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Estimation of the Long-Term Extreme Response of Drilling Riser by the Contour Line Method

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for
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Estimation of the Long-Term Extreme Response of Drilling Riser by the Contour Line Method

Estimering av Lang-tids Ekstrem Respons av Borestigerør ved Bruk av Konturlinjemetoden

The marine riser is an important component for various systems which are applied by the oil and gas industry. The integrity and reliability of such structural members are detrimental in order to avoid critical failures which may lead to major loss and severe consequences. For a drilling riser, a key requirement is that it should be able to operate in relatively high sea states without any significant risk of failure being associated with this operation.

The scope of the present project work is to discuss different methods for extreme response estimation of such risers and select one method to predict the extreme response of the riser.

The following subjects are to be addressed as part of this work:

1. The main steps related to dynamic response analysis and estimation of extreme response are to be summarized. This applies in particular to the following items: (i) Description of wave environmental conditions in terms of wave spectral densities as well as short-term and long-term modelling of the waves (ii) Method for linear and non-linear dynamic analysis of marine structures (iii) Different methods for prediction of characteristic values of extreme loads and response for marine structures, which should comprise the deterministic design wave method, the design storm method, stochastic long term response analysis as well as the contour line method.

2. An example riser system is selected for analysis based on discussion with the supervisor. Global static and dynamic response analysis is performed for the system by application of the computer program SIMA/RIFLEX.

3. Methods for estimation of extreme response are to be described in some more detail. In particular, the contour line method is focused upon. Results obtained by application of the contour line method to the example riser system are to be presented.

4. Parametric studies are performed to the extent that time allows. Examples of parameters to be varied are the following: Drilling riser material, static offset of the drilling vessel and riser top tension

The work scope may prove to be larger than initially anticipated. Subject to approval from the supervisor, topics may be deleted from the list above or reduced in extent.

In the thesis the candidate shall present his personal contribution to the resolution of problems within the scope of the thesis work. Theories and conclusions should be based on mathematical derivations and/or logic reasoning identifying the various steps in the deduction.

The candidate should utilise the existing possibilities for obtaining relevant literature.

The thesis should be organised in a rational manner to give a clear exposition of results, assessments, and conclusions. The text should be brief and to the point, with a clear language. Telegraphic language should be avoided.

The thesis shall contain the following elements: A text defining the scope, preface, list of contents, summary, main body of thesis, conclusions with recommendations for further work, list of symbols and acronyms, references and (optional) appendices. All figures, tables and equations shall be numbered.

The supervisor may require that the candidate, in an early stage of the work, presents a written plan for the completion of the work. The plan should include a budget for the use of computer and laboratory resources which will be charged to the department. Overruns shall be reported to the supervisor.

The original contribution of the candidate and material taken from other sources shall be clearly defined. Work from other sources shall be properly referenced using an acknowledged referencing system.

The thesis shall be submitted in electronic version:

- Signed by the candidate
- The text defining the scope included
- Drawings and/or computer prints which cannot be bound should be organised in a separate folder.

Supervisor: Professor Bernt J. Leira

Deadline: June 10th, 2014

Trondheim, January 16th, 2014

Bernt J. Leira

Preface

I would like to express my deepest appreciation to all those who provided me the possibility to work on this master thesis. A special gratitude I give to my supervisor, Professor Bernt Johan Leira, whose support, guidance, stimulating suggestions and encouragement helped me a lot to coordinate my thesis.

I would like to express my gratitude towards Mr. Andreas Amundsen, who is currently researcher at MARINTEK, for his guidance and for providing me the necessary information regarding the drilling riser RIFLEX model. My special thanks also go to Mr. Timothy Edward Kendon, who is currently principle researcher at STATOIL, for his continuous supports regarding modelling the numerical riser model in SIMA. I also would like to thank Dr. Rolf Baarholm, who is currently principle researcher at STATOIL, for providing me the environmental information including the contour lines.

My thanks and appreciations also go to all people who have willingly helped me out with their comments and advices and given me such attention and time.

Leila Dashtizadeh

June 5th, 2014

Trondheim, Norway

Summary

The main purpose of this master thesis was to estimate the long-term extreme bending moment on the drilling riser. Firstly, a pre-designed drilling riser was selected as the preliminary model and it was modified according to DNV-OS-F201 (2010), DNV-RP-C205 (2010) and API-RP-16Q (2001). The riser wall thickness has been decreased to 0.037 meters according to the design criteria in DNV-OS-F201 (2010). The required top tension applied by the tensioner system has been changed to 2978.61 KN according to DNV-RP-F205 (2010). Moreover, the drilling riser was redesigned in a way to fulfill the lower and upper flex joint angles limitations according to API-RP-16Q (2001).

Regarding the environmental condition, the irregular wave was described by the Torsethaugen spectrum. It was assumed that the extreme response occurs for the largest wave event. Therefore, the riser was exposed to the sea train of limited duration. Since the riser has been designed for the Norwegian Continental Shelf (NCS), the irregular wave was assumed to be stationary for 3 hours. In addition, it was assumed that the upper limit for drilling operation is the sea state with the highest significant wave height and the corresponding spectral peak period along the selected 0.63-probability contour line.

In principle, selecting a proper method to estimate the extreme response of the structures depends highly on the nature of the response under consideration. For marine risers, where the ratio of the wave height to the riser diameter as well as the ratio of the wave length to the riser diameter are high, the drag term of the Morison equation is dominant. As a result, in order to take care of the true frequency composition of the drag load, non-linear time domain analysis was performed. This method gives the response with sufficient accuracy as far as the assumption of the linear mechanical system is fulfilled; constant damping and stiffness coefficients.

In order to estimate the long-term extreme bending moment on the riser, all source of inherent randomness impacting the extreme bending moment on the riser must be taken into account. Two main source of randomness are:

1. The inherent randomness associated with the sea state characteristics.

2. The inherent randomness of the 3-hour extreme bending moment on the riser during a given short-term sea state.

The first source of randomness is accounted for by establishing a joint long-term probability density function for the short-term sea state characteristics, e.g. $f_{H_sT_p}(h,t)$. Moreover, the second source of randomness can be accounted for by establishing the conditional distribution function of the structural response under consideration given the environmental condition, e.g. $F_{(x_{3h}|H_s,T_p)}$.

The long-term distribution of the 3-hour extreme bending moment on the riser, X_{3h}, is given by:

$$F_{X_{3h}}(x) = \int_0^h \int_0^t F_{(x_{3h}|H_s,T_p)}(x|h,t)\ f_{H_sT_p}(h,t)dtdh \quad (1)$$

For a linear response problem, linear hydrodynamic loading and linear mechanical system, exposed to a Gaussian surface process, application of the full long-term analysis is very straight forward. However, for nonlinear response problems including drilling risers establishing the conditional distribution function of the 3-hour extreme bending moment on the riser is very time consuming and costly. In this case, a large number of 3-hour time domain simulations for a rather large number of environmental conditions must be carried out. As a result, an approximate method with reasonable accuracy must be utilized for predicating the long-term extreme bending moment. Therefore, contour line method was utilized as a short-term approach for predicting the long-term extremes.

Using this method, the distribution of the 3-hour maximum bending moment for the worst sea state along the 0.63-probability contour line was assumed to converge towards Gumbel distribution when the sample size becomes infinite. The uncertainty regarding the Gumbel assumption was studied by using the 3-step statistical inference that includes:

1. Selecting a probabilistic model
2. Fitting the proposed model to the available data
3. Testing if the fitted model is acceptable

Finally, by using the method of moments, the Gumbel distribution of the 3-hour extreme bending moment on the drilling riser for the assumed worst sea state along the 0.63-probability contour line was establish as:

$$F_{(x_{3h}|H_s,T_p)} = exp\left\{-exp\left\langle-\frac{x_{3h}-3430.82}{246.32}\right\rangle\right\} \quad (2)$$

An early estimation of the 0.63-probability extreme bending moment on the drilling riser was found by α-percentile of the Gumbel distribution function. Taking into account the short-term variability of the extreme response, a higher percentile instead of the 50-percentile was selected. Since, no information regarding q=0.63 was given in rules and standards, the same percentile level recommended by NORSOK-N-003 (2007) for $q=10^{-2}$ was applied for estimating the 0.63-probability response; the percentile level between 85-90.

In addition, adopting the Equation (2) as the true model, 25 samples of size 26 were generated by Monte Carlo simulation for assessment of the uncertainties with respect to:

1. Estimated Gumbel parameters from the limited amount of data
2. Estimated 0.63-probability extreme bending moment on the drilling riser

The estimated response from the assumed true Gumbel model and the uncertainty band found from the Monte Carlo simulations are presented in the Table 1.

Table 1 - The estimated response from different percentile level

Percentile level, α	Gumbel Scale, Y	Uncertainty range	From Eq. (2)
0.85	1.82	(3223.91 - 3776.96)	3878.38
0.87	1.97	(3250.57 - 3834.33)	3916.42
0.9	2.25	(3298.72 - 3937.97)	3985.13

Finally, it was concluded that the assumed true Gumbel model gives the extreme bending moment on the upper side, and it is safe to use it for estimating the 0.63-probability extreme bending moment on the riser.

Moreover, in order to verify the numerical riser model, sensitivity study with respect to:

1. Drilling riser material
2. Static offset of the drilling vessel in the positive X-direction
3. Static top tension provided by the tensioner system

were conducted.

Regarding the sensitivity study with respect to riser material, it was concluded that steel X100 gives the smallest required riser wall thickness according to the combined loading criteria in DNV-OS-F201 (2010). However, due to it`s susceptibility to the suddenly brittle fracture, steel X80 was selected as the best choice in order to fulfil the stability between the cost saving and avoiding brittle fracture; see Figure 1.

Studying the static offset variation showed that as the static offset of the vessel increases in the X-direction, the maximum value of the lower and upper flex joint angles increases. According to API-RP-16Q (2001) during the drilling operation, the maximum lower and upper flex joint angles for the drilling risers must be less than 4 degrees. Accordingly, it was concluded that the static offset of the drilling vessel must be set to zero meter in the positive X-direction during the drilling operation; see Figure 2.

