet weld $b_{w9} := 4mm$ $a_9 := \frac{b_{w9}}{\sqrt{2}} = 2.828\,mm$

Mid moments
Interpolated between 0.4 and 0.6 in Framework output.

$$M_{y9} := \left|\frac{[1.809 + (-1.876)]}{2}\right| \cdot 10^{-2} MN \cdot m = 0.335\,kN \cdot m$$

$$M_{z9} := \left|\frac{(5.130 + 3.161)}{2}\right| \cdot 10^{-2} MN \cdot m = 41.455\,kN \cdot m$$

craft couple at weld (conservative)

$$arm := h - 2 \cdot t_f = 0.262m$$

$$F_{my9} := \frac{M_{y9}}{arm} = 1.279kN \qquad F_{mz9} := \frac{M_{z9}}{arm} = 158.225kN$$

$$\tau_{pa9} := \frac{F_{my9} + F_{mz9}}{a_9 \cdot l_{w9}} = 80.562MPa$$

$$\sigma_{Mises9} := 3 \cdot \sqrt{\tau_{pa9}^2} = 241.685MPa$$

$$UF_{W9} := \frac{\sigma_{Mises9}}{f_{ud}} = 0.533$$

Summary

$UF_{W1} = 0.735$ $UF_{W2} = 0.155$ $UF_{W3} = 0.582$ $UF_{W4} = 0.39$

$UF_{W5} = 0.307$ $UF_{W6} = 0.554$ $UF_{W7} = 0.457$ $UF_{W8} = 0.726$

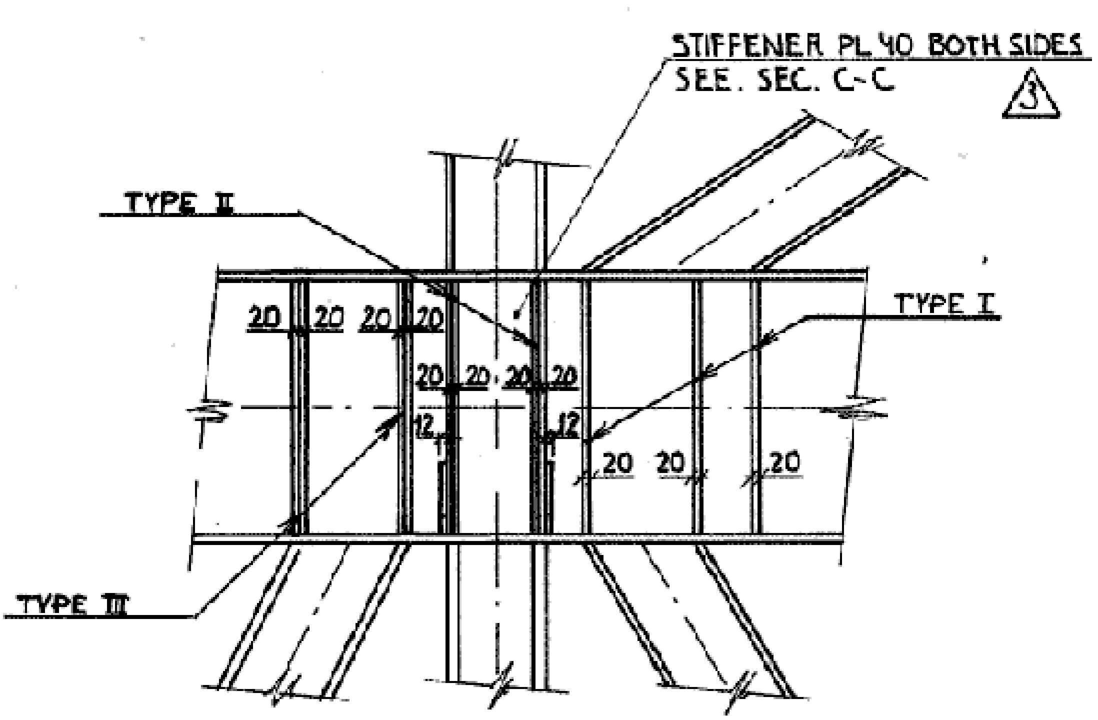
$UF_{W9} = 0.533$

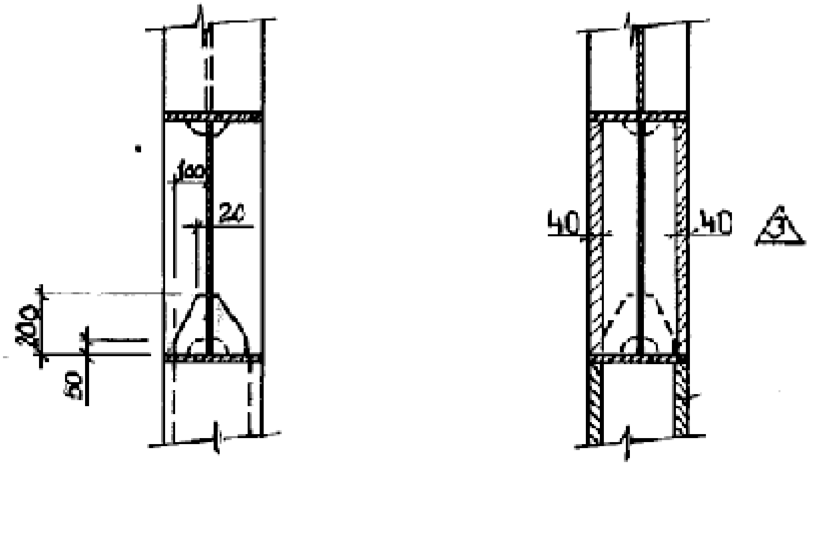
Weld nr.	Weld size		UF
	Part pen	Fillet	
1	10	10	0.73
2	0	4	0.15
3	15	15	0.58
4	10	10	0.39
5	4	4	0.31
6	15	15	0.55
7	10	10	0.46
8	10	10	0.73
9	0	4	0.53

