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Master Thesis of Offshore Subsea Technology

Fatigue study of conductor at the conductor guides' levels on the EKOFISK-K platform

Bita Jalali Mosalam

Spring 2012

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I would like to express appreciation to Professor Ove Tobias Gudmestad for continuous encouragement and valuable comments during all parts of my master study as well as during preparation of this master thesis. I am especially grateful to him to give me the opportunity to learn and work with the Orcaflex software. He is also has been my supervisor & advisor for this study.

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Bita Jalali Mosalam

Abstract

This master thesis presents the method & results from a fatigue study of conductor at the conductor guides' levels & static and dynamic hydrodynamic analysis of a 20'' conductor installed on the Ekofisk-K platform using the OrcaFlex 9.5 computer program. This study presents only the results from the analyses and does not comment on the program's efficiency or ability to model the various physical effects.

Due to the conductor's guide situation as well as the gaps between the conductor and it's guides which was reported by the offshore survey, the fatigue life study of the conductor is highly demanded.

The hydrodynamic analysis has been done with a Finite Element Software, the OrcaFlex 9.5, for regular waves for 1, 10 and 100 year return period sea states. Afterward, fatigue calculations have been done according to the output from the hydrodynamic analysis.

The main achievements from this study are:

- Some factors have been identified as the key factors which have a great influence for the fatigue life analysis of the conductor at the guides' levels: Bending moment, wall tension of the conductor, both hydrodynamic & structural damping factors are seen to be main sources of uncertainty, the clearances (gaps) between conductor and it's guides for the different guide decks.
- The bending moment could be reduced by reducing the gap for the conductor in the guides.
- By choosing the DFF (Dynamic Fatigue Damage) to be 2, the fatigue life of the conductor guides level will not match the requirement for conductor fatigue service life according to this master thesis; it needs inspection and modification.

Keywords: Conductor; Bending Moment; Fatigue Analysis; Damping Factors; Hydrodynamic Analysis.

Preface

This report is the result of the MSc thesis which is the last part of the two years master program in Offshore Subsea Technology at University of Stavanger (UiS).

This thesis consists of a literature study and an analysis part.

I choose to focus on fatigue life study of a conductor for my master thesis with Aibel AS in Stavanger; since, the fatigue study was completely new for me during my last 10 years work experience. On the other hand, due to the service life (20 years) of the platform in the upstream industry, the fatigue life would be a significantly important issue.

This subject was proposed to me by Aibel AS in last semester of my study. This subject is one of the concern study project of ConocoPhillips.

I chose the Ekofisk – K platform: Since, some offshore survey was done for this platform by Fabricon in 2008 and Aibel. So, I have had an opportunity to use the actual data & measurements for this analysis.

The literature study is performed to provide an introduction to the subject of fatigue study on conductor at the conductor guides levels The analysis in this report is performed with an analysis tool, OrcaFlex 9.5.

This master thesis is organized in the10 followings chapters:

Chapter 1, Introduction, describe the objectives, background and overall description of the Ekofisk field.

Chapter 2, Conductor & Wave theory, provides the theory for determining displacements and rotations at X-mass trees & conductor properties.

Chapter 3, Design Basis, is providing the environmental data, hydrodynamic data, loads & actions.

Chapter 4, Conductor Analysis, this chapter has an overview of conductor theory.

Chapter 5, Analysis, provides the conductor analysis theory by OrcaFlex 9.5.

Chapter 6, Modeling, describes the conductor modeling strategy & modeling in OrcaFlex 9.5.

Chapter 7, Hydrodynamic Analysis Results, shows the hydrodynamic results & stability checking of the conductors.

Chapter 8, Fatigue analysis for conductor at the guides' levels, presents the fatigue calculation methodology and fatigue life results

Chapter 9, Conclusion, the conclusion for this study has been presented.

Chapter 10, Proposal for further study, is provided as suggestion for further conductor analysis

Chapter 11, References.

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α	Deflection angle
a	Acceleration vector
A	Area
A_e	External cross-section area
A_i	Internal cross-sectional area
C_1	Stress loading factor
C_D	Drag coefficient
C_M	Inertia coefficient
C_m	Mass coefficient/added mass coefficient
C	Damping matrix
$C(p,v)$	the system damping load
δ	Displacement
dz	Unit length
ε_i	Phase angle
EI	Bending stiffness
f_D	Drag force
f_H	Hydrodynamic force
f_I	Inertia force
f_y	Distributed hydrodynamic force acting in the y-direction
F	Shear force
$F_x(X)$	Rayleigh distribution of the variable x
F_z	Axial force (wall tension from analysis results)
$F(p,v,t)$	The external load
I	Moment of inertia
I_y	Moment of inertia about the y-axis
I_z	Moment of inertia about the z-axis
L	Length from the bottom to the center of the resulting force

m_{xn}	Spectrum moments
M	Moment/bending moment
M_{tot}	Total mass
M_x	Bending about x-axis/x-bending moment (Bending moment 12 (SP) from analysis results)
M_y	Bending about y-axis/y-bending moment (Bending moment 34 (AF) from analysis results)
$M(p,a)$	The system inertia load
N	Axial force
ρ	Fluid density
P	Top tension
p_x	Lateral force component of the top tension
p	Position vector
p_e	External fluid pressure
p_i	Internal fluid pressure
r_i	Inner radius
r_e	Outer radius
r	System displacements/ vectors for displacements
σ	Tension
$\sigma_1, \sigma_2, \sigma_3$	Axial stresses
σ_{ab}	Total axial stress
σ_b	Bending stress
σ_c	Circumferential stress
σ_r	Radial stress
σ_p	End effect stress
σ_{ST}	Standard deviation
σ_{tw}	Axial stress
σ_{vm}	Equivalent Von Mises' stress
$S_X(\omega)$	Response spectrum

$S_X(\omega_i)$	Spectrum depending on frequency ω
$S_\varsigma(\omega_i)$	Wave spectrum
$\tau_{12}, \tau_{23}, \tau_{31}$	Shear stresses
t	Simulation time/time
ΔT	Variation of effective tension
T_e	Effective tension
T_{tw}	True wall tension
T_{xz}	The zero-up-crossing period
UTS	Ultimate tensile strength
u	Instantaneous velocity
$\dot{u}$	Instantaneous acceleration
V	Volume of sphere
v	Vector/lateral velocity of structure
VIV	Vortex induced vibrations
ω	Eigen frequency
ω_i	Frequency of response component
$\Delta\omega$	Frequency interval
W_a	Apparent weight
W_e	Displaced fluid weight
W_i	Internal fluid weight
W_t	Segment weight
X	Response variable
X_i	Amplitude
$X(t)$	Realization of a variable
y	Distance from the centre of the element, in calculation of tension

1.0 Introduction

1.1 Overal description

In collaboration with the University of Stavanger and the Structural Analysis Group in Aibel As, we & ConocoPhillips have found that all angular rotation and translational displacements, rotations and the occurrence number of these at the X-mass trees on the Ekofisk K installation due to the environment (wave) and gravitative loads acting upon conductor should be calculated. Because of the conductor guides' conditions and the clearance between the guides and conductors the fatigue life and the strength integrity of the conductor guides' level should be re-assessed.

This master thesis has been provided to investigate the structural stability and strength of the 20'' conductors, and the fatigue life of the conductor at the conductor guides' level installed on the EKOK platform.

The goals of the present conductor guides' level analysis are:

-Calculations of the environmental forces and bending moments which act upon the conductor guides' level;

- Make an estimation of the conductor guides' level fatigue integrity for safe offshore operations;

- Stability/Strength code checking of a 20''conductor

- Calculation of Fatigue life of a 20'' conductor guides' level located on the Upper Guide Deck & cellar guide Deck.

This analysis will be done with Finite Element software the OrcaFlex 9.5; the OrcaFlex modeling will be used in hydrodynamic analysis of a conductor for regular waves for 1, 10 and 100 year return period sea state. Contact forces, wall tension as well as the bending moments can be finding as a result of the OrcaFlex modeling. Furthermore, fatigue Calculations will be prepared due to the output from the hydrodynamic analysis according to Palmgren-Miner Damage summation method which will be described on chapter 8.0.

1.2 General

Ekofisk was Norway's first producing field and is also one of the largest on the Norwegian continental shelf. Production started in 1971. With the projects now under development, the lifetime of the field is prepared for production towards 2050, ref/1/.

Ekofisk is located in the southern part of the North Sea, 300 kilometers southwest of Stavanger.

The water depth in the Greater Ekofisk Area is 70-80 meters. Due to a drop in the reservoir pressure the seabed has been subsiding over the years. Efforts to protect the platforms against the effects of the subsidence started as early as in 1985. All steel platforms at the Ekofisk Complex (Figure 1-1) were jacked up six meters in 1987, and in 1989 a protective barrier wall was installed around the Ekofisk Tank. The rate of subsidence of the seabed has decreased in recent years, ref/1/.

Figure 1-1: Overview of Ekofisk Complex field, ref/1/

The Ekofisk Complex comprises all installations which are connected with bridges on the central Ekofisk field. As of 2011, this includes seven platforms plus bridge supports. In 2013/2014, a new accommodation and field center platform, Ekofisk 2/4 L, is planned to start operations at the Ekofisk Complex. In addition, a new wellhead platform, Ekofisk 2/4 Z, and a new seabed unit for water injection (Ekofisk 2/4 VB) are planned. The Ekofisk Complex was developed in stages, and has been upgraded and modernised several times. The Ekofisk Complex was given a major boost from 1998, when the 'new' Ekofisk facility came on stream. This was a huge transition with new and modern platforms, at the same time as unprofitable fields were closed down and several old platforms were taken out of service, ref/1/.

Ekofisk 2/4 J is a processing and transportation platform which became operational in 1998. It is connected with gangways to Ekofisk 2/4 X to the west and Ekofisk 2/4 M to the south. Ekofisk 2/4 J (Figure 1-2) is a hub for all production from the four fields in the Greater Ekofisk Area, ref/1/.

Figure 1-2: Overview of Ekofisk 2/4 J, ref/1/

Oil and gas are processed at the Ekofisk 2/4 J platform before being pressurised and shipped in the export lines. The unstable oil is shipped in a 354-kilometer long pipeline to the receiving terminal in Teesside in the UK, while the dry gas is shipped in a 440-kilometer long pipeline to Emden in Germany, ref/1/.

The central control room on the platform controls all processes on Ekofisk 2/4 J and the connected platforms, as well as the volumes running through the pipelines, ref/1/.

Ekofisk 2/4 J has a process capacity of 21.2 million cubic meters of gas and 350,000 barrels of oil per day. In addition, oil from Eldfisk can 'bypass' directly to the pipeline, ref/1/.

The Ekofisk 2/4 J platform is the largest energy producer in the Greater Ekofisk Area. The energy production is gas-based, adapted to the daily needs and is mainly used directly for processing, gas export, gas injection and oil transport. Two gas turbines totalling 44 MW installed capacity have also been installed to supply the integrated power grid on the Ekofisk field, ref/1/.

Ekofisk 2/4 X is a drilling and production platform connected to the platforms Ekofisk 2/4 C and Ekofisk 2/4 J via gangways, ref/1/.

Ekofisk 2/4 X (Figure 1-3) mainly performs two tasks: It is equipped with a separate drilling rig for drilling of wells, and it is also a wellhead platform receiving the reservoir production before being transferred to Ekofisk 2/4 J, ref/1/.

Ekofisk 2/4 X has been operational since 1996, ref/1/.

Figure 1-3: Overview of Ekofisk 2/4 X, ref/1/

Ekofisk 2/4 M is a combined production and process platform remotely controlled from Ekofisk 2/4 J, ref/1/.

Ekofisk 2/4 M (Figure 1-4) came on stream in 2005 and can accommodate 30 wells. One of the wells is used for reinjection of cuttings. The platform has no fixed derrick, so the drilling takes place using a leased drilling rig (jack-up). The temporary accommodation rig *Haven* has been connected to Ekofisk 2/4 M with gangway from August 2011, ref/1/.

The platform will also be the connection point for the new platforms Ekofisk 2/4 L and Ekofisk 2/4 Z, scheduled for installation in 2013/2014, ref/1/.

Figure 1-4: Overview of Ekofisk 2/4 M, ref/1/

Ekofisk 2/4 H is an accommodation platform with 134 cabins. The platform is equipped with facilities to service its guests, including a kitchen and mess, a separate power generator, dedicated water production and everything required to cater for the crew, ref/1/.

In addition to the accommodation functions, there is a cinema, gym, leisure rooms, coffee room, chapel, hospital and health personnel department. The platform also has equipment for technical training and storage capacity for a number of technical functions, such as helicopter traffic service, ref/1/.

Ekofisk 2/4 H (Figure 1-5) also functions as a field centre and is currently, together with the temporary accommodation rig Haven, the most important helicopter landing site in the area. Most of the helicopter traffic from Sola to the Greater Ekofisk Area lands at these platforms, while they are also the base for most of the daily shuttle traffic between the installations. Ekofisk 2/4 H was installed in 1977 and started operating in 1978, ref/1/.

Figure 1-5: Overview of Ekofisk 2/4 H, ref/1/

Ekofisk 2/4 C (Figure 1-6) is a combined production and compressor platform on the Ekofisk Complex. The platform is permanently staffed with operations personnel. It has gangway connections to Ekofisk 2/4 H, Ekofisk 2/4 Q and Ekofisk 2/4 X, ref/1/.

The production is transported to Ekofisk 2/4 J for separation and processing – and further on to the receiving terminals for oil (Teesside) and gas (Emden). Production from Ekofisk 2/4 C started in 1974, ref/1/.

Figure 1-6: Overview of Ekofisk 2/4 C, ref/1/

Ekofisk 2/4 Q was installed in 1972 and was originally a living quarter's platform with a helicopter deck and offices. The platform is not in daily use, but in stand-by.

The platform is bridged to the Ekofisk 2/4 FTP and the Ekofisk 2/4 C platforms.

Ekofisk 2/4 Q (Figure 1-7) is on the list of platforms to be decommissioned, ref/1/.

Figure 1-7: Overview of Ekofisk 2/4 Q, ref/1/

Ekofisk 2/4 FTP is an unmanned riser platform which receives the production from Ekofisk 2/4 A for transport to Ekofisk 2/4 J. It is connected to the Ekofisk Complex via a gangway to Ekofisk 2/4 Q, ref/1/.

The platform is unmanned, and is included in the plans for decommissioning of older installations, ref/1/.

Ekofisk 2/4 FTP (Figure 1-8) was installed in 1972, and came into operation in 1974, ref/1/.

Figure 1-8: Overview of Ekofisk 2/4 FTP, ref/1/

EKOFISK 2/4 K-B

Ekofisk 2/4 K-B (Figure 1-9) is located 2.3 kilometers north of the Ekofisk Complex. These two platforms have joint staffing and are connected with a gangway. Operations on the two platforms are controlled from the control room on Ekofisk 2/4 K, ref/1/.

Ekofisk 2/4 B is a production platform for oil and gas with 24 wells. The oil and the gas from 2/4 B is transported by pipelines to the Ekofisk Complex. Personnel who work daily on this platform live on Ekofisk 2/4 K, ref/1/.

Ekofisk 2/4 K is a water injection and accommodation platform with 30 wells. The living quarters module has 182 beds on five floors, and personnel working on this platform and on Ekofisk 2/4 B live here, ref/1/.

The water injection on Ekofisk started from Ekofisk 2/4 K in 1987. From 1990, Ekofisk 2/4 K has supplied injection water to other platforms as well. From 2010, when the seabed unit Ekofisk 2/4 VA came on stream, water injection on the Ekofisk field has been done either from 2/4 K or from this new unit, ref/1/.

The daily injection rate into the Ekofisk reservoir is approximately 450,000 barrels of water. Part of this injection water is supplied from Eldfisk 2/7 E and transported in a 24-kilometer long pipeline to Ekofisk 2/4 K for injection from there, ref/1/.

The total daily injection rate on Ekofisk and Eldfisk is approximately 650,000 barrels of water, ref/1/.

Water injection is used to increase the recovery of oil and gas. The function of the water is to maintain reservoir pressure at a stable level as oil and gas is recovered from the reservoir. Water injection is the single most important factor in keeping the production on the Ekofisk field at a high level, ref/1/. The water injection also reduces the subsidence.

Figure 1-9: Overview of Ekofisk 2/4 K-B, ref/1/

EKOFISK 2/4 VA

Ekofisk 2/4 VA is a seabed unit for water injection, and it is remotely operated from a control room in one of the company's integrated operations centres in the main office in Tananger, ref/1/.

The injection water comes from Ekofisk 2/4 K and is sent 4.1 kilometers through a pipeline before being injected under high pressure at the wellhead, around 70 meters below sea level, ref/1/.

The injection capacity is 120,000 barrels of water per day, divided among eight injection wells, ref/1/.

Ekofisk 2/4 VA (Figure 1-10) came into operation in 2010, and is the first seabed unit on Ekofisk after the early production in 1971 with the *Gulftide* rig, ref/1/.

Figure 1-10: Overview of Ekofisk 2/4 VA, ref/1/

EKOFISK 2/4 A

Ekofisk 2/4 A (Figure 1-11) is a production platform located 3.1 kilometers south of the Ekofisk Complex. The platform is normally unmanned. In cases where personnel are on board to perform maintenance or inspection, the platform is controlled from the local control room, ref/1/.

The production from Ekofisk 2/4 A is transported via the pipeline to Ekofisk 2/4 FTP and then on to Ekofisk 2/4 J for processing and further transport to the receiving terminals for unstable oil (Teesside, UK) and dry gas (Emden, Germany) , ref/1/.

Ekofisk 2/4 A was the first permanent platform in the Greater Ekofisk Area – and on the Norwegian continental shelf. The first oil production from well A-13 commenced on 25 April 1974, ref/1/.

Figure 1-11: Overview of Ekofisk 2/4 A, ref/1/

1.3 Background

Ekofisk K is subjected to an extended life study. The extended lifetime is set to 2028 and one of the functions that need to be studied is the safe operation of the risers.

The purpose of this study is accordingly to assess whether the integrity of the conductors (Figure 1-12) and (Figure 1-13) is sufficient for an extended lifespan.

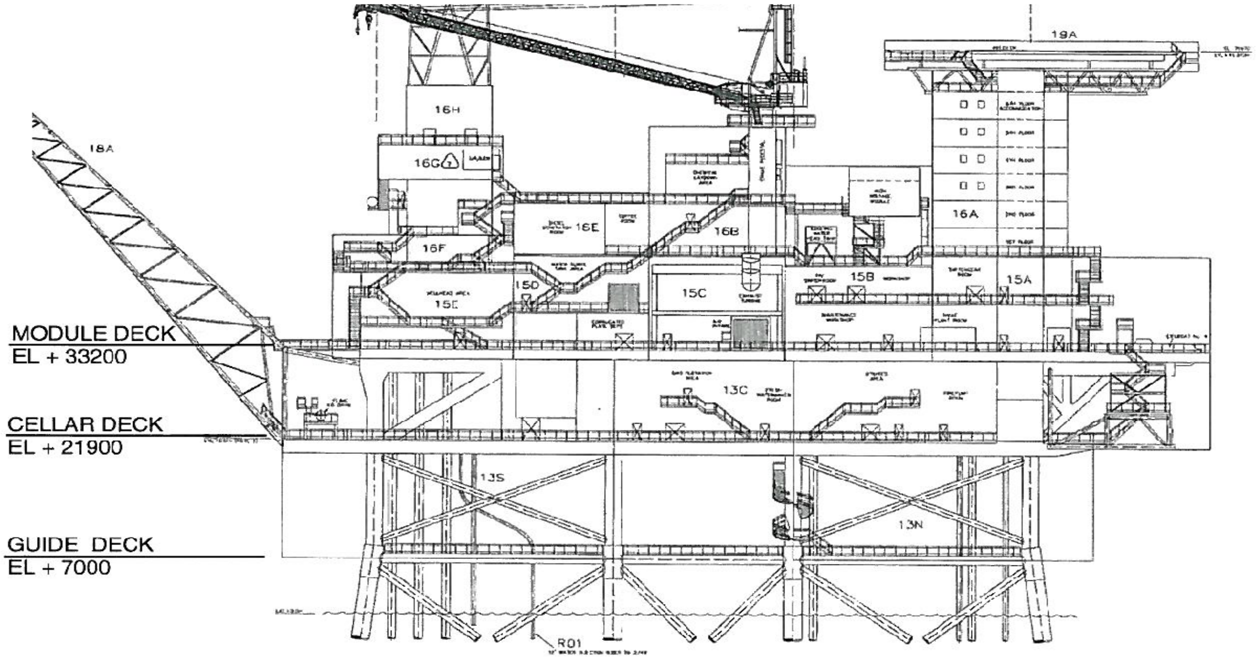

Figure 1-12: Conductor decks on EKOK platform, ref/1/

For most of the conductor guides there are no gap between the guide and the conductor. This has resulted in some vertical deformations of the plate around the conductor. All deformations on existing module deck are considered not critical to the structural strength, so these deformations will not be considered during this project. The deformations will most probable not exceed in the future due to low temperature variations in the conductors.

To achieve sufficient gap between conductors and guides one will flush away dirt and clean the area between conductors and guides.

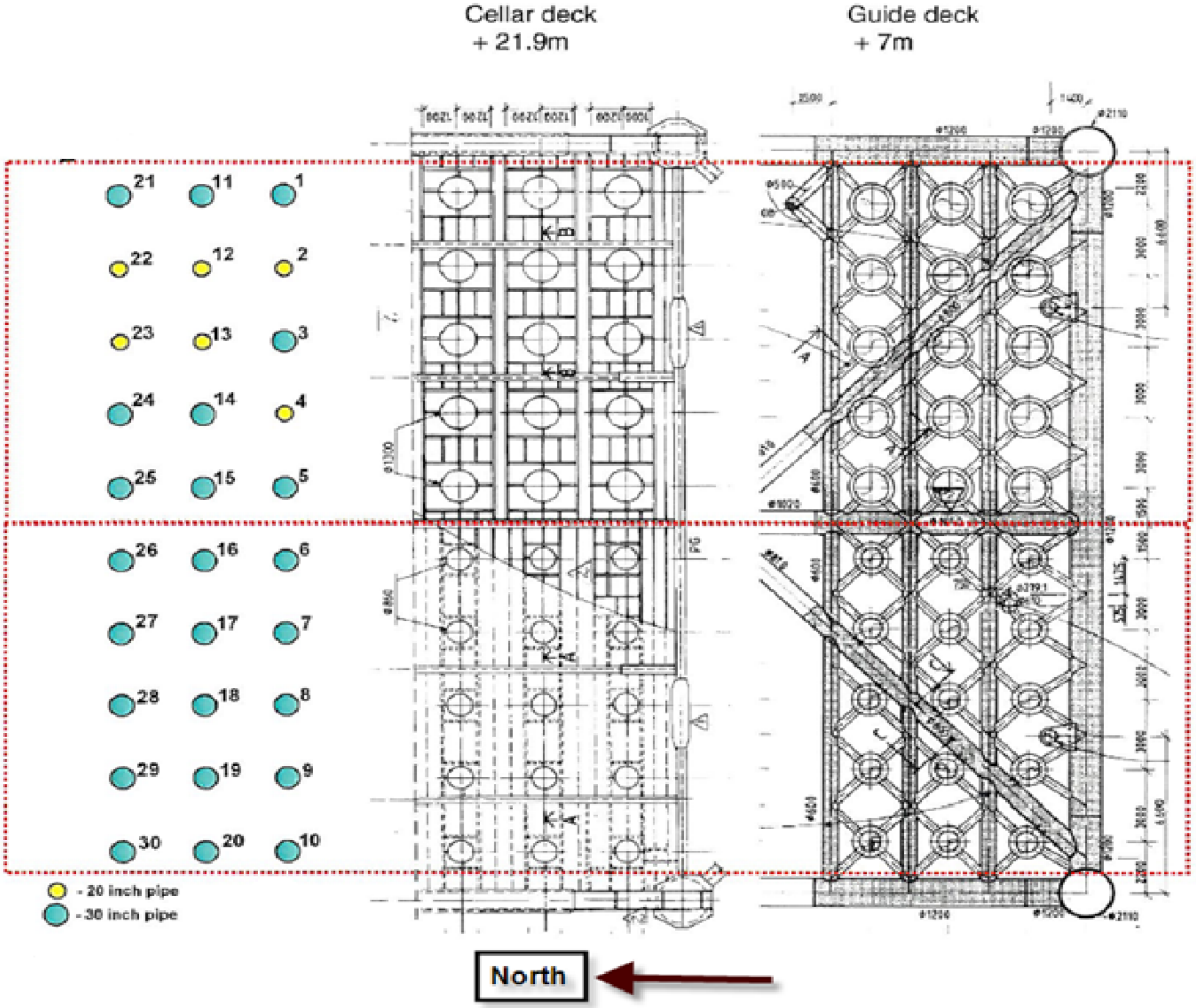

Figure 1-13: The view is showing the conductors configuration at the platform levels and their positions.

The guides, not shown here are configured in the splash zone at Sea level +7m.

Conductor sizes are shown to the left, ref/2/

The proposed design basis for this master thesis is to re-establish the given design criteria (clearance between conductor and guide) for all conductors on the EKOK. The design clearance for all conductor guides at each level is given in Table 1-1:

Table 1-1 *Design clearance*

Deck	Design clearance between conductor and guide
Module deck (+33.2m)	0mm
Cellar deck (+21.9m)	0mm
Guide deck (+7m)	0,3,5,10 mm

To achieve this solution for all guides (Figure 1-14) several operations have to be preformed.
In the section 1-4, 1-5 & 1-6 all guides are discussed in detail and a solution is presented, ref/2/.

1.4 Module deck

At module deck the conductor guides are divided into two groups.

Group 1: M1, M6, M14 & M25

Group 2: M2, M3, M4, M5, M7, M8, M9, M10, M11, M12, M13, M15, M16, M17, M18, M19, M20, M21, M23, M24, M26, M27, M28, M29 & M30

For most of the conductor guides there are no gap between the guide and the conductor. This has resulted in some vertical deformations of the plate around the conductor. All deformations on existing module deck are considered not critical to the structural strength, so these deformations will not be corrected during this project. The deformations will most probably not exceed in the future due to low temperature variations in the conductors.

To achieve sufficient gap between conductors and guides one will flush away dirt and clean the area between conductors and guides. After flushing the gap between the conductor and guide will be 3mm.

1.4.1 Solution for each group of conductor guides:

Conductor guides in group 1:

For these conductor guides the existing silicon will be removed and one will flush the area between the guide and conductor.

Conductor guides in group 2:

Concrete and dirt between the conductor and guide should be removed. After removing all dirt/obstacles the gap between the conductor and guide will be 3mm.

Surface protection:

No surface protection will be done on the conductor guides on module deck.

1.5 Cellar deck:

1.5.1 General:

The conductors are divided into three groups.

Group 1: C1, C2, C4, C5, C11, C12, C13, C14, C15, C21, C22, C23 & C25

Group 2: C3 & C24.

Group 3: C6, C7, C8, C9, C10, C16, C17, C18, C19, C20, C26, C27, C28, C29 & C30.

For guides in groups 1 and 2 a new conductor guide will be installed. The new guide will be prefabricated in two parts onshore and bolted together and into the existing top plate around the conductor.

For the other group of conductors the cap between the sleeve and conductor will be adjusted with wedges.

1.5.2 Solution for each group of conductor guides:

Conductor guides in group 1& 2:

Existing sleeve and wedges will be removed and new sleeves (Figure 1-14) & (Figure 1-15) will be installed and bolted to the existing top plate around the conductor. Two different sleeve sizes have to be made (5 for 30" conductors and 6 for 20" conductors).

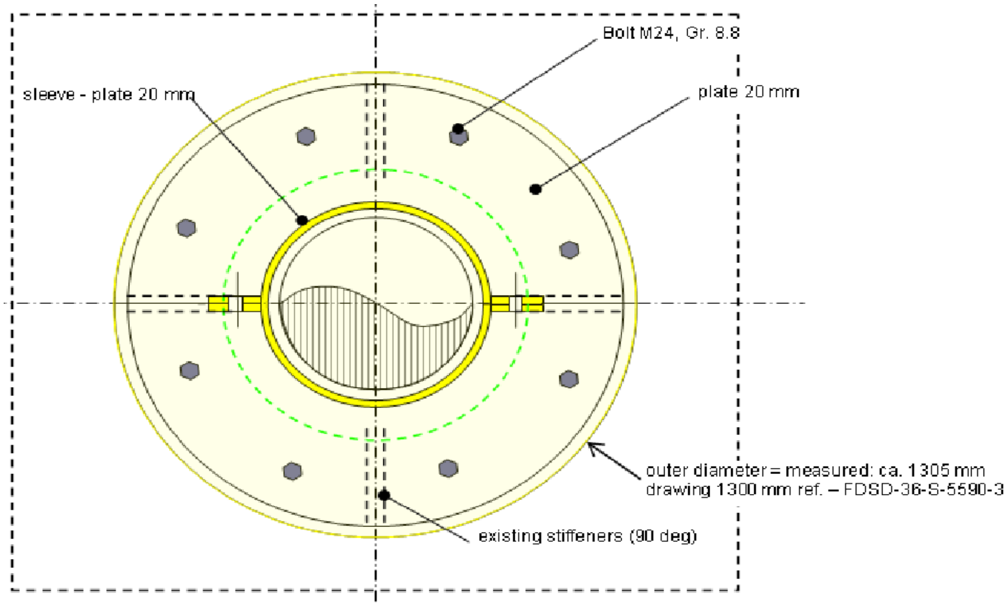

Figure 1-14: Top view of new sleeve, ref/2/

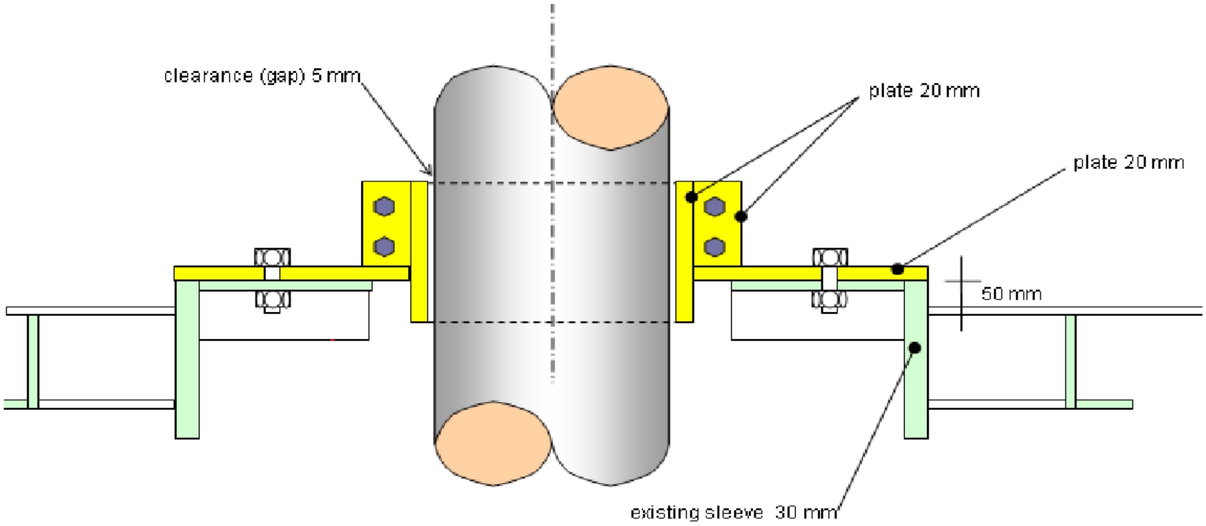

Figure 1-15: Side view of new sleeve, ref /2/

Conductor guides in group 3:

For this group of conductors the gap between the conductor and guide is bigger than the design criteria for the conductor guides. The gap between guide and conductor will be reduced by installing wedges which will be bolted in the existing sleeve.

Surface protection:

All new guides will be sandblasted and painted onshore

1.6 Guide deck:

1.6.1 General:

At this level the conductor guides have been divided into four groups dependent on the solution.

Group 1: G1, G5, G11, G14, G15, G21, G24 & G25
Group 2: G2, G4, G12, G13, G22, G23
Group 3: G3
Group 4: G6, G7, G8, G9, G10, G16, G17, G18, G19, G20, G26, G27, G28, G29 & G30.

Solution for each group of conductor guide:

Conductor guides in group 1:

After removing the additional wedges the gap between the conductor and guide will be 16 mm, see Figure (1-16) & (Figure 1-17).

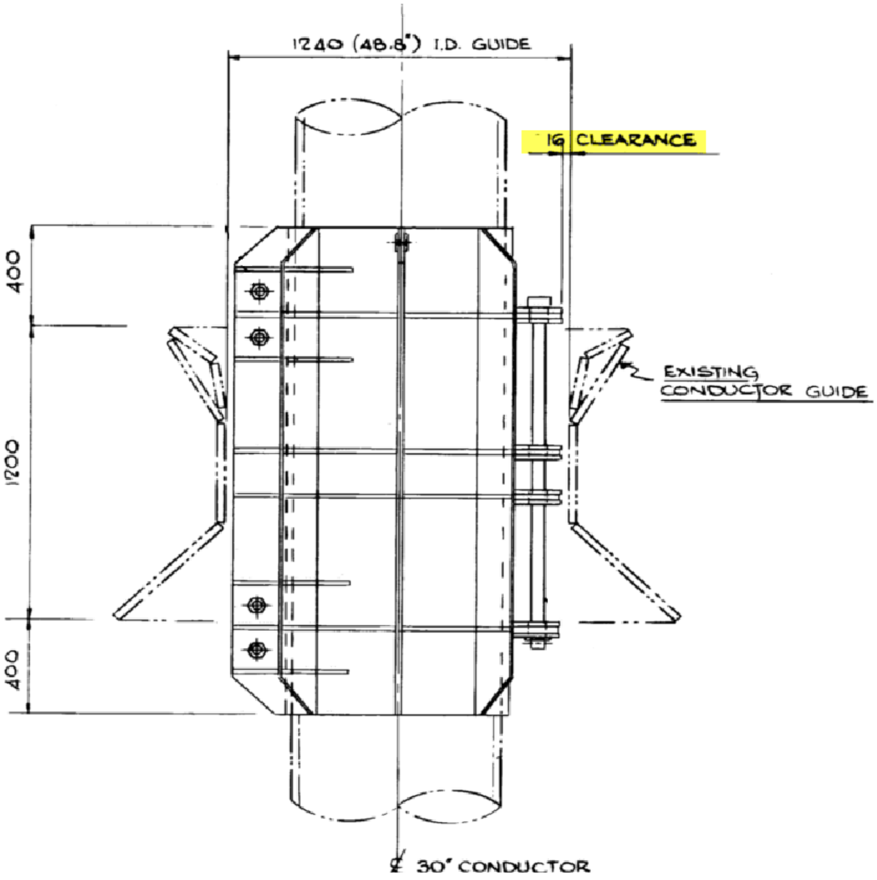

Figure 1-16: Conductor guide, ref /2/

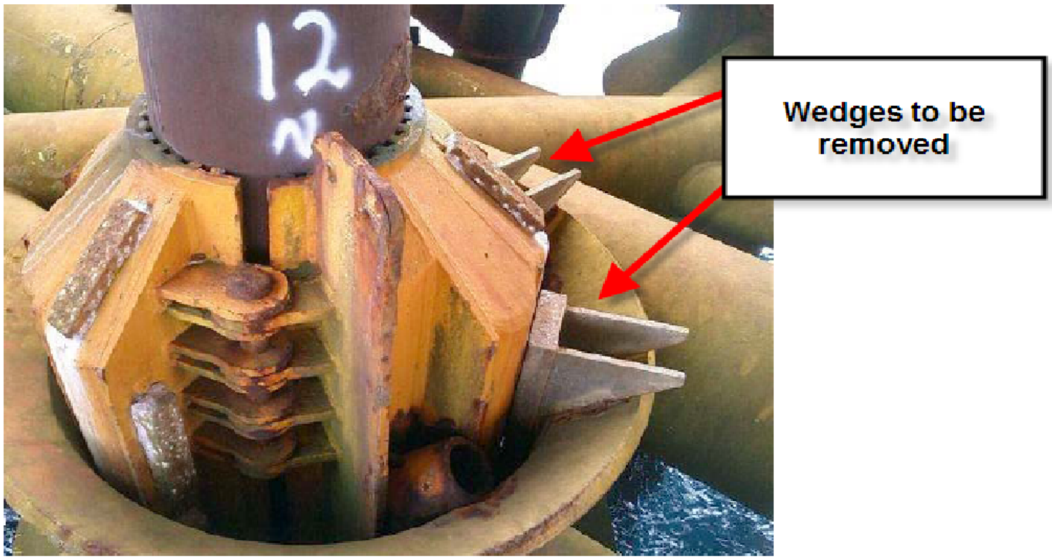

Figure 1-17: Example on wedges to be removed, ref /2/

Conductor guides in group 2:

All conductors are 20".

After removing the red marked restraint (see clip from drawing Figure 1-18) the gap between conductor and guide will be 20mm.

For some conductor guides there are installed wedges and restraints. For these cases both of the items will be removed (Figure 1-19).

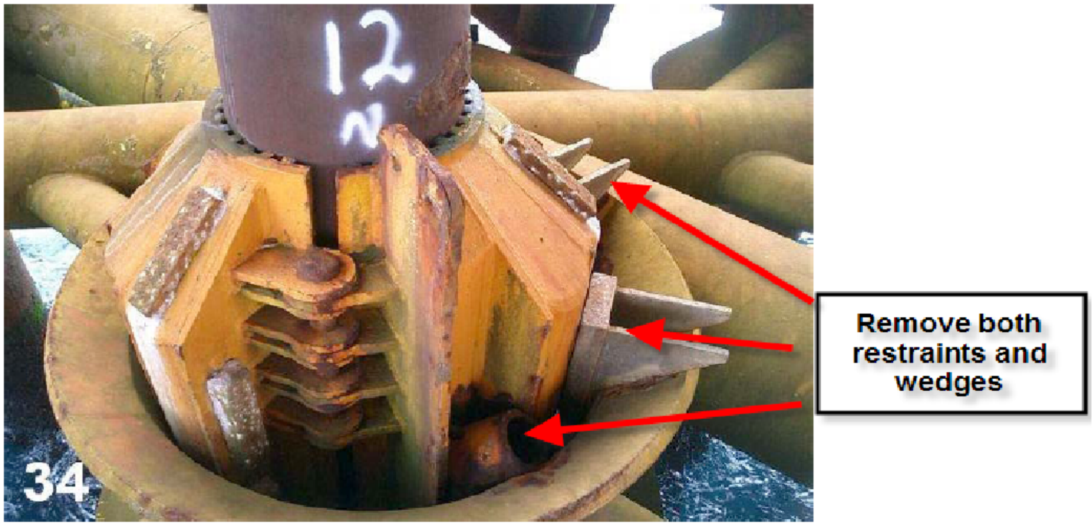

Figure 1-18: Example of conductor guide with both wedge and restraint, ref/2/

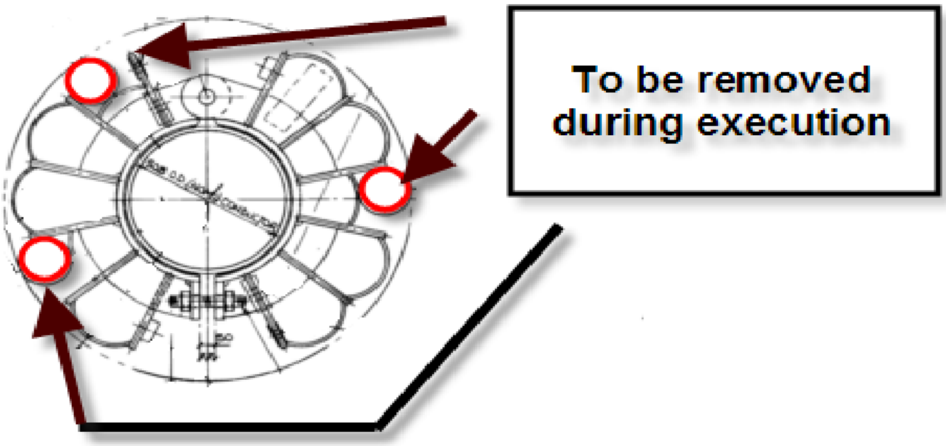

Figure 1-19: Items to be removed, ref /2/

Conductor guide in group 3:

This guide is OK as it is today. The gap between the conductor and guide is 15mm.

Conductor guides in group 4:

For all conductor guides in group 4 the gap between the conductor and guide will be 21mm after removing all welded wedges (Figure 1-20).

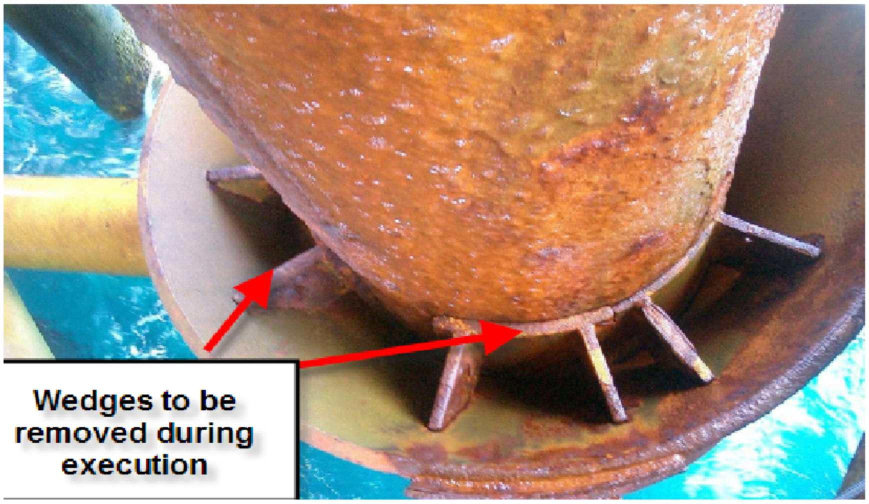

Figure 1-20: Example on wedges to be removed, ref /2/

Surface protection:

For all guides in group 4 the area where the wedges were welded on the guide has to be sandblasted and painted after removal.

The most critical gaps have been occurring for upper guide deck level. So, according to Table 1-1 the different clearances (0, 3, 5 and 10 mm) have been considered for guides in conductor upper guide deck level.

2.0 Conductors and wave theory

This chapter provides the theory for determining displacements and rotations at X-mass trees resulting from wave loadings on conductors.

Results shall be calculated for various ranges of significant wave heights needed for fatigue evaluations. The displacements/ rotations and associated number of occurrences will be used as a basis for the fatigue analysis. The displacements/rotations should be presented at the location of the X-mass trees.

A single conductor will be analyzed and shielding effects from neighboring conductors will be disregarded.

The conductors are supported at the seabed and guided horizontally at the upper guide deck and by conductor frames. The conductor frames and upper guide deck shall be simulated as fixed guides with given clearances to the conductors. The conductor is to be assumed to be centrally placed through the guides.

Wave loadings only should be considered. Vortex shedding effects from wind and current are considered to be negligible. The wave loadings and occurrences should be derived from the environmental criteria for the greater Ekofisk Area, ''Comprehensive Enviromental Criteria for The Greater Ekofisk Area'', ref/3/.

Seastates for the significant wave height as well as associated periods should be considered for waves; the scatter diagram should be used to determine the number of displacement oscillations per direction associated with the calculated displacement ranges per wave height and related period for fatigue life calculations.

Also, the design waves comprised of both regular waves and irregular waves are described as the followings:

- <u>Regular wave data</u>

The regular waves will be based on Stokes 5th order theory. The regular wave analysis has been performed with the headings, 0 to 45 degrees to select most critical heading, (Gudmestad, Ove T.), ref/22/.

According to Norsok- N-003, ref /5/, these analyses are based on design load cases for intact condition and damaged condition.

- <u>Irregular wave data</u>

The irregular wave should be based on Jonswap spectral parameter, Figure 2-1. These data will be used to help in concluding the maximum loads on the structures, (Gudmestad, Ove T.), ref /21/.