Figure 1 - Summary of the results for the sensitivity study with respect to riser material

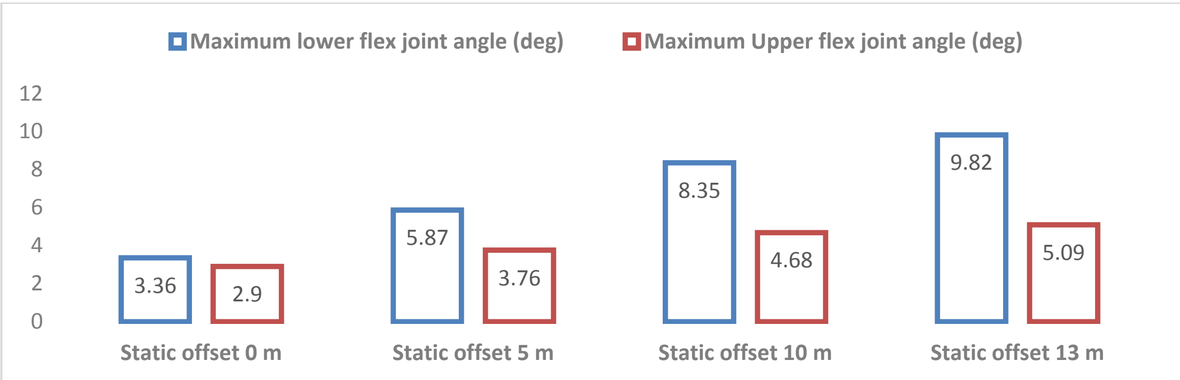

Figure 2 - Summary of the results for the sensitivity study with respect to the static offset in positive X-direction

And finally, with reference to Table 2, it was observed that applying 30% excess over the effective weight of the riser, W_E, as the static top tension is not adequate for this drilling riser; the combined loading criteria is more than 1. Moreover, applying 40% excess over the effective weight of the riser gave an answer close to the upper limit of the combined loading criteria; 1. Correspondingly, in order to ensure a safe design, higher static top tension equal to 50% excess over the effective weight of the riser must be applied.

Table 2 - Summary of the results for the sensitivity study with respect to static top tension

Case No.	Top tension (KN)		Combined loading criteria for the drilling riser
1	W_E + 30% W_E	2581.46	1.0314
2	W_E + 40% W_E	2780.04	0.9809
3	W_E + 50% W_E	2978.61	0.9456

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CHAPTER 1 **Introduction**

In order to design a drilling riser, it is essential to know the long-term extreme loads on the riser when it is exposed to a harsh environmental condition. Multiplying the long-term extreme response by a safety factor, the design load on the riser is obtained and the riser can be designed to withstand the design loads in it`s whole service life.

While the drilling operation is performed for a short period, there is the probability that the drilling riser is exposed to a 1-year, 10-year, 100-year or even a 10000-year in that short period. On the other hand, there are some environmental limitation for drilling operation that are provided by the riser`s and drilling vessel`s manufactures.

In general, estimating the long-term extreme response of the offshore structures can be conducted by various methods depending on the nature of the structure and the loads under consideration. The loads on the risers are of nonlinear nature even if the risers are exposed to the harmonic loads. This is due to the quadratic term of the wave particle velocity in the Morison equation that is coupled with nonlinear structural behavior. Therefore, the long-term extreme response of the drilling risers cannot be estimated correctly by deterministic design wave and design storm methods.

The best and the most exact method is performing a full long-term analysis of structure in order to estimate the design loads. This method is the recommended method for obtaining the design loads for the final design.

The full long-term analysis presents no problem for linear response problems, but may to some extent be inconvenient for nonlinear response problems that requires time domain simulations and/or model tests in order to establish the short-term distribution of the 3-hour extreme response.

The full long-term analysis is the recommended method for the final design. However, this method is very time consuming and in some cases very expensive to conduct; when model tests are required. Correspondingly, in the preliminary design, it was decided to use a short-term approach to estimate the long-term extremes.

The contour line method provides this possibility to estimate the long-term extremes from the short-term distribution of the response under consideration. However, the estimated responses from the contour line methods are approximately 10% smaller than the true value.

In order to conduct the contour line method, literature studies with respect to the following items are performed and the results are presented in this report:

1. Short-term and long-term modelling of the waves
2. Different types of the structures with respect to their linearity
3. Methods for estimating the extreme response on the structures
4. different methods for investigating the uncertainty associated with establishing the short-term distribution of the response under consideration
5. And last but not least, methods to take into account the short-term variability of the response under consideration when using the contour line method

After designing the riser, it is important to verify the numerical riser model to ensure that it provides more or less the same characteristics as the physical riser. As a result, the sensitivity studies with respect to three important parameters for drilling risers are conducted. They include sensitivity study with respect to:

1. Drilling riser material
2. Static offset of the drilling vessel
3. Static top tension provided by the tensioner system

CHAPTER 2 Description of Wave Condition

2.1 Introduction

In theory, wave conditions may be described either by a deterministic design wave or by the stochastic methods applying wave spectra. The application of the each method for modeling of the wave condition depends largely on the nature of the response problem. For drag-dominated structures including riser systems, the latter approach must be used. As a result, the stochastic methods for describing the wave condition are explained in the following.

2.2 Short-term modelling of the waves

The ocean waves are of random nature with respect to both space and time. However, during the short time periods, the wave process can be modeled as a stationary process. Two available models for describing wave conditions are explained shortly in the two following subsections; Gaussian and second order surface process.

2.2.1 Gaussian surface process

Under the assumption of a zero mean stationary Gaussian stochastic process, the probability density function of the surface elevation process at an arbitrary point in time can be described by the Gaussian density function:

$$f_{\Xi}(\xi) = \frac{1}{\sqrt{2\pi}\,\sigma_{\Xi}}\, exp\left\{-\frac{1}{2}\left(\frac{\xi}{\sigma_{\Xi}}\right)^2\right\} \tag{2.1}$$

Where:

σ_{Ξ}: the standard deviation of the surface process.

2.2.2 Second order surface process

The second order model for describing the surface elevation process consists of the Gaussian process and a second order correction. Second order correction consists of the sum and the difference frequency correction components, which accounts for the effects of finite water depth. A screen shot from a time domain simulation of a second order process presented in (S. K. Haver, 2011) is shown in Figure 2.1. The difference frequency component process are not presented in this figure. This is because it is typically much smaller than the other components. This simulations clearly shows that the sum frequency correction adds to the Gaussian crest while it tends to reduce the Gaussian troughs.

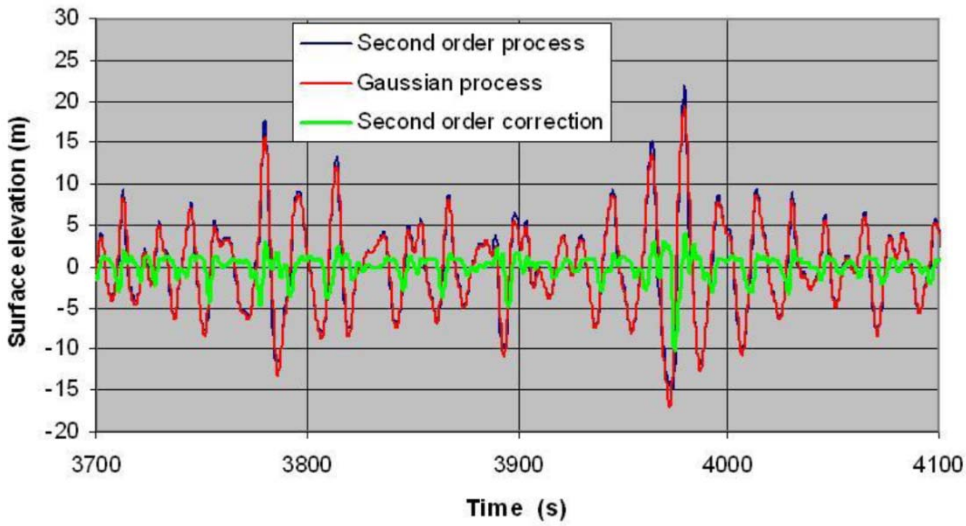

Figure 2.1 - Surface process components under the assumption of a second order model, Screen shot from (S. K. Haver, 2011)

The second order surface model is one of the most sophisticated random models available for routing engineering. However, in connection with the most extreme sea states, the observed largest crest may be slightly in the excess of what is predicted by the second order model.

2.3 Wave spectra

The random ocean wave can be described by an energy density spectrum. The wave energy spectrum describes the energy content of an ocean wave and its distribution over a frequency range of the random wave. The random wave is generally described by its statistical parameters e.g. significant wave height and the corresponding wave period, wave standard deviation, etc. (Chakrabarti, 2005).

Numerous models for the wave frequency spectrum are proposed over the years. These models are derived from the observed properties of the ocean waves and are empirical in nature. There are several wave spectra such as Pierson-Moskowitz (PM), International Ship and Offshore

Structures Congress (ISSC), Joint North Sea Wave Project (JONSWAP), Torsethaugen, and Ochi-Hubble Spectrum model. Among those wave spectra, PM, JONSWAP, and Torsethaugen wave spectra are described briefly in the following paragraphs.

The PM spectrum which is an one-parameter spectrum is developed on data collected in the North Atlantic under unlimited fetch conditions and the fully developed sea. The PM spectrum has one peak and a steep front at the low frequencies. This Spectrum is based on the assumption that it approaches the curve ω^{-5} for $\omega \rightarrow \infty$.

In addition, the growing pure wind sea can be well modelled by the JONSWAP spectrum (S. K. Haver, 2011). Referring to a H_S-T_P[1] space, the JONSWAP model is adequate for the sea states located not too far away from the relation given by Torsethaugen:

$$T_{p_0} = 0.78 f_e^{\frac{1}{6}} H_s^{\frac{1}{3}} \tag{2.2}$$

Where:

f_e: effective fetch (km)

H_S: the significant wave height (m)

Sea states which in the H_S-T_P space are located well away from the boundary defined by Equation (2.2) are of a combined nature, i.e. they consist of a wind sea superimposed on one or more swell systems. According to (S. K. Haver, 2011), for Norwegian Continental Shelf (NCS), the Torsethaugen spectrum is recommended to be used if the underlying sea state is of a combined nature.