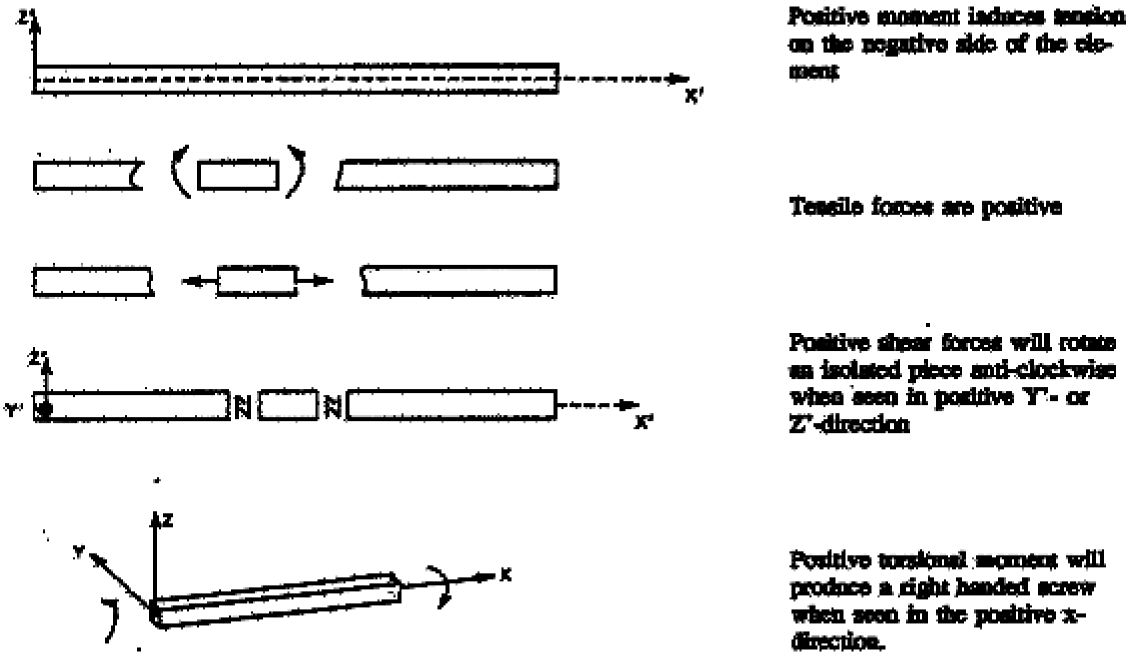
E. LOCAL ANALYSIS JOINTS

I. Critical joint J307031

Detail drawings of J307031







Framework output sign convention.

Member forces

Tab :=

Joint/Po D	Memb	PX	PY	PZ	MX	MY	MZ	
J307031	MZ307031	4,44E+00	-2,13E-02	4,32E-02	1,83E-03	9,67E-02	8,78E-02	
J307031	ME306010	1,72E+00	-2,95E-02	6,16E-04	-5,91E-08	-8,39E-03	-1,23E-02	
J307031	ME307031	-1,07E-01	2,96E-03	-1,03E-02	2,72E-05	-3,31E-02	-1,31E-02	
J307031	MF307031	1,06E+00	2,31E-02	-8,42E-04	-3,98E-06	-1,67E-02	-7,89E-03	
J307031	MY306031	-3,45E-01	-6,91E-04	1,71E-01	9,49E-05	-5,26E-01	-1,96E-03	
J307031	MY307031	-2,83E-03	1,32E-05	-8,22E-02	8,66E-05	-3,70E-01	-8,71E-05	
J307031	MZ307030	1,73E+00	-7,76E-02	5,54E-03	-5,09E-03	-1,73E-02	7,80E-02	

$PX_{MZ307031} := Tab_{0,0} \cdot MN$ $PY_{MZ307031} := Tab_{0,1} \cdot MN$ $PZ_{MZ307031} := Tab_{0,2} \cdot MN$

$MX_{MZ307031} := Tab_{0,3} \cdot MN \cdot m$ $MY_{MZ307031} := Tab_{0,4} \cdot MN \cdot m$ $MZ_{MZ307031} := Tab_{0,5} \cdot MN \cdot m$

$PX_{ME306010} := Tab_{1,0} \cdot MN$ $PY_{ME306010} := Tab_{1,1} \cdot MN$ $PZ_{ME306010} := Tab_{1,2} \cdot MN$

$MX_{ME306010} := Tab_{1,3} \cdot MN \cdot m$ $MY_{ME306010} := Tab_{1,4} \cdot MN \cdot m$ $MZ_{ME306010} := Tab_{1,5} \cdot MN \cdot m$

$PX_{ME307031} := Tab_{2,0} \cdot MN$ $PY_{ME307031} := Tab_{2,1} \cdot MN$ $PZ_{ME307031} := Tab_{2,2} \cdot MN$

$MX_{ME307031} := Tab_{2,3} \cdot MN \cdot m$ $MY_{ME307031} := Tab_{2,4} \cdot MN \cdot m$ $MZ_{ME307031} := Tab_{2,5} \cdot MN \cdot m$

$PX_{MF307031} := Tab_{3,0} \cdot MN$ $PY_{MF307031} := Tab_{3,1} \cdot MN$ $PZ_{MF307031} := Tab_{3,2} \cdot MN$

$MX_{MF307031} := Tab_{3,3} \cdot MN \cdot m$ $MY_{MF307031} := Tab_{3,4} \cdot MN \cdot m$ $MZ_{MF307031} := Tab_{3,5} \cdot MN \cdot m$

$PX_{MY306031} := Tab_{4,0} \cdot MN$ $PY_{MY306031} := Tab_{4,1} \cdot MN$ $PZ_{MY306031} := Tab_{4,2} \cdot MN$

$MX_{MY306031} := Tab_{4,3} \cdot MN \cdot m$ $MY_{MY306031} := Tab_{4,4} \cdot MN \cdot m$ $MZ_{MY306031} := Tab_{4,5} \cdot MN \cdot m$

$PX_{MY307031} := Tab_{5,0} \cdot MN$ $PY_{MY307031} := Tab_{5,1} \cdot MN$ $PZ_{MY307031} := Tab_{5,2} \cdot MN$

$MX_{MY307031} := Tab_{5,3} \cdot MN \cdot m$ $MY_{MY307031} := Tab_{5,4} \cdot MN \cdot m$ $MZ_{MY307031} := Tab_{5,5} \cdot MN \cdot m$

$PX_{MZ107030} := Tab_{6,0} \cdot MN$ $PY_{MZ107030} := Tab_{6,1} \cdot MN$ $PZ_{MZ107030} := Tab_{6,2} \cdot MN$

$MX_{MZ107030} := Tab_{6,3} \cdot MN \cdot m$ $MY_{MZ107030} := Tab_{6,4} \cdot MN \cdot m$ $MZ_{MZ107030} := Tab_{6,5} \cdot MN \cdot m$

Member Properties

Bxed HE300B

$W_{eyBHE300B} := 1.932 \cdot 10^{6} mm^{3}$ $W_{ezBHE300B} := 1.545 \cdot 10^{6} mm^{3}$

$b_{BHE300B} := 300mm$ $h_{BHE300B} := 300mm$

$t_{fBHE300B} := 19mm$ $t_{wBHE300B} := 11mm$

reinf
orcementplate: $t_{wrBHE300B} := 16mm$

HE300B

$W_{eyHE300B} := 1.932 \cdot 10^{6} mm^{3}$ $W_{ezHE300B} := 1.545 \cdot 10^{6} mm^{3}$