U_W is the wind speed at 10m above the sea surface

ω_p is the peak frequency calculated using equation above

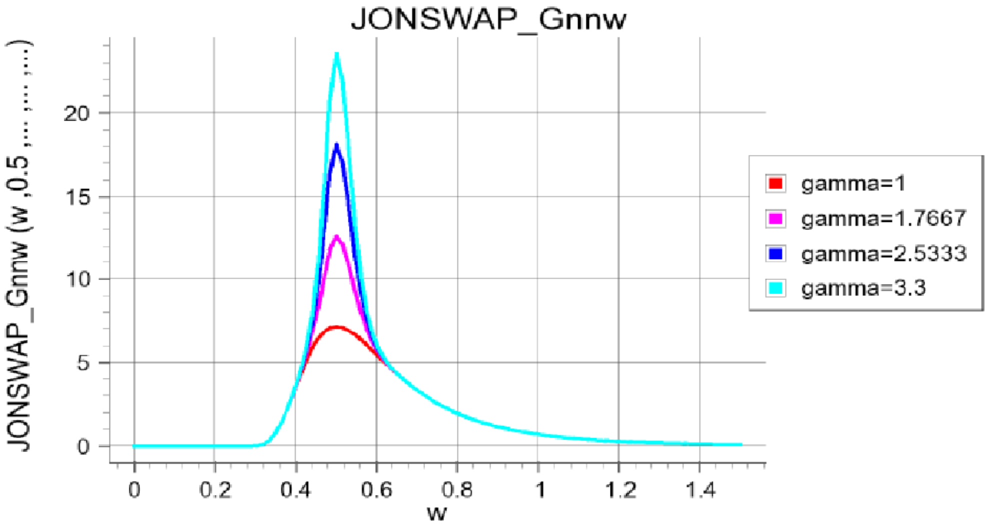

Figure 2-1: JONSWAP Spectrum

The conductor analysis covers both the conductor and the upper part (above mud line) of casings inside the conductor, particularly the outer casing which will along with the conductor prevent the inner pipes from damages caused by environmental loads.

The objective of a conductor analysis is to ensure safe operations offshore. By that means, to verify that the structural capacity of a conductor resist the environmental and gravitate loads which will be imposed on it. Displacements, rotations and associated number of occurrence at the X-mass tree on the conductor resulting from wave loadings should be calculated. Further, the reaction forces between conductor and guides must be determined for 1, 10,100 and 1000 year waves and current for medium and high risk platforms.

Conductor Properties:

20'' Conductor (OD=0.508 (m); ID=0.486 (m); t=0.0111 (m))

Base Mass:	m_{20}=15562 (kg)
Base Bending Stiffness:	EI=110702.3 (kNm^2)
Base Axial Stiffness:	EA=3585023 (kNm^2)

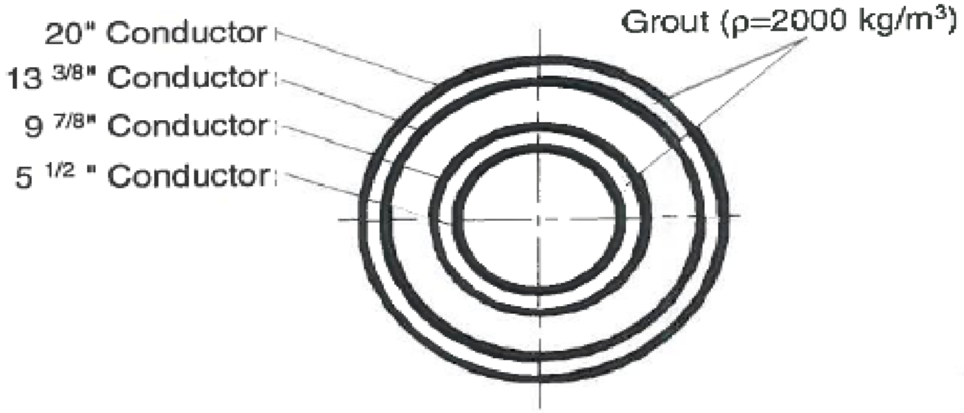

Figure 2-2: Overview of conductor's section, ref/2/

***Table 2-1:** Dimensions, masses and cross section properties of casing strings of EKOK'S Conductors*

Parameter	**Unit**	**Conductor**						**Grout**
		30"	**20"**	**13 3/8"**	**9 7/8"**	**9 5/8"**	**5 ½"**	
Outer Diam. OD	(m)	0.762	0.508	0.340	0.251	0.244	0.140	
Inner Diam. ID	(m)	0,711	0.486	0.315	0.219	0.217	0.124	
Wall thick. WT	(m)	0.0254	0.0111	0.0122	0.0159	0.0138	0.0077	
Inertia Mom. Ix, Iy	(m^4)	3.989e-03	5.348e-04	1.685e-04	0.813e-04	0.667e-04	0.7e-05	9.285e-3
Length	(m)	119.2	119.2	119.2	119.2	119.2	119.2	
Density	(kg/m^3)	7850	7850	7850	7850	7850	7850	
Young's mod. E	(kPa)	207e+06	207e+06	207e+06	207e+06	207e+06	207e+06	
Area	(m^2)	5.875e-02	1.732e-02	1.255e-02	1.173e-02	0.996e-02	0.32e-02	0.195
Axial Stiffness EA	(kN)	121.609e+04	358.02e+04	259.72e+04	242.79e+04	206.91e+04	66.064e+04	402.568e+04
Bend. Stiffness EI	(kNm^2)	825.77e+03	110.7e+03	34.874+03	16.825e+03	13.811e+03	1.444e+03	1921.93e+03
Total weight	(t)	53.13	15.67	11.35	10.61	9.05	2.89	
Total weight	(kN)	521.2	153.6	111.3	104.1	88.7	28.3	
Linear weight	(t/m)	0.461	0.136	0.0985	0.0921	0.0785	0.0251	0.389

3.0 Design Basis

3.1 Environmental Data

The conductors are directly exposed to environmental loads produced by waves and current, and indirectly by the loads produced by guide movements due to wave/current induced platform deflections.

For the present analysis the direct loads only have been considered. For a more complex and detailed conductor analysis the indirect loads have to be accounted for into the overall load condition.

Vortex shedding is normally not a problem for the conductors installed on Ekofisk Area. Therefore, the vortex shedding was not included in this analysis.

3.1.1 Water depth

Water depth from an appropriate bathymetric chart or from other available measurements can be used. The design water depth shall be corrected for the maximum design subsidence value.

$$D_{design} = d + v + s \tag{3-1}$$

Where;

d Original water depth (Lowest astronomical tide, LAT) equaling **70.1(m)**, *in accordance with Metocean Criteris for Greater Ekofisk Area, ref/3/.*

v The combined value of tidal and non tidal variations (tide and surge).

s Total subsidence at the location.

3.1.2 Tidal Variations

The difference between Highest and Lowest Astronomical Tide should be considered as the tidal variations.

3.1.3 Design SWL

The Still Water Level variability to be used with the design waves based on water levels and wave crest heights.

3.1.4 Waves

Significant wave heights and wave periods should be used for conductor analysis. These values can be found from Metocean Criteria for Greater Ekofisk Area, ref/3/ as given in the Tabe 3-1:

Table 3-1: *Recommended extreme wave values for Ekofisk area, ref/3/*

Return Period (Years)	Significant wave height; Hs(m)	Zero Up-crossing period; Tm02(s)	Individual wave height; Hmax (m)	Associated wave period; T Hmax (s)
1	9.59	9.91	17.3	12.44
10	11.74	10.94	21.28	13.49
100	13.79	11.87	25.19	14.39
1000	15.78	12.74	29.07	15.16
10000	17.71	13.55	32.96	15.86

3.1.5 Current

The current profile can be considered constant over the water depth until 3 m above seabed. The current velocities can be found from Metocean criteria for Greater Ekofisk Area, ref/3/ as given in Table 3-2:

Table 3-2: *Current velocities, ref/3/*

Return Period (Years)	Current Speed[m/s]
1	0.56
5	0.65
10	0.69
50	0.79
100	0.83

3.1.6 Marine Growth

Marine growth can increase the hydrodynamic actions, represents an increased weight and increased additional mass and may influence hydrodynamic instability as a result of vortex shedding and possible corrosion effects. "The roughness should be taken in to consideration when determining the drag coefficients in Morison's formula'', referring to Design methodology for offshore platform conductors, OTC paper 3902, 1980, ref/8/.

In calculation of structural actions, unless more accurate data are available, or if regular cleaning is not planned, thickness is referring to marine growth at the mean water level.

3.1.7 Seawater Temperature

Table 3-3 shows annual seawater temperatures for Ekofisk, ref/3/.

Table 3-3: *Ekofisk annual seawater temperature, ref/3/*

Depth (m)	**Mean Temperature (°C)**	**Min Temperature (°C)**	**Max Temperature (°C)**
0	11.0	2.6	20
-5	11.0	2.6	19.2
-15	11.1	2.6	19.0
-25	10.3	2.6	17.5
-35	9.0	2.7	16.7
-45	7.3	2.7	15.7
-55	6.5	2.9	14.7
-65	6.4	2.9	12.9
-75	6.4	3.5	11.6

3.2 Additional Parameters

3.2.1 Hydrodynamic Coefficients

For surface piercing framed structures consisting of tubular slender members (i.e. conventional jackets) extreme hydrodynamic actions on unshielded circular cylinders are calculated by Morison's formulae on the basis of:

- Stokes 5th order or Stream function wave kinematics and kinematics factor on the wave particle velocity, which is 0.95 for North Sea conditions. This kinematics factor is introduced in the regular wave approach to account for wave spreading and irregularity in real sea states.

- Drag and inertia coefficients according to NORSOK Standard N-003, ''ACTIONS AND ACTION EFFECTS'', ref/5/:

CD = 0.65 and CM = 1.6 for smooth members CD = 1.05 and CM = 1.2 for rough members

These values are applicable for
U_{max} Ti / D > 30;
Where;
U_{max} is the maximum horizontal particle velocity (m/s) at storm mean water level under the wave crest
Ti is the intrinsic wave period (s)
D is the leg diameter at the storm mean water

Flow conditions with
U_{max}Ti / D < 30

- in regular waves may arise with slender members in moderate sea states which are relevant for fatigue analysis. Fatigue analysis can normally be conducted with no current. The wave kinematics factor and conductor shielding factor should be taken to be 1.0.

CD and CM depend on the sea state level, as parameterized by KC, the Keulegan Carpenter Number.

For small waves with KC referred to the mean water level in the range 1.0 < KC < 6, CD = 0.65 and CM = 2.0 (for smooth members) and CD = 0.8 and CM = 2.0 (for rough members)

For (dynamic) spectral or time-domain analysis of surface piercing framed structures in random Gaussian waves and with use of modified Airy (Wheeler) kinematics with no account of the kinematics factor, the hydrodynamic coefficients should in absence of more detailed documentation be taken to be:

CD = 1.0 and CM = 2.0

These values apply both in stochastic analysis of extreme and fatigue action effects.

3.2.2 Operational Parameters

The operational offsets should be taken into consideration for conductors tied back from predrilled wells:

- Lateral Offset
- Rotational Offset

Further, zero degree inclination can be assumed for normal platform drilled conductors.

3.2.3 Geotechnical Parameters

The pile responses should be determined from an integrated soil, considering for the soil's non-linear response and ensuring load-deflection compatibility between the structure and the soil system. Such an analysis is normally carried out with characteristics soil strength parameters. (Norsok N-004, ref/6/)

The soil stiffness can be modeled as springs with varying stiffness in the soil. The stiffness of the springs should correspond to the stiffness of the actual soil, and can be found from p-y curves for the soil. The p-y curves relate unit soil resistance to pile deflection.

3.3 Earthquake criteria and sudden drop

The earthquake action should be determined as described in NORSOK N-003, ref/5/.

The Ekofisk field is exposed to seabed subsidence. The subsidence normally develops gradually over time. However, an immediate drop of the ground over some few seconds cannot be excluded. Dependent on the duration, such an event may induce significant dynamic response effects in the platform and conductor. Such potential effects will not be considered in this analysis, (Gudmestad, Ove T.), ref/4/

3.4 Loads

3.4.1 Axial Loads

The axial loads are defined as loads caused by the casing weight and the cement as well as the weight of the equipment such as the BOP, X-mass tree, snubbing unit, etc. In production mode, contents of fluid stream should also be included.
For buckling check purpose, a distinction should be made between the internal casing loads and external loads acting on top of the pipes, such as BOP weight or/and snubbing unit weight. Reason for this is that the internal loads give no (or very limited) contribution to the load potential during elastic buckling , referring to Design methodology for offshore platform conductors, OTC paper 3902, 1980, ref/8/.

In addition, the vertical friction also belongs to this load group, however it is usually negligible.

3.4.2 Thermal Effects

The temperature in the casings varies from the installation phase to the production phase and depends on heat transferring in both the radial direction and the vertical axial direction along the casings. Thermal effects may be of major importance for the injection wells.

For the predrilled wells which will be tied back after platform installation, thermal effects are one of the governing factors to be decided.

3.4.3 Environmental Loads

Conductors are exposed to wave and current loads which are acting directly on the conductors and indirectly through guide movements due to wave/current induced platform deflections.

Vortex shedding is usually not a problem for the conductors existing in the Ekofisk area. However for the conductors with a diameter equal or less than 20 inches, vortex shedding effect should be considered.

Shielding from adjacent conductors should normally be considered with regards to environmental loads according to DNV RP C205, sec 6.10.2.1,ref/12/.

3.4.4 Eccentricity Loads

The effect of clearance between the casings is taken into account by adding up the effect of the internal eccentricity moment due to maximum relative movements between the pipes.

This is of course a very conservative approach, particularly when the maximum offset between the conductor and the outer casing is assumed before cementing.

3.4.5 Loading Conditions

The conductor analysis should in principle cover the well completion/ workover operation condition and the full production condition in accordance with the ULS requirements. The most critical concerns in the full production condition are the fatigue and pipe contraction (injection wells). This procedure focuses on the workover operation condition.

Generally, the analysis method to be used for a conductor tied back from a predrilled well is the same as for a platform drilled well. Load conditions to be considered and the differences in analysis for the two mentioned well types are illustrated in Table 3-4.

Table 3-4: *Load Conditions, ref/3/,/12/&/14/*

	Platform-drilled Well	**Tied-back Well**
Work-Over Condition ULS 50yr wave+10yr current	- Soil interaction-Strength & Stability analysis. - Vortex shedding for conductors with a diameter less than 20".	- Strength & stability analysis. - Vortex shedding for conductors with a diameter less than 20".
Full Production Condition - ULS Low risk:100 yr wave + 10 yr current - ULS Med risk:100 yr wave + 0 yr current - ALS 1000 yr wave + 10 yr current	- Fatigue analysis for the segments within the splash zone. – Thermal effects should be considered for injection wells.	- Fatigue analysis for the segments within the splash zone.

3.4.6 Combination of environmental actions

Characteristic values of individual environmental actions are defined by the annual exceedence probabilities for ULS and for ALS.

However in order to achieve parity of structures, environmental criteria specific for each platform, with regards to conductor integrity, need to be utilized. This is dependent on the risk level as given below:

- Unmanned platform, low risk, no pollution risk:

100 yr ULS condition

- Unmanned platform, medium risk, pollution risk:

100 yr ULS + 1000 yr ALS condition

- Manned platform including new builds, high risk, pollution risk:

100 yr ULS + 10,000 yr ALS condition

The combination of environmental actions has to be divided into workover conditions and production conditions. Combination of 50 year wave and 10 year current has to be used during workover condition, while for the production condition 100 year wave and 10 year current has to be used.

In general, since the platform is in production from 1986, the conductor analysis will cover the full production condition in agreement with the ULS requirements (100 year wave and 10 year current)

In the full production condition the most critical verifications to be made are fatigue and pipe contraction, assuming that the K20" conductors installed on EKOK are for a platform drilled well.

4.0 Conductor Analysis

In this chapter an overview of conductor theory has been presented. This is essential background for the hydrodynamic analysis. This chapter is written according to C.P. Sparks (2007), ref/11/ and ISO 19902 ref /14/.

4.1 Tension, pressure and weight

A conductor is connected to the seabed and stretches up past the sea surface to the topside where it is connected to a tension system. To avoid buckling and failure several factors has to be considered, i.e. tension, pressure, weight etc.

4.1.1 Geometric stiffness

The conductor is supported by top tension to increase the lateral stiffness of the conductor. Due to long and slender structure with low elastic bending stiffness (EI), the conductor without the top tension encounter to large displacements when it is exposed to lateral forces, i.e. waves and currents. This is illustrated in Figure 4-1. The additional lateral stiffness that occurs is considered as a geometric stiffness.

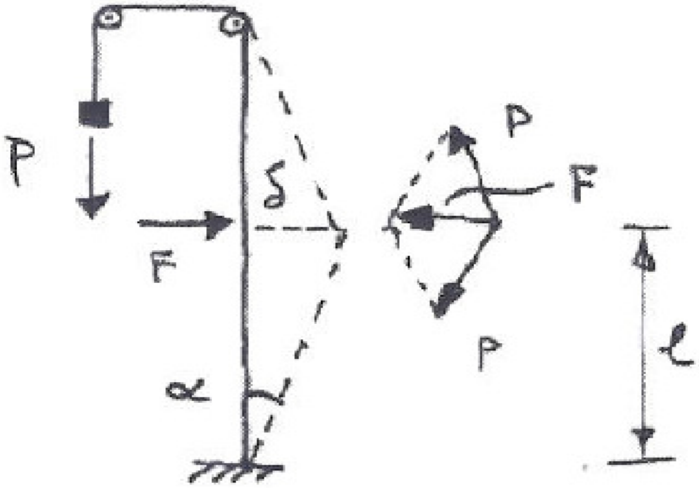

Figure 4-1: Illustration of tension effect on a slender beam, ref/11/

An expression of the geometric stiffness has been shown in Figure 4-1. Force equilibrium is assumed, which gives;

$$F = P_x^1 + P_x^2 = P\sin\alpha + P\sin\alpha = 2P\sin\alpha \qquad (P^1 = P^2 = P)$$

Where F is the resulting lateral force, P is the top tension; P_x is the lateral force component of the top tension and α is the deflection angle. Further, small angles are assumed and the following expressions can be derived;

$$F \approx 2P\alpha \qquad , \qquad \alpha = \frac{\delta}{l}$$

Where δ is the displacement and l is the length from the bottom to the center of the resulting force. This leads us to the geometric stiffness k_G;

$$F \approx 2P\alpha = 2P\frac{\delta}{l} = \frac{2P}{l}\delta = k_G\delta \quad \Longrightarrow \quad k_G = \frac{2P}{l}$$

4.1.2 Effective tension and apparent weight

The apparent weight, w_a, of the segment is the difference between the weight of the segment, w_t, and the displaced fluid, w_e, given by (Sparks, 2007), ref/11/;

Two methods can be used to find equilibrium of a conductor or its segment; i.e. use of effective tension and apparent weight or use of real weight, pressure and axial stress resultant. Both methods are valid, but use of effective tension is more convenient and causes no loss in accuracy.

Effective tension is used in computer OrcaFlex programs for static and dynamic analysis of conductor, as well as for calculation of buckling load and geometric stiffness due to tension in a slender beam.

To find the weight and tension in the conductor the Archimedes principles can be transferred to analyze a curved segment of a pipe, see Figure 4-2. The figure shows a pipe section subjected to both internal and external pressure, in form of fluid pressure. Moments and shear forces have been neglected to make the example easier. The total forces are split into three contributions, the forces acting on respectively the pipe segment itself, the internal and the external fluid (Sparks, 2007), ref/11/.

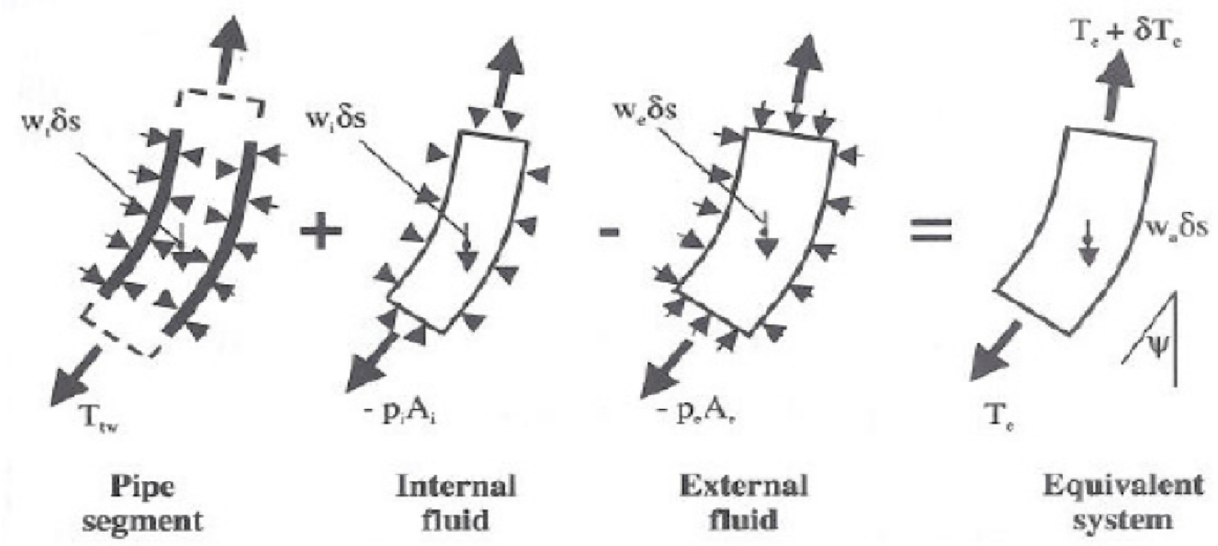

Figure 4-2: Equilibrium of pipe segment exposed to both internal and external fluids (Sparks, 2007), ref/11/

The pressure fields acting on both the internal and external fluid are closed, by adding pressure on the fluids in the axial direction. Corrective pressure resultants are superimposed to the equation because of this extra pressure in the axial direction. The force system acting on the internal fluid is added to the force system acting on the pipe section, and then the force system on the external/displaced fluid is subtracted to find the resulting force. The lateral forces in the three contributions cancel each other out.

The following equations give the resulting tension in the axial direction, the effective tension, and the apparent weight (Sparks, 2007);

$$T_e = T_{tw} + (-p_i A_i) - (-p_e A_e) \qquad w_a = w_t + w_i - w_e$$

Where T_{tw} is the true wall tension (axial tension) in the pipe section, p_i is the pressure in the internal fluid, A_i is the internal cross-sectional area, p_e is the pressure in the external fluid, A_e is the external cross-sectional area, w_i is the internal fluid weight and we is the displaced fluid weight. Notice that the effective tension is not the same as the axial tension. To find the stresses in the pipe wall the wall tension has to be known and it can be found from the equation above as long as the effective tension is known. Figure 4-3 gives the relationship between the effective tension and the apparent weight can be derived. The segment length is δs and all angles, ψ, are assumed to be small (Sparks, 2007), ref/11/;

$$\frac{dT_e}{ds} = w_a \cos\psi \approx w_a$$

The approach used in the previous section can be transformed to a more general definition and applied to more complex pipe systems. The presented equations are only limited by the condition of static equilibrium for the system. In other words there has been set no limiting conditions regarding the cross section density of the material or size of deflections of the pipe, i.e. the equations have general validity. This leads to the following equations and physical description for the effective tension and apparent weight (Sparks, 2007), ref/11/;

$$T_e = \sum T_{tw} + \sum(-p_i A_i) - \sum(-p_e A_e) \qquad w_a = \sum w_t + \sum w_i - \sum w_e$$

"Effective tension is the total axial force in the pipe column, including internal fluid columns, less the axial force in the displaced fluid column (tension positive)"

This makes it possible to calculate the effective tension in systems with; irregular shape, several pipes together. The definition gives that the effective tension in any point will be the sum of forces in all pipe walls and all internal fluids less the forced in the displaced fluid column.

4.2 Stresses

A conductor exposed to external and internal pressure and tension experience stresses in the structure. In the following the different types of stresses that will occur in a conductor subjected to these loads are presented.

It is assumed that the conductor is a circular cylindrical pipe made from isotropic elastic material. The distribution of the stresses depends on the material; for conductor made from isotropic elastic materials the distribution is governed by mechanical principles (Sparks, 2007), ref/11/.

4.2.1 Circumferential and radial stresses

Figure 4-3 shows the internal stresses in a cross-section of an elastic pipe exposed to internal and external pressure as well as tension. The stress acting tangentially to the pipe is called the circumferential stress, denoted σ_c, and the stress acting normal to the pipe wall is the radial stress, denoted σ_r. These stresses vary in the pipe as a function of the radial distance from the axis, but the sum of them is constant over the cross-section and equals the end effect stress, σ_p,;

$$\frac{\sigma_c+\sigma_r}{2} = constant = \sigma_p$$

The end effect stress is due to the internal and external pressure acting on the cross-sectional area of the pipe;

$$\sigma_p = \frac{p_i A_i - p_e A_e}{A_e - A_i}$$

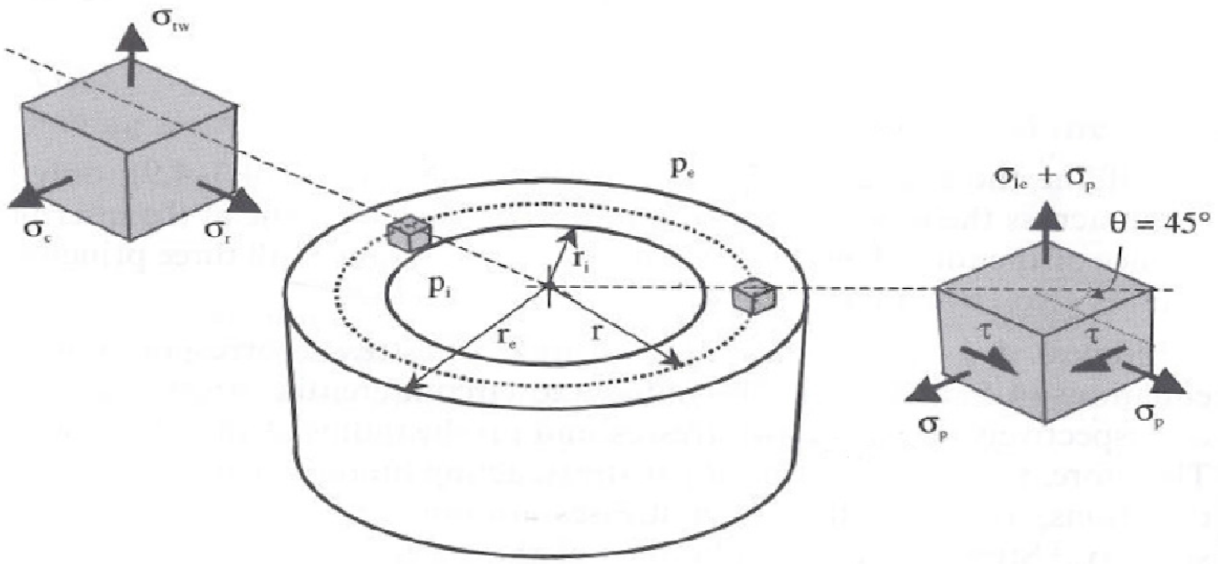

Figure 4-3: Stresses in the conductor wall,
Two equivalent systems are shown (Sparks, 2007), ref/11/

The circumferential and radial stresses can be expressed as functions of shear and end-effect stress:

$$\sigma_c = \sigma_p + \tau \qquad \sigma_r = \sigma_p - \tau$$

$$\tau = \frac{(p_i - p_e)A_i A_e}{(A_e - A_i)A_r}$$

Where;

A_r is the area of a circle with radius equal to the point in the pipe wall under consideration. The axial stresses in the figure will be discussed in the next sub-chapter.

4.2.2 Axial and bending stress

The stress acting vertically in the left box in Figure 4-3 is the axial stress, σ_{tw}, caused by the axial tension, i.e. the true wall tension T_{tw}. The axial stress in a pipe is given by the axial load, here axial tension, divided by the area of the cross-section the load is acting on (Irgens, 1999). The correlation between the stress and the tension in Figure 4-3 is then given by the following equation:

$$\sigma_{tw} = \frac{T_{tw}}{A_e - A_i}$$

The axial stress can be decomposed into a sum of the end effect stress and the effective stress, σ $_{le}$, in the pipe. This can be seen by rephrasing the expression of effective tension:

$$\sigma_{tw} = \frac{p_i A_i - p_e A_e}{A_e - A_i} + \frac{T_e}{A_e - A_i} = \sigma_p + \sigma_{le}$$

This relation makes it possible to find the effective tension and axial stress in a pipe as long as the geometry, pressure loads and axial tension are known. The effective stress has a physical significance and can be described as the part of the axial stress that exceeds the in-wall hydrostatic pressure, i.e. the end effect stresses. A conductor will in reality also be subjected to a bending moment, M, and stresses caused by this bending have to be taken into consideration as well. The bending stress, σ_b, for a structure with constant cross-section exposed to pure bending is assumed to be linearly distributed and given as (Arthur P. Boresi & Richard), ref/19/:

$$\sigma_b = \frac{M}{I} y$$

Where I is the second moment of area, y is the distance to the center axis in the pipe. Superposing the effect of the tensile load and the bending moment according to Navier's formula gives us the total axial stress σ_{ab};

$$\sigma_{ab} = \sigma_b + \sigma_{tw}$$

Assuming that the material is linear elastic, when yield is present the superposing will no longer be valid (Arthur P. Boresi & Richard), ref/19/.

4.2.3 Von Mises' equivalent stress – limit stress

Combination of stresses cause yielding and is therefore of significant importance to check in the calculation of stresses. The von Mises' equivalent stress for the general case of triaxial stress is given by (Sparks, 2007), ref/ 11/;

$$2\sigma_{vm}^2 = (\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 + 6(\tau_{12}^2 + \tau_{23}^2 + \tau_{31}^2)$$

Where σ_{vm} is the equivalent Von Mises' stress, σ_1, σ_2 and σ_3 is the axial stresses in the tree directions, the τ_{12}, τ_{23} and τ_{31} is the shear stresses. Yielding will occur when this stress equals the yield stress of the material. This equivalent stress can also be expressed with the effective axial stress, σ_{le}, and the shear stress, τ, see equation below (Sparks, 2007), ref/11/.

$$\sigma_{vm}^2 = \sigma_{le}^2 + 3\tau^2$$

When the conductor is subjected to bending this also has to be taken into the evaluation of the stress. The Von Mises' stress must be checked at both the inner surface, where the shear stress is at its maximum, and at the outer surface, where the bending stress is at its maximum. Equation can then be rewritten to include the bending stress, σ_b, (Sparks, 2007). Ref/11/;

$$\sigma_{vm}^2 = (\sigma_{le} + \sigma_b)^2 + 3\tau^2$$

4.3 Strains

Strains will affect a conductor in different ways. The interaction between conductor and kill lines can be influenced. Calculation of strains is defined by the material in the pipe; isotropic or anisotropic. In this thesis the strain theory for anisotropic pipes will not be presented, as this is more relevant for high performance composites. The steel pipes in focus in this thesis are isotropic (Sparks, 2007), ref/11/.

In general stresses are related to strains by the Young's modulus E and Poisson's ratio v. This is also the case for elastic isotropic pipes. The axial strain, ε_a, can be calculated with the basis in several stresses. In the expression below the axial strain is given by the true wall axial stress, the circumferential stress and the radial stress (Sparks, 2007). Ref/11/;

$$\varepsilon_a = \frac{1}{E}(\sigma_{tw} - \nu\sigma_c - \nu\sigma_r)$$

All the stresses mentioned in this section have been defined in the previous chapter. The circumferential and radial stresses are separately not constant over the pipe wall. When this equation is used the mean of the circumferential stress and the mean of the radial stress should be used when a thick walled pipe is evaluated (Sparks, 2007), ref /11/.

The mean of sum of the circumferential and radial stress on the other hand is constant and equals the end effect stress, see chapter 4.2.1. When this is implemented into the equation for the axial stress the following equally exact in term is achieved;

$$\varepsilon_a = \frac{1}{E}\left(\sigma_{tw} - 2\nu\sigma_p\right)$$

The effective stress can also be used to express the axial strain equally exact;

$$\varepsilon_a = \frac{1}{E}\left[\sigma_{le} + (1 - 2\nu)\sigma_p\right]$$

The in-wall shear stresses produce no axial strain and will therefore not appear as a factor in the equations. The axial strain can also be rewritten to be expressed by true wall tension or effective tension by substitution, respectively the first and second equation in the following;

$$\varepsilon_a = \frac{1}{E(A_e - A_i)}(T_{tw} - 2\nu p_i A_i + 2\nu p_e A_e)$$

$$\varepsilon_a = \frac{1}{E(A_e - A_i)}[T_e + (1 - 2\nu)p_i A_i - (1 - 2\nu)p_e A_e]$$

5.0 Analysis

The computer software used in hydrodynamic loads on conductor analysis in this thesis is OrcaFlex. OrcaFlex is a program used for static and dynamic analysis of several marine applications. It is a 3D non-linear time domain finite element program, which uses lumped mass element to simplify the mathematical formulation and make the calculation efficient. This chapter is in large extent written according to the user manual in OrcaFlex 9.5.2, ref/13/.

In OrcaFlex the model of conductor is built up from lines, links and springs by use of the graphical user interface in the program. A more detailed description of the model will be given in chapter 6. The process of the analysis can be divided in specific parts. First a model of the conductor is created. Next environmental must be chosen, i.e. waves and current have to be established. When this is established the simulation can be run and results can be collected for post-processing. In the following the element formulation, static and dynamic analysis used by OrcaFlex is presented, while theory about the subjects mentioned can be found in chapter 2.

5.1 Element formulation of line

In OrcaFlex the transfer of the physical conductor into a line model that can be used in calculations is done by dividing the actual conductor into segments. Each segment is then modeled individually by mass less segments with the same length and a node in each end, as illustrated in Figure 5-1:

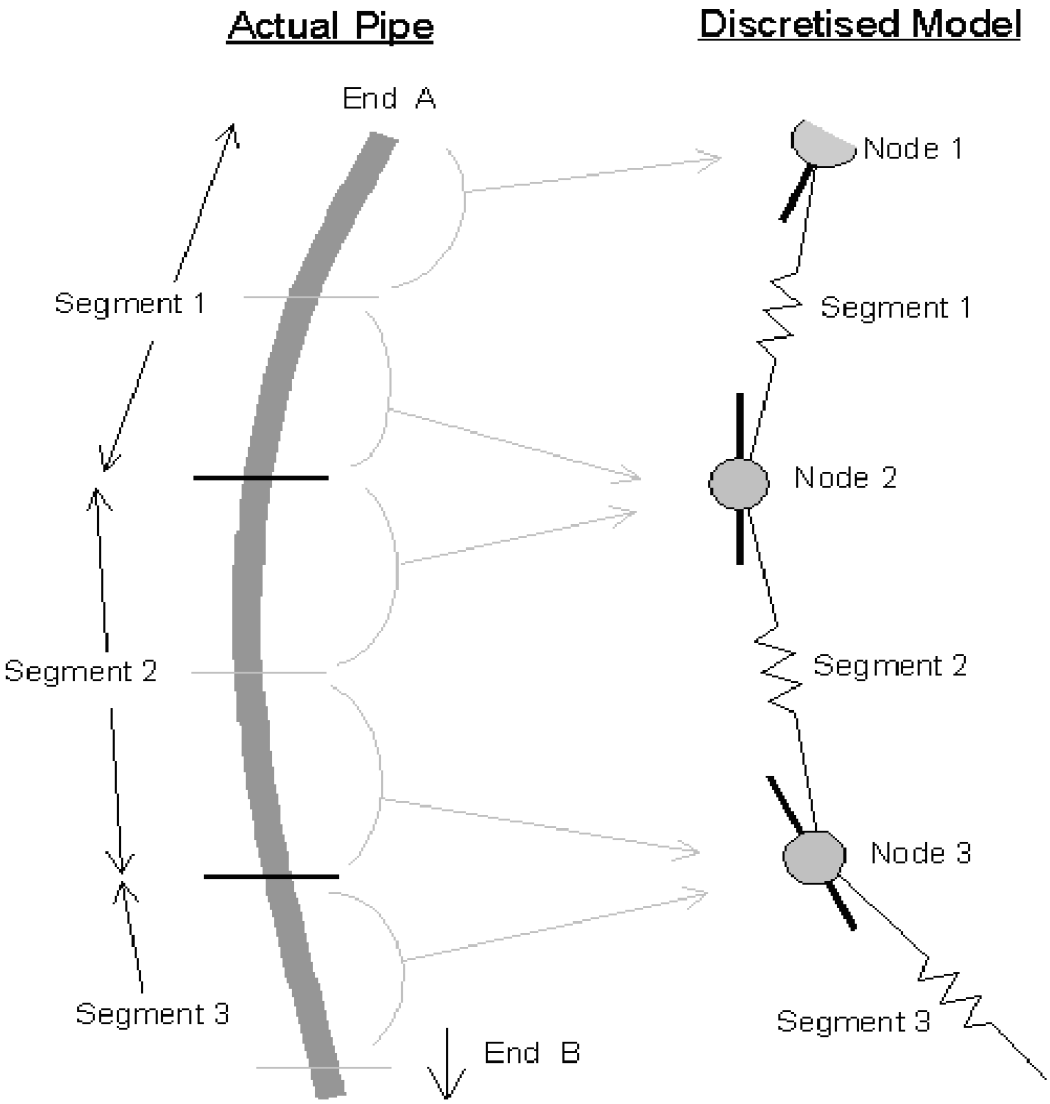

Figure 5-1: OrcaFlex Line model, ref/13/

5.1.1 Node

The nodes model the mass, weight, buoyancy and drag properties of the actual line segments. These properties of the nodes are defined by half of the segment length next to the node. See illustration with arrows in Figure 5-1.The node in each end is in itself modeled as a short rod that represents the combination of the properties of the half segment on each side of the node. Forces and moments are applied at the nodes.

5.1.2 Segment

The segment in the model gives the axial and torsional properties of the physical segment. The segment can be illustrated, see Figure 5-2.as two rods with coinciding axial centers that are connected with an axial and a torsial spring/damper-system. The axial spring/damper system is placed in the center of each segment in the model, and applies an equal and opposite effective tension to the nodes at each end of the segment. The torsional spring/damper system applies equal and opposite torque moments to the nodes at each end of the segment, this system is as the axial system also positioned at the center of each segment. The inclusion of torsion in the analysis is optional, but if it is not included in the analysis the torsional spring/damper system is not included in the model and the segment is free to twist relative to each other.

In addition to the two mentioned system a rotational spring/damper-system is positioned in the ends of each segment to maintain the bending properties assigned to the segments. This can also be seen in Figure 5-2, between the segment and the node. This system makes it possible to have different bending stiffness over the length of the model (Orcina 2011), ref/13/.

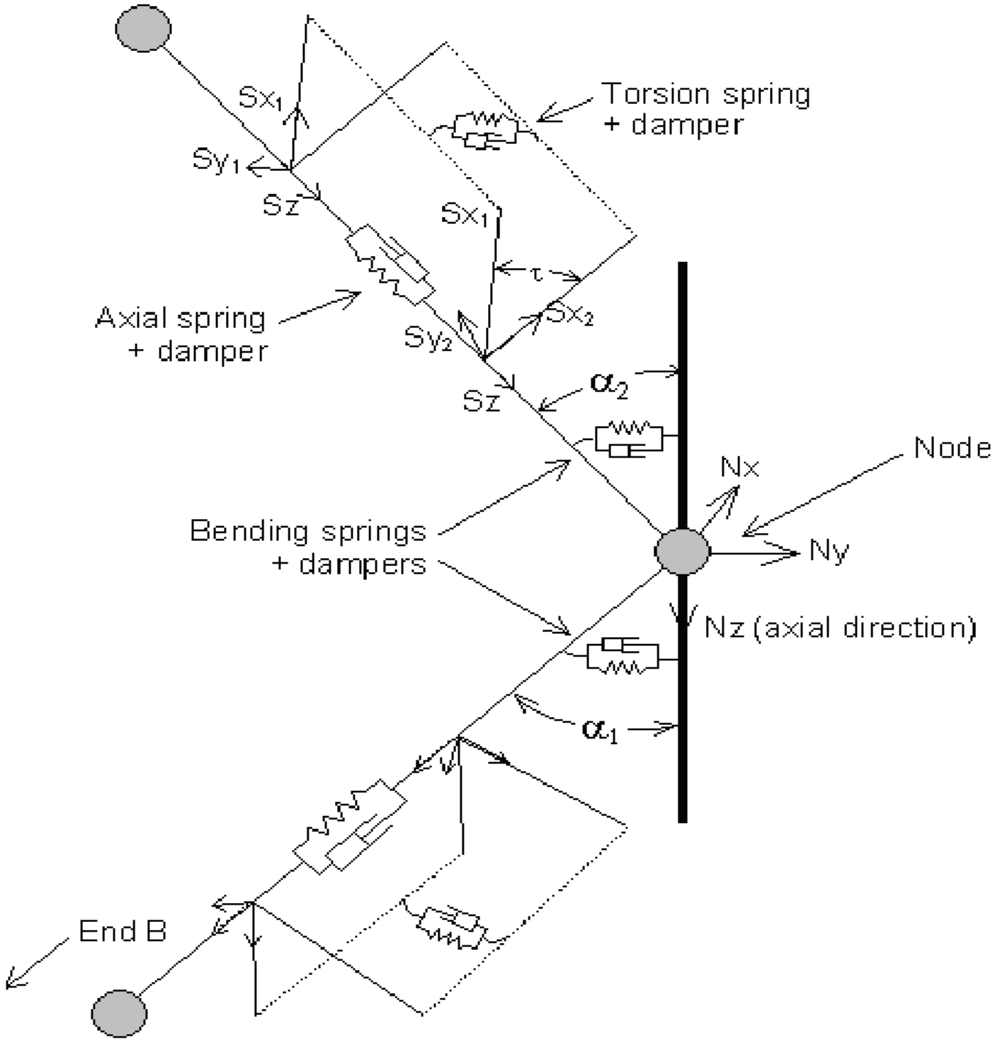

Figure 5-2: Detailed representation of the OrcaFlex line model, ref/13/

5.2 Static and dynamic analysis

The calculation of forces and moments in the line is a large part of the calculation in the analysis of the whole system. This calculation is performed in five stages, respectively in the following order:

- Tension forces
- Bending moment
- Shear forces
- Tension moments

- Torsion moments (if included)
- Total load

After modeling and applying the input data the model can be run by OrcaFlex software.

5.2.1Static analysis

A static analysis is performed to determine the equilibrium position of the conductor system under loads from the system itself, i.e. weight, buoyancy, drag etc. This position is calculated by iteration from the initial position of the system that is given by the input. The equilibrium configuration for each line is calculated with the assumption that the line ends are fixed. From this the out of balance force acting from the line is calculated. This is used to calculate a new position of the whole system. This is repeated until the out of balance force is zero. The position of equilibrium is further used as the starting configuration of the dynamic analysis (Orcina 2011), ref/13/.

OrcaFlex perform the static analysis for each line in the model. The calculation can be divided into two steps where the first is mandatory and the second is optional. The first step is to calculate a configuration of the line and the second step is calculation the equilibrium according to applied forces on the model. OrcaFlex offers several other options for calculation, if it should be computed for all degrees of freedom or none, to include links, and free bodies. This should be adapted to the specific case that is analyzed and the choices can help the model to converge (Orcina 2011), ref/13/.

5.2.2 Dynamic analysis

A dynamic analysis is performed to simulate the motions of the system in the given environment over a time period that is specified. These motions can further give the displacements, forces and moments occulting in the system with the given load. Before the main motion simulation there is a build-up stage where the wave motions are ramped from zero to the full size. This is done to smooth the transition from static to full dynamic motion. In OrcaFlex it is possible to leave out this time period in the results, as it is not representative for the full loads that affect the system.

The calculation performed in the dynamic analysis is done by solving the equation of motion for the given system. The equation of motion that OrcaFlex solves is (Orcina 2011), ref/13/:

$$M(p,a)+C(p,v)+K(p)=F(p,v,t)$$

Where;

$M(p,a)$	is the system interia load
$C(p,v)$	is the system damping load
$K(p)$	is the system stiffness load
$F(p,v,t)$	is the external load
p	position vector
v	velocity vector
a	acceleration vector
t	simulation time

In OrcaFlex the calculation for the dynamic can be performed by two methods. Both methods compute the new system geometry for each time step, i.e. the simulation takes full account for all geometric nonlinearity. The explicit method uses forward Euler with a constant time. Statics give the initial positions. The forces and moments acting on each free body and node in the system are calculated and then used to perform the individual local equation of motion for every free body and node in the system (Orcina 2011), ref/13/

$$M(p,a)=F(p,v,t)-C(p,v)-K(p)$$

This equation is solved for the acceleration at the beginning of the time step. Then integration using Euler forward integration gives the position and orientation of the nodes and the free bodies at the end of the time step. This process is repeated throughout the time of the simulation.

For the other method, the implicit method, the calculations forces, moments, damping, mass etc. are done in the same way as for the explicit method. The integration is done by use of the generalized- integration. And the equation of motion of the system is then solved at the end of the time step (Orcina 2011), ref/13/.