The Torsethaugen spectrum which is a double peaked spectrum is developed based on the measurements from the Norwegian Continental shelf (NCS). The input to this model is the significant wave height, H_S, and the spectral peak period, T_P. The remaining parameters for the wind sea system and the swell sea system are parameterized in terms of these characteristics. If $T_p \leq T_{p_0}$, the sea state is governed by the wind sea, while for $T_p > T_{p_0}$ the sea state is governed by the swell system (S. K. Haver, 2011). The difference between JONSWAP and Torsethaugen spectrum is that the high frequency tail of the Torsethaugen spectrum is assumed to be proportional to f^{-4} while f^{-5} is used for the JONAWAP spectrum.

2.4 Long-term modelling of waves

A short-term sea state is completely characterized by the wave spectrum parameters. Each wave spectrum is defined as a few number of environmental parameters. For instance, both the JONSWAP and the Torsethaugen spectral models are defined as the significant wave height,

[1] Spectral peak period

H_S, and the spectral peak period, T_P. In principle the main direction of propagation of the waves, $\emptyset$, is included. In the following, the long-term modeling of the waves is illustrated by utilizing these three sea states characteristics.

Since the short-term sea state is characterized by H_S, T_P and $\emptyset$, the long-term variability of the wave conditions can be described by the joint density function of these characteristics, $f_{H_s T_p \emptyset\,(h,t,\emptyset)}$. This joint density function is written as:

$$f_{H_s T_p \emptyset}(h,t,\emptyset) = f_{\emptyset}(\emptyset).f_{H_s T_p\,|\emptyset}(h,t\,|\emptyset) \tag{2.3}$$

Where:

$f_{\emptyset}(\emptyset)$: the marginal density function for the main direction of wave propagation

$f_{H_s T_p \emptyset}(h,t\,|\emptyset)$: the conditional joint density function for significant wave height and spectral peak period given the main direction of propagation (S. K. Haver, 2011)

Furthermore, the conditional joint density of H_S and T_P can be written as (S. K. Haver, 2011):

$$f_{H_s T_p\,|\emptyset}(h,t\,|\emptyset) = f_{H_s\,|\emptyset}(h\,|\emptyset).f_{T_p\,|H_s \emptyset}(t\,|h,\emptyset) \tag{2.4}$$

CHAPTER 3 Dynamic Analysis of Marine Structures

3.1 Introduction

In principle, the dynamic analysis of the marine structures can be performed either in the frequency domain or in the time domain. Obtaining the structural response by the frequency domain analysis is limited to the linear response problems. Linear response problems are the ones where both the mechanical system and the hydrodynamic loading are linear.

By linear mechanical system, it means that the damping coefficient, C, and the stiffness coefficient, K, is independent of the magnitude of $\dot{x}(t)$ and $x(t)$, respectively. Here x is a generalized motion which can be translation or rotation. Although the damping coefficient and the stiffness coefficient are of a non-linear nature, for a wide number of response problems, results of sufficient accuracy can be achieved by assuming a linear structural model. Moreover, as far as considering ULS and often also ALS design checks, the structural deformation stays within the elastic region and the structure can be well modelled as a linear mechanical system; constant C and K. However, the collapse loads can be obtained by utilizing a non-linear mechanical system.

On the other hand, the linear hydrodynamic loading can be obtained by defining the wave condition as the regular wave with frequency ω. According to the linear theory, this regular wave gives a response at the same frequency, ω, and the response amplitude is proportional to the wave amplitude. Moreover, if the surface elevation process for short-term periods can be assumed to be correctly modelled as a Gaussian process, the structural response can be simply calculated in the frequency domain. In this case, the response process is also Gaussian and can be described by the response spectrum. The response spectrum can be obtained by multiplying the absolute value of the transfer function squared by the wave spectrum. Under the assumption of a narrow banded surface elevation process, the individual maxima of the surface elevation process can be assumed to be Rayleigh distributed. The only Rayleigh parameter is the variance that can be calculated from the response spectrum. Calculating the structural response in the frequency domain is a simple approach compared to the time domain. However, the assumption of a linear hydrodynamic loading with respect to the surface elevation process is limited to only few response problems, e.g. the marine structures where the mass term of Morison equation is dominated.

For the marine structures where the drag term of the Morison equation is dominated, the frequency domain method either gives an approximate result or a result which is far from the exact response. However, the exact response can be calculated by the time domain method with sufficient accuracy in many cases, i.e. as far as the assumption of the linear mechanical system is fulfilled. This is because the correct frequency content are automatically included in the time domain dynamic analysis, since the drag forces are calculated directly from the Morison`s equation at each time step.

On the other hand, if these load components are included in the frequency domain analysis, firstly, the load components are calculated. Thereafter, the response from each load component is calculated by using the transfer function. In the case where the linear superposition is valid, the total response is finally obtained by adding all the calculated responses for each frequency component. In the case where the linear superposition is not valid, i.e. the frequency components cannot be separated, the drag force must be linearized. An example of this situation is when the structural response velocity becomes large compared to the wave induced velocity. In this case, the structural response can no longer be neglected and the relative velocity between the structural response and the wave induced velocity must be taken into account. Therefore, in order to perform frequency domain analysis in this situation, the drag force must be linearized. One of the disadvantages of the drag force linearization is the introduced error during this procedure.

Correspondingly, the preferred method for the drag governed structures is the time domain method. The reason is that this method takes care of the true frequency composition of the drag load. In addition, in this method, the total response can be obtained directly by the Morison`s equation and there is no need to use superposition or drag force linearization procedures. It must be noted that for the non-linear mechanical systems where the damping and the stiffness coefficients are not constant and must be updated in each time step, the time domain analysis cannot give the exact solution and model tests are required for verification.

3.2 Time domain analysis of marine structures

Time domain analysis basically means solving the equation of motion in the time domain step by step. The equation of motion is given by:

$$m\ddot{x}(t) + c(x,\dot{x})\dot{x}(t) + k(x,\dot{x})x(t) = F(t) \quad (3.1)$$

Where:

M: Mass of the system (added mass comes in addition to the structural mass when the structure is moving in water)

$c(x, \dot{x})$: Damping coefficient associated with the motion degree of freedom

$k(x, \dot{x})$: Stiffness coefficient associated with the motion degree of freedom

F(t): External load acting on the mass in the direction of the selected degree of freedom

The external load per unit length of the structures, F(z,t), is often calculated by the Morison equation. This equation which consists of two terms, i.e. mass and drag terms, is given by:

$$F(z,t) = C_m \rho \, A(z)\dot{u}(z,t) + \frac{1}{2} \, C_d \, \rho \, d(z)u(z,t)|u(z,t)| \tag{3.2}$$

Where:

C_m: Mass coefficient

C_d: Drag coefficient

A(z): Cross sectional area of the riser in the given depth, z

d(z): Riser diameter in the given depth, z

ρ: Density of sea water

u(z,t): Water particle speed at the center of the member if the structure had not been there

$\dot{u}(z,t)$: Water particle acceleration

With reference to (Faltinsen, 1999), for the marine risers where both the ratio of the wave height to the riser diameter and the ratio of the wave length to the riser diameter are large, the drag term of the Morison equation is dominant.

In general, the drag governed structures can be divided into two sub classes: quasi-static behaving structures and dynamically behaving structures (S. K. Haver, 2011).

3.2.1 Quasi-static structures

For the quasi-static structures, the mass and damping terms in the equation of motion can be neglected and there is more or less one to one correspondence between q-probability wave height[2] and the q-probability load or response. The response is defined by the instantaneous

[2] q-probability events simply mean the events corresponding to an annual exceedance probability of q.

external load and it is independent of the previous load history. Therefore, the response is simply given by:

$$x(t) = \frac{F(t)}{K} \tag{3.3}$$

An example of the quasi-static structures are jackets and jack-ups in shallow water where the largest natural period is much lower than the periods that are present in the load process. With reference to the natural period formula, $T_n \approx \sqrt{\frac{m}{k}}$, in which the natural period is proportional to the square root of mass of the system, it is seen that as water depth increases, the mass of the system and the natural period increases too.

Correspondingly, the largest natural period increases toward a period band of significant wave loading, direct loading or super harmonic loading. As a result, according to (S. K. Haver, 2011), for water depth above 150 meters damping and mass forces cannot be neglected.

3.2.2 Dynamically behaving structures

The dynamically behaving structures, e.g. marine risers, can be divided into two sub classes:

1. The marine risers where the structural velocity, $\dot{r}$, is small compared to the wave induced water particle motions, $u(t)$, and the structural velocity can be neglected. In this case the drag term of the Morison equation is calculated by:

   $$F_{d1} = \frac{1}{2}\, C_d\, \rho\, D\, \Delta l\, u(t)|u(t)| \tag{3.4}$$

2. The marine risers with too large structural displacement where the relative velocity must be taken into account. In this case, the drag term of the Morison`s equation is given by:

   $$F_{d2} = \frac{1}{2}\, C_d\, \rho\, D\, \Delta l\, [u(t) - \dot{r}]|u(t) - \dot{r}| \tag{3.5}$$

The definition of the parameters in the Equations (3.4) and (3.5) are presented in the Figure 3.1.

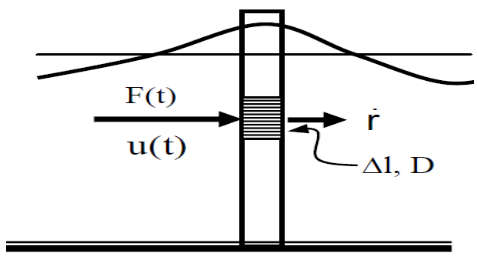

Figure 3.1 - Vertical riser (Larsen, 2005)

Under the assumption of the harmonic wave induced motion; $u(t) = u_0 \sin \omega t$, the dynamic equilibrium equation can be written for the two sub classes as:

1. Fixed riser:

$$m\ddot{r} + c\dot{r} + kr = F(t) + C_D^* u_0^2 \sin \omega t |\sin \omega t| \quad (3.6)$$

2. Oscillating riser:

$$m\ddot{r} + c\dot{r} + kr = F(t) + C_D^* (u_0 \sin \omega t - \dot{r}) |u_0 \sin \omega t - \dot{r}| \quad (3.7)$$

Where $C_D^* = \frac{1}{2} C_d\, \rho\, D\, \Delta l$, and F(t) represents other loads than the drag force (Larsen, 2005).