$b_{HE300B} := 300mm$ $h_{HE300B} := 300mm$

$t_{fHE300B} := 19mm$ $t_{wHE300B} := 11mm$

HE800B

$W_{eyHE800B} := 8.98 \cdot 10^{6} mm^{3}$ $W_{ezHE800B} := 9.94 \cdot 10^{5} mm^{3}$

$b_{HE800B} := 300mm$ $h_{HE800B} := 800mm$

$t_{fHE800B} := 33mm$ $t_{wHE800B} := 17.5mm$

BOX300

$W_{eyBOX300} := 2.472 \cdot 10^{6} mm^{3}$ $W_{ezBOX300} := 1.963 \cdot 10^{5} mm^{3}$

$b_{BOX300} := 220mm$ $h_{BOX300} := 300mm$

$t_{fBOX300} := 40mm$ $t_{wBOX300} := 40mm$

Joint check performed according to Eurocode 3, Design of joints (BS EN 1993-1-8)

Brace check MZ307031

$f_y := 355MPa \quad \gamma_{M5} := 1.1$

stiffener plate in HE800B web connected to MZ307031 $t_s := 40mm$

$$b_{eff} := \min\left[\left(t_{wHE800B} + 8\cdot t_{fHE800B}\right), b_{BHE300B} + \left(h_{BHE300B} - 2\cdot t_{fBHE300B}\right)\right] = 0.282\,m$$

$$b_{effs} := \min\left[\left(2t_s + 7\cdot t_{fHE800B}\right), b_{BHE300B} + \left(h_{BHE300B} - 2\cdot t_{fBHE300B}\right)\right] = 0.311\,m$$

$$p_{eff} := \min\left[b_{eff} + b_{effs}, b_{BHE300B} + \left(h_{BHE300B} - 2\cdot t_{fBHE300B}\right)\right] = 0.562\,m$$

Axial force

$$N_{bdMZ307031} := \frac{2\cdot f_y\cdot t_{fBHE300B}\cdot p_{eff}}{\gamma_{M5}} = 6.892\cdot MN$$

$$UF_{N1MZ307031} := \frac{PX_{MZ307031}}{N_{bdMZ307031}} = 0.644$$

Moment

$$MY_{d1MZ307031} := \frac{f_y\cdot t_{fBHE300B}\cdot p_{eff}\cdot\left(h_{BHE300B} - t_{fBHE300B}\right)}{\gamma_{M5}} = 968.349\cdot kN\cdot m$$

$$MZ_{d1MZ307031} := \frac{f_y\cdot t_{wBHE300B}\cdot p_{eff}\cdot\left(b_{BHE300B} - t_{wBHE300B}\right)}{\gamma_{M5}} = 576.584\cdot kN\cdot m$$

$$UF_{M1MZ307031} := \frac{\left|MY_{MZ307031}\right|}{MY_{d1MZ307031}} + \frac{\left|MZ_{MZ307031}\right|}{MZ_{d1MZ307031}} = 0.252$$

$$UF_{1MZ307031} := UF_{M1MZ307031} + UF_{N1MZ307031} = 0.896$$

Chord web check MZ307031:

Stiffener plates placed in line with BHE300B web e.g. full stress transfer through BHE300web and reinforcementplates:

radius cut away in stiffener perpendicular to HE800Bweb plates: $r_s := 45mm$

Effective length stiffener plates perpendicular toHE300Bweb:
$l_{pe} := b_{HE800B} - t_{wHE800B} - 2 \cdot r_s = 192.5mm$

Stiffener plates parallell to HE800B web:

$l_{pa} := b_{BHE300B} = 300 \cdot mm$

Effective web length:

$b_w := h_{BHE300B} + 5 \cdot t_{fHE800B}$

$$N_{cdMZ307031} := \frac{f_y \cdot \left[t_{wHE800B} \cdot b_w + t_s \cdot \left(l_{pe} + l_{pa}\right) \cdot 2\right]}{\sin(90deg) \cdot \gamma_{M5}} = 15.342 \cdot MN$$

$$UF_{N2MZ307031} := \frac{PX_{MZ307031}}{N_{cdMZ307031}} = 0.289$$

Moment

$$MY_{d2MZ307031} := 0.5 \cdot f_y \cdot \left(t_{wHE800B} + 2 \cdot l_{pa}\right) \cdot b_w \cdot h_{BHE300B} = 1.529 \times 10^4 \cdot kN \cdot m$$

$$MZ_{d2MZ307031} := 0.5 \cdot f_y \cdot b_{BHE300B} \cdot t_s \cdot b_{HE800B} = 639 \cdot kN \cdot m$$

$$UF_{M2MZ307031} := \frac{\left|MY_{MZ307031}\right|}{MY_{d2MZ307031}} + \frac{\left|MZ_{MZ307031}\right|}{MZ_{d2MZ307031}} = 0.144$$

Shear check:

$$A_{vHE800B} := h_{HE800B} \cdot \left(t_{fHE800B} + 2 \cdot t_s\right) = 9.04 \times 10^4 \cdot mm^2$$

$$N_{vdMZ307031} := \frac{f_y \cdot A_{vHE800B}}{\sqrt{3} \cdot \sin(90deg) \cdot \gamma_{M5}} = 1.684 \times 10^4 \, kN$$

$$UF_{VMZ307031} := \frac{PX_{MZ307031}}{N_{vdMZ307031}} = 0.264$$

Conservative $UF_{2MZ307031} := UF_{N2MZ307031} + UF_{M2MZ307031} + UF_{VMZ307031} = 0.697$

Brace ME307031

$\theta := \operatorname{atan}\left(\frac{4.5}{6.5}\right) = 34.695 \cdot deg$

stiffener plate in HE800B web connected to MZ307031 $t_s := 20mm$

$b_{eff} := \min\left[\left(t_{wHE800B} + 8 \cdot t_{fHE800B}\right), b_{HE300B} + \left(h_{HE300B} - 2 \cdot t_{fHE300B}\right)\right] = 0.282\,m$

$b_{effs} := 0 = 0$

$p_{eff} := \min\left[b_{eff} + b_{effs}, b_{BHE300B} + \left(h_{BHE300B} - 2 \cdot t_{fBHE300B}\right)\right] = 0.282\,m$

Axial force

$N_{bdME307031} := \frac{2 \cdot f_y \cdot t_{fHE300B} \cdot p_{eff}}{\gamma_{M5}} = 3.452 \cdot MN$

