University of Stavanger

Faculty of Science and Technology

MASTER'S THESIS

Study program/ Specialization: Offshore Technology/Subsea Technology	Spring semester, 2011 ~~Open~~ / Restricted access
Writer: Rika Afriana	.... (Writer's signature)
Faculty supervisor: Prof. Ove Tobias Gudmestad External supervisor(s): Prof. Jan Vidar Aarsnes Einar B. Glomnes	
Titel of thesis: Coupled Dynamic Analysis of Cylindrical FPSO, Moorings and Riser Based on Numerical Simulation	
Credits (ECTS): 30 ECTS	
Key words: Coupled Dynamic Analysis, Decoupled Analysis, Cylindrical Floater, Moorings, Riser WADAM/HYDRO D, RIFLEX, SIMO, SIMA MARINTEK	Pages: 222 pages + enclosure: 159 pages Stavanger, July 28, 2011 Date/year

Abstract

M.S.c. Thesis

Coupled Dynamic Analysis of Cylindrical FPSO, Moorings and Riser

Based on Numerical Simulation

The hostile environments are presently one of the challenges that should to be deal with in offshore floating system design where the hydrodynamic interaction effects and dynamic responses dominate the major consideration in its design.

Nowadays, the cylindrical FPSO is being extensively used as an offshore facility in the oil and gas industry. This system has been deployed widely around the world as a unique design facility which is regarded as a promising concept. As a floating offshore system, a cylindrical FPSO will be deployed together with slender members (moorings and risers) responding to wind, wave and current loading in complex ways.

In order to quantify the coupling effects between each component in an offshore floating system and the associated structural response in offshore structure design, two kind of analyses, the decoupled analysis and the nonlinear-coupled dynamic analysis have been presented in this thesis. It introduces a consistent analytical approach that ensures higher dynamic interaction between the floater, moorings and risers. The nonlinear-coupled dynamic analysis requires a complete model of the floating offshore system including the cylindrical S400 floater, 12 mooring lines and the feasible riser configurations for the 6” and 8” production risers. Furthermore, the results from the nonlinear-coupled dynamic analysis will also be compared to the separated analyses for each component as a discussion of the analysis results.

The frequency domain and time domain analysis will be implemented to solve the equation of motions at the simulations. The simulation will be conducted in two simulation schemes, static and dynamic conditions. The 3 hours + build up time will be used in the dynamic condition because the time domain requires a proper simulation length to have a steady result.

Several software computer programs will be used in the analyses. In the separated analysis for each component in offshore floating system, the cylindrical floater hydrodynamic analysis as a decoupled analysis is performed by using the integrated software program Hydro D which is related to several support software programs (Prefem, Wadam and Postresp). For mooring system analysis as a decoupled analysis will be analyzed by using SIMO in time domain analysis. In SIMO, two models (the body model and the station keeping model) will be required and the quasi-static design will be applied as the design method in mooring system analysis. The analysis for riser system also is done as the decoupled analysis in this study. The main purpose of this analysis is to find a feasible single arbitrary configuration for

each of the 6” and 8” production risers. The riser system analysis will also be performed in time domain analysis in RIFLEX for two simulation conditions, static and dynamic conditions.

After the separated analyses for each component, a single complete computer model that includes a cylindrical floater, moorings and risers with use of SIMA will be as the nonlinear-coupled dynamic analysis. The analysis is performed in time domain for two conditions, static and dynamic conditions. The SIMA Marintek computer will be used in this study because it has the capability to integrate the cylindrical S400 floater, moorings and risers as one complete model. As an integrated dynamic system, the environmental forces on the floater induce the motions which will be introduced in a detail FEM (Finite Element Model) of the moorings, risers and cylindrical S400 floater.

In the end, not only the accurate prediction of the responses of the overall system but also the individual responses of the floater, mooring and risers are obtained. The summary of results between the decoupled analysis and the nonlinear-coupled dynamic analysis will also be presented briefly in this study.

Acknowledgement

M.S.c. Thesis

Coupled Dynamic Analysis of Cylindrical FPSO, Moorings and Riser

Based on Numerical Simulation

This thesis is the final work of my graduate study at the Department of Offshore Technology, Faculty of Natural Science and Technology, University of Stavanger, Norway. The thesis has been carried out from February until June 2011 at the Research and Development Department in Sevan Marine AS, Arendal.

I would like to acknowledge and extend my heartfelt gratitude to the following persons who have made the completion of this thesis possible:

My supervisor, Professor Ove T. Gudmestad for his interest to this thesis and for his great motivation to me. Without his encouragement, guidance and endless supports, this thesis would not have been accomplished. Life blessed me with a lot of opportunity after I met him.

My supervisor in Sevan Marine AS, Professor Jan V. Aarsnes for his advices during this study.

My supervisor, Einar B. Glomnes who always helpful and willing to take some time togive me his guidances. His advices and knowledge are very valuable for this thesis.

Kåre Syvertsen, for giving me the opportunity and providing me with so many valuable facilities during the thesis work at the Research and Development Department in Sevan Marine AS, Arendal.

Kåre G. Breivik, for giving me the opportunity to write my thesis at the Research and Development Department in Sevan Marine AS, Arendal.

Knot Mo and Elizabeth Passano from Marintek, for providing guidance regarding SIMA Marintek computer software.

The people from the Research and Development Department Sevan Marine AS for giving me such a wonderful experience during this study. Tor Stokke, Irina Kjærstad, Torhild Konnestad, Alf Reidar Sandstad, Veslemøy U. Sandstad, Per Høyum.

All of my friends in University of Stavanger, Norway for they supportive and fun-filled environment during our study period in University of Stavanger. For Indonesian heroes this year: Iswan Herlianto, Adri Maijoni, Eko Yudhi Purwanto, Sari Savitri, Winia Farida and Dian Ekawati. We have to be very proud for our achievements. The special thanks for Adedayo Adebayo, Tonje Charlotte Stald, Morten Langhelle, Henry Ezeanaka, Bamidele Oyewole, Mina Jalali, Markus Humel, Jarle Gundersen, Ragnhild O Steigen, Sahr M. Hussain, Farhia B. Nur, Rakhshinda Ahmad and Fery Simbolon, Tomy Nurwanto, Hermanto Ang, Yahya Januarilham, Surya Dharma, Sakti Tanripada, Sanggi Raksagati. Our university can't be homie without you guys.

Hans Marthyn Franky Panjaitan, Iqbal Ruswandi, Dilly Soemantri, Ahmad Makintha Brany, Airindy Felisita, Maurina Adriana, Agung Ertanto, Miftachul Choiri, Ronny Costamte, Novithasari Dewi Anggraeni, Trimaharika Widarena and Ratna Nita Perwitasari. Many thanks for the guidance and valuable advices.

Apak and Amak, for teaching me the love of science and the belief that almost anything can be accomplished through hard work and determination. I especially dedicated this thesis for them. My brother and sister for their warm supports.

My loving, supportive, encouraging, and patient soulmate Indra Permana whose faithful and always give me his endless support from the beginning till the end of time. This thesis would not have been possible without his contributions. Thank you for always believe in me to chase my dream and pursuit our happiness. Happy wedding!

I offer my regards to all of those who supported me in any respect during the completion of this study. Finally, my greatest regards to Allah SWT for bestowing upon me the courage to face the complexities of life and complete this thesis.

Rika Afriana

Table of Contents

M.S.c. Thesis

Coupled Dynamic Analysis of Cylindrical FPSO, Moorings and Riser

Based on Numerical Simulation

List of Figures

List of Tables

CHAPTER

1

Introduction

M.S.c. Thesis

Coupled Dynamic Analysis of Cylindrical FPSO, Moorings and Riser

Based on Numerical Simulation

1.1 Background

Nowadays, the cylindrical FPSO is being extensively used as an offshore facility in the oil and gas industry. This system has been deployed widely around the world as a unique design facility which is regarded as a promising concept for an economic oil production since it has capability for storage and wider deck that is giving better layout flexibility. Moreover, it has also the ability to move and relocate after the operation is completed and is suitable for all offshore environments meeting the challenges of the oil and gas industry.

As a floating offshore system, a cylindrical FPSO will be deployed together with slender members (moorings and risers) responding to wind, wave and current loading in complex ways. In the traditional way, the hydrodynamic interaction among the floater, moorings and risers cannot be evaluated since the floater, moorings and risers are treated separately. Moreover, this traditional method, also known as the decoupled analysis, the hydrodynamic behavior of the system is only based on hydrodynamic behavior of the hull and ignores all or part of the interaction effects (mass, damping, stiffness, current loads) between the floater, moorings and risers.

In order to capture the interaction between the floater, moorings and risers, one extensive method has been introduced and developed in the last decade. This method, also known as the nonlinear-coupled dynamic analysis, ensures higher dynamic interaction among the components responding to environmental loading due to wind, waves and currents since the main coupling effects will be included automatically in the analysis. Hence, the accurate prediction of the response for the overall system as well as the individual response of floater, moorings and risers can be obtained.

Lately, the nonlinear-coupled dynamic analysis of the floating systems is becoming more and more important in order to evaluate the dynamic interaction among the floater, moorings and risers. Extensive work during last decade has been performed by many researches. Most of their implementations that are related to the study will be presented below:

Omberg and Larsen (1998) concluded that the uncoupled analysis may produce severely inaccurate results. Besides that, *Kim and Kim (2002)* have investigated the global motion of a turret-moored FPSO with 12 chain-polyester-chain mooring lines and 13 steel catenary risers in a fully coupled hull/mooring/riser dynamic analysis and concluded that the coupled behavior of vessel, moorings and riser will greatly enhance the understanding of the relevant physics and the overall performance assessment of the system. Furthermore, *Chaudry and Yo Ho (2000)* concluded that the full coupling of dynamic equilibrium in actual motions will be important for moorings and risers motion since the coupling effects give significant influence to the motion of moorings and risers.

Based on the reasons above, the nonlinear-coupled dynamic analysis has been addressed as the proper strategy to improve the understanding of the overall hydrodynamic behavior. This analysis will ensure higher dynamic interaction between the vessel and the slender system because of two reasons:

- The overall behavior of the floater will be influenced not only from the hydrodynamic behavior of the hull but also from the dynamic behavior of the slender members (moorings and risers)
- The coupling effects such as restoring, damping and added mass will be taken into account automatically in the process of analysis.

Hence, the nonlinear-coupled dynamic analysis represents a truly integrated system which ensures accurate prediction of all motions and responses without imposing conservatism.

In the study, the Western Isles Development Project (WIDP) that is located in the UKCS, Block 210/24 to the North East of Shetland will be taken as reference case. Moreover, the WIDP has shallow water conditions and also has harsh environment. These two major characteristics will influence the design of the overall system of the floating offshore system.

Furthermore, the study has been performed at the Research and Development Department in Sevan Marine AS, Arendal from February until June 2011. **All of information in this project is confidential**.

1.2 State of Art

Offshore structures are located in the ocean environments without continuous access to dry land and this causes offshore structures to have hydrodynamic interaction effects and dynamic response as major considerations for their design. They may be required to stay in position in all weather conditions. The configuration of an offshore structure may be classified by whether the structure is a fixed structure or floating structure. *Chakrabarti (2010)* has mentioned that the requirements for a floating structure are that it should be moored in place and that the facility under the action from the environment remains within a specified distance from a desired location achieved by the station keeping.

A floating offshore system consists of three principal structural components (**Figure 1.1**):

1. Floating hull: facilitating the space for the operations of the production work and storage for supplies
2. The station keeping: providing a connection between the structure and the seafloor for the purposes of securing the structure against the environmental loads, and
3. Riser system: achieving drilling operations or product transport

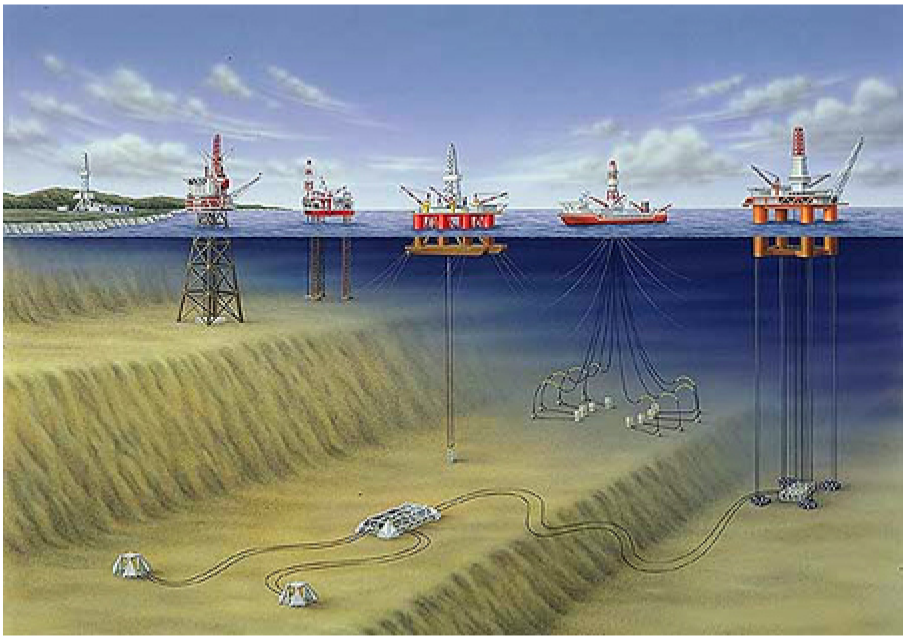


Figure 1.1 : Floating offshore structure.

Reference: Chakrabarti, 2010

The station-keeping may also be achieved by a dynamic positioning system solely using thrusters or in combination with mooring lines. The mooring lines and risers provide restoring forces to the floater.

Coupled versus Decoupled Analysis

Traditionally, the offshore industry has used de-coupled analysis as the methodology for design of floating offshore platforms with moorings and risers.

Nowadays, a lot of researches have suggested that the integration between the floating hull, mooring and the risers as a dynamic system is important in order to capture the interaction between them and obtain realistic motion values for each individual system.

Omberg et al. (1997 and 1998) concluded that the design of a Floater Production System (FPS) should consider the fact that the moored system and the risers comprise a truly integrated system; that is the overall behavior of the floating system is dictated not only by the hydrodynamic behavior of the hull but also by its interaction with the hydrodynamic/structural behavior of the lines.

Another suggestion has been presented by *Chakrabarti (2008)* regarding a specific recommendation for the systematic proces of the coupled analysis.

The de-coupled analysis

Based on DNV definition, *DNV-RP-F205 (2010),* a de-coupled analysis is performed of the floater motion in time domain, but the effects of the mooring and riser system are included quasi-statically using non linear springs, i.e. having quasi static restoring force characteristic. All other coupling effects such as contribution damping and current loading on the slender structures, need to be given as input to the analysis based on a separate assessment.

Chakrabarti (2008) explained that the de-coupled analysis represents the traditional methodology, in which the numerical analysis tool is based on the hydrodynamic behavior of the floater, uninfluenced by the nonlinear dynamic behavior of moorings or riser. Generally, little or no integration between the moored system and the riser takes place. It is still the common design practice for floating production systems.

The coupled analysis

On the other hand, based on *DNV-RP-F205 (2010),* the complete system of equations accounting for the rigid body model of the floater as well as the slender body model for the risers and mooring lines are solved simultaneously using a non-linear time domain approach for the dynamic analysis. Dynamic equilibrium is obtained by the time domain approach at each time step ensuring consistent treatment of the floater/slender structure coupling effect. The coupling effects are automatically included in the analysis scheme.

Specifically, the response of each component in such a system is influenced by the mechanical and hydrodynamic coupling effect and the proximity to the other components. Hence, all relevant coupling effects will be analyzed. The floater, moorings and risers system comprise an integrated dynamic system responding to environmental loadings due to wind, waves and currents. In an integrated dynamic system, the environmental forces on the floater induce the motions which will be introduced in a detailed finite element model of the moorings and risers. Furthermore, the coupled analysis will verify the integrations of radiation/diffraction theory with a beam finite element technique in time domain scenario analysis. With reference to *Connaire et al (2003),* a coupled analysis capability has been developed and extensively verified, which integrates radiation/diffraction theory with a beam finite element time-dependent structural analysis technique for slender offshore structures.

1.3 Problem Statement

As oil and gas exploitations move to deepwater and more harsh environment, the hydrodynamic integration between the floating hull, mooring and the risers as a dynamic system will be complex and become important. Hence, more advance methodologies are needed to provide a much deeper understanding of the system behavior. Moreover, the capacity to analyze and model test for this situation are challenged. Efficient tools and procedures on how to determine dimensioning response will be needed.

This study will emphasize on how to perform the nonlinear-coupled analysis of the floater, moorings and risers with efficient tools and procedures in order to capture the interaction between the floater, moorings and risers. This study will present a consistent analytical approach to ensure higher dynamic interaction between floater, moorings and risers.

As a consistent analytical approach, the study will implement numerical simulation steps by using several analysis programs such as Wadam/HYDRO D, SIMO and RIFLEX for an integrated program analysis.

A single and complete model will include a cylindrical S400 floater, 12 mooring lines and one of feasible riser configurations. The detailed model for each component, characterization of the environments in covering relevant load models and the simulation schemes will be presented in this study.

The analysis will be performed in the frequency domain and time domain in order to solve the problems during the analysis.

1.4 Purpose and Scope

The objective of the study is to document a consistent analytical approach for the nonlinear-coupled analysis of the floater, moorings and risers that ensure higher dynamic interaction between floater, moorings and risers.

Generally, the study will cover the following activities below:

1. The study of literature for a floating offshore system and each component, cylindrical FPSO, moorings and risers and the therotical background that provides deeper understanding on a consistent analytical approach for the numerical simulations.
2. The study of literature for the basic theory of Wadam/HYDRO D, SIMO and RIFLEX and other complementary programs such as PREFEM, POSTRESP and ORCAFLEX.
3. The nonlinear-coupled analysis perfomance in SIMA.

Chapter 2 presents the theoretical background that will be helpful to give the perspective for the analysis. The basic knowledge and key definitions that relate to the analysis will be presented here.

Chapter 3 presents the specification of data from the environment based on metaocean design criteria. The environmental conditions such as water depth, wind, waves and currents will be presented here.

Chapter 4 presents the methodology of the analysis. This chapter will explain the analysis procedures for system components, analysis method for nonlinear-coupled dynamic analysis and the numerical simulation steps in the nonlinear-coupled dynamic analysis. The analysis will be performed by using several programs such as Wadam/Hydro D, RIFLEX and SIMO. These programs will be used under an integrated scheme analysis to obtain a consistent analytical approach for the nonlinear-coupled dynamic analysis.

Chapter 5 presents the hydrodynamic analysis of the cylindrical S400 FPSO. The general description of the cylindrical S400 FPSO will be presented here. This chapter will present the analysis of the floater's load model based on diffraction theory to obtain the transfer function, mean wave drift forces and non linear damping. Furthermore, the analysis will be performed by using a diffraction program, Wadam/HYDRO D. The resulting analysis will not only present on the hydrodynamic but also the stability of the cylindrical floater. The hydrodynamic analysis of the hull is performed in the frequency domain analysis as a simple iterative technique to solve a linear equation of motions to obtain a set frequency dependent RAO.

Chapter 6 presents the general description and configuration of the moorings that will be used in the analysis. This chapter will also present the combined model between cylindrical floater and moorings in time domain analysis by using SIMO. In this analysis, the effect of wind and currents will be considered. SIMO as a computer software program for moored vessels will be used in order to include the mooring stiffness in the equation of the motions. Therefore, motions are found by time integration enforcing force equilibrium at all time steps. The corresponding mooring line tensions are established using a quasi static approach.

The result of the analysis will give us the result of a set of time series of the offset vessel value under LF motions and also the total motions (LF+WF motions).

Chapter 7 presents a feasible arbitrary riser configuration. The investigations of the riser configurations will use RIFLEX. Furthermore, the investigation will be performed under decoupled analysis to obtain a single arbitrary configuration. The analysis will also be performed in time domain under two simulation schemes, static and dynamic conditions. A discussion of the analysis results such as top angle (hang off position angle), effective tension, bending radius and seabed clearance will be presented here.

Chapter 8 presents a single complete model that includes the cylindrical floater, moorings and riser by using SIMA Marintek computer software. In principle, the SIMA will combine two nonlinear numerical simulations together those obtained by SIMO and RIFLEX. In other words, the cylindrical floater and moorings model from SIMO will be combined together with an arbitrary riser configuration from RIFLEX in time domain analysis.

The results of the analysis will be a set of accurate predictions for floater motions as well as the moorings and riser system with regard to the coupling effects. Furthermore, the resulting analysis for the riser will be presented and compared with the previous analysis based on the decoupled analysis from **Chapter 6** and **Chapter 7**.

Chapter 9 provides the conclusions and the recommended further studies from this study.

1.5 Location of Study

An overview of the location can be seen in **Figure 1.2**, *Dana Petroleum E&P Limited (2011)* has mentioned that the offshore field Western Isles is located in the UKCS Block 210/24 to the North East of Shetland. The nearest fixed facility is the Tern platform located 12 km East of Western Isles. The Western Isles Field is located approximately 61º 13’ 00” N, 0º 42’ 28” E.

Moreover, the offshore Western Isles Field is located in relatively on shallow water condition and also harsh environment. The water depth is approximately 170 m.

The design life is specified to be 20 years.

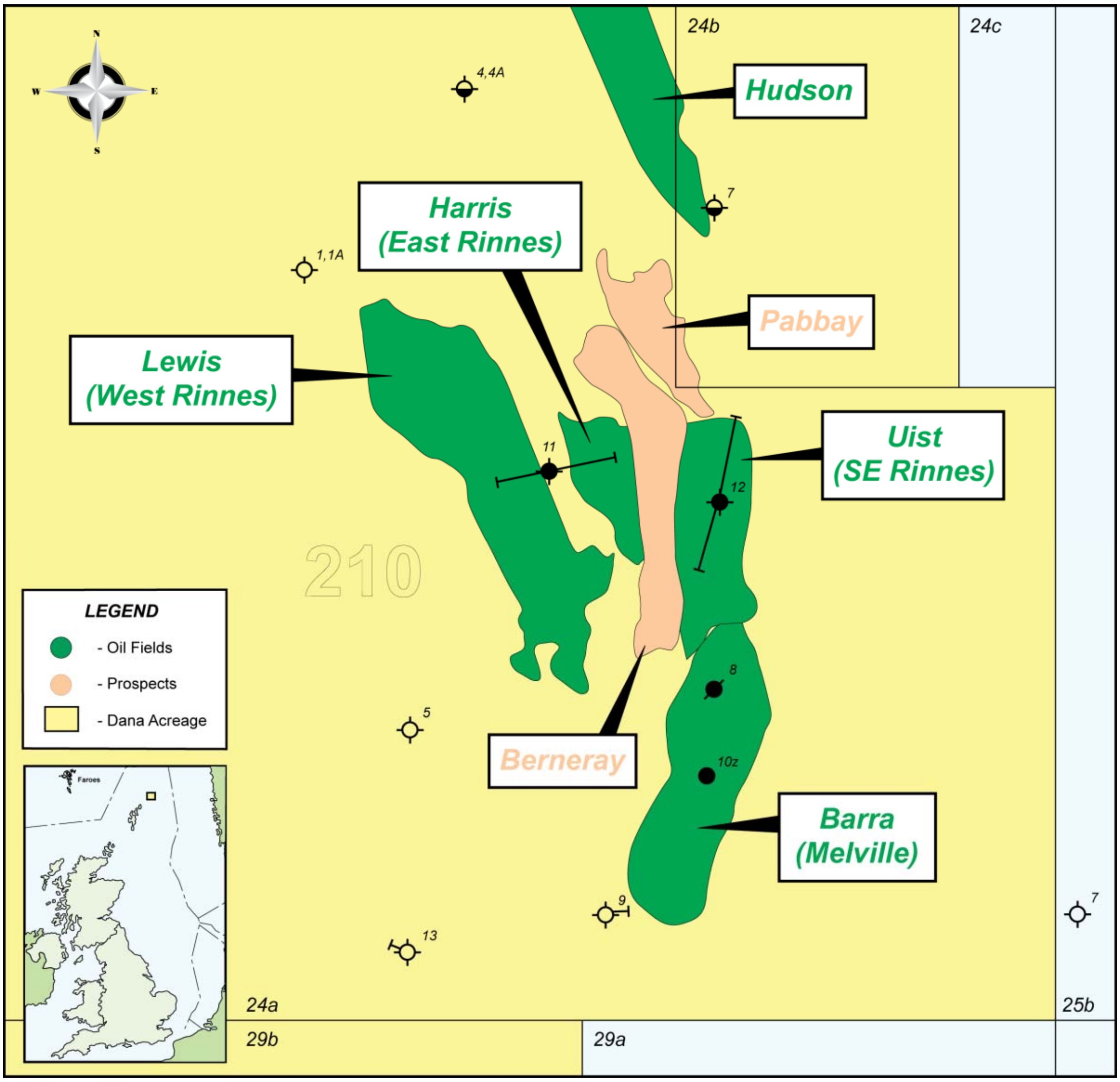


Figure 1.2 : Field overview.

Reference: Dana Petroleum E&P Limited (2011)

Chapter

2

Theoretical Background

M.S.c. Thesis

Coupled Dynamic Analysis of Cylindrical FPSO, Moorings and Riser

Based on Numerical Simulation

This chapter will review the basic knowledge to give a perspective for the analysis. Moreover the key definitions that are related to the analysis will also be explained here. The explanation about the equation of motion will be the starting point then we will continue to the structure response, non linear problems, frequency domain analysis and time domain, fundamental continuum mechanics and implementation of finite element method, and finaly coupling effects.

2.1 Equation of Motion for Floating Structure

Before the further explanation about the equation of motion for the floater, the relation between the motion of the floater and the influence on its responses will be presented below:

A floater is almost always taken as a 6 DOF (degrees of freedom) rigid body motions model for its response calculations. The basic theory about this can be clearly found in *Faltinsen (1990).* Further, the oscillatory rigid body translation motions can be referred to as surge, sway and heave while the oscillatory angular motions are referred to as roll, pitch and yaw based on **Figure 2.1.** below:

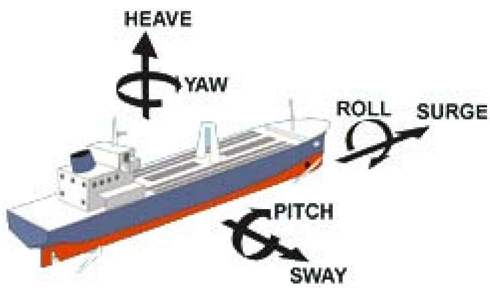


Figure 2.1. : Definition of rigid-body motion modes.

Reference: Journée and Massie (2001)

For the analyses of the floater motions it is needed to consider the different hydrodynamic effects on the floater. Generally, a structure responds to environmental forces due to wind, waves and currents with motions on three different time scales; Wave Frequency (WF), Low

Frequency (LF) and High Frequency (HF). The inviscous fluid effects mostly govern the wave frequency and high frequency motions while the low frequency motion will be determined by the viscous fluid effects.

The wave frequency motions (WF) are generated by the wave forces on the floater while the low frequency motions (LF) are driven by the mean wave (drift) and slowly-varying forces from waves or currents. On the other hand, the higher-order wave forces result from the high frequency motion (HF) that may induce springing or ringing response *(DNV-RP-F205 (2010)*).

Normally, a moored floater is dynamically excited by ordinary wave frequency load but also exposed to the mean wave (drift) and slowly-varying forces from waves or currents. *Løken et al. (1999)* mentioned that the dynamic equations of equilibrium forces are formulated in the terms of:

- excitation forces
- inertia forces
- damping forces
- and restoring forces

The solutions of the dynamic equations are found by frequency domain analysis or can be derived by time domain analysis. Generally, frequency domain analysis will be applicable for the environmental load that gives satisfactorily results by linearization theory while time domain analysis will be performed as direct numerical integration of the equation of motions which involves non linear functions to predict the maximum response and capture the higher order load effects.

The large volume body of a floater is represented by a 6 DOF (Degrees of Freedom) rigid body motions model. The floater will be assumed as having a rigid body, unrestrained and in a state of equilibrium when in calm water (steady state).

The basic theory concerning this can be clearly found in *Newman (1986)* and *Faltinsen (1990)*

The six components of inertia force which are associated with the body mass can be defined based on the linearized motion assumption as follows:

$$F_i = \sum_{j=1}^{6} M_{ij}\dot{U}_j \left(j = 1,\ldots,6 \right) \qquad (2.1)$$

where the mass matrix M_{ij} is defined by:

$$M_{ij} = \begin{vmatrix} M & 0 & 0 & 0 & 0 & -M_{yG} \\ 0 & M & 0 & 0 & 0 & 0 \\ 0 & 0 & M & M_{yG} & 0 & 0 \\ 0 & 0 & M_{yG} & I_{11} & I_{12} & I_{13} \\ 0 & 0 & 0 & I_{21} & I_{22} & I_{23} \\ -M_{yG} & 0 & 0 & I_{31} & I_{32} & I_{33} \end{vmatrix}$$

M_{yG} = the mass at the centre gravity
I_{ij} = the product of moment inertia w. r. t. coordinate system and the body mass is:

$$M = \iiint_{\mathcal{V}_B} \rho_B d\,\mathcal{V}$$

Further, six simultaneous equations of motion will be formulated by equating the inertia forces to the sum of the pressure forces of the fluid over the wetted surface and the forces due to the body weight which are incorporated in the total static restoring forces as follow:

$$\sum_{j=1}^{6} \xi_j \left(-c_{ij} + f_{ij}\right) + AX_i = -\omega^2 \sum_{j=1}^{6} M_{ij}\, \xi_j \;\; for\; (i = 1, \dots, 6)$$

Rearranging and adding the added mass (a_{ij}) and damping coeffecients correlations (b_{ij}), the equation will be:

$$\sum_{j=1}^{6} \xi_j \left[-\omega^2\left(M_{ij} + a_{ij}\right) + i\omega b_{ij} + c_{ij}\right] = AX_i \quad for\; (i = 1, \dots, 6)$$

The body motion (ξ_j) can be determined by standard matrix-inversion techniques as follow:

$$\xi_j = A \sum_{j=1}^{6} \left[C_{ij}\right]^{-1} X_i \quad for\; (i = 1, \dots, 6)$$

Where C_{ij} denotes the total matrix in the square bracket on the left hand side, $\left[-\omega^2\left(M_{ij} + a_{ij}\right) + i\omega b_{ij} + c_{ij}\right]$

Then the complex amplitude of the body motion in the j-th mode, in response to an incident wave of unit amplitude, frequency (ω) and direction (θ) can be described by the ratio below:

$$H_j(\omega, \theta) \equiv \frac{\xi_j}{A} = \sum_{j=1}^{6} \left[C_{ij}\right]^{-1} X_i \;\; for\; (i = 1, \dots, 6) \qquad (2.2)$$

The ratio is known as *the transfer function or response amplitude factor*. The transfer function can be calculated if the added mass, damping, exciting and hydrostatic forces are known.

Furthermore, in the case of a mechanical oscillator, the relation between the exciting force damping and resonant response can be found from the equations of motion.

The equations of motions for harmonic forcing motion e.g. regular waves of the rigid body systems are expressed in the global coordinate system below:

$$\sum_{j=1}^{6} \left[\left(M_{ij} + A_{ij}\right)\ddot{\xi}_j + B_{ij}\dot{\xi}_j + C_{ij}\xi_j\right] = F_i e^{-i\omega t} \;\; for\; (i = 1, \dots, 6) \qquad (2.3)$$

where:

M_{ij} = the mass matrix for the structure

A_{ij} = the added mass coefficients

B_{ij} = the damping coefficients

$F_i e^{-i\omega t}$ = the complex amplitudes of the exciting forces

(i is complex unit) for the six of components ($i = 1, \dots, 6$) of rigid body

The equation motion *(2.3)* can be solved by substituting $\xi_j = \bar{\xi}_j e^{-i\omega t}$ in the left hand side, where $\bar{\xi}_j$ are the complex amplitude of the motion modes. This leads to the six coupled algebraic equations for the real and imaginary parts of the complex amplitudes for surge, heave and pitch. A similar approach can be used to determine sway, roll and yaw. When the motions are found, the wave loads can be obtained using the expression for hydrodynamic forces. *Faltinsen (1990)* has emphasized that *equation (2.3)* is only generally valid for steady state sinusoidal motions.

On the other hand, the response in irregular waves can be given by using the following form below:

$$\sum_{j=1}^{N} A_j \left|H(\omega_j)\right| sin\left(\omega_j t + \delta(\omega_j) + \epsilon_j\right) \quad (2.4)$$

where:

$\left\|H(\omega_j)\right\|$	= the transfer function, which is the response amplitude per unit wave amplitude with frequency (ω_j)
$\delta(\omega_j)$	= a phase angle which is associated with the response
ω_j	= the frequencies of the oscillation
A_j	= $2\sqrt{S(\omega_j)\Delta\omega}$, $S(\omega_j)$ is the sea spectrum

The response in irregular waves can be formed as linear wave-induced motion or load on structure. In the limit as $N \to \infty$ and $\Delta\omega \to 0$, the variance of the response σ_r^2 can be obtained as follow:

$$\sigma_r^2 = \int_0^\infty S(\omega)|H(\omega)|^2 \, d\omega \quad (2.5)$$

2.2 Response of Single Body Structures

The response of the structures in irregular waves can be explained by the assistance of linear wave theory. *Faltinsen (1990)* has mentioned that a useful consequence of linear theory is that we can obtain the results in irregular waves by adding together results from the regular wave of different amplitudes, wave length and propagation directions.

Here, we consider a structure in incident regular waves of amplitude ζ_a where the wave steepness is small, i.e. the waves are far from breaking. Hence, the wave-induced motion and load amplitudes will be linearly proportional when the linear theory is applied.

Faltinsen (1990) has divided the hydrodynamics problem into two sub-problems as follow:

1. *Wave excitation load* and moments are produced by waves coming onto the restrained body. This load is composed of Frode-Kriloff and diffraction forces and moments.
2. *Hydromechanical load and moments* are induced by the harmonic oscillations of the rigid body which are moving on the undisturbed surface of the fluid. Moreover, the hydrodynamic loads are identified as added mass, damping and restoring terms.

Since the system is linear, the resulting motion in waves can be seen as a superposition of the motion of the body in still water and the forces on the restrained body in waves. The superposition loads can be seen in **Figure 2.2**.

More details about the wave excitation load and hydromechanical load can be found in *Faltinsen (1990)* and *Journée and Massie (2001)*.

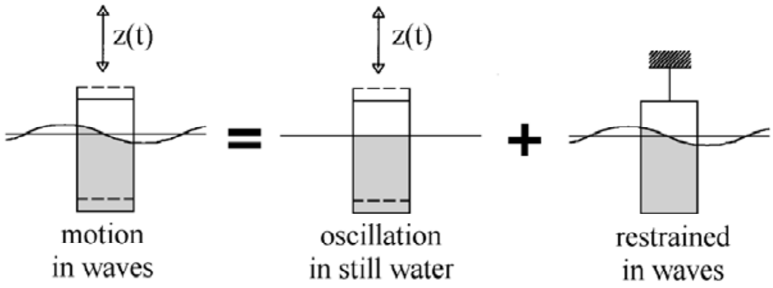


Figure 2.2. : Superposition of hydro mechanical and wave loads.

Reference: Journée and Massie (2001)

2.3 Second-Order Nonlinear Problems

Faltinsen (1990) has mentioned that the way to solve non-linear wave-structure problems for ship and offshore hydrodynamic is to use perturbation analysis with the wave amplitude as a small parameter. The potential theory is assumed then the problem is solved to the second-order in incident wave amplitude. This method is very powerful to give a solution for several practical problems.

In the linear solution, both the free-surface condition and the boundary condition are satisfied on the mean position of the free-surface and the submerged hull surface respectively. Further, the fluid pressure and the velocity of fluid particles on the free-surface are linearized.

On the other hand, the second-order theory will account more properly for the zero-normal flow condition on the body at the instantaneous position of the body. It also approximates more accurately the fluid pressure being equal to the atmospheric pressure on the instantaneous position of the free-surface. Further, the second-order theory will also account more properly for the non-linearities in the velocity of fluid particles on the free-surface. Hence, in a second-order theory, we keep all terms in the velocity potential and fluid pressure and wave loads that are either linear with respect to the wave amplitude or proportional to the square of the wave amplitude.

A simple way to illustrate the presence of non-linear wave effects is to consider the quadratic velocity in the complete Bernoulli's equation as follow:

$$-\frac{\rho}{2}(u^2 + v^2 + w^2) = -\frac{\rho}{2}|\nabla\phi|^2 \tag{2.6}$$

Where: $u, v, and\ w$ are the fluid velocity vectors

By emphasizing that equation *(2.6)* provides only one of the non-linear effects and also considering an idealized sea state which consists of two wave components of the circular frequencies $\omega_1\ and\ \omega_2$. The formula for an approximation of the x-component of the velocity can be written as follow:

$$u = A_1 \cos(\omega_1 t + \epsilon_1) + A_2 \cos(\omega_2 t + \epsilon_2)\,, v = 0\ and\ w = 0 \tag{2.7}$$

By introducing *equation (2.7)* to *equation (2.6)*, it now follows that:

$$-\frac{\rho}{2}u^2 = -\frac{\rho}{2}\Bigg[\frac{A_1^2}{2} + \frac{A_2^2}{2} + \frac{A_1^2}{2}\cos(2\omega_1 t + 2\epsilon_1) + \frac{A_2^2}{2}\cos(2\omega_2 + 2\epsilon_2)$$
$$+ A_1 A_2 cos[(\omega_1 - \omega_2)t \ + \epsilon_1 - \epsilon_2] + A_1 A_2 cos[(\omega_1 + \omega_2)t + \epsilon_1 + \epsilon_2]\Bigg]$$

(2.8)

The equation above gives the three components of the result; the mean wave (drift) forces, the forces oscillating in the difference frequencies and the forces oscillating in sum frequencies. Further, the two main second-order non linear terms that are the mean wave (drift) loads and slowly varying wave loads.

The effects of second order wave forces are most apparent in the behavior of anchored or moored floating structures. *Journée and Massie (2001)* show that the responses of a structure on the irregular waves for the horizontal motions of moored or anchored floating structures in a seaway include three important components:

1. A mean displacement of the structure, resulting from a constant load component. Obvious sources of these loads are current and wind. In addition to these, there is also a so-called **mean wave drift force**. This drift force is caused by non-linear (second order) wave potential effects. Together with the mooring system, these loads determine the new equilibrium position.
2. An oscillating displacement of the structure at frequencies corresponding to those of the waves; the wave-frequency region. These are linear motions with a harmonic character, caused by **the first order wave loads**. The time-averaged value of this wave load and the resulting motion component are zero.
3. An oscillating displacement of the structure at frequencies which are much lower than those of the irregular waves; the low-frequency region. These motions are caused by non-linear elements in the wave loads (**the low-frequency wave drift forces)**, in combination with the spring characteristics of the mooring system. Generally, a moored ship has a low natural frequency in its horizontal modes of motion as well as very little damping at such frequencies. Very large motion amplitudes can then result at resonance so that a major part of the ship's dynamic displacement (and resulting loads in the mooring system) can be caused by these low-frequency excitations.

2.3.1 The Mean Wave (Drift) Forces

In order to calculate mean wave (drift) forces on a structure, it is not necessary to solve the second order equations because the time dependence over one period of oscillation of the pressure is zero. It means that the second order potential does not result in mean loads.

Two methods that can be used to calculate the mean wave (drift) forces are the far field method and near field method. The far field method is based on the equation for conservation momentum in the fluid while the near field method is based on the direct pressure integration. The explanation of the difference between the far field method and the direct pressure integration can be found easily in *Faltinsen (1990)*.

Hung and Taylor has explained the differences of both methods clearly in the paper; *The formulation of mean drift forces and moments for floating bodies*. Furthermore, *Scalavounos (1987)* has pointed out the relative advantages and disadvantages between them, the far field method maybe more efficient and less demanding on numerical discretisation. On the other hand, the near field method is potentially more useful if one wishes to extend the solution to the calculation of time harmonic second order forces, that is useful for cross checking theoretical derivation and computational implementation.

The far field method was originated by *Maruo (1960)*. One way to obtain expressions for mean wave forces in regular waves is to use the equations for conservation of momentum *M(t)* in the fluid for a closed surface.

$$M(t) = \iiint_{\Omega} \rho V d\tau \qquad (2.9)$$

where: $V = (V_1, V_2, V_3)$ is the fluid velocity and Ω = the control volume

Further, the volume integral can be reduced to a surface integral by using vector algebra and the Gauss's divergence theorem as is shown below:

$$\frac{dM}{dt} = -\rho \iint_S \left[\left(\frac{p}{\rho} + gz\right) + V(V_n - U_n)\right] ds \qquad (2.10)$$

where:

$V_n = \frac{\partial \phi}{\partial n}$ = the normal component of the fluid velocity at the surface S

U_n = the normal component of the velocity of the surface S where the positive normal direction to be out of the fluid.

The closed surface S consists of the body surface S_B, a non-moving vertical circular cylindrical surface S_∞ away from the body, the free-surface S_F and the sea bottom S_0 inside S_∞ as the boundary conditions. Further, it should be noted that S_∞ does not need to be far away from the body.

Hence, the boundary condition can be written as follow:

$U_n = V_n \; on \; S_B \; and \; S_F$

$U_n = 0 \; on \; S_\infty \; and \; S_0$

By time averaging *equation (2.10)* over one period of oscillation and noting that the time average of $\frac{dM}{dt}$ is zero, the force on the body can be found:

$$\overline{F_i} = -\overline{\iint_{S_\infty} [p n_i + \rho V_i V_n] ds} \quad i = 1,2 \qquad (2.11)$$

Maruo (1960) used the equation (2.11) to derive a useful formula for drift forces on a two-dimensional body in incident regular deep-water waves. The body may be fixed or freely floating oscillating around a mean position and there is no current and no constant speed on the body. The result is:

$$\overline{F_2} = \frac{\rho g}{4} [\zeta_a^2 + A_R^2 - A_T^2] \qquad (2.12)$$

where:

ζ_a = the amplitude of the incident waves

A_R = the amplitude of the reflected waves

A_T = the amplitude of the transmitted waves

Further, Maruo's formula follows by assuming the average energy flux is zero through S_B. This means: $\zeta_a^2 = A_R^2 - A_T^2$

Hence, the equation (2.12) can be written:

$$\overline{F_2} = \frac{\rho g}{4} A_R^2 \qquad (2.13)$$

Long wavelengths relative to the cross-sectional dimensions of the body, will not disturb the wave field. This means, the reflected wave amplitude A_R^2 and the wave drift force become negligible. On the other hand, when the wavelengths are very short, the incident waves are totally reflected from a surface-piercing body with a vertical hull surface in the wave zone. This means, the wave drift-force can never be larger than $\left(\frac{\rho g}{2}\right) \zeta_a^2$.

When the body motions are large, the amplitude of the reflected waves A_R will be larger. This means, the wave-drift force will have a peak in a frequency range around the resonance frequency.

For a submerged body, $A_{R,}$ will go to zero when the wavelength goes to zero. In the special case of a submerged circular cylinder that is either restrained from oscillating or whose centre follows a circular orbit, A_R is zero for all frequencies and all depths of submergence (*Ogilvie (1963))*.

Further, the combined effect of waves and current have an effect on the wave field and therefore on the wave-drift forces. *Maruo (1960)* has also derived a formula similar to *equation (2.13)* for drift-forces on a three-dimensional structure in incident regular waves, with no current present, which can be written as follow:

$$\overline{F_2} = \frac{\rho g}{4} \int_0^{2\pi} A^2\,(\theta)(\sin\beta - \sin\theta)d\theta \qquad (2.14)$$

Here β is the wave propagation direction relative to the x-axis and $\frac{A(\theta)}{r^{1/2}}$ is the amplitude generated by the body far away at large horizontal radial distance $r = (x^2 + y^2)^2$ from the body and the angle θ is defined as $x = r\cos\theta$ *and* $y = r\sin\theta$

Another way to obtain the mean wave forces and moment is the near field method. This method was introduced by *Pinkster and van Oortmerssen (1977)* based on the direct pressure integration. Here, all three force components and three moments can be found. By analyzing an incident regular deep water waves on the vertical wall, the asymptotic value agreed with Maruo's formula.

Further, the mean wave (drift) force in irregular seas can be found from the result in regular sea by assuming a long-crested sea described by sea spectrum. The formula is written as follows:

$$\overline{F_i^S} = 2\int_0^\infty S(\omega)\left(\frac{\overline{F_i}(\omega;\beta)}{\zeta_a^2}\right)d\omega \quad i = 1,\dots,6 \qquad (2.15)$$

2.3.2 The Slowly Varying (Low frequency) Wave Forces

The slow-drift motions are resonance oscillations excited by non-linear interaction effect between the waves and the body motion. The slow-drift motions are of equal importance as the linear first-order motion in design of mooring systems for large-volume structures. For a moored structure, slow-drift resonance oscillations occur in surge, sway and yaw. For a freely floating structure with low water plane area, the second-order slow-drift motions are most important for large volume structures.

The slow-drift excitation load can be found by starting from *equation (2.8)* and formally writing

$$F_i^{SV} = \sum_{j=1}^{N}\sum_{k=1}^{N} A_j A_k \left[T_{jk}^{ic} \cos\{(\omega_k - \omega_j)t + (\epsilon_k - \epsilon_j)\} + T_{jk}^{is} \sin\{(\omega_k - \omega_j)t + (\epsilon_k - \epsilon_j)\}\right] \quad (2.16)$$

where:

A_i = the wave amplitudes

ω_i = the wave frequencies

ϵ_i = the random phase angles

N = the number of wave components

T_{jk}^{ic} *and* T_{jk}^{is} = the coefficients of the second-order transfer functions for the difference frequency loads associated with ω_j *and* ω_k.

Since the direct summation in *equation (2.16)* is still relatively time consuming. *Newman (1974)* has proposed a double summation approximation by using the square of a single series. This implies that only N terms should be added together at each time step compared to N^2 terms by *equation (2.17)*. The formula will be:

$$F_i^{SV} = 2\left(\sum_{j=1}^{N} A_j \left(T_{jj}^{ic}\right)^{1/2} \cos(\omega_j t + \epsilon_j)\right)^2 \quad (2.17)$$

Obviously *equation (2.17)* requires that T_{jj}^{ic} being a positive.

Faltinsen (1990) has suggested having the slow-drift excitation force in spectral form rather than in a time series form in order to have inconvenient solution.

According to *Pinkster (1975),* the spectral density of the low frequency will be:

$$S_F(\mu) = 8\int_0^{\infty} S(\omega)\, S(\omega+\mu) \left(\frac{\overline{F_i}\left(\omega+\frac{\mu}{2}\right)}{\zeta_a^2}\right)^2 d\omega \quad (2.18)$$

where $\overline{F_i}\left(\omega+\frac{\mu}{2}\right)$ is the mean wave load in direction i for frequency $\omega+\frac{\mu}{2}$.

2.4 Frequency Domain and Time Domain Analysis

Frequency domain and time domain analysis will be used in the study to solve several problems in the analysis.

2.4.1 Frequency Domain Analysis

A frequency domain analysis will be the basis for generating the transfer functions for frequency dependent excitation forces, added mass and damping. In a frequency domain analysis, the solutions of the equation of motions are solved by method of the harmonic analysis or methods using the Laplace and Fourier transforms. *DNV-RP-F205 (2010)* has explained that the equations of motion are solved for each of the incoming regular wave components for a wave frequency analysis. Further, the results of the analysis are given as descriptions of variables of interest such as floater motion and floater forces as a function of frequency.

Løken et al (1999) mentioned that a frequency domain analysis is naturally suited to the analysis of system exposed to random environments since it provides a clear and direct relationship between the spectrum of the environmental loads and the spectrum of the system response. The relation between the waves and the motion can be seen in **Figure 2.3**.

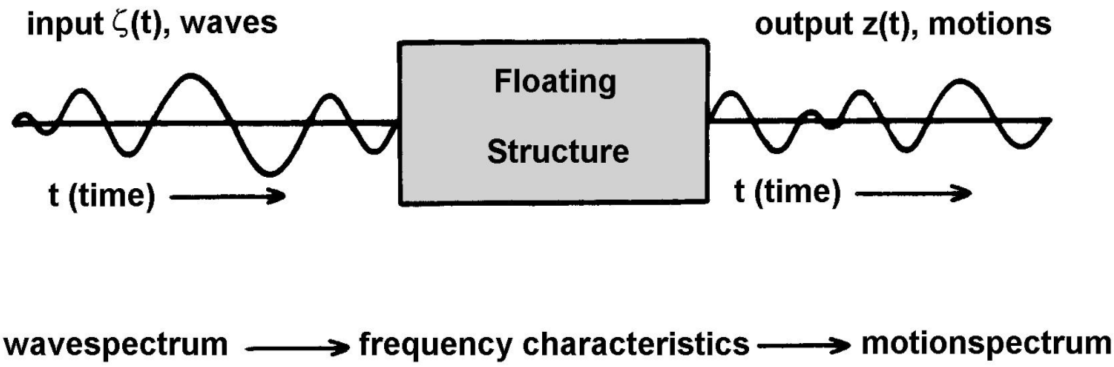


Figure 2.3. : The relation between the waves and the motions.

Reference: Journée and Massie (2001)

In the system above, the wave spectrum is input to a system that is considered to possess linear characteristics. Further, the output of the system is the motions which have an irregular behavior. Generally, the floater motion has a linear behavior, it means that the different ratios between the motion amplitudes and the wave amplitudes and also the phase shifts between the motions and the waves are constant.

As a consequence of linear theory, the resulting motions in irregular waves can be obtained by adding together results from regular waves of different amplitudes, frequencies and possibly propagation directions. With known wave energy spectra and the calculated frequency characteristics of the responses of the ship, the response spectra and the statistics of these responses can be found.

Løken et al (1999) also mentioned that analysis in the frequency domain will be a convenient method to calculate the inviscid hydrodynamic properties for a large floater where the wave scattering and radiation is important.

Furthermore, the frequency domain requires linear equation of motion and predominantly linear assumptions. The linear equation of motion for a single body will adapt *the equation of (2.3):*

$$\sum_{j=1}^{6}\left[\left(M_{ij}+A_{ij}\right)\ddot{\xi}_j+B_{ij}\dot{\xi}_j+C_{ij}\xi_j\right]=F_i e^{-i\omega t}\ \ for\ (i=1,\ldots,6)$$

where:

M_{ij} = the mass matrix for the structure

A_{ij} = the added mass coefficients

B_{ij} = the damping coefficients

$F_i e^{-i\omega t}$ = the complex amplitudes of the exciting forces

(i is complex unit) for the six of components ($i = 1, \ldots, 6$) of rigid body

2.4.2 Time Domain Analysis

In order to solve the problem as close as possibly to the real condition with regarding to non linear system, the foundation of the frequency domain approach - is no longer valid. *Løken et al. (1999)* has mentioned that the time domain analysis will a be very convenient way for extreme condition analysis since linearized analysis is not working efficiently. It also has advantage in allowing changing the boundary conditions and allowing non-linear forcing and stiffness functions.

The time domain analysis requires a proper simulation length to have a steady result. Furthermore, the time domain analysis procedure consists of a numerical solution of rigid-body equation of motion for the floater subject to external actions which may originate in the fluid motion due to waves, currents, floater motion, positioning system and also disturbing effects such as wind.

The direct numerical integration of the equation of motion will be applied in the time domain analyses. Hence, the non-linear functions of the relevant wave and motion variables such as drag forces, finite motion and finite wave amplitude effects, and the non-linear positioning due to mooring system will be involved in the analysis. The increase of computing time will be a major effect in the analysis since we adopt a direct numerical integration computation.

Moreover, a wave spectrum is used as a basis for the generation of the random time series. The first order wave exciting forces and second order slowly varying wave drift forces are both represented in the form of random time histories.

The theory of time domain analysis will be adopted from *Marintek (2008); "SIMO - Theory Manual Version 3.6, rev: 1"*.

The equation of motion for a freely moving floater or a moored structure in time domain analysis:

$$M\ddot{x}+C\dot{x}+D_1\dot{x}+D_2 f(\dot{x})+K(x)x=q(t,x,\dot{x}) \qquad (2.19)$$

$M = m + A(\omega)$

$A(\omega) = A_\infty + a(\omega), A_\infty = A(\omega = \infty)$

$C(\omega) = C_\infty + c(\omega), C_\infty = C(\omega = \infty) \equiv 0$

where:

M = frequency-dependent mass matrix
m = body mass matrix
A = frequency-dependent added-mass
C = frequency-dependent potential damping matrix
D_1 = linear damping matrix
D_2 = quadratic damping matrix
f = vector function where each element is given by $f_i = \dot{x}_i|\dot{x}_i|$
K = hydrostatic stiffness matrix
x = position vector
q = exciting force vector

The exciting forces on the right-hand side of *equation (2.19)* can be written as follow:

$$q(t, x, \dot{x}) = q_{WI} + q_{WA}^{(1)} + q_{WA}^{(2)} + q_{CU} + q_{ext} \quad (2.20)$$

where:

q_{WI} = the wind drag force

$q_{WA}^{(1)}$ = the first order wave excitation force

$q_{WA}^{(2)}$ = the second order wave excitation force

q_{ext} = any other forces (specified forces and forces from station keeping and coupling elements, etc.)

The wave frequency (WF) motions are excited by the first order wave excitation force while the low-frequency (LF) motions are excited by the slowly varying part of the second order wave excitation force, the wind drag force and the current drag force. The high-frequency (HF) motions are excited by the sum-frequency second-order wave excitation force.

Two different solution methods described in the following two subsections are available in SIMO; solution by convolution integral or by separation of motions.

A. Solution by Convolution Integral

Assume that the equations of motion can be written:

$$[m + A(\omega)]\ddot{x} + C(\omega)\dot{x} + Kx = f'(t) = q - D_2 f(\dot{x}) - D_1\dot{x} \quad (2.21)$$

By using the following equation below:

$A(\omega) = A_\infty + a(\omega), A_\infty = A(\omega = \infty)$

$C(\omega) = C_\infty + c(\omega), C_\infty = C(\omega = \infty) \equiv 0$

Also by using the inverse Fourier transform taking into account that the values of $h(t - \tau)$ for, t < 0, i.e. before the "experiment" started, is zero:

$$A_\infty \ddot{x}(t) + \int_0^t h(t-\tau)\,\dot{x}(\tau)d\tau = f(t) \tag{2.22}$$

Hence, the equation of motion becomes:

$$[m + A_\infty]\ddot{x} + D_1\dot{x} + D_2 f(\dot{x}) + Kx + \int_0^t h(t-\tau)\,\dot{x}(\tau)d\tau = q(t,x,\dot{x}) \tag{2.23}$$

$h(\tau)$, the retardation function is computed by a transform of the frequency-dependent added-mass and damping:

$$h(\tau) = \frac{1}{2\pi}\int_{-\infty}^{\infty}[c(\omega) + i\omega\, a(\omega)]e^{i\omega t}d\omega = \frac{1}{2\pi}\int_{-\infty}^{\infty} H(\omega)\, e^{i\omega t}d\omega \tag{2.24}$$

or similarly:

$$H(\omega) = \int_{-\infty}^{\infty} h(\tau)e^{i\omega t}d\tau = c(\omega) + i\omega\, a(\omega) \tag{2.25}$$

B. Separation of Motions

Solving the integral in *equation (2.23)* may be very time consuming, another method has been developed by using separated motions. The separated motion method is a common approach by using a multiple scale approach. This method separates the wave-frequency part from the low-frequency part. In this method, the quadratic damping D_2 is set to be zero and the stiffness K is constant.

The exciting force is separated in a high-frequency part, $q^{(1)}$ and a low-frequency part, $q^{(2)}$:

$$q(t,x,\dot{x}) = q^{(1)} + q^{(2)}$$
$$q^{(1)} = q_{WA}^{(1)}$$
$$q^{(2)} = q_{WI} + q_{WA}^{(2)} + q_{CU} + q_{ext} \tag{2.26}$$

The position vector can then be separated into:

$$x = x_{HF} + x_{LF}$$

Further, the high-frequency motions to be solved in frequency domain are expressed by:

$$[m + A(\omega)]\ddot{x}_{HF} + [D_1 + C(\omega)]\dot{x}_{HF} + Kx_{HF} = q_{WA}^{(1)}(\omega) \tag{2.27}$$

While the low-frequency motions are solved in the time domain, the dynamic equilibrium equation is written:

$$[m + A(\omega = 0)]\ddot{x}_{LF} + D_1\dot{x}_{LF} + D_2 f(\dot{x}) + Kx_{LF} = q_{WI} + q_{WA}^{(2)} + q_{CU} + q_{ext} \tag{2.28}$$

2.5 Fundamental Continuum Mechanics Theory and Implementation of the Finite Element Method

2.5.1 Fundamental Continuum Mechanics Theory

Finite element modeling will be the based on the slender structure modeling. This subchapter will present the basic theoretical background for finite element modeling, the fundamental continuum mechanics. The details in formulation can be found in *Malvern (1969).*

The Lagrangian description is used to describe the motion of the material particles. This motion is referred to a fixed global system where the rectangular Cartesian coordinate frames are defined by the base vector I_i. The motion of a material particle can be seen in **Figure 2.4** below:

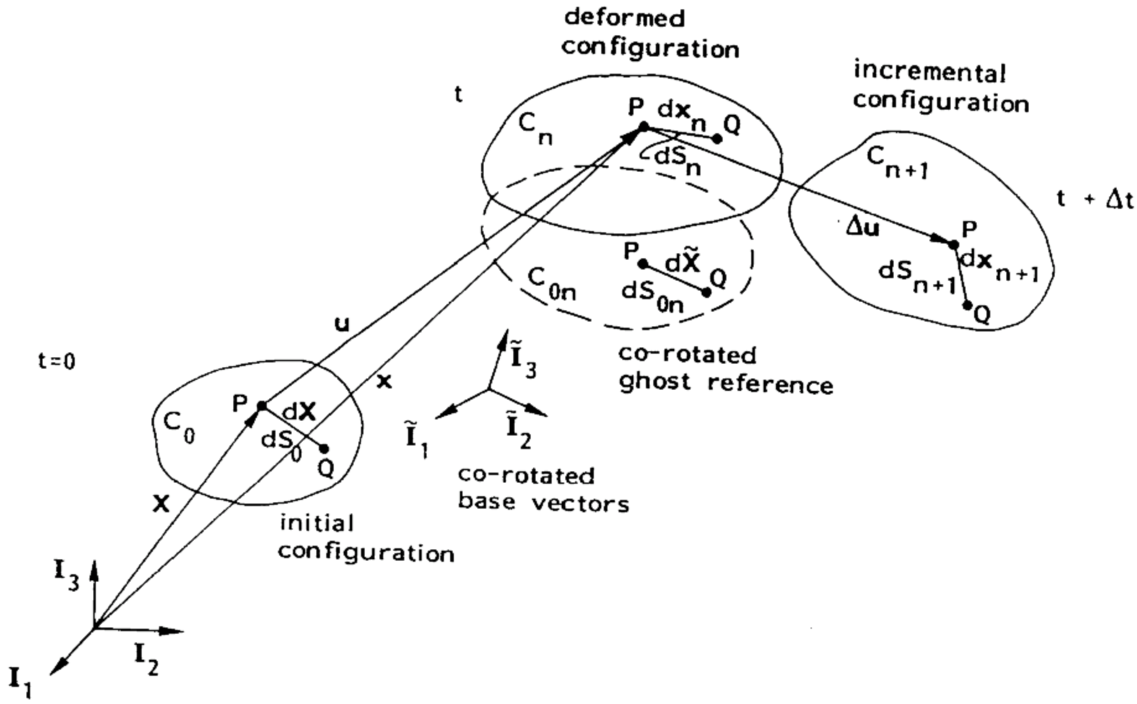


Figure 2.4. : Motion of a material particle.

Reference: *Marintek (2010)*

Furthermore, the motion of the particle for nonlinear analysis can be expressed as:

$x = x(X, t)$

$x = X + u$ *(2.29)*

C_o = the initial configuration of the body

C_n = the deformed configuration at a given time t

C_{n+1} = a new incremental configuration for time $t + \Delta t$

The strains in C_n and C_{n+1} are referred to the initial configuration C_o, usually this is termed as a *"total Lagrangian formulation"*. Generally, the total motion is determined by combining the motion of the local position vector and the motion of the local reference system.

Moreover, the formulation for the bar element and beam element will be adopted from *Marintek (2010); "RIFLEX Theory Manual Finite Element Formulation"*. In RIFLEX the bar elements are formulated using "*a total Lagrangian description*", while the beam elements formulation uses a so called "*a co-rotated ghost reference description*".

For the Lagrangian formulation, the strains are measured in terms of the **Green strain tensor *E***. If C_o is used as initial configuration, this strain tensor is defined by:

$dS_n^2 - dS_0^2 = 2dX \cdot \boldsymbol{E} \cdot dX$ *(2.30)* where: $dS_n^2 and\, dS_0^2$ are the length of the line segment PQ before and after deformation (**Figure 2.4**) and E is the strain tensor which can be expressed as follow:

$$\boldsymbol{E} = E_{ij} I_i I_j \tag{2.31}$$

Further, the rectangular components of $\boldsymbol{E}$ referred to $I_i and\ I_j$ may be expressed as:

$$E_{ij} = \frac{1}{2}\frac{\partial u_i}{\partial X_j} + \frac{\partial u_j}{\partial X_i} + \frac{\partial u_j}{\partial X_i}\frac{\partial u_i}{\partial X_j} \tag{2.32}$$

where: the component of the displacement vector u have been introduced.

From *equation (2.32),* we may conclude that $\boldsymbol{E}$ is a symmetric tensor consisting of both linear and quadratic terms.

The symmetric **Piola-Kirchhoff stress tensor *S*** will also be used here as a stress measure. Moreover, the symmetric Piola-Kirchhoff stress tensor **S** is always used in conjunction with Green strain tensor **E**. The symmetric Piola-Kirchhoff stress tensor **S** referred to the initial configuration C_o will be expressed as follow:

$$\boldsymbol{S} = S_{ij} I_i I_j \tag{2.33}$$

Hence the virtual work equation can be formulated by using Green Strain tensor **E** and Piola-Kirchhoff stress tensor **S** as below:

$$\int_{V_0} S: \partial \boldsymbol{E} dV_0 = \int_{A_0} t_0 \cdot \partial \boldsymbol{u} dA_0 + \int_{V_0} f_0 \cdot \partial \boldsymbol{u} dV_0 \tag{2.34}$$

where: A_0 and V_0 express the surface and volume of the initial reference configuration. The surface traction t_0 and body forces f_0 are referred to a unit surface and a unit volume in the initial reference state.

Further, an incremental form of the virtual work principle can be written as follow:

$$\int_{V_0} (S: \delta\Delta\boldsymbol{E} + \Delta\boldsymbol{S}: \delta\boldsymbol{E}) dV_0 = \int_{A_0} \Delta t_0 \cdot \delta\boldsymbol{u} dA_0 + \int_{V_0} \Delta f_0 \cdot \delta\boldsymbol{u} dV_0 \tag{2.35}$$

where: δ indicates virtual quantities and Δ is used to denote finite but small increments between C_n and C_{n+1} (**Figure 2.4**).

Equation (2.34) and *equation (2.35)* are valid for the bar elements and the beam elements.

Furthermore, the dynamic equilibrium equation expressed in terms of virtual work can be written, as *Remseth (1978)*:

$$\int_{V_0} S: \delta\boldsymbol{E} dV_0 + \int_{V_0} \rho_0 \ddot{u} \cdot \delta\boldsymbol{u} dV_0 + \int_{V_0} \tilde{c}\dot{u} \cdot \delta\boldsymbol{u} dV_0 = \int_{A_0} t_0 \cdot \delta\boldsymbol{u} dA_0 + \int_{V_0} f_0 \cdot \delta\boldsymbol{u} dV_0 \tag{2.36}$$

And the incremental form of the virtual work equation yields:

$$\int_{V_0} (S: \delta\Delta\boldsymbol{E} + \Delta\boldsymbol{S}: \delta\boldsymbol{E}) dV_0 + \int_{V_0} \rho_0 \Delta\ddot{u} \cdot \delta\boldsymbol{u} dV_0 + \int_{V_0} \tilde{c}\Delta\dot{u} \cdot \delta\boldsymbol{u} dV_0 = \int_{A_0} \Delta t_0 \cdot \delta\boldsymbol{u} dA_0 + \int_{V_0} \Delta f_0 \cdot \delta\boldsymbol{u} dV_0 \tag{2.37}$$

where: ρ_0 denotes mass density and $\tilde{c}$ is a viscous damping density function (i.e. damping forces are proportional to velocity).

2.5.2 Implementation of the Finite Element Method

The finite element nodal points may have up to six degrees of freedom, i.e. three in translations and three in rotation. The case of a node that is both translated and rotated must be treated more carefully. This is because large rotations in space are not true vectors and should be expressed by vectorial components in a base coordinate system. The orientation of the nodal point in space is uniquely defined by the base vector transformation:

$$\overline{\iota_i}^n = \overline{T_{\iota J}}^n I_j \qquad (2.38)$$

where: $\overline{\iota_i}^n$ are the base vectors, I_j are the global vetors and$\overline{T_{\iota J}}^n$ is the rotation matrix which has nine elements.

A nodal point with translational and rotational degrees of freedom can be seen in **Figure2.5** as follow:

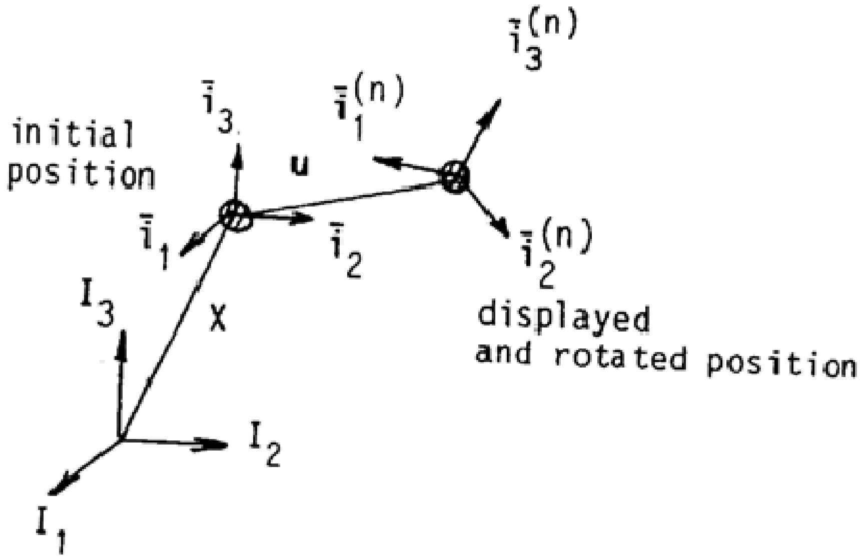


Figure 2.5. : Nodal point with translational and rotational degrees of freedom.

Reference: *Marintek (2010)*

Two of the elements that are mostly used in slender structure modeling are the bar element and the beam element.

A. The Bar Element

The spatial bar element is described in a total Langrangian formulation. It is adjusted to a formulation based on integrated cross-section forces and small strain theory.

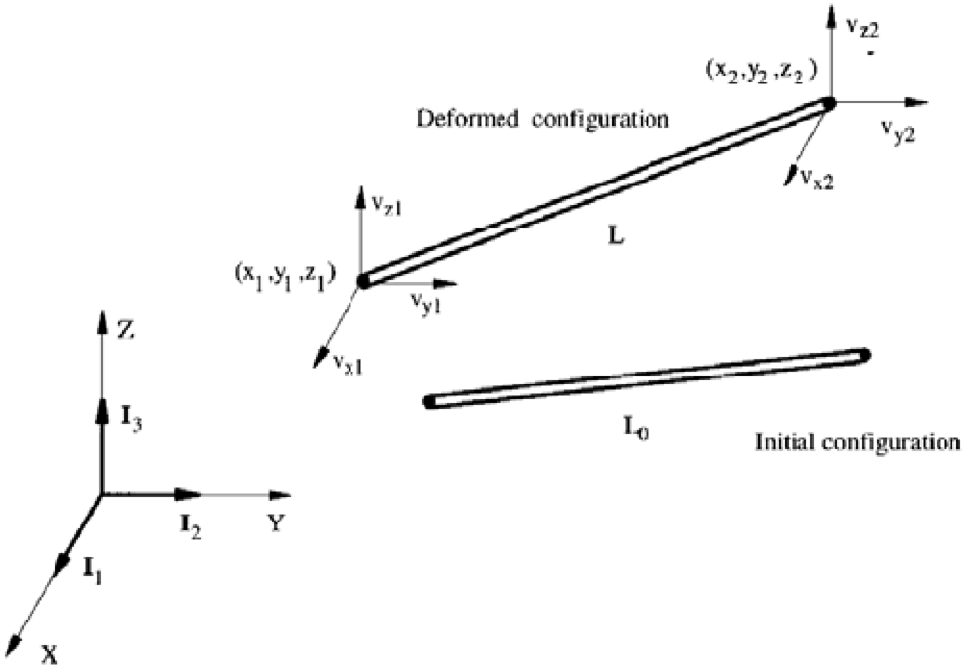


Figure 2.6. : Bar element in initial and deformed configuration.

Reference: *Marintek (2010)*

The element is assumed to be straight with an initial cross-sectional area A_0 which is constant along the element length. Each of the two nodes has three translational degrees of freedom, which are expressed directly in the global coordinate system. The element length is denoted L_o and L in the initial and deformed configuration, respectively (**Figure 2.6)**.

The deformed element length is given by:

$$L = \sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2} \tag{2.39}$$

where: $\Delta x = x_2 - x_1,\ \ \Delta y = y_2 - y_1, : \Delta z = z_2 - z_1$

Based on a total Langrangian formulation and linear displacement functions, the Green strain is expressed:

$$E_f = \frac{1}{2}\frac{L^2 - L_0^2}{L_0^2} = \frac{1}{2L_0^2}(\Delta x^2 + \Delta y^2 + \Delta z^2 - L_0^2) \tag{2.40}$$

And the Piola-Kirchhoff stress S_f can be found from the constitutive law:

$$S_f = S_f(E_f, E_0, S_0) \tag{2.41}$$

where: E_0 is initial strain and S_0 is initial stress.

Further, small strain theory is used, and it is assumed that $Lo\ ^2$and L^2 is the initial stress free element length. Thus, the axial force of the element N and the strain ε are given by:

$$N = \varepsilon(EA)\ and\ \varepsilon = \frac{L - L_0}{L_0} \tag{2.42}$$

where: EA is the axial stiffness.

B. The Beam Element

Marintek (2010) has described the beam element by using the concept of co-rotated ghost reference. A detailed discussion of this element together with examples demonstrating its capabilities may be found in *Mollestad (1983)* and *Engseth (1984)*.

The beam theory is based on the following assumptions:

- a plane section of the beam initially normal to the x-axis, remains plane and normal to the x-axis during deformations
- lateral contraction caused by axial elongation is neglected
- the strains are small
- shear deformations due to lateral loading are neglected, but St. Venant torsion is accounted for
- coupling effects between torsion and bending are neglected. Thus, warping resistance and torsional effects are neglected
- stability problems are not considered

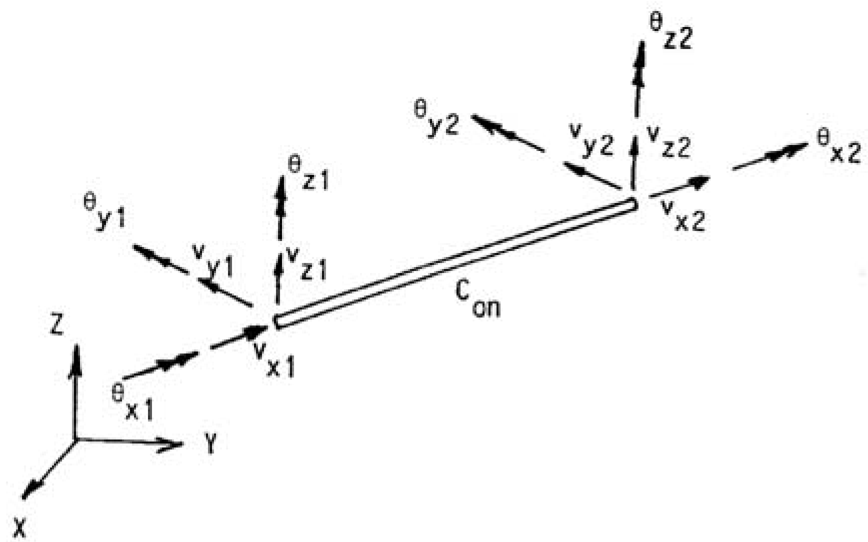


Figure 2.7. : Nodal degrees of freedom for beam element.

Reference: *Marintek (2010)*

As indicated in **Figure 2.7**, the beam has 3 translational and 3 rotational degrees of freedom at each node. They are defined in relation to the local x, y, and x-system in the C_{on} configuration. Further, the C_{on} configuration is oriented along the x-axis with cross-sectional principal axis in the y- and z-direction. It is important to note that the rotational degrees of freedom in **Figure 2.7** express deformational rotations in relation to the co-rotated straight element.

The explanation of the Green strain and the torsional behavior of the beam in the beam element will be based on **Figure 2.8** as follow:

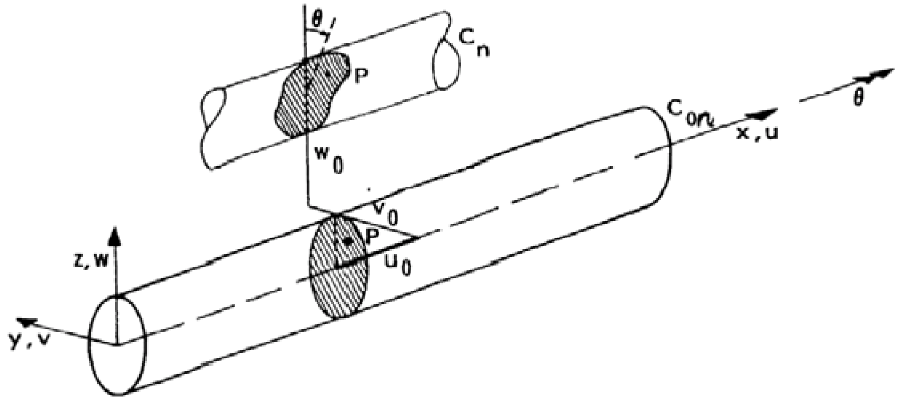


Figure 2.8. : Prismatic beam.

Reference: *Marintek (2010)*

As shown in **Figure 2.8**, the displacement of an arbitrary point P with coordinates x, y and z may be expressed as:

$$\boldsymbol{u}(x,y,z) = \boldsymbol{u}_0(x) - y\frac{dv_0}{dx} - z\frac{dv_0}{dx}$$

$$\boldsymbol{v}(x,y,z) = \boldsymbol{v}_0(x) - z\theta$$

$$\boldsymbol{z}(x,y,z) = \boldsymbol{w}_0(x) + y\theta$$

(2.43)

where: $\boldsymbol{u}_0, \boldsymbol{v}_0$ *and* $\boldsymbol{w}_0$ are the displacements of the corresponding point on the reference axis.

By using *equation (2.43)* and the assumption that quadratic strain terms that are zero on the x-axis are neglected, the Green strain can be formulated:

$$E_{xx} = \boldsymbol{u}_{0,xx} - y\boldsymbol{v}_{0,xx} - z\boldsymbol{w}_{0,xx} + \frac{1}{2}\left(v_{0,x}^2 + w_{0,x}^2\right) \quad (2.44)$$

The torsional behavior of the beam is based on the relationship:

$$M_\theta = GI_t\theta_x \quad (2.45)$$

where: M_θ is the moment of twist and GI_t is the torsional stiffness

Further, a standard element formulation gives:

$$\boldsymbol{u}_0 = N_u v_u \text{ where } v_u^T = [v_{x1}, v_{x2}]$$

$$\boldsymbol{v}_0 = N_v v_v \text{ where } v_v^T = [v_{y1}, \theta_{x1}, v_{y2}, \theta_{z2}]$$

$$\boldsymbol{w}_0 = N_w v_w \text{ where } v_w^T = [v_{z1}, \theta_{y1}, v_{z2}, \theta_{y2}]$$

(2.46)

where: N_u and N_θ are linear interpolation, while N_v and N_w express cubic interpolation functions.

2.6 Coupling Effects

Based on the explanation in *DNV-RP-F205 (2010)*, the coupling effects are referred to the influence on the floater mean position and dynamic response from the slender structure restoring, damping and inertia forces.

The following items are considered when discussing the coupling effects:

The restoring forces:

1) Static restoring force from the mooring and riser system as a function of floater offset
2) Current loading and its effects on the restoring force of the mooring and riser systems
3) Seafloor friction (if mooring lines and/or risers have bottom contact

The damping:

4) Damping from mooring and riser system due to dynamics, current, etc.
5) Friction forces due to hull/riser contact.

The inertia:

6) Additional inertia forces due to the mooring and riser system.

In a traditional de-coupled analysis, item 1) can be accurately accounted for. Items 2), 4) and 6) may be approximated. Generally, items 3) and 5) cannot be accounted for. A coupled analysis as described previously can include a consistent treatment of all these effects.

Chapter

3

Environmental Conditions

The environmental conditions are very important since they will be the key design factor for an offshore field development. Moreover, the hostile environmental conditions may give a high-level challenge that influences the options for the chosen technical solutions.

In this study, the offshore field "Western Isles" will be taken as a case study. The field is located in the northern North Sea which has three major characteristics; shallow water depth and harsh environment with strong currents.

The detail information about the location of the Western Isles is based on *PhyseE Ltd (2010)* for *"Metocean Criteria for Western Isles*".

This chapter will present meteorological and oceanographic (metocean) criteria for water levels, winds, waves and currents for the design conditions. These data are for the location in **Figure 3.1.** The red circle indicates the Western Isles location; the blue crosses are the BODC (British Oceanographic Data Centre) current data measurement locations, the blue circle is the NNS (Northern North Sea) wind waves data measurement set location, the black triangle is the POL (Proudman Oceanographic Laboratory) tidal and current data measurement location.

The study has also provided a set of wind, wave and current criteria associated with extreme events. The criteria are considered to be independent, i.e. no account is taken of the effects of joint probability. NORSOK N-003 *(2007)* will be taken as guidance for selection of environment condition. The relevant table from NORSOK Standard is presented in **Table 3.1**.

The study will be based on the return period combinations for 100 year waves and wind criteria and 10 years current criteria.

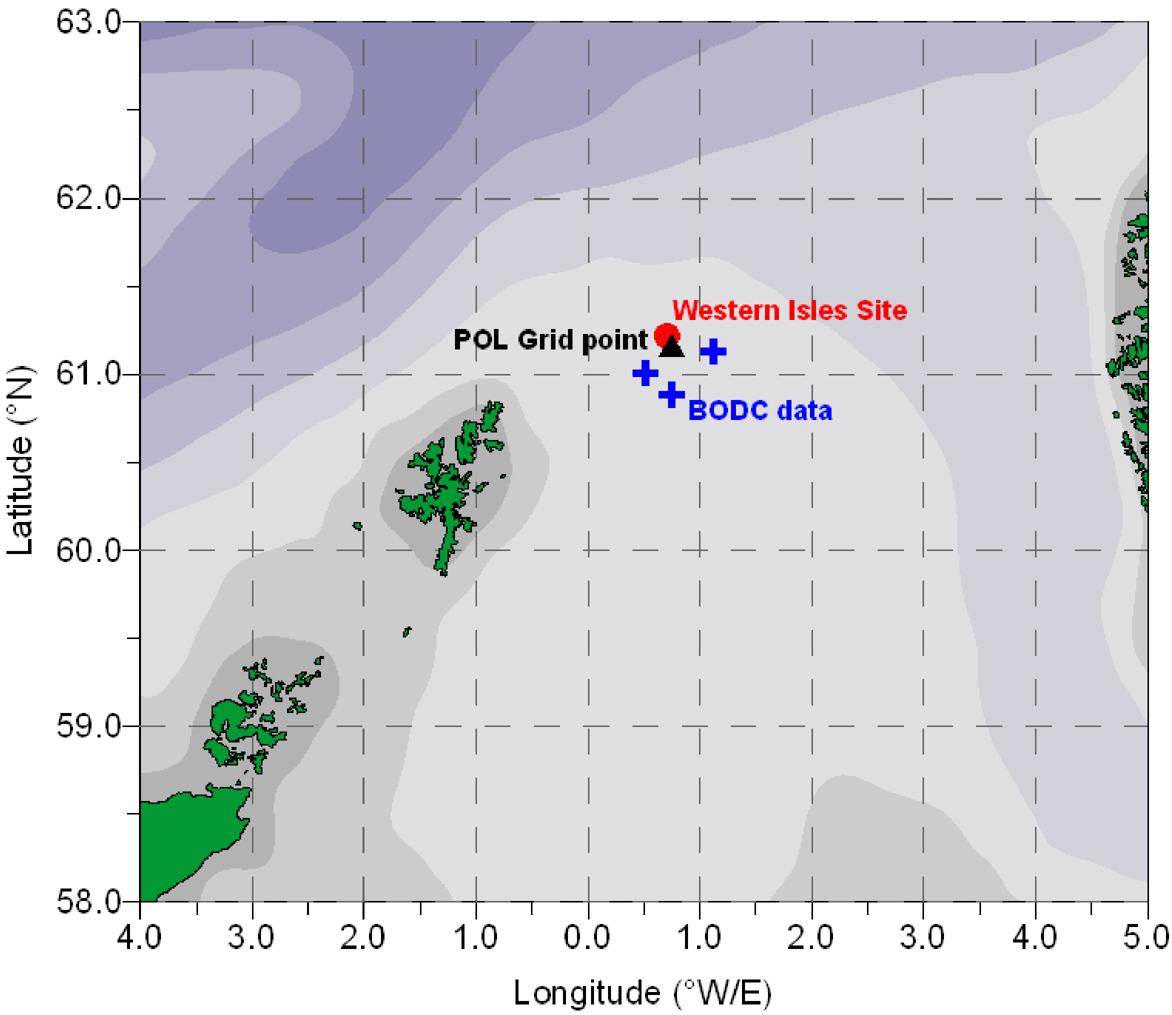


Figure 3. 1. : Definition of location and measurement points for metocean data.

Reference: PhyseE Ltd (2010)

Tabel 3. 1. : NORSOK Guidance Return Period Combinations in the Design

Limit state	Wind	Waves	Current	Ice	Snow	Earthquake	Sea level[1)]
Ultimate Limit State	10^{-2}	10^{-2}	10^{-1}	-	-	-	10^{-2}
	10^{-1}	10^{-1}	10^{-2}	-	-	-	10^{-2}
	10^{-1}	10^{-1}	10^{-1}	10^{-2}	-	-	m
	-	-	-	-	10^{-2}	-	m
	-	-	-	-	-	10^{-2}	m
Accidental Limit State	10^{-4}	10^{-2}	10^{-1}	-	-	-	m*
	10^{-2}	10^{-4}	10^{-1}	-	-	-	m*
	10^{-1}	10^{-1}	10^{-4}	-	-	-	m*
	-	-	-	10^{-4}	-	-	m
	-	-	-	-	-	10^{-4}	m

Reference: NORSOK Standard (2007)

3.1 Water Level

The water depths are in the range 155 – 170m. For the analysis, the water depth will be taken as 170 m a conservative value.

The still water level depth relative to the seabed and the surge displacement relative to LAT. (Lowest Astronomical Tide) can be seen in **Table 3.2** and the extreme water depth can be seen in **Table 3.3**.

The detail information above is on *PhyseE Ltd (2010).*

Tabel 3. 2. : Still Water Levels, Surges and Still Water Depths Based on a Nominal LAT Depth

	Tidal Levels (Rel. LAT) (m)	All-Year Criteria		
		Surge Displacement (Rel. LAT) (m)	Still Water Level (Rel. LAT) (m)	Still Water Depth (Rel. Sea Bed) (m)
Positive				
1000-Years	-	1.85	2.57	162.57
100-Years	-	1.78	2.53	162.53
50-Years	-	1.75	2.51	162.51
10-Years	-	1.68	2.46	162.46
1-Year	-	1.57	2.38	162.38
HAT	2.13	-	2.13	162.13
MHWS	1.77	-	1.77	161.77
MHWN	1.39	-	1.39	161.39
MSL	1.06	-	1.06	161.06
MLWN	0.74	-	0.74	160.74
MLWS	0.36	-	0.36	160.36
LAT	0.00	-	0.00	160.00

Reference: PhyseE Ltd (2010)

Tabel 3. 3. : Extreme Water Levels and Depths Based on a Nominal LAT Depth

	1-Year (m)	10-Years (m)	50-Years (m)	100-Years (m)	1,000-Years (m)	10,000-Years (m)
Crest Elevation	11.7	14.7	16.6	17.4	20.0	22.6
Extreme Water Level (Rel. LAT)	12.4	15.5	17.4	18.2	20.9	23.6
Extreme Water Depth	172.4	175.5	177.4	178.2	180.9	183.6

Reference: PhyseE Ltd (2010)

3.2 Winds

Based on the study of *Physe Ltd (2010)*, two estimates have been considered for wind speed design value (1-hourly mean wind speed at 10 m above sea level) for recommendation at the Western Isles location:

- The NNS data set which gives a value of 38.4 m/s
- The Guidance notes contours from *Department of Energy (1990),* which give a value of approximately 39 m/s

In light of the close agreement between the two of them, it is thought prudent to choose the slightly more conservative value of 39 m/s (at 1-hourly mean wind speed). Hence, a 100 year hourly wind speed design value of 39 m/s is recommended for the Western Isles.

The wind speed criteria for the eight directional sectors and the omni-directional wind speed can be seen in **Table 3.4** and **Table 3.5**. Note that in **Table 3.4,** wind direction is defined as "Coming from".

Tabel 3. 4. : Extreme Wind Speeds at 10 m asl- by Direction (From)

	24-hr (m/s)	12-hr (m/s)	6-hr (m/s)	3-hr (m/s)	**1-hr (m/s)**	10-min (m/s)	1-min (m/s)	15-sec (m/s)	5-sec (m/s)	3-sec (m/s)
100-years										
N	26.8	29.1	31.2	32.5	**33.5**	37.1	41.7	44.5	46.7	47.8
NE	24.0	26.1	27.9	29.1	**30.0**	33.0	36.9	39.3	41.1	42.0
E	21.7	23.6	25.2	26.3	**27.1**	29.7	33.0	35.0	36.6	37.3
SE	29.8	32.5	34.7	36.2	**37.3**	41.6	47.1	50.4	53.0	54.2
S	31.2	33.9	36.3	37.8	**39.0**	43.6	49.5	53.1	55.9	57.2
SW	27.8	30.3	32.4	33.8	**34.8**	38.6	43.6	46.5	48.9	50.0
W	29.0	31.6	33.8	35.2	**36.3**	40.4	45.7	48.8	51.3	52.5
NW	27.7	30.1	32.2	33.6	**34.6**	38.4	43.3	46.2	48.5	49.6

Reference: PhyseE Ltd (2010)

Tabel 3. 5. : Extreme Wind Speeds at 10 m asl- Omnidirectional

Return Period	24-hr (m/s)	12-hr (m/s)	6-hr (m/s)	3-hr (m/s)	**1-hr (m/s)**	10-min (m/s)	1-min (m/s)	15-sec (m/s)	5-sec (m/s)	3-sec (m/s)
All-year										
1-year	24.6	26.7	28.6	29.8	**30.7**	33.8	37.9	40.3	42.2	43.1
10-years	28.1	30.5	32.6	34.0	**35.1**	39.0	44.0	47.0	49.4	50.5
50-years	30.3	33.0	35.2	36.8	**37.9**	42.3	47.9	51.3	54.0	55.3
100-years	31.2	33.9	36.3	37.8	**39.0**	43.6	49.5	53.1	55.9	57.2
1,000-years	34.1	37.1	39.6	41.3	**42.6**	47.9	54.8	58.9	62.1	63.6
10K-years	36.8	40.0	42.8	44.6	**46.0**	52.0	59.8	64.5	68.2	69.9

Reference: PhyseE Ltd (2010)

3.2.1 The Wind Force Simulated In Time Domain

Chakrabarti, S. (2005) has mentioned that the wind generally has two effects, one from the mean speed and the other from fluctuations about this mean value. The mean speed is generally treated as a steady load on the offshore structure while the fluctuating wind (gust) is described by a wind spectrum. Moreover, the dynamic wind effect will be significant and should be not ignored for a floating structure.

The wind speed design for simulation will be taken as the average speed occurring for a period of 1-hour duration at a reference height, typically 30 ft (10m) above the mean still water level.

In the study, the wind loads on the floater will be simulated to be 2-dimensional, i.e. propagating parallel to the horizontal plane when using the software program in SIMO. Furthermore, the model includes gust spectra both in the mean direction and normal to the mean wind direction. The wind gust (the varying part of the wind velocity) is assumed to be a Gaussian stochastic process.

Further, NPD wind spectrum (*ISO 19901-1 (2005),* wind spectrum) will be used. The wind loads will be simulated in time domain, no transverse gust and no admittance function will be used. The basic theory about this can be found in *Marintek (2008)* in "*SIMO - Theory Manual Version 3.6, rev: 1*"

For strong wind conditions the design wind speed, $u(z,t)(^{\mathrm{m}}/_{s})$ at height $z(m)$ above sea level and corresponding to an averaging time period $t \leq t_0 = 3600s$ is given by:

$$u(z,t) = U(z)\left[1 - 0.41 \cdot I_u(z) \cdot \ln\left(\frac{t}{t_0}\right)\right] \qquad (3.1)$$

Where the 1 hour mean wind speed $U(z)$ (m/s) is given by:

$$U(z) = U_0\left[1 + C \cdot \ln\left(\frac{z}{10}\right)\right] \qquad (3.2)$$

$$C = 5.73 \cdot 10^{-2}(1 + 0.15 \cdot U_0)^{\frac{1}{2}} \qquad (3.3)$$

and where the turbulence intensity factor $I_u(z)$ is formulated by:

$$I_u(z) = 0.06[1 + 0.043 \cdot U_0]\left(\frac{z}{10}\right)^{-0.22} \qquad (3.4)$$

For a structure on which the wind fluctuations are important such as a floating structure, the wind spectrum for longitudinal wind speed fluctuations can be described by a formula below:

$$S(f) = \frac{320 \cdot \left(\frac{U_0}{10}\right)^2 \left(\frac{z}{10}\right)^{0.45}}{(1 + f_m^n)^{\frac{5}{3n}}} \text{ and}$$

$$f_m = 172 \cdot f \cdot \left(\frac{z}{10}\right)^{2/3} \cdot \left(\frac{U_0}{10}\right)^{-0.75} \qquad (3.5)$$

where: n= 0.468

$S(f)\left(^{m^2}/_{s}\right)$ = the spectral density at frequency $f(Hz)$

$z(m)$ = the height above sea level

$U_0(^{m}/_{s})$ = the 1 hour mean wind speed at 10 m above sea level

$f(Hz)$ = the frequency, ${}^{1}/_{600}\, Hz \leq f \leq 0.5\, Hz$

In SIMO implementation of the spectrum is set to zero above 0.5 hz and is limited in magnitude below 1/600 Hz (**Figure 3.2**).

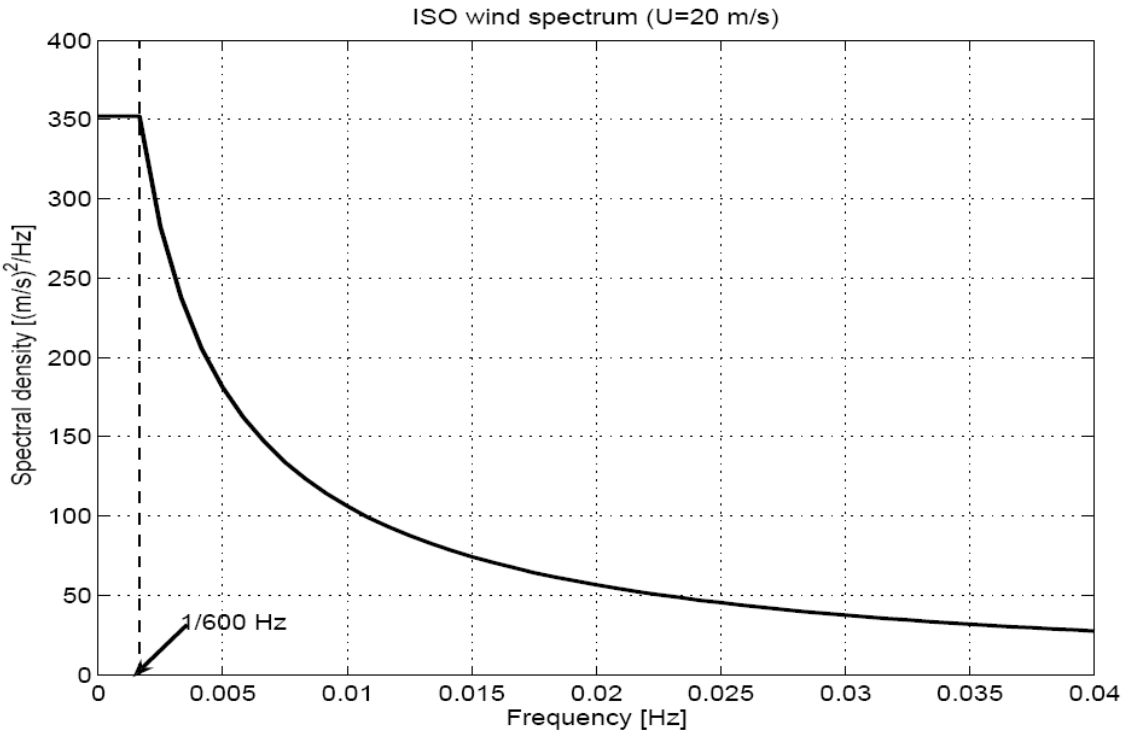


Figure 3. 2. : ISO 19901-1 wind spectrum for a mean wind speed of 20 m/s. In the SIMO implementation the magnitude is limited between 0 and 1/600 Hz.

Reference: Marintek (2008)

Faltinsen (1990) has also described that wind can produce slowly-varying oscillations of marine structures with high natural periods. This is caused by wind gusts with significant energy at periods of the order of the magnitude of a minute.

Since no important variation in the wind over the structure and the wind will flow to frontal area of the structure, the wind gusts force spectrum can be written by the expression below:

$$F_D = \frac{\rho_{air} C_D}{2} A U^2(t) \tag{3.6}$$

where: the mass density of the air is 1.21 kg/m³ at 20°C, and $U(t) = \overline{U} + u'$. $\overline{U}$ is the mean wind velocity while u' is the gust.

Further, the mean drag force can be defined as follow:

$$\overline{F_D} = \frac{\rho_{air} C_D}{2} A \overline{U^2} \tag{3.7}$$

By ignoring terms of order $\left({}^{u'}/_{\overline{U}}\right)^2$, the fluctuating drag force can be written as:

$$F_{D'}(t) = C_D A \rho_{air} \overline{U} u'(t) \tag{3.8}$$

Note that the fluctuating drag force is linearly dependent on the gust velocity. Hence, the power spectrum of $F_{D'}(t)$ is then related to the gust velocity spectrum by:

$$S_F(f) = (C_D A \rho_{air} \overline{U})^2 S(f) \quad (3.9)$$

The calculation of the slowly varying wind is the same as the calculation of the slowly varying wave. For instance if we consider head wind the mean square value of the surge motion is:

$$\sigma_x^2 = S_F^W(\omega_n) \frac{\pi}{2cb} \quad (3.10)$$

Where: the index W means wind then the relation between gust spectra expressed respectively by circular frequency ω and frequency f in hertz is:

$$S_F^W(\omega_n) d\omega = S_F(f) df, \omega = 2\pi f \quad (3.11)$$

3.3 Waves

The study will analyze the wave loads by using two forms; regular waves and irregular waves. The regular waves will be used to calculate the wave-induced motion and load on a cylindrical floater while the irregular waves will have contributions in describing the real condition of the surface sea which has a combination of many different waves with different heights and different periods.

The motions of the vessel at the frequency of the waves represent an important contribution to the floater loads analysis, particularly in shallow water. These motions can be obtained from regular or random waves by computer analysis by using frequency domain techniques. The frequency domain technique involves determining the response amplitude operator (RAO) as a function of the frequency over the full range of wave frequencies.

Moreover *Faltinsen (1990)* has also mentioned that the non linear effects of irregular seas are important in describing the horizontal motion of moored structures (a cylindrical floater with slender members).

Furthermore, linear wave theory will govern the response in regular wave (sinusoidal waves). On the other hand, Fourier series analysis will be used to describe the energy density spectrum of the irregular waves.

Furthermore in this study, the irregular wave analysis will be important to analyze the slow drift oscillation because it contains groups of waves. The slow drift oscillation period can be quite long and it can be managed by the large group envelope period. The group period excites the slow drift causing a large oscillation amplitude.

3.3.1 Regular waves

Chakrabarti, S. (2005) has described that regular waves have the characteristics of having a period such that each cycle has exactly the same form. Hence, the theory will describe the properties of one cycle in regular waves and these properties are invariant from cycle to cycle.

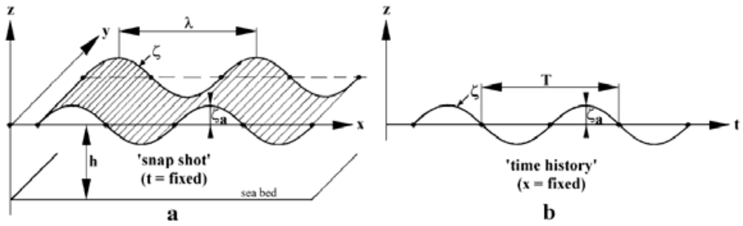


Figure 3. 3. : Harmonic wave definitions.
Reference: Journée and Massie (2001)

The potential theory will be used to solve the flow problem in regular waves (**Figure 3.3**). In order to use this linear theory with waves, it will be necessary to assume that the water surface slope is very small. This means that the wave steepness is so small that terms in the equations of the waves with a magnitude in the order of the steepness-squared can be ignored. Using the linear theory holds here that harmonic displacements, velocities and accelerations of the water particles and also the harmonic pressures will have a linear relation with respect to the wave surface elevation.

The clear theory can be found in *Gudmestad (2010)*.

A velocity potential φ can be used to describe the velocity vector at time t. The velocity potential $\varphi(x, z, t)$ of the harmonic waves has to fulfill the Continuity condition and the Laplace equation.

A function $\varphi(x, z, t)$ can be found from the partial derivatives of this function with respect to the directions that will be equal to the velocities in these directions. Since we operate with the partial derivatives of the velocities, $\frac{\partial u}{\partial x}, \frac{\partial v}{\partial y}, \frac{\partial w}{\partial z}$, the partial differential equation can be written as follow:

$$u = \frac{\partial \varphi}{\partial x}, v = \frac{\partial \varphi}{\partial y}, w = \frac{\partial \varphi}{\partial z}$$

$$\vec{U} = (u, v, w) = \left(\frac{\partial \varphi}{\partial x}, \frac{\partial \varphi}{\partial y}, \frac{\partial \varphi}{\partial z}\right)$$

and $\nabla\varphi = \vec{U} = \frac{\partial \varphi}{\partial x} \cdot \vec{\imath}, \frac{\partial \varphi}{\partial y} \cdot \vec{\jmath}, \frac{\partial \varphi}{\partial z} \cdot \vec{k}$ (3.12)

Two important assumptions will be used here; incompressible and inviscid flow.

1. Incompressible (Continuity equation for incompressible flow)
   $\nabla \cdot \vec{U} = 0$
   where: $\nabla \cdot \vec{U} = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$
2. Non-rotational/inviscid flow
   $\nabla \times \vec{U} = \vec{0}$
   where:

$$\nabla \times \bar{U} = \begin{vmatrix} \bar{i} & \bar{j} & \bar{k} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ u & v & w \end{vmatrix} = \bar{i}\left(\frac{\partial w}{\partial y} - \frac{\partial v}{\partial z}\right) - \bar{j}\left(\frac{\partial w}{\partial x} - \frac{\partial u}{\partial z}\right) + \bar{k}\left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right) \underset{non-rotational}{\overset{=}{\uparrow}} \bar{0}$$

By using two assumptions above, we will find the Laplace equation:

$$\frac{\partial^2\varphi}{\partial x^2}+\frac{\partial^2\varphi}{\partial y^2}+\frac{\partial^2\varphi}{\partial z^2}=0$$

$$\nabla^2\varphi=0 \tag{3.13}$$

The complete mathematical problem of finding a velocity potential of Non-rotational, incompressible fluid motion consists of the solution of the Laplace equation with relevant boundary conditions in the fluid. The boundary conditions will be found from physical considerations.

1. Bottom Condition

   No water can flow through the bottom, a flat bottom will be considered here.

   $$w\Big|_{z=-d}=0 \qquad \Rightarrow \qquad \left.\frac{\partial\varphi}{\partial z}\right|_{z=-d}=0 \tag{3.14}$$

   where: *d* is the water depth

2. Wall Condition

   No water can flow through the wall, a vertical wall at x=a will be considered here.

   $$u\,\Big|_{x=a}=0 \qquad \Rightarrow \qquad \left.\frac{\partial\varphi}{\partial x}\right|_{x=a}=0 \tag{3.15}$$

   For a moving wall,

   $$\left.\frac{\partial\varphi}{\partial x}\right|_{x=a(t)}=S(t) \tag{3.16}$$

   Where: S(t) is the velocity of the moving wall at time t.

   Hence, for a ship:

   $$\left.\frac{\partial\varphi}{\partial n}\right|_{(x_i,y_i,z_i)}=0 \tag{3.17}$$

   This condition means that there will be no flow through the ship surface.

3. Surface Condition

   The distinction between different types of fluid motion results from the condition of the boundaries imposed on the fluid domain. Two types of surface boundary conditions will be considered here:

   A. The kinematical surface condition

      "A water particle at the free surface will always remain at surface". Let's consider the velocity in the vertical direction as:

      $$w=\frac{\partial\varphi}{\partial z}=\left.\frac{Dz}{Dt}\right|_{z=\xi(x,t)}=\left.\left(\frac{\partial z}{\partial t}+u\cdot\frac{\partial z}{\partial x}\right)\right|_{z=\xi(x,t)}=\left(\frac{\partial\xi}{\partial t}+u\cdot\frac{\partial\xi}{\partial x}\right) \tag{3.18}$$

      Since we use the water surface slope is very small as an assumption, linearizing can be applied and gives:

$$\underbrace{\left.\frac{\partial\varphi}{\partial z}\right|_{z=\xi(x,t)}}_{\substack{\text{velocity at}\\ \text{wave surface}}} = \underbrace{\left.\frac{\partial\varphi}{\partial z}\right|_{z=0}}_{\substack{\text{velocity at}\\ \text{still surface}}} = \frac{\partial\xi}{\partial t} \qquad (3.19)$$

Here, the non-linear cross term $u\frac{\partial\xi}{\partial t}$ is disregarded, and the velocity at wave surface is set equal to the velocity at still surface.

B. The dynamic boundary condition

This criterion is corresponding with the forces on the boundary. At the free surface, the boundary condition is simply that the water pressure is equal to the constant atmospheric pressure p_0 on the free surface (**Figure 3.4**).

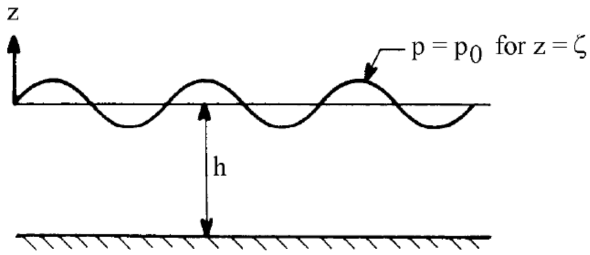


Figure 3. 4. : Atmospheric pressure at the free surface.
Reference: Journée and Massie (2001)

The Bernoulli equation for an unstationary irrotational flow:

$$\frac{P}{\rho} + g \cdot z + \frac{\partial\varphi}{\partial t} + \frac{1}{2}(u^2 + w^2) = Ct \qquad (3.20)$$

At surface $P = P_0$ and $z = \xi(x,t)$:

$$g \cdot \xi + \left.\frac{\partial\varphi}{dt}\right|_{z=\xi} + \frac{1}{2}(u^2 + w^2)\Big|_{z=\xi} = 0 \qquad (3.21)$$

Since we still use the water surface slope is very small as an assumption, linearizing can be applied. Hence the $\frac{1}{2}(u^2 + w^2)\Big|_{z=\xi} = 0$ terms can be neglected.

Also, the boundary $z = \xi \rightarrow z = 0$ can be applied here and we get:

$$\left.\frac{\partial\varphi}{\partial t}\right|_{z=\xi} = \left.\frac{\partial\varphi}{\partial t}\right|_{z=0} \qquad (3.22)$$

Hence, the equation of (3.22) at the surface can be written as follow:

$$g \cdot \xi + \left.\frac{\partial\varphi}{\partial t}\right|_{z=0} = 0 \quad \Rightarrow \quad \xi = -\frac{1}{g} \cdot \left.\frac{\partial\varphi}{\partial t}\right|_{z=0} \qquad (3.23)$$

By combining two boundaries, the kinematical surface condition and dynamic boundary condition:

$$\left.\frac{\partial \varphi}{\partial z}\right|_{z=0} = \frac{\partial \xi}{\partial t} = \frac{\partial}{\partial t}\left(-\frac{1}{g} \cdot \left.\frac{\partial \varphi}{\partial t}\right|_{z=0}\right)$$

$$\Rightarrow \frac{\partial^2 \varphi}{\partial t^2} + g \cdot \frac{\partial \varphi}{\partial z} = 0 \qquad \text{for } z = 0$$

(3.24)

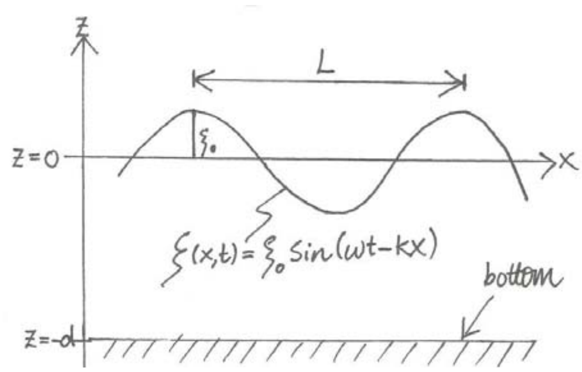


Figure 3. 5. : Sinusoidal wave profile.
Reference: Gudmestad(2010)

Hence, the velocity potential is given as:

$$\varphi(x,z,t) = \frac{\xi_0 \cdot g}{\omega} \cdot \underbrace{\frac{\cosh k(z+d)}{\cosh(kd)}}_{\textit{depth dependent}} \cdot \underbrace{\cos(\omega t - kx)}_{\textit{regular linear wave}}$$

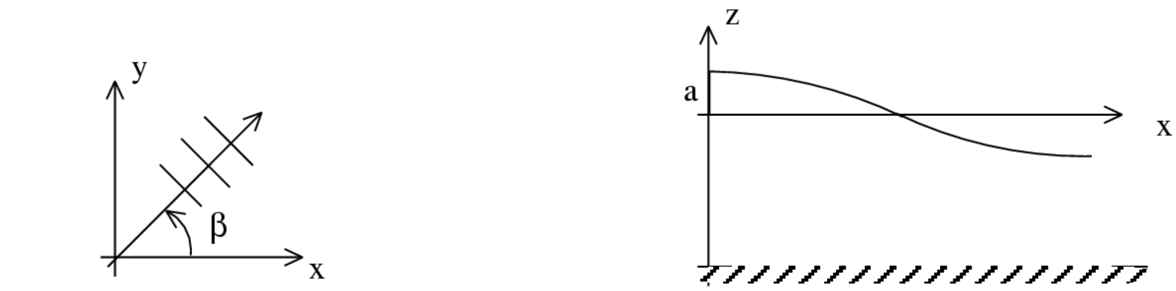
(3.25)

Where (**Figure 3.5)**:

$\xi = \xi(x,t) = \xi_0 \sin(wt - kx)$

Now the *equation (3.25)* satisfies all the requirements. However, the fluid should be follow the assumptions; incompressible and non-rotational.

Further, the theory above is also known as **Airy wave theory (first order potential theory)** and will be adopted in WADAM calculations. *Det Norske Veritas (2008)* in "Sesam User Manual for Wadam-Wave Analysis by Diffraction and Morison Theory" has defined that the incident waves may be specified by either wave lengths, wave angular frequencies or wave periods. The direction of the incident waves are specified by the angle β between the positive x-axis and the propagating direction while the wave profile represents a wave with its crest at the origin for t = 0 as shown in **Figure 3.6**.
The still water level is obtained by constant extrapolation in WADAM.



(a) wave propagation direction (b) wave phase at $t=0$

Figure 3. 6. : Surface wave definitions based on WADAM
Reference: Det Norske Veritas (2008)

The incident wave used in WADAM is defined as:

$\xi = Re\left[Ae^{i(\omega t - k(x\cos\beta + y\sin\beta))}\right]$

or $\xi = A\cos\ \omega t - k(x\cos\beta + y\sin\beta)$ (3.26)

The fluid velocity $v = v_x\boldsymbol{i} + v_y\boldsymbol{j} +\ v_z\boldsymbol{k}$ and acceleration $a = a_x\boldsymbol{i} + a_y\boldsymbol{j} +\ a_z\boldsymbol{k}$ for the incident wave:

$$v_h = v_x\boldsymbol{i} + v_y\boldsymbol{j} = \frac{A\omega}{k}\boldsymbol{k}\frac{\cosh(kz + kd)}{\sinh kd}\cos(\omega t - \boldsymbol{kx})$$

$$v_z = -A\omega\frac{\sinh(kz + kd)}{\sinh kd}\ \sin\,(\omega t - \boldsymbol{kx})$$

$$a_h = -a_x i + a_y j = \frac{A\omega^2}{k}\boldsymbol{k}\frac{\cosh(kz + kd)}{\sinh kd}\sin(\omega t - \boldsymbol{kx})$$

$$a_z = -\frac{A\omega^2}{k}\boldsymbol{k}\frac{\sinh(kz + kd)}{\sinh kd}\ \cos\,(\omega t - \boldsymbol{kx})$$

(3.27)

where:

d	= depth
k	= absolute value of wave number
ω	= wave angular frequency
A	= wave amplitude
$x = x\boldsymbol{i} + y\boldsymbol{j}$	= location in the x-y plane
$\boldsymbol{k} = k(i\cos\beta + j\sin\beta)$	= two dimensional wave number
z	= vertical coordinate with z-axis upward, z=0 at still water level
β	= direction of wave propagation

Further, WADAM will be used to calculate the wave frequency dependent floater motions and mean drift forces by using two kinds of regular waves; ULS regular wave (H_0 = 25 m) and FLS regular wave (H_0 = 6 m) as shown in **Figure 3.7**:

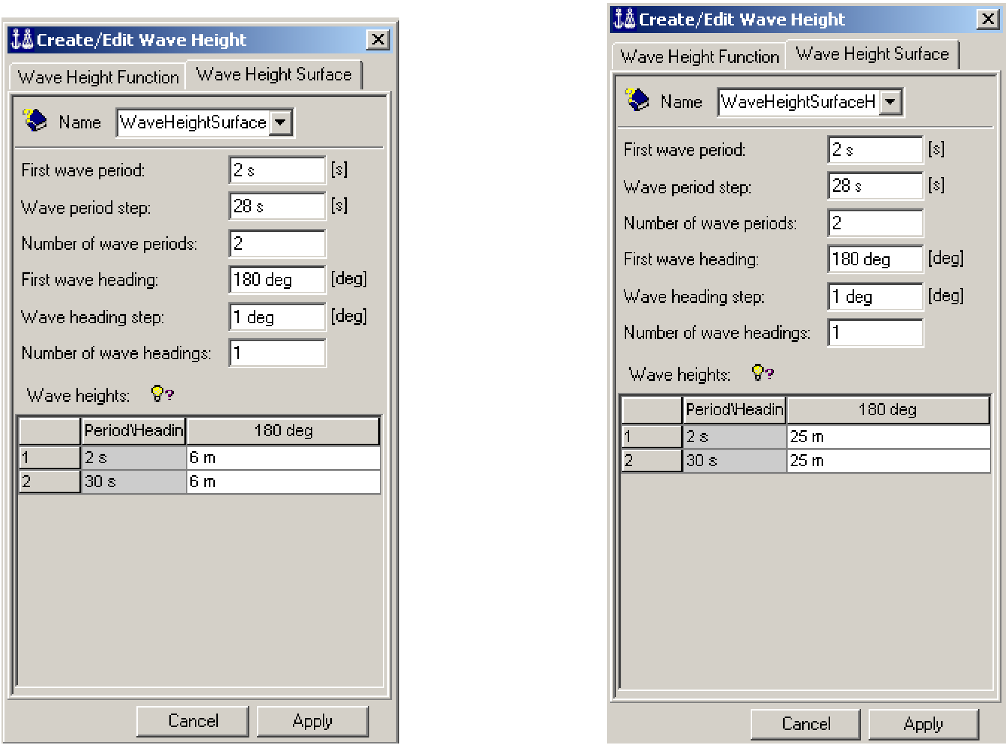


Figure 3. 7. : The data for regular waves calculation in WADAM analysis.

3.3.2 Irregular Waves

The ocean waves are random and not well represented by sinusoidal waves. Moreover, the real sea has a combination of many different waves with different heights and different periods. Hence, irregular waves will be a good representation action in order to describe the real condition.

Chakrabarti, S. (2005) has also mentioned that in a random ocean the waves appear in group and should be described by statistical or spectral form. One method of defining a group is to establish a threshold value and to consider a group to be a sequence of waves given by an envelope that exceeds this value. This threshold level may be the mean wave height, the significant wave height or a similar statistical wave height parameters.

A. Extreme Wave Criteria

In this study, the extreme wave criteria will be based on the return period combinations for 100 year wave criteria. The study from *Physe Ltd (2010)* has mentioned that the estimation for the 100 year significant wave height design value is based on:

- The NNS data set gives a value of 15.56 m
- The HSE report from *"HSE Research Report 392: Wave mapping in UK waters"* from *Physe Ltd (2005)* presents contours of 100 year Hs which give a value of approximately 15.8 m
- Knowledge of other criteria in the region suggest that a value of 15.6 m is very much in line with expectation for the Western Isles location

Hence, a 100 year significant wave height design value of 15.6 m is recommended for the Western Isles location. Furthermore, a 100 year significant wave height design value will be presented for the eight directional sectors. The omni-directional wave condition and the wave spectra will also be given.

The study from from *Physe Ltd (2010)* has presented the directional distributions of extreme significant wave heights as given in **Table 3.6** and Figure **3.8.**

Tabel 3. 6. : Directional hs Relative magnitudes

Directional Relative Magnitudes							
N	**NE**	**E**	**SE**	**S**	**SW**	**W**	**NW**
0.974	0.717	0.505	0.979	1.000	0.920	0.954	0.966

Reference: PhyseE Ltd (2010)

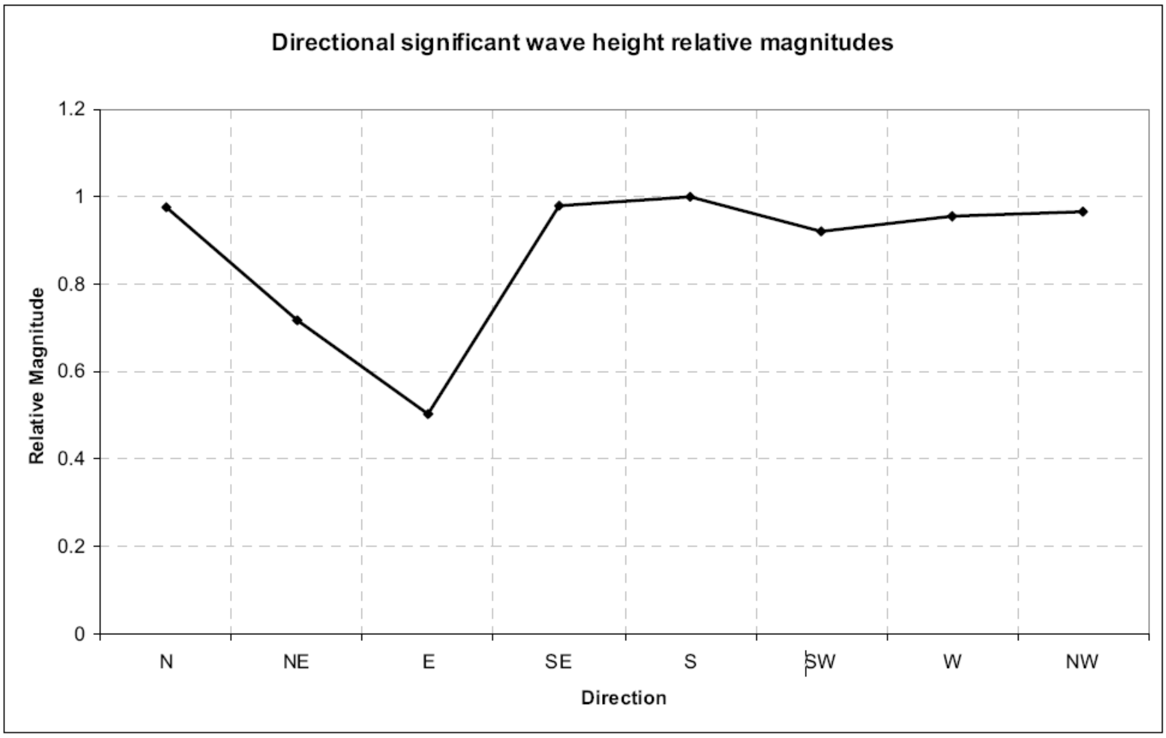


Figure 3. 8. : Directional relative magnitudes of significant wave height.
Reference: PhyseE Ltd (2010)

A 100 years form contour of Hs and Tp can be seen in **Figure 3.9.** The extreme wave criteria for the eight directional sectors and the omni-directional can be seen in **Table 3.7** and **Table 3.8**. Note that in **Table 3.7,** the wave direction is defined as “Coming from”.

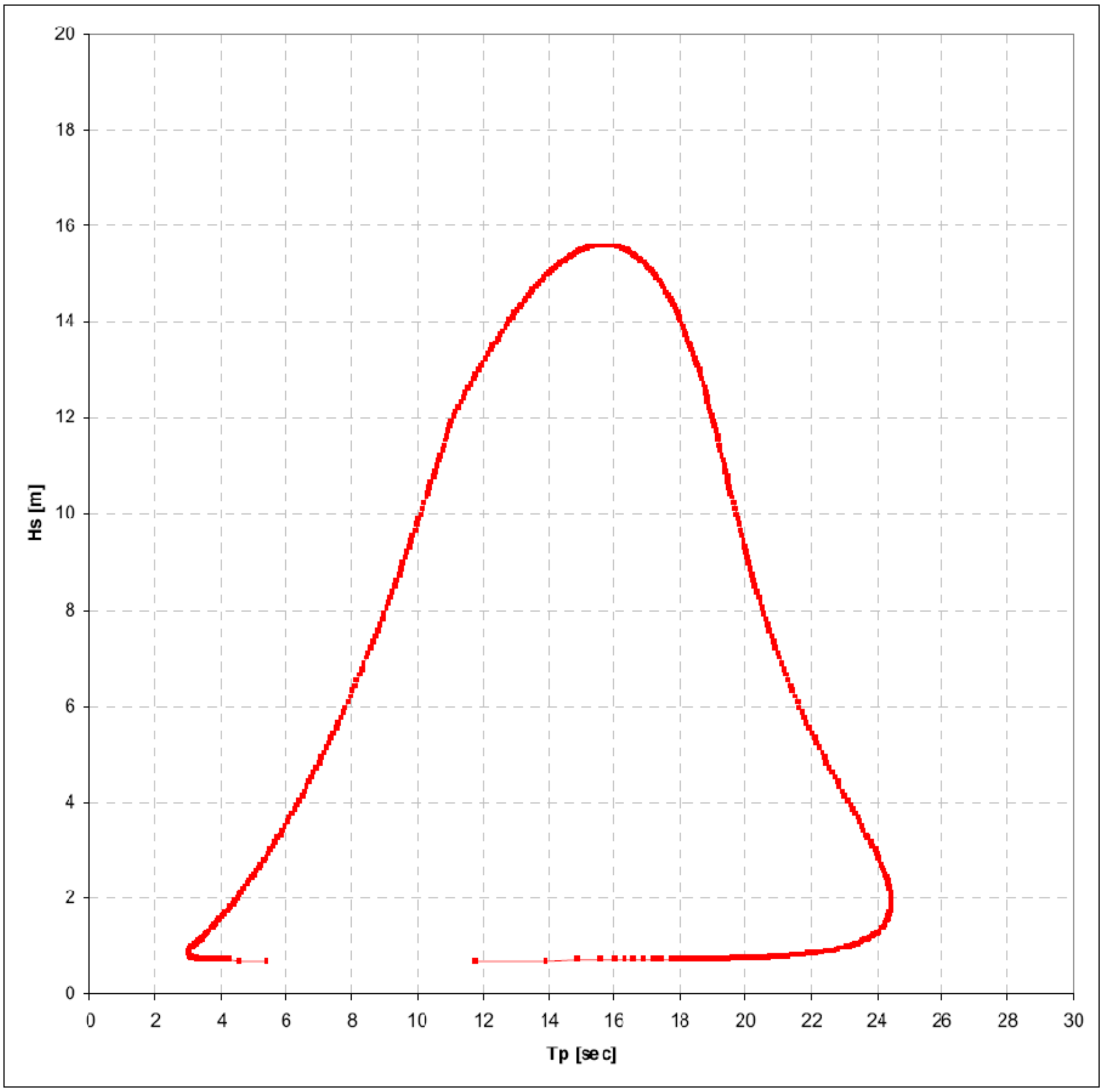


Figure 3. 9. : Hs/Tp Omni directional Hs-Tp contour for the 100-years return period sea state.
Reference: PhyseE Ltd (2010)

Tabel 3. 7. : Extreme Wave Criteria for eight directional

Return Period	Hs (m)	Tz (lower) (s)	Tz (central) (s)	Tz (upper) (s)	Tp, Tass (lower) (s)	Tp, Tass (central) (s)	Tp, Tass (upper) (s)	Hmax (m)	Crest Height (m)
100-years									
N	15.2	11.2	12.5	14.6	15.4	17.4	20.6	27.5	17.0
NE	11.2	9.7	10.7	12.6	13.2	14.9	17.7	20.2	12.5
E	7.9	8.1	9.0	10.6	11.1	12.5	14.9	14.2	8.8
SE	15.3	11.3	12.5	14.7	15.4	17.4	20.6	27.6	17.0
S	15.6	11.4	12.6	14.8	15.5	17.5	20.8	28.2	17.4
SW	14.4	10.9	12.1	14.2	14.9	16.8	20.0	26.0	16.0
W	14.9	11.1	12.4	14.5	15.3	17.2	20.5	26.9	16.6
NW	15.1	11.2	12.4	14.6	15.3	17.2	20.5	27.3	16.8

Reference: PhyseE Ltd (2010)

Tabel 3. 8. : Extreme Wave Height and Associated Periods- Omnidirectional

Return Period	Hs (m)	Tz (lower) (s)	Tz (central) (s)	Tz (upper) (s)	Tp, Tass (lower) (s)	Tp, Tass (central) (s)	Tp, Tass (upper) (s)	Hmax (m)	Crest Height (m)
All-year									
1-year	11.4	9.7	10.8	12.7	13.3	15.0	17.8	19.2	11.7
10-years	13.6	10.6	11.8	13.8	14.5	16.4	19.5	23.9	14.7
50-years	15.0	11.2	12.4	14.5	15.3	17.2	20.5	26.9	16.6
100-years	15.6	11.4	12.6	14.8	15.5	17.5	20.8	28.2	17.4
1,000-years	17.6	12.1	13.4	15.7	16.5	18.6	22.1	32.4	20.0
10,000-years	19.4	12.7	14.1	16.5	17.3	19.6	23.3	36.4	22.6

Reference: PhyseE Ltd (2010)

B. Description of Ocean Waves as Sea Spectrum

It is often useful to describe a sea state in terms of the linear random wave model by specifying a wave spectrum, which determines the energy in different frequency and/or direction bands. The most appropriate spectral form depends on the geographical area and the severity of the sea state to be modeled. The shape of wave spectra varies widely with the wave conditions, wind seas and swells. Wind seas are generated by the local wind while swell are not related to the local wind but originated from a wind-driven sea that travels out of an area.

In order to describe the real surface of the sea, the linear theory can be used to obtain the results in the irregular waves by adding together the results from the regular waves as a practice solution. In other words, the Fourier series analysis will be used to describe the irregular waves by using an assumption that the irregular waves contains a Fourier series of linear waves that do not interact with each other. Hence, the energy transfer from one wave component to another can be discarded.

The basic theory about this will be adopted from *Gudmestad (2010).* A certain limited history of measured waves in time history from 0 to time T will be considered. Further the height of the surface at a selected location in the sea, at x = 0, may be described by the process $\xi\ (t)$ during the time period from –T/2 to T/2. Then, $\xi\ (t)$ can be described by Fourier series:

$$\xi\ (t) = a_0 + \sum_{n=1}^{\infty}\left[a_n \cos\frac{2n\pi}{T}t + b_n\ \sin\frac{2n\pi}{T}t\right] \qquad (3.28)$$

After trigonometric manipulations, this can be written as:

$$\xi\ (t) = \sum_{n=1}^{\infty}\xi_n \cos(\omega_n t - \theta_n) \qquad (3.29)$$

where: $\xi_n = \sqrt{{a_n}^2 + {b_n}^2}$ and $\theta_n = arctg\ \left(\frac{b_n}{a_n}\right)$

Thus, any wave process can be written as a sum of "cosine" or "sinus" waves with given amplitudes ξ_n and phases θ_n.

The energy in a harmonic wave is proportional to the amplitude squared. The wave energy spectrum describes the energy content of an ocean wave and its distribution over a frequency range of the random wave. In order to investigate how the energy in the sea is distributed on the different frequencies, the wave spectrum as a function $S(\omega)$ will be given:

$$S(\omega_n) = \frac{1}{2}\frac{{\xi_n}^2}{\Delta\omega} \qquad (3.30)$$

The moment of the spectrum are defined by:

$$m_j = \int_0^{\infty}\omega^j S(\omega)d\omega \qquad (3.31)$$

where: $\sigma_\Xi^2 = m_0$

Significant wave height:

$$h_{m_0} = 4\sqrt{m_0} = 4\sigma_\Xi \qquad (3.32)$$

Expected period between zero up crossings:

$$t_{m_0{}^2} = 2\pi \sqrt{\frac{m_0}{m_2}} \tag{3.33}$$

and dominating harmonic period:

$$t_p = \frac{2\pi}{\omega_p} \tag{3.34}$$

The two most frequently used standard formulations of the wave frequency spectrum $S(\omega)$ are the Pierson-Moskowitz and the JONSWAP spectrum for developing sea. *PhyseE Ltd (2010)* has recommended the Jonswap spectrum as the formulation of the wave frequency spectrum for Western Isles.

Furthermore in the study, two spectrum formulas will be used; the Jonswap (Join North Sea wave Project) spectrum and Torsethaugen spectrum (the Jonswap double peaked) as a comparison.

1. Jonswap Spectrum (**Figure 3.10**):

$$S(\omega) = \alpha g^2 \omega^{-5} \exp\left(-1.25\left(\frac{\omega}{\omega_p}\right)^{-4}\right) \gamma \exp\left(-\frac{(\omega-\omega_p)^2}{2\sigma^2\omega_p{}^2}\right) \tag{3.35}$$

which has 5 parameters; $H_s, \omega_0, \gamma, \tau_a, \tau_b$

where:

α = Philip constant

γ = peakedness parameter

σ = spectral width parameter

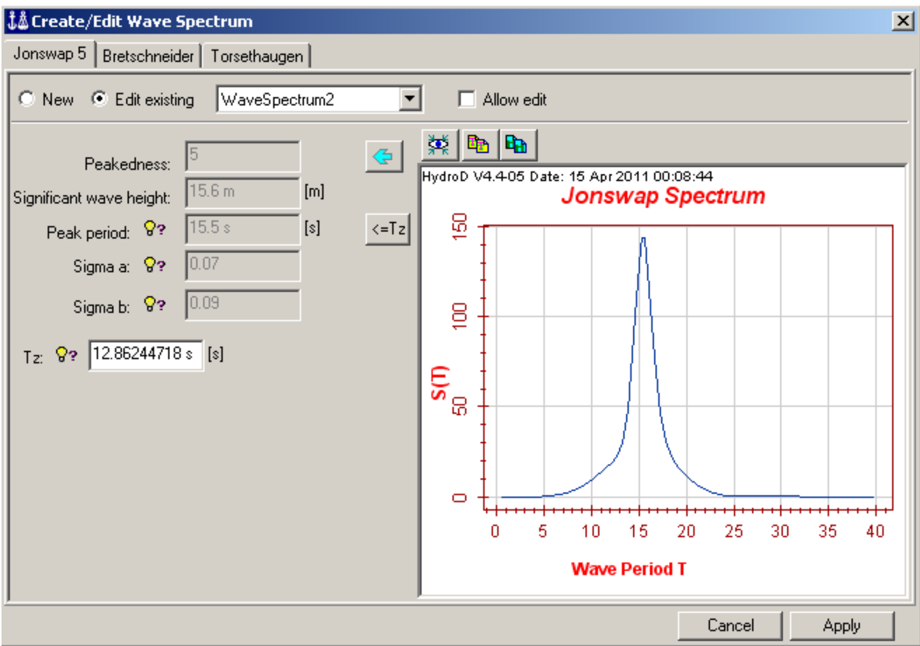


Figure 3. 10. : Jonswap spectrum.

2. Torsethaugen Spectrum based on *Torsethaugen, K. (2004),* (**Figure 3.11**):
   A double peak spectral for wind dominated sea $T_p < T_{pf}$, where T_p is the spectral period and T_{pf} = the spectral period for fully developed sea at the actual location. This means, the sea states have a significant wave height that is higher than value corresponding to locally fully developed sea with the given spectral period.
   Spectral parameter for wind dominated sea $T_p < T_{pf}$:
   - Primary Peak
     - Significant wave height:
       $H_{w1} = R_w H_s \qquad R_w = (1 - a_{10})e^{-\left(\frac{\varepsilon_l}{a_1}\right)^2} + a_{10}$
     - Spectral peak period:
       $T_{pw1} = T_p$
     - Peak enhancement factor:
       $\gamma = k_g s_p^{6/7} \quad s_p = \left(\frac{2\pi}{g}\right) H_{w1}/T_{pw1}^2$
   - Secondary Peak
     - Significant wave height:
       $H_{w2} = \left(1 - {R_w}^2\right)^{1/2} H_s$
     - Spectral peak period:
       $T_{pw2} = T_{pf} + b_1$
     - Peak enhancement factor:
       $\gamma = 1$

Where:

Parameter	Value	Used in formulae
a_f	6.6 $sm^{-1/3}$	13,41
a_e	2.0 $sm^{-1/2}$	26
a_u	25 s	27
a_{10}	0.7	31
a_1	0.5	31
k_g	35.0	33,39
b_1	2.0 s	35
a_{20}	0.6	37
a_2	0.3	37
a_3	6	39

Resulting spectral formula

$$S(f_n) = \sum_{j=1}^{2} E_j S_{jn}(f_n)$$

j = 1 primary sea system and j = 2 secondary sea system

$E_1 = \left(1/_{16}\right) H_1^2 T_{p1}$ *and* $E_2 = \left(1/_{16}\right) H_2^2 T_{p2}$

$S_{1n}(f_{1n}) = G_0 A_\gamma f_{1n}^{-4} e^{-f_{1n}^{-4}} \gamma^{\left(exp-\left(1/_{2\sigma^2}\right)(f_{1n})^2\right)} \sigma$

$S_{2n}(f_{2n}) = G_0 A_\gamma f_{2n}^{-4} e^{-f_{2n}^{-4}}$

$f_{1n} = f * T_{p1}$ *and* $f_{2n} = f * T_{p2}$

$G_0 = 3.26$ *and* $A_\gamma = (1 + 1.1[\ln\gamma]^{1.19})/\gamma$

And $\sigma = 0.07\ for\ f_n < 1\ and\ \sigma = 0.09\ for\ f_n > 1$
$H_1 = H_{w1}$ and $H_2 = H_{w2}$
$T_{p1} = T_{pw1}$ and $T_{p2} = T_{pw2}$

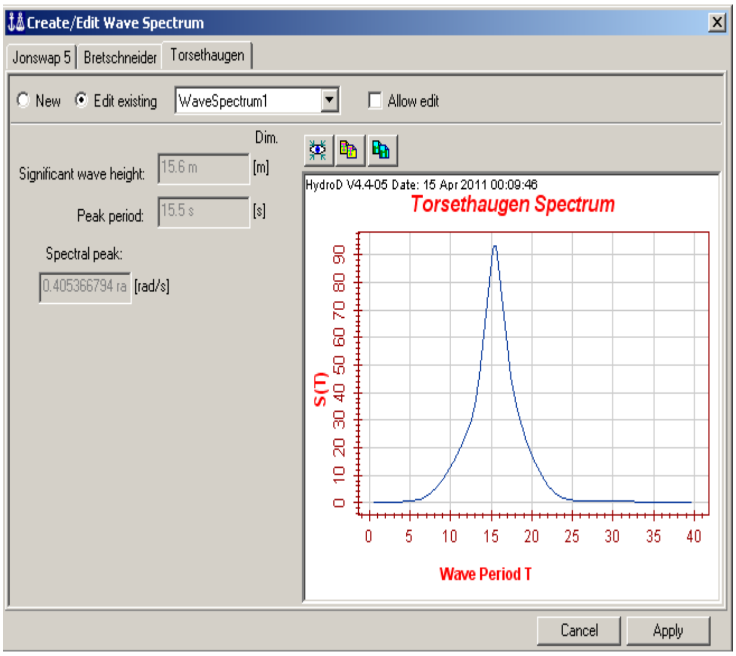


Figure 3. 11. : Torsethaugen spectrum.

3.4 Currents

Based on the study from *Physe Ltd (2010)*, the current data for the Western Isles location consist as: tide (M_2+S_2) (cm/s), surge current (cm/s) and total current (cm/s). The study will be based on the return period combinations for 10 years current criteria.

The current criteria will be presented for the eight directional sectors and the vertical current profile will be given. The vertical current profile for the Western Isles will be calculated from Guidance Notes; *Department of Energy (1990)* for *"Offshore Installations: Guidance on Design, Construction and Certification"*:

$$U_{t(z)} = \left(\frac{z}{0.32h}\right)^{1/7} \cdot U_t' \quad for\ 0 \le z \le 0.5h$$

$$U_{t(z)} = 1.07 \cdot U_t' \quad for\ 0.5 \le z \le h \tag{3.36}$$

where:

$U_{t(z)}$ = the speed of tidal current at height z above bed

U_t' = the depth mean speed of the tidal current

z = height above sea bed

h = total water depth

the speed of current is also considered to induce a current at the surface of 3% of the wind speed.

The 10 years current criteria for eight directional sectors can be seen in **Table 3.9** and **Table 3.10**. Note that in this table current direction is defined as "Towards" which the current is flowing. The graph of vertical current profile can be seen in **Figure 3.12**.

Tabel 3. 9. : Tide, Surge and Total Directional Depth Averaged Currents (cm/s) at Western Isles Location

All currents in cm/s	Tide (M_2+S_2)	Surge current (cm/s)				Total current (cm/s)			
Sector (° towards)	**cm/s**	**1yr**	**10yr**	**50yr**	**100yr**	**1yr**	**10yr**	**50yr**	**100yr**
N	19	11	13	15	16	32	34	35	35
NE	12	11	14	16	17	25	27	29	29
E	11	13	16	18	19	26	29	30	31
SE	17	13	17	19	20	34	37	39	39
S	19	23	29	33	35	42	47	50	52
SW	12	38	48	54	57	54	63	69	71
W	11	27	33	38	40	41	46	50	52
NW	17	11	13	15	16	30	31	32	33

Reference: PhyseE Ltd (2010)

Tabel 3. 10. : Extreme Total Current Profile (m/s) - by direction (direction are towards)

Height (asb)/Depth Ratio]	North	Northeast	East	Southeast	South	Southwest	West	Northwest	Omni
10 Years									
Surface	0.36	0.29	0.31	0.40	0.50	0.67	0.49	0.33	0.67
75% of Water Depth	0.36	0.29	0.31	0.40	0.50	0.67	0.49	0.33	0.67
50% of Water Depth	0.36	0.29	0.31	0.40	0.50	0.67	0.49	0.33	0.67
40% of Water Depth	0.35	0.28	0.30	0.38	0.49	0.65	0.47	0.32	0.65
30% of Water Depth	0.34	0.27	0.29	0.37	0.47	0.63	0.46	0.31	0.63
20% of Water Depth	0.32	0.25	0.27	0.35	0.44	0.59	0.43	0.29	0.59
10% of Water Depth	0.29	0.23	0.25	0.31	0.40	0.54	0.39	0.26	0.54
5% of Water Depth	0.26	0.21	0.22	0.29	0.36	0.49	0.35	0.24	0.49
Near Bed	0.21	0.17	0.18	0.23	0.30	0.40	0.29	0.20	0.40

Reference: PhyseE Ltd (2010)

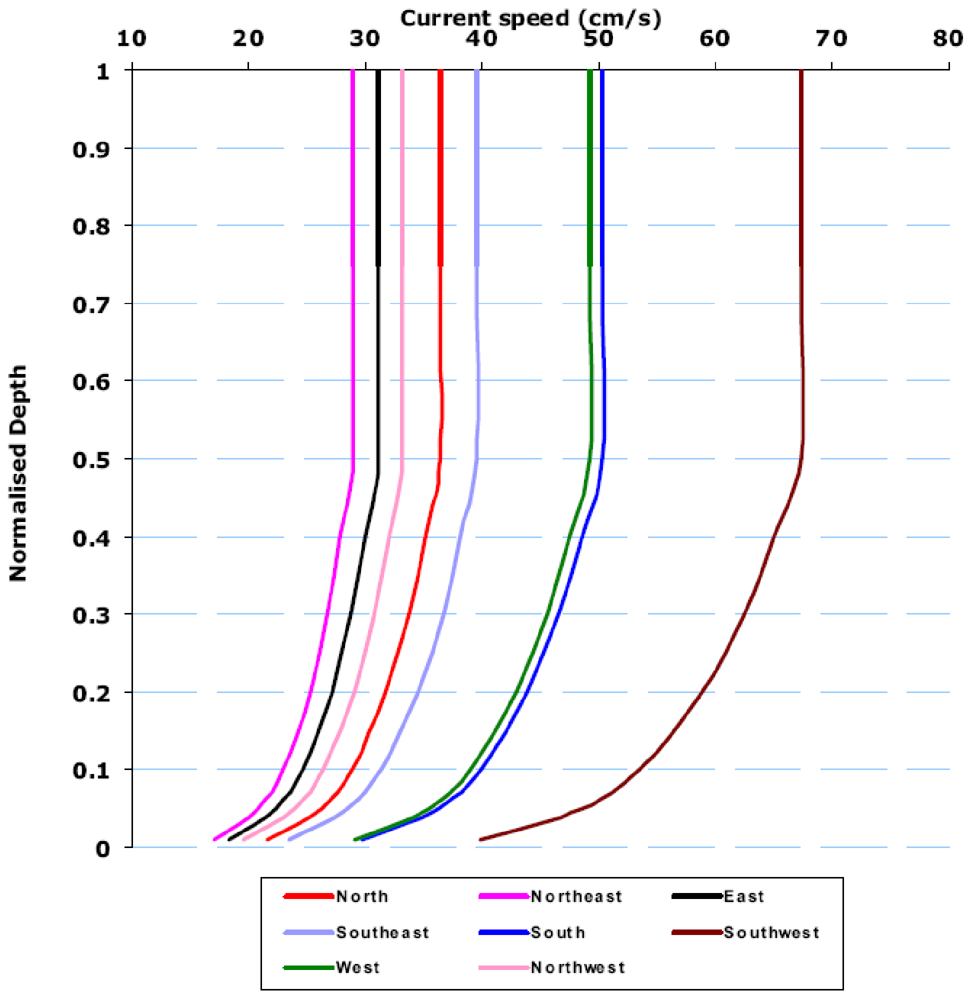


Figure 3. 12. : Ten years directional current profile. Directions are towards which current is flowing.
Reference: PhyseE Ltd (2010)

3.4.1 The Current Force Simulated In Time Domain

Current is a common occurrence in the open ocean. *Chakrabarti, S. (2005)* mentions that the current at the sea surface is mainly introduced by the wind effect on the water, variation of atmospheric pressure and tidal effects and that current is also presented in the subsurface and the seafloor regions. Furthermore, the total current is the vector sum of the current from local wind, tidal component, Strokes drift, ocean circulation, local density-driven current and set-up phenomena. The speed and direction of the current at specified water depths are represented by a current profile. The surface current may affect the drift of the floating structure.

Current loads on the ship can be representing by drag force in longitudinal direction due to the frictional force. Traditionally, the viscous hull surge and the sway forces and the yaw moment have been calculated based on the current coefficients and the instantaneous magnitude of the translational relative velocity between the vessel and the fluid. The basic theory about this can be found in *Faltinsen (1990)* and *Marintek (2008)* in "*SIMO - Theory Manual Version 3.6, rev: 1*".

The calculation procedure for surge follows the ship resistance estimation. The following approximate formula as follows:

$$F_1^c = \frac{0.075}{(\log_{10} Rn - 2)^2} \frac{1}{2} \rho S U_c^2 \cos\beta \, |\cos\beta| \tag{3.37}$$

where: β is the angle between the current velocity and the longitudinal x-axis. S is the wetted surface of the ship and Rn can be calculated from:

$$Rn = \frac{U_c L |\cos\beta|}{v} \tag{3.38}$$

where: U_c is current velocity, L is the length of ship, v is kinematic viscosity of the sea water

While the transverse viscous current forces and yaw moment follow the cross flow principle as long as the current direction is not close to the longitudinal axis of the ship, The transverse current force F_2^c for sway will be:

$$F_2^c = \frac{1}{2} \rho \left[\int_L dx C_D(x) D(x) U_c^2 \sin\beta \, |\sin\beta| \right] \tag{3.39}$$

Due to the quadratic nature of the viscous hull forces, the forces obtained from the vessel translation and the current, the forces obtained from a yaw induced cross flow cannot be separated and then added. Hence, the distributions of the cross flow along the hull for yaw moment F_6^c will be the sum of the Munk moment and the viscous yaw moment:

$$F_6^c = \frac{1}{2} \rho \left[\int_L dx C_D(x) D(x) U_c^2 \sin\beta \, |\sin\beta| \right] + \frac{1}{2} U_c^2 (A_{22} - A_{11}) \sin\beta \, |\sin\beta| \tag{3.40}$$

where: A_{22}, A_{11} are the added mass in surge and sway , respectively.