The forces and moments that are considered in the calculation of the motion equation vary with the given model, but weight, buoyancy, hydrodynamic and aerodynamic drag, hydrodynamic added mass effects, tension and shear, bending, contact forces with other objects are highly relevant in modeling of conductor. The choice of time step in the analysis is a balance between stable integration, accuracy in calculations and efficiency in computational time.

5.3 Loads

The loads on the system may include functional, environmental, accidental loads etc. To model the reality it is important to be aware of the loads affecting he system. Increasing water depths can introduce new concepts and material in the structure, which again can give new load combinations and failure modes. The loads that affect a conductor and that are important to take into consideration in an analysis include the following:

- Weights of the structure including internal fluid and buoyancy modules or other type of external add- on equipment.
- Hydrodynamic loads from waves and current including both drag and inertia forces, possibly aerodynamic loads from wind
- Hydrostatic forces from the water surrounding the conductor
- Forces occurring because of forces motion
- Top tension to avoid buckling in the conductor and minimize the load

The weight forces is using for calculation of effective tension. These forces are included in the static analysis when the static equilibrium is calculated. Top tension is also determined from the weight of the structure and the effective tension in the conductor.

Dynamic waves and currents acting on a conductor over along period of time generate fatigue stresses and fatigue is a parameter that has to be considered in this analysis.

5.3.1 Hydrodynamic pressure

A conductor is exposed to pressure from the surrounding water. The effect of this pressure on the conductor is included in the calculation of the tension in the system, either wall tension or effective tension, and they are all related to each other through the following expression which is used in OrcaFlex (Orcina 2011), ref/13/:

$$T_{tw} = C_1(T_e + p_i A_i - p_e A_e)$$

Where;

T_{tw} is the wall tension

C_1 is a stress loading factor used by OrcaFlex to specify the proportion of the loads used in the tension calculation

T_e is the effective tension;

$Te = EA.e + (1 - 2\nu)(PoAo - PiAi) + EA.e(dL/dt)/L0$

Where;

EA = axial stiffness of line, as specified on the line types form
e = mean axial strain = $(L - \lambda L0) / (\lambda L0)$
L = instantaneous length of segment
λ = expansion factor of segment
L0 = unstretched length of segment
ν = Poisson ratio
Pi, Po = internal pressure and external pressure respectively
Ai, Ao = internal and external cross section areas respectively
e = damping coefficient of the line, in seconds
dL/dt = rate of increase of length

p_i is the internal pressure calculated from contents pressure.

p_e is the pressure from surrounding water the external pressure The pressure from surrounding water the external pressure assumed to be zero at and above the mean water level. The internal and external cross-section areas,

A_i & Ae are both calculated from the respective stress diameters. The stress diameters are the diameters of the load bearing cylinder, i.e. effects of the kill and choke lines can be neglected and consideration is only given to the main pipe when this input is given to OrcaFlex.

5.3.2 Implementation of waves

In the dynamic analysis the model is subjected to waves. OrcaFlex gives several options for implementation of these waves in the model; they can be regular waves, random waves or specified by a time history. For the regular wave modeling the following choices are available: long-crested linear AIRY wave or nonlinear waves using Stokes' 5th. The waves are specified by input values for wave height, wave period and direction of propagation (Orcina 2011), ref/13/.

For random waves the program creates a wave history from the linear waves decided by the user by various input values. The wave components are chosen by use of an equal energy approach and the phase of the waves is given by a random number generator. For random waves the user has to specify the frequency spectra to model the random wave. The specter shows how the energy distributes over the frequency spectra to model the random wave. The specter shows how the energy distributes over the frequency occurring in the sea. The choices for spectrum are: JONSWAP, ISSC, Ochi-Hubble, Torsethaugen and Gaussian Swell (Orcina 2011), ref/13/. The respective spectra need different input values. According to NORSOK standard N-003, ref/5/ Torsethaugen or JONSWAP spectra is suited to represent the design sea state in the Norwagian Sea and North Sea.

JONSWAP (Joint North Sea Wave Project) is a wave specter which is created on the basis of the Pierson-Moskowitz spectrum and measured data from south-east parts of the North Sea. The specter is a good model for wind generated sea in the JONSWAP area. Input values required for OrcaFlex for this spectrum is the wave height, wave period and direction of propagation.

5.3.3 Hydrodynamic loads- Morison's equation

For slender structure with circular cross-section like the conductor the Morison's equation can be applied for calculation of the hydrodynamic forces. The equation has been considered controversial for many years, but it has been the marine method for calculation of hydrodynamic forces for almost 50 years because it calculates the forces with reasonable accuracy. It is considered controversial because the drag term in the equation is nonlinear. The equation is applied to the conductor by strip theory to calculate the hydrodynamic force, f_H , per unit length, d $_z$, in two dimensions. The forces given by this equation can be considered as the resultant of dynamic and static pressure fields acting on the conductor. The forces is built up form two contributions, respectively a drag force, f_D , and an inertia force, f_I (Sparks, 2007, ref/11/:

$$f_H = f_D + f_I$$

The drag forces are a result of the velocity of the flow that passes the conductor, while the inertia forces are a result of the acceleration of the flow.

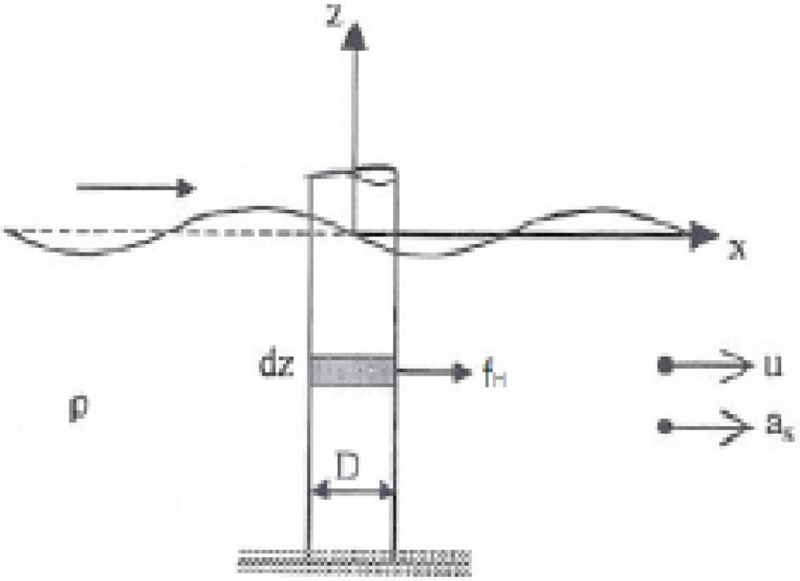

Figure 5-3- Illustration of strip division and the sizes in Morison's equation

5.3.3.1 Drag force

Testing in laboratories with steady flow has shown that the drag for a circular cylinder varies with the square of the velocity of the fluid past the body. The expression of the drag term for circular cylinders exposed to flow normal to its axis can be given as follows (Sparks, 2007), ref/11/:

$$f_D = \frac{1}{2}\rho C_D D u |u|$$

Where ρ is the fluid density, C_D is the drag coefficient, D is the conductor diameter and u is the instantaneous velocity (i.e. the velocity in the fluid as if the object was not present) normal to the cylinder axis. If the forces on the conductor cause the conductor to move laterally with a velocity v, this has to be taken into consideration in the calculation of the drag term. This is done by using the relative velocity, shown in the equation below (Sparks, 2007), ref/11/.

$$f_D = \frac{1}{2}\rho C_D D(u-v)|u-v|$$

5.3.3.2 Inertia force

Testing has also been done to investigate the inertia force due to the fluid acceleration. For a stationary sphere of volume V, with a density p, subjected to a uniform acceleration the inertia force can be expressed as (Sparks, 2007), ref/11/:

$$f_I = \rho C_M V \dot{u}$$

Where C_M is the inertia coefficient and $\dot{u}$ is the instantaneous acceleration of the fluid. The inertia force has two contributions, namely the hydrodynamic force acting on the displaced fluid in the absence of the sphere $\rho V \dot{u}$ and an additional force due to the acceleration of the fluid relative to the sphere $((C_M - 1)\rho V \dot{u})$. The expression including the inertia coefficient $(C_M - 1)$ is often set equal to C_M and termed mass coefficient or added mass coefficient in some literature. If the sphere itself is moving with acceleration, V, the relative acceleration has to be used. This result in the following equation:

$$f_I = \rho V \dot{u} + (C_M - 1)\rho V (\dot{u} - \dot{v})$$

$$f_I = \rho A_e \dot{u} + (C_M - 1)\rho A_e (\dot{u} - \dot{v})$$

where A $_e$ is the external cross-sectional area.

The two contributions result in the hydrodynamic force and per unit length of the conductor it can be expressed as follows:

$$f_H = \frac{1}{2}\rho C_D D(u - v)|u - v| + \rho A_e \dot{u} + (C_M - 1)\rho A_e (\dot{u} - \dot{v})$$

For conductor with a cross-section geometry consisting of more than a bare pipe the diameter and area used in the Morison' s equation has to be adjusted. This is the case for conductor where cylinder which has a small diameter compared to the length of the cylinder, and is situated in high Reynolds number, can be set to 1.2.additional lines are connected to the main pipe. An equivalent diameter and an equivalent area corresponding to the real pipe geometry should be used in the calculation of the forces. (Sparks, 2007), ref/11/.

The mass coefficients, C_M , and drag coefficient, C_D ,should be determined empirically for the specific case. The coefficient depends on many factors; some that can be mentioned are Reynolds number, Keulegan-Carpenter number, roughness number, relative current number, body form, free surface effects etc. For some familiar geometries typical values for the coefficients are known, i.e. assumptions of the values of the coefficients can be made. The inertia coefficient for a smooth cylinder at high Reynolds number has typically the value 2, i.e. the mass coefficient is 1 (The drag coefficient for a smooth circular)

5.3.3.3 Hydrodynamic forces in OrcaFlex

In OrcaFlex the hydrodynamic loads are calculated for lines & links used in the model, and the morison's equation is used to perform the calculation:

$$F_w = (\Delta a_w + C_m \Delta a_r) + \frac{1}{2}\rho V_r \left|V_r\right| C_D A$$

This is the same expression as shown in the previous sub-chapter, but it is not given per meter it is given for the whole length of the object in focus. F_w is the wave force, i.e. the hydrodynamic force F_h. The expression in the parentheses is the inertia force, where Δ is the mass of the fluid displaced by the body (volume times the density), a_w is the fluid acceleration, a_r is the fluid acceleration relative to the body. The last term in the equation is the drag force. V_r is the fluid velocity relative to the body and A is the drag area. (Orcina 2011), ref/13/.

The drag on the model is calculated using the cross flow principle, i.e. the fluid velocity is split into components acting normal and parallel to the line axis. The drag coefficients are also split into the respective directions, and the drag areas have to correspond to the directions as well. The drag coefficients normal to the axis can be specified constant or to vary with Reynolds number or height above seabed.

Added mass for the line model is built up from two contributions and is calculated separately for the local x-, y- and z-directions.

The lift on the model can also be calculated. The lift coefficients can be specified constant or to vary with Reynolds number or height above seabed. But if a symmetric cross-section is assumed there will be no lift force as there exists no pressure difference.

5.4 Coordinate system

OrcaFlex has three types of coordinate system. GXYZ is the global coordinate system. This global reference system must be a right handed system with the Z-axis directed upwards. The position of origin is chosen by the user, in conductor analysis it is often positioned in the water surface (Orcina, 2011), ref/13/, Figure 5-4:

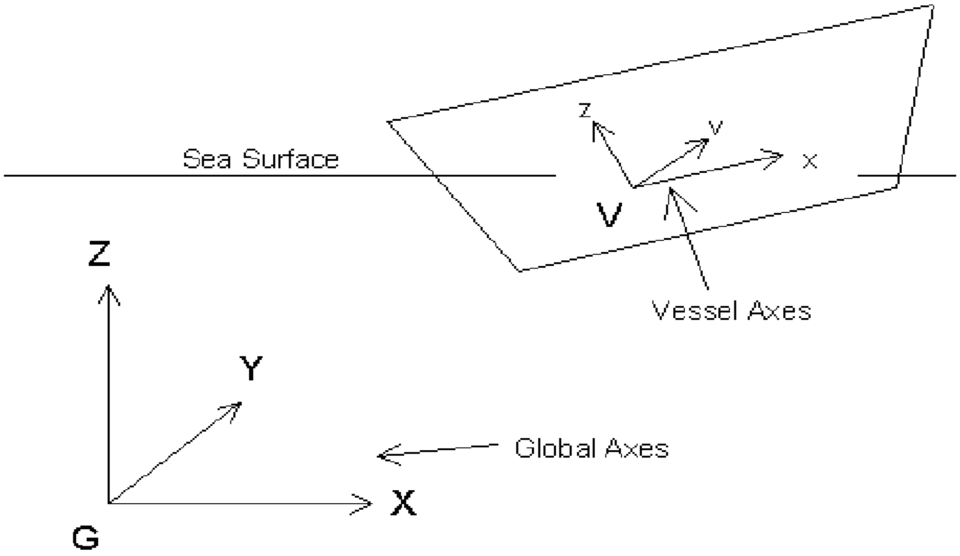

Figure 5-4: Illustration of coordinate system in OrcaFlex , ref/13/)

6.0 Modeling

The conductor is modeled as a pile exposed to currents & waves. The model created in this thesis is based on the conductor used on the Ekofisk K platform.
Analyses have been carried out by use of the software Orcaflex 9.5, ref /13/.

6.1 Methodology

Regular Stokes' 5th waves have been used to represent the different sea states. The wave heights are calculated as:

$$H_{max} = H_{m0} \cdot \sqrt{\frac{\ln(N)}{2}}$$

Where,

H_{m0}	significant wave height
N	number of wave amplitudes

$$N = \frac{T_{total}}{T_{m02}}$$

Where,

T_{total} -total duration of sea state. T_{total} = 3 hours = 10800 sec

T_{m02} -zero up-crossing period (s)

The most important part of the analysis is to know how much damping to consider. This parameter has been described in section 6.2.2.3.

The analyses are based on the following assumptions and simplifications:

1- The global jacket deflections are not taken into consideration.

2- There is no vertical force considered in the guide, since there is no friction between the conductor and it's guide.

3- Vortex shedding effects are not considered in hydrodynamic calculations.

4- The conductors and the guides are assumed to be straight.

5- He wave has been distributed in all of 8 directions including North (N), North-East (NE), East (East), South- East(SE), South (S), South –West (SW), West (West) & North- West (NW).

6- All damper elements have the same calculated damping factor.

6.2 Model

The model of a conductor will be a straight pinned beam with tension acting as a force at the top and which is free to translate in the vertical direction at the top end. The modeling and data input used for the conductor system in the analysis will be presented in the following.

The different components in the conductor system will be interpreted and added to the model as a stiff mass. The stiff mass will in most cases be close to rigid. Hydrodynamic coefficients used in this analysis are including both the normal drag coefficient and the associated drag diameters.

A general sketch containing the decks elevations and clearances between the guides & the 20 "conductors have been shown in Figure 6-1.

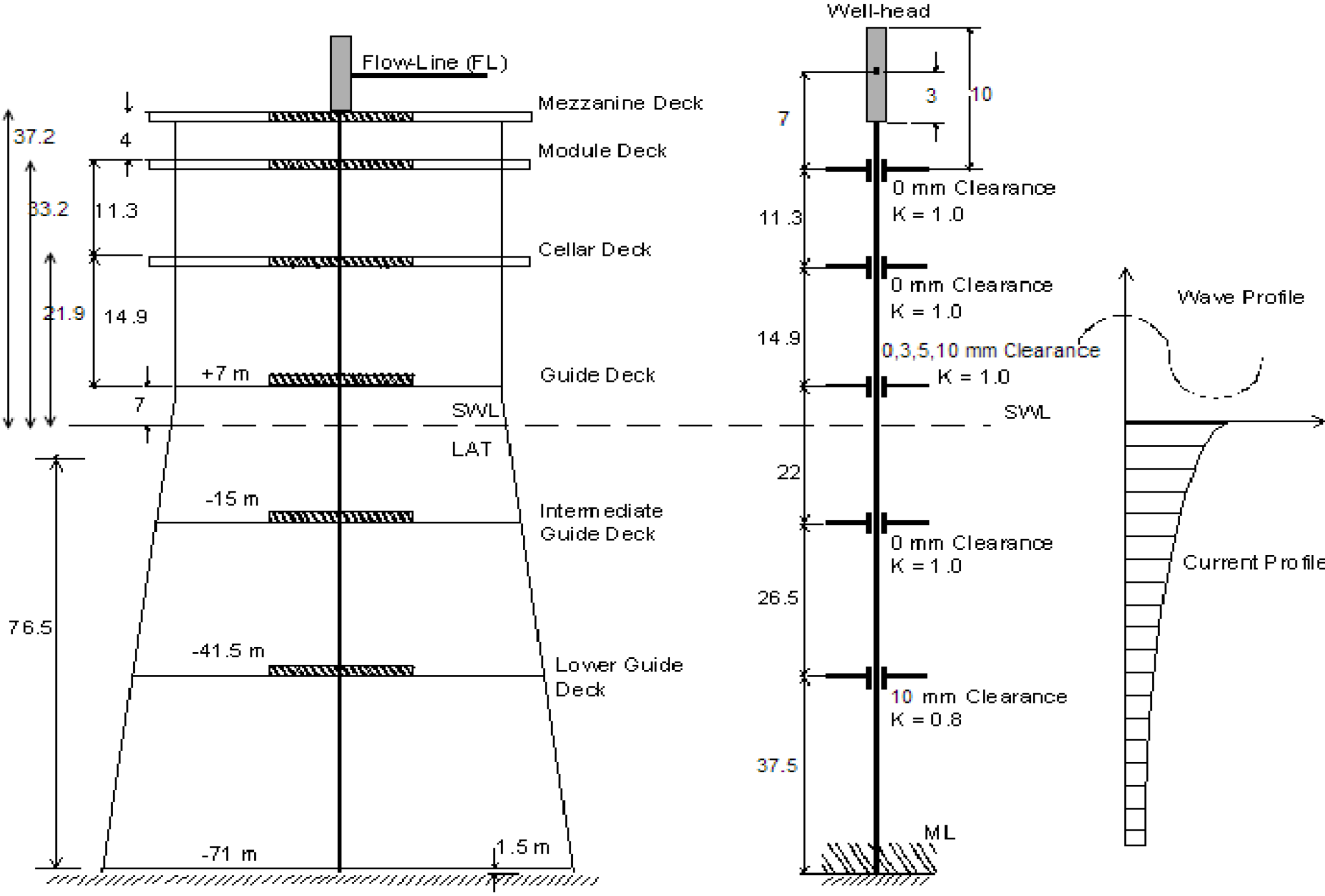

Figure 6-1: Deck elevations & clearances between conductor and it's guide
(The Deck elevation is shown in left side & guide clearances are shown in right side)

6.2.1 Model components and build-up in OrcaFlex

The model built in OrcaFlex consists of four lines representing conductors and seven springs representing the conductor guides & the X-mass tree. The conductor line is assumed to start, where the connection to the X-mass tree has a nonlinear stiffness and is given by the deflection angle and corresponding bending moment defined. OrcaFlex can interpolate linearly for values between the ones given as input. The model Geometry has been shown in Figure 6-2.

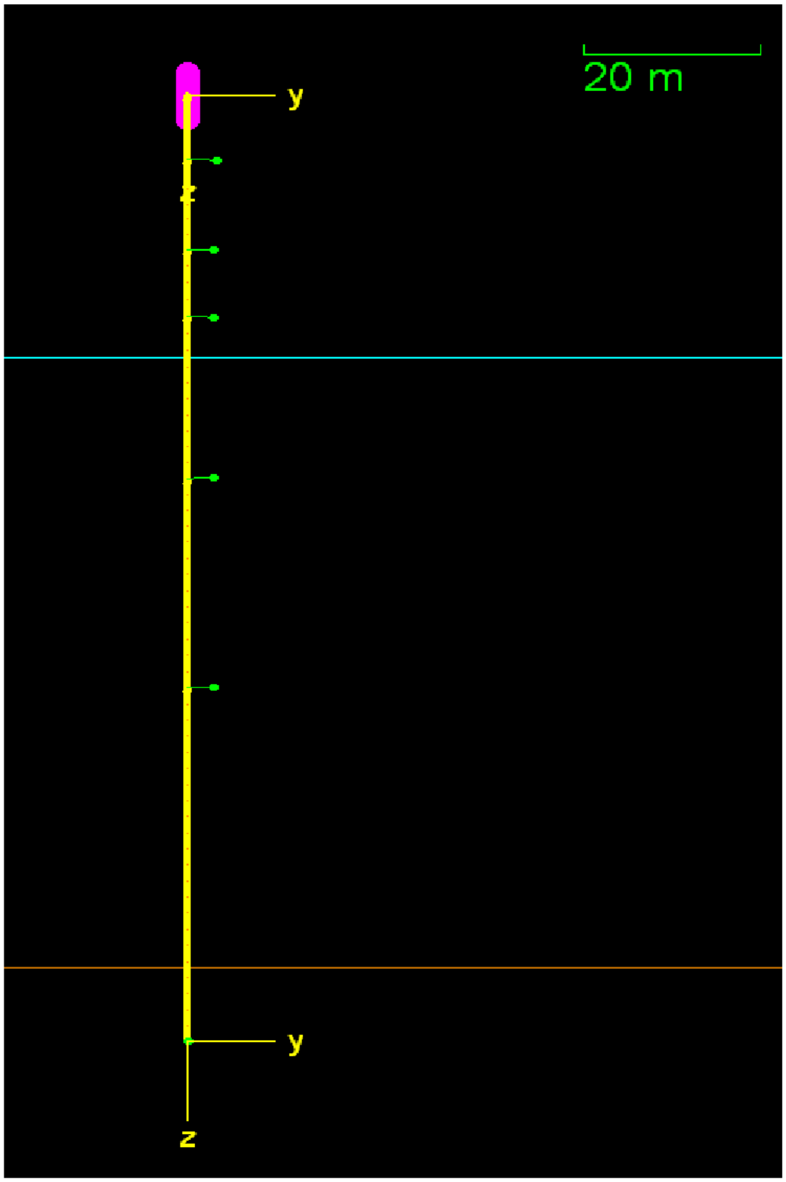

Figure 6-2- Model Geometry in OrcaFlex 9.5, ref/13/

A point of total fixation at the connection of the conductor with the Xmass tree is assumed at 3.0 m (6*D). This makes up the first line part of the conductor which is connected in the lower end as infinity stiff.

The single conductor has been modeled as line elements. The conductor is supported at the seabed and guided horizontally at the Module, cellar, Upper Guide, Intermediate & Lower decks with conductor frames.

The guides are modeled by use of non linear springs and linear dampers. The properties of the springs are given in Table 6-1 and shown in Figure 6-3. The linear damping value has been chosen 1000 (Ns/m). The conductor frames should be simulated as fixed guides with given clearances to the conductors. The clearances have been provided as described in Figure 6-1. Also, the conductor has been assumed to be centrally located through the guides.

***Table 6-1:** Spring properties*

Length(X) (mm)					**Force/meter (kN/m)**
Module deck (0mm gap)	Cellar deck (0mm gap)	Upper Guide deck (0,3,5,10 mm gap)	Intermediate Guide deck (0mm)	Lower Guide deck(10mm)	
-1000.0	-1000.0	-1000.0	-1000.0	-1000.0	-25E4
0	0	0,-3,-5,-10	0	-10.0	0.0
0	0	0,3,5,10	0	10.0	0.0
1000.0	1000.0	1000	1000	1000	25E4

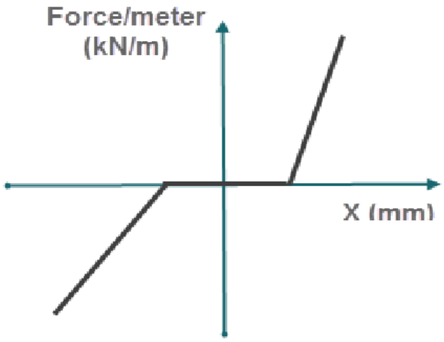

Figure 6-3: spring properties

6.2.2 Data for input and calculations

The data input has been presented as it is required to be given in OrcaFlex, and the choices for analysis parameters will be presented.

6.2.2.1 Environmental data

The environmental Data used in calculations is presented in Table 6-2.

The environment used in the model has been taken from the Metocean and Geophysical criteria for Greater Ekofisk Area, ref/ 3/.

Table 6-2: *Enviromental data for the Ekofisk field, ref /3/*

Enviromental data for the Ekofisk field		
Density air	1	(kg/m^3)
Density water	1.025	(kg/m^3)
Kinematic viscosity	1.5E-6	(m^2/s)
Water temperature	6.4	(°C)
Water depth	77.5	(m)
Current	Variable with depth	-
Wave	1, 10, 100	years
Frequency spectrum	Stokes' 5th	-
Direction	180	deg

6.2.2.2 Component data

- **Geometry and mass**

Data used in the calculations for the components and as input to OrcaFlex for geometry and mass are given in Table 6-3. All parts of the conductors are modeled as pipes. In OrcaFlex only simple cylinders are modeled, therefore equivalent diameters had to be calculated and used for the pipes. This is done to preserve the physical properties, e.g. weight and buoyancy. The data for input and calculations have been shown in chapter 2, table 2-1.

Table 6-3: *Properties for 20" conductor and X-mass tree*

	Mass (kg)	**Axial Stiffness EA (kN.m ^{2})**	**Bending stiffness EI (kN.m^2)**
Conductor 20"	15662	3585023.2	110702.3
X-mass tree	9463	7170046.4	221404.6

- **Stress**
  OrcaFlex also requires input data for stress calculations; this input is given in Table 6-4:

Table 6-4: *Input data for stress in OrcaFlex*

Component	**ID $_{stress}$ (m)**	**OD $_{stress}$ (m)**
20" conductor	0.486	0.508
13 3/8" conductor	0.315	0.340
9 7/8 " conductor	0.219	0.251
5 ½" conductor	0.124	0.140

- **Stiffness**

Bending and axial stiffness are also calculated for each line component and given as input to the model; this input is given in Table 6-5:

Table 6-5: *Input data for bending & axial stiffness in OrcaFlex*

Component	**Axial Stiffness EA (kN)**	**Bend. Stiffness EI(kN.m^2)**
20" conductor	358.02e+04	110.7e+03
13 3/8" conductor	259.72e+04	34.874+03
9 7/8 " conductor	242.79e+04	16.825e+03
5 ½" conductor	66.064e+04	1.444e+03

6.2.2.3 Damping

Damping in the analysis can be divided in two parts:

-Structural /hydrostatic damping

- Hydrodynamic damping due to squeezed water between conductor and conductor guides.

Structural /hydrostatic damping

The structural and hydrostatic damping is modeled by use of Rayleigh damping. The coefficients are calibrated to get 1.5 % of critical damping at 0.1 Hz to 20 Hz, (OTC - 3798, 1980), ref/9/.

The relative damping at a particular frequency is calculated with the following equation:

$$\xi = \frac{\alpha}{2 \cdot \omega} + \frac{\beta \cdot \omega}{2}$$

where:

ξ - relative damping;

ω - angular velocity ($2\pi\nu$)

α, β - constants in the Rayleigh damping formulation (mass and structural contributions)

Hydrodynamic damping

It has been estimated that the water squeezed between the conductors and guides can contribute to the overall damping with a factor of 5% of the critical damping - conductor's lowest frequency. (OTC -3861, 1980), ref/ 10/.

6.2.2.4 Analysis parameters

The analysis should be done both for static & dynamic situations.

To run complete 3 hours (10 800s) sea states for given significant wave height, analysis should be run.

Numbers of cycles for all 8 directions are calculated as:

$$N_{cycles} = N_{Sea\_States} \cdot \frac{T_{total}}{T_{m02}} = N_{Sea\_States} \cdot \frac{10800}{3.3\sqrt{H_{m0}}}$$

where:

"N_{Sea_States}"	is number of 3 hours sea states for given significant wave height,
H_{m0}	is significant wave height during 30 years,
10800	is total duration of each sea state given in seconds

7.0 HYDRODYMIC ANALYSIS RESULTS

For calculation of environmental loads a beam model was built in OrcaFlex program for conductor analysis with no shielding effect considered, referring to chapter 6.0. The results of the dynamic analysis are node forces calculated at each elevation of the conductor.

7.1 Beam Column analysis

In order to calculate the external moments caused by waves and current beam column analysis should be performed.

The conductor has to be meshed along its length with beam elements by the OrcaFlex program. The conductor and outer casing are modeled as one member with equivalent properties.

The main input needed in a beam column analysis is:
- Pipe properties (line type)
- Wave/current loads
- Live/dead loads
- Soil data

As output from the column analysis is the external moments that will represent the input to the final code check.

7.2 Code Check

The code check should be performed in accordance with the API RP 2A/AISC, ref/17/ & ref/18/ strength criterion and the modified stability criterion referring Amoco Production Co., B. Stahl et al.: *"Design Methodology for Offshore Platform, conductors"*, OTC Paper 3902, 1980, ref/8/.

By using OrcaFlex, the stability criterion should be applied to check the stability at the points of maximum moment.

The code check criteria are given as follows, referring API RP2A, ref/17/:

1. Strength criterion:

$$\frac{\gamma \cdot (P_i + P_E)}{P_y} + \frac{\gamma \cdot M}{1.18 \cdot M_p} \leq 1.0$$

2. Stability criterion:

$$\frac{\gamma \cdot P_i}{P_y} + \frac{\gamma \cdot P_E}{P_{crm}} + \frac{\gamma \cdot C_m \cdot M}{\left(1 - \frac{\gamma \cdot P_E}{P_e}\right) \cdot M_p} \leq 1.0$$

where:

γ - Load factor; γ = 1.7 (dead + live load); 1.3 (dead + live + environment load)

P_I - Internal axial forces caused by casing weight and thermal effect if applicable

P_e - Euler buckling load

P_y - Axial load capacity

P_E - External loads due to loads above considering point

M_p - Plastic hinge moment capacity

C_m - Column curvature coefficient; C_m = 0.85

P_{crm} - Modified critical buckling load;

$$P_{crm} = 1.7 \cdot A \cdot \frac{\sigma_{crm}}{\eta}$$

η - Safety factor defined in API/AISC code (η = 1.67).

7.2.1 Internal axial loads

Internal axial loads are applied to a conductor in two ways due to:

1. The hanging and pre-tensioning of the internal casings and strings (highest loads on a conductor)
2. The thermal expansion that occurs in the internal casings (neglected in calculations)

7.2.2 External Axial loads

The dead weight of equipment located on top of the conductor is considered to be an external load. These loads contribute to the instability of a conductor and cause the buckling failure.

External axial loads consist of:

- Dead weight of the BOP (blow out preventer) stack; - wellhead
- Casing spools; - valves & hoses
- drilling and/or production equipment situated on top of the conductor

The external load considered in present analysis comprises of the weight of X-mass tree and well head:

G = 94.6 kN situated on the top of the conductor, refer to Table 6-3, section 6.2.2.2.

7.2.3 Bending Loads

7.2.3.1 Internal Bending Loads

Internal bending moments are created by the eccentricity of internal casing strings. The internal bending stress is given by the internal axial loads when the strings are in tension and the eccentricity e.

$$e = \frac{ID_{external\_conductor}}{2} - \frac{ID_{internal\_conductor}}{2} - \sum WT_{interm\_strings}$$

$$M_{bending} = P_{internal} \cdot e$$

where:

ID - Internal pipe diameter
OD - outer pipe diameter
WT - wall thickness

7.2.3.2 External Bending Loads

External bending moments on a conductor are created by environmental loadings, such as wind, waves and current. These loads are determined by hydrodynamic analysis of the conductor by OrcaFlex program.

The bending moment diagram for different return wave period including 1, 10 and 100 years return periods for H_{max} & T_{max} are obtained by combining the maximum and minimum bending moments which act upon the conductor for different clearances according to Figure 6-1, chapter 6.0. The bending moment diagrams for every case have been presented in Appendix B.

7.3 Bending Moment Results

The maximum bending moments (1, 10 and 100 year return periods) for four different gaps (0.0, 3.0, 5.0 and 10.0 mm) are shown in Table 7.1 to Table 7.3.

Table 7-1 : *Max. bending moment between conductor and guides for 1, 10 and 100 year return periods and* ***0.0 mm clearance*** *at upper deck guide*

CASE 1	Clearance (mm)	Bending moment(kN.m)		
		1 Year	10 Years	100 Years
Module Deck Guide	0	856.66	846.88	830.72
Cellar Deck Guide	0	301.43	303.18	265.82
Upper Deck Guide	0	959.70	955.69	951.47
Intermediate Deck Guide	0	385.83	371.15	359.25
Lower Deck Guide	10	317.27	298.60	281.01

Table 7-2: *Max. bending moment between conductor and guides for 1, 10 and 100 year return periods and* ***3.0 mm clearance*** *at upper deck guide*

CASE 2	Clearance (mm)	Bending moment(kN.m)		
		1 Year	10 Years	100 Years
Module Deck Guide	0	676.38	661.40	640.81
Cellar Deck Guide	0	390.89	389.70	331.30
Upper Deck Guide	3	1208.84	1213.92	1219.75
Intermediate Deck Guide	0	744.43	737.07	730.78
Lower Deck Guide	10	625.44	616.45	611.80

Table 7-3: *Max. bending moment between conductor and guides for 1, 10 and 100 year return periods and **5.0 mm clearance** at upper deck guide*

CASE 3	**Clearance (mm)**	**Bending moment(kN.m)**		
		1 Year	**10 Years**	**100 Years**
Module Deck Guide	0	287.48	275.25	263.02
Cellar Deck Guide	0	195.94	276.69	313.57
Upper Deck Guide	5	1239.16	1230.70	1221.58
Intermediate Deck Guide	0	738.87	736.86	734.16
Lower Deck Guide	10	586.83	590.28	590.15

Table 7-4: *Max. bending moment between conductor and guides for 1, 10 and 100 year return periods and **10.0 mm clearance** at upper deck guide*

CASE 4	**Clearance (mm)**	**Bending moment(kN.m)**		
		1 Year	**10 Years**	**100 Years**
Module Deck Guide	0	166.03	211.64	232.15
Cellar Deck Guide	0	120.27	274.94	312.48
Upper Deck Guide	10	1075.44	1071.11	1066.59
Intermediate Deck Guide	0	820.01	820.62	821.34
Lower Deck Guide	10	216.46	224.36	209.68

The analysis show that the maximum bending moment of **1239.16 kN.m** generated by a 1 year return wave and current occur at the conductor-guide contacts situated on the upper guide Deck (see data in Table 7-3) in case of a 5.0mm clearance at the upper guide Deck.

The Bending moment results for Case 2 (3 mm clearances in upper guide deck) in comparison with case 3 (5 mm clearances in upper guide deck) are gradually decreased in the 4 different guides, while there is (2.4 %) increasing moment in the singular upper deck guide for 1, 10 and 100 years return periods.

Additionally, comparing results of case 2 (3 mm clearances in upper guide deck) with case 4 (10mm clearances in upper guide deck) show that the bending moment along the conductor is extremely decreased for different guides. Hence, it could be concluded that the bigger clearances provide a reduced bending moment. This fact may be proved according to shear forces component along the conductor, which is presented in section 7.6.

The bending moment diagrams for extreme condition (100 years return wave) are obtained by combining the maximum and minimum bending moments which act upon the conductor; see Figures 7-1 to Figure 7-4.

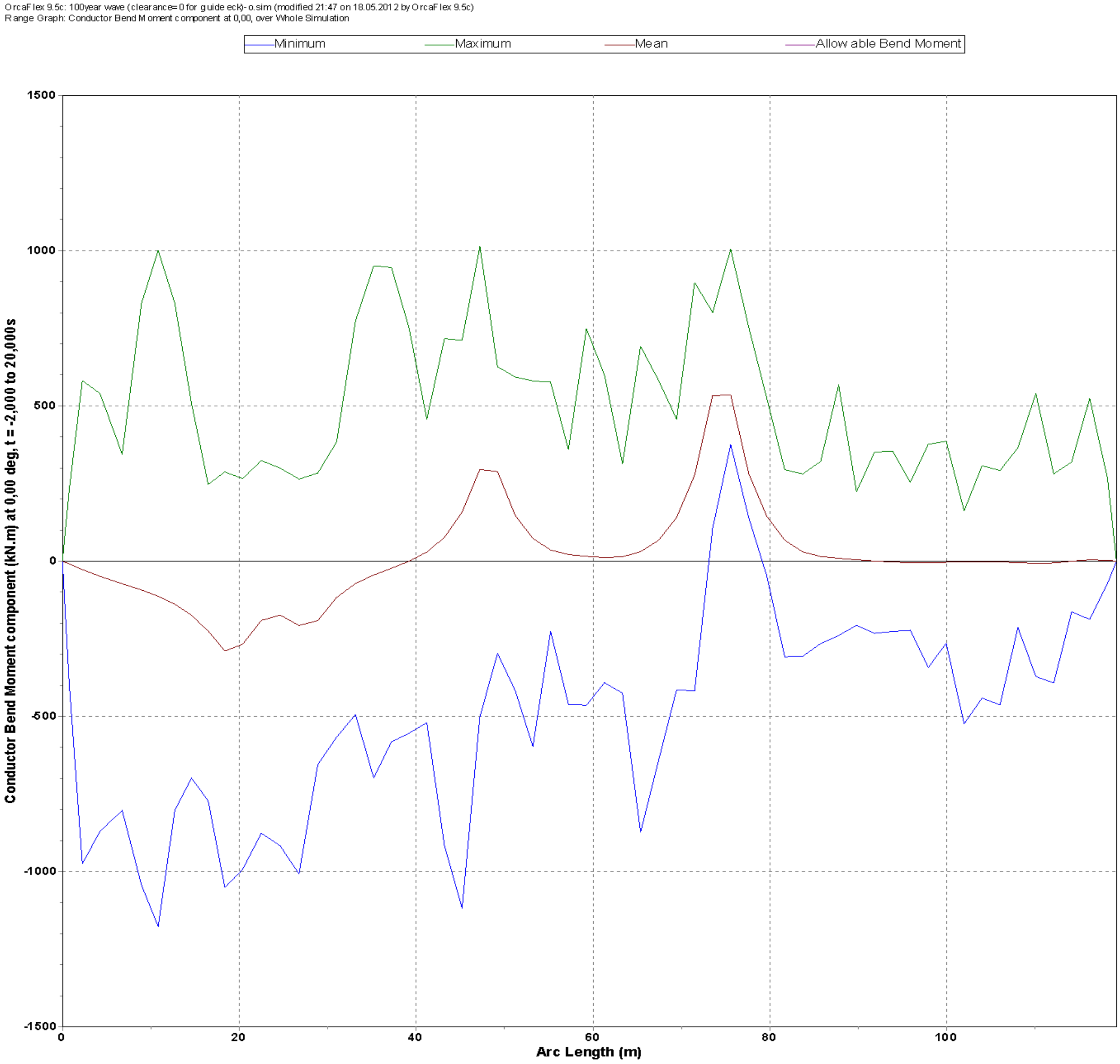

Figure 7-1: Maximum & Minimum bending moment along the conductor during 100 year wave period for **0 mm** clearance in the upper guide deck

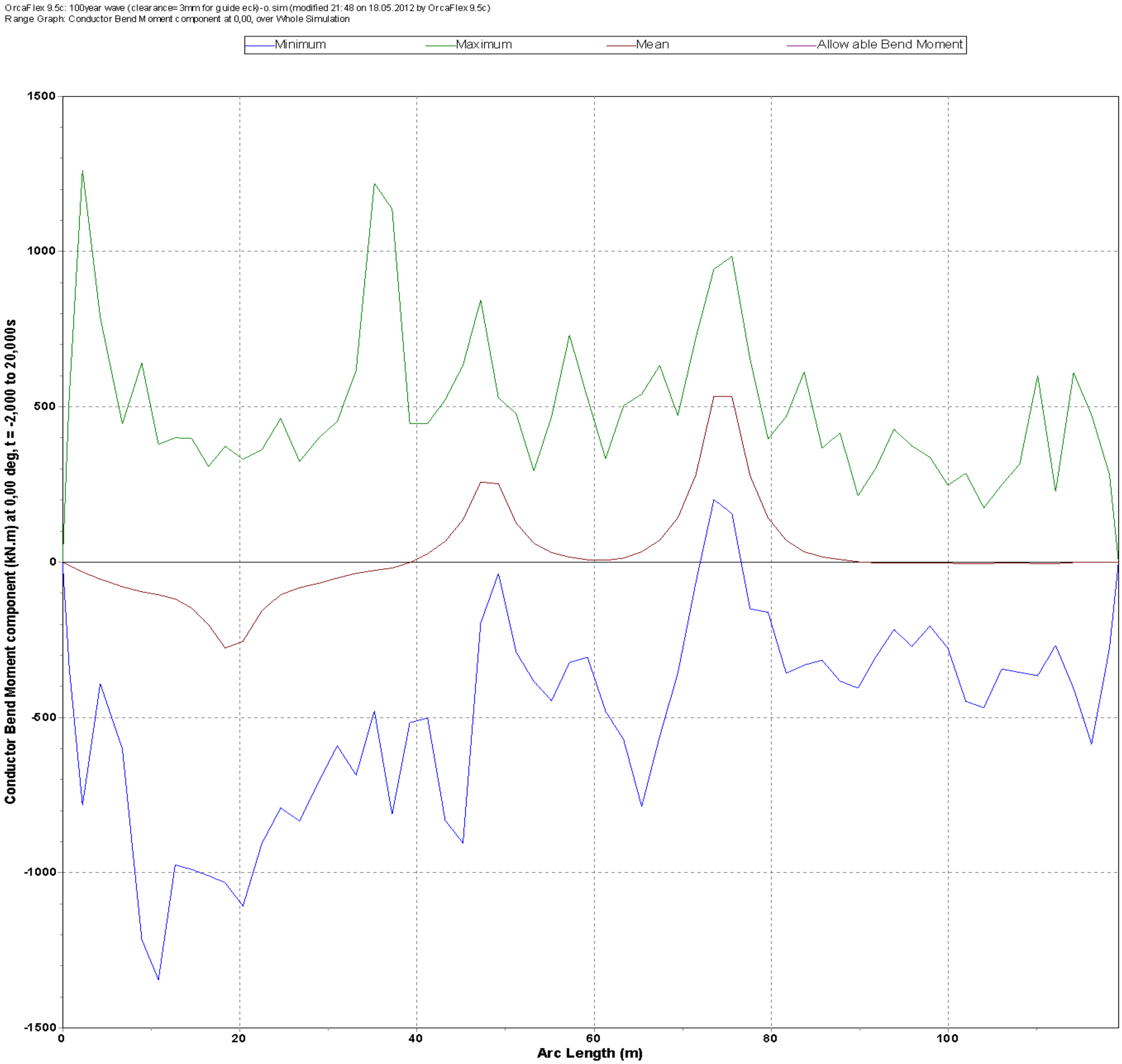

Figure 7-2: Maximum & Minimum bending moment along the conductor during 100 year wave period for **3 mm** clearance in upper guide deck

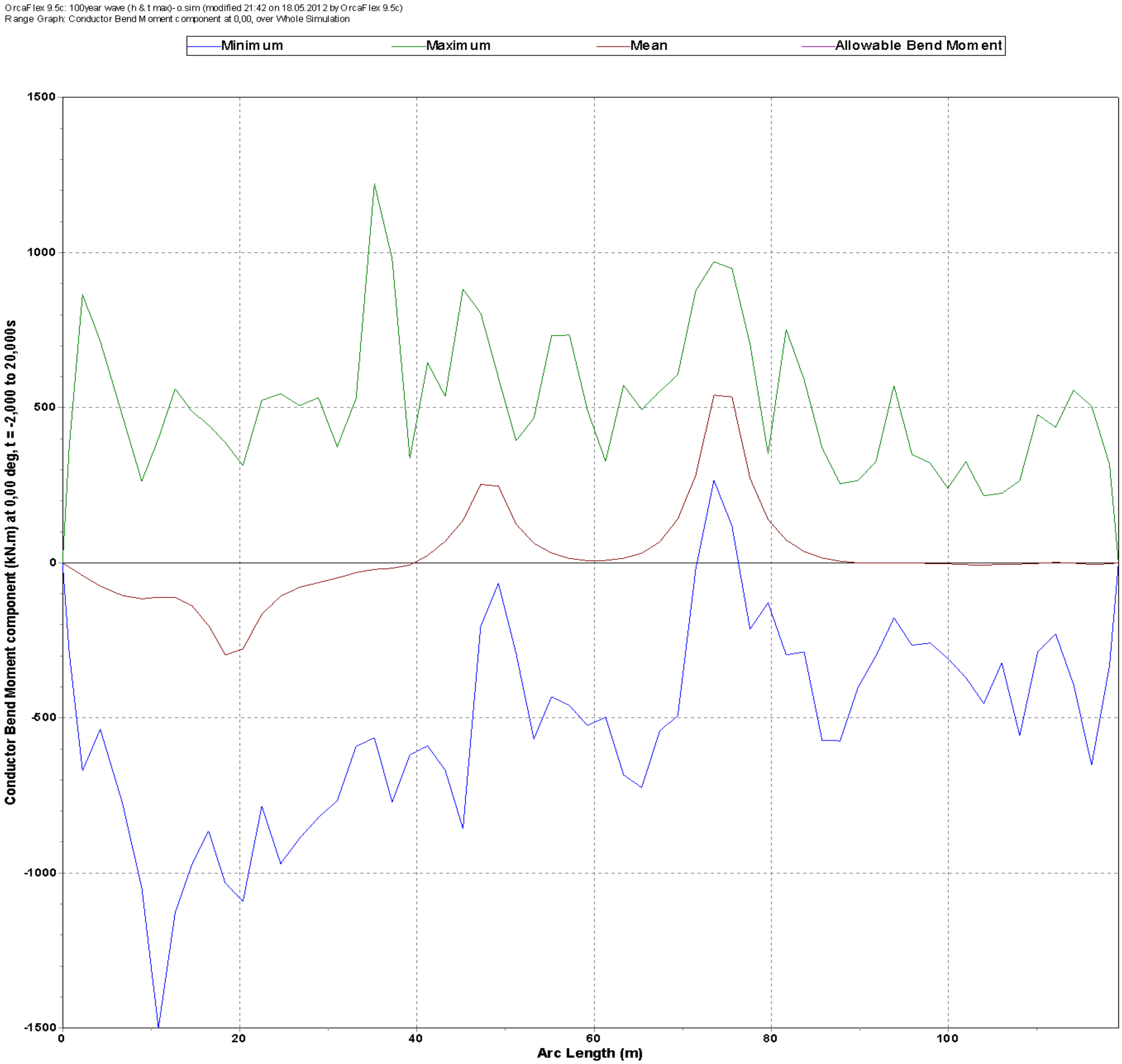

Figure 7-3: Maximum & Minimum bending moment along the conductor during 100 year wave period for **5 mm** clearance in upper guide deck

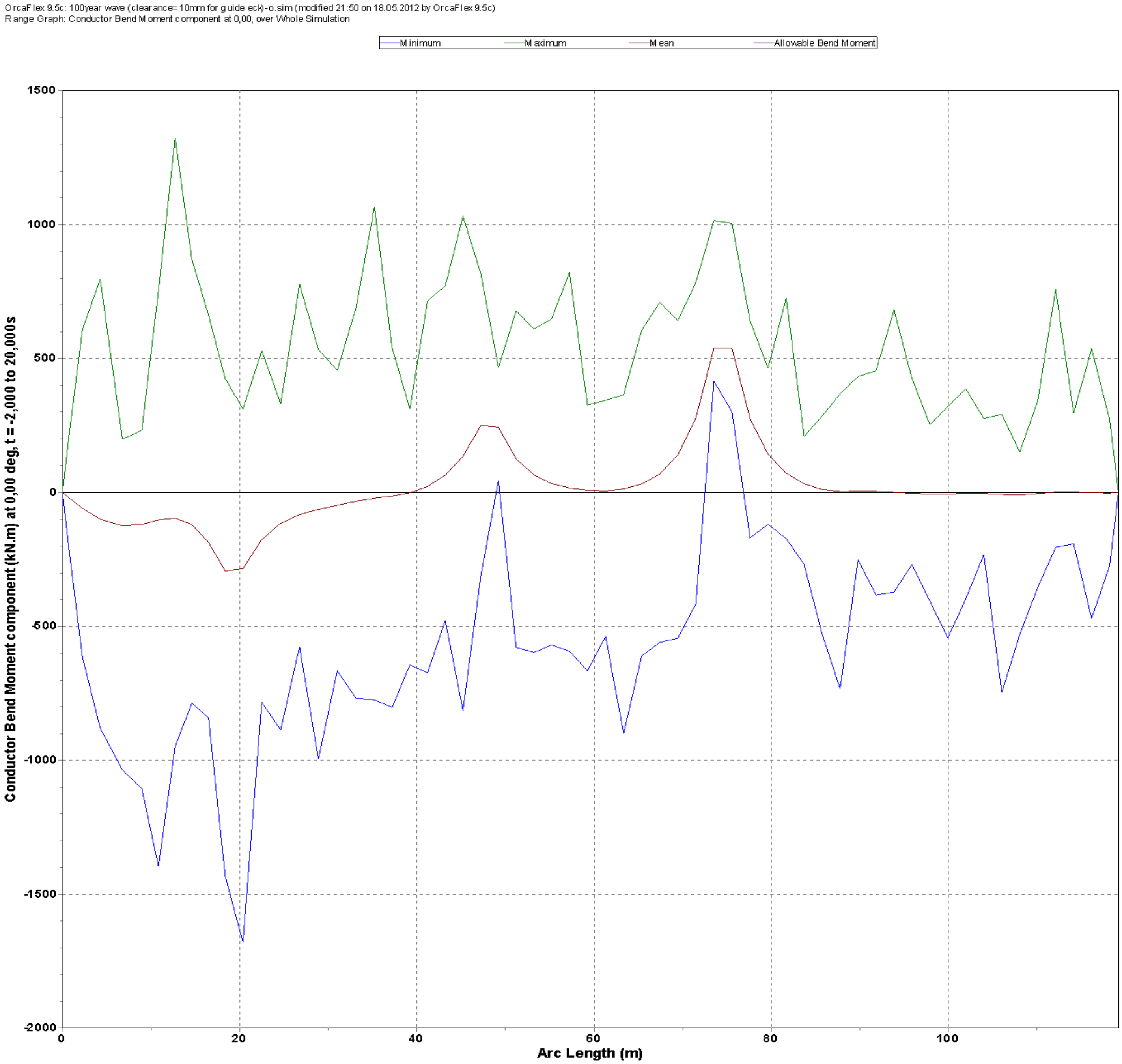

Figure 7-4: Maximum & Minimum bending moment along the conductor during 100 year wave period for **10 mm** clearance in upper guide deck

7.4 Displacements and rotations

The displacements and rotations are calculated where the flow line (FL) is connected to the well head. The flow line is connected at 41.2 meters above sea water level (SWL).