The $\sin \omega t |\sin \omega t|$ term demonstrates how the harmonic wave induced motion with frequency ω can gives a non-linear drag load with other frequencies than the wave frequency. It also demonstrates that the force is not proportional to the wave height since the term u_0^2 enters the equation. Therefore, since the response amplitude is not proportional to the wave amplitude, the transfer functions (frequency domain analysis) cannot be used for obtaining the response. Moreover, with reference to Equation (3.7), it is seen that the drag load consists of an external load and a damping term. Consequently, this force may excite the structure or provide damping.

In principle, when a structure vibrates in the fluid, part of the pressure from the fluid on the structure is in-phase with the velocity of the structure. This pressure results in the so-called hydrodynamic damping (Langen & Sigbjörnsson, 1979). The hydrodynamic damping is composed of two main parts. One part is proportional to the velocity of the structure, i.e. $c\dot{r}$ term in the Equation (3.7), and the second part is called drag damping which is due to vortex shedding and viscous effects in the water. The second term is proportional to the square of the relative velocity between the structure and the surrounding water particles, i.e. $C_D^* (u_0 \sin \omega t - \dot{r}) |u_0 \sin \omega t - \dot{r}|$ term in the Equation (3.7), (Langen & Sigbjörnsson, 1979). Moreover, since the drag force is a function of the velocity of the structure, $\dot{r}$, this quantity must be known in order to calculate the drag force. As a result, Equation (3.7) can be solved by including an iteration scheme.

For the oscillating riser the drag load is a function of the structural response velocity, $\dot{r}$, and the time domain procedure is given by (Larsen, 2005):

1. Assuming $\dot{r}_{i+1} = \dot{r}_i + \ddot{r}_i \Delta t$, where Δt is the time step and r_i, $\dot{r}_i$ and $\ddot{r}_i$ are known from the last step in the static analysis
2. Computing the drag load for time step i+1 according to Equation (3.7)
3. Computing the displacement, velocity and acceleration for time step i+1
4. Comparing the computed and the assumed velocity, and checking whether the difference is smaller than the convergence criterion or not

3.2.3 Non-linear mechanical system

Non-linear mechanical systems are the systems where the stiffness and damping coefficients are not constant and must be updated during the analysis. These systems can be analyzed in the time domain, but since the stiffness and damping properties must be updated for each time step, the computation time increases considerably. In addition, for highly non-linear systems the exact solution cannot be obtained only by the time domain simulations. Therefore, usually the calculated results are verified by means of model tests (S. K. Haver, 2011).

CHAPTER 4 Methods for Predicting Characteristic Loads on the Marine Structures

4.1 Introduction

The total load which a marine structure is designed to withstand is obtained by the summation of the multiplied load effect of each category (e.g. functional, environmental, accidental, etc.) by it`s corresponding load effect factor. For more illustration, design bending moment is given below as a specific example.

$$M_d = \gamma_f M_f + \gamma_E M_E + \gamma_A M_A \tag{4.1}$$

Where:

M_F: Bending moment from functional loads

M_E: Bending moment from environmental loads

M_A: Bending moment from accidental loads

γ_f: Functional load effect factor

γ_E: Environmental load effect factor

γ_A: Accidental load effect factor

Different rules and regulations recommend various load effect factors. See for instance DNV-OS-F201 (2010). Generally the load effect factors are calculated by checking different load combinations. The load combination which gives the highest design load is selected and the load effect factors in the selected load combination are taken as the final load effect factors.

The focus in this chapter is on how to properly estimate the characteristic environmental extreme value of the load under consideration. Most rules require that the characteristic load can be taken as the load corresponding to a given annual probability of exceedance. Regarding to the Ultimate Limit State (ULS) check, an annual probability of 10^{-2} is recommended by rules and regulations. According to NORSOK-N-003 (2007), the 100-year environmental condition, which corresponds to the environmental condition with annual exceedance probability of 10^{-2}, can be presented by the 100-year wave, mean wind speed and the 10-year current. An important part of any design process is to obtain proper estimates of the q-probability loads. The choice of method for predicting adequate structural responses depends to a large extent on the nature of the response problem under consideration. In the following, four commonly used approaches for calculating characteristic values of extreme load effects due to environmental loads for ULS design checks are discussed.

4.2 Deterministic design wave method

In this method, the structure is exposed to a deterministic design wave. The deterministic design wave is specified by the wave height, H, the wave period, T, and the direction of wave propagation, $\emptyset$. The structure is then exposed to different combination of wave periods, the q-probability wave height and different directions and the most unfavourable combination that results in the highest response is selected. The deterministic wave profile is typically assumed to be reasonably well described by the Stokes 5th order wave profile. The advantage of the 5th order Stokes profile compared to the lower order stoke waves as well as the other wave profiles is that the wave particle kinematics, i.e. speed and acceleration, are defined to the exact surface level.

The input data for the deterministic 5th order design wave profile can be selected by different methods. If a metocean design data report is available, the q-probability wave height can be selected with the most unfavourable wave period of the 90% confidence band. The most unfavourable wave period is the wave period which gives the highest structural response. In addition, design guidelines may be used to select the design wave. For instance, to simplify the calculations if more accurate estimates are not available, NORSOK-N-003 (2007) recommends to take $H_{100}=1.9\ H_{S,100}$, where $H_{S,100}$ is obtained from long-term statistics, when the duration of the sea state is 3 hours. Moreover, NORSOK-N-003 (2007) recommends to vary the wave period in the following range:

$$\sqrt{6.5\,H_{100}} \leq T \leq \sqrt{11\,H_{100}}$$

Where the left hand side criterion is based on a limiting wave steepness $\frac{H}{\lambda}$ of $\frac{1}{10}$.

The 10^{-2}-probability loads and responses are estimated by stepping the design wave through the structure. The load and responses are calculated for each time step. The 10^{-2}-probability response is taken as the maximum value obtained during this process. The calculated response is called the quasi-static response which belongs to a quasi-static structure; see section 3.2.1 for the definition of quasi-static structures.

In order to account for a modest effect of dynamics, the calculated q-probability response can be multiplied by a dynamic amplification factor, DAF, which is a function of the ratio between the wave period and the natural period as well as the damping. This simplified approach is only suitable for DAF less than 1.1.

4.2.1 Area of Application and drawbacks

This method is suitable for the quasi-static structures, e.g. jackets and jack-ups in shallow water. One of the applications of this method is to obtain reasonable local characteristic responses. However, according to (S. K. Haver, 2011) the wave characteristics should for cases like this be calibrated against global characteristic loads obtained by more accurate methods.

The accuracy of the characteristic response obtained by this method depends on to which extent the assumptions behind the method are fulfilled. For instance, the q-probability crest height is typically about 5% larger than the crest height of the q-probability wave height when a Stoke 5^{th} order profile is adopted. Therefore, the calculated response is underestimated. This is the case especially for the dynamically behaving drag dominated structures where the crest height is the most important quantity regarding the wave induced loads.

Moreover, for dynamically behaving structures and/or highly nonlinear structural models, the system has a high dependency on the wave period. Consequently, selecting a deterministic design wave omits some information and the method becomes questionable.

On the other hand, the resulting design wave corresponds to a lower annual exceedance probability than q. However, it does not mean that the calculated response from this design wave is larger than the true value. This is because the real extreme and irregular ocean waves have a different shape compared to the deterministic 5^{th} order stokes profile. Correspondingly, the design wave method used in the detailed design needs to be verified by the stochastic analysis.

This must be taken into account that for the drag dominated structures, the load is non-linear even if the sea surface elevation is assumed to be sinusoidal (which is not the case for the real ocean waves). In (Larsen, 2005) it is proved that the drag force has higher order frequency components than the wave frequency; odd frequency components in the case of wave loads and both odd and even frequency components in the case of current in combination with wave. Although, the dominating term is the term following wave frequency, ω, both 2ω and 3ω components have considerable magnitude. If this higher order frequency components hit one of the natural periods of the structure, a considerable dynamic amplification can occur even if the wave frequency, ω, and the natural frequency are well separated. Therefore, it may not be sufficient enough to only consider the dynamic effects by a DAF.

4.3 Design storm method

Compared to the deterministic design wave method, the wave condition in this method is defined as the realistic irregular sea state. According to DNV-RP-C205 (2010), 100-year design sea state is a sea state of duration 3-6 hours, with $H_{S,100}$ combined with adequately chosen characteristic values for the other sea state parameters. The 100-year significant wave height, $H_{S,100}$ can be found from the distribution function of the significant wave height. DNV-RP-C205 (2010) recommends to vary the accompanying T_P or T_Z values within a period band about the mean or median period. Alternatively, this standard recommends using the environmental contour line method to find the worst sea state along the q-probability contour of H_S and T_P. The environmental contour line method is explained in section 4.5.

In the design storm method, the DAF can be calculated by performing the time domain simulation of the equation of motion for with and without dynamics. This can be done by both executing quasi-static analysis (not permitting structure to move) and a full dynamic analysis. In (S. K. Haver, 2011), it is recommended to perform a rather large number of 3-hour simulations using different random seeds for the worst sea state. Thereafter, a sample of the largest 3-hour quasi-static and dynamic responses are available. By fitting a proper probabilistic model to the sample data, an estimation of the 3-hour largest quasi-static and dynamic response are obtained under the assumption that a reasonable percentile; α, is selected. Finally, an equivalent dynamic amplification factor can be calculated by:

$$EDAF = \frac{x_{\mathrm{dyn-3h}(\alpha)}}{x_{\mathrm{qs-3h}(\alpha)}} \tag{4.2}$$

4.3.1 Area of application and drawbacks

The area of application of this method is mostly similar to the deterministic design wave method. However, this method is more suitable when a significant dynamic amplification factor is obtained. S. K. Haver (2011) recommends the application of this method when the DAF is larger than 1.1.

Since in this method a long-term analysis is not necessary, this method is known as an attractive and simple method. However, large uncertainties are seen in connection with the design storm parameters.

4.4 Stochastic long-term response analysis

In principle, the structural response depends on the previous load history. It also depends on the different wave periods e.g., due to the geometrical reasons and the sea severity. Moreover, the largest response itself is a random variable. As a result, in order to predict proper estimates of the characteristic loads, all sources of randomness impacting the load under consideration must be accounted for. Therefore, the long-term distribution of the target response quantity is required.