3.5 Heading Dependency of Environmental Conditions

The heading position of the floater will influence the environmental criteria in the design. The distribution of heading probability of the environmental parameters in for all year data will be found in **Figure 3.13**. The environmental parameters contain waves, wind and current speed.

Moreover, the design significant wave height, H_s and wind speed, U_w, as function of heading are shown **in Figure 3.14**. The criteria will be based on the return period combinations for 100 year waves and wind. Note that the heading dependency of current speeds is not included. The data is presented as design H_s and U_w values for heading divided by design omni-directinal H_s and U_w value.

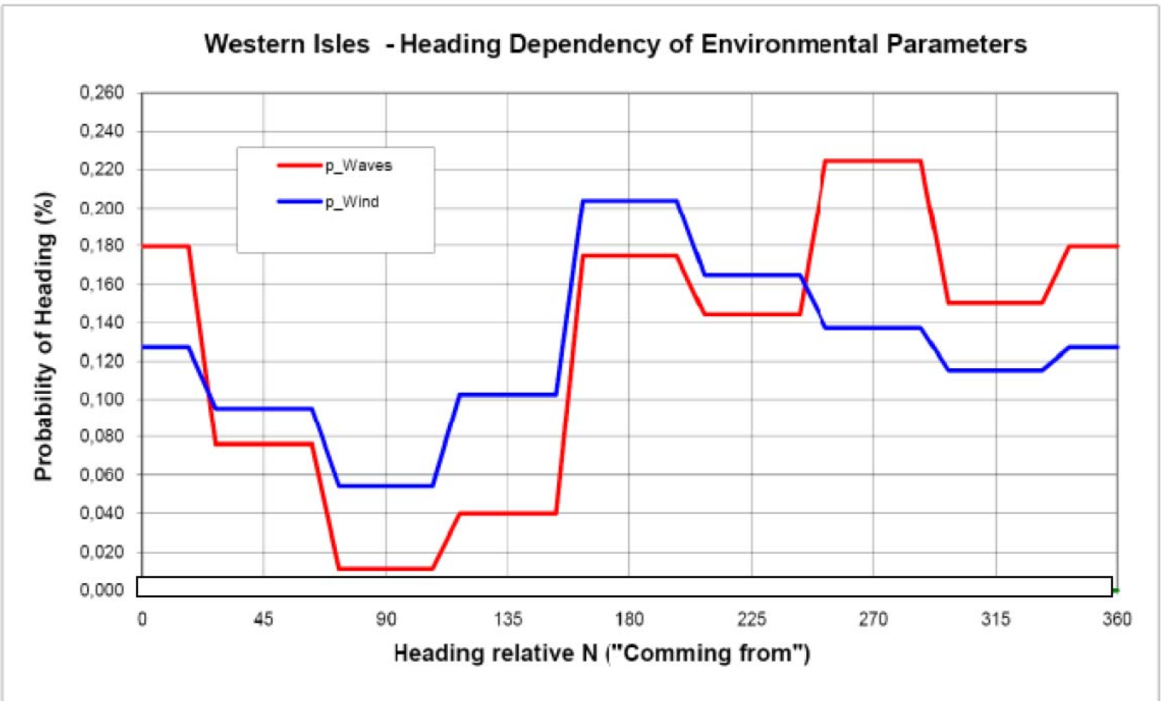


Figure 3. 13. : The distribution of heading probability of the environmental parameters for all year data.
Reference: Sevan Marine (2011)

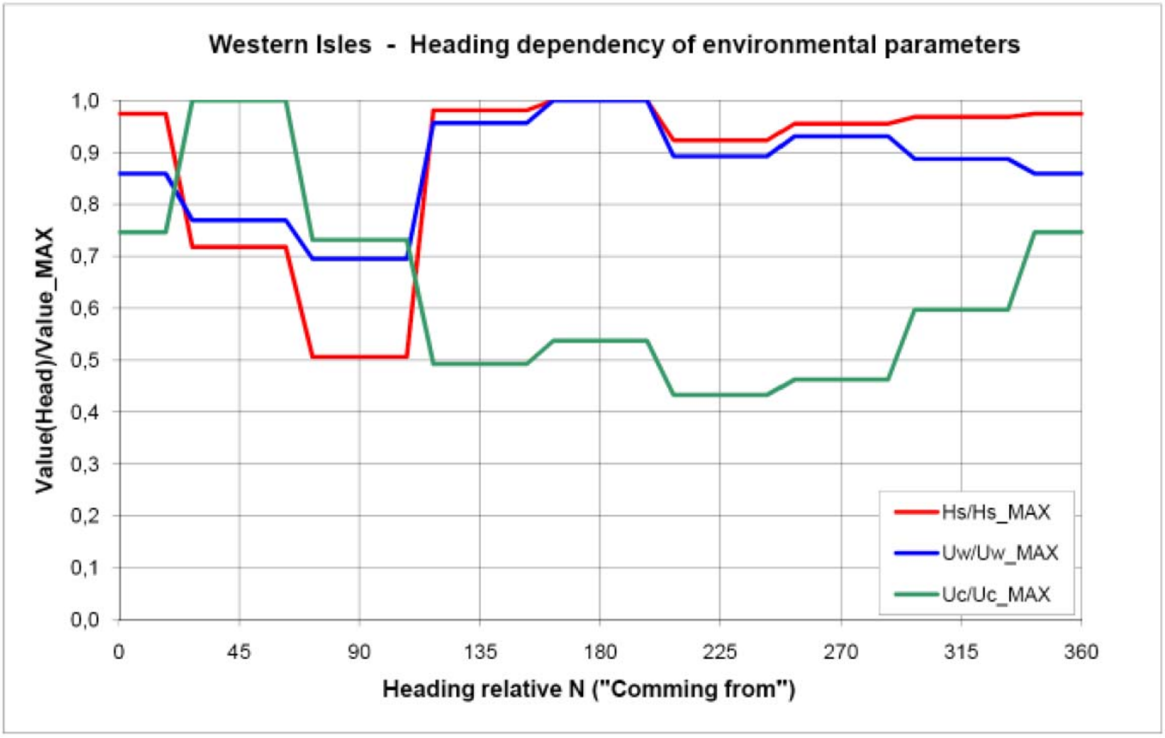


Figure 3. 14. : 100-years return period design significant wave height and wind speed as function of heading for all year data.
Reference: Sevan Marine (2011)

The study will be based on the return period combinations for 100 year waves and wind criteria and 10 years current criteria as basis design. The used design environmental conditions for return period condition wind and wave as function of heading are listed in **Table 3.11** respectively. Note that all environmental data in tables, concerning directions, are based on the definition "Coming From".

Tabel 3. 11. : The used design environmental conditions for return period condition wind and wave as function of heading

Heading	*Hs*	*Tp*	*Uw*	*Uc*
0 deg	15.2 m	15.4 s	33.5 m/s	0.50 m/s
45 deg	11.2 m	14.9 s	30.0 m/s	0.67 m/s
90 deg	7.9 m	11.1 s	27.1 m/s	0.49 m/s
135 deg	15.3 m	15.4 s	27.3 m/s	0.33 m/s
180 deg	15.6 m	15.5 s	39.0 m/s	0.36 m/s
225 deg	14.4 m	14.9 s	24.8 m/s	0.29 m/s
270 deg	14.9 m	15.3 s	36.3 m/s	0.31 m/s
315 deg	15.1 m	15.3 s	34.6 m/s	0.40 m/s

Reference: Sevan Marine (2011)

CHAPTER

4

Methodology of the Analysis

Two kind of analyses, the decoupled analysis and the coupled analysis, have been elaborated to quantify the coupling effects between a floating offshore system (a floater and the moorings and riser) and the associated structural response (e.g. motion responses) in offshore structure designs.

According to *Omberg, H. et al. (1997)*; traditionally way, the motions of a floating vessel and the load effects in moorings and risers have been analyzed by a separated two-step procedure (**Figure 4.1**):

1. Simulate motions of the floater based on "large body theory" in which load effects from moorings and risers are modeled as non linear position dependent forces only.
   Two simplifications are usually made in the vessel motion analysis. First, the velocity-dependent forces (damping) are neglected or implemented in a rough manner by linear damping forces acting on the floater itself. Second, the influence of current forces on the moorings and risers on the position-dependent vessel forces (stiffness) is incorporated as an additional current force on the vessel. Hence, the result for the horizontal forces and the line tension may be inaccurate.
2. Apply the vessel motions from the first step as top end excitation of the moorings and risers in order to calculate dynamic loads in these elements.

Furthermore, *Omberg and Larsen (1998)* also have mentioned the main shortcoming of this method such as:

1. The mean loads on moorings and risers are normally not accounted for. Hence, the interaction between current forces on the underwater elements and the mean offset and LF motions of the floater are neglected.
2. The important damping effect from moorings and risers on LF motions has to be included in a simple way, usually as linear damping forces acting on the floater.

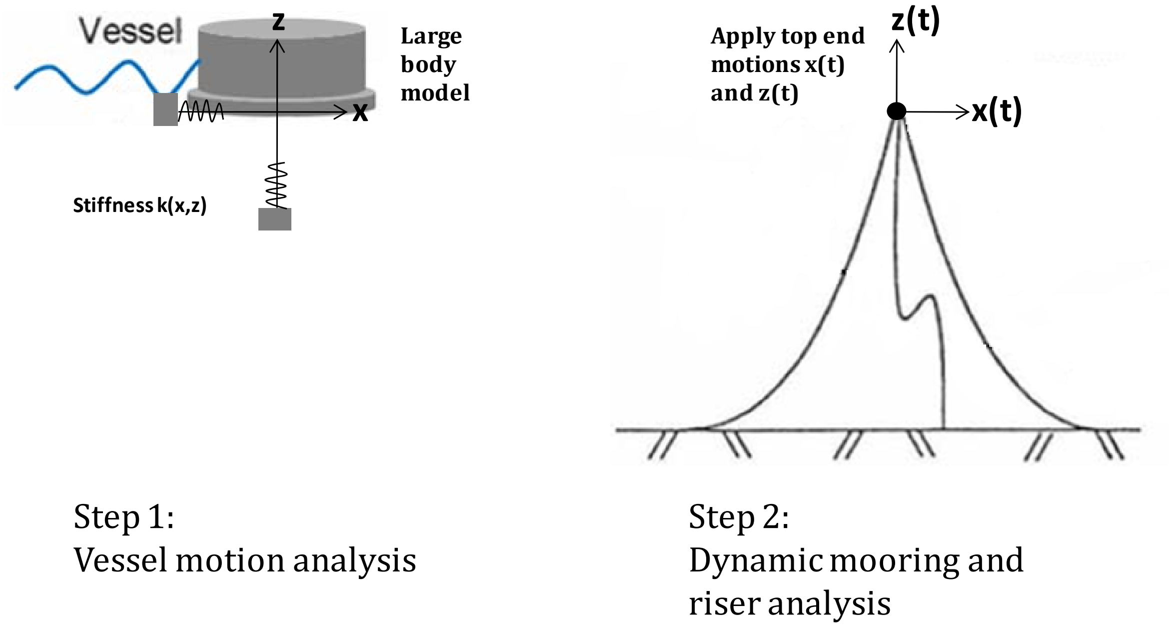


Figure 4. 1 : Illustration of traditional separated analysis; de-coupled analysis.

Reference: adapted from *Omberg and Larsen (1998)*

Hence, it's very clear that the de-coupled analysis is based on the hydrodynamic behavior of the floater only and uninfluenced by the nonlinear dynamic behavior of moorings or riser. As a consequence, the precision of the floater motions and the detailed slender structure response are difficult to obtain since the interaction between the components cannot be captured.

This method is sufficiently accurate to obtain good prediction of motion for mooring lines and riser dynamics but it may be severely inaccurate for a system that is sensitive to low frequency (LF) response, such as a moored ship.

Further, a new (coupled) method that ensures truly integrated dynamic system is required to minimize the effect of the main shortcomings. This method also known as the nonlinear-coupled dynamic analysis ensures evaluation of the dynamic interaction among them (a floater, moorings and risers) when responding to environmental loading due to wind, waves and currents since the main coupling effects will be included automatically in the analysis. This method presents a single complete model that includes the cylindrical floater, moorings and risers (**Figure 4.2**).

All relevant coupling effects can be adequately accounted for using a fully coupled analysis where the vessel force model is introduced in a detailed FE model of the complete slender structure system including moorings and risers.

Non linear time domain analysis, irregular wave frequency (WF) and low frequency (LF) environmental loading are required to give an adequate representation of the dynamic behavior of the coupled vessel and slender system (moorings and risers).

The total load (from environmental loading, dynamic included) from the "slender body models" of moorings and risers are transferred as a force into the "large body model" of the floater. The forces on of the floater are implemented as nodal force at the top end of finite element models of the moorings and risers.

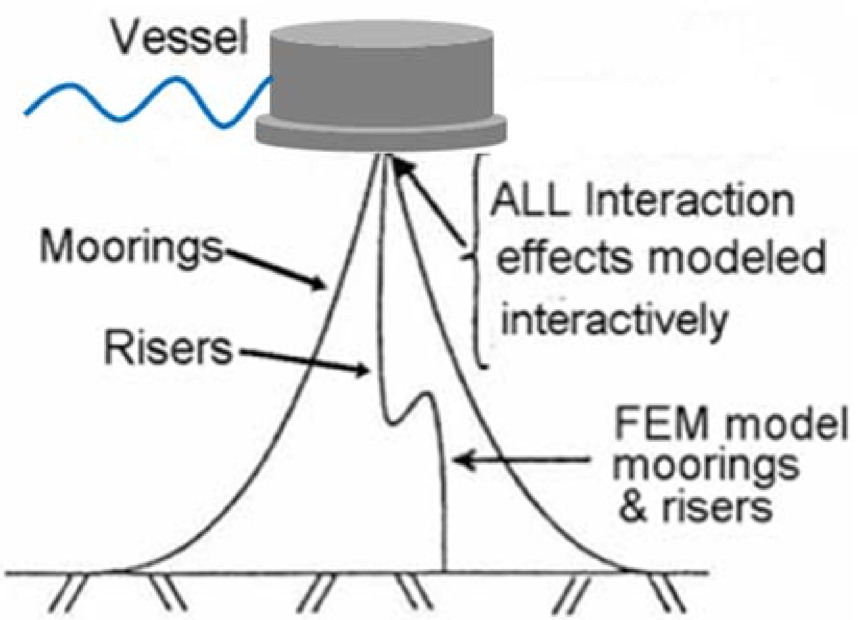


Figure 4. 2 : Schematic for nonlinear-coupled dynamic analysis.

Reference: adapted from *Omberg and Larsen (1998)*

The nonlinear-coupled dynamic analysis ensures higher dynamic interaction between the vessel and the slender systems because of the reasons below:

- The overall behavior of the floater will be influenced not only from the hydrodynamic behavior of the hull but also from the dynamic behavior of the slender members (moorings and risers). As an example, the mean current forces on moorings and risers will change the horizontal restoring force and mooring line tension for a given vessel offset.
- The coupling effects such as the restoring effect, damping and added mass will be taken into account automatically in the process of analysis. As an example, velocity dependent forces (damping) from moorings and risers are automatically included.

Hence, the nonlinear-coupled dynamic analysis represents a truly integrated system which ensures the accurate prediction of response simultaneously for the overall system as well as the individual response of floater, moorings and risers.

Since the accurate prediction of the response for the overall system can be generated, more accurate estimate of the mean offset and LF motion can be gained. As a consequence, this will also improve the estimates of the dynamic loads in moorings and risers. This is the main advantage for performing coupled analysis rather than decoupled analysis. Because in the de-coupled analysis, the offset value is not applied based on the equilibrium of the static result each time step but it is applied based on a single representative offset value only. Hence, too conservative results of a single representative offset value for dynamic loads in mooring and risers may be generated in the de-coupled analysis.

The approach to perform the nonlinear-coupled dynamic analysis can be adopted from *DNV-RP-F205* (2010) in **Figure 4.3**:

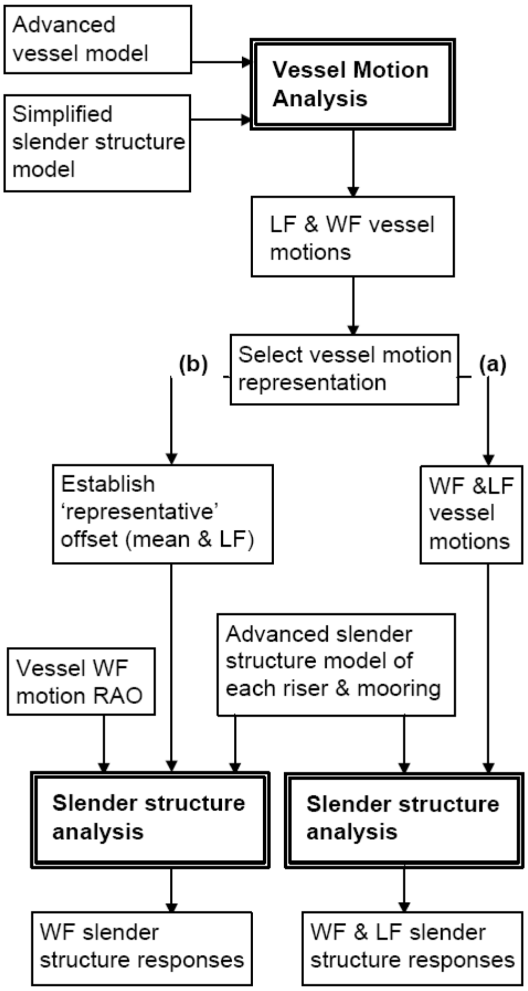


Figure 4. 3 : Coupled floater motion and slender structure analysis.

Reference: adapted from *DNV-RP-F205 (2010)*

Two branches of different alternatives for interfacing coupled motion analysis with subsequent slender structure analysis can be seen from **Figure 4.3**. The time series of floater motions (WF and LF motions) are computed by the coupled floater motion analysis as boundary conditions in the slender structure analysis (*branch a*). It will also capture possible LF slender structure dynamics as well as the influence from the LF response (possibly quasi-static) on the WF response. This effect will be important for moorings and risers designs.

The traditional assumptions which consider WF floater motion as dynamic excitation while LF floater motions are accounted by an additional offset (*branch b*). Then, the slender structure is consequently assumed to respond quasi-static to LF floater motions.

4.1 System Components

In this subchapter, system components; contains a brief explanation of a single complete model that includes cylindrical floater, moorings and riser exposed to environmental loading due to wind, waves and currents. All the system components are described in a Finite Element Model. As a single complete model that includes cylindrical floater, moorings and riser, the model will be quite complex and use a “master-slave” approach for connecting the riser and the frequency-dependent floater and moorings.

A. Hydrodynamic model of the floater

   The cylindrical FPSO will be modeled as a large volume body. This model is represented by a 6 DOF rigid body motion model. The wave forces acting on the vessel are calculated from a hydrodynamic analysis program which is based on diffraction theory (WADAM) obtaining a set of frequency dependent coefficient for inertia, damping and exciting forces. Linear and quadratic forces are included.

   Further the frequency dependent added mass and damping coefficients will be converted to a retardation function. The frequency dependent forces are included as a convolution integral, introducing a memory-effect in the time domain analysis.

   In vessel motion analysis, the floater motions may contain the following components:

   - Mean response due to steady currents, mean wave drift and mean wind load
   - WF response due to 1st order wave excitation
   - LF response due wave drift, wind gust and viscous drift

   These response components will consequently also be present in the slender structure response. Furthermore, the WF and LF are generally described as stochastic processes. The HF responses are not included in the analysis since the cylindrical FPSO are not sensitive to the HF response.

   Global position of the cylindrical FPSO will be calculated based on WF motion, LF motion and Total motion (WF+LF).

B. Slender Structures

   Slender structures are modeled by means of finite element line systems. Two different types of elements are introduced in the model, a 3D bar/cable element where the bending stiffness is negligible and a 3D beam element to include the bending stiffness.

   The bar element presents only 3 translational DOF per node and do not provide the rotational stiffness. Therefore, it will a suitable model to represent moorings.

   On the other hand, the beam element will incorporate rotational stiffness and it will be a suitable model to represent the flexible riser.

   Moreover, the bar element is formulated using a “total Lagrangian description”, while the beam element formulation uses a “co-rotated ghost reference description”.

   The basic theory about this can be found in **Chapter 2** based on Marintek (2010) for “RIFLEX Theory Manual Finite Element Formulation”. The procedure for a riser sytem model can be found in details in Marintek (2010) for “RIFLEX User Manual Finite Element Formulation”.

C. Environmental modeling

The external forces are mainly due to environmental loadings from wave and current that are acting on the submerged portion of the cylindrical FPSO and wind that is acting on the exposed portion of the topside.

The wave description may be defined as single regular wave which has a specified height, period, direction and phase characteristics. Irregular waves are also considered in the analysis based on Torsethaugen (double peak) spectra. In the irregular wave analysis, the seastate is represented in the time domain by an ensemble of regular wave components that are generated from the wave spectrum. Airy linear wave theory will be used as the basis for practical application in the analysis.

The wind is assumed to be 2D i.e. propagating parallel to the horizontal plane. The model includes gust spectra both in the mean direction and normal to the mean wind direction. The wind gust (the varying part of the wind velocity) is assumed to be a Gausian stochastic process. The varying part of the wind velocity in the mean direction is described by the NPD wind gust spectrum (Marintek (2008) for "SIMO - Theory Manual Version 3.6, rev: 1).

The wind forces will be calculated by the direction-dependent coefficient specifying linear and quadratic forces as functions of wind directions relative to the vessel.

The dynamic loading from wind and waves is modeled as a stationary stochastic process in a coupled analysis. Simulation of 3 hours will be performed to obtain extreme response estimates with sufficient statistical confidence.

The current velocity is normally assumed to be constant with time at a given position. It is described by the speed and direction. This can be done by input of discrete values and it will be interpolated to actual node position by definition of standard profiles. This current profile is assumed to move with surface i.e. during computation, the depth for interpolation within the current table is measured below the instantaneous wave surface. The interpolated value of the current velocity is added vectorially to the wave velocity. The current forces will be calculated by using the direction-dependent coefficients specifying linear and quadratic forces as functions of current directions relative to the vessel.

4.2 Method Analysis of Nonlinear-coupled dynamic

The method of analysis will be adopted from *Omberg, H. et al. (1997).* This method will generate the solution of the nonlinear-coupled dynamic analysis in time domain using a non-linear integration scheme that ensures consistent treatment of the coupling effect between the cylindrical FPSO and the slender members.

The governing dynamic equilibrium equation of the spatially discredited system is expressed by:

$$R^I(r,\ddot{r},t) + R^D(r,\dot{r},t) + R^S(r,t) = R^E(r,\dot{r},t) \qquad (4.1)$$

where: R^I, R^D, R^S represent inertia, damping and internal reaction force vectors respectively. R^E is the external load vectors. $r, \dot{r}, \ddot{r}$ are the structural displacement, velocity and acceleration vectors respectively.

The inertia force vectors $R^I(r, \ddot{r}, t)$ can be expressed as:

$$R^I(r, \ddot{r}, t) = M(r)\ddot{r} \tag{4.2}$$

where: M is the system mass matrix that includes structural mass, mass accounting for internal fluid flow and hydrodynamic mass.

while the damping force vectors $R^D(r, \dot{r}, t)$ can be expressed as:

$$R^D(r, \dot{r}, t) = C(r)\dot{r} \tag{4.3}$$

where: C is the system damping matrix that includes contributions from internal structural damping and discrete dashpot dampers.

The internal reaction force vector $R^S(r, t)$ is calculated based on instantaneous state of the stress in elements. The applied FEM procedure is a displacement formulation that allows for unlimited displacements and rotations in the 3-dimensional space while the strains are assumed to be moderate. The external load vector accounts for weight and buoyancy, forced displacement, environmental forces and specified forces.

Nonlinearities in *equation (4.1)* may be due to the displacement dependencies in the inertia and damping forces and also because of the coupling effect between the external load vector and structural displacement and velocity. The relationship between inertial reaction forces and deformations also may give nonlinearities in *equation (4.1)*.

Further, the numerical solution for *equation (4.1)* can be found from an incremental solution procedure using a dynamic time integration scheme according to the Newmark β family method. Newton–Raphson iteration is used for equilibrium iteration.

Introducing the tangential mass, damping and stiffness matrices at the start of the time increment and implementation of the residual force vector from the previous time step, the linearized incremental equation of motion is given by:

$$M\Delta\ddot{r} + C_t\Delta\dot{r} + K_t\Delta r = R^E_{t+\Delta t} - \left({R_t}^I + {R_t}^D + {R_t}^S\right) \tag{4.4}$$

where: Δr, $\Delta\dot{r}$, and $\Delta\ddot{r}$ are the incremental nodal displacements, velocities and accelerations respectively.

All force vectors and system matrices are established by assembly of element contributions and nodal component contributions.

In the coupled dynamic analysis, the cylindrical FPSO is regarded as a nodal component in the FEM model. The forces on the vessel are represented by a large volume body and computed separately for each time step and included in the external load vector R^E. Besides, the vessel inertia forces represent the vessel mass and the frequency-independent part of added mass that are included in the mass matrix of the system.

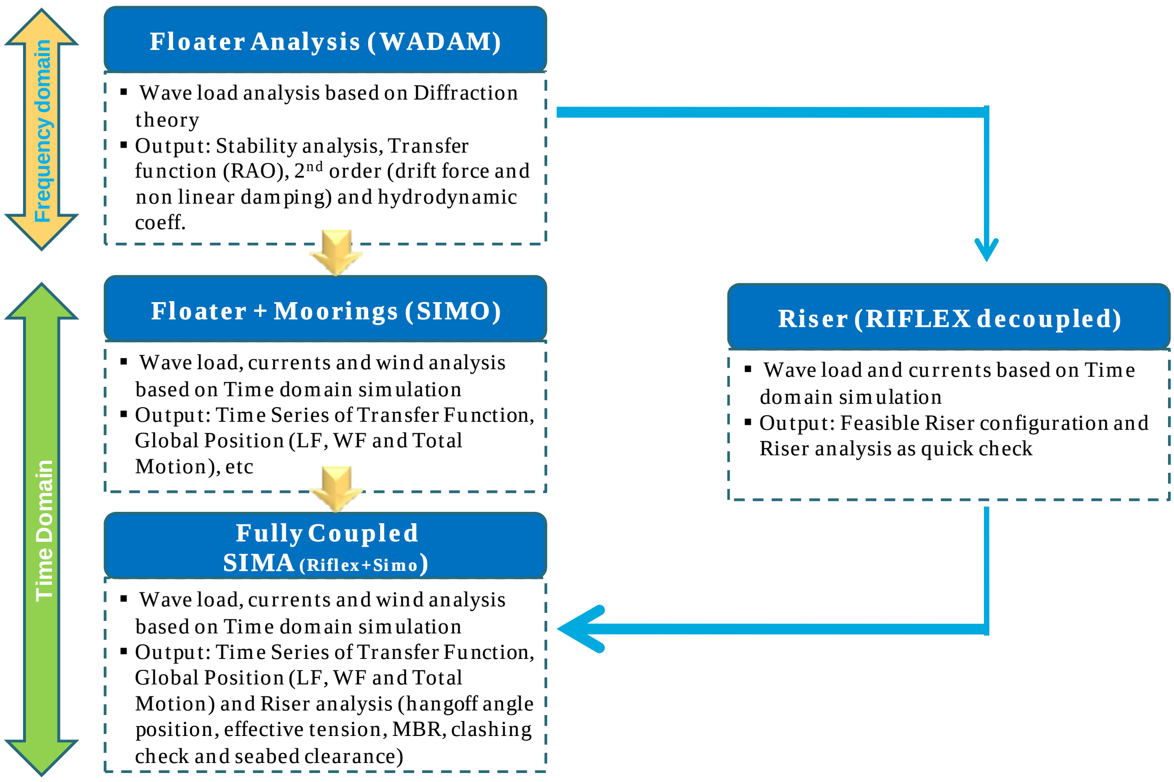
Omberg, H. et al. (1997) have also mentioned about the practical implementations for time domain analysis with irregular wind and wave excitation, the excitation time series should be generated by the FFT technique before the dynamic analysis. Time series of wave kinematics, including also 2nd order wave forces, and wind speed are stored for sufficient duration for a set of positions expected to be required in the analysis. In addition, a gradually build up of excitation should also be obtained in order to avoid instabilities in the start-up the analysis.

4.3 Numerical Simulation Steps

The nonlinear-coupled dynamic analysis demand substantial computer capacity since it requires a single and complete model including the cylindrical floater S400, 12 mooring lines and one feasible riser configurations. It also requires the detailed model for each component and characterization of the environments in covering relevant load models. Hence the analysis will be more time consuming than the de-coupled analysis. This is a main disadvantage when performing the coupled analysis. Efficient tools and procedures on how to perform the analysis will be needed.

Several strategies can be proposed to achieve computational efficiency but it should always give an adequate representation of the coupling effects. In the study, we will present a consistent analytical approach to ensure better dynamic interaction between floater, moorings and risers by implementing the numerical simulation steps in order to capture the interaction between the cylindrical floater, moorings and risers. The analysis will be performed by using several programs such as WADAM/Hydro D, RIFLEX and SIMO.

An integrated analysis scheme to obtain a consistent analytical approach for the nonlinear-coupled dynamic analysis can be seen in **Figure 4.4**. below:



Where: MBR = Minimum Bending Radius of the flexible pipes

Figure 4. 4 : An integrated scheme analysis.

As the first step, the cylindrical floater motion analysis will be performed as a decoupled analysis. The analysis will be done in WADAM to compute the rigid body floater motion of the S400 based on diffraction theory to obtain the transfer function, mean wave drift forces and non linear damping. In WADAM, the cylindrical floater will be modeled as a dual model configuration. Two kinds of Finite Element Models (FEM), a panel FEM and a Morison FEM will be combined in this configuration. For the structural analysis, the Morison FEM and the panel FEM are connected in a super element hierarchy. The resulting analysis will not only present the hydrodynamics but also the stability of the cylindrical floater. The analysis is performed in the frequency domain as a simple iterative technique to solve a linear equation of motions to obtain a set frequency dependent RAO.

Further, the cylindrical floater and the moorings will be analyzed in computer software program SIMO. The model configuration of the cylindrical floater and the resultsing analysis are converted to SIMO. SIMO is also used as tool to compute floater motion as like WADAM but in time domain analysis through use of retardation functions and it also analyzes the station-keeping behavior. The environmental loading due to wind, waves and currents will be considered here. The simulation will be performed for two cases; static and dynamic simulations. Static forces and moments on cylindrical floater S400 and mooring line tension will be obtained from the static results. In dynamic simulation, the sea states are simulated for 3 hours plus build-up time. Motions are found by time integration enforcing force equilibrium at each time steps. The corresponding mooring line tensions are established using a quasi static approach. The outputs of the analysis are floater motions in time domain, mooring line tension and the global position of cylindrical floater or the offset value, all given in time series.

Besides that, the dynamic slender structure analysis for riser configuration will also be performed in RIFLEX as decoupled analysis in order to reduce time analysis. The main purpose of the analysis is to find a feasible single arbitrary configuration. The analysis will also be performed in time domain under two simulation schemes, static and dynamic conditions. The vessel motions i.e. the transfer function from the WADAM results will be applied as top end excitation for the moorings and risers in order to calculate dynamic loads in these elements. For analysis results such as top angle (hang off position angle), effective tension, bending radius and seabed clearance will be given in order to get a feasible configuration.

As the final step, the cylindrical S400 floater and mooring from the SIMO analysis will be integrated with an arbitrary riser configuration from RIFLEX as a single and complete model by using SIMA. Hence, a consistent analysis ensuring higher dynamic interaction between floater, moorings and risers can be gained.

The analyses are performed in accordance with the scheme give in, **Figure 4.5**, below:

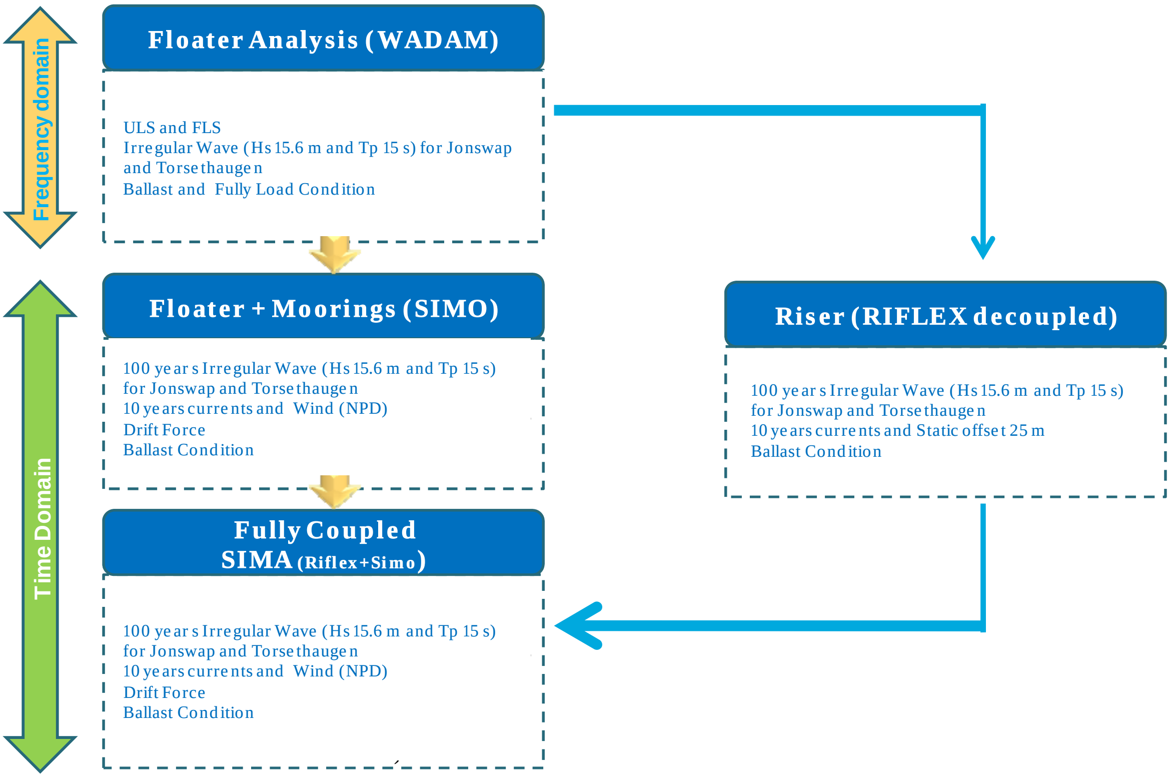


Figure 4. 5 : Load cases combinations scheme analysis.

CHAPTER

5

Hydrodynamic Analysis of Cylindrical FPSO S400

This chapter will present the general description of the cylindrical FPSO, S400 and present the hydrodynamic analysis of the floater based on diffraction theory to obtain hydrodynamic response of the floater. Moreover, the modeling concept and the analysis steps in Wadam will be presented briefly.

Furthermore, the analysis will be performed by using a diffraction program, Wadam/HYDRO D for single body (free cylindrical floater) without moorings (*Det Norske Veritas (2008)*). The analysis has been performed in the frequency domain analysis for problem solving.

From the resulting analysis the hydrodynamic responses such as: transfer function, mean wave drift forces and non linear damping and also the stability of the cylindrical floater Will be presented Further, the results from Wadam the analysis will be used to perform time domain simulation which includes second order wave and mooring analysis by the program SIMO.

5.1 General Description

The Sevan Floating, Production, Storage and Offloading vessel (FPSO) S400 is used for the floating production and storage of hydrocarbons. It has capability to store hydrocarbons within the range from 300 to 2.000.000 bbls. Other design characteristics include:

- no turret and swivel
- spread mooring
- segregated ballast
- wider and high deck load capacity
- offloading to tankers
- is moveable
- etc

The main particulars for S400 FPSO are summarized in **Table 5.1.** Two different platform drafts are specified for fully loaded and ballast conditions. Further, the 3D model and 2D model can be seen in **Figure 5.1** and **Figure 5.2**.

Tabel 5. 1. : S400 FPSO Main Particulars

Parameter	***Unit***	***Dimensions***
Diameter Main Hull Cylinder	m	70.0
Diameter Main Deck	m	78.0
Diameter Process Deck	m	84.0
Area Process Deck	m^2	5 675
Diameter Pontoon	m	87.5
Height Pontoon	m	2.5/5.0
Elevation Main Deck	m	32.0
Elevation Process Deck	m	38.0
Elevation start flare	m	24.0
Radius of gyration in roll	m	22.3
Radius of gyration in pitch	m	22.3
Radius of gyration in yaw	m	32
Ballast Draft		
Draft	m	16.35
Displacement	Ton	70 690
Freeboard to MD	m	15.7
Freeboard to PD	m	20.7
VCG	m	19.1
GM (inc correction for free surface)	m	6.5
Loaded Draft		
Draft	m	20.72
Displacement	Ton	92 950
Freeboard to MD	m	11.3
Freeboard to PD	m	16.3
VCG	m	18.23
GM (inc correction for free surface)	m	6.2

Reference: Sevan Marine *(2011)*

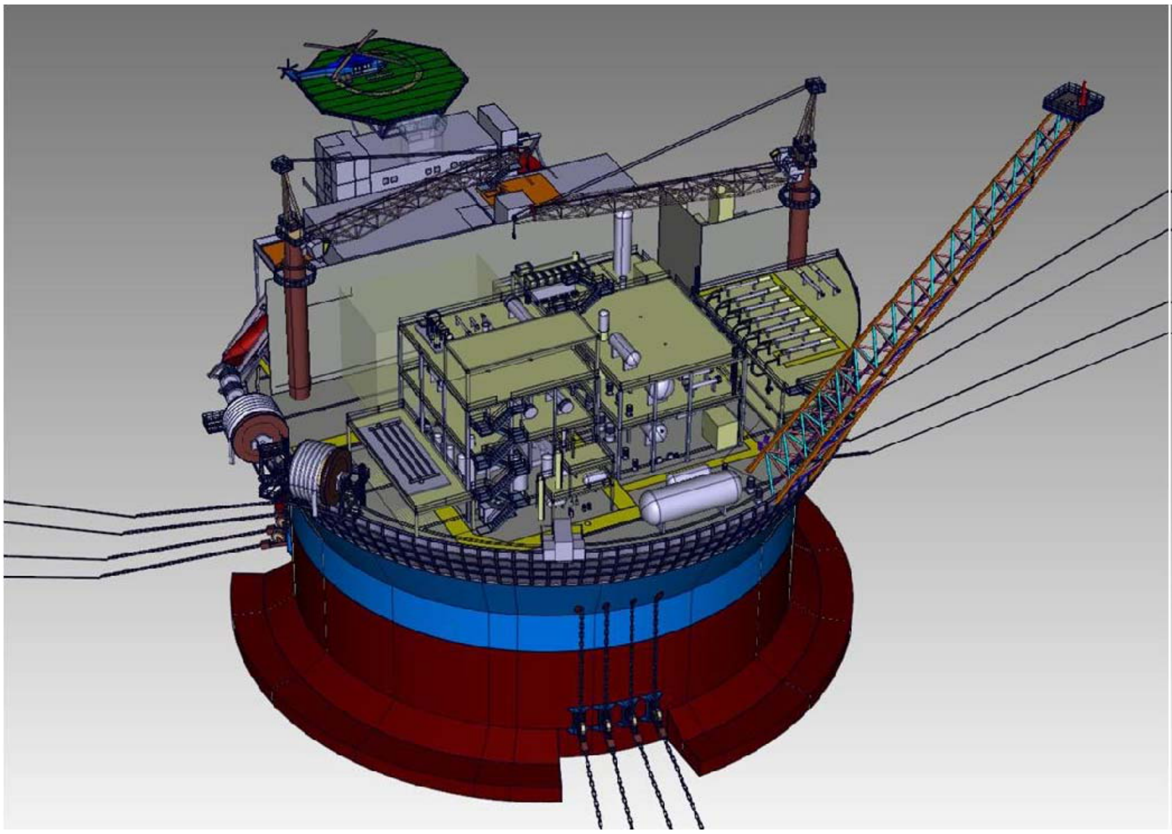


Figure 5. 1. : S400 FPSO - 3D model.

Reference: Reference: Sevan Marine *(2011)*

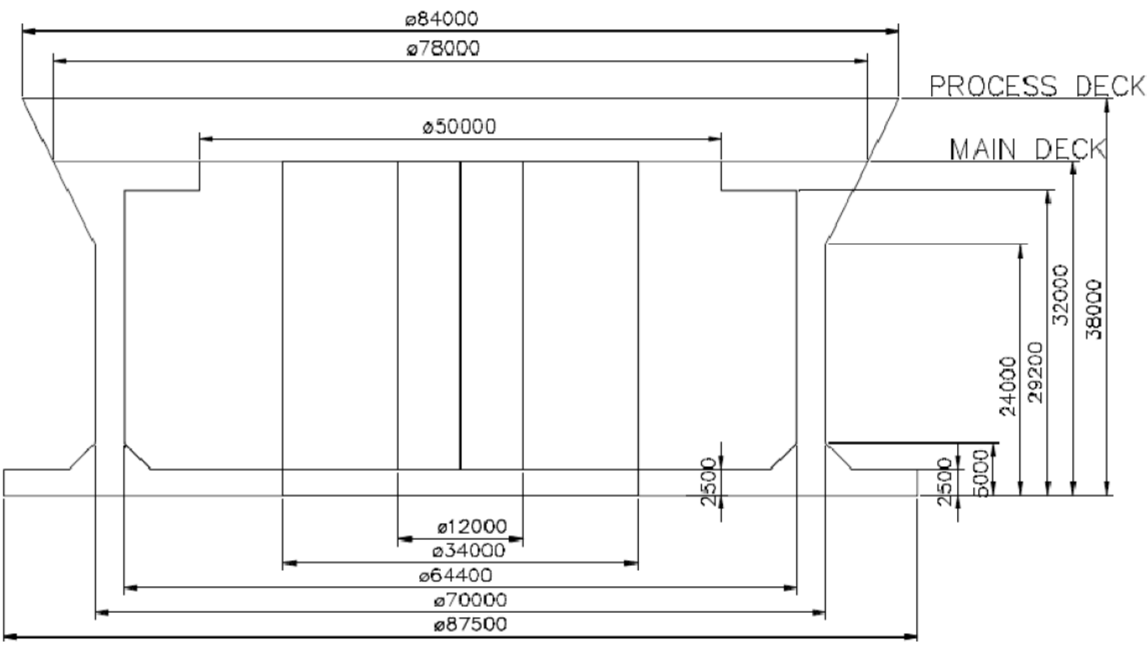


Figure 5. 2. : S400 FPSO - 2D model.

Reference: Reference: Sevan Marine *(2011)*

5.2 Model Concept and Analysis Steps

The cylindrical floater hydrodynamic analysis will be performed as a decoupled analysis. The analysis is based on the wave loads acting on the floater only, as the most important contributor to derive the response of motion in a floater.

A cylindrical S400 floater will be modeled both as a hydro and a mass model which do not involve the influence of moorings and risers. The hydro model will be used for calculating hydrodynamic loads from potential theory and Morison's equation while the mass model is used both in the hydrostatic calculations to report imbalances between weight and buoyancy of the structure and in the equation of motion.

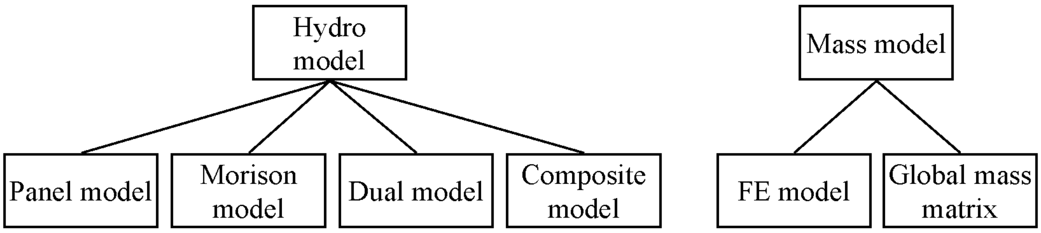


Figure 5. 3. : Overview of model types.

Reference: adapted from *Det Norske Veritas (2008)*

Frequency domain analysis is chosen in this analysis as a simple iterative technique to derive the motion response of a floater and the calculation of wave loads. The analysis will also be performed for regular waves and irregular waves. The regular waves are chosen to analyze the motion response of the floater in the frequency domain while the irregular waves are chosen to describe the real conditions.

Furthermore, the floater hydrodynamic analysis is performed by using the integrated software program HydroD. HydroD is an integral part of the SESAM system which is related to several programs such as Prefem, Wadam and Postresp in **Figure 5.4**.

Prefem has the function to generate a finite element model as basic hydro model in Wadam while Postresp has the function to present the resulting analysis. A simple flow diagram which describes the relation between Prefem, Wadam and Postresp as an integrated program for floater analysis can be seen in **Figure 5.5.**

First, the finite element models (T*.FEM) are build in Prefem as the basic hydro model input in HydroD then the models are read by Wadam from the Input Interface File (T-file). The Wadam analysis control data is generated by the Hydrodynamic design tool HydroD. Further, the results may be stored on a Hydrodynamic Results Interface File (G-file) for statistical postprocessing in Postresp.

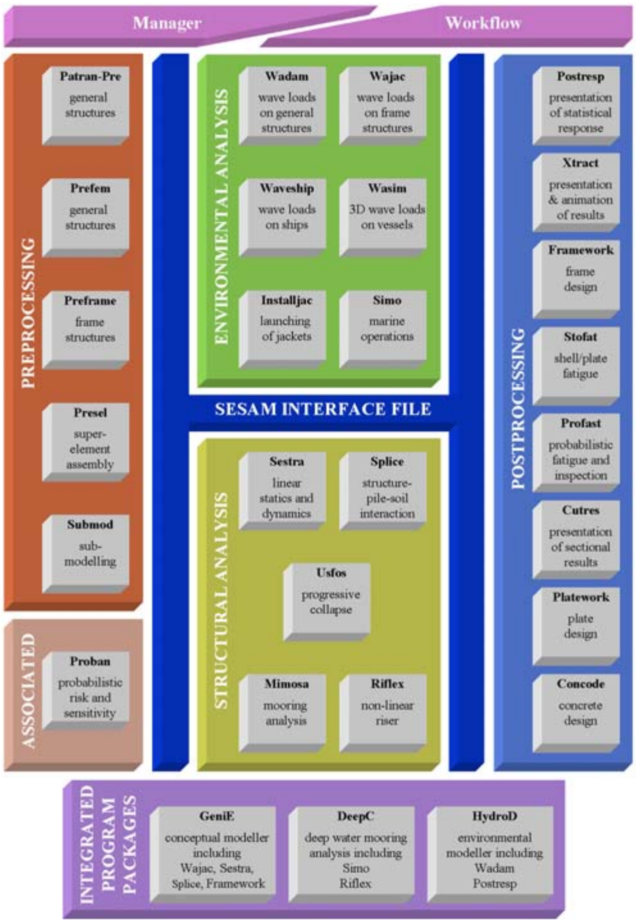


Figure 5. 4. : S400 FPSO - 2D model.

Reference: *Det Norske Veritas (2008)*

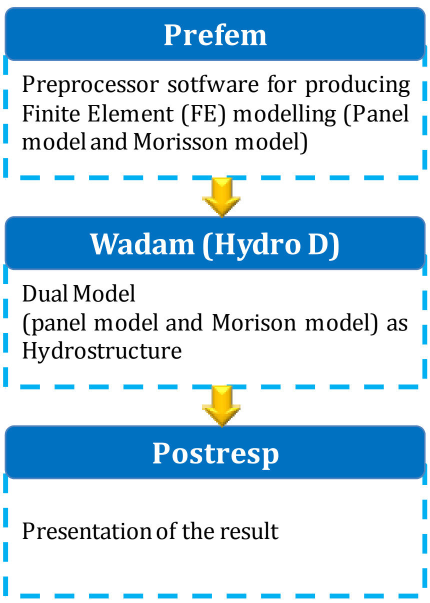


Figure 5. 5. : The relation between Prefem, Wadam and Postresp as an integrated program for analysis of a cylindrical S400 floater.

A simple procedure for the hydrodynamic analysis for a cylindrical floater S400 has been described in **Figure 5.6.**

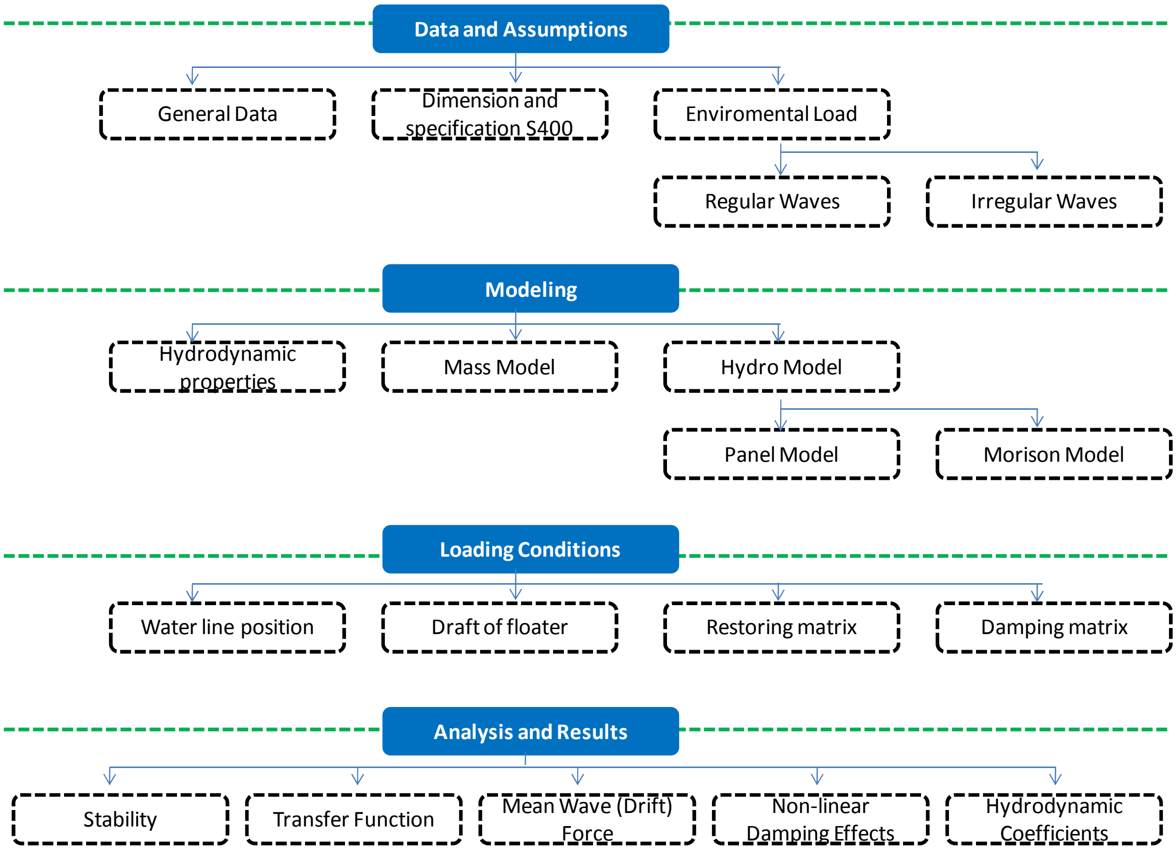


Figure 5. 6. : A simple procedure for the hydrodynamic analysis for a cylindrical floater S400.

The hydrodynamic analysis by using HydroD will be divided into data and assumptions, modeling the cylindrical floater, loading conditions and analysis and results.

The input for the analysis will be based on data and assumptions. It will be categorized as follow:

- General Data
- Dimensions and Specifications of the Cylindrical Floater S400
  The detail information of the dimensions and the specification for the cylindrical floater S400 can be found in subchapter **5.1 General Description**.
- Environment Load
  Regular wave and irregular waves will be considered as environmental loads which have directions set coming from 180 degree. Two forms of regular waves will be used in the analysis; ULS regular wave (H_0 = 25 m) and FLS regular wave (H_0 = 6 m) while two spectrum formulas will be used for the irregular waves; the Jonswap (Joint North Sea Wave Project) spectrum and The Torsethaugen spectrum (the Jonswap double peaked) to describe the real conditions. It also has a set of defined frequency ranges from 2 s - 30 s because the analysis will be performed by frequency domain analysis.

Further information for the wave input can be found in **Chapter 3, Environmental Conditions**.

Further, the analysis requires finite element models that have been built in Prefem as basic input for the Hydro model. Two types of finite element models are used a combination of a panel- and a Morison model - called a dual model. The dual model is used when both potential theory and Morison's equation shall be applied to the same part of the hydro model. The dual model must be used when pressure distribution from potential theory shall be transferred to a beam structural model. Note that different superelement number should be used in the analysis. An overview of the hydro model combination for the dual model can be seen in **Figure 5.7** while **Figure 5.8** describes the finite element models for a cylindrical floater S400 that are used in the analysis.

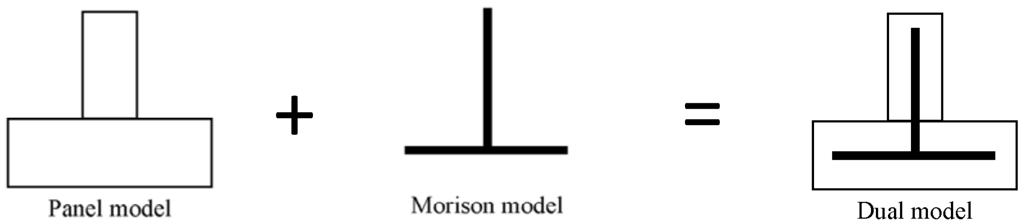


Figure 5. 7. : Hydro model combinations.

Reference: adapted from *Det Norske Veritas (2008)*

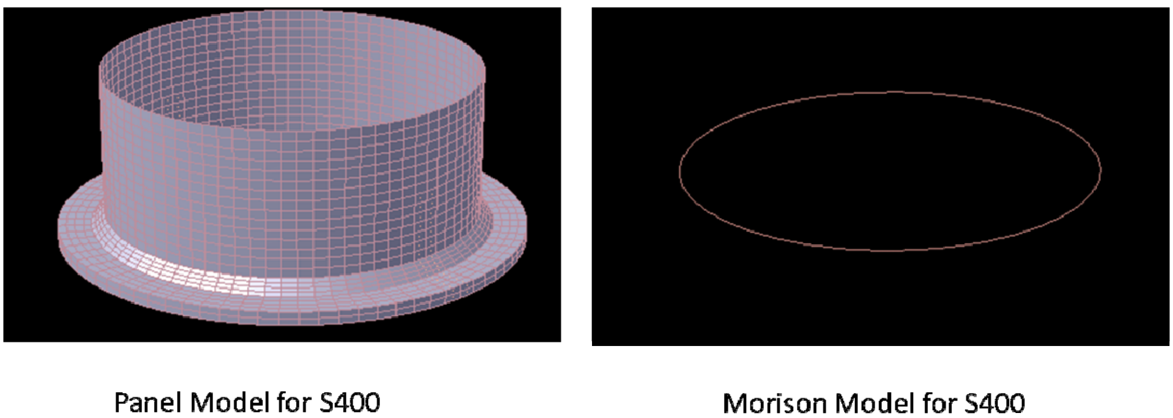
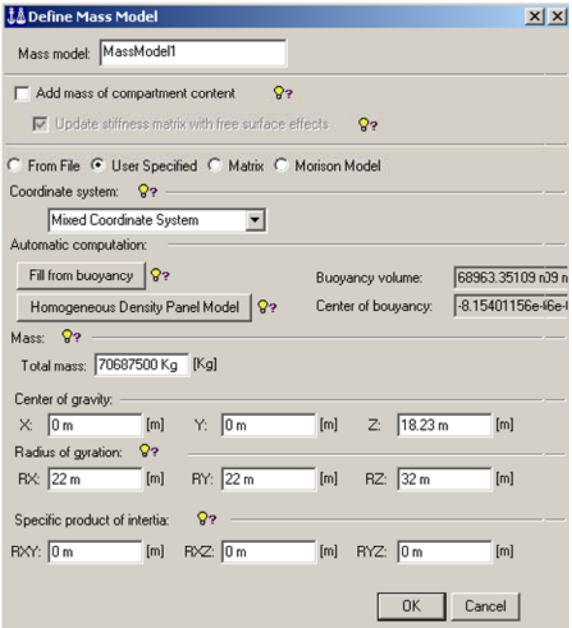


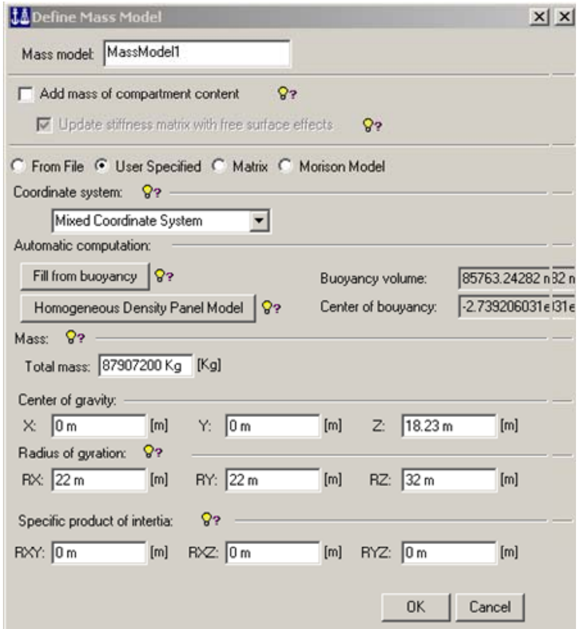
Figure 5. 8. : Finite element models for a cylindrical floater S400.

Besides the hydro model, the analysis also requires mass model. The mass model is relevant for the floating structure only and may be defined either by finite elements with mass properties or as a global mass matrix. The mass model is used to analyze the stability of the floater. Hence, two kinds of data will be used here with respect to loading conditions (**Figure 5.9**).

The floater will be heavier in fully loaded condition than in the ballast loading condition. Hence the buoyancy volume in the fully loaded condition will be higher.



Mass model for ballast loading condition



Mass model for fully load loading condition

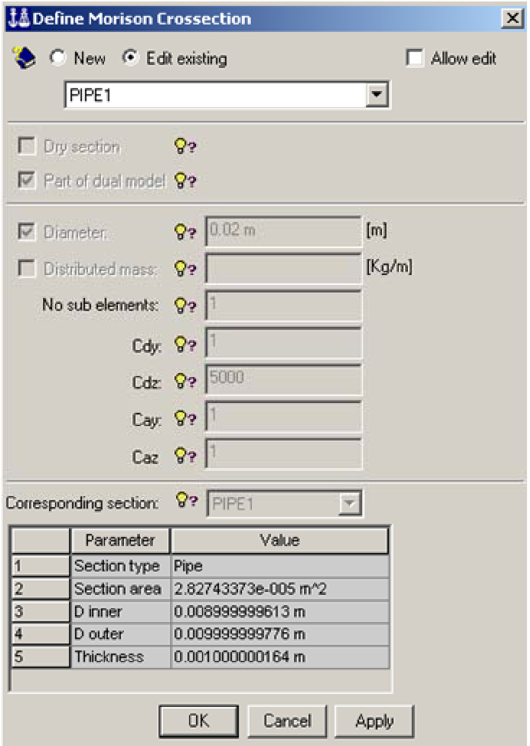
Figure 5. 9. : The data for the Wadam mass models for the cylindrical floater S400.

The hydrodynamic properties should be defined since they will influence the magnitude of the wave load acting on a floater. The drag coefficients and element diameters for calculating hydrodynamic loads are chosen with respect to the loading condition; ballasted and fully loaded conditions. Moreover, the drag coefficient on the Morison element is the most important parameter in the mass model, for fully loaded condition, we can use Cd = 5500 while Cd = 5000 for the ballasted condition *(Sevan Marine (2011)* (**Figure 5.10**). The physical properties of the air and water such as the density and kinematic viscosity are also listed in the environment modeling.

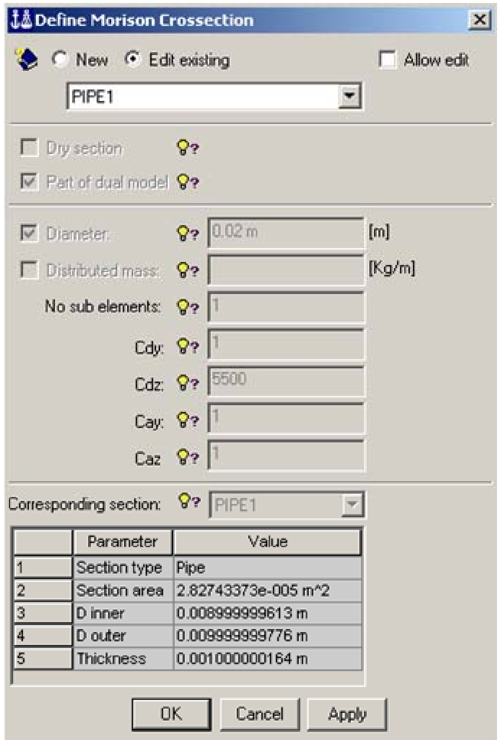
Further, the loading conditions will be defined based on the z-coordinate at the waterline. In this analysis, two loading conditions are chosen:

- Ballast loading condition, z =16.32 m
  The damping matrix and the restoring matrix for the ballasted loading condition can be seen in **Table 5.1**
- Fully load loading condition, z = 20.72 m
  The damping matrix and the restoring matrix for the fully loaded condition can be seen in **Table 5.2**

The damping and the restoring matrix have been provided from model tests carried out by *Sevan Marine (2011)*.



Mass model for ballast loading condition



Mass model for fully load loading condition

Figure 5. 10. : The hydrodynamic properties for mass model in Hydro D computer software program.

Table 5. 1 : The Damping and Restoring Matrices for the Ballasted Loading Condition.

	Damping Matrix for Ballast Loading Condition					
Motions	X	Y	Z	RX	RY	RZ
Surge	800000 N*s/m	0 N*s/m	0 N*s/m	0 N*s	0 N*s	0 N*s
Sway	0 N*s/m	800000 N*s/m	0 N*s/m	0 N*s	0 N*s	0 N*s
Heave	0 N*s/m	0 N*s/m	0 N*s/m	0 N*s	0 N*s	0 N*s
Roll	0 N*s	0 N*s	0 N*s	0 N*s*m	0 N*s*m	0 N*s*m
Pitch	0 N*s	0 N*s	0 N*s	0 N*s*m	0 N*s*m	0 N*s*m
Yaw	0 N*s	0 N*s	0 N*s	0 N*s*m	0 N*s*m	1e+010 N*s*m

	Restoring Matrix for Ballast Loading Condition					
Motions	X	Y	Z	RX	RY	RZ
Surge	1140000 N/m	0 N/m	0 N/m	0 N	-18500000 N	0 N
Sway	0 N/m	1140000 N/m	0 N/m	18500000 N	0 N	0 N
Heave	0 N/m	0 N/m	0 N/m	0 N	0 N	0 N
Roll	0 N	5930000 N	0 N	469000000 N*m	0 N*m	0 N*m
Pitch	-5930000 N	0 N	0 N	0 N*m	469000000 N*m	0 N*m
Yaw	0 N	0 N	0 N	0 N*m	0 N*m	0 N*m

Table 5. 2 : The Damping and Restoring Matrices for the Fully Loaded Condition.

	Damping Matrix for Fully Loading Condition					
Motions	X	Y	Z	RX	RY	RZ
Surge	800000 N*s/m	0 N*s/m	0 N*s/m	0 N*s	0 N*s	0 N*s
Sway	0 N*s/m	800000 N*s/m	0 N*s/m	0 N*s	0 N*s	0 N*s
Heave	0 N*s/m	0 N*s/m	0 N*s/m	0 N*s	0 N*s	0 N*s
Roll	0 N*s	0 N*s	0 N*s	0 N*s*m	0 N*s*m	0 N*s*m
Pitch	0 N*s	0 N*s	0 N*s	0 N*s*m	0 N*s*m	1e+010 N*s*m
Yaw	0 N*s	0 N*s	0 N*s	0 N*s*m	0 N*s*m	0 N*s*m

Restoring Matrix for Fully Loading Condition						
Motions	X	Y	Z	RX	RY	RZ
Surge	900000 N/m	0 N/m	0 N/m	0 N	0 N	0 N
Sway	0 N/m	900000 N/m	0 N/m	17000000 N	0 N	0 N
Heave	0 N/m	0 N/m	0 N/m	0 N	0 N	0 N
Roll	0 N	17000000 N	0 N	900000000 N*m	0 N*m	0 N*m
Pitch	0 N	0 N	0 N	0 N*m	900000000 N*m	0 N*m
Yaw	0 N	0 N	0 N	0 N*m	0 N*m	0 N*m

The appearance of the cylindrical floater S400 in HydroD can be seen in **Figure 5.11** and **Figure 5.12** below:

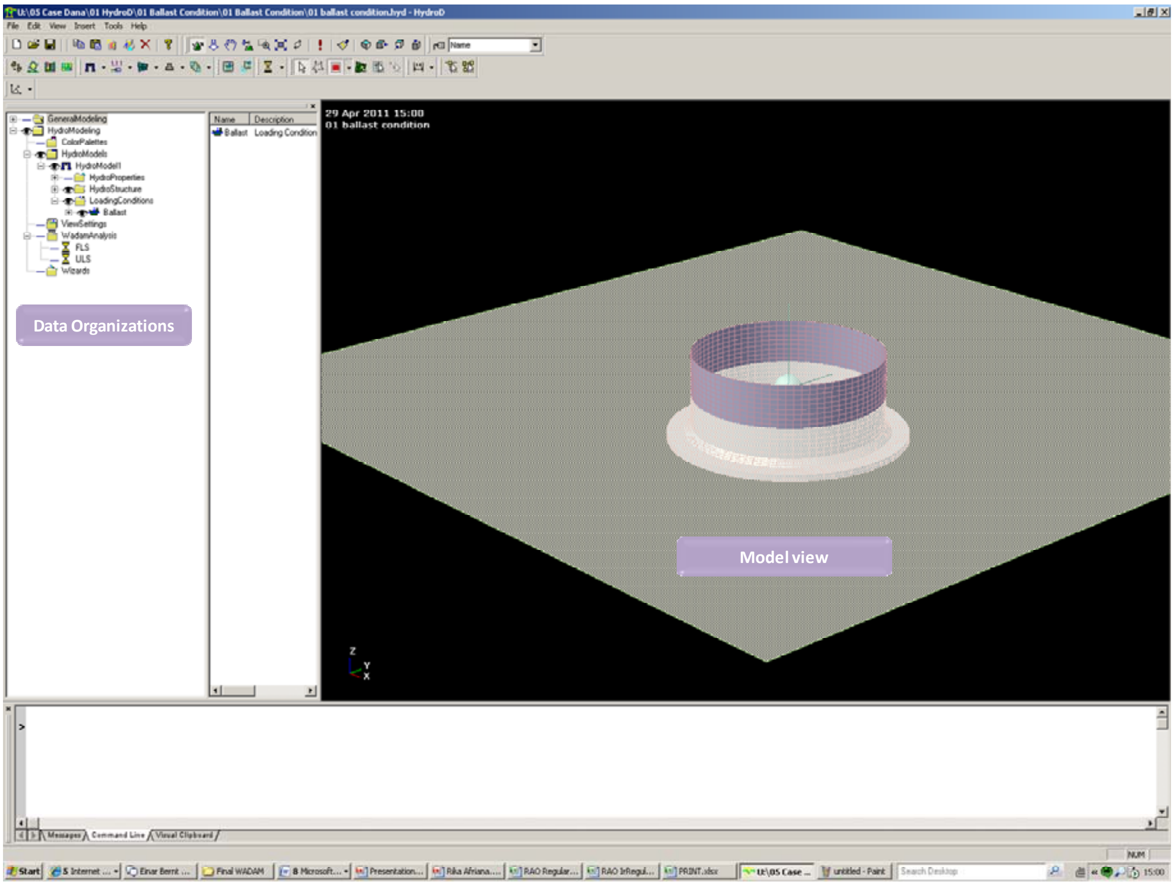


Figure 5. 11. : The appearance of HydroD.

From the **Figure 5.11** above, Hydro D has two main windows; the data organizations and the model view.

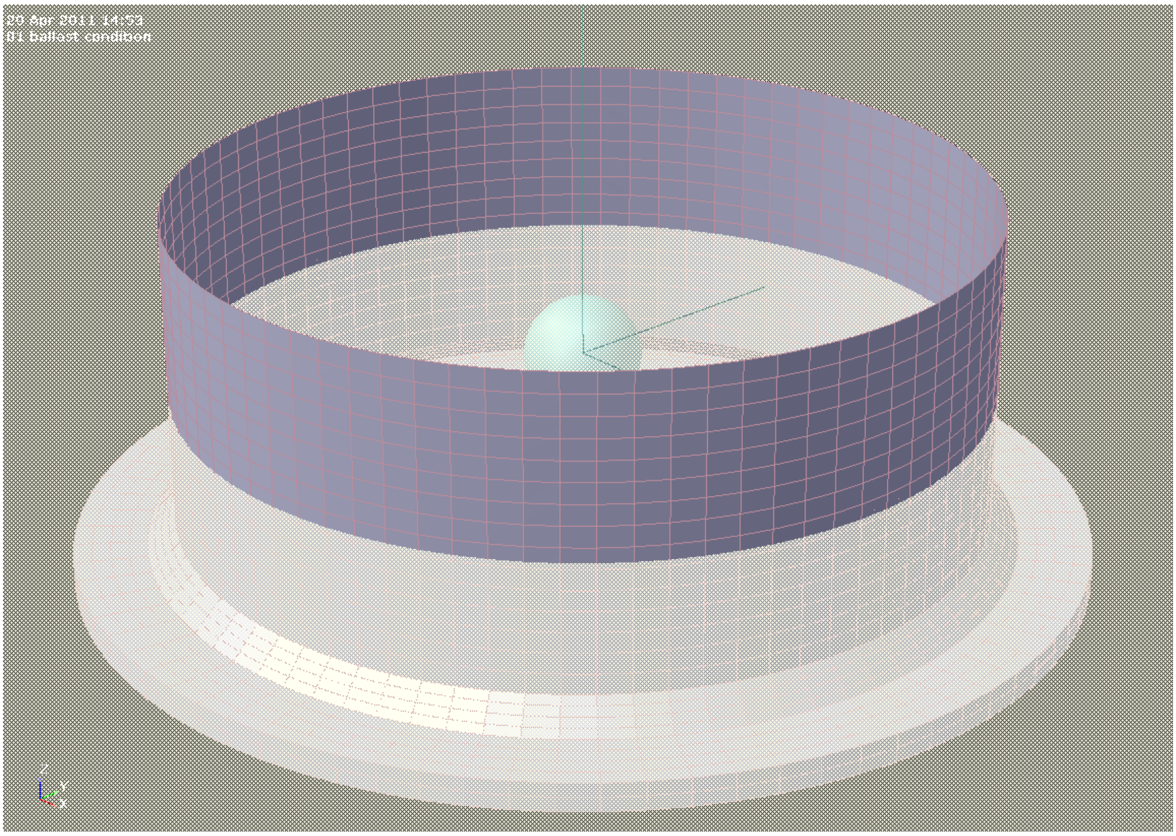


Figure 5. 12. : A cylindrical floater model of S400 model in HydroD.

5.3 Hydrodynamic Response and Stability Analysis

The response of the floater can be divided into hydrostatic analysis and hydrodynamic analysis. The hydrostatic analysis will be governed by the structure weight and buoyancy force balance. It will also be the starting point to analyze the stability of the floater and is also important for the success of subsequent hydrodynamic analysis. On the other hand, the hydrodynamic analysis will be the key factor to analyze the performance of the cylindrical floater from its motions.

The motions of the cylindrical floater are mainly constructed from the wave frequency motion and low frequency motion components. Furthermore, the wave frequency motion comes from the wave frequency loads as the first order wave loads and should be analyzed in the frequency domain analysis. This is a relatively simple and efficient method to solve the problem since we can assume a linear equation of motion. Further, the linear force transfer function or Response Amplitude Operator (RAO) can be generated from this analysis. On the other hand, the low frequency motion comes from secondary order wave loads such as the mean wave (drift) force and slowly varying wave force. Further, the quadratic transfer function can be produced from this analysis. The result will be strongly depending on the first order motions from the wave frequency load. Normally, it will give relatively smaller magnitude forces compared to first order force. However, it is very important for a cylindrical floater since it is related to the ability of the structure to produce waves. These waves may coincide with the natural frequency of its system and produce resonance.

In *subchapter 5.3*, the resulting of stability, first order motions and second order forces will be presented as the starting point to determine global performance of the cylindrical floater. The RAO of the cylindrical floater will be presented here as the parts of Wadam result while the QTF will not be presented since the analyses are done by the frequency domain analysis.

Eight combinations will be considered here with respect to environmental load and the waterline position as follow:

- Regular wave with Ho=25 m for ballasted at z=16.35 m as ULS ballast case
- Regular wave with Ho=6 m for ballasted at z=16.35 m as FLS ballast case
- Regular wave with Ho=25 m for fully loaded at z=20.73 m as ULS fully load case
- Regular wave with Ho=25 m for fully loaded at z=20.73 as FLS fully load case
- Irregular wave with Jonswap spectrum (Hs=15.6m and Tp=15.5s) for ballasted at z=16.35 m as Jonswap_Ballast case
- Irregular wave with Torsethaugen spectrum (Hs=15.6m and Tp=15.5s) for ballasted at z=16.35 m as Torsethaugen _Ballast case
- Irregular wave with Jonswap spectrum (Hs=15.6m and Tp=15.5s) for fully loaded at z=20.73 m as Jonswap_fullyload case
- Irregular wave with Torsethaugen spectrum(Hs=15.6m and Tp=15.5s) for fully loaded at z=20.73 m as Torsethaugen _fullyload case

5.3.1 Stability Analysis

Stability analysis describes the position of the floater in static equilibrium where the forces of gravity and buoyancy are equal and acting in opposite directions in line with one another. *Ship Hydrostatic (2002)* has mentioned that stability is the ability of a body, in this setting a ship or a floating vessel, to resist the overturning forces and return to its original position after the disturbing forces are removed. It requires initial stability. Initial stability is achieved from a small perturbation from its original position. We have initial stability when we have an uprighting moment larger than zero. Hence, the floater will be back to its initial position when the inclining moment is taken away.

Furthermore from *Gudmestad (2010*), an uprighting moment larger than zero can only be achieved if:

$$\overline{GM} > 0 \ \rightarrow M_r > 0$$

where:

$\overline{GM}$ = the metacentre height

M_r = the uprighting moment

From the geometry, the metacentre height is given as follows:

$$\overline{GM} = \overline{KB} + \overline{BM} - \overline{KG}$$

where:

$\overline{KB}$ = the distance between the keel K and the centre of buoyancy B

$\overline{BM}$ = the distance between the centre of buoyancy B and the metacentre M

$\overline{KG}$ = the distance between the keel K and the centre of gravity G

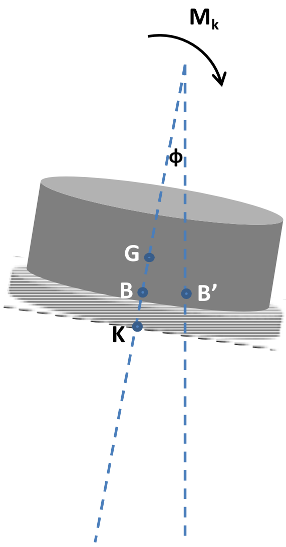


Figure 5. 13. : Inclined a cylindrical floater S400.
Reference: adapted from *Gudmestad (2010)*

The requirement for $\overline{GM} > 0$ will be related to freeboard F also. The stability of a cylindrical floater can be also analyzed from the roll period. A floater has higher stability if a floater has the ability to roll back in shorter time since $\overline{GM} \sim \frac{1}{(T_{roll})^2}$

$$T_{roll} = \frac{b}{\sqrt{\overline{GM}}}$$

where:
T_{roll} = the roll period
b = the width of ship
$\overline{GM}$ = the metacentre height

The result analysis for stability of a cylindrical floater S400 can be seen in **Table 5.3** until **Table 5.6** for ballasted and fully loaded conditions. Based on the results, a cylindrical floater S400 has good initial stability since $\overline{GM} > 0$ and the movement of $\overline{GM}$ from the ballasted to fully loaded condition can be seen in **Figure 5. 14.**

A. Stability Analysis for Ballast for z= 16.35m

Table 5. 3 : The mass properties for ballasted condition.

Mass Properties and Structural Data	Symbol	Values	Unit
Mass Of The Structure	M	7.07E+07	[M]
Weight Of The Structure	M*G	6.93E+08	[M*L/T**2]
Centre Of Gravity	XG	0.00E+00	[L]
	YG	0.00E+00	[L]
	ZG	1.82E+01	[L]
Roll Radius Of Gyration	XRAD	2.20E+01	[L]
Yaw Radius Of Gyration	YRAD	2.20E+01	[L]
Pitch Radius Of Gyration	ZRAD	3.20E+01	[L]
Roll-Pitch Centrifugal Moment	XYRAD	0.00E+00	[L**2]
Pitch-Yaw Centrifugal Moment	XZRAD	0.00E+00	[L**2]
Roll-Yaw Centrifugal Moment	YZRAD	0.00E+00	[L**2]

Table 5. 4 : The hydrostatic data for ballasted condition.

Hydrostatic Data	Symbol	Values	Unit
Displaced Volume	VOL	6.90E+04	[L**3]
Mass Of Displaced Volume	RHO*VOL	7.07E+07	[M]
Water Plane Area	WPLA	3.84E+03	[L**2]
Centre Of Buoyancy	XCB	3.24E-13	[L]
	YCB	-8.91E-13	[L]
	ZCB	7.58E+00	[L]
Longitudinal Metacentric Height	GM4	7.08E+00	[L]
Transverse Metacentric Height	GM5	7.08E+00	[L]
Heave-Heave Restoring Cefficient	C33	3.86E+07	[M/T**2]
Heave-Roll Restoring Cefficient	C34	0.00E+00	[M*L/T**2]
Heave-Pitch Restoring Cefficient	C35	0.00E+00	[M*L/T**2]
Roll-Roll Restoring Cefficient	C44	4.91E+09	[M*L**2/T**2]
Pitch-Pitch Restoring Cefficient	C55	4.91E+09	[M*L**2/T**2]
Roll-Pitch Restoring Cefficient	C45	0.00E+00	[M*L**2/T**2]

B. Stability Analysis for Fully load for z= 20.72m

Table 5. 5 : The mass properties for fully loaded condition.

Mass Properties and Structural Data	Symbol	Values	Unit
Mass Of The Structure	M	8.79E+07	[M]
Weight Of The Structure	M*G	8.62E+08	[M*L/T**2]
Centre Of Gravity	XG	0.00E+00	[L]
	YG	0.00E+00	[L]
	ZG	1.82E+01	[L]
Roll Radius Of Gyration	XRAD	2.20E+01	[L]
Yaw Radius Of Gyration	YRAD	2.20E+01	[L]
Pitch Radius Of Gyration	ZRAD	3.20E+01	[L]
Roll-Pitch Centrifugal Moment	XYRAD	0.00E+00	[L**2]
Pitch-Yaw Centrifugal Moment	XZRAD	0.00E+00	[L**2]
Roll-Yaw Centrifugal Moment	YZRAD	0.00E+00	[L**2]

Table 5. 6 : The hydrostatic data for fully loaded condition.

Hydrostatic Data	Symbol	Values	Unit
Displaced Volume	VOL	8.58E+04	[L**3]
Mass Of Displaced Volume	RHO*VOL	8.79E+07	[M]
Water Plane Area	WPLA	3.84E+03	[L**2]
Centre Of Buoyancy	XCB	2.61E-13	[L]
	YCB	-7.17E-13	[L]
	ZCB	9.73E+00	[L]
Longitudinal Metacentric Height	GM4	6.26E+00	[L]
Transverse Metacentric Height	GM5	6.26E+00	[L]
Heave-Heave Restoring Cefficient	C33	3.86E+07	[M/T**2]
Heave-Roll Restoring Cefficient	C34	0.00E+00	[M*L/T**2]
Heave-Pitch Restoring Cefficient	C35	0.00E+00	[M*L/T**2]
Roll-Roll Restoring Cefficient	C44	5.39E+09	[M*L**2/T**2]
Pitch-Pitch Restoring Cefficient	C55	5.39E+09	[M*L**2/T**2]
Roll-Pitch Restoring Cefficient	C45	0.00E+00	[M*L**2/T**2]

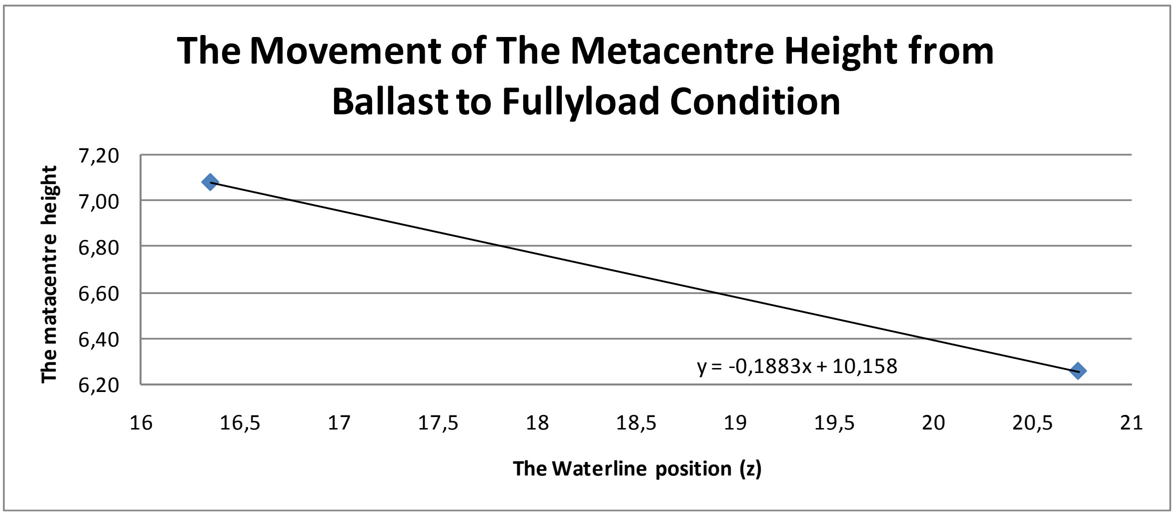


Figure 5. 14. : The movement of $\overline{GM}$ from the ballasted to fully loaded condition.

Figure 5.14 shows that the stability of the cylindrical floater S400 in ballasted condition (Z=16.35 m) is higher than in fully loaded condition (Z=20.73m).

In the ballasted condition, the metacentre height is $\overline{GM}$ =7.08 while in the fully loaded condition, the metacentre height is $\overline{GM}$ =6.26. When the ballast tanks are full, the keel position will move down and the distance between the keel and the buoyancy centre $\overline{KB}$ will be higher. However, the centre of gravity will also moves up and the distance between the keel K and the centre of gravity G $\overline{KG}$ will be also higher. Since the $\overline{KG}$ is higher than $\overline{KB}$, the $\overline{GM}$ will be lower. It is the main reason the stability of a cylindrical floater S400 becomes lower than its position in the ballast condition.

5.3.2 Transfer Functions

The transfer function or the Response Amplitude Operator (RAO) will represent the amplitude of harmonic or sinusoidal response to harmonic load. It means that the RAO will be produced from the first order force component i.e. the wave load. Further the energy from the wave load will be transferred to the floaters response by transfer functions RAO with respect to all 6 DOF (surge, sway, heave, roll, pitch and yaw).

The RAO is very important to reflecting the key performance of the floater because it can describe how the response of the vessel varies with the frequency. Below, the RAO of the cylindrical floater S400 will be presented by using two forms of regular waves, Ho= 25 m and Ho= 6 m from direction 180°. The regular waves are chosen as a practical solution to generate the RAO. In addition, the regular waves also give a good screening result to analyze the response of the cylindrical floater.

However, the irregular wave forms can also be used to generate the RAO in order to describe the real conditions of the sea. The irregular waves are based on Jonswap Spectrum, Hs=15.6 m and Tp= 15 s and Torsethaugen Spectrum, Hs=15.6 m and Tp= 15 s.

These cases are chosen based on environmental condition in **Chapter 3**.

The responses of the cylindrical floater S400 with respect to 6 DOFs can be seen in the figures below. The RAO in regular waves can be seen in **Figures 5.15 - 5.20** while the RAO in irregular waves can be seen in **Figures 5.21 - 5.25**.

A. Regular waves

Four conditions have been chosen to describe the amplitude of the response variable in regular wave condition with respect to 6 DOF motions of a floater.

- Regular wave with Ho=25 m for ballast at z=16.35 m as **ULS ballasted** case
- Regular wave with Ho=6 m for ballast at z=16.35 m as **FLS ballasted** case
- Regular wave with Ho=25 m for fully load at z=20.73 m as **ULS fully loaded** case
- Regular wave with Ho=25 m for fully load at z=20.73 as **FLS fully loaded** case

➢ *The surge motions*

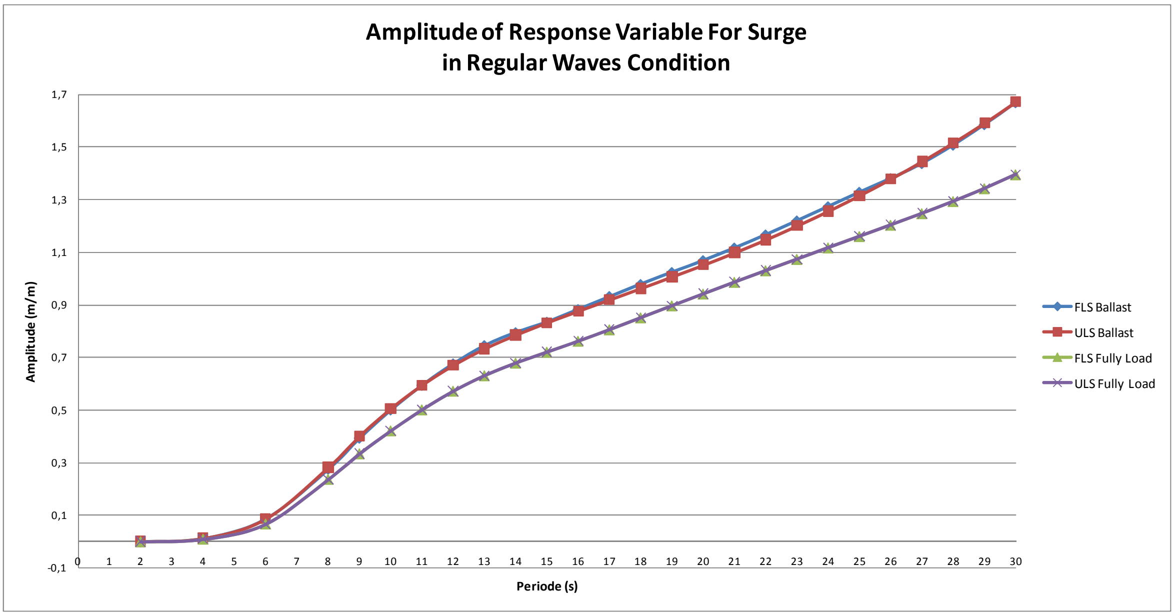


Figure 5. 15. : The amplitude of the response variable for surge in regular wave condition.

➢ *The sway motions*

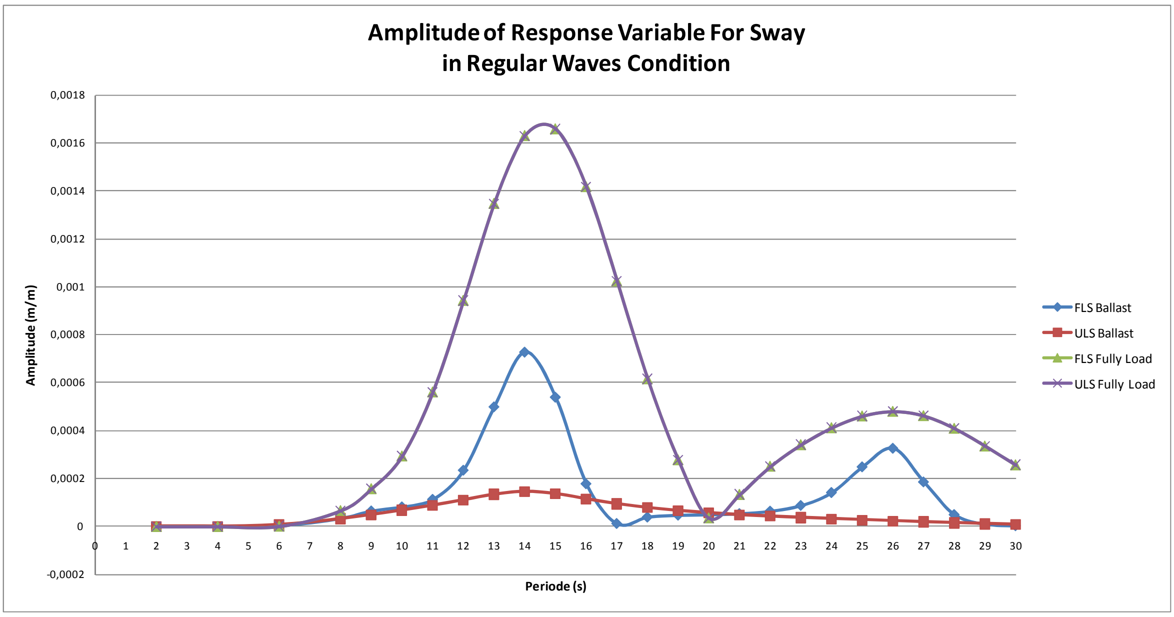


Figure 5. 16. : The amplitude of the response variable for sway in regular wave condition.

➢ *The heave motions*

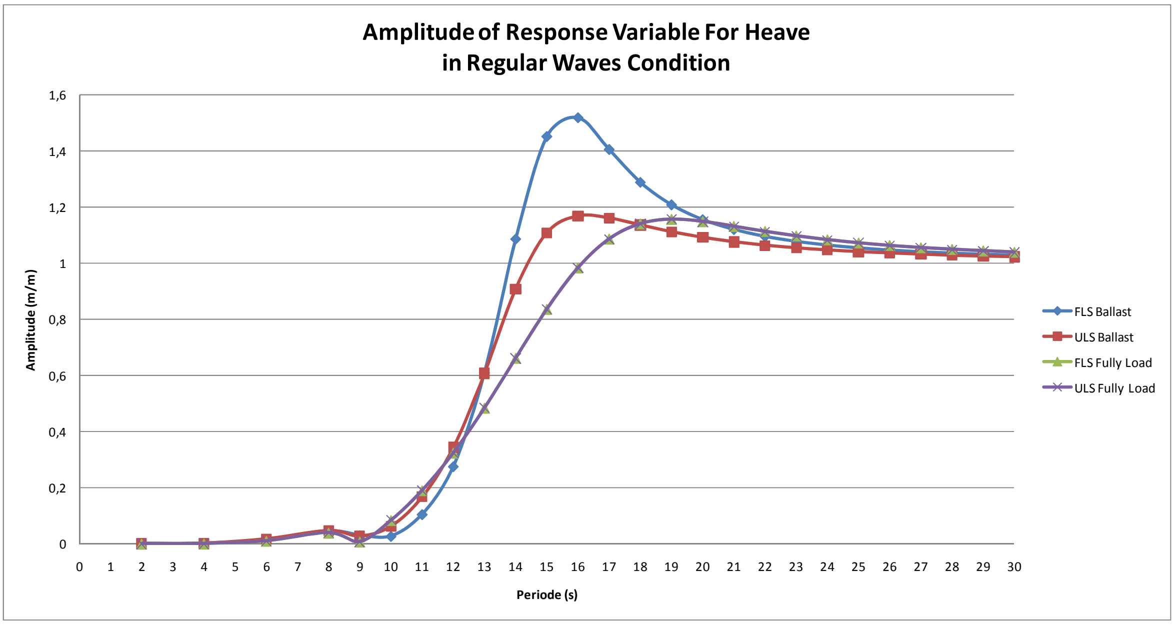


Figure 5. 17. : The amplitude of the response variable for heave in regular wave condition.

➢ *The roll motions*

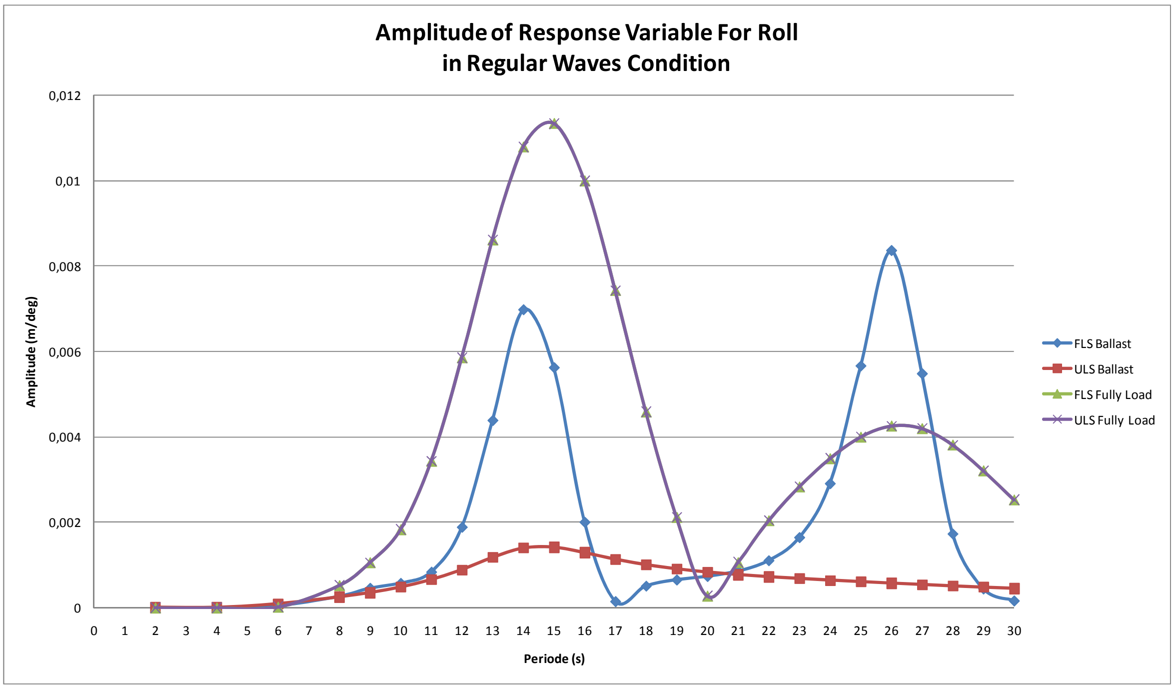


Figure 5. 18. : The amplitude of the response variable for roll in regular wave condition.

➢ *The pitch motions*

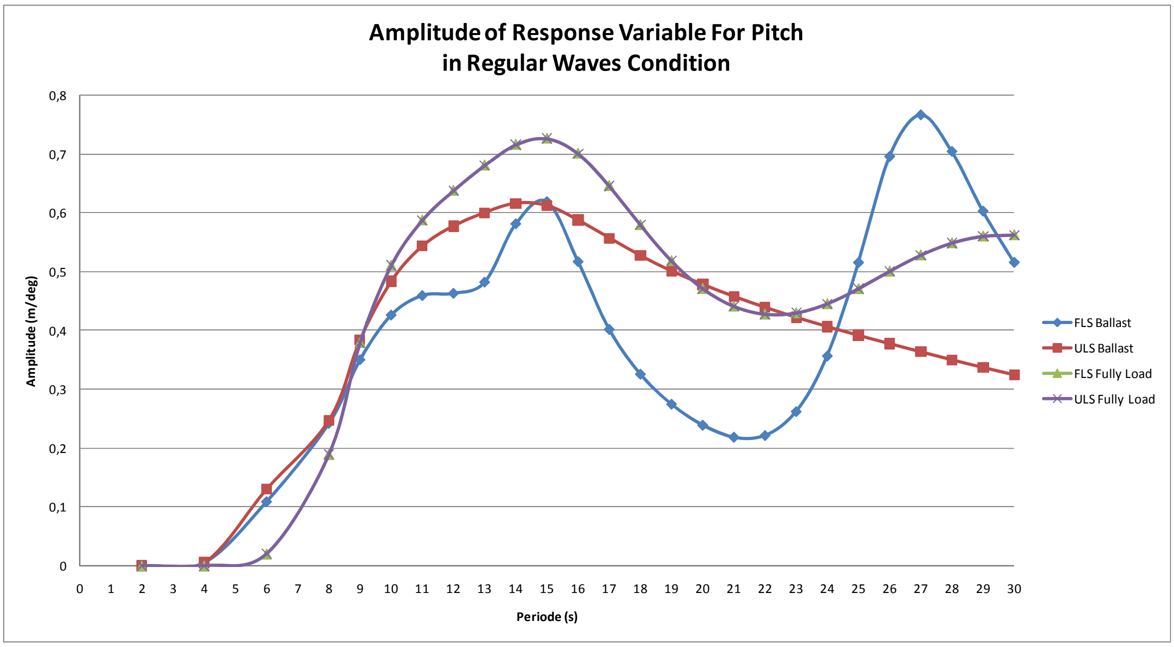


Figure 5. 19. : The amplitude of the response variable for pitch in regular wave condition.

➢ *The yaw motions*

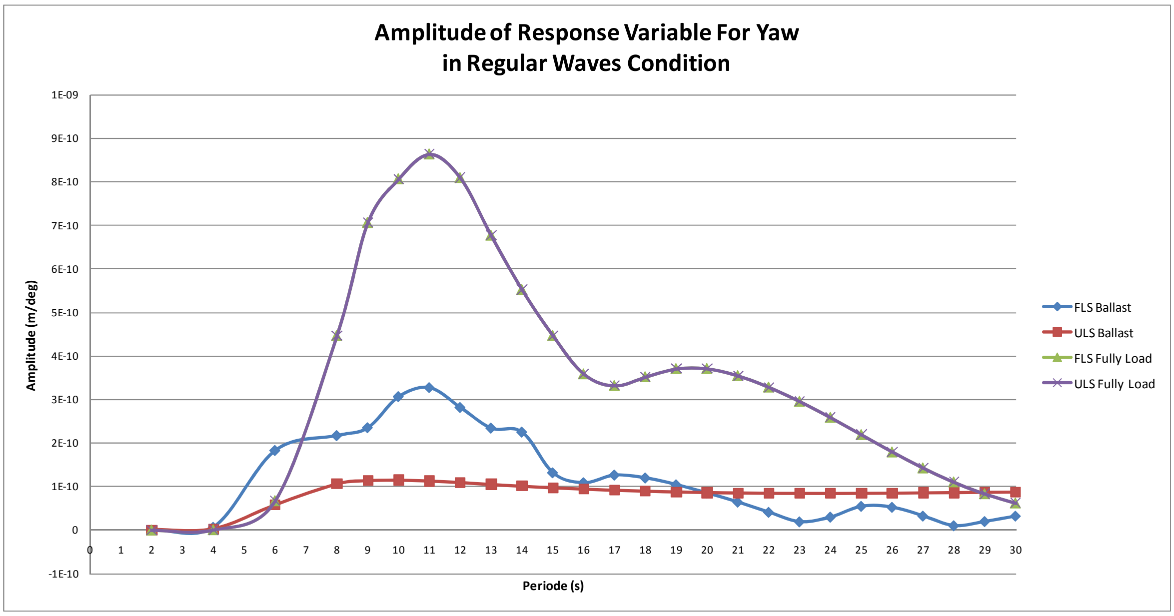


Figure 5. 20. : The amplitude of the response variable for yaw in regular wave condition.

Based on the information from **Figures 5.15, 5.16 and 5.20**, it may be seen that the cylindrical floater S400 has a tendency to be "soft" in the horizontal plane with respect to surge, sway and yaw motions when these motions are in longer periods. It means that the cylindrical floater S400 will follow the wave behavior and gives little resistance. However, the cylindrical floater S400 also gives significant responses for the surge motion for short periods, this happens because of the influence of the direction of wave comes from 180°.

The cylindrical floater has unique dimension characteristic, as a straight circular cylinder. Hence the axis in *x* and *y* will be symmetric. As examples, the surge motion in 0° will coincide with the sway in 90° and the surge motion in 90° will coincide with the sway in 0°.

Normally the motions in the vertical plane are decisive for the cylindrical floater, Hence **Figure 5.17 -5.19** shows that heave, roll and pitch motions will be important in the performance of the floater.

B. Irregular waves

Four conditions have been chosen to describe the amplitude of the response variable in irregular wave condition with respect to 6 DOF motions of a floater.

- Irregular wave with Jonswap spectrum (Hs=15.6m and Tp=15.5s) for ballasted at z=16.35 m as Jonswap Ballast case
- Irregular wave with Torsethaugen spectrum (Hs=15.6m and Tp=15.5s) for ballasted at z=16.35 m as Torsethaugen Ballast case
- Irregular wave with Jonswap spectrum (Hs=15.6m and Tp=15.5s) for fully loaded at z=20.73 m as Jonswap fullyload case

- Irregular wave with Torsethaugen spectrum (Hs=15.6m and Tp=15.5s) for fully loaded at z=20.73 m as Torsethaugen fullyload case

➢ *The surge motions*

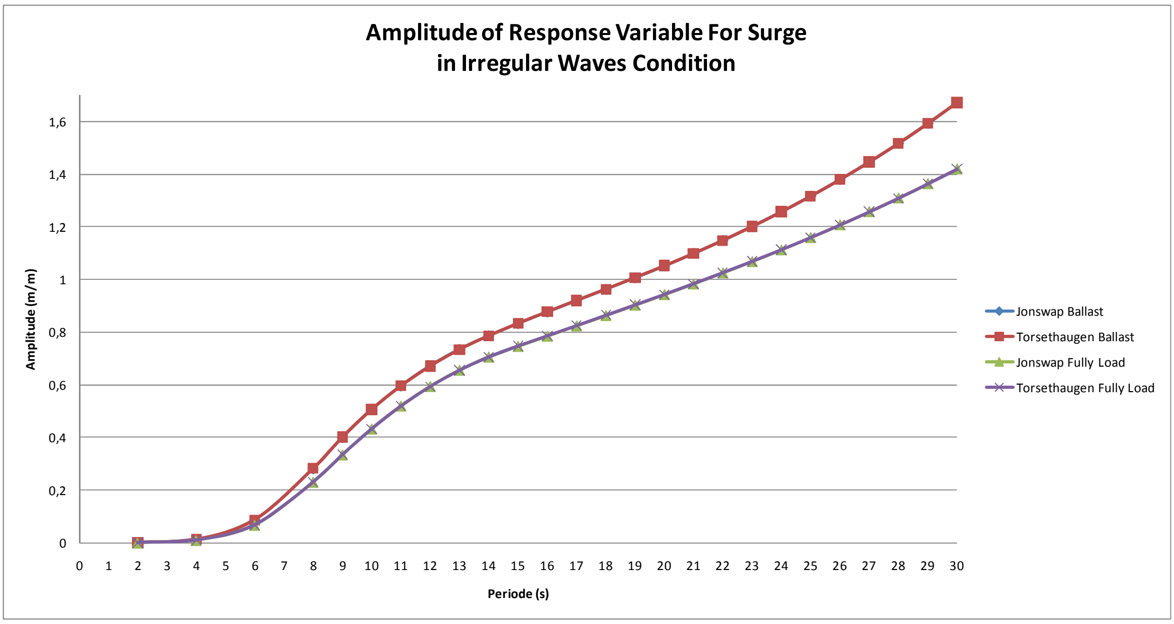


Figure 5. 21. : The amplitude of the response variable for surge in irregular wave condition.

➢ *The sway motions*

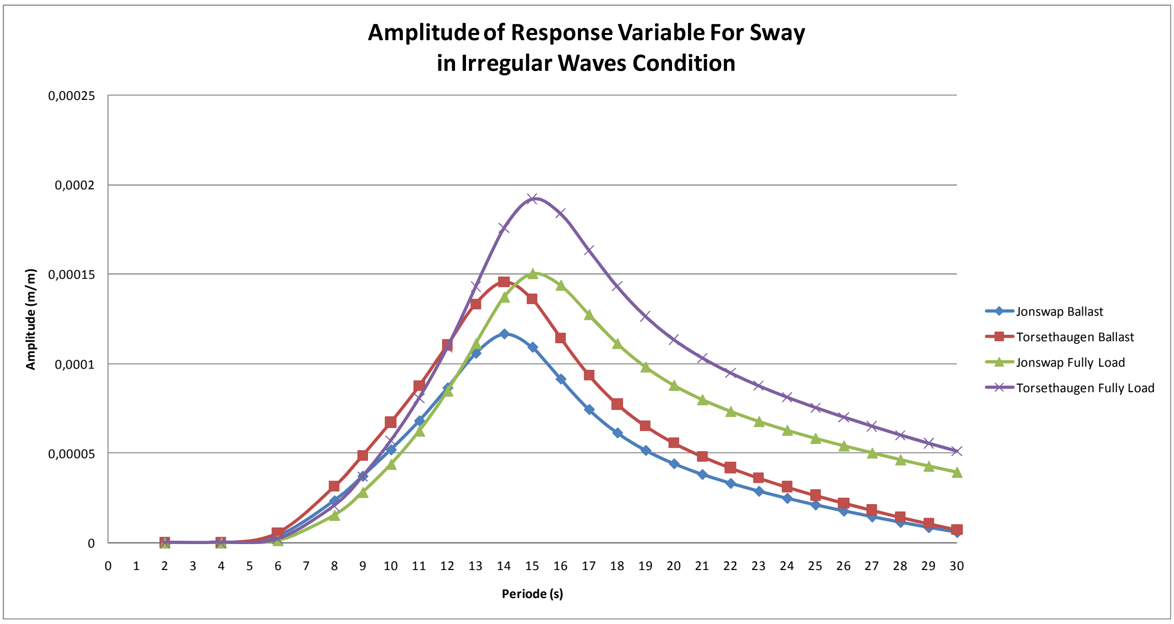


Figure 5. 22. : The amplitude of the response variable for sway in irregular wave condition.

➢ *The roll motions*

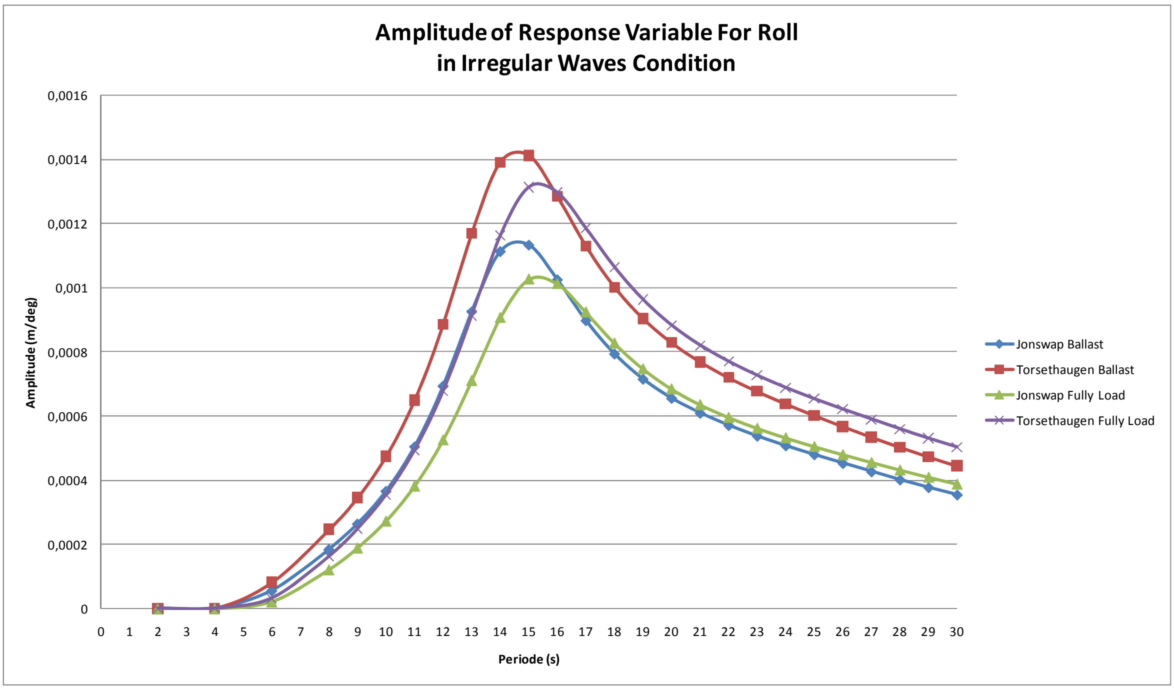


Figure 5. 23. : The amplitude of the response variable for roll in irregular wave condition.

➢ *The pitch motions*

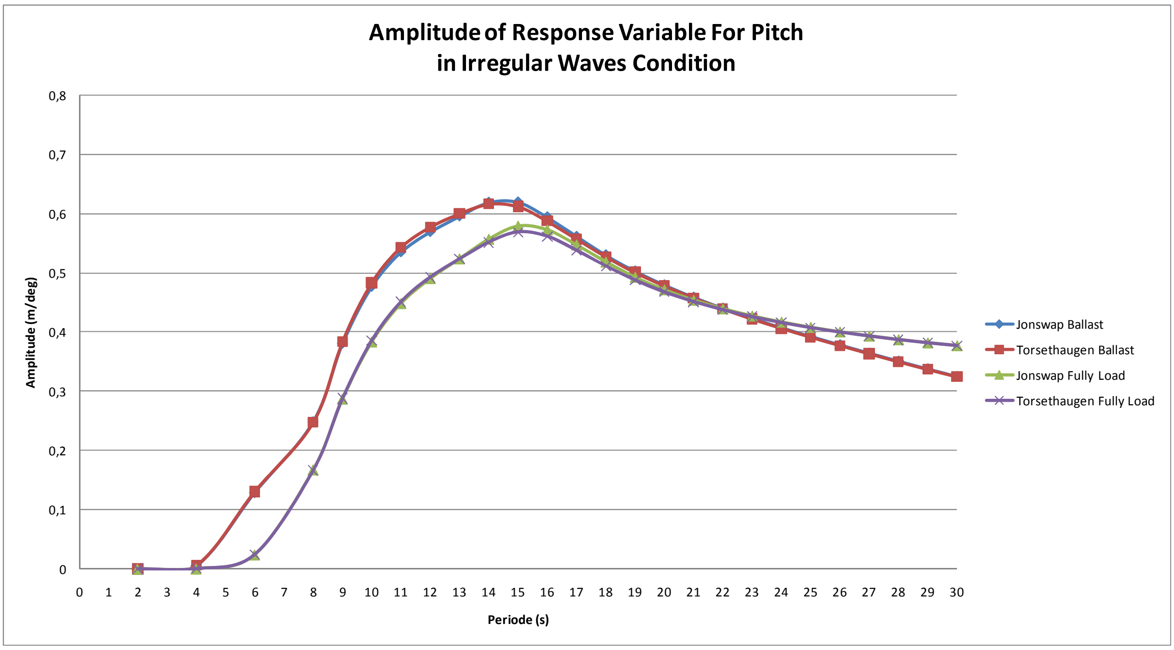


Figure 5. 24. : The amplitude of the response variable for pitch in irregular wave condition.

➢ *The yaw motions*

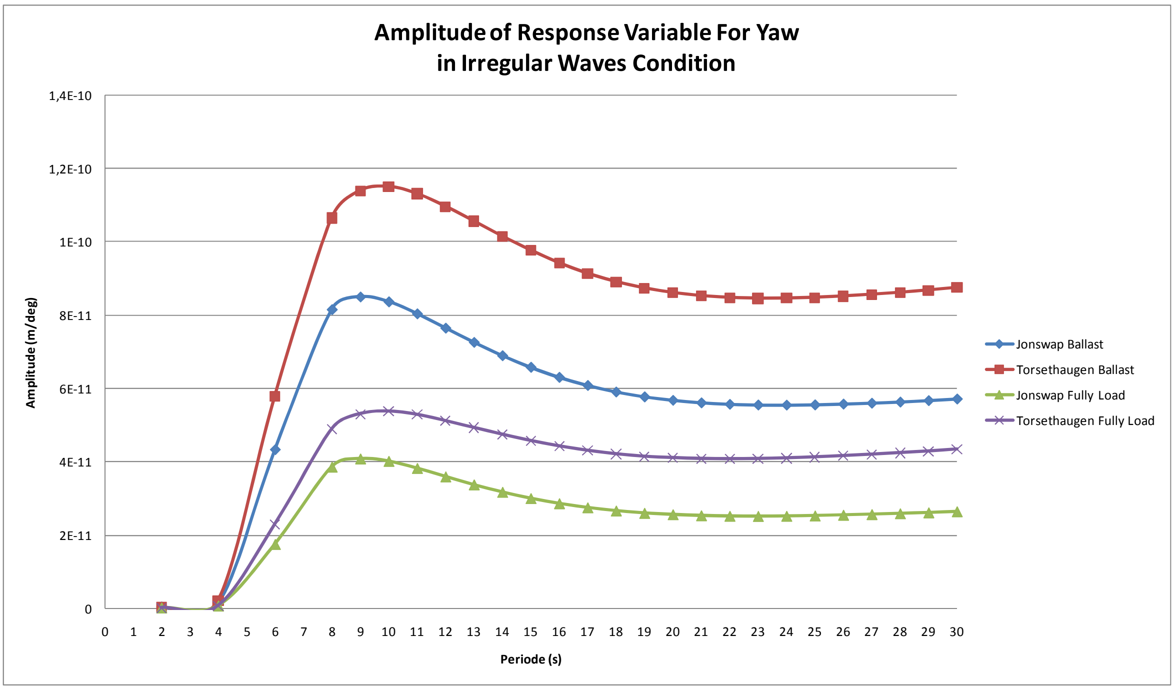


Figure 5. 25. : The amplitude of the response variable for yaw in irregular wave condition.

Based on the information from **Figures 5.21 - 5.25**, the RAOs in irregular waves may be seen to have the same tendency as the RAOs in the regular waves. Moreover, the RAOs in the irregular waves give better behavior for the responses. Hence, we will use the RAOs from the irregular wave analysis as the input to next step, the cylindrical floater motion and moorings analysis in SIMO.

5.3.3 Mean Wave (Drift) Force

The mean wave (drift) forces on a structure can be calculated due to linear incident waves in Wadam. It is not necessary to include the second order terms since the second order potential does not result in mean loads.

The mean wave (drift) force from the two calculation methods, the far field method and the near field method will be presented in **Figures 5.26 – 5.31.** The far field method is based on the equation for conservation of momentum in the fluid while the near field method is based on the direct pressure integration.

Furthermore, the mean wave (drift) force for the three horizontal degrees of freedom (surge, sway and yaw) based on conservation momentum versus the pressure integration calculation method can be seen in **Figures 5.26 - 5.28** while for the remaining degrees of freedom (heave, roll and pitch) the results based on the pressure integration calculation method can be seen in **Figures 5.29 - 5.31.**

As like as transfer functions in *subchapter 5.3.2*, the mean wave drift forces are also calculated for the irregular wave forms. The results can be seen in **Figures 5. 32 - 5. 37**.

A. Mean wave (drift) force for regular waves

➢ *The drift force in surge*

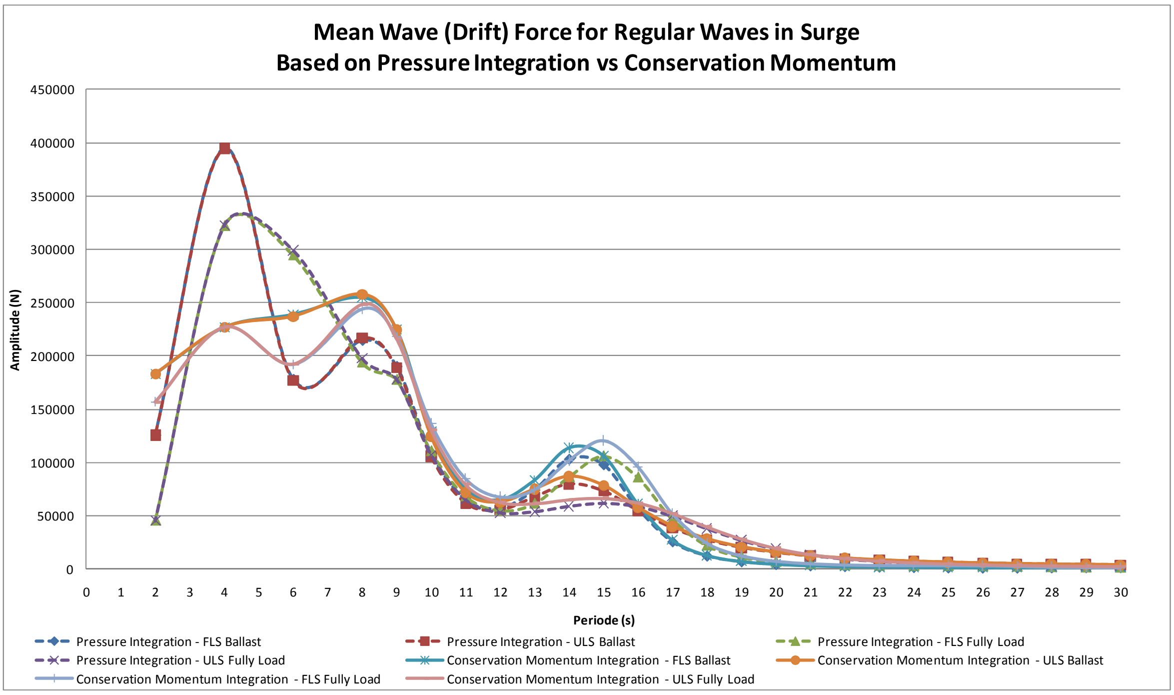


Figure 5. 26. : The drift force, far field versus the pressure integration in surge for regular waves.

➢ *The drift force in sway*

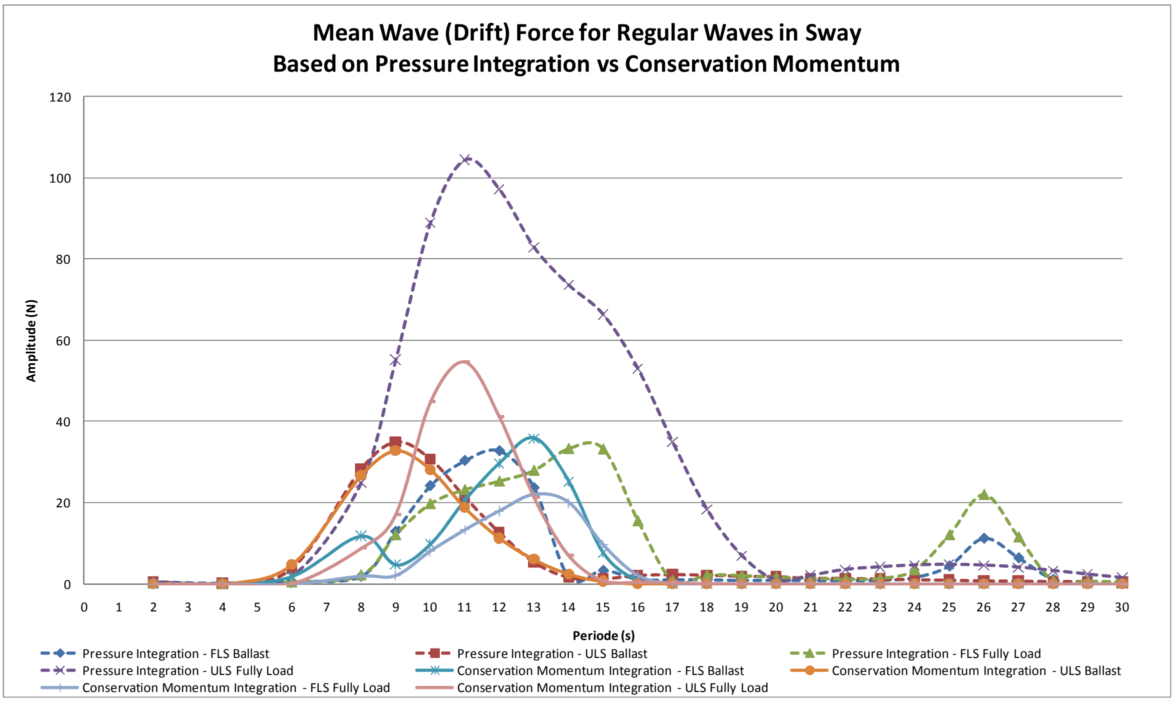


Figure 5. 27. : The drift force, far field versus the pressure integration in sway for regular waves.

➢ *The drift moment in yaw*

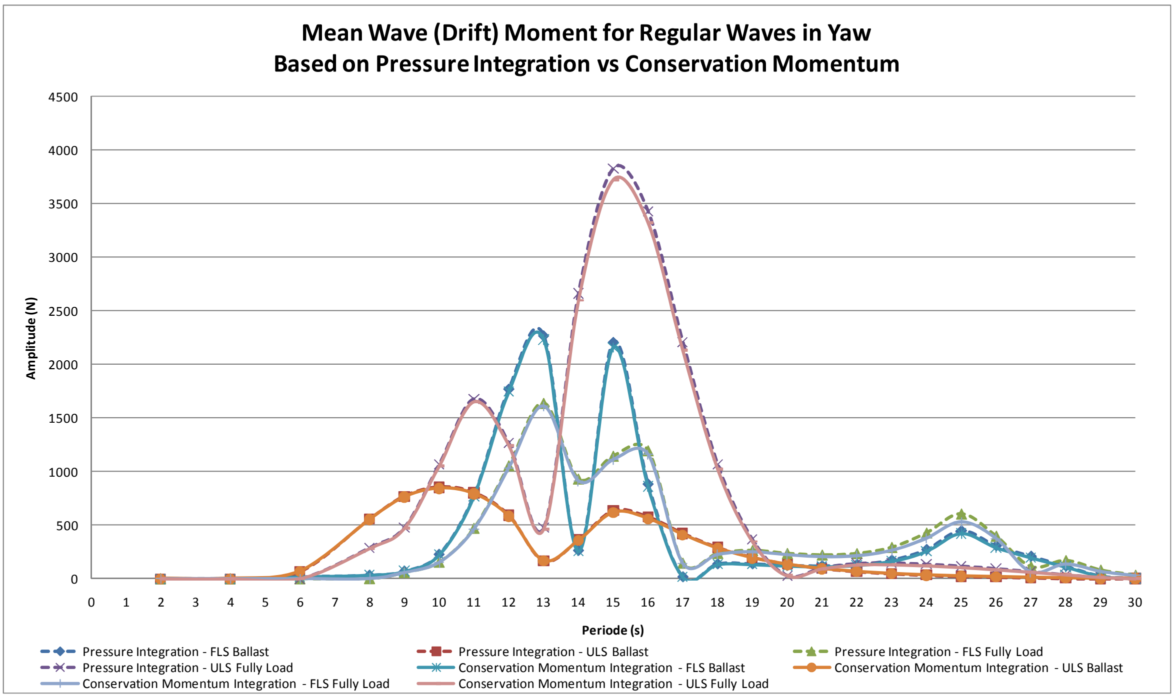


Figure 5. 28. : The drift moment, far field versus the pressure integration in yaw for regular waves.

From **Figure 5.26** above, the mean wave (drift) force based on conservation of momentum versus the pressure integration calculation method for surge shows some differences in calculation results in the range short periods below 10 s, however after 10 s the tendency in the results will be looking similar. Furthermore, the resulting calculations from the far field method give more well-organized results than the pressure integration method.

From **Figure 5.27** above, the mean wave (drift) force based on conservation of momentum versus the pressure integration calculation method for sway shows much variation in the calculation results. Calculation disturbance from numerical model effects is the main reason for the variation in the results. Furthermore, the resulting calculations from the far field method also give more well-organized results than the pressure integration method.

From **Figure 5.28** above, the mean wave (drift) force based on conservation of momentum versus the pressure integration calculation method for yaw shows some differences in the calculation results where most of them coincide along the periods.

Hence, these results from **Figures 5.26 – 5.28** agree with *Hung and Taylor and Scalavounos (1978),* have pointed that the far field method maybe more efficient than the pressure integration method since the the far field method is less demanding on numerical discretization.

The numerical discretization of the geometry for the cylindrical floater S400 are strongly related to the number of elements in the panel model. Hence, a finer discretization of the geometry is can only be generated if the FEM for the panel model has a good surface mesh (a more massive model).

➢ *The drift force in heave*

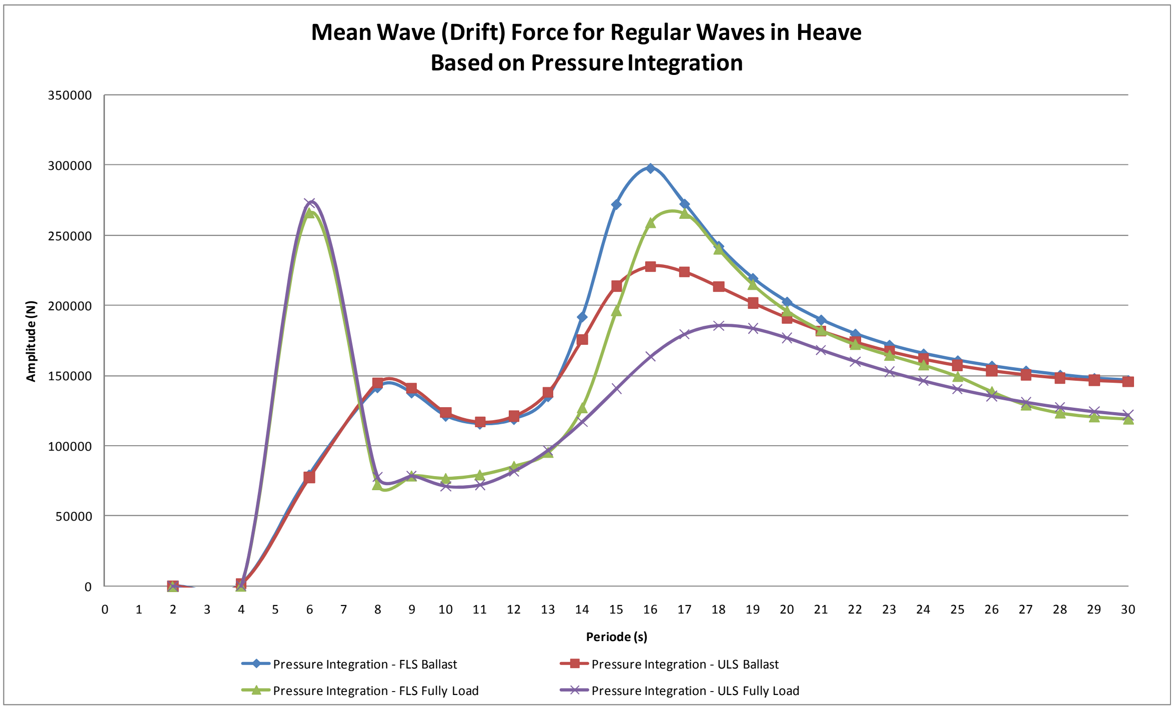


Figure 5. 29. : The drift force, pressure integration in heave for regular waves.

➢ *The drift moment in roll*

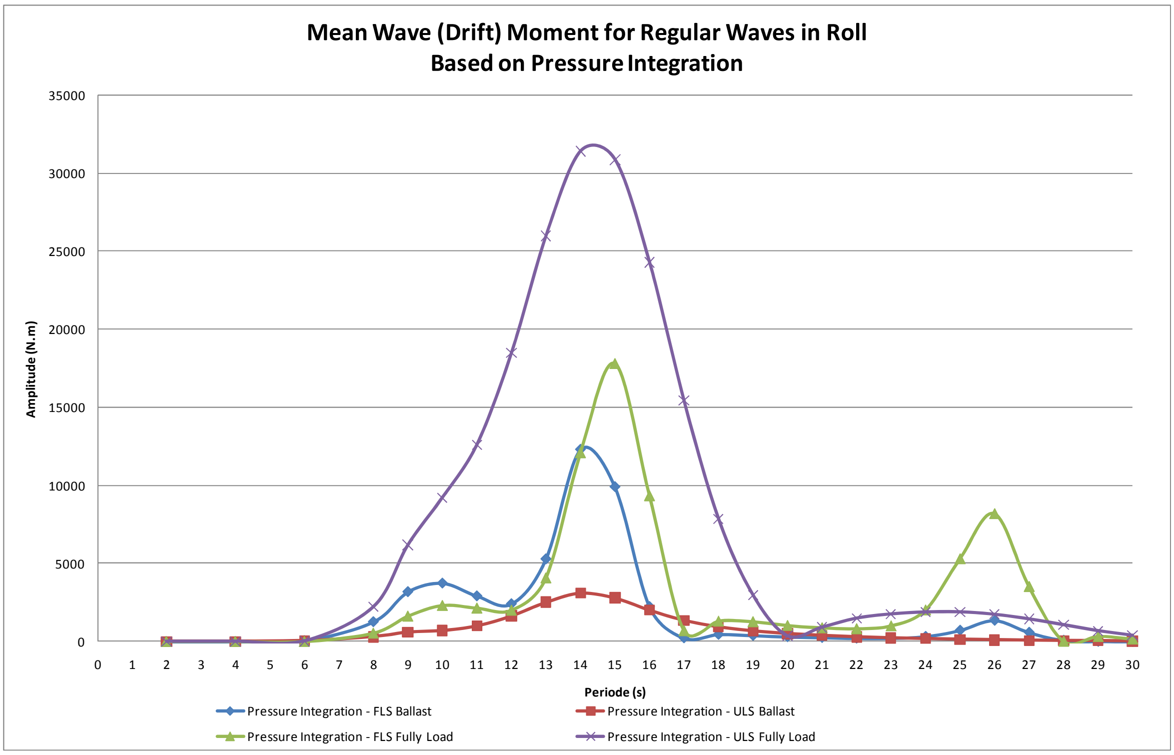


Figure 5. 30. : The drift moment, pressure integration in roll for regular waves.

➢ *The drift moment in pitch*

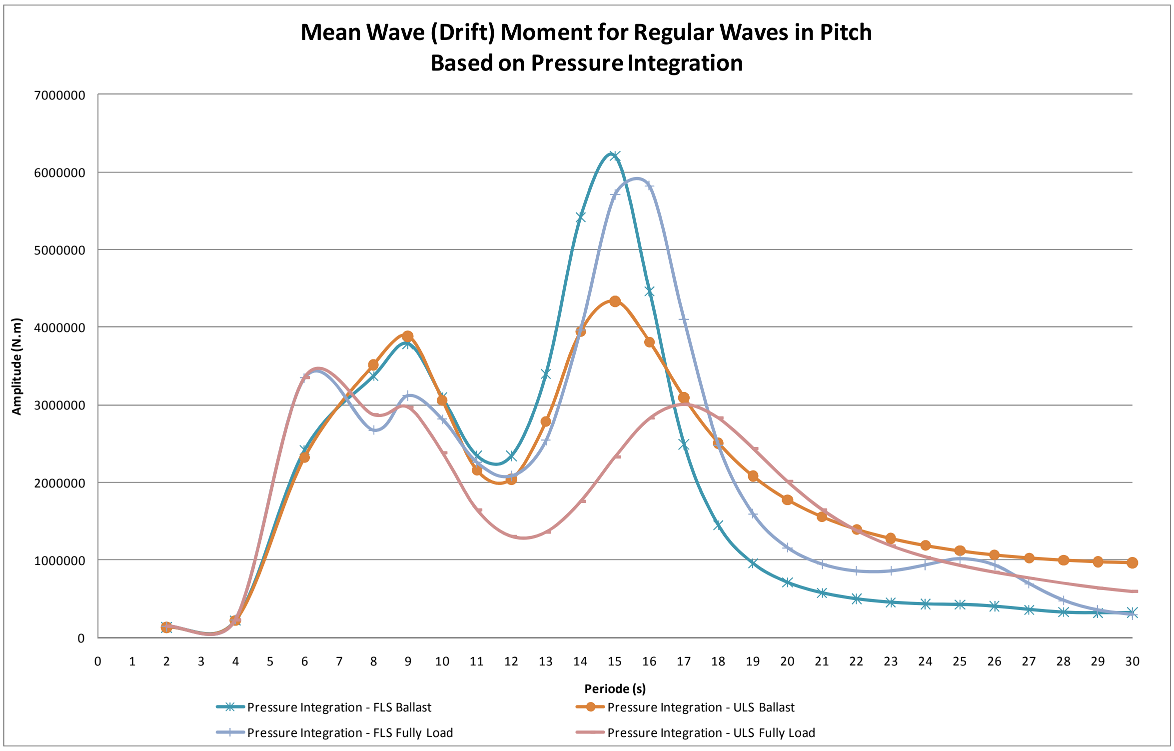


Figure 5. 31. : The drift moment, pressure integration in pitch for regular waves.

On the other hand, the pressure integration method is potentially more useful to obtain the solution for mean wave (drift) force in heave, roll and pitch (**Figures 5.29 – 5.31**) because the far field method has limitation in generating these particular solutions.

B. Mean wave (drift) force for irregular waves

➢ *The drift force in surge*

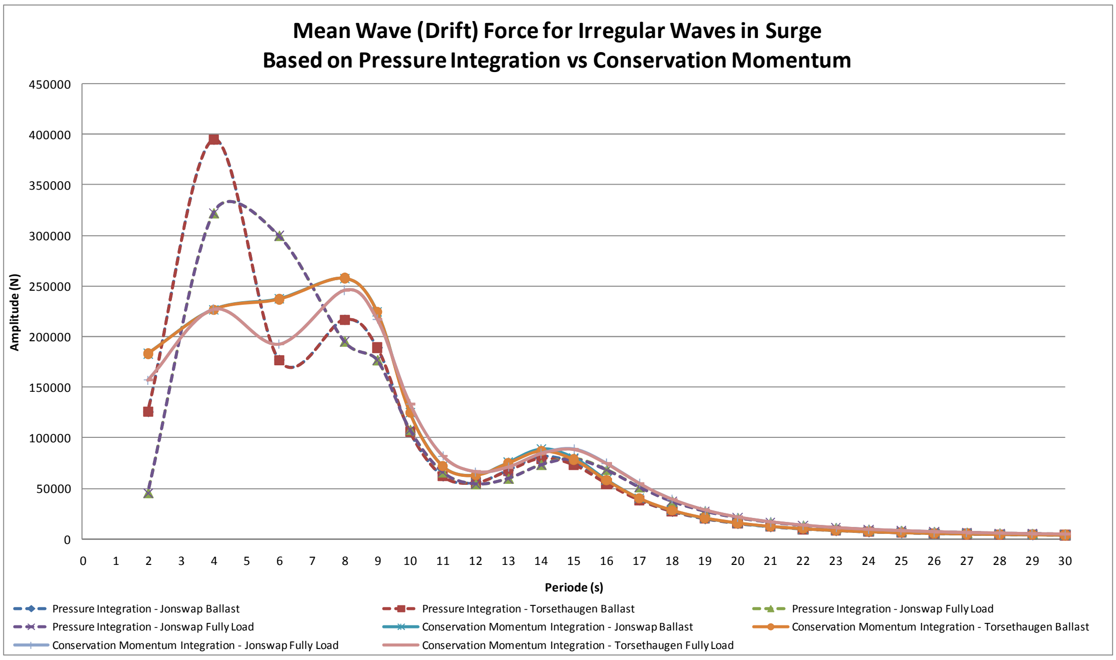


Figure 5. 32. : The drift force, far field versus pressure integration in surge for irregular waves.

➢ *The drift force in sway*

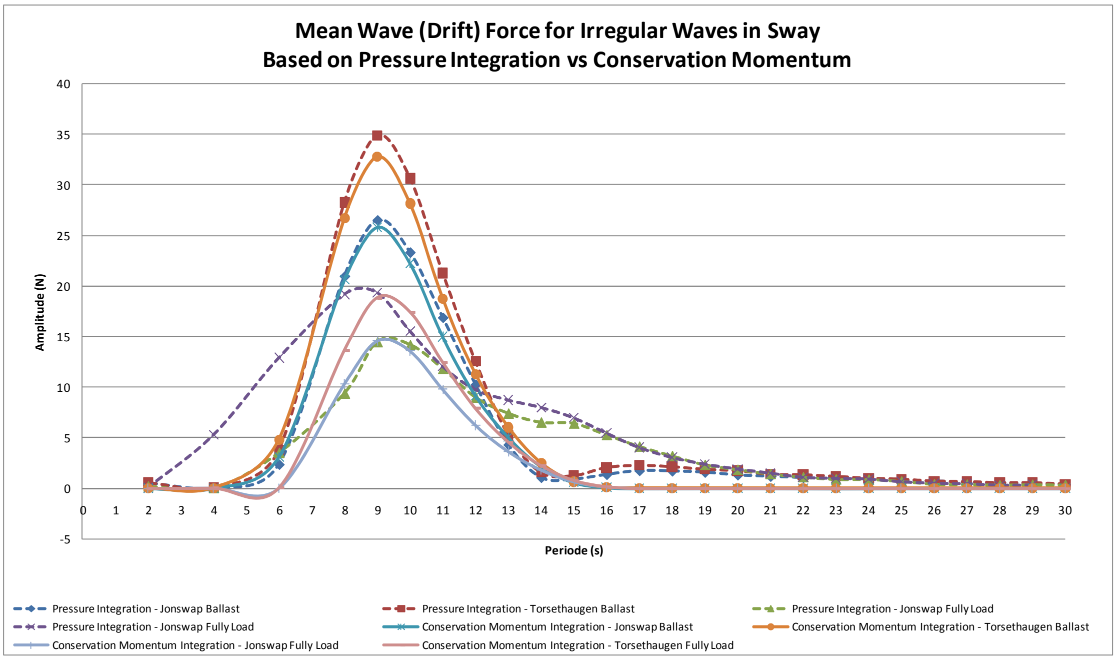


Figure 5. 33. : The drift force, far field versus pressure integration in sway for irregular waves.

➢ *The drift moment in yaw*

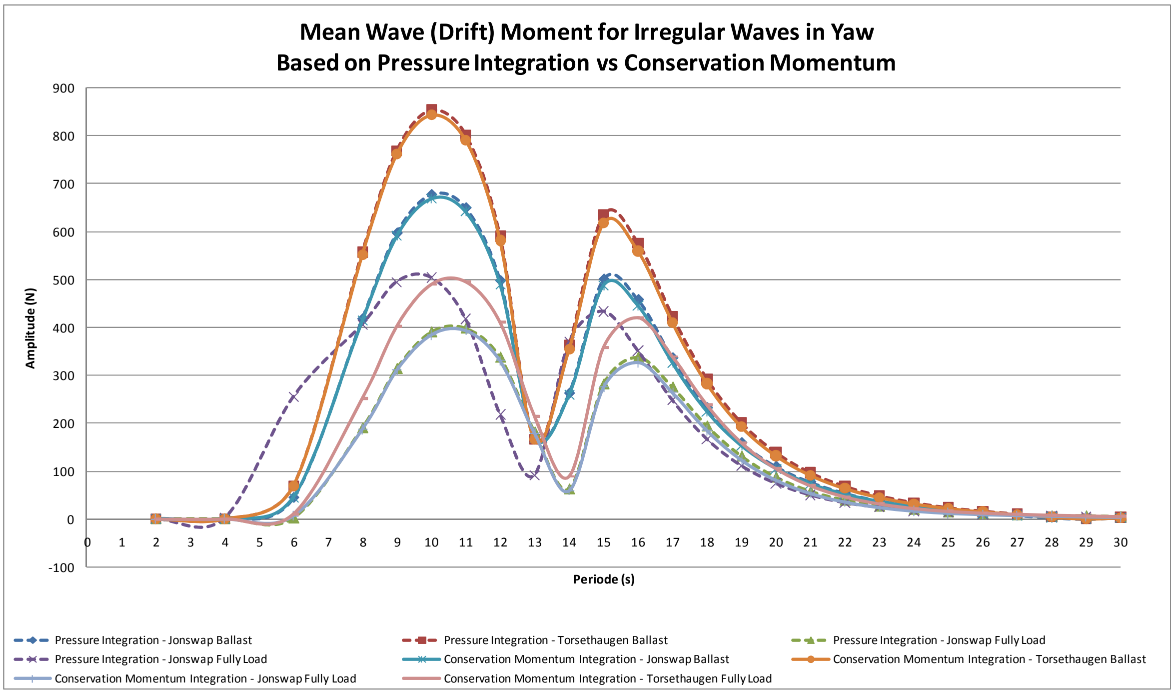


Figure 5. 34. : The drift moment, far field versus pressure integration in yaw for irregular waves.

➢ *The drift force in heave*

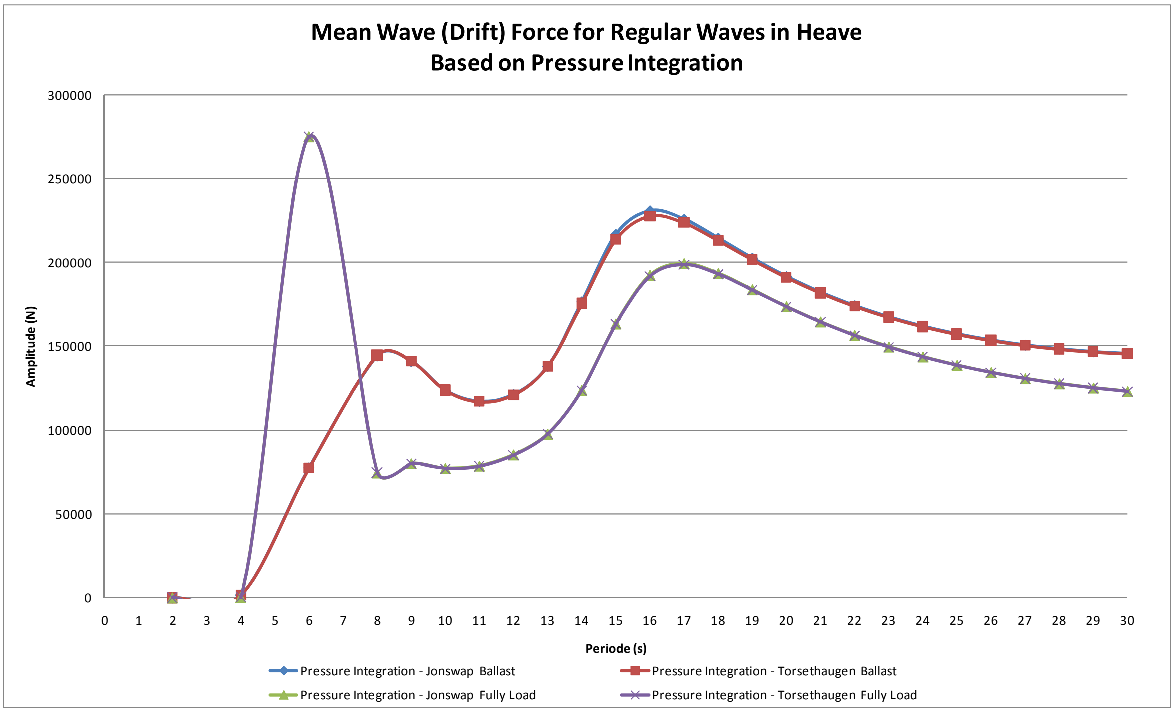


Figure 5. 35. : The drift force, pressure integration in heave for irregular waves.