$UF_{N1ME307031} := \frac{\left|PX_{ME307031}\right|}{N_{bdMZ307031}} = 0.016$

Moment

$MY_{d1ME307031} := \frac{f_y \cdot t_{fHE300B} \cdot p_{eff} \cdot \left(h_{HE300B} - t_{fHE300B}\right)}{\gamma_{M5}} = 485.036 \cdot kN \cdot m$

$MZ_{d1ME307031} := \frac{f_y \cdot t_{wHE300B} \cdot p_{eff} \cdot \left(b_{HE300B} - t_{wHE300B}\right)}{\gamma_{M5}} = 288.805 \cdot kN \cdot m$

$UF_{M1ME307031} := \frac{\left|MY_{ME307031}\right|}{MY_{d1ME307031}} + \frac{\left|MZ_{ME307031}\right|}{MZ_{d1ME307031}} = 0.114$

$UF_{1ME307031} := UF_{M1ME307031} + UF_{N1ME307031} = 0.129$

Chord web check ME307031:

Stiffener plates placed in line with HE300B web e.g. full stress transfer through HE300B web

radius cut away in stiffener perpendicular to HE800Bweb plates: $r_s := 45mm$

Effective length stiffener plates perpendicular toHE300Bweb:
$l_{pe} := b_{HE800B} - t_{wHE800B} - 2 \cdot r_s = 192.5\,mm$

Effective web length:

$b_w := b_{HE300B} + 5 \cdot t_{fHE800B}$

$$N_{cdME307031} := \frac{f_y \cdot \left[t_{wHE800B} \cdot b_w + t_s \cdot \left(l_{pe}\right) \cdot 2\right]}{\sin(\theta) \cdot \gamma_{M5}} = 8.979 \cdot MN$$

$$UF_{N2ME307031} := \frac{\left|PX_{ME307031}\right|}{N_{cdME307031}} = 0.012$$

Moment

$$MY_{d2ME307031} := 0.5 \cdot f_y \cdot \left(t_{wHE800B} + 2 \cdot l_{pa}\right) \cdot b_w \cdot h_{HE300B} = 1.529 \times 10^4 \cdot kN \cdot m$$

$$MZ_{d2ME307031} := 0.5 \cdot f_y \cdot b_{HE300B} \cdot t_s \cdot b_{HE800B} = 319.5 \cdot kN \cdot m$$

$$UF_{M2ME307031} := \frac{\left|MY_{ME307031}\right|}{MY_{d2ME307031}} + \frac{\left|MZ_{ME307031}\right|}{MZ_{d2ME307031}} = 0.043$$

Shear check:

$$A_{vHE800B} := h_{HE800B} \cdot \left(t_{fHE800B}\right) = 2.64 \times 10^4 \cdot mm^2$$

$$N_{vdME307031} := \frac{f_y \cdot A_{vHE800B}}{\sqrt{3} \cdot \sin(\theta) \cdot \gamma_{M5}} = 8.642 \times 10^3\,kN$$

$$UF_{VME307031} := \frac{\left|PX_{ME307031}\right|}{N_{vdME307031}} = 0.012$$

Conservative $UF_{2ME307031} := UF_{N2ME307031} + UF_{M2ME307031} + UF_{VME307031} = 0.068$

Lower side of J307031

$\theta := \operatorname{atan}\left(\frac{10.3m}{6m}\right) = 59.778 \cdot deg$

Gap calculation.
From detail drawing;
centre lines of brace ME306010, MZ107030 and MF307031 meet at the top of the HE800B beam.

section width HE300B:

$s_{wHE300B} := \frac{h_{HE300B}}{\sin(\theta)} = 347.189 \cdot mm$

Width between ME306010 and MF307031 at bottom of HE800B beam:

$\frac{h_{HE800B}}{\tan(\theta)} \cdot 2 = 932.039 \cdot mm$

$gap := \frac{\frac{h_{HE800B}}{\tan(\theta)} \cdot 2 - s_{wHE300B} - b_{BOX300}}{2} = 182.425 \cdot mm$

Large gap forces from ME306010 and 307031 do not influence on eachother.

Brace ME306010

stiffener plate in HE800B web connected to ME306010 $t_s := 40mm$

$b_{eff} := \min\left[\left(t_{wHE800B} + 8 \cdot t_{fHE800B}\right), b_{HE300B} + \left(h_{HE300B} - 2 \cdot t_{fHE300B}\right)\right] = 0.282\,m$

$p_{eff} := \min\left[b_{eff}, b_{BHE300B} + \left(h_{BHE300B} - 2 \cdot t_{fBHE300B}\right)\right] = 0.282\,m$

Axial force

$N_{bdME306010} := \frac{2 \cdot f_y \cdot t_{fHE300B} \cdot p_{eff}}{\gamma_{M5}} = 3.452 \cdot MN$

$UF_{N1ME306010} := \frac{\left|PX_{ME306010}\right|}{N_{bdME306010}} = 0.498$

Moment

$$MY_{d1ME306010} := \frac{f_y \cdot t_{fHE300B} \cdot p_{eff} \cdot (h_{HE300B} - t_{fHE300B})}{\gamma_{M5}} = 485.036 \cdot kN \cdot m$$

$$MZ_{d1ME306010} := \frac{f_y \cdot t_{wHE300B} \cdot p_{eff} \cdot (b_{HE300B} - t_{wHE300B})}{\gamma_{M5}} = 288.805 \cdot kN \cdot m$$

$$UF_{M1ME306010} := \frac{|MY_{ME306010}|}{MY_{d1ME306010}} + \frac{|MZ_{ME306010}|}{MZ_{d1ME306010}} = 0.06$$

$$UF_{1ME306010} := UF_{M1ME306010} + UF_{N1ME306010} = 0.558$$

Chord web check ME306010:

Stiffener plates placed in line with HE300B web e.g. full stress transfer through HE300B web

radius cut away in stiffener perpendicular to HE800Bweb plates: $r_s := 45mm$

Effective length stiffener plates perpendicular toHE300Bweb:
$l_{pe} := b_{HE800B} - t_{wHE800B} - 2 \cdot r_s = 192.5mm$

Effective web length:

$$b_w := b_{HE300B} + 5 \cdot t_{fHE800B}$$

$$N_{cdME306010} := \frac{f_y \cdot [t_{wHE800B} \cdot b_w + t_s \cdot (l_{pe}) \cdot 2]}{\sin(\theta) \cdot \gamma_{M5}} = 8.791 \cdot MN$$

$$UF_{N2ME306010} := \frac{|PX_{ME306010}|}{N_{cdME306010}} = 0.195$$

Moment

$$MY_{d2ME306010} := 0.5 \cdot f_y \cdot (t_{wHE800B} + 2 \cdot l_{pa}) \cdot b_w \cdot h_{HE300B} = 1.529 \times 10^4 \cdot kN \cdot m$$

$$MZ_{d2ME306010} := 0.5 \cdot f_y \cdot b_{HE300B} \cdot t_s \cdot b_{HE800B} = 639 \cdot kN \cdot m$$

$$UF_{M2ME306010} := \frac{|MY_{ME306010}|}{MY_{d2ME307031}} + \frac{|MZ_{ME306010}|}{MZ_{d2ME306010}} = 0.02$$