The long-term distribution of the response under consideration may be described in four different ways (S. K. Haver, 2011):

1. The individual maxima or cycle width of the target response process
2. The d-hour maximum of the target response process
3. The storm maximum of the target response process
4. The annual extreme value of the target response

Independent of the preferred method of analysis, the calculated probability is the resulting effect of two essentially different sources of randomness effecting the load as a random variable.

1. The inherent randomness associated with the sea state characteristics, i.e. wind, waves and current that is experienced for an arbitrary short-term period. This source of randomness is known as the long-term variability or the climate variability.
2. The inherent randomness of the maximum load or response during a given short-term sea state. This source of randomness is called the short-term variability.

The first source of randomness associated with the sea state condition is by far the most important source of randomness (S. Haver & Winterstein, 2009). In principle, the observed sea surface at a fixed location can be considered as a realization of a non-stationary process with slowly varying parameters. However, since a typical period for these parameters is much longer than a typical wave period, for short time periods, the process can be modelled as a stationary stochastic process. In addition, the environmental condition can for practical purposes be characterized by some few parameters varying slowly with time, e.g. significant wave height and spectral peak period.

The first source of randomness is accounted for by establishing a joint long-term probability density function for the short-term sea state characteristics. This function also takes into account the effect of non-observed sea states (S. Haver & Winterstein, 2009). Considering H_S and T_P as the sea state characteristics, a joint probabilistic model can be fitted to the simultaneous observations of H_S and T_P:

$$f_{H_sT_p}(h,t) = f_{H_s}(h) f_{(T_p|H_s)}(t|h) \tag{4.3}$$

In principle, there is no solid theoretical basis for the probabilistic models to be adopted for $f_{H_sT_p}(h,t)$. Therefore, the joint density function for the environment is mainly obtained by fitting an assumed probabilistic model (often based on experience) to the available observations (Sverre Haver & Kleiven, 2004). However, the major challenge is often the availability of good quality and sufficient data.

Moreover, the second source of randomness can be accounted for by establishing the conditional distribution function of the structural response under consideration given the environmental condition; e.g. H_S and T_P.

Finally, taking the second method to describe the long-term distribution of the response as an example, the long-term distribution of the 3-hour maximum response, X_{3h}, is given by:

$$F_{X_{3h}}(x) = \int_0^h \int_0^t F_{\left(x_{3h}|H_s,T_p\right)}(x|h,t)\ f_{H_sT_p}(h,t)dtdh \tag{4.4}$$

As a result, the value corresponding to a return period of T years, x_0, is given by:

$$1 - F_{X_{3h}}(x_0) = \frac{1}{m_{3h,T}} \tag{4.5}$$

Where $m_{3h,T}$ = T×365×8 is the number of 3-hour sea states in T years if all sea states are included in the sample.

One of the major challenges is to find a proper probabilistic model for the 3-hour maximum response, X_{3h}, given the environmental condition. For linear response problem exposed to a stationary Gaussian surface elevation, establishing the conditional distribution of largest response given the sea state is very straight forward. This is because, under the assumption of the Gaussian and narrow banded wave process, both the individual and global[1] maxima can be assumed to be Rayleigh distributed. On the other hand, for a Gaussian and wide banded wave process, the individual maxima can be assumed to be Rice distributed. However, according to (S. K. Haver, 2011) the Rayleigh distribution function can still be used for modelling the global maxima.

The characteristic largest response maxima during d hours is also a random variable. Therefore, this randomness can be accounted for by establishing the distribution function of the characteristic largest response maxima during d hours. The conditional distribution function of characteristic largest response maxima given sea state can be obtained by raising the Rayleigh distribution function of the global maxima to the power of number of zero-up crossings/global maxima during the same time period.

The distribution function of the characteristic largest maxima during d hours is normally converged toward an asymptotic extreme value distribution when number of the global maxima becomes very large. According to (J. Leira, 2010) the asymptotic form and convergence rate depends on the upper tail of the initial distribution function. According to the classification of extreme value distribution presented in (J. Leira, 2010), if the initial distribution is normal, log-normal, exponential, Weibull, Rayleigh or Rice, the Asymptotic Extreme value distribution is Gumbel. This approach is valid for both narrow banded and wide banded Gaussian wave

[1] Largest maxima between adjacent zero-up crossings

process. However, according to (Myrhaug & Lian, 2009) this approach is acceptable under two assumptions:

1. All global maxima are identically Rayleigh distributed which is probably good enough for prediction of extreme values.
2. All global maxima are statistically independent. This assumption can be questionable. A consequence of this is that the 100-year values are overestimated by some few percent. This is because of the correlation between adjacent maxima within a stationary sea state as well as the correlation between adjacent sea states.

On the other hand, if the response process cannot be assumed to be Gaussian, the assumption of Rayleigh distributed maxima is not fulfilled. However, the Gumbel distribution as an asymptotic distribution of the short-term extreme value may still be valid, but the Gumbel parameters are not a function of the response spectrum standard deviation. The Gumbel parameters can be obtained by different techniques; Method of Moments, Least squares methods, Gumbel estimators and Likelihood estimation. All four methods are explained in (J. Leira, 2010). The method of moment is explained in section 5.8.2 since this method is utilized in this project.

In addition, for non-Gaussian processes, the 2-parameter Weibull distribution may often be an adequate short-term model for the global maxima. In this case, the distribution function of the extreme value is obtained by raising the Weibull distribution to the number of global maxima. If the shape parameter of the 2-parameter Weibull distribution is equal or larger than 1, $\gamma \geq 1$, the Gumbel distribution is the asymptotic distribution for the extreme value of weibull distributed global maxima (Sverre Haver & Kleiven, 2004). If $\gamma < 1$ the convergence to the Gumbel model seems to be very slow and the Gumbel distribution must be utilized carefully.

For non-Gaussian response process, a more direct approach can be applied in order to avoid introducing uncertainties through the fitting of a 2-parameter Weibull model to the global maxima samples. If the Weibull model is not a proper model for the full sample space of the global maxima, Sverre Haver and Kleiven (2004) recommend focusing directly on observations of the short-term extreme value. A number of d-hour time domain simulations or model tests can be executed using different random seeds and the largest value of each time history is identified. A proper extreme value distribution is thereafter fitted to the sample of d hour extreme values. Duration of a stationary condition, d, depends strongly on the site location. For instance, in (S. Haver & Winterstein, 2009) it is recommended to use d=3 hours for Norwegian Continental Shelf (NCS) while for a hurricane governed sea, e.g. Gulf of Mexico (GoM), d=0.5 hours is suggested as a more proper choice.

It is observed that the assumption of Gaussian or non-Gaussian surface process influence the estimated response considerably. It is more important for drag dominated structures. This is because the drag load is proportional to particle speed squared. The horizontal particle speed is maximum under the wave crests, which is underestimated by the Gaussian assumption.

Therefore, it is recommended to model the surface elevation by a second order surface process, instead of the Gaussian surface process. Moreover, current has a significant influence on the drag load and it must be included in the joint environmental modelling. According to (S. K. Haver, 2011) a major difficulty in this connection is the availability of a sufficient amount of proper simultaneous data for waves and current.

4.5 Contour line method

A method developed to utilize short-term analysis of complex problems to estimate the long-term extremes is the environmental contour line method. The main steps of this method are:

1. Establishing the q-probability contour line
2. Executing a sufficient number of d-hour time domain simulations or model tests for different sea states along the q-probability contour line
3. Screening analysis to determine the worst sea state (at least among those tested) in view of the problem under consideration along the q-probability contour line
4. Establishing the distribution function for the 3-hour maximum response, X_{3h}, for the worst sea state along the q-probability contour line
5. Estimating the q-probability response by the α-percentile of the established distribution function for the 3-hour maximum response

The q-probability contour line can be determined by using the IFORM method form the field of structural reliability analysis. Since in this project, an available contour line is utilized, the approach for determining the contour line is not explained here and can be found in (Winterstein, Ude, Cornell, Bjerager, & Haver, 1993). When the contour line is available, finding the worst sea state along the contour line is straight forward. This is because for the most practical problems, it is rather simple to determine a narrow part on the contour line that includes the worst sea state.

In order to establish the conditional distribution function of X_{3h}, a large number of observations of X_{3h} for the worst sea state must be available. Therefore, a rather large number of 3-hour time domain simulations or model tests must be executed. The number of time domain simulations and/or model tests must be large enough to have some few observations above percentile level. S. Haver and Winterstein (2009) recommend to have at least 2 observations above percentile level. They also suggest to perform at least 20 d-hour time domain simulations or model tests for the worst sea state in order to be able to model the tail of the distribution model properly. The reason that the tail of the distribution model is very important is that the q-probability response is usually much larger than the mean of the response distribution. Hence the tail of the model is the most important part (Farnes & Moan, 1993).

If the short-term variability can be neglected, the median value of the 3-hour Gumbel extreme value distribution can be an estimation of the q-probability response.

In principle, the short-term variability of the 3-hour extreme response cannot be neglected. Consequently, in order to take into account the short-term variability of the extreme response, four alternative methods are available.

Three alternative methods are recommended in (S. K. Haver, 2011) and (Sverre Haver & Kleiven, 2004) which are listed in the following:

1. Inflating the q-probability contour line artificially in order to worsen the combination of the slowly varying parameters to account for the short-term variability.
2. Multiplying the estimated median response by a correction factor which is typically between 1.1-1.3.
3. Selecting a higher percentile instead of the 50-percentile. For instance, for $q=10^{-2}$, NORSOK-N-003 (2007) recommends to select a percentile level between (85%-90%).

Moreover, (Baarholm & Moan, 2001) suggest to increase the duration of the sea state, say more than 3 hours.

4.5.1 Area of application

For linear or nearly linear response problems, the full long-term analysis in principle is possible. While for strongly non-linear response problems, the problem is of such complexity that model test is required to establish the short-term variability. Therefore, a full long-term analysis is in practice out of reach. This is because model test is very time consuming and also it is a costly activity for complex response problems. Therefore, contour line method is utilized as a short-term approach for predicting the long-term extremes.