> *The drift moment in roll*

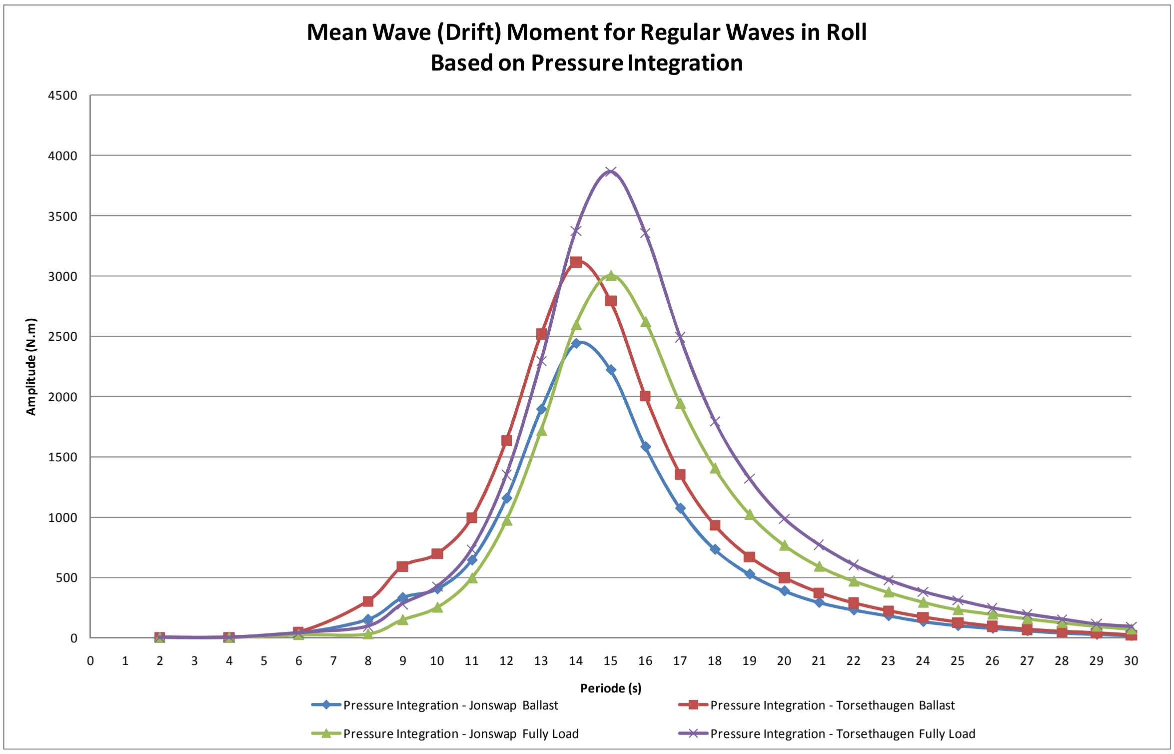


Figure 5. 36. : The drift moment, pressure integration in roll for irregular waves.

> *The drift moment in pitch*

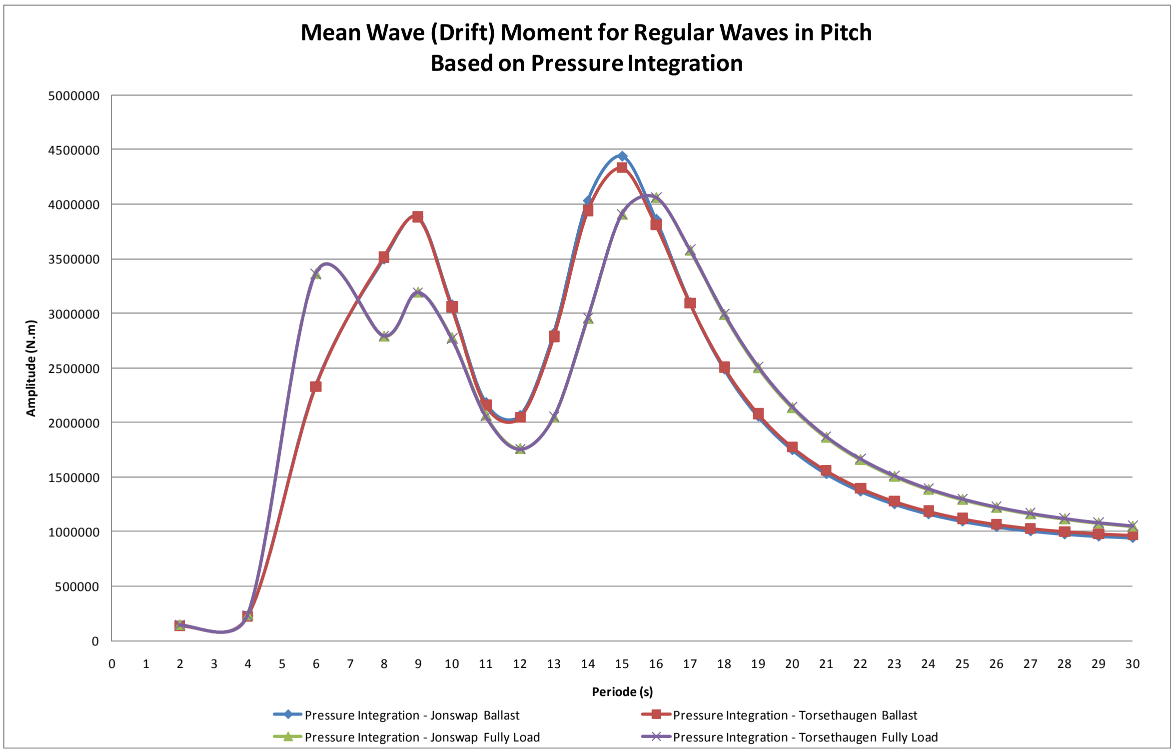


Figure 5. 37. : The drift moment, pressure integration in pitch for irregular waves.

Based on the information from **Figures 5.32 - 5.37**, the mean wave (drift) force in the irregular waves gives better and more well-organized results. Hence, we will use the irregular wave results as the input to next step, the cylindrical floater motion and moorings analysis in SIMO.

5.3.4 Nonlinear Damping Effect

The nonlinear damping effect can be described from the rate of change of the mean drift force between two forms of regular waves (Ho= 25m and Ho= 6m). The sign of this rate of change is in most cases negative, meaning that this will represent a damping mechanism for the slow drift motion excited by the second-order difference frequency forces or due to the interaction of the waves with the current. However, we use absolute value in this case in order to show the magnitude value of the force.

The calculation is based on the pressure integration methods hence the computation of the wave drift damping requires a free surface mesh which is defined as input exactly like the free surface mesh for the second-order analysis.

The non linear damping effects for the cylindrical floater S400 can be seen in **Figures 5.38 – 5.43** below:

- *The non linear damping effect in surge*

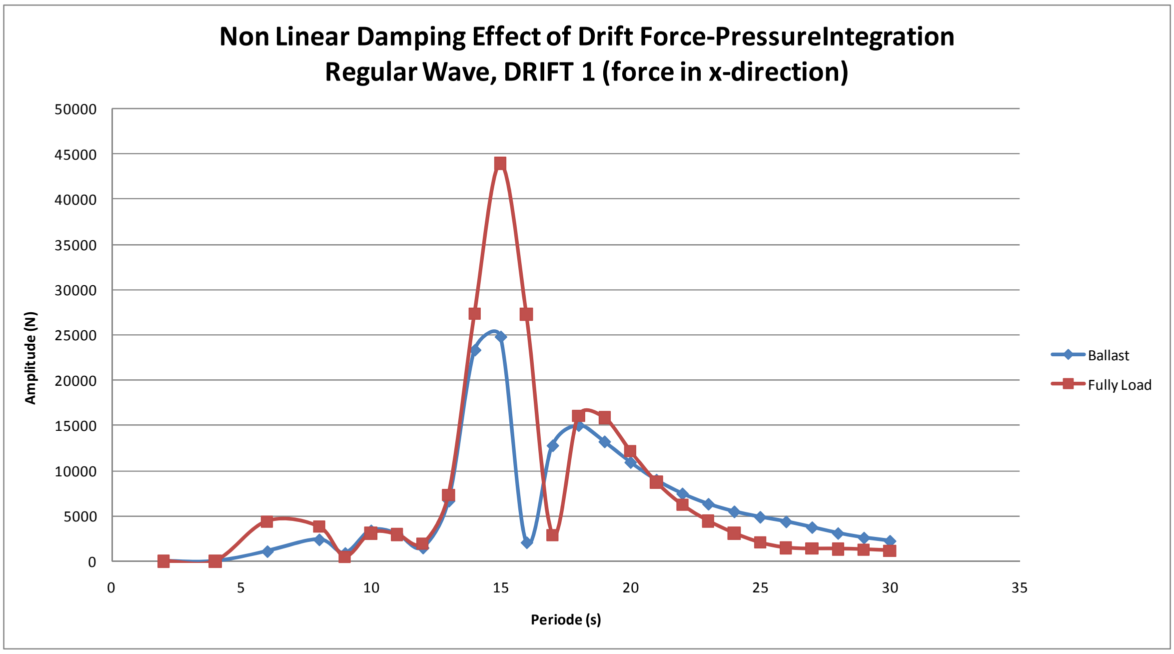


Figure 5. 38. : The non linear damping effect in surge for regular wave.

➢ *The non linear damping effect in sway*

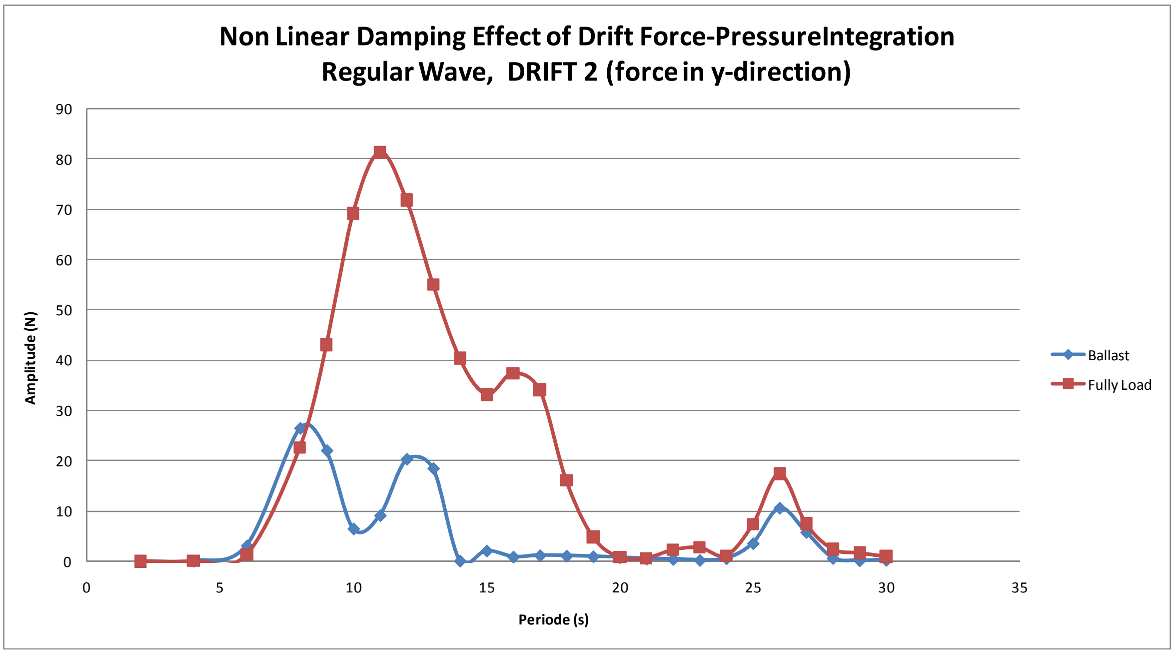


Figure 5. 39. : The non linear damping effect in sway for regular wave.

➢ *The non linear damping effect in heave*

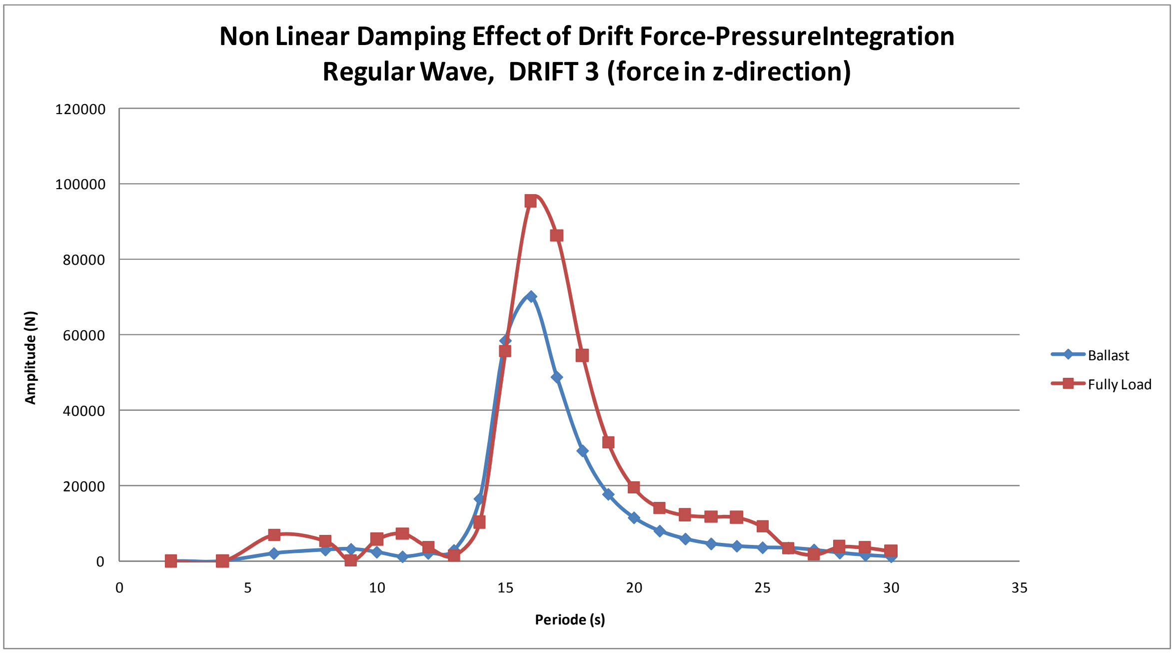


Figure 5. 40. : The non linear damping effect in heave for regular wave.

- *The non linear damping effect in roll*

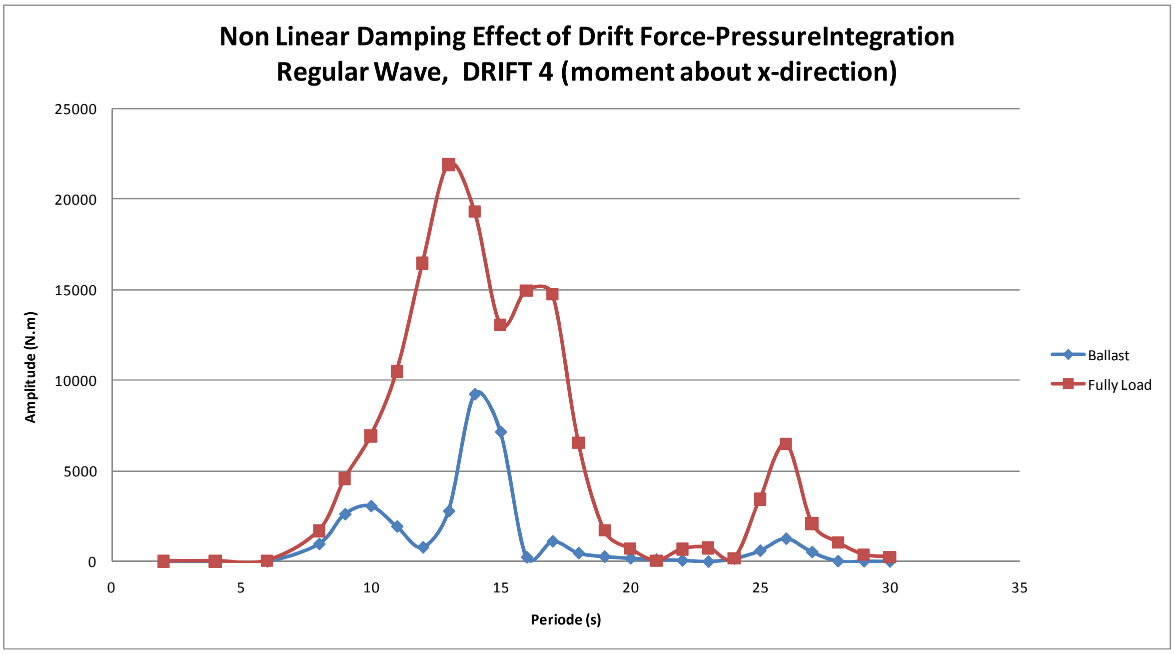


Figure 5. 41. : The non linear damping effect in roll for regular wave.

- *The non linear damping effect in pitch*

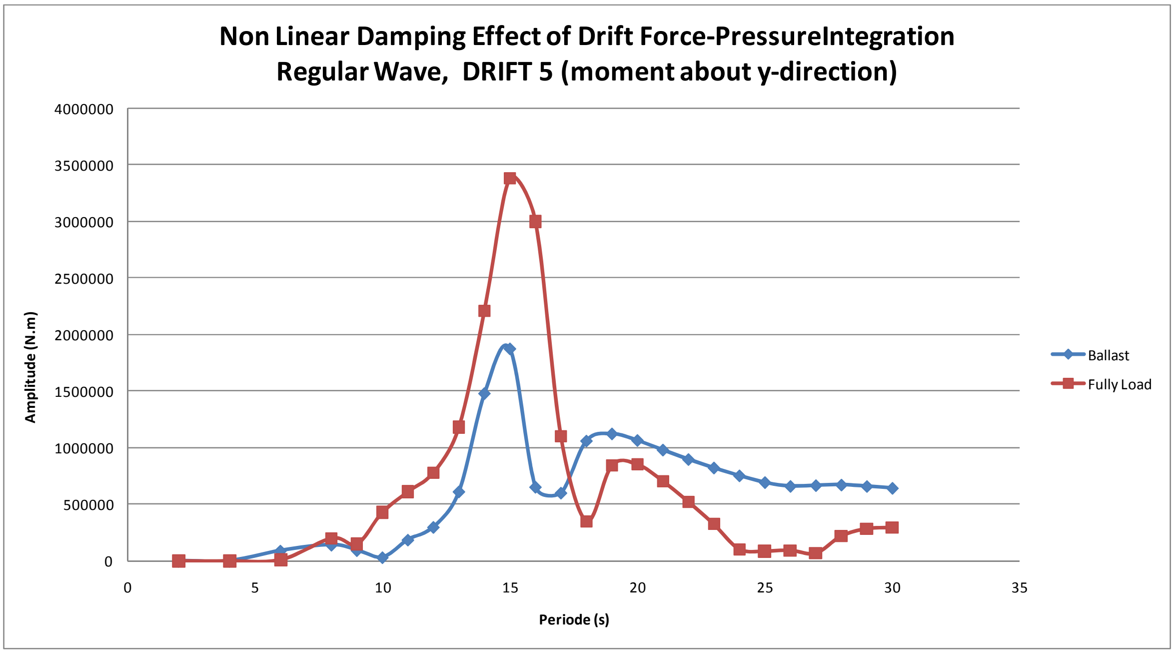


Figure 5. 42. : The non linear damping effect in pitch for regular wave.

- *The non linear damping effect in yaw*

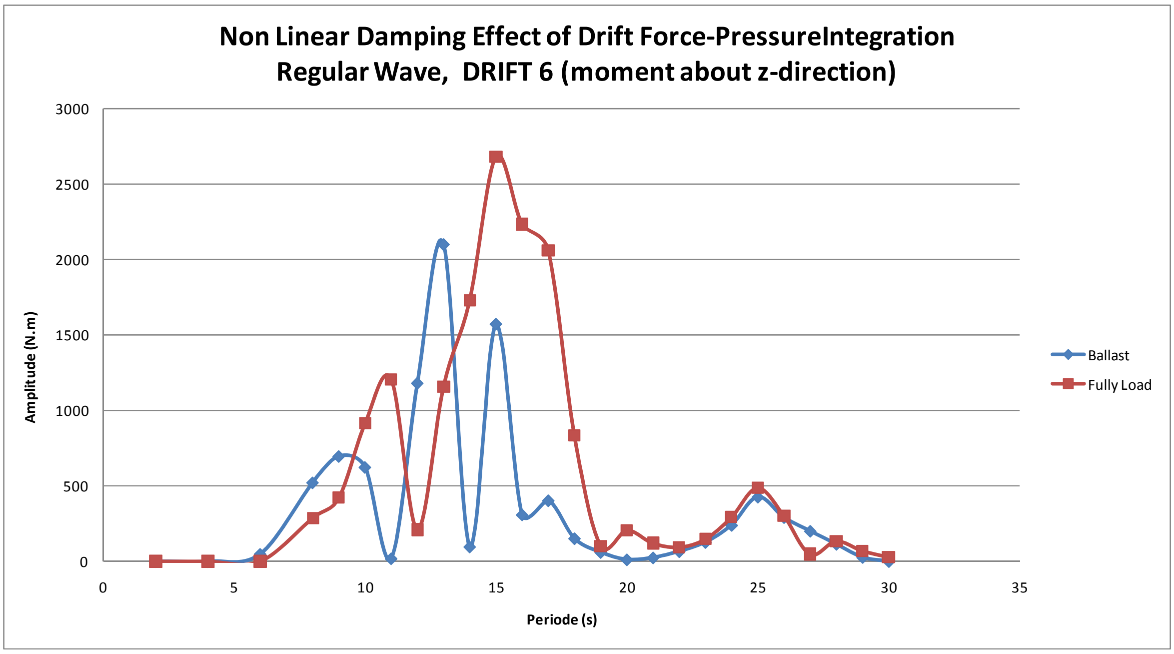


Figure 5. 43. : The non linear damping effect in yaw for regular wave.

Chapter

6

Moorings Analysis

M.S.c. Thesis

Coupled Dynamic Analysis of Cylindrical FPSO, Moorings and Riser

Based on Numerical Simulation

In this chapter the general description regarding the mooring system and the moorings analysis to obtain the horizontal offset values and moorings tension will be presented. Moreover, the modeling concept and the steps for the analysis in SIMO will be presented briefly.

Furthermore, the cylindrical S400 floater and moorings are modeled by using software SIMO for simulation of motions and station-keeping behavior of the floater, the analysis has been performed in time domain.

The moorings lay out and composition of lines will be presented here. The analysis has been performed in SIMO for static and dynamic conditions. The static condition will give results such as static moment and forces for a cylindrical S400 floater and moorings and also the bodies position in static condition; while in the dynamic condition the results will be motion response given by time series, the second order wave forces and also wave drift damping forces and also the positioning system forces for the moorings.

6.1 Mooring Systems

It is essential that floating structures have precise motions and position systems. Hence, the mooring system is important to hold the structure against winds, waves and currents (**Figure 6.1**). *Chakrabarti, S. (2005)* has mentioned that mooring system design is a trade-off between making the system compliant enough to avoid excessive forces on the floater and making it stiff enough to avoid difficulties due to excessive offsets. This is very difficult in shallow water. *Chakrabarti, S. (2005)* also suggests to develop increasingly integrated moorings/riser system design methods to optimize the system components to ensure lifetime system integrity.

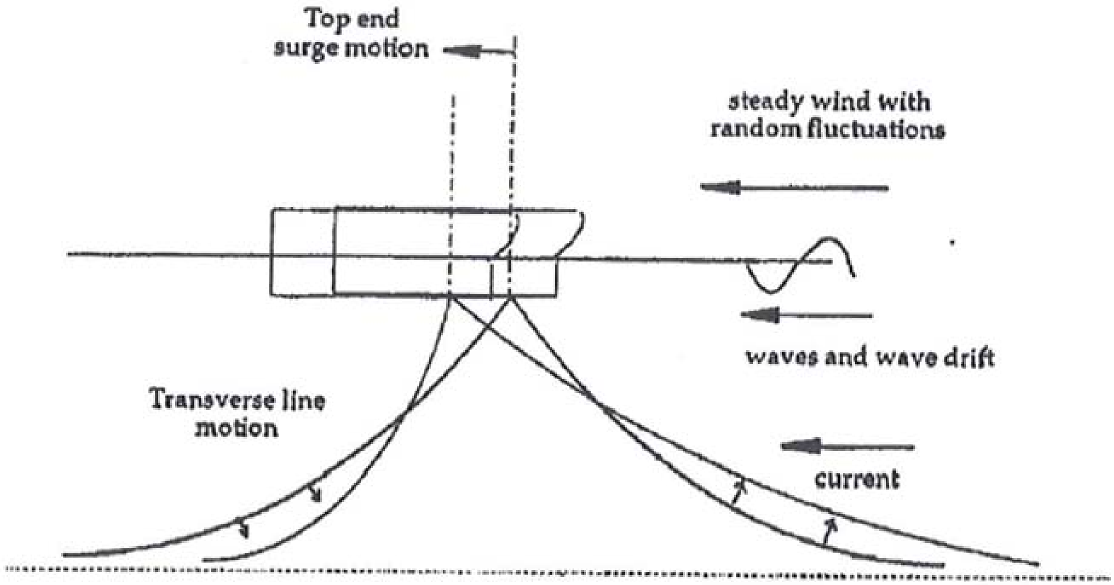


Figure 6. 1. : Environmental forces acting on a moored vessel in head conditions and the transverse motion of catenary mooring lines.

Reference: Chakrabarti S. *(2005)*

The mooring system for a cylindrical S400 floater will adopt the spread mooring system without using a thruster to stay in the desired position. The spread of mooring lines as in a conventionally mooring system each of the lines forms a catenary shape. A spread of mooring lines generates a non linear restoring force by relying on an increase or decreases in line tension as the mooring lines lift off or settle on the seabed. The force increases with the horizontal offset and balances quasy-steady environmental loads on the surface platform.

Furthermore, *Faltinsen (1990)* has mentioned that the tension forces in the lines depend on their weight and elastic properties and are also depending on the manner in which moorings are laid. Besides, the longitudinal motion and transverse motions of the moorings themselves can also influence the response of a floater through line dynamics. Hence, the moorings have an effective stiffness composed of an elastic and a geometric stiffness which combined with the motion of the unit will introduce forces on lines.

The mooring system for the cylindrical S400 floater consists of 12 mooring lines which are distributed on 3 clusters (3 groups of 4 lines). The overall line lay out of the mooring lines is shown in **Figure 6.2** below:

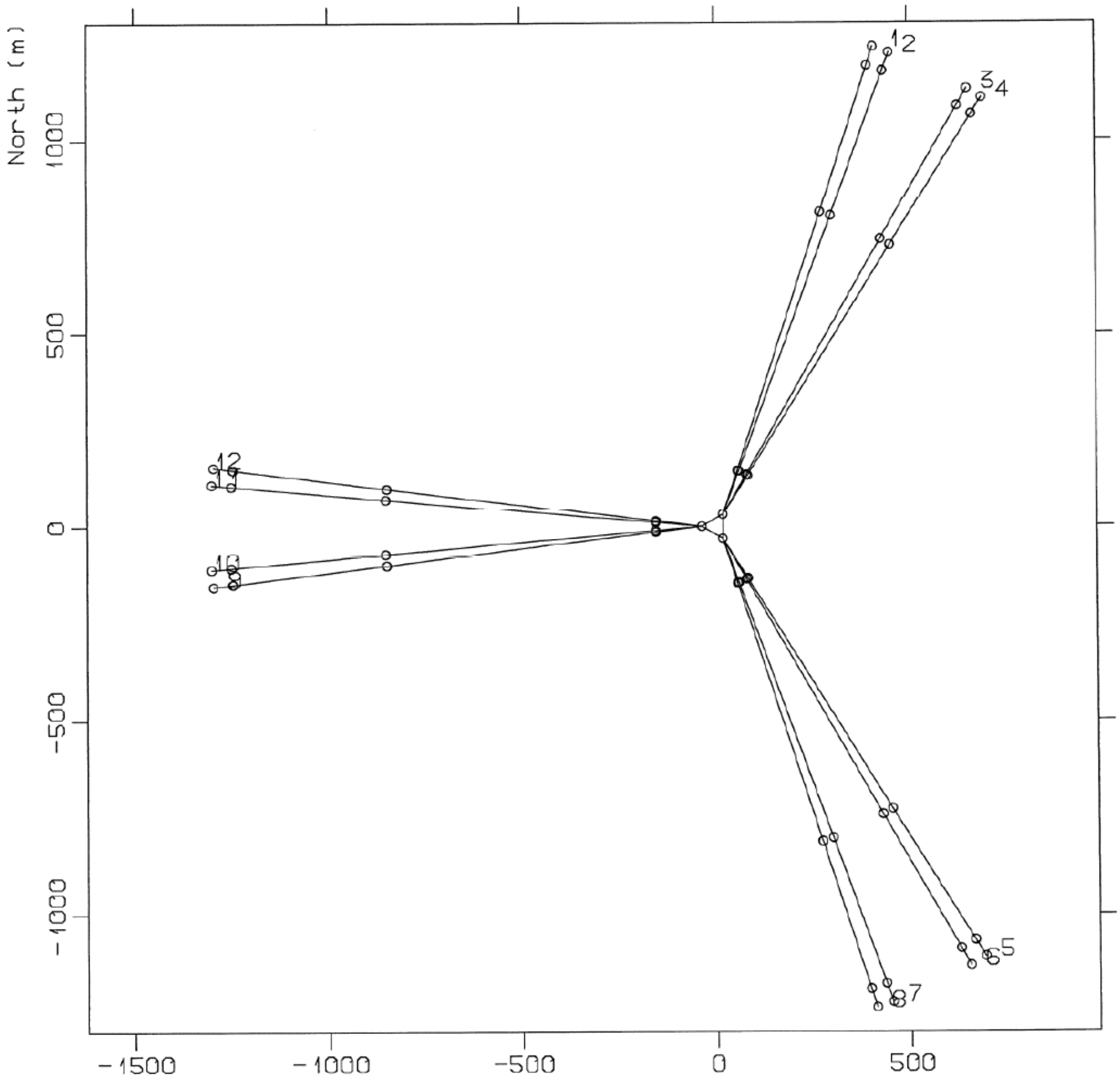


Figure 6. 2. : Mooring lines layout overview.

Reference: Sevan Marine *(2011)*

The mooring lines for a cylindrical S400 floater will be made from combination of chain and polyester rope. The polyester has been considered in the design because it has good characteristics such as being lighter, relatively very flexible and having capability to absorb imposed dynamic motions through extension without causing an excessive dynamic tension. Moreover, it also reduces the line length of mooring lines.

The composition of a mooring line for a cylindrical S400 floater will be fairlead, top chain segments, upper polyester segment and lower polyester segment, anchor chain segment and anchor. The given length of the top chain represent the "as installed" initial length of the top chain measured from fairlead to the polyester rope connection. The total length of this chain segment is 125 m.

The details of the composition of each of the 12 mooring lines are shown in **Table 6.1** and in **Figure 6.3**.

Table 6. 1. : Mooring Line Composition for Sevan 400 FPSO

Segment Type (From Anchor)	Lenghth (m)	Nominal diameter (mm)	Axial stiffness EA (kN)	Weight in air (kN/m)	Submerged Weight (kN/m)
Anchor	-	-	-	-	-
Anchor Chain	50	155	1.76E+06	4.71	4.1
Link	1	-	-	25	22
Lower Polyester Rope	400	260	See comments below	0.46	0.12
Buoy w. link	5	-	-	225	-125
Upper Polyester Rope	700	260	See comments below	0.46	0.12
Link	1	1	-	25	22
Top Chain	125	155	1.76E+06	4.71	4.1

Reference: Sevan Marine *(2011)*

Comments:

For the axial stiffness of the polyester rope, different mooring line stiffness values have to be considered. The following stiffness values are defined based on *DNV-OS-E301 (2004)*. Typical values of stiffness data for fibre moorings are determined from the test program of the actual polyester rope.

In this study, two typical values of stiffness data for polyester are used:

1. Static stiffness also called drift stiffness is the **intermediate** of stiffness values for polyester from 18.4 MBL (Minimum Breaking Load)
2. Dynamic stiffness also called storm stiffness is the **maximum** of stiffness values for polyester from 18.4 MBL (Minimum Breaking Load)

Moreover, the MBL of the polyester Rope and Chain are:

1. 260 mm Polyester Rope; MBL=19250 kN
2. 155 mm Chain, Grade R4; MBL=20802 kN

The corrosion properties for the chains are also considered in the design. According to ISO 19901-7 (2005), a corrosion allowance referred to the chain diameter, can be taken to be 0.4 mm/year for splash zone and 0.2 mm/year for the remaining length. Using the combined fairlead/chain stopper solution the entire load carrying part of the mooring chain (i.e. part outside the Chain stopper) will be below splash zone. 0.2 mm/year corrosion allowance has therefore been assumed. Based on the specified a design life of 20 years and assuming no replacement of mooring lines, this gives a reduction of the diameter of 4 mm, which implies: 155 mm Chain, Grade R4; MBL=19942 kN (Including 20 years corrosion margin).

The choice of anchor will be based on the actual soil conditions. At present, use of suction anchors is the base case.

Furthermore, the mooring line composition can also be seen in **Figure 6.3** below:

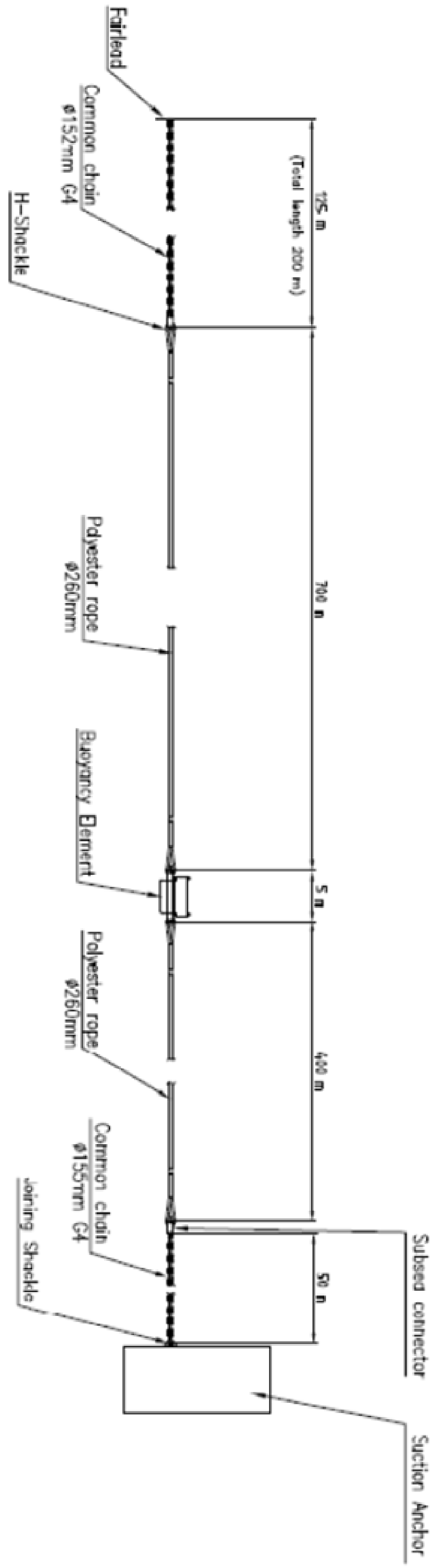


Figure 6. 3. : Mooring line composition.

Reference: Sevan Marine *(2011)*

The detailed orientation and the pretension of the lines will be given based on the SIMO configuration and can be seen in **Table 6.2** as follow:

Table 6. 2. : The Detailed Orientation and The Pretension of The Lines for Mooring System of Sevan 400 FPSO

Name	X (m)	Y (m)	Z (m)	Pretension (kN)	Direction (degree)
S400_Line1	31.2	-18	-9.35	1.75E+03	342
S400_Line2	31.2	-18	-9.35	1.75E+03	340
S400_Line3	31.2	-18	-9.35	1.75E+03	330
S400_Line4	31.2	-18	-9.35	1.75E+03	328
S400_Line5	-31.2	-18	-9.35	1.75E+03	212
S400_Line6	-31.2	-18	-9.35	1.75E+03	210
S400_Line7	-31.2	-18	-9.35	1.75E+03	200
S400_Line8	-31.2	-18	-9.35	1.75E+03	198
S400_Line9	0	36	-9.35	1.50E+03	97
S400_Line10	0	36	-9.35	1.50E+03	95
S400_Line11	0	36	-9.35	1.50E+03	85
S400_Line12	0	36	-9.35	1.50E+03	83

Reference: Sevan Marine *(2011)*

The initial tension or pre-tension in mooring lines are established by the use of winches on the floater. The winches pull on the mooring lines to set up the desirable configurations. Hence, a cylindrical S400 floater will be also equipped with the mooring winches. The mooring winches are located on the main deck. The mooring winches will be of the rotating type with one winch for each cluster. The winches can be skidded on rails on the main deck to cover the different lines in the cluster.

By using the winches, a cylindrical S400 floater can be moved to different positions relative to its defined zero position. The maximum radius will depend on the length of the top chain and the storage capacity of the chain lockers. The present mooring system solution is based on a maximum offset radius of 75 m. This imply that the Sevan Floater, may be located at any position within a radius of 75 m from its defined zero position.

The movable winches will be installed by one winch per cluster on the main deck. The typical winch that will be applied on a cylindrical S400 floater can be seen in **Figure 6.4** below:

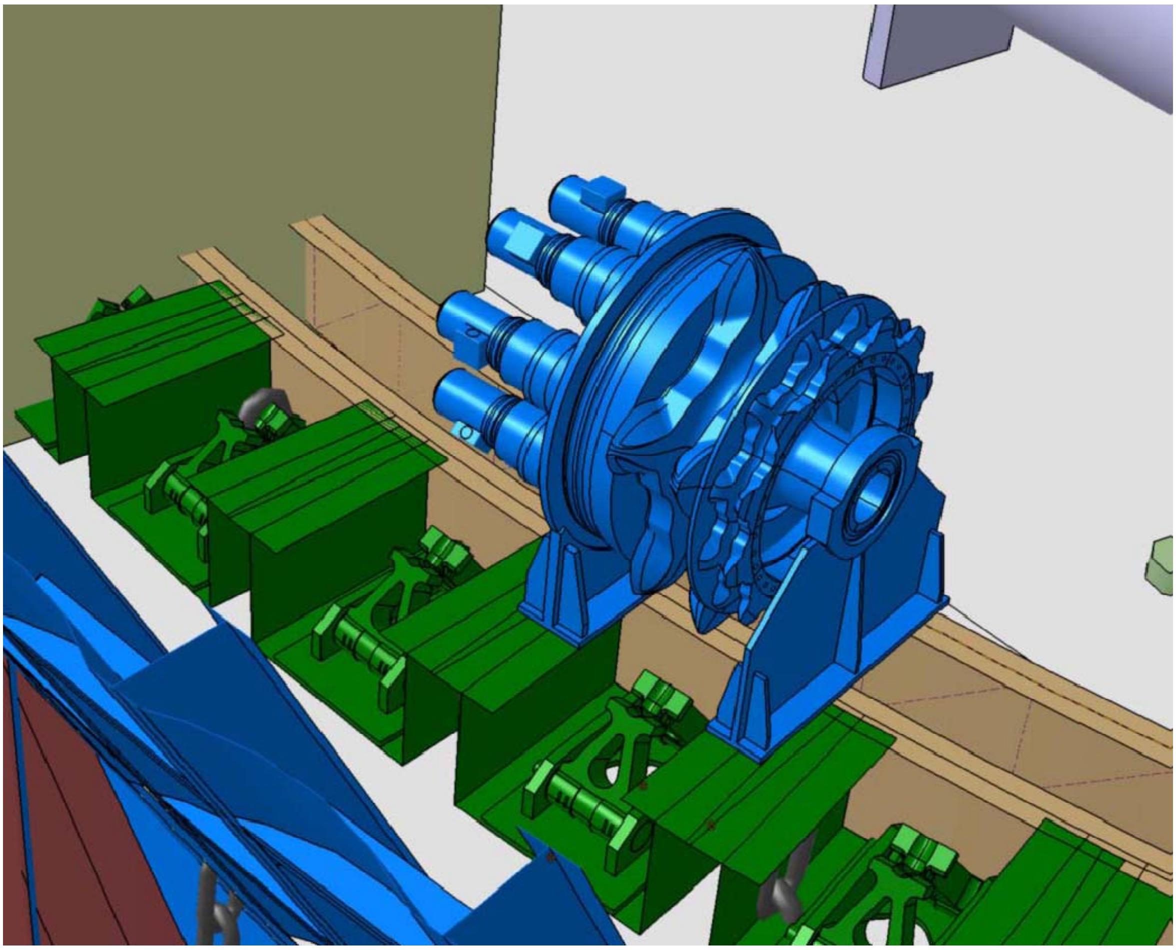


Figure 6. 4. : The movable winch on a cylindrical S400 floater.

Reference: Sevan Marine *(2011)*

Besides the moveable winches, a cylindrical S400 floater will be also equipped with combined fairlead/chain stoppers. This combined solution has the following advantages compared to the traditional solution with fairlead at the FPSO side and chain stopper at the main deck such as:

- Since the position of the chain stopper is below splash zone, it will gives less required corrosion allowance for the loaded part of the Chain (0.2 mm/year relative to 0.4 mm/year, according to *ISO 19901-7 (2005))*
- It also gives lower resulting mooring forces at fairlead interface towards hull structure and reduced strength requirements at main deck (no mooring forces transferred to this level)

However, this is also a drawback with this solution. It makes the chain stoppers not directly accessible for inspection and maintenance.

The fairlead and chain stoppers (i.e. chain stopper outside fairlead) are located at the bilge box; it can be seen in **Figure 6.5** below:

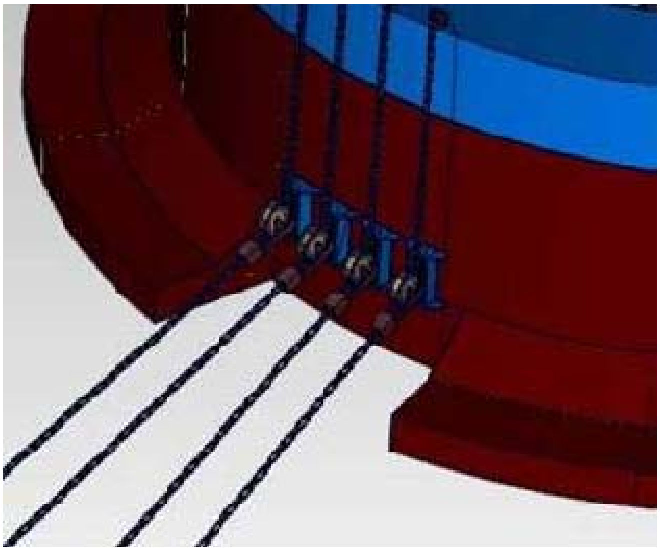


Figure 6. 5. : The combined fairlead/chain stopper on a cylindrical S400 floater.

Reference: Sevan Marine *(2011)*

6.2 Mooring System Design

The aim of the moorings analysis is to ensure that the mooring system has adequate capacity to generate a non-linear restoring force to provide the station-keeping function. This force will be expressed by the mooring tension that will also be influenced by the horizontal offset values.

6.2.1 Basic Theory for Design

Since a cylindrical S400 floater adopts the spread mooring system, the basic mechanics of catenary moorings is still satisfactory to be used as a basic theory for model the concept. Further, the basic mechanics of catenary moorings will be described by the catenary model. From the behavior of catenary moorings one can derive line tension and horizontal force in moorings. The theoretical background of the catenary mooring lines has been adopted from *Faltinsen (1990)* and *Chakrabarti, S. (2005).*

The catenary model for a single line mooring and the force acting on a segment of the mooring line is depicted in **Figure 6.6** and **Figure 6.7** below:

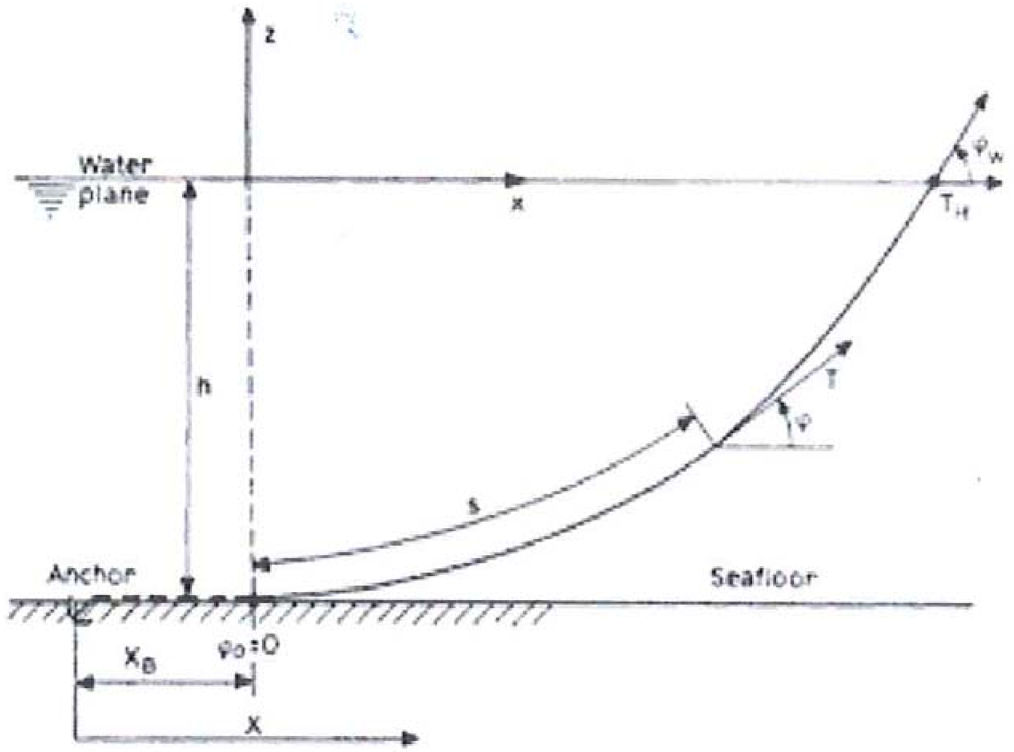


Figure 6. 6. : The cable line with symbols.

Reference: Chakrabarti, S. (2005)

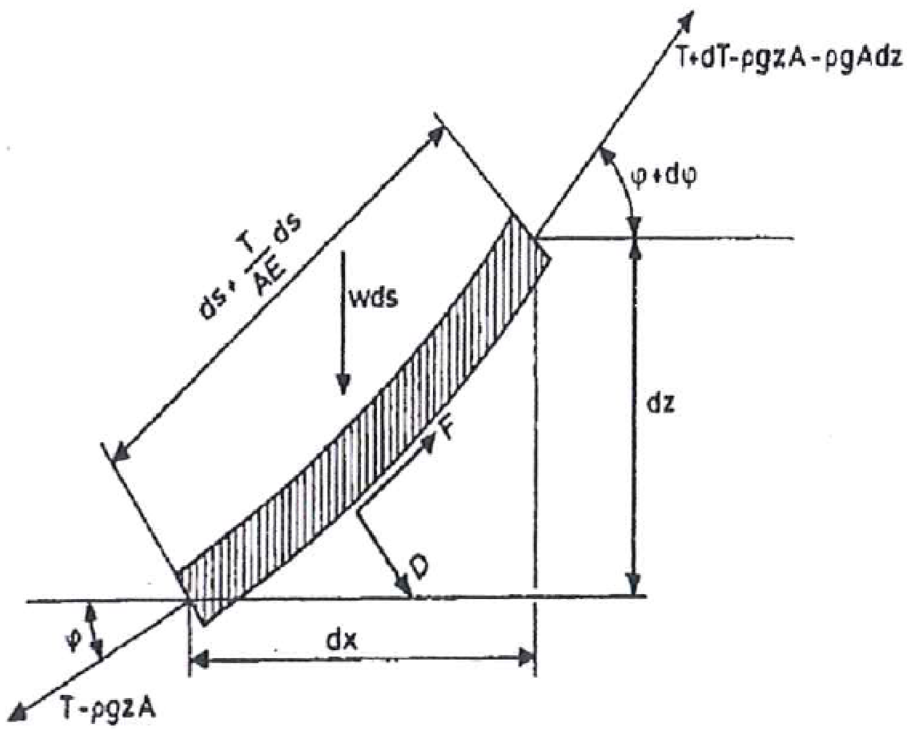


Figure 6. 7. : The forces acting on an element of mooring line.

Reference: Chakrabarti, S. (2005)

The term w represents the constant submerged line weight per unit length, T is the line tension, A is the cross-sectional area and E is the elastic modulus. The mean hydrodynamic forces on the element are given by D and F per unit length.

The assumptions are neglecting bending stiffness and the single line in a vertical plane coincides with the x-z plane. By analyzing the equilibrium in normal and tangential directions in one element of the mooring line, we can write equations as follow:

$$dT - \rho gAdz = \left[wsin\phi - F\left(\frac{T}{EA}\right)\right]ds \quad (6.1)$$

$$Td\phi - \rho gAdzd\phi = \left[wcos\phi + D\left(1 + \frac{T}{EA}\right)\right]ds \quad (6.2)$$

In order to simplify the equation above, the hydrodynamic forces from F and D will be neglected. It is noted that elastic stretch can be important and needs to be considered when lines become tight or for a large suspended line weight (large w or deepwater)

The vertical dimension, h, and the suspended line length, S, can be obtained as follow:

$$S = \left(\frac{T_H}{w}\right) sinh\left(\frac{wx}{T_H}\right) \quad (6.3)$$

$$h = \left(\frac{T_H}{w}\right)\left[cosh\left(\frac{wx}{T_H}\right) - 1\right] \quad (6.4)$$

Giving the tension in the line at the top, written in terms of the catenary length S and depth d as:

$$T = \frac{w(S^2+d^2)}{2d} \quad (6.5)$$

Hence, the vertical component of line tension at the top end becomes:

$$Tz = wS \quad (6.6)$$

and the horizontal component of line tension is constant along the line and is given by:

$$T_H = Tcos\phi_w \quad (6.7)$$

It is noted that the above analysis assumes that the line is horizontal at the lower end without no uplift. Furthermore, the multi-element lines made up by varying lengths and physical properties are used to increase the non-linear restoring force in the system.

6.2.2 Design Criteria

Chakrabarti, S. (2005) has mentioned that although the spread of mooring lines is the simplest in terms of design, it may not be the optimum in terms of performance. Hence, the design requirements should be considered to withstand environmental conditions and accommodate space restrictions caused by the subsea spatial layout or the riser system.

The design requirements of the mooring system for a cylindrical S400 floater have been listed by *Sevan Marine (2011)* as follow:

- The mooring system shall fulfill the requirements to safety factors both in intact condition and with mooring line failures and shall limit the lateral excursions within the limits of the riser design.

- The mooring system shall make the FPSO passively moored, i.e. the mooring system shall not depend on thruster assistance. Due it the circular shape of the Sevan FPSO weather vaning is not an issue.
- The Sevan FPSO mooring equipment and mooring system shall have sufficient structural/mechanical integrity with respect to continuous operations during the specified design life.
- The mooring system with the FPSO connected shall be designed to withstand 100-year return period storm conditions, including damage condition with one line broken
- The mooring system shall comply with required safety factors and offsets such that the FPSO can continue production operations in the 100 year return period storm conditions without interruptions caused by mooring constraints.

In this study, the application of design requirement for mooring line failures or damage condition with one line broken criteria will not be considered.

Besides the design requirements, *Sevan Marine (2011)* also listed the acceptance criteria for tension limits for Ultimate Limit States (ULS) based on *ISO 19901-7 (2005).* The design safety factor is defined as the ratio between the Minimum Breaking Load (MBL) of the mooring line component and the maximum tension in the same component.

The mooring system will be designed according to the specified minimum safety factors as defined in *ISO 19901-7 (2005).* For a mooring component, a tension limit should be expressed as a percentage of its MBL after reductions for corrosion and wear.

Tension limits for various conditions and analysis methods shall be set in accordance with **Table 6.3**, in which design safety factors are also listed.

Table 6. 3. : ULS Line Tension Limits and Design Safety Factors

Analysis condition	**Analysis method**	**Line tension limit** (percent of MBL)	**Design safety factor**
Intact	Quasi-static	50 %	2,00
Intact	Dynamic	60 %	1,67
Redundancy check	Quasi-static	70 %	1,43
Redundancy check	Dynamic	80 %	1,25
Transient	Quasi-static or dynamic	95 %	1,05

Reference: ISO 19901-7 (2005)

In this study, the design safety factor for the mooring line will be applied only in the intact condition for Ultimate Limit States (ULS).

The available design method that can be applied for the mooring system is as follow:

1. Quasi-static design
   Van den Boom (1985) has mentioned that the quasi-static design comprises dynamic motion analysis of the moored structure and computations of mooring line tension based on the extreme position of the floater and the static load-excursion characteristic of the mooring system.

Furthermore, *Chakrabarti, S. (2005)* has also explained that the quasi-static analysis is usually non-linear in that the catenary stiffness at each horizontal offset is used within the equations of motion. Further, the equations of motion are integrated in time domain.

$$(m + A)\ddot{x} + B\dot{x} + B_v\dot{x}|\dot{x}| + C_t x = F_x(t) \qquad (6.8)$$

In each degree of freedom to give the motions, x, coupling between the motions can also be included. The terms m, A, B and B_v refer to the floater mass, added mass, linear and viscous damping respectively with F_x representing the time varying external forcing.

There are two types of calculation that are carried out:

- A time domain simulation that allows for the wave induced floater forces and responses at the wave and drift frequency while treating wind and current forces as being steady and using the mooring stiffness curve without considering line dynamics.
- A frequency response method (where the mooring stiffness is treated as linear) Wave force and low frequency dynamic responses to both wave drift and wind gust effects are calculated as for a linear single degree of freedom system

2. Dynamic design

   Chakrabarti, S. (2005) has mentioned that the full dynamic analysis is usually performed in design. Generally, a static configuration must first be established with non-linear analysis where the effect of line dynamics on platform motion is mutually included in the time-domain solution. Dynamic methods also include the additional loads from the mooring system other than restoring forces, specifically the hydrodynamic damping effects caused by the relative motion between the line and fluid. Inertial effects between the line and fluid are also included.

   Two methods using discrete element techniques for dynamic simulation are:

   - The Lumped Mass Method (LMM)

     This technique involves the lumping of all effect of mass, external forces and internal reactions at a finite number of point ("nodes") along the line. By applying the equations of dynamic equilibrium and continuity (stress/strain) to each mass a set of discrete equation for the motion is derived. These equations may be solved in time domain directly using finite difference techniques. Material damping, bending and torsional moment from the lines are normally neglected.
   - and the Finite Element Method (FEM).

     The main difference between the LMM and FEM is the FEM utilizes interpolation functions to describe the behavior of a given variable internal to the element in terms of the displacement (or other generalized co-ordinates). The equation of motion for single elements are obtained by applying the interpolation function to the kinematic relations (strain/displacement), constitutive relations (stress/strain) and the equations of dynamic equilibrium. The solution procedure is similar to the LMM.

The research related to these methods can be found in *van den Boom (1985).* Furthermore, *van den Boom (1985)* has suggested that dynamic analysis should be performed in the design because the dynamic behavior of mooring lines strongly increases the maximum line tensions and may affect the low frequency motions of a moored structure by increase of the virtual stiffness and the damping of the system.

Further, in the design application the corresponding mooring line tensions are established both using a quasi-static approach and including the contribution from the mooring line dynamic. SIMO has the capability to perform both of them, quasi static analysis and simplified dynamic analysis. However in this chapter, mooring analysis will be performed in quasi-static while dynamic analysis (the Finite Element Method (FEM)) will be performed in **Chapter 8**.

6.2.3 Modeling Concept and Analysis Steps

The moorings system will be modeled by using the computer program, SIMO, with S400 ballasted at a draft of z=16.35. Here, the analysis has been performed in time domain for problem solving. The spread mooring system will be based on the model used in MIMOSA in the frequency domain. Moreover, the design of the mooring system in MIMOSA has been performed by *Sevan Marine (2011).* The analysis implementation will also include a cylindrical S400 floater as the body based on the model used in the diffraction program Wadam/Hydro D in **chapter 5**.

The steps of the moorings analysis for the cylindrical S400 floater can be seen in **Figure 6.8** as follow:

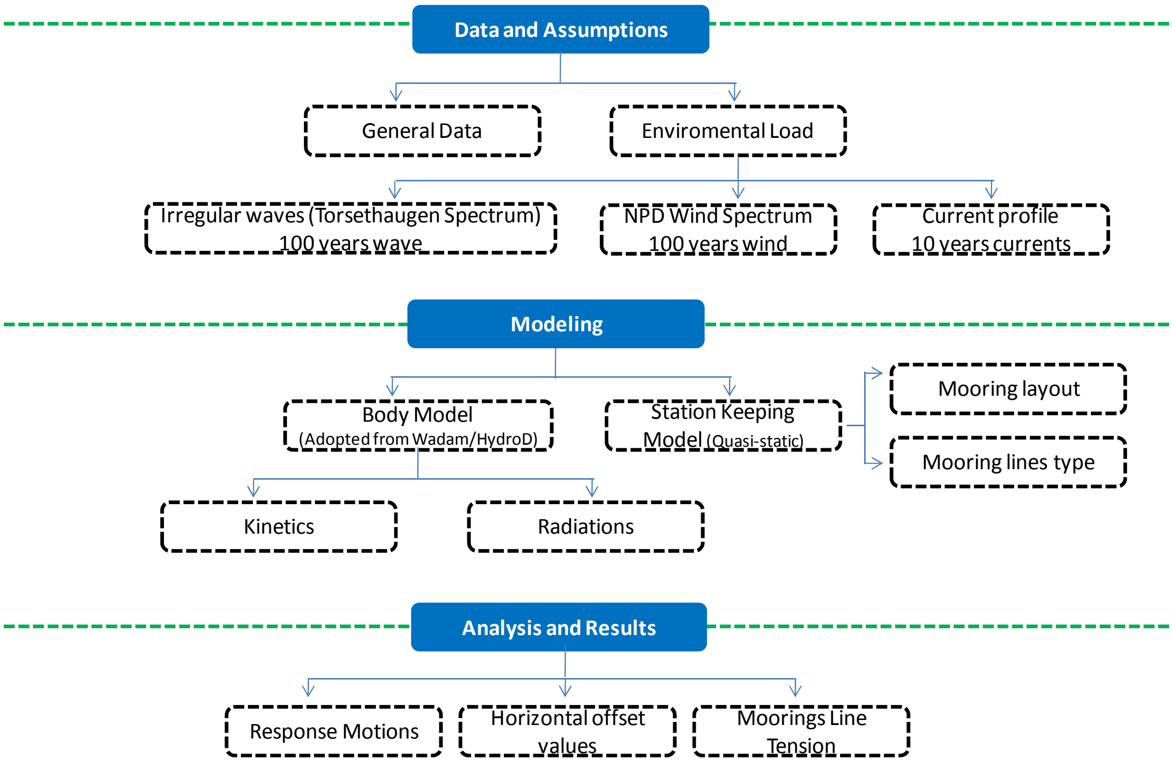


Figure 6. 8. : A simple procedure for mooring analysis.

The mooring analysis by using SIMO will be divided into data and assumptions, modeling and analysis and results.

The input for the analysis will be based on data and assumptions categorized as follow:

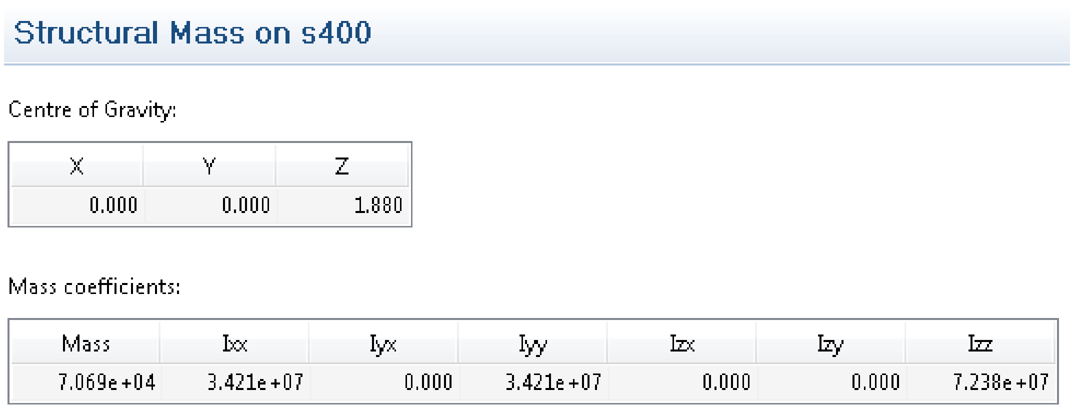
- General data
- Environmental Load
  The wave, wind and currents will be considered in the analysis and simulated in time series. The environmental load data will be based on the return period combinations for 100 year waves and wind criteria and 10 years current criteria.
  The analysis will use the load combination below:
  - The wave: Jonswap double peaked spectrum (Hs=15.6m and Tp=15.5s)
  - The wind: NPD Spectrum wind
  - The current: Current profile

The general data and the environmental load data will be input to INPMOD as a part of system descriptions. Further information about environmental load data can be found in **Chapter 3**.

Further, the analysis requires two models, the body model and the station keeping model.

The body model will be adopted from Wadam/Hydro D. The FEM model of a cylindrical S400 floater (Hydro and Mass model) and the wave load from Wadam/HydroD will be read into INPMOD. In addition, the kinetic and radiation data as the body data will be input to INPMOD to obtain the forces that are acting on the hull, such as:

1. Mass force
   The mass force will be determined by the body mass, the centre of gravity and the mass moment of inertia with respect to origin for a cylindrical S400 floater. The structural mass data can be seen in **Figure 6.9** below:


Structural Mass on s400

Centre of Gravity:

X	Y	Z
0.000	0.000	1.880

Mass coefficients:

Mass	Ixx	Iyx	Iyy	Izx	Izy	Izz
7.069e+04	3.421e+07	0.000	3.421e+07	0.000	0.000	7.238e+07

Figure 6. 9. : The structural mass data for a cylindrical S400 floater.

2. Low-frequency hydrodynamic damping forces

   The low frequency damping should be included in the design because the low frequency force can generate large amplitude resonant motions. When the damping at low frequency is very small, it causes the second order slowly varying forces to generate large amplitude resonant motions. Hence, the low frequency resonant amplitude motions can be predicted if the magnitude of the damping is known.

   The following low frequency damping contributions are considered not only from the body but also from the mooring lines for:

   - Viscous hull damping
   - Wave drift damping
   - Mooring line damping

   The viscous damping will partly be covered by the current force coefficient while the wave drift damping will be derived from the mean drift force. Mooring line damping is represented by a low frequency damping of the form:

$$F_i = B_{L,i} \cdot U_{SD,i} + B_{Q,i} \cdot U_{SD,i}\left|U_{SD,i}\right| \quad (6.9)$$

where:

$B_{L,i}$ = the linear low frequency damping in DOF number *i*

$B_{Q,i}$ = the quadratic low frequency damping in DOF number *i*

$U_{SD,i}$ = the slow drift velocities in DOF number *i*

In order to verify the magnitude value of the damping, Sevan Marine has recently performed model tests for Sevan FPSO's to define the damping coefficients for the calibration of the numerical model. *Sevan Marine (2011)* has mentioned that the linear and quadratic damping term will be highly different. Based on the calibration towards previous model test results and scaling to actual floater size, the following data have been established in **Table 6.4 - 6.5**:

Table 6. 4. : The Linear Damping Coefficients for Mooring Analysis

	Surge	Sway	Heave	Roll	Pitch	Yaw
Surge	9.90E-02	0	0	0	0	0
Sway	0	9.90E-02	0	0	0	2.20E-02
Heave	0	0	4.00E-04	0	0	0
Roll	0	0	0	4.00E-04	0	0
Pitch	0	0	0	0	4.00E-04	0
Yaw	0	2.20E-02	0	0	0	1.50E+06

Reference: Sevan Marine *(2011)*

Table 6. 5. : The Quadratic Damping Coefficients for Mooring Analysis

	Surge	Sway	Heave	Roll	Pitch	Yaw
Surge	1.40E+04	0	0	0	0	0
Sway	0	1.40E+04	0	0	0	2.20E-02
Heave	0	0	1.00E+03	0	0	0
Roll	0	0	0	3.50E+04	0	0
Pitch	0	0	0	0	3.50E+04	0
Yaw	0	2.20E-02	0	0	0	1.50E+06

Reference: Sevan Marine *(2011)*

3. Hydrostatic stiffness forces

   The hydrostatic stiffness fully governs the heave, pitch, and roll response motions. The coefficients for hydrostatic stiffness forces are determined from model test results. These data will be established based on the test results from *Sevan Marine (2011)* in **Table 6.6** below:

Table 6. 6. : The Linear Hydrostatic Stiffness Matrix for Mooring Analysis (kg.m/s^2)

	Surge	Sway	Heave	Roll	Pitch	Yaw
Surge	0	0	0	0	0	0
Sway	0	0	0	0	0	0
Heave	0	0	3.86E+04	0	0	0
Roll	0	0	0	4.41E+06	0	0
Pitch	0	0	0	0	4.41E+06	0
Yaw	0	0	0	0	0	0

Reference: Sevan Marine *(2011)*

4. Wave excitation forces

   A Floating structure moored at sea is subjected to forces that tend to shift them from its desired position. The forces on a floater caused by the wave excitation may be split into two parts:

   - First order oscillatory forces with the wave frequency
   - Second order slowly varying forces with frequencies much lower than the wave frequency

   Wichers and Huijisman (1984) has explained that the first order oscillatory wave forces on a floater cause ship motions with frequencies equal to the frequencies present in the spectrum of the waves while the second order wave forces, also known as the wave drift forces, have been shown to be proportional to the square of the wave height.

   Further, the first order wave forces are described in the frequency domain as a linear motion transfer function, also denoted Response Amplitude Operator (RAO) while the second order wave forces are described as the mean wave (drift) force. Both of them will be input to INPMOD as a part of the program input.

   Furthermore, the first order transfer motion (RAO) will be considered in 6 DOF motion of a floater for translational motions (surge, sway, and heave) and also rotational motions (roll, pitch and yaw). Both of them will be described from 0° to 90°.

The mean wave (drift) force will be considered for translation motions surge and sway from 0° to 90°. The mean wave (drift) force for the rest of DOF will be considered as zero.

The further details can be found in **Appendices A and B.**

5. Current forces
   The current forces are calculated using the following equation:

$$F_C = C_C \cdot {U_C}^2 \tag{6.10}$$

where: U_C is current speed, C_C is the force coefficients for current.

The current loads on a ship will be represented by drag forces in form of viscous hull surge and sway forces and also as yaw moment. These will be calculated based on current coefficients from current tests where the mooring and riser system were included.

The current coefficients are divided into the linear current force coefficients C_1 and quadratic current force coefficients C_2. Usually for the current drag forces acting on the hull, the linear coefficient, C_1 is not used in the analysis. The quadratic current force coefficients C_2 for the 6 DOF motions from 0 ° to 90 ° can be seen in **Table 6.7** below:

Table 6. 7. : The Quadratic Current Coefficients for 6 DOF Motions From 0 ° to 90 °

No	Direction (deg)	C_{21} Surge	C_{22} Sway	C_{23} Heave	C_{24} Roll	C_{25} Pitch	C_{26} Yaw
		(kNs²/m²)					
1	0	500	0	0	0	0	0
2	15	483	129	0	1.04E+03	-4.00E+03	0
3	30	433	250	0	2.00E+03	-3.86E+03	0
4	45	354	354	0	2.83E+03	-3.46E+03	0
5	60	250	433	0	3.46E+03	-2.83E+03	0
6	75	129	483	0	3.86E+03	-2.00E+03	0
7	90	0	500	0	4.00E+03	-1.04E+03	0

Reference: Sevan Marine *(2011)*

Besides, the coefficients above will be used to predict the viscous damping that is acting on a floater.

6. Wind forces
   The wind is calculated using the following equation:

$$F_W = C_{WI} \cdot {U_W}^2 \tag{6.11}$$

where: U_W is the wind speed, C_{WI} is the force coefficient for wind.

The wind coefficients for 6 DOF motions from 0 ° to 90 ° can be seen in **Table 6.8** below:

Table 6. 8. : The Wind Coefficients for 6 DOF Motions From 0 ° to 90 °

No	Wind Direction (deg)	W11 Surge	W12 Sway	W13 Heave	W14 Roll	W15 Pitch	W16 Yaw
		(kNs²/m²)					
1	0	1.35	0	0	0	21.6	0
2	15	1.3	0.35	0	-5.59	20.86	0
3	30	1.17	0.68	0	-8.71	15.72	0
4	45	0.95	0.95	0	-10.8	10.8	0
5	60	0.68	1.17	0	-15.72	8.71	0
6	75	0.35	1.3	0	-20.86	5.59	0
7	90	0	1.35	0	-21.6	0	0

Reference: Sevan Marine *(2011)*

7. Simplified wave drift damping forces

The wave drift damping forces will be very important to calculate the potential flow effect for the low frequency motions. *DNV-RP-F205 (2010)* has defined that the wave drift damping forces is the increase in the second-order difference frequency force experienced by a structure moving with a small forward speed in waves.

For a floater, the mean wave drift damping is considered based on an expansion of the mean drift force F_d:

$$F_d(\omega,\dot{x}) = F_d(\omega,0) - B(\omega)\dot{x} + O(\dot{x}^2) \tag{6.12}$$

where: $B(\omega) = -\frac{\partial F_d}{\partial \dot{x}} \mathrm{l}_{\dot{x}=0}$

In this analysis, the Newman method will be implemented. (*Marintek (2008)*)

The wave drift damping coefficients are given for two numbers of peak periods, 13s and 16s. These coefficients will be considered for the 2 DOF motions, surge and sway as can be seen in **Table 6.9** below:

Table 6. 9. : The Wave Drift Damping Coefficients

No	Periods	Wd1	Wd2
		(kNs²/m²)	
1	13	0.33	0.33
2	16	0.33	0.33

Reference: Sevan Marine *(2011)*

8. Potential damping forces

Potential damping can be determined from potential theory. This damping will happen due to the forces causing harmonic motions. It means this damping can be considered based on the first order wave forces. Generally, this damping should be used in the equation of motion for sinusoidal waves. Hence, the linear transfer functions (RAO) are important to give good prediction about the potential damping.

Hence, *Det Norske Veritas (2008)* in "Sesam User Manual for Wadam-Wave Analysis by Diffraction and Morison Theory" has mentioned that the transfer function should generally be smooth to avoid large jumps. Large jumps in the transfer functions will cause too large wave period step and cause difficulties to predict the potential damping.

Besides, the potential damping is also strongly related to the added mass due to the radiation effects. The radiation is found when a floater oscillates without waves. Moreover, it was shown by *(Cummins, 1962)* that the frequency dependence of added mass and potential damping can be seen as a consequence of a convolution term in the radiation potential.

Hence, the added mass coefficient will be considered in the analysis in order to describe the hydrodynamic interaction. Further, the added mass and potential damping will be included in retardation functions. The added mass coefficient can be seen in **Table 6.10** as follow:

Table 6. 10. : The Wave Drift Damping Coefficients

	Surge	Sway	Heave	Roll	Pitch	Yaw
Surge	3.70E+04	0	0	0	-6.33E+05	0
Sway	0	3.70E+04	0	6.33E+05	0	0
Heave	0	0	1.56E+05		0	0
Roll	0	6.34E+05	0	5.31E+07	0	0
Pitch	-6.34E+05	0	0	0	5.31E+07	0
Yaw	0	0	0	0	0	0

Reference: Sevan Marine *(2011)*

After the body model is made, the mooring lines will be attached for station keeping in the model of the system. The implementation of a catenary mooring line model in SIMO is based on the model used in the mooring analysis program MIMOSA based on quasi static analysis in the frequency domain. Further, in SIMO, the catenary mooring line model is extended to the time domain. The mooring lines are treated individually based on property characteristic such as: material, dimension, length etc.

Since a cylindrical S400 floater adopts the spread mooring system, the mooring lines are assumed to form catenaries and will be modeled by the catenary equations. Because the analysis method chose a quasy-static analysis thus the procedure for calculating the mooring line configuration is based on a "shooting method" or iteration on boundary conditions at one end in order to satisfy specified boundary conditions at the other. Using this procedure a fairly accurate static equilibrium configuration for a multi segment line can be obtained with a minimum of computational efforts.

By using the quasi-static model, the moorings tension arising due to a floater motions can be calculated. This not only for WF mooring line tension or LF mooring line tension but also for the combination of the LF and WF mooring line tension.

The procedure for a catenary mooring line model can be found in details in *Marintek (2007);* in the "Marintek Report: Mimosa 5.7 – User's Documentation".

As for the data such as the mooring line compositions (**Table 6.1**), the detailed orientation and the pretension for the mooring system will be input to INPMOD for the catenary mooring line model in SIMO.

Further, all inputs from the simple procedure for mooring analysis (**Figure 6.8**) will be integrated to SIMO in INPMOD module. Moreover, SIMO consist of six different modules (INPMOD, STAMOD, DYNMOD, OUTMOD and PLOMOD) by a file system as shown in **Figure 6.10** below:

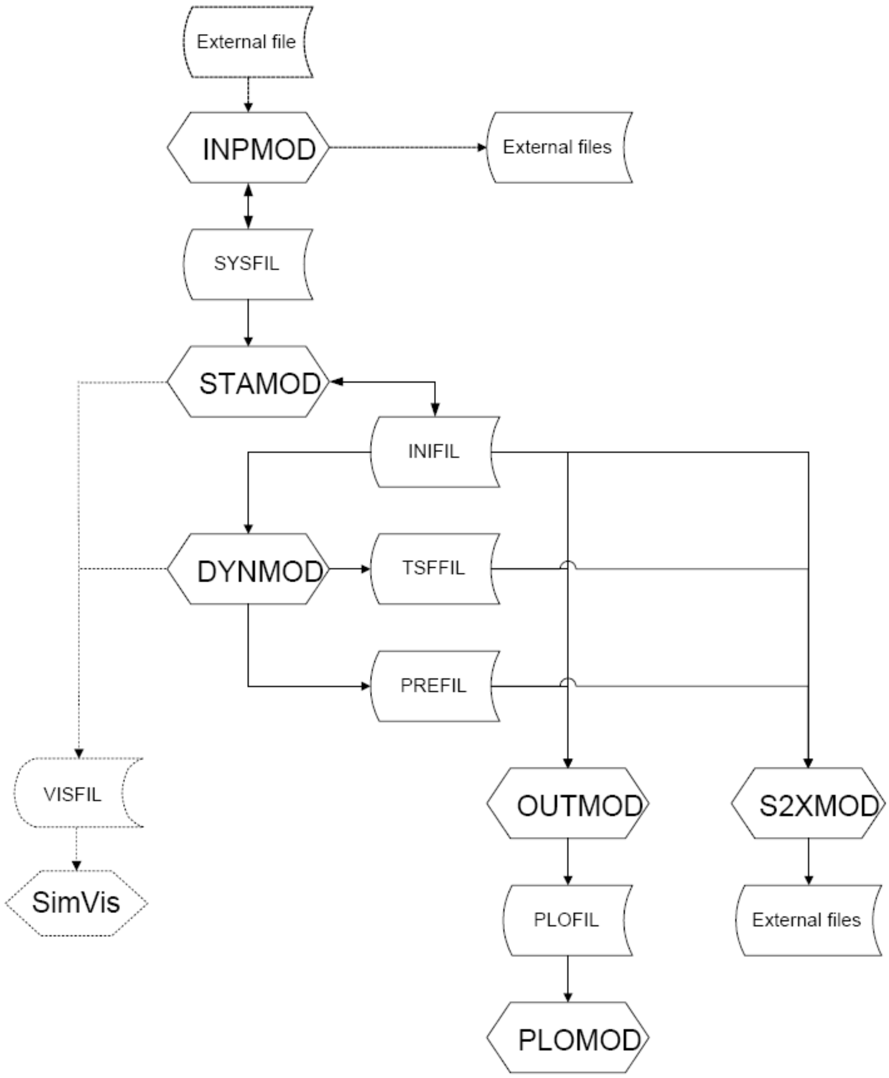


Figure 6. 10. : Layout of the SIMO program system and file communication between modules.

The INPMOD module has the function to gather all data inputs and also to provide interfaces for external input data sources from Wadam/Hydro D. The INPMOD module will generate the system description file, SYSFIL, which contains a description about the body, station keeping and also the environmental data. Further, these data will be read by STAMOD to define the initial condition for the dynamic simulation. A static equilibrium position and the static force will be calculated in this module. The dynamic simulation in time domain will be performed in DYNMOD module in order to calculate the response of the system. The result of the simulation in time series will be read by OUTMOD module then the plot of the time series and statistical parameters can be access from the PLOMOD module. The detail information about the input of these modules that are used in the analysis can be found in **Appendix C**. Further information can be seen in *Marintek (2008)*; "SIMO - Theory Manual Version 3.6, rev: 1."

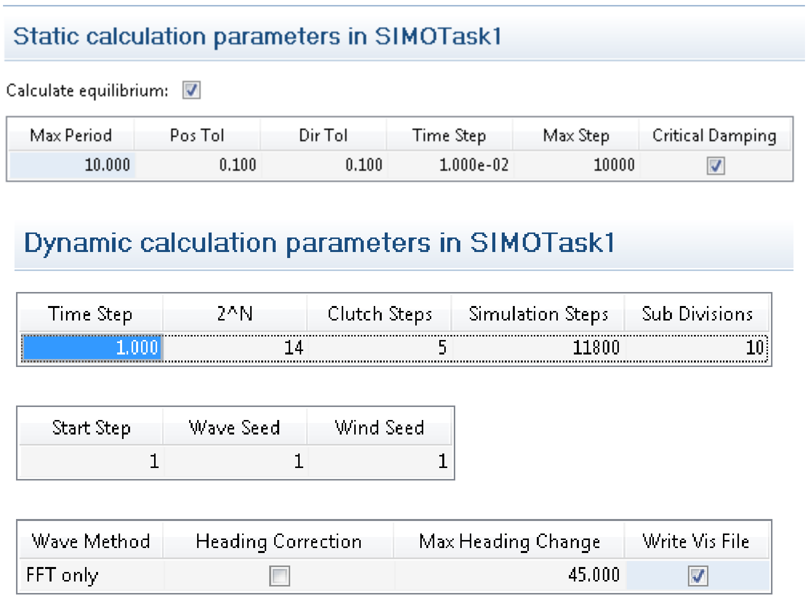
6.3 Moorings Analysis

The mooring analysis are carried out in two conditions, static and dynamic condition. The results from the static condition are derived without variation of the environmental loads while it will be taken into account in the dynamic condition.

The results from the static condition will be the final static body position and mooring line static tensions while the results from the dynamic condition are time series of second order wave forces and the wave drift damping forces. These also represent the mooring line dynamic tensions and the response motions of a cylindrical S400 floater. Further, the response motions will be used to define the horizontal offset of a cylindrical S400 floater.

The calculation parameters that will be used for mooring analysis can be seen in **Figure 6.11** below:

Figure 6. 11. : The calculation parameters for static and dynamic condition



6.3.1 Static Condition

A static equilibrium position for a cylindrical S400 floater can be seen in **Table 6.11**. Further, this position will be the initial condition for the dynamic simulation.

Table 6. 11. : The Final Static Body Position of A Cylindrical S400 Floater

Static Body Position						
Body	**X**	**Y**	**Z**	**Rx**	**Ry**	**Rz**
S400	0	0	0	0	0	0

While the static forces and moments that are acting on a cylindrical S400 floater can be seen in **Table 6.12**. and **Table 6.13**. These will also be the initial conditions for the dynamic simulation.

Table 6. 12. : The Static Forces and Moments on S400 Floater

Static results for in SIMOTask1

▼ **Static forces and moments on s400**

Name	Fx	Fy	Fz	Ftotal	Acceleration	Mx	My	Mz
Hydrostatic stiffness	5.050e-09	6.974e-10	0.145	0.145	2.046e-09	-2.141e-02	0.155	-4.123e-18
Wind forces	-843.750	-1.992e-04	0.000	843.750	1.194e-05	3.182e-03	-1.350e+04	0.000
Quadratic current	-180.000	0.000	0.000	180.000	2.546e-06	0.000	1.440e+03	0.000
Second order wave drift, wind	-2.766e+03	8.943e-14	0.000	2.766e+03	3.913e-05	0.000	0.000	0.000
Positioning elements	-1.921e-02	-56.097	-8.497e+03	8.497e+03	1.202e-04	3.837e+03	0.121	-2.441e-02
Total	-3.790e+03	-56.097	-8.497e+03	9.304e+03	1.316e-04	3.837e+03	-1.206e+04	-2.393e-02

Table 6. 13. : The Mooring Line Static Tensions

Static results for in SIMOTask1

▼ **Positioning element forces on s400**

Name	Ftotal	Fx	Fy	Fz	Mx	My	Mz
s400_line1	1.754e+03	1.522e+03	-494.450	-718.190	8.304e+03	8.179e+03	1.197e+04
s400_line2	1.754e+03	1.504e+03	-547.260	-718.190	7.811e+03	8.349e+03	9.990e+03
s400_line3	1.754e+03	1.386e+03	-800.040	-718.190	5.447e+03	9.451e+03	-18.483
s400_line4	1.754e+03	1.357e+03	-847.910	-718.190	4.999e+03	9.720e+03	-2.030e+03
s400_line5	1.754e+03	-1.357e+03	-847.910	-718.190	4.999e+03	-9.720e+03	2.030e+03
s400_line6	1.754e+03	-1.386e+03	-800.050	-718.190	5.447e+03	-9.451e+03	18.469
s400_line7	1.754e+03	-1.504e+03	-547.260	-718.190	7.811e+03	-8.349e+03	-9.990e+03
s400_line8	1.754e+03	-1.522e+03	-494.450	-718.190	8.304e+03	-8.179e+03	-1.197e+04
s400_line9	1.505e+03	-163.100	1.328e+03	-687.900	-1.234e+04	1.525e+03	5.872e+03
s400_line10	1.505e+03	-116.640	1.333e+03	-687.900	-1.230e+04	1.091e+03	4.199e+03
s400_line11	1.505e+03	116.640	1.333e+03	-687.900	-1.230e+04	-1.091e+03	-4.199e+03
s400_line12	1.505e+03	163.100	1.328e+03	-687.900	-1.234e+04	-1.525e+03	-5.872e+03

6.3.2 Dynamic Condition

The aims of mooring analysis are presented in this chapter. Since the analysis has been performed in time domain for problem solving, the floater motions in time domain, the horizontal offset values and the mooring line dynamic tensions will be presented as time series results.

Besides, the supported analysis results for the time series of second order wave forces and the wave drift damping forces will also be presented in this chapter.

The dynamic condition has been simulated for “3 hours +” build up time.

Further, these analysis results will be compared with the related results in **Chapter 8** (the floater motion, horizontal offset and mooring line tension).

A. The Floater Motions

The global motion response of a cylindrical S400 floater can be categorized based on their frequency of the motion. Generally, two types of frequency motions will be the results of the particular effects of the environmental loads.

First, the global motion response the wave frequency motions (WF motions), is generated by the first order wave force on a floater. Second, a global motion response, the low frequency motions (LF motions) is generated by the second order forces such as the mean wave (drift) forces and the slowly-varying forces from waves or currents.
Since the magnitude of the second order forces are small compared to the magnitude of the first order forces, the global motion response wave frequency motions (WF motions) will govern a floater's response characteristic mostly. Further, the global motion response, the wave frequency motions, will be described by a transfer function or a Response Amplitude Operator (RAO). Further information can be found in **chapter 5**.

The Second global motion response, the low frequency motions (LF motions) can be found from **Figure 6.12 to Figure 6.17.**

- *The global motion response, the low frequency motions for surge*

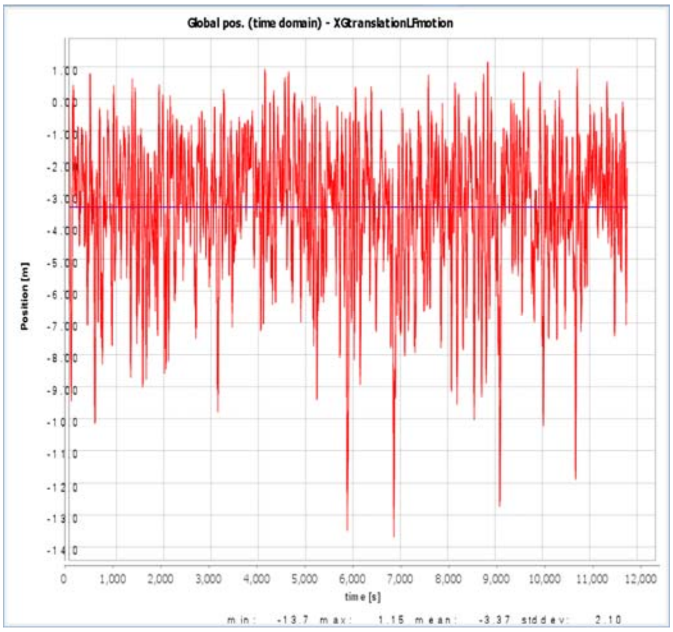


Figure 6. 12. : The global motion response, the low frequency motions for surge.

➢ *The global motion response, the low frequency motions for sway*

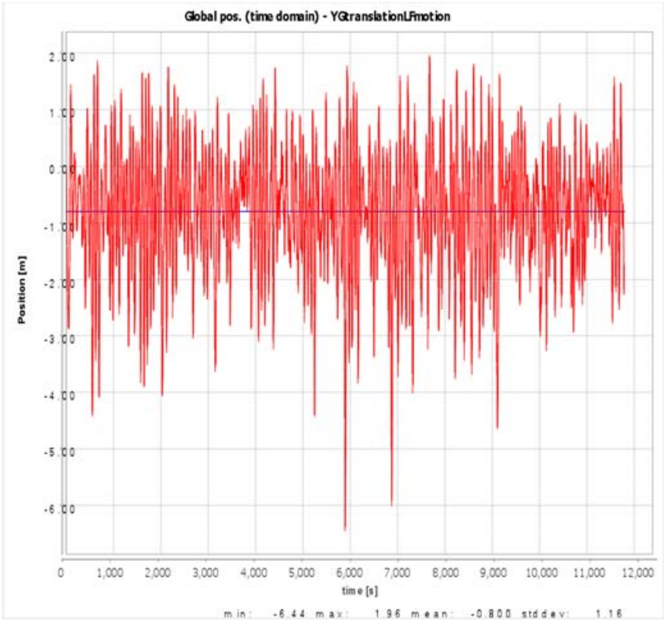


Figure 6. 13. : The global motion response, the low frequency motions for sway.

➢ *The global motion response, the low frequency motions for heave*

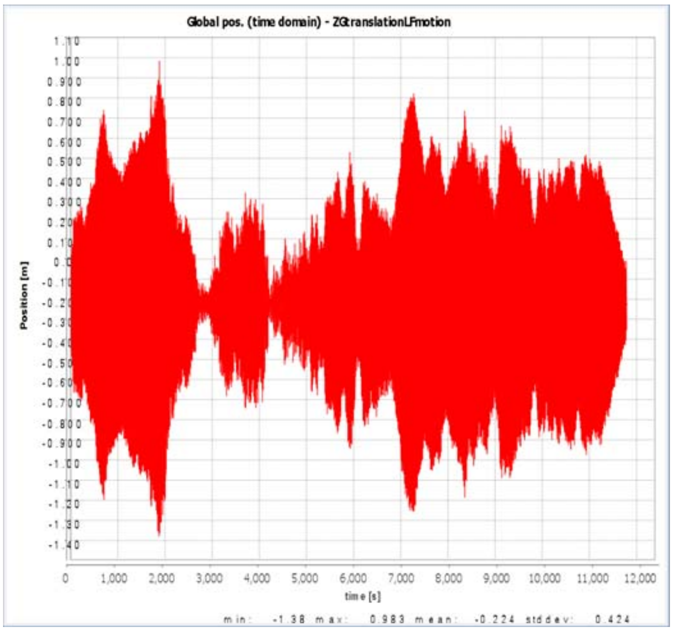


Figure 6. 14. : The global motion response, the low frequency motions for heave.

➢ *The global motion response, the low frequency motions for roll*

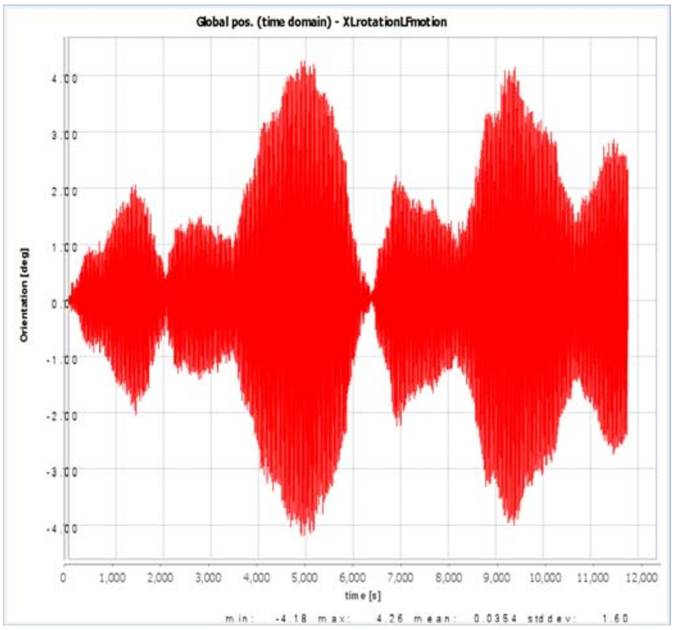


Figure 6. 15. : The global motion response, the low frequency motions for roll.

➢ *The global motion response, the low frequency motions for pitch*

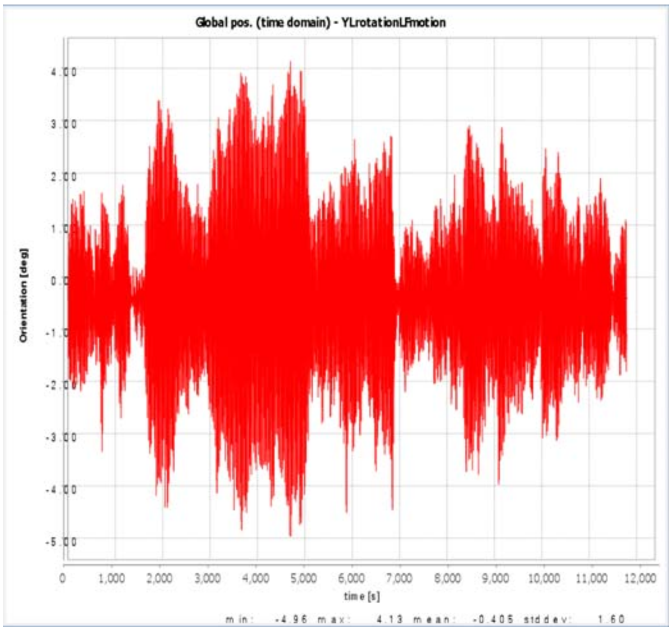


Figure 6. 16. : The global motion response, the low frequency motions for pitch.

➢ *The global motion response, the low frequency motions for yaw*

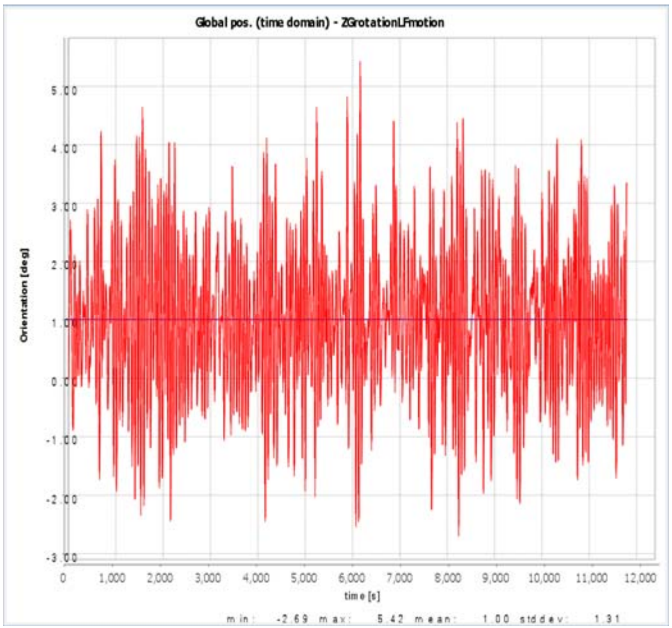


Figure 6. 17. : The global motion response, the low frequency motions for yaw.

Besides, the global motion response for the total motion as combination of the low frequency motions (LF motions) and wave frequency motions (WF motions) can be found from **Figure 6.18 to Figure 6.23.**

➢ *The total global motion response, the total frequency motions for surge*

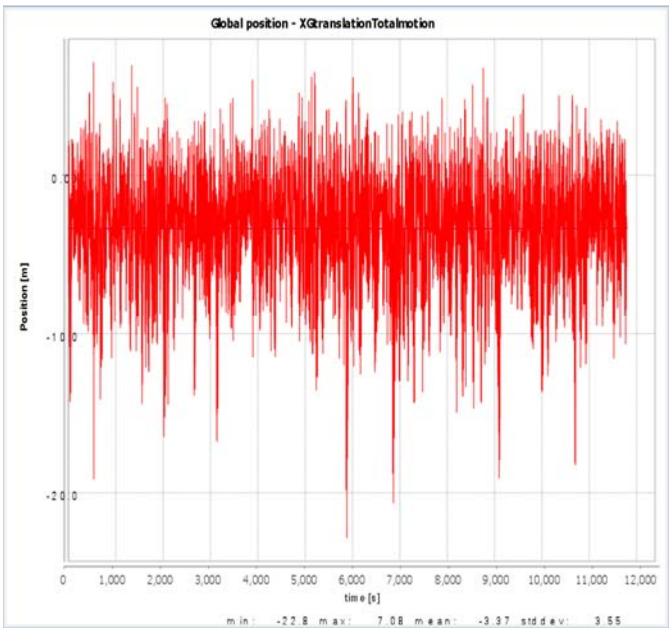


Figure 6. 18. : The total global motion response, the total frequency motions for surge.

➢ *The total global motion response, the total frequency motions for sway*

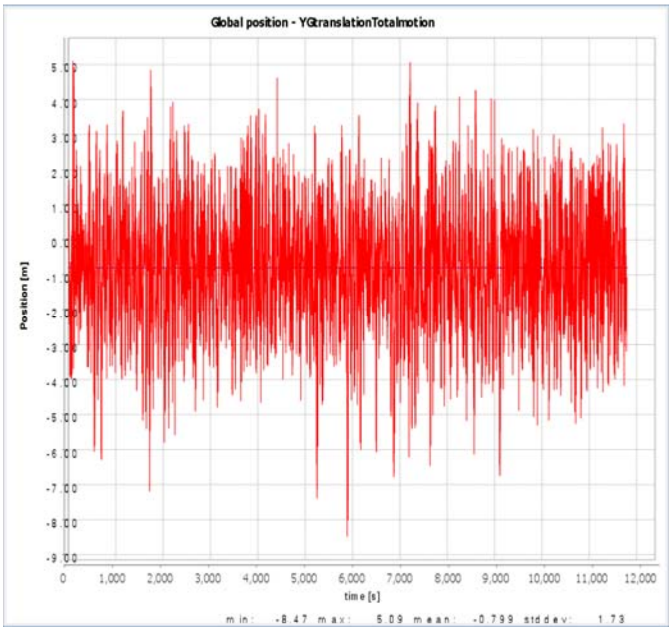


Figure 6. 19. : The total global motion response, the total frequency motions for sway.

➢ *The total global motion response, the total frequency motions for heave*

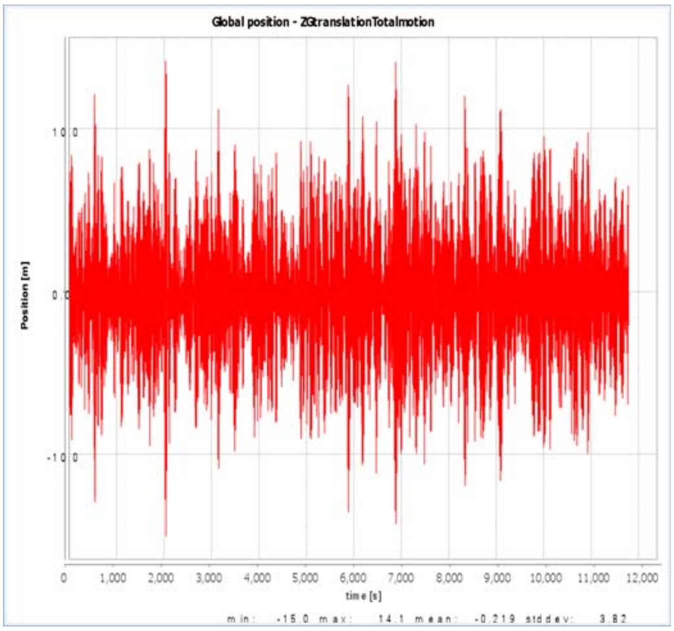


Figure 6. 20. : The total global motion response, the total frequency motions for heave.

➤ *The total global motion response, the total frequency motions for roll*

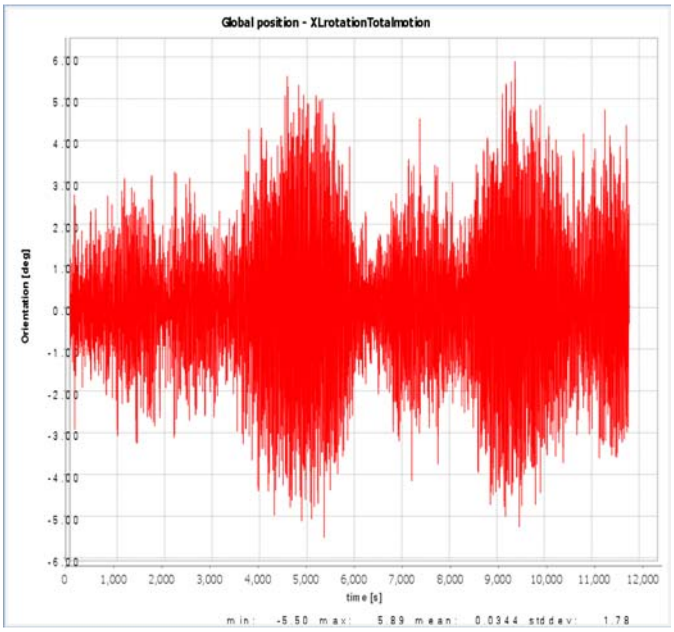


Figure 6. 21. : The total global motion response, the total frequency motions for roll.

➤ *The total global motion response, the total frequency motions for pitch*

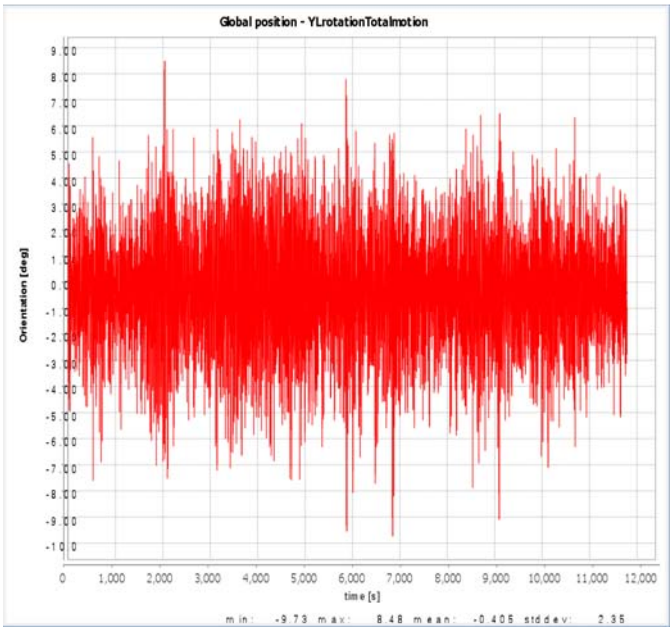


Figure 6. 22. : The total global motion response, the total frequency motions for pitch.

➢ *The total global motion response, the total frequency motions for yaw*

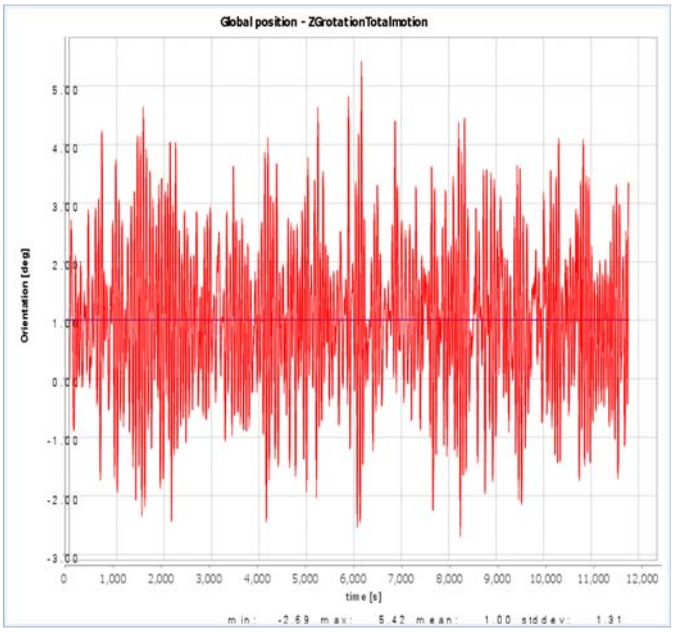


Figure 6. 23. : The total global motion response, the total frequency motions for roll.

B. The Horizontal Offset Values

The horizontal offset can be derived from the global motion response. The summary of the global motion response for the low frequency motions and the total frequency motions can be seen in **Table 6.14**. below:

Table 6. 14. : The Summary of The Global Motion Response of A Cylindrical S400 Floater

The Global Motion Response in Low Frequency Motions							
Channel		Min	Max	Mean	Std. Dev.	Skewness	Kurtosis
Surge	XG translation LF Motion	-13.86	1.15	-3.37	2.10	-0.89	4.32
Sway	YG translation LF Motion	-6.44	1.96	-0.80	1.60	-0.50	3.64
Heave	ZG translation LF Motion	-1.38	0.98	-0.22	0.42	0.00	2.28
Roll	XL rotation LF Motion	-4.80	4.26	0.04	1.60	0.00	2.83
Pitch	YL rotation LF Motion	-4.96	4.30	-0.40	1.60	0.00	2.60
Yaw	ZG rotation LF Motion	-2.96	5.42	1.00	1.31	0.05	2.73
The Global Motion Response in Total Frequency Motions							
Channel		**Min**	**Max**	**Mean**	**Std. Dev.**	**Skewness**	**Kurtosis**
Surge	XG translation Total Motion	-22.82	7.08	-3.37	3.55	-0.60	3.93
Sway	YG translation Total Motion	-8.47	5.09	-0.80	0.73	-0.15	3.19
Heave	ZG translation Total Motion	-15.02	4.14	-0.22	3.82	0.00	2.97
Roll	XL rotation Total Motion	-5.50	5.89	0.03	1.78	0.03	2.89
Pitch	YL rotation Total Motion	-9.73	8.48	-0.41	2.35	-0.09	2.91
Yaw	ZG rotation Total Motion	-2.69	5.42	1.00	1.31	0.05	2.73

Based on **Table 6.14**, it is clear that a cylindrical S400 floater will experience significant surge motion in LF and total frequency (LF+WF). These responses are resulting due to surge excitation from the second order force such as the mean wave (drift) forces and the slowly-varying forces from waves or currents.

Besides, the analysis also shows that a cylindrical S400 floater maybe particularly sensitive to total heave in total frequency motion (LF+WF). The magnitude of the values of the first order wave forces (Hs =15.6 m and Tp= 15s) should be the main reason for this result.

Further, the horizontal offset of a cylindrical S400 floater for the environmental data, 100 years wind + 100 years wave + 10 years currents can be determined as follow:

- The wave : Jonswap double peaked spectrum (Hs=15.6m and Tp=15.5s)
- The wind : NPD Spectrum wind
- The current : Current profile
- The static offset: : 3,37 m
- The max offset : 22,82 m

C. Mooring Line Dynamic Tensions

The mooring line dynamic tensions of a cylindrical S400 floater have been found for the environmental data: 100 years wind + 100 years wave + 10 years currents as follow:

- The wave : Jonswap double peaked spectrum (Hs=15.6m and Tp=15.5s)
- The wind : NPD Spectrum wind
- The current : Current profile

The summary of the mooring line dynamic tension for a cylindrical S400 floater can be seen in **Table 6.15** below:

Table 6. 15. : The Summary of Mooring Line Dynamic Tensions of a cylindrical S400 floater

Channel	Min Tension kN	Max Tension kN	Mean Tension kN	Std. Dev.	Skewness	Kurtosis
S400_Line1	1035.01	9634.71	2535.28	998.46	0.00	0.01
S400_Line2	1040.80	9547.82	2521.88	983.74	0.00	0.01
S400_Line3	1048.27	8967.19	2440.06	894.12	0.00	0.01
S400_Line4	1050.11	8822.99	2420.97	873.29	0.00	0.01
S400_Line5	764.80	3530.18	1418.10	340.04	0.00	0.01
S400_Line6	763.48	358.87	1418.32	343.36	0.00	0.01
S400_Line7	755.87	3791.81	1424.36	359.73	0.00	0.01
S400_Line8	754.84	3824.52	1426.53	362.89	0.00	0.01
S400_Line9	1060.31	3001.74	1586.37	253.12	0.00	0.01
S400_Line10	1061.07	3059.34	1607.36	264.08	0.00	0.01
S400_Line11	1068.95	3721.06	1724.61	347.89	0.00	0.01
S400_Line12	1071.35	4003.40	1750.27	370.04	0.00	0.01

While the result of mooring line dynamic tensions gives by time series for each line can be seen from **Figure 6.24 to Figure 6.35** below:

- *The mooring line dynamic tensions in time series for S400_Line1*

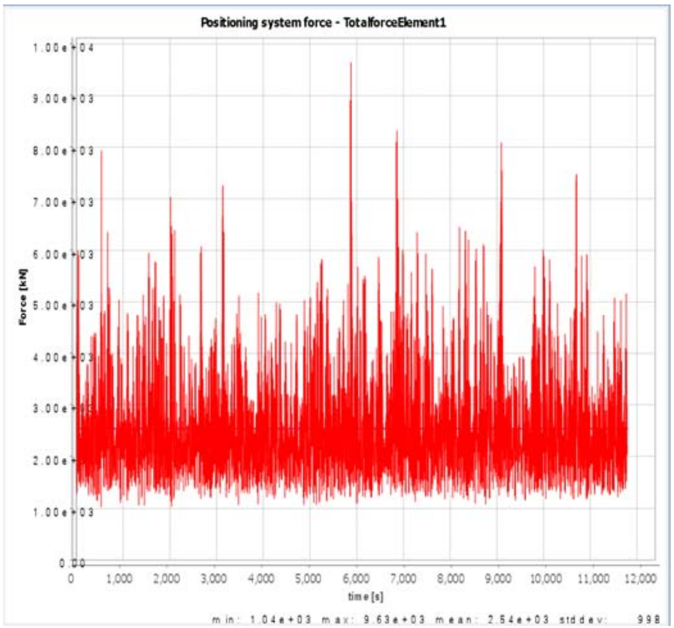


Figure 6. 24. : The mooring line dynamic tensions in time series for S400_Line1.

- *The mooring line dynamic tensions in time series for S400_Line2*

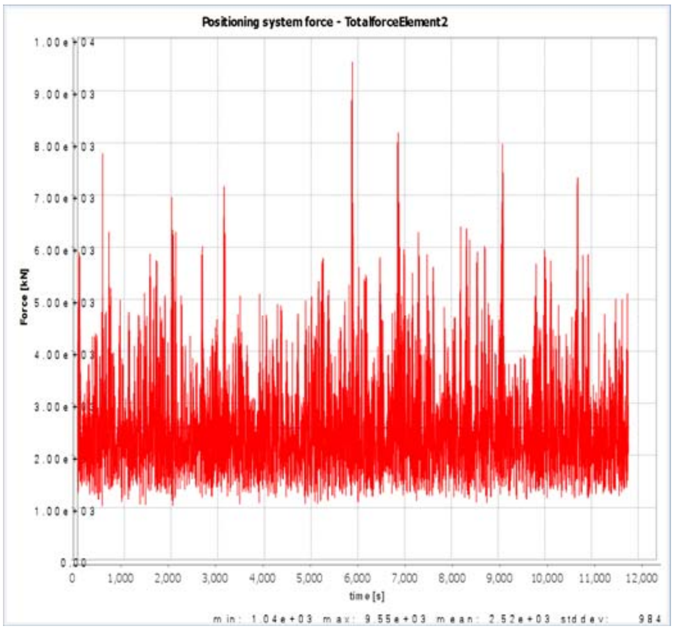


Figure 6. 25. : The mooring line dynamic tensions in time series for S400_Line2.

➢ *The mooring line dynamic tensions in time series for S400_Line3*

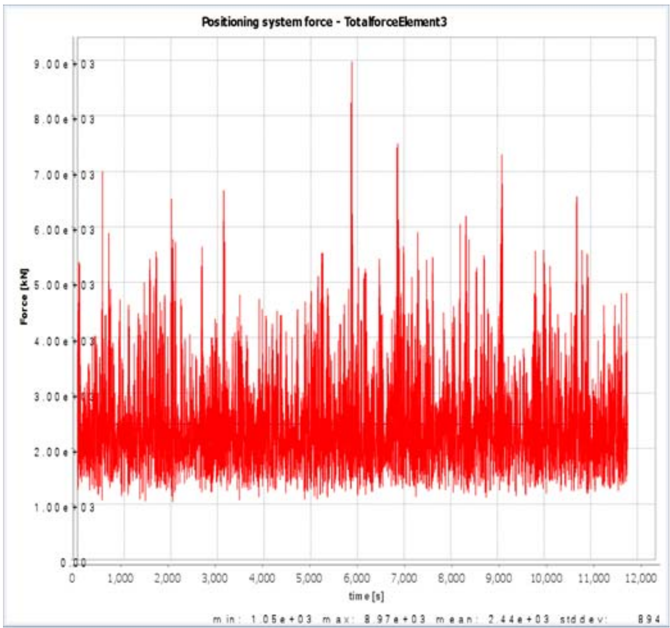


Figure 6. 26. : The mooring line dynamic tensions in time series for S400_Line3.

➢ *The mooring line dynamic tensions in time series for S400_Line4*

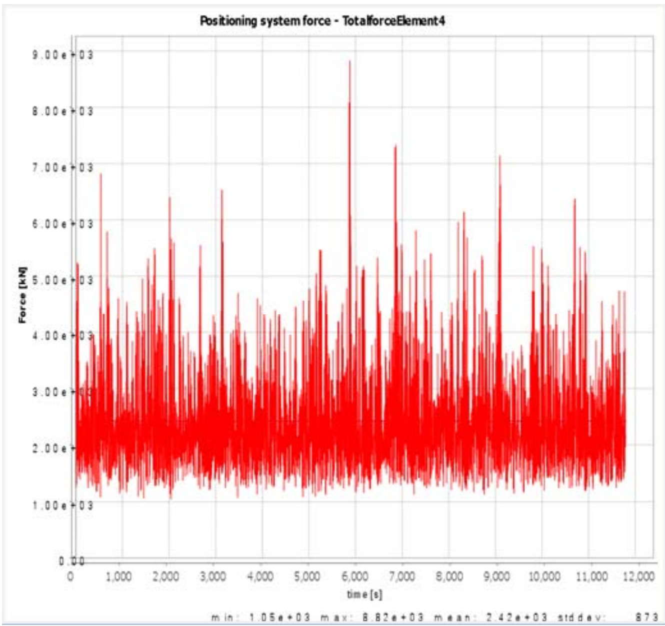


Figure 6. 27. : The mooring line dynamic tensions in time series for S400_Line4.

- *The mooring line dynamic tensions in time series for S400_Line5*

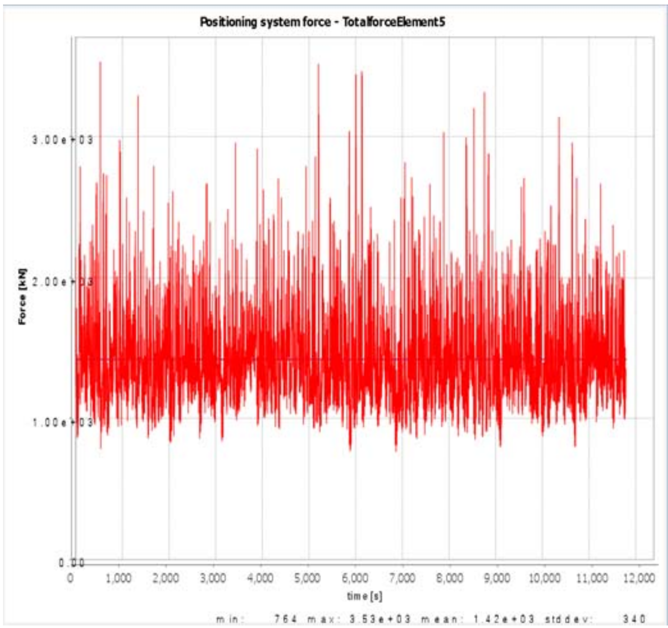


Figure 6. 28. : The mooring line dynamic tensions in time series for S400_Line5.

- *The mooring line dynamic tensions in time series for S400_Line6*

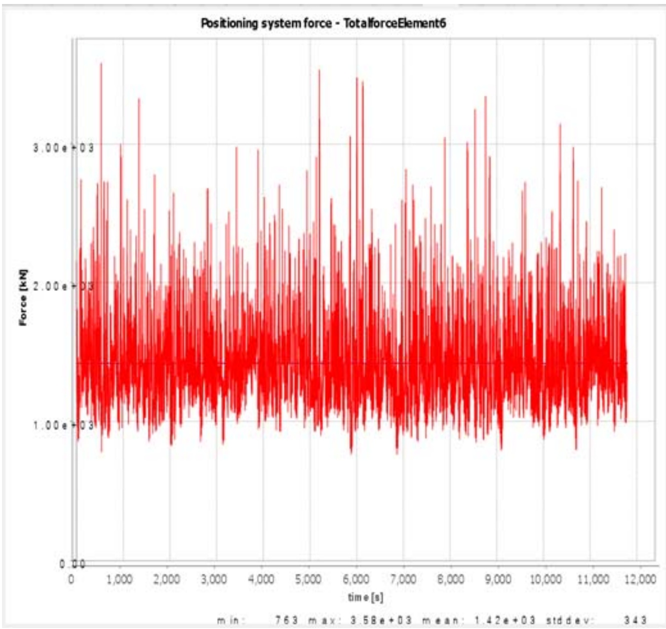


Figure 6. 29. : The mooring line dynamic tensions in time series for S400_Line6.

➢ *The mooring line dynamic tensions in time series for S400_Line7*

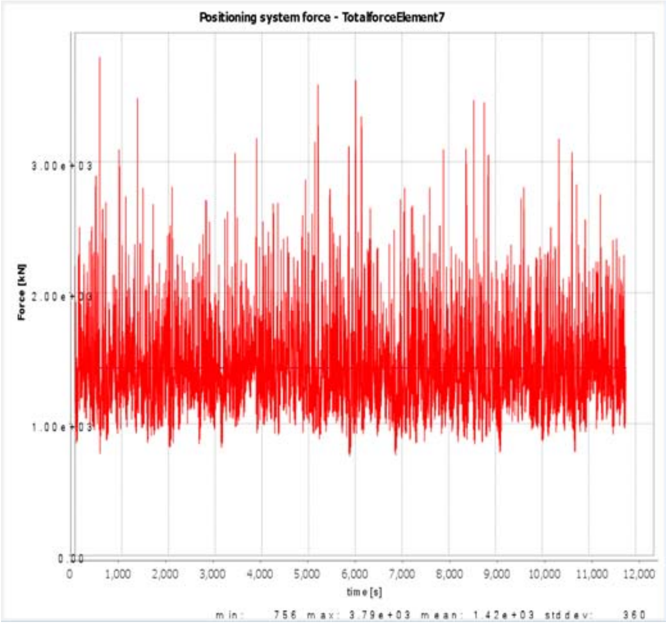


Figure 6. 30. : The mooring line dynamic tensions in time series for S400_Line7.

➢ *The mooring line dynamic tensions in time series for S400_Line8*

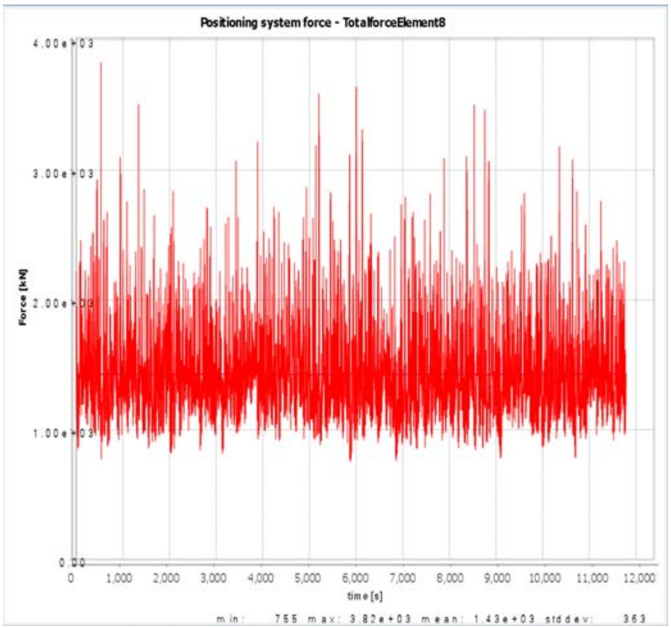


Figure 6. 31. : The mooring line dynamic tensions in time series for S400_Line7.

➢ *The mooring line dynamic tensions in time series for S400_Line9*

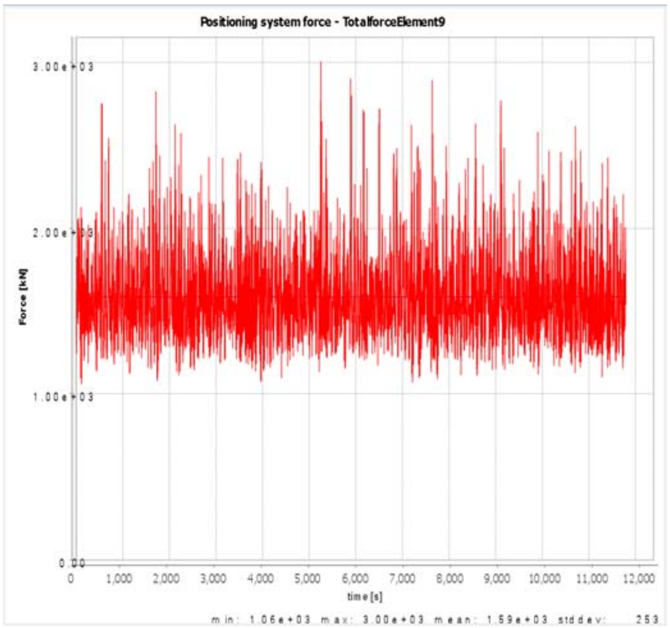


Figure 6. 32. : The mooring line dynamic tensions in time series for S400_Line9.

➢ *The mooring line dynamic tensions in time series for S400_Line10*

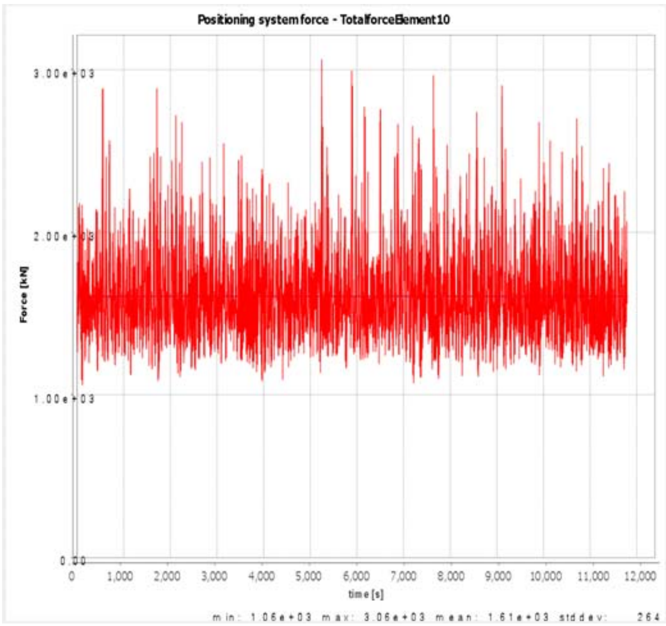


Figure 6. 33. : The mooring line dynamic tensions in time series for S400_Line10.

➢ *The mooring line dynamic tensions in time series for S400_Line11*

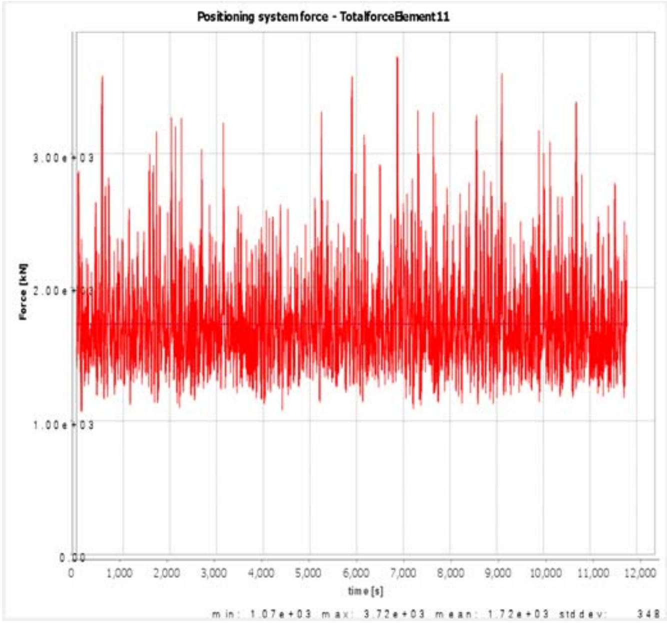


Figure 6. 34. : The mooring line dynamic tensions in time series for S400_Line11.

➢ *The mooring line dynamic tensions in time series for S400_Line12*

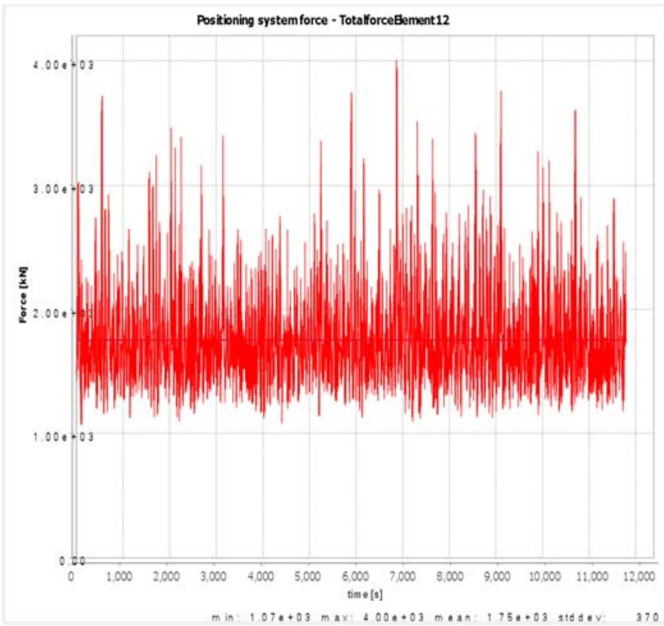


Figure 6. 35. : The mooring line dynamic tensions in time series for S400_Line12.

The forces in a mooring line will also be checked with the acceptance criteria for tension in the Ultimate Limit State (ULS) based on *ISO 19901-7 (2005)*. The results can be seen in **Table 6.16** below:

Table 6. 16. : The Summary of Line Tension Limit and Design Safety Factor

Channel	Min Tension kN	Max Tension kN	Mean Tension kN	Std. Dev.	Skewness	Kurtosis	Line Tension Limit (% of MBL)	Design Safety Factor
S400_Line1	1035.01	9634.71	2535.28	998.46	0.00	0.01	50.05	2.00
S400_Line2	1040.80	9547.82	2521.88	983.74	0.00	0.01	49.60	2.02
S400_Line3	1048.27	8967.19	2440.06	894.12	0.00	0.01	46.58	2.15
S400_Line4	1050.11	8822.99	2420.97	873.29	0.00	0.01	45.83	2.18
S400_Line5	764.80	3530.18	1418.10	340.04	0.00	0.01	18.34	5.45
S400_Line6	763.48	3581.87	1418.32	343.36	0.00	0.01	18.61	5.37
S400_Line7	755.87	3791.81	1424.36	359.73	0.00	0.01	19.70	5.08
S400_Line8	754.84	3824.52	1426.53	362.89	0.00	0.01	19.87	5.03
S400_Line9	1060.31	3001.74	1586.37	253.12	0.00	0.01	15.59	6.41
S400_Line10	1061.07	3059.34	1607.36	264.08	0.00	0.01	15.89	6.29
S400_Line11	1068.95	3721.06	1724.61	347.89	0.00	0.01	19.33	5.17
S400_Line12	1071.35	4003.40	1750.27	370.04	0.00	0.01	20.80	4.81

Based on *ISO 19901-7 (2005)*, the acceptance criteria for the tension in the Ultimate Limit State (ULS) for intact stability when using a quasi-static method should be line tension limit 50% of the Minimum Breaking Load (MBL) of the mooring line component. Moreover, the specified minimum safety factor is 2.00 as defined in *ISO 19901-7 (2005).*

Hence, the criteria above are met for the mooring system design for a cylindrical S400 floater.

D. The Results

The resulting analysis for dynamic condition such as the time series of second order wave forces and the wave drift damping forces will be also presented here. Further, these results will be compared to the result in **Chapter 8** to show the influence of the hydrodynamic interaction.

1. The second order wave forces

The summary of the results for the second order wave forces are described in surge, sway and yaw can be seen in **Table 6.17** while the graphs can be found from **Figure 6.36 to Figure 6.38.**

Table 6. 17. : The Summary of Second Order Wave Forces

Channel	Min Tension kN		Max Tension kN		Mean Tension kN		Std. Dev.	Skewness	Kurtosis
XR Force (in Surge)	-25039.92	kN	-0.01	kN	-2547.91	kN	25.79.33	0.00	0.01
YR Force (In Sway)	-501.86	kN	1287.17	kN	47.97	kN	102.76	0.00	0.02
Moment-ZR axis (in Yaw)	0.00	KNm	0.00	KNm	0.00	KNm	0.00	0.00	0.00

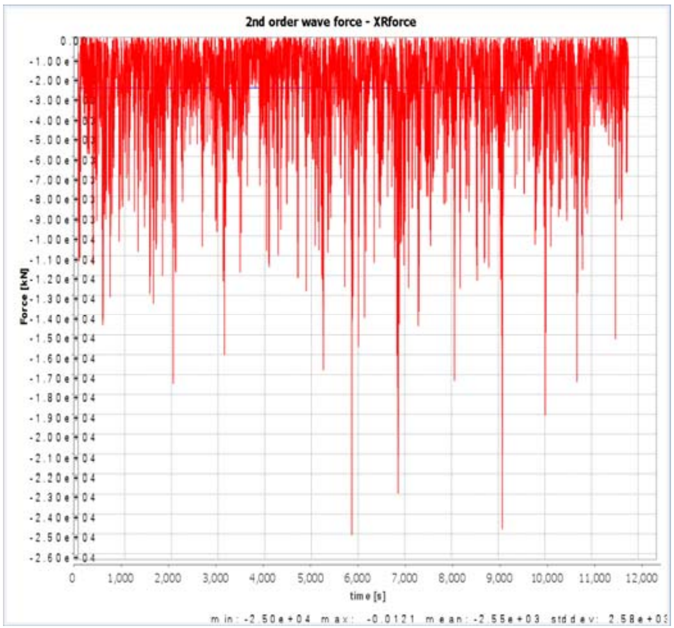


Figure 6. 36. : The second order wave forces – XR Forces (in Surge).

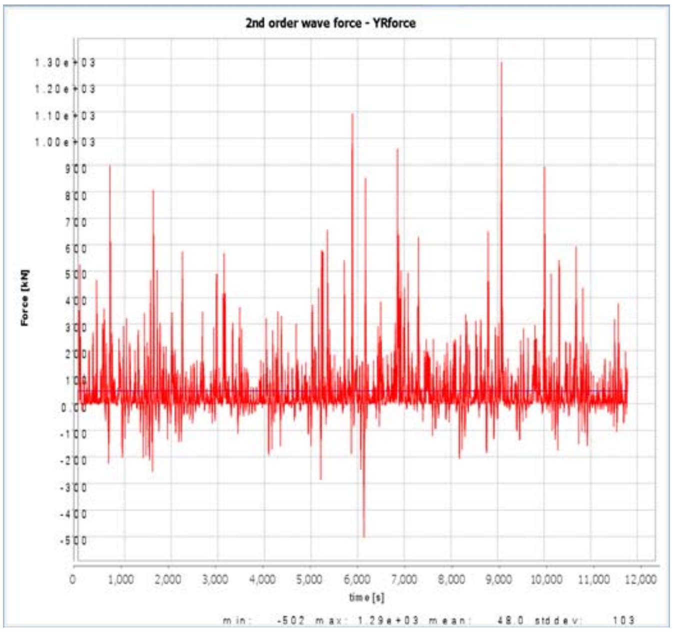


Figure 6. 37. : The second order wave forces – YR Forces (in Sway).

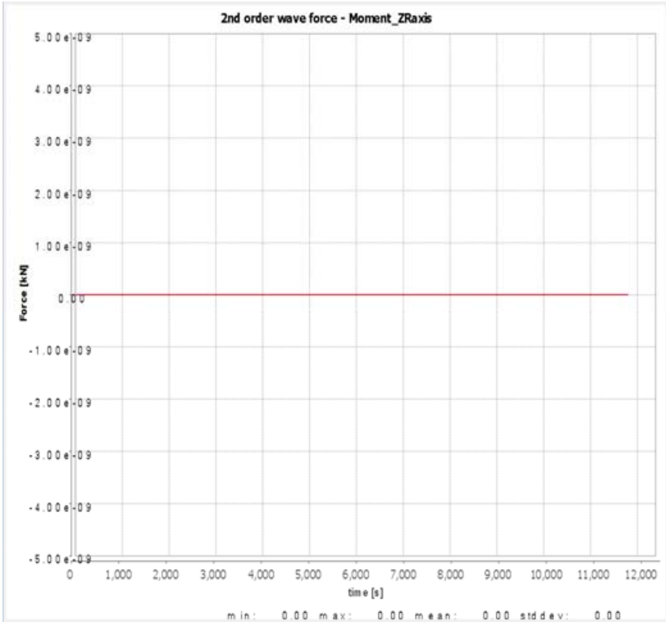


Figure 6. 38. : The second order wave moment – Moment ZR axis (in Yaw).

2. The wave drift damping forces
   The results for the wave drift damping forces are described for surge, sway and yaw. The summary can be seen in **Table 6.18** while the graphs can be found from **Figure 6.39 to Figure 6.41.**

Table 6. 18. : The Summary of wave drift damping forces

Channel	Min Tension kN		Max Tension kN		Mean Tension kN		Std. Dev.	Skewness	Kurtosis
XR Force (in Surge)	-4570.06	kN	2193.88	kN	-439.99	kN	441.26	0.00	0.01
YR Force (In Sway)	-37.70	kN	350.24	kN	9.77	kN	20.66	0.00	0.05
Moment-ZR axis (in Yaw)	0.00	KNm	0.00	KNm	0.00	KNm	0.00	0.00	0.00

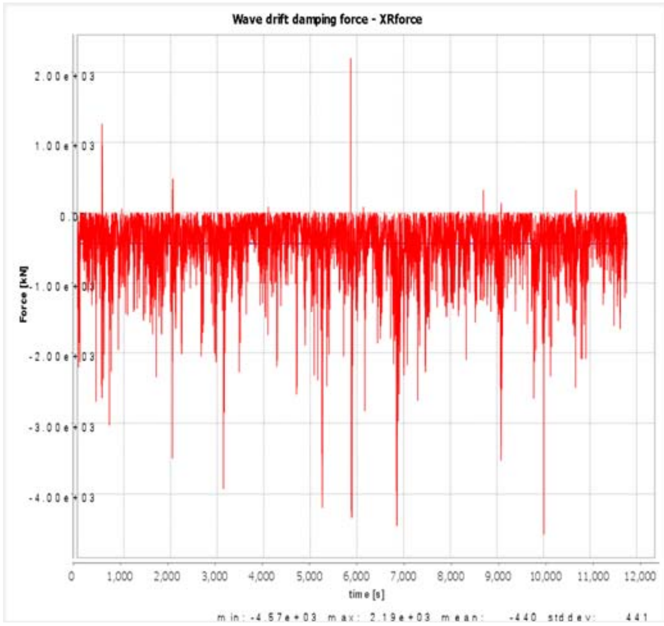


Figure 6. 39. : The drift damping forces – XR Forces (in Surge).

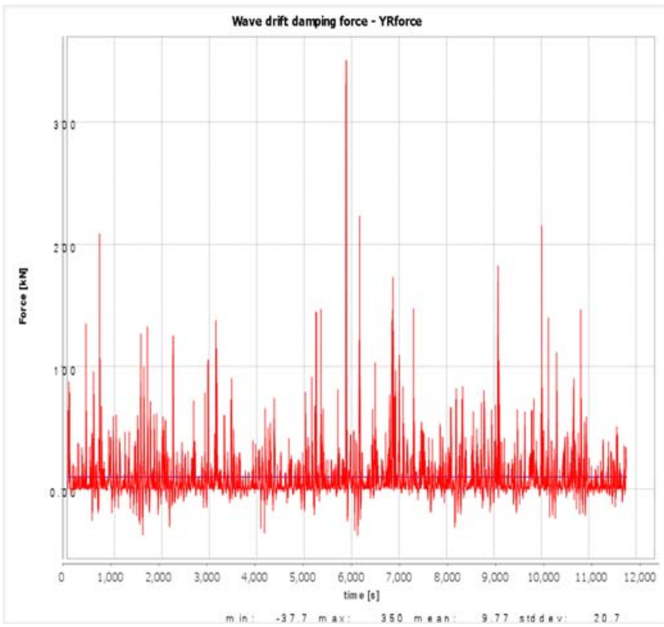


Figure 6. 40. : The drift damping forces – YR Forces (in Sway).

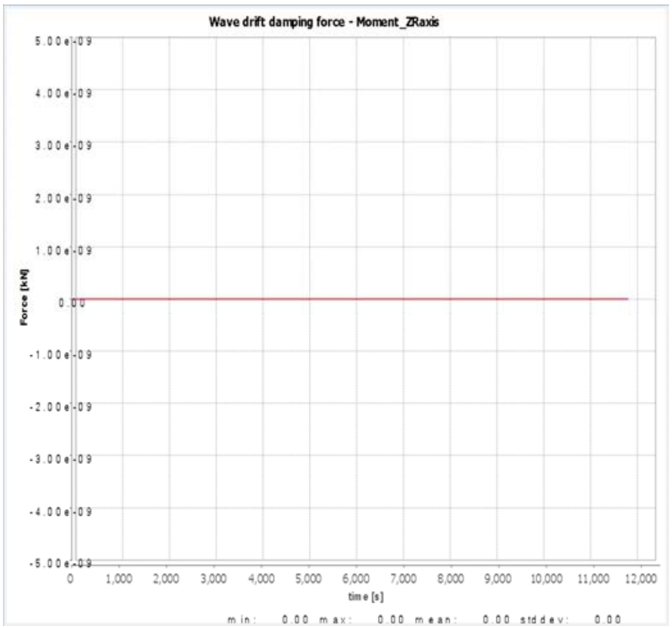


Figure 6. 41. : The drift damping forces – moment ZR axis (in Yaw).

Chapter

7

Riser Analysis

This chapter will present a general description of the riser system and present the riser analysis to obtain a feasible configuration for a floating offshore system. As we know, the nonlinear-coupled dynamic analysis represents a truly integrated system which ensures the accurate prediction of response simultaneously for the overall system as well as the individual response of floater, moorings and risers. This is the main advantage for performing coupled analysis rather than the decoupled analysis. On the other hand, it also requires many efforts and is very time consuming since this analysis demand substantial efforts since it requires a single and complete model including a floater, moorings and riser. It also requires the detailed model for each component and characterization of the environments in covering relevant load models.

Several strategies can be proposed to achieve higher efficiency analysis. In this case, the dynamic slender structure analysis for riser configuration will be performed in RIFLEX as a decoupled analysis in order to reduce time analysis. The main purpose of the analysis is to find a feasible single arbitrary configuration. The analysis will also be performed in time domain analysis under two simulation schemes, static and dynamic conditions. Moreover, the modeling concept and the steps when analysis in RIFLEX will be presented briefly.

In this chapter, the analysis results will be presented such as top angle (hang off position angle), effective tension, bending radius and seabed clearance briefly in order to document the feasible configurations.

Furthermore, this chapter will also explain the basic knowledge of a riser system to give the perspective for the analysis.

7.1 Production Riser Systems

Based on American Petroleum Institute definitions, *API (1998)*, the riser system is a key element in providing safety in all phases from drilling, completion/workover, production/injection to export. The main function of a riser is to transport fluids or gas from seabed to a host platform. Additional functions of risers according to area of application are provided as follows:

- Conveys fluid between the wells and the floater in production and injection risers.
- Export fluid from floater to pipeline for export risers.
- Guide drilling or workover tools and tubulars to and into the wells for drilling and workover risers.

In the riser system design, the dynamic behavior of the floater at the surface will mainly govern the chosen riser type. Hence, according to the ability to cope with floater motion, *DNV- OS-F201 (2001)* has categorized the production riser system into (**Figure 7.1**.):

- Top tensioned riser
- Compliant riser (flexible riser)
- Hybrid riser being a combination of tensioned and compliant risers.

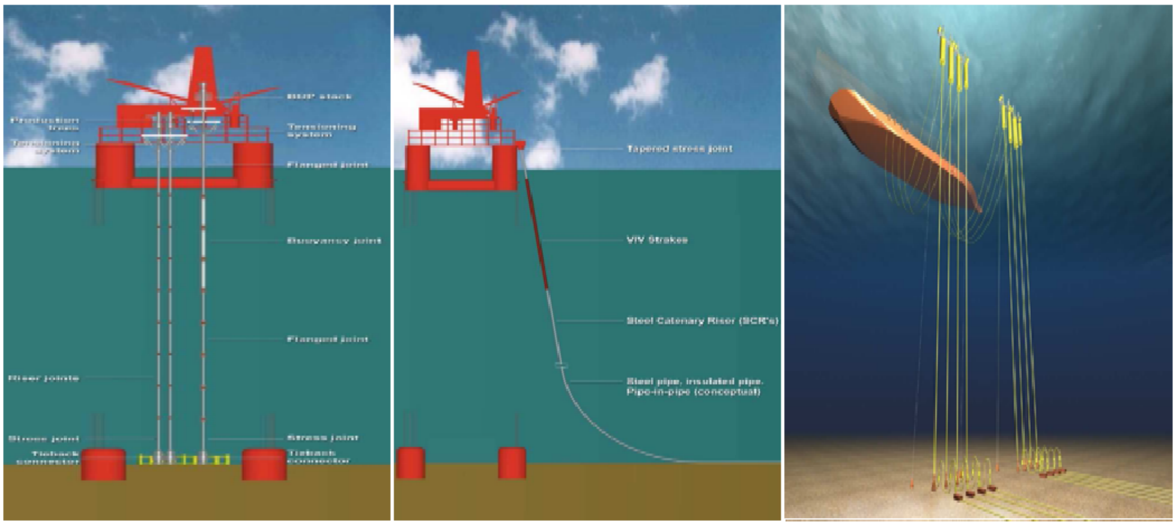


Figure 7. 1. : Examples of riser systems

Reference : Karunakaran (2008)

Besides the floater's motion, the riser system design will be governed by the floater type, water depth, design of pressure/temperature, mechanical characteristics of the riser, and environmental conditions.

The riser system design drivers also include a number of factors such as, host vessel access/hang-off location, field layout such as number and type of risers and mooring layout.

Since the base case for the study is in North Sea region and the facilities should be built to withstand very harsh weather conditions in shallow waters (approximately 170 m), the application of a flexible riser (compliant riser) will be very suitable in this floating offshore system. The flexible riser has been extensively applied in North Sea, Gulf of Mexico, Brazil and West of Africa.

According to *Chandwani and Larsen (1997)*, a flexible riser is defined as an unbonded flexible pipe designed to specific engineering requirements. Moreover, a flexible riser provides the flexibility to cope with the floater's motions. Configurations of flexible risers are formed such that they could absorb floater motions without having additional equipment e.g. heave compensation system. The design flexibility to have high dynamic resistance allows flexible riser to work in deeper waters and harsher environments.

Its structure consists of concentric extruded polymer and reinforcing helical metallic layers (**Figure 7.2**.). As shown, each metallic and polymer layer satisfies particular strength/weight/flexibility/ containment and chemical requirements. These layers will ensure that flexible risers could accommodate high curvature, allowing ease of installation and accommodation of dynamic motion.

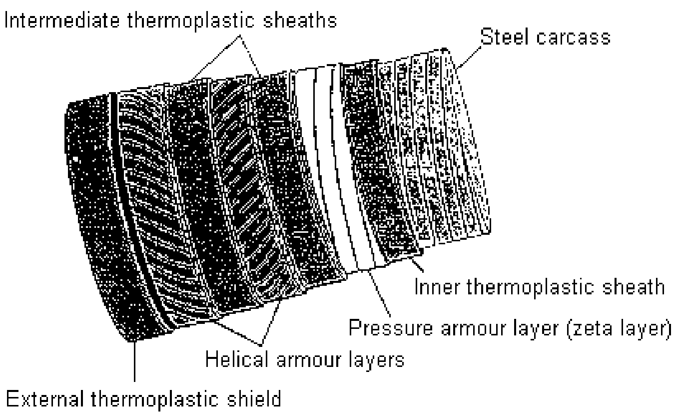


Figure 7. 2. : Flexible riser

Reference : Chandwani and Larsen (1997)

A dynamic flexible riser system can be designed for most types of floating production structures. The system flexibility is achieved by arranging the flexible pipe in some of the basic configurations below (**Figure 7.3**.):

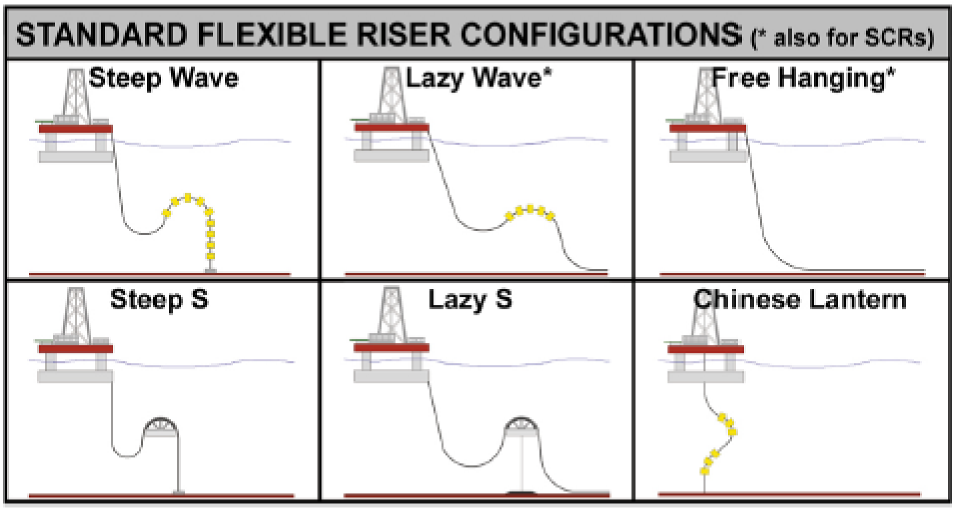


Figure 7. 3. : Standard flexible riser configurations.