Shear check:

$$A_{vHE800B} := h_{HE800B} \cdot (t_{fHE800B}) = 2.64 \times 10^4 \cdot mm^2$$

$$N_{vdME306010} := \frac{f_y \cdot A_{vHE800B}}{\sqrt{3} \cdot \sin(\theta) \cdot \gamma_{M5}} = 5.693 \times 10^3 \, kN$$

$$UF_{VME306010} := \frac{|PX_{ME306010}|}{N_{vdME306010}} = 0.302$$

Conservative $UF_{2ME306010} := UF_{N2ME306010} + UF_{M2ME306010} + UF_{VME306010} = 0.517$

Brace MF307031

$\theta = 59.778 \cdot deg$

stiffener plate in HE800B web connected to ME306010 $t_s := 20mm$

$$b_{eff} := \min\left[\left(t_{wHE800B} + 8 \cdot t_{fHE800B}\right), b_{HE300B} + \left(h_{HE300B} - 2 \cdot t_{fHE300B}\right)\right] = 0.282 \, m$$

$$p_{eff} := \min\left[b_{eff}, b_{BHE300B} + \left(h_{BHE300B} - 2 \cdot t_{fBHE300B}\right)\right] = 0.282 \, m$$

Axial force

$$N_{bdMF307031} := \frac{2 \cdot f_y \cdot t_{fHE300B} \cdot p_{eff}}{\gamma_{M5}} = 3.452 \cdot MN$$

$$UF_{N1MF307031} := \frac{|PX_{MF307031}|}{N_{bdMF307031}} = 0.308$$

Moment

$$MY_{d1MF307031} := \frac{f_y \cdot t_{fHE300B} \cdot p_{eff} \cdot \left(h_{HE300B} - t_{fHE300B}\right)}{\gamma_{M5}} = 485.036 \cdot kN \cdot m$$

$$MZ_{d1MF307031} := \frac{f_y \cdot t_{wHE300B} \cdot p_{eff} \cdot \left(b_{HE300B} - t_{wHE300B}\right)}{\gamma_{M5}} = 288.805 \cdot kN \cdot m$$

$$UF_{M1MF307031} := \frac{|MY_{MF307031}|}{MY_{d1MF307031}} + \frac{|MZ_{MF307031}|}{MZ_{d1MF307031}} = 0.062$$

$$UF_{1MF307031} := UF_{M1MF307031} + UF_{N1MF307031} = 0.369$$

Amund Lundqvist

Chord web check MF307031:

Stiffener plates placed in line with HE300B web e.g. full stress transfer through HE300B web

radius cut away in stiffener perpendicular to HE800Bweb plates: $r_s := 45mm$

Effective length stiffener plates perpendicular toHE300Bweb:
$l_{pe} := b_{HE800B} - t_{wHE800B} - 2 \cdot r_s = 192.5\,mm$

Effective web length:

$b_w := b_{HE300B} + 5 \cdot t_{fHE800B}$

$$N_{cdMF307031} := \frac{f_y \cdot \left[t_{wHE800B} \cdot b_w + t_s \cdot (l_{pe}) \cdot 2\right]}{\sin(\theta) \cdot \gamma_{M5}} = 5.915 \cdot MN$$

$$UF_{N2MF307031} := \frac{\left|PX_{MF307031}\right|}{N_{cdMF307031}} = 0.18$$

Moment

$$MY_{d2MF307031} := 0.5 \cdot f_y \cdot (t_{wHE800B} + 2 \cdot l_{pa}) \cdot b_w \cdot h_{HE300B} = 1.529 \times 10^4 \cdot kN \cdot m$$

$$MZ_{d2MF307031} := 0.5 \cdot f_y \cdot b_{HE300B} \cdot t_s \cdot b_{HE800B} = 319.5 \cdot kN \cdot m$$

$$UF_{M2MF307031} := \frac{\left|MY_{MF307031}\right|}{MY_{d2MF307031}} + \frac{\left|MZ_{MF307031}\right|}{MZ_{d2MF307031}} = 0.026$$

Shear check:

$$A_{vHE800B} := h_{HE800B} \cdot (t_{fHE800B}) = 2.64 \times 10^4 \cdot mm^2$$

$$N_{vdMF307031} := \frac{f_y \cdot A_{vHE800B}}{\sqrt{3} \cdot \sin(\theta) \cdot \gamma_{M5}} = 5.693 \times 10^3\,kN$$

$$UF_{VMF307031} := \frac{\left|PX_{MF307031}\right|}{N_{vdMF307031}} = 0.187$$

Conservative $UF_{2MF307031} := UF_{N2MF307031} + UF_{M2MF307031} + UF_{VMF307031} = 0.392$

Brace check MZ107030

Stiffener plate in HE800B web connected to MZ307031 $t_s := 40mm$

$$b_{eff} := \min\left[\left(t_{wHE800B} + 8 \cdot t_{fHE800B}\right), b_{BHE300B} + \left(h_{BHE300B} - 2 \cdot t_{fBHE300B}\right)\right] = 0.282\,m$$

$$b_{effs} := \min\left[\left(2t_s + 7 \cdot t_{fHE800B}\right), b_{BHE300B} + \left(h_{BHE300B} - 2 \cdot t_{fBHE300B}\right)\right] = 0.311\,m$$

$$p_{eff} := \min\left[b_{eff} + b_{effs}, b_{BHE300B} + \left(h_{BHE300B} - 2 \cdot t_{fBHE300B}\right)\right] = 0.562\,m$$

Axial force

$$N_{bdMZ107030} := \frac{2 \cdot f_y \cdot t_{fBOX300} \cdot p_{eff}}{\gamma_{M5}} = 14.51 \cdot MN$$

$$UF_{N1MZ107030} := \frac{PX_{MZ107030}}{N_{bdMZ107030}} = 0.12$$

Moment

$$MY_{d1MZ107030} := \frac{f_y \cdot t_{fBOX300} \cdot p_{eff} \cdot \left(h_{BOX300} - t_{fBOX300}\right)}{\gamma_{M5}} = 1.886 \times 10^3 \cdot kN \cdot m$$

$$MZ_{d1MZ107030} := \frac{f_y \cdot t_{wBOX300} \cdot p_{eff} \cdot \left(b_{BOX300} - t_{wBOX300}\right)}{\gamma_{M5}} = 1.306 \times 10^3 \cdot kN \cdot m$$

$$UF_{M1MZ107030} := \frac{\left|MY_{MZ107030}\right|}{MY_{d1MZ107030}} + \frac{\left|MZ_{MZ107030}\right|}{MZ_{d1MZ107030}} = 0.069$$

$$UF_{1MZ107030} := UF_{M1MZ107030} + UF_{N1MZ107030} = 0.188$$

Chord web check MZ307031:

Stiffener plates placed in line with BOX300 web e.g. full stress transfer through BHE300web and reinforcement plates:

radius cut away in stiffener perpendicular to HE800Bweb plates: $r_s := 45mm$

Effective length stiffener plates perpendicular toHE300Bweb:
$l_{pe} := b_{HE800B} - t_{wHE800B} - 2 \cdot r_s = 192.5mm$

Stiffener plates parallel to HE800B web:

$l_{pa} := b_{BHE300B} = 300 \cdot mm$

Effective web length:

$b_w := h_{BHE300B} + 5 \cdot t_{fHE800B}$

$$N_{cdMZ107030} := \frac{f_y \cdot \left[t_{wHE800B} \cdot b_w + t_s \cdot \left(l_{pe} + l_{pa}\right) \cdot 2\right]}{\sin(90deg) \cdot \gamma_{M5}} = 15.342 \cdot MN$$

$$UF_{N2MZ107030} := \frac{PX_{MZ107030}}{N_{cdMZ107030}} = 0.113$$

Moment

$$MY_{d2MZ107030} := 0.5 \cdot f_y \cdot \left(t_{wHE800B} + 2 \cdot l_{pa}\right) \cdot b_w \cdot h_{BOX300} = 1.529 \times 10^4 \cdot kN \cdot m$$

$$MZ_{d2MZ107030} := 0.5 \cdot f_y \cdot b_{BOX300} \cdot t_s \cdot b_{HE800B} = 468.6 \cdot kN \cdot m$$

$$UF_{M2MZ107030} := \frac{\left|MY_{MZ107030}\right|}{MY_{d2MZ107030}} + \frac{\left|MZ_{MZ107030}\right|}{MZ_{d2MZ107030}} = 0.167$$

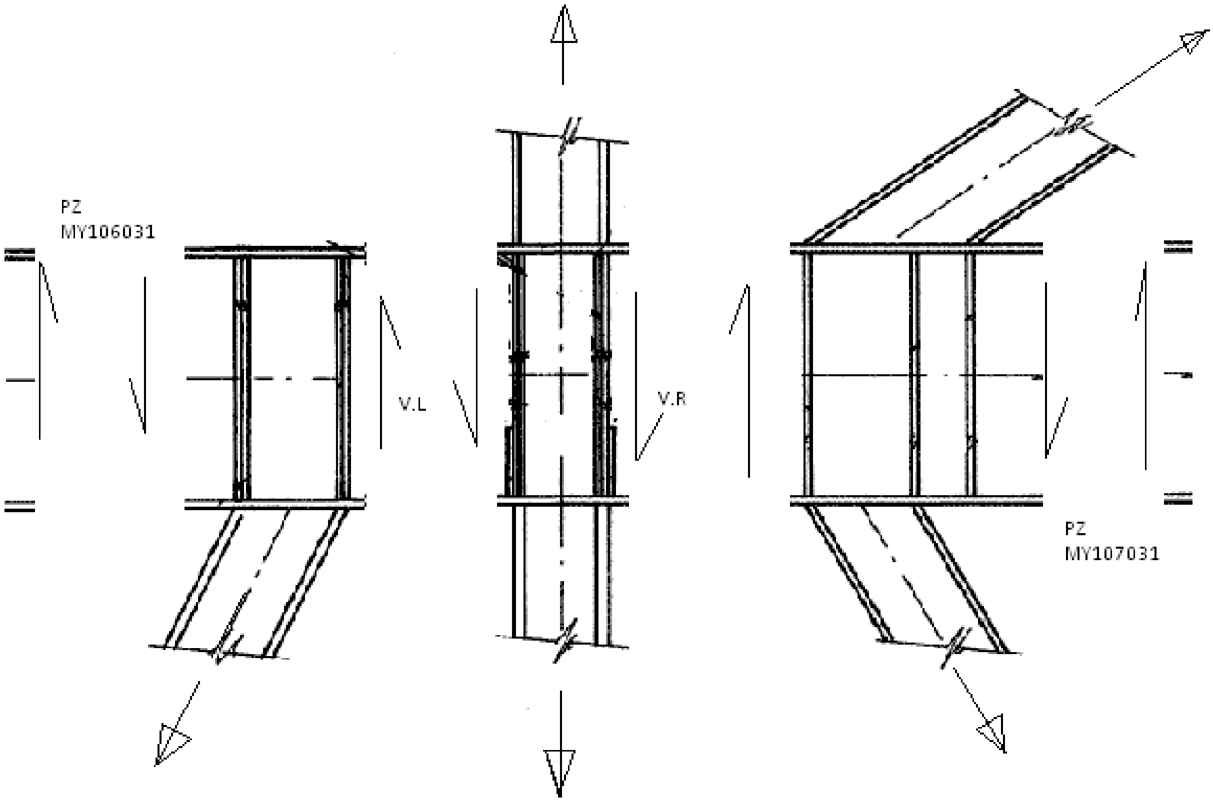
Shear check:

$$A_{vHE800B} := h_{HE800B} \cdot \left(t_{fHE800B} + 2 \cdot t_s\right) = 9.04 \times 10^4 \cdot mm^2$$

$$N_{vdMZ107030} := \frac{f_y \cdot A_{vHE800B}}{\sqrt{3} \cdot \sin(90deg) \cdot \gamma_{M5}} = 1.684 \times 10^4 kN$$

$$UF_{VMZ107030} := \frac{PX_{MZ107030}}{N_{vdMZ107030}} = 0.103$$

Conservative $UF_{2MZ107030} := UF_{N2MZ107030} + UF_{M2MZ107030} + UF_{VMZ10703}$



Neglect moment arms.

Angle between HE800B beam and ME306010 $\theta_1 := \operatorname{atan}\left(\frac{10.305m}{6.0m}\right) = 59.79\,deg$

Angle between HE800B beam and MEMF307031 $\theta_2 := \operatorname{atan}\left(\frac{10.305m}{6.5m}\right) = 57.76\,deg$

Angle between HE800B beam and ME307031 $\theta_3 := \operatorname{atan}\left(\frac{4.5m}{6.5m}\right) = 34.7\cdot deg$

$$A_{vHE800B} := h_{HE800B} \cdot \left(t_{fHE800B}\right) = 2.64 \times 10^4 \cdot mm^2$$

Design force: $V_d := \frac{f_y \cdot A_{vHE800B}}{\sqrt{3} \cdot \gamma_{M5}} = 4.919 \times 10^3\,kN$

Sign convention used from drawing above, and according to Framework Theory manual 3.3 abs. value added to the Framevork output results.