CHAPTER 5 Methodology and Assumptions

5.1 Environmental condition

As mentioned previously, selecting the environmental condition depends largely on the nature of the response problem under consideration. For a drilling riser with significant dynamic response, a non-linear random wave model is required. This irregular and random wave model allows for sum and difference frequency wave components caused by non-linear interaction between the individual wave components. In order to estimate the long-term extreme response, the drilling riser must in principle be exposed to the irregular sea in the form of a full time series. However, it is assumed that the extreme response occurs for the largest wave event. Therefore, the riser is exposed to the irregular sea train of limited duration which involves the target wave event. It is also assumed that the riser is designed for Norwegian Continental Shelf (NCS) and the wave condition is assumed to be stationary for duration of 3 hours.

Since the drilling riser is a drag-dominated structure and the drag term involves particle speed which with respect to horizontal speed attains its maximum at the wave crest, a non-Gaussian surface elevation process is utilized to compute the kinematics at the exact surface. Moreover, it is assumed that the surface elevation process is ergodic and the wave characteristics can be estimated by the time averages instead of ensemble averaging.

In addition, according to the DNV-RP-C205 (2010) the combined wind[1] seas and swell[2] can be described by a double peak spectrum. Therefore, since the riser is assumed to be installed in the Norwegian continental shelf, the Torsethaugen spectrum which is a double peak spectrum is utilized. This is because the Torsethaugen spectrum is obtained by fitting two generalized JONSWAP functions to averaged measured spectra from the Norwegian Continental Shelf (Torsethaugen & Haver, 2004).

[1] Wind waves are generated by local wind

[2] Swell waves are waves that are far from the areas where they are generated. Swell waves have no relation to the local wind (DNV-RP-C205, 2010)

Moreover, it is assumed that the sea is long crested; all wave components are assumed to propagate in the same direction. According to (S. K. Haver, 2011) this assumption is a conservative assumption for the most practical applications. The exception is for some special problems as e.g. ship rolling. In that case a short crested sea can give a larger response since excitation is experienced from different directions (S. K. Haver, 2011). As a result, it is assumed that the drilling riser is exposed to a long crested wave in 0 degree direction.

The contour line utilized in this project is obtained from a provided metocean report by the STATOIL. The report is presented in the Appendix A. The contour line is established by assuming that the only important slowly varying parameters are the significant wave height, H_S, and the spectral peak period, T_P. The q=0.63, 10^{-1}, 10^{-2} and 10^{-4} probability contour line of an omni-directional waves; long crested waves, with the duration of 3 hours are shown in Figure 5.1.

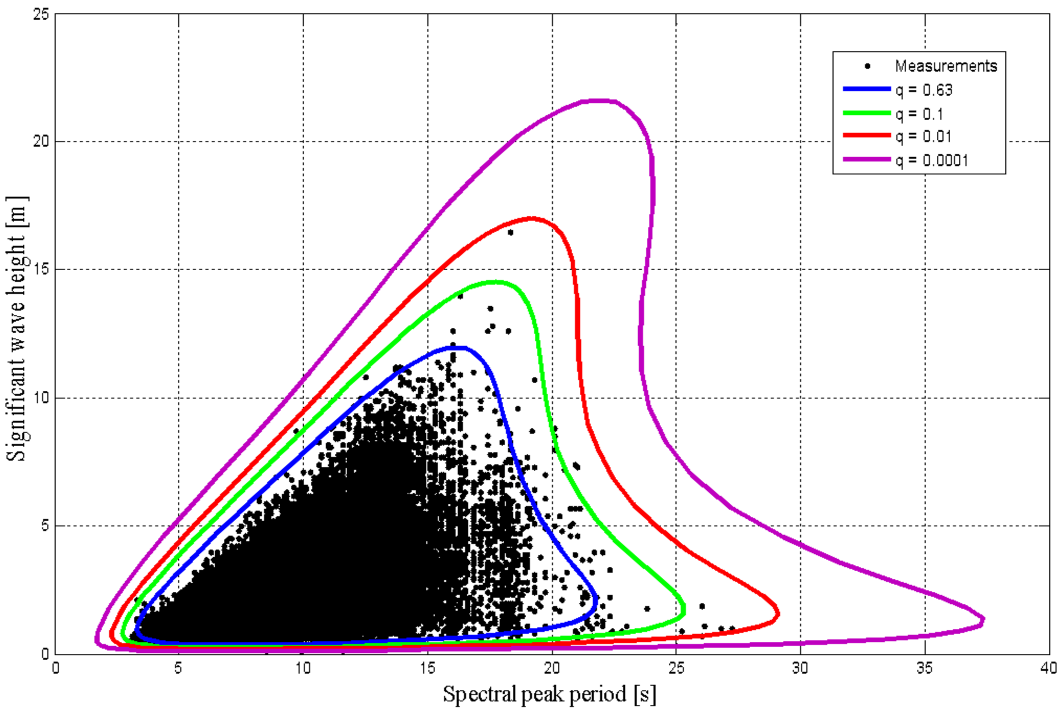

Figure 5.1 - The q-probability contour lines of H_S-T_P for q=0.63, 10^{-1}, 10^{-2} and 10^{-4} for omni-directional waves. Duration of sea state is 3 hours

Selecting the proper q-probability contour line depends largely on the drilling operating limits for the drilling vessel and the drilling riser. According to API-RP-16Q (2001), informations concerning drilling operation limits must be specified in the riser operating manual. Moreover, the manufacturers of the drilling vessel provide informations regarding the maximum wave height and the corresponding wave period in which drilling can be conducted. Since in this project none of these information are available and considering the fact, that the drilling riser must be disconnected from the BOP stack in the high sea states, the sea state with the highest significant wave height and the corresponding spectral peak period along the 0.63-probability contour line is assumed to be the limiting sea state for drilling operation; See Table 5.1.

Table 5.1 - Drilling operating limit

Annual probability of exceedance	Significant wave height, H_S (m)	Spectral peak period, T_P (s)
0.63	11.8	16.1

In addition, with reference to API-RP-16Q (2001) drilling operation in the current with velocity exceeding two knots (1.02 m/s) causes some difficulties due to the high drag loads and vortex induced vibrations (VIV) on the riser. Correspondingly, a current profile is assumed in line with the wave propagation with 1.00 m/s current speed on the sea surface. The reason for exposing the riser to high current is because the aim of this project is estimating the q-probability response of the drilling riser. Table 5.2 and Figure 5.2 present current information.

Table 5.2 - Current speed and direction in different water depth

Water depth (m)	Current speed (m/s)	Direction (°)
0	1.00	0
-133	0.40	0

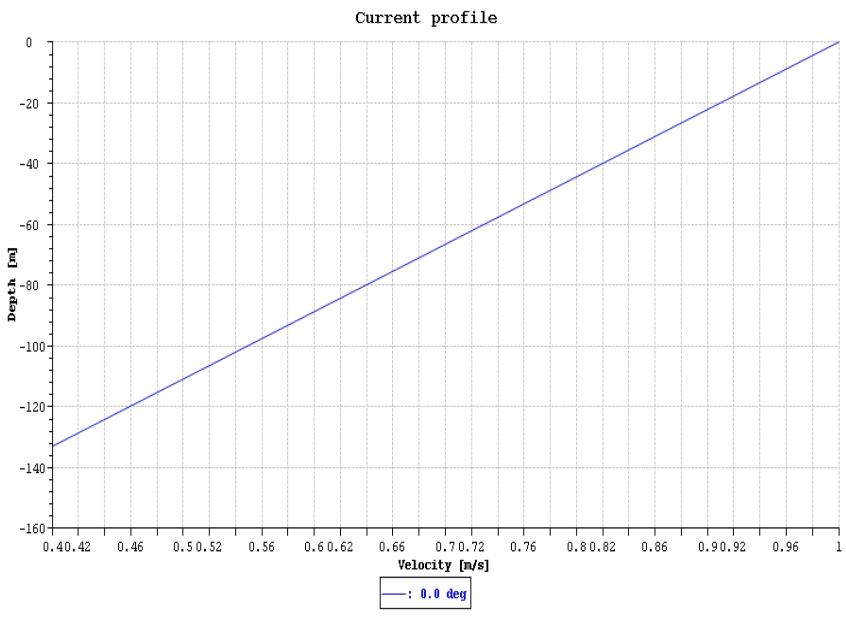

Figure 5.2 - Current Profile (screen shot from SIMA)

5.2 Applied top tension

Since the drilling risers have very little inherent structural stability, the applied top tension plays a key role in the structural stability to resist environmental loads. Various considerations in selecting a proper top tension for the drilling riser must be conducted. For instance, the maximum angles at both the lower and upper flex joints have an upper limit which are presented in section 5.4. Moreover, according to DNV-RP-F205 (2010), the lower bound for the applied top tension to avoid compression in the riser at static position is specified in terms of excess over the effective weight of the riser system. Therefore, a higher top tension is applied in a typical range of 30-60% of effective weight of the riser system. In addition, according to API-RP-16Q (2001), the tensioner system must provide sufficient top tension even if one tensioner line or a pair of tensioners become out of service for maintenance or repair. As a result, in this project the tensioner system is designed with 4 tensioner lines in which one can becomes out of service while the applied top tension by three other tensioner lines are sufficient for keeping the drilling riser in the stable condition.