Reference : Karunakaran (2010)

Furthermore, the riser configuration design shall be performed according to the production requirements and the site-specific environmental conditions. According to *Yong Bai et al (2005)*, some basic requirements shall be taken into account while determining the riser configurations such as the global behavior and geometry of riser, structural integrity, rigidity and continuity of riser, cross sectional properties, means of support, material and costs.

7.2 Flexible Riser Design in Shallow Water and Harsh Environments

In this study, many key issues of riser system design which are related to the combination of shallow water and harsh environmental conditions will be the primary focus. These situations will give the challenges of designing the riser system and will increase the complexity of riser system design.

Since the field is located in shallow water condition and also harsh environment, the application of cylindrical FPSO will give many advantages. However, it also gives real challenges for riser system design.

The combination of harsh environment and limited water depth conditions leads to significant challenges in riser design:

- Limited water depth gives very little room between the FPSO and the seabed. This condition leads to significant impact from the environmental loading and the vessel motion itself.
- Another challenge comes from the configuration itself. Limited water depth leads to large vessel offset and this will govern the pliancy requirements for the two extreme configurations, the far and near conditions, in the riser design.

Influence of the large vessel motion and the harsh environmental loadings

In deep water, the vessel motion represents a significant loading impact and it will be damped gradually along the riser length. This condition cannot happen smoothly in shallow water. Furthermore, the impact of the vessel's motion from pitch and roll will be significant in shallow water. These motions will be one of the reasons why the effective top tension becomes larger at the hang off position. Not only the effective top tension but also the angle position will be larger at the hang off position.

The harsh environment also leads to a significant dynamic riser behavior. In shallow water, large drag forces from the environment will result from the combination of strong current and large waves. For small submerged weight of riser under extreme currents, potential clashing with adjacent moorings is high. Another potential problem is risk of compression forces at touchdown area (TDA).

Another condition that will be a main consideration is the impact loading that generates from shock due to snapping in slack condition. Significant vessel motion, (roll and pitch motion) creates slack in one position. This stored energy releases quickly when the wave passes and snapping occurs in the riser system, generating a significant shock for the system.

Influence of large vessel offset

As the riser system has to absorb vessel motions, large vessel motions will have direct impact on the riser behavior. As vessel offset increases due to harsh environment, options for riser configuration become limited. Hence, a **Top tensioned riser may not be applied, or conventional free hanging steel catenary riser will experience high bending moment at touchdown point**.

Didier Hanoge (2010) has mentioned that vessel offset has major influence on the riser configuration design. It governs the pliancy requirement and the riser system must accommodate the two extreme configurations; far and near conditions, as presented in **Figure 7.4.** below:

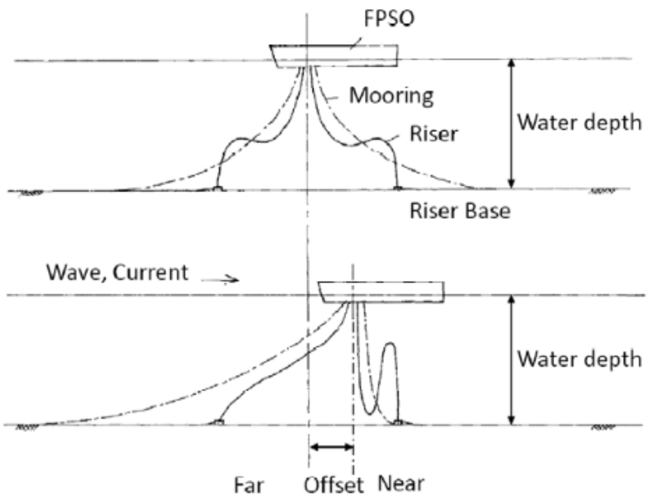


Figure 7. 4. : The influence of vessel offset in riser design.

Reference: Didier Hanoge (2010)

Furthermore, the deeper the water depth, the higher the offset value is. However in terms of percentage, the value will be eminent. Since the riser system will be designed according to the decoupled analysis, the distance between the vessel's centers of motions to the riser hang off will be taken as single representative offset (a conservative value) due to the vessel motions (pitch and surge). In the far case, the riser length must be long enough to avoid an over stretch that would result in an unacceptable tension, while in the near case the riser length must be short enough to avoid over bending or clashing issues.

7.2.1 Riser Configuration Selections

These real challenges discussed above will represent essential information to design the optimum riser configuration for a floating offshore system in Western Isles Field. As we mention above, the dynamic response of a riser system to the environmental conditions will play the key role in selection of a feasible configuration for a riser.

Hoffman et al (1991) has also mentioned about the important factors that should also be considered during the configuration selection:

- Interference with others, such as riser systems and moorings (design layout)
- Activity of other vessels in the vicinity
- Ease of laying and retrieval and future requirements of maintenance (future development)
- Inspection and worker operations

It should be highlighted that the dynamic responses of a riser are strong related to the environmental loading due to the wave-current combination and the interaction arising from the structural non-linear behavior of the riser itself. In shallow water and harsh environmental conditions, the effects of the wave-current combination are very significant in the magnitude and in the direction of fluid forces. Hence, these effects will have significant influence from hydrodynamic force coefficients, current velocity profiles and relative direction of waves and currents.

A number of riser concepts offer technical and commercial advantages for shallow water and harsh environmental condition. The alternative riser concepts that can be developed for these situations are:

1. **Flexible riser**
   Most of fields with floating production around the world are associated with flexible risers. The flexible risers were specified and installed in the Encova field offshore Brazil as part of a floating production system (*Machado and Dumay (1980)*) then these risers have been used extensively at North Sea, Gulf of Mexico, Brazil and West of Africa. This leads to flexible riser as a proven technology especially for shallow to mid water depth. *Chandwani and Larsen (1997)* has also stated that the flexible riser is suitable for shallow to medium water depths (>600m).
   The flexible riser has the ability to accommodate high curvature and dynamic motions which results in good performance for harsh environments such as Offshore Norway. It is easy to install, retrieve, corrosion resistant and reusable.
   Hoffman et al (1991) also pointed out some prominent characteristics for flexible risers, such as:

- The riser accommodates the floating platform motion and hydrodynamic loading by being flexible. In storm conditions the riser undergoes large dynamic deflections and must remain in tension throughout their response. Hence it must have high structural axial stiffness and relatively low structural bending stiffness.
- Besides that, it also provides small resistance to lateral disturbances caused by wave and current induced hydrodynamic loadings.

And *Karve et al. (1988)* have also mentioned that a flexible riser offers the advantage of having inherent heave compliance in the catenary thereby greatly reducing the complexity of the riser-to-rig and riser-to-subsea interfaces. Moreover, these risers are available in continuous lengths thereby avoiding seals and makeup joints every 50 feet as required by steel risers.

These risers have also relatively lower fatigue sensitivity than steel catenary risers by being flexible and can be applied in many possibility configurations such as the steep wave, steep-S, lazy wave, lazy-S and free hanging.

2. **Steel catenary riser**

The Steel Catenary Riser (SCR) is one direct alternative to the flexible riser. It may be used at larger diameters, higher pressures and temperatures and also may be produced more easily. It has the capacity to be suspended in longer lengths, removing the need for mid-depth buoys. These risers are cheaper than the flexible risers and also can be used in greater water depths without a disproportionate increase in cost.

However, the SCRs are very sensitive to environmental loading. Large heave and surge motions from host platform due to harsh environment result in buckling issues at the touchdown point. The length of pipe between the supports changes when the host platform moves. This makes the seabed touchdown point shift, hence moving the point of maximum curvature up and down along the length of the pipe at the seabed. As a result, at the touchdown area, the pipe is subjected to maximum and almost zero curvature, making the region highly sensitive to the fatigue damage. The vortex induced vibrations due to currents in deepwater application another issue for SCR design.

Hence, the SCRs could be the economical solution but these risers require good engineering studies to minimize the risks due to their potential problems in design.

In shallow water riser design, the riser system must be strong enough to withstand high tension and bending moments due to the harsh environment and significant vessel motions. Comparing the two riser types above, the application of flexible riser (compliant riser) will be very suitable in this floating offshore system. A Lazy Wave riser configuration has been chosen in this project. Increasing pliancy of the system is the main reasons to modify the configuration by introducing a lazy wave with a multiple buoyancy section at the hog bend position. This riser configuration will hopefully not only be a robust solution for riser but also as an economic design.

As one of the solutions to reduce the impact of the vessel's motions and the environmental loading, buoyancy modules are used to reduce overall tension at the upper region and improve the curvature at the lower region. Besides that, the buoyancy modules will create the riser shape desired easier. Furthermore, the hog bend position gives positive significant effects for the response of the riser system.

Other ancillary components will be used to fulfill pliancy requirements in the riser design optimization. The bending stiffeners can be used to avoid overbending and increase the curvature to acceptable levels at the hang off connection.

7.2.2 Design Parameters

The design of a flexible riser system should be related to many design parameters such as environmental conditions, vessel motions and riser properties. These parameters should be well defined. The main design parameters are the choice of riser configuration, the length of the riser, the system geometry and the sizing of riser and ancillary components. The other factors that should also be considered are the hang off location, the location of touchdown point and also the position of the wells. All of these parameters should be optimized to gain a feasible riser configuration.

The system design will be checked by static and dynamic analysis. In the static analysis only the static riser configuration with and without vessel offset and dynamic analysis of the entire system will be performed by combining static loads with dynamic environmental loads based on the movements of the riser at the top (far and near).

The riser will be analyzed in a short term periodic condition (i.e. just after installation (at 0 years operation) without any variation of riser characteristics (e.g. the dimension and weight of the riser and the ancillary components).

A. **Limit State Design Criteria and Design Conditions**

   In this analysis, the limit state design criteria will be the Ultimate Limit State (ULS) to determine the level of safety required for the riser conditions. Based on DNV, *DNV-OS-F201 (2001)*, the Ultimate Limit State (ULS) requires that the riser must remain intact and avoid rupture, but not necessary be able to operate. For the operating condition this limit state corresponds to the maximum resistance to an applied loads with a 10^{-2} annual exceedence probability. Hence the load combination for the riser will be defined as follow:

   - 100 years Irregular Wave (Hs=15,6 m and Tp=15,5 s) for Torsethaugen (Jonswap double peaked)
   - 10 years currents
   - Static offset ± 25 m
   - At Ballast condition , draft z =16.32 m

   Furthermore, riser system design will cover normal operations (when the riser is filled with the operating contents). Hence, the riser will always be filled with stabilized crude (i.e. the riser will not be empty or gas filled or in the other words, not analyzed in a condition with slug). The analysis will also not cover for compartment damage in order to simplify the study.

B. **Sensitivity analysis**

   A sensitivity analysis will be done to study the variation of the output results for different variations of the input data to enhance and increase the understanding of the riser system’s behavior and to reduce the error possibilities.

Sensitivity analysis should be done with respect to:

- Dimension and weight of the riser
- Buoyancy elements
- Seabed friction

Due to short time available for the thesis work, the sensitivity analysis will not be reported in this study.

C. Load designs

Yong Bai et al. (2005) have categorized the loads acting on marine risers as follows:

- Functional loads

  Loads due to the existence of the riser system without environmental and accidental effects. The following shall be considered as functional loads:

  1. Weight of riser and contents
  2. Pressures due to internal contents and external hydrostatics
  3. Buoyancy
  4. Thermal effects
  5. Nominal top tension

  The following should be considered as appropriate:

  1. Weight of marine growth, attachments, tubing contents
  2. Loads due to internal contents flow, surges, slugs or pigs
  3. Loads due to installation
  4. Loads due to vessel restraints

- Environmental loads

  Loads caused by the surrounding environment that are not classified as functional or accidental loads. The following shall be considered as environmental loads:

  1. Wave loads
  2. Current loads

- Accidental loads

  Loads caused by the surrounding environment that are not classified as functional or accidental loads. The following shall be considered as accidental loads:

  1. Partial loss of station keeping capability
  2. Dropped objects
  3. Riser collisions, vessel impact and operational malfunction

7.2.3 Design Criterion

The design of a flexible riser system is usually based on the allowable pipe curvature or MBR (Minimum Bending Radius) and allowable tensions which are prescribed by the manufacturer. These criteria will also be influenced by the clearance area between the riser and other parts of the floating offshore system.

The allowable curvature and the tension are based on a full scales test from the manufacturer combined with stress analysis carried out by the manufacturer and these limits ensure that the flexible pipe will not be overstressed when responding to dynamic loads and vessel motions.

The system should also be designed such that the flexible pipe is always in tension throughout its dynamic response cycle. The minimum clearances are also specified to avoid clashing problems between the riser and the seabed or the riser and the vessel or the riser and mooring lines.

The main requirements from the results of the analysis will be based on:

A. Top angle position

In this design analysis, maximum top angle positions for the design will be limited to around 15-20 deg in static analysis and less than 45 deg at dynamic analysis for the Ultimate Limit State (ALS). This is to ensure that overstressing or compression will not happen along the upper location around the hang off position.

B. Effective tension

In this design analysis, any compression would be avoided with upper limit of 5 kN because compression may cause (birdcaging and) buckling which may affect the integrity of the riser adversely and reduce the service life.

C. Bending radius

Minimum bending radius (MBR) for the flexible pipe is governed by the allowable strain of the polymeric layers and the permissible relative movements of the wires in the metallic armour layers during pipe bending. Minimum bending radius (MBR) criterions are determined based on *Braestrup (2005):*

Bending radius requirements can be seen in **Table 7.1** below:

Table 7. 1. : Design MBR requirements

MBR	Design Criterion
Static application	1,0 times storage MBR
Dynamic application	
Normal operation	1,5 times storage MBR
Abnormal operation	1,25 times storage MBR

Reference: Braestrup (2005)

D. Seabed clearance and line clashing

Minimum clearances are specified to avoid clashing problems between the riser and the seabed or the riser and the vessel and between the riser or other adjacent risers, the cables or the mooring systems. Seabed clearance at the sag bend position is 5 m and line clashing checks are performed.

7.2.4 Methodology Design and Analysis Steps

In this chapter, the riser system will be analyzed by using RIFLEX for decoupled analysis in order to reduce time analysis. In the de-coupled analysis, the results of simulated motions of a cylindrical S400 floater based on “large body theory” in WADAM will be transferred as top end excitation of the riser in order to calculate dynamic loads in these elements.

Moreover, this analysis only considers the vessel motion where the wave load comes from the wave frequency loads as first order wave loads while the low frequency motion that comes from secondary order wave load such as the mean wave (drift) force and slowly varying wave force will be neglected. This analysis only depends on the vessel’s Response Amplitude Operator (RAO) as input without any influence from secondary order force. Hence, there is only little integration between the cylindrical S400 floater and the riser.

Further, these effects from the vessel motions and environmental loadings will be simulated in the two extreme riser configurations; far and near conditions. These far and near conditions will be represented by a representative offset value. These values should also accommodate the mean and low frequency motion (LF) since we neglect these terms of the vessel motions in this simulation.

The variations of representative offset values are carried to investigate the effect on the riser based on different vessel positions. Hence, the static configuration of the riser system will be strongly influenced by the variations of the representative offset value.

Generally, this value is determined by hypothetical or empirical calculations from the previous projects. Furthermore, the deeper the water depth, the higher the offset value is. However in terms of percentage, the value will be reduced with depth. Besides the water depth, the environment characteristics in the area will also influence the magnitude of the representative offset value.

Further the analysis will be performed in time domain as problem solving method. Time domain analysis should be used in the riser analysis since we have to deal with non linear systems such as drag forces, finite motion and finite wave amplitude effects.

The riser design is iterative and the process may continue until all the design requirements are optimum. A methodology is needed to provide a systematic design to fulfill the requirements of the global analysis. Simple steps of the riser analysis for the cylindrical S400 floater based on the decoupled analysis can be seen in **Figure 7.5.**:

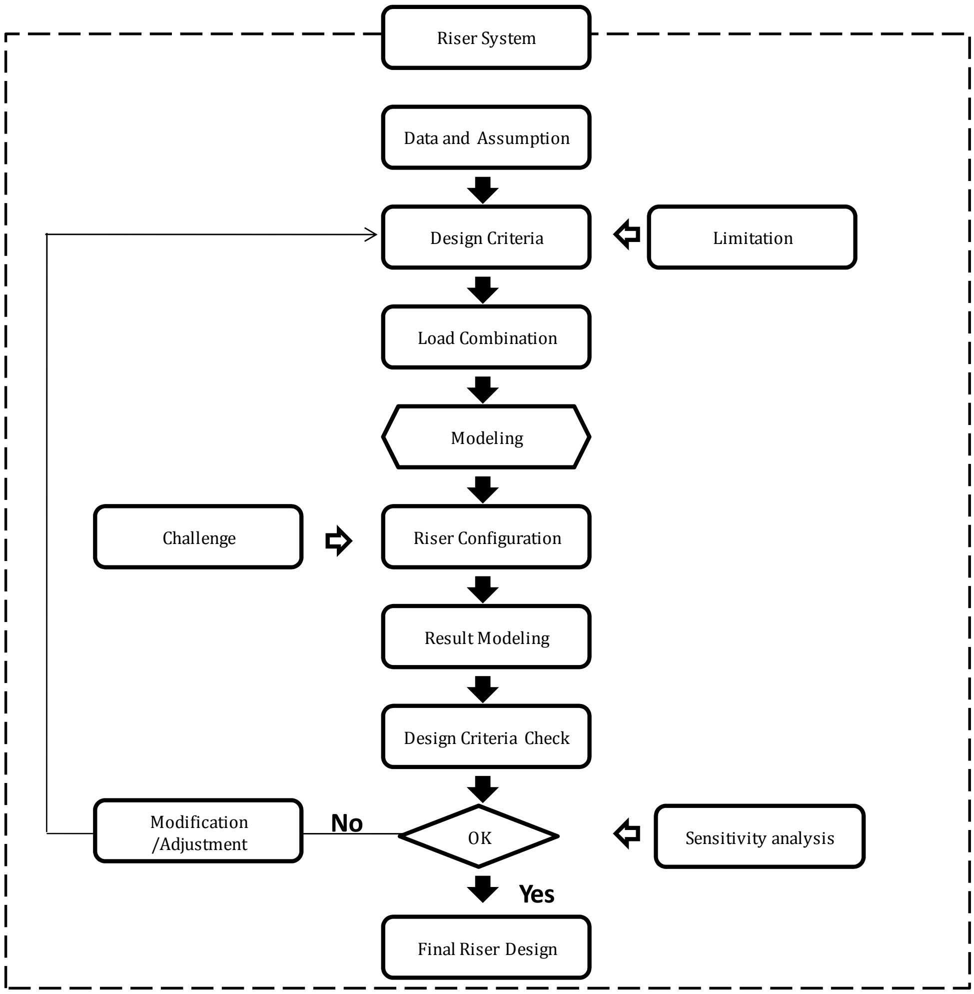


Figure 7. 5. : Methodology design for a riser system.

In this study, the riser system for the Western Isles Field will be modeled as a single production riser for with 6" and 8" diameter in RIFLEX. A Lazy Wave riser configuration has been chosen based on reasonable proponents discussed in **subchapter 7.2.1.**

As the first step in the riser system design, the data and assumptions used as input will be identified to provide all relevant situations for the design criterions and limit states. Furthermore, the data and the assumptions will be categorized as below:

- The field layout data
  Water depth and orientation of the riser and hang off coordinates of the riser can be determined from Western Isles Field layout
- Pipe data sheets and ancillary components
  Type of pipe (flexible riser), the conveyed fluid and contents data, the dimension specification for the risers (e.g. internal diameter, outside diameter, etc), the structure and limit specification (e.g. bending stiffness, axial stiffness and minimum bending radius) and the ancillary components data.

The detail information about the field layout data, pipe data sheets and ancillary components can be found in **Subchapter 7.2.5.**

- The environmental data
  Current profile for 10 years condition, wave profile for 100 years condition and seabed friction coefficient
- The vessel response and the variations of a representative offset value
  The vessel response will be based on the first order wave forces which are described in the frequency domain as a linear motion transfer function, also denoted Response Amplitude Operator (RAO). The further details can be found in **Appendix A**.
  The vessel offset will be determined as a representative offset value by hypothetically empirical calculations. These values will accommodate mean and low frequency motion (LF). The variations of the representative offset values are carried out to investigate the effect on the riser based on different vessel positions for two extreme riser configurations; the far and near conditions.

The detail information about a representative offset value can be found in **Subchapter 7.2.5.**

7.2.5 The Western Isles Field Layout and Model Properties for the Riser System

A. The Western Isles Field Layout

The Western Isles Field consists of two drill centers denoted North Drill Centre and South Drill Centre. Separate risers are routed to the two drill centers. However, the study will only model two risers for the South Drill Centre; for 6” and 8” production risers in RIFLEX as depicted in **Figure 7.6.** below:

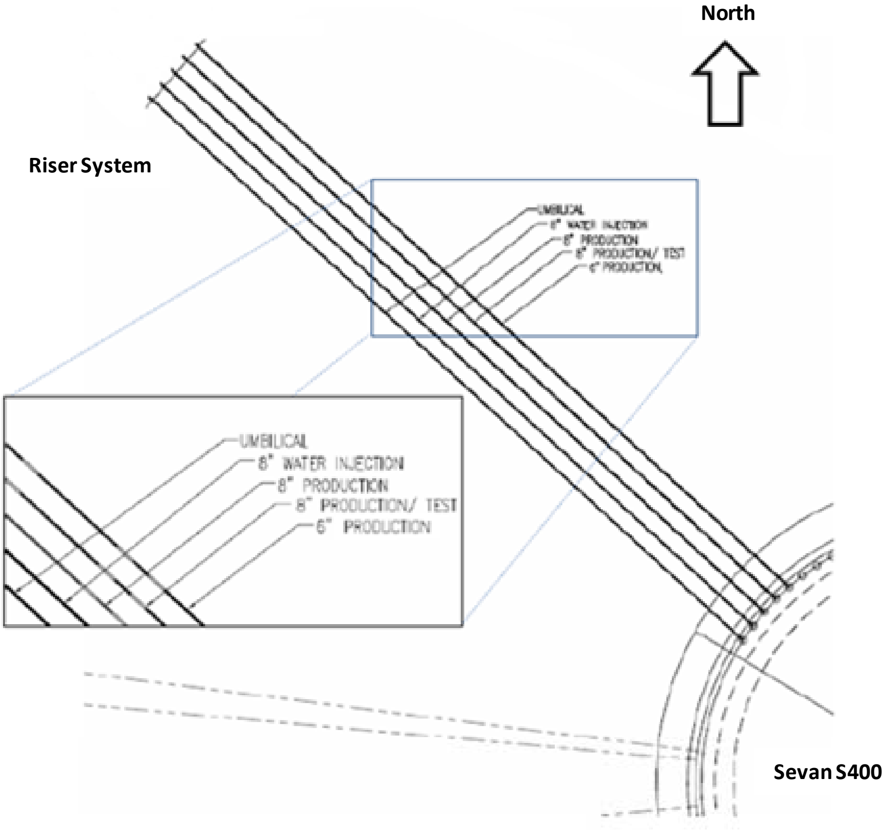


Figure 7. 6. : The riser system for South Drill Centre.

Moreover, the offshore field Western Isles Field is located on shallow water conditions and also harsh environment. The water depth is approximately 170 m.

The orientation of the riser system will be at 330 degrees relative Grid North. Spacing of Risers at FPSO hang-off is 3.0 m both at radius 33.5 m from FPSO center. Since the analysis will be modeled in ballast loading condition (z =16.32 m), Hence the riser hang off position will be at (33.5m; -16.32m).

B. Model Properties for the Riser System

1. Flexible riser properties

   The flexible riser properties contain the data about dimensions and weight of the riser, the structural limit prescribed from manufacture and hydrodynamic coefficients.

   A. Physical properties for the risers

      Dimension and weight of the riser will give contributions to the functional loads on the riser and the strength capability of the riser. *Gudmestad (2007)* has mentioned that the thickness has a linear relation to the strength capability of the riser. Higher thickness gives higher strength value. On other side, the economical reason should be the main consideration because higher thickness will spend higher resources. Optimization has to be done to get proper dimensions based on the design conditions such as pressure and mass flow.

      The structural limits are given by maximum tension, bending stiffness, axial tensile stiffness and minimum bending radius.

      As slender structures, the risers will also experience drag forces and lift forces in constant currents. The drag forces are caused by the friction between the cylinder and the fluid. These forces will be affected by the roughness of the cylinder. A rough cylinder will set up larger eddy currents and the forces will be larger. In this analysis, we are only concerned with the drag forces. On the other hand, the lift forces will be neglected because they will not have a big difference pressure between upstream and downstream.

      The data about dimensions and weight for risers, structural limits and also hydrodynamic coefficients can be found in **Table 7.2** and **Table 7.3** below:

Table 7. 2. : Physical Properties for Risers

Parameter	Unit	6"	8"
Outer diameter	mm	270.9	311.7
Inner diameter	mm	156.9	208.5
Weight in air	kg/m	145	150
Bending stiffness @ 20 deg C	kNm^2	33	40
Axial stiffness	MN	500	1000
MBR storage	m	1.76	2.02

Reference: Sevan Marine (2011)

Table 7. 3. : Physical Properties for Risers

	Normal drag	Tangential drag	Normal added mass
Bare line	0.2	0.2	0
Bouyancy modules	0.25	0.2	0.2

Reference: Sevan Marine (2011)

2. Bending stiffener
   The bending stiffeners are used to avoid overbending and increase the curvature to acceptable levels. It will be applied at the top position of the risers to reduce the free floating of the sag bend. In the analysis, it will be assigned as a variable parameter.
3. Buoyancy modules
   The analysis will include buoyancy modules in order to:
   - Achieving stable configuration, distributed buoyancy will be used to comply the motions of the FSU without undue stress onto the flexible riser due to the environmental forces
   - Minimizing compression and excessive bending in the touchdown region as buffer
   - Decreasing the tension required at the surface

   In the analysis, buoyancy modules are distributed over specific lengths of the riser configuration and the suitable dry weight of buoyant elements will be assigned along the buoyancy section as a variable parameter.

7.2.6 Modeling Concept by RIFLEX

The riser design will be modeled by using RIFLEX based on the finite element technique which has proved to be a powerful tool for several applications. Moreover, the riser will be modeled with beam elements which will be formulated by using a “co-rotated ghost reference description”. The basic theory about this can be found in **Chapter 2** based on *Marintek (2010)* for “RIFLEX Theory Manual Finite Element Formulation”.

The procedure for the riser system model can be found in details in *Marintek (2010) “RIFLEX User Manual Finite Element Formulation”*. The program system consists of three programs or modules communicating by a file system as shown in **Figure 7.7.** below:

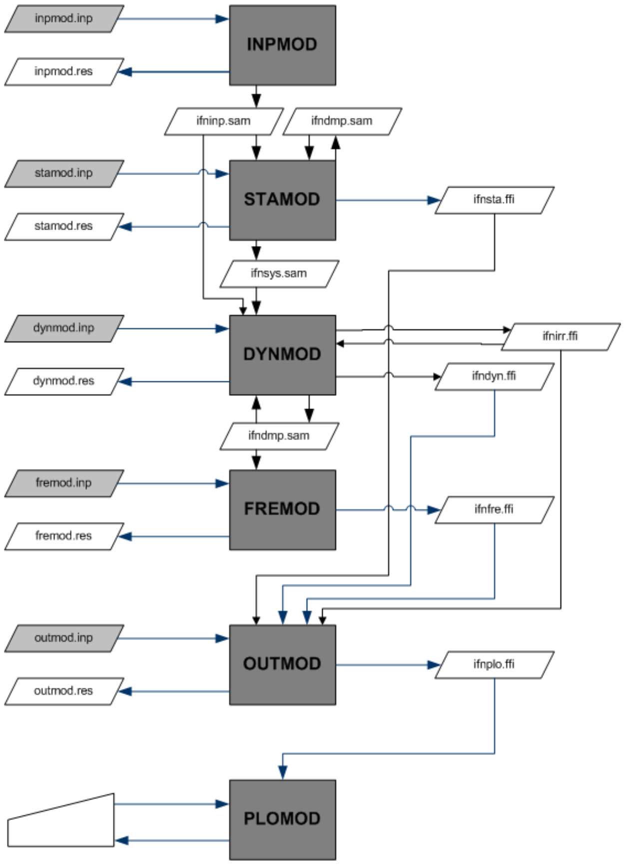


Figure 7. 7. : Layout of the RIFLEX program system and file communication between modules.

The FREMOD and PLOMOD modules will not be used in this analysis; PLOMOD module is just a plot routine. The INPMOD module has the function to gather all data inputs and organizes a data base for use during the subsequent analyses in STAMOD. The STAMOD module has the function to perform several types of static analyses. Further these results are used to define the initial configuration for a succeeding dynamic analysis in DYNMOD module. The data for the element mesh, stressfree configuration and key data for the finite element analysis are also generated by STAMOD module based on system data given as input to INPMOD module. In the DYNMOD module, time domain dynamic analyses based on the final static configuration will be performed in order to calculate the responses of the system. The results of the simulation in time series format will be read by OUTMOD module then the plot of the time series and statistical parameters can be access from PLOMOD. The detailed information about the input to these modules as being used in the analysis can be found in **Appendix D**.

The flexible riser that will be modeled in RIFLEX will adopt an Arbitrary Riser system configuration (AR). This system will determine the layout configuration of a riser based on its topology and boundary conditions. The system definition starts with definition of the topology and proceeds in increasing detail to the line and component descriptions. The system topology is in general described in terms of branching points and terminal points. These points are denoted supernodes. Further, these supernodes are classified as free, fixed or prescribed depending on their boundary condition modelling.

We use a Lazy Wave riser configuration in this project. It will use supernodes which are denoted as free or fixed. A free constrained node will be used for modeling a joint point between a bending stiffener and a body line of the riser while a fixed constrained node will be used for modeling at hangoff position and at connection to the seabed. If a supernode is denoted free, all degrees of freedom are free while in the fixed constrained node, all degrees of freedom are fixed.

Besides supernodes, the initial layout configuration of a riser will also be defined as a stressfree configuration. This configuration will represent the initial and no structural forces/deformations along a riser. Furthermore, this configuration will be used as a basis for calculation of structural forces and deformations in the finite element analysis. The stressfree configuration for the Arbitrary Riser system configuration (AR) is defined by the input and can be seen in the file sima_inpmod (RES file). Further between two supernodes, the riser system will be identified as a line which contains elements. The number of elements in each segment will influence the accuracy of the result. The description of the layout configuration design in the Arbitrary Riser system configuration (AR) can be seen in **Figure 7.8.** below:

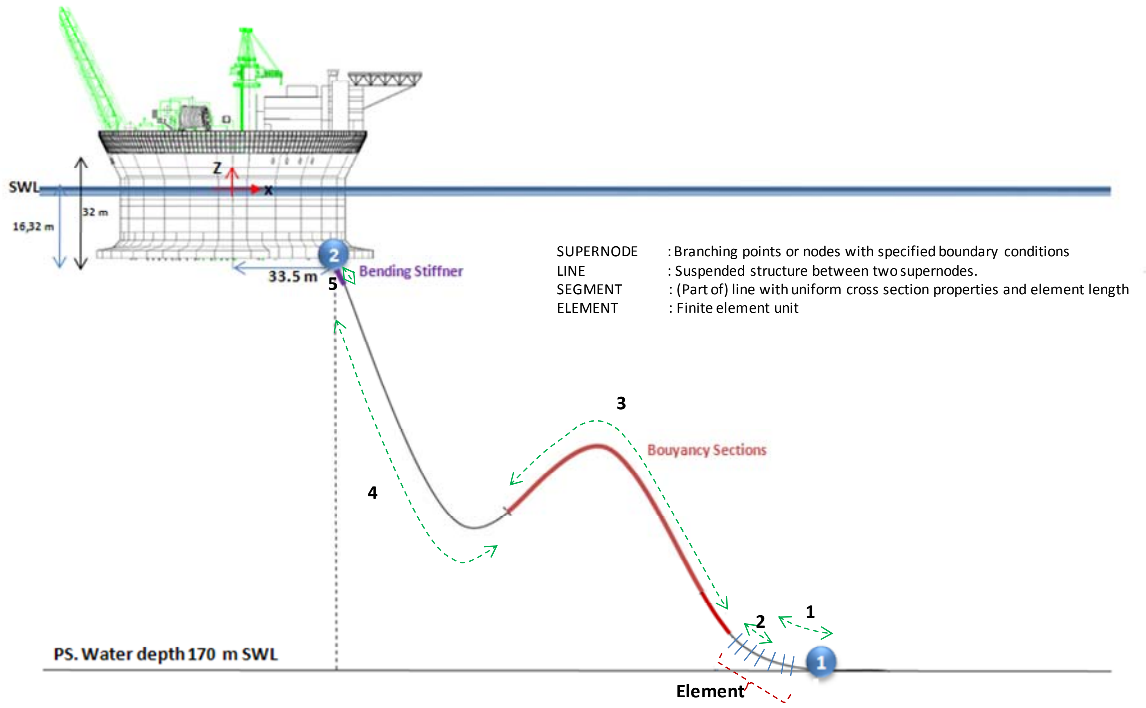


Figure 7. 8. : System definition for the description of the layout configuration design of the Arbitrary Riser system configuration (AR).

Hence, the riser line in the layout configuration design of the riser will be defined as Arbitrary Riser system (AR) which has 2 supernodes and 5 segments with many elements in each segment.

Moreover, the riser design will be modeled by using RIFLEX in two stages:

1. Static analyses
   As the first stage of the modeling, the result from the static analysis will determine the acceptable system layout for the riser. In this stage, the effects of changing the design parameters (i.e. system geometry and length) on the static curvature and tension will be investigated. Based on these parameters, the design will select a suitable range of system geometries and lengths that satisfy the design criteria. Moreover, the static effects of the vessel offset (based on far and near conditions) and the current loading are investigated for different locations.
   The static analysis is based on a complete non-linear formulation. However, the catenary theory will also be implemented to reduce the computing time as a good starting point.
   Static analysis comprises:
   - Equilibrium configuration
   - Parameter variations of tension or position parameters, current velocity and direction
2. Dynamic time domain analysis including eigen value analysis
   In the second stage, the dynamic analysis of the system will be performed to assess the global dynamic response. An acceptable system layout from the previous stage and the dynamic loadings will be considered here. The analysis will combine the loads from the combination of waves and current, vessel positions and riser contents in order to prove the acceptance condition based on the design criteria. The results of these analyses such as the dynamic curvatures, tensions and clearance area should be checked against the design limits.
   Time domain analysis is based on step by step numerical integration of the dynamic equilibrium equations.
   Dynamic analysis comprises:
   - Eigenvalue analysis, natural frequencies and mode shapes
   - Response to harmonic motion and wave excitation
   - Response to irregular wave- and motion excitation

7.3 Riser Analysis

7.3.1 Layout and Schematic Riser Configurations

The riser design is an iterative and complicated process that may continue until all the design requirements are optimum.

Since the riser system design will be the focus in the combination of shallow water and harsh environmental conditions, the challenges from this condition will introduce some modifications in order to obtain a feasible riser configuration.

The main challenges that will be faced in the design process come from the large vessel motion and vessel offset due to limited space between the FPSO and the seabed. The harsh environmental loading will also give impact on the dynamic riser behavior. Beside, the external influence from the environmental condition, the configuration itself will govern the pliancy requirement and the riser system should accommodate two extreme configurations, the far and the near conditions. In the far case, the riser length must be long enough to avoid an over stretching that would result in an unacceptable tension, while in the near case the riser length must be short enough to avoid over bending or clashing issues.

Hence, some modifications have been made as follows:

- Heavy weight riser
  By increasing the weight of the riser to reduce the free floating loads from the riser makes the configuration more stable
- A multiple buoyancy section at the hog bend position
  By introducing a lazy wave with a multiple buoyancy section at the hog bend position, this riser configuration will not only represent a robust solution for the riser but also be an economic design.
  As one of the solutions to reduce the impact of the vessel motion and the environmental loading, buoyancy modules are used to reduce the overall tension at the upper region and improve the curvature at the lower region. Besides that, the buoyancy modules will create the riser shape desired easier. Furthermore, the hog bend position gives significant positive effects for the response of the riser system.

By referring to the design parameters, the feasible riser configurations for 6” and 8” production risers in the Western Isle field can be seen in **Figure 7. 9.** and **Figure 7. 10**.

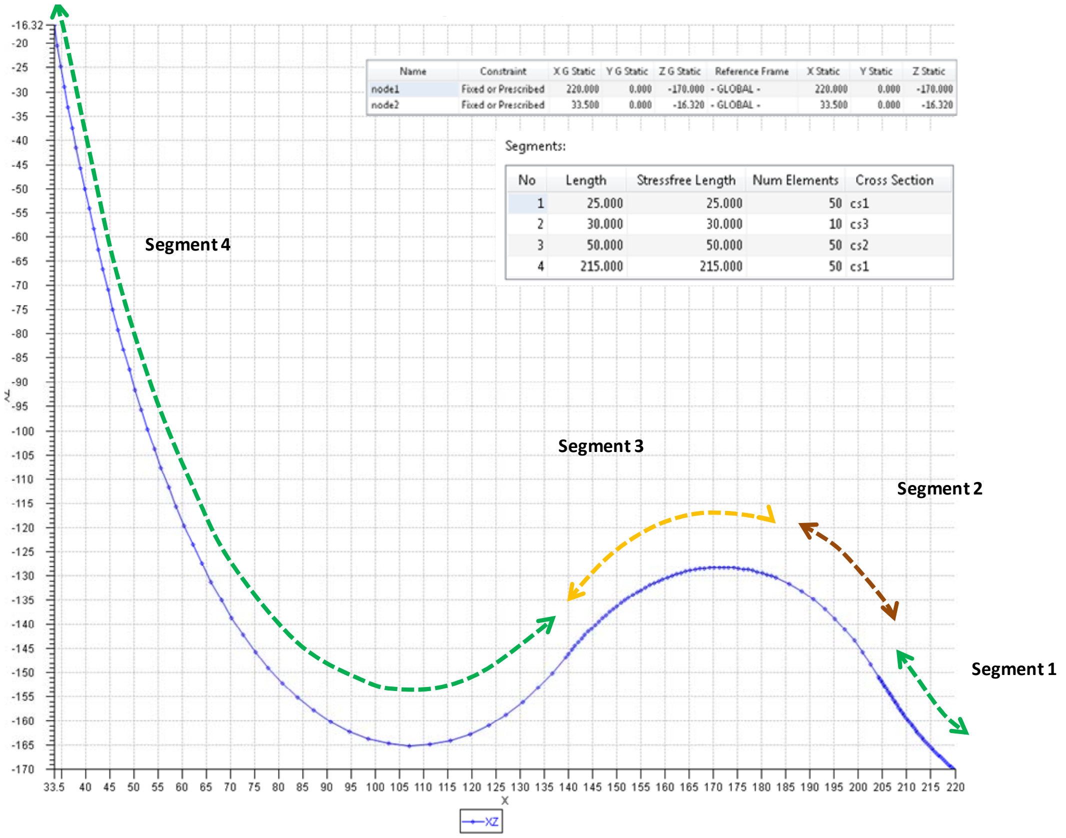


Figure 7. 9. : The riser configuration of the 6” production riser for the Western Isle Field.

The feasible configuration for the 6” production riser will adopt a Lazy Wave riser configuration with multiple buoyancy sections at the hog bend position. The upper buoyancy modules are shown by segment 3 and the lower buoyancy modules are shown by segment 2 in **Figure 7.9**.

The upper buoyancy modules will help to reduce the overall tension at the upper region from the vessel motion and environmental loading (the combination of waves and currents) while the lower buoyancy modules will help to improve the curvature at the lower region. Hence the buoyancy modules will create the riser shape desired easier.

The hog bend position influences positive significantly the response of the riser system. The tip of the hog bend will be put in range -130 m below the surface in order to minimize riser pay load on the FPSO and to obtain good dynamic response of the riser system. The weight risers itself will be heavy having a length of 320 m. The detailed information about its cross section and the buoyancy module’s cross section can be found in **Appendix D**.

As like the feasible configuration for the 6” production riser, the 8” production riser will also adopt a Lazy Wave riser configuration with multiple buoyancy sections at the hog bend position. The upper buoyancy modules are shown by segment 3 and the lower buoyancy modules are shown by segment 2 in **Figure 7.10**. The hog bend position gives significant positive effects for the response of the riser system. The tip of the hog bend will be put at a range -120 m below the surface. The weight of the riser itself will also be heavy riser having a length 320 m. The detailed information about its cross section and the buoyancy module’s cross section can be found in **Appendix D**.

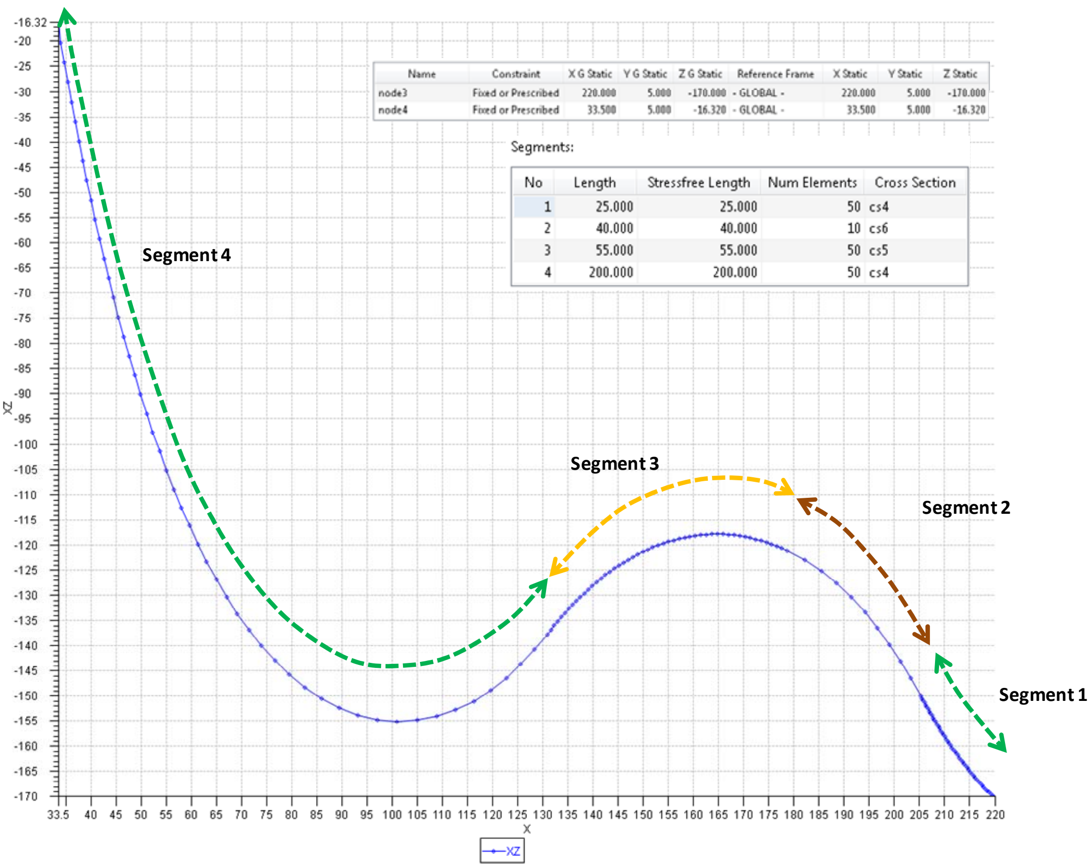


Figure 7. 10. : The riser configuration of the 8” production riser for the Western Isle Field.

The system design will be checked by static and dynamic analysis. In the static analysis only the static riser configuration with and without vessel offset will be considered while the dynamic analysis of the entire system will be performed by combining static loads with dynamic environmental loads based on movements of the riser.

7.3.2 Static Condition

The purpose of the static analysis is to determine the acceptable system layout for a riser based on the input parameters. The main design parameters are such as the choice of riser configuration, the length of riser, the system geometry and the sizing of riser and ancillary components based on the consideration of the hang off location and the location for the touchdown point will be simulated in the static condition.

The main requirements for the result of the analysis are such as the top angle position, effective tension, bending radius and seabed clearance and clashing.

The top angle position and seabed clearance can be seen in **Figure 7.9**. and **Figure 7.10**. The top angle positions in static condition are less than 15 deg while the seabed clearance in static condition are around 5 m to 15 m on the lowest point in the sag bend area.

The other results such as the static forces, bending moment and bending radius can be seen below. The static forces will be represented by the effective tension, the riser itself should always be in tension because compression along the riser should be avoided as it will cause (birdcaging and) buckling which may affect the integrity of the riser adversely and reduce the service life. The bending moment and the curvature of the riser will show the performance of the riser. Furthermore, the curvature of the riser will show the capability of the riser to be bent until its limits without kinking or damaging it and it depends on its minimum bending radius. The smaller the bending radius, the greater is the material flexibility (as the radius of curvature decreases, the curvature increases).

A. Effective tension

The effective tensions for the 6”and 8” production risers can be seen in **Figure 7.11**. and **Figure 7.12.**

The maximum effective tension for the 6” production riser is 180 kN while the minimum will be 32,08 kN.

The range of values for the effective tension for the 8” production riser is slightly different. The maximum effective tension for the 8” production riser is 155 kN while the minimum will be 26,58 kN.

These results are quite good and any compression can be avoided.

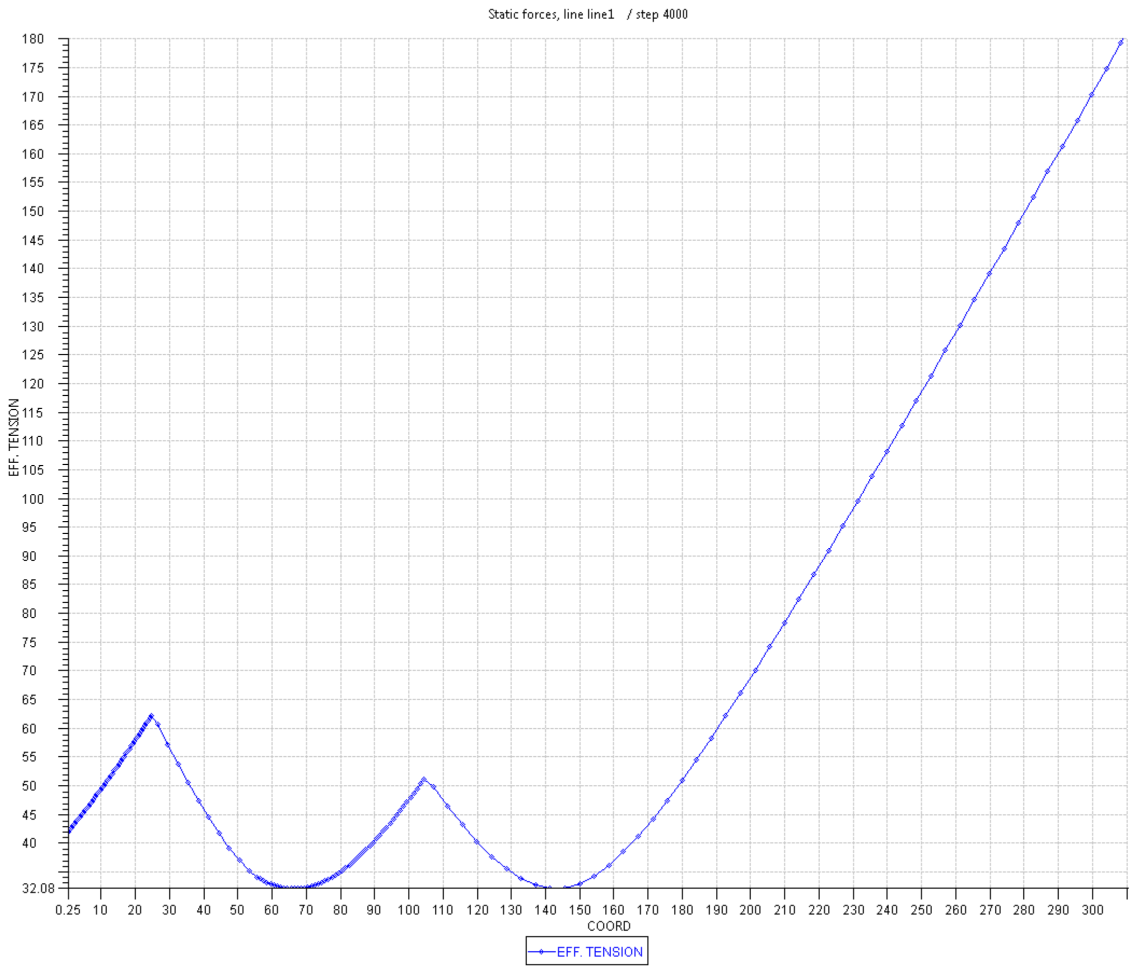


Figure 7. 11. : The static effective tension for the 6" production riser for the Western Isle Field.

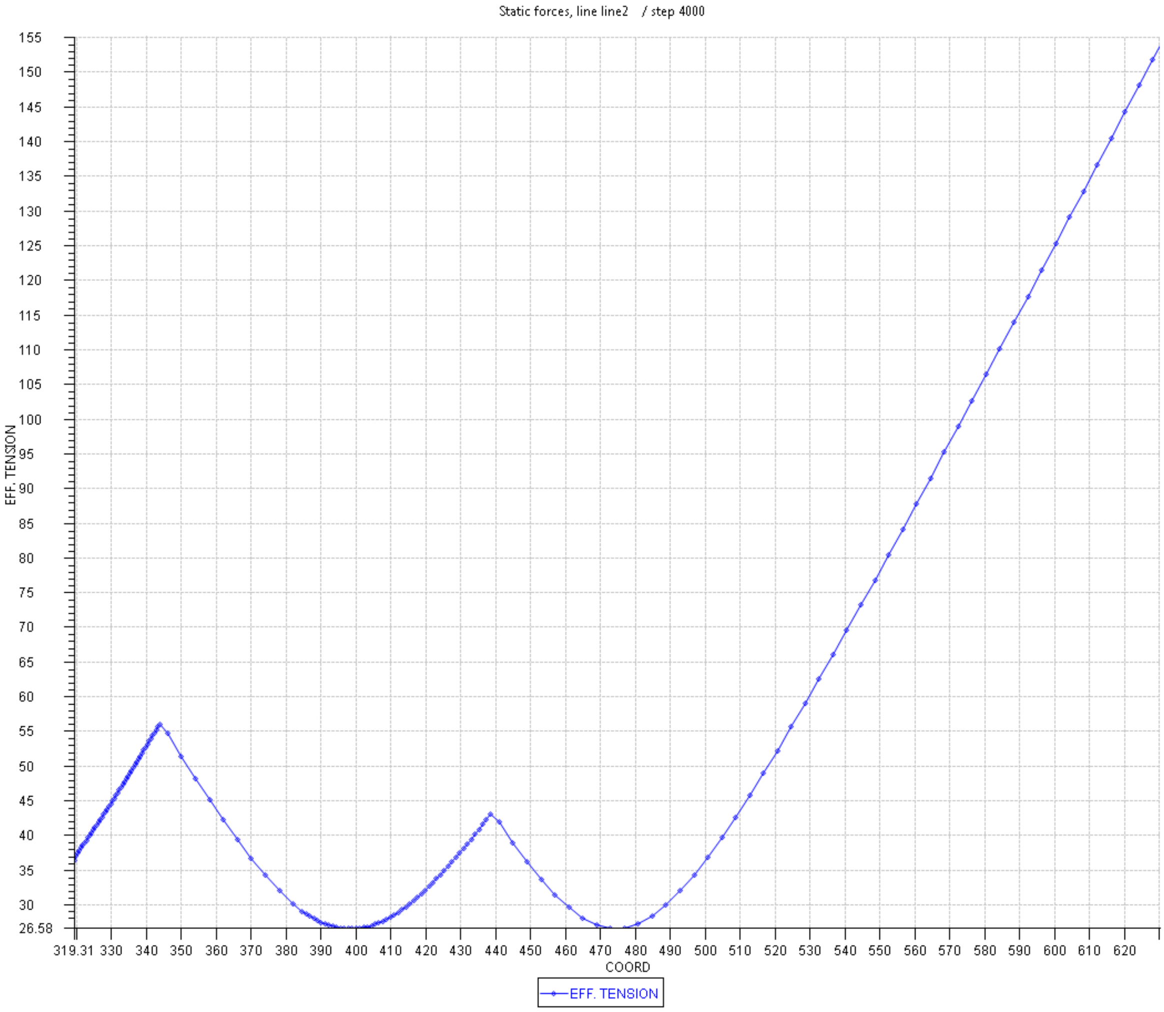


Figure 7. 12. : The static effective tension for the 8” production riser for the Western Isle Field.

B. Bending Moment and Curvature

The bending moments for the 6”and 8” production risers can be seen in **Figure 7.13**. and **Figure 7.14**. while the curvatures for the 6”and 8” production risers can be seen in **Figure 7.15.** and **Figure 7.16**.

The maximum bending moment and curvature for the 6” and 8” production risers are found in the hang off position. The results are quite good since they are still within the allowable limit.

Based on the design criterion, in the static condition; the minimum bending radius (MBR) of a riser should be same or less than that of the MBR at storage. The MBR for a 6” riser is 1,76 m or in the terms of curvature this will be 0,57 (1/1,76). The MBR for a 8” riser is 2,02 m or in the terms of curvature this will be 0,5 (1/2,02).

These results are quite good since the curvatures of the risers are less than 0,5 (**Figure 7.15.** and **Figure 7.16.**)

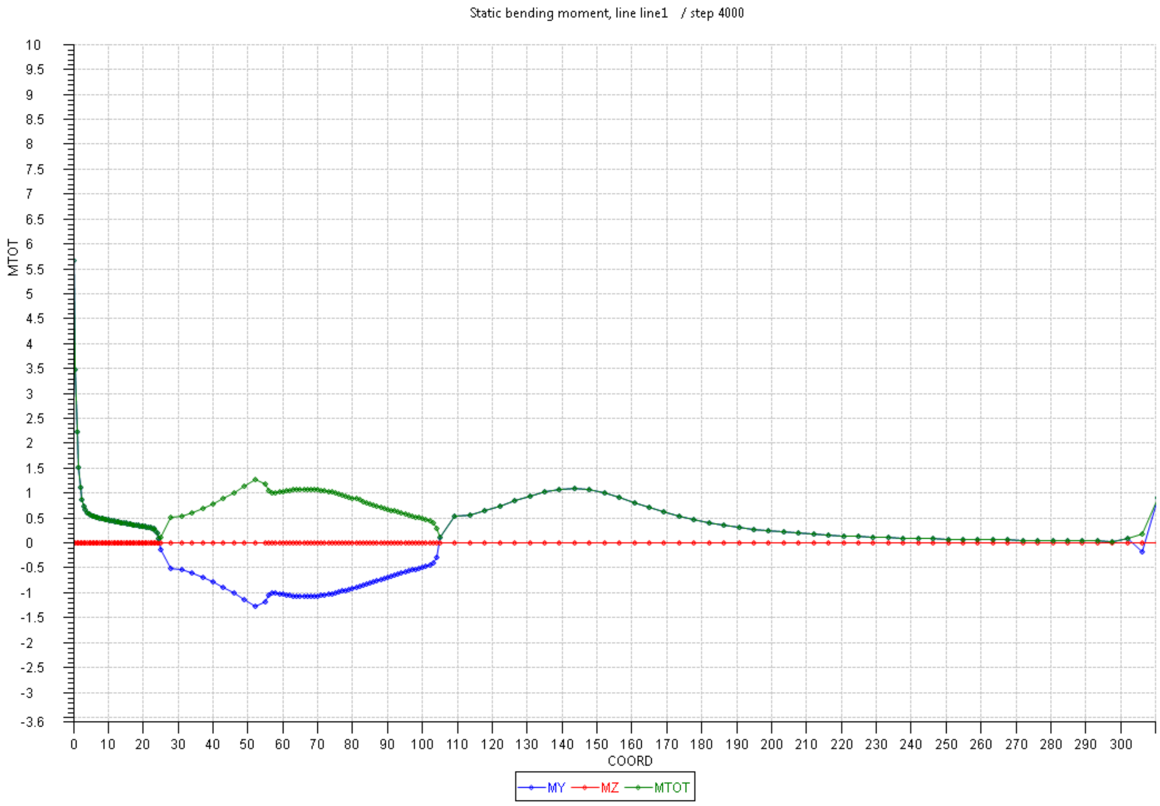


Figure 7. 13. : The static bending moment for the 6" production riser for the Western Isle Field.

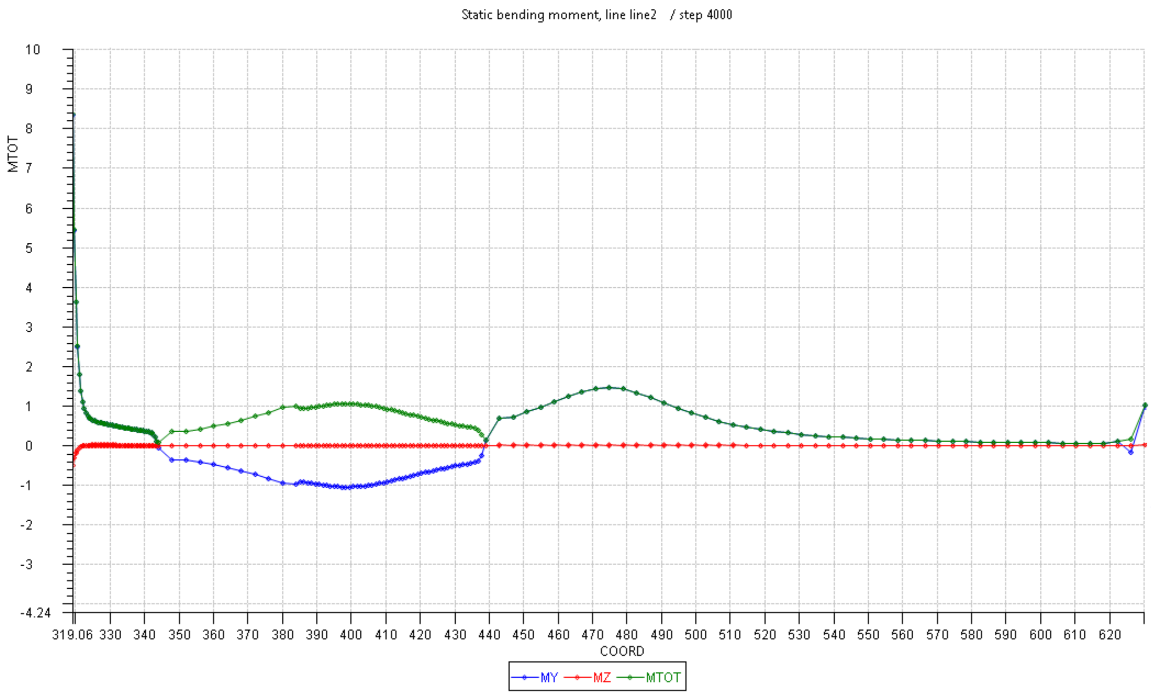


Figure 7. 14. : The static bending moment for the 8" production riser for the Western Isle Field.

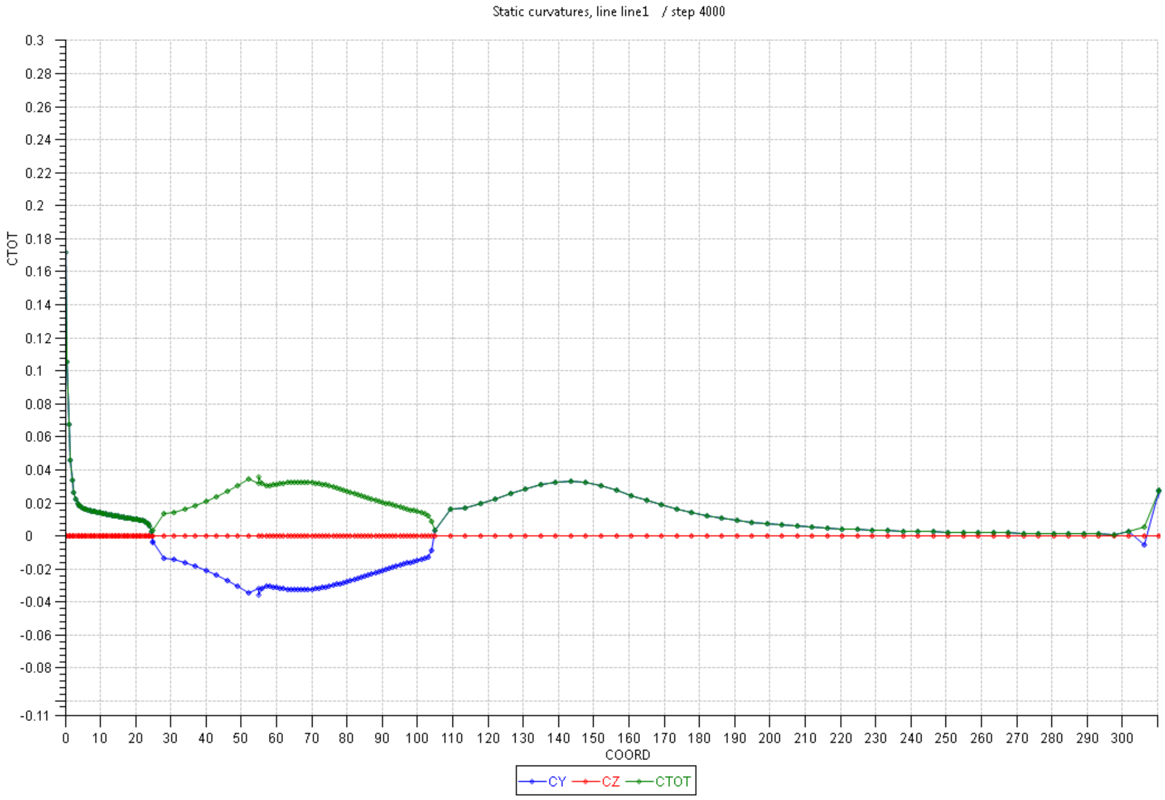


Figure 7. 15. : The static curvatures for the 6" production riser for the Western Isle Field.

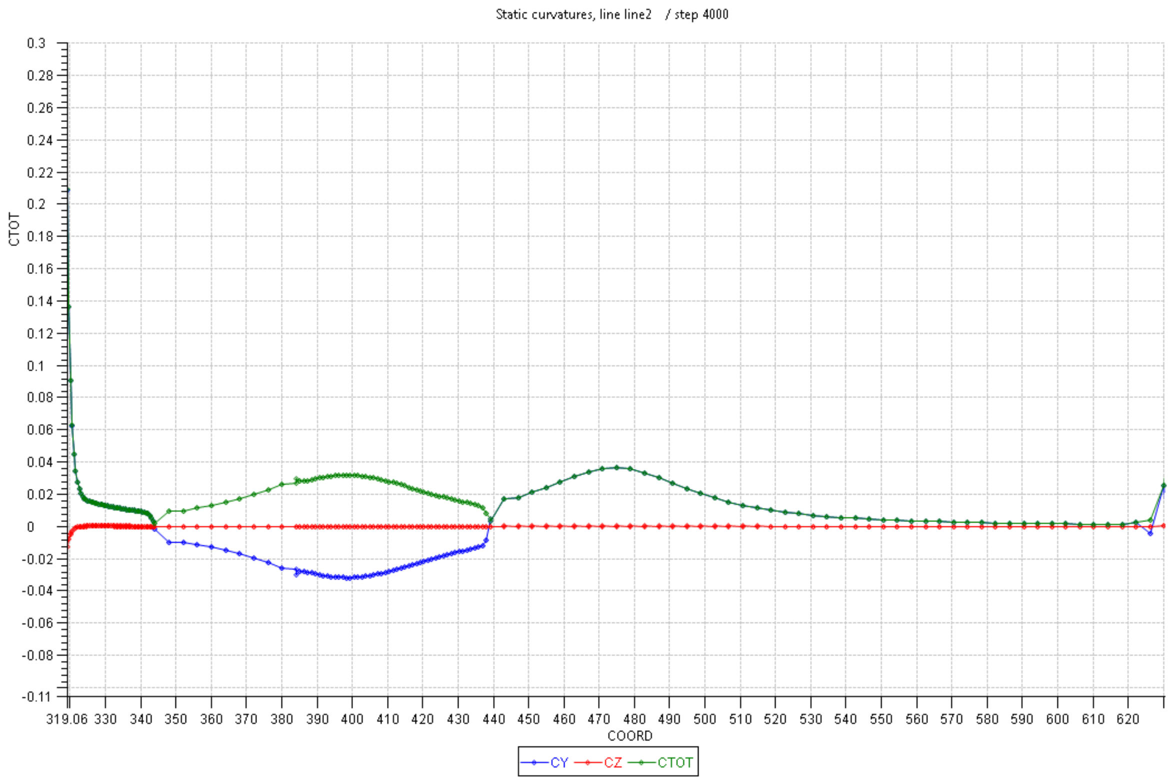


Figure 7. 16. : The static curvatures for the 8" production riser for the Western Isle Field.

7.3.3 Dynamic Condition

In the dynamic condition, time domain dynamic analyses will be performed based on the final static configuration in order to calculate the global dynamic responses of the system. Furthermore, the results of these analyses such as the dynamic tensions and curvatures should be checked against the design limits.

During the dynamic simulation, the feasible riser configurations for 6" and 8" production risers in the Western Isle field as shown in **Figure 7. 9.** and **Figure 7. 10**. will move in a range in a response to hydrodynamic loading. The movements of a riser will be recorded in the diagram showing the displacement envelope curvature.

The diagram of the displacement envelope curvatures for the 6"and 8" production risers can be seen in **Figure 7.17.** and **Figure 7.18.**

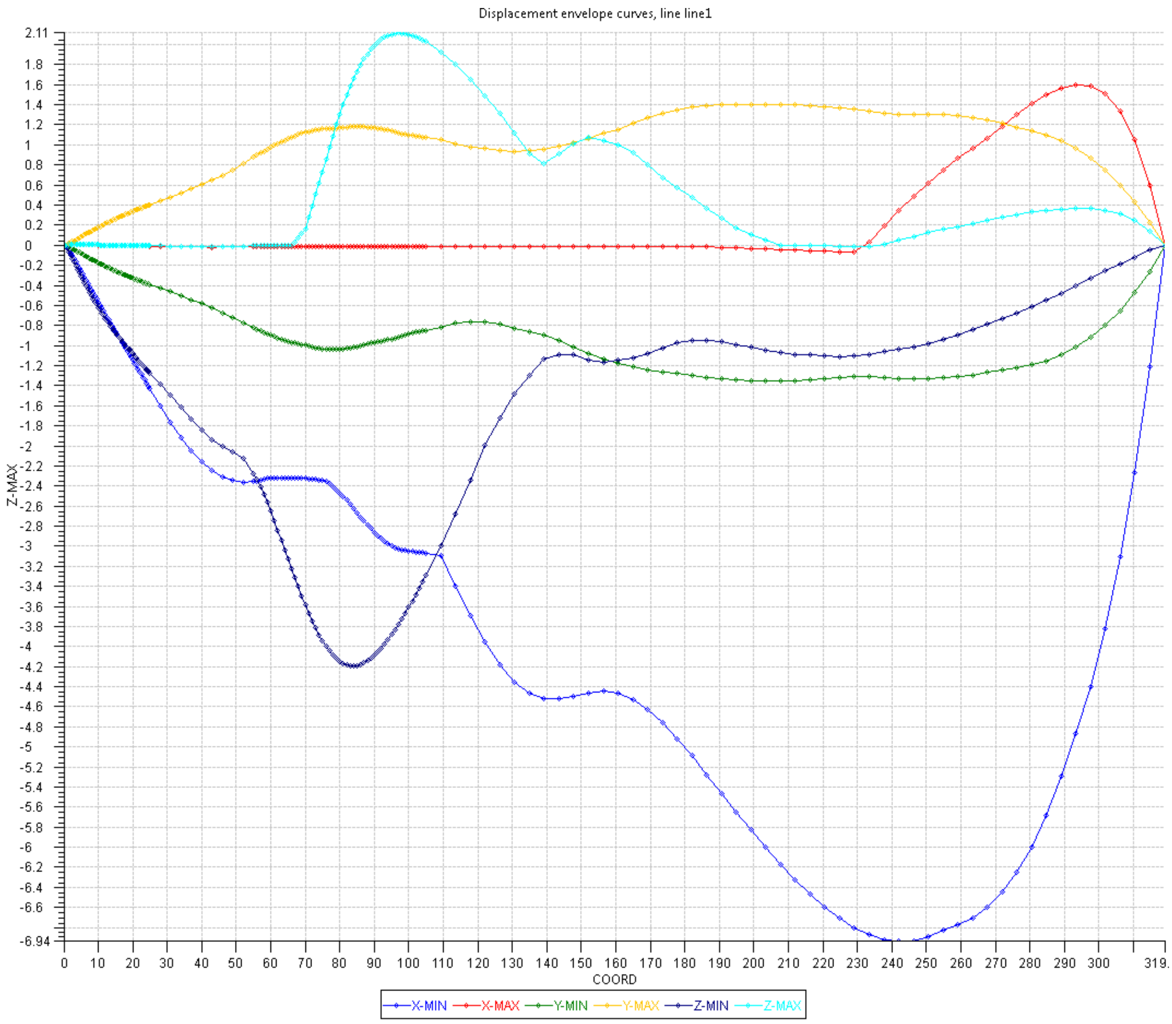


Figure 7. 17. : The displacement envelope curvature for the 6" production riser for the Western Isle Field.

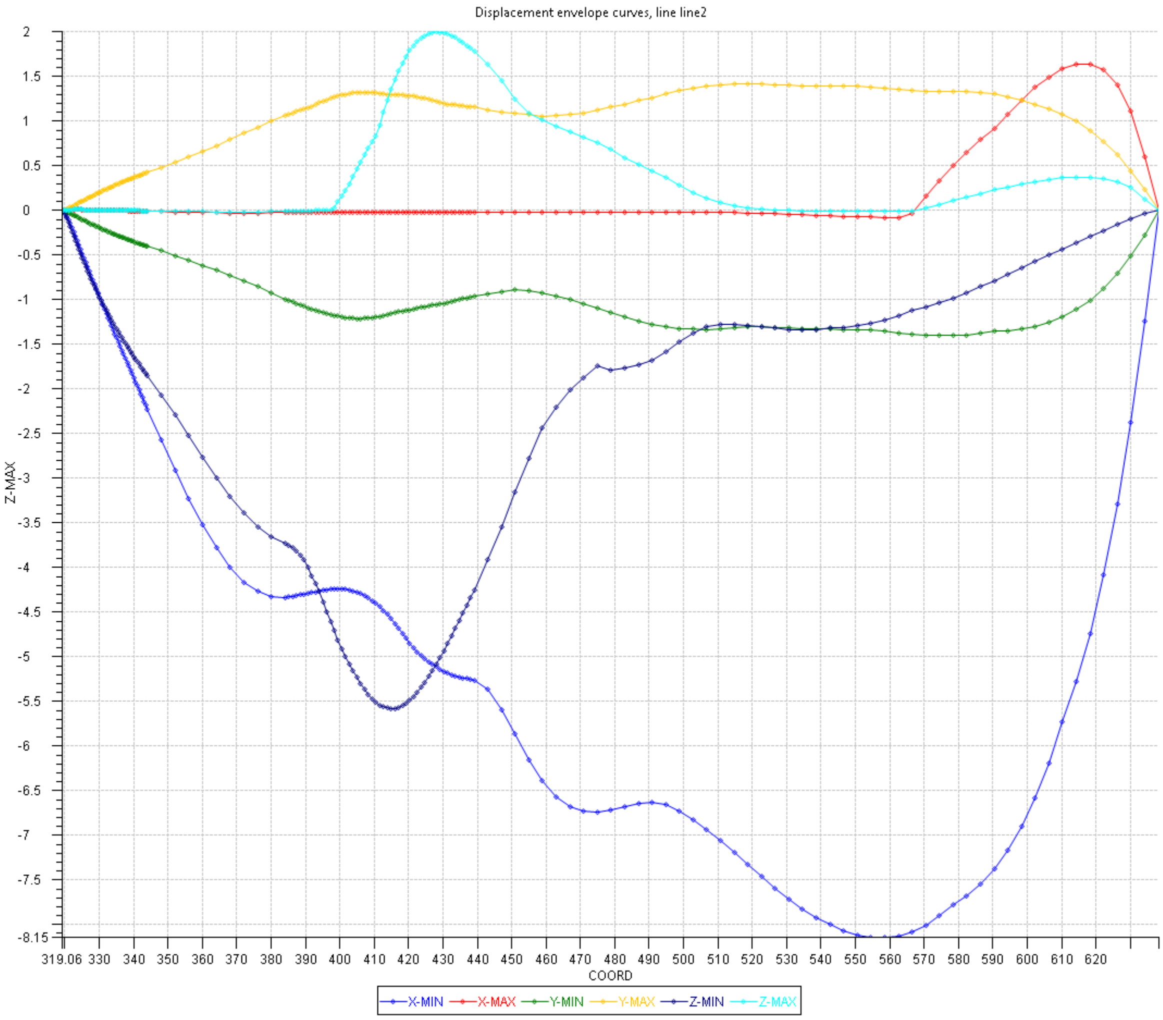


Figure 7. 18. : The displacement envelope curvature for the 8" production riser for the Western Isle Field.

The other results such as the dynamic tensions and curvatures can be seen below.

A. Effective tension

The effective tensions for the 6"and 8" production risers can be seen in **Figure 7.19**. and **Figure 7.20**.

The maximum effective tension for the 6" production riser is 240 kN while the minimum will be 23,94 kN.

The range of values for the effective tension for the 8" production riser is slightly different. The maximum effective tension for the 8" production riser is 220 kN while the minimum will be 10 kN.

These results are quite good and any compression can be avoided.

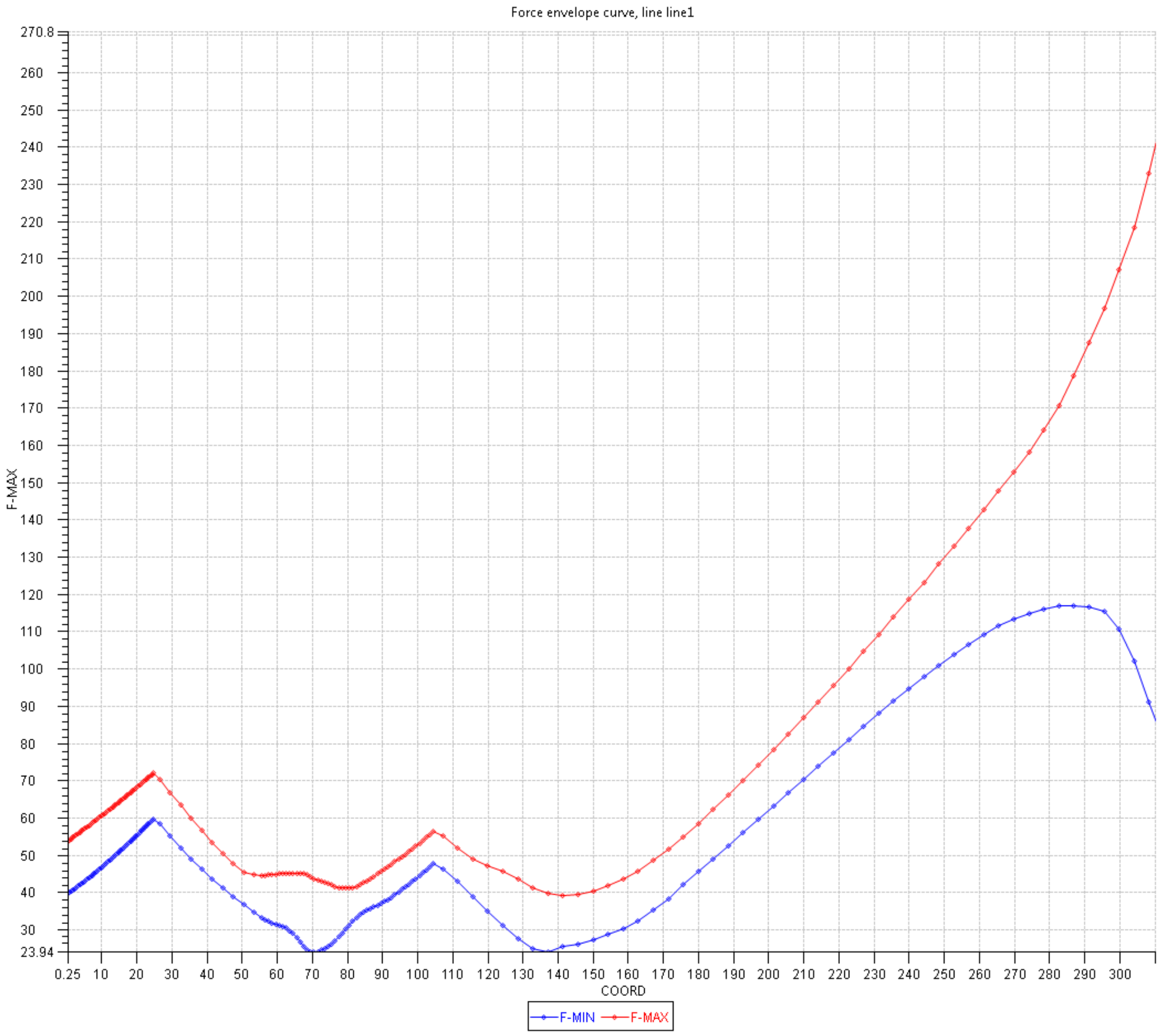


Figure 7. 19. : The dynamic effective tension for the 6" production riser for the Western Isle Field.

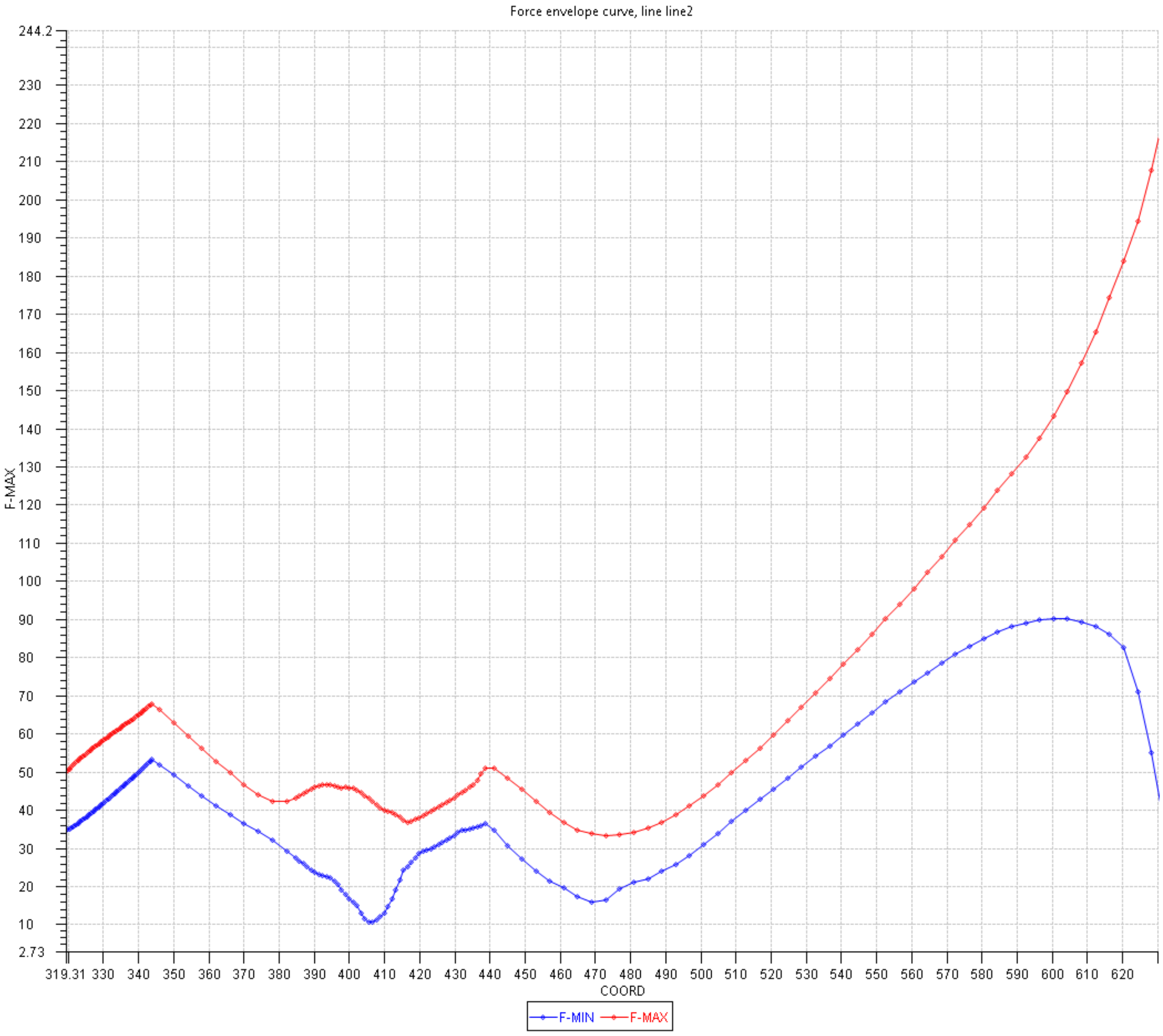


Figure 7. 20. : The dynamic effective tension for the 8" production riser for the Western Isle Field.

B. Bending Moment and Curvature

The bending moments for the 6"and 8" production risers can be seen in **Figure 7.21**. and **Figure 7.22**. while the curvatures for the 6"and 8" production risers can be seen in **Figure 7.23.** and **Figure 7.24**.

The maximum bending moment and curvature for 6" and 8" production risers are found in the hang off position. The results are quite good since they are still within the allowable limit.

Based on the design criterion, in the dynamic condition; the minimum bending radius (MBR) of a riser should be same or less than 1,5 times that of the MBR at storage. The MBR for a 6" riser is 1,76 m or in terms of the curvature this will be 0,57 (1/1,76). Hence the limit MBR in the dynamic condition is 0,38.

While, the MBR for a 8" riser is 2,02 m or in terms of the curvature this will be 0,5 (1/2,02). Hence the limit MBR in the dynamic condition is 0,33.

These results are quite good since the curvatures of the risers are less than 0,3 (**Figure 7.23.** and **Figure 7.24.**)

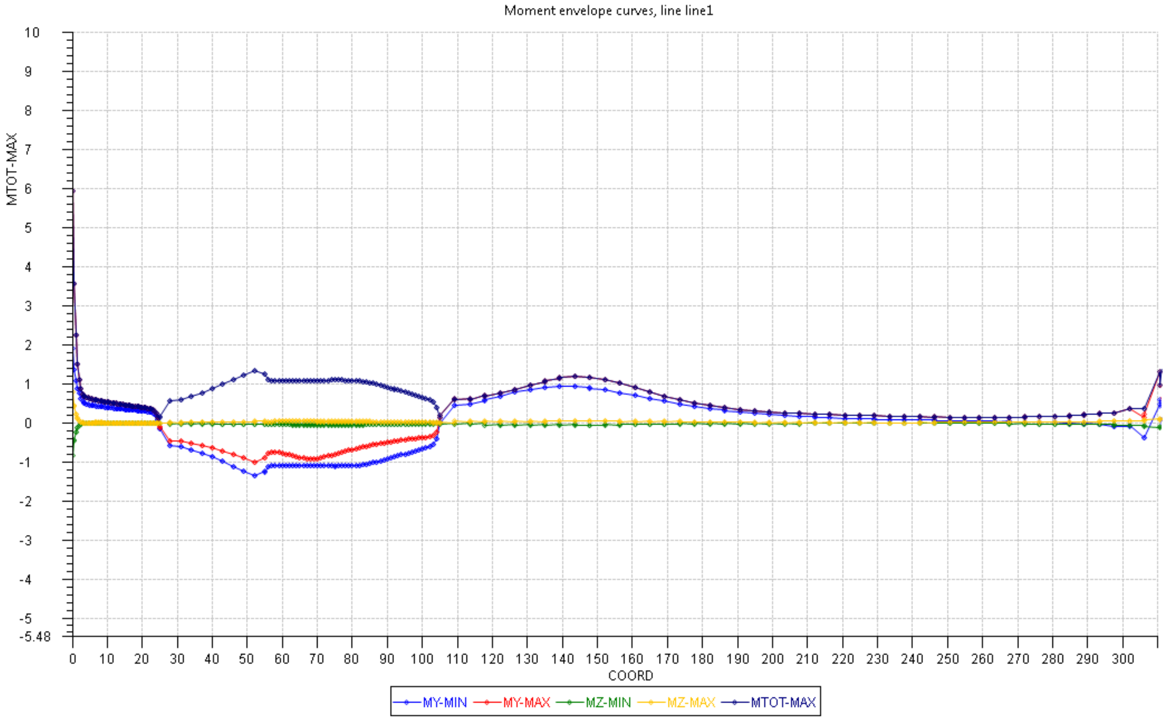


Figure 7. 21. : The dynamic bending moment for the 6" production riser for the Western Isle Field.

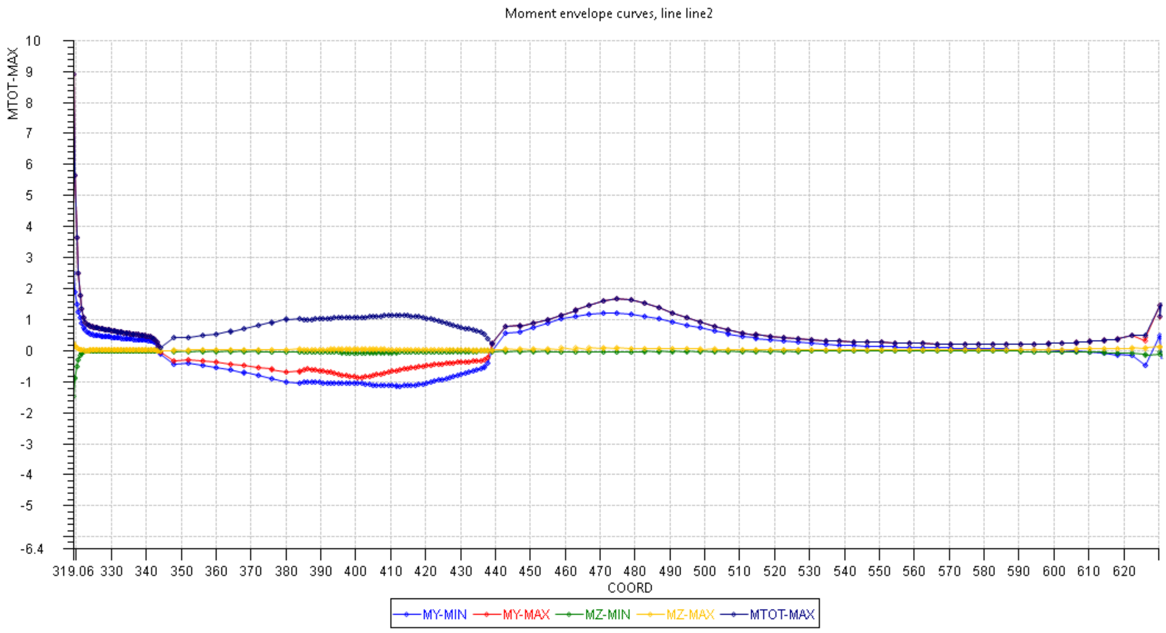


Figure 7. 22. : The dynamic bending moment for the 8" production riser for the Western Isle Field.

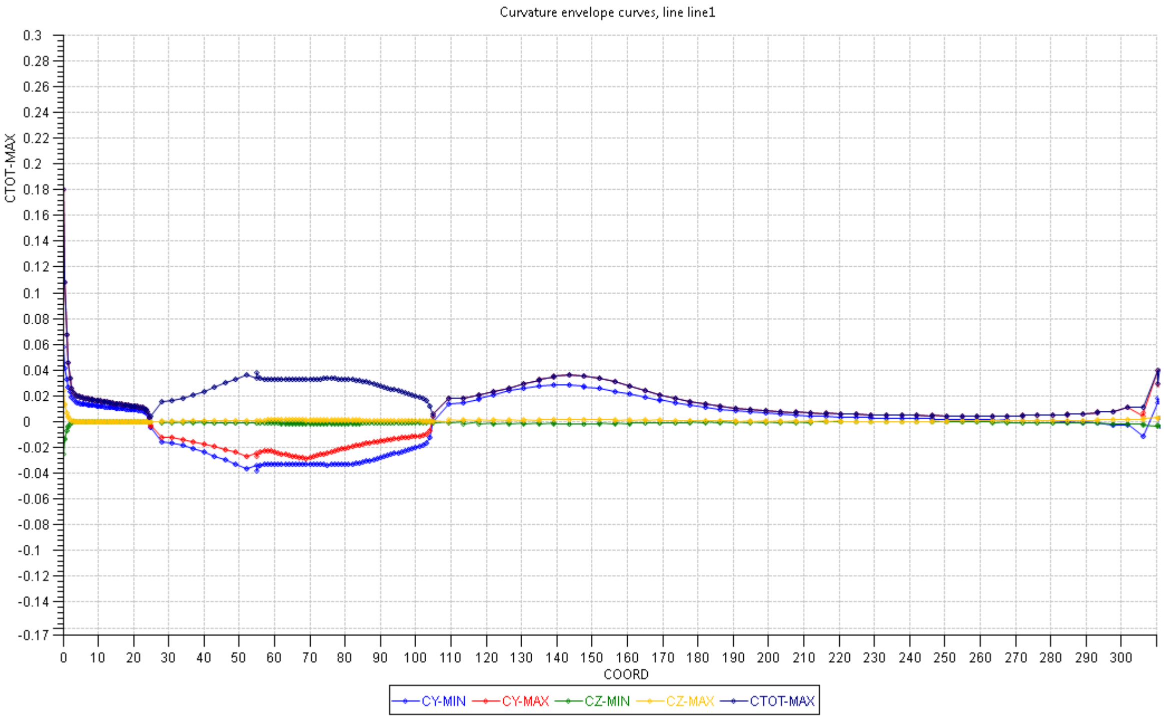


Figure 7. 23. : The dynamic curvatures for the 6” production riser for the Western Isle Field.

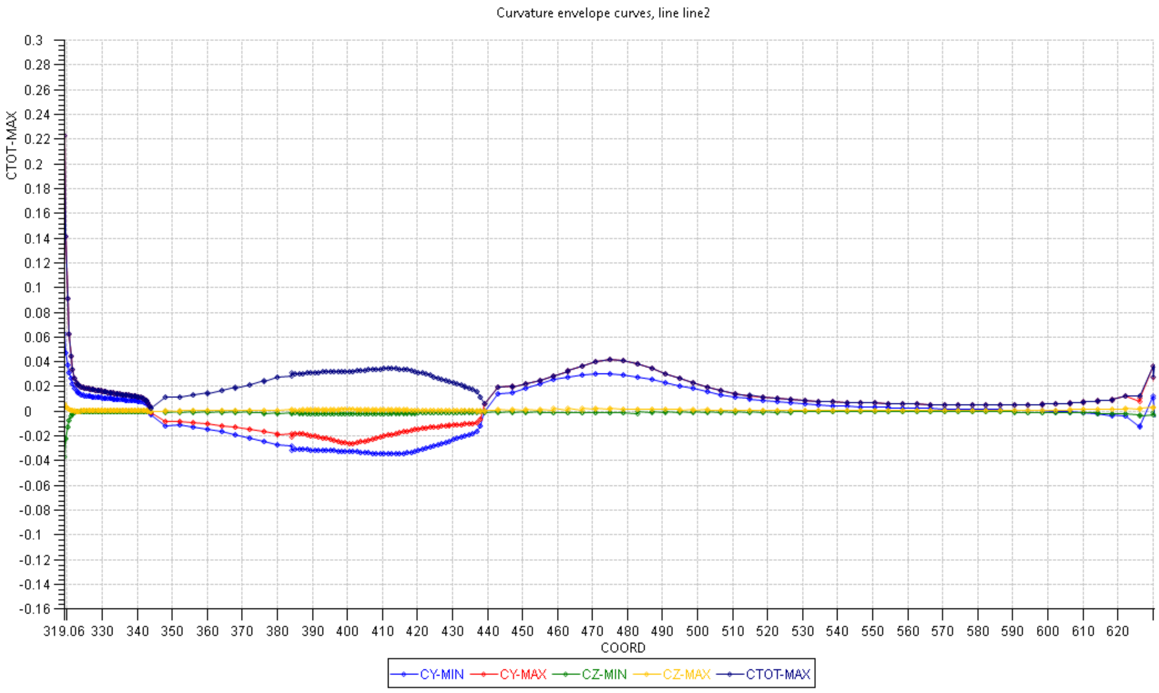


Figure 7. 24. : The dynamic curvatures for the 8” production riser for the Western Isle Field.

CHAPTER

8

Coupled Dynamic Analysis

This chapter will present a single complete computer model that includes the cylindrical floater, moorings and riser with use of SIMA. In principle, SIMA will combine two nonlinear numerical simulations, a SIMO and a RIFLEX analysis. In other words, the cylindrical floater and moorings model from SIMO will be combined with an AR (arbitrary riser) configuration from RIFLEX in time domain analysis.

A set of accurate predictions of the response of the overall system will be obtained because the nonlinear-coupled dynamic analysis ensures a truly integrated system. Not only the accurate prediction of the response of the overall system but also the individual responses of the floater, moorings and risers are obtained. Hence, the accurate prediction of the floater motions will be presented here. The accurate prediction of the motions of the cylindrical floater will refer to the global motion response for the total motion as combinations of the low frequency motions (LF motions) and the wave frequency motions (WF motions) and will be presented here. Further, these results will be compared to the results from the global motion response for the total motion as found in **Chapter 6** (*Subchapter 6.3.2 points A and B*).

Besides the accurate prediction of the motion of the cylindrical floater, the results from the riser analysis will also be presented here. In this chapter, the riser analysis will be performed by using the nonlinear-coupled dynamic analysis in time domain under two simulation schemes, static and dynamic conditions. As for the response of the floater, the results will be compared to the results from the decoupled analysis of the top angle (hang off position angle), effective tension, bending radius and seabed clearance in **Chapter 7** (*Subchapters 7.3.2 and 7.3.3*).

Furthermore, this chapter will also give a description of the analysis program that will be used, SIMA to give the perspective for the analysis.

8.1 Modeling Concept by SIMA Marintek

As the final step, the cylindrical floater S400, 12 mooring lines and two of feasible riser configurations for a production riser with 6" and 8" diameter will be modeled as one complete model which is required in the nonlinear-coupled dynamic analysis to obtain a consistent treatment of the coupling effect between the cylindrical FPSO and the slender members. This method will generate the solution of the nonlinear-coupled dynamic analysis in time domain using a non-linear integration scheme and will adopt the dynamic equilibrium equation of the spatially discredited system (*Omberg, H. et al. (1997))*.

Further, The SIMA Marintek computer software will be used in this study because it has the capability to integrate the cylindrical floater S400, moorings and riser as one complete model. Here, a complete model of the floating offshore system will be modeled in one module of The SIMA Marintek/the RIFLEX Coupled model (combination software for RIFLEX and SIMO which are run together). In other words, a model of the cylindrical floater S400 with moorings system as established from SIMO will be combined with a model of a feasible riser system from RIFLEX into a complete model in RIFLEX Coupled and are run together in a time domain analysis.

The SIMA Marintek software is developed as a Joint Industry Project by MARINTEK and Statoil.

The SIMA Marintek is a powerful tool for modeling and analysis of tasks within the field of marine technology. Beside it has the capability to integrate each components of a floating offshore system, The SIMA Marintek has also the capability to support several programs that will be used in this study such as RIFLEX and SIMO. Hence, the analysis can be accessed in a single file as done in the library data system of SIMA Marintek (**Figure 8.1)**.

In the nonlinear-coupled dynamic analysis, the complete model of the floating offshore system will consist of three principal structural components such as the cylindrical floater, moorings and riser responding to the environmental loading due to wind, waves and currents. Moreover, a previous model of the cylindrical floater and the mooring system from **Chapters 5 and 6** will be modeled as the body while a previous feasible riser configuration model will be extracted from **Chapter 7** to be modeled as an AR (arbitrary riser configuration) system.

Further information about how to model the system components can be found in **Chapter 4**.

As an integrated dynamic system, the environmental forces on the floater induce the motions which will be introduced in a detailed Finite Element Model of the moorings and risers. The finite element model has been used to describe the behavior of a given variable internal to the element in terms of the displacement (or other generalized co-ordinates) by utilizing interpolation functions (*van den Boom (1985)*).

Here, two different types of elements are introduced in the model, a 3D bar/cable element where the bending stiffness is negligible and a 3D beam element to include the bending stiffness.

The bar element presents only 3 translational DOF per node and do not provide the rotational stiffness. Therefore, it will be a suitable model to represent the moorings. On the other hand, the beam element will incorporate rotational stiffness and it will be a suitable model to represent the flexible riser. Moreover, the bar element is formulated using a "total

Lagrangian description", while the beam element formulation uses a "co-rotated ghost reference description". The basic theory about this can be found in **Chapter 2** based on *Marintek (2010)* for "RIFLEX Theory Manual Finite Element Formulation". The procedure for the riser system model can be found in details in *Marintek (2010) "RIFLEX User Manual Finite Element Formulation"*.

Since a Finite Element Model has been applied to slender members (moorings and risers), a dynamic analysis will be performed during the design because the dynamic behavior of the slender members strongly increases the maximum line tensions and may affect the low frequency motions of the moored structure by increasing the virtual stiffness and damping of the system.

Moreover, the application of the Finite Element Model will be for all system components, including the body of the cylindrical S400 floater. The FEM model of the cylindrical S400 floater (Hydro and Mass model) that originated from Wadam/HydroD will be taken as input. This input has been adopted from SIMO as a body model directly. In addition, the kinetic and radiation data will also be taken as inputs to obtain the forces that are acting on the hull.

Since the model will be quite complex, a "master-slave" approach will be used to connect the riser and the frequency-dependent floater and moorings. This connection will be placed in the body section as a so called AR (arbitrary riser) Connection.

Here, the environmental loading from winds, waves and currents will be considered. The study has also provided a set of wind, wave and current criteria associated with the extreme events. The criteria are considered to be independent, i.e. no account is taken of the effects of joint probability. The study will be based on the return period combination of 100 years waves and wind criteria and 10 years current criteria.

The wind forces will be simulated in the time domain. The wind speed design for simulation will be taken as the average speed occurring for a period of 1-hour duration at a reference height, typically 30 ft (10m) above the mean still water level. NPD wind spectrum (*ISO 19901-1 (2005),* wind spectrum) will be used. The wind loads will be simulated in time domain, no transverse gust and no admittance function will be used.

The study will analyze the wave loads by using irregular waves. The irregular waves will have contributions in describing the real condition of the surface sea. The wave data will be based to the study from *Physe Ltd (2010)*. All-year omni-directional extreme significant wave heights have been assessed by using NNS (Northern North Sea) measured data set. The full NNS measured data set was used to create frequency distributions and the data were extrapolated by applying a range of functional fits. Peaks Over Threshold (POT) analysis was also performed on the time series data, picking 40, 60 and 80 storms to determine the best fit. The EVA (Extreme Value Analysis) results for extreme significant wave heights are given in **Table 8.1** below:

Table 8.1. : The EVA Analysis Results for 100 Years Waves

Data	Weibull 95%	FT3 95%	Weibull 10%	FT3 10%	POT 80	POT 60	POT 40
NNS	15.23	15.50	15.48	15.58	15.64	15.64	15.74
	Average of CFE Analysis 15.45				Average of POT analysis 15.67		
	Data Set Average 15.56						

Reference: PhyseE Ltd (2010)

Where: FT3 = Fisher-Tippett distribution, Type 3, POT= Peaks Over Threshold (POT) (40, 60 and 80 storms)

CFE = Cumulative Frequency Extrapolation

Fit quality

Very Good	Good	Fair	Poor	Very Poor

Further, the extreme significant wave height values for return periods of 100 years were calculated from the NNS measured data. The complete NNS data set was extrapolated applying both a 10% and a 95% Weibull fit to each data set. Hence, a 100 year significant wave height design value of 15.6 m is recommended for the Western Isles location.

According to *Physe Ltd (2010),* the final recommendations for the waves at the Western Isles location are given **Table 8.2.** below:

Table 8.2. : Extreme Wave Height and Associated Periods- Omnidirectional

Return Period	Hs (m)	Tz (lower) (s)	Tz (central) (s)	Tz (upper) (s)	Tp, Tass (lower) (s)	Tp, Tass (central) (s)	Tp, Tass (upper) (s)	Hmax (m)	Crest Height (m)
All-year									
1-year	11.4	9.7	10.8	12.7	13.3	15.0	17.8	19.2	11.7
10-years	13.6	10.6	11.8	13.8	14.5	16.4	19.5	23.9	14.7
50-years	15.0	11.2	12.4	14.5	15.3	17.2	20.5	26.9	16.6
100-years	15.6	11.4	12.6	14.8	15.5	17.5	20.8	28.2	17.4
1,000-years	17.6	12.1	13.4	15.7	16.5	18.6	22.1	32.4	20.0
10,000-years	19.4	12.7	14.1	16.5	17.3	19.6	23.3	36.4	22.6

Reference: PhyseE Ltd (2010)

Further, this waves criteria (Hs = 15,6m and Tp= 15,5s) will be modeled by the Torsethaugen Spectrum (Jonswap double peaked). It will be simulated for “3 hours +” build up time in the SIMA Marintek.

The current criteria are based on the 10 years current criteria. The vertical current profile for the Western Isles will be calculated from Guidance Notes; *Department of Energy (1990)* for "Offshore Installations: Guidance on Design, Construction and Certification".

Further, the floating offshore system will be modeled for two conditions, the static and dynamic conditions. The calculation parameters for each condition will be set differently depending on their functions. The static condition stage has as functions to obtain a static equilibrium position and generate the initial condition for the dynamic simulation while the dynamic simulation will be performed in the dynamic condition in order to calculate the responses of the system responding to the dynamic loading conditions.

Since the analysis has been performed as a time domain analysis, it requires a proper simulation length to obtain a steady result. Moreover, in the dynamic condition the environmental criteria (the wind, waves and current criteria) has been simulated for "3 hours +" build up time. According to Omberg et al. (1998), the extreme values found from "3 hours +" simulations will represent a reasonable max expected value for the simulated time series, in particular as we for the floater motion have that "the statistical variability, in terms of coefficient of variation, is in the range of 4-5% for the model results and 2-3% for the simulations". For the member tension "the variability is 3-4% for the simulations".

Further the floater's response (floater motions and the horizontal offset values) and the slender member's response such as mooring line dynamic tensions as the mooring system's response and the effective tension and the bending moment and curvature as the riser's system's response will be presented in the next subchapters. These results are presented as time series which have the maximum, minimum and mean values. Furthermore, the results will be highlighted to the maximum or minimum values to show the deviation of each result.

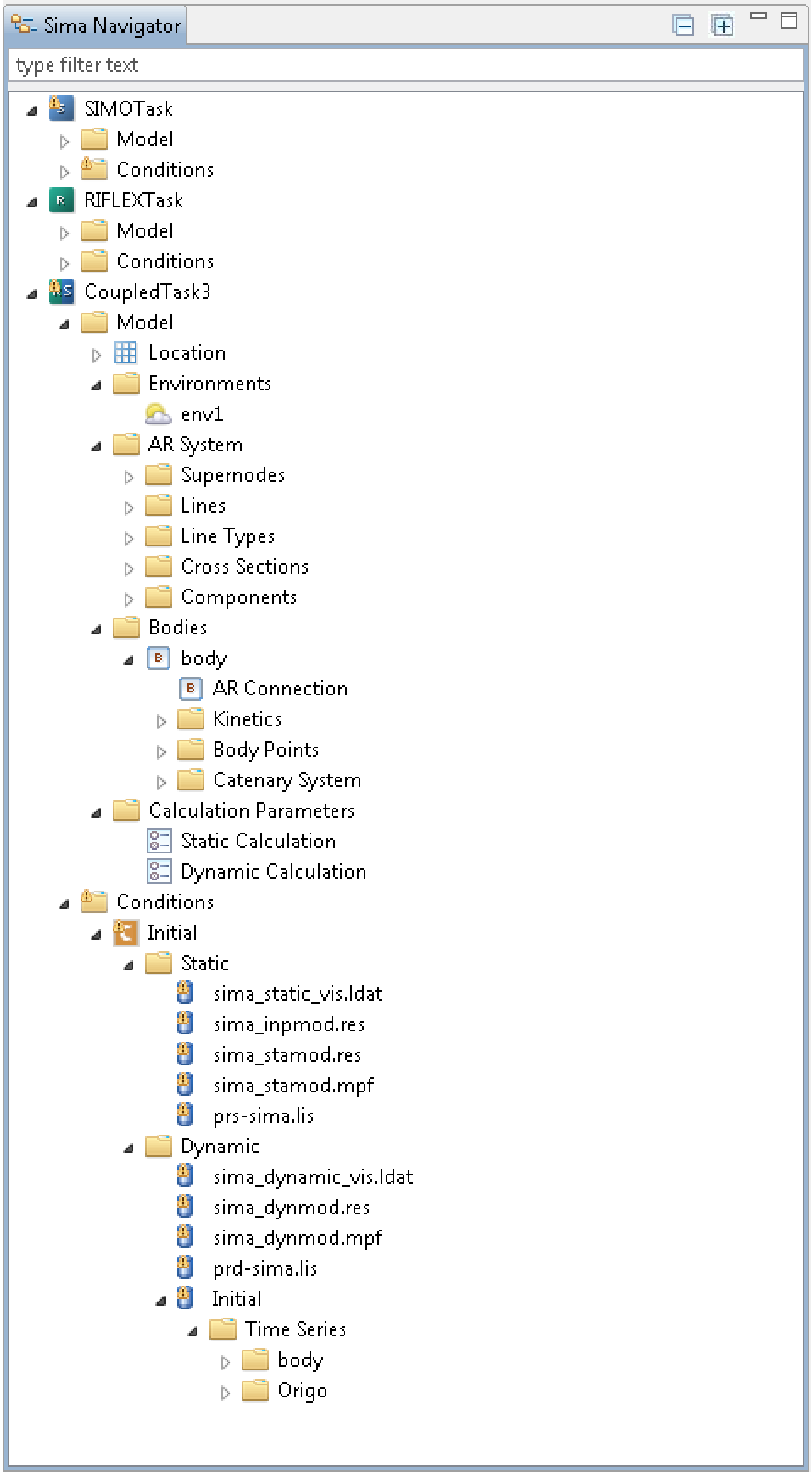


Figure 8. 1 : Library data system of the SIMA Marintek.

Reference: Marintek, 2010

8.2 The System Response in the Nonlinear-Coupled Dynamic Analysis

The main reason for performing a coupled dynamic analysis is to obtain an accurate prediction of the response, simultaneously for the overall system as well as the individual response of the floater, moorings and risers.

The accurate prediction of the response for the overall system can be obtained since the coupled dynamic analysis ensures a truly integrated dynamic interaction between the components in the offshore floating system.

Hence, the estimation of the mean offset and the floater motions can be generated accurately to quantify the coupling effects between the floating offshore system (the floater, moorings and riser) and the associated structural response (e.g. motion responses) for offshore structure design.

Since the analysis has been performed in the time domain for problem solving, the floater motions in the time domain, the horizontal offset values and the mooring line dynamic tensions will be presented as time series results.

The resulting analysis for the floater motions and the horizontal offset values will be presented in time series below:

8.2.1 Floater Motions

In the nonlinear-coupled dynamic analysis , the global motion response of the cylindrical S400 floater will be represented by the total frequency motions as combinations of the low frequency motions (LF motions) and wave frequency motions (WF motions).

The summary of the global motion response i.e. the total frequency motions can be seen in **Table 8.3** below:

Table 8.3. : The Summary of The Global Motion Response of The cylindrical S400 Floater in the Nonlinear-Coupled Dynamic Analysis

The Global Motion Response in Total Frequency Motions					
Channel		**Min**	**Max**	**Mean**	**Std. Dev.**
Surge	XG translation Total Motion	32.11	33.50	32.61	0.07
Sway	YG translation Total Motion	-0.30	0.00	-0.26	0.01
Heave	ZG translation Total Motion	-9.19	-9.05	-9.15	0.00
Roll	XL rotation Total Motion	-1.87	0.66	-0.63	0.27
Pitch	YL rotation Total Motion	0.00	3.17	1.84	0.35
Yaw	ZG rotation Total Motion	-7.61	0.00	-4.27	0.20

Further, the global motion response for the total motion as combinations of the low frequency motions (LF motions) and wave frequency motions (WF motions) can be found from **Figure 8.2** to **Figure 8.7**

- ➢ *The total global motion response, the total frequency motions for surge*

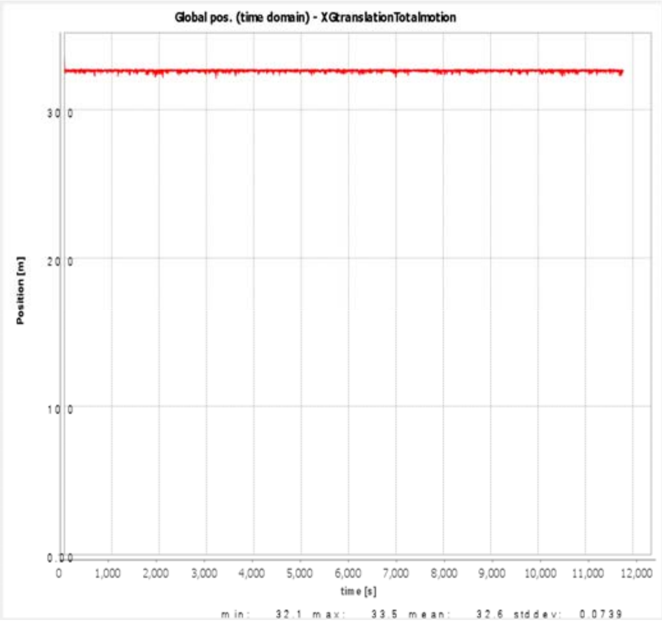


Figure 8. 2 : The total global motion response, the total frequency motions for surge.

- ➢ *The total global motion response, the total frequency motions for sway*

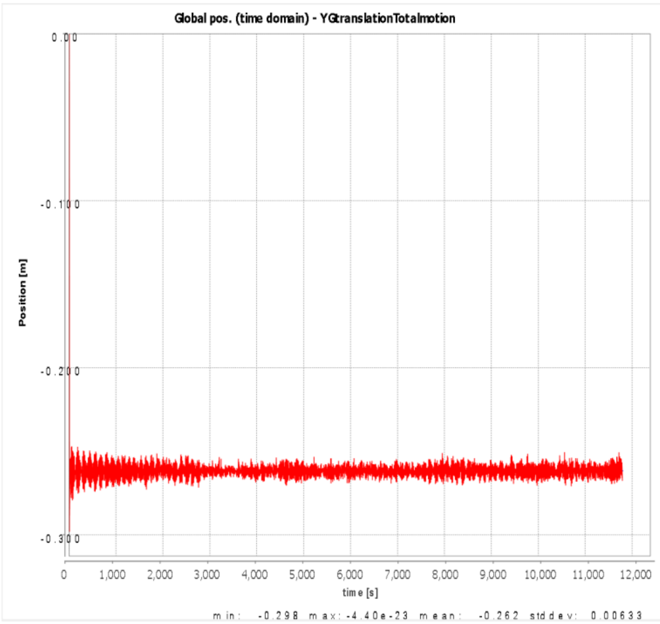


Figure 8. 3 : The total global motion response, the total frequency motions for sway

➢ *The total global motion response, the total frequency motions for heave*

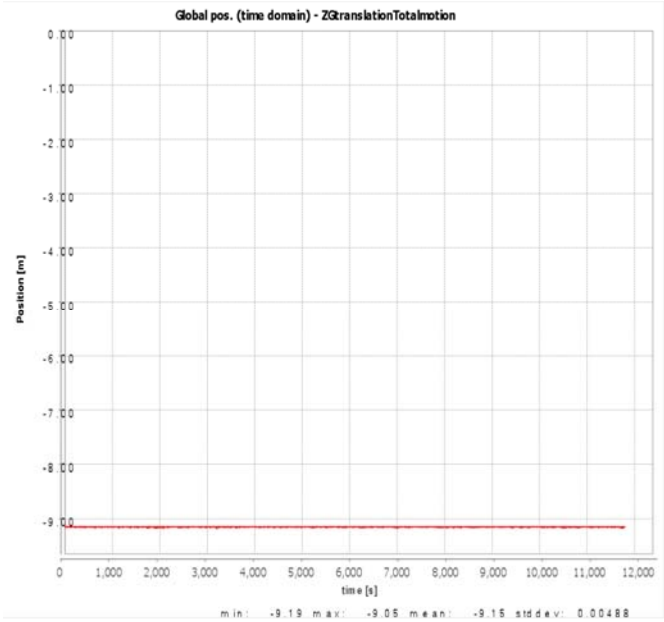


Figure 8. 4 : The total global motion response, the total frequency motions for heave.

➢ *The total global motion response, the total frequency motions for roll*

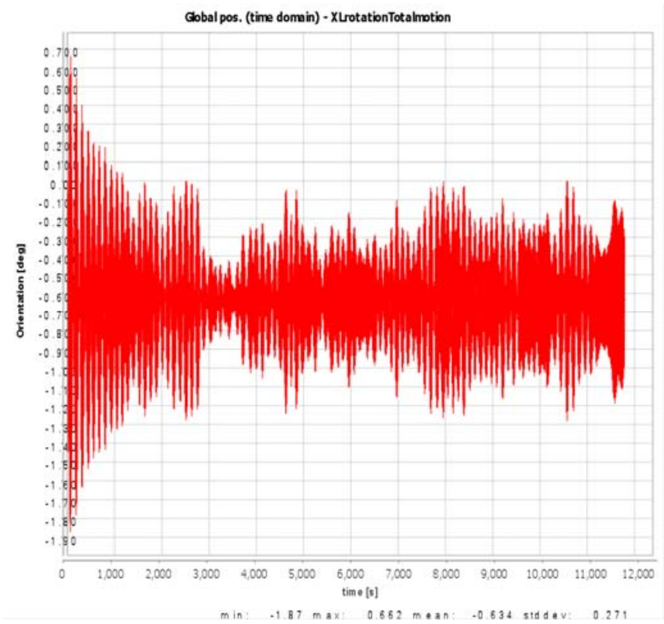


Figure 8. 5 : The total global motion response, the total frequency motions for roll.

- *The total global motion response, the total frequency motions for pitch*

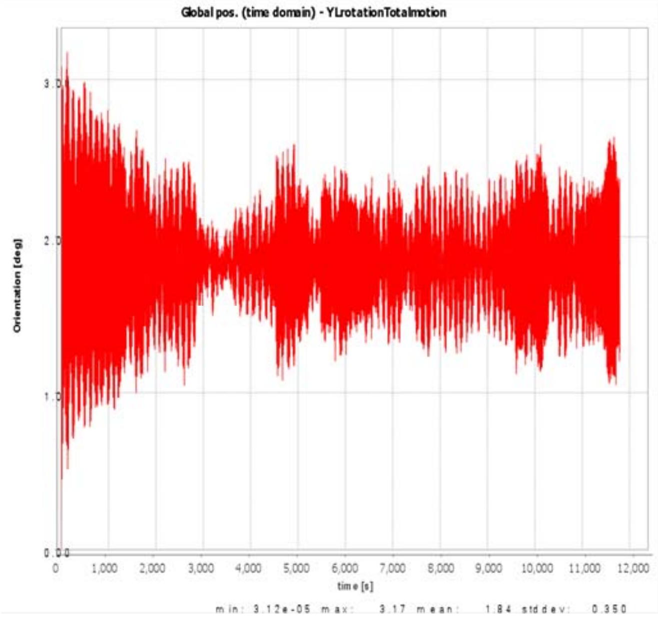


Figure 8. 6 : The total global motion response, the total frequency motions for pitch.

- *The total global motion response, the total frequency motions for yaw*

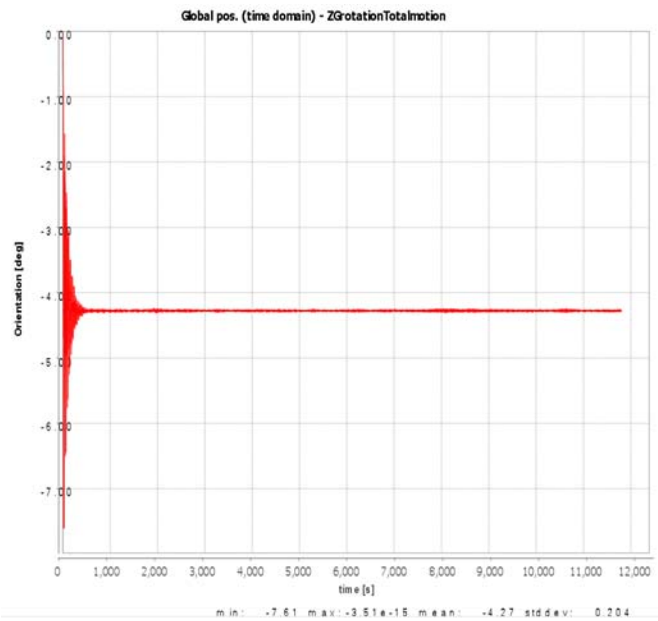


Figure 8. 7 : The total global motion response, the total frequency motions for yaw.

Moreover, the total global motion responses of the cylindrical S400 for the total frequency motions in the nonlinear-coupled dynamic analysis are slightly different from the total global motion responses of the cylindrical S400 for the total frequency motions as found by the SIMO results analysis in **Chapter 6**.

The difference of results analysis can be seen in **Table 8.4** as follow:

Table 8.4. : The Summary of The Global Motion Response of the Cylindrical S400 Floater in the Nonlinear-Coupled Dynamic Analysis and the Station Keeping System Modeling results as found from SIMO (Chapter 6)

Channel		The Global Motion Response in Total Frequency Motions (nonlinear-coupled dynamic analysis)				The Global Motion Response in Total Frequency Motions (Chapter 6)			
		Min	Max	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.
Surge	XG translation Total Motion	32.11	33.50	32.61	0.07	-22.82	7.08	-3.37	3.55
Sway	YG translation Total Motion	-0.30	0.00	-0.26	0.01	-8.47	5.09	-0.80	0.73
Heave	ZG translation Total Motion	-9.19	-9.05	-9.15	0.00	-15.02	4.14	-0.22	3.82
Roll	XL rotation Total Motion	-1.87	0.66	-0.63	0.27	-5.50	5.89	0.03	1.78
Pitch	YL rotation Total Motion	0.00	3.17	1.84	0.35	-9.73	8.48	-0.41	2.35
Yaw	ZG rotation Total Motion	-7.61	0.00	-4.27	0.20	-2.69	5.42	1.00	1.31

Based on the results in **Table 8.2,** the total frequency global motion responses for the nonlinear-coupled dynamic analysis are caused by some reasons as follows:

1. The different applications for the design modeling
   In **Chapter 6**, the cylindrical S400 floater and 12 mooring lines are modeled in SIMO as a station keeping system. Further, this system uses the Quasi-static design method which comprises a dynamic motion analysis of the moored structure and computations of mooring line tension based on the extreme position of the floater and the static load-excursion characteristics of the mooring system.
   On the other hand, the nonlinear-coupled dynamic analysis comprises a single complete computer model that includes the cylindrical floater, moorings and riser as an offshore floating system in SIMA. Further, this system uses the dynamic, Finite Element Method (FEM) as design method.
   By using the Finite Element Method (FEM), not only a static configuration will be established with non linear elements but the effect of line dynamics on the platform motion will be included in the simulation such as the additional loads from the mooring system and the hydrodynamic damping effects from the relative motion between the line and the fluid.
   This technique, the Finite Element Method (FEM) will ensure higher contribution from the nonlinear dynamic behavior because the inertial effects between the line and the fluid are also included. Hence, it may affect the low frequency motions specifically and also the total frequency global motion responses of the moored structure.

2. The influence of the risers structure
   In the nonlinear-coupled dynamic analysis, the overall behavior of the floater will be influenced not only from the hydrodynamic behavior of the hull and moorings system but also from the dynamic behavior of the risers because it comprises a single

complete computer model (the cylindrical floater, moorings and riser) as an offshore floating system.

In the analysis, the riser system has used two heavy weight 6” and 8” production risers for study in the arbitrary riser system. Its characteristics are based on the mechanical characteristics of the riser and the mean current forces on risers may affect the horizontal restoring force of the system which then influences the total frequency global motion responses of the moored structure.

8.2.2 The Horizontal Offset Values

The horizontal offset values of the offshore floating system are very important in order to determine the global performance of the floater structure in the survival or operation conditions. These values will influence the design of the other components in the offshore floating system such as the mooring system and the riser system.

In terms of the moorings system, mooring system design is a trade-off between making the system compliant enough to avoid excessive forces on the floater and making it stiff enough to avoid difficulties due to excessive offsets (*Chakrabarti, S. (2005))*.

In terms of riser system, the horizontal offset values will represented two extreme riser configurations; far and near conditions. Moreover, the variations of a representative offset value will strongly influence the final static configuration in riser system design.

Based on the reasons above, the horizontal offset values are very important in the offshore floating system design and should be estimated accurately.

In this study, the horizontal offset values of the cylindrical S400 floater have been established from numerical simulations in three ways:

1. First, the horizontal offset value has been established from the station keeping system simulation in **Chapter 6**. In this simulation, the cylindrical S400 floater and moorings are modeled by using SIMO in a time domain analysis. In this chapter, the mooring analysis has been performed in quasi- static model for ”3 hours +” build up time.
   Further, the representative horizontal offset values are derived from the total global motion response (the total frequency motions for surge). This can be seen in **Figure 8.8**. below. From this simulation, the horizontal representative offset value for the cylindrical S400 floater has been found which maximum values around 22,82 m ~23 m.
   The detailed information can be found in **Chapter 6**.
2. The horizontal offset value has also tentatively been established for the riser system design in **Chapter 7**. In this simulation, the cylindrical S400 floater and feasible riser configurations (for 6” and 8” production risers) are modeled by using RIFLEX in a decoupled analysis. Further, the simulation has been performed in time domain analysis for ”3 hours +” build up time. Moreover, in this simulation the FEM (Finite Element Model) has been applied as the design method.
   In this chapter, the representative horizontal offset value is taken as a conservative value. Because, this value will not only represent two extreme riser configurations; the far and near conditions but it also should accommodate the mean and low

frequency motions (LF) since we neglect these terms from the vessel motions in the simulation. From the empirical calculations, the horizontal representative offset value for the cylindrical S400 floater has been found to be around ± 25 m as the static offset.

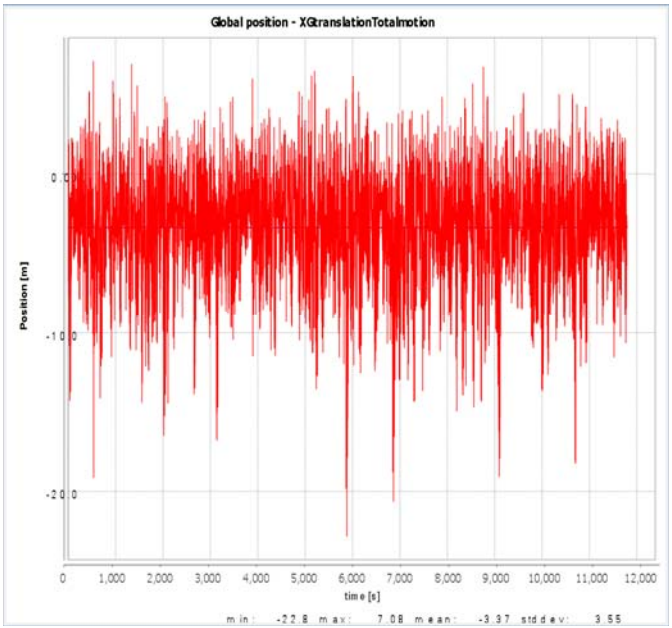


Figure 8. 8 : The total global motion response, the total frequency motions for surge from the station keeping system modeling in SIMO (**Chapter 6**).

3. Last, the horizontal offset value has also been established from a single complete computer model that includes the cylindrical floater S400, 12 mooring lines and two 6" and 8" of feasible riser configurations for the production riser as the nonlinear-coupled dynamic analysis in one module of SIMA Marintek/the RIFLEX Coupled model (combination software for RIFLEX and SIMO which are run together).
   In this analysis, the simulation has been performed by a FEM (Finite Element Model) for "3 hours +" build up time. Further, the representative horizontal offset values are derived from the total global motion response (the total frequency motions for surge). This can be seen in **Figure 8.2**. above. From this simulation, the horizontal representative offset value for the cylindrical S400 floater has been found with maximum value around 33 m.

Method 3 is the best way to predict the representative values for the horizontal offset of the cylindrical floater S400.
This analysis uses a consistent analytical approach which ensures a truly integrated dynamic system in order to quantify the dynamic interaction between the vessel and the slender systems. Hence, the accurate prediction of the response simultaneously for the overall system as well as the individual response components (the floater, moorings and risers) including the estimation of the horizontal offset value can be gained accurately.

8.3 The Nonlinear-Coupled Dynamic Analysis for Slender Members

In the nonlinear-coupled dynamic analysis, two different types of elements have been introduced to represent the moorings and the risers as the slender members in the offshore floating system. These elements will be modeled in FEM (Finite Element Model). The simulation will be performed in time domain for "3 hours +" build up.

The nonlinear-coupled dynamic analysis applies the FEM (Finite Element Model) as design method. The resulting analysis for 6" and 8" production risers are not much different from the results of **Chapter 7**. However, the resulting analysis for the mooring line dynamic tensions is slightly different from the results of the analysis for the mooring line dynamic tension in **Chapter 6**.

Since the nonlinear-coupled dynamic analysis will be performed by FEM (Finite Element Model) as design method, the maximum line tensions of slender members will be increased due to the dynamic behavior of the slender members and may affect the low frequency motions of the moored structure.

The summary of the mooring line dynamic tensions of the cylindrical S400 floater in the nonlinear-coupled dynamic analysis can be seen in **Table 8.5** below:

Table 8.5. : The summary of mooring line dynamic tensions of the cylindrical S400 floater in the nonlinear-coupled dynamic analysis

Channel	Min Tension kN	Max Tension kN	Mean Tension kN	Line Tension Limit (% of MBL)	Design Safety Factor
Mooring Line1	1675.21	8689.94	2684.66	45.14	2.22
Mooring Line2	1676.55	8691.23	2686.54	45.15	2.21
Mooring Line3	1693.32	8703.47	2699.96	45.21	2.21
Mooring Line4	1697.83	8706.85	1703.41	45.23	2.21
Mooring Line5	10235.47	10762.22	10407.62	55.91	1.79
Mooring Line6	10405.46	10976.55	10581.34	57.02	1.75
Mooring Line7	10073.67	10854.45	10265.22	56.39	1.77
Mooring Line8	10069.85	10980.17	10363.85	57.04	1.75
Mooring Line9	2068.59	8357.34	2211.57	43.41	2.30
Mooring Line10	1847.79	8067.47	2961.11	41.91	2.39
Mooring Line11	1195.67	8232.31	2220.41	42.77	2.34
Mooring Line12	1130.80	8153.46	2144.68	42.36	2.36

Table 8.5 above will represent the range of tension force along the mooring line. The mooring lines should always be in tension. Further, these forces should also be checked with the acceptance criteria for tension limits for the ULS (Ultimate Limit State) based on *ISO 19901-7 (2005)*.

ISO 19901-7 (2005) has mentioned that the acceptance criteria for tension forces for the Ultimate Limit States (ULS) should have a specified minimum safety factor higher than 1,67 for intact condition by using dynamic analysis (FEM) method.

ISO 19901-7 (2005) has also mentioned the line tension limit for intact condition in dynamic analysis (FEM) method. It should have the line tension limit of 60% of the Minimum Breaking Load (MBL) of the mooring line component.

Hence, the criteria above are met for the mooring system design for the cylindrical S400 floater.

In the riser analysis, two feasible configurations of production risers, 6" and 8", from **Chapter 7** are checked by static and dynamic analysis. In the static analysis only the static riser configuration with and without the vessel offset and the dynamic analysis of the entire system will be performed by combining the static loads with dynamic environmental loads based on the movements of the riser.

The main results of the analysis such as effective tension, bending moment and curvatures for static and dynamic condition will be presented below:

A. Static condition

The purpose of the static analysis is to re-check two 6" and 8" feasible configurations of production risers from **Chapter 7**. The main design parameters are such as the choice of riser configuration, the length of riser, the system geometry and the sizing of riser and ancillary components based on the consideration of the hang off location and the location of the touchdown point will be simulated in the static condition.

1. **Effective tension**

   The effective tensions for the 6"and 8" production risers can be seen in **Figure 8.9**. and **Figure 8.10.**

   The maximum effective tension for the 6" production riser is 180 kN while the minimum will be 32,08 kN.

   The range of values for the effective tension for the 8" production riser is slightly different. The maximum effective tension for the 8" production riser is 155 kN while the minimum will be 26,58 kN.

   These results are quite good and any compression can be avoided.

2. **Bending Moment and Curvature**

   The bending moments for the 6"and 8" production risers can be seen in **Figure 8.11**. and **Figure 8.12**. while the curvature for the 6"and 8" production risers can be seen in **Figure 8.13.** and **Figure 8.14**.

   The maximum bending moment and curvature for the 6" and 8" production risers are found in the hang off position. The results are quite good and still within allowable limit.

   Based on the design criterion, in the static condition; the minimum bending radius (MBR) of a riser should be the same or less than the MBR at storage. The MBR for a 6" riser is 1,76 m or in the curvature terms will be 0,57 (1/1,76). The MBR for a 8" riser is 2,02 m or in the curvature terms this will be 0,5 (1/2,02).

   These results are quite good and the curvature of the risers are less than 0,5 (**Figure 8.13.** and **Figure 8.14**.)

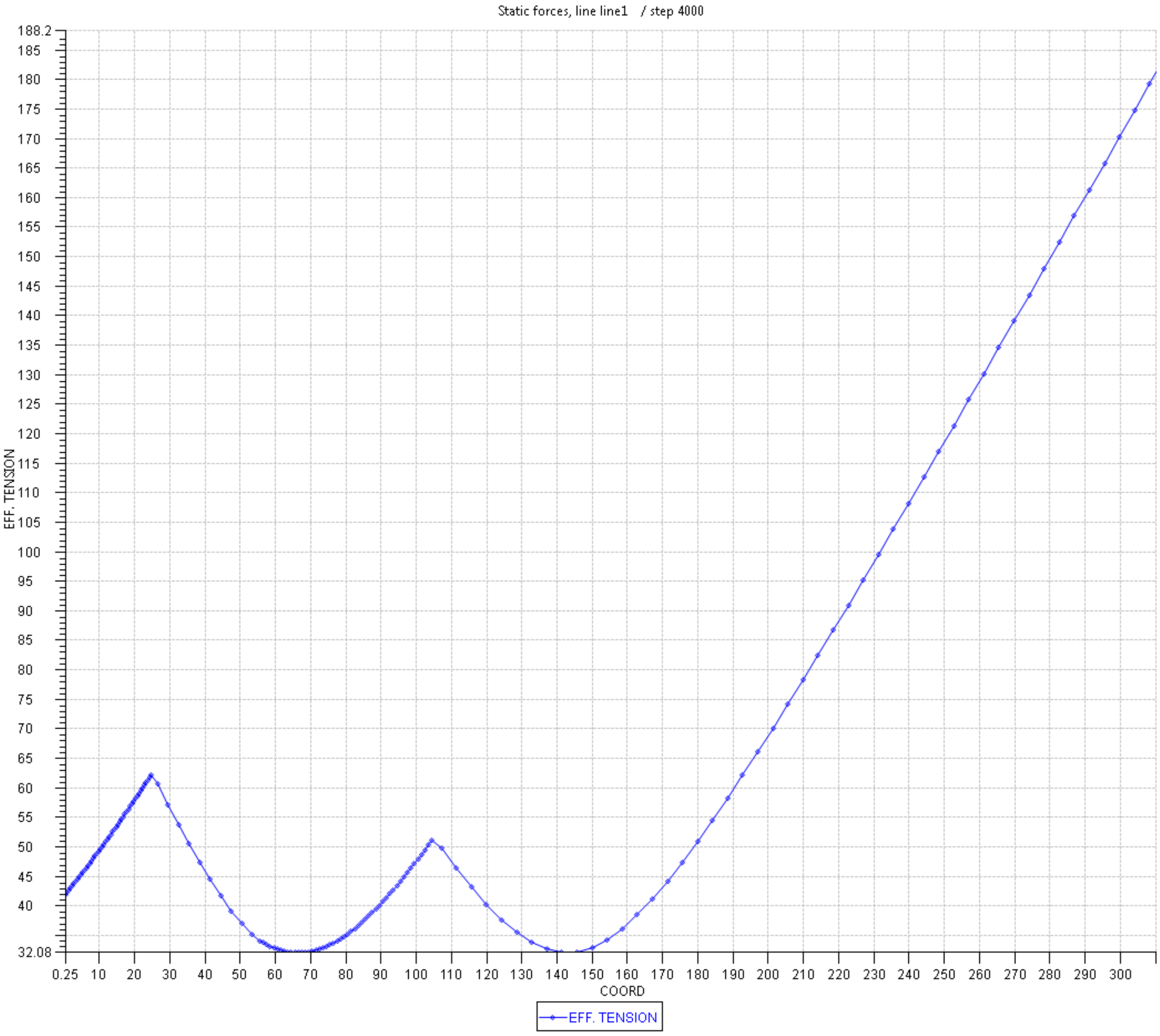


Figure 8. 9 : The static effective tension for the 6" production riser for the Western Isle Field in the nonlinear-coupled dynamic analysis.

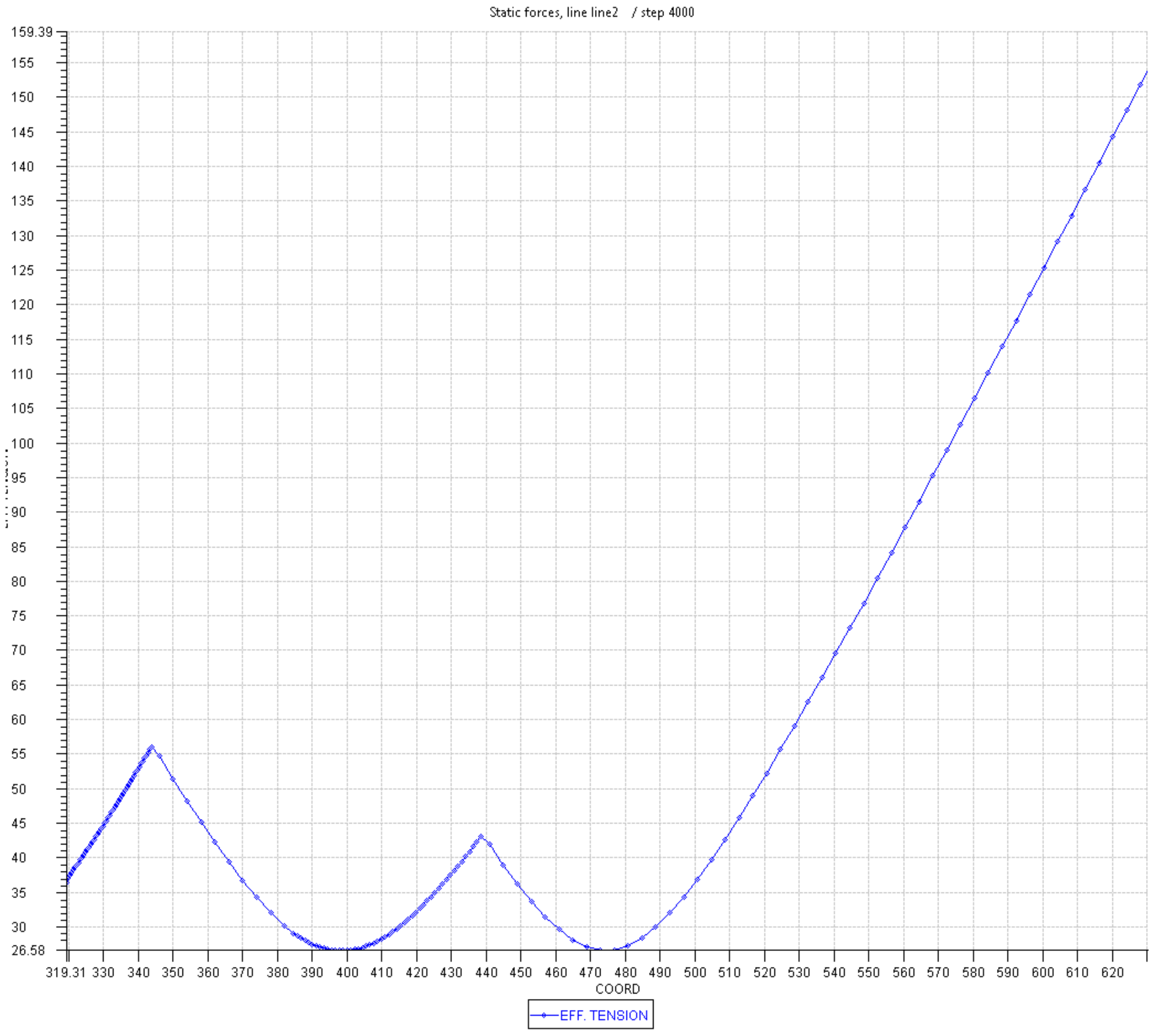


Figure 8. 10 : The static effective tension for the 8" production riser for the Western Isle Field in the nonlinear-coupled dynamic analysis.

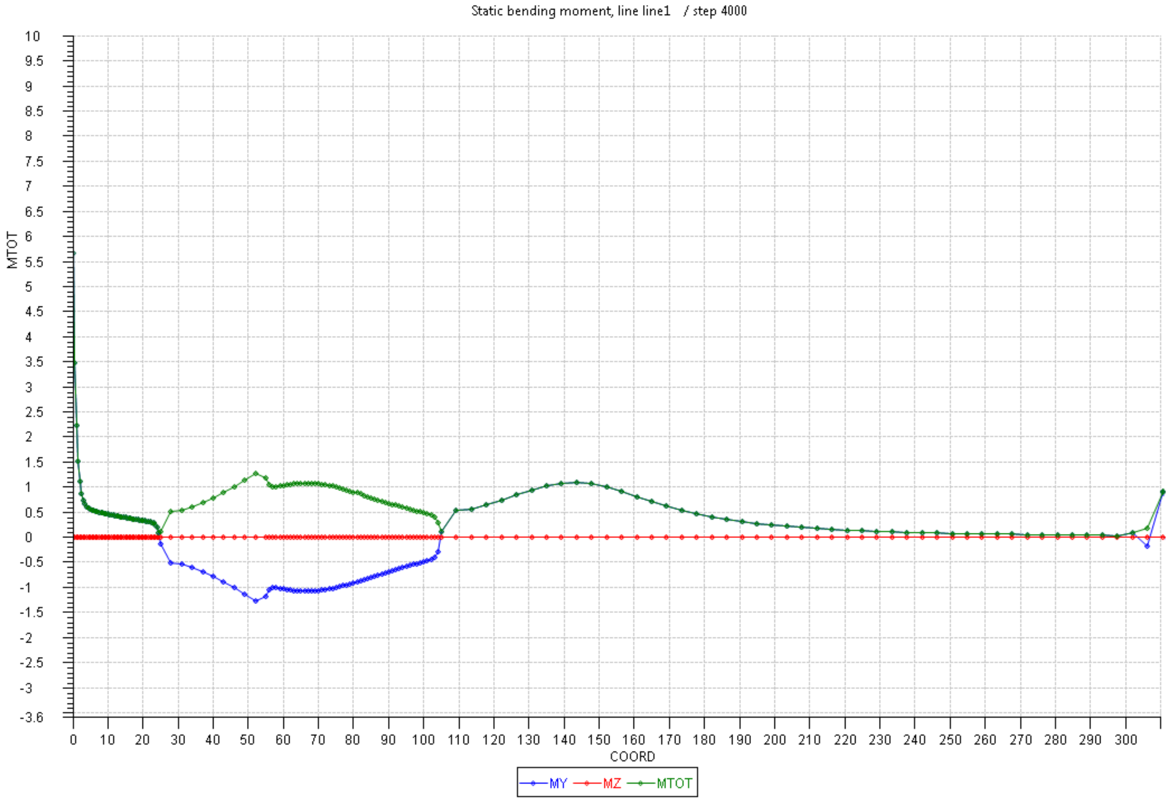


Figure 8. 11 : The static bending moment for the 6" production riser for the Western Isle Field in the nonlinear-coupled dynamic analysis.