Displacements and rotations resulting from OrcaFlex wave loading analysis and the associated number of occurrences are given in Table 7-5 to Table 7-6.

The horizontal displacements (Δ_{Hor}) are considered to be negative when oriented towards the direction of wave propagation.

- The vertical displacements (Δ_{Ver}) are considered positive when oriented downwards. Rotation of 0.00 deg. means that the well-head is standing vertically.

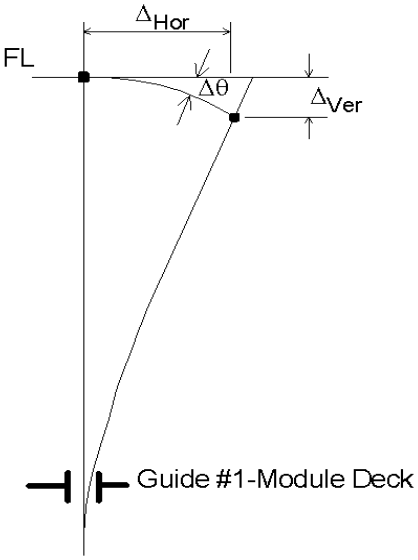

Figure 7- 5: Displacements and rotations

***Table 7-5**: Displacement and rotations for 0.0 mm clearance at upper guide Deck (100 year return period)*

Hs(m)	ΔH_{hor} (mm)	ΔH_{ver} (mm)	$\Delta\theta$(°)	Based on North Chart, scatter diagram									
				N	NE	E	SE	S	SW	W	NW	All	Accum
1.00	0.1	0.0	0.0	2014	792	1394	1808	2290	3632	3133	2152	17215	72566
1.08	0.1	0.0	0.0	2014	792	1394	1808	2290	3632	3133	2152	17215	72566
1.07	0.3	0.0	0.0	2014	792	1394	1808	2290	3632	3133	2152	17215	72566
1.23	-0.3	0.0	0.0	2014	792	1394	1808	2290	3632	3133	2152	17215	72566
1.53	-0.9	0.0	0.0	1615	608	1423	1791	2095	3614	3054	1791	15991	55351
2.01	-3.7	0.0	0.0	995	368	1216	1461	1510	2922	2529	1277	12278	39360
2.68	-5.6	0.0	0.0	582	251	1011	1074	1038	2220	1906	859	8941	27082
3.55	-11.2	0.0	0.0	193	92	603	440	494	988	997	381	4188	11781
4.62	-11.1	0.0	0.0	71	41	285	181	234	342	448	170	1772	4681
5.85	-6.2	0.0	0.0	30	18	66	61	125	122	181	102	705	1715
7.21	1.3	0.0	0.0	6	4	11	10	20	19	30	24	124	312
8.64	-8.2	0.0	0.0	2,4	1,5	1,8	1,5	3,0	3,0	6,1	9,6	28,90	70,2
10.08	-24.2	0.0	0.0	0,44	0,27	0,12	0,07	0,11	0,11	0,58	1,83	3,53	8,35
11.47	-29.6	0.0	0.0	0,26	0,16	0,07	0,04	0,06	0,06	0,34	1,08	2,07	4,82
12.74	-25.8	0.0	0.0	0,051	0,032	0,014	0,009	0,013	0,013	0,068	0,214	0,414	0,975
13.83	-23.2	0.0	0.0	0,016	0,010	0,004	0,003	0,004	0,004	0,021	0,066	0,128	0,324
14.72	-26	0.0	0.0	0,006	0,004	0,002	0,001	0,001	0,001	0,008	0,025	0,048	0,115
15.36	-32	0.0	0.0	0,00350	0,0022	0,00095	0,0006	0,00087	0,00087	0,0047	0,0148	0,028	0,067
15.77	-34.5	0.0	0.0	0,00190	0,0012	0,00052	0,00033	0,00047	0,00047	0,0026	0,0081	0,016	0,039
15.96	-32.3	0.0	0.0	0,00190	0,0012	0,00052	0,00033	0,00047	0,00047	0,0026	0,0081	0,016	0,039
16.01	-32.9	0.0	0.0	0,00120	0,00074	0,00032	0,0002	0,00029	0,00029	0,0016	0,0050	0,010	0,023

***Table 7-6**: Displacement and rotations for 5.0 mm clearance at upper guide Deck (100 year return period)*

Hs(m)	**ΔH_{hor} (mm)**	**ΔH_{ver} (mm)**	**$\Delta\theta$(°)**	**Based on North Chart, scatter diagram**									
				N	**NE**	**E**	**SE**	**S**	**SW**	**W**	**NW**	**All**	**Accum**
1.00	0.1	0.0	0.0	2014	792	1394	1808	2290	3632	3133	2152	17215	72566
1.01	0.1	0.0	0.0	2014	792	1394	1808	2290	3632	3133	2152	17215	72566
1.07	0.1	0.0	0.0	2014	792	1394	1808	2290	3632	3133	2152	17215	72566
1.23	-0.2	0.0	0.0	2014	792	1394	1808	2290	3632	3133	2152	17215	72566
1.53	-0.8	0.0	0.0	1615	608	1423	1791	2095	3614	3054	1791	15991	55351
2.06	-1.1	0.0	0.0	995	368	1216	1461	1510	2922	2529	1277	12278	39360
2.68	-1.0	0.0	0.0	582	251	1011	1074	1038	2220	1906	859	8941	27082
3.55	-1.6	0.0	0.0	193	92	603	440	494	988	997	381	4188	11781
4.62	-2.3	0.0	0.0	71	41	285	181	234	342	448	170	1772	4681
5.85	-2.4	0.0	0.0	30	18	66	61	125	122	181	102	705	1715
7.21	-2.5	0.0	0.0	6	4	11	10	20	19	30	24	124	312
8.64	-3.3	0.0	0.0	2,4	1,5	1,8	1,5	3,0	3,0	6,1	9,6	28,90	70,2
10.07	-4.1	0.0	0.0	0,44	0,27	0,12	0,07	0,11	0,11	0,58	1,83	3,53	8,35
11.47	-4.7	0.0	0.0	0,26	0,16	0,07	0,04	0,06	0,06	0,34	1,08	2,07	4,82
12.74	-5.1	0.0	0.0	0,051	0,032	0,014	0,009	0,013	0,013	0,068	0,214	0,414	0,975
13.83	-5.9	0.0	0.0	0,016	0,010	0,004	0,003	0,004	0,004	0,021	0,066	0,128	0,324
14.72	-7.4	0.0	0.0	0,006	0,004	0,002	0,001	0,001	0,001	0,008	0,025	0,048	0,115
15.36	-8.6	0.0	0.0	0,00350	0,0022	0,00095	0,0006	0,00087	0,00087	0,0047	0,0148	0,028	0,067
15.77	-9.4	0.0	0.0	0,00190	0,0012	0,00052	0,00033	0,00047	0,00047	0,0026	0,0081	0,016	0,039
15.96	-10.9	0.0	0.0	0,00190	0,0012	0,00052	0,00033	0,00047	0,00047	0,0026	0,0081	0,016	0,039
16.01	-12.5	0.0	0.0	0,00120	0,00074	0,00032	0,0002	0,00029	0,00029	0,0016	0,0050	0,010	0,023

7.5 Contact forces between conductor and it's guide Result

The values of the contact forces in different wave conditions (1, 10 and 100 year return periods) and four different gaps at the upper guide deck (0.0, 3.0, 5.0 and 10.0 mm) are given in Table 7-1 to 7-10. Also, contact force diagrams for the extreme condition (100 years return wave) are obtained due to waves which act upon conductor; see Figures 7-6 to Figure 7-9.

Table 7-7: *Contact force between conductor and guides for 1, 10 and 100 year return periods and **0.0 mm** clearance at upper guide deck*

CASE 1	**Clearance (mm)**	**Contact forces (kN)**		
		1 Year	**10 Years**	**100 Years**
Module Deck Guide	0	29.05	39.77	47.30
Cellar Deck Guide	0	117.64	138.11	145.42
Upper Deck Guide	0	20.62	21.35	31.58
Intermediate Deck Guide	0	7.46	8.25	9.31
Lower Deck Guide	10	12.79	13.66	14.75

Table 7-8: *Contact force between conductor and guides for 1, 10 and 100 year return periods and **3.0 mm** clearance at upper guide deck*

CASE 2	**Clearance (mm)**	**Contact forces (kN)**		
		1 Year	**10 Years**	**100 Years**
Module Deck Guide	0	33.20	62.96	40.46
Cellar Deck Guide	0	103.50	134.81	162.95
Upper Deck Guide	3.0	11.90	13.08	14.42
Intermediate Deck Guide	0	7.40	8.35	9.90
Lower Deck Guide	10	13.09	13.63	14.76

Table 7-9: *Contact force between conductor and guides for 1, 10 and 100 year return periods and **5.0 mm** clearance at upper guide deck*

CASE 3	**Clearance (mm)**	**Contact forces (kN)**		
		1 Year	**10 Years**	**100 Years**
Module Deck Guide	0	36.53	47.05	54.25
Cellar Deck Guide	0	149.93	190.52	197.48
Upper Deck Guide	5.0	9.96	10.58	13.90
Intermediate Deck Guide	0	7.03	7.94	9.99
Lower Deck Guide	10	13.84	14.28	14.90

Table 7-10: *Contact force between conductor and guides for 1, 10 and 100 year return periods and **10.0 mm** clearance at upper guide deck*

CASE 4	**Clearance (mm)**	**Contact forces (kN)**		
		1 Year	**10 Years**	**100 Years**
Module Deck Guide	0	31.35	46.89	54.08
Cellar Deck Guide	0	149.54	190.22	197.32
Upper Deck Guide	10.0	9.11	11.00	13.86
Intermediate Deck Guide	0	7.13	8.28	10.04
Lower Deck Guide	10	14.05	14.61	14.87

The maximum contact force of 197.48 kN generated by a 100 year return wave and 100 year current occurs at the cellar deck guide in case of a 5.0mm clearance at upper guide Deck. (See Table 7-9)

The maximum contact forces are ranging from a peak value of 197.48 kN, in the presence of a 5 mm gap at cellar Deck (case 3) to a value of 145.42 kN in case of zero gap (Case 1).

The analyses' results indicate that the contact forces at the upper guide deck level are lesser in the case of the presence of no gaps at the upper guide deck.
The highest contact forces could be for cellar deck guide due to present of wind.
The contact forces increase at the Cellar deck level, Module deck and in Lower Guide deck for the 100 years wave period. (See Tables 7-7, 7-9 & 7-10)

The contact force diagrams for the extreme condition (100 years return wave) are obtained due to waves which act upon conductor; see Figures 7-6 to Figure 7-9.

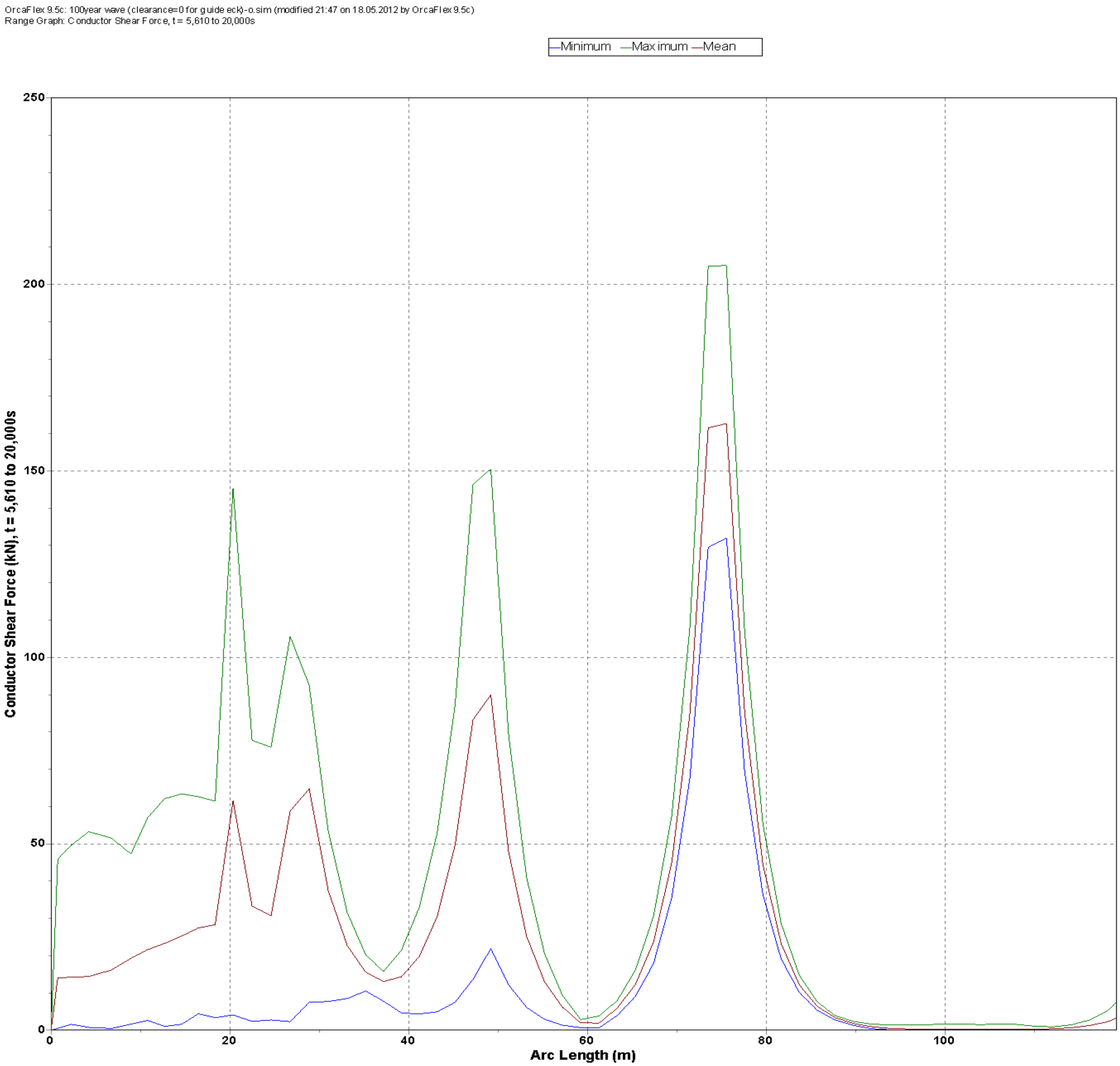

Figure 7-6: Maximum & Minimum contact forces along the conductor during 100 year wave period for **0 mm** clearance in upper guide deck

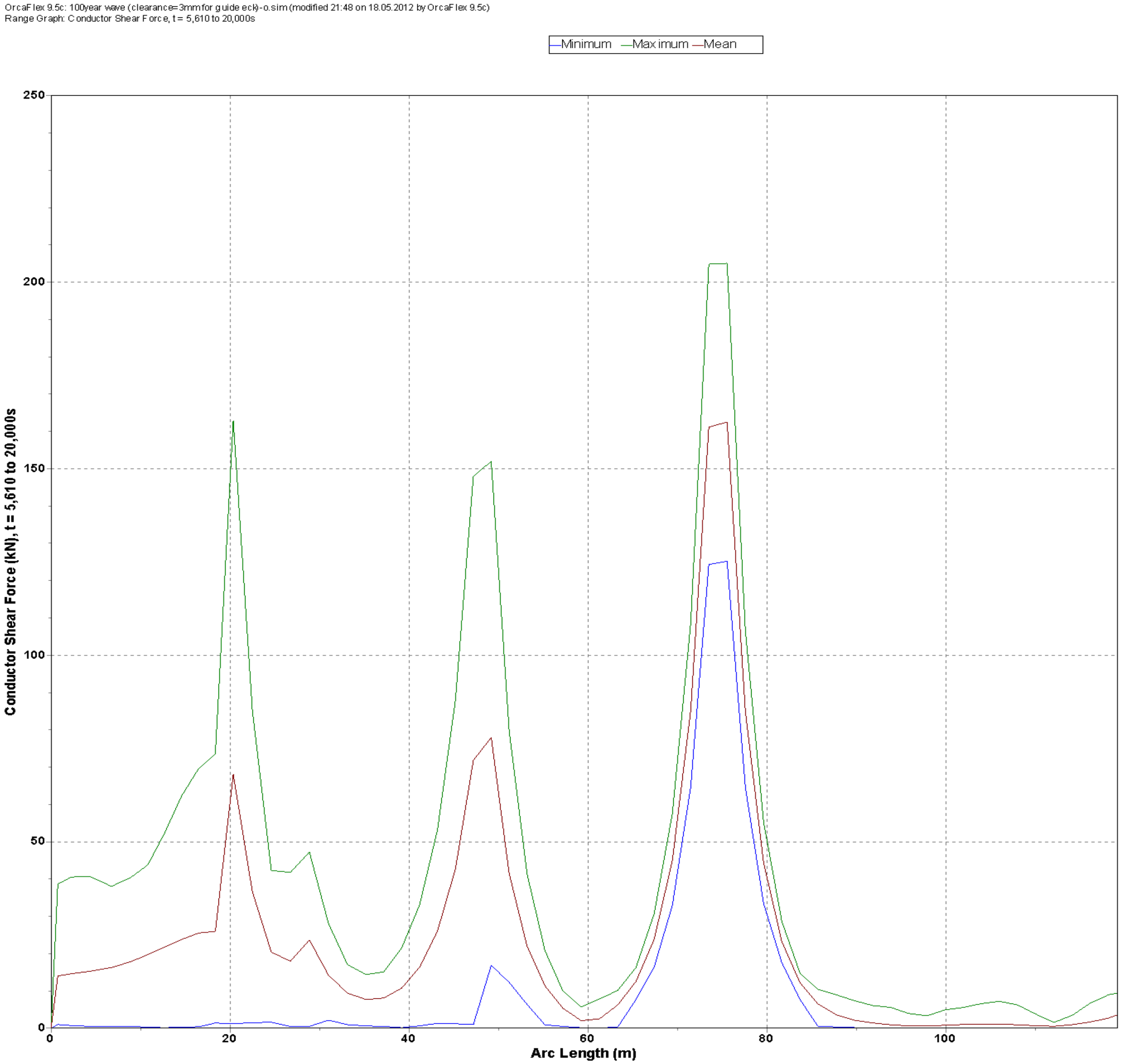

Figure 7-7: Maximum & Minimum contact forces along the conductor during 100 year wave period for **3 mm** clearance in upper guide deck

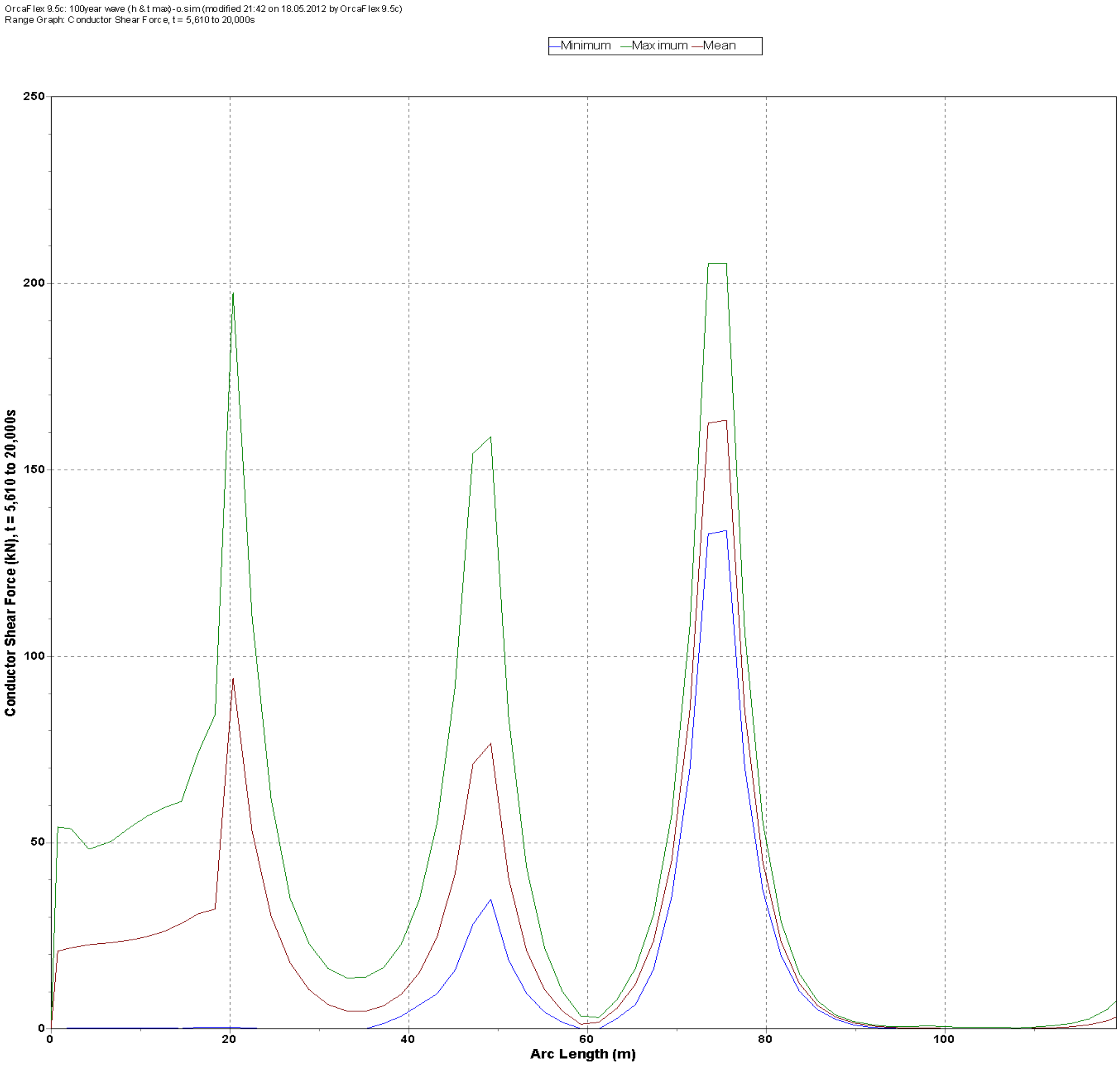

Figure 7-8: Maximum & Minimum contact forces along the conductor during 100 year wave period for **5 mm** clearance in upper guide deck

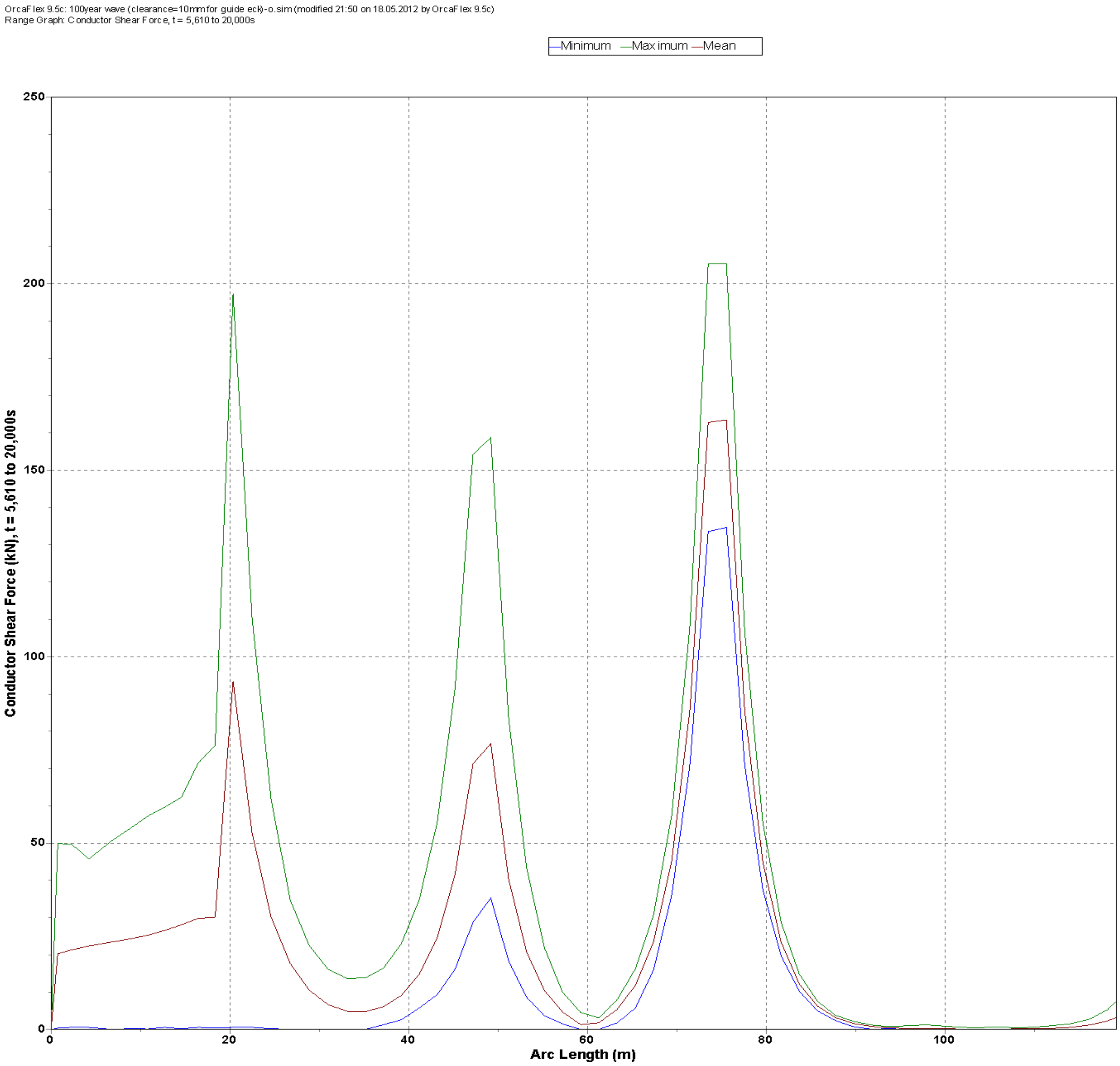

Figure 7-9: Maximum & Minimum contact forces along the conductor during 100 year wave period for **10 mm** clearance in upper guide deck

7.6 Shear forces component

The philosophy for finding the shear force component referring to OrcaFlex software is that the conductor is stiff in bending, the bending moment varies linearly along the conductor and the shear force in the conductor is equal to the rate of change of the bending moment along the length. It is therefore given by:

Shear forces component= $(M_2 - M_1) / L$ (kN)

Where;

- L (m) is the direct length of the segment of the conductor
- M_1 and M_2 (kN.m) are the bending moment vector. This vector is applied (with opposite signs) to the nodes at each end of the segment.

The maximum shear forces component (1, 10 and 100 year return periods) for four different gaps (0.0, 3.0, 5.0 and 10.0 mm) are shown in Table 7-11 to Table 7-14.

Table 7-11: *Shear force component along conductor for 1, 10 and 100 year return periods and **0.0 mm** clearance at upper guide deck*

CASE 1	**Clearance (mm)**	**Shear forces component (kN)**		
		1 Year	**10 Years**	**100 Years**
Module Deck Guide	0	17.88	12.51	16.13
Cellar Deck Guide	0	61.77	73.76	91.59
Upper Deck Guide	0	61.23	73.64	86.87
Intermediate Deck Guide	0	46.65	40.44	43.83
Lower Deck Guide	10	32.61	47.59	68.52

Table 7-12: *Shear force component along conductor for 1, 10 and 100 year return periods and* ***3.0 mm*** *clearance at upper guide deck*

CASE 2	Clearance (mm)	Shear forces component (kN)		
		1 Year	10 Years	100 Years
Module Deck Guide	0	4.58	4.80	4.50
Cellar Deck Guide	0	27.87	30.73	28.60
Upper Deck Guide	3.0	7.18	10.64	9.65
Intermediate Deck Guide	0	4.11	5.52	7.37
Lower Deck Guide	10	4.67	7.44	3.60

Table 7-13: *Shear force component along conductor for 1, 10 and 100 year return periods and* ***5.0 mm*** *clearance at upper guide deck*

CASE 3	Clearance (mm)	Shear forces component (kN)		
		1 Year	10 Years	100 Years
Module Deck Guide	0	1.85	3.12	4,50
Cellar Deck Guide	0	1.92	3.11	28.59
Upper Deck Guide	5.0	1.55	3.16	9.65
Intermediate Deck Guide	0	1.13	2.42	7.37
Lower Deck Guide	10	1.24	2.74	3.59

Table 7-14: *Shear force component along conductor for 1, 10 and 100 year return periods and **10.0 mm** clearance at upper guide deck*

CASE 4	**Clearance (mm)**	**Shear forces component (kN)**		
		1 Year	**10 Years**	**100 Years**
Module Deck Guide	0	1.74	2.78	3.36
Cellar Deck Guide	0	1.70	2.88	3.94
Upper Deck Guide	10.0	1.17	2.42	2.92
Intermediate Deck Guide	0	0.79	1.93	2.25
Lower Deck Guide	10	1.24	1.53	1.52

The results show that the shear forces component are significantly decreased by increasing the clearances.

The maximum shear force component occurs in case of zero gaps (case 1) with the range of 91.59 (kN) in cellar deck guide. Then, it is gradually reduced to 3.94 (kN) by providing 10 mm gaps.

Also, shear component force diagrams for the extreme condition (100 years return wave) are obtained due to waves which act upon conductor, see Figures 7-10 to Figure 7-13.

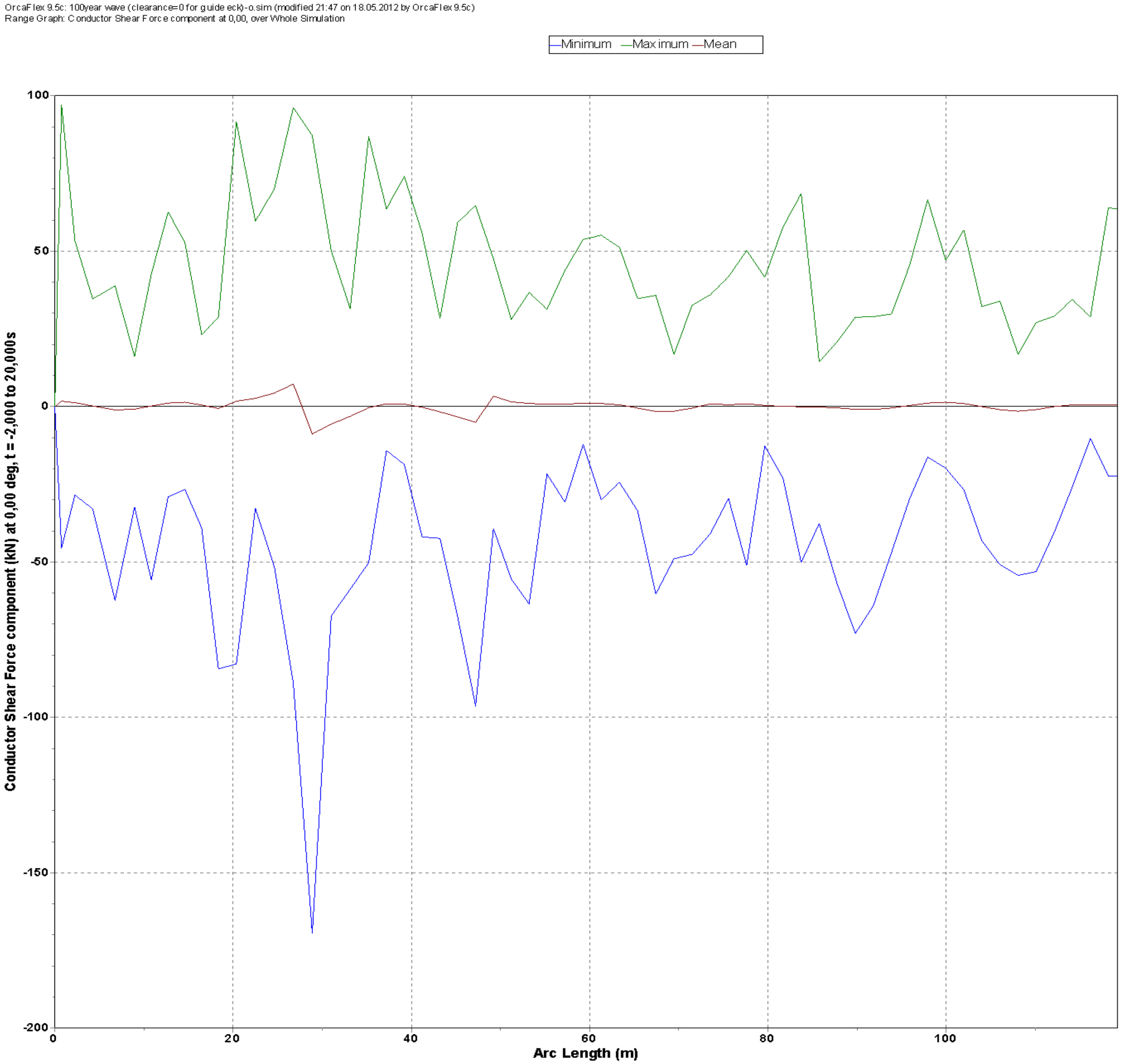

Figure 7-10: Maximum & Minimum shear component forces along the conductor during 100 year wave period for **0 mm** clearance in upper guide deck

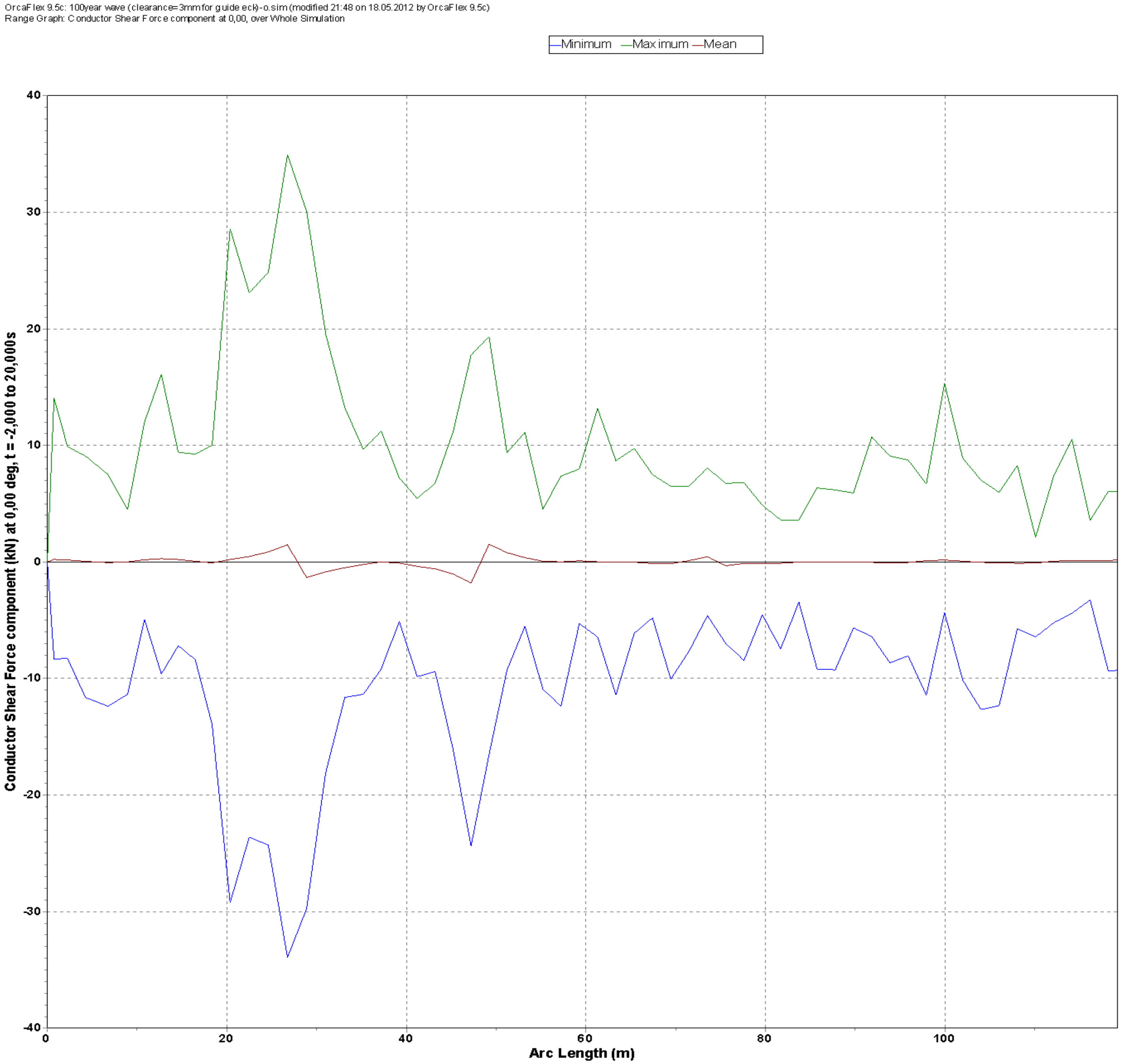

Figure 7-11: Maximum & Minimum shear component forces along the conductor during 100 year wave period for **3 mm** clearance in upper guide deck