Distance from joint midpoint to mid gap: $l_{gap} := \frac{gap}{2} + \frac{b_{HE300B}}{2} = 241.212mm$

Member MY306031

Shear force in z - direction: $PZ_{MY306031} = 171kN$

Shear force at left side of J307031 - V_L

Sum of forces in z - direction:

$$-\left|PZ_{MY306031}\right| - \left|PX_{ME306010}\right| \cdot \sin(\theta_1) + V_L = 0$$

$$V_L := \left|PX_{ME306010}\right| \cdot \sin(\theta_1) + \left|PZ_{MY306031}\right| = 1.656 \times 10^3 \, kN$$

$$UF_{VL} := \frac{V_L}{V_d} = 0.337$$

Member MY307031

Shear force in z -direction: $PZ_{MY307031} = -82.19kN$ (downwards)

Sum of forces in z direction:

$$-\left|PX_{MF307031}\right| \cdot \sin(\theta_2) - \left|PZ_{MY307031}\right| - \left|PX_{ME307031}\right| \cdot \sin(\theta_3) + V_R = 0$$

$$V_R := \left|PZ_{MY307031}\right| + \left|PX_{MF307031}\right| \cdot \sin(\theta_2) + \left|PX_{ME307031}\right| \cdot \sin(\theta_3) = 1.041 \times 10^3 \, kN$$

$PZ_{MY307031} = -82.19 \, kN$ $PX_{ME307031} \cdot \sin(\theta_2) = -90.501 \, kN$ $PX_{MF307031} \cdot \sin(\theta_3) = 604.501 \, kN$

$$UF_{VR} := \frac{V_R}{V_d} = 0.212$$

Summation of forces in mid-part of J307031:

$$PX_{MZ307031} - PX_{MZ107030} - V_L - V_R = 8.987 \, kN$$

Rest forces due to FEA, and neglecting contribution from shear force in ME307031, MF307031 and ME306010
From the results and $UF_{VL} = 0.337$ the shear utilization of the HE800B web is small, so the simplification made above has no effect on the final result.

Summary code check Eurocode:

Member	UF Brace	UF Chord
MZ307031	0.90	0.70
ME307031	0.13	0.07
ME306010	0.56	0.52
MF307031	0.37	0.39
MZ307030	0.19	0.38

Summary shear check in gap:

Member	Shear Force	UF shear
	[kN]	
MY306031	1041.34	0.21
MY307031	1655.68	0.34

Amund Lundqvist

F. OFFSHORE PREPARATIONS

I. Reinforcement check upper deck

Check for reinforcement need during padeye installation

$\gamma_m := 1.15$ $f_y := 355MPa$ $f_d := \frac{f_y}{\gamma_m} = 308.696MPa$

Section properties

$h := 800mm$ $t_f := 33mm$ $t_w := 17.5mm$ $r := 30mm$

Section class HE800B web

$$\varepsilon := \sqrt{\frac{235MPa}{355MPa}} = 0.814$$

$$d := h - 2 \cdot t_f - 2 \cdot r = 674 \cdot mm$$

$\frac{d}{t_w \cdot \varepsilon} = 47.337$ < 72ε section class 1.

Cut away for pad eye installation implies that the web of the HE800B section have to take all the forces in the beam end.

Moment capacity of HE800B web:

$$W_p := \frac{t_w \cdot h^2}{4} = 2.8 \times 10^6 \cdot mm^3$$

ULS - a governing load case.

$$M_d := W_p \cdot f_d = 864.348 kN \cdot m$$

Design resistance Md=		864347,8261	
Beam	Joint	Moment [kNm]	UF
MY103040	J104040	273	0,00
MY104040	J104040	309	0,00
MY303040	J304040	281	0,00
MY304040	J304040	319	0,00
MY106140	J107040	607	0,00
MY107040	J107040	550	0,00
MY306140	J307040	664	0,00
MY307040	J307040	604	0,00

No UF above 1.0, no temporary reinforcements have to be installed.

G. FRAMEWORK RESULTS SESAM ANALYSIS

```
1

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




                 *********************************************
                 *                                           *
                 *            F R A M E W O R K              *
                 *                                           *
                 *    Postprocessing of Frame Structures     *
                 *                                           *
                 *********************************************


                     Marketing and Support by DNV Software


  Program id   : 3.4-04                 Computer         : 586
  Release date : 31-JAN-2007            Impl. update     :
  Access time  : 28-MAY-2009 12:49:41   Operating system : Win NT 5.1 [2600]
  User id      : 176198                 CPU id           : 1966439629
                                        Installation     : , AKBPW81570
```

```
 28-MAY-2009 12:49 PROGRAM: SESAM    FRAMEWORK 3.4-04  31-JAN-2007  PAGE:
1


                   MEMBER check: EC3/NS3472 ENV 1993-1-1/Ed 3
                   Run:      Superelement:     Loadset:
                   TRN       T1                LOAD
                   Priority....: Worst Loadcase
                   Usage factor: Above   0.80                    SUB PAGE:
1



 NOMENCLATURE:

 Member      Name of member
 LoadCase    Name of loadcase
 CND         Operational, storm or earthquake condition
 Type        Section type
 Joint/Po    Joint name or position within the member
 Outcome     Outcome message from the code check
 UsfTot      Total usage factor: UsfTot = UsfAx + UsfMy + UsfMz
 UsfAx       Usage factor due to axial stress
 Phase       Phase angle in degrees
 SctNam      Section name
 EleNum      Element number
 UsfMy       Usage factor due to bending about y-axis
 UsfMz       Usage factor due to bending about z-axis

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2


                   MEMBER check: EC3/NS3472 ENV 1993-1-1/Ed 3
                   Run:      Superelement:     Loadset:
                   TRN       T1                LOAD
                   Priority....: Worst Loadcase
                   Usage factor: Above   0.80                    SUB PAGE:
2

 Member   LoadCase CND Type     Joint/Po Outcome  UsfTot   UsfAx
           Phase       SctNam   EleNum                     UsfMy
                                                           UsfMz
 ----------------------------------------------------------------
 MY104010 43           I        0.40         Stab   0.978   0.269
                       I1210    1612                        0.648
                                                            0.061

 MZ307010 33           BOX      0.50         StaL   0.960   0.544
                       BOX300   2536                        0.065
                                                            0.351

 MF305031 37           I        0.50         StaL   0.921   0.853
                       HE300B   2467                        0.039
                                                            0.029

 MY306010 35           I        0.50         Stab   0.892   0.290
                       I1210    2517                        0.567
                                                            0.035

 MF107031 34           I        0.46         StaL   0.868   0.580
                       HE300B   1795                        0.181
                                                            0.106
```