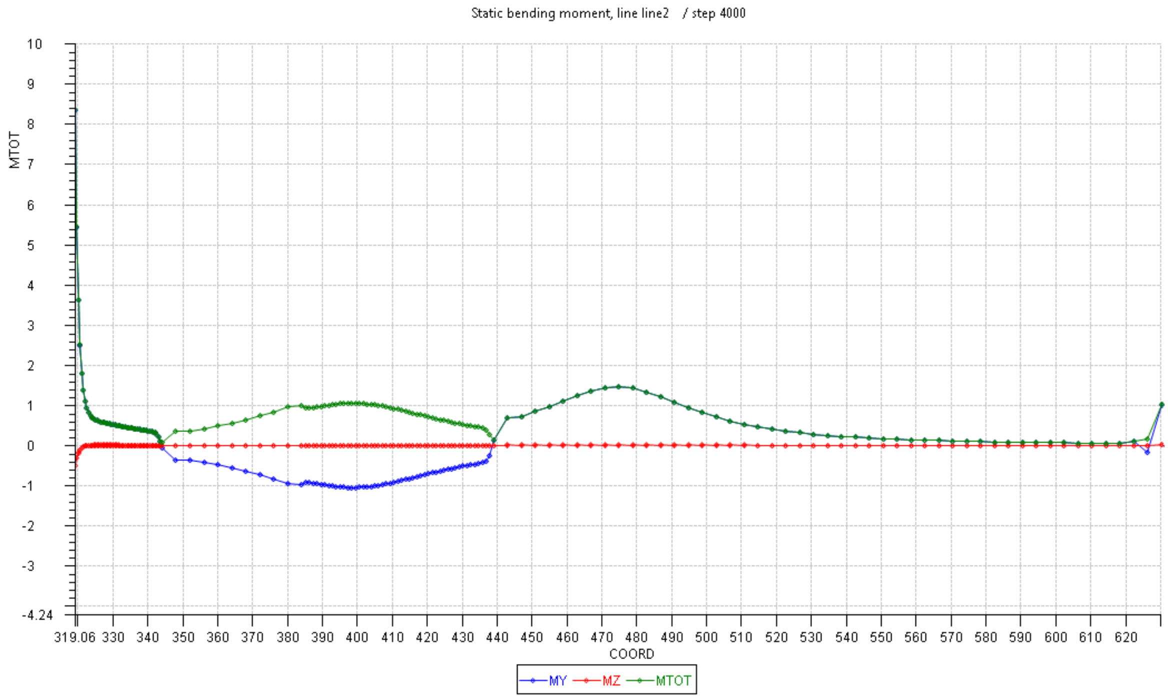


Figure 8. 12 : The static bending moment for the 8" production riser for the Western Isle Field in the nonlinear-coupled dynamic analysis.

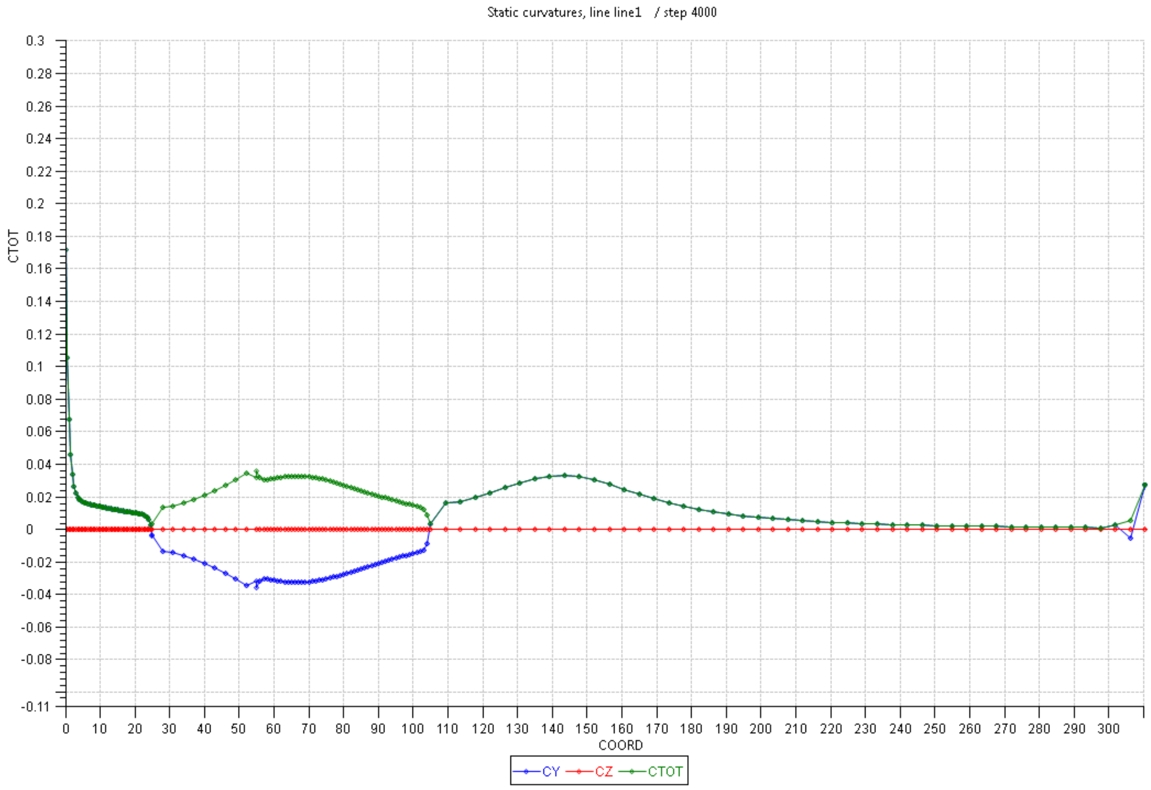


Figure 8. 13 : The static curvatures for the 6” production riser for the Western Isle Field in the nonlinear-coupled dynamic analysis.

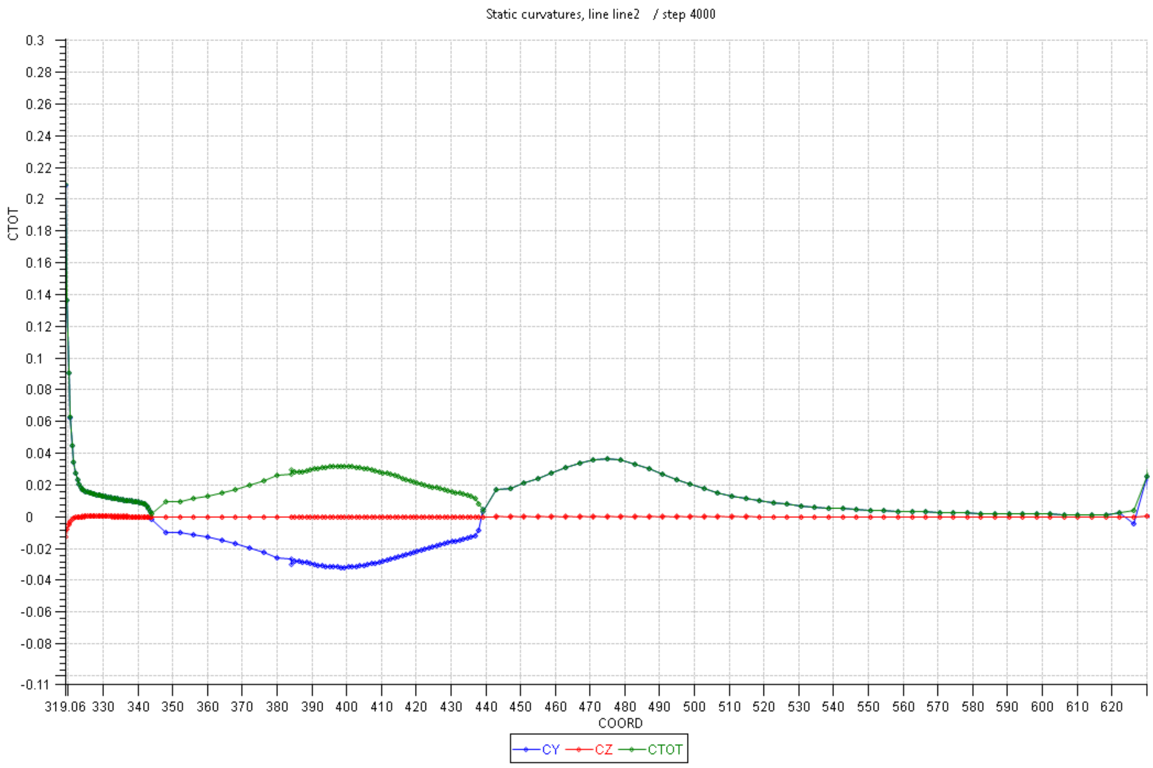


Figure 8. 14 : The static curvatures for the 8” production riser for the Western Isle Field in the nonlinear-coupled dynamic analysis.

B. Dynamic condition

In the dynamic condition, time domain dynamic analyses will be performed based on the final static configuration in order to calculate the global dynamic responses of the system. Furthermore, the results of these analyses such as the dynamic tensions and curvatures should be checked against the design limits.

The diagram of displacement envelope curvatures for 6"and 8" production risers can be seen in **Figure 8.15.** and **Figure 8.16.**

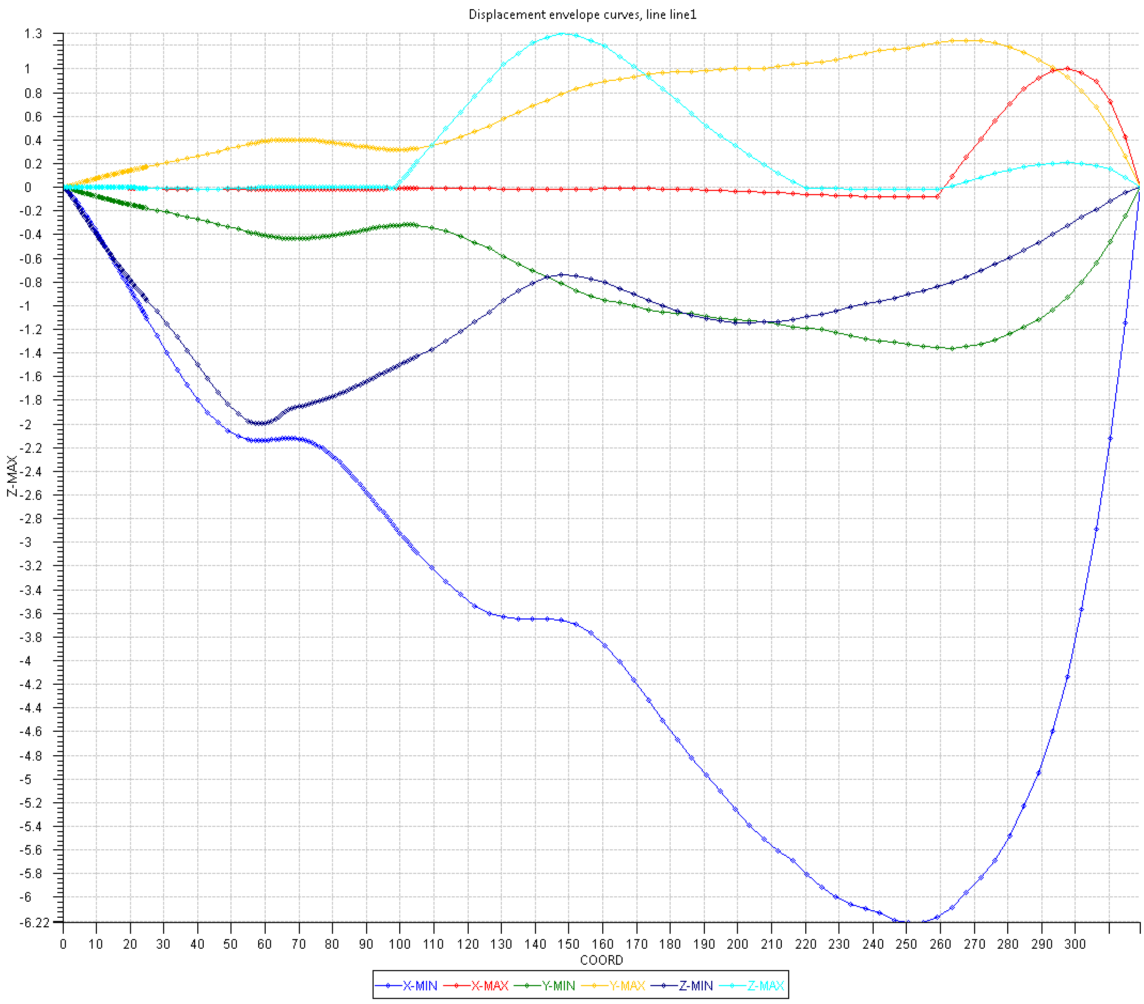


Figure 8. 15 : The displacement envelope curvature for the 6" production riser for the Western Isle Field in the nonlinear-coupled dynamic analysis.

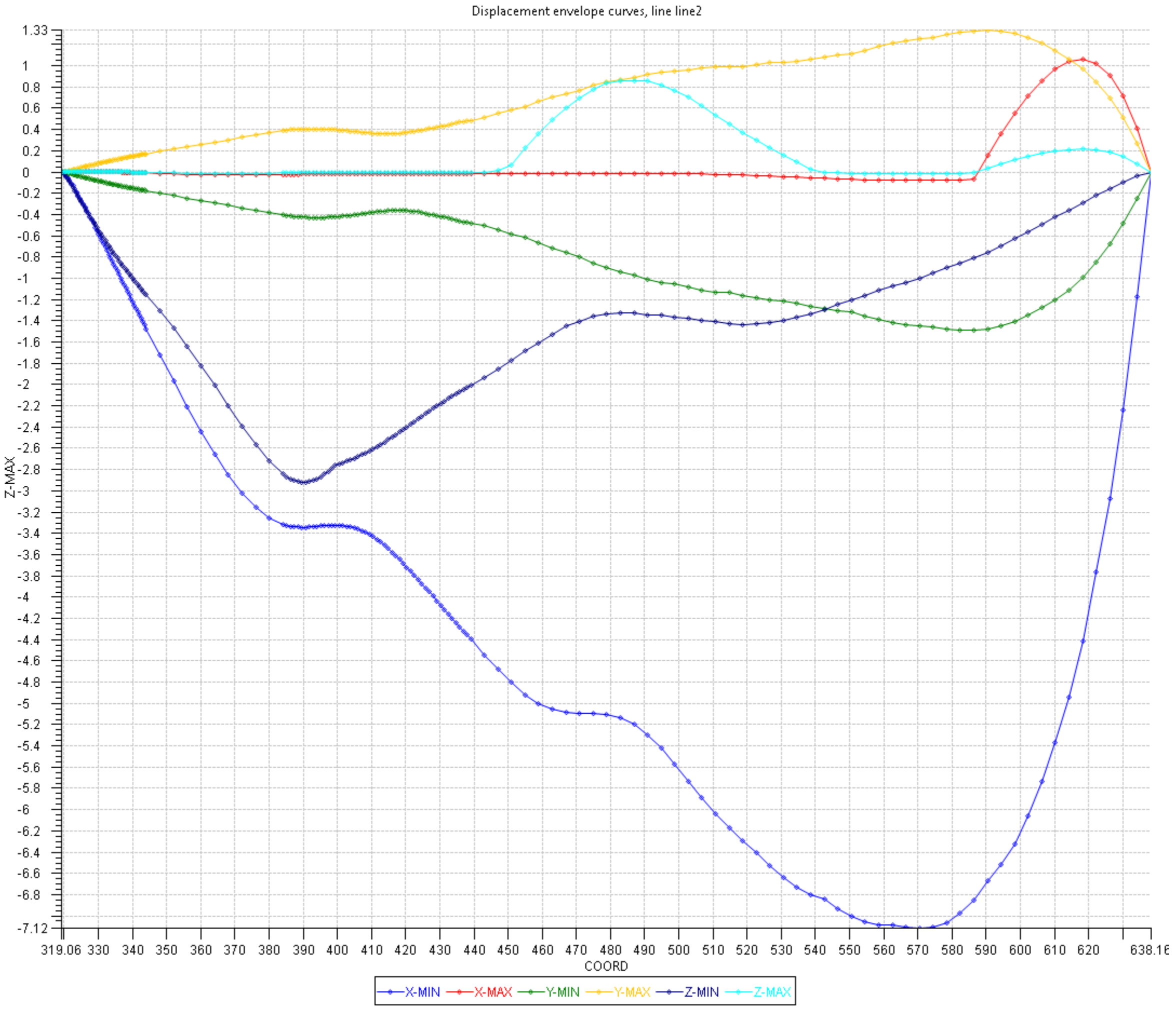


Figure 8. 16 : The displacement envelope curvature for the 8" production riser for the Western Isle Field in the nonlinear-coupled dynamic analysis.

The other results such as such as the dynamic tensions and curvatures can be seen below.

1. **Effective tension**

   The effective tension for the 6"and 8" production risers can be seen in **Figure 8.17**. and **Figure 8.18**.

   The maximum effective tension for the 6" production riser is 230 kN while the minimum will be 31,37 kN.

   The range of values for the effective tension for the 8" production riser is slightly different. The maximum effective tension for the 8" production riser is 200 kN while the minimum will be 24,9 kN.

   These results are quite good and any compression can be avoided.

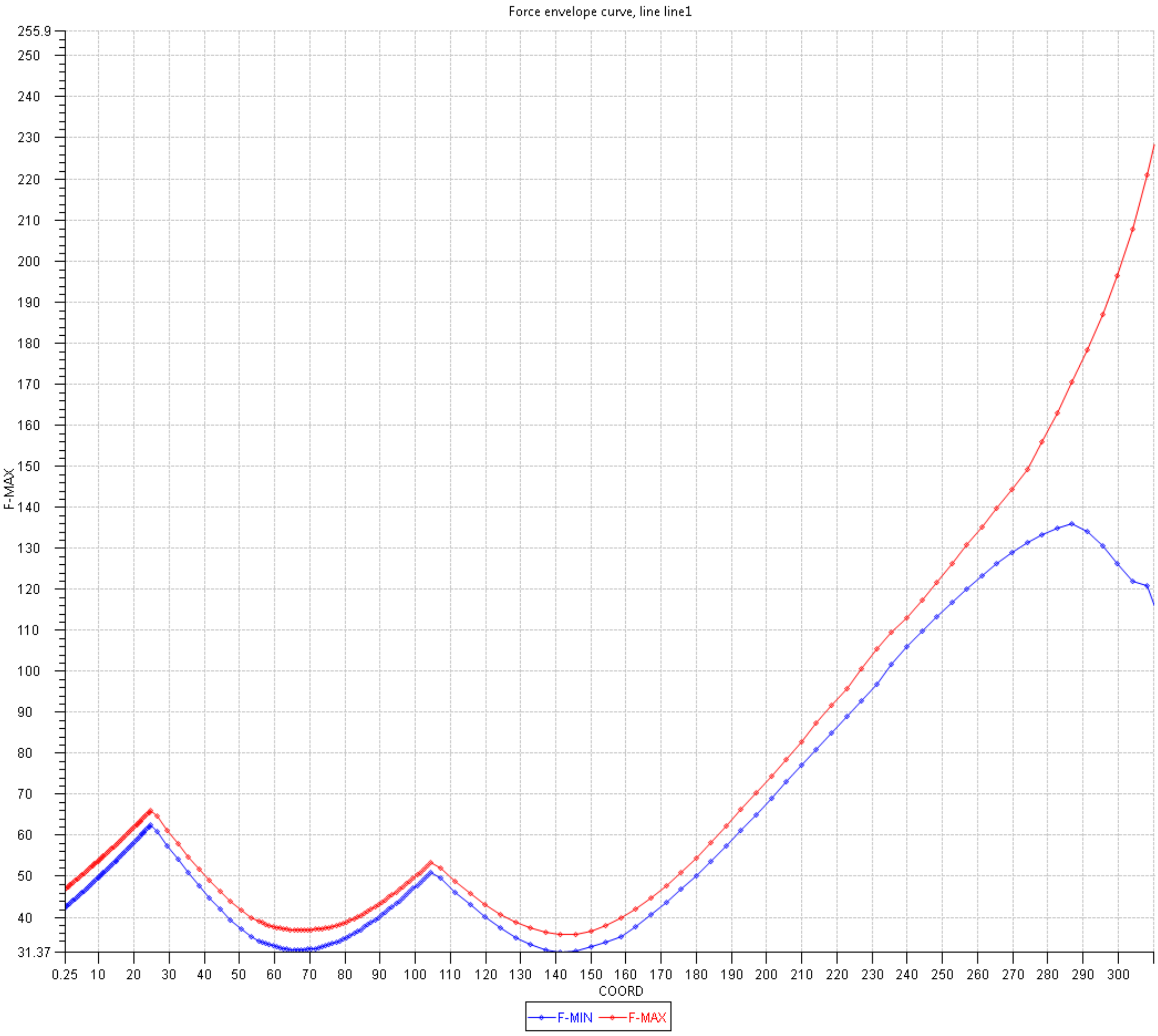


Figure 8. 17 : The dynamic effective tension for the 6” production riser for the Western Isle Field in the nonlinear-coupled dynamic analysis.

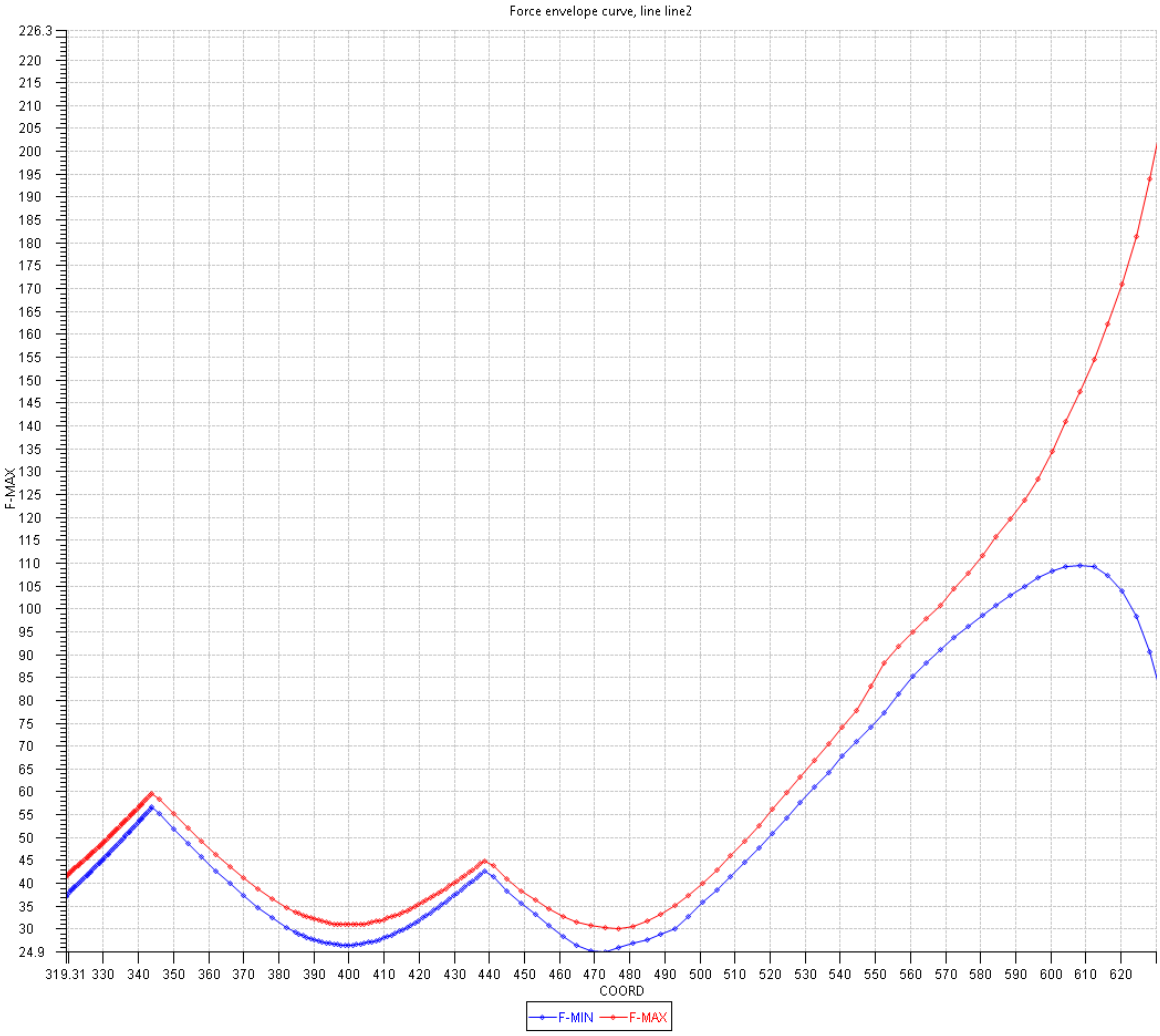


Figure 8. 18 : The dynamic effective tension for the 8" production riser for the Western Isle Field in the nonlinear-coupled dynamic analysis.

2. Bending Moment and Curvature

The bending moments for the 6"and 8" production risers can be seen in **Figure 8.19**. and **Figure 8.20**. while the curvatures for the 6"and 8" production risers can be seen in **Figure 8.21.** and **Figure 8.22**.

The maximum bending moments and curvatures for the 6" and 8" production risers are occur in the hang off position. The results are quite good since the result are still in the allowable limit.

Based on the design criterion, in the dynamic condition; the minimum bending radius (MBR) of the riser should be the same or less than 1,5 times that of the MBR at storage. The MBR for the 6"riser is 1,76 m or in the curvature terms this will be 0,57 (1/1,76). Hence the limiting MBR in the dynamic condition is 0,38.

While, the MBR for the 8" riser is 2,02 m or in is the curvature terms will be 0,5 (1/2,02). Hence the limiting MBR in the dynamic condition is 0,33.

These results are quite good since the curvature of the risers are less than 0,3 (**Figure 8.21.** and **Figure 8.22.**)

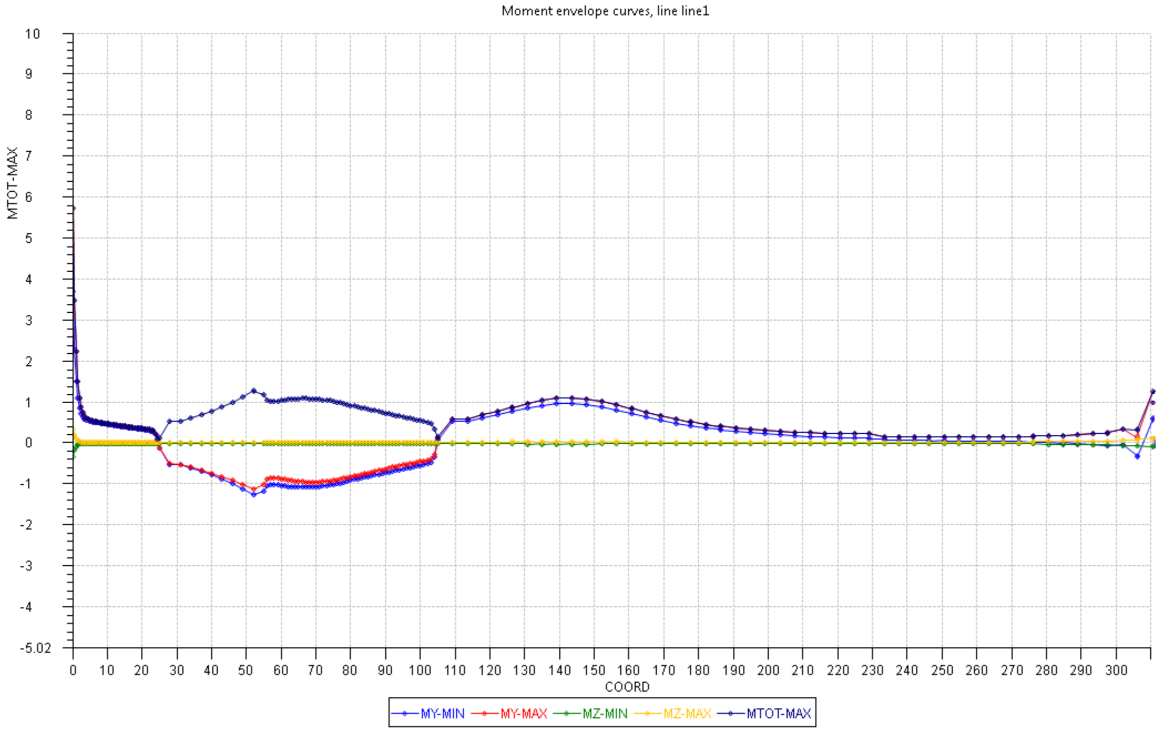


Figure 8. 19 : The dynamic bending moment for the 6" production riser for the Western Isle Field in the nonlinear-coupled dynamic analysis.

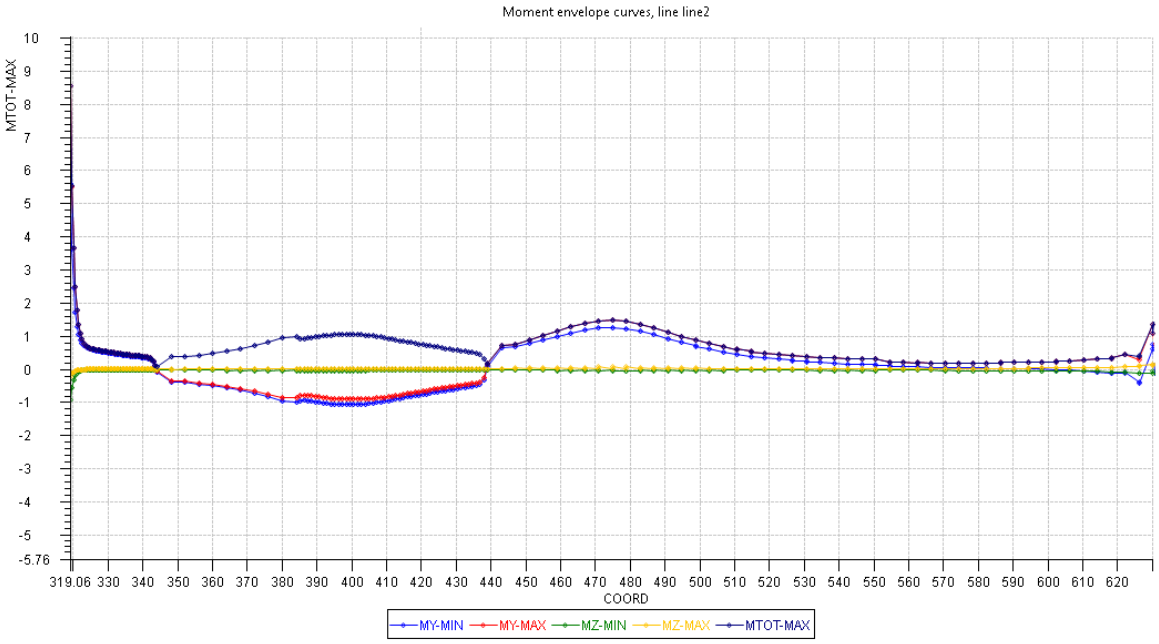


Figure 8. 20 : The dynamic bending moment for the 8" production riser for the Western Isle Field in the nonlinear-coupled dynamic analysis.

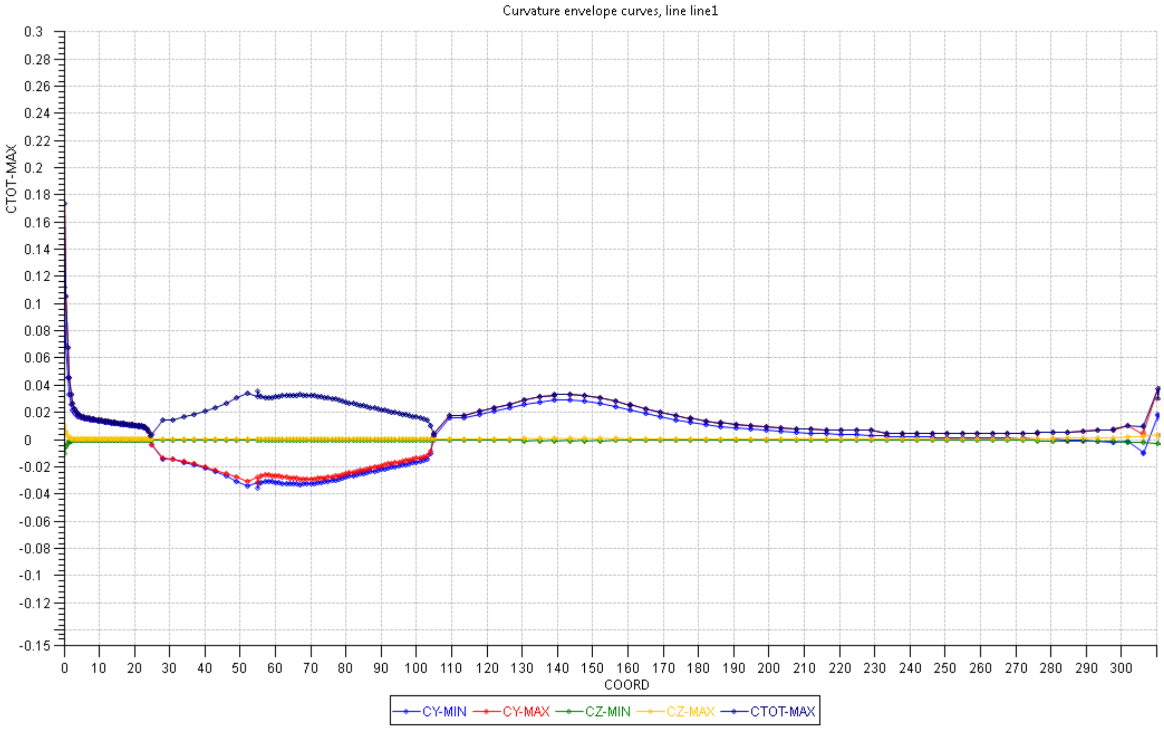


Figure 8. 21 : The dynamic curvatures for the 6" production riser for the Western Isle Field in the nonlinear-coupled dynamic analysis.

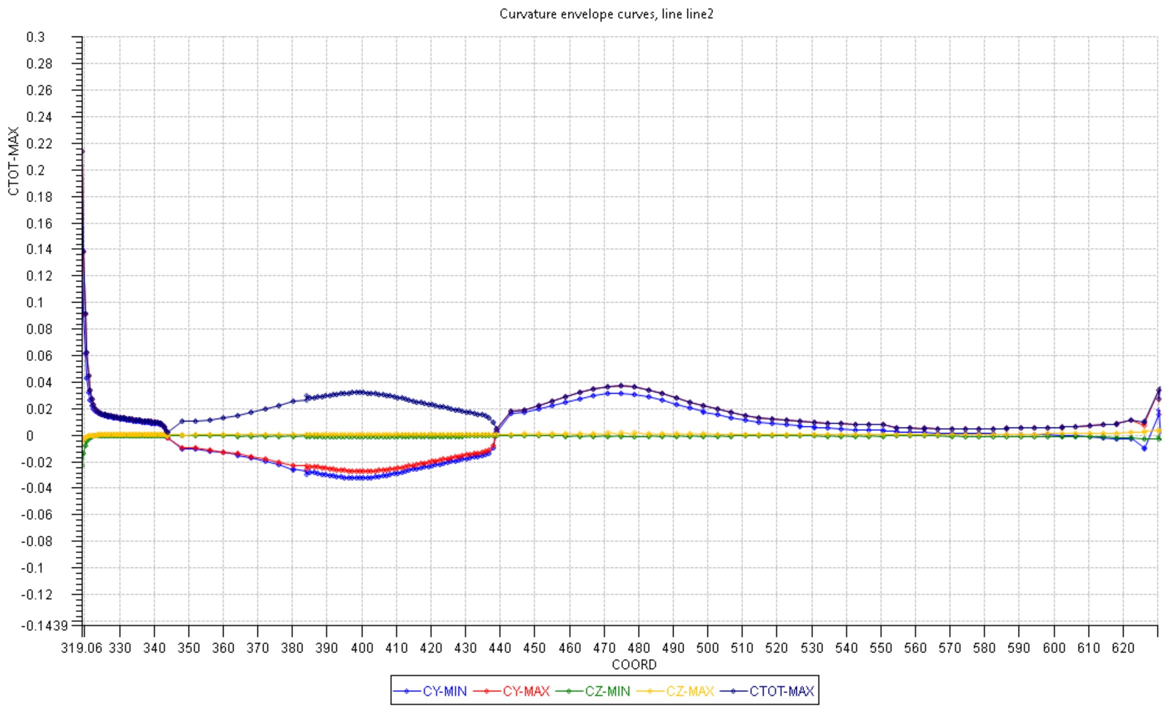


Figure 8. 22 : The dynamic curvatures for the 8" production riser for the Western Isle Field in the nonlinear-coupled dynamic analysis.

CHAPTER

9

Conclusions and Further Studies

9.1 Conclusions

The hydrodynamic interaction effects and dynamic responses dominate the major consideration in the design of floating structures.

Two kind of analyses, the decoupled analysis and the nonlinear-coupled dynamic analysis have been presented in this thesis in order to quantify the coupling effects between each components in an offshore floating system. It also has a purpose to introduce a consistent analytical approach that ensures the higher dynamic interaction between the floater, moorings and risers be taken into account. The nonlinear-coupled dynamic analysis requires a complete model of the floating offshore system including the cylindrical S400 floater, the 12 mooring lines and the feasible riser configurations for the 6" and 8" production risers. Furthermore, the results from the nonlinear-coupled dynamic analysis have also been compared to the separated analyses for each component in the discussion of the analysis results.

Separated analyses for each component can be found in several chapters; **Chapter 5** (the floater analysis), **Chapter 6** (the mooring system analysis), **Chapter 7** (the risers system analysis) while **Chapter 8** presents a complete model of the floating offshore system.

Frequency domain and time domain analysis have been implemented to solve the equation of motions in the simulations. Moreover, the frequency domain analysis has been adopted in the hydrodynamic analysis of the cylindrical S400 floater (**Chapter 5**) as a simple iterative technique to solve the linear equation of motions to obtain a set of frequency dependent RAO (Response Amplitude Operator) while the time domain analysis has been implemented in the remains chapters (**Chapters 6, 7 and 8**) in order to solve the problems as close to the real condition as possible with regard to the non linear system where the frequency domain analysis is no longer valid to be used. The simulation has been conducted in two simulation schemes, static and dynamic conditions. A "3 hours +" build up time will be used in the dynamic condition because the time domain requires a proper simulation length to have a steady result.

The cylindrical floater hydrodynamic analysis as a decoupled analysis can be found in **Chapter 5**. The floater hydrodynamic analysis is performed by using the integrated software program Hydro D which is related to several support software programs (Prefem, Wadam and Postresp). Furthermore, the analysis is only based on the wave loads acting on the floater as the most important contributor to derive the response of motion of the floater. Two types of waves, regular waves and irregular waves as environmental loads have been simulated in two loading conditions. The loading conditions have been defined based on the z-coordinate at the waterline. Two loading conditions are chosen in this analysis, ballast loading condition (z = 16.32m) and fully load loading condition (z = 20.72m).

From the stability analysis, the positions of the floater in static equilibrium where the forces of gravity and buoyancy are equal and acting in opposite directions in line with one another, are presented. Based on the analysis results, the cylindrical S400 floater has good stability since $\overline{GM} > 0$. The change of $\overline{\mathrm{GM}}$ from the ballast to fully loaded condition is as follows: the metacentre height in the ballast condition ($\overline{GM}$ =7.08) is higher than the metacentre height in the fully load condition ($\overline{GM}$ =6.26). It happens because the keel position will move down when the ballast tanks are full. Hence, the distance between the keel and the buoyancy centre $\overline{KB}$ will be higher. However, the centre of gravity $\overline{KG}$ will also move up and the distance between the keel K and the centre of gravity $\overline{KG}$ will be also higher. Since the $\overline{KG}$ is higher than $\overline{KB}$, the $\overline{GM}$ will be lower. It is the main reason why the stability of a cylindrical S400 floater becomes lower than its position in the ballast condition.

The transfer function between waves and responses or the RAO (Response Amplitude Operator) and the mean wave (drift) force are also generated from the wave excitation in the hydrodynamic analysis. The RAO represents as the first order wave forces while the second order wave forces are described as the mean wave (drift) forces. Further, these results are presented with respect to all 6 DOF (surge, sway, heave, roll, pitch and yaw) as the response of the floater. Beside the RAO (Response Amplitude Operator) and the mean wave (drift) force, the non linear damping effects are also presented in this analysis in order to quantify the low frequency damping from an expansion of the mean drift force. It is important to predict the non linear damping effects in the design because the mean drift forces can generate large amplitude resonant motions. Furthermore, all of the results in the hydrodynamic analysis and the rigid body model of cylindrical S400 floater have been used to perform the time domain simulation which includes the moorings system by using the software program SIMO in **Chapter 6**.

The mooring system is important to hold the offshore floating system against winds, waves and currents. The mooring system for a cylindrical S400 floater adopts the spread mooring system without using a thruster to stay in the desired position. It consists of 12 mooring lines which are distributed in 3 clusters. These mooring lines will be made from combination of chain and polyester rope. Moreover, each line consists of fairlead, top chain segments, upper polyester segment and lower polyester segment, anchor chain and anchor. The present mooring system solution is based on a maximum offset radius of 75 m. This implies that the Sevan Floater maybe located at any position within a radius of 75m from its defined zero position.

Further, this mooring system has been analyzed by using SIMO in time domain analysis. In SIMO, two models (the body model and the station keeping model) are required and the quasi-static design has been applied as the design method in the mooring system analysis.

Hence, it comprises the dynamic motion analysis of the moored structure and computations of mooring line tension based on the extreme position of the floater and the static load-excursion characteristic of mooring system. Furthermore, the wave, wind and current have been considered in the analysis. These environmental load data have been based on the return period combinations for 100 years waves and wind criteria and 10 years current criteria at ballast loading position (z = 16.32m).

The aim of the moorings analysis has been to ensure that the mooring system has adequate capacity to generate a non-linear restoring force the station keeping function. This force has been expressed by the mooring tension that will also be influenced by horizontal offset values.

In order to calculate the mooring tension and horizontal offset value, mooring analysis are carried out in two conditions, static and dynamic conditions. The results from the static condition are derived without variation of the environmental loads then it has been taken into account in the dynamic condition.

The results from the static condition have been used as the final static body position and mooring line tensions while the results from the static condition are time series of second order wave forces, the wave drift damping forces, the mooring line dynamic tensions and the response motions of the cylindrical S400 floater. Further, the response motion has been used to define the horizontal offset of the cylindrical S400 floater.

The horizontal offset values of an offshore floating system are very important to determine the global performance of the floater structure in the survival or operation conditions. These values will influence the design of the other components in the offshore floating system such as moorings system and risers system.

The horizontal offset values of the cylindrical S400 floater has been established in a quasi-static "3 hours +" build up time simulation. Further, the representative horizontal offset values are derived from the total global motion response (the total frequency motions for surge). From this analysis, the horizontal representative offset values for a cylindrical S400 floater have been found which having maximum value around 22,82 m ~23 m.

By using the quasi-static design method, the moorings tension arising due to the floater motions have been calculated. This not only for WF (Wave Frequency) mooring line tension or LF (Low Frequency) mooring line tension but also for the combination of the LF and WF mooring line tension.

From the analysis results, the maximum range of tension forces along the mooring lines are found to meet the criteria of the mooring system design for the cylindrical S400 floater and it is also found that the design safety factor for the mooring system is higher than 2,0. The acceptance criteria for tension limits for the ULS (Ultimate Limit State) are based on *ISO 19901-7 (2005)*. It has there been mentioned that the acceptance criteria for tension forces for the Ultimate Limit States (ULS) should have a specified minimum safety factor around 2,0 for intact condition when using a quasi-static design method.

Besides the mooring system, an offshore floating body also has the riser system as can be modeled as slender members. The analysis for the riser system is first done as a decoupled analysis in this study. The main purpose of this analysis is to find a feasible single arbitrary configuration for each of the 6" and 8" production risers. The riser system analysis in **Chapter 7** will also be performed in time domain analysis in RIFLEX for two simulation conditions, static and dynamic conditions. The riser system design for the offshore Western Isles Field has real challenges since it is located in relatively shallow water condition (~170m) and also a harsh environment. The main challenges that will be faced in the design process come from the relatively large vessel motions and vessel offset due to limited space between the the FPSO and the seabed. Harsh environmental loading will also give impact on the dynamic riser behavior. Besides, the external influence from the environmental condition, the configuration itself will govern the pliancy requirement and the riser system itself should accommodate two extreme configurations, the far and the near conditions. In dealing with these challenges, the application of flexible riser (compliant riser) will be very suitable in this offshore floating system. A Lazy Wave riser configuration has been chosen with some modifications in order to have a riser system which has robust solution and economic design. The riser system design will be introduced with a multiple buoyancy at the hog bend position and heavy weight riser. Multiple buoyancies have functions to reduce the overall tension at the upper region and improve the curvature at the lower region while a heavy riser has been used to reduce the free floating loads from the riser. This makes the configuration more stable.

Further, this riser system design will be checked by static and dynamic analysis. In the static analysis only the static riser configuration with or without vessel offset will be considered while the dynamic analysis of the entire system will be performed by combining the static loads with the dynamic environmental loads based on the movement of the riser.

The purpose of the static analysis has been to determine the acceptable system layout for the riser based on the input parameters while the dynamic analysis has the purposes to calculate the global dynamic responses of the system due to the environmental loadings based on the final static configuration. Furthermore, the wave, wind and current have been considered in the analysis. These environmental load data have been based on the return period combinations for 100 years waves and wind criteria and 10 years current criteria at ballast loading position (z = 16.32m).

The main parameters are such as the choice of riser configurations, the length of riser, the system geometry and the sizing of riser and ancillary components based on the consideration of the hangoff and touchdown positions. The main requirements for the result of the analysis are such as the top angle position, effective tension, bending radius and seabed clearance and clashing.

From the static analysis, the top angle positions are less than 15 deg while the seabed clearances are around 5 to 15 m at the lowest point in the sag bend area. The results for the effective tension are quite good and any compression is avoided. The riser itself should always be in tension because compression along the riser should be avoided as it will cause (birdcaging and) buckling which may affect the integrity of the riser adversely and reduce the service life. The maximum effective tension for the 6” production riser is 180kN while the minimum will be 32,08kN. The maximum tension for the 8” production riser is 155kN while the minimum will be 26,58kN.

The effective tensions in the dynamic analysis for the 6” and 8” production risers are slightly different than found in the static analysis. The maximum effective tension for the 6” production riser is 240kN while the minimum will be 23,94kN. The maximum tension for the 8” production riser is 220kN while the minimum will be 10kN.

The bending moments and the curvatures of the riser show the performance of the riser. Furthermore, the curvature of the riser show the capability of the riser to be bent until its limits without kinking or damaging, which depends on its minimum bending radius. The smaller the bending radius, the greater is the material flexibility (as the radius of curvature decreases, the curvature increases).

From the static analysis, the results for bending moment and the curvature for 6" and 8" production risers are found still to be within the allowable limit. The curvatures of the risers are less than 0,5 in the static analysis while in the dynamic analysis, the curvatures of the risers are less than 0,3.

Following the separated analyses for each component in the previous chapters (**Chapters 5,6 and 7)**, a single complete computer model that included the cylindrical floater, moorings and risers with use of SIMA has been introduced in **Chapter 8** as a nonlinear-coupled dynamic analysis. The analysis is performed in time domain for two conditions, static and dynamic conditions. The SIMA Marintek computer has been used in this study because it has the capability to integrate the cylindrical S400 floater, moorings and risers as one complete model. As an integrated dynamic system, the environmental forces on the floater induce the motions which have been introduced in a detail FEM (Finite Element Model) of the moorings and risers. 3D bar/cable elements represent the mooring while 3D beam elements represent the flexible riser. Moreover, the application of the FEM has not only been used for moorings and risers but also for the floater. The FEM model of the cylindrical S400 floater originated from WADAM/HydroD.

Further, this complete model simulated the static and dynamic conditions in responding to environmental loading due to wind, waves and currents. These environmental load data were based on the return period combinations for 100 years waves and wind criteria and 10 years current criteria at ballast loading position (z = 16.32m). The environmental data were based on the Jonswap double peaked spectrum (Hs=15.6m and Tp=15.5s) for the wave and the NPD Spectrum for the wind while the currents have been based on the current profile on the Western Isle Offshore field.

The static equilibrium position and the initial condition for the dynamic simulation have been generated in the static condition. In the dynamic condition, the results of the nonlinear-coupled dynamic analysis have been presented in time series as the responses of the system due to the dynamic loading conditions. Thus, the nonlinear-coupled dynamic analysis ensures a truly integrated system. The dynamic analysis has been simulated for "3 hours +" build up time. Not only the accurate prediction of the responses of the overall system but also the individual responses of the floater, mooring and risers have been obtained. The summary of the results between the decoupled analysis and the nonlinear-coupled dynamic analysis will be presented as follow:

A. Floater motions

   The global motion response of the cylindrical S400 floater is represented by the total frequency motions as a combination of the low frequency motions (LF motions) and the wave frequency motions (WF motions). Moreover, the total global motion responses of the cylindrical S400 floater in the nonlinear-coupled dynamic analysis are slightly different from the total global motion responses of the cylindrical S400 floater for the total frequency motions in the decoupled dynamic analysis. The difference in the analysis results can be seen in **Table 9.1** below:

Table 9.1. : The Summary of The Global Motion Response of A Cylindrical S400 Floater in the Nonlinear-Coupled Dynamic Analysis and the Station Keeping System Modeling results as found from SIMO (**Chapter 6**)

Channel		The Global Motion Response in Total Frequency Motions (nonlinear-coupled dynamic analysis)				The Global Motion Response in Total Frequency Motions (Chapter 6)			
		Min	Max	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.
Surge	XG translation Total Motion	32.11	33.50	32.61	0.07	-22.82	7.08	-3.37	3.55
Sway	YG translation Total Motion	-0.30	0.00	-0.26	0.01	-8.47	5.09	-0.80	0.73
Heave	ZG translation Total Motion	-9.19	-9.05	-9.15	0.00	-15.02	4.14	-0.22	3.82
Roll	XL rotation Total Motion	-1.87	0.66	-0.63	0.27	-5.50	5.89	0.03	1.78
Pitch	YL rotation Total Motion	0.00	3.17	1.84	0.35	-9.73	8.48	-0.41	2.35
Yaw	ZG rotation Total Motion	-7.61	0.00	-4.27	0.20	-2.69	5.42	1.00	1.31

These different responses are generated by the different approaches to design modelling. In **Chapter 6**, the cylindrical S400 floater and 12 mooring lines are modelled in SIMO as a station keeping system. This system uses the Quasi-static design method while the nonlinear-coupled dynamic analysis (**Chapter 8**) comprises a single complete computer model that includes a cylindrical floater, moorings and risers as an offshore floating system in SIMA by using the dynamic FEM (Finite Element Model) as design method.

By using FEM, not only a static configuration will be established with the nonlinear analysis model but the effect of line dynamics on the platform motion will be included in the simulation. Hence, this technique ensures that the higher contributions from the nonlinear dynamic behavior are included. These affect the low frequency motions specifically and also the total frequency global motion responses of the moored structure.

Another reason comes from the influence of the riser structure. In the nonlinear-coupled dynamic analysis, the overall behavior of the floater is influenced not only from the hydrodynamic behavior of the hull and mooring system but also from the dynamic behavior of the risers because this analysis comprises a single complete computer model (a cylindrical floater, moorings and riser) as an offshore floating system. The mechanical characteristics of the riser and the mean current forces on the riser may affect the horizontal restoring force the system which then influences the total frequency global motions of the moored structure.

Further, the horizontal offset value can be established from the total frequency global motions of the moored structure. **Table 9.1** shows that the horizontal representative offset value for the cylindrical S400 floater has been found with a maximum value around 33m in the nonlinear-coupled dynamic analysis while the value is 23m in the decoupled dynamic analysis. It is clear that a cylindrical S400 floater could experience significant surge motions due to the surge excitation from the second order force such as the mean wave (drift) forces and slowly-varying forces from waves or currents.

B. Mooring line dynamic tension

Mooring line dynamic tensions in the nonlinear-coupled dynamic analysis are still within the allowable limit although the safety factors are slightly different from the mooring line dynamic tensions in the decoupled dynamic analysis (as found from **Chapter 6**).

The differences in the analysis results can be seen in **Table 9.2** below.

Table 9.2. : The Summary of Mooring Line Dynamic Tensions in The Nonlinear-Coupled Dynamic Analysis and Mooring Line Dynamic Tensions Results as Found from SIMO (**Chapter 6**)

The in the Nonlinear-Coupled Dynamic Analysis for Station Keeping System Modeling (Chapter 8)					
Channel	**Min tension kN**	**Max tension kN**	**Mean tension kN**	**Line Tension Limit (% of MBL)**	**Design Safety Factor**
Mooring Line 1	1675.21	8689.94	2684.66	45.14	2.22
Mooring line 2	1676.55	8691.23	2686.54	45.15	2.21
Mooring Line 3	1693.32	8703.47	2699.96	45.21	2.21
Mooring Line 4	1697.83	8706.85	1703.41	45.23	2.21
Mooring Line 5	10235.47	10762.22	10407.62	55.91	1.79
Mooring Line 6	10405.46	10976.55	10581.34	57.02	1.75
Mooring Line 7	10073.67	10854.45	10265.22	56.39	1.77
Mooring Line 8	10069.85	10980.17	10363.85	57.04	1.75
Mooring Line 9	2068.59	8357.34	2211.57	43.41	2.30
Mooring Line 10	1847.79	8067.47	2691.11	41.91	2.39
Mooring Line 11	1195.67	8232.31	2220.41	42.77	2.34
Mooring Line 12	1130.80	8153.46	2144.68	42.36	2.36

The Decoupled Analysis for Station Keeping System Modeling (Chapter 6)					
Channel	**Min tension kN**	**Max tension kN**	**Mean tension kN**	**Line Tension Limit (% of MBL)**	**Design Safety Factor**
Mooring Line 1	1035.01	9634.71	2535.28	50.05	2.00
Mooring line 2	1040.80	9547.82	2521.88	49.60	2.02
Mooring Line 3	1048.27	8967.19	2440.06	46.58	2.15
Mooring Line 4	1050.11	8822.99	2420.97	45.83	2.18
Mooring Line 5	764.80	3530.18	1418.10	18.34	5.45
Mooring Line 6	763.48	3581.87	1418.32	18.61	5.37
Mooring Line 7	755.87	3791.81	1424.36	19.70	5.08
Mooring Line 8	754.84	3824.52	1426.53	19.87	5.03
Mooring Line 9	1060.31	3001.74	1586.37	15.59	6.41
Mooring Line 10	1061.07	3059.34	1607.36	15.89	6.29
Mooring Line 11	1068.95	3721.06	1724.61	19.33	5.17
Mooring Line 12	1071.35	4003.40	1750.27	20.8	4.81

These different results are generated by the different design modelling. In **Chapter 6**, the cylindrical S400 floater and 12 mooring lines are modelled in SIMO as a station keeping system. This system uses the Quasi-static design method while the nonlinear-coupled dynamic analysis (**Chapter 8**) comprises a single complete computer model that includes the cylindrical floater, moorings and risers as an offshore floating system in SIMA by using the dynamic FEM (Finite Element Model) as design method.

By using FEM, the line tensions of the slender members (moorings) will be increased due to the dynamic behavior of the slender members.

The acceptance criteria for tension limits in the ULS (Ultimate Limit State) as based on *ISO19901-7 (2005)* should have a specified minimum safety factor higher than 1.67 for intact condition by using dynamic analysis FEM method while it should be higher than 2.0 for the intact condition by using the Quasi-static method.

C. Riser analysis

In this analysis, two feasible riser production riser configurations of 6” and 8” are checked by the nonlinear-coupled dynamic analysis and the decoupled dynamic analysis. The main design parameters, such as the choice of riser configuration, the length of riser, the system geometry and the sizing of riser and ancillary component will be in same parameter for both of the analyses. Not only these parameters but also the position of hang off and touchdown will be put in the same locations.

The main requirements for the results of the analysis such as top angle position, effective tension, bending radius and seabed clearance and clashing are compared between these analyses. After the results are compared, these results are not much different in the static and dynamic analysis. Moreover, these results are still shown to be within allowable limits for all main requirements.

The top angle positions in the static condition for both analyses are less than 15 deg while in the dynamic condition are less than 45 deg. The seabed clearance is around 5-15 m on the lowest point in the sag bend area for both analyses.

The results from the analyses for the effective tensions are quite good since any compression can be avoided.

The effective tension in the decoupled analysis:

In the static condition, the maximum effective tension for the 6” production riser is 180 kN while the minimum will be 32,08 kN and the maximum effective tension for the 8” production riser is 155 kN while the minimum will be 26,58 kN.

In the dynamic condition, the maximum effective tension for the 6” production riser is 240 kN while the minimum will be 23,94 kN and the maximum effective tension for the 8” production riser is 220 kN while the minimum will be 10 kN.

The effective tension in the nonlinear-coupled dynamic analysis:

In the static condition, the maximum effective tension for the 6” production riser is 180 kN while the minimum will be 32,08 kN and the maximum effective tension for the 8” production riser is 155 kN while the minimum will be 26,58 kN.

In the dynamic condition, the maximum effective tension for the 6” production riser is 230 kN while the minimum will be 31,37 kN and the maximum effective tension for the 8” production riser is 200 kN while the minimum will be 24,9 kN.

9.2 Further Studies

Further studies are needed to improve the offshore floating design:

- Additional limit states design analysis
  The analysis should be performed not only in ULS (Ultimate Limit State) but also in other limit states designs such as ALS (Accidental Limit State) and FLS (Fatigue Limit State).
- Sensitivity analyses
  Sensitivity analyses for different wave periods and vessel headings should have been performed to check the effect of variations in the FSU's motion characteristics. Sensitivity analyses of the variation of the mass in the ancillary components such as the ballast modules and the buoyancy modules should also be performed.

API (1998): "Design of Risers for Floating Production Systems (FPSs) and Tension-Leg Platforms (TLPs)", Recommended Practice 2RD First Edition, American Petroleum Institute, June, USA.

Bai, Yong and Bai, Qiang (2005): "Subsea Pipelines and Risers", Elsevier, Kidlington, Oxford, UK.

Braestrup, Mikael W et al (2005): "Design and Installation of Marine Pipelines", Blackwell, Australia.

Chakrabarti, S. (2010): "Handbook of Coastal and Ocean Engineering", edited by Young C Kim, Section 24 Offshore Structure, World Scientific Publishing Co. Pte. Ltd., Singapore.

Chakrabarti, S. (2008): "Challenges for a Total System Analysis on Deepwater Floating Systems", The open mechanics journal, 2008, 2, 28-46

Chakrabarti, S. (2005): "Handbook of Offshore Engineering", edited by Subrata Chakrabarti, Volume 1, Elsevier, Oxford, UK.

Chandwani, R and Larsen, I (1997): "Design of Flexible Risers", Workshop on Subsea Pipelines, December 8-9. University of Brasil, Rio de Janeiro, Brasil

Chaudhury, G. and Yo Ho, C. (2000):"Coupled Dynamic Analysis of Platforms, Riser and Moorings", Offshore Technology Conference, 12084-MS, May 1-4, Houston, Texas, USA.

Connaire, A. D., Lang, D.W., Galvin, C.D., MCS (2003) : "Closely-Moored Floating Bodies in a Production and Offloading Facility – Requirement for and Application of a Coupled Analysis Capability", Offshore Technology Conference, 15378-MS, May 5-8, Houston, Texas, USA.

Cummins, W., (1962): "The impulse response function and ship motions", Departement of the Navy, david taylor Model Basin, Washington, D. C., Report 1661, October 1962.

Dana Petroleum (E&P) Limited (2011): "Western Isles Development Project Basis of Design", No. Document: ADIL-DWI-DV- BOD-0001.

Department of Energy (1990): "Offshore Installations: Guidance on Design, Construction and Certification".

Det Norske Veritas (2010): "Global Performance Analysis of Deepwater Floating Structures", Recommended Practice, DNV-RP-F205, October 2010.

Det Norske Veritas (2008): “Sesam User Manual for Wadam – Wave Analysis by Diffraction and Morison Theory”, Høvik, Norway.

Det Norske Veritas (2004): “Position Mooring”, Offshore Standard, DNV-OS-E301, October 2004.

Det Norske Veritas (2001): “Dynamic Risers”, Offshore Standard, DNV-OS-F201, January 2001.

Engseth, A., Bech, A. and Larsen, C.M. (1988): “Efficient Method for Analysis of Flexible Risers”, Proc. of the Int. Conf. on Behaviour of Offshore Structures (BOSS), Vol. 3, pp. 1357-1371, Tapir, Trondheim, Norway.

Faltinsen, O. M. (1990): “Sea Loads on Ships and Offshore Structures”, Cambridge University Press, USA-Australia.

Gudmestad, O. T. (2010): Marine Technology and Design Compendium. University of Stavanger, Stavanger, Norway.

Hanoge, D., (Technip) and Luppi, A., Seal Engineering SA (2010): “Challenges of Flexible Riser System in Shallow Waters”, Offshore Technology Conference,OTC 20578, 3-6 May,Houston, Texas, USA.

Hoffmam, D., (HMC Offshore Corp.), Ismail, N., M., and Nielsen, R., (Wellstream Corp.) and Chandwani, R., (Zentech) (1991): “The Design of Flexible Marine Riser in Deep and Shallow ware”, Offshore Technology Conference, OTC 6724, 6-9 May,Houston, Texas, USA.

Hung, S. M. and Taylor R. E., **(1988):** “The Formulation of Mean Drift Forces and Moments for Floating Bodies”, London Centre for Marine Technology, University College London, UK.

International Standard (2005): “Petroleum and natural gas industries — Specific requirements for offshore structures - Part 1: Metocean design and operating considerations”, ISO 19901-1, Geneva, Switzerland.

International Standard (2005): “Petroleum and natural gas industries — Specific requirements for offshore structures - Part 7: Station keeping systems for floating offshore structures and mobile offshore units”, Geneva, Switzerland.

Journée, J. M. J. and Massie, W. W. (2001): “Offshore Hydromechanics”, First Edition, Delft University of Technology, http://www.shipmotions.nl., (Delft University course material).

Karunakaran, D., K. (2010): “Pipeline and Riser Compendium”, University of Stavanger, Stavanger, Norway

Karve, S., (MacDermott Intl. Inc.), O’Brien, P., J., (Marine Computation Services) and McNamara, J., F., (University College Galway) (1988): “Comparison of Dynamic Response of Alternate Flexible Riser Product”, Offshore Technology Conference, OTC 5796, 3-6 May,Houston, Texas, USA.

Kim, Y. B. and Kim, M.H., (2002):” Hull/Mooring/Riser Coupled Dynamic Analysis of a Tanker-based Turret-Moored FPSO in Deepwater”, International Offshore and Polar Engineering Conference, May 26-31, ISBN 1-880653-58-3, Kitakyushu, Japan.

Løken, A. E., Sødahl, N., Hagen, O., DNV (1999): ”Efficient Integrated Analysis methods for Deepwater Platforms”, OTC 10809, Offshore Technology Conference, OTC 10809, May 3-6, Houston, Texas, USA.

Machado, Z., L., and Dumay, J., M., (1980): "Dynamic Production Riser on Enchova Field Offshore Brazil", Offshore Brazil Conference, Latin America Oils Show, Rio de Janeiro, Brazil.

Malvern, L. E. (1969): "Introduction to the Mechanics of a Continuous Medium", Prentice-Hall, New York.

Marintek (2010): "RIFLEX - Theory Manual Finite Element Formulation", SINTEF, P.O.Box 4125 Valentinlyst NO-7450, Trondheim, Norway.

Marintek (2010): "RIFLEX - User Manual Finite Element Formulation", SINTEF, P.O.Box 4125 Valentinlyst NO-7450, Trondheim, Norway.

Marintek (2008): "SIMO - Theory Manual Version 3.6, rev: 1", SINTEF, P.O.Box 4125 Valentinlyst NO-7450, Trondheim, Norway.

Marintek (2007): "Marintek Report: Mimosa 5.7 – User's Documentation", SINTEF, P.O.Box 4125 Valentinlyst NO-7450, Trondheim, Norway.

Maruo, H. (1960): "The Drift of a Body Floating in waves", *J*. Ship. Res., 4, 3, 1-10.

Mollestad, E. (1983): "Techniques for Static and Dynamic Solution for Nonlinear Finite Element Problems", ISBN 82-90240-14-7. Department Of Structural Engineering, Norwegian University Of Science And Technology, N–7491 Trondheim, Norway

Newman, J. N. (1974): "Second Order, Slowly Varying Forces on Vessel in Irregular Waves. In Proc. Int. Symp. Dynamics of Marine Vehicles and Structures in Waves, ed. R. E. D. Bishop & W. G. Price, pp. 182-6, London: Mechanical Engineering Publications Ltd.

Newman, J. N. (1986): "Marine Hydrodynamics", The Massachusetts Institute of Technology, Cambridge, USA.

NORSOK Standard (2007): "Actions and Actions Effects – N003", Standard Norway, Lysaker, Norway.

Ogilvie, T. F. (1963): "First- and Second-Order Forces on a Cylinder Submerged Under a Free Surface, *J*. Fluid Mech., 16, 451-72.

Ormberg, H., Fylling, I., J., Larsen, K., and Sødahl, N. (1997): " Coupled Analysis of Vessel Motions and Mooring and Riser System Dynamics", OMAE 1997, Volume I-A, Offshore Technology.

Omberg, H. and Larsen, K. (1998): "Coupled Analysis of Floater Motion and Moorings Dynamics for a Turret-Moored Ship", Appl Ocean Res. (1998), Vol 20, pp.55-67, 8th International Conference on the Behaviour of Off-Shore Structure (BOSS'97), Delft, Netherlands.

Ormberg, H., Sødahl, N., and Steinkjer O. (1998) : "Efficient Analysis of Mooring System using De-coupled and Coupled Analysis", OMAE 1998-0351.

PhysE Ltd (2005): "HSE Research Report 392: Wave mapping in UK waters"

PhysE Ltd (2010): "Metocean Criteria for Western Isles (UK Block 210/24)", R-393-10 F2, SM Document Id: 54850-DAN-J-RA-0001

Pinkster, J. A. (1975): "Low-Frequency Phenomena Associated with Vessels Moored at Sea, Society of Petroleum Engineers *J*ournal, December, 487-94.

Pinkster, J. A. and van Oortmerssen, G. (1977): Computation of the First- and Second–Order Wave Forces on Oscillating Bodies in Regular Waves, In Proc. Second Int. Conf. Numerical Ship Hydrodynamics, ed. J. V. Wehausen & N. Salvesen, pp. 136-56, Berkeley: University Extension Publication, University of California, Berkeley. USA.

Remseth, S. N. (1978): “Nonlinear Static and Dynamic Analysis of Space Structures”, Division of Structural Mechanics, The Norwegian Institute of Technology, University of Trondheim, Norway.

Sclavounos, P. D., (1987): “The vertical wave drift forces on floating bodies”, 2nd International Workshop on Water Waves and Floating Bodies, University of Bristol, March 1987.

Sevan Marine (2011): “Western Isles Development Project (WIDP) FPSO - FEED Study - Mooring Analysis Report”, 54850-SMA-J-RA-0010.

Sevan Marine (2011): “Western Isles Development Project (WIDP) FPSO - FEED Study - Riser Analysis Report”, 54850-SMA-X-XX-####

Ship Hydrostatics, 2002: http://web.nps.navy.mil/~me/tsse/NavArchWeb/1/module7/basics.htm#

Torsethaugen, K., (2004): “Simplified double peak spectral model for ocean waves”, SINTEF, STF80 A048052, SINTEF Fisheries and Aquaculture, Trondheim.

Van den Boom, H., J., J., (2005): ”Dynamic Behaviour of Mooring Lines”, Maritime Research Institute Netherlands-Wageningen, Elsevier Science Publisher B.V, Amsterdams, Netherlands.

Wichers, J., E., W., and Huijsmans, R., M., H., (1984): “On the Low-Frequency Hydrodynamic Damping Forces Acting on Offshore moored Vessel”, Offshore Technology Conference, OTC 4813, May 7-9, Houston, Texas, USA.

APPENDIX

A

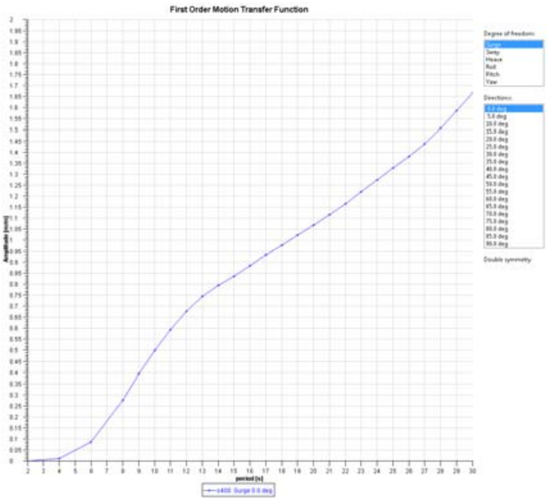
Response Amplitude Operator (RAO)

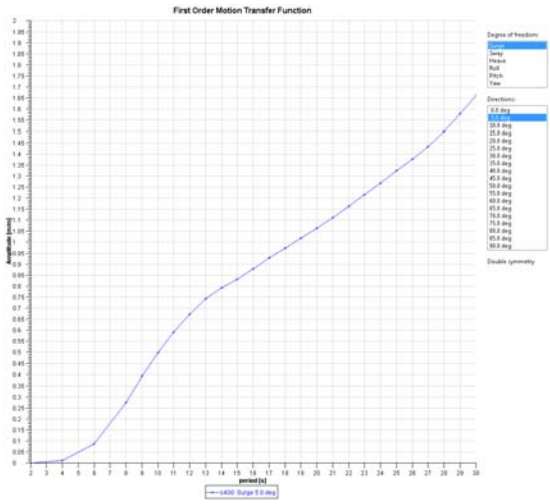
M.S.c. Thesis

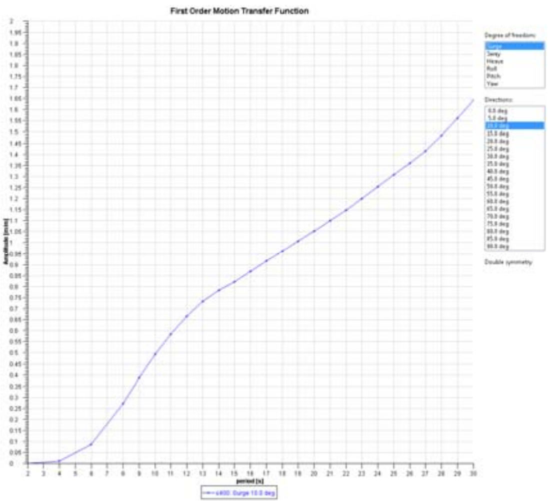
Coupled Dynamic Analysis of Cylindrical FPSO, Moorings and Riser

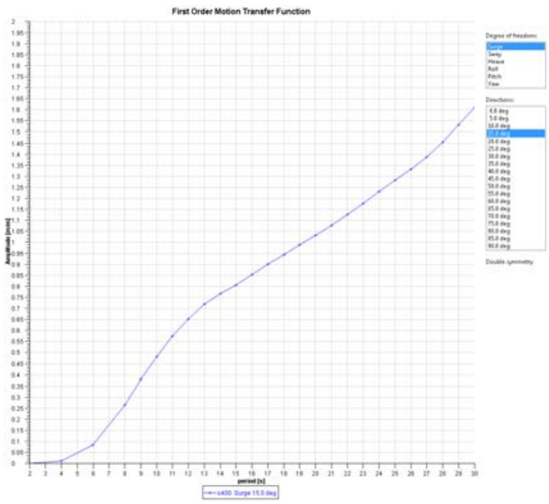
Based on Numerical Simulation

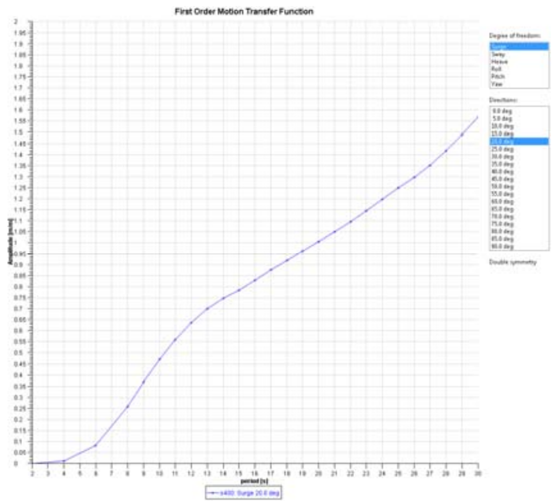
A. Response Amplitude Operator for Surge (0-90°)

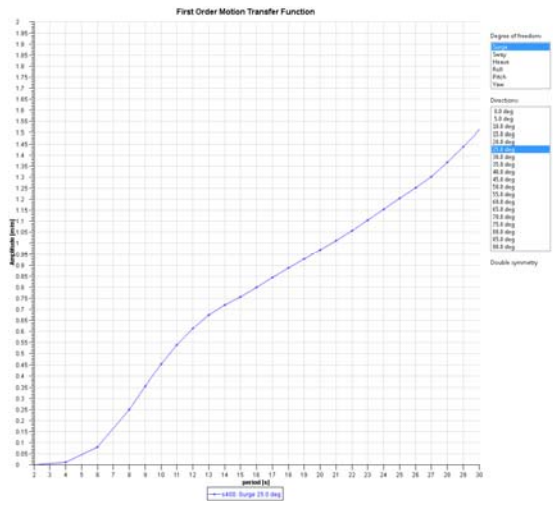


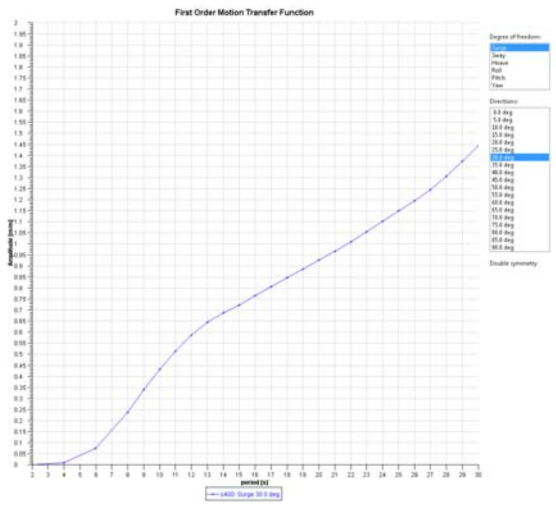


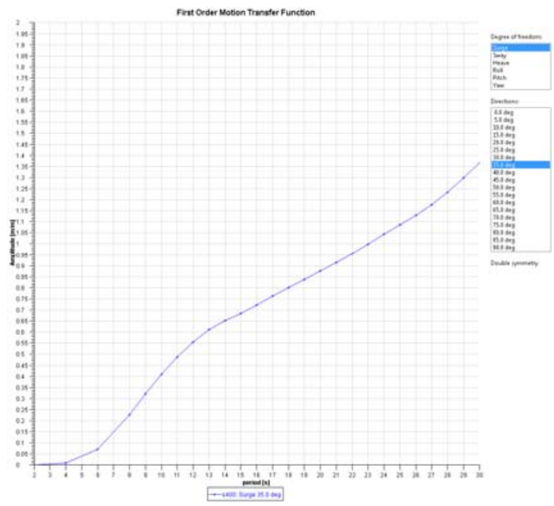


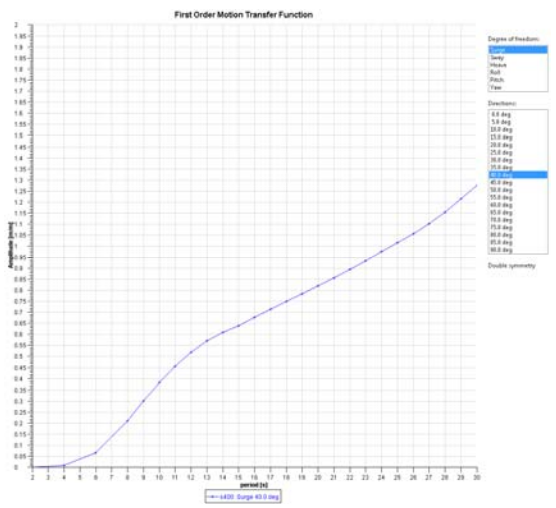


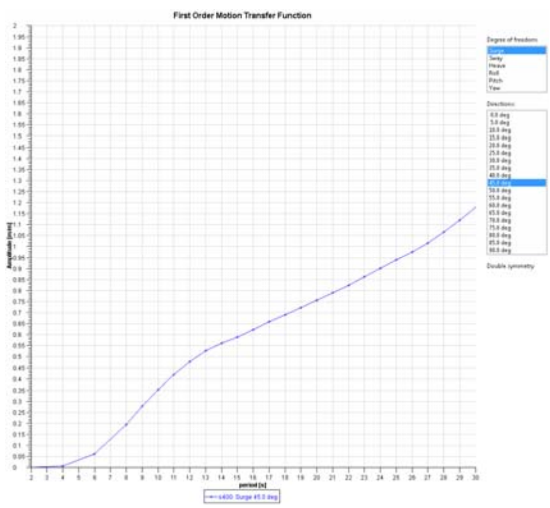

First Order Motion Transfer Function
Amplitude [m/m]
period [s]
s400: Surge 20.0 deg

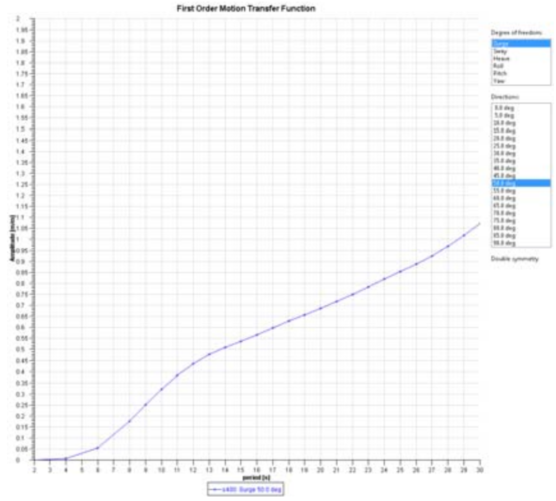

First Order Motion Transfer Function
Amplitude [m/m]
period [s]
s400: Surge 25.0 deg

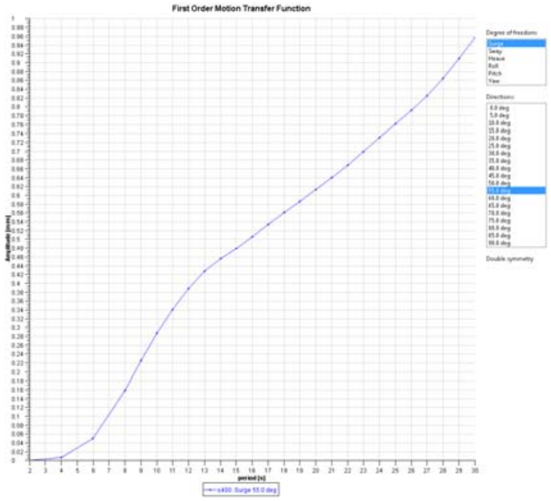

First Order Motion Transfer Function
Amplitude [m/m]
period [s]
s400: Surge 30.0 deg

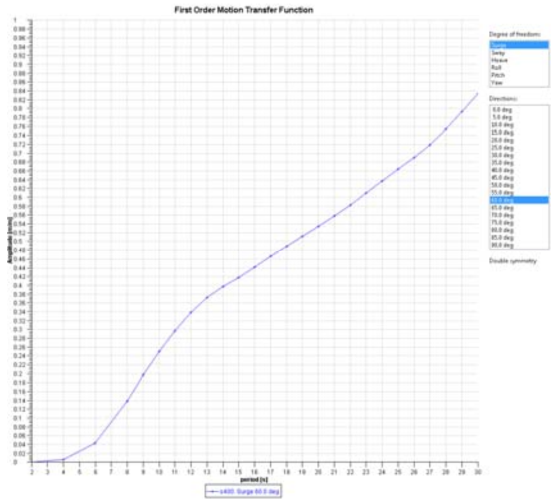

First Order Motion Transfer Function
Amplitude [m/m]
period [s]
s400: Surge 35.0 deg

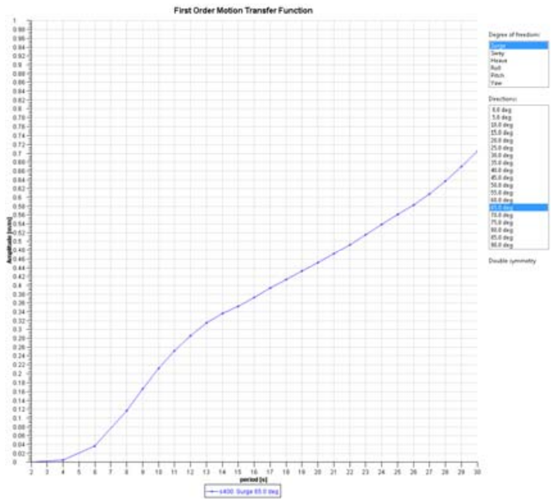

First Order Motion Transfer Function
Amplitude [m/m]
period [s]
s400: Surge 40.0 deg

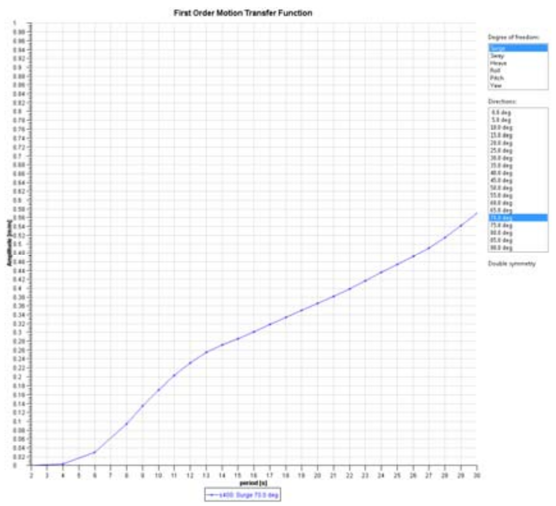

First Order Motion Transfer Function
Amplitude [m/m]
period [s]
s400: Surge 45.0 deg

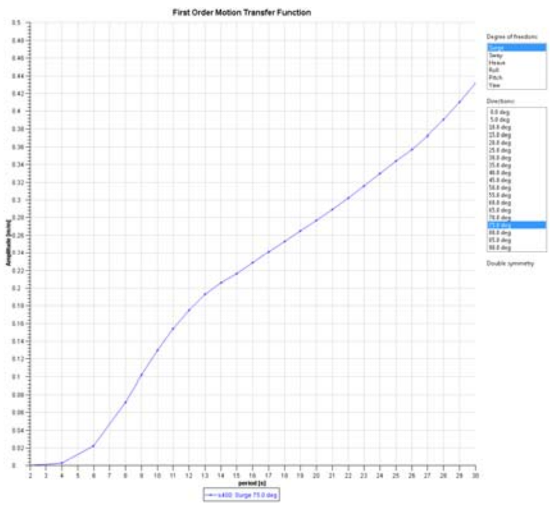

First Order Motion Transfer Function
period [s]
Surge 50.0 deg
Degree of freedom:
Directions:
Double symmetry

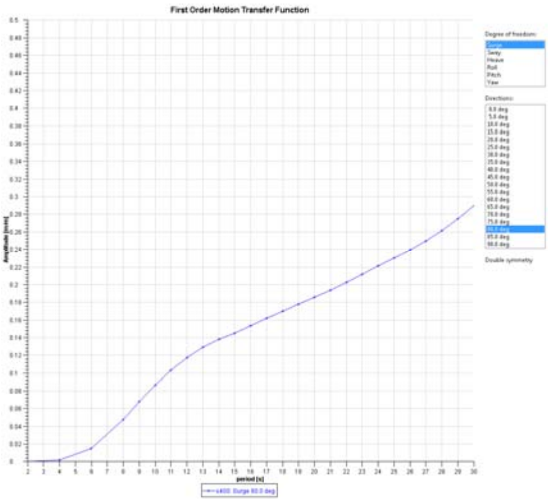

First Order Motion Transfer Function
period [s]
Surge 55.0 deg
Degree of freedom:
Directions:
Double symmetry

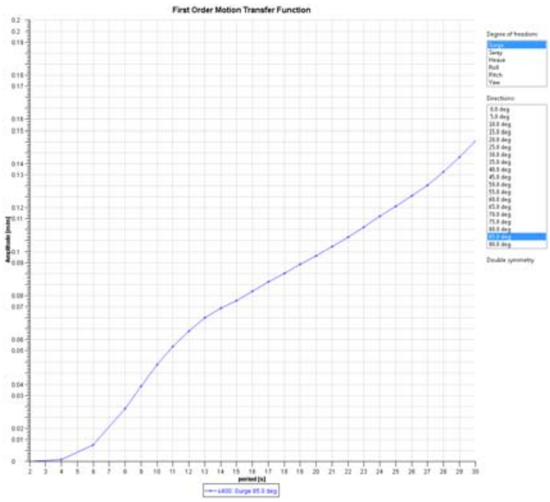

First Order Motion Transfer Function
period [s]
Surge 60.0 deg
Degree of freedom:
Directions:
Double symmetry

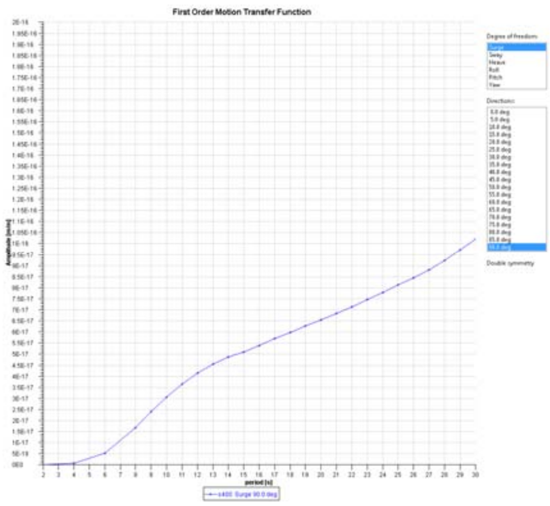

First Order Motion Transfer Function
period [s]
Surge 65.0 deg
Degree of freedom:
Directions:
Double symmetry


First Order Motion Transfer Function
period [s]
Surge 70.0 deg
Degree of freedom:
Directions:
Double symmetry

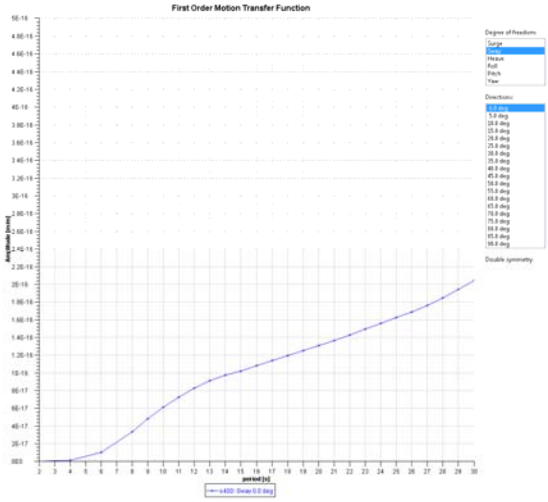

First Order Motion Transfer Function
period [s]
Surge 75.0 deg
Degree of freedom:
Directions:
Double symmetry

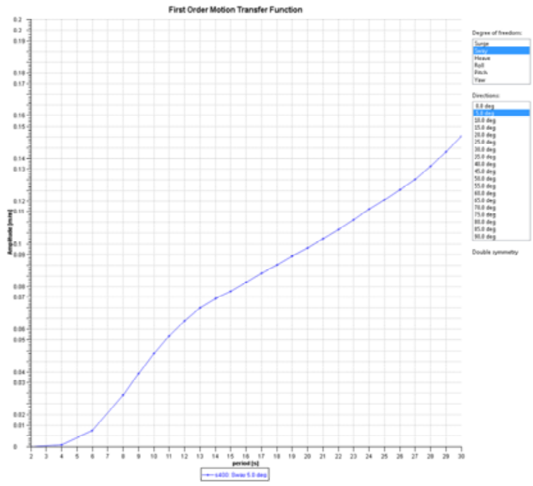

First Order Motion Transfer Function
Amplitude [m/m]
period [s]
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry
s400 Surge 80.0 deg

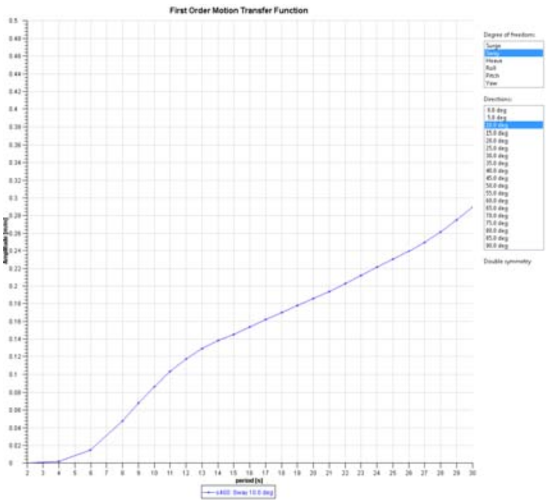

First Order Motion Transfer Function
Amplitude [m/m]
period [s]
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry
s400 Surge 85.0 deg

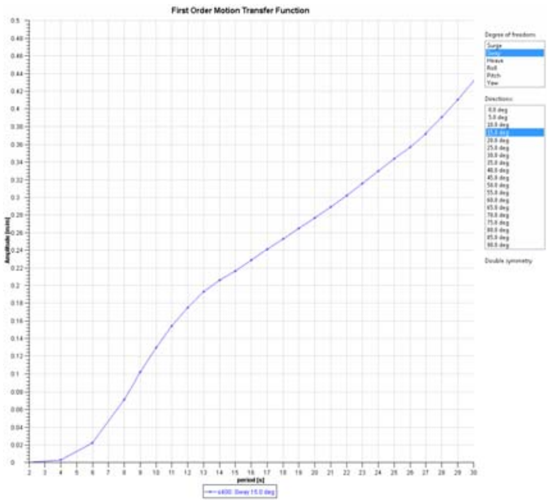

First Order Motion Transfer Function
Amplitude [m/m]
period [s]
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry
s400 Surge 90.0 deg

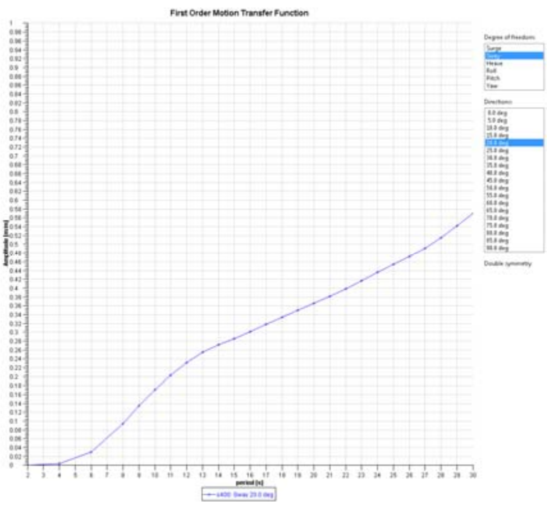
B. Response Amplitude Operator for Sway (0-90°)

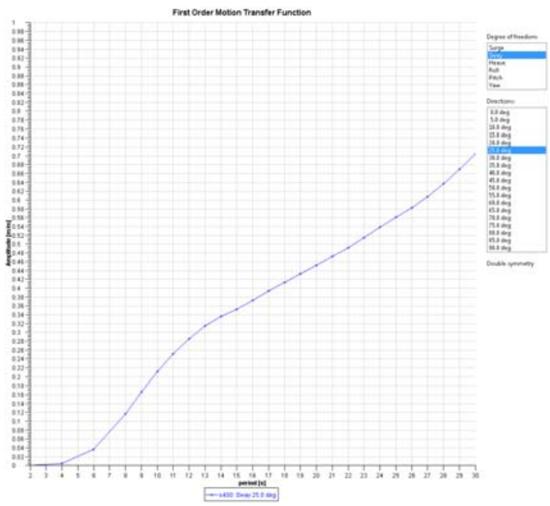


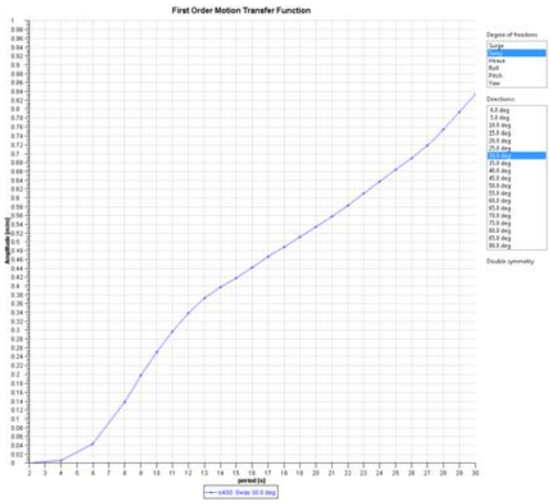


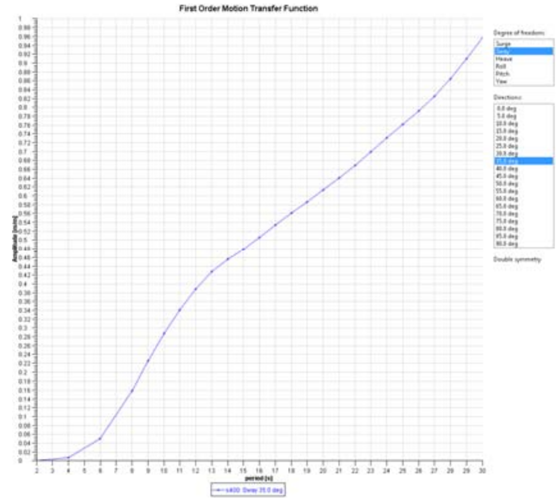


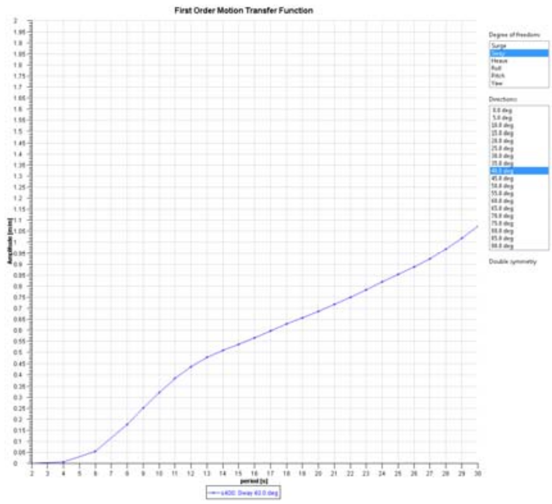


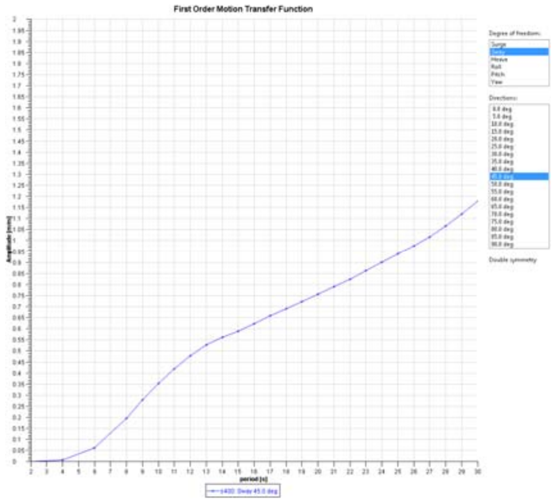


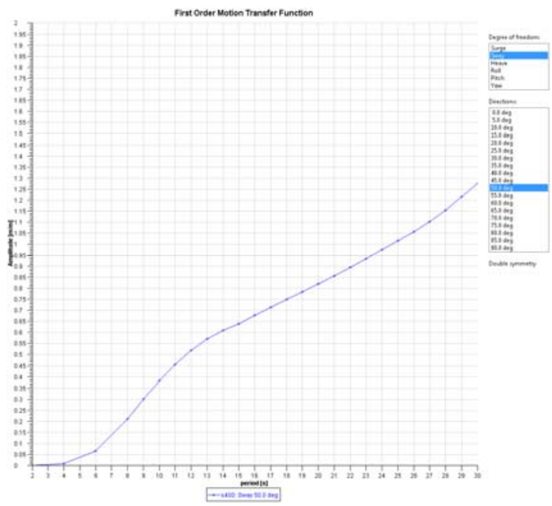


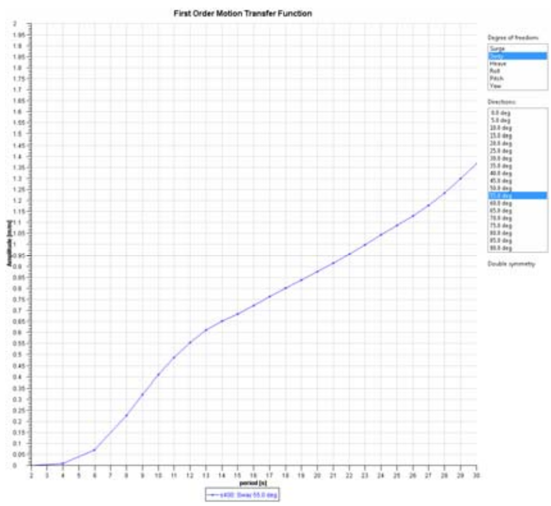

First Order Motion Transfer Function
Degree of freedom:
Directions:
Double symmetry
period [s]
s400: Sway 30.0 deg

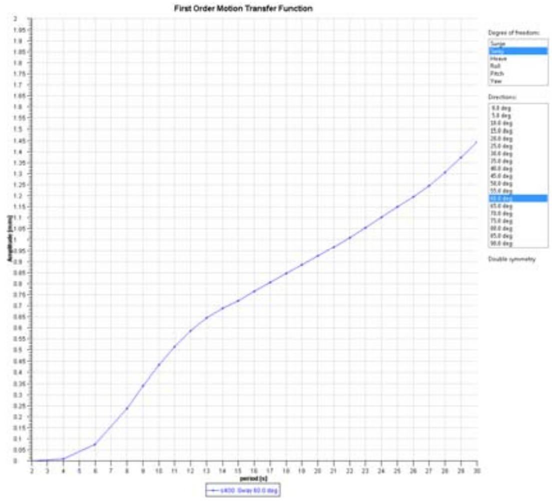

First Order Motion Transfer Function
Degree of freedom:
Directions:
Double symmetry
period [s]
s400: Sway 35.0 deg

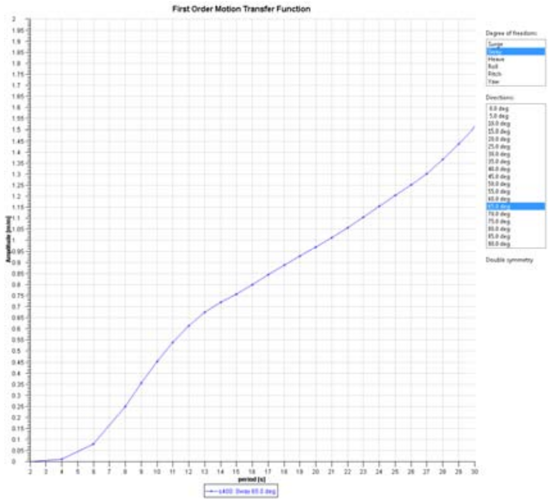

First Order Motion Transfer Function
Degree of freedom:
Directions:
Double symmetry
period [s]
s400: Sway 40.0 deg

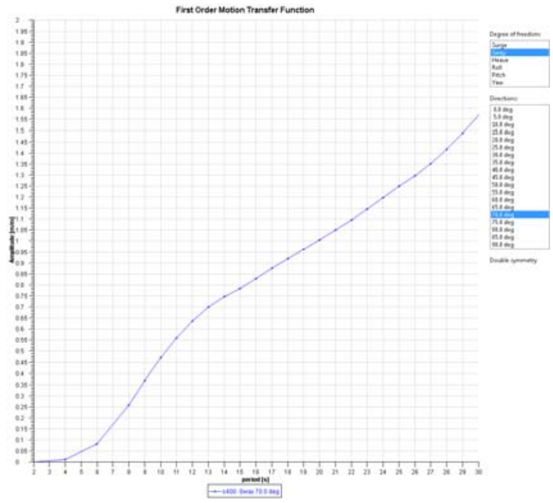

First Order Motion Transfer Function
Degree of freedom:
Directions:
Double symmetry
period [s]
s400: Sway 45.0 deg

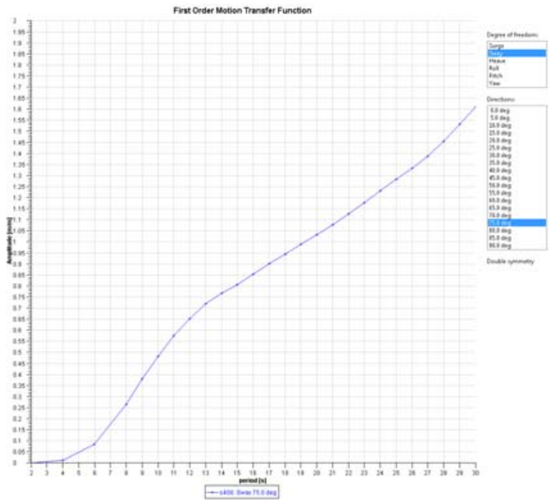

First Order Motion Transfer Function
Degree of freedom:
Directions:
Double symmetry
period [s]
s400: Sway 50.0 deg

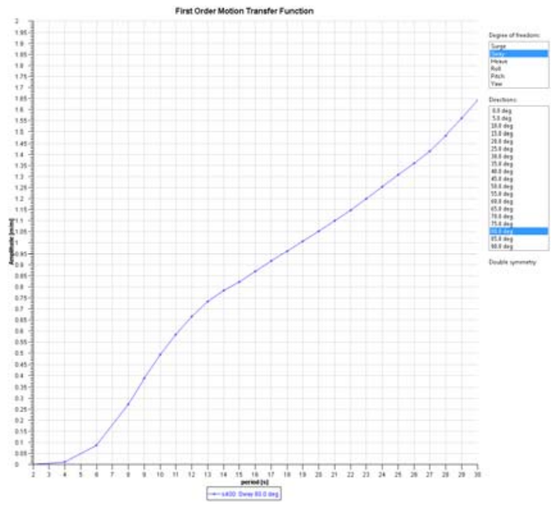

First Order Motion Transfer Function
Degree of freedom:
Directions:
Double symmetry
period [s]

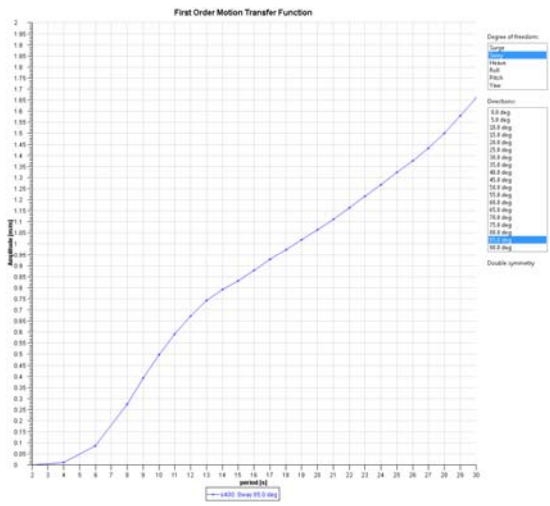

First Order Motion Transfer Function
Degree of freedom:
Surge
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry
period [s]

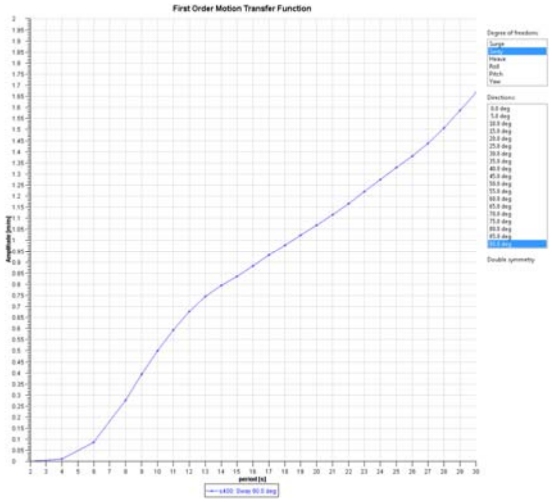

First Order Motion Transfer Function
Degree of freedom:
Directions:
Double symmetry
period [s]


First Order Motion Transfer Function
Degree of freedom:
Directions:
Double symmetry
period [s]

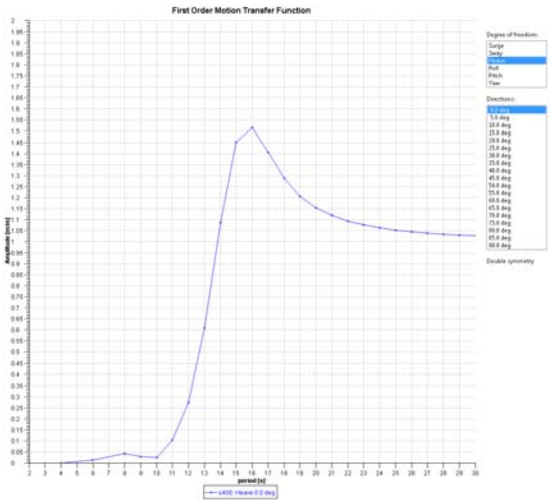

First Order Motion Transfer Function
Degree of freedom:
Directions:
Double symmetry
period [s]

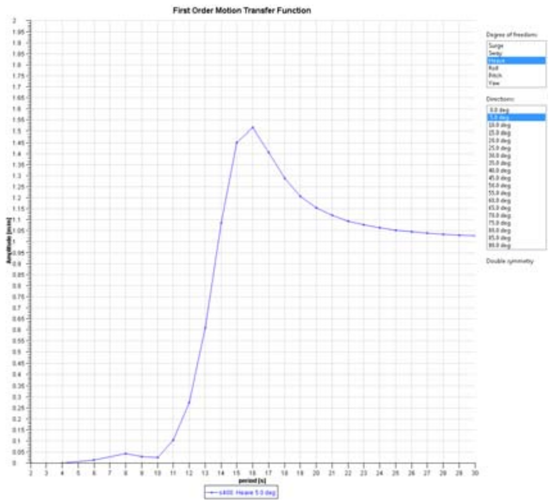

First Order Motion Transfer Function
Degree of freedom:
Directions:
Double symmetry
period [s]

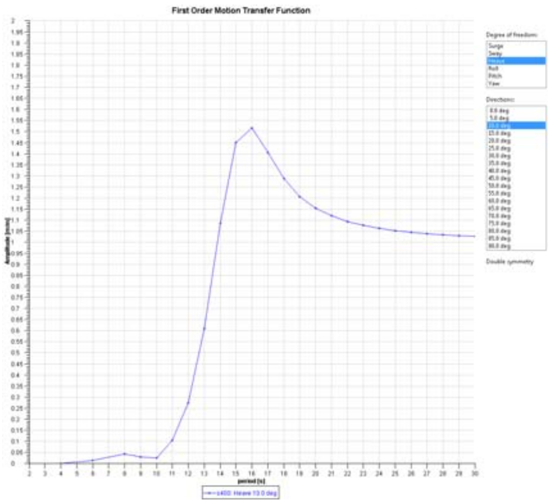

First Order Motion Transfer Function
Degree of freedom:
Directions:
Double symmetry
period [s]

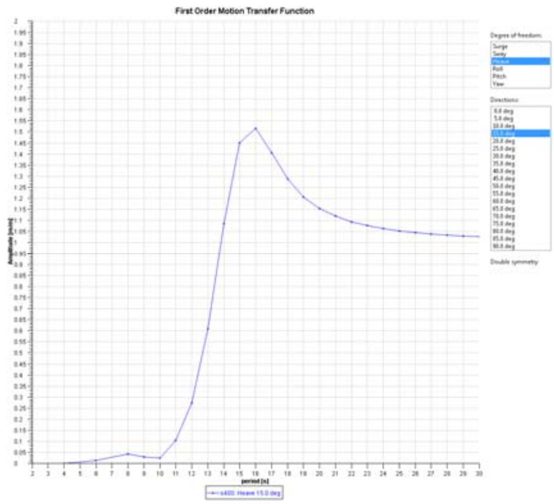

First Order Motion Transfer Function
Amplitude [m/m]
period [s]
Degree of freedom:
Surge
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry

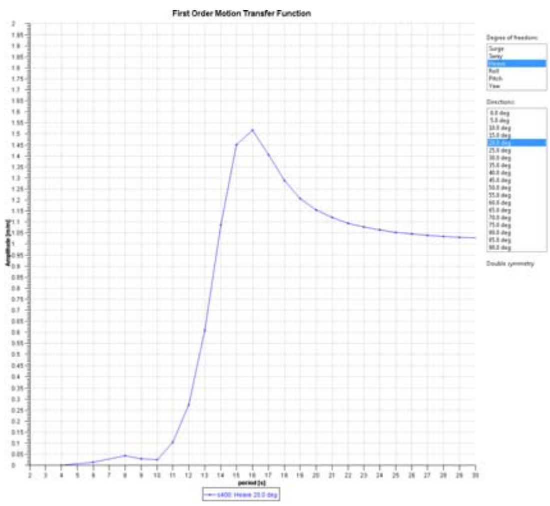
C. Response Amplitude Operator for Heave (0-90°)

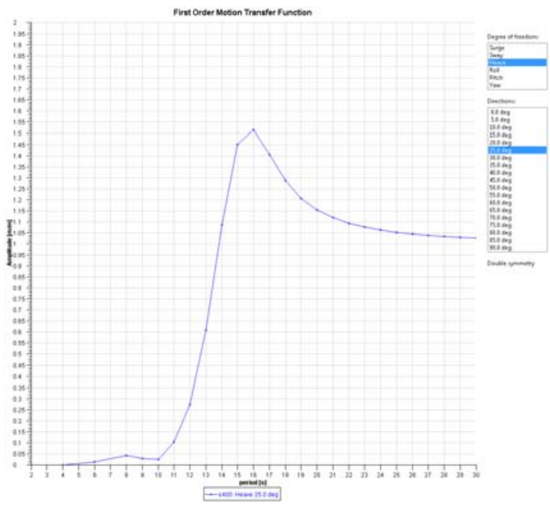


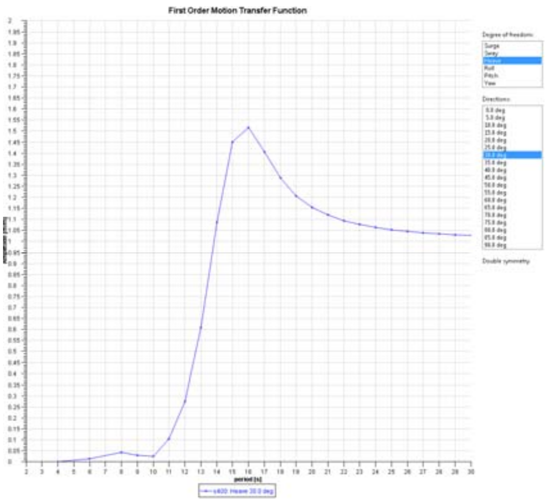


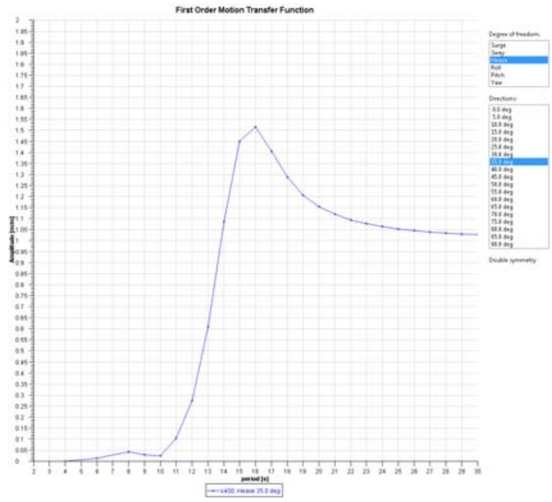


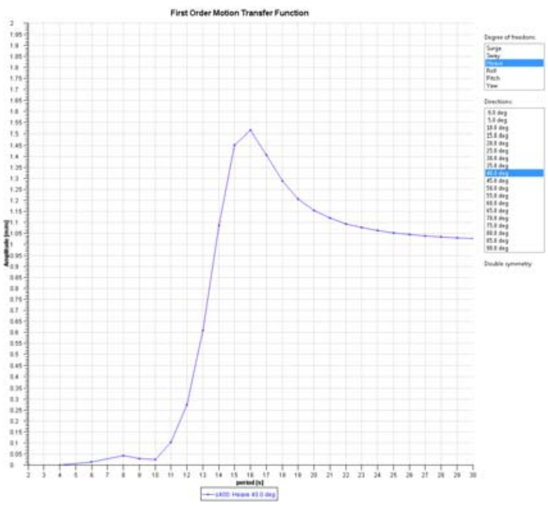


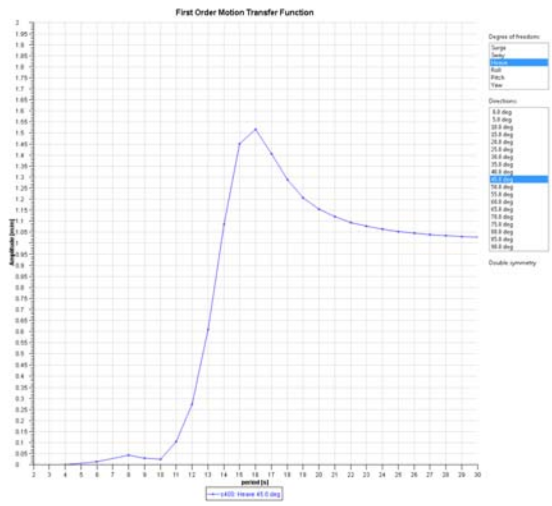


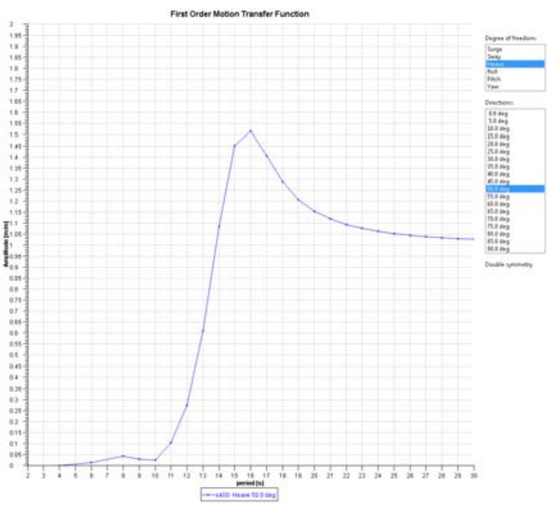


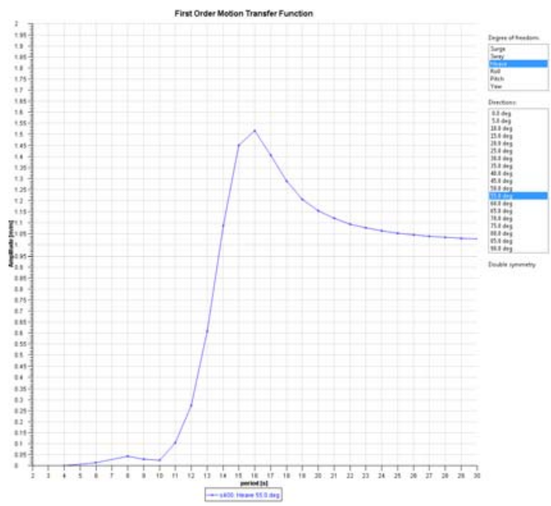

First Order Motion Transfer Function
period [s]

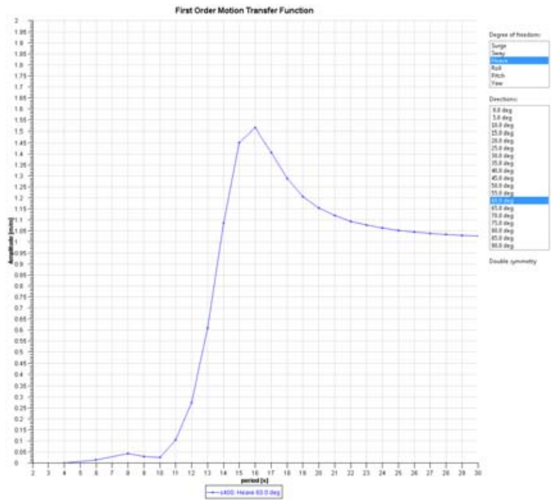

First Order Motion Transfer Function
period [s]

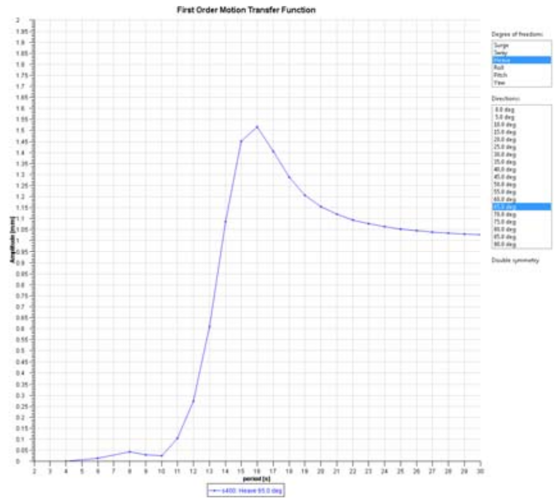

First Order Motion Transfer Function
period [s]

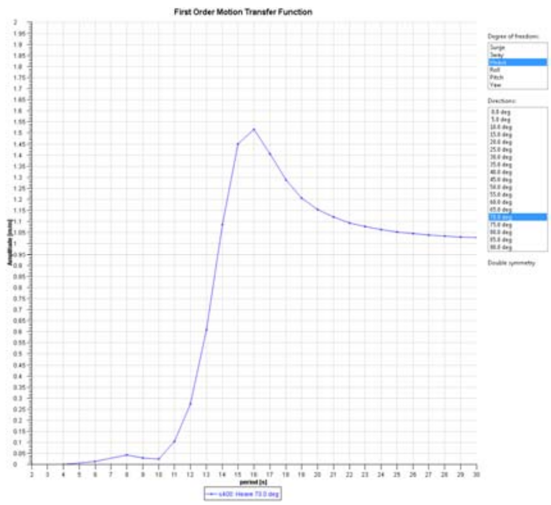

First Order Motion Transfer Function
period [s]

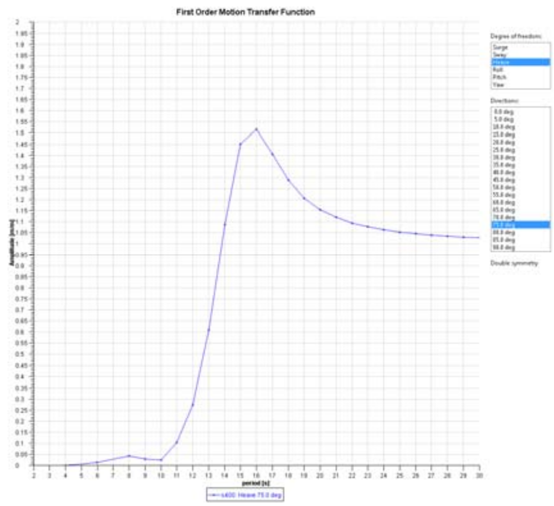

First Order Motion Transfer Function
period [s]

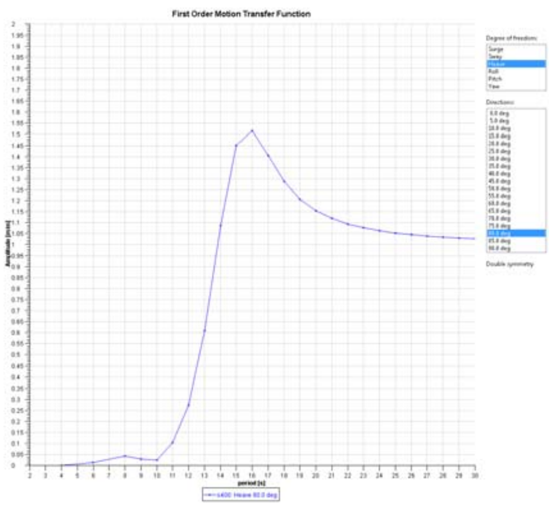

First Order Motion Transfer Function
period [s]

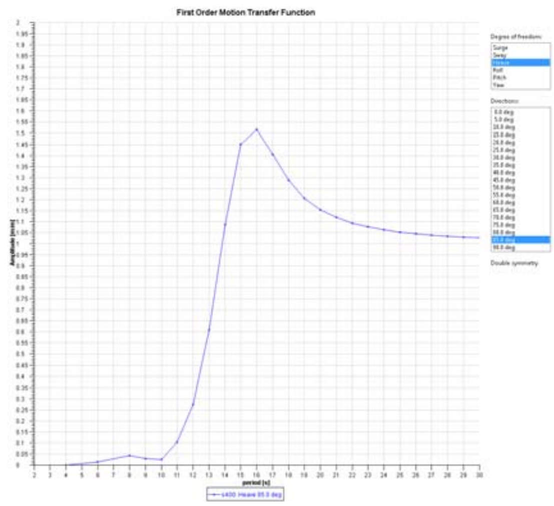

First Order Motion Transfer Function
period [s]
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry

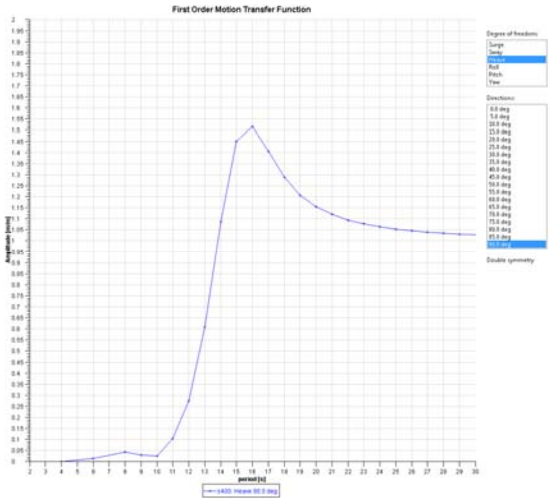

First Order Motion Transfer Function
period [s]
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry


First Order Motion Transfer Function
period [s]
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry

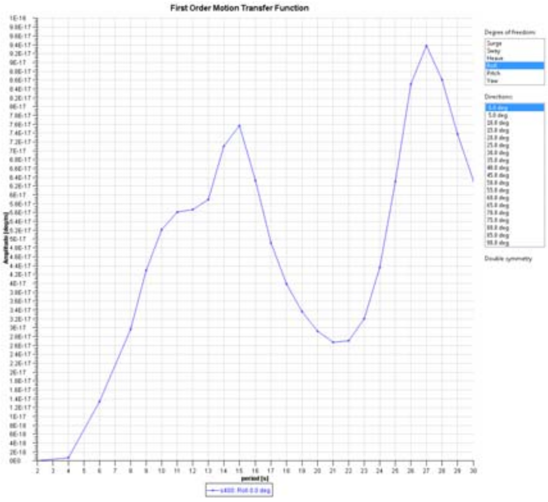

First Order Motion Transfer Function
period [s]
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry

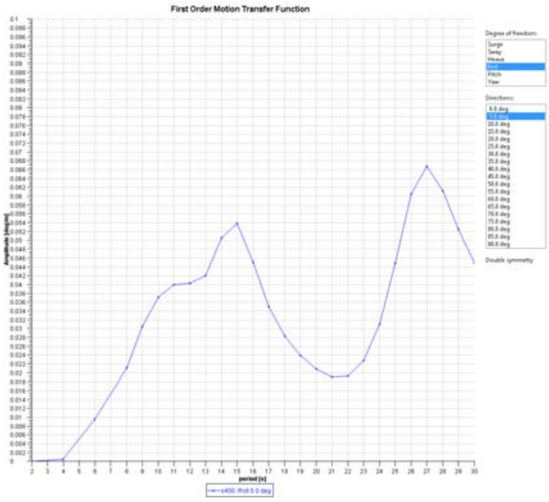

First Order Motion Transfer Function
period [s]
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry

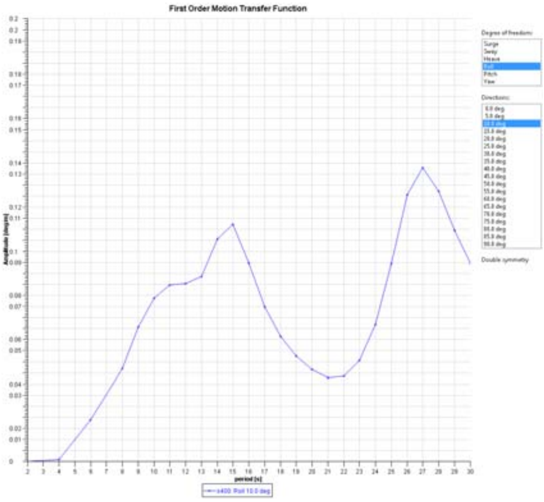

First Order Motion Transfer Function
period [s]
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry

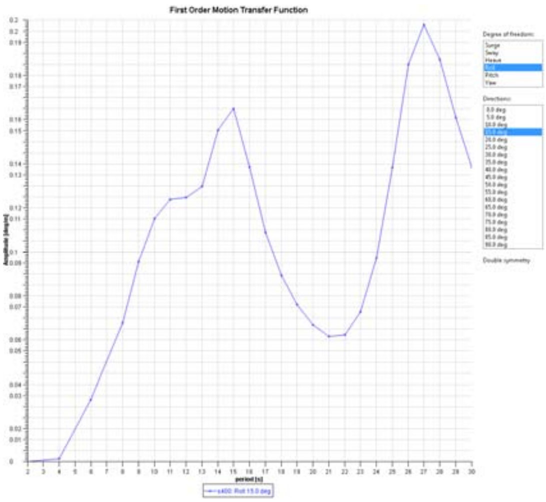

First Order Motion Transfer Function
Amplitude [m/m]
period [s]
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry

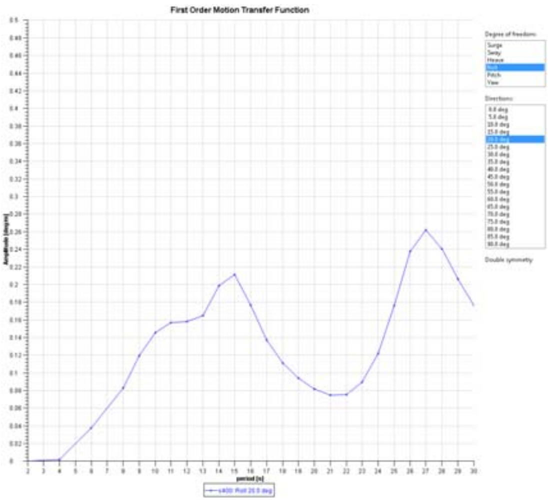
D. Response Amplitude Operator for Roll (0-90°)

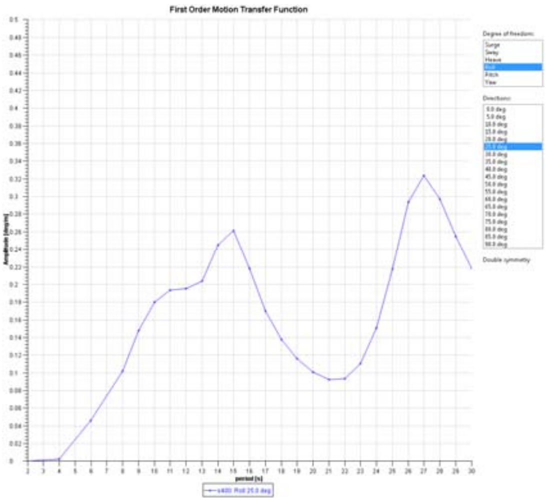


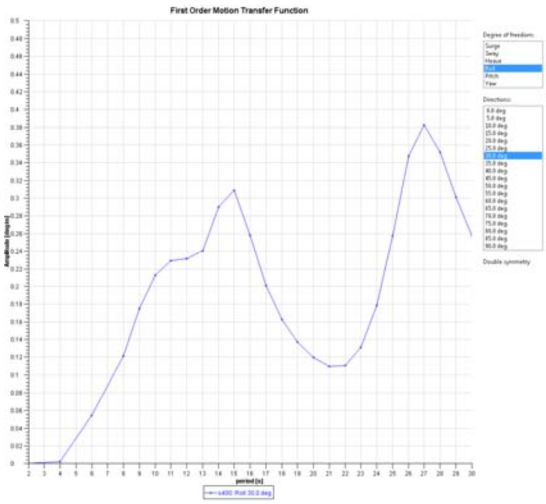


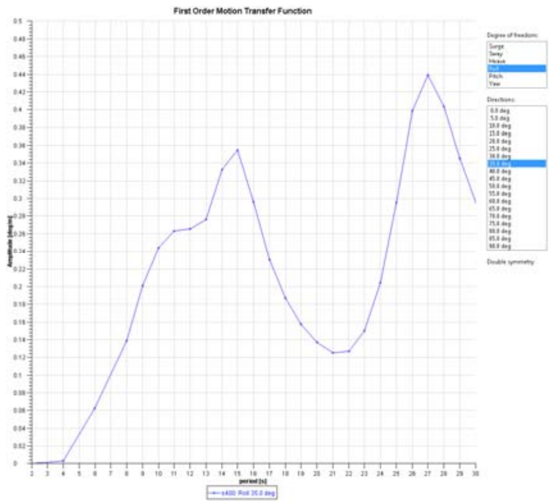


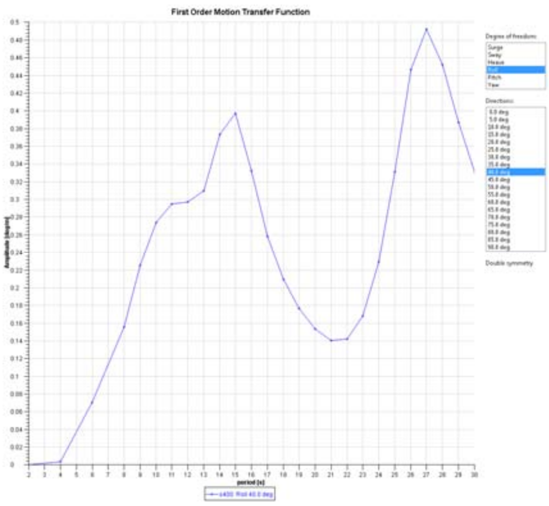


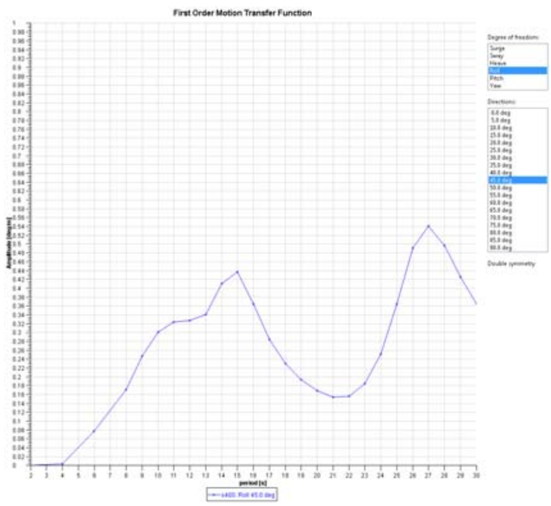


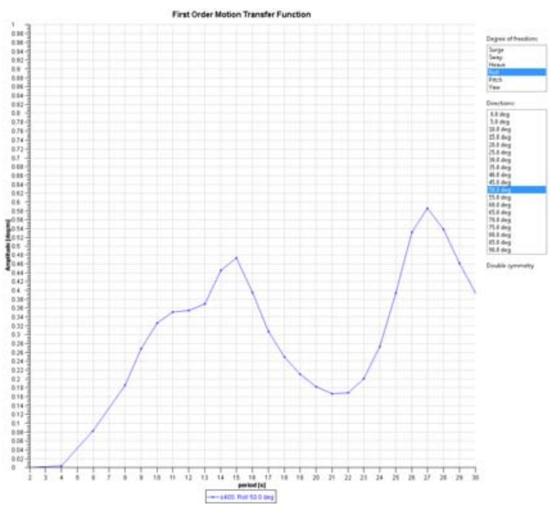


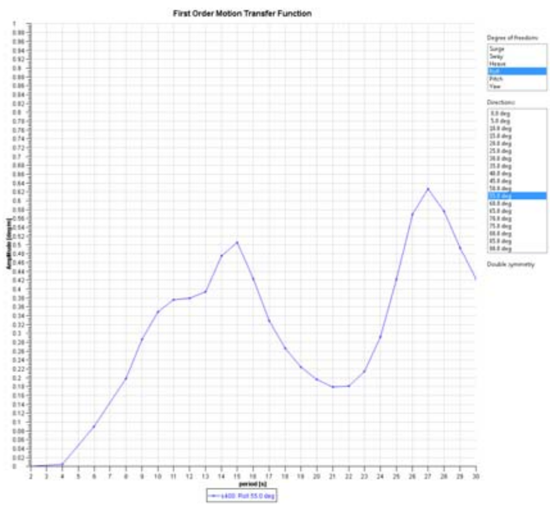

First Order Motion Transfer Function
Amplitude [deg/m]
period [s]
s400: Roll 30.0 deg

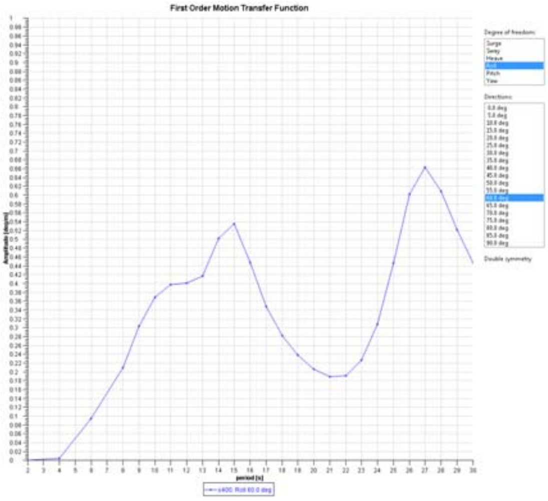

First Order Motion Transfer Function
Amplitude [deg/m]
period [s]
s400: Roll 35.0 deg

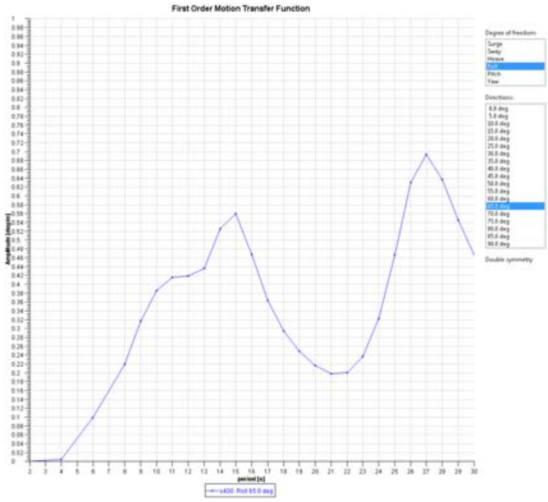

First Order Motion Transfer Function
Amplitude [deg/m]
period [s]
s400: Roll 40.0 deg

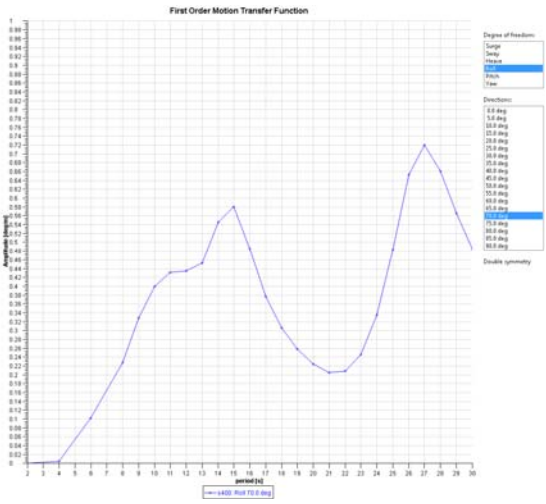

First Order Motion Transfer Function
Amplitude [deg/m]
period [s]
s400: Roll 45.0 deg

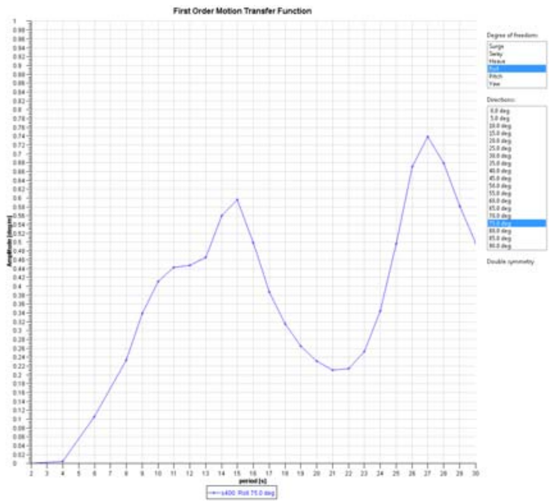

First Order Motion Transfer Function
Amplitude [deg/m]
period [s]
s400: Roll 50.0 deg

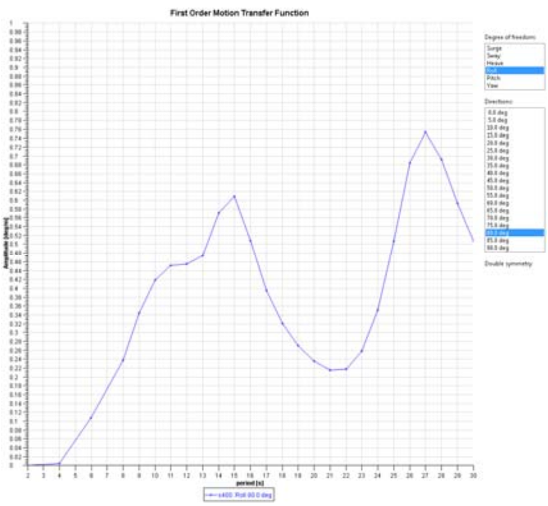

First Order Motion Transfer Function
Amplitude [deg/m]
period [s]
s400: Roll 55.0 deg

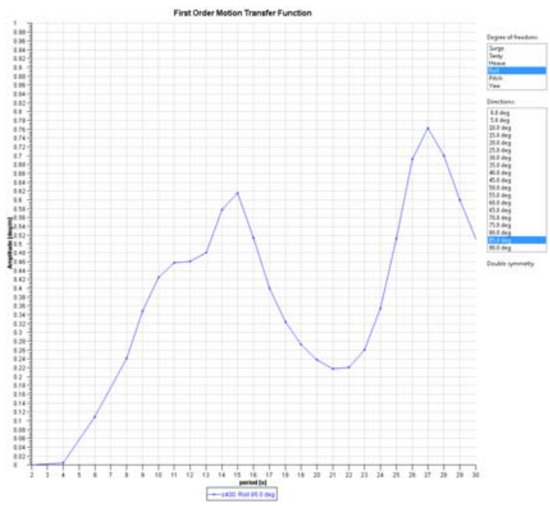

First Order Motion Transfer Function
Amplitude [deg/m]
period [s]
s400 Roll 60.0 deg
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry

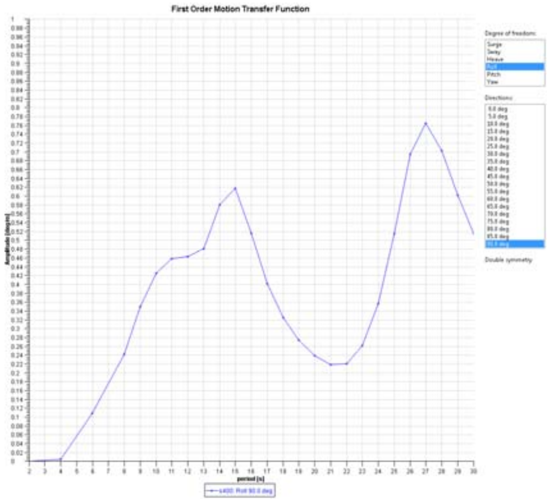

First Order Motion Transfer Function
Amplitude [deg/m]
period [s]
s400 Roll 65.0 deg
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry


First Order Motion Transfer Function
Amplitude [deg/m]
period [s]
s400 Roll 70.0 deg
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry

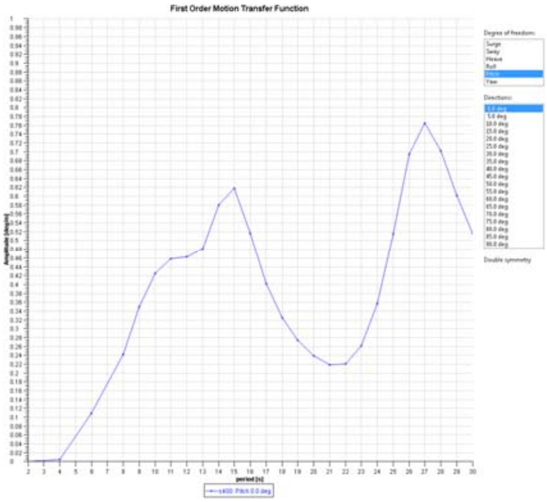

First Order Motion Transfer Function
Amplitude [deg/m]
period [s]
s400 Roll 75.0 deg
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry

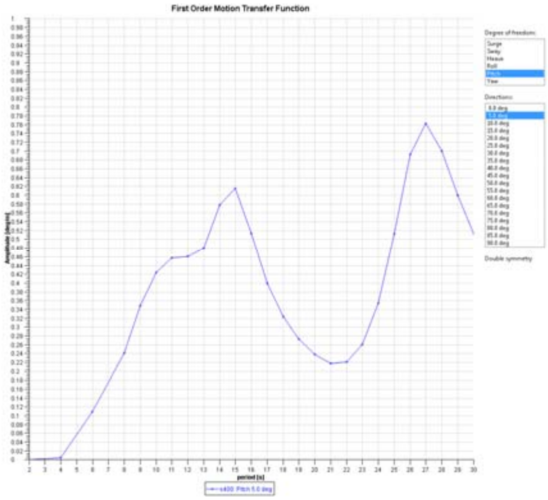

First Order Motion Transfer Function
Amplitude [deg/m]
period [s]
s400 Roll 80.0 deg
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry

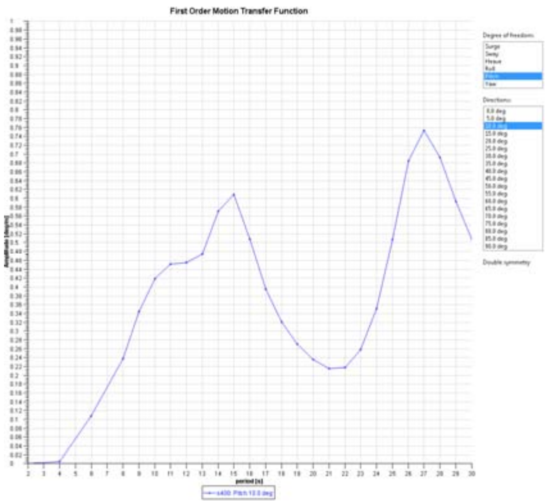

First Order Motion Transfer Function
Amplitude [deg/m]
period [s]
s400 Roll 85.0 deg
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry

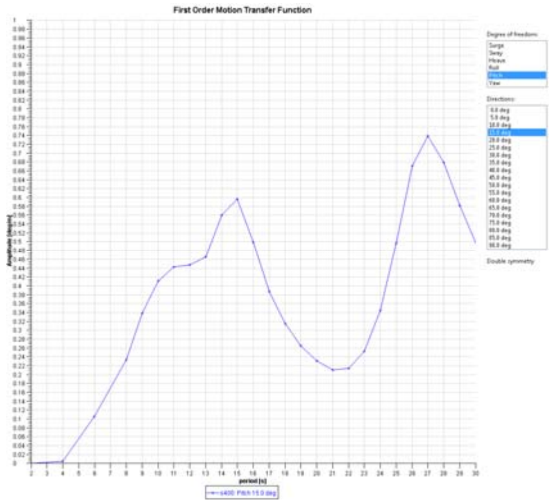

First Order Motion Transfer Function
Amplitude [deg/m]
period [s]
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
0.0 deg
5.0 deg
10.0 deg
15.0 deg
20.0 deg
25.0 deg
30.0 deg
35.0 deg
40.0 deg
45.0 deg
50.0 deg
55.0 deg
60.0 deg
65.0 deg
70.0 deg
75.0 deg
80.0 deg
85.0 deg
90.0 deg
Double symmetry
s400: Roll 90.0 deg

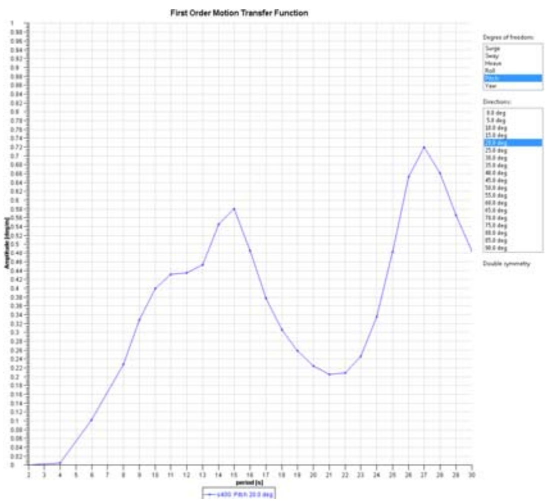
E. Response Amplitude Operator for Pitch (0-90°)

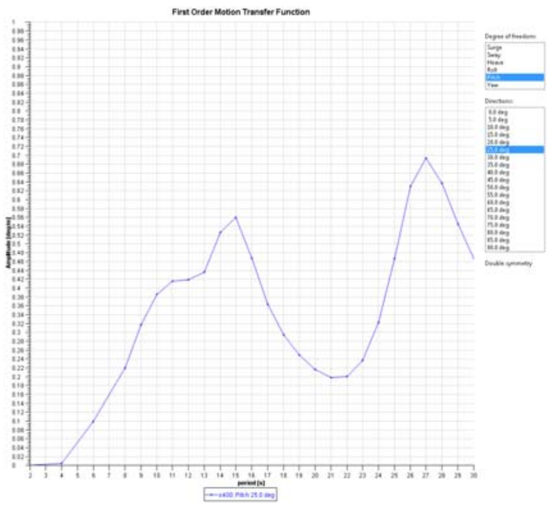


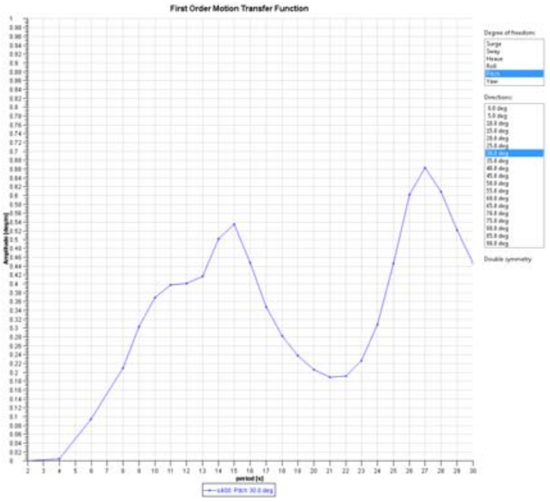


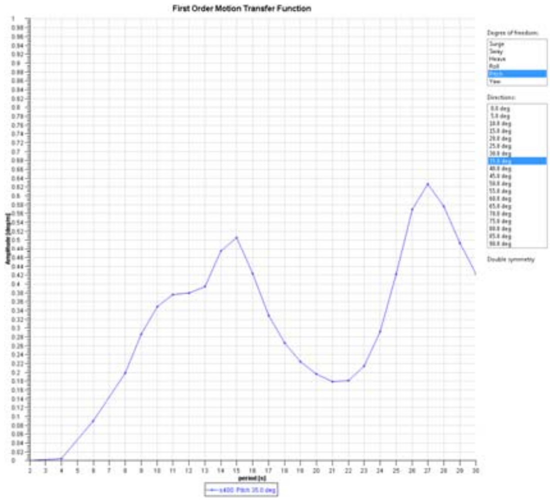


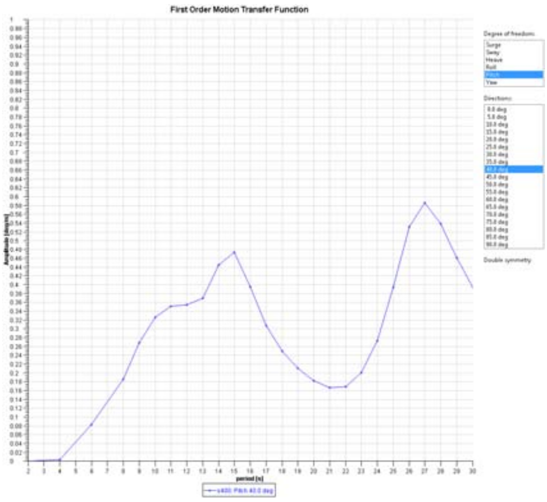


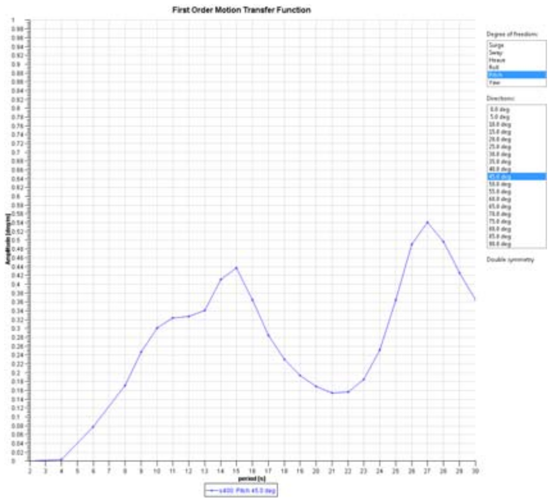


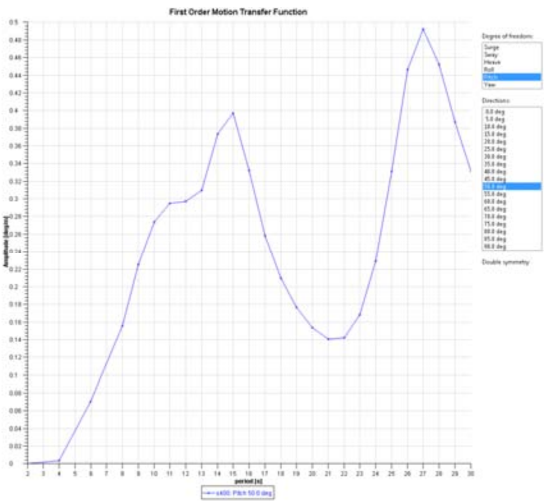


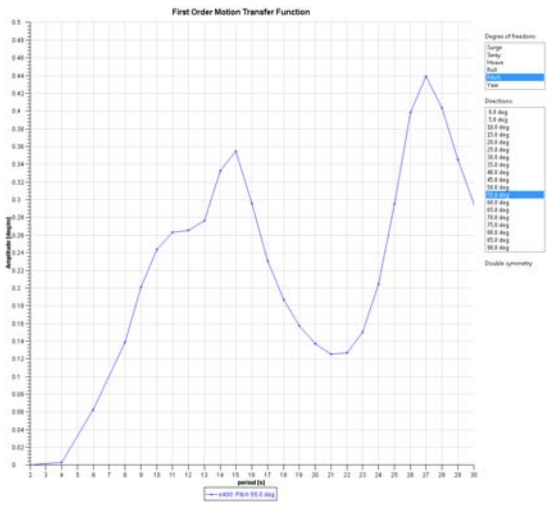

First Order Motion Transfer Function
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry
Amplitude [deg/m]
period [s]
s400: Pitch 30.0 deg

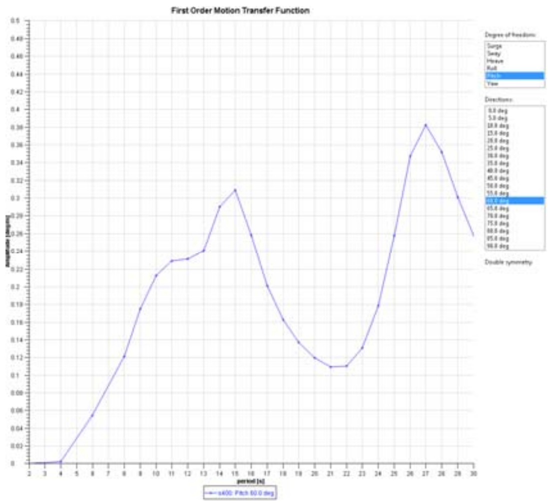

First Order Motion Transfer Function
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry
Amplitude [deg/m]
period [s]
s400: Pitch 35.0 deg

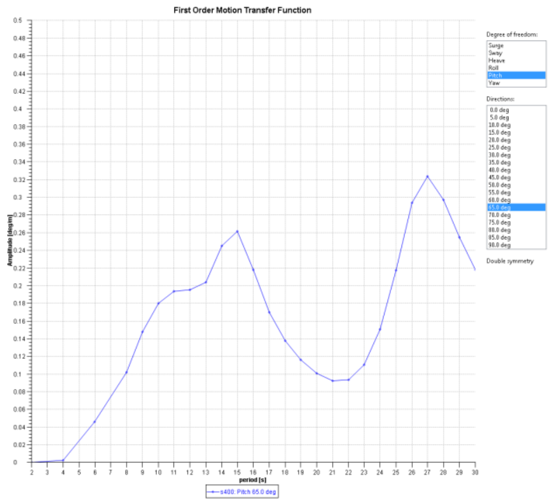

First Order Motion Transfer Function
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry
Amplitude [deg/m]
period [s]
s400: Pitch 40.0 deg

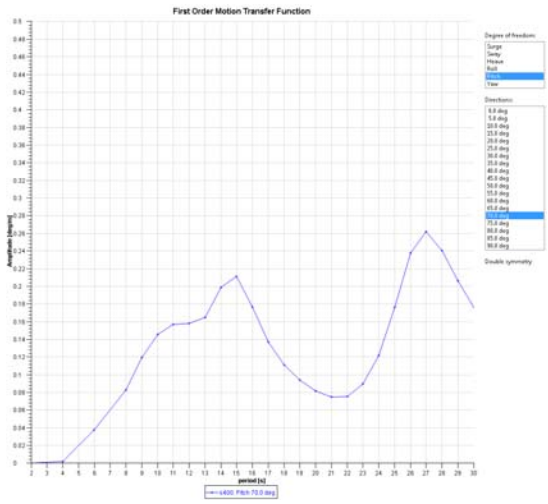

First Order Motion Transfer Function
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry
Amplitude [deg/m]
period [s]
s400: Pitch 45.0 deg

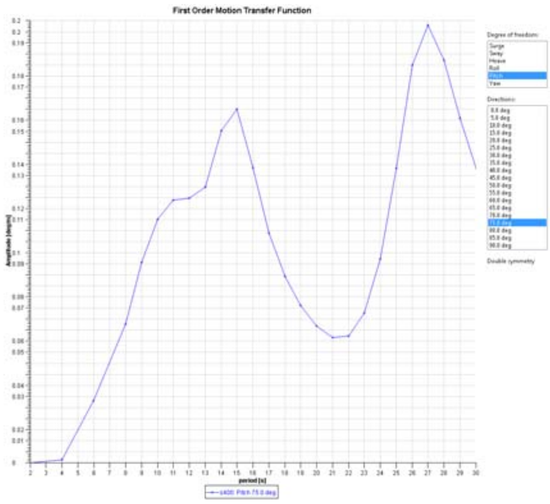

First Order Motion Transfer Function
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry
Amplitude [deg/m]
period [s]
s400: Pitch 50.0 deg

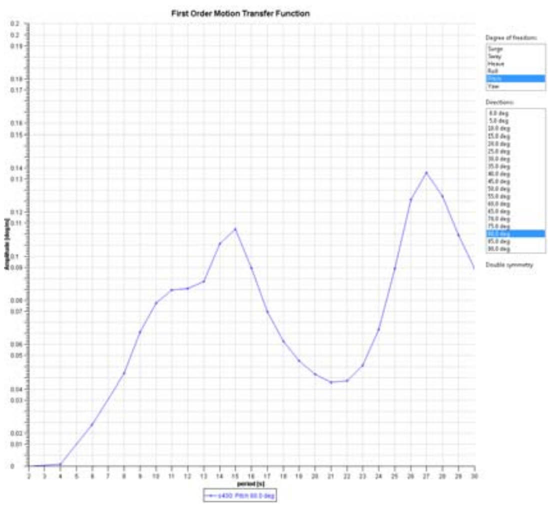

First Order Motion Transfer Function
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry
Amplitude [deg/m]
period [s]
s400: Pitch 55.0 deg

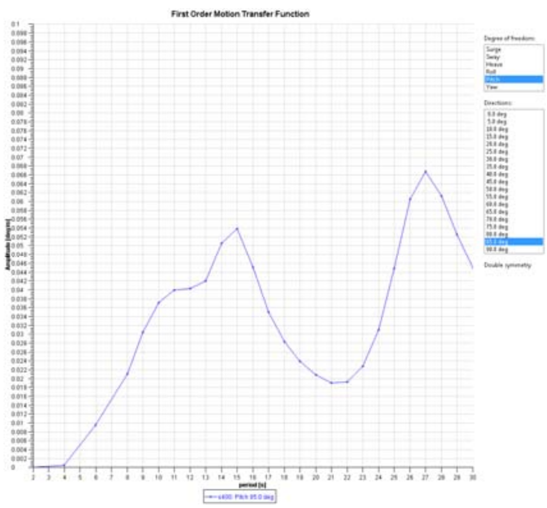

First Order Motion Transfer Function
Amplitude [deg/m]
period [s]
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry
s400: Pitch 60.0 deg

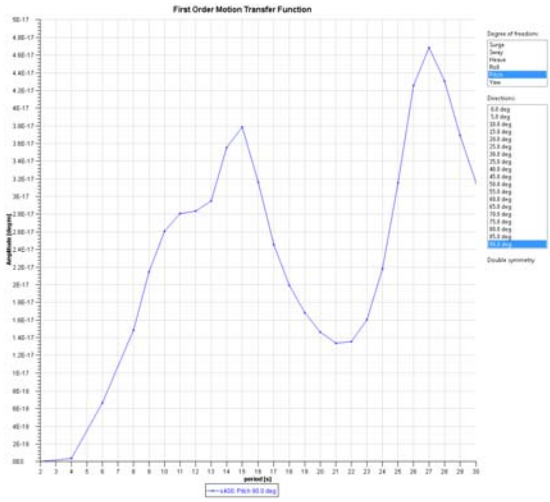

First Order Motion Transfer Function
Amplitude [deg/m]
period [s]
Degree of freedom:
Directions:
Double symmetry
s400: Pitch 65.0 deg


First Order Motion Transfer Function
Amplitude [deg/m]
period [s]
Degree of freedom:
Directions:
Double symmetry
s400: Pitch 70.0 deg

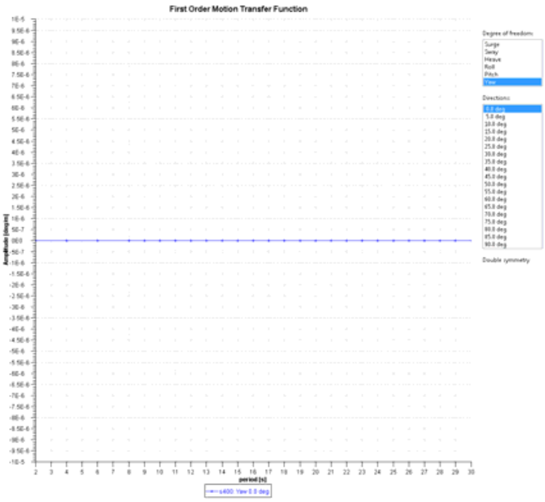

First Order Motion Transfer Function
Amplitude [deg/m]
period [s]
Degree of freedom:
Directions:
Double symmetry
s400: Pitch 75.0 deg

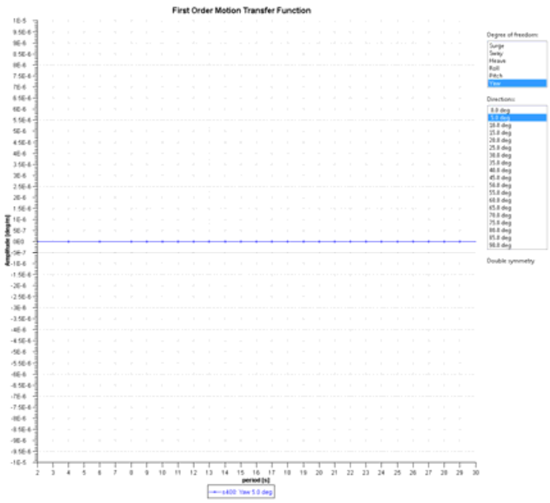

First Order Motion Transfer Function
Amplitude [deg/m]
period [s]
Degree of freedom:
Directions:
Double symmetry
s400: Pitch 80.0 deg

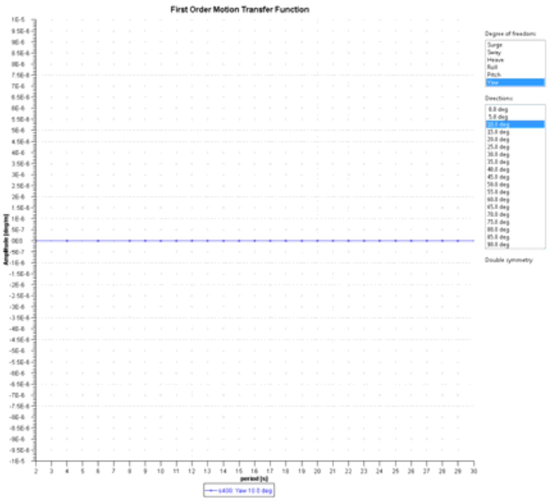

First Order Motion Transfer Function
Amplitude [deg/m]
period [s]
Degree of freedom:
Directions:
Double symmetry
s400: Pitch 85.0 deg

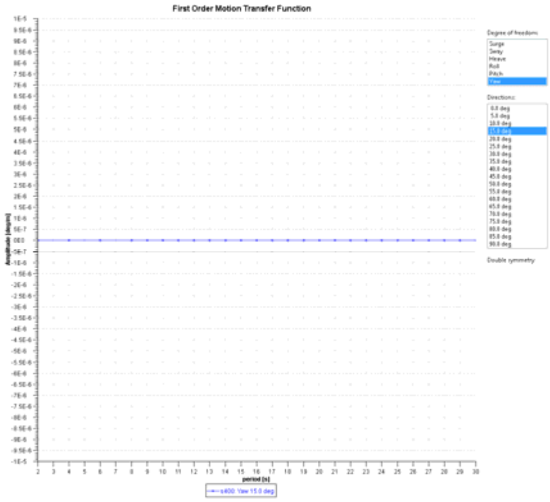

First Order Motion Transfer Function
Amplitude [deg/m]
period [s]
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry

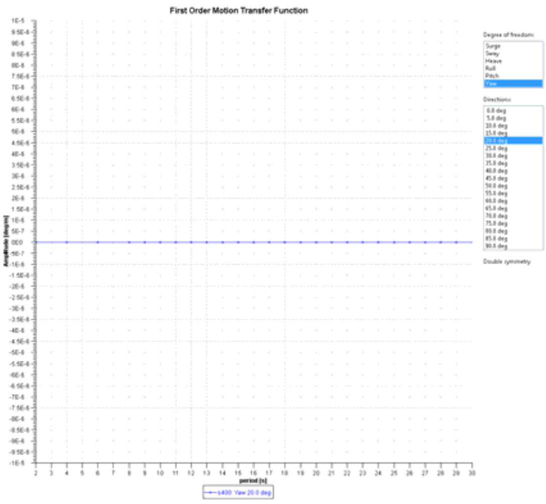
F. Response Amplitude Operator for Yaw (0-90°)

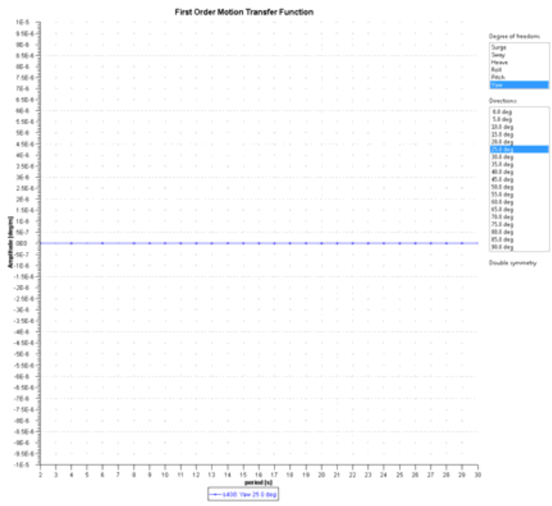


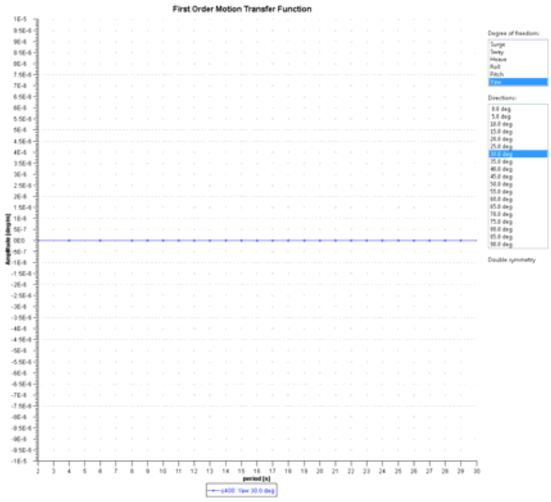


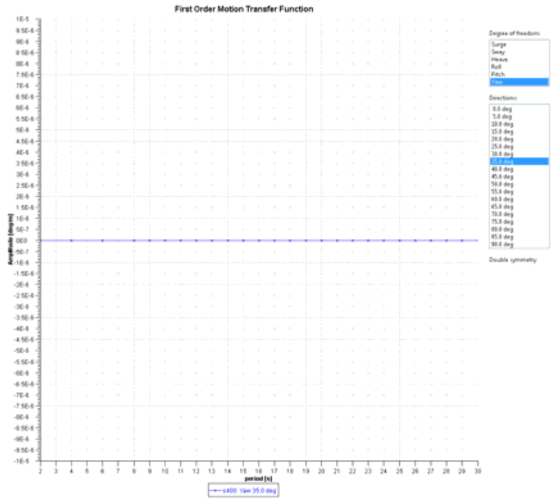


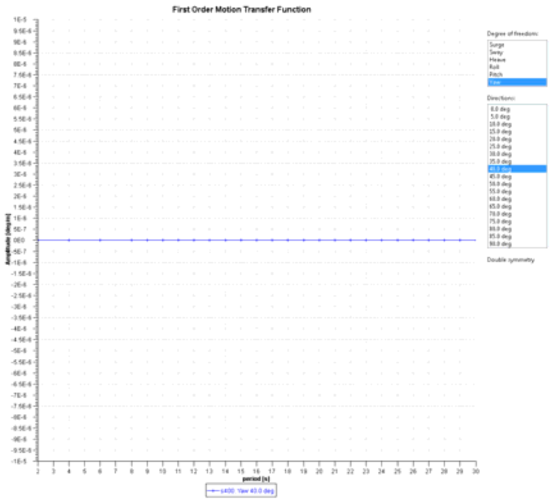


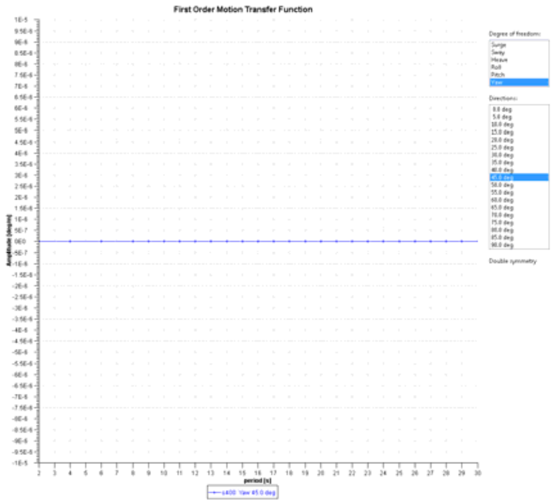


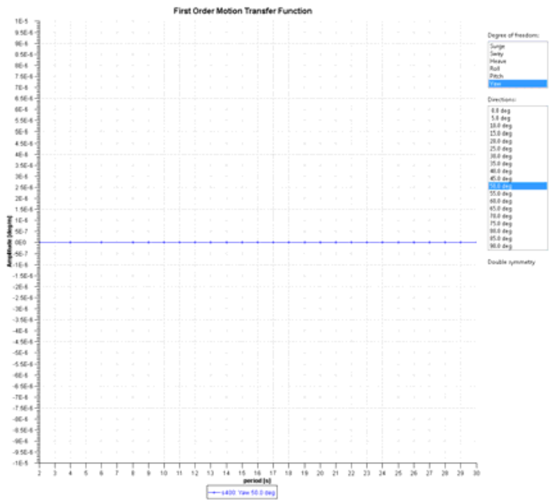


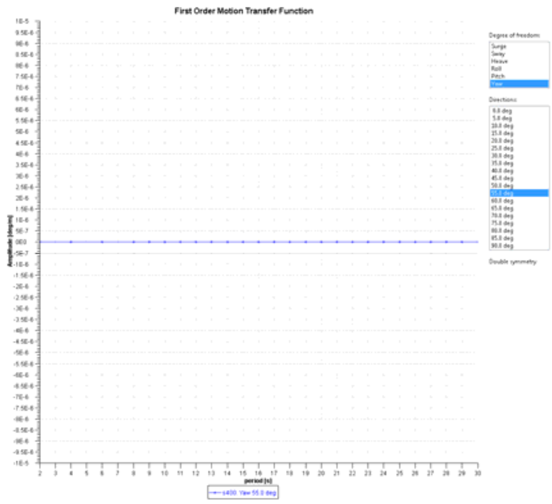

First Order Motion Transfer Function
Amplitude [deg/m]
period [s]
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry
s400: Yaw 30.0 deg

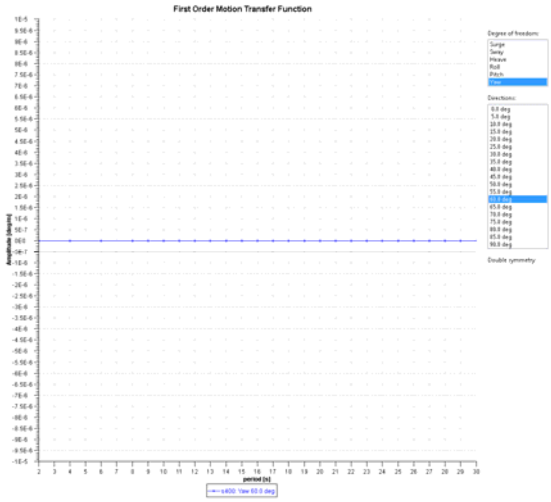

First Order Motion Transfer Function
Amplitude [deg/m]
period [s]
Degree of freedom:
Directions:
Double symmetry
s400: Yaw 35.0 deg

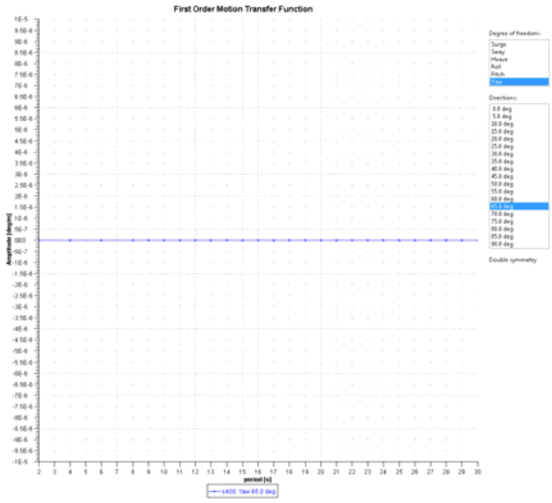

First Order Motion Transfer Function
Amplitude [deg/m]
period [s]
Degree of freedom:
Directions:
Double symmetry
s400: Yaw 40.0 deg

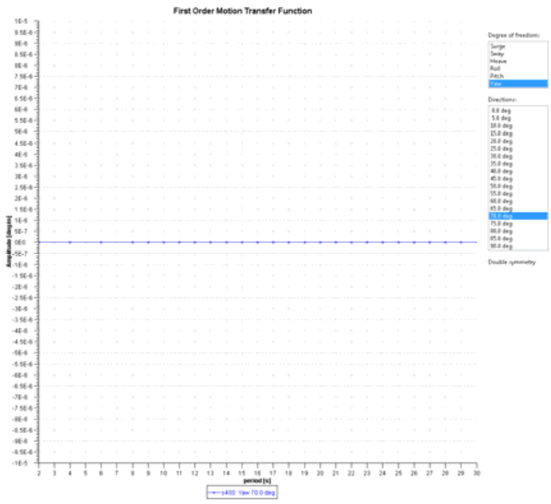

First Order Motion Transfer Function
Amplitude [deg/m]
period [s]
Degree of freedom:
Directions:
Double symmetry
s400: Yaw 45.0 deg

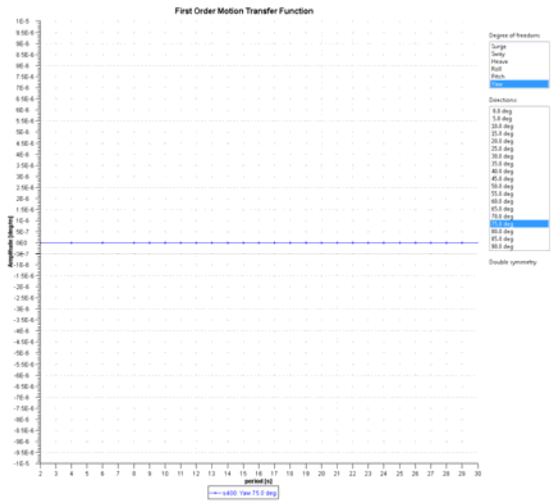

First Order Motion Transfer Function
Amplitude [deg/m]
period [s]
Degree of freedom:
Directions:
Double symmetry
s400: Yaw 50.0 deg

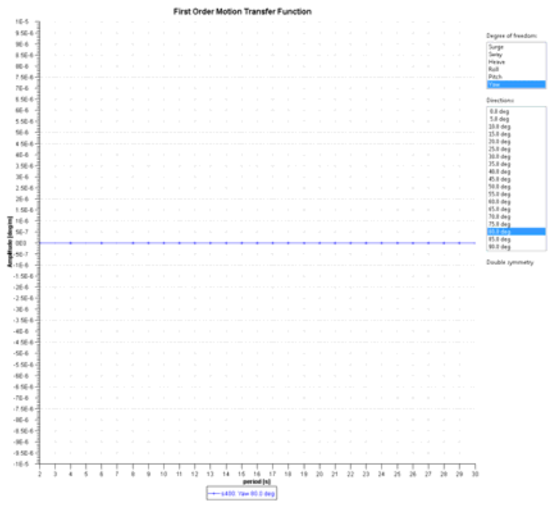

First Order Motion Transfer Function
Amplitude [deg/m]
period [s]
Degree of freedom:
Directions:
Double symmetry
s400: Yaw 55.0 deg

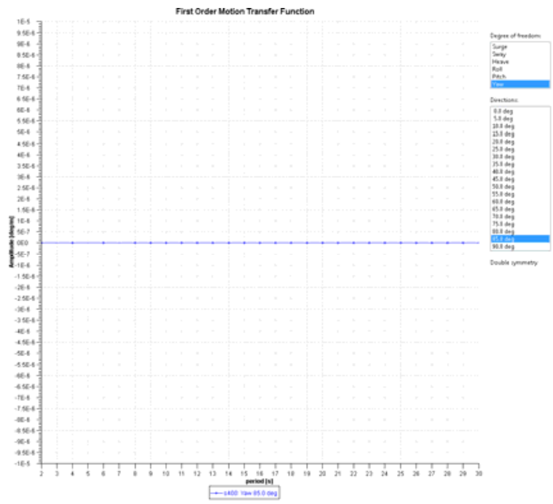

First Order Motion Transfer Function
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry
Amplitude [deg/m]
period [s]
s400: Yaw 60.0 deg

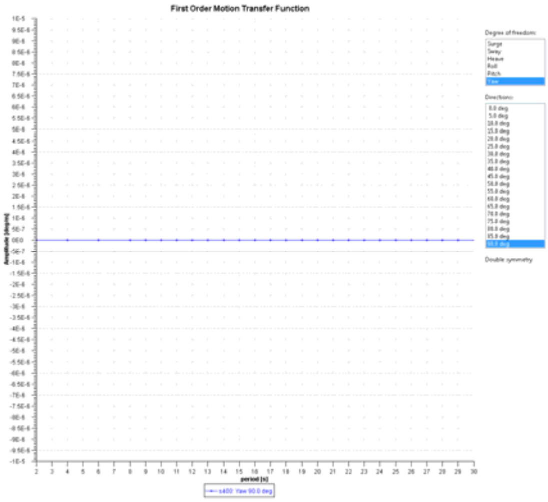

First Order Motion Transfer Function
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry
Amplitude [deg/m]
period [s]
s400: Yaw 65.0 deg


First Order Motion Transfer Function
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry
Amplitude [deg/m]
period [s]
s400: Yaw 70.0 deg


First Order Motion Transfer Function
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry
Amplitude [deg/m]
period [s]
s400: Yaw 75.0 deg


First Order Motion Transfer Function
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry
Amplitude [deg/m]
period [s]
s400: Yaw 80.0 deg


First Order Motion Transfer Function
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry
Amplitude [deg/m]
period [s]
s400: Yaw 85.0 deg


First Order Motion Transfer Function
Amplitude [deg/m]
period [s]
s400: Yaw 90.0 deg
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry

APPENDIX

B

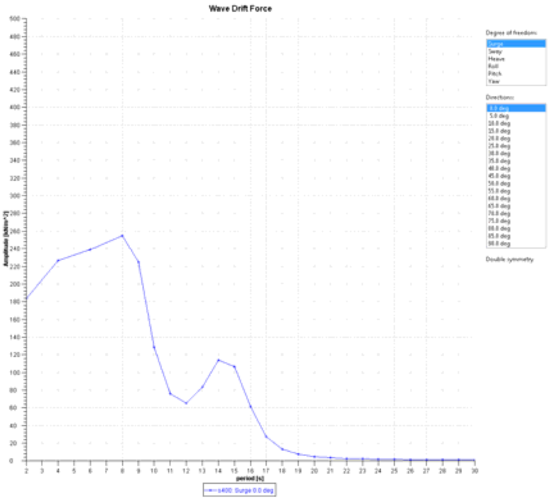
Wave Drift Force

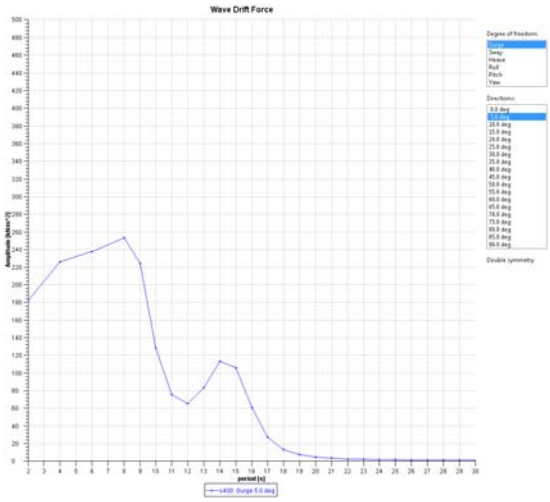
M.S.c. Thesis

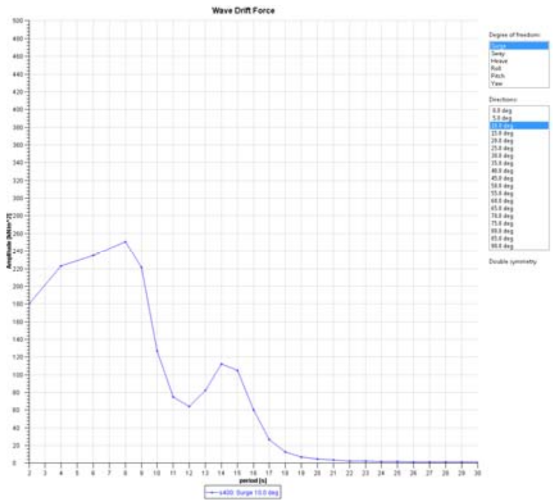
Coupled Dynamic Analysis of Cylindrical FPSO, Moorings and Riser

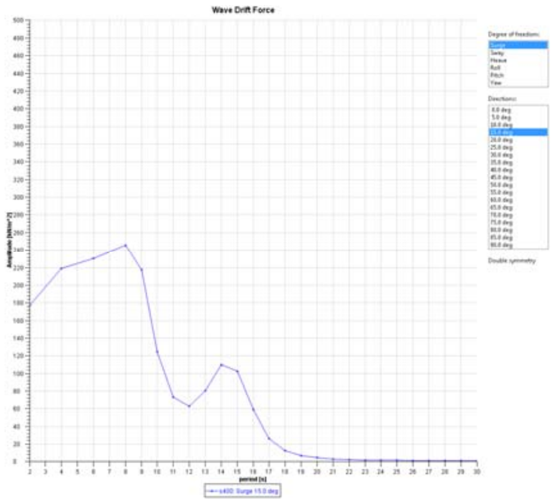
Based on Numerical Simulation

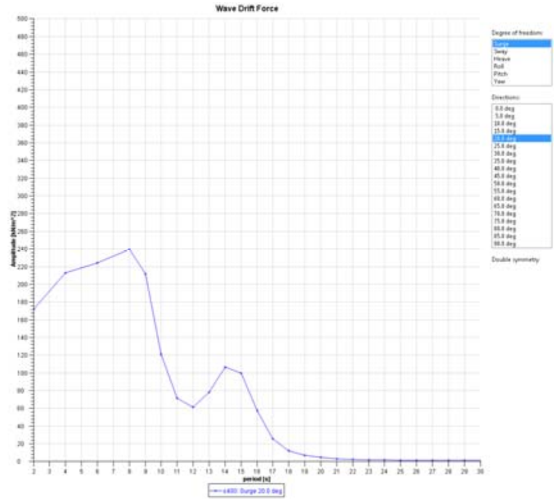
A. Wave Drift Force for Surge (0-90°)

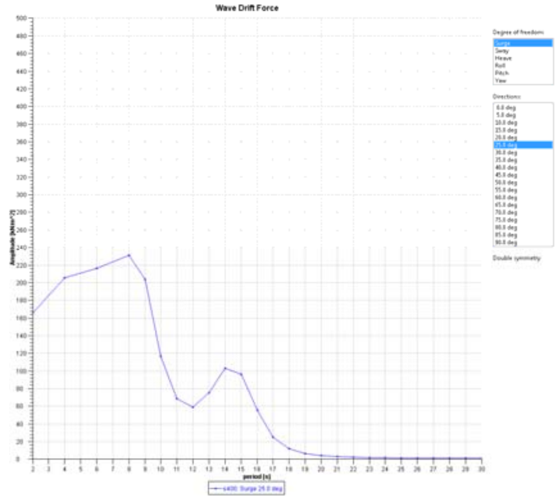


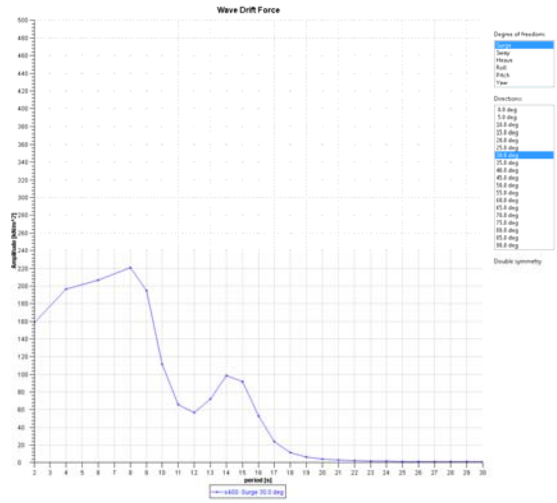


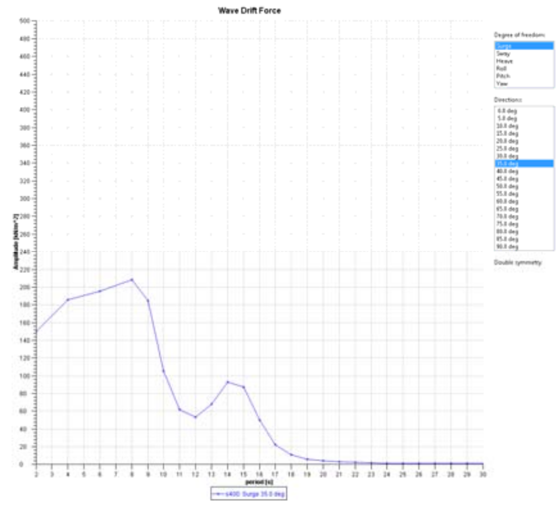


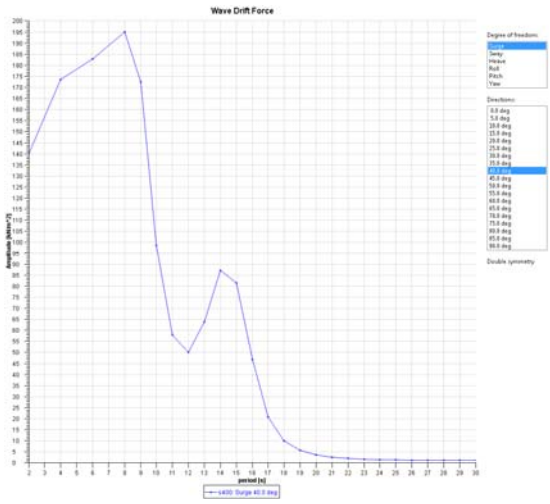


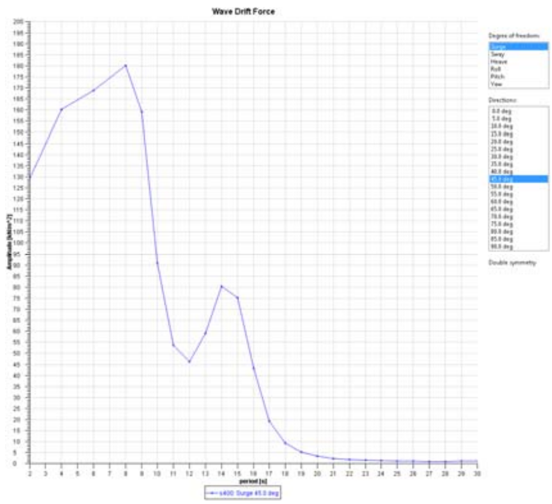

Wave Drift Force
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry
period [s]
s400: Surge 20.0 deg

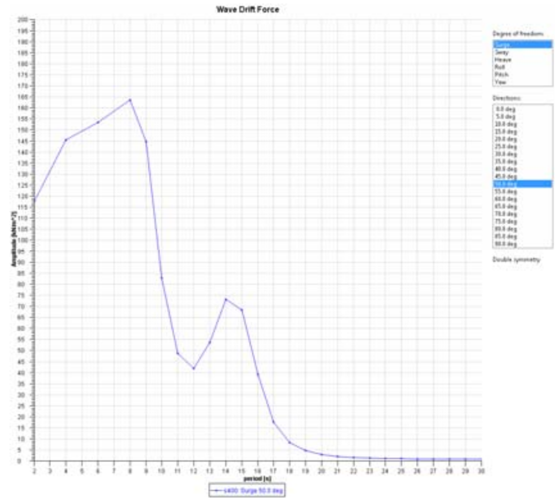

Wave Drift Force
Degree of freedom:
Directions:
Double symmetry
period [s]
s400: Surge 25.0 deg

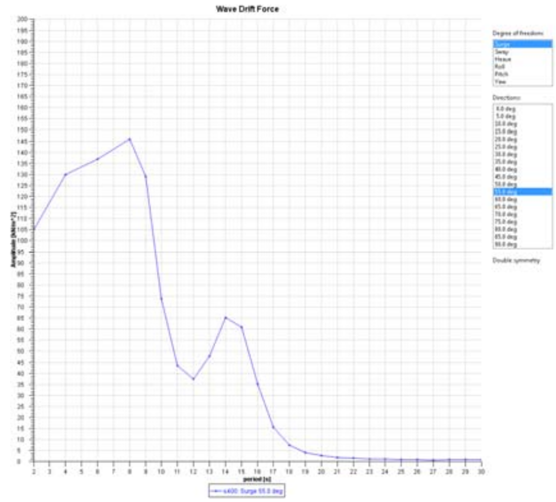

Wave Drift Force
Degree of freedom:
Directions:
Double symmetry
period [s]
s400: Surge 30.0 deg

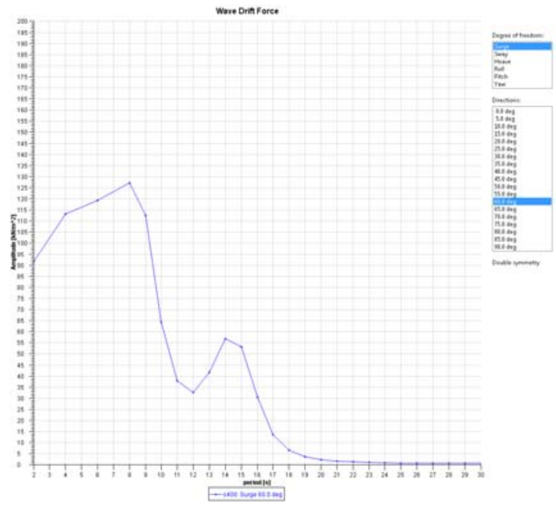

Wave Drift Force
Degree of freedom:
Directions:
Double symmetry
period [s]
s400: Surge 35.0 deg

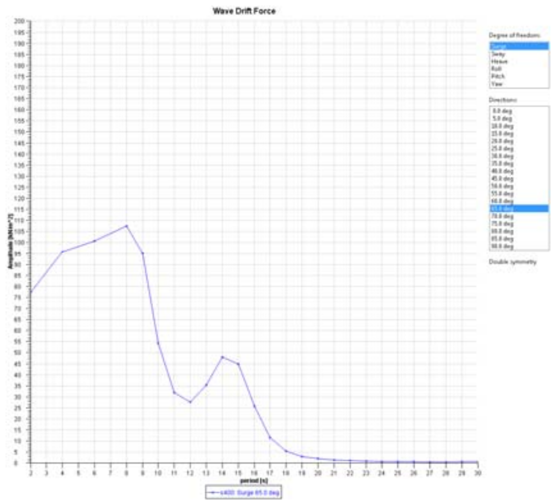

Wave Drift Force
Degree of freedom:
Directions:
Double symmetry
period [s]
s400: Surge 40.0 deg

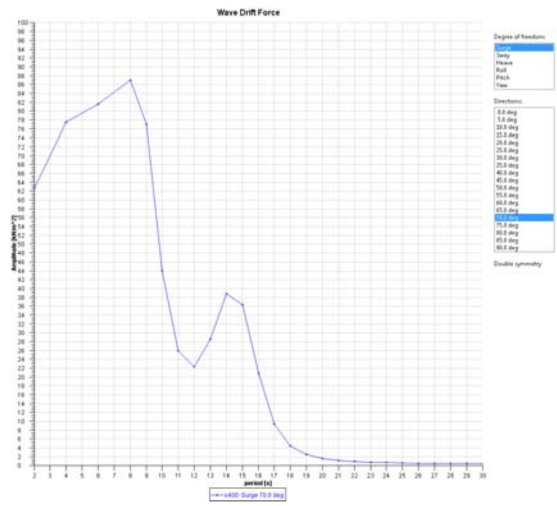

Wave Drift Force
Degree of freedom:
Directions:
Double symmetry
period [s]
s400: Surge 45.0 deg

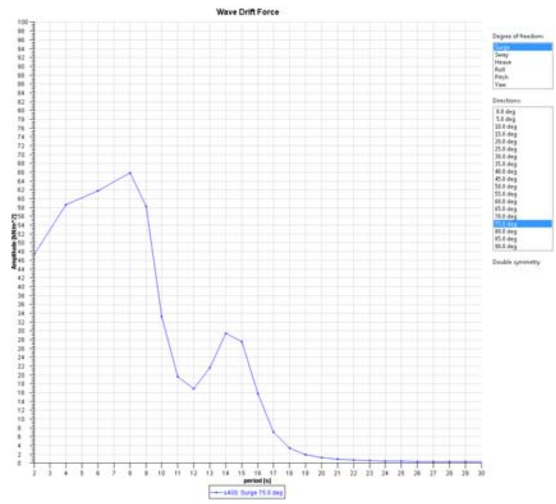

Wave Drift Force
period [s]
s400: Surge 50.0 deg

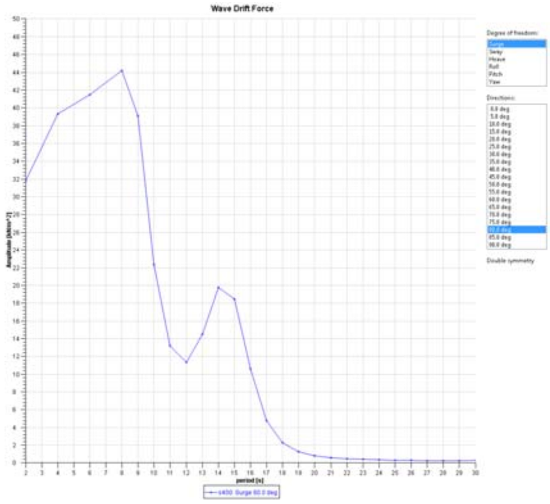

Wave Drift Force
period [s]
s400: Surge 55.0 deg

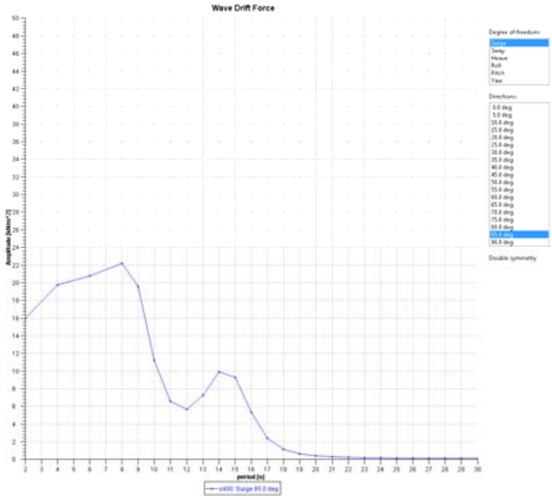

Wave Drift Force
period [s]
s400: Surge 60.0 deg

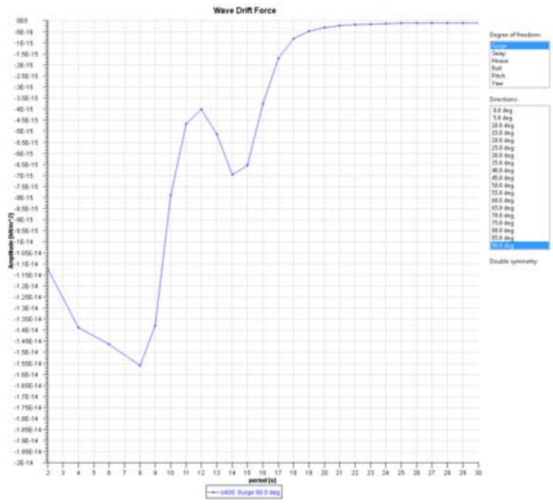

Wave Drift Force
period [s]
s400: Surge 65.0 deg


Wave Drift Force
period [s]
s400: Surge 70.0 deg

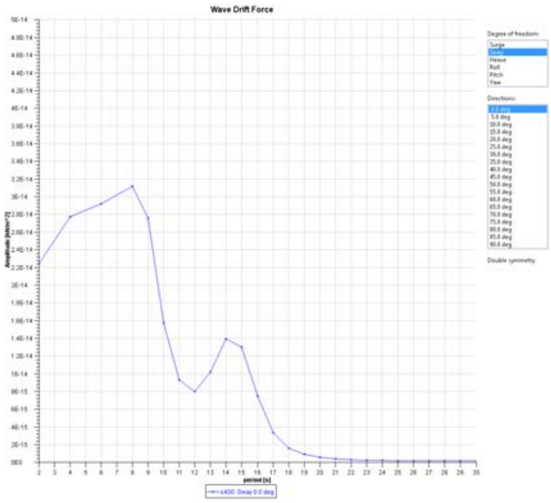

Wave Drift Force
period [s]
s400: Surge 75.0 deg

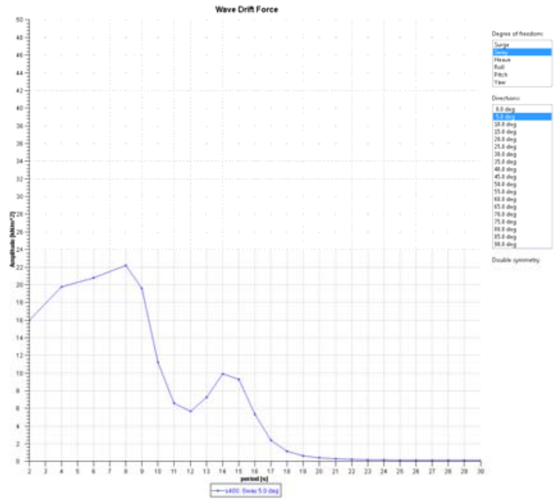

Wave Drift Force
period [s]
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry

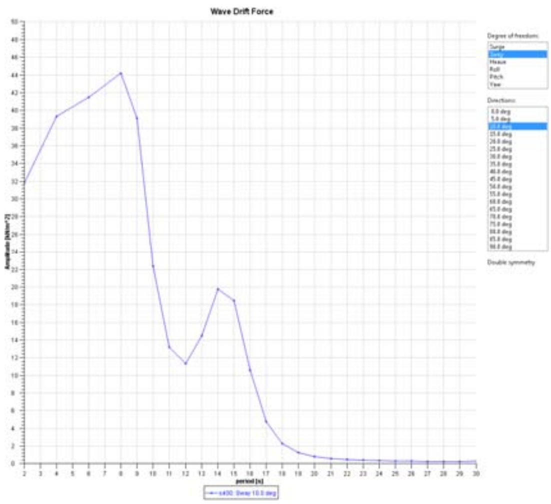

Wave Drift Force
period [s]
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry

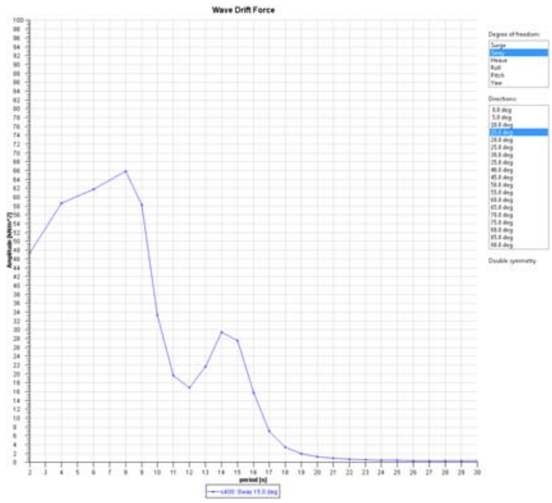

Wave Drift Force
period [s]
Degree of freedom:
Surge
Sway
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry

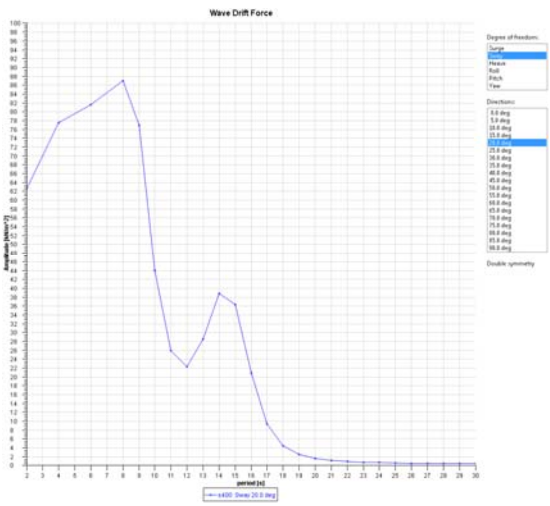
B. Wave Drift Force for Sway (0-90°)

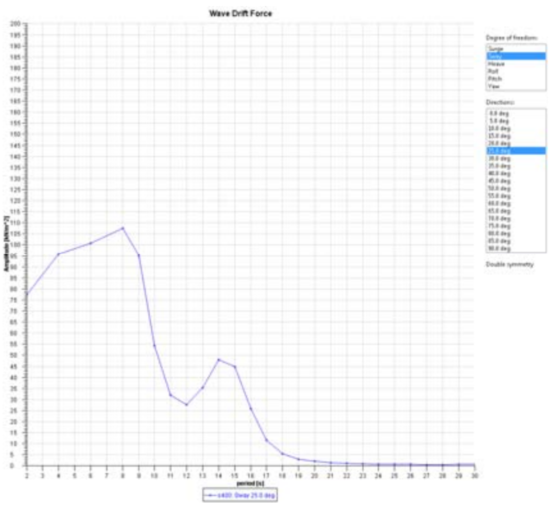


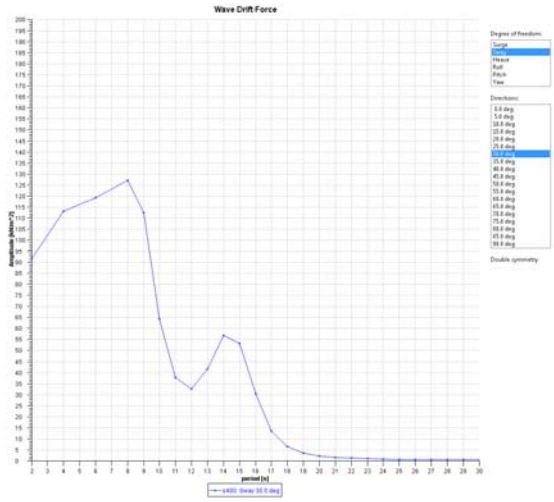


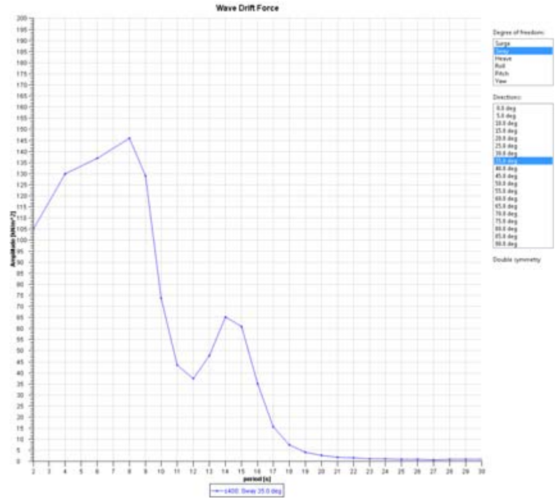


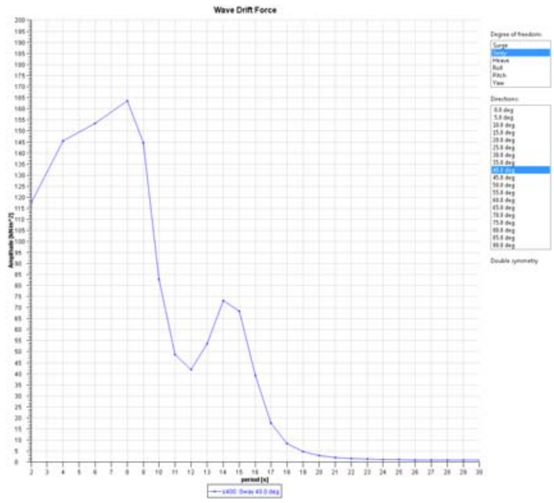


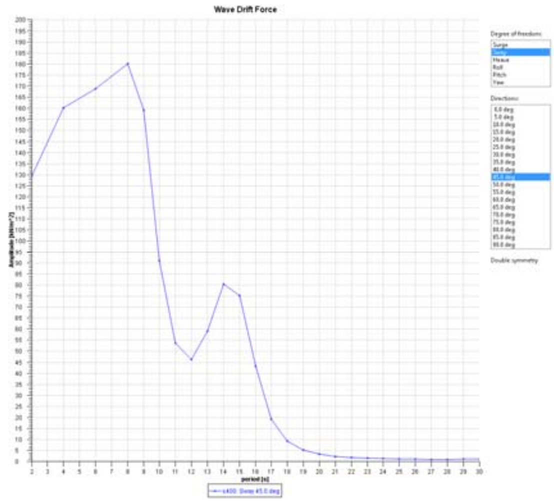


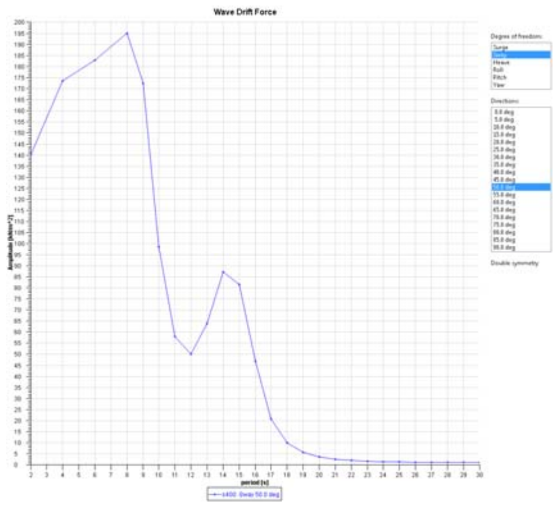


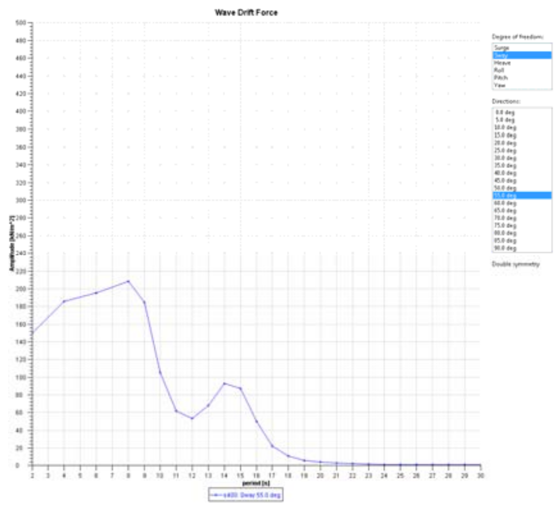

Wave Drift Force
Degree of freedom:
Surge
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry
period [s]
s400 Sway 30.0 deg

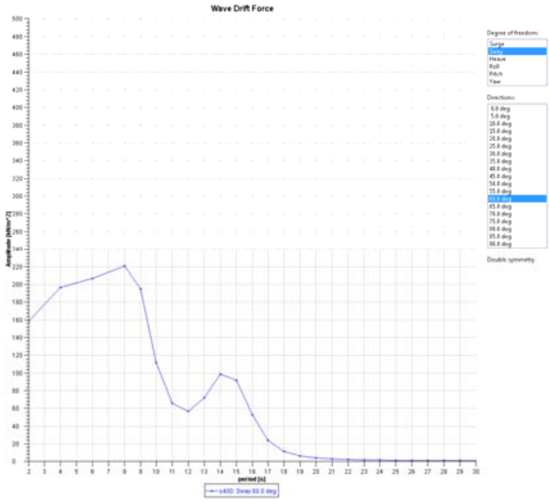

Wave Drift Force
Degree of freedom:
Surge
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry
period [s]
s400 Sway 35.0 deg

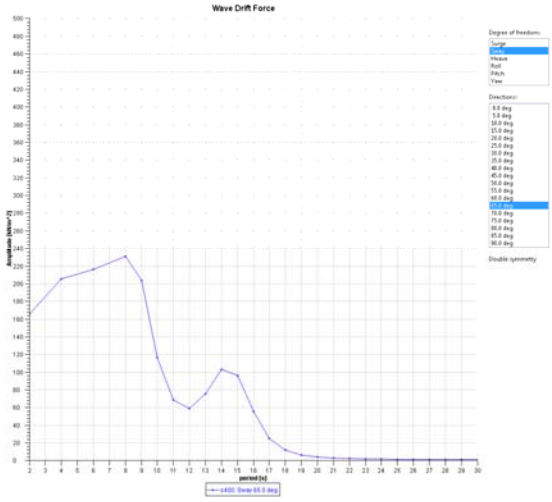

Wave Drift Force
Degree of freedom:
Surge
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry
period [s]
s400 Sway 40.0 deg

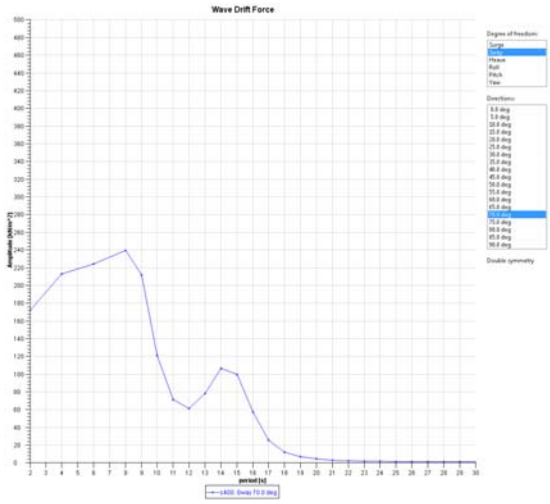

Wave Drift Force
Degree of freedom:
Surge
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry
period [s]
s400 Sway 45.0 deg

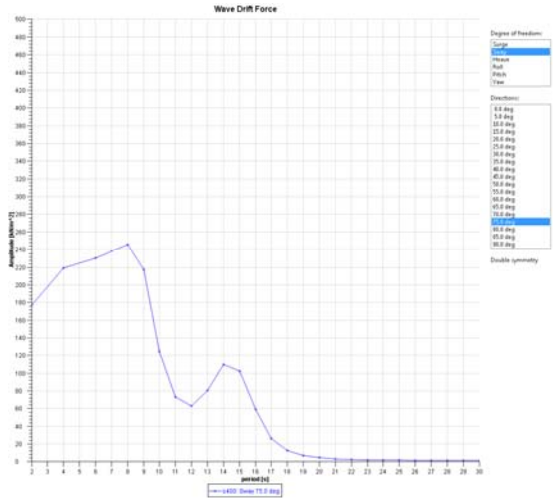

Wave Drift Force
Degree of freedom:
Surge
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry
period [s]
s400 Sway 50.0 deg

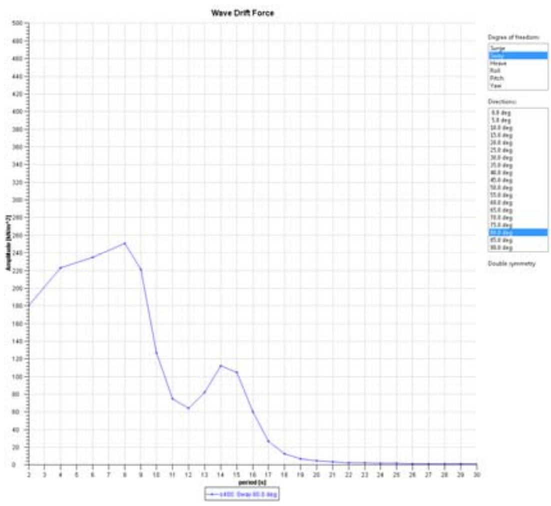

Wave Drift Force
Degree of freedom:
Surge
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry
period [s]
s400 Sway 55.0 deg

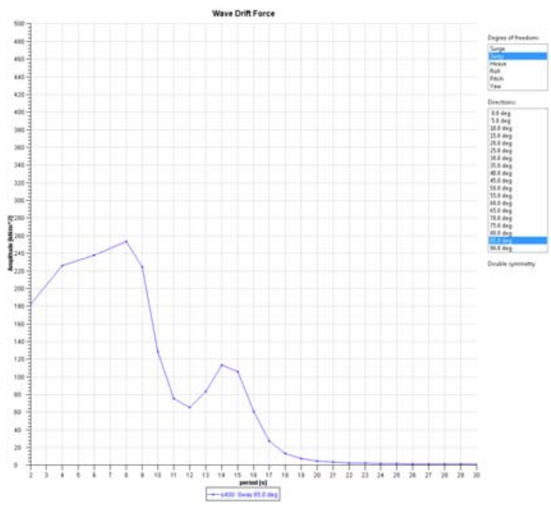

Wave Drift Force
Amplitude [kN/m^2]
period [s]
Degree of freedom:
Directions:
Double symmetry

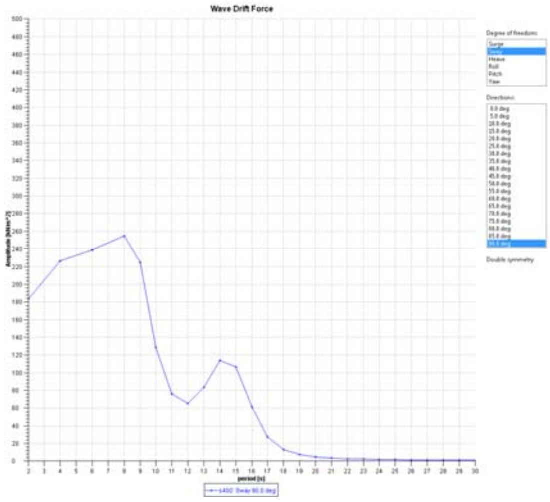

Wave Drift Force
Amplitude [kN/m^2]
period [s]
Degree of freedom:
Directions:
Double symmetry


Wave Drift Force
Amplitude [kN/m^2]
period [s]
Degree of freedom:
Directions:
Double symmetry


Wave Drift Force
Amplitude [kN/m^2]
period [s]
Degree of freedom:
Directions:
Double symmetry


Wave Drift Force
Amplitude [kN/m^2]
period [s]
Degree of freedom:
Directions:
Double symmetry


Wave Drift Force
Amplitude [kN/m^2]
period [s]
Degree of freedom:
Directions:
Double symmetry


Wave Drift Force
Amplitude [kN/m^2]
period [s]
s400 Sway 90.0 deg
Degree of freedom:
Surge
Heave
Roll
Pitch
Yaw
Directions:
Double symmetry

Appendix

C

System Description SIMO

M.S.c. Thesis

Coupled Dynamic Analysis of Cylindrical FPSO, Moorings and Riser

Based on Numerical Simulation

```
'*************************************************************
SYSTEM DESCRIPTION SIMO
'*************************************************************
'txsys, 3 lines



'LENUNI TIMUNI MASUNI GRAV  RHOW  RHOA
 m     s     Mg    9.81  1.025 0.00125
'DEPTH  DIRSLO   SLOPE
   170.0
'***************************************************
 ENVIRONMENT DATA SPECIFICATION
'***************************************************

 Env. Conditions
 ------oo-------
'*************************************************************
 IRREGULAR WAVE SPECIFICATION
'*************************************************************
'  CHIRWA
 Wa
'  IWASP1    IWADR1    IWASP2   IWADR2
     24      1       0      0
'-------------------------------------------------
 WAVE SPECTRUM WIND
'-------------------------------------------------
'  siwahe   tpeak
   10.0   14.0
'-------------------------------------------------
 WAVE DIRECTION PARAMETERS
'-------------------------------------------------
'  wadir1   expo1   ndir1
  180      4      11
'*************************************************************
CURRENT  SPECIFICATION
'*************************************************************
' Chcurr     L_extern
 Cu       0
' Ncur
  1
' Curvel  Curdir  Curlev
  0.6    180    -100
'*************************************************************
WIND SPECIFICATION
'*************************************************************
' CHWI
 Wi
'iwitype
   5
'widir   zref  alphwi winref gamma(dummy) fri
 180    10.   .11    25.0     1.      .002
'*************************************************************
BODY DATA SPECIFICATION
'*************************************************************
'CHBDY
s400
```

```
'txbdy, 3 lines
txbdy
txbdy
txbdy
'IBDTYP
         2
'============================================================
BODY LOCATION DATA
'============================================================
'  Xglob      Yglob      Zglob      Phi       Theta      Psi
  0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
'============================================================
BODY MASS DATA
'============================================================
'txmass, 2 lines


'xcog   ycog   zcog
  0.000     0.000     1.880
'---------------------------------------------------------
 MASS COEFFICIENTS
'---------------------------------------------------------
'   rm      rixx      riyx      riyy      rizx      rizy      rizz
 0.7069E+05 0.3421E+08  0.000    0.3421E+08  0.000     0.000    0.7238E+08
'---------------------------------------------------------
 ADDED MASS ZERO
'---------------------------------------------------------
'  amz1      amz2      amz3      amz4      amz5      amz6
 0.3703E+05  0.000     0.000     0.000    -.6329E+06  0.000
  0.000    0.3703E+05  0.000    0.6329E+06  0.000     0.000
  0.000     0.000    0.1563E+06  0.000     0.000     0.000
  0.000    0.6343E+06  0.000    0.5312E+08  0.000     0.000
 -.6343E+06  0.000     0.000     0.000    0.5312E+08  0.000
  0.000     0.000     0.000     0.000     0.000     0.000
'============================================================
LINEAR DAMPING
'============================================================
'txdmpl. 2 lines


'dli1      dli2      dli3      dli4      dli5      dli6
 9.90e-02   0.000     0.000     0.000     0.000     0.000
  0.000    9.90e-02   0.000     0.000     0.000    2.20e-2
  0.000     0.000    4.00e-4    0.000     0.000     0.000
  0.000     0.000     0.000    4.00e-4    0.000     0.000
  0.000     0.000     0.000     0.000    4.00e-4    0.000
  0.000    2.20e-02   0.000     0.000     0.000    1.500e6
'============================================================
QUADRATIC DAMPING
'============================================================
'txdmpl. 2 lines


'dqi1      dqi2      dqi3      dqi4      dqi5      dqi6
 1.400e4    0.000     0.000     0.000     0.000     0.000
  0.000    1.400e4    0.000     0.000     0.000     0.000
  0.000     0.000    1.000e3    0.000     0.000     0.000
  0.000     0.000     0.000    3.500e4    0.000     0.000
  0.000     0.000     0.000     0.000    3.500e4    0.000
  0.000     0.000     0.000     0.000     0.000    1.500e6
'============================================================
 WAVE DRIFT DAMPING
'============================================================
'txwadd. 2 lines
 Simplified
 wave - current interaction
' icof
  1
' nwadd
  2
' wdper wd11 wd12
  13    0.33  0.33
  16    0.33  0.33
'============================================================
QUADRATIC CURRENT COEFFICIENTS
'============================================================
'txc2co. 2 lines


'nc2dir  ic2sym  istrip   rltot     rlori
   7      2      0       0.        0.
' dir     dof1     dof2     dof3    dof4     dof5     dof6
   0       500      0        0       0     -4000      0
  15       483     129       0     1035    -3864      0
  30       433     250       0     2000    -3464      0
  45       354     354       0     2828    -2828      0
```

```
 60      250    433       0   3464    -2000      0
 75      129    483       0   3864    -1035      0
 90        0    500       0   4000       0      0
'=============================================================
WIND FORCE COEFFICIENTS
'=============================================================
'txwico. 2 lines


'nwidir  iwisym    wiarea      zcoef
   7     2        2000.      10.00
' dir     dof1    dof2    dof3   dof4     dof5    dof6
   0     1.35    0.00    0.00   0.00    21.60    0.00
  15     1.30    0.35    0.00  -5.59    20.86    0.00
  30     1.17    0.68    0.00 -10.80    18.71    0.00
  45     0.95    0.95    0.00 -15.27    15.27    0.00
  60     0.68    1.17    0.00 -18.71    10.80    0.00
  75     0.35    1.30    0.00 -20.86     5.59    0.00
  90     0.00    1.35    0.00 -21.60     0.00    0.00
'=============================================================
HYDROSTATIC STIFFNESS DATA
'=============================================================
'txstif, 2 lines


'istmod
  1
'----------------------------------------------------------
 STIFFNESS REFERENCE
'----------------------------------------------------------
'  refx     refy      refz     rphi     rtheta     rpsi
 0.000     0.000     0.000     0.000     0.000     0.000
'----------------------------------------------------------
 LINEAR STIFFNESS MATRIX
'----------------------------------------------------------
'kmati1    kmati2    kmati3    kmati4    kmati5    kmati6
 0.000     0.000     0.000     0.000     0.000     0.000
 0.000     0.000     0.000     0.000     0.000     0.000
 0.000     0.000     0.3864E+05  0.000     0.000     0.000
 0.000     0.000     0.000     0.4441E+07  0.000     0.000
 0.000     0.000     0.000     0.000     0.4441E+07  0.000
 0.000     0.000     0.000     0.000     0.000     0.000
'=============================================================
FIRST ORDER MOTION TRANSFER FUNCTION
'=============================================================
'txmo1, 2 lines


'nmodir  nmofre  imosym   itypin
    19     26      2      2
'----------------------------------------------------------
 WAVE DIRECTIONS MOTION TRANSFER FUNCTIONS
'----------------------------------------------------------
'imodir   modir
     1       0.00000
     2       5.00000
     3       10.0000
     4       15.0000
     5       20.0000
     6       25.0000
     7       30.0000
     8       35.0000
     9       40.0000
    10       45.0000
    11       50.0000
    12       55.0000
    13       60.0000
    14       65.0000
    15       70.0000
    16       75.0000
    17       80.0000
    18       85.0000
    19       90.0000
'----------------------------------------------------------
 WAVE FREQUENCIES MOTION TRANSFER FUNCTIONS
'----------------------------------------------------------
'imofre   mofre
     1     0.209440
     2     0.216662
     3     0.224399
     4     0.232711
     5     0.241661
     6     0.251327
     7     0.261799
     8     0.273182
     9     0.285599
```

10	0.299199
11	0.314159
12	0.330694
13	0.349066
14	0.369599
15	0.392699
16	0.418879
17	0.448799
18	0.483322
19	0.523599
20	0.571199
21	0.628319
22	0.698132
23	0.785398
24	1.04720
25	1.57080
26	3.14159

'---

SURGE MOTION TRANSFER FUNCTION

'---

'idir	ifreq	ampl	phase
1	1	1.669	-87.20
1	2	1.586	-87.28
1	3	1.508	-87.22
1	4	1.438	-86.98
1	5	1.381	-86.77
1	6	1.329	-86.93
1	7	1.274	-87.21
1	8	1.220	-87.45
1	9	1.167	-87.62
1	10	1.117	-87.73
1	11	1.069	-87.79
1	12	1.024	-87.80
1	13	0.9786	-87.74
1	14	0.9325	-87.54
1	15	0.8831	-87.02
1	16	0.8350	-85.89
1	17	0.7955	-84.89
1	18	0.7458	-84.62
1	19	0.6767	-83.63
1	20	0.5950	-81.18
1	21	0.5010	-76.81
1	22	0.3941	-69.42
1	23	0.2762	-56.10
1	24	0.8741E-01	21.22
1	25	0.1257E-01	-72.40
1	26	0.3199E-03	-38.62
2	1	1.662	-87.20
2	2	1.580	-87.28
2	3	1.502	-87.22
2	4	1.433	-86.98
2	5	1.376	-86.77
2	6	1.324	-86.93
2	7	1.269	-87.21
2	8	1.215	-87.45
2	9	1.163	-87.62
2	10	1.113	-87.73
2	11	1.065	-87.79
2	12	1.020	-87.80
2	13	0.9749	-87.74
2	14	0.9290	-87.54
2	15	0.8797	-87.02
2	16	0.8318	-85.89
2	17	0.7925	-84.89
2	18	0.7429	-84.62
2	19	0.6742	-83.63
2	20	0.5927	-81.18
2	21	0.4991	-76.81
2	22	0.3926	-69.42
2	23	0.2752	-56.10
2	24	0.8708E-01	21.22
2	25	0.1253E-01	-72.40
2	26	0.3187E-03	-38.62
3	1	1.643	-87.20
3	2	1.562	-87.28
3	3	1.485	-87.22
3	4	1.416	-86.98
3	5	1.360	-86.77
3	6	1.309	-86.93
3	7	1.255	-87.21
3	8	1.201	-87.45
3	9	1.149	-87.62
3	10	1.100	-87.73
3	11	1.053	-87.79
3	12	1.008	-87.80
3	13	0.9638	-87.74

3	14	0.9184	-87.54
3	15	0.8697	-87.02
3	16	0.8223	-85.89
3	17	0.7834	-84.89
3	18	0.7344	-84.62
3	19	0.6665	-83.63
3	20	0.5859	-81.18
3	21	0.4934	-76.81
3	22	0.3881	-69.42
3	23	0.2720	-56.10
3	24	0.8608E-01	21.22
3	25	0.1238E-01	-72.40
3	26	0.3151E-03	-38.62
4	1	1.612	-87.20
4	2	1.532	-87.28
4	3	1.457	-87.22
4	4	1.389	-86.98
4	5	1.334	-86.77
4	6	1.283	-86.93
4	7	1.231	-87.21
4	8	1.178	-87.45
4	9	1.127	-87.62
4	10	1.079	-87.73
4	11	1.033	-87.79
4	12	0.9887	-87.80
4	13	0.9453	-87.74
4	14	0.9008	-87.54
4	15	0.8530	-87.02
4	16	0.8065	-85.89
4	17	0.7684	-84.89
4	18	0.7204	-84.62
4	19	0.6537	-83.63
4	20	0.5747	-81.18
4	21	0.4839	-76.81
4	22	0.3806	-69.42
4	23	0.2668	-56.10
4	24	0.8443E-01	21.22
4	25	0.1215E-01	-72.40
4	26	0.3090E-03	-38.62
5	1	1.568	-87.20
5	2	1.490	-87.28
5	3	1.417	-87.22
5	4	1.351	-86.98
5	5	1.298	-86.77
5	6	1.249	-86.93
5	7	1.197	-87.21
5	8	1.146	-87.45
5	9	1.097	-87.62
5	10	1.050	-87.73
5	11	1.005	-87.79
5	12	0.9618	-87.80
5	13	0.9196	-87.74
5	14	0.8763	-87.54
5	15	0.8298	-87.02
5	16	0.7846	-85.89
5	17	0.7475	-84.89
5	18	0.7008	-84.62
5	19	0.6359	-83.63
5	20	0.5591	-81.18
5	21	0.4708	-76.81
5	22	0.3703	-69.42
5	23	0.2596	-56.10
5	24	0.8214E-01	21.22
5	25	0.1182E-01	-72.40
5	26	0.3006E-03	-38.62
6	1	1.512	-87.20
6	2	1.437	-87.28
6	3	1.367	-87.22
6	4	1.303	-86.98
6	5	1.252	-86.77
6	6	1.204	-86.93
6	7	1.155	-87.21
6	8	1.105	-87.45
6	9	1.058	-87.62
6	10	1.012	-87.73
6	11	0.9692	-87.79
6	12	0.9277	-87.80
6	13	0.8869	-87.74
6	14	0.8452	-87.54
6	15	0.8003	-87.02
6	16	0.7567	-85.89
6	17	0.7210	-84.89
6	18	0.6759	-84.62
6	19	0.6133	-83.63
6	20	0.5392	-81.18
6	21	0.4541	-76.81

6	22	0.3571	-69.42
6	23	0.2503	-56.10
6	24	0.7922E-01	21.22
6	25	0.1140E-01	-72.40
6	26	0.2900E-03	-38.62
7	1	1.445	-87.20
7	2	1.374	-87.28
7	3	1.306	-87.22
7	4	1.245	-86.98
7	5	1.196	-86.77
7	6	1.151	-86.93
7	7	1.104	-87.21
7	8	1.056	-87.45
7	9	1.011	-87.62
7	10	0.9674	-87.73
7	11	0.9261	-87.79
7	12	0.8864	-87.80
7	13	0.8475	-87.74
7	14	0.8076	-87.54
7	15	0.7648	-87.02
7	16	0.7231	-85.89
7	17	0.6889	-84.89
7	18	0.6459	-84.62
7	19	0.5861	-83.63
7	20	0.5153	-81.18
7	21	0.4339	-76.81
7	22	0.3413	-69.42
7	23	0.2392	-56.10
7	24	0.7570E-01	21.22
7	25	0.1089E-01	-72.40
7	26	0.2771E-03	-38.62
8	1	1.367	-87.20
8	2	1.299	-87.28
8	3	1.235	-87.22
8	4	1.178	-86.98
8	5	1.131	-86.77
8	6	1.088	-86.93
8	7	1.044	-87.21
8	8	0.9991	-87.45
8	9	0.9560	-87.62
8	10	0.9150	-87.73
8	11	0.8760	-87.79
8	12	0.8385	-87.80
8	13	0.8016	-87.74
8	14	0.7639	-87.54
8	15	0.7234	-87.02
8	16	0.6840	-85.89
8	17	0.6516	-84.89
8	18	0.6109	-84.62
8	19	0.5544	-83.63
8	20	0.4874	-81.18
8	21	0.4104	-76.81
8	22	0.3228	-69.42
8	23	0.2263	-56.10
8	24	0.7160E-01	21.22
8	25	0.1030E-01	-72.40
8	26	0.2621E-03	-38.62
9	1	1.278	-87.20
9	2	1.215	-87.28
9	3	1.155	-87.22
9	4	1.102	-86.98
9	5	1.058	-86.77
9	6	1.018	-86.93
9	7	0.9761	-87.21
9	8	0.9343	-87.45
9	9	0.8940	-87.62
9	10	0.8557	-87.73
9	11	0.8192	-87.79
9	12	0.7841	-87.80
9	13	0.7497	-87.74
9	14	0.7144	-87.54
9	15	0.6765	-87.02
9	16	0.6396	-85.89
9	17	0.6094	-84.89
9	18	0.5713	-84.62
9	19	0.5184	-83.63
9	20	0.4558	-81.18
9	21	0.3838	-76.81
9	22	0.3019	-69.42
9	23	0.2116	-56.10
9	24	0.6696E-01	21.22
9	25	0.9632E-02	-72.40
9	26	0.2451E-03	-38.62
10	1	1.180	-87.20
10	2	1.121	-87.28
10	3	1.066	-87.22

10	4	1.017	-86.98
10	5	0.9765	-86.77
10	6	0.9396	-86.93
10	7	0.9010	-87.21
10	8	0.8624	-87.45
10	9	0.8252	-87.62
10	10	0.7899	-87.73
10	11	0.7562	-87.79
10	12	0.7238	-87.80
10	13	0.6920	-87.74
10	14	0.6594	-87.54
10	15	0.6244	-87.02
10	16	0.5904	-85.89
10	17	0.5625	-84.89
10	18	0.5273	-84.62
10	19	0.4785	-83.63
10	20	0.4207	-81.18
10	21	0.3543	-76.81
10	22	0.2786	-69.42
10	23	0.1953	-56.10
10	24	0.6181E-01	21.22
10	25	0.8891E-02	-72.40
10	26	0.2262E-03	-38.62
11	1	1.073	-87.20
11	2	1.019	-87.28
11	3	0.9693	-87.22
11	4	0.9244	-86.98
11	5	0.8877	-86.77
11	6	0.8541	-86.93
11	7	0.8191	-87.21
11	8	0.7840	-87.45
11	9	0.7502	-87.62
11	10	0.7180	-87.73
11	11	0.6874	-87.79
11	12	0.6579	-87.80
11	13	0.6290	-87.74
11	14	0.5994	-87.54
11	15	0.5676	-87.02
11	16	0.5367	-85.89
11	17	0.5113	-84.89
11	18	0.4794	-84.62
11	19	0.4350	-83.63
11	20	0.3824	-81.18
11	21	0.3220	-76.82
11	22	0.2533	-69.42
11	23	0.1775	-56.10
11	24	0.5618E-01	21.22
11	25	0.8082E-02	-72.40
11	26	0.2057E-03	-38.62
12	1	0.9572	-87.20
12	2	0.9097	-87.28
12	3	0.8649	-87.22
12	4	0.8249	-86.98
12	5	0.7921	-86.77
12	6	0.7622	-86.93
12	7	0.7309	-87.21
12	8	0.6996	-87.45
12	9	0.6694	-87.62
12	10	0.6407	-87.73
12	11	0.6134	-87.79
12	12	0.5871	-87.80
12	13	0.5613	-87.74
12	14	0.5349	-87.54
12	15	0.5065	-87.02
12	16	0.4789	-85.89
12	17	0.4563	-84.89
12	18	0.4278	-84.62
12	19	0.3882	-83.63
12	20	0.3413	-81.18
12	21	0.2874	-76.81
12	22	0.2260	-69.42
12	23	0.1584	-56.10
12	24	0.5014E-01	21.22
12	25	0.7212E-02	-72.40
12	26	0.1835E-03	-38.62
13	1	0.8344	-87.20
13	2	0.7930	-87.28
13	3	0.7540	-87.22
13	4	0.7191	-86.98
13	5	0.6905	-86.77
13	6	0.6644	-86.93
13	7	0.6371	-87.21
13	8	0.6098	-87.45
13	9	0.5835	-87.62
13	10	0.5585	-87.73
13	11	0.5347	-87.79

13	12	0.5118	-87.80
13	13	0.4893	-87.74
13	14	0.4663	-87.54
13	15	0.4415	-87.02
13	16	0.4175	-85.89
13	17	0.3978	-84.89
13	18	0.3729	-84.62
13	19	0.3384	-83.63
13	20	0.2975	-81.18
13	21	0.2505	-76.81
13	22	0.1970	-69.42
13	23	0.1381	-56.10
13	24	0.4370E-01	21.22
13	25	0.6287E-02	-72.40
13	26	0.1600E-03	-38.62
14	1	0.7053	-87.20
14	2	0.6703	-87.28
14	3	0.6373	-87.22
14	4	0.6078	-86.98
14	5	0.5836	-86.77
14	6	0.5616	-86.93
14	7	0.5385	-87.21
14	8	0.5155	-87.45
14	9	0.4932	-87.62
14	10	0.4721	-87.73
14	11	0.4519	-87.79
14	12	0.4326	-87.80
14	13	0.4136	-87.74
14	14	0.3941	-87.54
14	15	0.3732	-87.02
14	16	0.3529	-85.89
14	17	0.3362	-84.89
14	18	0.3152	-84.62
14	19	0.2860	-83.63
14	20	0.2514	-81.18
14	21	0.2117	-76.81
14	22	0.1665	-69.42
14	23	0.1167	-56.10
14	24	0.3694E-01	21.22
14	25	0.5314E-02	-72.40
14	26	0.1352E-03	-38.62
15	1	0.5708	-87.20
15	2	0.5425	-87.28
15	3	0.5157	-87.22
15	4	0.4919	-86.98
15	5	0.4723	-86.77
15	6	0.4545	-86.93
15	7	0.4358	-87.21
15	8	0.4171	-87.45
15	9	0.3992	-87.62
15	10	0.3820	-87.73
15	11	0.3657	-87.79
15	12	0.3501	-87.80
15	13	0.3347	-87.74
15	14	0.3189	-87.54
15	15	0.3020	-87.02
15	16	0.2856	-85.89
15	17	0.2721	-84.89
15	18	0.2551	-84.62
15	19	0.2315	-83.63
15	20	0.2035	-81.18
15	21	0.1714	-76.81
15	22	0.1348	-69.42
15	23	0.9447E-01	-56.10
15	24	0.2990E-01	21.22
15	25	0.4300E-02	-72.40
15	26	0.1094E-03	-38.62
16	1	0.4319	-87.20
16	2	0.4105	-87.28
16	3	0.3903	-87.22
16	4	0.3722	-86.98
16	5	0.3574	-86.77
16	6	0.3439	-86.93
16	7	0.3298	-87.21
16	8	0.3157	-87.45
16	9	0.3021	-87.62
16	10	0.2891	-87.73
16	11	0.2768	-87.79
16	12	0.2649	-87.80
16	13	0.2533	-87.74
16	14	0.2414	-87.54
16	15	0.2286	-87.02
16	16	0.2161	-85.89
16	17	0.2059	-84.89
16	18	0.1930	-84.62
16	19	0.1752	-83.63

16	20	0.1540	-81.18
16	21	0.1297	-76.81
16	22	0.1020	-69.42
16	23	0.7149E-01	-56.10
16	24	0.2262E-01	21.22
16	25	0.3254E-02	-72.40
16	26	0.8281E-04	-38.62
17	1	0.2898	-87.20
17	2	0.2754	-87.28
17	3	0.2618	-87.22
17	4	0.2497	-86.98
17	5	0.2398	-86.77
17	6	0.2307	-86.93
17	7	0.2213	-87.21
17	8	0.2118	-87.45
17	9	0.2027	-87.62
17	10	0.1940	-87.73
17	11	0.1857	-87.79
17	12	0.1777	-87.80
17	13	0.1699	-87.74
17	14	0.1619	-87.54
17	15	0.1533	-87.02
17	16	0.1450	-85.89
17	17	0.1381	-84.89
17	18	0.1295	-84.62
17	19	0.1175	-83.63
17	20	0.1033	-81.18
17	21	0.8700E-01	-76.82
17	22	0.6843E-01	-69.42
17	23	0.4796E-01	-56.10
17	24	0.1518E-01	21.22
17	25	0.2183E-02	-72.40
17	26	0.5556E-04	-38.62
18	1	0.1454	-87.20
18	2	0.1382	-87.28
18	3	0.1314	-87.22
18	4	0.1253	-86.98
18	5	0.1204	-86.77
18	6	0.1158	-86.93
18	7	0.1111	-87.21
18	8	0.1063	-87.45
18	9	0.1017	-87.62
18	10	0.9736E-01	-87.73
18	11	0.9320E-01	-87.79
18	12	0.8921E-01	-87.80
18	13	0.8529E-01	-87.74
18	14	0.8128E-01	-87.54
18	15	0.7696E-01	-87.02
18	16	0.7277E-01	-85.89
18	17	0.6933E-01	-84.89
18	18	0.6500E-01	-84.62
18	19	0.5898E-01	-83.63
18	20	0.5185E-01	-81.18
18	21	0.4367E-01	-76.82
18	22	0.3434E-01	-69.42
18	23	0.2407E-01	-56.10
18	24	0.7618E-02	21.22
18	25	0.1096E-02	-72.40
18	26	0.2788E-04	-38.62
19	1	0.1022E-15	92.80
19	2	0.9712E-16	92.72
19	3	0.9233E-16	92.78
19	4	0.8806E-16	93.02
19	5	0.8456E-16	93.23
19	6	0.8136E-16	93.07
19	7	0.7802E-16	92.79
19	8	0.7468E-16	92.55
19	9	0.7146E-16	92.38
19	10	0.6840E-16	92.27
19	11	0.6548E-16	92.21
19	12	0.6268E-16	92.20
19	13	0.5992E-16	92.26
19	14	0.5710E-16	92.46
19	15	0.5407E-16	92.98
19	16	0.5113E-16	94.11
19	17	0.4871E-16	95.11
19	18	0.4567E-16	95.38
19	19	0.4144E-16	96.37
19	20	0.3643E-16	98.82
19	21	0.3068E-16	103.18
19	22	0.2413E-16	110.58
19	23	0.1691E-16	123.90
19	24	0.5352E-17	-158.78
19	25	0.7699E-18	107.60
19	26	0.1959E-19	141.38

'--

SWAY MOTION TRANSFER FUNCTION

'---

'idir	ifreq	ampl	phase
1	1	0.2044E-15	-87.20
1	2	0.1942E-15	-87.28
1	3	0.1847E-15	-87.22
1	4	0.1761E-15	-86.98
1	5	0.1691E-15	-86.77
1	6	0.1627E-15	-86.93
1	7	0.1560E-15	-87.21
1	8	0.1494E-15	-87.45
1	9	0.1429E-15	-87.62
1	10	0.1368E-15	-87.73
1	11	0.1310E-15	-87.79
1	12	0.1254E-15	-87.80
1	13	0.1198E-15	-87.74
1	14	0.1142E-15	-87.54
1	15	0.1081E-15	-87.02
1	16	0.1023E-15	-85.89
1	17	0.9742E-16	-84.89
1	18	0.9133E-16	-84.62
1	19	0.8288E-16	-83.63
1	20	0.7286E-16	-81.18
1	21	0.6136E-16	-76.82
1	22	0.4826E-16	-69.42
1	23	0.3383E-16	-56.10
1	24	0.1070E-16	21.22
1	25	0.1540E-17	-72.40
1	26	0.3918E-19	-38.62
2	1	0.1454	-87.20
2	2	0.1382	-87.28
2	3	0.1314	-87.22
2	4	0.1253	-86.98
2	5	0.1204	-86.77
2	6	0.1158	-86.93
2	7	0.1111	-87.21
2	8	0.1063	-87.45
2	9	0.1017	-87.62
2	10	0.9736E-01	-87.73
2	11	0.9320E-01	-87.79
2	12	0.8921E-01	-87.80
2	13	0.8529E-01	-87.74
2	14	0.8128E-01	-87.54
2	15	0.7696E-01	-87.02
2	16	0.7277E-01	-85.89
2	17	0.6933E-01	-84.89
2	18	0.6500E-01	-84.62
2	19	0.5898E-01	-83.63
2	20	0.5185E-01	-81.18
2	21	0.4367E-01	-76.82
2	22	0.3434E-01	-69.42
2	23	0.2407E-01	-56.10
2	24	0.7618E-02	21.22
2	25	0.1096E-02	-72.40
2	26	0.2788E-04	-38.62
3	1	0.2898	-87.20
3	2	0.2754	-87.28
3	3	0.2618	-87.22
3	4	0.2497	-86.98
3	5	0.2398	-86.77
3	6	0.2307	-86.93
3	7	0.2213	-87.21
3	8	0.2118	-87.45
3	9	0.2027	-87.62
3	10	0.1940	-87.73
3	11	0.1857	-87.79
3	12	0.1777	-87.80
3	13	0.1699	-87.74
3	14	0.1619	-87.54
3	15	0.1533	-87.02
3	16	0.1450	-85.89
3	17	0.1381	-84.89
3	18	0.1295	-84.62
3	19	0.1175	-83.63
3	20	0.1033	-81.18
3	21	0.8700E-01	-76.82
3	22	0.6843E-01	-69.42
3	23	0.4796E-01	-56.10
3	24	0.1518E-01	21.22
3	25	0.2183E-02	-72.40
3	26	0.5556E-04	-38.62
4	1	0.4319	-87.20
4	2	0.4105	-87.28
4	3	0.3903	-87.22
4	4	0.3722	-86.98
4	5	0.3574	-86.77

4	6	0.3439	-86.93
4	7	0.3298	-87.21
4	8	0.3157	-87.45
4	9	0.3021	-87.62
4	10	0.2891	-87.73
4	11	0.2768	-87.79
4	12	0.2649	-87.80
4	13	0.2533	-87.74
4	14	0.2414	-87.54
4	15	0.2286	-87.02
4	16	0.2161	-85.89
4	17	0.2059	-84.89
4	18	0.1930	-84.62
4	19	0.1752	-83.63
4	20	0.1540	-81.18
4	21	0.1297	-76.81
4	22	0.1020	-69.42
4	23	0.7149E-01	-56.10
4	24	0.2262E-01	21.22
4	25	0.3254E-02	-72.40
4	26	0.8281E-04	-38.62
5	1	0.5708	-87.20
5	2	0.5425	-87.28
5	3	0.5157	-87.22
5	4	0.4919	-86.98
5	5	0.4723	-86.77
5	6	0.4545	-86.93
5	7	0.4358	-87.21
5	8	0.4171	-87.45
5	9	0.3992	-87.62
5	10	0.3820	-87.73
5	11	0.3657	-87.79
5	12	0.3501	-87.80
5	13	0.3347	-87.74
5	14	0.3189	-87.54
5	15	0.3020	-87.02
5	16	0.2856	-85.89
5	17	0.2721	-84.89
5	18	0.2551	-84.62
5	19	0.2315	-83.63
5	20	0.2035	-81.18
5	21	0.1714	-76.81
5	22	0.1348	-69.42
5	23	0.9447E-01	-56.10
5	24	0.2990E-01	21.22
5	25	0.4300E-02	-72.40
5	26	0.1094E-03	-38.62
6	1	0.7053	-87.20
6	2	0.6703	-87.28
6	3	0.6373	-87.22
6	4	0.6078	-86.98
6	5	0.5836	-86.77
6	6	0.5616	-86.93
6	7	0.5385	-87.21
6	8	0.5155	-87.45
6	9	0.4932	-87.62
6	10	0.4721	-87.73
6	11	0.4519	-87.79
6	12	0.4326	-87.80
6	13	0.4136	-87.74
6	14	0.3941	-87.54
6	15	0.3732	-87.02
6	16	0.3529	-85.89
6	17	0.3362	-84.89
6	18	0.3152	-84.62
6	19	0.2860	-83.63
6	20	0.2514	-81.18
6	21	0.2117	-76.81
6	22	0.1665	-69.42
6	23	0.1167	-56.10
6	24	0.3694E-01	21.22
6	25	0.5314E-02	-72.40
6	26	0.1352E-03	-38.62
7	1	0.8344	-87.20
7	2	0.7930	-87.28
7	3	0.7540	-87.22
7	4	0.7191	-86.98
7	5	0.6905	-86.77
7	6	0.6644	-86.93
7	7	0.6371	-87.21
7	8	0.6098	-87.45
7	9	0.5835	-87.62
7	10	0.5585	-87.73
7	11	0.5347	-87.79
7	12	0.5118	-87.80
7	13	0.4893	-87.74

7	14	0.4663	-87.54
7	15	0.4415	-87.02
7	16	0.4175	-85.89
7	17	0.3978	-84.89
7	18	0.3729	-84.62
7	19	0.3384	-83.63
7	20	0.2975	-81.18
7	21	0.2505	-76.81
7	22	0.1970	-69.42
7	23	0.1381	-56.10
7	24	0.4370E-01	21.22
7	25	0.6287E-02	-72.40
7	26	0.1600E-03	-38.62
8	1	0.9572	-87.20
8	2	0.9097	-87.28
8	3	0.8649	-87.22
8	4	0.8249	-86.98
8	5	0.7921	-86.77
8	6	0.7622	-86.93
8	7	0.7309	-87.21
8	8	0.6996	-87.45
8	9	0.6694	-87.62
8	10	0.6407	-87.73
8	11	0.6134	-87.79
8	12	0.5871	-87.80
8	13	0.5613	-87.74
8	14	0.5349	-87.54
8	15	0.5065	-87.02
8	16	0.4789	-85.89
8	17	0.4563	-84.89
8	18	0.4278	-84.62
8	19	0.3882	-83.63
8	20	0.3413	-81.18
8	21	0.2874	-76.81
8	22	0.2260	-69.42
8	23	0.1584	-56.10
8	24	0.5014E-01	21.22
8	25	0.7212E-02	-72.40
8	26	0.1835E-03	-38.62
9	1	1.073	-87.20
9	2	1.019	-87.28
9	3	0.9693	-87.22
9	4	0.9244	-86.98
9	5	0.8877	-86.77
9	6	0.8541	-86.93
9	7	0.8191	-87.21
9	8	0.7840	-87.45
9	9	0.7502	-87.62
9	10	0.7180	-87.73
9	11	0.6874	-87.79
9	12	0.6579	-87.80
9	13	0.6290	-87.74
9	14	0.5994	-87.54
9	15	0.5676	-87.02
9	16	0.5367	-85.89
9	17	0.5113	-84.89
9	18	0.4794	-84.62
9	19	0.4350	-83.63
9	20	0.3824	-81.18
9	21	0.3220	-76.82
9	22	0.2533	-69.42
9	23	0.1775	-56.10
9	24	0.5618E-01	21.22
9	25	0.8082E-02	-72.40
9	26	0.2057E-03	-38.62
10	1	1.180	-87.20
10	2	1.121	-87.28
10	3	1.066	-87.22
10	4	1.017	-86.98
10	5	0.9765	-86.77
10	6	0.9396	-86.93
10	7	0.9010	-87.21
10	8	0.8624	-87.45
10	9	0.8252	-87.62
10	10	0.7899	-87.73
10	11	0.7562	-87.79
10	12	0.7238	-87.80
10	13	0.6920	-87.74
10	14	0.6594	-87.54
10	15	0.6244	-87.02
10	16	0.5904	-85.89
10	17	0.5625	-84.89
10	18	0.5273	-84.62
10	19	0.4785	-83.63
10	20	0.4207	-81.18
10	21	0.3543	-76.81

10	22	0.2786	-69.42
10	23	0.1953	-56.10
10	24	0.6181E-01	21.22
10	25	0.8891E-02	-72.40
10	26	0.2262E-03	-38.62
11	1	1.278	-87.20
11	2	1.215	-87.28
11	3	1.155	-87.22
11	4	1.102	-86.98
11	5	1.058	-86.77
11	6	1.018	-86.93
11	7	0.9761	-87.21
11	8	0.9343	-87.45
11	9	0.8940	-87.62
11	10	0.8557	-87.73
11	11	0.8192	-87.79
11	12	0.7841	-87.80
11	13	0.7497	-87.74
11	14	0.7144	-87.54
11	15	0.6765	-87.02
11	16	0.6396	-85.89
11	17	0.6094	-84.89
11	18	0.5713	-84.62
11	19	0.5184	-83.63
11	20	0.4558	-81.18
11	21	0.3838	-76.81
11	22	0.3019	-69.42
11	23	0.2116	-56.10
11	24	0.6696E-01	21.22
11	25	0.9632E-02	-72.40
11	26	0.2451E-03	-38.62
12	1	1.367	-87.20
12	2	1.299	-87.28
12	3	1.235	-87.22
12	4	1.178	-86.98
12	5	1.131	-86.77
12	6	1.088	-86.93
12	7	1.044	-87.21
12	8	0.9991	-87.45
12	9	0.9560	-87.62
12	10	0.9150	-87.73
12	11	0.8760	-87.79
12	12	0.8385	-87.80
12	13	0.8016	-87.74
12	14	0.7639	-87.54
12	15	0.7234	-87.02
12	16	0.6840	-85.89
12	17	0.6516	-84.89
12	18	0.6109	-84.62
12	19	0.5544	-83.63
12	20	0.4874	-81.18
12	21	0.4104	-76.81
12	22	0.3228	-69.42
12	23	0.2263	-56.10
12	24	0.7160E-01	21.22
12	25	0.1030E-01	-72.40
12	26	0.2621E-03	-38.62
13	1	1.445	-87.20
13	2	1.374	-87.28
13	3	1.306	-87.22
13	4	1.245	-86.98
13	5	1.196	-86.77
13	6	1.151	-86.93
13	7	1.104	-87.21
13	8	1.056	-87.45
13	9	1.011	-87.62
13	10	0.9674	-87.73
13	11	0.9261	-87.79
13	12	0.8864	-87.80
13	13	0.8475	-87.74
13	14	0.8076	-87.54
13	15	0.7648	-87.02
13	16	0.7231	-85.89
13	17	0.6889	-84.89
13	18	0.6459	-84.62
13	19	0.5861	-83.63
13	20	0.5153	-81.18
13	21	0.4339	-76.81
13	22	0.3413	-69.42
13	23	0.2392	-56.10
13	24	0.7570E-01	21.22
13	25	0.1089E-01	-72.40
13	26	0.2771E-03	-38.62
14	1	1.512	-87.20
14	2	1.437	-87.28
14	3	1.367	-87.22

14	4	1.303	-86.98
14	5	1.252	-86.77
14	6	1.204	-86.93
14	7	1.155	-87.21
14	8	1.105	-87.45
14	9	1.058	-87.62
14	10	1.012	-87.73
14	11	0.9692	-87.79
14	12	0.9277	-87.80
14	13	0.8869	-87.74
14	14	0.8452	-87.54
14	15	0.8003	-87.02
14	16	0.7567	-85.89
14	17	0.7210	-84.89
14	18	0.6759	-84.62
14	19	0.6133	-83.63
14	20	0.5392	-81.18
14	21	0.4541	-76.81
14	22	0.3571	-69.42
14	23	0.2503	-56.10
14	24	0.7922E-01	21.22
14	25	0.1140E-01	-72.40
14	26	0.2900E-03	-38.62
15	1	1.568	-87.20
15	2	1.490	-87.28
15	3	1.417	-87.22
15	4	1.351	-86.98
15	5	1.298	-86.77
15	6	1.249	-86.93
15	7	1.197	-87.21
15	8	1.146	-87.45
15	9	1.097	-87.62
15	10	1.050	-87.73
15	11	1.005	-87.79
15	12	0.9618	-87.80
15	13	0.9196	-87.74
15	14	0.8763	-87.54
15	15	0.8298	-87.02
15	16	0.7846	-85.89
15	17	0.7475	-84.89
15	18	0.7008	-84.62
15	19	0.6359	-83.63
15	20	0.5591	-81.18
15	21	0.4708	-76.81
15	22	0.3703	-69.42
15	23	0.2596	-56.10
15	24	0.8214E-01	21.22
15	25	0.1182E-01	-72.40
15	26	0.3006E-03	-38.62
16	1	1.612	-87.20
16	2	1.532	-87.28
16	3	1.457	-87.22
16	4	1.389	-86.98
16	5	1.334	-86.77
16	6	1.283	-86.93
16	7	1.231	-87.21
16	8	1.178	-87.45
16	9	1.127	-87.62
16	10	1.079	-87.73
16	11	1.033	-87.79
16	12	0.9887	-87.80
16	13	0.9453	-87.74
16	14	0.9008	-87.54
16	15	0.8530	-87.02
16	16	0.8065	-85.89
16	17	0.7684	-84.89
16	18	0.7204	-84.62
16	19	0.6537	-83.63
16	20	0.5747	-81.18
16	21	0.4839	-76.81
16	22	0.3806	-69.42
16	23	0.2668	-56.10
16	24	0.8443E-01	21.22
16	25	0.1215E-01	-72.40
16	26	0.3090E-03	-38.62
17	1	1.643	-87.20
17	2	1.562	-87.28
17	3	1.485	-87.22
17	4	1.416	-86.98
17	5	1.360	-86.77
17	6	1.309	-86.93
17	7	1.255	-87.21
17	8	1.201	-87.45
17	9	1.149	-87.62
17	10	1.100	-87.73
17	11	1.053	-87.79

17	12	1.008	-87.80
17	13	0.9638	-87.74
17	14	0.9184	-87.54
17	15	0.8697	-87.02
17	16	0.8223	-85.89
17	17	0.7834	-84.89
17	18	0.7344	-84.62
17	19	0.6665	-83.63
17	20	0.5859	-81.18
17	21	0.4934	-76.81
17	22	0.3881	-69.42
17	23	0.2720	-56.10
17	24	0.8608E-01	21.22
17	25	0.1238E-01	-72.40
17	26	0.3151E-03	-38.62
18	1	1.662	-87.20
18	2	1.580	-87.28
18	3	1.502	-87.22
18	4	1.433	-86.98
18	5	1.376	-86.77
18	6	1.324	-86.93
18	7	1.269	-87.21
18	8	1.215	-87.45
18	9	1.163	-87.62
18	10	1.113	-87.73
18	11	1.065	-87.79
18	12	1.020	-87.80
18	13	0.9749	-87.74
18	14	0.9290	-87.54
18	15	0.8797	-87.02
18	16	0.8318	-85.89
18	17	0.7925	-84.89
18	18	0.7429	-84.62
18	19	0.6742	-83.63
18	20	0.5927	-81.18
18	21	0.4991	-76.81
18	22	0.3926	-69.42
18	23	0.2752	-56.10
18	24	0.8708E-01	21.22
18	25	0.1253E-01	-72.40
18	26	0.3187E-03	-38.62
19	1	1.669	-87.20
19	2	1.586	-87.28
19	3	1.508	-87.22
19	4	1.438	-86.98
19	5	1.381	-86.77
19	6	1.329	-86.93
19	7	1.274	-87.21
19	8	1.220	-87.45
19	9	1.167	-87.62
19	10	1.117	-87.73
19	11	1.069	-87.79
19	12	1.024	-87.80
19	13	0.9786	-87.74
19	14	0.9325	-87.54
19	15	0.8831	-87.02
19	16	0.8350	-85.89
19	17	0.7955	-84.89
19	18	0.7458	-84.62
19	19	0.6767	-83.63
19	20	0.5950	-81.18
19	21	0.5010	-76.81
19	22	0.3941	-69.42
19	23	0.2762	-56.10
19	24	0.8741E-01	21.22
19	25	0.1257E-01	-72.40
19	26	0.3199E-03	-38.62

'---

HEAVE MOTION TRANSFER FUNCTION

'---

'idir	ifreq	ampl	phase
1	1	1.028	-0.19
1	2	1.031	-0.22
1	3	1.035	-0.26
1	4	1.040	-0.33
1	5	1.046	-0.41
1	6	1.054	-0.47
1	7	1.064	-0.54
1	8	1.077	-0.67
1	9	1.095	-0.90
1	10	1.120	-1.28
1	11	1.155	-1.94
1	12	1.208	-3.16
1	13	1.288	-5.67
1	14	1.405	-11.24
1	15	1.518	-23.54

1	16	1.451	-45.02
1	17	1.086	-71.28
1	18	0.6098	-93.15
1	19	0.2757	-101.33
1	20	0.1050	-92.95
1	21	0.2714E-01	-48.73
1	22	0.3003E-01	61.13
1	23	0.4434E-01	92.98
1	24	0.1488E-01	172.36
1	25	0.8410E-03	105.80
1	26	0.1232E-05	173.26
2	1	1.028	-0.19
2	2	1.031	-0.22
2	3	1.035	-0.26
2	4	1.040	-0.33
2	5	1.046	-0.41
2	6	1.054	-0.47
2	7	1.064	-0.54
2	8	1.077	-0.67
2	9	1.095	-0.90
2	10	1.120	-1.28
2	11	1.155	-1.94
2	12	1.208	-3.16
2	13	1.288	-5.67
2	14	1.405	-11.24
2	15	1.518	-23.54
2	16	1.451	-45.02
2	17	1.086	-71.28
2	18	0.6098	-93.15
2	19	0.2757	-101.33
2	20	0.1050	-92.95
2	21	0.2714E-01	-48.73
2	22	0.3003E-01	61.13
2	23	0.4434E-01	92.98
2	24	0.1488E-01	172.36
2	25	0.8410E-03	105.80
2	26	0.1232E-05	173.26
3	1	1.028	-0.19
3	2	1.031	-0.22
3	3	1.035	-0.26
3	4	1.040	-0.33
3	5	1.046	-0.41
3	6	1.054	-0.47
3	7	1.064	-0.54
3	8	1.077	-0.67
3	9	1.095	-0.90
3	10	1.120	-1.28
3	11	1.155	-1.94
3	12	1.208	-3.16
3	13	1.288	-5.67
3	14	1.405	-11.24
3	15	1.518	-23.54
3	16	1.451	-45.02
3	17	1.086	-71.28
3	18	0.6098	-93.15
3	19	0.2757	-101.33
3	20	0.1050	-92.95
3	21	0.2714E-01	-48.73
3	22	0.3003E-01	61.13
3	23	0.4434E-01	92.98
3	24	0.1488E-01	172.36
3	25	0.8410E-03	105.80
3	26	0.1232E-05	173.26
4	1	1.028	-0.19
4	2	1.031	-0.22
4	3	1.035	-0.26
4	4	1.040	-0.33
4	5	1.046	-0.41
4	6	1.054	-0.47
4	7	1.064	-0.54
4	8	1.077	-0.67
4	9	1.095	-0.90
4	10	1.120	-1.28
4	11	1.155	-1.94
4	12	1.208	-3.16
4	13	1.288	-5.67
4	14	1.405	-11.24
4	15	1.518	-23.54
4	16	1.451	-45.02
4	17	1.086	-71.28
4	18	0.6098	-93.15
4	19	0.2757	-101.33
4	20	0.1050	-92.95
4	21	0.2714E-01	-48.73
4	22	0.3003E-01	61.13
4	23	0.4434E-01	92.98

4	24	0.1488E-01	172.36
4	25	0.8410E-03	105.80
4	26	0.1232E-05	173.26
5	1	1.028	-0.19
5	2	1.031	-0.22
5	3	1.035	-0.26
5	4	1.040	-0.33
5	5	1.046	-0.41
5	6	1.054	-0.47
5	7	1.064	-0.54
5	8	1.077	-0.67
5	9	1.095	-0.90
5	10	1.120	-1.28
5	11	1.155	-1.94
5	12	1.208	-3.16
5	13	1.288	-5.67
5	14	1.405	-11.24
5	15	1.518	-23.54
5	16	1.451	-45.02
5	17	1.086	-71.28
5	18	0.6098	-93.15
5	19	0.2757	-101.33
5	20	0.1050	-92.95
5	21	0.2714E-01	-48.73
5	22	0.3003E-01	61.13
5	23	0.4434E-01	92.98
5	24	0.1488E-01	172.36
5	25	0.8410E-03	105.80
5	26	0.1232E-05	173.26
6	1	1.028	-0.19
6	2	1.031	-0.22
6	3	1.035	-0.26
6	4	1.040	-0.33
6	5	1.046	-0.41
6	6	1.054	-0.47
6	7	1.064	-0.54
6	8	1.077	-0.67
6	9	1.095	-0.90
6	10	1.120	-1.28
6	11	1.155	-1.94
6	12	1.208	-3.16
6	13	1.288	-5.67
6	14	1.405	-11.24
6	15	1.518	-23.54
6	16	1.451	-45.02
6	17	1.086	-71.28
6	18	0.6098	-93.15
6	19	0.2757	-101.33
6	20	0.1050	-92.95
6	21	0.2714E-01	-48.73
6	22	0.3003E-01	61.13
6	23	0.4434E-01	92.98
6	24	0.1488E-01	172.36
6	25	0.8410E-03	105.80
6	26	0.1232E-05	173.26
7	1	1.028	-0.19
7	2	1.031	-0.22
7	3	1.035	-0.26
7	4	1.040	-0.33
7	5	1.046	-0.41
7	6	1.054	-0.47
7	7	1.064	-0.54
7	8	1.077	-0.67
7	9	1.095	-0.90
7	10	1.120	-1.28
7	11	1.155	-1.94
7	12	1.208	-3.16
7	13	1.288	-5.67
7	14	1.405	-11.24
7	15	1.518	-23.54
7	16	1.451	-45.02
7	17	1.086	-71.28
7	18	0.6098	-93.15
7	19	0.2757	-101.33
7	20	0.1050	-92.95
7	21	0.2714E-01	-48.73
7	22	0.3003E-01	61.13
7	23	0.4434E-01	92.98
7	24	0.1488E-01	172.36
7	25	0.8410E-03	105.80
7	26	0.1232E-05	173.26
8	1	1.028	-0.19
8	2	1.031	-0.22
8	3	1.035	-0.26
8	4	1.040	-0.33
8	5	1.046	-0.41

8	6	1.054	-0.47
8	7	1.064	-0.54
8	8	1.077	-0.67
8	9	1.095	-0.90
8	10	1.120	-1.28
8	11	1.155	-1.94
8	12	1.208	-3.16
8	13	1.288	-5.67
8	14	1.405	-11.24
8	15	1.518	-23.54
8	16	1.451	-45.02
8	17	1.086	-71.28
8	18	0.6098	-93.15
8	19	0.2757	-101.33
8	20	0.1050	-92.95
8	21	0.2714E-01	-48.73
8	22	0.3003E-01	61.13
8	23	0.4434E-01	92.98
8	24	0.1488E-01	172.36
8	25	0.8410E-03	105.80
8	26	0.1232E-05	173.26
9	1	1.028	-0.19
9	2	1.031	-0.22
9	3	1.035	-0.26
9	4	1.040	-0.33
9	5	1.046	-0.41
9	6	1.054	-0.47
9	7	1.064	-0.54
9	8	1.077	-0.67
9	9	1.095	-0.90
9	10	1.120	-1.28
9	11	1.155	-1.94
9	12	1.208	-3.16
9	13	1.288	-5.67
9	14	1.405	-11.24
9	15	1.518	-23.54
9	16	1.451	-45.02
9	17	1.086	-71.28
9	18	0.6098	-93.15
9	19	0.2757	-101.33
9	20	0.1050	-92.95
9	21	0.2714E-01	-48.73
9	22	0.3003E-01	61.13
9	23	0.4434E-01	92.98
9	24	0.1488E-01	172.36
9	25	0.8410E-03	105.80
9	26	0.1232E-05	173.26
10	1	1.028	-0.19
10	2	1.031	-0.22
10	3	1.035	-0.26
10	4	1.040	-0.33
10	5	1.046	-0.41
10	6	1.054	-0.47
10	7	1.064	-0.54
10	8	1.077	-0.67
10	9	1.095	-0.90
10	10	1.120	-1.28
10	11	1.155	-1.94
10	12	1.208	-3.16
10	13	1.288	-5.67
10	14	1.405	-11.24
10	15	1.518	-23.54
10	16	1.451	-45.02
10	17	1.086	-71.28
10	18	0.6098	-93.15
10	19	0.2757	-101.33
10	20	0.1050	-92.95
10	21	0.2714E-01	-48.73
10	22	0.3003E-01	61.13
10	23	0.4434E-01	92.98
10	24	0.1488E-01	172.36
10	25	0.8410E-03	105.80
10	26	0.1232E-05	173.26
11	1	1.028	-0.19
11	2	1.031	-0.22
11	3	1.035	-0.26
11	4	1.040	-0.33
11	5	1.046	-0.41
11	6	1.054	-0.47
11	7	1.064	-0.54
11	8	1.077	-0.67
11	9	1.095	-0.90
11	10	1.120	-1.28
11	11	1.155	-1.94
11	12	1.208	-3.16
11	13	1.288	-5.67

11	14	1.405	-11.24
11	15	1.518	-23.54
11	16	1.451	-45.02
11	17	1.086	-71.28
11	18	0.6098	-93.15
11	19	0.2757	-101.33
11	20	0.1050	-92.95
11	21	0.2714E-01	-48.73
11	22	0.3003E-01	61.13
11	23	0.4434E-01	92.98
11	24	0.1488E-01	172.36
11	25	0.8410E-03	105.80
11	26	0.1232E-05	173.26
12	1	1.028	-0.19
12	2	1.031	-0.22
12	3	1.035	-0.26
12	4	1.040	-0.33
12	5	1.046	-0.41
12	6	1.054	-0.47
12	7	1.064	-0.54
12	8	1.077	-0.67
12	9	1.095	-0.90
12	10	1.120	-1.28
12	11	1.155	-1.94
12	12	1.208	-3.16
12	13	1.288	-5.67
12	14	1.405	-11.24
12	15	1.518	-23.54
12	16	1.451	-45.02
12	17	1.086	-71.28
12	18	0.6098	-93.15
12	19	0.2757	-101.33
12	20	0.1050	-92.95
12	21	0.2714E-01	-48.73
12	22	0.3003E-01	61.13
12	23	0.4434E-01	92.98
12	24	0.1488E-01	172.36
12	25	0.8410E-03	105.80
12	26	0.1232E-05	173.26
13	1	1.028	-0.19
13	2	1.031	-0.22
13	3	1.035	-0.26
13	4	1.040	-0.33
13	5	1.046	-0.41
13	6	1.054	-0.47
13	7	1.064	-0.54
13	8	1.077	-0.67
13	9	1.095	-0.90
13	10	1.120	-1.28
13	11	1.155	-1.94
13	12	1.208	-3.16
13	13	1.288	-5.67
13	14	1.405	-11.24
13	15	1.518	-23.54
13	16	1.451	-45.02
13	17	1.086	-71.28
13	18	0.6098	-93.15
13	19	0.2757	-101.33
13	20	0.1050	-92.95
13	21	0.2714E-01	-48.73
13	22	0.3003E-01	61.13
13	23	0.4434E-01	92.98
13	24	0.1488E-01	172.36
13	25	0.8410E-03	105.80
13	26	0.1232E-05	173.26
14	1	1.028	-0.19
14	2	1.031	-0.22
14	3	1.035	-0.26
14	4	1.040	-0.33
14	5	1.046	-0.41
14	6	1.054	-0.47
14	7	1.064	-0.54
14	8	1.077	-0.67
14	9	1.095	-0.90
14	10	1.120	-1.28
14	11	1.155	-1.94
14	12	1.208	-3.16
14	13	1.288	-5.67
14	14	1.405	-11.24
14	15	1.518	-23.54
14	16	1.451	-45.02
14	17	1.086	-71.28
14	18	0.6098	-93.15
14	19	0.2757	-101.33
14	20	0.1050	-92.95
14	21	0.2714E-01	-48.73

14	22	0.3003E-01	61.13
14	23	0.4434E-01	92.98
14	24	0.1488E-01	172.36
14	25	0.8410E-03	105.80
14	26	0.1232E-05	173.26
15	1	1.028	-0.19
15	2	1.031	-0.22
15	3	1.035	-0.26
15	4	1.040	-0.33
15	5	1.046	-0.41
15	6	1.054	-0.47
15	7	1.064	-0.54
15	8	1.077	-0.67
15	9	1.095	-0.90
15	10	1.120	-1.28
15	11	1.155	-1.94
15	12	1.208	-3.16
15	13	1.288	-5.67
15	14	1.405	-11.24
15	15	1.518	-23.54
15	16	1.451	-45.02
15	17	1.086	-71.28
15	18	0.6098	-93.15
15	19	0.2757	-101.33
15	20	0.1050	-92.95
15	21	0.2714E-01	-48.73
15	22	0.3003E-01	61.13
15	23	0.4434E-01	92.98
15	24	0.1488E-01	172.36
15	25	0.8410E-03	105.80
15	26	0.1232E-05	173.26
16	1	1.028	-0.19
16	2	1.031	-0.22
16	3	1.035	-0.26
16	4	1.040	-0.33
16	5	1.046	-0.41
16	6	1.054	-0.47
16	7	1.064	-0.54
16	8	1.077	-0.67
16	9	1.095	-0.90
16	10	1.120	-1.28
16	11	1.155	-1.94
16	12	1.208	-3.16
16	13	1.288	-5.67
16	14	1.405	-11.24
16	15	1.518	-23.54
16	16	1.451	-45.02
16	17	1.086	-71.28
16	18	0.6098	-93.15
16	19	0.2757	-101.33
16	20	0.1050	-92.95
16	21	0.2714E-01	-48.73
16	22	0.3003E-01	61.13
16	23	0.4434E-01	92.98
16	24	0.1488E-01	172.36
16	25	0.8410E-03	105.80
16	26	0.1232E-05	173.26
17	1	1.028	-0.19
17	2	1.031	-0.22
17	3	1.035	-0.26
17	4	1.040	-0.33
17	5	1.046	-0.41
17	6	1.054	-0.47
17	7	1.064	-0.54
17	8	1.077	-0.67
17	9	1.095	-0.90
17	10	1.120	-1.28
17	11	1.155	-1.94
17	12	1.208	-3.16
17	13	1.288	-5.67
17	14	1.405	-11.24
17	15	1.518	-23.54
17	16	1.451	-45.02
17	17	1.086	-71.28
17	18	0.6098	-93.15
17	19	0.2757	-101.33
17	20	0.1050	-92.95
17	21	0.2714E-01	-48.73
17	22	0.3003E-01	61.13
17	23	0.4434E-01	92.98
17	24	0.1488E-01	172.36
17	25	0.8410E-03	105.80
17	26	0.1232E-05	173.26
18	1	1.028	-0.19
18	2	1.031	-0.22
18	3	1.035	-0.26

18	4	1.040	-0.33
18	5	1.046	-0.41
18	6	1.054	-0.47
18	7	1.064	-0.54
18	8	1.077	-0.67
18	9	1.095	-0.90
18	10	1.120	-1.28
18	11	1.155	-1.94
18	12	1.208	-3.16
18	13	1.288	-5.67
18	14	1.405	-11.24
18	15	1.518	-23.54
18	16	1.451	-45.02
18	17	1.086	-71.28
18	18	0.6098	-93.15
18	19	0.2757	-101.33
18	20	0.1050	-92.95
18	21	0.2714E-01	-48.73
18	22	0.3003E-01	61.13
18	23	0.4434E-01	92.98
18	24	0.1488E-01	172.36
18	25	0.8410E-03	105.80
18	26	0.1232E-05	173.26
19	1	1.028	-0.19
19	2	1.031	-0.22
19	3	1.035	-0.26
19	4	1.040	-0.33
19	5	1.046	-0.41
19	6	1.054	-0.47
19	7	1.064	-0.54
19	8	1.077	-0.67
19	9	1.095	-0.90
19	10	1.120	-1.28
19	11	1.155	-1.94
19	12	1.208	-3.16
19	13	1.288	-5.67
19	14	1.405	-11.24
19	15	1.518	-23.54
19	16	1.451	-45.02
19	17	1.086	-71.28
19	18	0.6098	-93.15
19	19	0.2757	-101.33
19	20	0.1050	-92.95
19	21	0.2714E-01	-48.73
19	22	0.3003E-01	61.13
19	23	0.4434E-01	92.98
19	24	0.1488E-01	172.36
19	25	0.8410E-03	105.80
19	26	0.1232E-05	173.26

'---

ROLL MOTION TRANSFER FUNCTION

'---

'idir	ifreq	ampl	phase
1	1	0.1102E-17	-95.77
1	2	0.1288E-17	-101.86
1	3	0.1504E-17	-112.55
1	4	0.1637E-17	-129.93
1	5	0.1486E-17	-151.73
1	6	0.1101E-17	-168.38
1	7	0.7621E-18	-172.65
1	8	0.5602E-18	-165.67
1	9	0.4734E-18	-151.93
1	10	0.4672E-18	-137.49
1	11	0.5109E-18	-126.27
1	12	0.5871E-18	-118.63
1	13	0.6960E-18	-113.62
1	14	0.8584E-18	-110.60
1	15	0.1104E-17	-110.80
1	16	0.1322E-17	-116.92
1	17	0.1241E-17	-123.16
1	18	0.1030E-17	-116.69
1	19	0.9892E-18	-105.97
1	20	0.9812E-18	-99.87
1	21	0.9105E-18	-94.67
1	22	0.7486E-18	-86.17
1	23	0.5176E-18	-66.35
1	24	0.2335E-18	23.06
1	25	0.1197E-19	-72.44
1	26	0.1270E-24	-107.38
2	1	0.7840E-03	-95.77
2	2	0.9163E-03	-101.86
2	3	0.1070E-02	-112.55
2	4	0.1165E-02	-129.93
2	5	0.1057E-02	-151.73
2	6	0.7836E-03	-168.38
2	7	0.5424E-03	-172.65

2	8	0.3987E-03	-165.67
2	9	0.3369E-03	-151.93
2	10	0.3325E-03	-137.49
2	11	0.3636E-03	-126.27
2	12	0.4178E-03	-118.63
2	13	0.4953E-03	-113.62
2	14	0.6109E-03	-110.60
2	15	0.7858E-03	-110.80
2	16	0.9406E-03	-116.92
2	17	0.8835E-03	-123.16
2	18	0.7328E-03	-116.69
2	19	0.7040E-03	-105.97
2	20	0.6983E-03	-99.87
2	21	0.6480E-03	-94.67
2	22	0.5327E-03	-86.17
2	23	0.3684E-03	-66.35
2	24	0.1662E-03	23.06
2	25	0.8517E-05	-72.44
2	26	0.9040E-10	-107.38
3	1	0.1562E-02	-95.77
3	2	0.1826E-02	-101.86
3	3	0.2133E-02	-112.55
3	4	0.2321E-02	-129.93
3	5	0.2107E-02	-151.73
3	6	0.1561E-02	-168.38
3	7	0.1081E-02	-172.65
3	8	0.7944E-03	-165.67
3	9	0.6713E-03	-151.93
3	10	0.6625E-03	-137.49
3	11	0.7244E-03	-126.27
3	12	0.8325E-03	-118.63
3	13	0.9868E-03	-113.62
3	14	0.1217E-02	-110.60
3	15	0.1566E-02	-110.80
3	16	0.1874E-02	-116.92
3	17	0.1760E-02	-123.16
3	18	0.1460E-02	-116.69
3	19	0.1403E-02	-105.97
3	20	0.1391E-02	-99.87
3	21	0.1291E-02	-94.67
3	22	0.1061E-02	-86.17
3	23	0.7339E-03	-66.35
3	24	0.3310E-03	23.06
3	25	0.1697E-04	-72.44
3	26	0.1801E-09	-107.38
4	1	0.2328E-02	-95.77
4	2	0.2721E-02	-101.86
4	3	0.3179E-02	-112.55
4	4	0.3459E-02	-129.93
4	5	0.3140E-02	-151.73
4	6	0.2327E-02	-168.38
4	7	0.1611E-02	-172.65
4	8	0.1184E-02	-165.67
4	9	0.1001E-02	-151.93
4	10	0.9874E-03	-137.49
4	11	0.1080E-02	-126.27
4	12	0.1241E-02	-118.63
4	13	0.1471E-02	-113.62
4	14	0.1814E-02	-110.60
4	15	0.2333E-02	-110.80
4	16	0.2793E-02	-116.92
4	17	0.2624E-02	-123.16
4	18	0.2176E-02	-116.69
4	19	0.2091E-02	-105.97
4	20	0.2074E-02	-99.87
4	21	0.1924E-02	-94.67
4	22	0.1582E-02	-86.17
4	23	0.1094E-02	-66.35
4	24	0.4934E-03	23.06
4	25	0.2529E-04	-72.44
4	26	0.2685E-09	-107.38
5	1	0.3076E-02	-95.77
5	2	0.3596E-02	-101.86
5	3	0.4201E-02	-112.55
5	4	0.4571E-02	-129.93
5	5	0.4149E-02	-151.73
5	6	0.3075E-02	-168.38
5	7	0.2128E-02	-172.65
5	8	0.1565E-02	-165.67
5	9	0.1322E-02	-151.93
5	10	0.1305E-02	-137.49
5	11	0.1427E-02	-126.27
5	12	0.1640E-02	-118.63
5	13	0.1944E-02	-113.62
5	14	0.2397E-02	-110.60
5	15	0.3084E-02	-110.80

5	16	0.3691E-02	-116.92
5	17	0.3467E-02	-123.16
5	18	0.2876E-02	-116.69
5	19	0.2763E-02	-105.97
5	20	0.2740E-02	-99.87
5	21	0.2543E-02	-94.67
5	22	0.2091E-02	-86.17
5	23	0.1446E-02	-66.35
5	24	0.6520E-03	23.06
5	25	0.3342E-04	-72.44
5	26	0.3547E-09	-107.38
6	1	0.3801E-02	-95.77
6	2	0.4443E-02	-101.86
6	3	0.5190E-02	-112.55
6	4	0.5648E-02	-129.93
6	5	0.5127E-02	-151.73
6	6	0.3800E-02	-168.38
6	7	0.2630E-02	-172.65
6	8	0.1933E-02	-165.67
6	9	0.1634E-02	-151.93
6	10	0.1612E-02	-137.49
6	11	0.1763E-02	-126.27
6	12	0.2026E-02	-118.63
6	13	0.2402E-02	-113.62
6	14	0.2962E-02	-110.60
6	15	0.3810E-02	-110.80
6	16	0.4561E-02	-116.92
6	17	0.4284E-02	-123.16
6	18	0.3554E-02	-116.69
6	19	0.3414E-02	-105.97
6	20	0.3386E-02	-99.87
6	21	0.3142E-02	-94.67
6	22	0.2583E-02	-86.17
6	23	0.1786E-02	-66.35
6	24	0.8057E-03	23.06
6	25	0.4130E-04	-72.44
6	26	0.4383E-09	-107.38
7	1	0.4497E-02	-95.77
7	2	0.5257E-02	-101.86
7	3	0.6141E-02	-112.55
7	4	0.6682E-02	-129.93
7	5	0.6066E-02	-151.73
7	6	0.4495E-02	-168.38
7	7	0.3111E-02	-172.65
7	8	0.2287E-02	-165.67
7	9	0.1933E-02	-151.93
7	10	0.1907E-02	-137.49
7	11	0.2086E-02	-126.27
7	12	0.2397E-02	-118.63
7	13	0.2841E-02	-113.62
7	14	0.3505E-02	-110.60
7	15	0.4508E-02	-110.80
7	16	0.5396E-02	-116.92
7	17	0.5068E-02	-123.16
7	18	0.4204E-02	-116.69
7	19	0.4039E-02	-105.97
7	20	0.4006E-02	-99.87
7	21	0.3717E-02	-94.67
7	22	0.3056E-02	-86.17
7	23	0.2113E-02	-66.35
7	24	0.9532E-03	23.06
7	25	0.4886E-04	-72.44
7	26	0.5186E-09	-107.38
8	1	0.5159E-02	-95.77
8	2	0.6030E-02	-101.86
8	3	0.7045E-02	-112.55
8	4	0.7665E-02	-129.93
8	5	0.6959E-02	-151.73
8	6	0.5157E-02	-168.38
8	7	0.3569E-02	-172.65
8	8	0.2624E-02	-165.67
8	9	0.2217E-02	-151.93
8	10	0.2188E-02	-137.49
8	11	0.2393E-02	-126.27
8	12	0.2750E-02	-118.63
8	13	0.3260E-02	-113.62
8	14	0.4020E-02	-110.60
8	15	0.5171E-02	-110.80
8	16	0.6190E-02	-116.92
8	17	0.5814E-02	-123.16
8	18	0.4823E-02	-116.69
8	19	0.4633E-02	-105.97
8	20	0.4596E-02	-99.87
8	21	0.4264E-02	-94.67
8	22	0.3506E-02	-86.17
8	23	0.2424E-02	-66.35

8	24	0.1093E-02	23.06
8	25	0.5605E-04	-72.44
8	26	0.5949E-09	-107.38
9	1	0.5782E-02	-95.77
9	2	0.6758E-02	-101.86
9	3	0.7895E-02	-112.55
9	4	0.8590E-02	-129.93
9	5	0.7798E-02	-151.73
9	6	0.5779E-02	-168.38
9	7	0.4000E-02	-172.65
9	8	0.2940E-02	-165.67
9	9	0.2485E-02	-151.93
9	10	0.2452E-02	-137.49
9	11	0.2681E-02	-126.27
9	12	0.3082E-02	-118.63
9	13	0.3653E-02	-113.62
9	14	0.4506E-02	-110.60
9	15	0.5795E-02	-110.80
9	16	0.6937E-02	-116.92
9	17	0.6516E-02	-123.16
9	18	0.5405E-02	-116.69
9	19	0.5192E-02	-105.97
9	20	0.5150E-02	-99.87
9	21	0.4779E-02	-94.67
9	22	0.3929E-02	-86.17
9	23	0.2717E-02	-66.35
9	24	0.1225E-02	23.06
9	25	0.6282E-04	-72.44
9	26	0.6667E-09	-107.38
10	1	0.6360E-02	-95.77
10	2	0.7434E-02	-101.86
10	3	0.8685E-02	-112.55
10	4	0.9450E-02	-129.93
10	5	0.8578E-02	-151.73
10	6	0.6358E-02	-168.38
10	7	0.4400E-02	-172.65
10	8	0.3235E-02	-165.67
10	9	0.2734E-02	-151.93
10	10	0.2698E-02	-137.49
10	11	0.2950E-02	-126.27
10	12	0.3390E-02	-118.63
10	13	0.4018E-02	-113.62
10	14	0.4956E-02	-110.60
10	15	0.6375E-02	-110.80
10	16	0.7631E-02	-116.92
10	17	0.7168E-02	-123.16
10	18	0.5946E-02	-116.69
10	19	0.5712E-02	-105.97
10	20	0.5666E-02	-99.87
10	21	0.5257E-02	-94.67
10	22	0.4322E-02	-86.17
10	23	0.2989E-02	-66.35
10	24	0.1348E-02	23.06
10	25	0.6910E-04	-72.44
10	26	0.7334E-09	-107.38
11	1	0.6890E-02	-95.77
11	2	0.8054E-02	-101.86
11	3	0.9408E-02	-112.55
11	4	0.1024E-01	-129.93
11	5	0.9293E-02	-151.73
11	6	0.6887E-02	-168.38
11	7	0.4767E-02	-172.65
11	8	0.3504E-02	-165.67
11	9	0.2961E-02	-151.93
11	10	0.2922E-02	-137.49
11	11	0.3196E-02	-126.27
11	12	0.3673E-02	-118.63
11	13	0.4353E-02	-113.62
11	14	0.5370E-02	-110.60
11	15	0.6907E-02	-110.80
11	16	0.8267E-02	-116.92
11	17	0.7765E-02	-123.16
11	18	0.6441E-02	-116.69
11	19	0.6188E-02	-105.97
11	20	0.6138E-02	-99.87
11	21	0.5695E-02	-94.67
11	22	0.4682E-02	-86.17
11	23	0.3238E-02	-66.35
11	24	0.1460E-02	23.06
11	25	0.7486E-04	-72.44
11	26	0.7946E-09	-107.38
12	1	0.7368E-02	-95.77
12	2	0.8612E-02	-101.86
12	3	0.1006E-01	-112.55
12	4	0.1095E-01	-129.93
12	5	0.9938E-02	-151.73