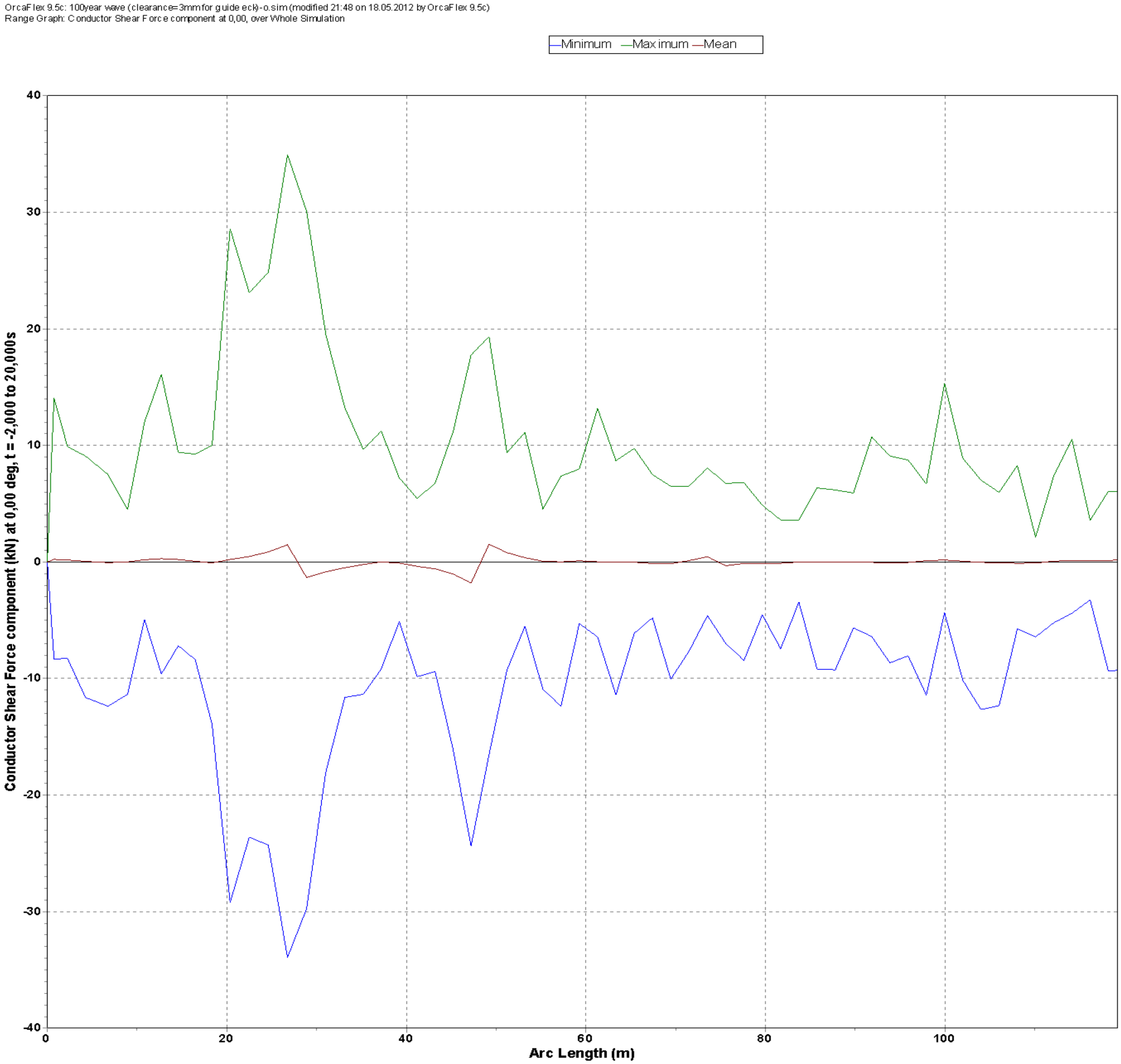

Figure 7-12: Maximum & Minimum shear component forces along the conductor during 100 year wave period for **5 mm** clearance in upper guide deck

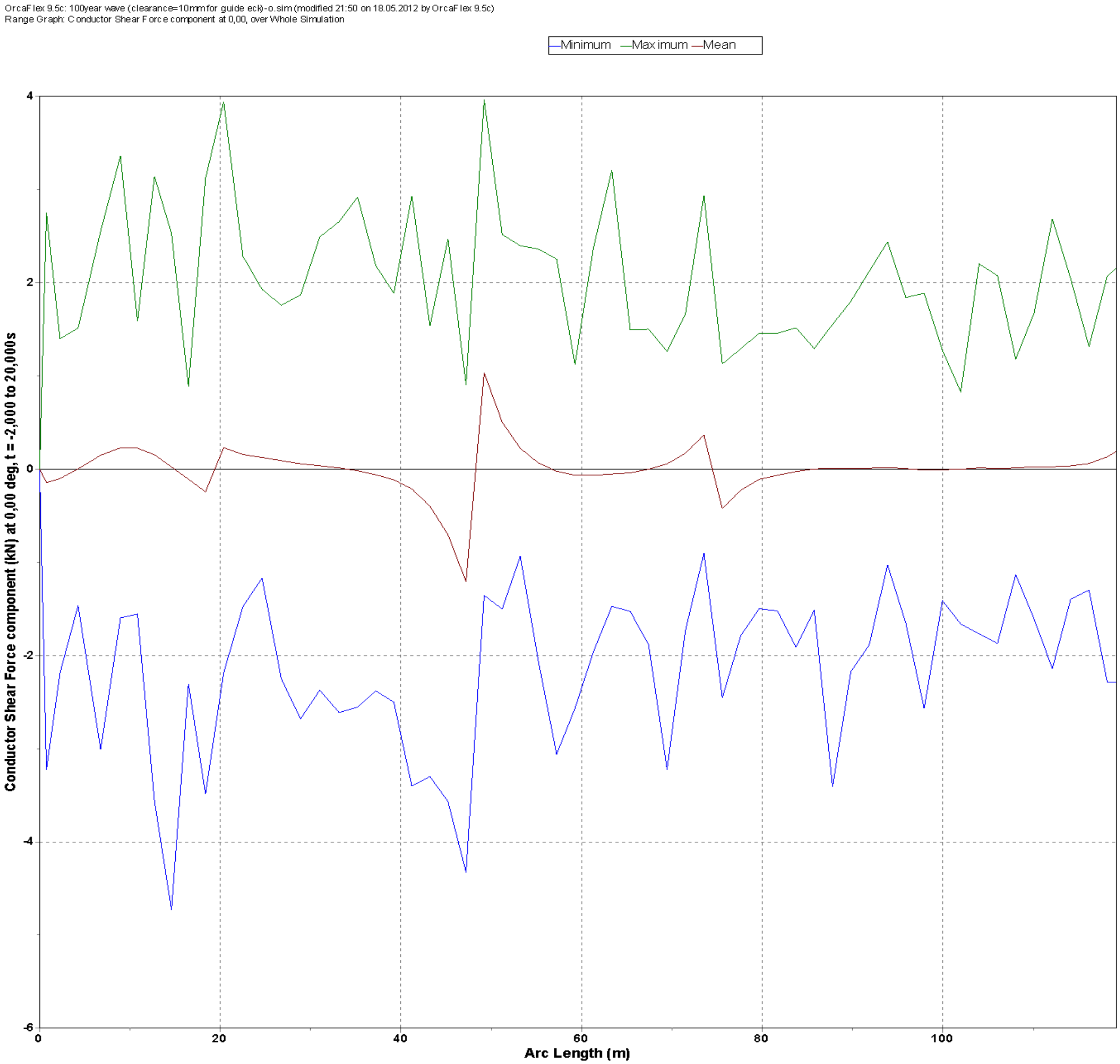

Figure 7-13: Maximum & Minimum shear component forces along the conductor during 100 year wave period for **10 mm** clearance in upper guide deck

8.0 Fatigue analysis for the conductor at the guides' level

8.1General:

The Fatigue Limit State (FLS) has long been recognized as an important consideration for the design of offshore structures.

The purpose of this chapter is to calculate the fatigue life of the conductor at conductor guides' level in the most critical location. The most critical guide, according to the analysis from chapter 7.0, is situated at the elevation of +15.5 m (Cellar Guide Deck) for the guides of the 20" conductor on the EKOK platform. The platform was installed in 1986 and has a service life of 20 years so the platform has already exceeded its service life.

The hydrodynamic analysis results in chapter 7.0 show that the maximum contact force is **197.48 kN** in the cellar deck guide in case of **5 mm** clearances in the upper guide deck.

All fatigue analyses are performed considering 10 wave cycles and wave data (regular waves) from the scatter diagram given in Appendix A, ref/3/.

8.2 Methodology

Fatigue refers to the cumulative damage caused by the repeated application of time-varying stresses at a specific location in the conductor. These time-varying stresses are caused by the variable actions due to waves.

However, fatigue is the cumulative effect of an irregular load history which for typical offshore structures is a period of 20 years, or the order of 10^8 cycles assuming an average wave frequency, ref/16/.

The cumulative damage could be described by the Palmgren-Miners Damage hypothesis and an S-N curve.

The results are found by applying an S-N curve which is obtained from DNV-RP-C203, October 2011, figure 2-8, "S-N curve for members in sea water with cathodic protection", ref /15/. The S-N curve is shown in Figure 8-1.

8.3 Palmgren-Miners Damage hypothesis

The Palmgren- Miners hypothesis damage states that fatigue failure will occur when the sum of the partial damages is equal to one. The fatigue life is then calculated with use of the load cycles. Refer to Fatigue Handbook of offshore structure, Edited by A. Almar- Naess, ref /16/. The stresses of the cycles are then compared with the S-N curve which is shown in Figure 8-1.

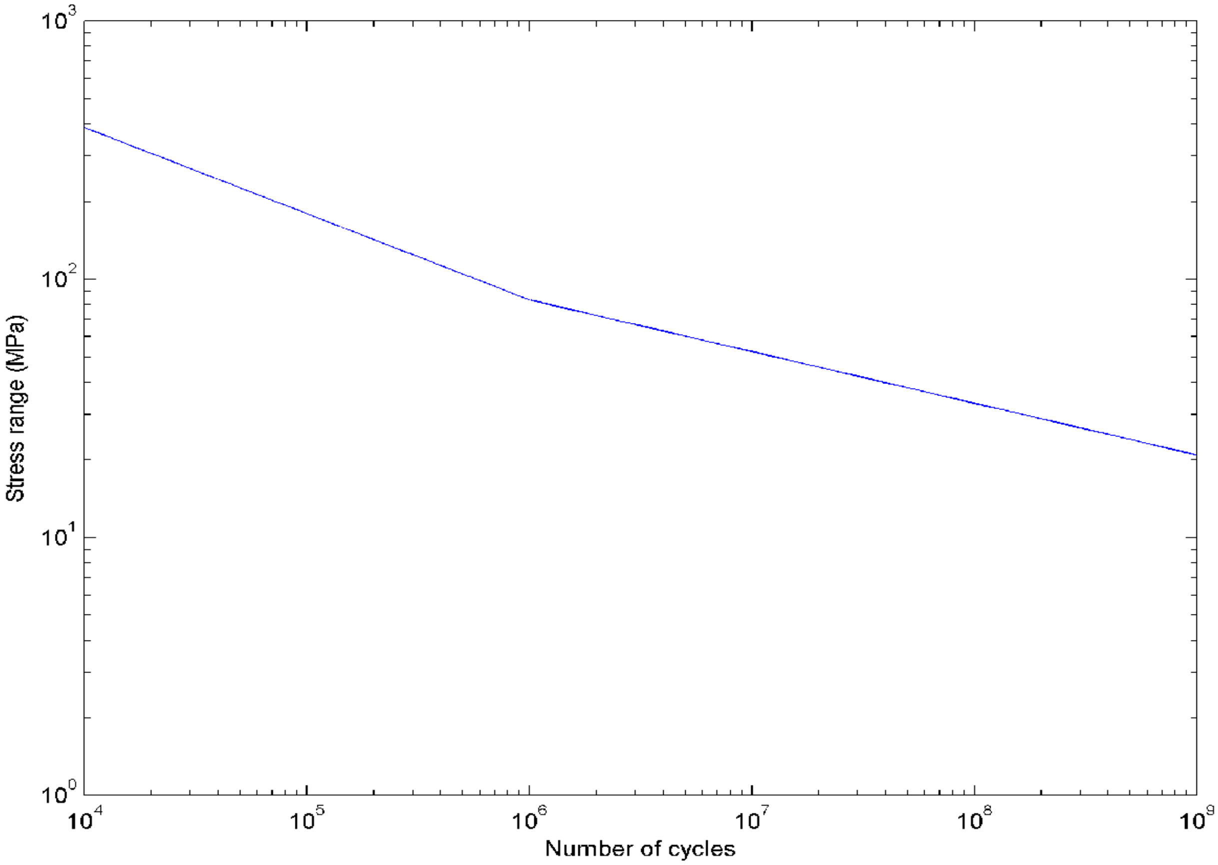

Figure 8-1: S-N curve in seawater with cathodic protection, refer to DNV-RP-C203, October 2011, ref/15/

The curve in Figure 8-1 can also be described by the following equation:

$$\log N = \log \bar{a} - m \cdot \log\left(\Delta\sigma \cdot \left(\frac{t}{t_{ref}} \right)^{k} \right)$$

where:

$\Delta\sigma$ = the stress range

N = the number of cycles

log a = 11.764 if N ≤ 10^6; log a = 15.606 if N > 10^6 (SN-curve type D, refer to DNV-RP-C203, October 2011)

$m = 3.0$ if $N \leq 10^6$; $m = 5.0$ if $N > 10^6$
t = the thickness thought
$t_{ref} = 32$ mm; $k = 0.1$
This equation is used to calculate the number of cycles of a certain stress range before fatigue failure. The actual number of cycles is the divided by this number and this gives the partial damage of the cycle having that stress range. In general, all partial damages are weighted against the wave frequency data and an estimation of the fatigue life can be made.

According to OrcaFlex 9.5, the S-N curve defines the number of cycles to failure, N(S), for the stress range S, and also defines an endurance limit, F_L, below which no damage occurs. OrcaFlex uses these to calculate a damage value D(S) given by:

$D(S) = 1/N(S)$ if $S > F_L$

$D(S) = 0$ if $S \leq F_L$

This damage value can be considered as the proportion of the fatigue life that is used up by 1 cycle of stress range S.

However, the stresses in the conductor guides' level could be related to the wall tension referring to chapter 4-conductor analysis. This relation has been defined by the following formula in chapter 4:

$$\sigma_{tw} = \frac{T_{tw}}{A_e - A_i}$$

Where;
T_{tw} is the wall tension in the conductor
A_i is the internal cross-sectional area,
A_e is the external cross-sectional area

Therefore, the T-N curve could be handled in a similar way; A T-N curve defines the number of cycles to failure, N (T), for wall tension range T.

As for S-N curves, OrcaFlex 9.5 defines damage as:

D(T) = 1/N(T)

The summation of damage is then performed in an identical way to that performed for S-N curves.

8.4 Fatigue life results

The aim of fatigue design is to ensure that the structure has an adequate fatigue life.

The Fatigue analysis has been done by Orcaflex 9.5 along the conductor located between the cellar deck and upper guide deck level.

As described in section 8.3, the stresses could be obtained from the tension in the wall, which is automatically calculated by Orcaflex 9.5. The wall tensions from the time history results are presented in Figure 8-2.

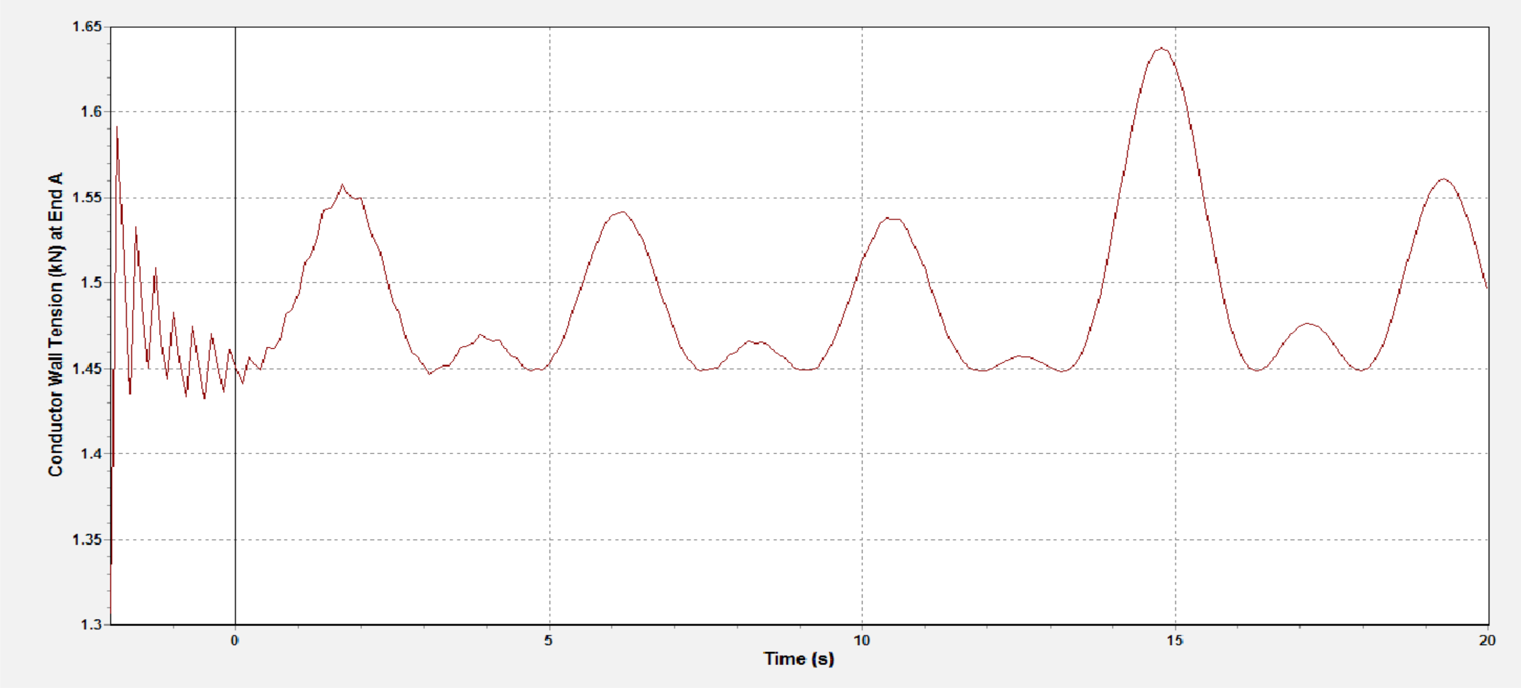

Figure 8-2: Wall tension (kN) in the conductor for H_{max} & T_{max} for 100 year return periods and **5.0 mm** clearance at the upper guide deck as found from OrcaFlex analysis.

The Fatigue analysis show fatigue results as presented in Figure 8-3.

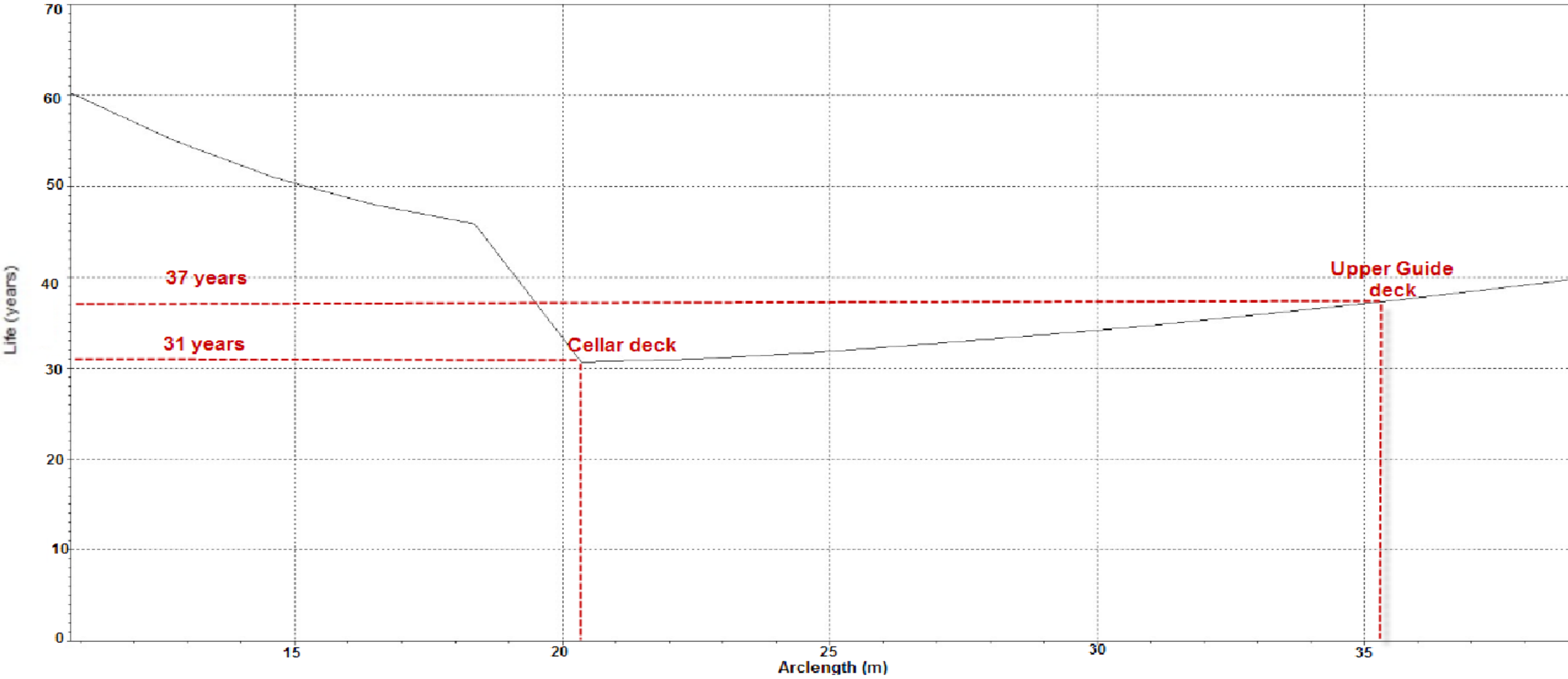

Figure 8-3: The Fatigue life for conductor guide' level between cellar deck guide level & upper guide deck level result

The fatigue life is presented at the cellar deck and upper guide deck as the followings:

- For conductor at the cellar guide deck (31 years): 1986 - 2017
- For conductor at the upper guide deck (37 years): 1986 – 2023

The fatigue life of a structure is normally considered to be the calculated fatigue life divided by the DFF, Table 8-1. In cases where the fatigue life is longer than the planned design life (Service life), use of the structure is acceptable until the fatigue life is reached (DNV-RP-C203, ref /15/ & Norsok N-004 ref /6/).

$$SF > \frac{FatigueLife}{DFF} \Rightarrow \frac{FatigueLife}{DFF \times SF} > 1$$

Service life of the platform is to be 20 years.

In order to discuss and make a conclusion for the fatigue life along the conductor, the design fatigue factor (DFF) should be considered in accordance with the following discussion:

According to Norsok-001, ref/4/, the design fatigue factors (DFF) are defined as given in Table 8-1:

Table 8-1: *Design Fatigue Factors, DFF, for the conductor guides' level fatigue life analysis, (Norsok N-001, ref/4/ &Norsok N-004, ref/6/)*

Classification of structural components based on damage consequence **Classification of structural components based on damage consequence**		**Access for Inspection and Repair**		
		No access or in the splash zone	**Accessible**	
			Below splash zone	**Above splash zone**
(1)Substantial consequences	•Brace/stub to chord welds in main load transferring joints in vertical plans. •Chord/cone to leg welds, between leg sections. •Brace to stub and brace to brace welds in main Load transferring members in vertical plans. •Shear plates and yoke plate's incl. Stiffening. •Piles and bucket foundation plates incl.stiffening.	**10**	**3**	**2**
(2)Without substantial consequences	•Brace/stub to chord welds in joints in horizontal plans. • Chord/cone to brace welds and welds between sections in horizontal plans. • Appurtenance supports. • Anodes, doublers plates. • Outfitting steel.	**3**	**2**	**1**

(1) ''Substantial consequences" in this context means that failure of the joint will entail danger of loss of human life; significant pollution; major financial consequences"

(2) ''without substantial consequences" is understood failure where it can be demonstrated that the structure satisfy the requirement to damaged condition according to the ALS with failure in the actual joint as the defined damage.

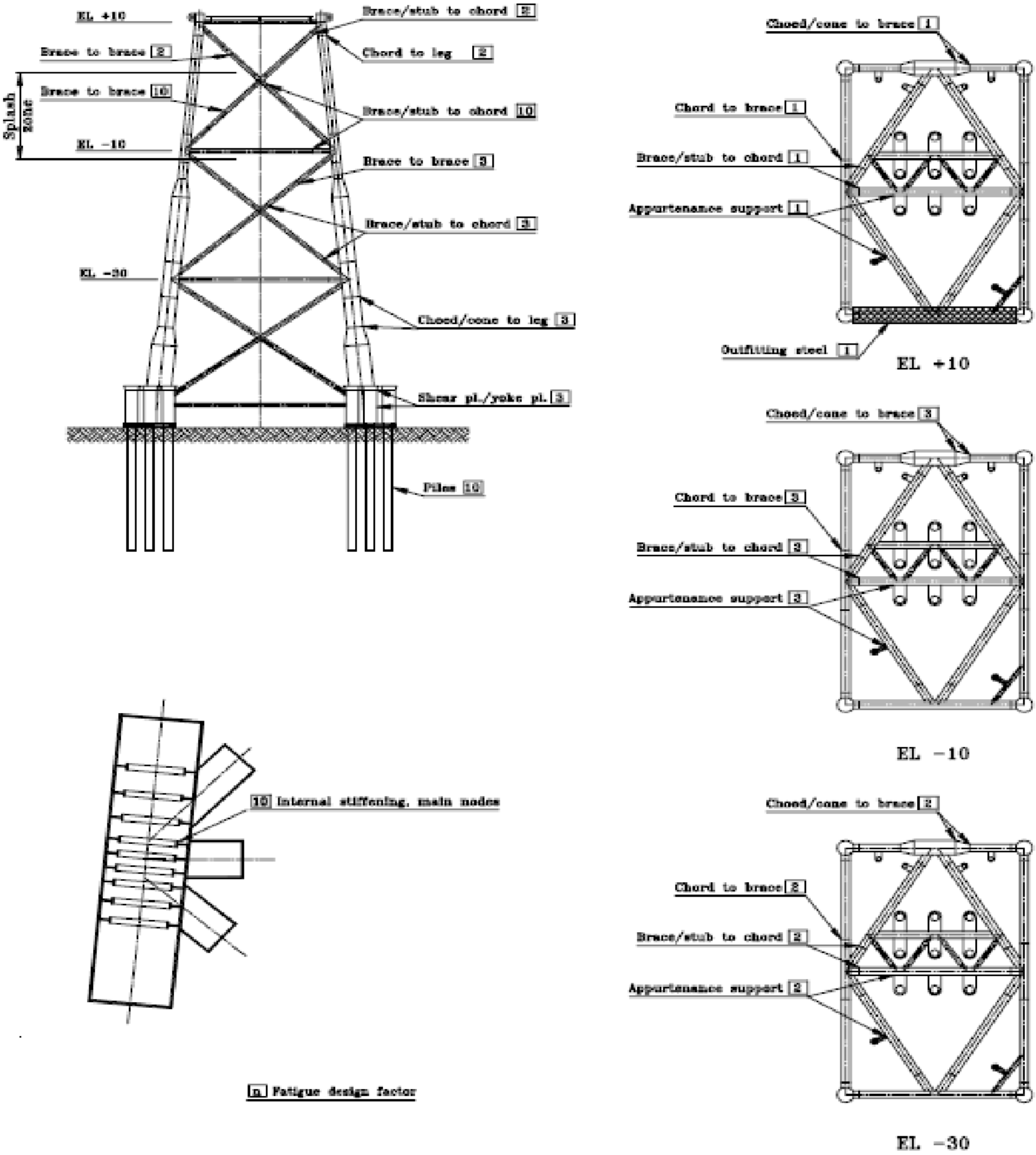

Figure 8-4: Typical fatigue design factor in jacket, Norsok 004, ref/6/

The conductor and it's guide are part of the jacket structure that is classified by Table 8-1 and Figure 8-4. Note that there are two scenarios for fatigue life of the conductors:

- Scenario 1: Due to the above splash zone requirement for inspection and repair of the conductor at the conductor guide located on the upper guide deck & cellar guide deck and substantial consequences for the structural integrity, the Design Fatigue Factor (DFF) is set to be 2.

- Scenario 2: Due to the above splash zone requirement for inspection and repair of the conductor at the conductor guide located on the upper guide deck & cellar guide deck without substantial consequences for the structural integrity, the Design Fatigue Factor (DFF) is set to be 1.

In general, the total design fatigue life factors for conductors at the guide levels for both two scenarios (the two different conductor guide' levels including cellar deck and upper guide deck levels) are given in Table 8-2:

Table 8-2: *Total Design Fatigue Life for conductor guides' level*

Scenario	**Conductor guides' level**	**Period (years)**	**Design Fatigue Factor (DFF)**	**Total Design Fatigue Life (years)**
1	Cellar guide deck level	31	2	62
	Upper guide deck level	37		74
2	Cellar guide deck level	31	1	31
	Upper guide deck level	37		37

In case of **scenario 1,**

$$\frac{FatigueLife}{DFF \times SF} = \frac{31}{2 \times 20} = 0.775 < 1$$

&

$$\frac{FatigueLife}{DFF \times SF} = \frac{37}{2 \times 20} = 0.925 < 1$$

So, the fatigue life of the conductor at the guide levels will not match the requirement for conductor fatigue service life. It needs inspection and modification. However, large uncertainties are normally associated with fatigue life assessments. Reliability methods could be used to illustrate the effect of the uncertainties on the probability of a fatigue failure.

Similarly, the results from the scenario 2 indicate that the estimated lifetime of the conductors at the conductor guides' levels will be very short:

$$\frac{FatigueLife}{DFF \times SF} = \frac{31}{1 \times 20} = 1.55 > 1$$

&

$$\frac{FatigueLife}{DFF \times SF} = \frac{37}{1 \times 20} = 1.85 > 1$$

9.0 Conclusions

It can be concluded that the conductor at the guide levels will not match with the requirements for the service life of the platform of 20 years.

The results from the calculations show that when including the gap between conductor and it's guides, the estimated lifetime of the conductor at conductor guides' level will be either very short or unsuccessful.

The fatigue results show that the life time for the conductor at the cellar guide is 31 years. Similarly, the conductor at the upper guide deck has been found to have a life time of up to 37 years.

In case of setting of the design fatigue factor (DFF) to be 2, the conductor in the upper guide deck level and cellar guide deck needs inspection and modification before failure.

The recommendation is therefore that if the bending moment could be reduced by reducing the gap for conductor in the guides, then the gap in upper guide deck at elevation (+7.0 m) should be reduced. This modification creates a smaller gap between the conductor and its conductor guides. The same modification can therefore be made by inserting steel parts and/ casting with rubber to reduce the gap in the conductor guides.

10.0 Proposal for further study

This chapter is provided as suggestion for further conductor analysis:

It is recommended to perform a study to investigate the possibility of introducing designed damping of the conductors.

In addition, the analyses should include the shielding and vortex shedding phenomena (VIV); the effects of the structure surrounding the Guide deck structure and its influence on any conductor or on the overall guide frame assembly should be analyzed.

Further development of the OrcaFlex modeling should be carried out by implementing the clearances between the conductors and the conductor guides at the Module & Cellar & Intermediate guide decks according to real measurements which should be done by an offshore survey. Furthermore, the p-y curves of the soil should be modeled for coupled analysis according to ISO 19901-4 recommendations.

Also, further development of the model could be performed by carrying out measurements of the accelerations/vibrations at the well-head level; measurement of the axial movements on the top of the well-head; and measurement of contact loads between conductor and guide at intermediate guide decks (below the SWL).

In real life, the assumptions in the fatigue life calculations might be affected by the guide's structure; a further analysis has to be carried out by considering the detailed contact with the conductor's guide as well as the clamp-guide interface.

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12.0 APPENDIX A – SCATTER DIAGRAM FOR EKOFISK AREA

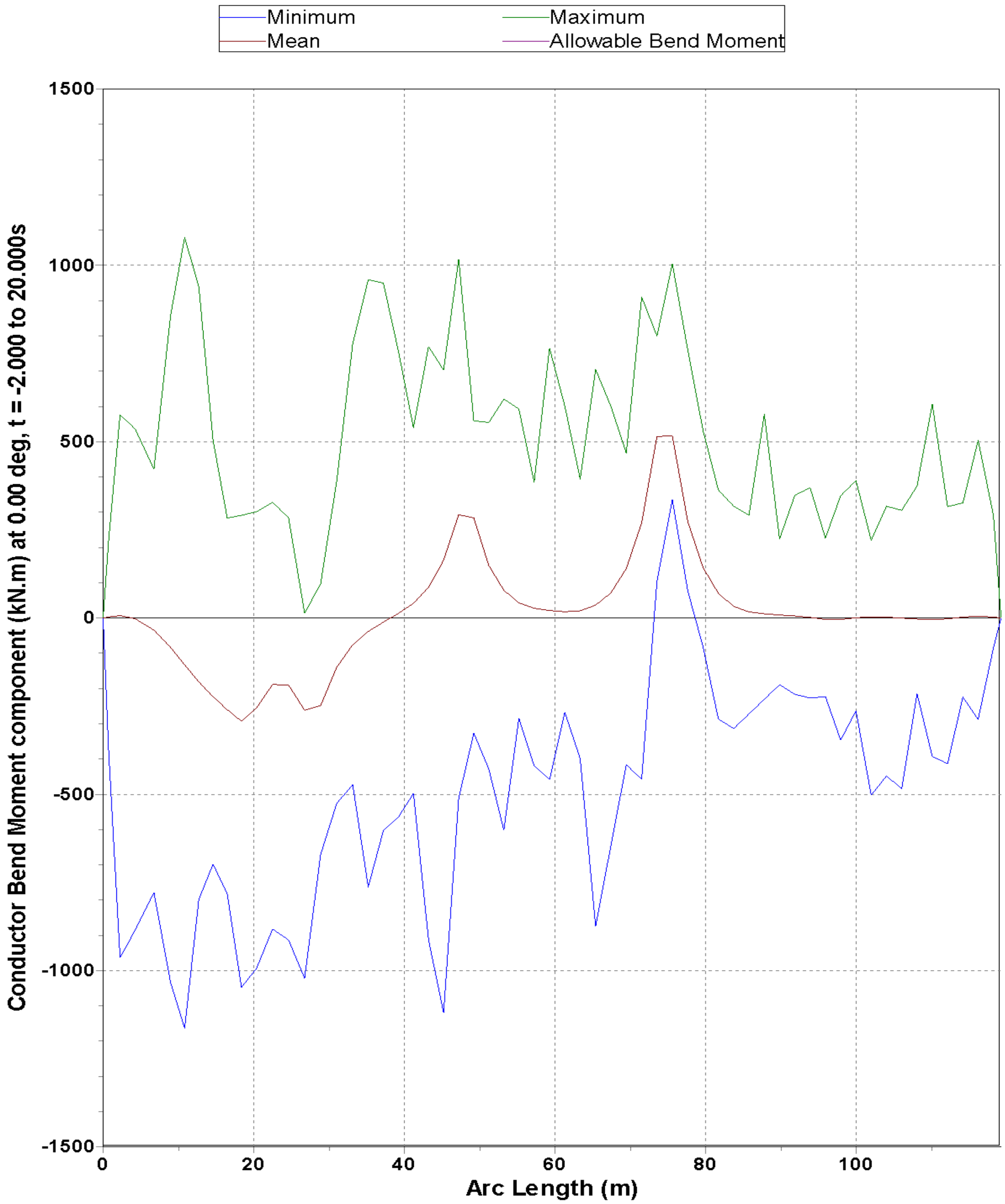
Table A.1 - Scatter diagram for significant wave heights & direction given as numbers of 3 hour events during 30 years /3/

H_{m0}	**Range of H_{m0}**	**Number of Cycles - Based on Chart North Diagram /3/**									
(m)	(m) - (m)	N	NE	E	SE	S	SW	W	NW	All	Accum.
0,25	0,0 - 0,5	247	108	155	196	264	380	352	256	1958	87620
0,75	0,5 - 1,0	1532	602	1061	1375	1742	2763	2384	1637	13096	85662
1,25	1,0 - 1,5	2014	792	1394	1808	2290	3632	3133	2152	17215	72566
1,75	1,5 - 2,0	1615	608	1423	1791	2095	3614	3054	1791	15991	55351
2,25	2,0 - 2,5	995	368	1216	1461	1510	2922	2529	1277	12278	39360
2,75	2,5 - 3,0	582	251	1011	1074	1038	2220	1906	859	8941	27082
3,25	3,0 - 3,5	414	178	719	764	739	1579	1356	611	6360	18141
3,75	3,5 - 4,0	193	92	603	440	494	988	997	381	4188	11781
4,25	4,0 - 4,5	134	64	419	306	344	687	693	265	2912	7593
4,75	4,5 - 5,0	71	41	285	181	234	342	448	170	1772	4681
5,25	5,0 - 5,5	48	27	192	122	158	230	302	115	1194	2909
5,75	5,5 - 6,0	30	18	66	61	125	122	181	102	705	1715
6,25	6,0 - 6,5	19	12	42	39	80	78	116	66	452	1010
6,75	6,5 - 7,0	10	6	23	21	44	43	63	36	246	558
7,25	7,0 - 7,5	6	4	11	10	20	19	30	24	124	312
7,75	7,5 - 8,0	4,4	2,7	5,6	5	10,2	10	16,7	17,2	71,8	187,8
8,25	8,0 - 8,5	3,3	2,0	3,3	2,8	5,7	5,5	10,2	13,1	45,9	116,1
8,75	8,5 - 9	2,4	1,5	1,8	1,5	3,0	3,0	6,1	9,6	28,90	70,2
9,25	9,0 - 9,5	1,6	1,0	1,0	0,8	1,5	1,5	3,5	6,7	17,60	41,2
9,75	9,5 - 10	0,97	0,60	0,46	0,35	0,64	0,63	1,77	4,01	9,43	23,49
10,25	10,0 - 10,5	0,65	0,40	0,23	0,17	0,28	0,28	1,01	2,70	5,72	14,07
10,75	10,5 - 11	0,44	0,27	0,12	0,07	0,11	0,11	0,58	1,83	3,53	8,35
11,25	11,0 - 11,5	0,26	0,16	0,07	0,04	0,06	0,06	0,34	1,08	2,07	4,82
11,75	11,5 - 12	0,13	0,08	0,04	0,02	0,03	0,03	0,18	0,56	1,07	2,73
12,25	12,0 - 12,5	0,084	0,052	0,023	0,014	0,021	0,021	0,112	0,35	0,678	1,652
12,75	12,5 - 13,0	0,051	0,032	0,014	0,009	0,013	0,013	0,068	0,214	0,414	0,975
13,25	13,0 13,5	0,030	0,018	0,008	0,005	0,007	0,007	0,039	0,124	0,238	0,562
13,75	13,5 14,0	0,016	0,010	0,004	0,003	0,004	0,004	0,021	0,066	0,128	0,324
14,25	14,0 14,5	0,010	0,006	0,003	0,002	0,002	0,002	0,013	0,042	0,080	0,196
14,75	14,5 15,0	0,006	0,004	0,002	0,001	0,001	0,001	0,008	0,025	0,048	0,115
15,25	15,0 15,5	0,00350	0,0022	0,00095	0,0006	0,00087	0,00087	0,0047	0,0148	0,028	0,067
15,75	15,5 16,0	0,00190	0,0012	0,00052	0,00033	0,00047	0,00047	0,0026	0,0081	0,016	0,039
16,25	16,0 16,5	0,00120	0,00074	0,00032	0,0002	0,00029	0,00029	0,0016	0,0050	0,010	0,023
16,75	16,5 17,0	0,00072	0,00045	0,00019	0,00012	0,00017	0,00017	0,00095	0,0030	0,0058	0,014
17,25	17,0 17,5	0,00042	0,00026	0,00011	7,1E-05	0,00010	0,00010	0,00056	0,00180	0,003	0,008
17,75	17,5 18,0	0,00023	0,00015	0,000063	0,00004	0,000057	0,000057	0,000310	0,000980	0,002	0,004
18,25	18,0 18,5	0,00014	0,000087	0,000037	2,4E-05	0,000034	0,000034	0,000019	0,000058	0,0004	0,002
		7924	3180	8633	9660	11199	19640	17585	9800	87620	

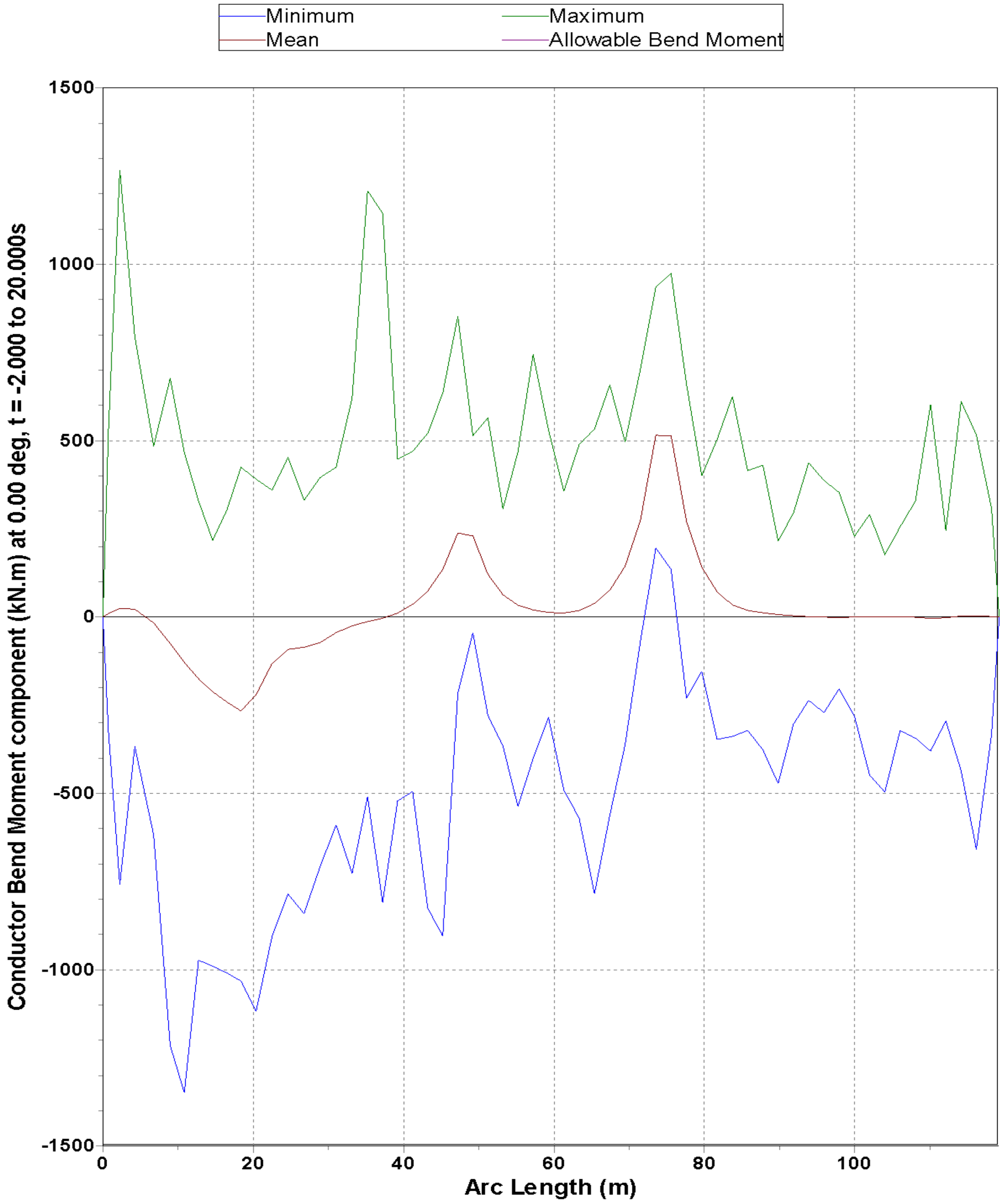
13.0 APPENDIX B- RESULTS FROM OrcaFlex 9.5