With reference to DNV-OS-F201 (2010), the effective weight or on the other word the submerged weight of a riser including it`s content can be calculated by the following formula:

$$W_E = m_p g + A_i \rho_i g - A_o \rho_o g \tag{5.1}$$

Where:

W_E: Effective weight

M_p: Mass of the riser joint

A_o,A_i: External and internal cross sectional areas of the riser joint

ρ_o, ρ_i: External and internal fluid densities; here internal fluid density is equal to the drilling mud density = 1600 Kg/m^3, and external fluid density is the sea water density = 1025 Kg/m^3

g = Acceleration of gravity = 9.81 m/s^2

5.3 Riser wall thickness

Riser wall thickness is selected according to ULS design approach and especially the combined loading criteria which are presented in DNV-OS-F201 (2010). At the water depth range with the maximum bending moment on the riser, the riser is subjected to net internal overpressure. As a result, the combined loading criteria for the risers subjected to net internal overpressure is utilized. The formula is:

$$\{\gamma_{SC}.\gamma_m\}\left\{\left(\frac{|M_d|}{M_k}.\sqrt{1-\left(\frac{P_{ld}-P_e}{P_b(t)}\right)^2}\right)+\left(\frac{T_{ed}}{T_k}\right)^2\right\}+\left(\frac{P_{ld}-P_e}{P_b(t)}\right)^2 \leq 1 \tag{5.2}$$

Where:

$M_d = \gamma_F . M_F + \gamma_E . M_E$; Design bending moment

$M_k = f_y \cdot \alpha_c \cdot (D - t)^2 \cdot t$; Plastic bending moment resistance

$T_{ed} = \gamma_F . T_{eF} + \gamma_E . T_{eE}$; Design effective tension

$T_k = f_y \cdot \alpha_c \cdot \pi \cdot (D - t) \cdot t$; Plastic axial force resistance

M_F, T_{eF}: Bending moment and effective tension from functional loads

M_E, T_{eE}: Bending moment and effective tension from environmental loads

M_A, T_{eA}: Bending moment and effective tension from accidental loads

γ_F, γ_E: Functional and environmental load effect factors

γ_{SC}: Safety class resistance factor

γ_m: Material resistance factor

$\alpha_c = (1 - \beta) + \beta \cdot \frac{f_u}{f_y}$; Strain hardening factor

$$\beta = \begin{cases} (0.4 + q_h) & , \quad 15 > \frac{D}{t} \\ (0.4 + q_h)(60 - \frac{D}{t})/45, & 15 < \frac{D}{t} < 60 \end{cases}$$

$$\beta = 0, \quad \frac{D}{t} > 60$$

$$q_h = \begin{cases} \frac{(p_{ld} - p_e)}{p_b(t)} \cdot \frac{2}{\sqrt{3}}, & p_{ld} > p_e \\ 0 & , \ else \end{cases}$$

Table 5.3 - Load effect and material resistance factors

γ_F	γ_E	γ_m
1.1	1.3	1.15

Regarding to the safety class resistance factor, with reference to table 2-3 in DNV-OS-F201 (2010), for conditions with risk of human injury, considerable environmental pollution and high economic loss, normal safety class is applied. Correspondingly, the safety class resistance factor, γ_{SC}, is taken as 1.14. Moreover, the load effect factors have two different combinations in DNV standards. The combination which gives the highest design load is selected in this project. The load effect factors as well as the material resistance factor for Ultimate Limit State (ULS) are presented in Table 5.3.

In order to find the riser wall thickness which fulfills the combined loading criteria, firstly an initial riser wall thickness is assumed. The assumption was based on the previously designed drilling risers that studied before designing this riser. The initial riser wall thickness assumed to be equal 0.035 m. Thereafter, the required top tension was calculated for the assumed riser wall thickness; see sections 5.2 and 6.75.2 for top tension calculation procedure. Subsequently, the riser was exposed to the wave with annual probability of exceedance of 0.63; $H_S = 11.8$ (m), and $T_P = 16.1$ (s). After executing both static and dynamic analyses, the maximum bending moment on the drilling riser as well as the water depth in which the maximum bending moment on the riser occurred was stored. Thereafter, the corresponding effective tension on the same depth was estimated and inserted into the combined loading criteria formula. The maximum dynamic bending moment on the drilling riser was set as the environmental bending moment and the maximum dynamic effective tension in the same water depth was taken as the environmental effective tension. Thereafter, the functional loads (i.e. functional bending moment and effective tension) were estimated by running the static analysis without exposing the structure to any environmental loads. Finally, the combined loading criteria was calculated to check whether it is less than 1 or not.

If the result of the combined loading was more than 1, in order to find the acceptable riser thickness, the formula was utilized as the method to find the thickness which fulfills the combined loading criteria. In order to do that, a MATLAB code which is presented in Appendix B is used. Afterward, the estimated thickness by the MATLAB code was used as the initial thickness, and the mentioned procedure was repeated till the combined loading criteria was fulfilled. The final results regarding the riser wall thickness are presented in section 6.4.

5.4 Flex joint angles

In addition to checking the combined loading criteria, the upper and lower flex joint angles are calculated in order to check whether it fulfills the API-RP-16Q (2001) limitation for maximum upper and lower flex joint angle in the drilling mode or not. With reference to table 3-1 in API-RP-16Q (2001) , the maximum upper and lower flex joint angles in the drilling mode must not exceed 4.0 degrees. In addition, the mean upper and lower flex joint angles must be lower than 2 degrees. In SIMA, the flex joint angle cannot be obtained directly. However, the nodal displacement in X, Y and Z directions are stored at each time step. As a result, the flex joint angle is calculated by using the nodal displacements for four nodes, i.e. two nodes corresponds to a segment above the flex joint, and two nodes corresponds to a segment below the flex joint. Finally, the angle between the two segments is taken as the flex joint angle. Microsoft Office Excel is utilized for flex joint angle calculation.

5.5 Time domain analysis

The drilling riser is assumed to have a linear mechanical system in which the damping and stiffness coefficients are constant and there is no need to update their properties in each time step. For the drilling riser exposed to a nonlinear load the equation of motions is:

$$m\ddot{x} + c\dot{x} + kx = q(t) \tag{5.3}$$

In principle, two techniques are available for conducting the time domain analysis; linear and non-linear. The choice of analysis technique depends on the structural nonlinearity. According to table 4-2 in DNV-OS-F201 (2010) the extreme response of a top tensioned riser can be estimated by executing a linear time domain analysis. This is because, the top tension risers have small to moderate structural nonlinearities. However, this standard recommends using an advanced type of analysis to verify the selected simplified analysis. According to table 4-3 in DNV-OS-F201 (2010) the nonlinear time domain analysis must be performed for verifying the linear time domain analysis. Therefore, due to the time limitation for performing verification analysis, it is concluded to perform a non-linear time domain analysis in this project.

Moreover, two methods for numerical time integration of the dynamic equilibrium equations are available on the RIFLEX software; Newmark β-family and the Wilson θ methods. A description of both methods can be found in (S. K. Haver, 2011), (RIFLEX, 2012) and (Langen & Sigbjörnsson, 1979). In this project, the Newmark β-family method is utilized for the step by step numerical integration of the dynamic equilibrium equations.

The Newmark β-family has three parameters; γ, β and θ. θ is always equal to 1 for this method while values of γ and β must be selected based on the assumptions made with respect to damping and acceleration. It means that the value of γ indicates the numerical damping of the integration method. In addition, the values of β depends on the assumption regarding acceleration behaviour during the time step. In this project, $\gamma = 0.5$ is used which indicates no numerical damping of the integration method. According to (RIFLEX, 2012) this value, which is also the default value in the RIFLEX software, gives a 2^{nd} order accuracy. Moreover, β is set equal to 0.25 which gives a constant average acceleration.

In addition, in order to achieve the results with high accuracy, the time step must be sufficiently small. This is because the stable numerical solution is governed by the highest Eigen mode in the structural model. Therefore, in order to be sure that all Eigen modes are integrated accurately, the time step must be sufficiently small. DNV-OS-F201 (2010) recommends using time step in the range of (0.1-0.4) seconds for numerically well-behaved systems. In this project, the time step is set to 0.1s.

In order to obtain the extreme response by executing non-linear time domain analysis of the drilling riser in RIFLEX/SIMA the following steps are performed:

1. A possible realization of the stochastic surface elevation process based on the COS-series using random seed is simulated for the duration of 3 hours.
2. The corresponding kinematics in the fluid covering the load on the riser is calculated on the exact surface with sufficient accuracy.
3. The load vector of the submerged part of the riser at each time step during the simulation length defined for the irregular response analysis in the RIFLEX/SIMA is calculated.
4. The equation of motion for the given load vector is solved.
5. By repeating the step no.4 for all time steps, time histories of duration 3 hours for all nodal displacements and forces are available. From this time histories the largest maxima in 3 hours is estimated.
6. Since the purpose is to estimate the extreme response and the extreme response itself is a random variable, it is necessary to repeat the simulations with different random seeds in order to reflect the inherent randomness of extreme response. As a result, M (M must be sufficiently large, say $M \geq 24$) time histories of the response process is simulated. And finally, M estimates of the 3-hour extreme value are available which can be used to establish a proper 3-hour extreme value distribution.

5.6 Contour line method

For predicting the extreme response of the drilling riser, the contour line method is utilized. As mentioned in section 4.5, this is a simplified method for predicting reasonable estimates of extremes corresponding to a given return period, i.e. annual probability of being exceeded, for response problems requiring time domain simulations or model tests in order to establish proper short-term distributions of the response extremes.

5.7 Selecting the worst sea state along the contour line

In order to select the worst sea state along the 0.63-probability contour line, a few number of sea states along the contour in the region with high values of significant wave height are selected. For each sea state, the time domain simulation with different random seeds are performed and the largest response for each simulation is stored. Here the response quantity under consideration is the maximum bending moment on the drilling riser. By taking the average of the all values obtained for the largest bending moment, an estimation of the largest bending moment on the riser for each sea state is obtained. Finally, the worst sea state is selected by the screening analysis, i.e. the sea state which gives the largest average bending moment on the drilling riser is assumed to be the worst sea state.

5.8 Statistical inference

As the worst sea state is known, next step is to establish the distribution function of the 3-hour extreme bending moment on the riser for the worst sea state. In general, neither the type of the distribution nor the characteristic parameters are known. This problem can be solved by using statistical inference which includes three steps:

1. Selecting a probabilistic model
2. Fitting the proposed model to the available data
3. Testing if the fitted model is acceptable

5.8.1 Selecting a probabilistic model for the 3-hour extreme bending moment distribution

It is assumed that the distribution function of the 3-hour extreme bending moment on the riser converges towards Gumbel distribution function when the sample size becomes infinite. Information regarding the background for this selection is given in the section 4.4. Therefore, M different time domain simulations for the worst sea state using random seeds are performed. Since, the drilling riser is exposed to a non-Gaussian sea surface elevation, the individual maxima are not Rayleigh distributed. However, it is assumed that the global maxima are well modelled by the Gumbel distribution function.