12	6	0.7365E-02	-168.38
12	7	0.5097E-02	-172.65
12	8	0.3747E-02	-165.67
12	9	0.3167E-02	-151.93
12	10	0.3125E-02	-137.49
12	11	0.3417E-02	-126.27
12	12	0.3927E-02	-118.63
12	13	0.4655E-02	-113.62
12	14	0.5742E-02	-110.60
12	15	0.7385E-02	-110.80
12	16	0.8841E-02	-116.92
12	17	0.8303E-02	-123.16
12	18	0.6888E-02	-116.69
12	19	0.6617E-02	-105.97
12	20	0.6563E-02	-99.87
12	21	0.6090E-02	-94.67
12	22	0.5007E-02	-86.17
12	23	0.3462E-02	-66.35
12	24	0.1562E-02	23.06
12	25	0.8005E-04	-72.44
12	26	0.8496E-09	-107.38
13	1	0.7790E-02	-95.77
13	2	0.9105E-02	-101.86
13	3	0.1064E-01	-112.55
13	4	0.1157E-01	-129.93
13	5	0.1051E-01	-151.73
13	6	0.7786E-02	-168.38
13	7	0.5389E-02	-172.65
13	8	0.3962E-02	-165.67
13	9	0.3348E-02	-151.93
13	10	0.3304E-02	-137.49
13	11	0.3613E-02	-126.27
13	12	0.4152E-02	-118.63
13	13	0.4922E-02	-113.62
13	14	0.6070E-02	-110.60
13	15	0.7808E-02	-110.80
13	16	0.9346E-02	-116.92
13	17	0.8779E-02	-123.16
13	18	0.7282E-02	-116.69
13	19	0.6996E-02	-105.97
13	20	0.6939E-02	-99.87
13	21	0.6439E-02	-94.67
13	22	0.5294E-02	-86.17
13	23	0.3660E-02	-66.35
13	24	0.1651E-02	23.06
13	25	0.8463E-04	-72.44
13	26	0.8983E-09	-107.38
14	1	0.8152E-02	-95.77
14	2	0.9529E-02	-101.86
14	3	0.1113E-01	-112.55
14	4	0.1211E-01	-129.93
14	5	0.1100E-01	-151.73
14	6	0.8149E-02	-168.38
14	7	0.5640E-02	-172.65
14	8	0.4146E-02	-165.67
14	9	0.3504E-02	-151.93
14	10	0.3458E-02	-137.49
14	11	0.3781E-02	-126.27
14	12	0.4345E-02	-118.63
14	13	0.5150E-02	-113.62
14	14	0.6353E-02	-110.60
14	15	0.8171E-02	-110.80
14	16	0.9781E-02	-116.92
14	17	0.9187E-02	-123.16
14	18	0.7621E-02	-116.69
14	19	0.7321E-02	-105.97
14	20	0.7262E-02	-99.87
14	21	0.6738E-02	-94.67
14	22	0.5540E-02	-86.17
14	23	0.3831E-02	-66.35
14	24	0.1728E-02	23.06
14	25	0.8857E-04	-72.44
14	26	0.9400E-09	-107.38
15	1	0.8452E-02	-95.77
15	2	0.9880E-02	-101.86
15	3	0.1154E-01	-112.55
15	4	0.1256E-01	-129.93
15	5	0.1140E-01	-151.73
15	6	0.8449E-02	-168.38
15	7	0.5848E-02	-172.65
15	8	0.4299E-02	-165.67
15	9	0.3633E-02	-151.93
15	10	0.3585E-02	-137.49
15	11	0.3920E-02	-126.27
15	12	0.4505E-02	-118.63
15	13	0.5340E-02	-113.62

15	14	0.6587E-02	-110.60
15	15	0.8472E-02	-110.80
15	16	0.1014E-01	-116.92
15	17	0.9525E-02	-123.16
15	18	0.7901E-02	-116.69
15	19	0.7591E-02	-105.97
15	20	0.7529E-02	-99.87
15	21	0.6986E-02	-94.67
15	22	0.5744E-02	-86.17
15	23	0.3972E-02	-66.35
15	24	0.1791E-02	23.06
15	25	0.9183E-04	-72.44
15	26	0.9747E-09	-107.38
16	1	0.8688E-02	-95.77
16	2	0.1016E-01	-101.86
16	3	0.1186E-01	-112.55
16	4	0.1291E-01	-129.93
16	5	0.1172E-01	-151.73
16	6	0.8685E-02	-168.38
16	7	0.6011E-02	-172.65
16	8	0.4419E-02	-165.67
16	9	0.3734E-02	-151.93
16	10	0.3685E-02	-137.49
16	11	0.4029E-02	-126.27
16	12	0.4631E-02	-118.63
16	13	0.5489E-02	-113.62
16	14	0.6771E-02	-110.60
16	15	0.8709E-02	-110.80
16	16	0.1042E-01	-116.92
16	17	0.9791E-02	-123.16
16	18	0.8122E-02	-116.69
16	19	0.7803E-02	-105.97
16	20	0.7739E-02	-99.87
16	21	0.7181E-02	-94.67
16	22	0.5904E-02	-86.17
16	23	0.4083E-02	-66.35
16	24	0.1841E-02	23.06
16	25	0.9440E-04	-72.44
16	26	0.1002E-08	-107.38
17	1	0.8858E-02	-95.77
17	2	0.1035E-01	-101.86
17	3	0.1210E-01	-112.55
17	4	0.1316E-01	-129.93
17	5	0.1195E-01	-151.73
17	6	0.8854E-02	-168.38
17	7	0.6128E-02	-172.65
17	8	0.4505E-02	-165.67
17	9	0.3807E-02	-151.93
17	10	0.3757E-02	-137.49
17	11	0.4108E-02	-126.27
17	12	0.4721E-02	-118.63
17	13	0.5597E-02	-113.62
17	14	0.6903E-02	-110.60
17	15	0.8879E-02	-110.80
17	16	0.1063E-01	-116.92
17	17	0.9983E-02	-123.16
17	18	0.8281E-02	-116.69
17	19	0.7955E-02	-105.97
17	20	0.7891E-02	-99.87
17	21	0.7322E-02	-94.67
17	22	0.6020E-02	-86.17
17	23	0.4162E-02	-66.35
17	24	0.1877E-02	23.06
17	25	0.9624E-04	-72.44
17	26	0.1021E-08	-107.38
18	1	0.8961E-02	-95.77
18	2	0.1047E-01	-101.86
18	3	0.1224E-01	-112.55
18	4	0.1331E-01	-129.93
18	5	0.1209E-01	-151.73
18	6	0.8957E-02	-168.38
18	7	0.6199E-02	-172.65
18	8	0.4557E-02	-165.67
18	9	0.3851E-02	-151.93
18	10	0.3800E-02	-137.49
18	11	0.4156E-02	-126.27
18	12	0.4776E-02	-118.63
18	13	0.5661E-02	-113.62
18	14	0.6983E-02	-110.60
18	15	0.8982E-02	-110.80
18	16	0.1075E-01	-116.92
18	17	0.1010E-01	-123.16
18	18	0.8376E-02	-116.69
18	19	0.8047E-02	-105.97
18	20	0.7982E-02	-99.87
18	21	0.7406E-02	-94.67

18	22	0.6089E-02	-86.17
18	23	0.4210E-02	-66.35
18	24	0.1899E-02	23.06
18	25	0.9735E-04	-72.44
18	26	0.1033E-08	-107.38
19	1	0.8995E-02	-95.77
19	2	0.1051E-01	-101.86
19	3	0.1228E-01	-112.55
19	4	0.1336E-01	-129.93
19	5	0.1213E-01	-151.73
19	6	0.8991E-02	-168.38
19	7	0.6223E-02	-172.65
19	8	0.4575E-02	-165.67
19	9	0.3866E-02	-151.93
19	10	0.3815E-02	-137.49
19	11	0.4172E-02	-126.27
19	12	0.4794E-02	-118.63
19	13	0.5683E-02	-113.62
19	14	0.7009E-02	-110.60
19	15	0.9016E-02	-110.80
19	16	0.1079E-01	-116.92
19	17	0.1014E-01	-123.16
19	18	0.8408E-02	-116.69
19	19	0.8078E-02	-105.97
19	20	0.8012E-02	-99.87
19	21	0.7435E-02	-94.67
19	22	0.6112E-02	-86.17
19	23	0.4227E-02	-66.35
19	24	0.1906E-02	23.06
19	25	0.9773E-04	-72.44
19	26	0.1037E-08	-107.38

'---

PITCH MOTION TRANSFER FUNCTION

'---

'idir	ifreq	ampl	phase
1	1	0.8995E-02	84.23
1	2	0.1051E-01	78.14
1	3	0.1228E-01	67.45
1	4	0.1336E-01	50.07
1	5	0.1213E-01	28.27
1	6	0.8991E-02	11.62
1	7	0.6223E-02	7.35
1	8	0.4575E-02	14.33
1	9	0.3866E-02	28.07
1	10	0.3815E-02	42.51
1	11	0.4172E-02	53.73
1	12	0.4794E-02	61.37
1	13	0.5683E-02	66.38
1	14	0.7009E-02	69.40
1	15	0.9016E-02	69.20
1	16	0.1079E-01	63.08
1	17	0.1014E-01	56.84
1	18	0.8408E-02	63.31
1	19	0.8078E-02	74.03
1	20	0.8012E-02	80.13
1	21	0.7435E-02	85.33
1	22	0.6112E-02	93.83
1	23	0.4227E-02	113.65
1	24	0.1906E-02	-156.94
1	25	0.9773E-04	107.56
1	26	0.1037E-08	72.62
2	1	0.8961E-02	84.23
2	2	0.1047E-01	78.14
2	3	0.1224E-01	67.45
2	4	0.1331E-01	50.07
2	5	0.1209E-01	28.27
2	6	0.8957E-02	11.62
2	7	0.6199E-02	7.35
2	8	0.4557E-02	14.33
2	9	0.3851E-02	28.07
2	10	0.3800E-02	42.51
2	11	0.4156E-02	53.73
2	12	0.4776E-02	61.37
2	13	0.5661E-02	66.38
2	14	0.6983E-02	69.40
2	15	0.8982E-02	69.20
2	16	0.1075E-01	63.08
2	17	0.1010E-01	56.84
2	18	0.8376E-02	63.31
2	19	0.8047E-02	74.03
2	20	0.7982E-02	80.13
2	21	0.7406E-02	85.33
2	22	0.6089E-02	93.83
2	23	0.4210E-02	113.65
2	24	0.1899E-02	-156.94
2	25	0.9735E-04	107.56

2	26	0.1033E-08	72.62
3	1	0.8858E-02	84.23
3	2	0.1035E-01	78.14
3	3	0.1210E-01	67.45
3	4	0.1316E-01	50.07
3	5	0.1195E-01	28.27
3	6	0.8854E-02	11.62
3	7	0.6128E-02	7.35
3	8	0.4505E-02	14.33
3	9	0.3807E-02	28.07
3	10	0.3757E-02	42.51
3	11	0.4108E-02	53.73
3	12	0.4721E-02	61.37
3	13	0.5597E-02	66.38
3	14	0.6903E-02	69.40
3	15	0.8879E-02	69.20
3	16	0.1063E-01	63.08
3	17	0.9983E-02	56.84
3	18	0.8281E-02	63.31
3	19	0.7955E-02	74.03
3	20	0.7891E-02	80.13
3	21	0.7322E-02	85.33
3	22	0.6020E-02	93.83
3	23	0.4162E-02	113.65
3	24	0.1877E-02	-156.94
3	25	0.9624E-04	107.56
3	26	0.1021E-08	72.62
4	1	0.8688E-02	84.23
4	2	0.1016E-01	78.14
4	3	0.1186E-01	67.45
4	4	0.1291E-01	50.07
4	5	0.1172E-01	28.27
4	6	0.8685E-02	11.62
4	7	0.6011E-02	7.35
4	8	0.4419E-02	14.33
4	9	0.3734E-02	28.07
4	10	0.3685E-02	42.51
4	11	0.4029E-02	53.73
4	12	0.4631E-02	61.37
4	13	0.5489E-02	66.38
4	14	0.6771E-02	69.40
4	15	0.8709E-02	69.20
4	16	0.1042E-01	63.08
4	17	0.9791E-02	56.84
4	18	0.8122E-02	63.31
4	19	0.7803E-02	74.03
4	20	0.7739E-02	80.13
4	21	0.7181E-02	85.33
4	22	0.5904E-02	93.83
4	23	0.4083E-02	113.65
4	24	0.1841E-02	-156.94
4	25	0.9440E-04	107.56
4	26	0.1002E-08	72.62
5	1	0.8452E-02	84.23
5	2	0.9880E-02	78.14
5	3	0.1154E-01	67.45
5	4	0.1256E-01	50.07
5	5	0.1140E-01	28.27
5	6	0.8449E-02	11.62
5	7	0.5848E-02	7.35
5	8	0.4299E-02	14.33
5	9	0.3633E-02	28.07
5	10	0.3585E-02	42.51
5	11	0.3920E-02	53.73
5	12	0.4505E-02	61.37
5	13	0.5340E-02	66.38
5	14	0.6587E-02	69.40
5	15	0.8472E-02	69.20
5	16	0.1014E-01	63.08
5	17	0.9525E-02	56.84
5	18	0.7901E-02	63.31
5	19	0.7591E-02	74.03
5	20	0.7529E-02	80.13
5	21	0.6986E-02	85.33
5	22	0.5744E-02	93.83
5	23	0.3972E-02	113.65
5	24	0.1791E-02	-156.94
5	25	0.9183E-04	107.56
5	26	0.9747E-09	72.62
6	1	0.8152E-02	84.23
6	2	0.9529E-02	78.14
6	3	0.1113E-01	67.45
6	4	0.1211E-01	50.07
6	5	0.1100E-01	28.27
6	6	0.8149E-02	11.62
6	7	0.5640E-02	7.35

6	8	0.4146E-02	14.33
6	9	0.3504E-02	28.07
6	10	0.3458E-02	42.51
6	11	0.3781E-02	53.73
6	12	0.4345E-02	61.37
6	13	0.5150E-02	66.38
6	14	0.6353E-02	69.40
6	15	0.8171E-02	69.20
6	16	0.9781E-02	63.08
6	17	0.9187E-02	56.84
6	18	0.7621E-02	63.31
6	19	0.7321E-02	74.03
6	20	0.7262E-02	80.13
6	21	0.6738E-02	85.33
6	22	0.5540E-02	93.83
6	23	0.3831E-02	113.65
6	24	0.1728E-02	-156.94
6	25	0.8857E-04	107.56
6	26	0.9400E-09	72.62
7	1	0.7790E-02	84.23
7	2	0.9105E-02	78.14
7	3	0.1064E-01	67.45
7	4	0.1157E-01	50.07
7	5	0.1051E-01	28.27
7	6	0.7786E-02	11.62
7	7	0.5389E-02	7.35
7	8	0.3962E-02	14.33
7	9	0.3348E-02	28.07
7	10	0.3304E-02	42.51
7	11	0.3613E-02	53.73
7	12	0.4152E-02	61.37
7	13	0.4922E-02	66.38
7	14	0.6070E-02	69.40
7	15	0.7808E-02	69.20
7	16	0.9346E-02	63.08
7	17	0.8779E-02	56.84
7	18	0.7282E-02	63.31
7	19	0.6996E-02	74.03
7	20	0.6939E-02	80.13
7	21	0.6439E-02	85.33
7	22	0.5294E-02	93.83
7	23	0.3660E-02	113.65
7	24	0.1651E-02	-156.94
7	25	0.8463E-04	107.56
7	26	0.8983E-09	72.62
8	1	0.7368E-02	84.23
8	2	0.8612E-02	78.14
8	3	0.1006E-01	67.45
8	4	0.1095E-01	50.07
8	5	0.9938E-02	28.27
8	6	0.7365E-02	11.62
8	7	0.5097E-02	7.35
8	8	0.3747E-02	14.33
8	9	0.3167E-02	28.07
8	10	0.3125E-02	42.51
8	11	0.3417E-02	53.73
8	12	0.3927E-02	61.37
8	13	0.4655E-02	66.38
8	14	0.5742E-02	69.40
8	15	0.7385E-02	69.20
8	16	0.8841E-02	63.08
8	17	0.8303E-02	56.84
8	18	0.6888E-02	63.31
8	19	0.6617E-02	74.03
8	20	0.6563E-02	80.13
8	21	0.6090E-02	85.33
8	22	0.5007E-02	93.83
8	23	0.3462E-02	113.65
8	24	0.1562E-02	-156.94
8	25	0.8005E-04	107.56
8	26	0.8496E-09	72.62
9	1	0.6890E-02	84.23
9	2	0.8054E-02	78.14
9	3	0.9408E-02	67.45
9	4	0.1024E-01	50.07
9	5	0.9293E-02	28.27
9	6	0.6887E-02	11.62
9	7	0.4767E-02	7.35
9	8	0.3504E-02	14.33
9	9	0.2961E-02	28.07
9	10	0.2922E-02	42.51
9	11	0.3196E-02	53.73
9	12	0.3673E-02	61.37
9	13	0.4353E-02	66.38
9	14	0.5370E-02	69.40
9	15	0.6907E-02	69.20

9	16	0.8267E-02	63.08
9	17	0.7765E-02	56.84
9	18	0.6441E-02	63.31
9	19	0.6188E-02	74.03
9	20	0.6138E-02	80.13
9	21	0.5695E-02	85.33
9	22	0.4682E-02	93.83
9	23	0.3238E-02	113.65
9	24	0.1460E-02	-156.94
9	25	0.7486E-04	107.56
9	26	0.7946E-09	72.62
10	1	0.6360E-02	84.23
10	2	0.7434E-02	78.14
10	3	0.8685E-02	67.45
10	4	0.9450E-02	50.07
10	5	0.8578E-02	28.27
10	6	0.6358E-02	11.62
10	7	0.4400E-02	7.35
10	8	0.3235E-02	14.33
10	9	0.2734E-02	28.07
10	10	0.2698E-02	42.51
10	11	0.2950E-02	53.73
10	12	0.3390E-02	61.37
10	13	0.4018E-02	66.38
10	14	0.4956E-02	69.40
10	15	0.6375E-02	69.20
10	16	0.7631E-02	63.08
10	17	0.7168E-02	56.84
10	18	0.5946E-02	63.31
10	19	0.5712E-02	74.03
10	20	0.5666E-02	80.13
10	21	0.5257E-02	85.33
10	22	0.4322E-02	93.83
10	23	0.2989E-02	113.65
10	24	0.1348E-02	-156.94
10	25	0.6910E-04	107.56
10	26	0.7334E-09	72.62
11	1	0.5782E-02	84.23
11	2	0.6758E-02	78.14
11	3	0.7895E-02	67.45
11	4	0.8590E-02	50.07
11	5	0.7798E-02	28.27
11	6	0.5779E-02	11.62
11	7	0.4000E-02	7.35
11	8	0.2940E-02	14.33
11	9	0.2485E-02	28.07
11	10	0.2452E-02	42.51
11	11	0.2681E-02	53.73
11	12	0.3082E-02	61.37
11	13	0.3653E-02	66.38
11	14	0.4506E-02	69.40
11	15	0.5795E-02	69.20
11	16	0.6937E-02	63.08
11	17	0.6516E-02	56.84
11	18	0.5405E-02	63.31
11	19	0.5192E-02	74.03
11	20	0.5150E-02	80.13
11	21	0.4779E-02	85.33
11	22	0.3929E-02	93.83
11	23	0.2717E-02	113.65
11	24	0.1225E-02	-156.94
11	25	0.6282E-04	107.56
11	26	0.6667E-09	72.62
12	1	0.5159E-02	84.23
12	2	0.6030E-02	78.14
12	3	0.7045E-02	67.45
12	4	0.7665E-02	50.07
12	5	0.6959E-02	28.27
12	6	0.5157E-02	11.62
12	7	0.3569E-02	7.35
12	8	0.2624E-02	14.33
12	9	0.2217E-02	28.07
12	10	0.2188E-02	42.51
12	11	0.2393E-02	53.73
12	12	0.2750E-02	61.37
12	13	0.3260E-02	66.38
12	14	0.4020E-02	69.40
12	15	0.5171E-02	69.20
12	16	0.6190E-02	63.08
12	17	0.5814E-02	56.84
12	18	0.4823E-02	63.31
12	19	0.4633E-02	74.03
12	20	0.4596E-02	80.13
12	21	0.4264E-02	85.33
12	22	0.3506E-02	93.83
12	23	0.2424E-02	113.65

12	24	0.1093E-02	-156.94
12	25	0.5605E-04	107.56
12	26	0.5949E-09	72.62
13	1	0.4497E-02	84.23
13	2	0.5257E-02	78.14
13	3	0.6141E-02	67.45
13	4	0.6682E-02	50.07
13	5	0.6066E-02	28.27
13	6	0.4495E-02	11.62
13	7	0.3111E-02	7.35
13	8	0.2287E-02	14.33
13	9	0.1933E-02	28.07
13	10	0.1907E-02	42.51
13	11	0.2086E-02	53.73
13	12	0.2397E-02	61.37
13	13	0.2841E-02	66.38
13	14	0.3505E-02	69.40
13	15	0.4508E-02	69.20
13	16	0.5396E-02	63.08
13	17	0.5068E-02	56.84
13	18	0.4204E-02	63.31
13	19	0.4039E-02	74.03
13	20	0.4006E-02	80.13
13	21	0.3717E-02	85.33
13	22	0.3056E-02	93.83
13	23	0.2113E-02	113.65
13	24	0.9532E-03	-156.94
13	25	0.4886E-04	107.56
13	26	0.5186E-09	72.62
14	1	0.3801E-02	84.23
14	2	0.4443E-02	78.14
14	3	0.5190E-02	67.45
14	4	0.5648E-02	50.07
14	5	0.5127E-02	28.27
14	6	0.3800E-02	11.62
14	7	0.2630E-02	7.35
14	8	0.1933E-02	14.33
14	9	0.1634E-02	28.07
14	10	0.1612E-02	42.51
14	11	0.1763E-02	53.73
14	12	0.2026E-02	61.37
14	13	0.2402E-02	66.38
14	14	0.2962E-02	69.40
14	15	0.3810E-02	69.20
14	16	0.4561E-02	63.08
14	17	0.4284E-02	56.84
14	18	0.3554E-02	63.31
14	19	0.3414E-02	74.03
14	20	0.3386E-02	80.13
14	21	0.3142E-02	85.33
14	22	0.2583E-02	93.83
14	23	0.1786E-02	113.65
14	24	0.8057E-03	-156.94
14	25	0.4130E-04	107.56
14	26	0.4383E-09	72.62
15	1	0.3076E-02	84.23
15	2	0.3596E-02	78.14
15	3	0.4201E-02	67.45
15	4	0.4571E-02	50.07
15	5	0.4149E-02	28.27
15	6	0.3075E-02	11.62
15	7	0.2128E-02	7.35
15	8	0.1565E-02	14.33
15	9	0.1322E-02	28.07
15	10	0.1305E-02	42.51
15	11	0.1427E-02	53.73
15	12	0.1640E-02	61.37
15	13	0.1944E-02	66.38
15	14	0.2397E-02	69.40
15	15	0.3084E-02	69.20
15	16	0.3691E-02	63.08
15	17	0.3467E-02	56.84
15	18	0.2876E-02	63.31
15	19	0.2763E-02	74.03
15	20	0.2740E-02	80.13
15	21	0.2543E-02	85.33
15	22	0.2091E-02	93.83
15	23	0.1446E-02	113.65
15	24	0.6520E-03	-156.94
15	25	0.3342E-04	107.56
15	26	0.3547E-09	72.62
16	1	0.2328E-02	84.23
16	2	0.2721E-02	78.14
16	3	0.3179E-02	67.45
16	4	0.3459E-02	50.07
16	5	0.3140E-02	28.27

16	6	0.2327E-02	11.62
16	7	0.1611E-02	7.35
16	8	0.1184E-02	14.33
16	9	0.1001E-02	28.07
16	10	0.9874E-03	42.51
16	11	0.1080E-02	53.73
16	12	0.1241E-02	61.37
16	13	0.1471E-02	66.38
16	14	0.1814E-02	69.40
16	15	0.2333E-02	69.20
16	16	0.2793E-02	63.08
16	17	0.2624E-02	56.84
16	18	0.2176E-02	63.31
16	19	0.2091E-02	74.03
16	20	0.2074E-02	80.13
16	21	0.1924E-02	85.33
16	22	0.1582E-02	93.83
16	23	0.1094E-02	113.65
16	24	0.4934E-03	-156.94
16	25	0.2529E-04	107.56
16	26	0.2685E-09	72.62
17	1	0.1562E-02	84.23
17	2	0.1826E-02	78.14
17	3	0.2133E-02	67.45
17	4	0.2321E-02	50.07
17	5	0.2107E-02	28.27
17	6	0.1561E-02	11.62
17	7	0.1081E-02	7.35
17	8	0.7944E-03	14.33
17	9	0.6713E-03	28.07
17	10	0.6625E-03	42.51
17	11	0.7244E-03	53.73
17	12	0.8325E-03	61.37
17	13	0.9868E-03	66.38
17	14	0.1217E-02	69.40
17	15	0.1566E-02	69.20
17	16	0.1874E-02	63.08
17	17	0.1760E-02	56.84
17	18	0.1460E-02	63.31
17	19	0.1403E-02	74.03
17	20	0.1391E-02	80.13
17	21	0.1291E-02	85.33
17	22	0.1061E-02	93.83
17	23	0.7339E-03	113.65
17	24	0.3310E-03	-156.94
17	25	0.1697E-04	107.56
17	26	0.1801E-09	72.62
18	1	0.7840E-03	84.23
18	2	0.9163E-03	78.14
18	3	0.1070E-02	67.45
18	4	0.1165E-02	50.07
18	5	0.1057E-02	28.27
18	6	0.7836E-03	11.62
18	7	0.5424E-03	7.35
18	8	0.3987E-03	14.33
18	9	0.3369E-03	28.07
18	10	0.3325E-03	42.51
18	11	0.3636E-03	53.73
18	12	0.4178E-03	61.37
18	13	0.4953E-03	66.38
18	14	0.6109E-03	69.40
18	15	0.7858E-03	69.20
18	16	0.9406E-03	63.08
18	17	0.8835E-03	56.84
18	18	0.7328E-03	63.31
18	19	0.7040E-03	74.03
18	20	0.6983E-03	80.13
18	21	0.6480E-03	85.33
18	22	0.5327E-03	93.83
18	23	0.3684E-03	113.65
18	24	0.1662E-03	-156.94
18	25	0.8517E-05	107.56
18	26	0.9040E-10	72.62
19	1	0.5508E-18	-95.77
19	2	0.6438E-18	-101.86
19	3	0.7520E-18	-112.55
19	4	0.8183E-18	-129.93
19	5	0.7429E-18	-151.73
19	6	0.5505E-18	-168.38
19	7	0.3810E-18	-172.65
19	8	0.2801E-18	-165.67
19	9	0.2367E-18	-151.93
19	10	0.2336E-18	-137.49
19	11	0.2554E-18	-126.27
19	12	0.2936E-18	-118.63
19	13	0.3480E-18	-113.62

19	14	0.4292E-18	-110.60
19	15	0.5521E-18	-110.80
19	16	0.6608E-18	-116.92
19	17	0.6207E-18	-123.16
19	18	0.5149E-18	-116.69
19	19	0.4946E-18	-105.97
19	20	0.4906E-18	-99.87
19	21	0.4552E-18	-94.67
19	22	0.3743E-18	-86.17
19	23	0.2588E-18	-66.35
19	24	0.1167E-18	23.06
19	25	0.5984E-20	-72.44
19	26	0.6351E-25	-107.38

'---

YAW MOTION TRANSFER FUNCTION

'---

'idir	ifreq	ampl	phase
1	1	0.000	0.00
1	2	0.000	0.00
1	3	0.000	0.00
1	4	0.000	0.00
1	5	0.000	0.00
1	6	0.000	0.00
1	7	0.000	0.00
1	8	0.000	0.00
1	9	0.000	0.00
1	10	0.000	0.00
1	11	0.000	0.00
1	12	0.000	0.00
1	13	0.000	0.00
1	14	0.000	0.00
1	15	0.000	0.00
1	16	0.000	0.00
1	17	0.000	0.00
1	18	0.000	0.00
1	19	0.000	0.00
1	20	0.000	0.00
1	21	0.000	0.00
1	22	0.000	0.00
1	23	0.000	0.00
1	24	0.000	0.00
1	25	0.000	0.00
1	26	0.000	0.00
2	1	0.000	0.00
2	2	0.000	0.00
2	3	0.000	0.00
2	4	0.000	0.00
2	5	0.000	0.00
2	6	0.000	0.00
2	7	0.000	0.00
2	8	0.000	0.00
2	9	0.000	0.00
2	10	0.000	0.00
2	11	0.000	0.00
2	12	0.000	0.00
2	13	0.000	0.00
2	14	0.000	0.00
2	15	0.000	0.00
2	16	0.000	0.00
2	17	0.000	0.00
2	18	0.000	0.00
2	19	0.000	0.00
2	20	0.000	0.00
2	21	0.000	0.00
2	22	0.000	0.00
2	23	0.000	0.00
2	24	0.000	0.00
2	25	0.000	0.00
2	26	0.000	0.00
3	1	0.000	0.00
3	2	0.000	0.00
3	3	0.000	0.00
3	4	0.000	0.00
3	5	0.000	0.00
3	6	0.000	0.00
3	7	0.000	0.00
3	8	0.000	0.00
3	9	0.000	0.00
3	10	0.000	0.00
3	11	0.000	0.00
3	12	0.000	0.00
3	13	0.000	0.00
3	14	0.000	0.00
3	15	0.000	0.00
3	16	0.000	0.00
3	17	0.000	0.00

3	18	0.000	0.00
3	19	0.000	0.00
3	20	0.000	0.00
3	21	0.000	0.00
3	22	0.000	0.00
3	23	0.000	0.00
3	24	0.000	0.00
3	25	0.000	0.00
3	26	0.000	0.00
4	1	0.000	0.00
4	2	0.000	0.00
4	3	0.000	0.00
4	4	0.000	0.00
4	5	0.000	0.00
4	6	0.000	0.00
4	7	0.000	0.00
4	8	0.000	0.00
4	9	0.000	0.00
4	10	0.000	0.00
4	11	0.000	0.00
4	12	0.000	0.00
4	13	0.000	0.00
4	14	0.000	0.00
4	15	0.000	0.00
4	16	0.000	0.00
4	17	0.000	0.00
4	18	0.000	0.00
4	19	0.000	0.00
4	20	0.000	0.00
4	21	0.000	0.00
4	22	0.000	0.00
4	23	0.000	0.00
4	24	0.000	0.00
4	25	0.000	0.00
4	26	0.000	0.00
5	1	0.000	0.00
5	2	0.000	0.00
5	3	0.000	0.00
5	4	0.000	0.00
5	5	0.000	0.00
5	6	0.000	0.00
5	7	0.000	0.00
5	8	0.000	0.00
5	9	0.000	0.00
5	10	0.000	0.00
5	11	0.000	0.00
5	12	0.000	0.00
5	13	0.000	0.00
5	14	0.000	0.00
5	15	0.000	0.00
5	16	0.000	0.00
5	17	0.000	0.00
5	18	0.000	0.00
5	19	0.000	0.00
5	20	0.000	0.00
5	21	0.000	0.00
5	22	0.000	0.00
5	23	0.000	0.00
5	24	0.000	0.00
5	25	0.000	0.00
5	26	0.000	0.00
6	1	0.000	0.00
6	2	0.000	0.00
6	3	0.000	0.00
6	4	0.000	0.00
6	5	0.000	0.00
6	6	0.000	0.00
6	7	0.000	0.00
6	8	0.000	0.00
6	9	0.000	0.00
6	10	0.000	0.00
6	11	0.000	0.00
6	12	0.000	0.00
6	13	0.000	0.00
6	14	0.000	0.00
6	15	0.000	0.00
6	16	0.000	0.00
6	17	0.000	0.00
6	18	0.000	0.00
6	19	0.000	0.00
6	20	0.000	0.00
6	21	0.000	0.00
6	22	0.000	0.00
6	23	0.000	0.00
6	24	0.000	0.00
6	25	0.000	0.00

6	26	0.000	0.00
7	1	0.000	0.00
7	2	0.000	0.00
7	3	0.000	0.00
7	4	0.000	0.00
7	5	0.000	0.00
7	6	0.000	0.00
7	7	0.000	0.00
7	8	0.000	0.00
7	9	0.000	0.00
7	10	0.000	0.00
7	11	0.000	0.00
7	12	0.000	0.00
7	13	0.000	0.00
7	14	0.000	0.00
7	15	0.000	0.00
7	16	0.000	0.00
7	17	0.000	0.00
7	18	0.000	0.00
7	19	0.000	0.00
7	20	0.000	0.00
7	21	0.000	0.00
7	22	0.000	0.00
7	23	0.000	0.00
7	24	0.000	0.00
7	25	0.000	0.00
7	26	0.000	0.00
8	1	0.000	0.00
8	2	0.000	0.00
8	3	0.000	0.00
8	4	0.000	0.00
8	5	0.000	0.00
8	6	0.000	0.00
8	7	0.000	0.00
8	8	0.000	0.00
8	9	0.000	0.00
8	10	0.000	0.00
8	11	0.000	0.00
8	12	0.000	0.00
8	13	0.000	0.00
8	14	0.000	0.00
8	15	0.000	0.00
8	16	0.000	0.00
8	17	0.000	0.00
8	18	0.000	0.00
8	19	0.000	0.00
8	20	0.000	0.00
8	21	0.000	0.00
8	22	0.000	0.00
8	23	0.000	0.00
8	24	0.000	0.00
8	25	0.000	0.00
8	26	0.000	0.00
9	1	0.000	0.00
9	2	0.000	0.00
9	3	0.000	0.00
9	4	0.000	0.00
9	5	0.000	0.00
9	6	0.000	0.00
9	7	0.000	0.00
9	8	0.000	0.00
9	9	0.000	0.00
9	10	0.000	0.00
9	11	0.000	0.00
9	12	0.000	0.00
9	13	0.000	0.00
9	14	0.000	0.00
9	15	0.000	0.00
9	16	0.000	0.00
9	17	0.000	0.00
9	18	0.000	0.00
9	19	0.000	0.00
9	20	0.000	0.00
9	21	0.000	0.00
9	22	0.000	0.00
9	23	0.000	0.00
9	24	0.000	0.00
9	25	0.000	0.00
9	26	0.000	0.00
10	1	0.000	0.00
10	2	0.000	0.00
10	3	0.000	0.00
10	4	0.000	0.00
10	5	0.000	0.00
10	6	0.000	0.00
10	7	0.000	0.00

10	8	0.000	0.00
10	9	0.000	0.00
10	10	0.000	0.00
10	11	0.000	0.00
10	12	0.000	0.00
10	13	0.000	0.00
10	14	0.000	0.00
10	15	0.000	0.00
10	16	0.000	0.00
10	17	0.000	0.00
10	18	0.000	0.00
10	19	0.000	0.00
10	20	0.000	0.00
10	21	0.000	0.00
10	22	0.000	0.00
10	23	0.000	0.00
10	24	0.000	0.00
10	25	0.000	0.00
10	26	0.000	0.00
11	1	0.000	0.00
11	2	0.000	0.00
11	3	0.000	0.00
11	4	0.000	0.00
11	5	0.000	0.00
11	6	0.000	0.00
11	7	0.000	0.00
11	8	0.000	0.00
11	9	0.000	0.00
11	10	0.000	0.00
11	11	0.000	0.00
11	12	0.000	0.00
11	13	0.000	0.00
11	14	0.000	0.00
11	15	0.000	0.00
11	16	0.000	0.00
11	17	0.000	0.00
11	18	0.000	0.00
11	19	0.000	0.00
11	20	0.000	0.00
11	21	0.000	0.00
11	22	0.000	0.00
11	23	0.000	0.00
11	24	0.000	0.00
11	25	0.000	0.00
11	26	0.000	0.00
12	1	0.000	0.00
12	2	0.000	0.00
12	3	0.000	0.00
12	4	0.000	0.00
12	5	0.000	0.00
12	6	0.000	0.00
12	7	0.000	0.00
12	8	0.000	0.00
12	9	0.000	0.00
12	10	0.000	0.00
12	11	0.000	0.00
12	12	0.000	0.00
12	13	0.000	0.00
12	14	0.000	0.00
12	15	0.000	0.00
12	16	0.000	0.00
12	17	0.000	0.00
12	18	0.000	0.00
12	19	0.000	0.00
12	20	0.000	0.00
12	21	0.000	0.00
12	22	0.000	0.00
12	23	0.000	0.00
12	24	0.000	0.00
12	25	0.000	0.00
12	26	0.000	0.00
13	1	0.000	0.00
13	2	0.000	0.00
13	3	0.000	0.00
13	4	0.000	0.00
13	5	0.000	0.00
13	6	0.000	0.00
13	7	0.000	0.00
13	8	0.000	0.00
13	9	0.000	0.00
13	10	0.000	0.00
13	11	0.000	0.00
13	12	0.000	0.00
13	13	0.000	0.00
13	14	0.000	0.00
13	15	0.000	0.00

13	16	0.000	0.00
13	17	0.000	0.00
13	18	0.000	0.00
13	19	0.000	0.00
13	20	0.000	0.00
13	21	0.000	0.00
13	22	0.000	0.00
13	23	0.000	0.00
13	24	0.000	0.00
13	25	0.000	0.00
13	26	0.000	0.00
14	1	0.000	0.00
14	2	0.000	0.00
14	3	0.000	0.00
14	4	0.000	0.00
14	5	0.000	0.00
14	6	0.000	0.00
14	7	0.000	0.00
14	8	0.000	0.00
14	9	0.000	0.00
14	10	0.000	0.00
14	11	0.000	0.00
14	12	0.000	0.00
14	13	0.000	0.00
14	14	0.000	0.00
14	15	0.000	0.00
14	16	0.000	0.00
14	17	0.000	0.00
14	18	0.000	0.00
14	19	0.000	0.00
14	20	0.000	0.00
14	21	0.000	0.00
14	22	0.000	0.00
14	23	0.000	0.00
14	24	0.000	0.00
14	25	0.000	0.00
14	26	0.000	0.00
15	1	0.000	0.00
15	2	0.000	0.00
15	3	0.000	0.00
15	4	0.000	0.00
15	5	0.000	0.00
15	6	0.000	0.00
15	7	0.000	0.00
15	8	0.000	0.00
15	9	0.000	0.00
15	10	0.000	0.00
15	11	0.000	0.00
15	12	0.000	0.00
15	13	0.000	0.00
15	14	0.000	0.00
15	15	0.000	0.00
15	16	0.000	0.00
15	17	0.000	0.00
15	18	0.000	0.00
15	19	0.000	0.00
15	20	0.000	0.00
15	21	0.000	0.00
15	22	0.000	0.00
15	23	0.000	0.00
15	24	0.000	0.00
15	25	0.000	0.00
15	26	0.000	0.00
16	1	0.000	0.00
16	2	0.000	0.00
16	3	0.000	0.00
16	4	0.000	0.00
16	5	0.000	0.00
16	6	0.000	0.00
16	7	0.000	0.00
16	8	0.000	0.00
16	9	0.000	0.00
16	10	0.000	0.00
16	11	0.000	0.00
16	12	0.000	0.00
16	13	0.000	0.00
16	14	0.000	0.00
16	15	0.000	0.00
16	16	0.000	0.00
16	17	0.000	0.00
16	18	0.000	0.00
16	19	0.000	0.00
16	20	0.000	0.00
16	21	0.000	0.00
16	22	0.000	0.00
16	23	0.000	0.00

16	24	0.000	0.00
16	25	0.000	0.00
16	26	0.000	0.00
17	1	0.000	0.00
17	2	0.000	0.00
17	3	0.000	0.00
17	4	0.000	0.00
17	5	0.000	0.00
17	6	0.000	0.00
17	7	0.000	0.00
17	8	0.000	0.00
17	9	0.000	0.00
17	10	0.000	0.00
17	11	0.000	0.00
17	12	0.000	0.00
17	13	0.000	0.00
17	14	0.000	0.00
17	15	0.000	0.00
17	16	0.000	0.00
17	17	0.000	0.00
17	18	0.000	0.00
17	19	0.000	0.00
17	20	0.000	0.00
17	21	0.000	0.00
17	22	0.000	0.00
17	23	0.000	0.00
17	24	0.000	0.00
17	25	0.000	0.00
17	26	0.000	0.00
18	1	0.000	0.00
18	2	0.000	0.00
18	3	0.000	0.00
18	4	0.000	0.00
18	5	0.000	0.00
18	6	0.000	0.00
18	7	0.000	0.00
18	8	0.000	0.00
18	9	0.000	0.00
18	10	0.000	0.00
18	11	0.000	0.00
18	12	0.000	0.00
18	13	0.000	0.00
18	14	0.000	0.00
18	15	0.000	0.00
18	16	0.000	0.00
18	17	0.000	0.00
18	18	0.000	0.00
18	19	0.000	0.00
18	20	0.000	0.00
18	21	0.000	0.00
18	22	0.000	0.00
18	23	0.000	0.00
18	24	0.000	0.00
18	25	0.000	0.00
18	26	0.000	0.00
19	1	0.000	0.00
19	2	0.000	0.00
19	3	0.000	0.00
19	4	0.000	0.00
19	5	0.000	0.00
19	6	0.000	0.00
19	7	0.000	0.00
19	8	0.000	0.00
19	9	0.000	0.00
19	10	0.000	0.00
19	11	0.000	0.00
19	12	0.000	0.00
19	13	0.000	0.00
19	14	0.000	0.00
19	15	0.000	0.00
19	16	0.000	0.00
19	17	0.000	0.00
19	18	0.000	0.00
19	19	0.000	0.00
19	20	0.000	0.00
19	21	0.000	0.00
19	22	0.000	0.00
19	23	0.000	0.00
19	24	0.000	0.00
19	25	0.000	0.00
19	26	0.000	0.00

'==

SECOND ORDER WAVE DRIFT

'==

'txwadr, 2 lines

```
'nfodir   nfofre   ifosym    itypin
    19     26      2
'--------------------------------------------------------
 WAVE DIRECTIONS DRIFT COEFFICIENTS
'--------------------------------------------------------
'ifodir   fodir
     1       0.00000
     2       5.00000
     3       10.0000
     4       15.0000
     5       20.0000
     6       25.0000
     7       30.0000
     8       35.0000
     9       40.0000
    10       45.0000
    11       50.0000
    12       55.0000
    13       60.0000
    14       65.0000
    15       70.0000
    16       75.0000
    17       80.0000
    18       85.0000
    19       90.0000
'--------------------------------------------------------
 WAVE FREQUENCIES DRIFT COEFFICIENTS
'--------------------------------------------------------
'ifofre   fofre
     1      0.209440
     2      0.216662
     3      0.224399
     4      0.232711
     5      0.241661
     6      0.251327
     7      0.261799
     8      0.273182
     9      0.285599
    10      0.299199
    11      0.314159
    12      0.330694
    13      0.349066
    14      0.369599
    15      0.392699
    16      0.418879
    17      0.448799
    18      0.483322
    19      0.523599
    20      0.571199
    21      0.628319
    22      0.698132
    23      0.785398
    24       1.04720
    25       1.57080
    26       3.14159
'--------------------------------------------------------
SURGE WAVE DRIFT COEFFICIENTS
'--------------------------------------------------------
'idir     ifreq      ampl
     1     1        1.643
     1     2        1.620
     1     3        1.591
     1     4        1.577
     1     5        1.645
     1     6        1.790
     1     7        2.000
     1     8        2.303
     1     9        2.763
     1    10         3.512
     1    11         4.836
     1    12         7.432
     1    13         13.18
     1    14         27.47
     1    15         61.16
     1    16         106.5
     1    17         113.8
     1    18         83.52
     1    19         65.39
     1    20         75.89
     1    21         128.9
     1    22         225.1
     1    23         254.7
     1    24         238.8
     1    25         226.7
     1    26         183.3
```

2	1	1.637
2	2	1.614
2	3	1.585
2	4	1.571
2	5	1.639
2	6	1.783
2	7	1.992
2	8	2.294
2	9	2.753
2	10	3.498
2	11	4.818
2	12	7.404
2	13	13.13
2	14	27.37
2	15	60.93
2	16	106.0
2	17	113.3
2	18	83.21
2	19	65.14
2	20	75.60
2	21	128.4
2	22	224.3
2	23	253.7
2	24	237.9
2	25	225.8
2	26	182.6
3	1	1.618
3	2	1.596
3	3	1.567
3	4	1.553
3	5	1.620
3	6	1.762
3	7	1.969
3	8	2.268
3	9	2.721
3	10	3.458
3	11	4.763
3	12	7.319
3	13	12.98
3	14	27.05
3	15	60.24
3	16	104.8
3	17	112.0
3	18	82.26
3	19	64.39
3	20	74.73
3	21	126.9
3	22	221.7
3	23	250.8
3	24	235.2
3	25	223.2
3	26	180.6
4	1	1.587
4	2	1.565
4	3	1.537
4	4	1.523
4	5	1.589
4	6	1.729
4	7	1.932
4	8	2.225
4	9	2.669
4	10	3.392
4	11	4.671
4	12	7.179
4	13	12.73
4	14	26.53
4	15	59.08
4	16	102.8
4	17	109.9
4	18	80.68
4	19	63.16
4	20	73.30
4	21	124.5
4	22	217.5
4	23	246.0
4	24	230.7
4	25	219.0
4	26	177.1
5	1	1.544
5	2	1.523
5	3	1.495
5	4	1.482
5	5	1.546
5	6	1.682
5	7	1.879
5	8	2.164

5	9	2.596
5	10	3.300
5	11	4.545
5	12	6.984
5	13	12.39
5	14	25.81
5	15	57.48
5	16	100.0
5	17	106.9
5	18	78.49
5	19	61.44
5	20	71.31
5	21	121.1
5	22	211.6
5	23	239.3
5	24	224.4
5	25	213.0
5	26	172.3
6	1	1.489
6	2	1.469
6	3	1.442
6	4	1.429
6	5	1.491
6	6	1.622
6	7	1.812
6	8	2.087
6	9	2.504
6	10	3.183
6	11	4.383
6	12	6.736
6	13	11.95
6	14	24.90
6	15	55.43
6	16	96.48
6	17	103.1
6	18	75.70
6	19	59.26
6	20	68.78
6	21	116.8
6	22	204.0
6	23	230.8
6	24	216.4
6	25	205.4
6	26	166.2
7	1	1.423
7	2	1.403
7	3	1.378
7	4	1.366
7	5	1.425
7	6	1.550
7	7	1.732
7	8	1.995
7	9	2.393
7	10	3.041
7	11	4.188
7	12	6.436
7	13	11.42
7	14	23.79
7	15	52.97
7	16	92.19
7	17	98.53
7	18	72.33
7	19	56.63
7	20	65.72
7	21	111.6
7	22	195.0
7	23	220.6
7	24	206.8
7	25	196.3
7	26	158.8
8	1	1.346
8	2	1.327
8	3	1.303
8	4	1.292
8	5	1.348
8	6	1.466
8	7	1.638
8	8	1.887
8	9	2.263
8	10	2.877
8	11	3.962
8	12	6.088
8	13	10.80
8	14	22.50
8	15	50.10
8	16	87.20

8	17	93.20
8	18	68.42
8	19	53.56
8	20	62.16
8	21	105.6
8	22	184.4
8	23	208.6
8	24	195.6
8	25	185.7
8	26	150.2
9	1	1.259
9	2	1.241
9	3	1.219
9	4	1.208
9	5	1.260
9	6	1.371
9	7	1.532
9	8	1.764
9	9	2.117
9	10	2.690
9	11	3.705
9	12	5.693
9	13	10.10
9	14	21.04
9	15	46.85
9	16	81.55
9	17	87.16
9	18	63.98
9	19	50.09
9	20	58.13
9	21	98.72
9	22	172.5
9	23	195.1
9	24	182.9
9	25	173.6
9	26	140.4
10	1	1.162
10	2	1.146
10	3	1.125
10	4	1.115
10	5	1.163
10	6	1.265
10	7	1.414
10	8	1.629
10	9	1.954
10	10	2.483
10	11	3.420
10	12	5.255
10	13	9.322
10	14	19.42
10	15	43.25
10	16	75.28
10	17	80.45
10	18	59.06
10	19	46.23
10	20	53.66
10	21	91.13
10	22	159.2
10	23	180.1
10	24	168.9
10	25	160.3
10	26	129.6
11	1	1.056
11	2	1.042
11	3	1.023
11	4	1.014
11	5	1.057
11	6	1.150
11	7	1.285
11	8	1.480
11	9	1.776
11	10	2.257
11	11	3.109
11	12	4.777
11	13	8.474
11	14	17.66
11	15	39.32
11	16	68.43
11	17	73.13
11	18	53.69
11	19	42.03
11	20	48.78
11	21	82.84
11	22	144.7
11	23	163.7
11	24	153.5

11	25	145.7
11	26	117.8
12	1	0.9426
12	2	0.9294
12	3	0.9124
12	4	0.9045
12	5	0.9436
12	6	1.026
12	7	1.147
12	8	1.321
12	9	1.585
12	10	2.014
12	11	2.774
12	12	4.263
12	13	7.562
12	14	15.76
12	15	35.08
12	16	61.06
12	17	65.26
12	18	47.91
12	19	37.50
12	20	43.53
12	21	73.92
12	22	129.1
12	23	146.1
12	24	137.0
12	25	130.0
12	26	105.2
13	1	0.8217
13	2	0.8102
13	3	0.7954
13	4	0.7885
13	5	0.8226
13	6	0.8948
13	7	0.9998
13	8	1.152
13	9	1.382
13	10	1.756
13	11	2.418
13	12	3.716
13	13	6.592
13	14	13.74
13	15	30.58
13	16	53.23
13	17	56.89
13	18	41.76
13	19	32.69
13	20	37.94
13	21	64.44
13	22	112.6
13	23	127.3
13	24	119.4
13	25	113.3
13	26	91.67
14	1	0.6945
14	2	0.6848
14	3	0.6723
14	4	0.6665
14	5	0.6953
14	6	0.7563
14	7	0.8451
14	8	0.9734
14	9	1.168
14	10	1.484
14	11	2.044
14	12	3.141
14	13	5.571
14	14	11.61
14	15	25.85
14	16	44.99
14	17	48.08
14	18	35.30
14	19	27.63
14	20	32.07
14	21	54.46
14	22	95.15
14	23	107.6
14	24	100.9
14	25	95.80
14	26	77.48
15	1	0.5620
15	2	0.5542
15	3	0.5441
15	4	0.5394
15	5	0.5627
15	6	0.6121

15	7	0.6839
15	8	0.7877
15	9	0.9450
15	10	1.201
15	11	1.654
15	12	2.542
15	13	4.509
15	14	9.396
15	15	20.92
15	16	36.41
15	17	38.91
15	18	28.57
15	19	22.36
15	20	25.96
15	21	44.08
15	22	77.00
15	23	87.10
15	24	81.67
15	25	77.53
15	26	62.71
16	1	0.4253
16	2	0.4194
16	3	0.4117
16	4	0.4082
16	5	0.4258
16	6	0.4632
16	7	0.5176
16	8	0.5961
16	9	0.7151
16	10	0.9089
16	11	1.252
16	12	1.924
16	13	3.412
16	14	7.110
16	15	15.83
16	16	27.55
16	17	29.45
16	18	21.62
16	19	16.92
16	20	19.64
16	21	33.35
16	22	58.27
16	23	65.91
16	24	61.80
16	25	58.67
16	26	47.45
17	1	0.2854
17	2	0.2814
17	3	0.2762
17	4	0.2738
17	5	0.2857
17	6	0.3108
17	7	0.3472
17	8	0.3999
17	9	0.4798
17	10	0.6098
17	11	0.8398
17	12	1.291
17	13	2.289
17	14	4.770
17	15	10.62
17	16	18.49
17	17	19.76
17	18	14.50
17	19	11.35
17	20	13.18
17	21	22.38
17	22	39.10
17	23	44.22
17	24	41.47
17	25	39.36
17	26	31.84
18	1	0.1432
18	2	0.1412
18	3	0.1386
18	4	0.1374
18	5	0.1434
18	6	0.1560
18	7	0.1743
18	8	0.2007
18	9	0.2408
18	10	0.3061
18	11	0.4215
18	12	0.6477
18	13	1.149
18	14	2.394

18	15	5.331
18	16	9.278
18	17	9.916
18	18	7.280
18	19	5.699
18	20	6.614
18	21	11.23
18	22	19.62
18	23	22.20
18	24	20.81
18	25	19.76
18	26	15.98
19	1	-0.1006E-15
19	2	-0.9922E-16
19	3	-0.9741E-16
19	4	-0.9656E-16
19	5	-0.1007E-15
19	6	-0.1096E-15
19	7	-0.1224E-15
19	8	-0.1410E-15
19	9	-0.1692E-15
19	10	-0.2150E-15
19	11	-0.2961E-15
19	12	-0.4551E-15
19	13	-0.8072E-15
19	14	-0.1682E-14
19	15	-0.3745E-14
19	16	-0.6518E-14
19	17	-0.6967E-14
19	18	-0.5114E-14
19	19	-0.4004E-14
19	20	-0.4647E-14
19	21	-0.7891E-14
19	22	-0.1379E-13
19	23	-0.1559E-13
19	24	-0.1462E-13
19	25	-0.1388E-13
19	26	-0.1123E-13

'--
SWAY WAVE DRIFT COEFFICIENTS
'--

'idir	ifreq	ampl
1	1	0.2012E-15
1	2	0.1984E-15
1	3	0.1948E-15
1	4	0.1931E-15
1	5	0.2015E-15
1	6	0.2192E-15
1	7	0.2449E-15
1	8	0.2821E-15
1	9	0.3384E-15
1	10	0.4300E-15
1	11	0.5923E-15
1	12	0.9102E-15
1	13	0.1614E-14
1	14	0.3364E-14
1	15	0.7490E-14
1	16	0.1304E-13
1	17	0.1393E-13
1	18	0.1023E-13
1	19	0.8007E-14
1	20	0.9294E-14
1	21	0.1578E-13
1	22	0.2757E-13
1	23	0.3119E-13
1	24	0.2924E-13
1	25	0.2776E-13
1	26	0.2245E-13
2	1	0.1432
2	2	0.1412
2	3	0.1386
2	4	0.1374
2	5	0.1434
2	6	0.1560
2	7	0.1743
2	8	0.2007
2	9	0.2408
2	10	0.3061
2	11	0.4215
2	12	0.6477
2	13	1.149
2	14	2.394
2	15	5.331
2	16	9.278
2	17	9.916
2	18	7.280

2	19	5.699
2	20	6.614
2	21	11.23
2	22	19.62
2	23	22.20
2	24	20.81
2	25	19.76
2	26	15.98
3	1	0.2854
3	2	0.2814
3	3	0.2762
3	4	0.2738
3	5	0.2857
3	6	0.3108
3	7	0.3472
3	8	0.3999
3	9	0.4798
3	10	0.6098
3	11	0.8398
3	12	1.291
3	13	2.289
3	14	4.770
3	15	10.62
3	16	18.49
3	17	19.76
3	18	14.50
3	19	11.35
3	20	13.18
3	21	22.38
3	22	39.10
3	23	44.22
3	24	41.47
3	25	39.36
3	26	31.84
4	1	0.4253
4	2	0.4194
4	3	0.4117
4	4	0.4082
4	5	0.4258
4	6	0.4632
4	7	0.5176
4	8	0.5961
4	9	0.7151
4	10	0.9089
4	11	1.252
4	12	1.924
4	13	3.412
4	14	7.110
4	15	15.83
4	16	27.55
4	17	29.45
4	18	21.62
4	19	16.92
4	20	19.64
4	21	33.35
4	22	58.27
4	23	65.91
4	24	61.80
4	25	58.67
4	26	47.45
5	1	0.5620
5	2	0.5542
5	3	0.5441
5	4	0.5394
5	5	0.5627
5	6	0.6121
5	7	0.6839
5	8	0.7877
5	9	0.9450
5	10	1.201
5	11	1.654
5	12	2.542
5	13	4.509
5	14	9.396
5	15	20.92
5	16	36.41
5	17	38.91
5	18	28.57
5	19	22.36
5	20	25.96
5	21	44.08
5	22	77.00
5	23	87.10
5	24	81.67
5	25	77.53
5	26	62.71

6	1	0.6945
6	2	0.6848
6	3	0.6723
6	4	0.6665
6	5	0.6953
6	6	0.7563
6	7	0.8451
6	8	0.9734
6	9	1.168
6	10	1.484
6	11	2.044
6	12	3.141
6	13	5.571
6	14	11.61
6	15	25.85
6	16	44.99
6	17	48.08
6	18	35.30
6	19	27.63
6	20	32.07
6	21	54.46
6	22	95.15
6	23	107.6
6	24	100.9
6	25	95.80
6	26	77.48
7	1	0.8217
7	2	0.8102
7	3	0.7954
7	4	0.7885
7	5	0.8226
7	6	0.8948
7	7	0.9998
7	8	1.152
7	9	1.382
7	10	1.756
7	11	2.418
7	12	3.716
7	13	6.592
7	14	13.74
7	15	30.58
7	16	53.23
7	17	56.89
7	18	41.76
7	19	32.69
7	20	37.94
7	21	64.44
7	22	112.6
7	23	127.3
7	24	119.4
7	25	113.3
7	26	91.67
8	1	0.9426
8	2	0.9294
8	3	0.9124
8	4	0.9045
8	5	0.9436
8	6	1.026
8	7	1.147
8	8	1.321
8	9	1.585
8	10	2.014
8	11	2.774
8	12	4.263
8	13	7.562
8	14	15.76
8	15	35.08
8	16	61.06
8	17	65.26
8	18	47.91
8	19	37.50
8	20	43.53
8	21	73.92
8	22	129.1
8	23	146.1
8	24	137.0
8	25	130.0
8	26	105.2
9	1	1.056
9	2	1.042
9	3	1.023
9	4	1.014
9	5	1.057
9	6	1.150
9	7	1.285
9	8	1.480

9	9	1.776
9	10	2.257
9	11	3.109
9	12	4.777
9	13	8.474
9	14	17.66
9	15	39.32
9	16	68.43
9	17	73.13
9	18	53.69
9	19	42.03
9	20	48.78
9	21	82.84
9	22	144.7
9	23	163.7
9	24	153.5
9	25	145.7
9	26	117.8
10	1	1.162
10	2	1.146
10	3	1.125
10	4	1.115
10	5	1.163
10	6	1.265
10	7	1.414
10	8	1.629
10	9	1.954
10	10	2.483
10	11	3.420
10	12	5.255
10	13	9.322
10	14	19.42
10	15	43.25
10	16	75.28
10	17	80.45
10	18	59.06
10	19	46.23
10	20	53.66
10	21	91.13
10	22	159.2
10	23	180.1
10	24	168.9
10	25	160.3
10	26	129.6
11	1	1.259
11	2	1.241
11	3	1.219
11	4	1.208
11	5	1.260
11	6	1.371
11	7	1.532
11	8	1.764
11	9	2.117
11	10	2.690
11	11	3.705
11	12	5.693
11	13	10.10
11	14	21.04
11	15	46.85
11	16	81.55
11	17	87.16
11	18	63.98
11	19	50.09
11	20	58.13
11	21	98.72
11	22	172.5
11	23	195.1
11	24	182.9
11	25	173.6
11	26	140.4
12	1	1.346
12	2	1.327
12	3	1.303
12	4	1.292
12	5	1.348
12	6	1.466
12	7	1.638
12	8	1.887
12	9	2.263
12	10	2.877
12	11	3.962
12	12	6.088
12	13	10.80
12	14	22.50
12	15	50.10
12	16	87.20

12	17	93.20
12	18	68.42
12	19	53.56
12	20	62.16
12	21	105.6
12	22	184.4
12	23	208.6
12	24	195.6
12	25	185.7
12	26	150.2
13	1	1.423
13	2	1.403
13	3	1.378
13	4	1.366
13	5	1.425
13	6	1.550
13	7	1.732
13	8	1.995
13	9	2.393
13	10	3.041
13	11	4.188
13	12	6.436
13	13	11.42
13	14	23.79
13	15	52.97
13	16	92.19
13	17	98.53
13	18	72.33
13	19	56.63
13	20	65.72
13	21	111.6
13	22	195.0
13	23	220.6
13	24	206.8
13	25	196.3
13	26	158.8
14	1	1.489
14	2	1.469
14	3	1.442
14	4	1.429
14	5	1.491
14	6	1.622
14	7	1.812
14	8	2.087
14	9	2.504
14	10	3.183
14	11	4.383
14	12	6.736
14	13	11.95
14	14	24.90
14	15	55.43
14	16	96.48
14	17	103.1
14	18	75.70
14	19	59.26
14	20	68.78
14	21	116.8
14	22	204.0
14	23	230.8
14	24	216.4
14	25	205.4
14	26	166.2
15	1	1.544
15	2	1.523
15	3	1.495
15	4	1.482
15	5	1.546
15	6	1.682
15	7	1.879
15	8	2.164
15	9	2.596
15	10	3.300
15	11	4.545
15	12	6.984
15	13	12.39
15	14	25.81
15	15	57.48
15	16	100.0
15	17	106.9
15	18	78.49
15	19	61.44
15	20	71.31
15	21	121.1
15	22	211.6
15	23	239.3
15	24	224.4

15	25	213.0
15	26	172.3
16	1	1.587
16	2	1.565
16	3	1.537
16	4	1.523
16	5	1.589
16	6	1.729
16	7	1.932
16	8	2.225
16	9	2.669
16	10	3.392
16	11	4.671
16	12	7.179
16	13	12.73
16	14	26.53
16	15	59.08
16	16	102.8
16	17	109.9
16	18	80.68
16	19	63.16
16	20	73.30
16	21	124.5
16	22	217.5
16	23	246.0
16	24	230.7
16	25	219.0
16	26	177.1
17	1	1.618
17	2	1.596
17	3	1.567
17	4	1.553
17	5	1.620
17	6	1.762
17	7	1.969
17	8	2.268
17	9	2.721
17	10	3.458
17	11	4.763
17	12	7.319
17	13	12.98
17	14	27.05
17	15	60.24
17	16	104.8
17	17	112.0
17	18	82.26
17	19	64.39
17	20	74.73
17	21	126.9
17	22	221.7
17	23	250.8
17	24	235.2
17	25	223.2
17	26	180.6
18	1	1.637
18	2	1.614
18	3	1.585
18	4	1.571
18	5	1.639
18	6	1.783
18	7	1.992
18	8	2.294
18	9	2.753
18	10	3.498
18	11	4.818
18	12	7.404
18	13	13.13
18	14	27.37
18	15	60.93
18	16	106.0
18	17	113.3
18	18	83.21
18	19	65.14
18	20	75.60
18	21	128.4
18	22	224.3
18	23	253.7
18	24	237.9
18	25	225.8
18	26	182.6
19	1	1.643
19	2	1.620
19	3	1.591
19	4	1.577
19	5	1.645
19	6	1.790

19	7	2.000
19	8	2.303
19	9	2.763
19	10	3.512
19	11	4.836
19	12	7.432
19	13	13.18
19	14	27.47
19	15	61.16
19	16	106.5
19	17	113.8
19	18	83.52
19	19	65.39
19	20	75.89
19	21	128.9
19	22	225.1
19	23	254.7
19	24	238.8
19	25	226.7
19	26	183.3

'---

YAW WAVE DRIFT COEFFICIENTS

'---

'idir	ifreq	ampl
1	1	0.000
1	2	0.000
1	3	0.000
1	4	0.000
1	5	0.000
1	6	0.000
1	7	0.000
1	8	0.000
1	9	0.000
1	10	0.000
1	11	0.000
1	12	0.000
1	13	0.000
1	14	0.000
1	15	0.000
1	16	0.000
1	17	0.000
1	18	0.000
1	19	0.000
1	20	0.000
1	21	0.000
1	22	0.000
1	23	0.000
1	24	0.000
1	25	0.000
1	26	0.000
2	1	0.000
2	2	0.000
2	3	0.000
2	4	0.000
2	5	0.000
2	6	0.000
2	7	0.000
2	8	0.000
2	9	0.000
2	10	0.000
2	11	0.000
2	12	0.000
2	13	0.000
2	14	0.000
2	15	0.000
2	16	0.000
2	17	0.000
2	18	0.000
2	19	0.000
2	20	0.000
2	21	0.000
2	22	0.000
2	23	0.000
2	24	0.000
2	25	0.000
2	26	0.000
3	1	0.000
3	2	0.000
3	3	0.000
3	4	0.000
3	5	0.000
3	6	0.000
3	7	0.000
3	8	0.000
3	9	0.000
3	10	0.000

3	11	0.000
3	12	0.000
3	13	0.000
3	14	0.000
3	15	0.000
3	16	0.000
3	17	0.000
3	18	0.000
3	19	0.000
3	20	0.000
3	21	0.000
3	22	0.000
3	23	0.000
3	24	0.000
3	25	0.000
3	26	0.000
4	1	0.000
4	2	0.000
4	3	0.000
4	4	0.000
4	5	0.000
4	6	0.000
4	7	0.000
4	8	0.000
4	9	0.000
4	10	0.000
4	11	0.000
4	12	0.000
4	13	0.000
4	14	0.000
4	15	0.000
4	16	0.000
4	17	0.000
4	18	0.000
4	19	0.000
4	20	0.000
4	21	0.000
4	22	0.000
4	23	0.000
4	24	0.000
4	25	0.000
4	26	0.000
5	1	0.000
5	2	0.000
5	3	0.000
5	4	0.000
5	5	0.000
5	6	0.000
5	7	0.000
5	8	0.000
5	9	0.000
5	10	0.000
5	11	0.000
5	12	0.000
5	13	0.000
5	14	0.000
5	15	0.000
5	16	0.000
5	17	0.000
5	18	0.000
5	19	0.000
5	20	0.000
5	21	0.000
5	22	0.000
5	23	0.000
5	24	0.000
5	25	0.000
5	26	0.000
6	1	0.000
6	2	0.000
6	3	0.000
6	4	0.000
6	5	0.000
6	6	0.000
6	7	0.000
6	8	0.000
6	9	0.000
6	10	0.000
6	11	0.000
6	12	0.000
6	13	0.000
6	14	0.000
6	15	0.000
6	16	0.000
6	17	0.000
6	18	0.000

6	19	0.000
6	20	0.000
6	21	0.000
6	22	0.000
6	23	0.000
6	24	0.000
6	25	0.000
6	26	0.000
7	1	0.000
7	2	0.000
7	3	0.000
7	4	0.000
7	5	0.000
7	6	0.000
7	7	0.000
7	8	0.000
7	9	0.000
7	10	0.000
7	11	0.000
7	12	0.000
7	13	0.000
7	14	0.000
7	15	0.000
7	16	0.000
7	17	0.000
7	18	0.000
7	19	0.000
7	20	0.000
7	21	0.000
7	22	0.000
7	23	0.000
7	24	0.000
7	25	0.000
7	26	0.000
8	1	0.000
8	2	0.000
8	3	0.000
8	4	0.000
8	5	0.000
8	6	0.000
8	7	0.000
8	8	0.000
8	9	0.000
8	10	0.000
8	11	0.000
8	12	0.000
8	13	0.000
8	14	0.000
8	15	0.000
8	16	0.000
8	17	0.000
8	18	0.000
8	19	0.000
8	20	0.000
8	21	0.000
8	22	0.000
8	23	0.000
8	24	0.000
8	25	0.000
8	26	0.000
9	1	0.000
9	2	0.000
9	3	0.000
9	4	0.000
9	5	0.000
9	6	0.000
9	7	0.000
9	8	0.000
9	9	0.000
9	10	0.000
9	11	0.000
9	12	0.000
9	13	0.000
9	14	0.000
9	15	0.000
9	16	0.000
9	17	0.000
9	18	0.000
9	19	0.000
9	20	0.000
9	21	0.000
9	22	0.000
9	23	0.000
9	24	0.000
9	25	0.000
9	26	0.000

10	1	0.000
10	2	0.000
10	3	0.000
10	4	0.000
10	5	0.000
10	6	0.000
10	7	0.000
10	8	0.000
10	9	0.000
10	10	0.000
10	11	0.000
10	12	0.000
10	13	0.000
10	14	0.000
10	15	0.000
10	16	0.000
10	17	0.000
10	18	0.000
10	19	0.000
10	20	0.000
10	21	0.000
10	22	0.000
10	23	0.000
10	24	0.000
10	25	0.000
10	26	0.000
11	1	0.000
11	2	0.000
11	3	0.000
11	4	0.000
11	5	0.000
11	6	0.000
11	7	0.000
11	8	0.000
11	9	0.000
11	10	0.000
11	11	0.000
11	12	0.000
11	13	0.000
11	14	0.000
11	15	0.000
11	16	0.000
11	17	0.000
11	18	0.000
11	19	0.000
11	20	0.000
11	21	0.000
11	22	0.000
11	23	0.000
11	24	0.000
11	25	0.000
11	26	0.000
12	1	0.000
12	2	0.000
12	3	0.000
12	4	0.000
12	5	0.000
12	6	0.000
12	7	0.000
12	8	0.000
12	9	0.000
12	10	0.000
12	11	0.000
12	12	0.000
12	13	0.000
12	14	0.000
12	15	0.000
12	16	0.000
12	17	0.000
12	18	0.000
12	19	0.000
12	20	0.000
12	21	0.000
12	22	0.000
12	23	0.000
12	24	0.000
12	25	0.000
12	26	0.000
13	1	0.000
13	2	0.000
13	3	0.000
13	4	0.000
13	5	0.000
13	6	0.000
13	7	0.000
13	8	0.000

13	9	0.000
13	10	0.000
13	11	0.000
13	12	0.000
13	13	0.000
13	14	0.000
13	15	0.000
13	16	0.000
13	17	0.000
13	18	0.000
13	19	0.000
13	20	0.000
13	21	0.000
13	22	0.000
13	23	0.000
13	24	0.000
13	25	0.000
13	26	0.000
14	1	0.000
14	2	0.000
14	3	0.000
14	4	0.000
14	5	0.000
14	6	0.000
14	7	0.000
14	8	0.000
14	9	0.000
14	10	0.000
14	11	0.000
14	12	0.000
14	13	0.000
14	14	0.000
14	15	0.000
14	16	0.000
14	17	0.000
14	18	0.000
14	19	0.000
14	20	0.000
14	21	0.000
14	22	0.000
14	23	0.000
14	24	0.000
14	25	0.000
14	26	0.000
15	1	0.000
15	2	0.000
15	3	0.000
15	4	0.000
15	5	0.000
15	6	0.000
15	7	0.000
15	8	0.000
15	9	0.000
15	10	0.000
15	11	0.000
15	12	0.000
15	13	0.000
15	14	0.000
15	15	0.000
15	16	0.000
15	17	0.000
15	18	0.000
15	19	0.000
15	20	0.000
15	21	0.000
15	22	0.000
15	23	0.000
15	24	0.000
15	25	0.000
15	26	0.000
16	1	0.000
16	2	0.000
16	3	0.000
16	4	0.000
16	5	0.000
16	6	0.000
16	7	0.000
16	8	0.000
16	9	0.000
16	10	0.000
16	11	0.000
16	12	0.000
16	13	0.000
16	14	0.000
16	15	0.000
16	16	0.000

16	17	0.000
16	18	0.000
16	19	0.000
16	20	0.000
16	21	0.000
16	22	0.000
16	23	0.000
16	24	0.000
16	25	0.000
16	26	0.000
17	1	0.000
17	2	0.000
17	3	0.000
17	4	0.000
17	5	0.000
17	6	0.000
17	7	0.000
17	8	0.000
17	9	0.000
17	10	0.000
17	11	0.000
17	12	0.000
17	13	0.000
17	14	0.000
17	15	0.000
17	16	0.000
17	17	0.000
17	18	0.000
17	19	0.000
17	20	0.000
17	21	0.000
17	22	0.000
17	23	0.000
17	24	0.000
17	25	0.000
17	26	0.000
18	1	0.000
18	2	0.000
18	3	0.000
18	4	0.000
18	5	0.000
18	6	0.000
18	7	0.000
18	8	0.000
18	9	0.000
18	10	0.000
18	11	0.000
18	12	0.000
18	13	0.000
18	14	0.000
18	15	0.000
18	16	0.000
18	17	0.000
18	18	0.000
18	19	0.000
18	20	0.000
18	21	0.000
18	22	0.000
18	23	0.000
18	24	0.000
18	25	0.000
18	26	0.000
19	1	0.000
19	2	0.000
19	3	0.000
19	4	0.000
19	5	0.000
19	6	0.000
19	7	0.000
19	8	0.000
19	9	0.000
19	10	0.000
19	11	0.000
19	12	0.000
19	13	0.000
19	14	0.000
19	15	0.000
19	16	0.000
19	17	0.000
19	18	0.000
19	19	0.000
19	20	0.000
19	21	0.000
19	22	0.000
19	23	0.000
19	24	0.000

```
    19     25        0.000
    19     26        0.000
' ========================
POSITIONING SYSTEM DATA
' ========================
 12 mooring
 lines
' =======
 CATENARY SYSTEM DATA
'
'==================='
' Cluster 1.  N (N-E) '
'==================='
 LINE DATA
'  iline  lichar  imeth  iwirun  icpro
     1      1      1      0      1
'  x        y       z
  31.2               -18.0             -9.35
'  dir   preten   xwinch
  342.0    1750.0    .00000E+00
'  ifail  ftime  btens
    0     0.   6000.
 LINE DATA
'  iline  lichar  imeth  iwirun  icpro
     2      1      1      0      1
'  x        y       z
  31.2               -18.0             -9.35
'  dir   preten   xwinch
  340.0    1750.0    .00000E+00
'  ifail  ftime  btens
    0     0.   6000.
 LINE DATA
'  iline  lichar  imeth  iwirun  icpro
     3      1      1      0      1
'  x        y       z
  31.2               -18.0             -9.35
'  dir   preten   xwinch
  330.0    1750.0    .00000E+00
'  ifail  ftime  btens
    0     0.   6000.
 LINE DATA
'  iline  lichar  imeth  iwirun  icpro
     4      1      1      0      1
'  x        y       z
  31.2               -18.0             -9.35
'  dir   preten   xwinch
  328.0    1750.0    .00000E+00
'  ifail  ftime  btens
    0     0.   6000.
'==================='
' Cluster 2. S ( S-E ) '
'==================='
 LINE DATA
'  iline  lichar  imeth  iwirun  icpro
     5      1      1      0      1
'  x        y       z
  -31.2              -18.0             -9.35
'  dir   preten   xwinch
  212.0    1750.0    .00000E+00
'  ifail  ftime  btens
    0     0.   6000.
 LINE DATA
'  iline  lichar  imeth  iwirun  icpro
     6      1      1      0      1
'  x        y       z
  -31.2              -18.0             -9.35
'  dir   preten   xwinch
  210.0    1750.0    .00000E+00
'  ifail  ftime  btens
    0     0.   6000.
 LINE DATA
'  iline  lichar  imeth  iwirun  icpro
     7      1      1      0      1
'  x        y       z
  -31.2              -18.0             -9.35
'  dir   preten   xwinch
  200.0    1750.0    .00000E+00
'  ifail  ftime  btens
    0     0.   6000.
 LINE DATA
'  iline  lichar  imeth  iwirun  icpro
     8      1      1      0      1
'  x        y       z
  -31.2              -18.0             -9.35
'  dir   preten   xwinch
  198.0    1750.0    .00000E+00
```

```
'  ifail  ftime  btens
    0     0.   6000.
'==================='
' Cluster 3   West '
'==================='
 LINE DATA
'  iline   lichar  imeth   iwirun  icpro
     9      1      1      0      1
'  x         y       z
   0.0                   36.0              -9.35
'  dir   preten   xwinch
  97.0    1500.0    .00000E+00
'  ifail  ftime  btens
    0     0.   6000.
 LINE DATA
'  iline   lichar  imeth   iwirun  icpro
    10      1      1      0      1
'  x         y       z
   0.0                   36.0              -9.35
'  dir   preten   xwinch
  95.0    1500.0    .00000E+00
'  ifail  ftime  btens
    0     0.   6000.
 LINE DATA
'  iline   lichar  imeth   iwirun  icpro
    11      1      1      0      1
'  x         y       z
   0.0                   36.0              -9.35
'  dir   preten   xwinch
  85.0    1500.0    .00000E+00
'  ifail  ftime  btens
    0     0.   6000.
 LINE DATA
'  iline   lichar  imeth   iwirun  icpro
    12      1      1      0      1
'  x         y       z
   0.0                   36.0              -9.35
'  dir   preten   xwinch
  83.0    1500.0    .00000E+00
'  ifail  ftime  btens
    0     0.   6000.
'
LINE CHARACTERISTICS DATA
'  lichar  type   npth   nptv   vrange
    1      2     50     5      25.
'  nseg   ibotco   slope   zglb    tmax   thmin
    5      1      0.    -160.   15000.  0.
'  iseg   ityp   nel   ibuoy   sleng  fric  nea   itynea
   1     0    20     0     50.   0.   0    2
   2     0    30     0    400.   0.   0    2
   3     0     1     0      5.   0.   0    2
   4     0    40     0    700.   0.   0    2
   5     0    30     0    125.   0.   0    2
'  iseg   dia     emod   emfac   uwia    watfac  cdn   cdl
    1   0.155  0.46E08    2.    4.714    0.87   2.5    0.
    2   0.260  0.87E07    1.    0.56     0.27   1.5    0.
    3   0.155  0.46E08    1.   25.000   -1.00   2.5    0.
    4   0.260  0.87E07    1.    0.56     0.27   1.5    0.
    5   0.155  0.46E08    2.    4.714    0.87   2.5    0.
'***********************************************************
END
'***********************************************************
```

APPENDIX

D

RIFLEX DECOUPLED INPUT

M.S.c. Thesis

Coupled Dynamic Analysis of Cylindrical FPSO, Moorings and Riser

Based on Numerical Simulation

A. SIMA INPMOD RIFLEX (INP)

```
'***********************************************************************
 INPMOD IDENTIFICATION TEXT 3.7.9
'***********************************************************************



'-----------------------------------------------------------------------
 UNIT NAMES SPECIFICATION
'-----------------------------------------------------------------------
'ut ul um uf grav      gcons
 s  m  Mg kN 9.8100000 1.0000000
'***********************************************************************
 NEW SINGLE RISER
'***********************************************************************
'atyps idris
 AR    ARSYS
'***********************************************************************
 ARBITRARY SYSTEM AR
'***********************************************************************
'nsnod nlin nsnfix nves nricon nspr nack
 4     2    4      1    0      0    0
'ibtang zbot          ibot3d
 0      -1000.0000000 0
'B 6.5: LINE TOPOLOGY DEFINITION
'lineid lintyp-id snod1-id snod2-id
 line1  ltyp1     node1    node2
 line2  ltyp2     node3    node4
'FIXED NODES
'snod-id ipos ix iy iz irx iry irz chcoo  chupro
 node1   0    1  1  1  1   1   1   GLOBAL NO
'x0          y0        z0           x1          y1        z1           rot       dir
 270.0000000 0.0000000 -170.0000000 220.0000000 0.0000000 -170.0000000 0.0000000 0.0000000
'snod-id ipos ix iy iz irx iry irz chcoo  chupro
 node2   0    1  1  1  1   1   1   GLOBAL NO
'x0        y0        z0        x1         y1        z1          rot        dir
 0.0000000 0.0000000 0.0000000 33.5000000 0.0000000 -16.3200000 84.0000000 0.0000000
'snod-id ipos ix iy iz irx iry irz chcoo  chupro
 node3   0    1  1  1  1   1   1   GLOBAL NO
'x0          y0        z0           x1          y1        z1           rot       dir
 270.0000000 5.0000000 -170.0000000 220.0000000 5.0000000 -170.0000000 0.0000000 0.0000000
'snod-id ipos ix iy iz irx iry irz chcoo  chupro
 node4   0    1  1  1  1   1   1   GLOBAL NO
'x0        y0        z0        x1         y1        z1          rot        dir
 0.0000000 0.0000000 0.0000000 33.5000000 5.0000000 -16.3200000 84.0000000 0.0000000
'FREE NODES
```

```
'ives idwftr xg        yg        zg        dirx
 1    su36   0.0000000 0.0000000 0.0000000 0.0000000
'B.10 Line and segment specification
'*********************************************************************
 NEW LINE DATA
'*********************************************************************
'lintyp-id nseg ncmpty2 flutyp
 ltyp1     4    0       fluid1
'crstyp ncmpty1 exwtyp nelseg slgth      nstrps nstrpd slgth0     isoity
 cs1    0       0      50     25.0000000 3      5      25.0000000 0
 cs3    0       0      10     30.0000000 3      5      30.0000000 0
 cs2    0       0      50     50.0000000 3      5      50.0000000 0
 cs1    0       0      50     215.0000000 3      5      215.0000000 0
'*********************************************************************
 NEW LINE DATA
'*********************************************************************
'lintyp-id nseg ncmpty2 flutyp
 ltyp2     4    0       fluid1
'crstyp ncmpty1 exwtyp nelseg slgth      nstrps nstrpd slgth0     isoity
 cs4    0       0      50     25.0000000 3      5      25.0000000 0
 cs6    0       0      10     40.0000000 3      5      40.0000000 0
 cs5    0       0      50     55.0000000 3      5      55.0000000 0
 cs4    0       0      50     200.0000000 3      5      200.0000000 0
'*********************************************************************
 NEW COMPONENT CRS1
'*********************************************************************
'cmptyp-id temp       alpha     beta
 cs1       20.0000000 0.0000000 0.0000000
'ams       ae            ai            rgyr
 0.1450000 5.0600000e-02 1.9360000e-02 0.0000000
'iea iej igt ipress imf harpar
 1   1   1   0      0   0.0000000
'ea
 500000.0000000
'ejy        mf
 33.0000000 0.0000000
'gtminus
 5000.0000000
'cqx       cqy       cax       cay       clx       cly       icode
 0.2000000 0.2000000 0.0000000 0.0000000 0.0000000 0.0000000 1
'tb              ycurmx
 1000000.0000000 0.4000000
'*********************************************************************
 NEW COMPONENT CRS1
'*********************************************************************
'cmptyp-id temp       alpha     beta
 cs2       20.0000000 0.0000000 0.0000000
'ams       ae        ai            rgyr
 0.1600000 0.3000000 5.0600000e-02 0.0000000
'iea iej igt ipress imf harpar
 1   1   1   0      0   0.0000000
'ea
 500000.0000000
'ejy        mf
 33.0000000 0.0000000
'gtminus
 5000.0000000
'cqx       cqy       cax       cay       clx       cly       icode
 0.2500000 0.2000000 0.2000000 0.2000000 0.0000000 0.0000000 1
'tb              ycurmx
 1000000.0000000 0.4000000
'*********************************************************************
 NEW COMPONENT CRS1
'*********************************************************************
'cmptyp-id temp       alpha     beta
 cs3       20.0000000 0.0000000 0.0000000
'ams       ae        ai            rgyr
 0.1000000 0.2500000 1.9360000e-02 0.0000000
'iea iej igt ipress imf harpar
 1   1   1   0      0   0.0000000
'ea
 500000.0000000
'ejy        mf
 37.0000000 0.0000000
```

```
'gtminus
 5000.0000000
'cqx       cqy       cax       cay       clx       cly       icode
 0.2500000 0.2000000 0.0000000 0.0000000 0.0000000 0.0000000 1
'tb             ycurmx
 1000000.0000000 0.4000000
'**********************************************************************
 NEW COMPONENT CRS1
'**********************************************************************
'cmptyp-id temp       alpha     beta
 cs4       20.0000000 0.0000000 0.0000000
'ams       ae            ai            rgyr
 0.1500000 7.6300000e-02 3.4130000e-02 0.0000000
'iea iej igt ipress imf harpar
 1   1   1   0      0   0.0000000
'ea
 500000.0000000
'ejy        mf
 40.0000000 0.0000000
'gtminus
 5000.0000000
'cqx       cqy       cax       cay       clx       cly       icode
 0.2000000 0.2000000 0.0000000 0.0000000 0.0000000 0.0000000 1
'tb             ycurmx
 1000000.0000000 0.4000000
'**********************************************************************
 NEW COMPONENT CRS1
'**********************************************************************
'cmptyp-id temp       alpha     beta
 cs5       20.0000000 0.0000000 0.0000000
'ams       ae        ai            rgyr
 0.1600000 0.3000000 7.6300000e-02 0.0000000
'iea iej igt ipress imf harpar
 1   1   1   0      0   0.0000000
'ea
 500000.0000000
'ejy        mf
 33.0000000 0.0000000
'gtminus
 5000.0000000
'cqx       cqy       cax       cay       clx       cly       icode
 0.2500000 0.2000000 0.2000000 0.2000000 0.0000000 0.0000000 1
'tb             ycurmx
 1000000.0000000 0.4000000
'**********************************************************************
 NEW COMPONENT CRS1
'**********************************************************************
'cmptyp-id temp       alpha     beta
 cs6       20.0000000 0.0000000 0.0000000
'ams       ae        ai            rgyr
 0.1000000 0.2500000 7.6300000e-02 0.0000000
'iea iej igt ipress imf harpar
 1   1   1   0      0   0.0000000
'ea
 500000.0000000
'ejy        mf
 37.0000000 0.0000000
'gtminus
 5000.0000000
'cqx       cqy       cax       cay       clx       cly       icode
 0.2500000 0.2000000 0.0000000 0.0000000 0.0000000 0.0000000 1
'tb             ycurmx
 1000000.0000000 0.4000000
'**********************************************************************
 NEW COMPONENT FLUID
'**********************************************************************
'cmptyp-id
 fluid1
'rhoi      vveli     pressi    dpress    idir
 0.8000000 0.0000000 0.0000000 0.0000000 1
'**********************************************************************
 SUPPORT VESSEL IDENTIFICATION
'**********************************************************************
```

```
'idhftr
 su36
'----------------------------------------------------------------------
 HFTRANSFER REFERENCE POSITION
'----------------------------------------------------------------------
'zg
 0.0000000
'----------------------------------------------------------------------
 HFTRANSFER CONTROL DATA
'----------------------------------------------------------------------
'ndhftr nwhftr isymhf itypin
 19     26     2      2
'----------------------------------------------------------------------
 WAVE DIRECTIONS
'----------------------------------------------------------------------
'ihead head
 1     0.0000000
 2     5.0000000
 3     10.0000000
 4     15.0000000
 5     20.0000000
 6     25.0000000
 7     30.0000000
 8     35.0000000
 9     40.0000000
 10    45.0000000
 11    50.0000000
 12    55.0000000
 13    60.0000000
 14    65.0000000
 15    70.0000000
 16    75.0000000
 17    80.0000000
 18    85.0000000
 19    90.0000000
'----------------------------------------------------------------------
 WAVE FREQUENCIES
'----------------------------------------------------------------------
'ifreq whftr
 1     0.2094400
 2     0.2166620
 3     0.2243990
 4     0.2327110
 5     0.2416610
 6     0.2513270
 7     0.2617990
 8     0.2731820
 9     0.2855990
 10    0.2991990
 11    0.3141590
 12    0.3306940
 13    0.3490660
 14    0.3695990
 15    0.3926990
 16    0.4188790
 17    0.4487990
 18    0.4833220
 19    0.5235990
 20    0.5711990
 21    0.6283190
 22    0.6981320
 23    0.7853980
 24    1.0472000
 25    1.5708000
 26    3.1415900
'----------------------------------------------------------------------
 HFTRANSFER FUNCTION SURGE
'----------------------------------------------------------------------
'idir ifreq amplitude phase[deg]
 1    1     1.6690000 -87.2000000
 1    2     1.5860000 -87.2800000
 1    3     1.5080000 -87.2200000
 1    4     1.4380000 -86.9800000
 1    5     1.3810000 -86.7700000
```

1	6	1.3290000	-86.9300000
1	7	1.2740000	-87.2100000
1	8	1.2200000	-87.4500000
1	9	1.1670000	-87.6200000
1	10	1.1170000	-87.7300000
1	11	1.0690000	-87.7900000
1	12	1.0240000	-87.8000000
1	13	0.9786000	-87.7400000
1	14	0.9325000	-87.5400000
1	15	0.8831000	-87.0200000
1	16	0.8350000	-85.8900000
1	17	0.7955000	-84.8900000
1	18	0.7458000	-84.6200000
1	19	0.6767000	-83.6300000
1	20	0.5950000	-81.1800000
1	21	0.5010000	-76.8100000
1	22	0.3941000	-69.4200000
1	23	0.2762000	-56.1000000
1	24	8.7410000e-02	21.2200000
1	25	1.2570000e-02	-72.4000000
1	26	3.1990000e-04	-38.6200000
2	1	1.6620000	-87.2000000
2	2	1.5800000	-87.2800000
2	3	1.5020000	-87.2200000
2	4	1.4330000	-86.9800000
2	5	1.3760000	-86.7700000
2	6	1.3240000	-86.9300000
2	7	1.2690000	-87.2100000
2	8	1.2150000	-87.4500000
2	9	1.1630000	-87.6200000
2	10	1.1130000	-87.7300000
2	11	1.0650000	-87.7900000
2	12	1.0200000	-87.8000000
2	13	0.9749000	-87.7400000
2	14	0.9290000	-87.5400000
2	15	0.8797000	-87.0200000
2	16	0.8318000	-85.8900000
2	17	0.7925000	-84.8900000
2	18	0.7429000	-84.6200000
2	19	0.6742000	-83.6300000
2	20	0.5927000	-81.1800000
2	21	0.4991000	-76.8100000
2	22	0.3926000	-69.4200000
2	23	0.2752000	-56.1000000
2	24	8.7080000e-02	21.2200000
2	25	1.2530000e-02	-72.4000000
2	26	3.1870000e-04	-38.6200000
3	1	1.6430000	-87.2000000
3	2	1.5620000	-87.2800000
3	3	1.4850000	-87.2200000
3	4	1.4160000	-86.9800000
3	5	1.3600000	-86.7700000
3	6	1.3090000	-86.9300000
3	7	1.2550000	-87.2100000
3	8	1.2010000	-87.4500000
3	9	1.1490000	-87.6200000
3	10	1.1000000	-87.7300000
3	11	1.0530000	-87.7900000
3	12	1.0080000	-87.8000000
3	13	0.9638000	-87.7400000
3	14	0.9184000	-87.5400000
3	15	0.8697000	-87.0200000
3	16	0.8223000	-85.8900000
3	17	0.7834000	-84.8900000
3	18	0.7344000	-84.6200000
3	19	0.6665000	-83.6300000
3	20	0.5859000	-81.1800000
3	21	0.4934000	-76.8100000
3	22	0.3881000	-69.4200000
3	23	0.2720000	-56.1000000
3	24	8.6080000e-02	21.2200000
3	25	1.2380000e-02	-72.4000000
3	26	3.1510000e-04	-38.6200000
4	1	1.6120000	-87.2000000

4	2	1.5320000	-87.2800000
4	3	1.4570000	-87.2200000
4	4	1.3890000	-86.9800000
4	5	1.3340000	-86.7700000
4	6	1.2830000	-86.9300000
4	7	1.2310000	-87.2100000
4	8	1.1780000	-87.4500000
4	9	1.1270000	-87.6200000
4	10	1.0790000	-87.7300000
4	11	1.0330000	-87.7900000
4	12	0.9887000	-87.8000000
4	13	0.9453000	-87.7400000
4	14	0.9008000	-87.5400000
4	15	0.8530000	-87.0200000
4	16	0.8065000	-85.8900000
4	17	0.7684000	-84.8900000
4	18	0.7204000	-84.6200000
4	19	0.6537000	-83.6300000
4	20	0.5747000	-81.1800000
4	21	0.4839000	-76.8100000
4	22	0.3806000	-69.4200000
4	23	0.2668000	-56.1000000
4	24	8.4430000e-02	21.2200000
4	25	1.2150000e-02	-72.4000000
4	26	3.0900000e-04	-38.6200000
5	1	1.5680000	-87.2000000
5	2	1.4900000	-87.2800000
5	3	1.4170000	-87.2200000
5	4	1.3510000	-86.9800000
5	5	1.2980000	-86.7700000
5	6	1.2490000	-86.9300000
5	7	1.1970000	-87.2100000
5	8	1.1460000	-87.4500000
5	9	1.0970000	-87.6200000
5	10	1.0500000	-87.7300000
5	11	1.0050000	-87.7900000
5	12	0.9618000	-87.8000000
5	13	0.9196000	-87.7400000
5	14	0.8763000	-87.5400000
5	15	0.8298000	-87.0200000
5	16	0.7846000	-85.8900000
5	17	0.7475000	-84.8900000
5	18	0.7008000	-84.6200000
5	19	0.6359000	-83.6300000
5	20	0.5591000	-81.1800000
5	21	0.4708000	-76.8100000
5	22	0.3703000	-69.4200000
5	23	0.2596000	-56.1000000
5	24	8.2140000e-02	21.2200000
5	25	1.1820000e-02	-72.4000000
5	26	3.0060000e-04	-38.6200000
6	1	1.5120000	-87.2000000
6	2	1.4370000	-87.2800000
6	3	1.3670000	-87.2200000
6	4	1.3030000	-86.9800000
6	5	1.2520000	-86.7700000
6	6	1.2040000	-86.9300000
6	7	1.1550000	-87.2100000
6	8	1.1050000	-87.4500000
6	9	1.0580000	-87.6200000
6	10	1.0120000	-87.7300000
6	11	0.9692000	-87.7900000
6	12	0.9277000	-87.8000000
6	13	0.8869000	-87.7400000
6	14	0.8452000	-87.5400000
6	15	0.8003000	-87.0200000
6	16	0.7567000	-85.8900000
6	17	0.7210000	-84.8900000
6	18	0.6759000	-84.6200000
6	19	0.6133000	-83.6300000
6	20	0.5392000	-81.1800000
6	21	0.4541000	-76.8100000
6	22	0.3571000	-69.4200000
6	23	0.2503000	-56.1000000

6	24	7.9220000e-02	21.2200000
6	25	1.1400000e-02	-72.4000000
6	26	2.9000000e-04	-38.6200000
7	1	1.4450000	-87.2000000
7	2	1.3740000	-87.2800000
7	3	1.3060000	-87.2200000
7	4	1.2450000	-86.9800000
7	5	1.1960000	-86.7700000
7	6	1.1510000	-86.9300000
7	7	1.1040000	-87.2100000
7	8	1.0560000	-87.4500000
7	9	1.0110000	-87.6200000
7	10	0.9674000	-87.7300000
7	11	0.9261000	-87.7900000
7	12	0.8864000	-87.8000000
7	13	0.8475000	-87.7400000
7	14	0.8076000	-87.5400000
7	15	0.7648000	-87.0200000
7	16	0.7231000	-85.8900000
7	17	0.6889000	-84.8900000
7	18	0.6459000	-84.6200000
7	19	0.5861000	-83.6300000
7	20	0.5153000	-81.1800000
7	21	0.4339000	-76.8100000
7	22	0.3413000	-69.4200000
7	23	0.2392000	-56.1000000
7	24	7.5700000e-02	21.2200000
7	25	1.0890000e-02	-72.4000000
7	26	2.7710000e-04	-38.6200000
8	1	1.3670000	-87.2000000
8	2	1.2990000	-87.2800000
8	3	1.2350000	-87.2200000
8	4	1.1780000	-86.9800000
8	5	1.1310000	-86.7700000
8	6	1.0880000	-86.9300000
8	7	1.0440000	-87.2100000
8	8	0.9991000	-87.4500000
8	9	0.9560000	-87.6200000
8	10	0.9150000	-87.7300000
8	11	0.8760000	-87.7900000
8	12	0.8385000	-87.8000000
8	13	0.8016000	-87.7400000
8	14	0.7639000	-87.5400000
8	15	0.7234000	-87.0200000
8	16	0.6840000	-85.8900000
8	17	0.6516000	-84.8900000
8	18	0.6109000	-84.6200000
8	19	0.5544000	-83.6300000
8	20	0.4874000	-81.1800000
8	21	0.4104000	-76.8100000
8	22	0.3228000	-69.4200000
8	23	0.2263000	-56.1000000
8	24	7.1600000e-02	21.2200000
8	25	1.0300000e-02	-72.4000000
8	26	2.6210000e-04	-38.6200000
9	1	1.2780000	-87.2000000
9	2	1.2150000	-87.2800000
9	3	1.1550000	-87.2200000
9	4	1.1020000	-86.9800000
9	5	1.0580000	-86.7700000
9	6	1.0180000	-86.9300000
9	7	0.9761000	-87.2100000
9	8	0.9343000	-87.4500000
9	9	0.8940000	-87.6200000
9	10	0.8557000	-87.7300000
9	11	0.8192000	-87.7900000
9	12	0.7841000	-87.8000000
9	13	0.7497000	-87.7400000
9	14	0.7144000	-87.5400000
9	15	0.6765000	-87.0200000
9	16	0.6396000	-85.8900000
9	17	0.6094000	-84.8900000
9	18	0.5713000	-84.6200000
9	19	0.5184000	-83.6300000

9	20	0.4558000	-81.1800000
9	21	0.3838000	-76.8100000
9	22	0.3019000	-69.4200000
9	23	0.2116000	-56.1000000
9	24	6.6960000e-02	21.2200000
9	25	9.6320000e-03	-72.4000000
9	26	2.4510000e-04	-38.6200000
10	1	1.1800000	-87.2000000
10	2	1.1210000	-87.2800000
10	3	1.0660000	-87.2200000
10	4	1.0170000	-86.9800000
10	5	0.9765000	-86.7700000
10	6	0.9396000	-86.9300000
10	7	0.9010000	-87.2100000
10	8	0.8624000	-87.4500000
10	9	0.8252000	-87.6200000
10	10	0.7899000	-87.7300000
10	11	0.7562000	-87.7900000
10	12	0.7238000	-87.8000000
10	13	0.6920000	-87.7400000
10	14	0.6594000	-87.5400000
10	15	0.6244000	-87.0200000
10	16	0.5904000	-85.8900000
10	17	0.5625000	-84.8900000
10	18	0.5273000	-84.6200000
10	19	0.4785000	-83.6300000
10	20	0.4207000	-81.1800000
10	21	0.3543000	-76.8100000
10	22	0.2786000	-69.4200000
10	23	0.1953000	-56.1000000
10	24	6.1810000e-02	21.2200000
10	25	8.8910000e-03	-72.4000000
10	26	2.2620000e-04	-38.6200000
11	1	1.0730000	-87.2000000
11	2	1.0190000	-87.2800000
11	3	0.9693000	-87.2200000
11	4	0.9244000	-86.9800000
11	5	0.8877000	-86.7700000
11	6	0.8541000	-86.9300000
11	7	0.8191000	-87.2100000
11	8	0.7840000	-87.4500000
11	9	0.7502000	-87.6200000
11	10	0.7180000	-87.7300000
11	11	0.6874000	-87.7900000
11	12	0.6579000	-87.8000000
11	13	0.6290000	-87.7400000
11	14	0.5994000	-87.5400000
11	15	0.5676000	-87.0200000
11	16	0.5367000	-85.8900000
11	17	0.5113000	-84.8900000
11	18	0.4794000	-84.6200000
11	19	0.4350000	-83.6300000
11	20	0.3824000	-81.1800000
11	21	0.3220000	-76.8200000
11	22	0.2533000	-69.4200000
11	23	0.1775000	-56.1000000
11	24	5.6180000e-02	21.2200000
11	25	8.0820000e-03	-72.4000000
11	26	2.0570000e-04	-38.6200000
12	1	0.9572000	-87.2000000
12	2	0.9097000	-87.2800000
12	3	0.8649000	-87.2200000
12	4	0.8249000	-86.9800000
12	5	0.7921000	-86.7700000
12	6	0.7622000	-86.9300000
12	7	0.7309000	-87.2100000
12	8	0.6996000	-87.4500000
12	9	0.6694000	-87.6200000
12	10	0.6407000	-87.7300000
12	11	0.6134000	-87.7900000
12	12	0.5871000	-87.8000000
12	13	0.5613000	-87.7400000
12	14	0.5349000	-87.5400000
12	15	0.5065000	-87.0200000

12	16	0.4789000	-85.8900000
12	17	0.4563000	-84.8900000
12	18	0.4278000	-84.6200000
12	19	0.3882000	-83.6300000
12	20	0.3413000	-81.1800000
12	21	0.2874000	-76.8100000
12	22	0.2260000	-69.4200000
12	23	0.1584000	-56.1000000
12	24	5.0140000e-02	21.2200000
12	25	7.2120000e-03	-72.4000000
12	26	1.8350000e-04	-38.6200000
13	1	0.8344000	-87.2000000
13	2	0.7930000	-87.2800000
13	3	0.7540000	-87.2200000
13	4	0.7191000	-86.9800000
13	5	0.6905000	-86.7700000
13	6	0.6644000	-86.9300000
13	7	0.6371000	-87.2100000
13	8	0.6098000	-87.4500000
13	9	0.5835000	-87.6200000
13	10	0.5585000	-87.7300000
13	11	0.5347000	-87.7900000
13	12	0.5118000	-87.8000000
13	13	0.4893000	-87.7400000
13	14	0.4663000	-87.5400000
13	15	0.4415000	-87.0200000
13	16	0.4175000	-85.8900000
13	17	0.3978000	-84.8900000
13	18	0.3729000	-84.6200000
13	19	0.3384000	-83.6300000
13	20	0.2975000	-81.1800000
13	21	0.2505000	-76.8100000
13	22	0.1970000	-69.4200000
13	23	0.1381000	-56.1000000
13	24	4.3700000e-02	21.2200000
13	25	6.2870000e-03	-72.4000000
13	26	1.6000000e-04	-38.6200000
14	1	0.7053000	-87.2000000
14	2	0.6703000	-87.2800000
14	3	0.6373000	-87.2200000
14	4	0.6078000	-86.9800000
14	5	0.5836000	-86.7700000
14	6	0.5616000	-86.9300000
14	7	0.5385000	-87.2100000
14	8	0.5155000	-87.4500000
14	9	0.4932000	-87.6200000
14	10	0.4721000	-87.7300000
14	11	0.4519000	-87.7900000
14	12	0.4326000	-87.8000000
14	13	0.4136000	-87.7400000
14	14	0.3941000	-87.5400000
14	15	0.3732000	-87.0200000
14	16	0.3529000	-85.8900000
14	17	0.3362000	-84.8900000
14	18	0.3152000	-84.6200000
14	19	0.2860000	-83.6300000
14	20	0.2514000	-81.1800000
14	21	0.2117000	-76.8100000
14	22	0.1665000	-69.4200000
14	23	0.1167000	-56.1000000
14	24	3.6940000e-02	21.2200000
14	25	5.3140000e-03	-72.4000000
14	26	1.3520000e-04	-38.6200000
15	1	0.5708000	-87.2000000
15	2	0.5425000	-87.2800000
15	3	0.5157000	-87.2200000
15	4	0.4919000	-86.9800000
15	5	0.4723000	-86.7700000
15	6	0.4545000	-86.9300000
15	7	0.4358000	-87.2100000
15	8	0.4171000	-87.4500000
15	9	0.3992000	-87.6200000
15	10	0.3820000	-87.7300000
15	11	0.3657000	-87.7900000

15	12	0.3501000	-87.8000000
15	13	0.3347000	-87.7400000
15	14	0.3189000	-87.5400000
15	15	0.3020000	-87.0200000
15	16	0.2856000	-85.8900000
15	17	0.2721000	-84.8900000
15	18	0.2551000	-84.6200000
15	19	0.2315000	-83.6300000
15	20	0.2035000	-81.1800000
15	21	0.1714000	-76.8100000
15	22	0.1348000	-69.4200000
15	23	9.4470000e-02	-56.1000000
15	24	2.9900000e-02	21.2200000
15	25	4.3000000e-03	-72.4000000
15	26	1.0940000e-04	-38.6200000
16	1	0.4319000	-87.2000000
16	2	0.4105000	-87.2800000
16	3	0.3903000	-87.2200000
16	4	0.3722000	-86.9800000
16	5	0.3574000	-86.7700000
16	6	0.3439000	-86.9300000
16	7	0.3298000	-87.2100000
16	8	0.3157000	-87.4500000
16	9	0.3021000	-87.6200000
16	10	0.2891000	-87.7300000
16	11	0.2768000	-87.7900000
16	12	0.2649000	-87.8000000
16	13	0.2533000	-87.7400000
16	14	0.2414000	-87.5400000
16	15	0.2286000	-87.0200000
16	16	0.2161000	-85.8900000
16	17	0.2059000	-84.8900000
16	18	0.1930000	-84.6200000
16	19	0.1752000	-83.6300000
16	20	0.1540000	-81.1800000
16	21	0.1297000	-76.8100000
16	22	0.1020000	-69.4200000
16	23	7.1490000e-02	-56.1000000
16	24	2.2620000e-02	21.2200000
16	25	3.2540000e-03	-72.4000000
16	26	8.2810000e-05	-38.6200000
17	1	0.2898000	-87.2000000
17	2	0.2754000	-87.2800000
17	3	0.2618000	-87.2200000
17	4	0.2497000	-86.9800000
17	5	0.2398000	-86.7700000
17	6	0.2307000	-86.9300000
17	7	0.2213000	-87.2100000
17	8	0.2118000	-87.4500000
17	9	0.2027000	-87.6200000
17	10	0.1940000	-87.7300000
17	11	0.1857000	-87.7900000
17	12	0.1777000	-87.8000000
17	13	0.1699000	-87.7400000
17	14	0.1619000	-87.5400000
17	15	0.1533000	-87.0200000
17	16	0.1450000	-85.8900000
17	17	0.1381000	-84.8900000
17	18	0.1295000	-84.6200000
17	19	0.1175000	-83.6300000
17	20	0.1033000	-81.1800000
17	21	8.7000000e-02	-76.8200000
17	22	6.8430000e-02	-69.4200000
17	23	4.7960000e-02	-56.1000000
17	24	1.5180000e-02	21.2200000
17	25	2.1830000e-03	-72.4000000
17	26	5.5560000e-05	-38.6200000
18	1	0.1454000	-87.2000000
18	2	0.1382000	-87.2800000
18	3	0.1314000	-87.2200000
18	4	0.1253000	-86.9800000
18	5	0.1204000	-86.7700000
18	6	0.1158000	-86.9300000
18	7	0.1111000	-87.2100000

```
 18   8     0.1063000 -87.4500000
 18   9     0.1017000 -87.6200000
 18   10    9.7360000e-02 -87.7300000
 18   11    9.3200000e-02 -87.7900000
 18   12    8.9210000e-02 -87.8000000
 18   13    8.5290000e-02 -87.7400000
 18   14    8.1280000e-02 -87.5400000
 18   15    7.6960000e-02 -87.0200000
 18   16    7.2770000e-02 -85.8900000
 18   17    6.9330000e-02 -84.8900000
 18   18    6.5000000e-02 -84.6200000
 18   19    5.8980000e-02 -83.6300000
 18   20    5.1850000e-02 -81.1800000
 18   21    4.3670000e-02 -76.8200000
 18   22    3.4340000e-02 -69.4200000
 18   23    2.4070000e-02 -56.1000000
 18   24    7.6180000e-03 21.2200000
 18   25    1.0960000e-03 -72.4000000
 18   26    2.7880000e-05 -38.6200000
 19   1     1.0220000e-16 92.8000000
 19   2     9.7120000e-17 92.7200000
 19   3     9.2330000e-17 92.7800000
 19   4     8.8060000e-17 93.0200000
 19   5     8.4560000e-17 93.2300000
 19   6     8.1360000e-17 93.0700000
 19   7     7.8020000e-17 92.7900000
 19   8     7.4680000e-17 92.5500000
 19   9     7.1460000e-17 92.3800000
 19   10    6.8400000e-17 92.2700000
 19   11    6.5480000e-17 92.2100000
 19   12    6.2680000e-17 92.2000000
 19   13    5.9920000e-17 92.2600000
 19   14    5.7100000e-17 92.4600000
 19   15    5.4070000e-17 92.9800000
 19   16    5.1130000e-17 94.1100000
 19   17    4.8710000e-17 95.1100000
 19   18    4.5670000e-17 95.3800000
 19   19    4.1440000e-17 96.3700000
 19   20    3.6430000e-17 98.8200000
 19   21    3.0680000e-17 103.1800000
 19   22    2.4130000e-17 110.5800000
 19   23    1.6910000e-17 123.9000000
 19   24    5.3520000e-18 -158.7800000
 19   25    7.6990000e-19 107.6000000
 19   26    1.9590000e-20 141.3800000
'-----------------------------------------------------------------------
 HFTRANSFER FUNCTION SWAY
'-----------------------------------------------------------------------
'idir ifreq amplitude phase[deg]
 1    1     2.0440000e-16 -87.2000000
 1    2     1.9420000e-16 -87.2800000
 1    3     1.8470000e-16 -87.2200000
 1    4     1.7610000e-16 -86.9800000
 1    5     1.6910000e-16 -86.7700000
 1    6     1.6270000e-16 -86.9300000
 1    7     1.5600000e-16 -87.2100000
 1    8     1.4940000e-16 -87.4500000
 1    9     1.4290000e-16 -87.6200000
 1    10    1.3680000e-16 -87.7300000
 1    11    1.3100000e-16 -87.7900000
 1    12    1.2540000e-16 -87.8000000
 1    13    1.1980000e-16 -87.7400000
 1    14    1.1420000e-16 -87.5400000
 1    15    1.0810000e-16 -87.0200000
 1    16    1.0230000e-16 -85.8900000
 1    17    9.7420000e-17 -84.8900000
 1    18    9.1330000e-17 -84.6200000
 1    19    8.2880000e-17 -83.6300000
 1    20    7.2860000e-17 -81.1800000
 1    21    6.1360000e-17 -76.8200000
 1    22    4.8260000e-17 -69.4200000
 1    23    3.3830000e-17 -56.1000000
 1    24    1.0700000e-17 21.2200000
 1    25    1.5400000e-18 -72.4000000
```

1	26	3.9180000e-20 -38.6200000
2	1	0.1454000 -87.2000000
2	2	0.1382000 -87.2800000
2	3	0.1314000 -87.2200000
2	4	0.1253000 -86.9800000
2	5	0.1204000 -86.7700000
2	6	0.1158000 -86.9300000
2	7	0.1111000 -87.2100000
2	8	0.1063000 -87.4500000
2	9	0.1017000 -87.6200000
2	10	9.7360000e-02 -87.7300000
2	11	9.3200000e-02 -87.7900000
2	12	8.9210000e-02 -87.8000000
2	13	8.5290000e-02 -87.7400000
2	14	8.1280000e-02 -87.5400000
2	15	7.6960000e-02 -87.0200000
2	16	7.2770000e-02 -85.8900000
2	17	6.9330000e-02 -84.8900000
2	18	6.5000000e-02 -84.6200000
2	19	5.8980000e-02 -83.6300000
2	20	5.1850000e-02 -81.1800000
2	21	4.3670000e-02 -76.8200000
2	22	3.4340000e-02 -69.4200000
2	23	2.4070000e-02 -56.1000000
2	24	7.6180000e-03 21.2200000
2	25	1.0960000e-03 -72.4000000
2	26	2.7880000e-05 -38.6200000
3	1	0.2898000 -87.2000000
3	2	0.2754000 -87.2800000
3	3	0.2618000 -87.2200000
3	4	0.2497000 -86.9800000
3	5	0.2398000 -86.7700000
3	6	0.2307000 -86.9300000
3	7	0.2213000 -87.2100000
3	8	0.2118000 -87.4500000
3	9	0.2027000 -87.6200000
3	10	0.1940000 -87.7300000
3	11	0.1857000 -87.7900000
3	12	0.1777000 -87.8000000
3	13	0.1699000 -87.7400000
3	14	0.1619000 -87.5400000
3	15	0.1533000 -87.0200000
3	16	0.1450000 -85.8900000
3	17	0.1381000 -84.8900000
3	18	0.1295000 -84.6200000
3	19	0.1175000 -83.6300000
3	20	0.1033000 -81.1800000
3	21	8.7000000e-02 -76.8200000
3	22	6.8430000e-02 -69.4200000
3	23	4.7960000e-02 -56.1000000
3	24	1.5180000e-02 21.2200000
3	25	2.1830000e-03 -72.4000000
3	26	5.5560000e-05 -38.6200000
4	1	0.4319000 -87.2000000
4	2	0.4105000 -87.2800000
4	3	0.3903000 -87.2200000
4	4	0.3722000 -86.9800000
4	5	0.3574000 -86.7700000
4	6	0.3439000 -86.9300000
4	7	0.3298000 -87.2100000
4	8	0.3157000 -87.4500000
4	9	0.3021000 -87.6200000
4	10	0.2891000 -87.7300000
4	11	0.2768000 -87.7900000
4	12	0.2649000 -87.8000000
4	13	0.2533000 -87.7400000
4	14	0.2414000 -87.5400000
4	15	0.2286000 -87.0200000
4	16	0.2161000 -85.8900000
4	17	0.2059000 -84.8900000
4	18	0.1930000 -84.6200000
4	19	0.1752000 -83.6300000
4	20	0.1540000 -81.1800000
4	21	0.1297000 -76.8100000

4	22	0.1020000	-69.4200000
4	23	7.1490000e-02	-56.1000000
4	24	2.2620000e-02	21.2200000
4	25	3.2540000e-03	-72.4000000
4	26	8.2810000e-05	-38.6200000
5	1	0.5708000	-87.2000000
5	2	0.5425000	-87.2800000
5	3	0.5157000	-87.2200000
5	4	0.4919000	-86.9800000
5	5	0.4723000	-86.7700000
5	6	0.4545000	-86.9300000
5	7	0.4358000	-87.2100000
5	8	0.4171000	-87.4500000
5	9	0.3992000	-87.6200000
5	10	0.3820000	-87.7300000
5	11	0.3657000	-87.7900000
5	12	0.3501000	-87.8000000
5	13	0.3347000	-87.7400000
5	14	0.3189000	-87.5400000
5	15	0.3020000	-87.0200000
5	16	0.2856000	-85.8900000
5	17	0.2721000	-84.8900000
5	18	0.2551000	-84.6200000
5	19	0.2315000	-83.6300000
5	20	0.2035000	-81.1800000
5	21	0.1714000	-76.8100000
5	22	0.1348000	-69.4200000
5	23	9.4470000e-02	-56.1000000
5	24	2.9900000e-02	21.2200000
5	25	4.3000000e-03	-72.4000000
5	26	1.0940000e-04	-38.6200000
6	1	0.7053000	-87.2000000
6	2	0.6703000	-87.2800000
6	3	0.6373000	-87.2200000
6	4	0.6078000	-86.9800000
6	5	0.5836000	-86.7700000
6	6	0.5616000	-86.9300000
6	7	0.5385000	-87.2100000
6	8	0.5155000	-87.4500000
6	9	0.4932000	-87.6200000
6	10	0.4721000	-87.7300000
6	11	0.4519000	-87.7900000
6	12	0.4326000	-87.8000000
6	13	0.4136000	-87.7400000
6	14	0.3941000	-87.5400000
6	15	0.3732000	-87.0200000
6	16	0.3529000	-85.8900000
6	17	0.3362000	-84.8900000
6	18	0.3152000	-84.6200000
6	19	0.2860000	-83.6300000
6	20	0.2514000	-81.1800000
6	21	0.2117000	-76.8100000
6	22	0.1665000	-69.4200000
6	23	0.1167000	-56.1000000
6	24	3.6940000e-02	21.2200000
6	25	5.3140000e-03	-72.4000000
6	26	1.3520000e-04	-38.6200000
7	1	0.8344000	-87.2000000
7	2	0.7930000	-87.2800000
7	3	0.7540000	-87.2200000
7	4	0.7191000	-86.9800000
7	5	0.6905000	-86.7700000
7	6	0.6644000	-86.9300000
7	7	0.6371000	-87.2100000
7	8	0.6098000	-87.4500000
7	9	0.5835000	-87.6200000
7	10	0.5585000	-87.7300000
7	11	0.5347000	-87.7900000
7	12	0.5118000	-87.8000000
7	13	0.4893000	-87.7400000
7	14	0.4663000	-87.5400000
7	15	0.4415000	-87.0200000
7	16	0.4175000	-85.8900000
7	17	0.3978000	-84.8900000

7	18	0.3729000	-84.6200000
7	19	0.3384000	-83.6300000
7	20	0.2975000	-81.1800000
7	21	0.2505000	-76.8100000
7	22	0.1970000	-69.4200000
7	23	0.1381000	-56.1000000
7	24	4.3700000e-02	21.2200000
7	25	6.2870000e-03	-72.4000000
7	26	1.6000000e-04	-38.6200000
8	1	0.9572000	-87.2000000
8	2	0.9097000	-87.2800000
8	3	0.8649000	-87.2200000
8	4	0.8249000	-86.9800000
8	5	0.7921000	-86.7700000
8	6	0.7622000	-86.9300000
8	7	0.7309000	-87.2100000
8	8	0.6996000	-87.4500000
8	9	0.6694000	-87.6200000
8	10	0.6407000	-87.7300000
8	11	0.6134000	-87.7900000
8	12	0.5871000	-87.8000000
8	13	0.5613000	-87.7400000
8	14	0.5349000	-87.5400000
8	15	0.5065000	-87.0200000
8	16	0.4789000	-85.8900000
8	17	0.4563000	-84.8900000
8	18	0.4278000	-84.6200000
8	19	0.3882000	-83.6300000
8	20	0.3413000	-81.1800000
8	21	0.2874000	-76.8100000
8	22	0.2260000	-69.4200000
8	23	0.1584000	-56.1000000
8	24	5.0140000e-02	21.2200000
8	25	7.2120000e-03	-72.4000000
8	26	1.8350000e-04	-38.6200000
9	1	1.0730000	-87.2000000
9	2	1.0190000	-87.2800000
9	3	0.9693000	-87.2200000
9	4	0.9244000	-86.9800000
9	5	0.8877000	-86.7700000
9	6	0.8541000	-86.9300000
9	7	0.8191000	-87.2100000
9	8	0.7840000	-87.4500000
9	9	0.7502000	-87.6200000
9	10	0.7180000	-87.7300000
9	11	0.6874000	-87.7900000
9	12	0.6579000	-87.8000000
9	13	0.6290000	-87.7400000
9	14	0.5994000	-87.5400000
9	15	0.5676000	-87.0200000
9	16	0.5367000	-85.8900000
9	17	0.5113000	-84.8900000
9	18	0.4794000	-84.6200000
9	19	0.4350000	-83.6300000
9	20	0.3824000	-81.1800000
9	21	0.3220000	-76.8200000
9	22	0.2533000	-69.4200000
9	23	0.1775000	-56.1000000
9	24	5.6180000e-02	21.2200000
9	25	8.0820000e-03	-72.4000000
9	26	2.0570000e-04	-38.6200000
10	1	1.1800000	-87.2000000
10	2	1.1210000	-87.2800000
10	3	1.0660000	-87.2200000
10	4	1.0170000	-86.9800000
10	5	0.9765000	-86.7700000
10	6	0.9396000	-86.9300000
10	7	0.9010000	-87.2100000
10	8	0.8624000	-87.4500000
10	9	0.8252000	-87.6200000
10	10	0.7899000	-87.7300000
10	11	0.7562000	-87.7900000
10	12	0.7238000	-87.8000000
10	13	0.6920000	-87.7400000

10	14	0.6594000	-87.5400000
10	15	0.6244000	-87.0200000
10	16	0.5904000	-85.8900000
10	17	0.5625000	-84.8900000
10	18	0.5273000	-84.6200000
10	19	0.4785000	-83.6300000
10	20	0.4207000	-81.1800000
10	21	0.3543000	-76.8100000
10	22	0.2786000	-69.4200000
10	23	0.1953000	-56.1000000
10	24	6.1810000e-02	21.2200000
10	25	8.8910000e-03	-72.4000000
10	26	2.2620000e-04	-38.6200000
11	1	1.2780000	-87.2000000
11	2	1.2150000	-87.2800000
11	3	1.1550000	-87.2200000
11	4	1.1020000	-86.9800000
11	5	1.0580000	-86.7700000
11	6	1.0180000	-86.9300000
11	7	0.9761000	-87.2100000
11	8	0.9343000	-87.4500000
11	9	0.8940000	-87.6200000
11	10	0.8557000	-87.7300000
11	11	0.8192000	-87.7900000
11	12	0.7841000	-87.8000000
11	13	0.7497000	-87.7400000
11	14	0.7144000	-87.5400000
11	15	0.6765000	-87.0200000
11	16	0.6396000	-85.8900000
11	17	0.6094000	-84.8900000
11	18	0.5713000	-84.6200000
11	19	0.5184000	-83.6300000
11	20	0.4558000	-81.1800000
11	21	0.3838000	-76.8100000
11	22	0.3019000	-69.4200000
11	23	0.2116000	-56.1000000
11	24	6.6960000e-02	21.2200000
11	25	9.6320000e-03	-72.4000000
11	26	2.4510000e-04	-38.6200000
12	1	1.3670000	-87.2000000
12	2	1.2990000	-87.2800000
12	3	1.2350000	-87.2200000
12	4	1.1780000	-86.9800000
12	5	1.1310000	-86.7700000
12	6	1.0880000	-86.9300000
12	7	1.0440000	-87.2100000
12	8	0.9991000	-87.4500000
12	9	0.9560000	-87.6200000
12	10	0.9150000	-87.7300000
12	11	0.8760000	-87.7900000
12	12	0.8385000	-87.8000000
12	13	0.8016000	-87.7400000
12	14	0.7639000	-87.5400000
12	15	0.7234000	-87.0200000
12	16	0.6840000	-85.8900000
12	17	0.6516000	-84.8900000
12	18	0.6109000	-84.6200000
12	19	0.5544000	-83.6300000
12	20	0.4874000	-81.1800000
12	21	0.4104000	-76.8100000
12	22	0.3228000	-69.4200000
12	23	0.2263000	-56.1000000
12	24	7.1600000e-02	21.2200000
12	25	1.0300000e-02	-72.4000000
12	26	2.6210000e-04	-38.6200000
13	1	1.4450000	-87.2000000
13	2	1.3740000	-87.2800000
13	3	1.3060000	-87.2200000
13	4	1.2450000	-86.9800000
13	5	1.1960000	-86.7700000
13	6	1.1510000	-86.9300000
13	7	1.1040000	-87.2100000
13	8	1.0560000	-87.4500000
13	9	1.0110000	-87.6200000

13	10	0.9674000	-87.7300000
13	11	0.9261000	-87.7900000
13	12	0.8864000	-87.8000000
13	13	0.8475000	-87.7400000
13	14	0.8076000	-87.5400000
13	15	0.7648000	-87.0200000
13	16	0.7231000	-85.8900000
13	17	0.6889000	-84.8900000
13	18	0.6459000	-84.6200000
13	19	0.5861000	-83.6300000
13	20	0.5153000	-81.1800000
13	21	0.4339000	-76.8100000
13	22	0.3413000	-69.4200000
13	23	0.2392000	-56.1000000
13	24	7.5700000e-02	21.2200000
13	25	1.0890000e-02	-72.4000000
13	26	2.7710000e-04	-38.6200000
14	1	1.5120000	-87.2000000
14	2	1.4370000	-87.2800000
14	3	1.3670000	-87.2200000
14	4	1.3030000	-86.9800000
14	5	1.2520000	-86.7700000
14	6	1.2040000	-86.9300000
14	7	1.1550000	-87.2100000
14	8	1.1050000	-87.4500000
14	9	1.0580000	-87.6200000
14	10	1.0120000	-87.7300000
14	11	0.9692000	-87.7900000
14	12	0.9277000	-87.8000000
14	13	0.8869000	-87.7400000
14	14	0.8452000	-87.5400000
14	15	0.8003000	-87.0200000
14	16	0.7567000	-85.8900000
14	17	0.7210000	-84.8900000
14	18	0.6759000	-84.6200000
14	19	0.6133000	-83.6300000
14	20	0.5392000	-81.1800000
14	21	0.4541000	-76.8100000
14	22	0.3571000	-69.4200000
14	23	0.2503000	-56.1000000
14	24	7.9220000e-02	21.2200000
14	25	1.1400000e-02	-72.4000000
14	26	2.9000000e-04	-38.6200000
15	1	1.5680000	-87.2000000
15	2	1.4900000	-87.2800000
15	3	1.4170000	-87.2200000
15	4	1.3510000	-86.9800000
15	5	1.2980000	-86.7700000
15	6	1.2490000	-86.9300000
15	7	1.1970000	-87.2100000
15	8	1.1460000	-87.4500000
15	9	1.0970000	-87.6200000
15	10	1.0500000	-87.7300000
15	11	1.0050000	-87.7900000
15	12	0.9618000	-87.8000000
15	13	0.9196000	-87.7400000
15	14	0.8763000	-87.5400000
15	15	0.8298000	-87.0200000
15	16	0.7846000	-85.8900000
15	17	0.7475000	-84.8900000
15	18	0.7008000	-84.6200000
15	19	0.6359000	-83.6300000
15	20	0.5591000	-81.1800000
15	21	0.4708000	-76.8100000
15	22	0.3703000	-69.4200000
15	23	0.2596000	-56.1000000
15	24	8.2140000e-02	21.2200000
15	25	1.1820000e-02	-72.4000000
15	26	3.0060000e-04	-38.6200000
16	1	1.6120000	-87.2000000
16	2	1.5320000	-87.2800000
16	3	1.4570000	-87.2200000
16	4	1.3890000	-86.9800000
16	5	1.3340000	-86.7700000

16	6	1.2830000	-86.9300000
16	7	1.2310000	-87.2100000
16	8	1.1780000	-87.4500000
16	9	1.1270000	-87.6200000
16	10	1.0790000	-87.7300000
16	11	1.0330000	-87.7900000
16	12	0.9887000	-87.8000000
16	13	0.9453000	-87.7400000
16	14	0.9008000	-87.5400000
16	15	0.8530000	-87.0200000
16	16	0.8065000	-85.8900000
16	17	0.7684000	-84.8900000
16	18	0.7204000	-84.6200000
16	19	0.6537000	-83.6300000
16	20	0.5747000	-81.1800000
16	21	0.4839000	-76.8100000
16	22	0.3806000	-69.4200000
16	23	0.2668000	-56.1000000
16	24	8.4430000e-02	21.2200000
16	25	1.2150000e-02	-72.4000000
16	26	3.0900000e-04	-38.6200000
17	1	1.6430000	-87.2000000
17	2	1.5620000	-87.2800000
17	3	1.4850000	-87.2200000
17	4	1.4160000	-86.9800000
17	5	1.3600000	-86.7700000
17	6	1.3090000	-86.9300000
17	7	1.2550000	-87.2100000
17	8	1.2010000	-87.4500000
17	9	1.1490000	-87.6200000
17	10	1.1000000	-87.7300000
17	11	1.0530000	-87.7900000
17	12	1.0080000	-87.8000000
17	13	0.9638000	-87.7400000
17	14	0.9184000	-87.5400000
17	15	0.8697000	-87.0200000
17	16	0.8223000	-85.8900000
17	17	0.7834000	-84.8900000
17	18	0.7344000	-84.6200000
17	19	0.6665000	-83.6300000
17	20	0.5859000	-81.1800000
17	21	0.4934000	-76.8100000
17	22	0.3881000	-69.4200000
17	23	0.2720000	-56.1000000
17	24	8.6080000e-02	21.2200000
17	25	1.2380000e-02	-72.4000000
17	26	3.1510000e-04	-38.6200000
18	1	1.6620000	-87.2000000
18	2	1.5800000	-87.2800000
18	3	1.5020000	-87.2200000
18	4	1.4330000	-86.9800000
18	5	1.3760000	-86.7700000
18	6	1.3240000	-86.9300000
18	7	1.2690000	-87.2100000
18	8	1.2150000	-87.4500000
18	9	1.1630000	-87.6200000
18	10	1.1130000	-87.7300000
18	11	1.0650000	-87.7900000
18	12	1.0200000	-87.8000000
18	13	0.9749000	-87.7400000
18	14	0.9290000	-87.5400000
18	15	0.8797000	-87.0200000
18	16	0.8318000	-85.8900000
18	17	0.7925000	-84.8900000
18	18	0.7429000	-84.6200000
18	19	0.6742000	-83.6300000
18	20	0.5927000	-81.1800000
18	21	0.4991000	-76.8100000
18	22	0.3926000	-69.4200000
18	23	0.2752000	-56.1000000
18	24	8.7080000e-02	21.2200000
18	25	1.2530000e-02	-72.4000000
18	26	3.1870000e-04	-38.6200000
19	1	1.6690000	-87.2000000

```
 19   2      1.5860000 -87.2800000
 19   3      1.5080000 -87.2200000
 19   4      1.4380000 -86.9800000
 19   5      1.3810000 -86.7700000
 19   6      1.3290000 -86.9300000
 19   7      1.2740000 -87.2100000
 19   8      1.2200000 -87.4500000
 19   9      1.1670000 -87.6200000
 19   10     1.1170000 -87.7300000
 19   11     1.0690000 -87.7900000
 19   12     1.0240000 -87.8000000
 19   13     0.9786000 -87.7400000
 19   14     0.9325000 -87.5400000
 19   15     0.8831000 -87.0200000
 19   16     0.8350000 -85.8900000
 19   17     0.7955000 -84.8900000
 19   18     0.7458000 -84.6200000
 19   19     0.6767000 -83.6300000
 19   20     0.5950000 -81.1800000
 19   21     0.5010000 -76.8100000
 19   22     0.3941000 -69.4200000
 19   23     0.2762000 -56.1000000
 19   24     8.7410000e-02 21.2200000
 19   25     1.2570000e-02 -72.4000000
 19   26     3.1990000e-04 -38.6200000
'---------------------------------------------------------------------
 HFTRANSFER FUNCTION HEAVE
'---------------------------------------------------------------------
'idir ifreq amplitude phase[deg]
 1    1      1.0280000 -0.1900000
 1    2      1.0310000 -0.2200000
 1    3      1.0350000 -0.2600000
 1    4      1.0400000 -0.3300000
 1    5      1.0460000 -0.4100000
 1    6      1.0540000 -0.4700000
 1    7      1.0640000 -0.5400000
 1    8      1.0770000 -0.6700000
 1    9      1.0950000 -0.9000000
 1    10     1.1200000 -1.2800000
 1    11     1.1550000 -1.9400000
 1    12     1.2080000 -3.1600000
 1    13     1.2880000 -5.6700000
 1    14     1.4050000 -11.2400000
 1    15     1.5180000 -23.5400000
 1    16     1.4510000 -45.0200000
 1    17     1.0860000 -71.2800000
 1    18     0.6098000 -93.1500000
 1    19     0.2757000 -101.3300000
 1    20     0.1050000 -92.9500000
 1    21     2.7140000e-02 -48.7300000
 1    22     3.0030000e-02 61.1300000
 1    23     4.4340000e-02 92.9800000
 1    24     1.4880000e-02 172.3600000
 1    25     8.4100000e-04 105.8000000
 1    26     1.2320000e-06 173.2600000
 2    1      1.0280000 -0.1900000
 2    2      1.0310000 -0.2200000
 2    3      1.0350000 -0.2600000
 2    4      1.0400000 -0.3300000
 2    5      1.0460000 -0.4100000
 2    6      1.0540000 -0.4700000
 2    7      1.0640000 -0.5400000
 2    8      1.0770000 -0.6700000
 2    9      1.0950000 -0.9000000
 2    10     1.1200000 -1.2800000
 2    11     1.1550000 -1.9400000
 2    12     1.2080000 -3.1600000
 2    13     1.2880000 -5.6700000
 2    14     1.4050000 -11.2400000
 2    15     1.5180000 -23.5400000
 2    16     1.4510000 -45.0200000
 2    17     1.0860000 -71.2800000
 2    18     0.6098000 -93.1500000
 2    19     0.2757000 -101.3300000
```

2	20	0.1050000 -92.9500000
2	21	2.7140000e-02 -48.7300000
2	22	3.0030000e-02 61.1300000
2	23	4.4340000e-02 92.9800000
2	24	1.4880000e-02 172.3600000
2	25	8.4100000e-04 105.8000000
2	26	1.2320000e-06 173.2600000
3	1	1.0280000 -0.1900000
3	2	1.0310000 -0.2200000
3	3	1.0350000 -0.2600000
3	4	1.0400000 -0.3300000
3	5	1.0460000 -0.4100000
3	6	1.0540000 -0.4700000
3	7	1.0640000 -0.5400000
3	8	1.0770000 -0.6700000
3	9	1.0950000 -0.9000000
3	10	1.1200000 -1.2800000
3	11	1.1550000 -1.9400000
3	12	1.2080000 -3.1600000
3	13	1.2880000 -5.6700000
3	14	1.4050000 -11.2400000
3	15	1.5180000 -23.5400000
3	16	1.4510000 -45.0200000
3	17	1.0860000 -71.2800000
3	18	0.6098000 -93.1500000
3	19	0.2757000 -101.3300000
3	20	0.1050000 -92.9500000
3	21	2.7140000e-02 -48.7300000
3	22	3.0030000e-02 61.1300000
3	23	4.4340000e-02 92.9800000
3	24	1.4880000e-02 172.3600000
3	25	8.4100000e-04 105.8000000
3	26	1.2320000e-06 173.2600000
4	1	1.0280000 -0.1900000
4	2	1.0310000 -0.2200000
4	3	1.0350000 -0.2600000
4	4	1.0400000 -0.3300000
4	5	1.0460000 -0.4100000
4	6	1.0540000 -0.4700000
4	7	1.0640000 -0.5400000
4	8	1.0770000 -0.6700000
4	9	1.0950000 -0.9000000
4	10	1.1200000 -1.2800000
4	11	1.1550000 -1.9400000
4	12	1.2080000 -3.1600000
4	13	1.2880000 -5.6700000
4	14	1.4050000 -11.2400000
4	15	1.5180000 -23.5400000
4	16	1.4510000 -45.0200000
4	17	1.0860000 -71.2800000
4	18	0.6098000 -93.1500000
4	19	0.2757000 -101.3300000
4	20	0.1050000 -92.9500000
4	21	2.7140000e-02 -48.7300000
4	22	3.0030000e-02 61.1300000
4	23	4.4340000e-02 92.9800000
4	24	1.4880000e-02 172.3600000
4	25	8.4100000e-04 105.8000000
4	26	1.2320000e-06 173.2600000
5	1	1.0280000 -0.1900000
5	2	1.0310000 -0.2200000
5	3	1.0350000 -0.2600000
5	4	1.0400000 -0.3300000
5	5	1.0460000 -0.4100000
5	6	1.0540000 -0.4700000
5	7	1.0640000 -0.5400000
5	8	1.0770000 -0.6700000
5	9	1.0950000 -0.9000000
5	10	1.1200000 -1.2800000
5	11	1.1550000 -1.9400000
5	12	1.2080000 -3.1600000
5	13	1.2880000 -5.6700000
5	14	1.4050000 -11.2400000
5	15	1.5180000 -23.5400000

5	16	1.4510000	-45.0200000
5	17	1.0860000	-71.2800000
5	18	0.6098000	-93.1500000
5	19	0.2757000	-101.3300000
5	20	0.1050000	-92.9500000
5	21	2.7140000e-02	-48.7300000
5	22	3.0030000e-02	61.1300000
5	23	4.4340000e-02	92.9800000
5	24	1.4880000e-02	172.3600000
5	25	8.4100000e-04	105.8000000
5	26	1.2320000e-06	173.2600000
6	1	1.0280000	-0.1900000
6	2	1.0310000	-0.2200000
6	3	1.0350000	-0.2600000
6	4	1.0400000	-0.3300000
6	5	1.0460000	-0.4100000
6	6	1.0540000	-0.4700000
6	7	1.0640000	-0.5400000
6	8	1.0770000	-0.6700000
6	9	1.0950000	-0.9000000
6	10	1.1200000	-1.2800000
6	11	1.1550000	-1.9400000
6	12	1.2080000	-3.1600000
6	13	1.2880000	-5.6700000
6	14	1.4050000	-11.2400000
6	15	1.5180000	-23.5400000
6	16	1.4510000	-45.0200000
6	17	1.0860000	-71.2800000
6	18	0.6098000	-93.1500000
6	19	0.2757000	-101.3300000
6	20	0.1050000	-92.9500000
6	21	2.7140000e-02	-48.7300000
6	22	3.0030000e-02	61.1300000
6	23	4.4340000e-02	92.9800000
6	24	1.4880000e-02	172.3600000
6	25	8.4100000e-04	105.8000000
6	26	1.2320000e-06	173.2600000
7	1	1.0280000	-0.1900000
7	2	1.0310000	-0.2200000
7	3	1.0350000	-0.2600000
7	4	1.0400000	-0.3300000
7	5	1.0460000	-0.4100000
7	6	1.0540000	-0.4700000
7	7	1.0640000	-0.5400000
7	8	1.0770000	-0.6700000
7	9	1.0950000	-0.9000000
7	10	1.1200000	-1.2800000
7	11	1.1550000	-1.9400000
7	12	1.2080000	-3.1600000
7	13	1.2880000	-5.6700000
7	14	1.4050000	-11.2400000
7	15	1.5180000	-23.5400000
7	16	1.4510000	-45.0200000
7	17	1.0860000	-71.2800000
7	18	0.6098000	-93.1500000
7	19	0.2757000	-101.3300000
7	20	0.1050000	-92.9500000
7	21	2.7140000e-02	-48.7300000
7	22	3.0030000e-02	61.1300000
7	23	4.4340000e-02	92.9800000
7	24	1.4880000e-02	172.3600000
7	25	8.4100000e-04	105.8000000
7	26	1.2320000e-06	173.2600000
8	1	1.0280000	-0.1900000
8	2	1.0310000	-0.2200000
8	3	1.0350000	-0.2600000
8	4	1.0400000	-0.3300000
8	5	1.0460000	-0.4100000
8	6	1.0540000	-0.4700000
8	7	1.0640000	-0.5400000
8	8	1.0770000	-0.6700000
8	9	1.0950000	-0.9000000
8	10	1.1200000	-1.2800000
8	11	1.1550000	-1.9400000

8	12	1.2080000	-3.1600000
8	13	1.2880000	-5.6700000
8	14	1.4050000	-11.2400000
8	15	1.5180000	-23.5400000
8	16	1.4510000	-45.0200000
8	17	1.0860000	-71.2800000
8	18	0.6098000	-93.1500000
8	19	0.2757000	-101.3300000
8	20	0.1050000	-92.9500000
8	21	2.7140000e-02	-48.7300000
8	22	3.0030000e-02	61.1300000
8	23	4.4340000e-02	92.9800000
8	24	1.4880000e-02	172.3600000
8	25	8.4100000e-04	105.8000000
8	26	1.2320000e-06	173.2600000
9	1	1.0280000	-0.1900000
9	2	1.0310000	-0.2200000
9	3	1.0350000	-0.2600000
9	4	1.0400000	-0.3300000
9	5	1.0460000	-0.4100000
9	6	1.0540000	-0.4700000
9	7	1.0640000	-0.5400000
9	8	1.0770000	-0.6700000
9	9	1.0950000	-0.9000000
9	10	1.1200000	-1.2800000
9	11	1.1550000	-1.9400000
9	12	1.2080000	-3.1600000
9	13	1.2880000	-5.6700000
9	14	1.4050000	-11.2400000
9	15	1.5180000	-23.5400000
9	16	1.4510000	-45.0200000
9	17	1.0860000	-71.2800000
9	18	0.6098000	-93.1500000
9	19	0.2757000	-101.3300000
9	20	0.1050000	-92.9500000
9	21	2.7140000e-02	-48.7300000
9	22	3.0030000e-02	61.1300000
9	23	4.4340000e-02	92.9800000
9	24	1.4880000e-02	172.3600000
9	25	8.4100000e-04	105.8000000
9	26	1.2320000e-06	173.2600000
10	1	1.0280000	-0.1900000
10	2	1.0310000	-0.2200000
10	3	1.0350000	-0.2600000
10	4	1.0400000	-0.3300000
10	5	1.0460000	-0.4100000
10	6	1.0540000	-0.4700000
10	7	1.0640000	-0.5400000
10	8	1.0770000	-0.6700000
10	9	1.0950000	-0.9000000
10	10	1.1200000	-1.2800000
10	11	1.1550000	-1.9400000
10	12	1.2080000	-3.1600000
10	13	1.2880000	-5.6700000
10	14	1.4050000	-11.2400000
10	15	1.5180000	-23.5400000
10	16	1.4510000	-45.0200000
10	17	1.0860000	-71.2800000
10	18	0.6098000	-93.1500000
10	19	0.2757000	-101.3300000
10	20	0.1050000	-92.9500000
10	21	2.7140000e-02	-48.7300000
10	22	3.0030000e-02	61.1300000
10	23	4.4340000e-02	92.9800000
10	24	1.4880000e-02	172.3600000
10	25	8.4100000e-04	105.8000000
10	26	1.2320000e-06	173.2600000
11	1	1.0280000	-0.1900000
11	2	1.0310000	-0.2200000
11	3	1.0350000	-0.2600000
11	4	1.0400000	-0.3300000
11	5	1.0460000	-0.4100000
11	6	1.0540000	-0.4700000
11	7	1.0640000	-0.5400000

11	8	1.0770000	-0.6700000
11	9	1.0950000	-0.9000000
11	10	1.1200000	-1.2800000
11	11	1.1550000	-1.9400000
11	12	1.2080000	-3.1600000
11	13	1.2880000	-5.6700000
11	14	1.4050000	-11.2400000
11	15	1.5180000	-23.5400000
11	16	1.4510000	-45.0200000
11	17	1.0860000	-71.2800000
11	18	0.6098000	-93.1500000
11	19	0.2757000	-101.3300000
11	20	0.1050000	-92.9500000
11	21	2.7140000e-02	-48.7300000
11	22	3.0030000e-02	61.1300000
11	23	4.4340000e-02	92.9800000
11	24	1.4880000e-02	172.3600000
11	25	8.4100000e-04	105.8000000
11	26	1.2320000e-06	173.2600000
12	1	1.0280000	-0.1900000
12	2	1.0310000	-0.2200000
12	3	1.0350000	-0.2600000
12	4	1.0400000	-0.3300000
12	5	1.0460000	-0.4100000
12	6	1.0540000	-0.4700000
12	7	1.0640000	-0.5400000
12	8	1.0770000	-0.6700000
12	9	1.0950000	-0.9000000
12	10	1.1200000	-1.2800000
12	11	1.1550000	-1.9400000
12	12	1.2080000	-3.1600000
12	13	1.2880000	-5.6700000
12	14	1.4050000	-11.2400000
12	15	1.5180000	-23.5400000
12	16	1.4510000	-45.0200000
12	17	1.0860000	-71.2800000
12	18	0.6098000	-93.1500000
12	19	0.2757000	-101.3300000
12	20	0.1050000	-92.9500000
12	21	2.7140000e-02	-48.7300000
12	22	3.0030000e-02	61.1300000
12	23	4.4340000e-02	92.9800000
12	24	1.4880000e-02	172.3600000
12	25	8.4100000e-04	105.8000000
12	26	1.2320000e-06	173.2600000
13	1	1.0280000	-0.1900000
13	2	1.0310000	-0.2200000
13	3	1.0350000	-0.2600000
13	4	1.0400000	-0.3300000
13	5	1.0460000	-0.4100000
13	6	1.0540000	-0.4700000
13	7	1.0640000	-0.5400000
13	8	1.0770000	-0.6700000
13	9	1.0950000	-0.9000000
13	10	1.1200000	-1.2800000
13	11	1.1550000	-1.9400000
13	12	1.2080000	-3.1600000
13	13	1.2880000	-5.6700000
13	14	1.4050000	-11.2400000
13	15	1.5180000	-23.5400000
13	16	1.4510000	-45.0200000
13	17	1.0860000	-71.2800000
13	18	0.6098000	-93.1500000
13	19	0.2757000	-101.3300000
13	20	0.1050000	-92.9500000
13	21	2.7140000e-02	-48.7300000
13	22	3.0030000e-02	61.1300000
13	23	4.4340000e-02	92.9800000
13	24	1.4880000e-02	172.3600000
13	25	8.4100000e-04	105.8000000
13	26	1.2320000e-06	173.2600000
14	1	1.0280000	-0.1900000
14	2	1.0310000	-0.2200000
14	3	1.0350000	-0.2600000