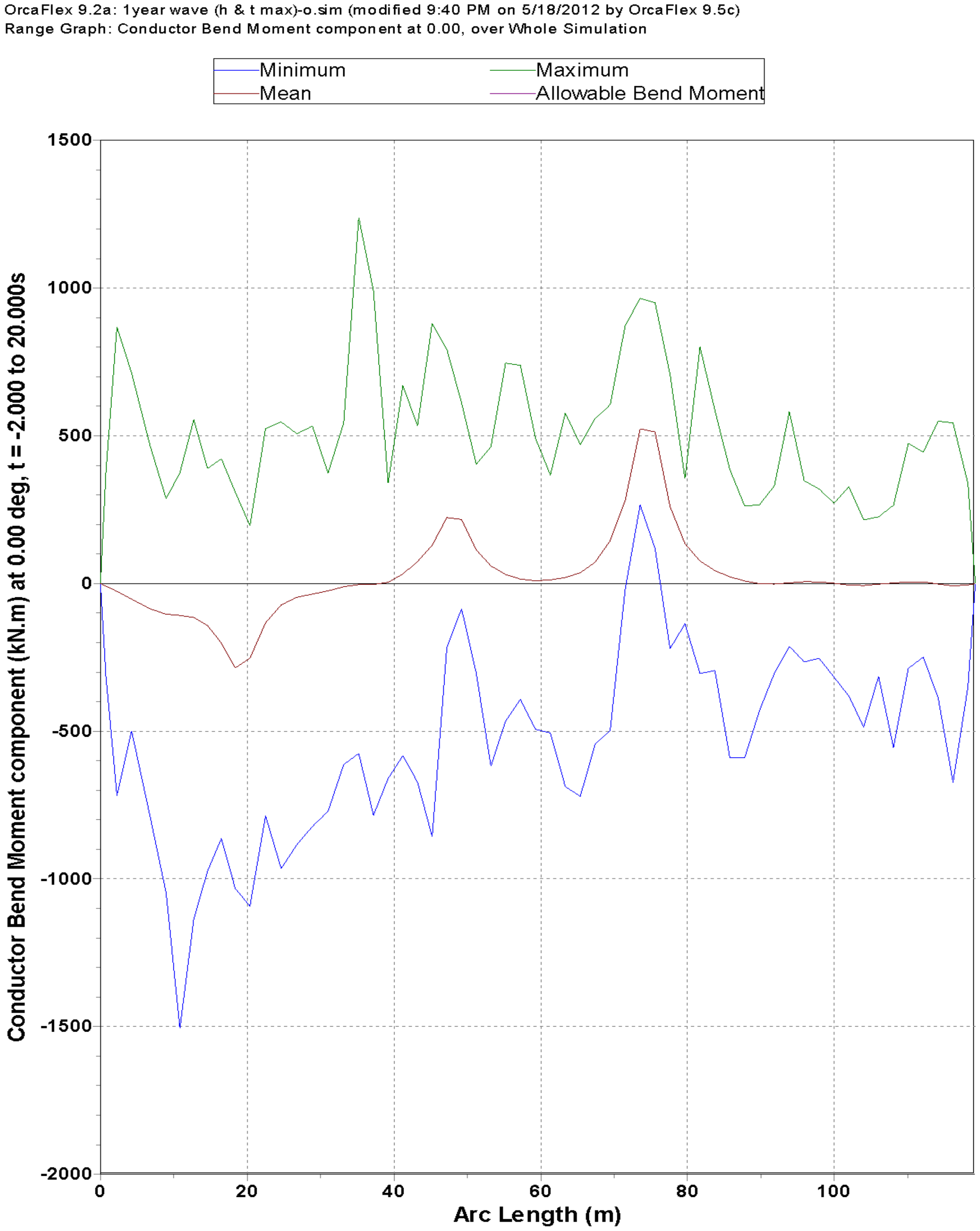
13.1 BENDING MOMENT DIAGRAMS

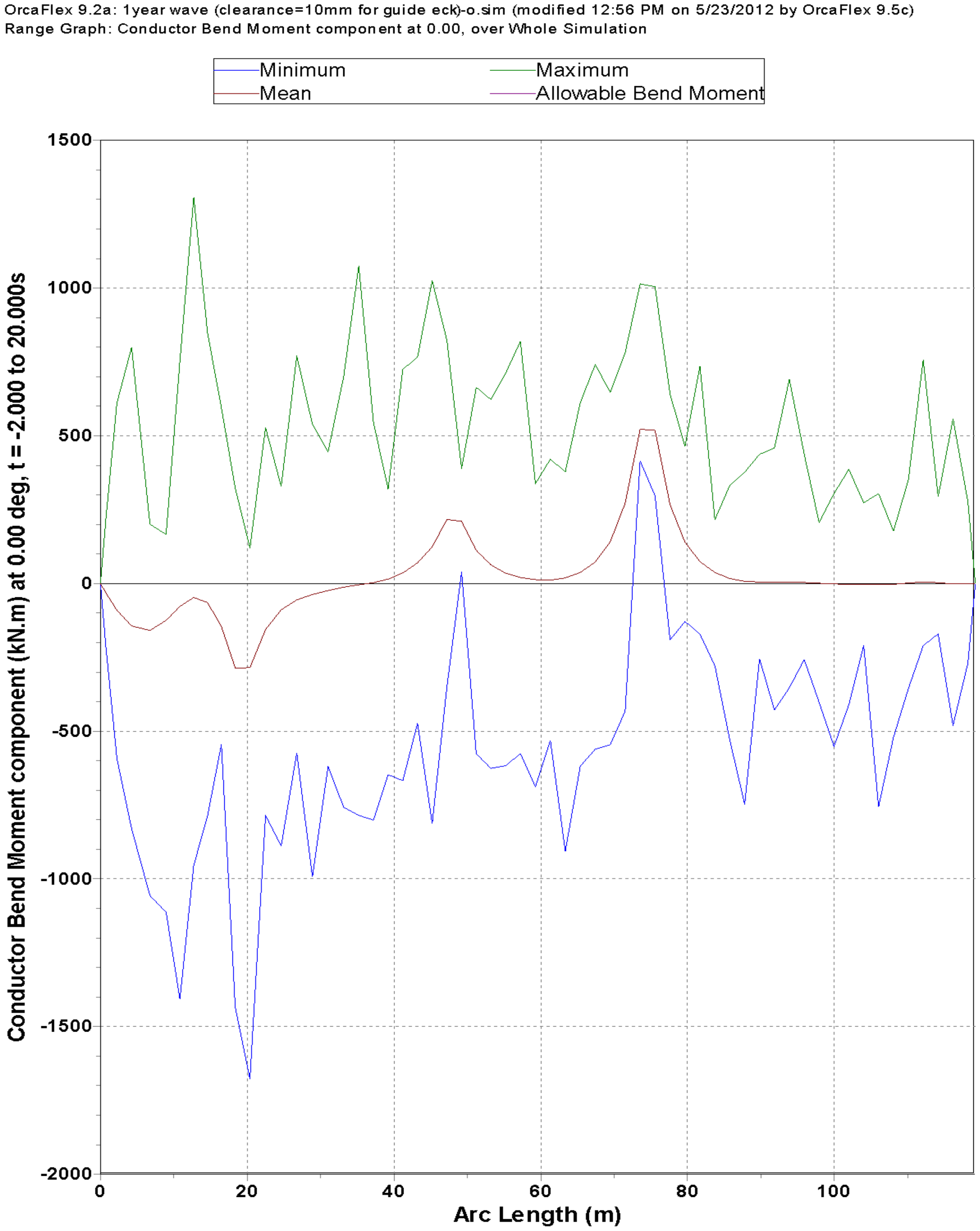
OrcaFlex 9.2a: 1year wave (clearance=0 for guide eck).sim (modified 12:27 PM on 5/23/2012 by OrcaFlex 9.5c)
Range Graph: Conductor Bend Moment component at 0.00, over Whole Simulation

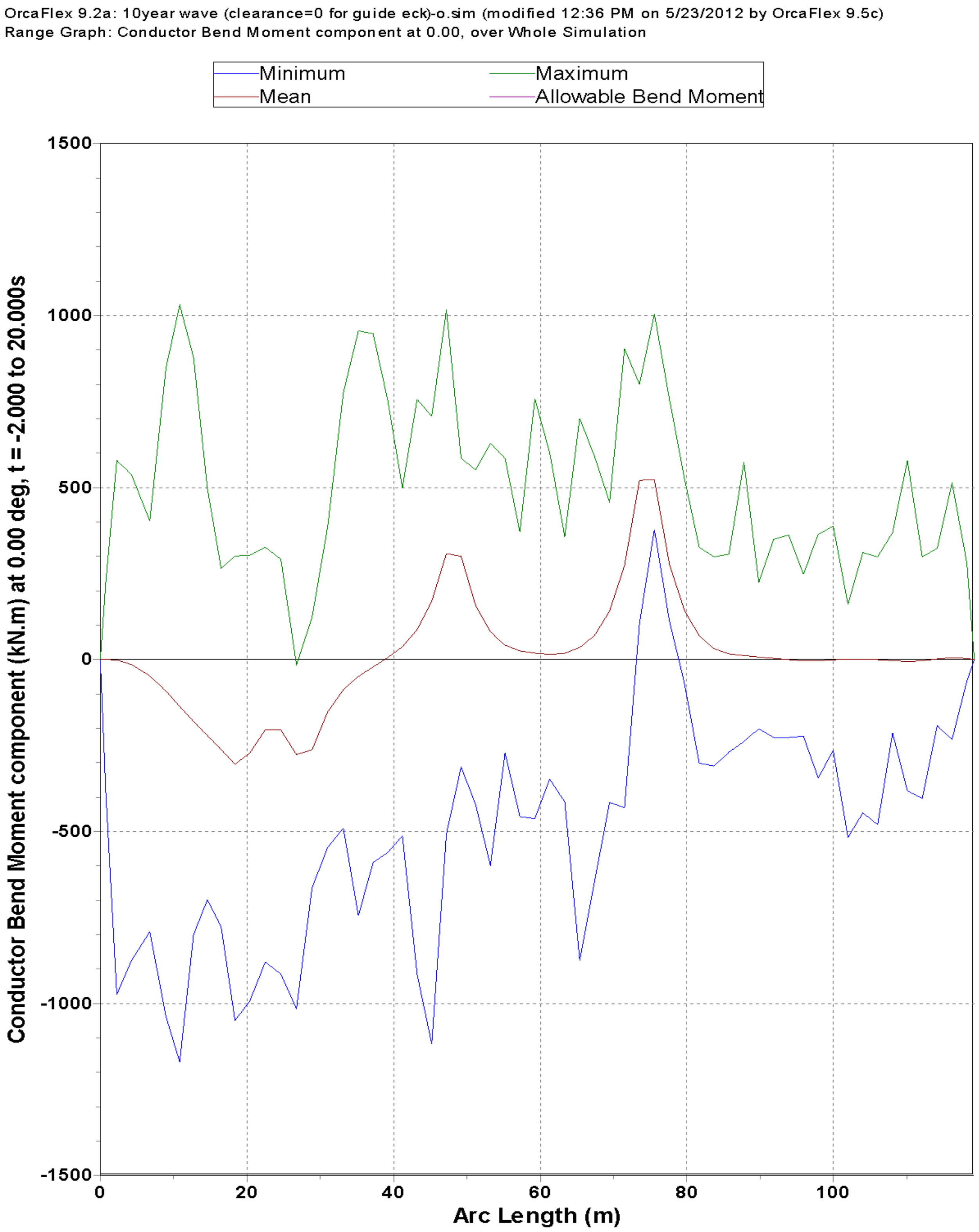


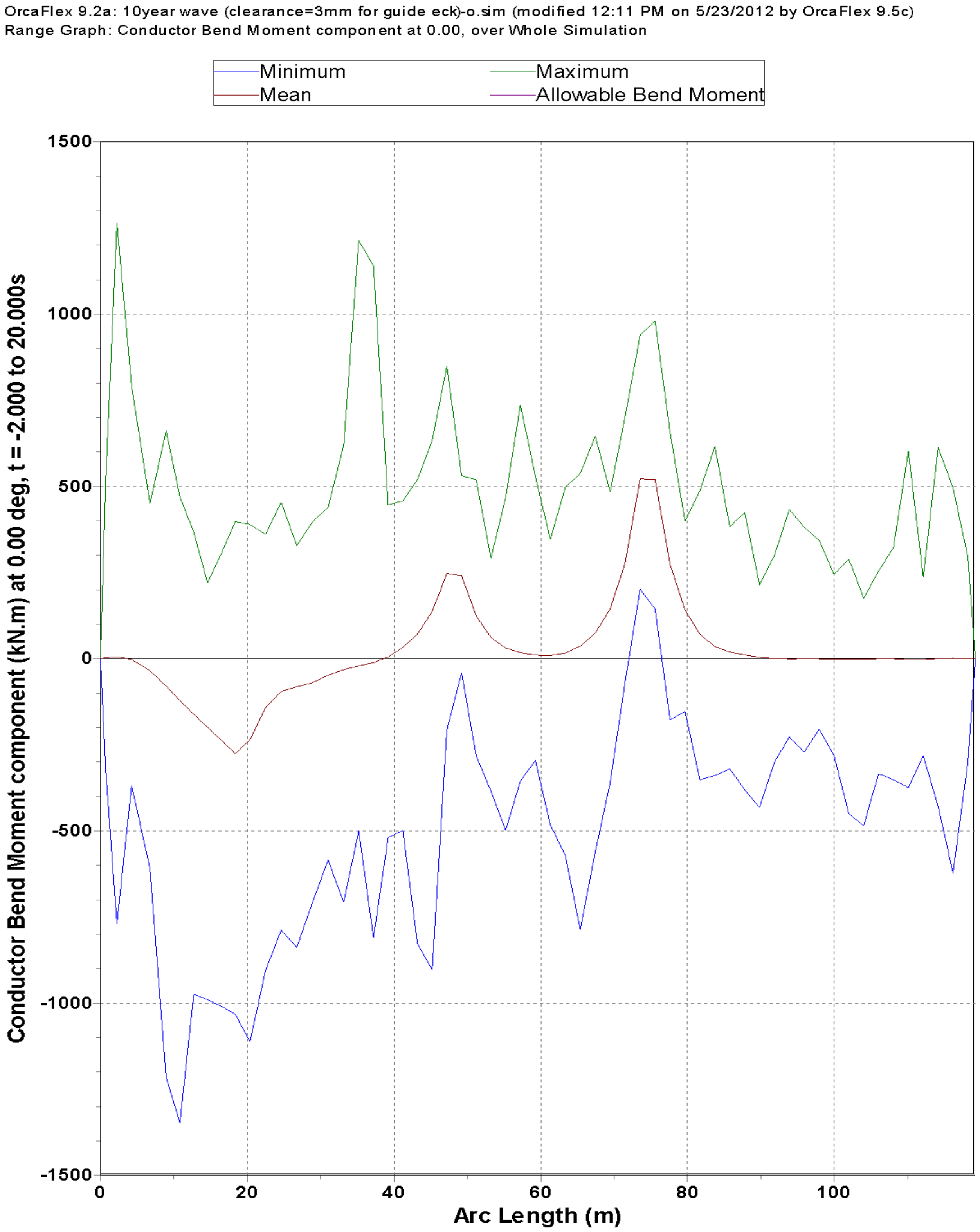
OrcaFlex 9.2a: 1year wave (clearance=3mm for guide eck)-o.sim (modified 12:22 PM on 5/23/2012 by OrcaFlex 9.5c)
Range Graph: Conductor Bend Moment component at 0.00, over Whole Simulation




OrcaFlex 9.2a: 1year wave (h & t max)-o.sim (modified 9:40 PM on 5/18/2012 by OrcaFlex 9.5c)
Range Graph: Conductor Bend Moment component at 0.00, over Whole Simulation
Minimum
Maximum
Mean
Allowable Bend Moment
1500
1000
500
0
-500
-1000
-1500
-2000
0
20
40
60
80
100
Conductor Bend Moment component (kN.m) at 0.00 deg, t = -2.000 to 20.000s
Arc Length (m)

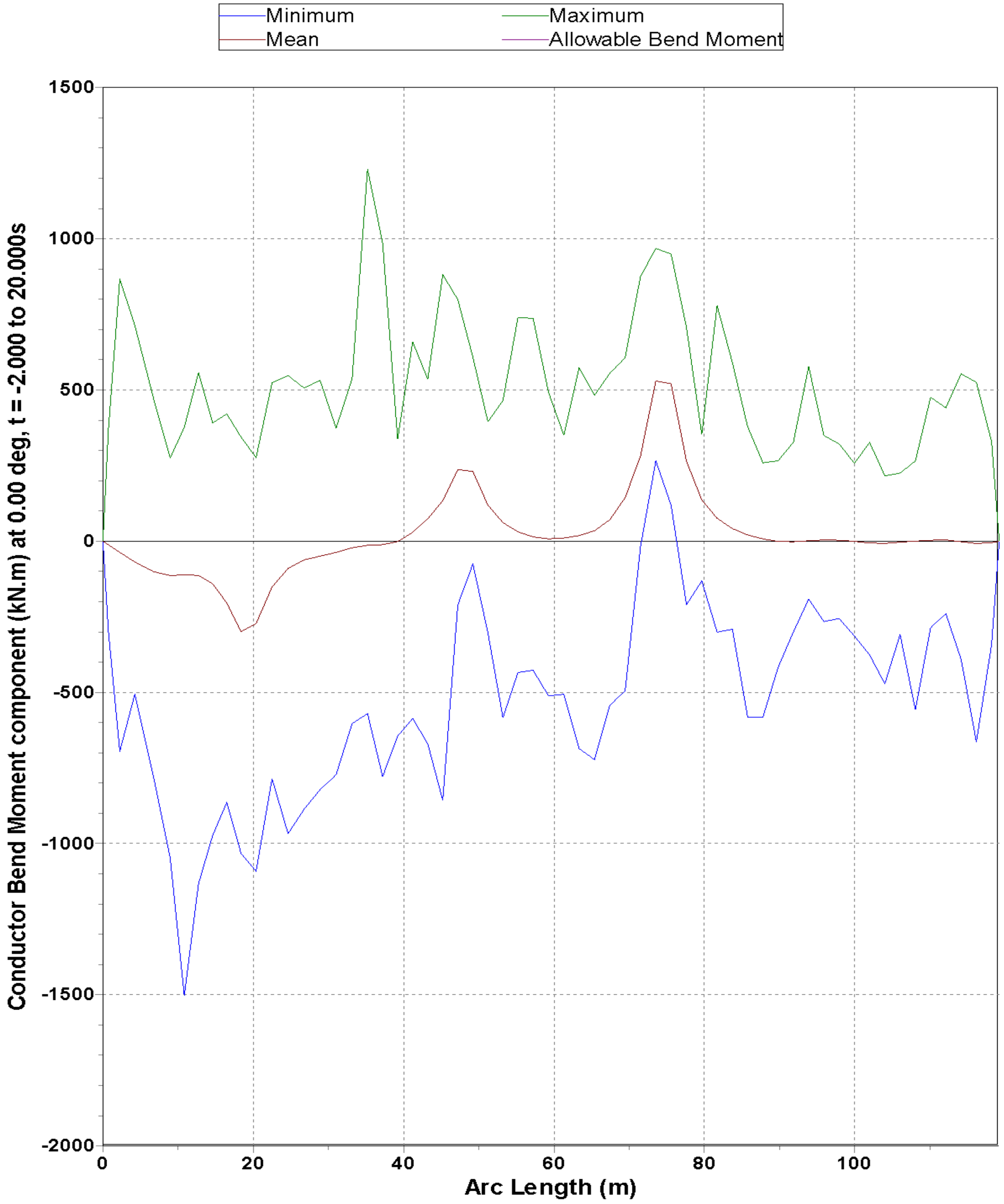

OrcaFlex 9.2a: 1year wave (clearance=10mm for guide eck)-o.sim (modified 12:56 PM on 5/23/2012 by OrcaFlex 9.5c)
Range Graph: Conductor Bend Moment component at 0.00, over Whole Simulation
Minimum
Maximum
Mean
Allowable Bend Moment
Conductor Bend Moment component (kN.m) at 0.00 deg, t = -2.000 to 20.000s
1500
1000
500
0
-500
-1000
-1500
-2000
0
20
40
60
80
100
Arc Length (m)


OrcaFlex 9.2a: 10year wave (clearance=0 for guide eck)-o.sim (modified 12:36 PM on 5/23/2012 by OrcaFlex 9.5c)
Range Graph: Conductor Bend Moment component at 0.00, over Whole Simulation
Minimum
Maximum
Mean
Allowable Bend Moment
Conductor Bend Moment component (kN.m) at 0.00 deg, t = -2.000 to 20.000s
1500
1000
500
0
-500
-1000
-1500
0
20
40
60
80
100
Arc Length (m)

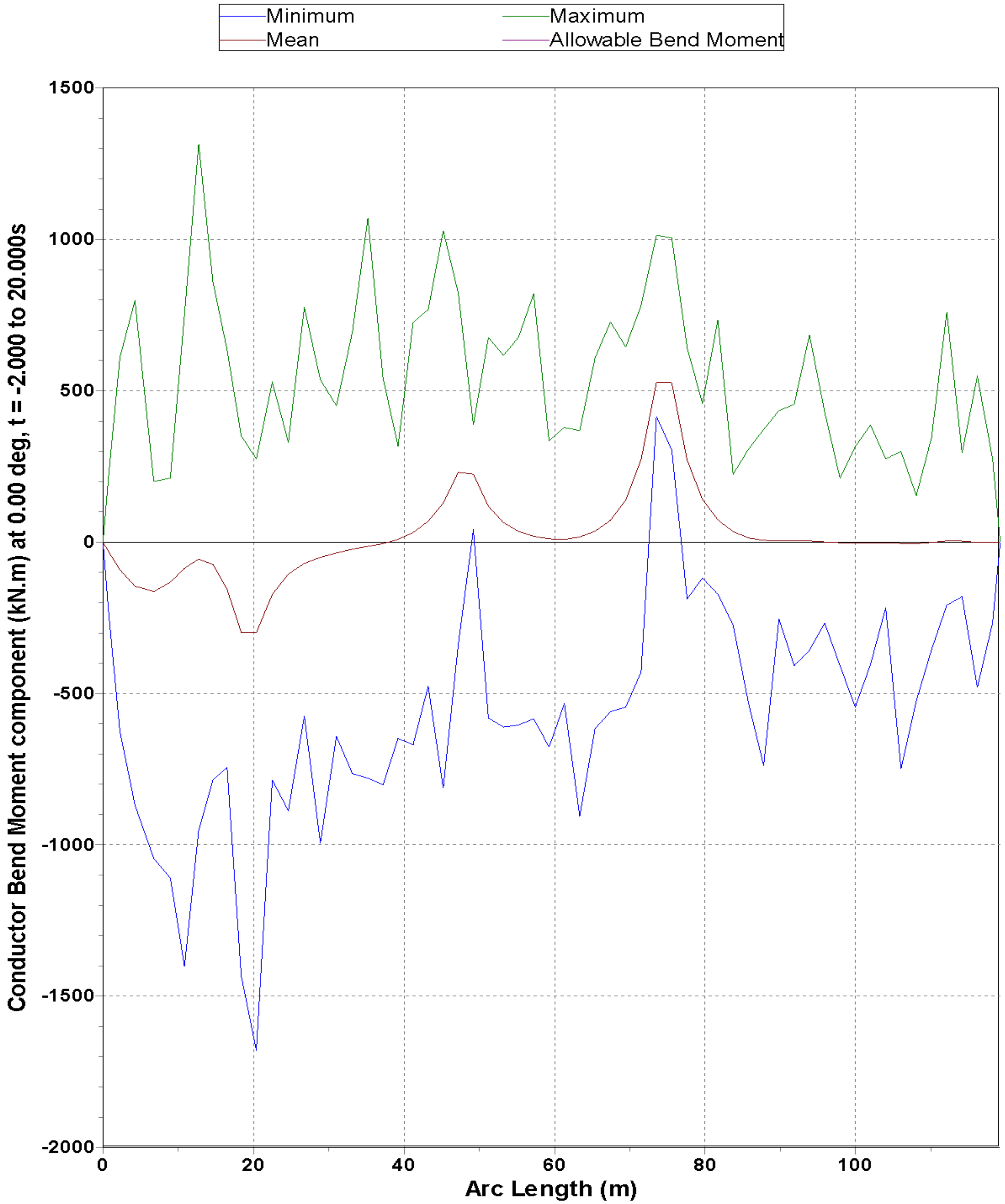


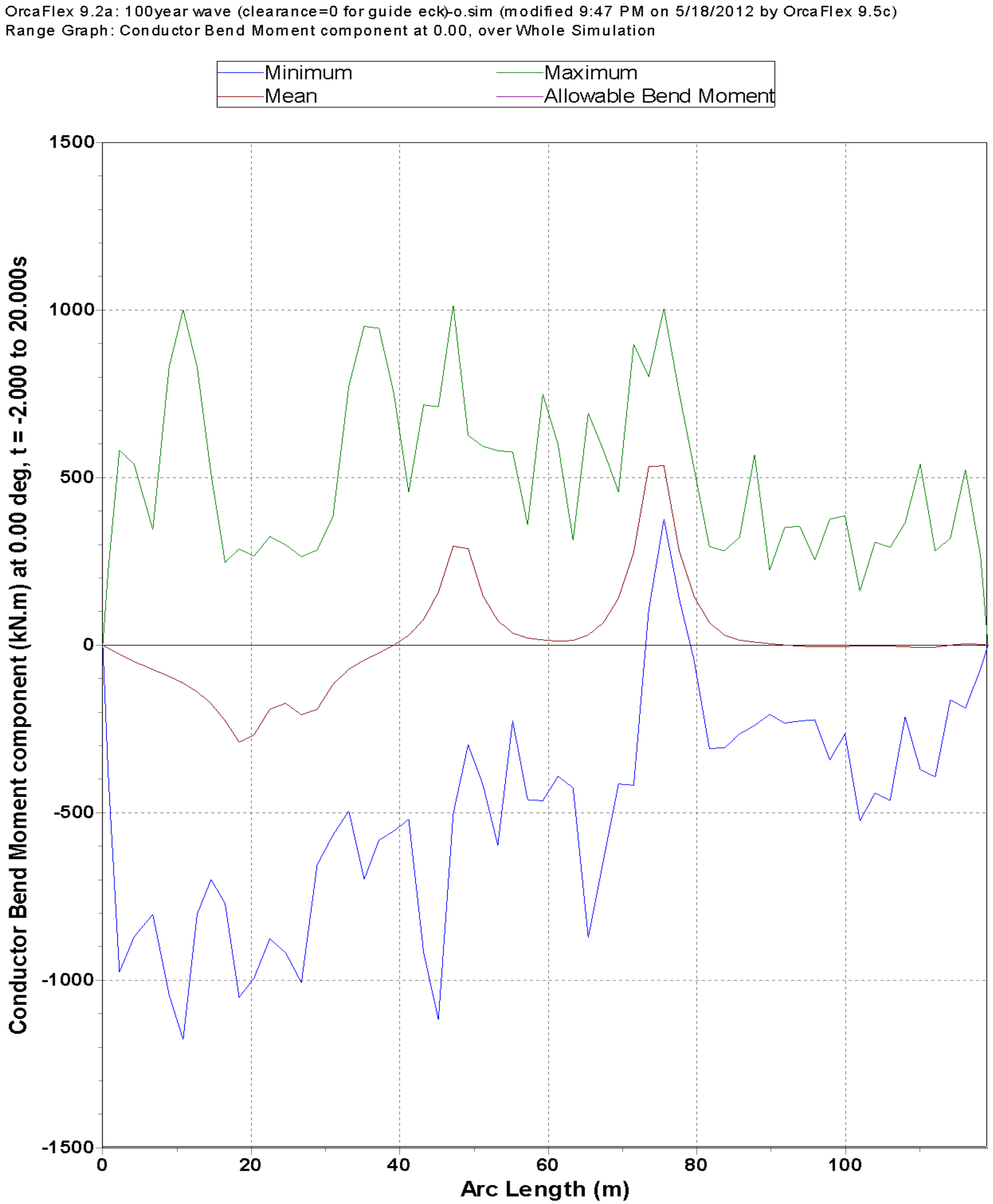
OrcaFlex 9.2a: 10year wave (clearance=3mm for guide eck)-o.sim (modified 12:11 PM on 5/23/2012 by OrcaFlex 9.5c)
Range Graph: Conductor Bend Moment component at 0.00, over Whole Simulation

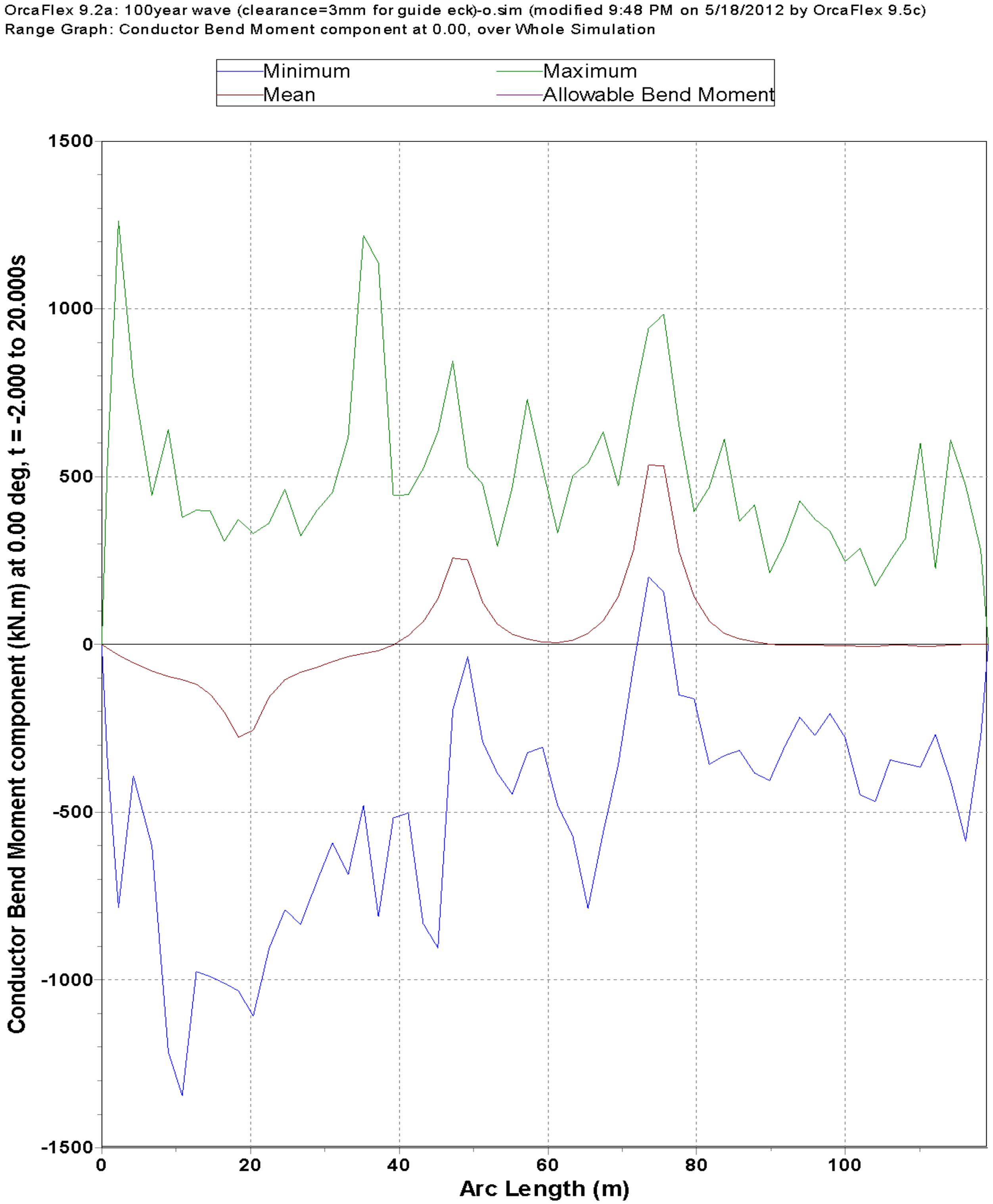
OrcaFlex 9.2a: 10year wave (h & t max)-o.sim (modified 9:41 PM on 5/18/2012 by OrcaFlex 9.5c)
Range Graph: Conductor Bend Moment component at 0.00, over Whole Simulation

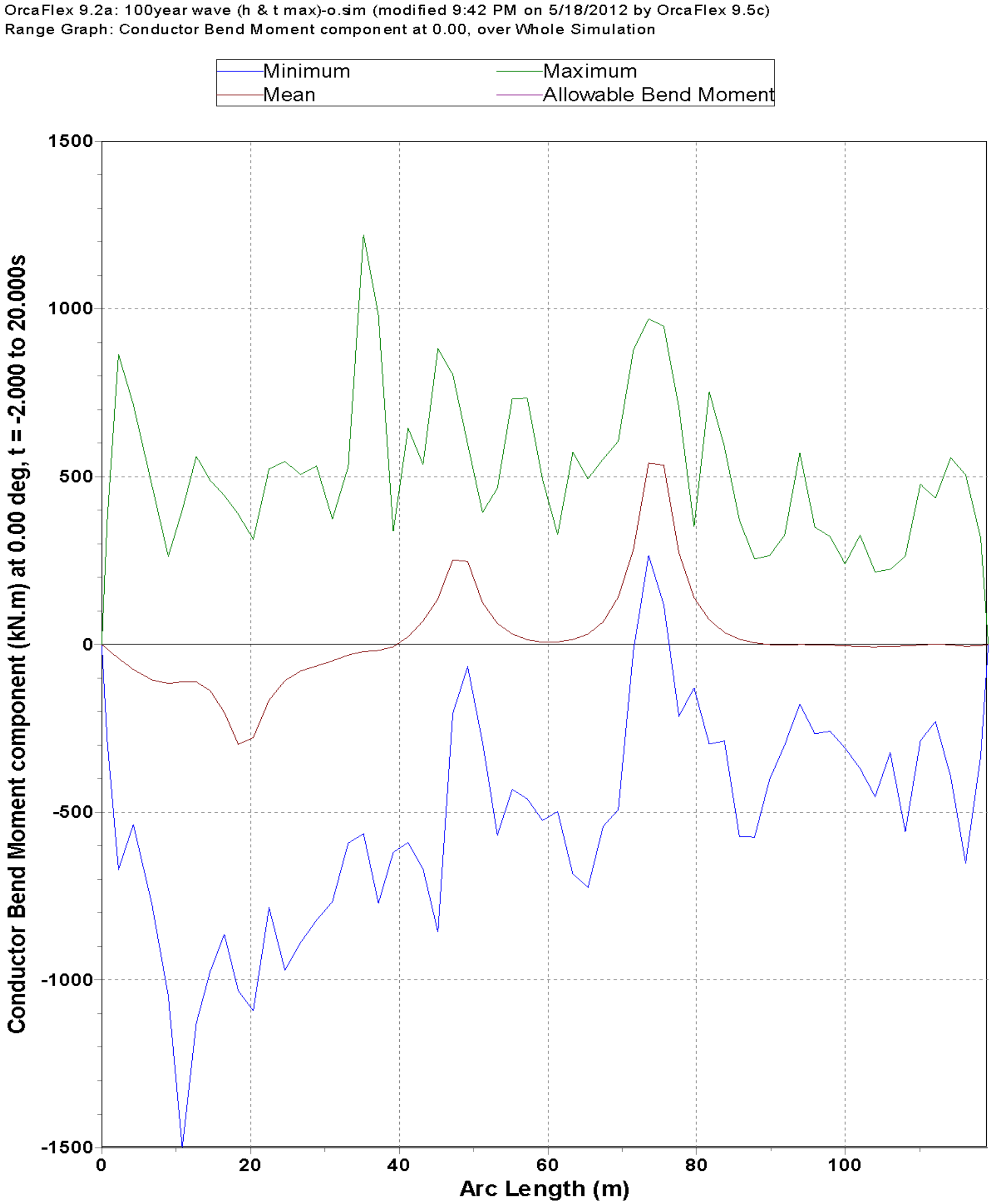


OrcaFlex 9.2a: 10year wave (clearance=10mm for guide eck)-o.sim (modified 12:49 PM on 5/23/2012 by OrcaFlex 9.5c)
Range Graph: Conductor Bend Moment component at 0.00, over Whole Simulation

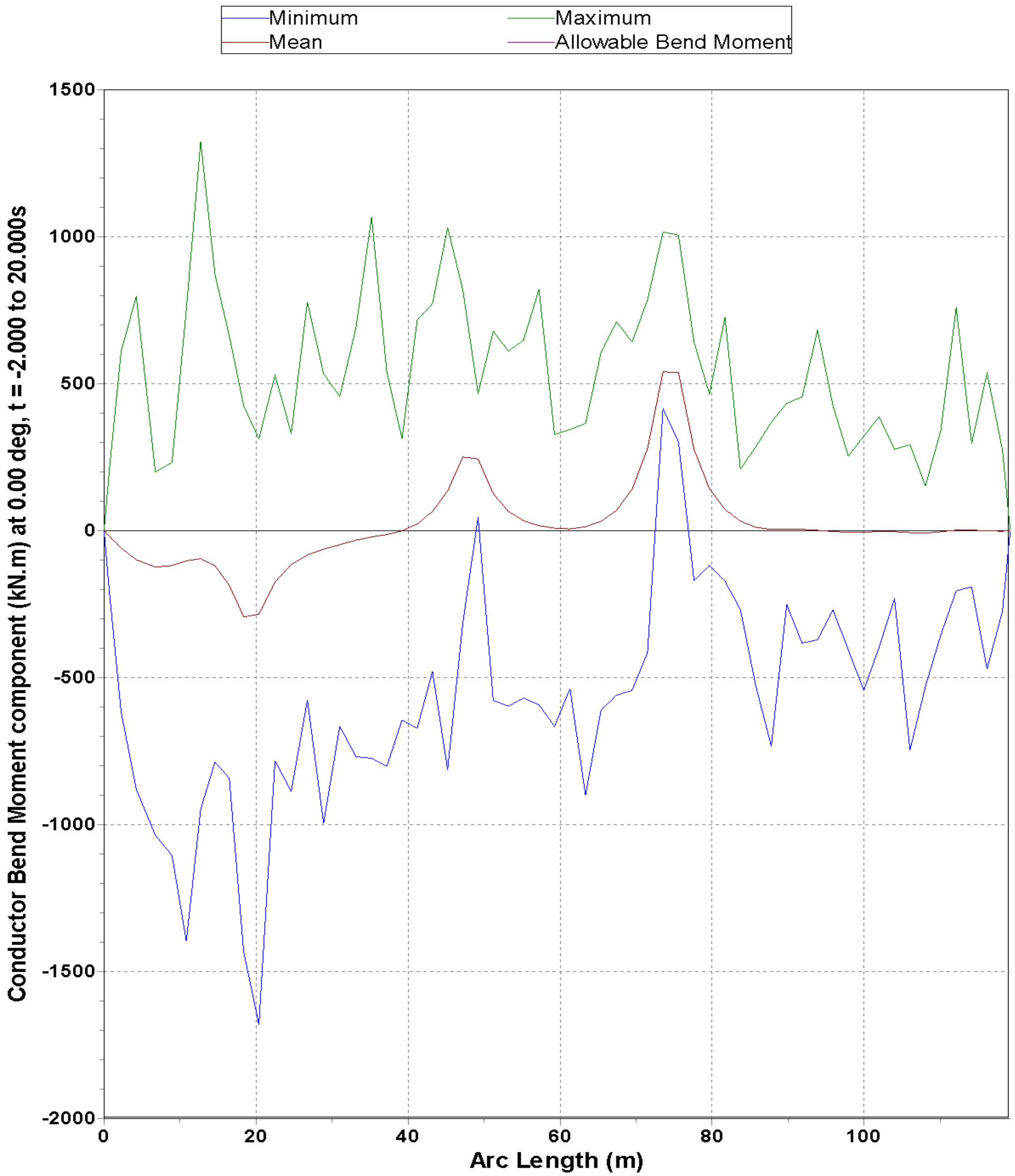


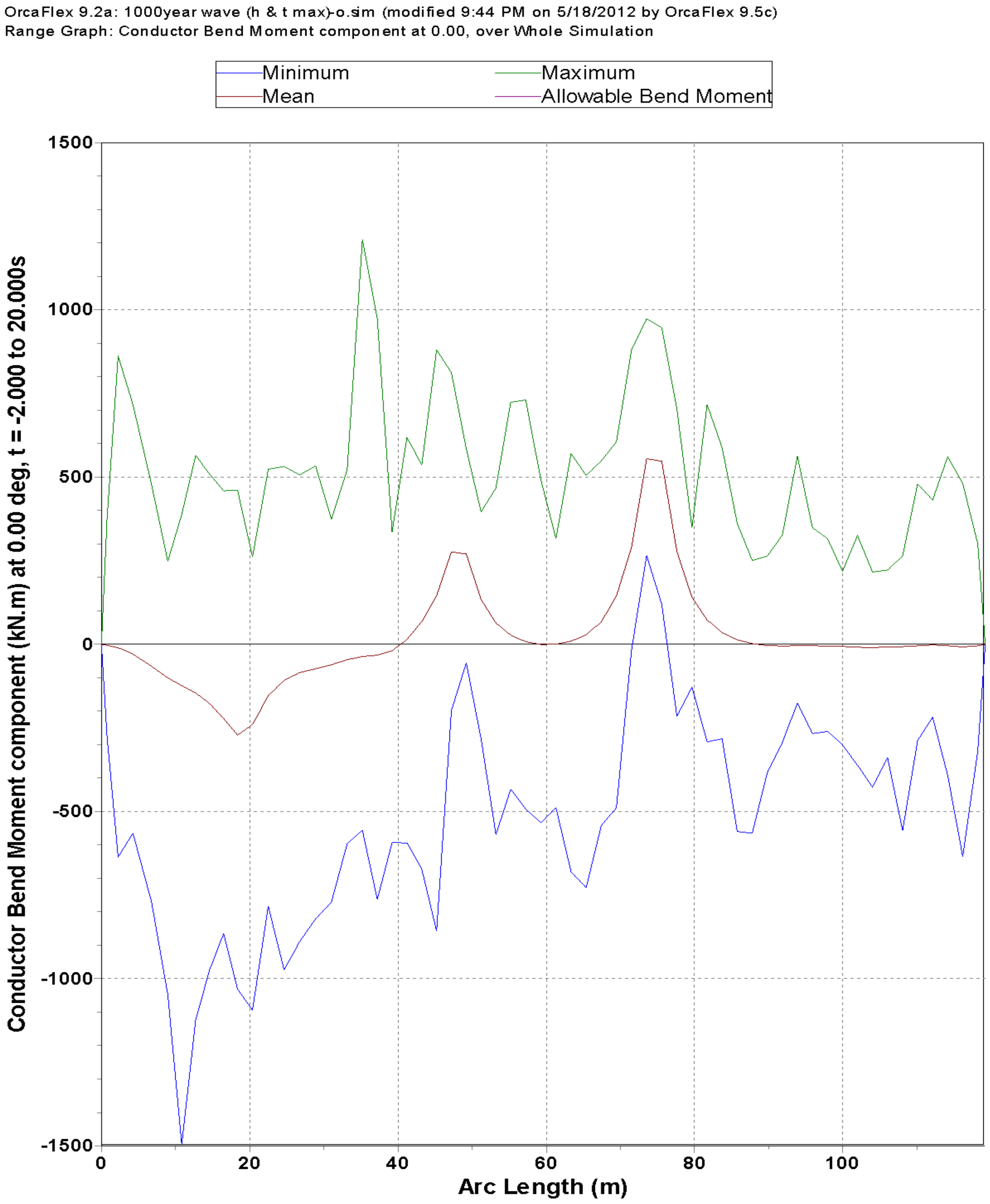

OrcaFlex 9.2a: 100year wave (clearance=0 for guide eck)-o.sim (modified 9:47 PM on 5/18/2012 by OrcaFlex 9.5c)
Range Graph: Conductor Bend Moment component at 0.00, over Whole Simulation
Minimum
Maximum
Mean
Allowable Bend Moment
Conductor Bend Moment component (kN.m) at 0.00 deg, t = -2.000 to 20.000s
1500
1000
500
0
-500
-1000
-1500
0
20
40
60
80
100
Arc Length (m)