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 28-MAY-2009 12:49 PROGRAM: SESAM    FRAMEWORK 3.4-04  31-JAN-2007  PAGE:
3

                   MEMBER check: EC3/NS3472 ENV 1993-1-1/Ed 3
                   Run:      Superelement:     Loadset:
                   CRIT115   T1                LOAD
                   Priority....: Selected Members and Loadcases
                   Usage factor: Above   0.60                   SUB PAGE:
1

  28-MAY-2009 12:49 PROGRAM: SESAM    FRAMEWORK 3.4-04  31-JAN-2007  PAGE:
4

                   MEMBER check: EC3/NS3472 ENV 1993-1-1/Ed 3
                   Run:      Superelement:     Loadset:
                   CRIT115   T1                LOAD
                   Priority....: Selected Members and Loadcases
                   Usage factor: Above   0.60                   SUB PAGE:
2

 Member   LoadCase CND Type     Joint/Po Outcome  UsfTot   UsfAx
           Phase       SctNam   EleNum                     UsfMy
                                                           UsfMz
 -------------------------------------------------------------
 MX106140 103          I        0.46         Stab   0.609   0.002
                       HE800B   2005                        0.595
                                                            0.012

 28-MAY-2009 12:50 PROGRAM: SESAM    FRAMEWORK 3.4-04  31-JAN-2007  PAGE:
5

                   MEMBER check: EC3/NS3472 ENV 1993-1-1/Ed 3
                   Run:      Superelement:     Loadset:
                   CRIT130   T1                LOAD
                   Priority....: Selected Members and Loadcases
                   Usage factor: Above   0.60                   SUB PAGE:
1
```

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 28-MAY-2009 12:50 PROGRAM: SESAM    FRAMEWORK 3.4-04  31-JAN-2007  PAGE:
6

                   MEMBER check: EC3/NS3472 ENV 1993-1-1/Ed 3
                   Run:      Superelement:     Loadset:
                   CRIT130   T1                LOAD
                   Priority....: Selected Members and Loadcases
                   Usage factor: Above   0.60                   SUB PAGE:
2

 Member   LoadCase CND Type     Joint/Po Outcome  UsfTot   UsfAx
           Phase       SctNam   EleNum                     UsfMy
                                                           UsfMz
 ----------------------------------------------------------------
 MZ104031 104          BOX      J104031      AxLd   0.644   0.644
                       BOXEDHEB 1601                        0.000
                                                            0.000
                                0.20         AxLd   0.644   0.644
                                1602                        0.000
                                                            0.000
                                0.40         AxLd   0.645   0.645
                                1603                        0.000
                                                            0.000
                                0.60         AxLd   0.645   0.645
                                1604                        0.000
                                                            0.000
                                0.80         AxLd   0.646   0.646
                                1605                        0.000
                                                            0.000
                                J104040      AxLd   0.646   0.646
                                1605                        0.000
                                                            0.000

 MZ107031 104          BOX      J107031      AxLd   0.673   0.673
                       BOXEDHEB 1759                        0.000
                                                            0.000
                                0.20         AxLd   0.674   0.674
                                1760                        0.000
                                                            0.000
                                0.40         AxLd   0.674   0.674
                                1761                        0.000
                                                            0.000
                                0.60         AxLd   0.675   0.675
                                1762                        0.000
                                                            0.000
                                0.80         AxLd   0.676   0.676
                                1763                        0.000
                                                            0.000
                                J107040      AxLd   0.676   0.676
                                1763                        0.000
                                                            0.000

 MZ304031 104          BOX      J304031      AxLd   0.648   0.648
                       BOXEDHEB 2387                        0.000
                                                            0.000
                                0.20         AxLd   0.649   0.649
                                2388                        0.000
                                                            0.000
```

```
 28-MAY-2009 12:50 PROGRAM: SESAM    FRAMEWORK 3.4-04  31-JAN-2007  PAGE:
7


                   MEMBER check: EC3/NS3472 ENV 1993-1-1/Ed 3
                   Run:      Superelement:     Loadset:
                   CRIT130   T1                LOAD
                   Priority....: Selected Members and Loadcases
                   Usage factor: Above   0.60                    SUB PAGE:
3

 Member   LoadCase CND Type     Joint/Po Outcome  UsfTot   UsfAx
           Phase       SctNam   EleNum                     UsfMy
                                                           UsfMz
 ----------------------------------------------------------------
                                0.40         AxLd   0.649   0.649
                                2389                        0.000
                                                            0.000
                                0.60         AxLd   0.650   0.650
                                2390                        0.000
                                                            0.000
                                0.80         AxLd   0.650   0.650
                                2391                        0.000
                                                            0.000
                                J304040      AxLd   0.651   0.651
                                2391                        0.000
                                                            0.000

 MZ307031 104          BOX      J307031      AxLd   0.691   0.691
                       BOXEDHEB 2545                        0.000
                                                            0.000
                                0.20         AxLd   0.691   0.691
                                2546                        0.000
                                                            0.000
                                0.40         AxLd   0.692   0.692
                                2547                        0.000
                                                            0.000
                                0.60         AxLd   0.692   0.692
                                2548                        0.000
                                                            0.000
                                0.80         AxLd   0.693   0.693
                                2549                        0.000
                                                            0.000
                                J307040      AxLd   0.693   0.693
                                2549                        0.000
                                                            0.000
```

H. READ ME TO ENCLOSED CD

Documents:

Aker Solutions inhouse document, ref [1]:
Structural _Design_Premises.pdf

Coordinate transformation sheet

Points genie.xls - Transforms global TCP2 coordinates to local M32 coordinates.

```
************************************
*** Input and analysis files    ***
************************************
```

Catalog strucutre for input files:

Root folder

\M32\
    \ana\ - All Sesam analysis files

        \Coupled\ - Analysis files for the coupled result
        \lift\ - Analysis files for the lifting condition
        \transport\ - Analysis files for the transportation condition

    \geo\ - Input files to Genie

    \model\-Genie computer model

General file description

Analysis files:

* Files in the \ana\ folder named *_IN is input files to Sesam.
* Files starting with Manager_* denotes files to start routines in Sesam manager described in each Manager_* input file.

The \Results\ folder contains result files from all analysis.

Geneie input files \Geo\:

* Prop.js - Member, plate and material Properties
* Geom.js - Original geometry of M32 module
* Plates.js - Shear plates
* Reinfbox2.js - Adds reinforcement to critical columns

Abaqus folder contains computer model of the critical column.