14	4	1.0400000	-0.3300000
14	5	1.0460000	-0.4100000
14	6	1.0540000	-0.4700000
14	7	1.0640000	-0.5400000
14	8	1.0770000	-0.6700000
14	9	1.0950000	-0.9000000
14	10	1.1200000	-1.2800000
14	11	1.1550000	-1.9400000
14	12	1.2080000	-3.1600000
14	13	1.2880000	-5.6700000
14	14	1.4050000	-11.2400000
14	15	1.5180000	-23.5400000
14	16	1.4510000	-45.0200000
14	17	1.0860000	-71.2800000
14	18	0.6098000	-93.1500000
14	19	0.2757000	-101.3300000
14	20	0.1050000	-92.9500000
14	21	2.7140000e-02	-48.7300000
14	22	3.0030000e-02	61.1300000
14	23	4.4340000e-02	92.9800000
14	24	1.4880000e-02	172.3600000
14	25	8.4100000e-04	105.8000000
14	26	1.2320000e-06	173.2600000
15	1	1.0280000	-0.1900000
15	2	1.0310000	-0.2200000
15	3	1.0350000	-0.2600000
15	4	1.0400000	-0.3300000
15	5	1.0460000	-0.4100000
15	6	1.0540000	-0.4700000
15	7	1.0640000	-0.5400000
15	8	1.0770000	-0.6700000
15	9	1.0950000	-0.9000000
15	10	1.1200000	-1.2800000
15	11	1.1550000	-1.9400000
15	12	1.2080000	-3.1600000
15	13	1.2880000	-5.6700000
15	14	1.4050000	-11.2400000
15	15	1.5180000	-23.5400000
15	16	1.4510000	-45.0200000
15	17	1.0860000	-71.2800000
15	18	0.6098000	-93.1500000
15	19	0.2757000	-101.3300000
15	20	0.1050000	-92.9500000
15	21	2.7140000e-02	-48.7300000
15	22	3.0030000e-02	61.1300000
15	23	4.4340000e-02	92.9800000
15	24	1.4880000e-02	172.3600000
15	25	8.4100000e-04	105.8000000
15	26	1.2320000e-06	173.2600000
16	1	1.0280000	-0.1900000
16	2	1.0310000	-0.2200000
16	3	1.0350000	-0.2600000
16	4	1.0400000	-0.3300000
16	5	1.0460000	-0.4100000
16	6	1.0540000	-0.4700000
16	7	1.0640000	-0.5400000
16	8	1.0770000	-0.6700000
16	9	1.0950000	-0.9000000
16	10	1.1200000	-1.2800000
16	11	1.1550000	-1.9400000
16	12	1.2080000	-3.1600000
16	13	1.2880000	-5.6700000
16	14	1.4050000	-11.2400000
16	15	1.5180000	-23.5400000
16	16	1.4510000	-45.0200000
16	17	1.0860000	-71.2800000
16	18	0.6098000	-93.1500000
16	19	0.2757000	-101.3300000
16	20	0.1050000	-92.9500000
16	21	2.7140000e-02	-48.7300000
16	22	3.0030000e-02	61.1300000
16	23	4.4340000e-02	92.9800000
16	24	1.4880000e-02	172.3600000
16	25	8.4100000e-04	105.8000000

16	26	1.2320000e-06 173.2600000
17	1	1.0280000 -0.1900000
17	2	1.0310000 -0.2200000
17	3	1.0350000 -0.2600000
17	4	1.0400000 -0.3300000
17	5	1.0460000 -0.4100000
17	6	1.0540000 -0.4700000
17	7	1.0640000 -0.5400000
17	8	1.0770000 -0.6700000
17	9	1.0950000 -0.9000000
17	10	1.1200000 -1.2800000
17	11	1.1550000 -1.9400000
17	12	1.2080000 -3.1600000
17	13	1.2880000 -5.6700000
17	14	1.4050000 -11.2400000
17	15	1.5180000 -23.5400000
17	16	1.4510000 -45.0200000
17	17	1.0860000 -71.2800000
17	18	0.6098000 -93.1500000
17	19	0.2757000 -101.3300000
17	20	0.1050000 -92.9500000
17	21	2.7140000e-02 -48.7300000
17	22	3.0030000e-02 61.1300000
17	23	4.4340000e-02 92.9800000
17	24	1.4880000e-02 172.3600000
17	25	8.4100000e-04 105.8000000
17	26	1.2320000e-06 173.2600000
18	1	1.0280000 -0.1900000
18	2	1.0310000 -0.2200000
18	3	1.0350000 -0.2600000
18	4	1.0400000 -0.3300000
18	5	1.0460000 -0.4100000
18	6	1.0540000 -0.4700000
18	7	1.0640000 -0.5400000
18	8	1.0770000 -0.6700000
18	9	1.0950000 -0.9000000
18	10	1.1200000 -1.2800000
18	11	1.1550000 -1.9400000
18	12	1.2080000 -3.1600000
18	13	1.2880000 -5.6700000
18	14	1.4050000 -11.2400000
18	15	1.5180000 -23.5400000
18	16	1.4510000 -45.0200000
18	17	1.0860000 -71.2800000
18	18	0.6098000 -93.1500000
18	19	0.2757000 -101.3300000
18	20	0.1050000 -92.9500000
18	21	2.7140000e-02 -48.7300000
18	22	3.0030000e-02 61.1300000
18	23	4.4340000e-02 92.9800000
18	24	1.4880000e-02 172.3600000
18	25	8.4100000e-04 105.8000000
18	26	1.2320000e-06 173.2600000
19	1	1.0280000 -0.1900000
19	2	1.0310000 -0.2200000
19	3	1.0350000 -0.2600000
19	4	1.0400000 -0.3300000
19	5	1.0460000 -0.4100000
19	6	1.0540000 -0.4700000
19	7	1.0640000 -0.5400000
19	8	1.0770000 -0.6700000
19	9	1.0950000 -0.9000000
19	10	1.1200000 -1.2800000
19	11	1.1550000 -1.9400000
19	12	1.2080000 -3.1600000
19	13	1.2880000 -5.6700000
19	14	1.4050000 -11.2400000
19	15	1.5180000 -23.5400000
19	16	1.4510000 -45.0200000
19	17	1.0860000 -71.2800000
19	18	0.6098000 -93.1500000
19	19	0.2757000 -101.3300000
19	20	0.1050000 -92.9500000
19	21	2.7140000e-02 -48.7300000

```
 19   22    3.0030000e-02 61.1300000
 19   23    4.4340000e-02 92.9800000
 19   24    1.4880000e-02 172.3600000
 19   25    8.4100000e-04 105.8000000
 19   26    1.2320000e-06 173.2600000
'----------------------------------------------------------------------
 HFTRANSFER FUNCTION ROLL
'----------------------------------------------------------------------
'idir ifreq amplitude phase[deg]
 1    1     2.4638719e-16 -95.7700000
 1    2     2.6912798e-16 -101.8600000
 1    3     2.9298461e-16 -112.5500000
 1    4     2.9653089e-16 -129.9300000
 1    5     2.4961393e-16 -151.7300000
 1    6     1.7099201e-16 -168.3800000
 1    7     1.0907978e-16 -172.6500000
 1    8     7.3638975e-17 -165.6700000
 1    9     5.6935592e-17 -151.9300000
 1    10    5.1197830e-17 -137.4900000
 1    11    5.0781543e-17 -126.2700000
 1    12    5.2665772e-17 -118.6300000
 1    13    5.6035487e-17 -113.6200000
 1    14    6.1644898e-17 -110.6000000
 1    15    7.0229324e-17 -110.8000000
 1    16    7.3913418e-17 -116.9200000
 1    17    6.0441750e-17 -123.1600000
 1    18    4.3254680e-17 -116.6900000
 1    19    3.5396107e-17 -105.9700000
 1    20    2.9502014e-17 -99.8700000
 1    21    2.2624999e-17 -94.6700000
 1    22    1.5067588e-17 -86.1700000
 1    23    8.2315893e-18 -66.3500000
 1    24    2.0887989e-18 23.0600000
 1    25    4.7590621e-20 -72.4400000
 1    26    1.2623324e-25 -107.3800000
 2    1     0.1752882 -95.7700000
 2    2     0.1914612 -101.8600000
 2    3     0.2084398 -112.5500000
 2    4     0.2110315 -129.9300000
 2    5     0.1775518 -151.7300000
 2    6     0.1216979 -168.3800000
 2    7     7.7634003e-02 -172.6500000
 2    8     5.2409603e-02 -165.6700000
 2    9     4.0518802e-02 -151.9300000
 2    10    3.6436812e-02 -137.4900000
 2    11    3.6140476e-02 -126.2700000
 2    12    3.7478725e-02 -118.6300000
 2    13    3.9876978e-02 -113.6200000
 2    14    4.3871002e-02 -110.6000000
 2    15    4.9987503e-02 -110.8000000
 2    16    5.2589229e-02 -116.9200000
 2    17    4.3030045e-02 -123.1600000
 2    18    3.0773815e-02 -116.6900000
 2    19    2.5190921e-02 -105.9700000
 2    20    2.0995981e-02 -99.8700000
 2    21    1.6102141e-02 -94.6700000
 2    22    1.0722020e-02 -86.1700000
 2    23    5.8588050e-03 -66.3500000
 2    24    1.4867596e-03 23.0600000
 2    25    3.3862099e-05 -72.4400000
 2    26    8.9854209e-11 -107.3800000
 3    1     0.3492348 -95.7700000
 3    2     0.3815432 -101.8600000
 3    3     0.4155161 -112.5500000
 3    4     0.4204326 -129.9300000
 3    5     0.3539277 -151.7300000
 3    6     0.2424328 -168.3800000
 3    7     0.1547241 -172.6500000
 3    8     0.1044249 -165.6700000
 3    9     8.0736931e-02 -151.9300000
 3    10    7.2599663e-02 -137.4900000
 3    11    7.2002643e-02 -126.2700000
 3    12    7.4679365e-02 -118.6300000
 3    13    7.9448015e-02 -113.6200000
```

3	14	8.7397299e-02	-110.6000000
3	15	9.9618770e-02	-110.8000000
3	16	0.1047759	-116.9200000
3	17	8.5719161e-02	-123.1600000
3	18	6.1312459e-02	-116.6900000
3	19	5.0202930e-02	-105.9700000
3	20	4.1823585e-02	-99.8700000
3	21	3.2080037e-02	-94.6700000
3	22	2.1355478e-02	-86.1700000
3	23	1.1671490e-02	-66.3500000
3	24	2.9609954e-03	23.0600000
3	25	6.7469744e-05	-72.4400000
3	26	1.7901264e-10	-107.3800000
4	1	0.5204985	-95.7700000
4	2	0.5685538	-101.8600000
4	3	0.6192806	-112.5500000
4	4	0.6265732	-129.9300000
4	5	0.5274480	-151.7300000
4	6	0.3613973	-168.3800000
4	7	0.2305833	-172.6500000
4	8	0.1556382	-165.6700000
4	9	0.1203898	-151.9300000
4	10	0.1082036	-137.4900000
4	11	0.1073479	-126.2700000
4	12	0.1113238	-118.6300000
4	13	0.1184313	-113.6200000
4	14	0.1302701	-110.6000000
4	15	0.1484103	-110.8000000
4	16	0.1561575	-116.9200000
4	17	0.1277995	-123.1600000
4	18	9.1380761e-02	-116.6900000
4	19	7.4821330e-02	-105.9700000
4	20	6.2359537e-02	-99.8700000
4	21	4.7809444e-02	-94.6700000
4	22	3.1842004e-02	-86.1700000
4	23	1.7398297e-02	-66.3500000
4	24	4.4137617e-03	23.0600000
4	25	1.0054861e-04	-72.4400000
4	26	2.6687893e-10	-107.3800000
5	1	0.6877377	-95.7700000
5	2	0.7513853	-101.8600000
5	3	0.8183699	-112.5500000
5	4	0.8280041	-129.9300000
5	5	0.6969369	-151.7300000
5	6	0.4775662	-168.3800000
5	7	0.3045818	-172.6500000
5	8	0.2057212	-165.6700000
5	9	0.1589963	-151.9300000
5	10	0.1430076	-137.4900000
5	11	0.1418384	-126.2700000
5	12	0.1471161	-118.6300000
5	13	0.1565129	-113.6200000
5	14	0.1721375	-110.6000000
5	15	0.1961841	-110.8000000
5	16	0.2063649	-116.9200000
5	17	0.1688570	-123.1600000
5	18	0.1207771	-116.6900000
5	19	9.8867209e-02	-105.9700000
5	20	8.2384345e-02	-99.8700000
5	21	6.3190964e-02	-94.6700000
5	22	4.2086998e-02	-86.1700000
5	23	2.2996287e-02	-66.3500000
5	24	5.8325348e-03	23.0600000
5	25	1.3287206e-04	-72.4400000
5	26	3.5255850e-10	-107.3800000
6	1	0.8498346	-95.7700000
6	2	0.9283662	-101.8600000
6	3	1.0110307	-112.5500000
6	4	1.0230950	-129.9300000
6	5	0.8612185	-151.7300000
6	6	0.5901632	-168.3800000
6	7	0.3764333	-172.6500000
6	8	0.2540952	-165.6700000
6	9	0.1965204	-151.9300000

6	10	0.1766500	-137.4900000
6	11	0.1752356	-126.2700000
6	12	0.1817422	-118.6300000
6	13	0.1933868	-113.6200000
6	14	0.2127122	-110.6000000
6	15	0.2423675	-110.8000000
6	16	0.2550069	-116.9200000
6	17	0.2086482	-123.1600000
6	18	0.1492496	-116.6900000
6	19	0.1221617	-105.9700000
6	20	0.1018078	-99.8700000
6	21	7.8075505e-02	-94.6700000
6	22	5.1989821e-02	-86.1700000
6	23	2.8403436e-02	-66.3500000
6	24	7.2074743e-03	23.0600000
6	25	1.6420156e-04	-72.4400000
6	26	4.3565376e-10	-107.3800000
7	1	1.0054475	-95.7700000
7	2	1.0984517	-101.8600000
7	3	1.1962889	-112.5500000
7	4	1.2103967	-129.9300000
7	5	1.0189489	-151.7300000
7	6	0.6981009	-168.3800000
7	7	0.4452791	-172.6500000
7	8	0.3006289	-165.6700000
7	9	0.2324810	-151.9300000
7	10	0.2089774	-137.4900000
7	11	0.2073406	-126.2700000
7	12	0.2150227	-118.6300000
7	13	0.2287311	-113.6200000
7	14	0.2517071	-110.6000000
7	15	0.2867697	-110.8000000
7	16	0.3016920	-116.9200000
7	17	0.2468322	-123.1600000
7	18	0.1765463	-116.6900000
7	19	0.1445258	-105.9700000
7	20	0.1204495	-99.8700000
7	21	9.2363670e-02	-94.6700000
7	22	6.1510218e-02	-86.1700000
7	23	3.3603841e-02	-66.3500000
7	24	8.5269511e-03	23.0600000
7	25	1.9425879e-04	-72.4400000
7	26	5.1546895e-10	-107.3800000
8	1	1.1534587	-95.7700000
8	2	1.2599703	-101.8600000
8	3	1.3723913	-112.5500000
8	4	1.3884601	-129.9300000
8	5	1.1689525	-151.7300000
8	6	0.8009135	-168.3800000
8	7	0.5108329	-172.6500000
8	8	0.3449280	-165.6700000
8	9	0.2666375	-151.9300000
8	10	0.2397707	-137.4900000
8	11	0.2378552	-126.2700000
8	12	0.2466886	-118.6300000
8	13	0.2624651	-113.6200000
8	14	0.2886912	-110.6000000
8	15	0.3289455	-110.8000000
8	16	0.3460848	-116.9200000
8	17	0.2831655	-123.1600000
8	18	0.2025411	-116.6900000
8	19	0.1657806	-105.9700000
8	20	0.1381892	-99.8700000
8	21	0.1059561	-94.6700000
8	22	7.0567678e-02	-86.1700000
8	23	3.8549792e-02	-66.3500000
8	24	9.7775468e-03	23.0600000
8	25	2.2284497e-04	-72.4400000
8	26	5.9130829e-10	-107.3800000
9	1	1.2927502	-95.7700000
9	2	1.4120861	-101.8600000
9	3	1.5379744	-112.5500000
9	4	1.5560173	-129.9300000
9	5	1.3098852	-151.7300000

9	6	0.8975139	-168.3800000
9	7	0.5725221	-172.6500000
9	8	0.3864666	-165.6700000
9	9	0.2988698	-151.9300000
9	10	0.2687009	-137.4900000
9	11	0.2664813	-126.2700000
9	12	0.2764706	-118.6300000
9	13	0.2941058	-113.6200000
9	14	0.3235926	-110.6000000
9	15	0.3686403	-110.8000000
9	16	0.3878498	-116.9200000
9	17	0.3173557	-123.1600000
9	18	0.2269821	-116.6900000
9	19	0.1857830	-105.9700000
9	20	0.1548465	-99.8700000
9	21	0.1187533	-94.6700000
9	22	7.9081691e-02	-86.1700000
9	23	4.3209482e-02	-66.3500000
9	24	1.0958367e-02	23.0600000
9	25	2.4976130e-04	-72.4400000
9	26	6.6267479e-10	-107.3800000
10	1	1.4219805	-95.7700000
10	2	1.5533365	-101.8600000
10	3	1.6918692	-112.5500000
10	4	1.7118002	-129.9300000
10	5	1.4409073	-151.7300000
10	6	0.9874361	-168.3800000
10	7	0.6297744	-172.6500000
10	8	0.4252447	-165.6700000
10	9	0.3288169	-151.9300000
10	10	0.2956587	-137.4900000
10	11	0.2932189	-126.2700000
10	12	0.3040998	-118.6300000
10	13	0.3234922	-113.6200000
10	14	0.3559088	-110.6000000
10	15	0.4055362	-110.8000000
10	16	0.4266515	-116.9200000
10	17	0.3491108	-123.1600000
10	18	0.2497013	-116.6900000
10	19	0.2043900	-105.9700000
10	20	0.1703612	-99.8700000
10	21	0.1306311	-94.6700000
10	22	8.6991873e-02	-86.1700000
10	23	4.7535202e-02	-66.3500000
10	24	1.2058676e-02	23.0600000
10	25	2.7472948e-04	-72.4400000
10	26	7.2897209e-10	-107.3800000
11	1	1.5404789	-95.7700000
11	2	1.6828857	-101.8600000
11	3	1.8327122	-112.5500000
11	4	1.8549030	-129.9300000
11	5	1.5610109	-151.7300000
11	6	1.0695931	-168.3800000
11	7	0.6823033	-172.6500000
11	8	0.4606051	-165.6700000
11	9	0.3561181	-151.9300000
11	10	0.3202056	-137.4900000
11	11	0.3176704	-126.2700000
11	12	0.3294863	-118.6300000
11	13	0.3504633	-113.6200000
11	14	0.3856397	-110.6000000
11	15	0.4393786	-110.8000000
11	16	0.4622105	-116.9200000
11	17	0.3781871	-123.1600000
11	18	0.2704887	-116.6900000
11	19	0.2214225	-105.9700000
11	20	0.1845530	-99.8700000
11	21	0.1415150	-94.6700000
11	22	9.4237841e-02	-86.1700000
11	23	5.1495143e-02	-66.3500000
11	24	1.3060584e-02	23.0600000
11	25	2.9763023e-04	-72.4400000
11	26	7.8980260e-10	-107.3800000
12	1	1.6473510	-95.7700000

12	2	1.7994800	-101.8600000
12	3	1.9597242	-112.5500000
12	4	1.9835145	-129.9300000
12	5	1.6693562	-151.7300000
12	6	1.1438294	-168.3800000
12	7	0.7295363	-172.6500000
12	8	0.4925477	-165.6700000
12	9	0.3808936	-151.9300000
12	10	0.3424512	-137.4900000
12	11	0.3396370	-126.2700000
12	12	0.3522713	-118.6300000
12	13	0.3747776	-113.6200000
12	14	0.4123544	-110.6000000
12	15	0.4697858	-110.8000000
12	16	0.4943030	-116.9200000
12	17	0.4043899	-123.1600000
12	18	0.2892604	-116.6900000
12	19	0.2367732	-105.9700000
12	20	0.1973316	-99.8700000
12	21	0.1513303	-94.6700000
12	22	0.1007793	-86.1700000
12	23	5.5057500e-02	-66.3500000
12	24	1.3973036e-02	23.0600000
12	25	3.1826476e-04	-72.4400000
12	26	8.4447053e-10	-107.3800000
13	1	1.7417025	-95.7700000
13	2	1.9024925	-101.8600000
13	3	2.0727103	-112.5500000
13	4	2.0958231	-129.9300000
13	5	1.7654390	-151.7300000
13	6	1.2092132	-168.3800000
13	7	0.7713305	-172.6500000
13	8	0.5208097	-165.6700000
13	9	0.4026624	-151.9300000
13	10	0.3620668	-137.4900000
13	11	0.3591186	-126.2700000
13	12	0.3724549	-118.6300000
13	13	0.3962739	-113.6200000
13	14	0.4359093	-110.6000000
13	15	0.4966944	-110.8000000
13	16	0.5225377	-116.9200000
13	17	0.4275730	-123.1600000
13	18	0.3058064	-116.6900000
13	19	0.2503348	-105.9700000
13	20	0.2086369	-99.8700000
13	21	0.1600026	-94.6700000
13	22	0.1065560	-86.1700000
13	23	5.8206369e-02	-66.3500000
13	24	1.4769195e-02	23.0600000
13	25	3.3647404e-04	-72.4400000
13	26	8.9287651e-10	-107.3800000
14	1	1.8226392	-95.7700000
14	2	1.9910874	-101.8600000
14	3	2.1681640	-112.5500000
14	4	2.1936402	-129.9300000
14	5	1.8477478	-151.7300000
14	6	1.2655894	-168.3800000
14	7	0.8072562	-172.6500000
14	8	0.5449968	-165.6700000
14	9	0.4214244	-151.9300000
14	10	0.3789428	-137.4900000
14	11	0.3758172	-126.2700000
14	12	0.3897680	-118.6300000
14	13	0.4146304	-113.6200000
14	14	0.4562326	-110.6000000
14	15	0.5197861	-110.8000000
14	16	0.5468587	-116.9200000
14	17	0.4474443	-123.1600000
14	18	0.3200426	-116.6900000
14	19	0.2619641	-105.9700000
14	20	0.2183486	-99.8700000
14	21	0.1674324	-94.6700000
14	22	0.1115074	-86.1700000
14	23	6.0925847e-02	-66.3500000

14	24	1.5458006e-02	23.0600000
14	25	3.5213879e-04	-72.4400000
14	26	9.3432474e-10	-107.3800000
15	1	1.8897137	-95.7700000
15	2	2.0644289	-101.8600000
15	3	2.2480335	-112.5500000
15	4	2.2751545	-129.9300000
15	5	1.9149386	-151.7300000
15	6	1.3121812	-168.3800000
15	7	0.8370274	-172.6500000
15	8	0.5651088	-165.6700000
15	9	0.4369392	-151.9300000
15	10	0.3928601	-137.4900000
15	11	0.3896333	-126.2700000
15	12	0.4041208	-118.6300000
15	13	0.4299274	-113.6200000
15	14	0.4730370	-110.6000000
15	15	0.5389337	-110.8000000
15	16	0.5669305	-116.9200000
15	17	0.4639063	-123.1600000
15	18	0.3318012	-116.6900000
15	19	0.2716254	-105.9700000
15	20	0.2263765	-99.8700000
15	21	0.1735950	-94.6700000
15	22	0.1156134	-86.1700000
15	23	6.3168224e-02	-66.3500000
15	24	1.6021579e-02	23.0600000
15	25	3.6509998e-04	-72.4400000
15	26	9.6881524e-10	-107.3800000
16	1	1.9424790	-95.7700000
16	2	2.1229350	-101.8600000
16	3	2.3103707	-112.5500000
16	4	2.3385545	-129.9300000
16	5	1.9686913	-151.7300000
16	6	1.3488334	-168.3800000
16	7	0.8603577	-172.6500000
16	8	0.5808830	-165.6700000
16	9	0.4490864	-151.9300000
16	10	0.4038185	-137.4900000
16	11	0.4004675	-126.2700000
16	12	0.4154236	-118.6300000
16	13	0.4419235	-113.6200000
16	14	0.4862507	-110.6000000
16	15	0.5540101	-110.8000000
16	16	0.5825853	-116.9200000
16	17	0.4768615	-123.1600000
16	18	0.3410821	-116.6900000
16	19	0.2792113	-105.9700000
16	20	0.2326907	-99.8700000
16	21	0.1784405	-94.6700000
16	22	0.1188339	-86.1700000
16	23	6.4933499e-02	-66.3500000
16	24	1.6468860e-02	23.0600000
16	25	3.7531785e-04	-72.4400000
16	26	9.9595042e-10	-107.3800000
17	1	1.9804879	-95.7700000
17	2	2.1626356	-101.8600000
17	3	2.3571235	-112.5500000
17	4	2.3838402	-129.9300000
17	5	2.0073260	-151.7300000
17	6	1.3750801	-168.3800000
17	7	0.8771039	-172.6500000
17	8	0.5921878	-165.6700000
17	9	0.4578661	-151.9300000
17	10	0.4117086	-137.4900000
17	11	0.4083198	-126.2700000
17	12	0.4234970	-118.6300000
17	13	0.4506187	-113.6200000
17	14	0.4957301	-110.6000000
17	15	0.5648244	-110.8000000
17	16	0.5943265	-116.9200000
17	17	0.4862127	-123.1600000
17	18	0.3477592	-116.6900000
17	19	0.2846503	-105.9700000

```
 17   20    0.2372609 -99.8700000
 17   21    0.1819443 -94.6700000
 17   22    0.1211687 -86.1700000
 17   23    6.6189866e-02 -66.3500000
 17   24    1.6790901e-02 23.0600000
 17   25    3.8263336e-04 -72.4400000
 17   26    1.0148357e-09 -107.3800000
 18   1     2.0035169 -95.7700000
 18   2     2.1877096 -101.8600000
 18   3     2.3843960 -112.5500000
 18   4     2.4110117 -129.9300000
 18   5     2.0308428 -151.7300000
 18   6     1.3910767 -168.3800000
 18   7     0.8872662 -172.6500000
 18   8     0.5990232 -165.6700000
 18   9     0.4631579 -151.9300000
 18   10    0.4164207 -137.4900000
 18   11    0.4130908 -126.2700000
 18   12    0.4284308 -118.6300000
 18   13    0.4557714 -113.6200000
 18   14    0.5014752 -110.6000000
 18   15    0.5713766 -110.8000000
 18   16    0.6010357 -116.9200000
 18   17    0.4919111 -123.1600000
 18   18    0.3517487 -116.6900000
 18   19    0.2879422 -105.9700000
 18   20    0.2399970 -99.8700000
 18   21    0.1840316 -94.6700000
 18   22    0.1225575 -86.1700000
 18   23    6.6953228e-02 -66.3500000
 18   24    1.6987705e-02 23.0600000
 18   25    3.8704653e-04 -72.4400000
 18   26    1.0267633e-09 -107.3800000
 19   1     2.0111187 -95.7700000
 19   2     2.1960676 -101.8600000
 19   3     2.3921882 -112.5500000
 19   4     2.4200688 -129.9300000
 19   5     2.0375619 -151.7300000
 19   6     1.3963571 -168.3800000
 19   7     0.8907013 -172.6500000
 19   8     0.6013893 -165.6700000
 19   9     0.4649620 -151.9300000
 19   10    0.4180645 -137.4900000
 19   11    0.4146811 -126.2700000
 19   12    0.4300455 -118.6300000
 19   13    0.4575426 -113.6200000
 19   14    0.5033424 -110.6000000
 19   15    0.5735395 -110.8000000
 19   16    0.6032721 -116.9200000
 19   17    0.4938593 -123.1600000
 19   18    0.3530926 -116.6900000
 19   19    0.2890515 -105.9700000
 19   20    0.2408990 -99.8700000
 19   21    0.1847522 -94.6700000
 19   22    0.1230204 -86.1700000
 19   23    6.7223586e-02 -66.3500000
 19   24    1.7050324e-02 23.0600000
 19   25    3.8855734e-04 -72.4400000
 19   26    1.0307391e-09 -107.3800000
'-------------------------------------------------------------------
 HFTRANSFER FUNCTION PITCH
'-------------------------------------------------------------------
'idir ifreq amplitude phase[deg]
 1    1     2.0111187 84.2300000
 1    2     2.1960676 78.1400000
 1    3     2.3921882 67.4500000
 1    4     2.4200688 50.0700000
 1    5     2.0375619 28.2700000
 1    6     1.3963571 11.6200000
 1    7     0.8907013 7.3500000
 1    8     0.6013893 14.3300000
 1    9     0.4649620 28.0700000
 1    10    0.4180645 42.5100000
 1    11    0.4146811 53.7300000
```

1	12	0.4300455	61.3700000
1	13	0.4575426	66.3800000
1	14	0.5033424	69.4000000
1	15	0.5735395	69.2000000
1	16	0.6032721	63.0800000
1	17	0.4938593	56.8400000
1	18	0.3530926	63.3100000
1	19	0.2890515	74.0300000
1	20	0.2408990	80.1300000
1	21	0.1847522	85.3300000
1	22	0.1230204	93.8300000
1	23	6.7223586e-02	113.6500000
1	24	1.7050324e-02	-156.9400000
1	25	3.8855734e-04	107.5600000
1	26	1.0307391e-09	72.6200000
2	1	2.0035169	84.2300000
2	2	2.1877096	78.1400000
2	3	2.3843960	67.4500000
2	4	2.4110117	50.0700000
2	5	2.0308428	28.2700000
2	6	1.3910767	11.6200000
2	7	0.8872662	7.3500000
2	8	0.5990232	14.3300000
2	9	0.4631579	28.0700000
2	10	0.4164207	42.5100000
2	11	0.4130908	53.7300000
2	12	0.4284308	61.3700000
2	13	0.4557714	66.3800000
2	14	0.5014752	69.4000000
2	15	0.5713766	69.2000000
2	16	0.6010357	63.0800000
2	17	0.4919111	56.8400000
2	18	0.3517487	63.3100000
2	19	0.2879422	74.0300000
2	20	0.2399970	80.1300000
2	21	0.1840316	85.3300000
2	22	0.1225575	93.8300000
2	23	6.6953228e-02	113.6500000
2	24	1.6987705e-02	-156.9400000
2	25	3.8704653e-04	107.5600000
2	26	1.0267633e-09	72.6200000
3	1	1.9804879	84.2300000
3	2	2.1626356	78.1400000
3	3	2.3571235	67.4500000
3	4	2.3838402	50.0700000
3	5	2.0073260	28.2700000
3	6	1.3750801	11.6200000
3	7	0.8771039	7.3500000
3	8	0.5921878	14.3300000
3	9	0.4578661	28.0700000
3	10	0.4117086	42.5100000
3	11	0.4083198	53.7300000
3	12	0.4234970	61.3700000
3	13	0.4506187	66.3800000
3	14	0.4957301	69.4000000
3	15	0.5648244	69.2000000
3	16	0.5943265	63.0800000
3	17	0.4862127	56.8400000
3	18	0.3477592	63.3100000
3	19	0.2846503	74.0300000
3	20	0.2372609	80.1300000
3	21	0.1819443	85.3300000
3	22	0.1211687	93.8300000
3	23	6.6189866e-02	113.6500000
3	24	1.6790901e-02	-156.9400000
3	25	3.8263336e-04	107.5600000
3	26	1.0148357e-09	72.6200000
4	1	1.9424790	84.2300000
4	2	2.1229350	78.1400000
4	3	2.3103707	67.4500000
4	4	2.3385545	50.0700000
4	5	1.9686913	28.2700000
4	6	1.3488334	11.6200000
4	7	0.8603577	7.3500000

4	8	0.5808830	14.3300000
4	9	0.4490864	28.0700000
4	10	0.4038185	42.5100000
4	11	0.4004675	53.7300000
4	12	0.4154236	61.3700000
4	13	0.4419235	66.3800000
4	14	0.4862507	69.4000000
4	15	0.5540101	69.2000000
4	16	0.5825853	63.0800000
4	17	0.4768615	56.8400000
4	18	0.3410821	63.3100000
4	19	0.2792113	74.0300000
4	20	0.2326907	80.1300000
4	21	0.1784405	85.3300000
4	22	0.1188339	93.8300000
4	23	6.4933499e-02	113.6500000
4	24	1.6468860e-02	-156.9400000
4	25	3.7531785e-04	107.5600000
4	26	9.9595042e-10	72.6200000
5	1	1.8897137	84.2300000
5	2	2.0644289	78.1400000
5	3	2.2480335	67.4500000
5	4	2.2751545	50.0700000
5	5	1.9149386	28.2700000
5	6	1.3121812	11.6200000
5	7	0.8370274	7.3500000
5	8	0.5651088	14.3300000
5	9	0.4369392	28.0700000
5	10	0.3928601	42.5100000
5	11	0.3896333	53.7300000
5	12	0.4041208	61.3700000
5	13	0.4299274	66.3800000
5	14	0.4730370	69.4000000
5	15	0.5389337	69.2000000
5	16	0.5669305	63.0800000
5	17	0.4639063	56.8400000
5	18	0.3318012	63.3100000
5	19	0.2716254	74.0300000
5	20	0.2263765	80.1300000
5	21	0.1735950	85.3300000
5	22	0.1156134	93.8300000
5	23	6.3168224e-02	113.6500000
5	24	1.6021579e-02	-156.9400000
5	25	3.6509998e-04	107.5600000
5	26	9.6881524e-10	72.6200000
6	1	1.8226392	84.2300000
6	2	1.9910874	78.1400000
6	3	2.1681640	67.4500000
6	4	2.1936402	50.0700000
6	5	1.8477478	28.2700000
6	6	1.2655894	11.6200000
6	7	0.8072562	7.3500000
6	8	0.5449968	14.3300000
6	9	0.4214244	28.0700000
6	10	0.3789428	42.5100000
6	11	0.3758172	53.7300000
6	12	0.3897680	61.3700000
6	13	0.4146304	66.3800000
6	14	0.4562326	69.4000000
6	15	0.5197861	69.2000000
6	16	0.5468587	63.0800000
6	17	0.4474443	56.8400000
6	18	0.3200426	63.3100000
6	19	0.2619641	74.0300000
6	20	0.2183486	80.1300000
6	21	0.1674324	85.3300000
6	22	0.1115074	93.8300000
6	23	6.0925847e-02	113.6500000
6	24	1.5458006e-02	-156.9400000
6	25	3.5213879e-04	107.5600000
6	26	9.3432474e-10	72.6200000
7	1	1.7417025	84.2300000
7	2	1.9024925	78.1400000
7	3	2.0727103	67.4500000

7	4	2.0958231	50.0700000
7	5	1.7654390	28.2700000
7	6	1.2092132	11.6200000
7	7	0.7713305	7.3500000
7	8	0.5208097	14.3300000
7	9	0.4026624	28.0700000
7	10	0.3620668	42.5100000
7	11	0.3591186	53.7300000
7	12	0.3724549	61.3700000
7	13	0.3962739	66.3800000
7	14	0.4359093	69.4000000
7	15	0.4966944	69.2000000
7	16	0.5225377	63.0800000
7	17	0.4275730	56.8400000
7	18	0.3058064	63.3100000
7	19	0.2503348	74.0300000
7	20	0.2086369	80.1300000
7	21	0.1600026	85.3300000
7	22	0.1065560	93.8300000
7	23	5.8206369e-02	113.6500000
7	24	1.4769195e-02	-156.9400000
7	25	3.3647404e-04	107.5600000
7	26	8.9287651e-10	72.6200000
8	1	1.6473510	84.2300000
8	2	1.7994800	78.1400000
8	3	1.9597242	67.4500000
8	4	1.9835145	50.0700000
8	5	1.6693562	28.2700000
8	6	1.1438294	11.6200000
8	7	0.7295363	7.3500000
8	8	0.4925477	14.3300000
8	9	0.3808936	28.0700000
8	10	0.3424512	42.5100000
8	11	0.3396370	53.7300000
8	12	0.3522713	61.3700000
8	13	0.3747776	66.3800000
8	14	0.4123544	69.4000000
8	15	0.4697858	69.2000000
8	16	0.4943030	63.0800000
8	17	0.4043899	56.8400000
8	18	0.2892604	63.3100000
8	19	0.2367732	74.0300000
8	20	0.1973316	80.1300000
8	21	0.1513303	85.3300000
8	22	0.1007793	93.8300000
8	23	5.5057500e-02	113.6500000
8	24	1.3973036e-02	-156.9400000
8	25	3.1826476e-04	107.5600000
8	26	8.4447053e-10	72.6200000
9	1	1.5404789	84.2300000
9	2	1.6828857	78.1400000
9	3	1.8327122	67.4500000
9	4	1.8549030	50.0700000
9	5	1.5610109	28.2700000
9	6	1.0695931	11.6200000
9	7	0.6823033	7.3500000
9	8	0.4606051	14.3300000
9	9	0.3561181	28.0700000
9	10	0.3202056	42.5100000
9	11	0.3176704	53.7300000
9	12	0.3294863	61.3700000
9	13	0.3504633	66.3800000
9	14	0.3856397	69.4000000
9	15	0.4393786	69.2000000
9	16	0.4622105	63.0800000
9	17	0.3781871	56.8400000
9	18	0.2704887	63.3100000
9	19	0.2214225	74.0300000
9	20	0.1845530	80.1300000
9	21	0.1415150	85.3300000
9	22	9.4237841e-02	93.8300000
9	23	5.1495143e-02	113.6500000
9	24	1.3060584e-02	-156.9400000
9	25	2.9763023e-04	107.5600000

9	26	7.8980260e-10	72.6200000
10	1	1.4219805	84.2300000
10	2	1.5533365	78.1400000
10	3	1.6918692	67.4500000
10	4	1.7118002	50.0700000
10	5	1.4409073	28.2700000
10	6	0.9874361	11.6200000
10	7	0.6297744	7.3500000
10	8	0.4252447	14.3300000
10	9	0.3288169	28.0700000
10	10	0.2956587	42.5100000
10	11	0.2932189	53.7300000
10	12	0.3040998	61.3700000
10	13	0.3234922	66.3800000
10	14	0.3559088	69.4000000
10	15	0.4055362	69.2000000
10	16	0.4266515	63.0800000
10	17	0.3491108	56.8400000
10	18	0.2497013	63.3100000
10	19	0.2043900	74.0300000
10	20	0.1703612	80.1300000
10	21	0.1306311	85.3300000
10	22	8.6991873e-02	93.8300000
10	23	4.7535202e-02	113.6500000
10	24	1.2058676e-02	-156.9400000
10	25	2.7472948e-04	107.5600000
10	26	7.2897209e-10	72.6200000
11	1	1.2927502	84.2300000
11	2	1.4120861	78.1400000
11	3	1.5379744	67.4500000
11	4	1.5560173	50.0700000
11	5	1.3098852	28.2700000
11	6	0.8975139	11.6200000
11	7	0.5725221	7.3500000
11	8	0.3864666	14.3300000
11	9	0.2988698	28.0700000
11	10	0.2687009	42.5100000
11	11	0.2664813	53.7300000
11	12	0.2764706	61.3700000
11	13	0.2941058	66.3800000
11	14	0.3235926	69.4000000
11	15	0.3686403	69.2000000
11	16	0.3878498	63.0800000
11	17	0.3173557	56.8400000
11	18	0.2269821	63.3100000
11	19	0.1857830	74.0300000
11	20	0.1548465	80.1300000
11	21	0.1187533	85.3300000
11	22	7.9081691e-02	93.8300000
11	23	4.3209482e-02	113.6500000
11	24	1.0958367e-02	-156.9400000
11	25	2.4976130e-04	107.5600000
11	26	6.6267479e-10	72.6200000
12	1	1.1534587	84.2300000
12	2	1.2599703	78.1400000
12	3	1.3723913	67.4500000
12	4	1.3884601	50.0700000
12	5	1.1689525	28.2700000
12	6	0.8009135	11.6200000
12	7	0.5108329	7.3500000
12	8	0.3449280	14.3300000
12	9	0.2666375	28.0700000
12	10	0.2397707	42.5100000
12	11	0.2378552	53.7300000
12	12	0.2466886	61.3700000
12	13	0.2624651	66.3800000
12	14	0.2886912	69.4000000
12	15	0.3289455	69.2000000
12	16	0.3460848	63.0800000
12	17	0.2831655	56.8400000
12	18	0.2025411	63.3100000
12	19	0.1657806	74.0300000
12	20	0.1381892	80.1300000
12	21	0.1059561	85.3300000

12	22	7.0567678e-02	93.8300000
12	23	3.8549792e-02	113.6500000
12	24	9.7775468e-03	-156.9400000
12	25	2.2284497e-04	107.5600000
12	26	5.9130829e-10	72.6200000
13	1	1.0054475	84.2300000
13	2	1.0984517	78.1400000
13	3	1.1962889	67.4500000
13	4	1.2103967	50.0700000
13	5	1.0189489	28.2700000
13	6	0.6981009	11.6200000
13	7	0.4452791	7.3500000
13	8	0.3006289	14.3300000
13	9	0.2324810	28.0700000
13	10	0.2089774	42.5100000
13	11	0.2073406	53.7300000
13	12	0.2150227	61.3700000
13	13	0.2287311	66.3800000
13	14	0.2517071	69.4000000
13	15	0.2867697	69.2000000
13	16	0.3016920	63.0800000
13	17	0.2468322	56.8400000
13	18	0.1765463	63.3100000
13	19	0.1445258	74.0300000
13	20	0.1204495	80.1300000
13	21	9.2363670e-02	85.3300000
13	22	6.1510218e-02	93.8300000
13	23	3.3603841e-02	113.6500000
13	24	8.5269511e-03	-156.9400000
13	25	1.9425879e-04	107.5600000
13	26	5.1546895e-10	72.6200000
14	1	0.8498346	84.2300000
14	2	0.9283662	78.1400000
14	3	1.0110307	67.4500000
14	4	1.0230950	50.0700000
14	5	0.8612185	28.2700000
14	6	0.5901632	11.6200000
14	7	0.3764333	7.3500000
14	8	0.2540952	14.3300000
14	9	0.1965204	28.0700000
14	10	0.1766500	42.5100000
14	11	0.1752356	53.7300000
14	12	0.1817422	61.3700000
14	13	0.1933868	66.3800000
14	14	0.2127122	69.4000000
14	15	0.2423675	69.2000000
14	16	0.2550069	63.0800000
14	17	0.2086482	56.8400000
14	18	0.1492496	63.3100000
14	19	0.1221617	74.0300000
14	20	0.1018078	80.1300000
14	21	7.8075505e-02	85.3300000
14	22	5.1989821e-02	93.8300000
14	23	2.8403436e-02	113.6500000
14	24	7.2074743e-03	-156.9400000
14	25	1.6420156e-04	107.5600000
14	26	4.3565376e-10	72.6200000
15	1	0.6877377	84.2300000
15	2	0.7513853	78.1400000
15	3	0.8183699	67.4500000
15	4	0.8280041	50.0700000
15	5	0.6969369	28.2700000
15	6	0.4775662	11.6200000
15	7	0.3045818	7.3500000
15	8	0.2057212	14.3300000
15	9	0.1589963	28.0700000
15	10	0.1430076	42.5100000
15	11	0.1418384	53.7300000
15	12	0.1471161	61.3700000
15	13	0.1565129	66.3800000
15	14	0.1721375	69.4000000
15	15	0.1961841	69.2000000
15	16	0.2063649	63.0800000
15	17	0.1688570	56.8400000

15	18	0.1207771	63.3100000
15	19	9.8867209e-02	74.0300000
15	20	8.2384345e-02	80.1300000
15	21	6.3190964e-02	85.3300000
15	22	4.2086998e-02	93.8300000
15	23	2.2996287e-02	113.6500000
15	24	5.8325348e-03	-156.9400000
15	25	1.3287206e-04	107.5600000
15	26	3.5255850e-10	72.6200000
16	1	0.5204985	84.2300000
16	2	0.5685538	78.1400000
16	3	0.6192806	67.4500000
16	4	0.6265732	50.0700000
16	5	0.5274480	28.2700000
16	6	0.3613973	11.6200000
16	7	0.2305833	7.3500000
16	8	0.1556382	14.3300000
16	9	0.1203898	28.0700000
16	10	0.1082036	42.5100000
16	11	0.1073479	53.7300000
16	12	0.1113238	61.3700000
16	13	0.1184313	66.3800000
16	14	0.1302701	69.4000000
16	15	0.1484103	69.2000000
16	16	0.1561575	63.0800000
16	17	0.1277995	56.8400000
16	18	9.1380761e-02	63.3100000
16	19	7.4821330e-02	74.0300000
16	20	6.2359537e-02	80.1300000
16	21	4.7809444e-02	85.3300000
16	22	3.1842004e-02	93.8300000
16	23	1.7398297e-02	113.6500000
16	24	4.4137617e-03	-156.9400000
16	25	1.0054861e-04	107.5600000
16	26	2.6687893e-10	72.6200000
17	1	0.3492348	84.2300000
17	2	0.3815432	78.1400000
17	3	0.4155161	67.4500000
17	4	0.4204326	50.0700000
17	5	0.3539277	28.2700000
17	6	0.2424328	11.6200000
17	7	0.1547241	7.3500000
17	8	0.1044249	14.3300000
17	9	8.0736931e-02	28.0700000
17	10	7.2599663e-02	42.5100000
17	11	7.2002643e-02	53.7300000
17	12	7.4679365e-02	61.3700000
17	13	7.9448015e-02	66.3800000
17	14	8.7397299e-02	69.4000000
17	15	9.9618770e-02	69.2000000
17	16	0.1047759	63.0800000
17	17	8.5719161e-02	56.8400000
17	18	6.1312459e-02	63.3100000
17	19	5.0202930e-02	74.0300000
17	20	4.1823585e-02	80.1300000
17	21	3.2080037e-02	85.3300000
17	22	2.1355478e-02	93.8300000
17	23	1.1671490e-02	113.6500000
17	24	2.9609954e-03	-156.9400000
17	25	6.7469744e-05	107.5600000
17	26	1.7901264e-10	72.6200000
18	1	0.1752882	84.2300000
18	2	0.1914612	78.1400000
18	3	0.2084398	67.4500000
18	4	0.2110315	50.0700000
18	5	0.1775518	28.2700000
18	6	0.1216979	11.6200000
18	7	7.7634003e-02	7.3500000
18	8	5.2409603e-02	14.3300000
18	9	4.0518802e-02	28.0700000
18	10	3.6436812e-02	42.5100000
18	11	3.6140476e-02	53.7300000
18	12	3.7478725e-02	61.3700000
18	13	3.9876978e-02	66.3800000

```
 18   14    4.3871002e-02 69.4000000
 18   15    4.9987503e-02 69.2000000
 18   16    5.2589229e-02 63.0800000
 18   17    4.3030045e-02 56.8400000
 18   18    3.0773815e-02 63.3100000
 18   19    2.5190921e-02 74.0300000
 18   20    2.0995981e-02 80.1300000
 18   21    1.6102141e-02 85.3300000
 18   22    1.0722020e-02 93.8300000
 18   23    5.8588050e-03 113.6500000
 18   24    1.4867596e-03 -156.9400000
 18   25    3.3862099e-05 107.5600000
 18   26    8.9854209e-11 72.6200000
 19   1     1.2314888e-16 -95.7700000
 19   2     1.3452220e-16 -101.8600000
 19   3     1.4649231e-16 -112.5500000
 19   4     1.4822922e-16 -129.9300000
 19   5     1.2479017e-16 -151.7300000
 19   6     8.5496004e-17 -168.3800000
 19   7     5.4532734e-17 -172.6500000
 19   8     3.6819488e-17 -165.6700000
 19   9     2.8467796e-17 -151.9300000
 19   10    2.5598915e-17 -137.4900000
 19   11    2.5385802e-17 -126.2700000
 19   12    2.6337371e-17 -118.6300000
 19   13    2.8017743e-17 -113.6200000
 19   14    3.0822449e-17 -110.6000000
 19   15    3.5121024e-17 -110.8000000
 19   16    3.6945527e-17 -116.9200000
 19   17    3.0230616e-17 -123.1600000
 19   18    2.1623141e-17 -116.6900000
 19   19    1.7698053e-17 -105.9700000
 19   20    1.4751007e-17 -99.8700000
 19   21    1.1311257e-17 -94.6700000
 19   22    7.5337941e-18 -86.1700000
 19   23    4.1157946e-18 -66.3500000
 19   24    1.0439522e-18 23.0600000
 19   25    2.3791335e-20 -72.4400000
 19   26    6.3126558e-26 -107.3800000
'----------------------------------------------------------------------
 HFTRANSFER FUNCTION YAW
'----------------------------------------------------------------------
'idir ifreq amplitude phase[deg]
 1    1     0.0000000 0.0000000
 1    2     0.0000000 0.0000000
 1    3     0.0000000 0.0000000
 1    4     0.0000000 0.0000000
 1    5     0.0000000 0.0000000
 1    6     0.0000000 0.0000000
 1    7     0.0000000 0.0000000
 1    8     0.0000000 0.0000000
 1    9     0.0000000 0.0000000
 1    10    0.0000000 0.0000000
 1    11    0.0000000 0.0000000
 1    12    0.0000000 0.0000000
 1    13    0.0000000 0.0000000
 1    14    0.0000000 0.0000000
 1    15    0.0000000 0.0000000
 1    16    0.0000000 0.0000000
 1    17    0.0000000 0.0000000
 1    18    0.0000000 0.0000000
 1    19    0.0000000 0.0000000
 1    20    0.0000000 0.0000000
 1    21    0.0000000 0.0000000
 1    22    0.0000000 0.0000000
 1    23    0.0000000 0.0000000
 1    24    0.0000000 0.0000000
 1    25    0.0000000 0.0000000
 1    26    0.0000000 0.0000000
 2    1     0.0000000 0.0000000
 2    2     0.0000000 0.0000000
 2    3     0.0000000 0.0000000
 2    4     0.0000000 0.0000000
 2    5     0.0000000 0.0000000
```

2	6	0.0000000	0.0000000
2	7	0.0000000	0.0000000
2	8	0.0000000	0.0000000
2	9	0.0000000	0.0000000
2	10	0.0000000	0.0000000
2	11	0.0000000	0.0000000
2	12	0.0000000	0.0000000
2	13	0.0000000	0.0000000
2	14	0.0000000	0.0000000
2	15	0.0000000	0.0000000
2	16	0.0000000	0.0000000
2	17	0.0000000	0.0000000
2	18	0.0000000	0.0000000
2	19	0.0000000	0.0000000
2	20	0.0000000	0.0000000
2	21	0.0000000	0.0000000
2	22	0.0000000	0.0000000
2	23	0.0000000	0.0000000
2	24	0.0000000	0.0000000
2	25	0.0000000	0.0000000
2	26	0.0000000	0.0000000
3	1	0.0000000	0.0000000
3	2	0.0000000	0.0000000
3	3	0.0000000	0.0000000
3	4	0.0000000	0.0000000
3	5	0.0000000	0.0000000
3	6	0.0000000	0.0000000
3	7	0.0000000	0.0000000
3	8	0.0000000	0.0000000
3	9	0.0000000	0.0000000
3	10	0.0000000	0.0000000
3	11	0.0000000	0.0000000
3	12	0.0000000	0.0000000
3	13	0.0000000	0.0000000
3	14	0.0000000	0.0000000
3	15	0.0000000	0.0000000
3	16	0.0000000	0.0000000
3	17	0.0000000	0.0000000
3	18	0.0000000	0.0000000
3	19	0.0000000	0.0000000
3	20	0.0000000	0.0000000
3	21	0.0000000	0.0000000
3	22	0.0000000	0.0000000
3	23	0.0000000	0.0000000
3	24	0.0000000	0.0000000
3	25	0.0000000	0.0000000
3	26	0.0000000	0.0000000
4	1	0.0000000	0.0000000
4	2	0.0000000	0.0000000
4	3	0.0000000	0.0000000
4	4	0.0000000	0.0000000
4	5	0.0000000	0.0000000
4	6	0.0000000	0.0000000
4	7	0.0000000	0.0000000
4	8	0.0000000	0.0000000
4	9	0.0000000	0.0000000
4	10	0.0000000	0.0000000
4	11	0.0000000	0.0000000
4	12	0.0000000	0.0000000
4	13	0.0000000	0.0000000
4	14	0.0000000	0.0000000
4	15	0.0000000	0.0000000
4	16	0.0000000	0.0000000
4	17	0.0000000	0.0000000
4	18	0.0000000	0.0000000
4	19	0.0000000	0.0000000
4	20	0.0000000	0.0000000
4	21	0.0000000	0.0000000
4	22	0.0000000	0.0000000
4	23	0.0000000	0.0000000
4	24	0.0000000	0.0000000
4	25	0.0000000	0.0000000
4	26	0.0000000	0.0000000
5	1	0.0000000	0.0000000

5	2	0.0000000	0.0000000
5	3	0.0000000	0.0000000
5	4	0.0000000	0.0000000
5	5	0.0000000	0.0000000
5	6	0.0000000	0.0000000
5	7	0.0000000	0.0000000
5	8	0.0000000	0.0000000
5	9	0.0000000	0.0000000
5	10	0.0000000	0.0000000
5	11	0.0000000	0.0000000
5	12	0.0000000	0.0000000
5	13	0.0000000	0.0000000
5	14	0.0000000	0.0000000
5	15	0.0000000	0.0000000
5	16	0.0000000	0.0000000
5	17	0.0000000	0.0000000
5	18	0.0000000	0.0000000
5	19	0.0000000	0.0000000
5	20	0.0000000	0.0000000
5	21	0.0000000	0.0000000
5	22	0.0000000	0.0000000
5	23	0.0000000	0.0000000
5	24	0.0000000	0.0000000
5	25	0.0000000	0.0000000
5	26	0.0000000	0.0000000
6	1	0.0000000	0.0000000
6	2	0.0000000	0.0000000
6	3	0.0000000	0.0000000
6	4	0.0000000	0.0000000
6	5	0.0000000	0.0000000
6	6	0.0000000	0.0000000
6	7	0.0000000	0.0000000
6	8	0.0000000	0.0000000
6	9	0.0000000	0.0000000
6	10	0.0000000	0.0000000
6	11	0.0000000	0.0000000
6	12	0.0000000	0.0000000
6	13	0.0000000	0.0000000
6	14	0.0000000	0.0000000
6	15	0.0000000	0.0000000
6	16	0.0000000	0.0000000
6	17	0.0000000	0.0000000
6	18	0.0000000	0.0000000
6	19	0.0000000	0.0000000
6	20	0.0000000	0.0000000
6	21	0.0000000	0.0000000
6	22	0.0000000	0.0000000
6	23	0.0000000	0.0000000
6	24	0.0000000	0.0000000
6	25	0.0000000	0.0000000
6	26	0.0000000	0.0000000
7	1	0.0000000	0.0000000
7	2	0.0000000	0.0000000
7	3	0.0000000	0.0000000
7	4	0.0000000	0.0000000
7	5	0.0000000	0.0000000
7	6	0.0000000	0.0000000
7	7	0.0000000	0.0000000
7	8	0.0000000	0.0000000
7	9	0.0000000	0.0000000
7	10	0.0000000	0.0000000
7	11	0.0000000	0.0000000
7	12	0.0000000	0.0000000
7	13	0.0000000	0.0000000
7	14	0.0000000	0.0000000
7	15	0.0000000	0.0000000
7	16	0.0000000	0.0000000
7	17	0.0000000	0.0000000
7	18	0.0000000	0.0000000
7	19	0.0000000	0.0000000
7	20	0.0000000	0.0000000
7	21	0.0000000	0.0000000
7	22	0.0000000	0.0000000
7	23	0.0000000	0.0000000

7	24	0.0000000	0.0000000
7	25	0.0000000	0.0000000
7	26	0.0000000	0.0000000
8	1	0.0000000	0.0000000
8	2	0.0000000	0.0000000
8	3	0.0000000	0.0000000
8	4	0.0000000	0.0000000
8	5	0.0000000	0.0000000
8	6	0.0000000	0.0000000
8	7	0.0000000	0.0000000
8	8	0.0000000	0.0000000
8	9	0.0000000	0.0000000
8	10	0.0000000	0.0000000
8	11	0.0000000	0.0000000
8	12	0.0000000	0.0000000
8	13	0.0000000	0.0000000
8	14	0.0000000	0.0000000
8	15	0.0000000	0.0000000
8	16	0.0000000	0.0000000
8	17	0.0000000	0.0000000
8	18	0.0000000	0.0000000
8	19	0.0000000	0.0000000
8	20	0.0000000	0.0000000
8	21	0.0000000	0.0000000
8	22	0.0000000	0.0000000
8	23	0.0000000	0.0000000
8	24	0.0000000	0.0000000
8	25	0.0000000	0.0000000
8	26	0.0000000	0.0000000
9	1	0.0000000	0.0000000
9	2	0.0000000	0.0000000
9	3	0.0000000	0.0000000
9	4	0.0000000	0.0000000
9	5	0.0000000	0.0000000
9	6	0.0000000	0.0000000
9	7	0.0000000	0.0000000
9	8	0.0000000	0.0000000
9	9	0.0000000	0.0000000
9	10	0.0000000	0.0000000
9	11	0.0000000	0.0000000
9	12	0.0000000	0.0000000
9	13	0.0000000	0.0000000
9	14	0.0000000	0.0000000
9	15	0.0000000	0.0000000
9	16	0.0000000	0.0000000
9	17	0.0000000	0.0000000
9	18	0.0000000	0.0000000
9	19	0.0000000	0.0000000
9	20	0.0000000	0.0000000
9	21	0.0000000	0.0000000
9	22	0.0000000	0.0000000
9	23	0.0000000	0.0000000
9	24	0.0000000	0.0000000
9	25	0.0000000	0.0000000
9	26	0.0000000	0.0000000
10	1	0.0000000	0.0000000
10	2	0.0000000	0.0000000
10	3	0.0000000	0.0000000
10	4	0.0000000	0.0000000
10	5	0.0000000	0.0000000
10	6	0.0000000	0.0000000
10	7	0.0000000	0.0000000
10	8	0.0000000	0.0000000
10	9	0.0000000	0.0000000
10	10	0.0000000	0.0000000
10	11	0.0000000	0.0000000
10	12	0.0000000	0.0000000
10	13	0.0000000	0.0000000
10	14	0.0000000	0.0000000
10	15	0.0000000	0.0000000
10	16	0.0000000	0.0000000
10	17	0.0000000	0.0000000
10	18	0.0000000	0.0000000
10	19	0.0000000	0.0000000

10	20	0.0000000	0.0000000
10	21	0.0000000	0.0000000
10	22	0.0000000	0.0000000
10	23	0.0000000	0.0000000
10	24	0.0000000	0.0000000
10	25	0.0000000	0.0000000
10	26	0.0000000	0.0000000
11	1	0.0000000	0.0000000
11	2	0.0000000	0.0000000
11	3	0.0000000	0.0000000
11	4	0.0000000	0.0000000
11	5	0.0000000	0.0000000
11	6	0.0000000	0.0000000
11	7	0.0000000	0.0000000
11	8	0.0000000	0.0000000
11	9	0.0000000	0.0000000
11	10	0.0000000	0.0000000
11	11	0.0000000	0.0000000
11	12	0.0000000	0.0000000
11	13	0.0000000	0.0000000
11	14	0.0000000	0.0000000
11	15	0.0000000	0.0000000
11	16	0.0000000	0.0000000
11	17	0.0000000	0.0000000
11	18	0.0000000	0.0000000
11	19	0.0000000	0.0000000
11	20	0.0000000	0.0000000
11	21	0.0000000	0.0000000
11	22	0.0000000	0.0000000
11	23	0.0000000	0.0000000
11	24	0.0000000	0.0000000
11	25	0.0000000	0.0000000
11	26	0.0000000	0.0000000
12	1	0.0000000	0.0000000
12	2	0.0000000	0.0000000
12	3	0.0000000	0.0000000
12	4	0.0000000	0.0000000
12	5	0.0000000	0.0000000
12	6	0.0000000	0.0000000
12	7	0.0000000	0.0000000
12	8	0.0000000	0.0000000
12	9	0.0000000	0.0000000
12	10	0.0000000	0.0000000
12	11	0.0000000	0.0000000
12	12	0.0000000	0.0000000
12	13	0.0000000	0.0000000
12	14	0.0000000	0.0000000
12	15	0.0000000	0.0000000
12	16	0.0000000	0.0000000
12	17	0.0000000	0.0000000
12	18	0.0000000	0.0000000
12	19	0.0000000	0.0000000
12	20	0.0000000	0.0000000
12	21	0.0000000	0.0000000
12	22	0.0000000	0.0000000
12	23	0.0000000	0.0000000
12	24	0.0000000	0.0000000
12	25	0.0000000	0.0000000
12	26	0.0000000	0.0000000
13	1	0.0000000	0.0000000
13	2	0.0000000	0.0000000
13	3	0.0000000	0.0000000
13	4	0.0000000	0.0000000
13	5	0.0000000	0.0000000
13	6	0.0000000	0.0000000
13	7	0.0000000	0.0000000
13	8	0.0000000	0.0000000
13	9	0.0000000	0.0000000
13	10	0.0000000	0.0000000
13	11	0.0000000	0.0000000
13	12	0.0000000	0.0000000
13	13	0.0000000	0.0000000
13	14	0.0000000	0.0000000
13	15	0.0000000	0.0000000

13	16	0.0000000	0.0000000
13	17	0.0000000	0.0000000
13	18	0.0000000	0.0000000
13	19	0.0000000	0.0000000
13	20	0.0000000	0.0000000
13	21	0.0000000	0.0000000
13	22	0.0000000	0.0000000
13	23	0.0000000	0.0000000
13	24	0.0000000	0.0000000
13	25	0.0000000	0.0000000
13	26	0.0000000	0.0000000
14	1	0.0000000	0.0000000
14	2	0.0000000	0.0000000
14	3	0.0000000	0.0000000
14	4	0.0000000	0.0000000
14	5	0.0000000	0.0000000
14	6	0.0000000	0.0000000
14	7	0.0000000	0.0000000
14	8	0.0000000	0.0000000
14	9	0.0000000	0.0000000
14	10	0.0000000	0.0000000
14	11	0.0000000	0.0000000
14	12	0.0000000	0.0000000
14	13	0.0000000	0.0000000
14	14	0.0000000	0.0000000
14	15	0.0000000	0.0000000
14	16	0.0000000	0.0000000
14	17	0.0000000	0.0000000
14	18	0.0000000	0.0000000
14	19	0.0000000	0.0000000
14	20	0.0000000	0.0000000
14	21	0.0000000	0.0000000
14	22	0.0000000	0.0000000
14	23	0.0000000	0.0000000
14	24	0.0000000	0.0000000
14	25	0.0000000	0.0000000
14	26	0.0000000	0.0000000
15	1	0.0000000	0.0000000
15	2	0.0000000	0.0000000
15	3	0.0000000	0.0000000
15	4	0.0000000	0.0000000
15	5	0.0000000	0.0000000
15	6	0.0000000	0.0000000
15	7	0.0000000	0.0000000
15	8	0.0000000	0.0000000
15	9	0.0000000	0.0000000
15	10	0.0000000	0.0000000
15	11	0.0000000	0.0000000
15	12	0.0000000	0.0000000
15	13	0.0000000	0.0000000
15	14	0.0000000	0.0000000
15	15	0.0000000	0.0000000
15	16	0.0000000	0.0000000
15	17	0.0000000	0.0000000
15	18	0.0000000	0.0000000
15	19	0.0000000	0.0000000
15	20	0.0000000	0.0000000
15	21	0.0000000	0.0000000
15	22	0.0000000	0.0000000
15	23	0.0000000	0.0000000
15	24	0.0000000	0.0000000
15	25	0.0000000	0.0000000
15	26	0.0000000	0.0000000
16	1	0.0000000	0.0000000
16	2	0.0000000	0.0000000
16	3	0.0000000	0.0000000
16	4	0.0000000	0.0000000
16	5	0.0000000	0.0000000
16	6	0.0000000	0.0000000
16	7	0.0000000	0.0000000
16	8	0.0000000	0.0000000
16	9	0.0000000	0.0000000
16	10	0.0000000	0.0000000
16	11	0.0000000	0.0000000

16	12	0.0000000	0.0000000
16	13	0.0000000	0.0000000
16	14	0.0000000	0.0000000
16	15	0.0000000	0.0000000
16	16	0.0000000	0.0000000
16	17	0.0000000	0.0000000
16	18	0.0000000	0.0000000
16	19	0.0000000	0.0000000
16	20	0.0000000	0.0000000
16	21	0.0000000	0.0000000
16	22	0.0000000	0.0000000
16	23	0.0000000	0.0000000
16	24	0.0000000	0.0000000
16	25	0.0000000	0.0000000
16	26	0.0000000	0.0000000
17	1	0.0000000	0.0000000
17	2	0.0000000	0.0000000
17	3	0.0000000	0.0000000
17	4	0.0000000	0.0000000
17	5	0.0000000	0.0000000
17	6	0.0000000	0.0000000
17	7	0.0000000	0.0000000
17	8	0.0000000	0.0000000
17	9	0.0000000	0.0000000
17	10	0.0000000	0.0000000
17	11	0.0000000	0.0000000
17	12	0.0000000	0.0000000
17	13	0.0000000	0.0000000
17	14	0.0000000	0.0000000
17	15	0.0000000	0.0000000
17	16	0.0000000	0.0000000
17	17	0.0000000	0.0000000
17	18	0.0000000	0.0000000
17	19	0.0000000	0.0000000
17	20	0.0000000	0.0000000
17	21	0.0000000	0.0000000
17	22	0.0000000	0.0000000
17	23	0.0000000	0.0000000
17	24	0.0000000	0.0000000
17	25	0.0000000	0.0000000
17	26	0.0000000	0.0000000
18	1	0.0000000	0.0000000
18	2	0.0000000	0.0000000
18	3	0.0000000	0.0000000
18	4	0.0000000	0.0000000
18	5	0.0000000	0.0000000
18	6	0.0000000	0.0000000
18	7	0.0000000	0.0000000
18	8	0.0000000	0.0000000
18	9	0.0000000	0.0000000
18	10	0.0000000	0.0000000
18	11	0.0000000	0.0000000
18	12	0.0000000	0.0000000
18	13	0.0000000	0.0000000
18	14	0.0000000	0.0000000
18	15	0.0000000	0.0000000
18	16	0.0000000	0.0000000
18	17	0.0000000	0.0000000
18	18	0.0000000	0.0000000
18	19	0.0000000	0.0000000
18	20	0.0000000	0.0000000
18	21	0.0000000	0.0000000
18	22	0.0000000	0.0000000
18	23	0.0000000	0.0000000
18	24	0.0000000	0.0000000
18	25	0.0000000	0.0000000
18	26	0.0000000	0.0000000
19	1	0.0000000	0.0000000
19	2	0.0000000	0.0000000
19	3	0.0000000	0.0000000
19	4	0.0000000	0.0000000
19	5	0.0000000	0.0000000
19	6	0.0000000	0.0000000
19	7	0.0000000	0.0000000

```
 19   8      0.0000000 0.0000000
 19   9      0.0000000 0.0000000
 19   10     0.0000000 0.0000000
 19   11     0.0000000 0.0000000
 19   12     0.0000000 0.0000000
 19   13     0.0000000 0.0000000
 19   14     0.0000000 0.0000000
 19   15     0.0000000 0.0000000
 19   16     0.0000000 0.0000000
 19   17     0.0000000 0.0000000
 19   18     0.0000000 0.0000000
 19   19     0.0000000 0.0000000
 19   20     0.0000000 0.0000000
 19   21     0.0000000 0.0000000
 19   22     0.0000000 0.0000000
 19   23     0.0000000 0.0000000
 19   24     0.0000000 0.0000000
 19   25     0.0000000 0.0000000
 19   26     0.0000000 0.0000000
'**********************************************************************
 ENVIRONMENT IDENTIFICATION
'**********************************************************************

'idenv
 env1
'-----------------------------------------------------------------------
 WATERDEPTH AND WAVETYPE
'-----------------------------------------------------------------------
'wdepth       noirw norw ncusta
 1000.0000000 1     0    1
'-----------------------------------------------------------------------
 ENVIRONMENT CONSTANTS
'-----------------------------------------------------------------------
'airden        watden    wakivi        airkivi
 1.2500000e-03 1.0250000 1.1880000e-06 1.8240000e-05
'-----------------------------------------------------------------------
 NEW IRREGULAR SEASTATE
'-----------------------------------------------------------------------
'nirwc iwasp1 iwadr1 iwasp2 iwadr2
 1     10     1      0      0
'-----------------------------------------------------------------------
 WAVE SPECTRUM WIND
'-----------------------------------------------------------------------
'siwahe     tpeak
 15.6000000 15.5000000
'-----------------------------------------------------------------------
 DIRECTION PARAMETERS
'-----------------------------------------------------------------------
'wadr1       expo1
 180.0000000 4.0000000
'-----------------------------------------------------------------------
 NEW CURRENT STATE
'-----------------------------------------------------------------------
'icusta nculev l_ext
 1      3      0
'curlev    curdir      curvel
 0.0000000 180.0000000 0.6700000
 -100.0000000 180.0000000 0.6700000
 -170.0000000 180.0000000 0.490000
'**********************************************************************
 END
'**********************************************************************
```

B. SIMA STAMOD RIFLEX (INP)

```
'A1     STAMOD IDENTIFICATION TEXT
'***********************************************************************
 STAMOD CONTROL INFORMATION 3.7.9
'***********************************************************************


'A1.3   OPTION AND PRINT SWITCHES
'irunco idris ianal iprdat iprcat iprfem ipform iprnor ifilm ifilco
 1      ARSYS 1     2      1      1      1      1      2     0
'-----------------------------------------------------------------------
 RUN IDENTIFICATION
'-----------------------------------------------------------------------
'idres
 SIMA
'-----------------------------------------------------------------------
 ENVIRONMENT REFERENCE IDENTIFIER
'-----------------------------------------------------------------------
'idenv
 env1
'-----------------------------------------------------------------------
 STORE VISUALISATION RESPONSES
'-----------------------------------------------------------------------
'***********************************************************************
 STATIC CONDITION INPUT
'***********************************************************************
'lcomp icurin curfac    isolvr
 0     1      1.0000000 2
'***********************************************************************
 COMPUTATIONAL PROCEDURE
'***********************************************************************
'ameth
 FEM
'-----------------------------------------------------------------------
 FEM ANALYSIS PARAMETERS
'-----------------------------------------------------------------------
'.......................................................................
 LOAD GROUP DATA
'.......................................................................
'nstep maxit racu
 2000  10    1.0000000e-06
'lotype ispec
 VOLU   0
'.......................................................................
 LOAD GROUP DATA
'.......................................................................
'nstep maxit racu
 2000  10    1.0000000e-06
'lotype ispec
 DISP   0
'***********************************************************************
 END
'***********************************************************************
```

C. SIMA DYNMOD RIFLEX (INP)

```
'A1    DYNMOD CONTROL INFORMATION
'***********************************************************************
 DYNMOD CONTROL INFORMATION 3.7.9
'***********************************************************************



'irunco ianal     idris idenv idstat idirr idres
 ANAL   IRREGULAR ARSYS env1  SIMA   XX    SIMA
'**********************************************************************
'
'           DATA GROUP D, IRREGULAR RESPONSE ANALYSIS
'
'***********************************************************************
 IRREGULAR TIMESERIES PARAMETERS
'***********************************************************************
'irand timgen        dtgen     chmeth iopamp
 1     11800.0000000 1.0000000 FFT    0
'-----------------------------------------------------------------------
 IRREGULAR RESPONSE ANALYSIS
'-----------------------------------------------------------------------
'ircno time          dt        chwav chmot chlmf tbeg      iscale
 1     11800.0000000 1.0000000 NEW   STAT  NONE  0.0000000 0
'-----------------------------------------------------------------------
 IRREGULAR WAVE PROCEDURE
'-----------------------------------------------------------------------
'iuppos icosim kinoff chstep nodstp zlower       zupper    iopdif
 1      1      0      NODE   1      -170.0000000 0.0000000 0
'**********************************************************************
'
'           DATA GROUP E
' Time domain procedure and file storage parameters
'
'***********************************************************************
 TIME DOMAIN PROCEDURE
'***********************************************************************
'itdmet inewil idisst iforst icurst
 2      1      1      1      1
'E1.3   TIME INTEGRATION
'betin     gamma     theta     a1        a2        a1t       a1to      a1b
a2t       a2t0      a2b
 4.0000000 0.5000000 1.0000000 0.0000000 0.3000000 0.0000000 0.0000000 0.0000000
0.0000000 0.0000000 0.0000000
'E1.4    NONLINEAR FORCE MODEL
'indint indhyd maxhit epshyd        tramp indrel iconre istepr ldamp
 1      1      5      1.0000000e-02 /     0      0      0      0
'-----------------------------------------------------------------------
 NONLINEAR INTEGRATION PROCEDURE
'-----------------------------------------------------------------------
'itfreq isolit maxit daccu         icocod ivarst itstat
 1      1      10    1.0000000e-05 1      2      1
'-----------------------------------------------------------------------
 DISPLACEMENT RESPONSE STORAGE
'-----------------------------------------------------------------------
'idisp nodisp idisfm cfndis
 1     1      0
'line-id iseg inod
 line1   1    ALL
'-----------------------------------------------------------------------
 FORCE RESPONSE STORAGE
'-----------------------------------------------------------------------
'ifor noforc iforfm cfnfor
```

```
 1    1      0
'line-id iseg iel
 line1   1    ALL
'-----------------------------------------------------------------------
 CURVATURE RESPONSE STORAGE
'-----------------------------------------------------------------------
'icurv nocurv icurfm cfncur
 1     1      0
'line-id iseg iel
 line1   1    ALL
'E6.1
'-----------------------------------------------------------------------
 ENVELOPE CURVE SPECIFICATION
'-----------------------------------------------------------------------
'ienvd ienvf ienvc tenvs     tenve         nprend nprenf nprenc ifilmp
 1     1     1     0.0000000 1.0000000e+07 1      1      1      2
'-----------------------------------------------------------------------
 STORE VISUALISATION RESPONSES
'-----------------------------------------------------------------------
'tconds tconde        delt      chform
 /      11800.0000000 0.5000000 VIS
'***********************************************************************
 END
'***********************************************************************
```

Appendix

E

SIMA (RIFLEX+SIMO) COUPLED INPUT

M.S.c. Thesis

Coupled Dynamic Analysis of Cylindrical FPSO, Moorings and Riser

Based on Numerical Simulation

A. SIMA INPMOD RIFLEX (INP)

```
'***********************************************************************
 INPMOD IDENTIFICATION TEXT 3.7.9
'***********************************************************************



'-----------------------------------------------------------------------
 UNIT NAMES SPECIFICATION
'-----------------------------------------------------------------------
'ut ul um uf grav      gcons
 s  m  Mg kN 9.8100000 1.0000000
'***********************************************************************
 NEW SINGLE RISER
'***********************************************************************
'atyps idris
 AR    ARSYS
'***********************************************************************
 ARBITRARY SYSTEM AR
'***********************************************************************
'nsnod nlin nsnfix nves nricon nspr nack
 4     2    4      0    0      0    0
'ibtang zbot         ibot3d
 0      -170.0000000 0
'B 6.5: LINE TOPOLOGY DEFINITION
'lineid lintyp-id snod1-id snod2-id
 line1  ltyp1     node1    node2
 line2  ltyp2     node3    node4
'FIXED NODES
'snod-id ipos ix iy iz irx iry irz chcoo  chupro
 node1   0    1  1  1  1   1   1   GLOBAL NO
'x0          y0        z0            x1          y1        z1            rot
dir
 270.0000000 0.0000000 -170.0000000 220.0000000 0.0000000 -170.0000000 0.0000000
0.0000000
'snod-id ipos ix iy iz irx iry irz chcoo  chupro
 node2   0    1  1  1  1   1   1   GLOBAL NO
'x0        y0        z0        x1         y1        z1          rot        dir
 0.0000000 0.0000000 0.0000000 33.5000000 0.0000000 -16.3200000 84.0000000
0.0000000
'snod-id ipos ix iy iz irx iry irz chcoo  chupro
```

```
 node3   0    1  1  1  1   1   1   GLOBAL NO
'x0          y0        z0           x1          y1        z1           rot
dir
 270.0000000 5.0000000 -170.0000000 220.0000000 5.0000000 -170.0000000 0.0000000
0.0000000
'snod-id ipos ix iy iz irx iry irz chcoo  chupro
 node4   0    1  1  1  1   1   1   GLOBAL NO
'x0        y0        z0        x1         y1        z1          rot        dir
 0.0000000 0.0000000 0.0000000 33.5000000 5.0000000 -16.3200000 84.0000000
0.0000000
'FREE NODES
'B.10 Line and segment specification
'*********************************************************************
 NEW LINE DATA
'*********************************************************************
'lintyp-id nseg ncmpty2 flutyp
 ltyp1     4    0       fluid1
'crstyp ncmpty1 exwtyp nelseg slgth      nstrps nstrpd slgth0     isoity
 cs1    0       0      50     25.0000000 3      5      25.0000000 0
 cs3    0       0      10     30.0000000 3      5      30.0000000 0
 cs2    0       0      50     50.0000000 3      5      50.0000000 0
 cs1    0       0      50     215.0000000 3      5      215.0000000 0
'*********************************************************************
 NEW LINE DATA
'*********************************************************************
'lintyp-id nseg ncmpty2 flutyp
 ltyp2     4    0       fluid1
'crstyp ncmpty1 exwtyp nelseg slgth      nstrps nstrpd slgth0     isoity
 cs4    0       0      50     25.0000000 3      5      25.0000000 0
 cs6    0       0      10     40.0000000 3      5      40.0000000 0
 cs5    0       0      50     55.0000000 3      5      55.0000000 0
 cs4    0       0      50     200.0000000 3      5      200.0000000 0
'*********************************************************************
 NEW COMPONENT CRS1
'*********************************************************************
'cmptyp-id temp       alpha     beta
 cs1       20.0000000 0.0000000 0.0000000
'ams       ae            ai            rgyr
 0.1450000 5.0600000e-02 1.9360000e-02 0.0000000
'iea iej igt ipress imf harpar
 1   1   1   0      0   0.0000000
'ea
 500000.0000000
'ejy        mf
 33.0000000 0.0000000
'gtminus
 5000.0000000
'cqx       cqy       cax       cay       clx       cly       icode
 0.2000000 0.2000000 0.0000000 0.0000000 0.0000000 0.0000000 1
'tb              ycurmx
 1000000.0000000 0.4000000
'*********************************************************************
 NEW COMPONENT CRS1
'*********************************************************************
'cmptyp-id temp       alpha     beta
 cs2       20.0000000 0.0000000 0.0000000
'ams       ae        ai            rgyr
 0.1600000 0.3000000 5.0600000e-02 0.0000000
'iea iej igt ipress imf harpar
 1   1   1   0      0   0.0000000
'ea
 500000.0000000
'ejy        mf
 33.0000000 0.0000000
'gtminus
```

```
 5000.0000000
'cqx       cqy       cax       cay       clx       cly       icode
 0.2500000 0.2000000 0.2000000 0.2000000 0.0000000 0.0000000 1
'tb             ycurmx
 1000000.0000000 0.4000000
'***********************************************************************
 NEW COMPONENT CRS1
'***********************************************************************
'cmptyp-id temp       alpha     beta
 cs3       20.0000000 0.0000000 0.0000000
'ams       ae        ai            rgyr
 0.1000000 0.2500000 1.9360000e-02 0.0000000
'iea iej igt ipress imf harpar
 1   1   1   0      0   0.0000000
'ea
 500000.0000000
'ejy        mf
 37.0000000 0.0000000
'gtminus
 5000.0000000
'cqx       cqy       cax       cay       clx       cly       icode
 0.2500000 0.2000000 0.0000000 0.0000000 0.0000000 0.0000000 1
'tb             ycurmx
 1000000.0000000 0.4000000
'***********************************************************************
 NEW COMPONENT CRS1
'***********************************************************************
'cmptyp-id temp       alpha     beta
 cs4       20.0000000 0.0000000 0.0000000
'ams       ae            ai            rgyr
 0.1500000 7.6300000e-02 3.4130000e-02 0.0000000
'iea iej igt ipress imf harpar
 1   1   1   0      0   0.0000000
'ea
 500000.0000000
'ejy        mf
 40.0000000 0.0000000
'gtminus
 5000.0000000
'cqx       cqy       cax       cay       clx       cly       icode
 0.2000000 0.2000000 0.0000000 0.0000000 0.0000000 0.0000000 1
'tb             ycurmx
 1000000.0000000 0.4000000
'***********************************************************************
 NEW COMPONENT CRS1
'***********************************************************************
'cmptyp-id temp       alpha     beta
 cs5       20.0000000 0.0000000 0.0000000
'ams       ae        ai            rgyr
 0.1600000 0.3000000 7.6300000e-02 0.0000000
'iea iej igt ipress imf harpar
 1   1   1   0      0   0.0000000
'ea
 500000.0000000
'ejy        mf
 33.0000000 0.0000000
'gtminus
 5000.0000000
'cqx       cqy       cax       cay       clx       cly       icode
 0.2500000 0.2000000 0.2000000 0.2000000 0.0000000 0.0000000 1
'tb             ycurmx
 1000000.0000000 0.4000000
'***********************************************************************
 NEW COMPONENT CRS1
'***********************************************************************
```

```
'cmptyp-id temp       alpha     beta
 cs6       20.0000000 0.0000000 0.0000000
'ams       ae        ai            rgyr
 0.1000000 0.2500000 7.6300000e-02 0.0000000
'iea iej igt ipress imf harpar
 1   1   1   0      0   0.0000000
'ea
 500000.0000000
'ejy        mf
 37.0000000 0.0000000
'gtminus
 5000.0000000
'cqx       cqy       cax       cay       clx       cly       icode
 0.2500000 0.2000000 0.0000000 0.0000000 0.0000000 0.0000000 1
'tb              ycurmx
 1000000.0000000 0.4000000
'***********************************************************************
 NEW COMPONENT FLUID
'***********************************************************************
'cmptyp-id
 fluid1
'rhoi      vveli     pressi    dpress    idir
 0.8000000 0.0000000 0.0000000 0.0000000 1
'***********************************************************************
 FLOATER FORCE MODEL
'***********************************************************************
'nsbody
 1
'chbody
 s400
'line-id iseg iel iend rotx      roty      rotz      ist
 line1   4    50  1    0.0000000 0.0000000 0.0000000 0
'***********************************************************************
 END
'***********************************************************************
```

B. SIMA STAMOD RIFLEX (INP)

```
'A1     STAMOD IDENTIFICATION TEXT
'*********************************************************************
 STAMOD CONTROL INFORMATION 3.7.9
'*********************************************************************


'A1.3   OPTION AND PRINT SWITCHES
'irunco idris ianal iprdat iprcat iprfem ipform iprnor ifilm ifilco
 1      ARSYS 1     2      1      1      1      1      2     0
'---------------------------------------------------------------------
 RUN IDENTIFICATION
'---------------------------------------------------------------------
'idres
 SIMA
'---------------------------------------------------------------------
 ENVIRONMENT REFERENCE IDENTIFIER
'---------------------------------------------------------------------
'idenv
 env1
'---------------------------------------------------------------------
 STORE VISUALISATION RESPONSES
'---------------------------------------------------------------------
'*********************************************************************
 STATIC CONDITION INPUT
'*********************************************************************
'lcomp icurin curfac    isolvr
 0     1      1.0000000 1
'*********************************************************************
 COMPUTATIONAL PROCEDURE
'*********************************************************************
'ameth
 FEM
'---------------------------------------------------------------------
 FEM ANALYSIS PARAMETERS
'---------------------------------------------------------------------
'.....................................................................
 LOAD GROUP DATA
'.....................................................................
'nstep maxit racu
 2000  10    1.0000000e-06
'lotype ispec
 VOLU   0
'.....................................................................
 LOAD GROUP DATA
'.....................................................................
'nstep maxit racu
 2000  10    1.0000000e-06
'lotype ispec
 DISP   0
'*********************************************************************
 END
'*********************************************************************
```

C. SIMA DYNMOD RIFLEX (INP)

```
'A1    DYNMOD CONTROL INFORMATION
'**********************************************************************
 DYNMOD CONTROL INFORMATION 3.7.9
'**********************************************************************



'irunco ianal     idris idenv idstat idirr idres
 ANAL   IRREGULAR ARSYS env1  SIMA   XX    SIMA
'*********************************************************************
'
'           DATA GROUP D, IRREGULAR RESPONSE ANALYSIS
'
'**********************************************************************
 IRREGULAR TIMESERIES PARAMETERS
'**********************************************************************
'irand timgen       dtgen     chmeth iopamp
 1     2048.0000000 1.0000000 FFT    0
'----------------------------------------------------------------------
 IRREGULAR RESPONSE ANALYSIS
'----------------------------------------------------------------------
'ircno time          dt        chwav chmot chlmf tbeg      iscale
 1     11800.0000000 1.0000000 NEW   STAT  NONE  0.0000000 0
'----------------------------------------------------------------------
 IRREGULAR WAVE PROCEDURE
'----------------------------------------------------------------------
'iuppos icosim kinoff chstep nodstp zlower       zupper    iopdif
 1      1      0      NODE   1      -100.0000000 0.0000000 0
'*********************************************************************
'
'           DATA GROUP E
' Time domain procedure and file storage parameters
'
'**********************************************************************
 TIME DOMAIN PROCEDURE
'**********************************************************************
'itdmet inewil idisst iforst icurst
 2      1      1      1      1
'E1.3   TIME INTEGRATION
'betin     gamma     theta     a1        a2        a1t       a1to      a1b
a2t       a2t0      a2b
 4.0000000 0.5000000 1.0000000 0.0000000 0.3000000 0.0000000 0.0000000 0.0000000
0.0000000 0.0000000 0.0000000
'E1.4    NONLINEAR FORCE MODEL
'indint indhyd maxhit epshyd        tramp indrel iconre istepr ldamp
 1      1      5      1.0000000e-02 /     0      0      0      0
'----------------------------------------------------------------------
 NONLINEAR INTEGRATION PROCEDURE
'----------------------------------------------------------------------
'itfreq isolit maxit daccu         icocod ivarst itstat
 1      1      10    1.0000000e-05 1      2      1
'----------------------------------------------------------------------
 DISPLACEMENT RESPONSE STORAGE
'----------------------------------------------------------------------
'idisp nodisp idisfm cfndis
 1     2      0
'line-id iseg inod
 line1   1    ALL
 line2   1    ALL
'----------------------------------------------------------------------
 FORCE RESPONSE STORAGE
'----------------------------------------------------------------------
'ifor noforc iforfm cfnfor
```

```
 1    2      0
'line-id iseg iel
 line1   1    ALL
 line2   1    ALL
'-----------------------------------------------------------------------
 CURVATURE RESPONSE STORAGE
'-----------------------------------------------------------------------
'icurv nocurv icurfm cfncur
 1     2      0
'line-id iseg iel
 line1   1    ALL
 line2   1    ALL
'E6.1
'-----------------------------------------------------------------------
 ENVELOPE CURVE SPECIFICATION
'-----------------------------------------------------------------------
'ienvd ienvf ienvc tenvs     tenve         nprend nprenf nprenc ifilmp
 1     1     1     0.0000000 1.0000000e+07 1      1      1      2
'-----------------------------------------------------------------------
 STORE VISUALISATION RESPONSES
'-----------------------------------------------------------------------
'tconds tconde     delt      chform
 /      72.0000000 0.5000000 VIS
'***********************************************************************
 END
'***********************************************************************
```

Appendix

F

Hydro D Model

M.S.c. Thesis

Coupled Dynamic Analysis of Cylindrical FPSO, Moorings and Riser

Based on Numerical Simulation

```
// HydroD V4.4-05 started 31-Jan-2011 17:28:06
// HydroD V4.4-05 ended 31-Jan-2011 17:28:06
// HydroD V4.4-05 started 31-Jan-2011 17:28:06
// ************************************************************
WaveHeightSurfaceH25 = WaveHeightSurface(2 s, 28 s, 2, 180 deg, 1 deg, 1);
WaveHeightSurfaceH25.set(2 s, 180 deg, 25 m);
WaveHeightSurfaceH25.set(30 s, 180 deg, 25 m);
// ************************************************************
DirectionSet1 = DirectionSet(Array(0 deg,45 deg,90 deg,135 deg,180 deg));
// ************************************************************
WaveSpectrum1 = Torsethaugen(15.6 m, 15.5 s);
// ************************************************************
FrequencySet1 = FrequencySet(FrequencyTypePeriod, Array(2 s,4 s,6 s,8 s,9 s,10 s,11 s,12 s,13 s,14 s,15 s,16 s,17 s,18 s,19 s,20 s,21 s,22 s,23 s,24 s,25 s,26 s,27 s,28 s,29 s,30 s));
// ************************************************************
WaveHeightSurfaceH6 = WaveHeightSurface(2 s, 28 s, 2, 180 deg, 1 deg, 1);
WaveHeightSurfaceH6.set(2 s, 180 deg, 6 m);
WaveHeightSurfaceH6.set(30 s, 180 deg, 6 m);
// ************************************************************
WaveSpectrum2 = Jonswap5Para(14 m, 13.5 s, 5, 0.07, 0.09);
// ************************************************************
Location1 = Location();
Location1.setDepth(170 m);
Location1.gravity = 9.80665 m/s^2;
Location1.air().density = 1.226 Kg/m^3;
Location1.air().kinematicViscosity = 1.462e-005 m^2/s;
Location1.water().density = 1025 Kg/m^3;
Location1.water().kinematicViscosity = 1.19e-006 m^2/s;
Location1.seabed().normaldirection = Vector3d(0 m,0 m,1 m);
// ************************************************************
Condition5 = FrequencyDomain(Location1);
Condition5.waterSurface().directionSet = DirectionSet1;
Condition5.waterSurface().frequencySet = FrequencySet1;
Condition5.water().setNoCurrent();
```

```
// *********************************************************
RegWaveH25 = StochasticSeaState(Location1);
RegWaveH25.setNoSpreading();
RegWaveH25.waveHeightEvaluator = WaveHeightSurfaceH25;
RegWaveH25.randomSeed = 1;
// *********************************************************
RegWaveH6 = StochasticSeaState(Location1);
RegWaveH6.setNoSpreading();
RegWaveH6.waveHeightEvaluator = WaveHeightSurfaceH6;
RegWaveH6.randomSeed = 1;
// *********************************************************
SeaStateTor = StochasticSeaState(Location1);
SeaStateTor.addDirectionalSpectrum(180 deg, WaveSpectrum1);
SeaStateTor.setNoSpreading();
SeaStateTor.setNoWaveHeightEvaluator();
SeaStateTor.duration = 3;
SeaStateTor.randomSeed = 1;
// *********************************************************
HydroModel1 = HydroModel(HydroModelFloating);
HydroModel1.setColumnStabilized(false);
HydroModel1.setBaselineZPos(0 m);
HydroModel1.setAPXPos(0 m);
HydroModel1.setFPXPos(100 m);
HydroModel1.clearReportMetaCenterRotationAxisAzim();
HydroModel1.addReportMetaCenterRotationAxisAzim(0 deg);
HydroModel1.addReportMetaCenterRotationAxisAzim(90 deg);
HydroModel1.clearReportHeelTrimCombinations();
HydroModel1.addReportHeelTrimCombination(0 deg, 0 deg);
HydroModel1.clearReportZWaterlines();
HydroModel1.addReportZWaterline(0 m);
HydroModel1.addReportZWaterline(0.5 m);
HydroModel1.addReportZWaterline(1 m);
HydroModel1.addReportZWaterline(1.5 m);
HydroModel1.addReportZWaterline(2 m);
HydroModel1.addReportZWaterline(2.5 m);
HydroModel1.addReportZWaterline(3 m);
HydroModel1.addReportZWaterline(3.5 m);
HydroModel1.addReportZWaterline(4 m);
HydroModel1.addReportZWaterline(4.5 m);
HydroModel1.addReportZWaterline(5 m);
HydroModel1.addReportZWaterline(5.5 m);
HydroModel1.addReportZWaterline(6 m);
HydroModel1.addReportZWaterline(6.5 m);
HydroModel1.addReportZWaterline(7 m);
HydroModel1.addReportZWaterline(7.5 m);
HydroModel1.addReportZWaterline(8 m);
HydroModel1.addReportZWaterline(8.5 m);
HydroModel1.addReportZWaterline(9 m);
HydroModel1.addReportZWaterline(9.5 m);
HydroModel1.addReportZWaterline(10 m);
HydroModel1.addReportZWaterline(10.5 m);
HydroModel1.addReportZWaterline(11 m);
```

```
HydroModel1.addReportZWaterline(11.5 m);
HydroModel1.addReportZWaterline(12 m);
HydroModel1.addReportZWaterline(12.5 m);
HydroModel1.addReportZWaterline(13 m);
HydroModel1.addReportZWaterline(13.5 m);
HydroModel1.addReportZWaterline(14 m);
HydroModel1.addReportZWaterline(14.5 m);
HydroModel1.addReportZWaterline(15 m);
HydroModel1.addReportZWaterline(15.5 m);
HydroModel1.addReportZWaterline(16 m);
HydroModel1.addReportZWaterline(16.5 m);
HydroModel1.addReportZWaterline(17 m);
HydroModel1.addReportZWaterline(17.5 m);
HydroModel1.addReportZWaterline(18 m);
HydroModel1.addReportZWaterline(18.5 m);
HydroModel1.addReportZWaterline(19 m);
HydroModel1.addReportZWaterline(19.5 m);
HydroModel1.addReportZWaterline(20 m);
HydroModel1.addReportZWaterline(20.5 m);
HydroModel1.addReportZWaterline(21 m);
HydroModel1.addReportZWaterline(21.5 m);
HydroModel1.addReportZWaterline(22 m);
HydroModel1.addReportZWaterline(22.5 m);
HydroModel1.addReportZWaterline(23 m);
HydroModel1.addReportZWaterline(23.5 m);
HydroModel1.addReportZWaterline(24 m);
HydroModel1.addReportZWaterline(24.5 m);
HydroModel1.addReportZWaterline(25 m);
HydroModel1.addReportZWaterline(25.5 m);
HydroModel1.addReportZWaterline(26 m);
HydroModel1.addReportZWaterline(26.5 m);
HydroModel1.addReportZWaterline(27 m);
HydroModel1.addReportZWaterline(27.5 m);
HydroModel1.addReportZWaterline(28 m);
HydroModel1.addReportZWaterline(28.5 m);
HydroModel1.addReportZWaterline(29 m);
HydroModel1.addReportZWaterline(29.5 m);
HydroModel1.addReportZWaterline(30 m);
HydroModel1.addReportZWaterline(30.5 m);
HydroModel1.addReportZWaterline(31 m);
HydroModel1.addReportZWaterline(31.5 m);
HydroModel1.addReportZWaterline(32 m);
HydroModel1.addReportZWaterline(32.5 m);
HydroModel1.addReportZWaterline(33 m);
HydroModel1.addReportZWaterline(33.5 m);
HydroModel1.addReportZWaterline(34 m);
HydroModel1.addReportZWaterline(34.5 m);
HydroModel1.addReportZWaterline(35 m);
HydroModel1.addReportZWaterline(35.5 m);
HydroModel1.addReportZWaterline(36 m);
HydroModel1.addReportZWaterline(36.5 m);
HydroModel1.addReportZWaterline(37 m);
```

```
HydroModel1.addReportZWaterline(37.5 m);
HydroModel1.addReportZWaterline(38 m);
HydroModel1.addReportZWaterline(38.5 m);
HydroModel1.addReportZWaterline(39 m);
HydroModel1.addReportZWaterline(39.5 m);
HydroModel1.addReportZWaterline(40 m);
HydroModel1.addReportZWaterline(40.5 m);
HydroModel1.addReportZWaterline(41 m);
HydroModel1.addReportZWaterline(41.5 m);
HydroModel1.addReportZWaterline(42 m);
HydroModel1.addReportZWaterline(42.5 m);
HydroModel1.addReportZWaterline(43 m);
HydroModel1.addReportZWaterline(43.5 m);
HydroModel1.setKidTag("17f01e80-e62b-4487-8e02-48a9067b9007");
// ***********************************************************
PIPE1 = MorisonSection(HydroModel1);
PIPE1.drySection(false);
PIPE1.setSectionName("PIPE1");
PIPE1.retainedDiameter(false);
PIPE1.setDiameter(0.02 m);
PIPE1.setDragCoefficientY(1);
PIPE1.setDragCoefficientZ(5000);
PIPE1.setAddedMassCoefficientY(1);
PIPE1.setAddedMassCoefficientZ(1);
PIPE1.partOfDualModel(true);
PIPE1.retainedMass(true);
PIPE1.setNoSubElements(1);
PIPE1.setKidTag("131b06dc-324b-443d-b8c6-9a91032b05d0");
// ***********************************************************
PanelModel1 = PanelModel(HydroModel1, ElementEnumsFEMFile, "T1.FEM", false, false);
PanelModel1.setKidTag("9e484fa1-937c-43cd-82c7-2565ed585db9");
// ***********************************************************
MorisonModel1 = MorisonModel(HydroModel1, ElementEnumsFEMFile, "T2.FEM");
MorisonModel1.refreshMorisonSections();
MorisonModel1.setKidTag("e85094e3-c518-4158-be95-2528fe813d28");
// ***********************************************************
LoadingCondition1ball = LoadingCondition(HydroModel1, 16.35 m, 0 deg, 0 deg);
LoadingCondition1ball.interpolateDampingMatrices(false);
LoadingCondition1ball.addDampingMatricesToWadam(true);
LoadingCondition1ball.setKidTag("127ba402-18c4-4862-af78-9839f695a320");
// ***********************************************************
DampingMatrix3 = AdditionalDampingMatrix(LoadingCondition1ball);
DampingMatrix3.setTranslationalTerm(1, 1, 800000 N*s/m);
DampingMatrix3.setTranslationalTerm(1, 2, 0 N*s/m);
DampingMatrix3.setTranslationalTerm(1, 3, 0 N*s/m);
DampingMatrix3.setCoupledTerm(1, 4, 0 N*s);
DampingMatrix3.setCoupledTerm(1, 5, 0 N*s);
DampingMatrix3.setCoupledTerm(1, 6, 0 N*s);
DampingMatrix3.setTranslationalTerm(2, 1, 0 N*s/m);
DampingMatrix3.setTranslationalTerm(2, 2, 800000 N*s/m);
DampingMatrix3.setTranslationalTerm(2, 3, 0 N*s/m);
DampingMatrix3.setCoupledTerm(2, 4, 0 N*s);
```

```
DampingMatrix3.setCoupledTerm(2, 5, 0 N*s);
DampingMatrix3.setCoupledTerm(2, 6, 0 N*s);
DampingMatrix3.setTranslationalTerm(3, 1, 0 N*s/m);
DampingMatrix3.setTranslationalTerm(3, 2, 0 N*s/m);
DampingMatrix3.setTranslationalTerm(3, 3, 0 N*s/m);
DampingMatrix3.setCoupledTerm(3, 4, 0 N*s);
DampingMatrix3.setCoupledTerm(3, 5, 0 N*s);
DampingMatrix3.setCoupledTerm(3, 6, 0 N*s);
DampingMatrix3.setCoupledTerm(4, 1, 0 N*s);
DampingMatrix3.setCoupledTerm(4, 2, 0 N*s);
DampingMatrix3.setCoupledTerm(4, 3, 0 N*s);
DampingMatrix3.setRotationalTerm(4, 4, 0 N*s*m);
DampingMatrix3.setRotationalTerm(4, 5, 0 N*s*m);
DampingMatrix3.setRotationalTerm(4, 6, 0 N*s*m);
DampingMatrix3.setCoupledTerm(5, 1, 0 N*s);
DampingMatrix3.setCoupledTerm(5, 2, 0 N*s);
DampingMatrix3.setCoupledTerm(5, 3, 0 N*s);
DampingMatrix3.setRotationalTerm(5, 4, 0 N*s*m);
DampingMatrix3.setRotationalTerm(5, 5, 0 N*s*m);
DampingMatrix3.setRotationalTerm(5, 6, 0 N*s*m);
DampingMatrix3.setCoupledTerm(6, 1, 0 N*s);
DampingMatrix3.setCoupledTerm(6, 2, 0 N*s);
DampingMatrix3.setCoupledTerm(6, 3, 0 N*s);
DampingMatrix3.setRotationalTerm(6, 4, 0 N*s*m);
DampingMatrix3.setRotationalTerm(6, 5, 0 N*s*m);
DampingMatrix3.setRotationalTerm(6, 6, 1e+010 N*s*m);
DampingMatrix3.setKidTag("3c92e764-a475-41a2-83d2-a44b01c48865");
// *********************************************************
RestoringMatrix2 = AdditionalRestoringMatrix(LoadingCondition1ball);
RestoringMatrix2.setTranslationalTerm(1, 1, 900000 N/m);
RestoringMatrix2.setTranslationalTerm(1, 2, 0 N/m);
RestoringMatrix2.setTranslationalTerm(1, 3, 0 N/m);
RestoringMatrix2.setCoupledTerm(1, 4, 0 N);
RestoringMatrix2.setCoupledTerm(1, 5, 0 N);
RestoringMatrix2.setCoupledTerm(1, 6, 0 N);
RestoringMatrix2.setTranslationalTerm(2, 1, 0 N/m);
RestoringMatrix2.setTranslationalTerm(2, 2, 900000 N/m);
RestoringMatrix2.setTranslationalTerm(2, 3, 0 N/m);
RestoringMatrix2.setCoupledTerm(2, 4, 12000000 N);
RestoringMatrix2.setCoupledTerm(2, 5, 0 N);
RestoringMatrix2.setCoupledTerm(2, 6, 0 N);
RestoringMatrix2.setTranslationalTerm(3, 1, 0 N/m);
RestoringMatrix2.setTranslationalTerm(3, 2, 0 N/m);
RestoringMatrix2.setTranslationalTerm(3, 3, 0 N/m);
RestoringMatrix2.setCoupledTerm(3, 4, 0 N);
RestoringMatrix2.setCoupledTerm(3, 5, 0 N);
RestoringMatrix2.setCoupledTerm(3, 6, 0 N);
RestoringMatrix2.setCoupledTerm(4, 1, 0 N);
RestoringMatrix2.setCoupledTerm(4, 2, 12000000 N);
RestoringMatrix2.setCoupledTerm(4, 3, 0 N);
RestoringMatrix2.setRotationalTerm(4, 4, 650000000 N*m);
RestoringMatrix2.setRotationalTerm(4, 5, 0 N*m);
```

```
RestoringMatrix2.setRotationalTerm(4, 6, 0 N*m);
RestoringMatrix2.setCoupledTerm(5, 1, 0 N);
RestoringMatrix2.setCoupledTerm(5, 2, 0 N);
RestoringMatrix2.setCoupledTerm(5, 3, 0 N);
RestoringMatrix2.setRotationalTerm(5, 4, 0 N*m);
RestoringMatrix2.setRotationalTerm(5, 5, 650000000 N*m);
RestoringMatrix2.setRotationalTerm(5, 6, 0 N*m);
RestoringMatrix2.setCoupledTerm(6, 1, 0 N);
RestoringMatrix2.setCoupledTerm(6, 2, 0 N);
RestoringMatrix2.setCoupledTerm(6, 3, 0 N);
RestoringMatrix2.setRotationalTerm(6, 4, 0 N*m);
RestoringMatrix2.setRotationalTerm(6, 5, 0 N*m);
RestoringMatrix2.setRotationalTerm(6, 6, 0 N*m);
RestoringMatrix2.setKidTag("3ad94d6f-15b6-4644-bc1d-587d41d718f3");
// **********************************************************
MassModel1 = MassModel(LoadingCondition1ball, MassModelSpecified);
MassModel1.setUserMassCoordinateSystem(MixedCoordinateSystem);
MassModel1.setTotalMass(70687500 Kg);
MassModel1.setCOG(Point(0 m,0 m,18.23 m));
MassModel1.setRadiusGyration(Vector3d(22 m,22 m,32 m));
MassModel1.setSpecificProductInertia(0 m, 0 m, 0 m);
MassModel1.addTankMass(false);
MassModel1.updateStiffnessWithFreeSurfaceEffect(true);
MassModel1.setKidTag("caac3eae-b8b5-4eea-aebd-eea0399d5428");
// **********************************************************
LoadingCondition2Loa = LoadingCondition(HydroModel1, 20.72 m, 0 deg, 0 deg);
LoadingCondition2Loa.interpolateDampingMatrices(false);
LoadingCondition2Loa.addDampingMatricesToWadam(true);
LoadingCondition2Loa.setKidTag("fdd251df-53d0-44e6-b2ff-7846067ed809");
// **********************************************************
RestoringMatrix1 = AdditionalRestoringMatrix(LoadingCondition2Loa);
RestoringMatrix1.setTranslationalTerm(1, 1, 900000 N/m);
RestoringMatrix1.setTranslationalTerm(1, 2, 0 N/m);
RestoringMatrix1.setTranslationalTerm(1, 3, 0 N/m);
RestoringMatrix1.setCoupledTerm(1, 4, 0 N);
RestoringMatrix1.setCoupledTerm(1, 5, 0 N);
RestoringMatrix1.setCoupledTerm(1, 6, 0 N);
RestoringMatrix1.setTranslationalTerm(2, 1, 0 N/m);
RestoringMatrix1.setTranslationalTerm(2, 2, 900000 N/m);
RestoringMatrix1.setTranslationalTerm(2, 3, 0 N/m);
RestoringMatrix1.setCoupledTerm(2, 4, 17000000 N);
RestoringMatrix1.setCoupledTerm(2, 5, 0 N);
RestoringMatrix1.setCoupledTerm(2, 6, 0 N);
RestoringMatrix1.setTranslationalTerm(3, 1, 0 N/m);
RestoringMatrix1.setTranslationalTerm(3, 2, 0 N/m);
RestoringMatrix1.setTranslationalTerm(3, 3, 0 N/m);
RestoringMatrix1.setCoupledTerm(3, 4, 0 N);
RestoringMatrix1.setCoupledTerm(3, 5, 0 N);
RestoringMatrix1.setCoupledTerm(3, 6, 0 N);
RestoringMatrix1.setCoupledTerm(4, 1, 0 N);
RestoringMatrix1.setCoupledTerm(4, 2, 17000000 N);
RestoringMatrix1.setCoupledTerm(4, 3, 0 N);
```

```
RestoringMatrix1.setRotationalTerm(4, 4, 900000000 N*m);
RestoringMatrix1.setRotationalTerm(4, 5, 0 N*m);
RestoringMatrix1.setRotationalTerm(4, 6, 0 N*m);
RestoringMatrix1.setCoupledTerm(5, 1, 0 N);
RestoringMatrix1.setCoupledTerm(5, 2, 0 N);
RestoringMatrix1.setCoupledTerm(5, 3, 0 N);
RestoringMatrix1.setRotationalTerm(5, 4, 0 N*m);
RestoringMatrix1.setRotationalTerm(5, 5, 900000000 N*m);
RestoringMatrix1.setRotationalTerm(5, 6, 0 N*m);
RestoringMatrix1.setCoupledTerm(6, 1, 0 N);
RestoringMatrix1.setCoupledTerm(6, 2, 0 N);
RestoringMatrix1.setCoupledTerm(6, 3, 0 N);
RestoringMatrix1.setRotationalTerm(6, 4, 0 N*m);
RestoringMatrix1.setRotationalTerm(6, 5, 0 N*m);
RestoringMatrix1.setRotationalTerm(6, 6, 0 N*m);
RestoringMatrix1.setKidTag("3ad94d6f-15b6-4644-bc1d-587d41d718f3");
// *********************************************************
DampingMatrix1 = AdditionalDampingMatrix(LoadingCondition2Loa);
DampingMatrix1.setTranslationalTerm(1, 1, 800000 N*s/m);
DampingMatrix1.setTranslationalTerm(1, 2, 0 N*s/m);
DampingMatrix1.setTranslationalTerm(1, 3, 0 N*s/m);
DampingMatrix1.setCoupledTerm(1, 4, 0 N*s);
DampingMatrix1.setCoupledTerm(1, 5, 0 N*s);
DampingMatrix1.setCoupledTerm(1, 6, 0 N*s);
DampingMatrix1.setTranslationalTerm(2, 1, 0 N*s/m);
DampingMatrix1.setTranslationalTerm(2, 2, 800000 N*s/m);
DampingMatrix1.setTranslationalTerm(2, 3, 0 N*s/m);
DampingMatrix1.setCoupledTerm(2, 4, 0 N*s);
DampingMatrix1.setCoupledTerm(2, 5, 0 N*s);
DampingMatrix1.setCoupledTerm(2, 6, 0 N*s);
DampingMatrix1.setTranslationalTerm(3, 1, 0 N*s/m);
DampingMatrix1.setTranslationalTerm(3, 2, 0 N*s/m);
DampingMatrix1.setTranslationalTerm(3, 3, 0 N*s/m);
DampingMatrix1.setCoupledTerm(3, 4, 0 N*s);
DampingMatrix1.setCoupledTerm(3, 5, 0 N*s);
DampingMatrix1.setCoupledTerm(3, 6, 0 N*s);
DampingMatrix1.setCoupledTerm(4, 1, 0 N*s);
DampingMatrix1.setCoupledTerm(4, 2, 0 N*s);
DampingMatrix1.setCoupledTerm(4, 3, 0 N*s);
DampingMatrix1.setRotationalTerm(4, 4, 0 N*s*m);
DampingMatrix1.setRotationalTerm(4, 5, 0 N*s*m);
DampingMatrix1.setRotationalTerm(4, 6, 0 N*s*m);
DampingMatrix1.setCoupledTerm(5, 1, 0 N*s);
DampingMatrix1.setCoupledTerm(5, 2, 0 N*s);
DampingMatrix1.setCoupledTerm(5, 3, 0 N*s);
DampingMatrix1.setRotationalTerm(5, 4, 0 N*s*m);
DampingMatrix1.setRotationalTerm(5, 5, 0 N*s*m);
DampingMatrix1.setRotationalTerm(5, 6, 0 N*s*m);
DampingMatrix1.setCoupledTerm(6, 1, 0 N*s);
DampingMatrix1.setCoupledTerm(6, 2, 0 N*s);
DampingMatrix1.setCoupledTerm(6, 3, 0 N*s);
DampingMatrix1.setRotationalTerm(6, 4, 0 N*s*m);
```

```
DampingMatrix1.setRotationalTerm(6, 5, 0 N*s*m);
DampingMatrix1.setRotationalTerm(6, 6, 1e+010 N*s*m);
DampingMatrix1.setKidTag("ce6284b7-16f3-4aeb-a5dd-21420782a6fa");
// *******************************************************
MassModel2 = MassModel(LoadingCondition2Loa, MassModelSpecified);
MassModel2.setUserMassCoordinateSystem(MixedCoordinateSystem);
MassModel2.setTotalMass(87907200 Kg);
MassModel2.setCOG(Point(0 m,0 m,18.23 m));
MassModel2.setRadiusGyration(Vector3d(22 m,22 m,32 m));
MassModel2.setSpecificProductInertia(0 m, 0 m, 0 m);
MassModel2.addTankMass(true);
MassModel2.updateStiffnessWithFreeSurfaceEffect(true);
MassModel2.setKidTag("fa56a61a-877c-4b72-82b0-6b8f67ea8f57");
// *******************************************************
WadamBalH25 = WadamRun();
WadamBalH25.useMultiBody(false);
WadamBalH25.setHydroModel(HydroModel1);
WadamBalH25.setLoadingCondition(LoadingCondition1ball);
WadamBalH25.setEnvironmentData(Condition5);
WadamBalH25.useSeaState(true);
WadamBalH25.setSeaState(RegWaveH25);
WadamBalH25.dataCheck(false);
WadamBalH25.setAnalysisType(WadamRunGlobalResponse);
WadamBalH25.setDragType(WadamRunWaveHeigtsDrag);
WadamBalH25.setDragTranslationalConvergenceCriteria(0.1);
WadamBalH25.setDragRotationalConvergenceCriteria(0.1);
WadamBalH25.setDragMaxNoIterations(10);
WadamBalH25.setWaveType(WadamRunIncidentWave);
WadamBalH25.calculateDrift(false);
WadamBalH25.driftByPressureIntegration(true);
WadamBalH25.driftByFarFieldIntegration(true);
WadamBalH25.waveDriftDamping(false);
WadamBalH25.setSolverType(WadamRunDirectSolver);
WadamBalH25.setMaxMatrixDimension(3000);
WadamBalH25.setSingularityType(WadamRunAnalyticalSingularity);
WadamBalH25.setIntegrationType(WadamRunOneNodeGauss);
WadamBalH25.setPanelDimensionType(WadamRunMaximumDiagonalPanelDimension);
WadamBalH25.removeIrrFrequencies(false);
WadamBalH25.saveTempWamitFiles(false);
WadamBalH25.stopBeforePotenExecution(false);
WadamBalH25.bypassPotenExecution(false);
WadamBalH25.stopBeforeFirstForceExecution(false);
WadamBalH25.bypassFirstForceExecution(false);
WadamBalH25.useWadamMassCalculation(false);
WadamBalH25.stopBeforeSecondForceExecution(false);
WadamBalH25.bypassSecondForceExecution(false);
WadamBalH25.useSaveRestart(false);
WadamBalH25.setPrintType(WadamRunNormalPrint);
WadamBalH25.setResponseFileType(WadamRunSIFFormatted);
WadamBalH25.calculateEigenvalues(true);
WadamBalH25.setWaterlinePanelMethod(WadamRunNoPanelPressureAdjustment);
WadamBalH25.sumFrequencyResults(false);
```

```
WadamBalH25.differenceFrequencyResults(false);
WadamBalH25.setToleranceWaterLine(0.1);
WadamBalH25.setToleranceCOG(0.1);
WadamBalH25.setCharacteristicLength(1 m);
WadamBalH25.calculateRollDamping(false);
WadamBalH25.specifyOutputDirectory(true);
WadamBalH25.setOutputDirectory("C:/DNV/Workspaces/Dana/30_HydroD/");
WadamBalH25.setOutputPrefix("BalH25");
WadamBalH25.autoOwerwriteExistingResultFiles(true);
WadamBalH25.setKidTag("02f9799d-896a-4896-bfa6-884573fa3feb");
// *********************************************************
WadamBalH6 = WadamRun();
WadamBalH6.useMultiBody(false);
WadamBalH6.setHydroModel(HydroModel1);
WadamBalH6.setLoadingCondition(LoadingCondition1ball);
WadamBalH6.setEnvironmentData(Condition5);
WadamBalH6.useSeaState(true);
WadamBalH6.setSeaState(RegWaveH6);
WadamBalH6.dataCheck(false);
WadamBalH6.setAnalysisType(WadamRunGlobalResponse);
WadamBalH6.setDragType(WadamRunWaveHeigtsDrag);
WadamBalH6.setDragTranslationalConvergenceCriteria(0.1);
WadamBalH6.setDragRotationalConvergenceCriteria(0.1);
WadamBalH6.setDragMaxNoIterations(10);
WadamBalH6.setWaveType(WadamRunIncidentWave);
WadamBalH6.calculateDrift(false);
WadamBalH6.driftByPressureIntegration(true);
WadamBalH6.driftByFarFieldIntegration(true);
WadamBalH6.waveDriftDamping(false);
WadamBalH6.setSolverType(WadamRunDirectSolver);
WadamBalH6.setMaxMatrixDimension(3000);
WadamBalH6.setSingularityType(WadamRunAnalyticalSingularity);
WadamBalH6.setIntegrationType(WadamRunOneNodeGauss);
WadamBalH6.setPanelDimensionType(WadamRunMaximumDiagonalPanelDimension);
WadamBalH6.removeIrrFrequencies(false);
WadamBalH6.saveTempWamitFiles(false);
WadamBalH6.stopBeforePotenExecution(false);
WadamBalH6.bypassPotenExecution(false);
WadamBalH6.stopBeforeFirstForceExecution(false);
WadamBalH6.bypassFirstForceExecution(false);
WadamBalH6.useWadamMassCalculation(false);
WadamBalH6.stopBeforeSecondForceExecution(false);
WadamBalH6.bypassSecondForceExecution(false);
WadamBalH6.useSaveRestart(false);
WadamBalH6.setPrintType(WadamRunNormalPrint);
WadamBalH6.setResponseFileType(WadamRunSIFFormatted);
WadamBalH6.calculateEigenvalues(true);
WadamBalH6.setWaterlinePanelMethod(WadamRunNoPanelPressureAdjustment);
WadamBalH6.sumFrequencyResults(false);
WadamBalH6.differenceFrequencyResults(false);
WadamBalH6.setToleranceWaterLine(0.1);
WadamBalH6.setToleranceCOG(0.1);
```

```
WadamBalH6.setCharacteristicLength(1 m);
WadamBalH6.calculateRollDamping(false);
WadamBalH6.specifyOutputDirectory(true);
WadamBalH6.setOutputDirectory("C:/DNV/Workspaces/Dana/30_HydroD/");
WadamBalH6.setOutputPrefix("BalH6");
WadamBalH6.autoOwerwriteExistingResultFiles(false);
WadamBalH6.setKidTag("f2db880a-1d69-4313-80ca-5fd143d9f688");
// ********************************************************
WadamBalIR = WadamRun();
WadamBalIR.useMultiBody(false);
WadamBalIR.setHydroModel(HydroModel1);
WadamBalIR.setLoadingCondition(LoadingCondition1ball);
WadamBalIR.setEnvironmentData(Condition5);
WadamBalIR.useSeaState(true);
WadamBalIR.setSeaState(SeaStateTor);
WadamBalIR.dataCheck(false);
WadamBalIR.setAnalysisType(WadamRunGlobalResponse);
WadamBalIR.setDragType(WadamRunStochasticDrag);
WadamBalIR.setDragTranslationalConvergenceCriteria(0.1);
WadamBalIR.setDragRotationalConvergenceCriteria(0.1);
WadamBalIR.setDragMaxNoIterations(10);
WadamBalIR.setWaveType(WadamRunIncidentWave);
WadamBalIR.calculateDrift(true);
WadamBalIR.driftByPressureIntegration(true);
WadamBalIR.driftByFarFieldIntegration(true);
WadamBalIR.waveDriftDamping(false);
WadamBalIR.setSolverType(WadamRunDirectSolver);
WadamBalIR.setMaxMatrixDimension(3000);
WadamBalIR.setSingularityType(WadamRunAnalyticalSingularity);
WadamBalIR.setIntegrationType(WadamRunOneNodeGauss);
WadamBalIR.setPanelDimensionType(WadamRunMaximumDiagonalPanelDimension);
WadamBalIR.removeIrrFrequencies(false);
WadamBalIR.saveTempWamitFiles(false);
WadamBalIR.stopBeforePotenExecution(false);
WadamBalIR.bypassPotenExecution(false);
WadamBalIR.stopBeforeFirstForceExecution(false);
WadamBalIR.bypassFirstForceExecution(false);
WadamBalIR.useWadamMassCalculation(false);
WadamBalIR.stopBeforeSecondForceExecution(false);
WadamBalIR.bypassSecondForceExecution(false);
WadamBalIR.useSaveRestart(false);
WadamBalIR.setPrintType(WadamRunNormalPrint);
WadamBalIR.setResponseFileType(WadamRunSIFFormatted);
WadamBalIR.calculateEigenvalues(true);
WadamBalIR.setWaterlinePanelMethod(WadamRunNoPanelPressureAdjustment);
WadamBalIR.sumFrequencyResults(false);
WadamBalIR.differenceFrequencyResults(false);
WadamBalIR.setToleranceWaterLine(0.1);
WadamBalIR.setToleranceCOG(0.1);
WadamBalIR.setCharacteristicLength(1 m);
WadamBalIR.calculateRollDamping(false);
WadamBalIR.specifyOutputDirectory(true);
```

```
WadamBalIR.setOutputDirectory("C:/DNV/Workspaces/Dana/30_HydroD/WadamRunBalIR/");
WadamBalIR.setOutputPrefix("BalIR");
WadamBalIR.autoOwerwriteExistingResultFiles(true);
WadamBalIR.setKidTag("653a2ca1-bb4f-4ee4-8b0a-693cb13cc5b9");
// *******************************************************
WadamLoaH25 = WadamRun();
WadamLoaH25.useMultiBody(false);
WadamLoaH25.setHydroModel(HydroModel1);
WadamLoaH25.setLoadingCondition(LoadingCondition2Loa);
WadamLoaH25.setEnvironmentData(Condition5);
WadamLoaH25.useSeaState(true);
WadamLoaH25.setSeaState(RegWaveH25);
WadamLoaH25.dataCheck(false);
WadamLoaH25.setAnalysisType(WadamRunGlobalResponse);
WadamLoaH25.setDragType(WadamRunWaveHeigtsDrag);
WadamLoaH25.setDragTranslationalConvergenceCriteria(0.1);
WadamLoaH25.setDragRotationalConvergenceCriteria(0.1);
WadamLoaH25.setDragMaxNoIterations(10);
WadamLoaH25.setWaveType(WadamRunIncidentWave);
WadamLoaH25.calculateDrift(true);
WadamLoaH25.driftByPressureIntegration(true);
WadamLoaH25.driftByFarFieldIntegration(true);
WadamLoaH25.waveDriftDamping(false);
WadamLoaH25.setSolverType(WadamRunDirectSolver);
WadamLoaH25.setMaxMatrixDimension(3000);
WadamLoaH25.setSingularityType(WadamRunAnalyticalSingularity);
WadamLoaH25.setIntegrationType(WadamRunOneNodeGauss);
WadamLoaH25.setPanelDimensionType(WadamRunMaximumDiagonalPanelDimension);
WadamLoaH25.removeIrrFrequencies(false);
WadamLoaH25.saveTempWamitFiles(false);
WadamLoaH25.stopBeforePotenExecution(false);
WadamLoaH25.bypassPotenExecution(false);
WadamLoaH25.stopBeforeFirstForceExecution(false);
WadamLoaH25.bypassFirstForceExecution(false);
WadamLoaH25.useWadamMassCalculation(false);
WadamLoaH25.stopBeforeSecondForceExecution(false);
WadamLoaH25.bypassSecondForceExecution(false);
WadamLoaH25.useSaveRestart(false);
WadamLoaH25.setPrintType(WadamRunNormalPrint);
WadamLoaH25.setResponseFileType(WadamRunSIFFormatted);
WadamLoaH25.calculateEigenvalues(true);
WadamLoaH25.setWaterlinePanelMethod(WadamRunNoPanelPressureAdjustment);
WadamLoaH25.sumFrequencyResults(false);
WadamLoaH25.differenceFrequencyResults(false);
WadamLoaH25.setToleranceWaterLine(0.1);
WadamLoaH25.setToleranceCOG(0.1);
WadamLoaH25.setCharacteristicLength(1 m);
WadamLoaH25.calculateRollDamping(false);
WadamLoaH25.specifyOutputDirectory(true);
WadamLoaH25.setOutputDirectory("C:/DNV/Workspaces/Dana/30_HydroD/WadamRunLoaH25/");
WadamLoaH25.setOutputPrefix("LoaH25");
WadamLoaH25.autoOwerwriteExistingResultFiles(true);
```

```
WadamLoaH25.setKidTag("1c63f368-c217-4ef5-9013-141f90b5dbad");
// ********************************************************
WadamLoaH6 = WadamRun();
WadamLoaH6.useMultiBody(false);
WadamLoaH6.setHydroModel(HydroModel1);
WadamLoaH6.setLoadingCondition(LoadingCondition2Loa);
WadamLoaH6.setEnvironmentData(Condition5);
WadamLoaH6.useSeaState(true);
WadamLoaH6.setSeaState(RegWaveH6);
WadamLoaH6.dataCheck(false);
WadamLoaH6.setAnalysisType(WadamRunGlobalResponse);
WadamLoaH6.setDragType(WadamRunWaveHeigtsDrag);
WadamLoaH6.setDragTranslationalConvergenceCriteria(0.1);
WadamLoaH6.setDragRotationalConvergenceCriteria(0.1);
WadamLoaH6.setDragMaxNoIterations(10);
WadamLoaH6.setWaveType(WadamRunIncidentWave);
WadamLoaH6.calculateDrift(false);
WadamLoaH6.driftByPressureIntegration(true);
WadamLoaH6.driftByFarFieldIntegration(true);
WadamLoaH6.waveDriftDamping(false);
WadamLoaH6.setSolverType(WadamRunDirectSolver);
WadamLoaH6.setMaxMatrixDimension(3000);
WadamLoaH6.setSingularityType(WadamRunAnalyticalSingularity);
WadamLoaH6.setIntegrationType(WadamRunOneNodeGauss);
WadamLoaH6.setPanelDimensionType(WadamRunMaximumDiagonalPanelDimension);
WadamLoaH6.removeIrrFrequencies(false);
WadamLoaH6.saveTempWamitFiles(false);
WadamLoaH6.stopBeforePotenExecution(false);
WadamLoaH6.bypassPotenExecution(false);
WadamLoaH6.stopBeforeFirstForceExecution(false);
WadamLoaH6.bypassFirstForceExecution(false);
WadamLoaH6.useWadamMassCalculation(false);
WadamLoaH6.stopBeforeSecondForceExecution(false);
WadamLoaH6.bypassSecondForceExecution(false);
WadamLoaH6.useSaveRestart(false);
WadamLoaH6.setPrintType(WadamRunNormalPrint);
WadamLoaH6.setResponseFileType(WadamRunSIFFormatted);
WadamLoaH6.calculateEigenvalues(true);
WadamLoaH6.setWaterlinePanelMethod(WadamRunNoPanelPressureAdjustment);
WadamLoaH6.sumFrequencyResults(false);
WadamLoaH6.differenceFrequencyResults(false);
WadamLoaH6.setToleranceWaterLine(0.1);
WadamLoaH6.setToleranceCOG(0.1);
WadamLoaH6.setCharacteristicLength(1 m);
WadamLoaH6.calculateRollDamping(false);
WadamLoaH6.specifyOutputDirectory(true);
WadamLoaH6.setOutputDirectory("C:/DNV/Workspaces/Dana/30_HydroD/");
WadamLoaH6.setOutputPrefix("LoaH6");
WadamLoaH6.autoOwerwriteExistingResultFiles(true);
WadamLoaH6.setKidTag("36839d3d-513c-497d-aea0-5f10b09f70da");
// ********************************************************
WadamLoaIR = WadamRun();
```

```
WadamLoaIR.useMultiBody(false);
WadamLoaIR.setHydroModel(HydroModel1);
WadamLoaIR.setLoadingCondition(LoadingCondition2Loa);
WadamLoaIR.setEnvironmentData(Condition5);
WadamLoaIR.useSeaState(true);
WadamLoaIR.setSeaState(SeaStateTor);
WadamLoaIR.dataCheck(false);
WadamLoaIR.setAnalysisType(WadamRunGlobalResponse);
WadamLoaIR.setDragType(WadamRunStochasticDrag);
WadamLoaIR.setDragTranslationalConvergenceCriteria(0.1);
WadamLoaIR.setDragRotationalConvergenceCriteria(0.1);
WadamLoaIR.setDragMaxNoIterations(10);
WadamLoaIR.setWaveType(WadamRunIncidentWave);
WadamLoaIR.calculateDrift(true);
WadamLoaIR.driftByPressureIntegration(true);
WadamLoaIR.driftByFarFieldIntegration(true);
WadamLoaIR.waveDriftDamping(false);
WadamLoaIR.setSolverType(WadamRunDirectSolver);
WadamLoaIR.setMaxMatrixDimension(3000);
WadamLoaIR.setSingularityType(WadamRunAnalyticalSingularity);
WadamLoaIR.setIntegrationType(WadamRunOneNodeGauss);
WadamLoaIR.setPanelDimensionType(WadamRunMaximumDiagonalPanelDimension);
WadamLoaIR.removeIrrFrequencies(false);
WadamLoaIR.saveTempWamitFiles(false);
WadamLoaIR.stopBeforePotenExecution(false);
WadamLoaIR.bypassPotenExecution(false);
WadamLoaIR.stopBeforeFirstForceExecution(false);
WadamLoaIR.bypassFirstForceExecution(false);
WadamLoaIR.useWadamMassCalculation(false);
WadamLoaIR.stopBeforeSecondForceExecution(false);
WadamLoaIR.bypassSecondForceExecution(false);
WadamLoaIR.useSaveRestart(false);
WadamLoaIR.setPrintType(WadamRunNormalPrint);
WadamLoaIR.setResponseFileType(WadamRunSIFFormatted);
WadamLoaIR.calculateEigenvalues(true);
WadamLoaIR.setWaterlinePanelMethod(WadamRunNoPanelPressureAdjustment);
WadamLoaIR.sumFrequencyResults(false);
WadamLoaIR.differenceFrequencyResults(false);
WadamLoaIR.setToleranceWaterLine(0.1);
WadamLoaIR.setToleranceCOG(0.1);
WadamLoaIR.setCharacteristicLength(1 m);
WadamLoaIR.calculateRollDamping(false);
WadamLoaIR.specifyOutputDirectory(true);
WadamLoaIR.setOutputDirectory("C:/DNV/Workspaces/Dana/30_HydroD/WadamRunLoaIR/");
WadamLoaIR.setOutputPrefix("LoaIR");
WadamLoaIR.autoOwerwriteExistingResultFiles(false);
WadamLoaIR.setKidTag("a6fedb2b-dfdf-4745-acd6-7169346065ce");
Delete(WadamBalH25);
Delete(WadamBalH6);
Delete(WadamBalIR);
Delete(WadamLoaH25);
Delete(WadamLoaH6);
```

```
Delete(WadamLoaIR);
Delete(LoadingCondition2Loa);
HydroModel1.setActiveFolder();
PanelModel1.setFileName("C:/Documents and Settings/raf/My Documents/Projects/Western Isles/Sesam/WI/HullT1.FEM");
PanelModel1.setSymmetry(true,true);
PanelModel1.regenerateGeometry();
MorisonModel1.setFileName("C:/Documents and Settings/raf/My Documents/Projects/Western Isles/Sesam/WI/RingT2.FEM");
MorisonModel1.regenerateGeometry();
LoadingCondition1ball.setLoadingCondition(16.35 m,0 deg,0 deg);
LoadingCondition1ball.setByDraft(false);
Rename(LoadingCondition1ball,"Ballast");
PanelPressures1 = PressurePanels(PanelModel1);
PanelPressures1.addPanelElementPressure(1,10);
PanelPressures1.addPanelElementPressure(1,20);
PanelPressures1.addPanelElementPressure(1,30);
PanelPressures1.addPanelElementPressure(1,40);
PanelPressures1.addPanelElementPressure(1,50);
PanelPressures1.addPanelElementPressure(1,60);
PanelPressures1.addPanelElementPressure(1,70);
PanelPressures1.addPanelElementPressure(1,80);
PanelPressures1.addPanelElementPressure(1,90);
PanelPressures1.addPanelElementPressure(1,100);
PanelPressures1.addPanelElementPressure(1,110);
PanelPressures1.addPanelElementPressure(1,120);
PanelPressures1.addPanelElementPressure(1,130);
PanelPressures1.addPanelElementPressure(1,140);
PanelPressures1.addPanelElementPressure(1,150);
PanelPressures1.addPanelElementPressure(1,160);
PanelPressures1.addPanelElementPressure(1,221);
PanelPressures1.addPanelElementPressure(1,241);
PanelPressures1.addPanelElementPressure(1,261);
PanelPressures1.addPanelElementPressure(1,262);
PanelPressures1.addPanelElementPressure(1,263);
PanelPressures1.addPanelElementPressure(1,264);
PanelPressures1.addPanelElementPressure(1,341);
PanelPressures1.addPanelElementPressure(1,361);
PanelPressures1.addPanelElementPressure(1,381);
PanelPressures1.addPanelElementPressure(1,401);
PanelPressures1.addPanelElementPressure(1,421);
PanelPressures1.addPanelElementPressure(1,441);
PanelPressures1.addPanelElementPressure(1,461);
PanelPressures1.addPanelElementPressure(1,481);
PanelPressures1.addPanelElementPressure(1,501);
PanelPressures1.addPanelElementPressure(1,521);
PanelPressures1.addPanelElementPressure(1,541);
WadamRun1 = WadamRun();
// Start Input **********
WadamRun1.setHydroModel(HydroModel1);
WadamRun1.useMultiBody(false);
WadamRun1.setLoadingCondition(Ballast);
```

```
WadamRun1.setEnvironmentData(Condition5);
WadamRun1.useSeaState(true);
WadamRun1.setSeaState(SeaStateTor);
// End Input **********
// Start Execution Directives **********
WadamRun1.dataCheck(false);
WadamRun1.setAnalysisType(WadamRunGlobalResponse);
  // Start Constants **********
WadamRun1.setToleranceWaterLine(0.01);
WadamRun1.setToleranceCOG(0.01);
WadamRun1.setCharacteristicLength(1);
  // End Constants **********
  // Start Wave **********
WadamRun1.setDragType(WadamRunStochasticDrag);
WadamRun1.setWaveType(WadamRunIncidentWave);
WadamRun1.setDragTranslationalConvergenceCriteria(0.1);
WadamRun1.setDragRotationalConvergenceCriteria(0.1);
WadamRun1.setDragMaxNoIterations(10);
  // End Wave **********
  // Start Drift Forces **********
WadamRun1.calculateDrift(true);
WadamRun1.driftByPressureIntegration(true);
WadamRun1.driftByFarFieldIntegration(true);
WadamRun1.waveDriftDamping(false);
  // End Drift Forces **********
  // Start Roll Damping **********
WadamRun1.calculateRollDamping(false);
  // End Roll Damping **********
  // Start Equation Solver **********
WadamRun1.setSolverType(WadamRunDirectSolver);
WadamRun1.setMaxMatrixDimension(3000);
  // End Equation Solver **********
  // Start Print **********
WadamRun1.setPrintType(WadamRunNormalPrint);
  // End Print **********
  // Start Result Files **********
    // Start Global Response **********
WadamRun1.setResponseFileType(WadamRunSIFFormatted);
WadamRun1.calculateEigenvalues(true);
WadamRun1.sumFrequencyResults(false);
WadamRun1.differenceFrequencyResults(false);
    // End Global Response **********
    // Start Load Transfer **********
    // End Load Transfer **********
  // End Result Files **********
  // Start Advanced **********
WadamRun1.setSingularityType(WadamRunNumericalSingularity);
WadamRun1.setIntegrationType(WadamRunOneNodeGauss);
WadamRun1.setPanelDimensionType(WadamRunAreaPanelDimension);
WadamRun1.useWadamMassCalculation(false);
WadamRun1.removeIrrFrequencies(false);
WadamRun1.saveTempWamitFiles(false);
```

```
WadamRun1.stopBeforePotenExecution(false);
WadamRun1.bypassPotenExecution(false);
WadamRun1.stopBeforeFirstForceExecution(false);
WadamRun1.bypassFirstForceExecution(false);
WadamRun1.stopBeforeSecondForceExecution(false);
WadamRun1.bypassSecondForceExecution(false);
WadamRun1.useSaveRestart(false);
  // End Advanced **********
// End Execution Directives **********
// Start Output Directory **********
WadamRun1.specifyOutputDirectory(false);
WadamRun1.autoOwerwriteExistingResultFiles(false);
// End Output Directory **********
DirectionSet1.removeAll();
DirectionSet1.add(180 deg);
// HydroD V4.4-05 ended 31-Jan-2011 17:53:11
// HydroD V4.4-05 started 01-Feb-2011 14:40:57
RestoringMatrix2.setTranslationalTerm(1,1,1.14E+06);
RestoringMatrix2.setTranslationalTerm(1,2,0);
RestoringMatrix2.setTranslationalTerm(1,3,0);
RestoringMatrix2.setCoupledTerm(1,4,0);
RestoringMatrix2.setCoupledTerm(1,5,-1.85E+07);
RestoringMatrix2.setCoupledTerm(1,6,0);
RestoringMatrix2.setTranslationalTerm(2,1,0);
RestoringMatrix2.setTranslationalTerm(2,2,1.14E+06);
RestoringMatrix2.setTranslationalTerm(2,3,0);
RestoringMatrix2.setCoupledTerm(2,4,1.85E+07);
RestoringMatrix2.setCoupledTerm(2,5,0);
RestoringMatrix2.setCoupledTerm(2,6,0);
RestoringMatrix2.setTranslationalTerm(3,1,0);
RestoringMatrix2.setTranslationalTerm(3,2,0);
RestoringMatrix2.setTranslationalTerm(3,3,0);
RestoringMatrix2.setCoupledTerm(3,4,0);
RestoringMatrix2.setCoupledTerm(3,5,0);
RestoringMatrix2.setCoupledTerm(3,6,0);
RestoringMatrix2.setCoupledTerm(4,1,0);
RestoringMatrix2.setCoupledTerm(4,2,5.93E+06);
RestoringMatrix2.setCoupledTerm(4,3,0);
RestoringMatrix2.setRotationalTerm(4,4,4.69E+08);
RestoringMatrix2.setRotationalTerm(4,5,0);
RestoringMatrix2.setRotationalTerm(4,6,0);
RestoringMatrix2.setCoupledTerm(5,1,-5.93E+06);
RestoringMatrix2.setCoupledTerm(5,2,0);
RestoringMatrix2.setCoupledTerm(5,3,0);
RestoringMatrix2.setRotationalTerm(5,4,0);
RestoringMatrix2.setRotationalTerm(5,5,4.69E+08);
RestoringMatrix2.setRotationalTerm(5,6,0);
RestoringMatrix2.setCoupledTerm(6,1,0);
RestoringMatrix2.setCoupledTerm(6,2,0);
RestoringMatrix2.setCoupledTerm(6,3,0);
RestoringMatrix2.setRotationalTerm(6,4,0);
RestoringMatrix2.setRotationalTerm(6,5,0);
```

```
RestoringMatrix2.setRotationalTerm(6,6,0);
Rename(WadamRun1,"ULS");
ULS_1 = ULS.copy();
remapRelations();
Rename(ULS_1,"FLS");
// Start Input **********
FLS.setSeaState(RegWaveH6);
// End Input **********
// Start Execution Directives **********
  // Start Constants **********
  // End Constants **********
  // Start Wave **********
  // End Wave **********
  // Start Drift Forces **********
  // End Drift Forces **********
  // Start Roll Damping **********
  // End Roll Damping **********
  // Start Equation Solver **********
  // End Equation Solver **********
  // Start Print **********
  // End Print **********
  // Start Result Files **********
    // Start Global Response **********
    // End Global Response **********
    // Start Load Transfer **********
    // End Load Transfer **********
  // End Result Files **********
  // Start Advanced **********
  // End Advanced **********
// End Execution Directives **********
// Start Output Directory **********
FLS.specifyOutputDirectory(true);
FLS.setOutputDirectory("C:/Documents and Settings/ebg/My Documents/Projects/Western Isles/Sesam/WI/");
FLS.setOutputPrefix("BalFLS");
// End Output Directory **********
// Start Input **********
// End Input **********
// Start Execution Directives **********
  // Start Constants **********
  // End Constants **********
  // Start Wave **********
  // End Wave **********
  // Start Drift Forces **********
  // End Drift Forces **********
  // Start Roll Damping **********
  // End Roll Damping **********
  // Start Equation Solver **********
  // End Equation Solver **********
  // Start Print **********
  // End Print **********
  // Start Result Files **********
```

```
    // Start Global Response **********
    // End Global Response **********
    // Start Load Transfer **********
    // End Load Transfer **********
  // End Result Files **********
  // Start Advanced **********
  // End Advanced **********
// End Execution Directives **********
// Start Output Directory **********
ULS.specifyOutputDirectory(true);
ULS.setOutputDirectory("C:/Documents and Settings/ebg/My Documents/Projects/Western Isles/Sesam/WI/");
ULS.setOutputPrefix("BalULS");
// End Output Directory **********
// Start Input **********
// End Input **********
// Start Execution Directives **********
  // Start Constants **********
  // End Constants **********
  // Start Wave **********
FLS.setDragType(WadamRunWaveHeigtsDrag);
  // End Wave **********
  // Start Drift Forces **********
  // End Drift Forces **********
  // Start Roll Damping **********
  // End Roll Damping **********
  // Start Equation Solver **********
  // End Equation Solver **********
  // Start Print **********
  // End Print **********
  // Start Result Files **********
    // Start Global Response **********
    // End Global Response **********
    // Start Load Transfer **********
    // End Load Transfer **********
  // End Result Files **********
  // Start Advanced **********
  // End Advanced **********
// End Execution Directives **********
// Start Output Directory **********
// End Output Directory **********
// HydroD V4.4-05 ended 01-Feb-2011 15:25:13
// HydroD V4.4-05 started 01-Feb-2011 15:25:13
// HydroD V4.4-05 ended 01-Feb-2011 15:25:14
```

APPENDIX

G

Panel Model and Morison Model (PREFEM)

M.S.c. Thesis

Coupled Dynamic Analysis of Cylindrical FPSO, Moorings and Riser

Based on Numerical Simulation

A. Panel Model

```
%%
%% PROGRAM:  SESAM PREFEM       VERSION:     7.1-05 13-MAY-2003
%%
 GENERATE SURFACE A1 1 2 1 16 1 2 1 20 END
 CYLINDRICAL 0 0 0 0 0 1 0 1 0
 0 0 0
 43.75 0 0 END
 0.0 -90 0 END
%
%
 CHECK ELEMENT-SHAPE ALL-ELEMENTS-INCLUDED END
 CHANGE NORMAL-OF-SURFACE -Z-GLOBAL-INFINITY ALL-SURFACES-INCLUDED
 NORMAL-OF-SURFACE -Z-GLOBAL-INFINITY ALL-SURFACES-INCLUDED
 END
%
%%
%%
%%%
 GENERATE SURFACE B 1 2 1 20 1 2 1 2 END
 CYLINDRICAL 0 0 0 0 0 1 1 0 0
 43.75 0 0
 0.0 90 0 END
```

```
0.0 0 2.5 END
%%
%%
GENERATE SURFACE C 1 2 1 4 1 2 1 20 END
CYLINDRICAL 0 0 0 0 0 1 1 0 0
 37.5 0  2.5
 6.25 0 0 END
 0 90 0 END
%%
%%%
GENERATE SURFACE D 1 2 1 20 1 2 1 2 END
CYLINDRICAL 0 0 0 0 0 1 1 0 0
  37.5 0 2.5
  0 90 0 END
 -2.5 0 2.5 END
%%
%%%
GENERATE SURFACE E 1 2 1 20 1 2 1 15 END
CYLINDRICAL 0 0 0 0 0 1 1 0 0
 35.0 0 5.0
 0 90 0 END
 0 0 27.0 END
%%
%  CHANGE NORMAL-OF-SURFACE -Z-GLOBAL-INFINITY
%%%
%%
%%

SET ELEMENT-TYPE SURFACE ALL-SURFACES-INCLUDED SHELL-4NODES END
END
MESH ALL
%
,
SET GRAPHICS DEVICE WINDOWS
..
,
SET GRAPHICS INPUT ON
PROPERTY LOAD 1 HYDRO-PRESSURE ALL-SURFACES-INCLUDED OUTSIDE
 OUTSIDE-SURFACE
END
END
```

B. Morison Model

```
%
% PROGRAM:  SESAM PREFEM        VERSION:      7.1-05 13-MAY-2003
%
 DEFINE POINT OR   0.000   0.000  1.25
              E1  39.375   0.000  1.25
              E2   0.000  39.375  1.25
              E3 -39.375   0.000  1.25
              E4   0.000 -39.375  1.25
       END
       ARC    AR1 E1 E2 OR 10
              AR2 E2 E3 OR 10
              AR3 E3 E4 OR 10
              AR4 E4 E1 OR 10
       END
 END
 SET ELEMENT-TYPE LINE ALL-LINES-INCLUDED BEAM-2NODES END
 END
 PROPERTY SECTION Pipe1 PIPE 0.01 0.001 1.0 1.0
  ..
 CONNECT  SECTION Pipe1 ALL-LINES-INCLUDED
  ..
%
 MESH ALL
%
 ,
 SET GRAPHICS DEVICE WINDOWS
  ..
 ,
 SET GRAPHICS INPUT ON
..
```