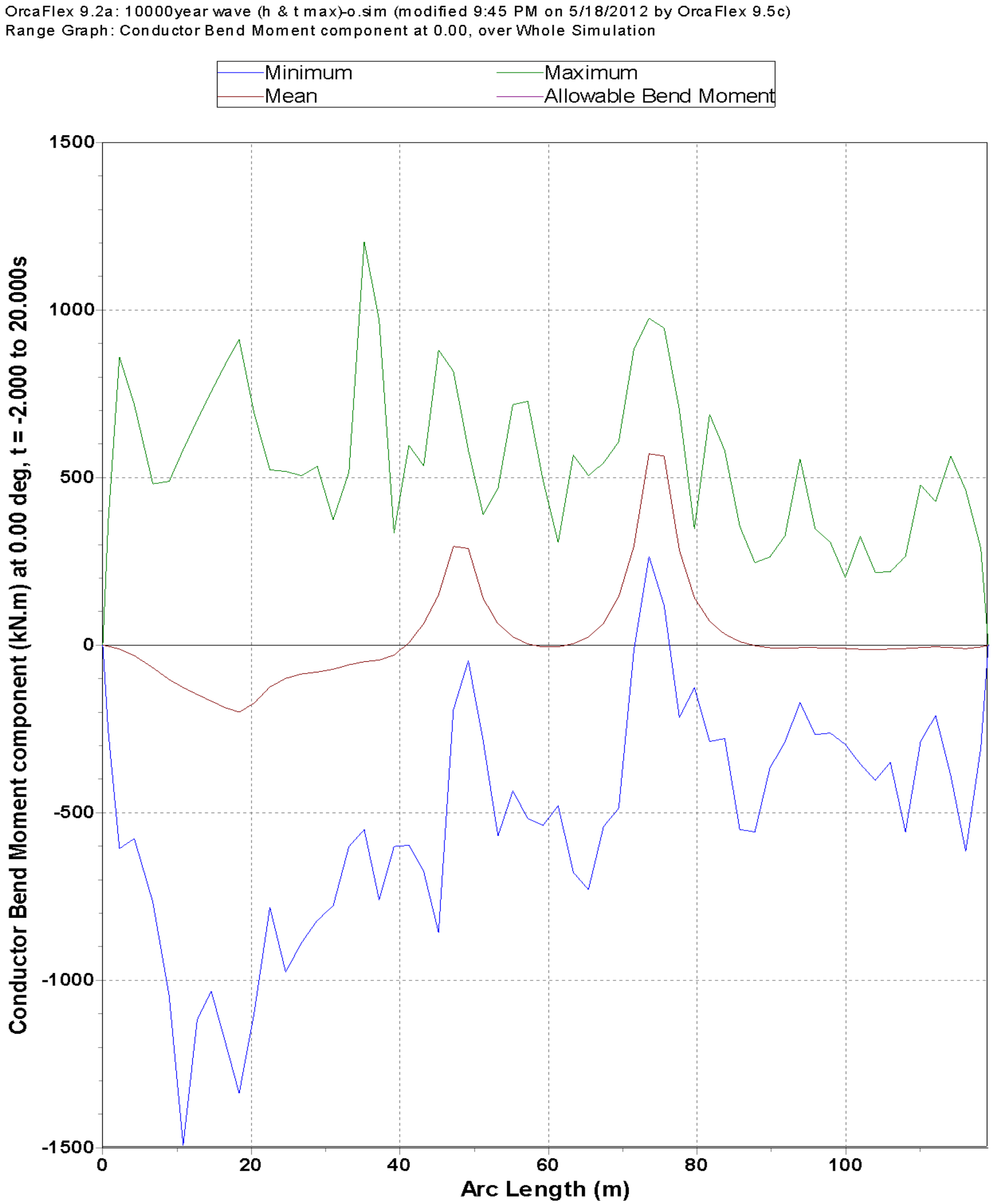

OrcaFlex 9.2a: 100year wave (clearance=3mm for guide eck)-o.sim (modified 9:48 PM on 5/18/2012 by OrcaFlex 9.5c)
Range Graph: Conductor Bend Moment component at 0.00, over Whole Simulation
Minimum
Maximum
Mean
Allowable Bend Moment
1500
1000
500
0
-500
-1000
-1500
Conductor Bend Moment component (kN.m) at 0.00 deg, t = -2.000 to 20.000s
0
20
40
60
80
100
Arc Length (m)


OrcaFlex 9.2a: 100year wave (h & t max)-o.sim (modified 9:42 PM on 5/18/2012 by OrcaFlex 9.5c)
Range Graph: Conductor Bend Moment component at 0.00, over Whole Simulation
Minimum
Maximum
Mean
Allowable Bend Moment
1500
1000
500
0
-500
-1000
-1500
0
20
40
60
80
100
Conductor Bend Moment component (kN.m) at 0.00 deg, t = -2.000 to 20.000s
Arc Length (m)

OrcaFlex 9.2a: 100year wave (clearance=10mm for guide eck)-o.sim (modified 9:50 PM on 5/18/2012 by OrcaFlex 9.5c)
Range Graph: Conductor Bend Moment component at 0.00, over Whole Simulation

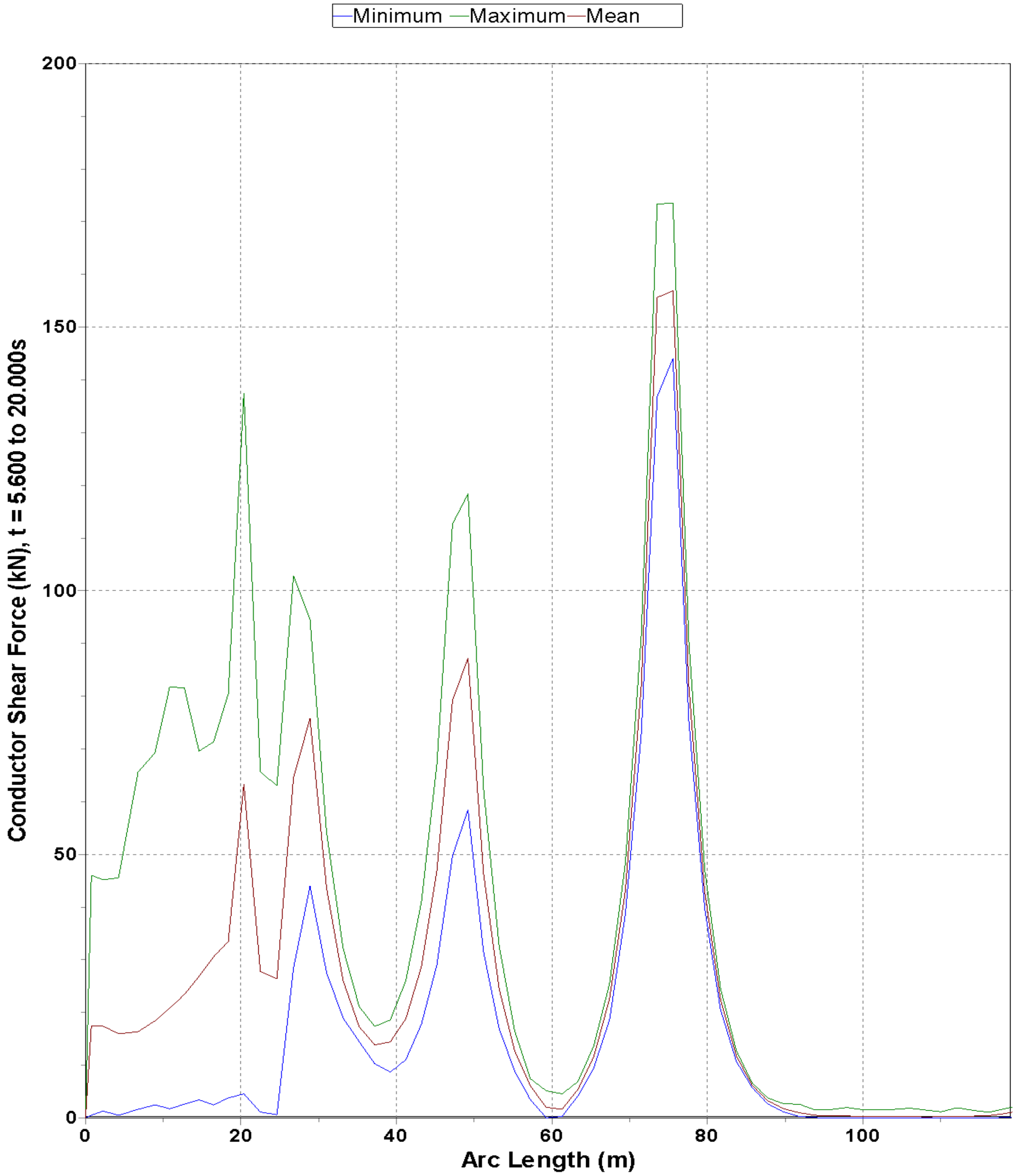



OrcaFlex 9.2a: 1000year wave (h & t max)-o.sim (modified 9:44 PM on 5/18/2012 by OrcaFlex 9.5c)
Range Graph: Conductor Bend Moment component at 0.00, over Whole Simulation
Minimum
Maximum
Mean
Allowable Bend Moment
Conductor Bend Moment component (kN.m) at 0.00 deg, t = -2.000 to 20.000s
1500
1000
500
0
-500
-1000
-1500
0
20
40
60
80
100
Arc Length (m)

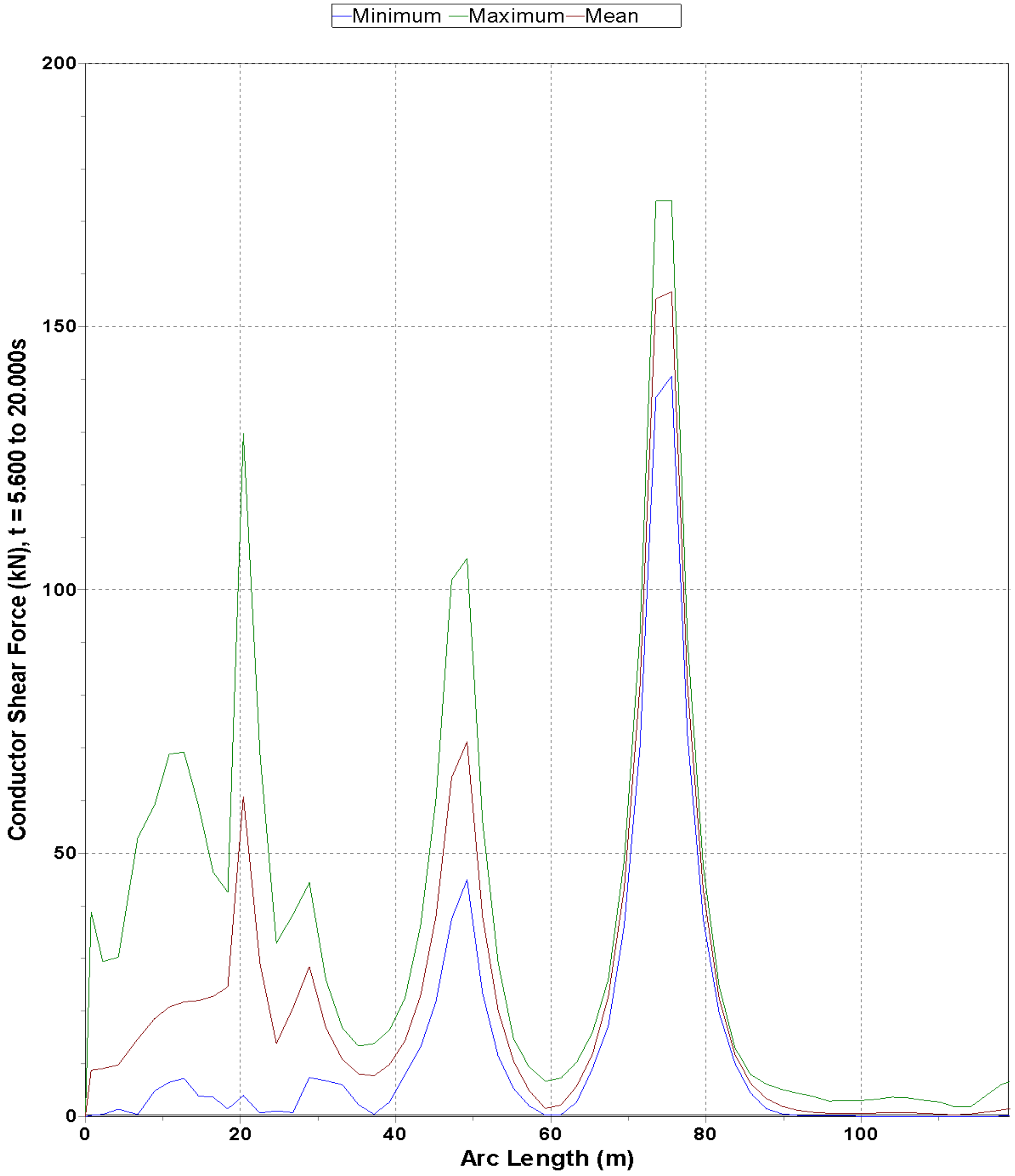

OrcaFlex 9.2a: 10000year wave (h & t max)-o.sim (modified 9:45 PM on 5/18/2012 by OrcaFlex 9.5c)
Range Graph: Conductor Bend Moment component at 0.00, over Whole Simulation
Minimum
Maximum
Mean
Allowable Bend Moment
1500
1000
500
0
-500
-1000
-1500
Conductor Bend Moment component (kN.m) at 0.00 deg, t = -2.000 to 20.000s
0
20
40
60
80
100
Arc Length (m)

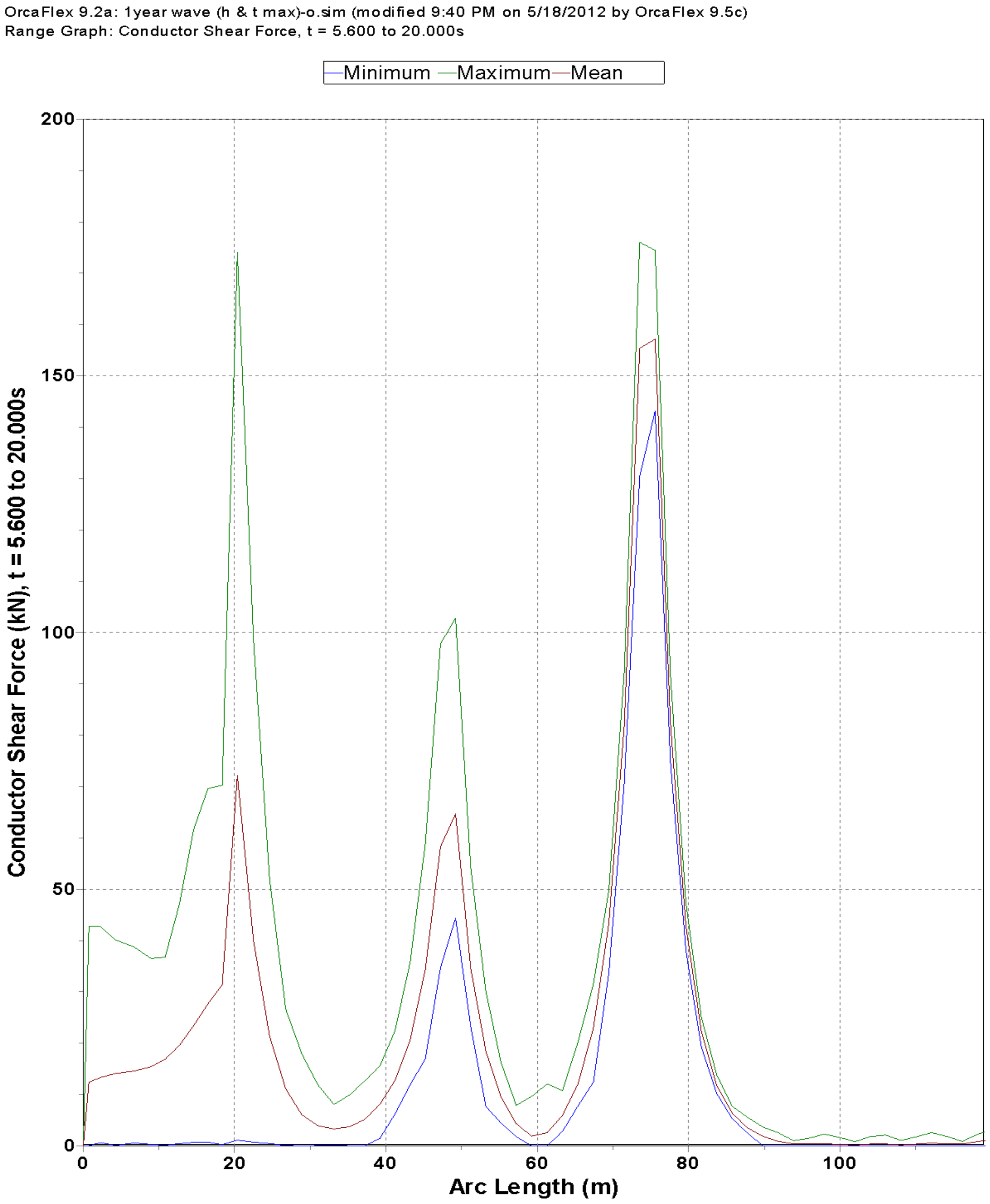
13.2 CONTACT FORCES DIAGRAMS

OrcaFlex 9.2a: 1year wave (clearance=0 for guide eck).sim (modified 12:27 PM on 5/23/2012 by OrcaFlex 9.5c)
Range Graph: Conductor Shear Force, t = 5.600 to 20.000s

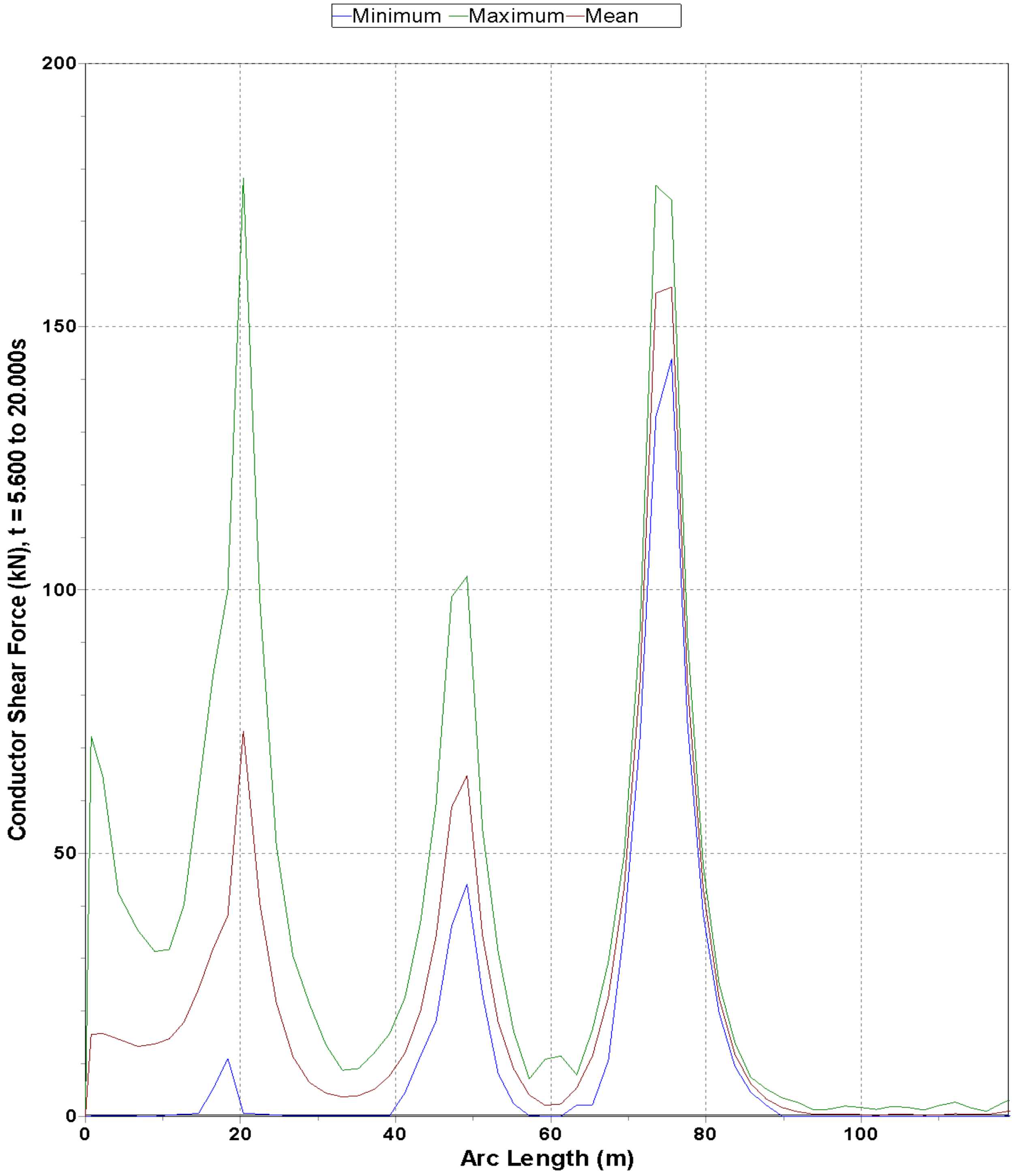


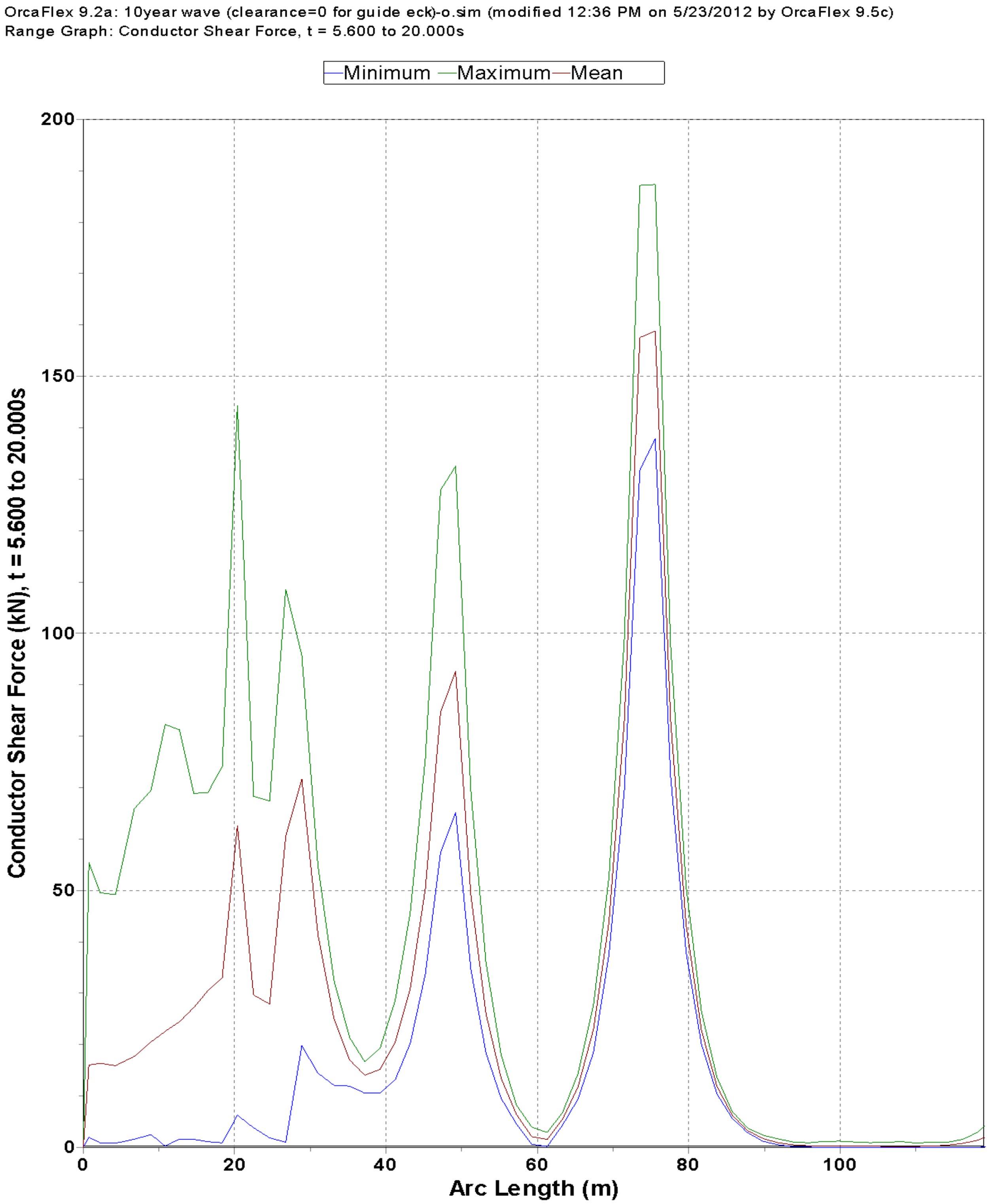
OrcaFlex 9.2a: 1year wave (clearance=3mm for guide eck)-o.sim (modified 12:22 PM on 5/23/2012 by OrcaFlex 9.5c)
Range Graph: Conductor Shear Force, t = 5.600 to 20.000s



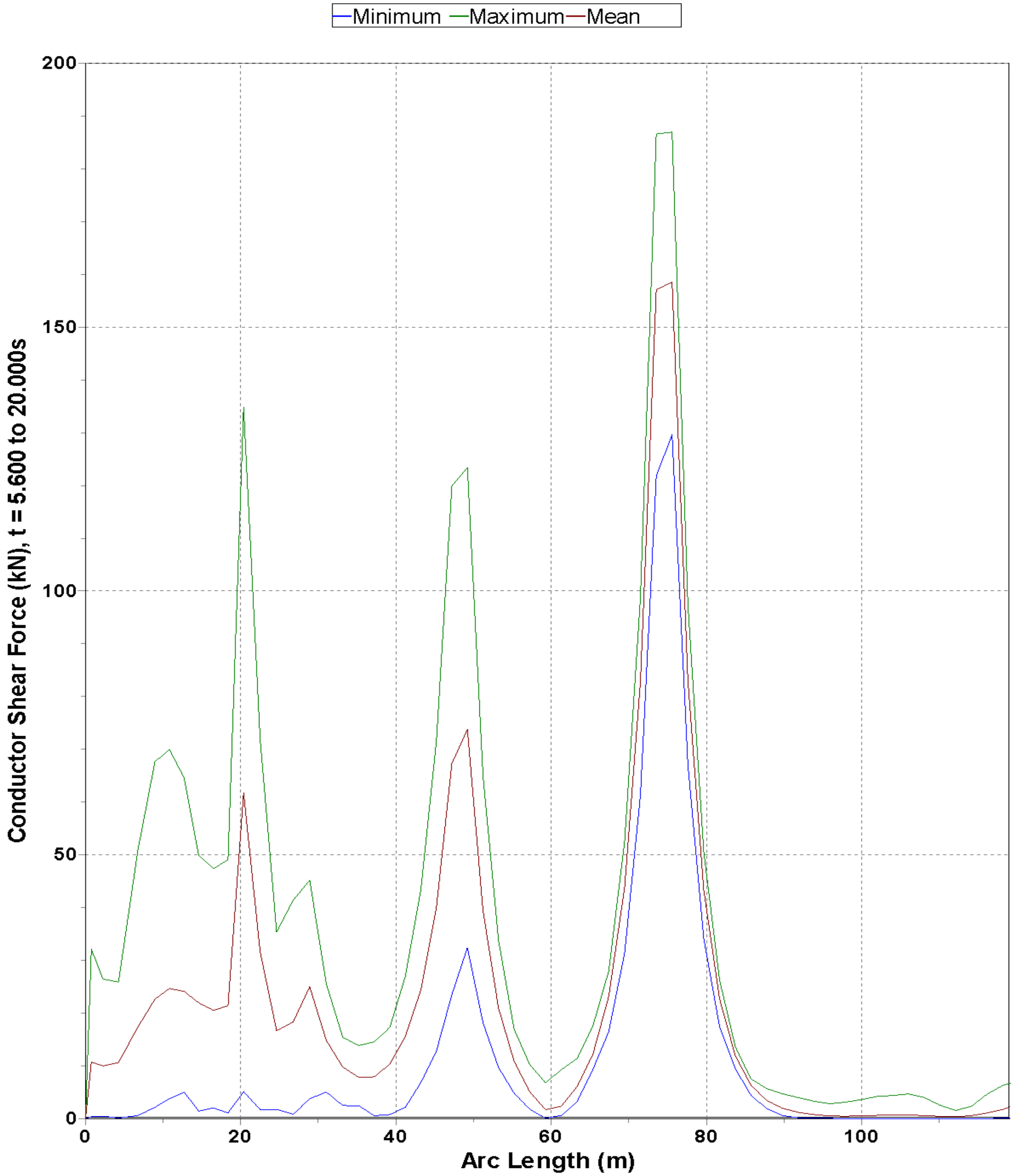

OrcaFlex 9.2a: 1year wave (h & t max)-o.sim (modified 9:40 PM on 5/18/2012 by OrcaFlex 9.5c)
Range Graph: Conductor Shear Force, t = 5.600 to 20.000s
Minimum
Maximum
Mean
Conductor Shear Force (kN), t = 5.600 to 20.000s
200
150
100
50
0
0
20
40
60
80
100
Arc Length (m)

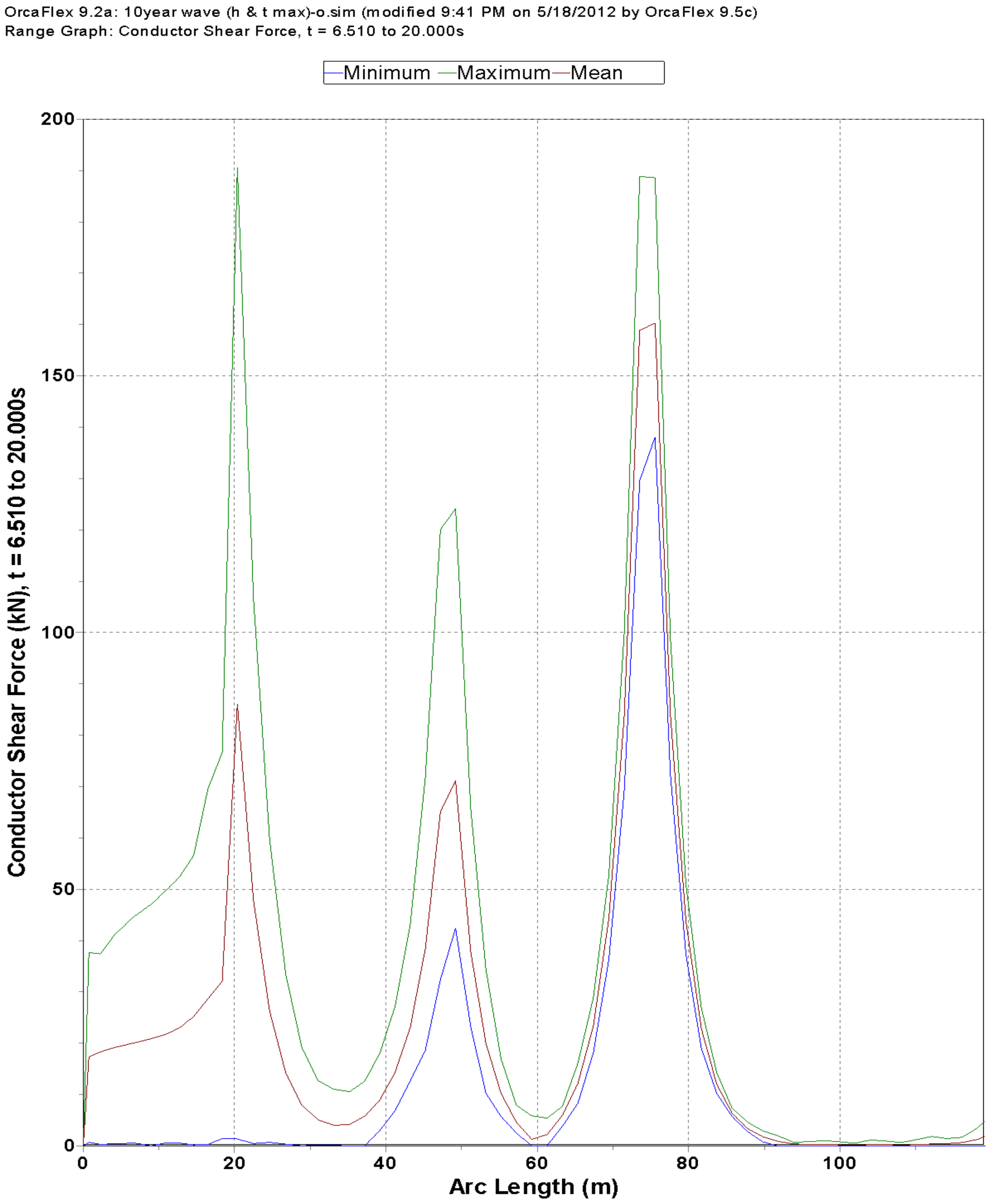
OrcaFlex 9.2a: 1year wave (clearance=10mm for guide eck)-o.sim (modified 12:56 PM on 5/23/2012 by OrcaFlex 9.5c)
Range Graph: Conductor Shear Force, t = 5.600 to 20.000s




OrcaFlex 9.2a: 10year wave (clearance=0 for guide eck)-o.sim (modified 12:36 PM on 5/23/2012 by OrcaFlex 9.5c)
Range Graph: Conductor Shear Force, t = 5.600 to 20.000s
Minimum
Maximum
Mean
Conductor Shear Force (kN), t = 5.600 to 20.000s
200
150
100
50
0
0
20
40
60
80
100
Arc Length (m)

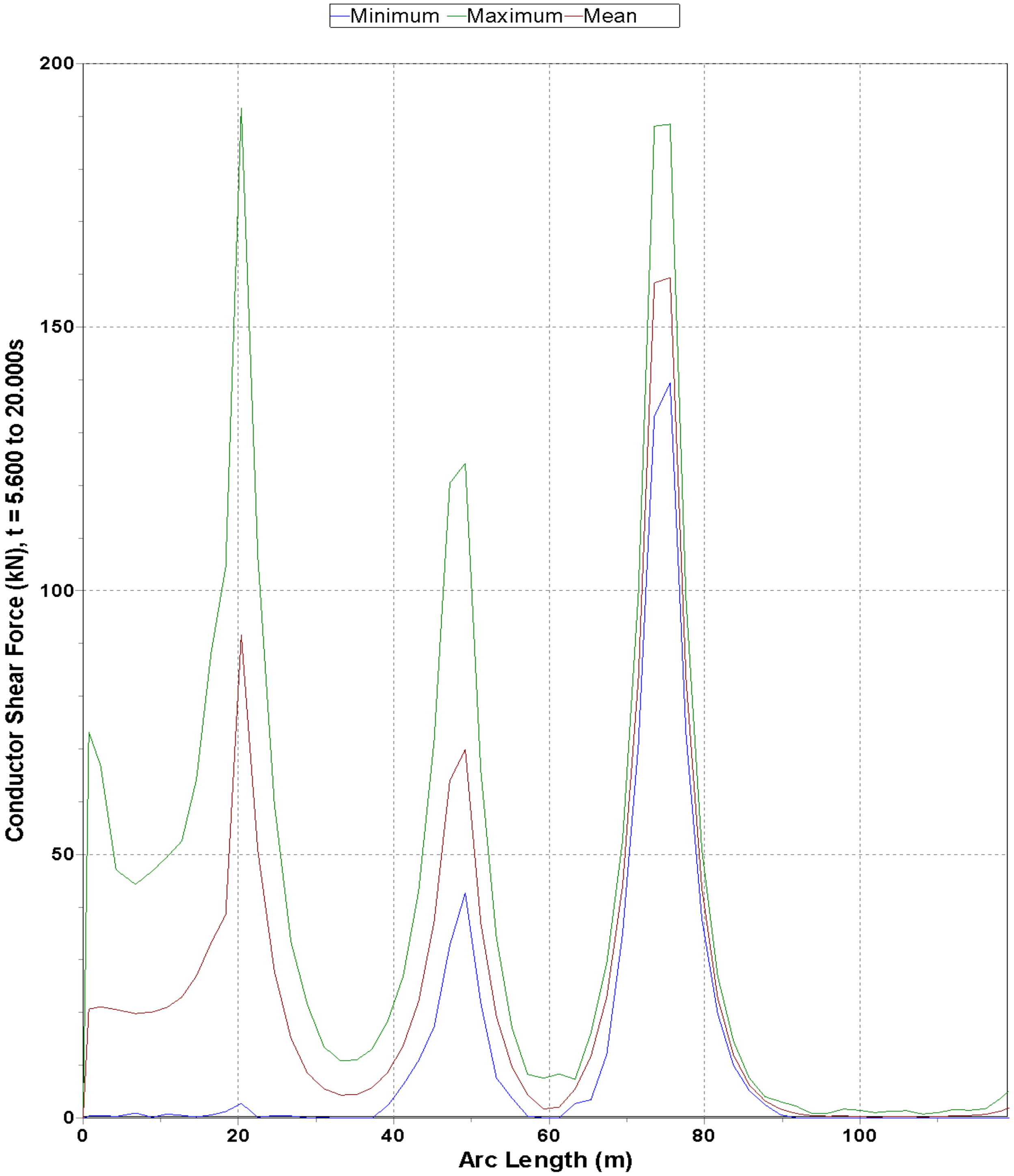
OrcaFlex 9.2a: 10year wave (clearance=3mm for guide eck)-o.sim (modified 12:11 PM on 5/23/2012 by OrcaFlex 9.5c)
Range Graph: Conductor Shear Force, t = 5.600 to 20.000s



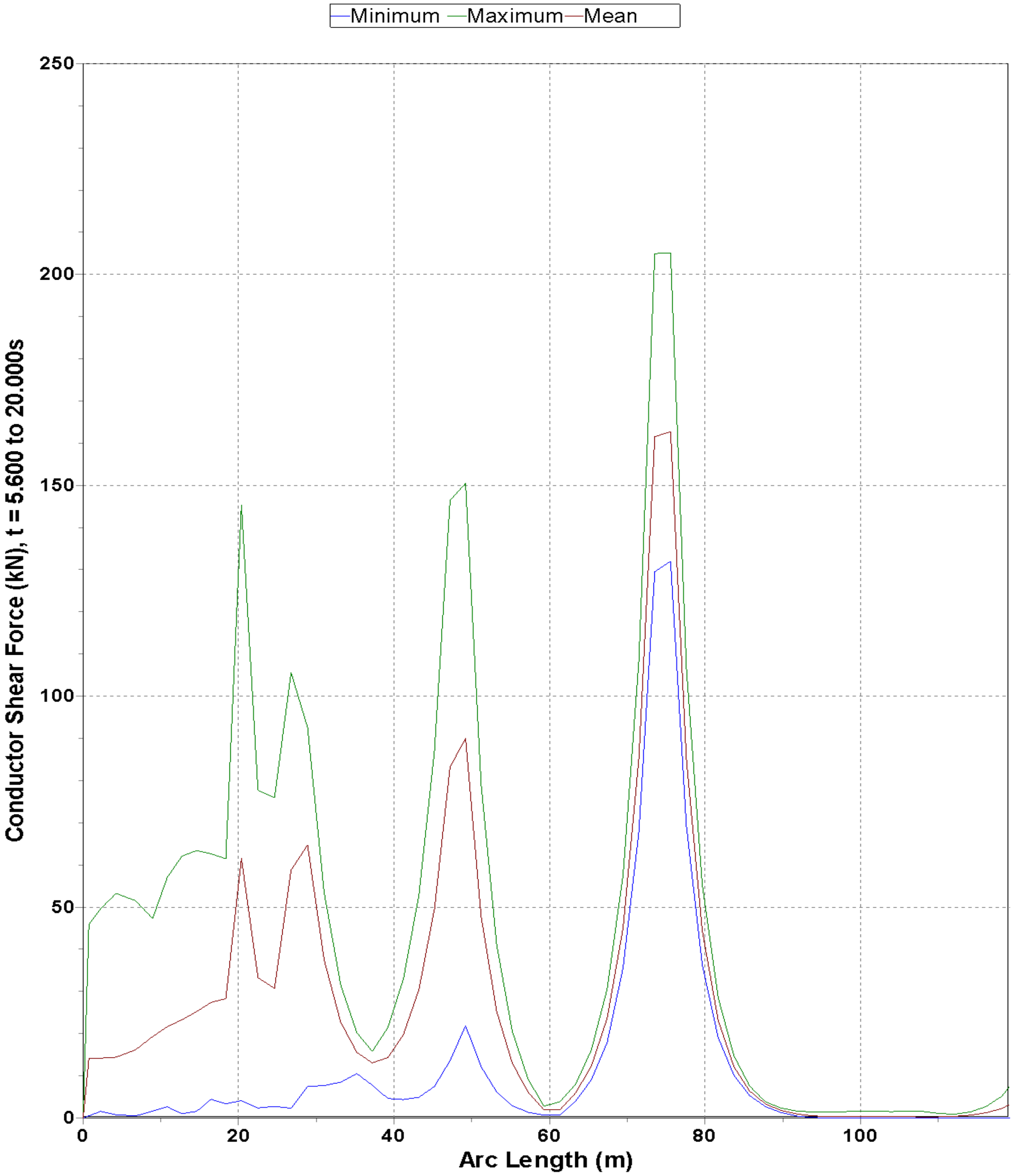


OrcaFlex 9.2a: 10year wave (h & t max)-o.sim (modified 9:41 PM on 5/18/2012 by OrcaFlex 9.5c)
Range Graph: Conductor Shear Force, t = 6.510 to 20.000s

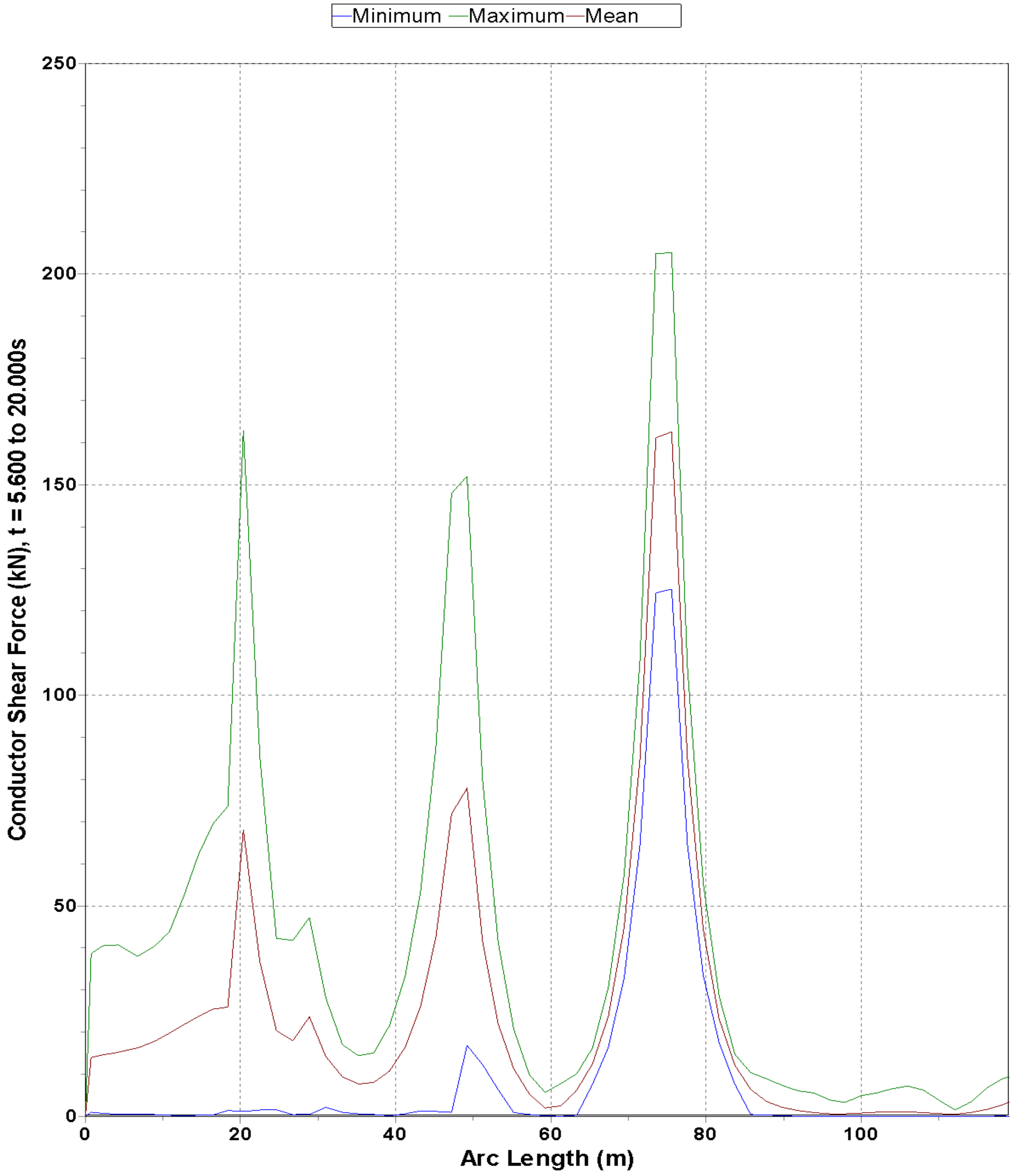
OrcaFlex 9.2a: 10year wave (clearance=10mm for guide eck)-o.sim (modified 12:49 PM on 5/23/2012 by OrcaFlex 9.5c)
Range Graph: Conductor Shear Force, t = 5.600 to 20.000s

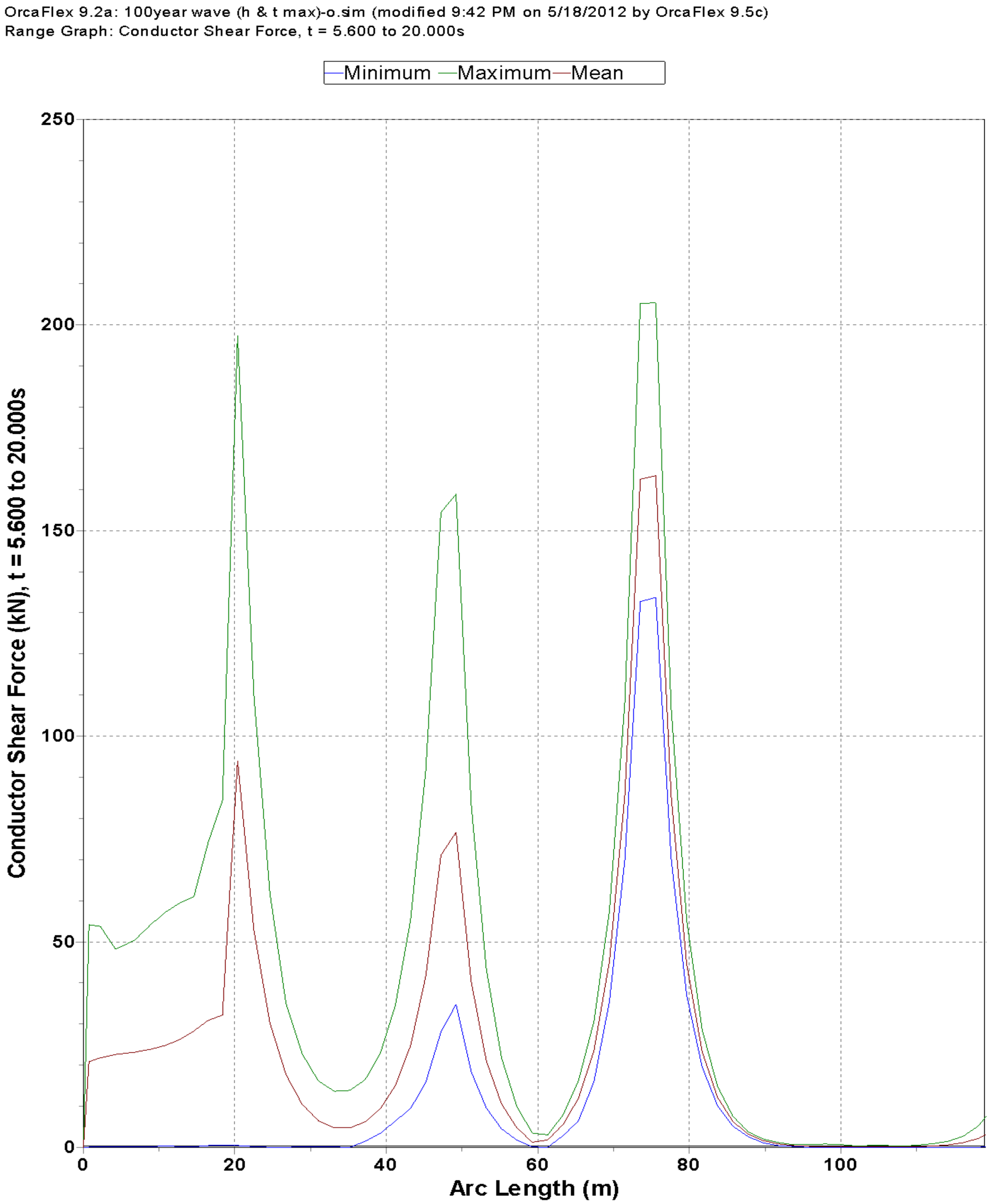


OrcaFlex 9.2a: 100year wave (clearance=0 for guide eck)-o.sim (modified 9:47 PM on 5/18/2012 by OrcaFlex 9.5c)
Range Graph: Conductor Shear Force, t = 5.600 to 20.000s

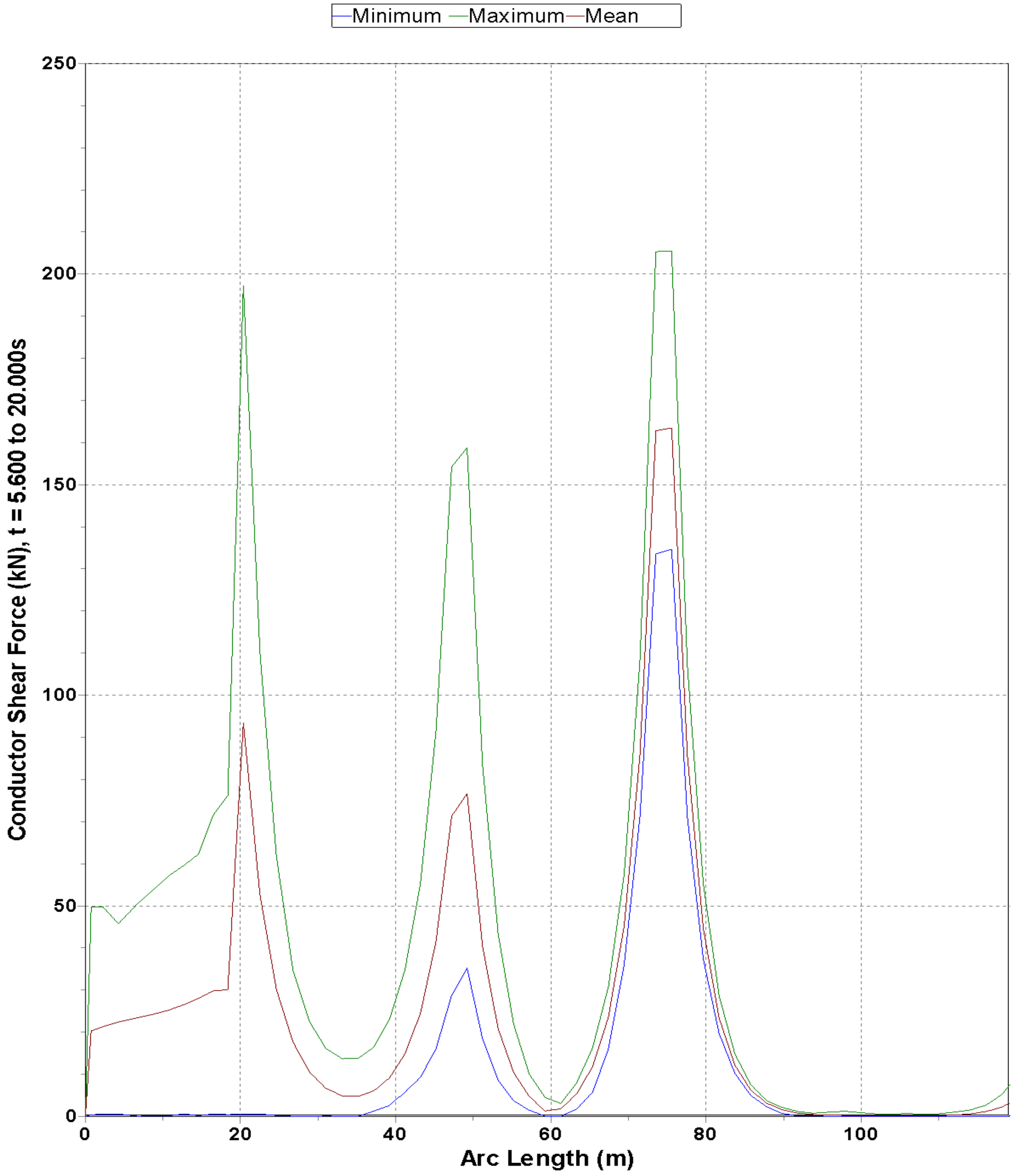


OrcaFlex 9.2a: 100year wave (clearance=3mm for guide eck)-o.sim (modified 9:48 PM on 5/18/2012 by OrcaFlex 9.5c)
Range Graph: Conductor Shear Force, t = 5.600 to 20.000s



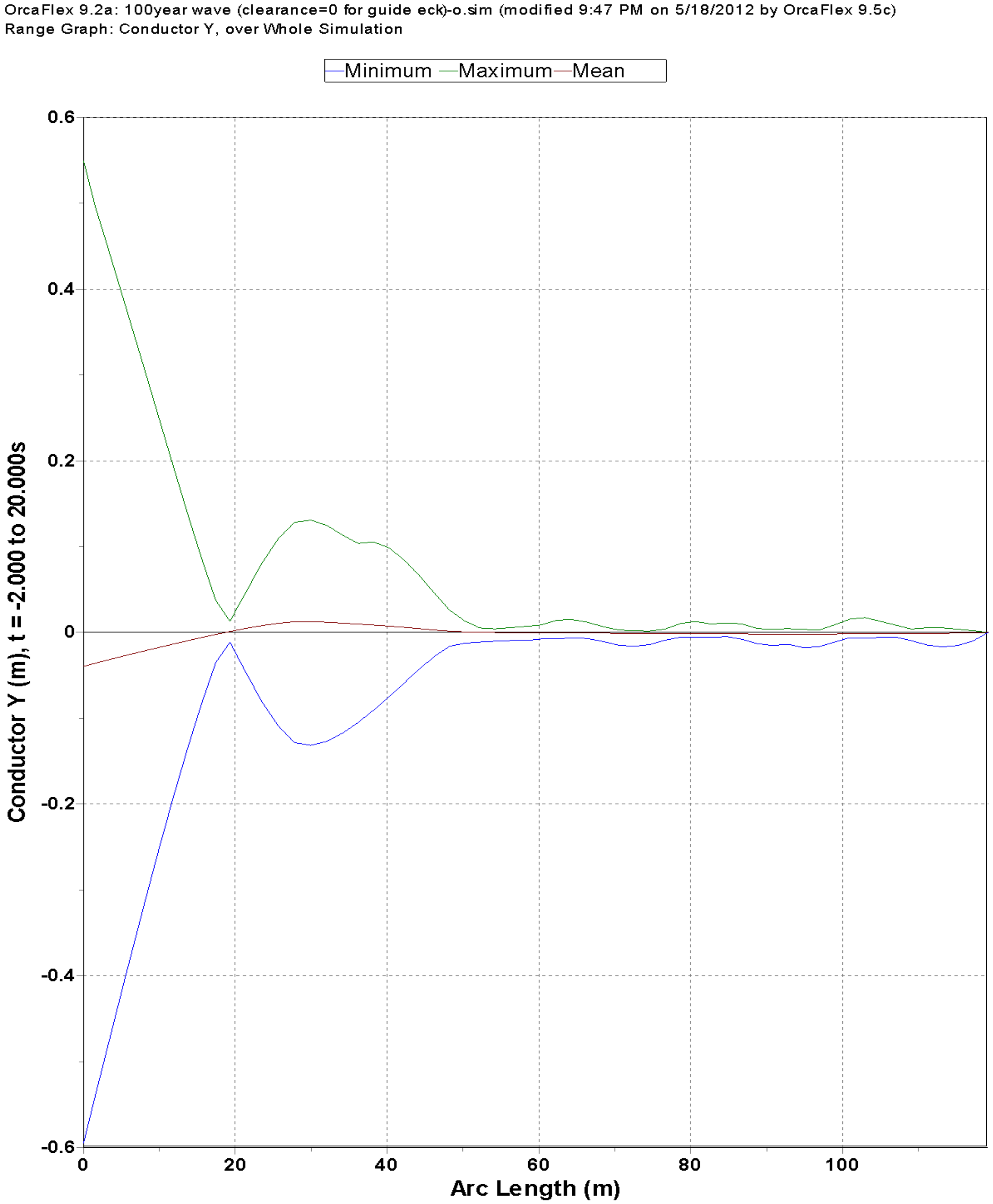


OrcaFlex 9.2a: 100year wave (h & t max)-o.sim (modified 9:42 PM on 5/18/2012 by OrcaFlex 9.5c)
Range Graph: Conductor Shear Force, t = 5.600 to 20.000s

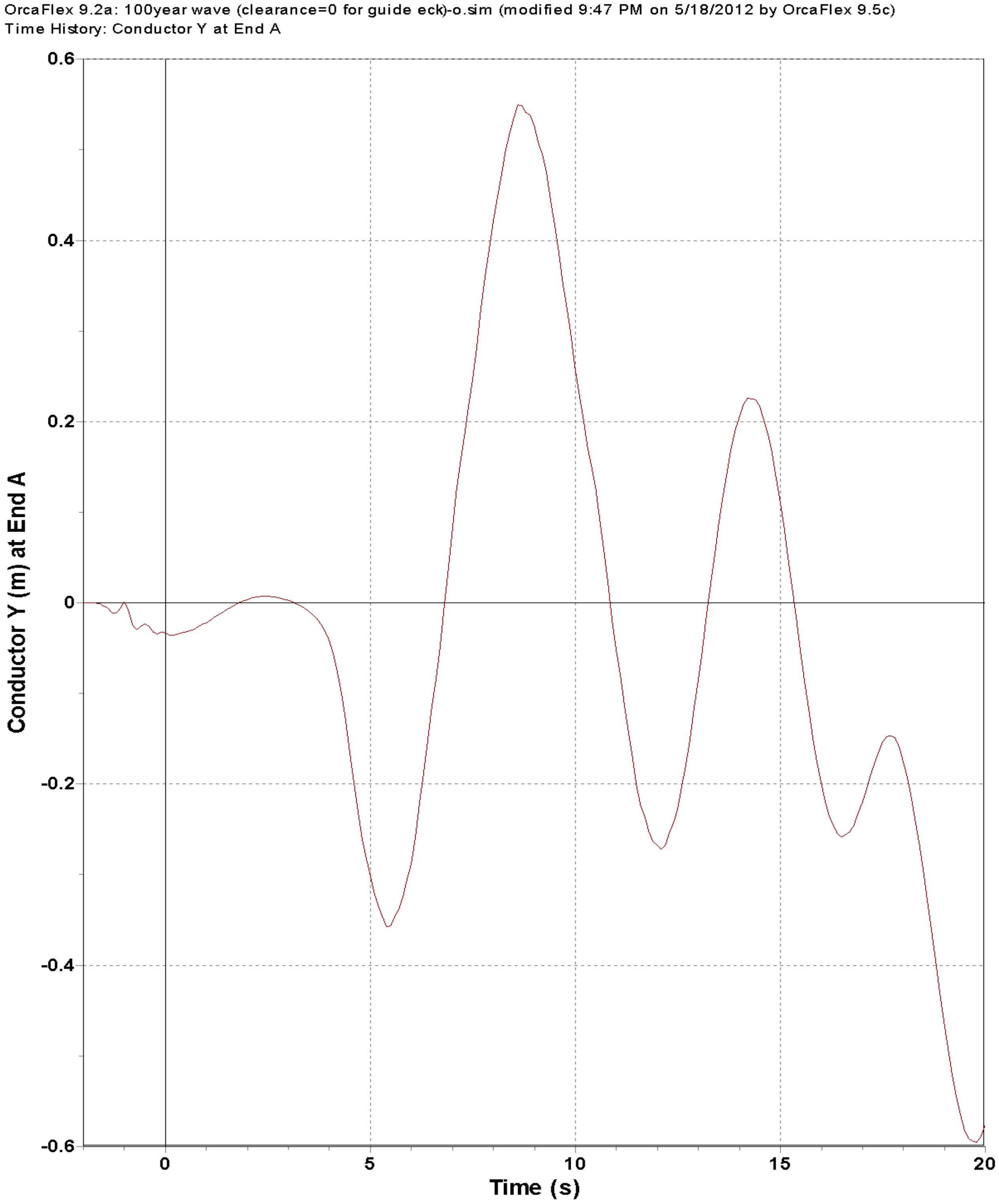


OrcaFlex 9.2a: 100year wave (clearance=10mm for guide eck)-o.sim (modified 9:50 PM on 5/18/2012 by OrcaFlex 9.5c)
Range Graph: Conductor Shear Force, t = 5.600 to 20.000s

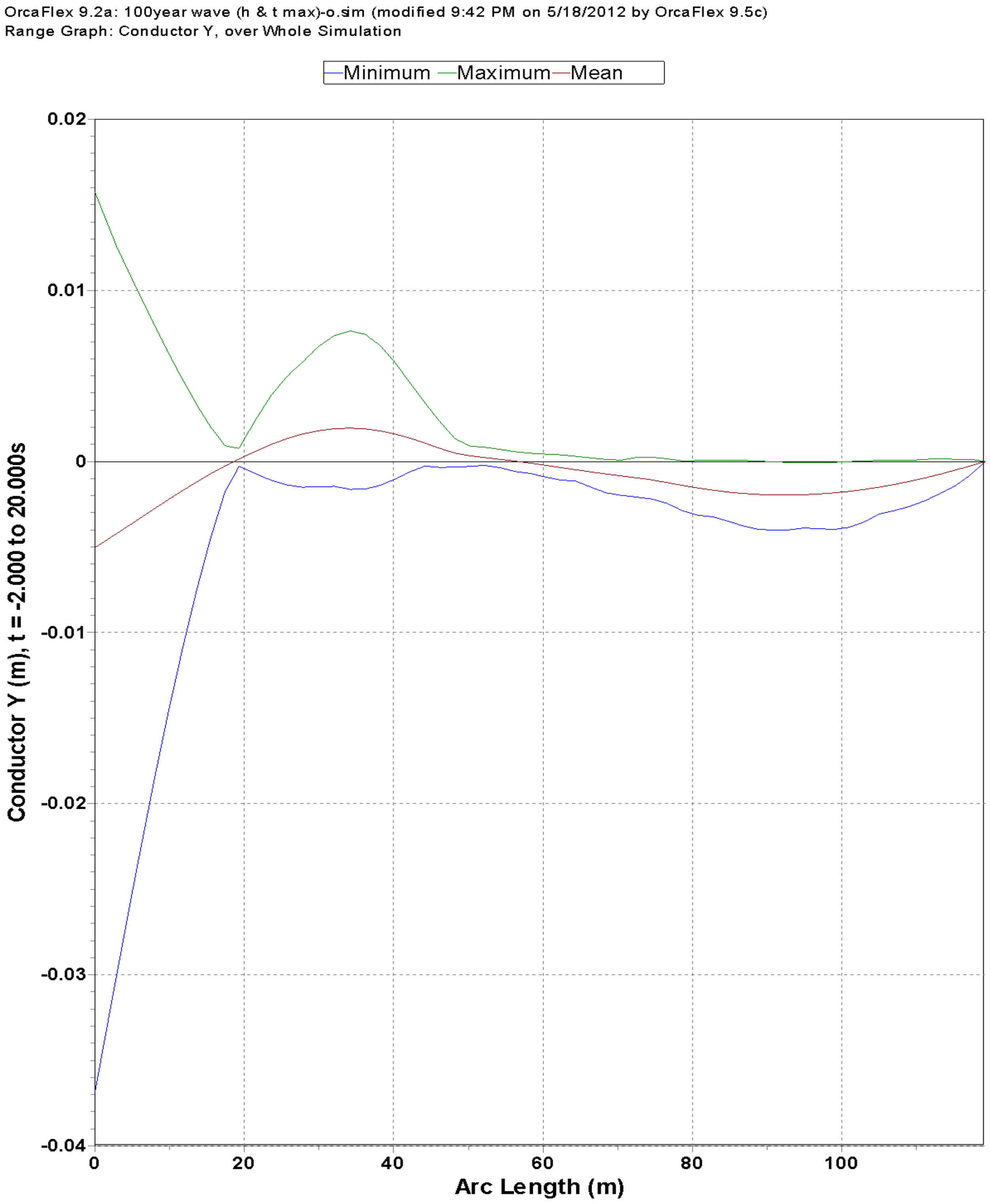
13.3 Displacement DIAGRAMS (0 mm clearances in upper guide deck)



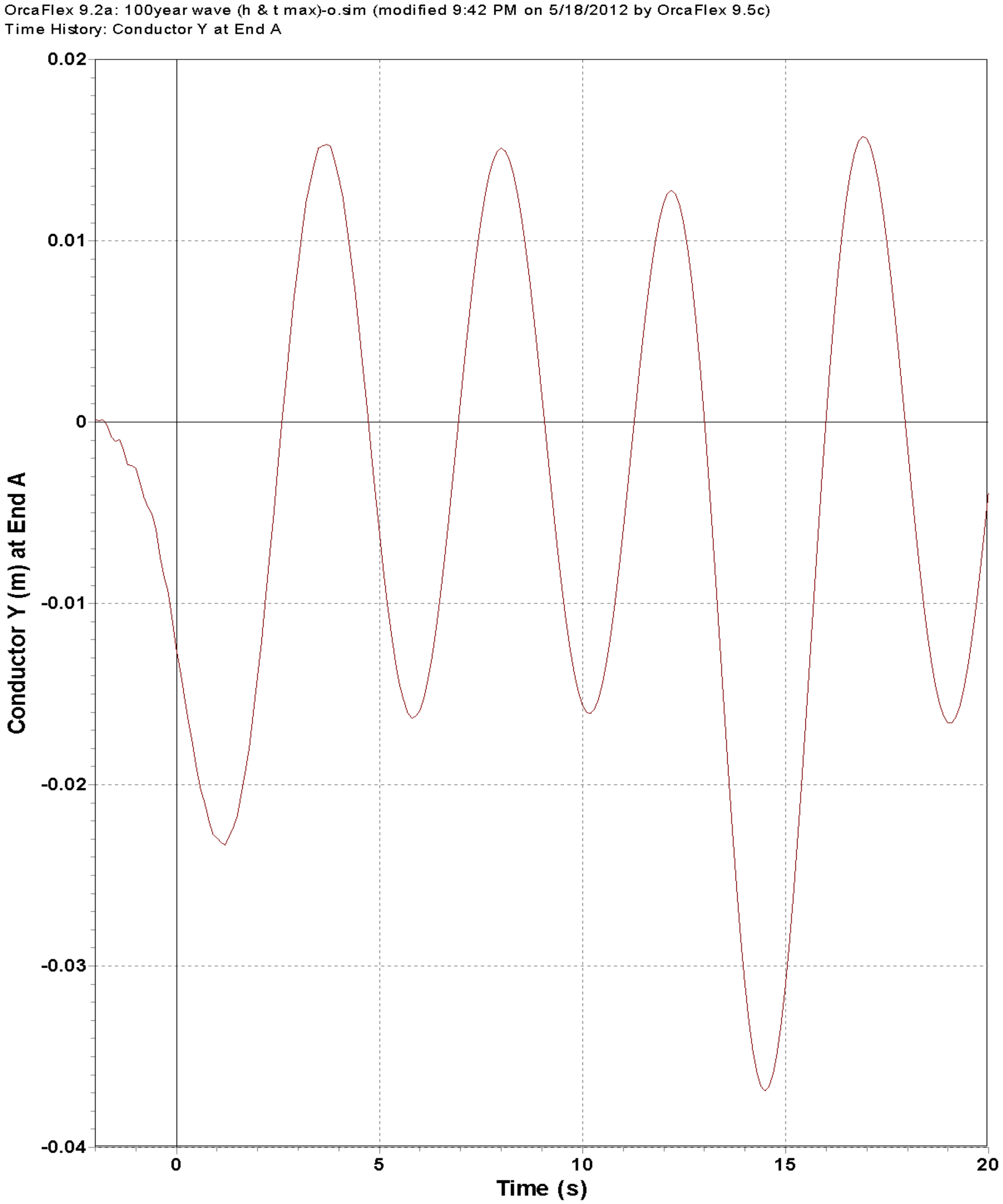
(0 mm clearances in upper guide deck)



(5 mm clearances in upper guide deck)

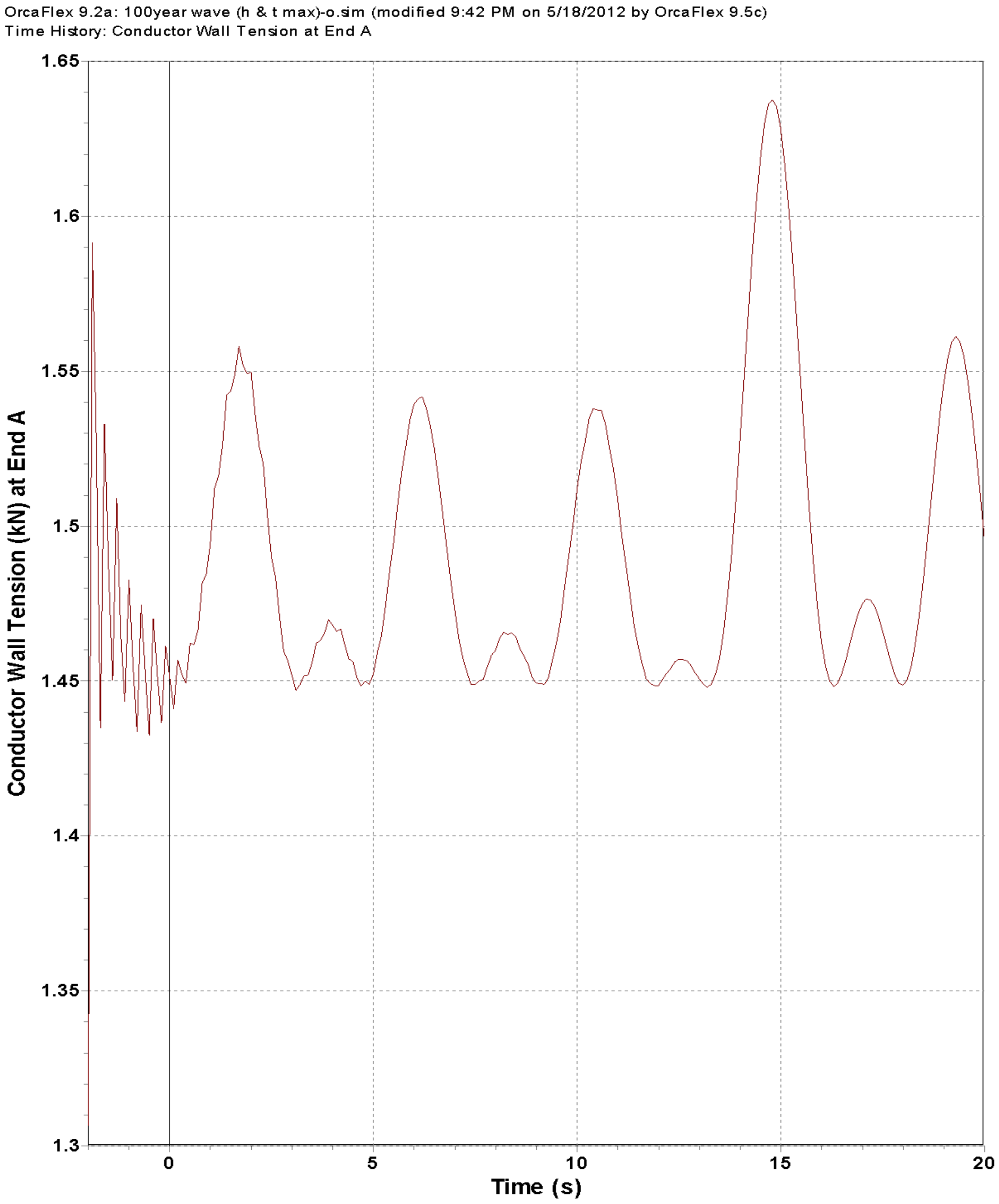


(5 mm clearances in upper guide deck)

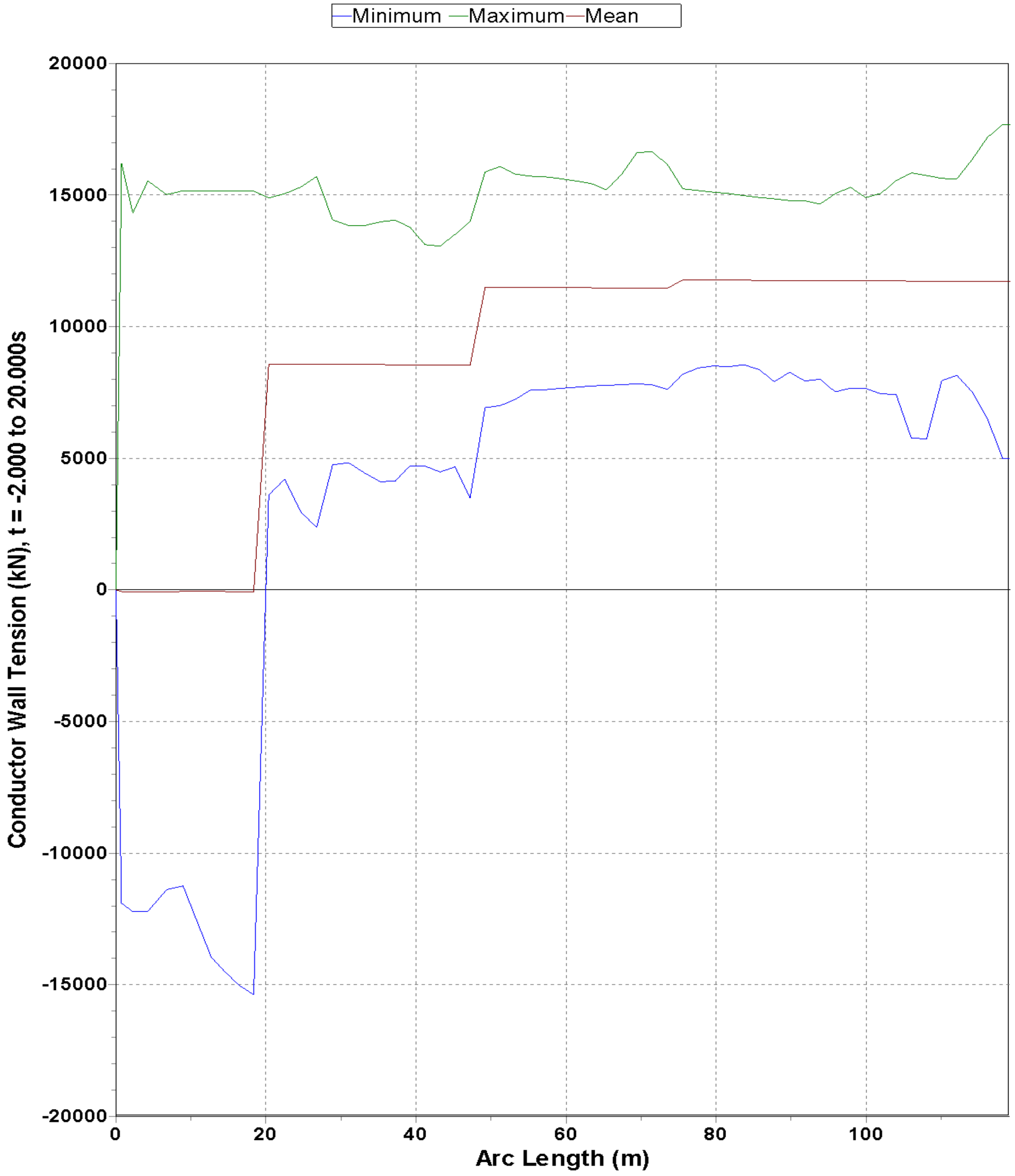

OrcaFlex 9.2a: 100year wave (h & t max)-o.sim (modified 9:42 PM on 5/18/2012 by OrcaFlex 9.5c)
Time History: Conductor Y at End A
Conductor Y (m) at End A
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
0
5
10
15
20
Time (s)

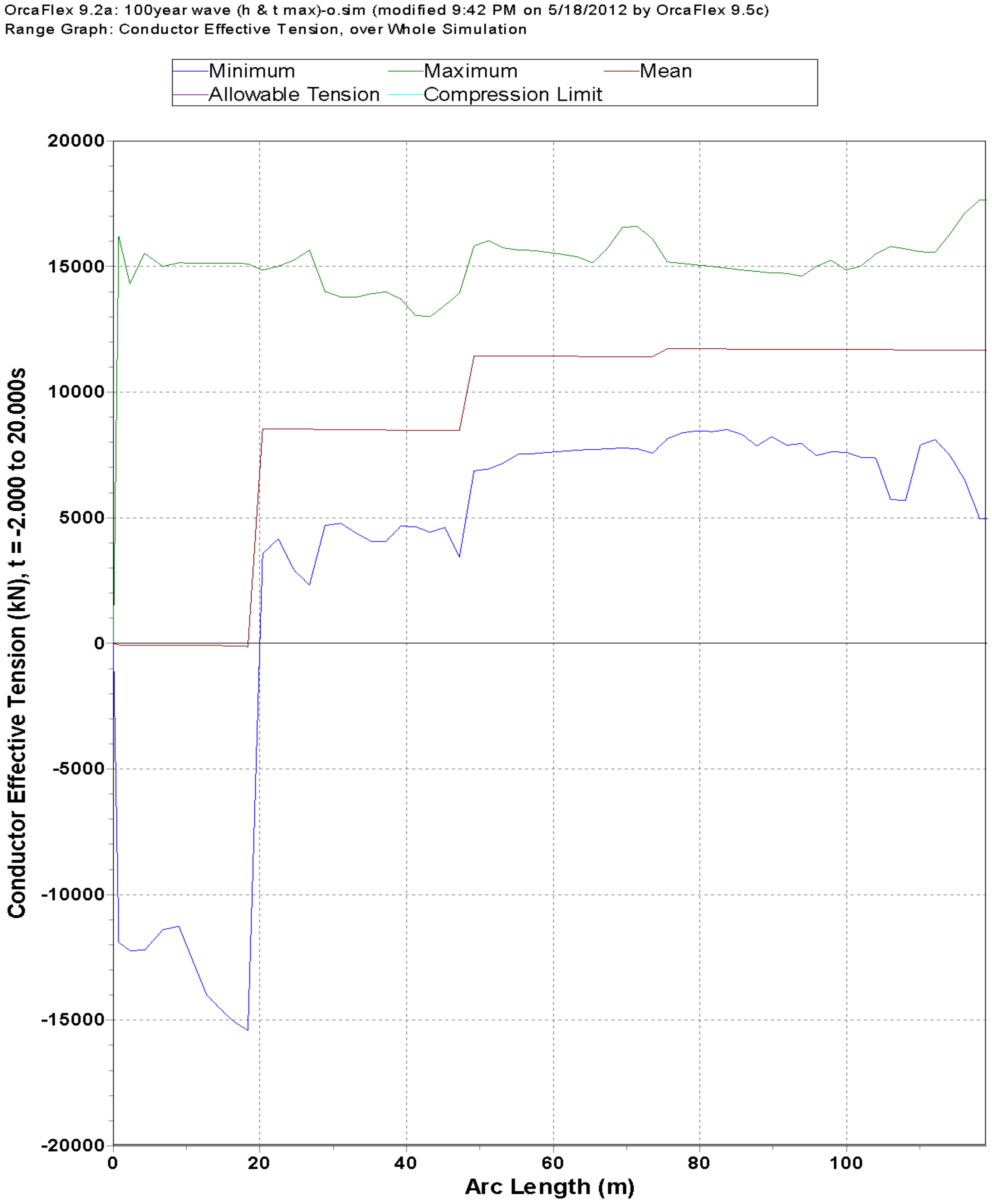
13.4 Conductor wall tension

(5 mm clearances in upper guide deck)


OrcaFlex 9.2a: 100year wave (h & t max)-o.sim (modified 9:42 PM on 5/18/2012 by OrcaFlex 9.5c)
Time History: Conductor Wall Tension at End A
1.65
1.6
1.55
1.5
1.45
1.4
1.35
1.3
Conductor Wall Tension (kN) at End A
0
5
10
15
20
Time (s)

OrcaFlex 9.2a: 100year wave (h & t max)-o.sim (modified 9:42 PM on 5/18/2012 by OrcaFlex 9.5c)
Range Graph: Conductor Wall Tension, over Whole Simulation




OrcaFlex 9.2a: 100year wave (h & t max)-o.sim (modified 9:42 PM on 5/18/2012 by OrcaFlex 9.5c)
Range Graph: Conductor Effective Tension, over Whole Simulation
Minimum
Maximum
Mean
Allowable Tension
Compression Limit
20000
15000
10000
5000
0
-5000
-10000
-15000
-20000
Conductor Effective Tension (kN), t = -2.000 to 20.000s
0
20
40
60
80
100
Arc Length (m)

14.0 APPENDIX C- FATIGUE CALCULATION

Table C.1- DAMAGE TABLES

Fatigue Damage Tables

OrcaFlex 9.5c: 100year wave (h & t max)-fatigue.ftg (modified 20:28 on 24.05.2012 by OrcaFlex 9.5c)
Title: FATIGUE FOR 100 YEAR -5 mm gaps

Analysis Type: Regular

Worst Damage	
Damage over total exposure	1.63312E-05
Total exposure time (years)	0.0005
Life (years)	30.7136
Arc Length (m)	20.3643

Arc Length (m)	Excessive Damage (> 1) Total
(none)	(none)

	Effective Tension (kN)
Min	-266.9114685
Max	8621.603516

Arc Length (m)	Overall Damage over total exposure	Life (years)
10.825	8.32427E-06	60.2564
12.7083	9.10513E-06	55.0888
14.5917	9.82734E-06	51.0403
16.475	1.04468E-05	48.0138
18.3583	1.09265E-05	45.906
20.3643	1.63312E-05	30.7136
22.4929	1.61787E-05	31.0032
24.6214	1.58156E-05	31.7149
26.75	1.53806E-05	32.6119
28.8786	1.49133E-05	33.6337
31.0071	1.44381E-05	34.7409
33.1357	1.39524E-05	35.95
35.2	1.34725E-05	37.2306
37.2	1.30033E-05	38.5742
39.2	1.25274E-05	40.0395

10,825 m (Segment 6)	Damage over total exposure
T-N Curve1	
Load Case	
Case 1 (100,0 cycles)	7.56752E-07
Case 2 (1000,0 cycles)	7.56752E-06
Overall Total	8.32427E-06

12,7083333333333 m (Segment 7)	Damage over total exposure
T-N Curve1	
Load Case	
Case 1 (100,0 cycles)	8.27739E-07
Case 2 (1000,0 cycles)	8.27739E-06
Overall Total	9.10513E-06

14,5916666666667 m (Segment 8)	Damage over total exposure
T-N Curve1	
Load Case	
Case 1 (100,0 cycles)	8.93395E-07
Case 2 (1000,0 cycles)	8.93395E-06
Overall Total	9.82734E-06

16,475 m (Segment 9)	Damage over total exposure
T-N Curve1	
Load Case	
Case 1 (100,0 cycles)	9.49709E-07
Case 2 (1000,0 cycles)	9.49709E-06
Overall Total	1.04468E-05

18,3583333333333 m (Segment 10)	Damage over total exposure
T-N Curve1	
Load Case	
Case 1 (100,0 cycles)	9.93315E-07
Case 2 (1000,0 cycles)	9.93315E-06
Overall Total	1.09265E-05

20,3642857142857 m (Segment 11)	Damage over total exposure
T-N Curve1	
Load Case	
Case 1 (100,0 cycles)	1.48465E-06
Case 2 (1000,0 cycles)	1.48465E-05
Overall Total	1.63312E-05

22,4928571428571 m (Segment 12)	Damage over total exposure
T-N Curve1	
Load Case	
Case 1 (100,0 cycles)	1.47079E-06
Case 2 (1000,0 cycles)	1.47079E-05
Overall Total	1.61787E-05

24,6214285714286 m (Segment 13) T-N Curve1	Damage over total exposure
Load Case	
Case 1 (100,0 cycles)	1.43778E-06
Case 2 (1000,0 cycles)	1.43778E-05
Overall Total	1.58156E-05

26,75 m (Segment 14) T-N Curve1	Damage over total exposure
Load Case	
Case 1 (100,0 cycles)	1.39824E-06
Case 2 (1000,0 cycles)	1.39824E-05
Overall Total	1.53806E-05

28,8785714285714 m (Segment 15) T-N Curve1	Damage over total exposure
Load Case	
Case 1 (100,0 cycles)	1.35576E-06
Case 2 (1000,0 cycles)	1.35576E-05
Overall Total	1.49133E-05

31,0071428571429 m (Segment 16) T-N Curve1	Damage over total exposure
Load Case	
Case 1 (100,0 cycles)	1.31255E-06
Case 2 (1000,0 cycles)	1.31255E-05
Overall Total	1.44381E-05

33,1357142857143 m (Segment 17) T-N Curve1	Damage over total exposure
Load Case	
Case 1 (100,0 cycles)	1.2684E-06
Case 2 (1000,0 cycles)	1.2684E-05
Overall Total	1.39524E-05

35,2 m (Segment 18) T-N Curve1	Damage over total exposure
Load Case	
Case 1 (100,0 cycles)	1.22478E-06
Case 2 (1000,0 cycles)	1.22478E-05
Overall Total	1.34725E-05

37,2 m (Segment 19) T-N Curve1	Damage over total exposure
Load Case	
Case 1 (100,0 cycles)	1.18212E-06
Case 2 (1000,0 cycles)	1.18212E-05
Overall Total	1.30033E-05

39,2 m (Segment 20) T-N Curve1 Load Case	Damage over total exposure
Case 1 (100,0 cycles)	1.13885E-06
Case 2 (1000,0 cycles)	1.13885E-05
Overall Total	1.25274E-05

Table C.2- LOAD CASE 1

OrcaFlex 9.5c: 100year wave (h & t max)-fatigue.ftg (modified 20:28 on 24.05.2012 by OrcaFlex 9.5c)
Title: FATIGUE FOR 100 YEAR -5 mm gaps

Analysis Type: Regular
Simulation file: F:\last\100year wave (h & t max)-o.sim (18.05.2012 on 21:42)
Simulation period: Latest wave
Number of cycles: 100

Line details	Value
Name	conductor
Torsion Included	No

Current details at surface	Value
Speed (m/s)	0.6889
Direction (deg)	160.0

Wave details	Wave1
Wave Type	Stokes' 5th
Wave Height (m)	25.19
Wave Period (s)	14.39
Wave Direction (deg)	180.0

Worst Damage for Load Case	
Damage per year	0.032558824
Arc Length (m)	20.3643

Load Case Damage (per year)				
Arclength (m)	**Effective Tension (kN)**			**Damage**
	Min	**Max**	**Range**	
10.825	-231.3502	-35.0212	196.329	0.016595734
12.7083	-240.7812	-38.4958	202.2854	0.018152513
14.5917	-249.9419	-42.4437	207.4983	0.019592349
16.475	-258.6834	-46.9138	211.7696	0.020827344
18.3583	-266.9115	-51.9491	214.9623	0.021783628
20.3643	8375.8262	8621.6035	245.7773	0.032558824
22.4929	8372.4102	8617.4199	245.0098	0.032254726
24.6214	8369.04	8612.2031	243.1631	0.031530881
26.75	8365.7227	8606.6357	240.9131	0.030663685
28.8786	8362.4717	8600.9199	238.4482	0.029732098
31.0071	8359.2324	8595.1201	235.8877	0.028784523
33.1357	8356.0391	8589.252	233.2129	0.027816394
35.2	8352.9795	8583.4873	230.5078	0.026859636
37.2	8350.0469	8577.8467	227.7998	0.025924072
39.2	8347.1445	8572.1309	224.9863	0.024975348

Table C.3- LOAD CASE 2

Analysis Type: Regular
Simulation file: 100year wave (h & t max)- 5mm.sim
(23.05.2012 on 11:57)
Simulation period: Latest wave
Number of cycles: 1000

Line details	Value
Name	conductor
Torsion Included	No

Current details at surface	Value
Speed (m/s)	0.6889
Direction (deg)	160.0

Wave details	Wave1
Wave Type	Stokes' 5th
Wave Height (m)	25.19
Wave Period (s)	14.39
Wave Direction (deg)	180.0

Worst Damage for Load Case	
Damage per year	0.032558824
Arc Length (m)	20.3643

Load Case Damage (per year)				
Arclength (m)	**Effective Tension (kN)**			**Damage**
	Min	**Max**	**Range**	
10.825	-231.3502	-35.0212	196.329	0.016595734
12.7083	-240.7812	-38.4958	202.2854	0.018152513
14.5917	-249.9419	-42.4437	207.4983	0.019592349
16.475	-258.6834	-46.9138	211.7696	0.020827344
18.3583	-266.9115	-51.9491	214.9623	0.021783628
20.3643	8375.8262	8621.6035	245.7773	0.032558824
22.4929	8372.4102	8617.4199	245.0098	0.032254726
24.6214	8369.04	8612.2031	243.1631	0.031530881
26.75	8365.7227	8606.6357	240.9131	0.030663685
28.8786	8362.4717	8600.9199	238.4482	0.029732098
31.0071	8359.2324	8595.1201	235.8877	0.028784523
33.1357	8356.0391	8589.252	233.2129	0.027816394
35.2	8352.9795	8583.4873	230.5078	0.026859636
37.2	8350.0469	8577.8467	227.7998	0.025924072
39.2	8347.1445	8572.1309	224.9863	0.024975348