In principle, there are two different forms for the Gumbel distribution:

$$F(x) = exp\left\{-exp\left\langle-\frac{x-\alpha}{\beta}\right\rangle\right\} \tag{5.4}$$

And,

$$F(x) = exp\{-exp\langle-\theta(x-\alpha)\rangle\} \tag{5.5}$$

Where:

$$\theta = \frac{1}{\beta}$$

S. K. Haver (2011) recommends using the first equation when the Gumbel parameters are to be estimated from limited amount of data. As a result, this form of the Gumbel model is utilized to be fitted to the sample of size M.

5.8.2 Estimating parameters for the Gumbel distribution

The Gumbel parameters are calculated using the method of moments. The moment principle states that the moments of the Gumbel model are equal to the moments of the sample. On the other word, it states that if the Gumbel model is a good model for the available data, the expected value, $[E]$, and the variance, σ, of the model must be equal those of the sample. Therefore, the mean and the standard deviation of the sample is calculated by Equations (5.6) and (5.7), respectively. Moreover, the moments of the Gumbel distribution can be calculated from the probability density functions; see Equation (5.8).

The mean value can be calculated by:

$$[E] = \frac{1}{n}\sum_{i=1}^{n} x_i = m_X{}^{(1)} \tag{5.6}$$

The standard deviation can be calculated by:

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - m_X)^2} \tag{5.7}$$

And the moments can be obtained by:

$$m_X^{(n)} = \frac{1}{n}\sum_{i=1}^{n} x_i{}^n = \int_0^\infty x^n f_x(x)dx \tag{5.8}$$

Where:

$f_x(x)$: The probability density function

Finally, by using the moment principle, the Gumbel parameters are estimated by:

$$\hat{\beta} = 0.779\sigma \tag{5.9}$$

$$\hat{\alpha} = [E] - 0.57722\hat{\beta} \tag{5.10}$$

5.8.3 Testing the Gumbel distribution

In order to test whether the proposed model is acceptable or not, several techniques are available. Some of these commonly used techniques are:

1. Plotting in probability paper
2. Chi-square test
3. The Kolmogorov test

In principle, there is not any method that can determine whether a selected model is completely right or wrong. The available methods can only determine whether the proposed model is reasonable or not. A comprehensive explanation of all methods can be found in (J. Leira, 2010). Since the probability paper technique is utilized in this project, it is explained in the following.

5.8.3.1 Probability paper

This method is a good way to get an early indication of whether the Gumbel distribution is a good model for the data or not. The first step is to order the observations in the increasing order with respect to their values; $\{x_1, x_2, \dots, x_k, \dots, x_n\}$. Based on these observations, an empirical distribution function for x is:

$$\hat{F}_X(x_k) = \frac{k}{n+1} \tag{5.11}$$

Thereafter, the calculated empirical distribution function of x is inserted in the below formula that is the reorganized form of the Gumbel function:

$$y = -ln\left\{-ln\{\hat{F}_X(x_k)\}\right\} = \frac{(x-\alpha)}{\beta} \tag{5.12}$$

If in a coordinate system with x as the horizontal axis and y as the vertical axis, the resulting curve is more or less a straight line, the Gumbel model is an adequate model for the data.

5.9 Verifying the adequacy of the Gumbel parameters by Monte Carlo simulation

In order to test whether the Gumbel parameters are biased or not, Monte Carlo simulation is used. For this purpose, it is assumed that the obtained Gumbel model from M time domain simulations is the true model. From this Gumbel model, 25 samples of size M are generated by the Monte Carlo Simulation. Subsequently, the 25 Gumbel models are fitted to the 25 generated samples. As a result, 25 different estimates for the Gumbel parameters are available. Thereafter, the average of the Gumbel parameters is calculated and it is compared to the parameters of the Gumbel distribution used for the Monte Carlo simulations. If the average value equals more or less the background values, the estimated parameters are unbiased.

5.10 Estimating the 0.63-probability response

In principle, the q-probability response can be estimated by the α-percentile of all 26 obtained Gumbel distribution functions. Since the contour line method is an approximate method, some uncertainties are associated with the estimated q-probability response that one of them is the selected percentile level, α.

In principle, the percentile level, α, varies for the response quantity under consideration. The percentile also depend on whether maxima or minima are considered (Baarholm, Haver, & Økland, 2010). It also depends on the nature of the response problem; the degree of non-linearity and the number of important slowly varying parameters (S. K. Haver, 2011). The uncertainty to the percentile level can be reduced by increasing the number of time domain simulations and/or model tests. The only way to verify the selected percentile level is performing a full long-term analysis. However, some guidance regarding the choice of α can be found in NORSOK-N-003 (2007).

As mentioned in section 5.1, regarding the environmental condition, the upper drilling operation limit is assumed to be the sea state with the highest significant wave height and the corresponding spectral peak period along the 0.63-probability contour line. Since, no information regarding q=0.63 is given in rules and standards, the same percentile level recommended by NORSOK-N-003 (2007) for $q=10^{-2}$ is applied for estimating the 0.63-probability response.

Accordingly, the estimated response is overestimated by few percent and gives the design loads on the upper side. However, it is assumed that the difference between the true and the estimated response is not very large and the overestimated response can increase the safety level of the drilling operation. NORSOK-N-003 (2007) recommends to select a percentile level between (0.85-0.9) For $q=10^{-2}$. A sensitivity study with respect to the different percentile levels is performed in the section 8.6.

CHAPTER 6 Design Bases and Model Description

6.1 Introduction

The numerical riser models are typically reused from a previous global response analysis. One of the available top tensioned riser samples[1] in the software tools of the SINTEF website is utilized as the preliminary drilling riser model for this project.

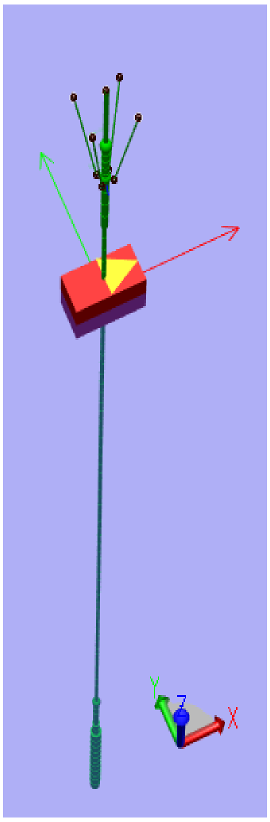

Figure 6.1 - Screen shot from SIMA

[1] The RIFLEX samples can be reached at : https://project.sintef.no/eRoom/Marintek3/MTAvd70-SoftwareTools-NTNU

The modifications applied to the preliminary riser model are presented in this chapter. The Riflex files including the inpmod, stamod and dynmod for the modified riser model are given in Appendix C. The drilling riser model located in 133 meters water depth is shown in Figure 6.1. It must be noted that the red box is used as a symbol for presence of the drilling vessel in SIMA and the drilling semi-submersible is not located in this location in reality; see Figure 6.2 for better illustration of the semi-submersible location.

6.2 Blow Out Preventer [BOP]

The Blow Out Preventer, BOP, is modelled by one line which has the length of 19.35 meters. The lower node which is located 1 meter above the seabed is the connection point between the BOP and the wellhead and it is fixed in all degrees of freedom. The upper end of the BOP line is connected to the Lower Marine Riser Package, LMRP. The BOP has the total weight of 200,000 Kg and it`s axial, bending and torsion stiffness are equal to 1×10^{11} $N.m^2$.

6.3 Lower Marine Riser Package [LMRP]

LMRP, which is located between the BOP and the drilling riser, is modelled by on line with 10.1 meters length. The stiffest lines in the model, BOP and LMRP have the same axial, bending and torsion stiffness properties (equal to 1×10^{11} $N.m^2$). The total weight of LMRP is 101,200 Kg.

6.4 Drilling riser

The riser line is modelled by 58 beam elements giving a total riser length of 114.3 meters. A single cross section is utilized for the whole riser line. The main characteristics of the drilling riser are listed in Table 6.1.

Table 6.1 - The main drilling riser characteristics

Mass coefficient (Kg/m)	1.448×10^3
Internal diameter (m)	0.495
External diameter (Hydrodynamic diameter) (m)	0.569
Riser thickness (m)	0.037
Axial stiffness ($N.m^2$)	8.128×10^{10}
Bending stiffness ($N.m^2$)	3.212×10^9
Torsion stiffness ($N.m^2$)	2.484×10^9

The riser wall thickness is calculated according to DNV-OS-F201 (2010); see section 5.3 for method applied in the riser wall thickness calculation.

Table 6.2 presents the input parameters for calculation of the riser wall thickness. Functional loads are estimated by performing the time domain analysis on the drilling riser when no environmental loads are applied. The environmental loads are estimated by performing the time domain analysis of the riser when it is exposed to both current and wave loads.

Table 6.2 - The input parameters for calculation of the riser wall thickness

Parameters	Sea state		Functional loads		Environmental loads		Water depth	Static tension	Combined loading criteria
	H_S	T_P	M_F	T_F	M_E	T_E	H	T_{App}	
Unit	(m)	(s)	(KN.m)	(KN)	(KN.m)	(KN)	(m)	(KN)	
Value	11.8	16.1	0	2439	3225	2512	98.43	992.87	0.945

6.4.1 Drilling riser material

Since the drilling riser is exposed to the combined loads from waves, current, applied tension, drilling rig`s motions and drilling fluid weight, high yield steels are commonly used for its construction. According to API-RP-16Q (2001), the common steel grades utilized for drilling risers are X52, X65 and X80. In this project, steel X80 is selected as the riser material. The mechanical properties of X80 are presented in Table 6.3.

Table 6.3 - Mechanical properties of X80

Steel grade	Yield strength (MPa)	Tensile strength (MPa)
X80	555-750	621-827

6.5 Flex joint

Allowing a limited angular misalignment between the drilling riser and the LMRP as well as reducing the bending moment on the drilling riser are the tasks of the lower flex joint which is located on top of the LMRP. In addition, another flex joint is used at top of the drilling riser to allow for the motions of the rig.

In principle, SIMA provides four alternatives for modelling flex joints, i.e. the flex joints can be modelled by fixed, free, linear and nonlinear stiffness properties. Both upper and lower flex joints are modelled by linear stiffness rotations around local axes. The stiffness properties of the flex joints are given in Table 6.4.

Table 6.4 - The stiffness properties of the upper and the lower flex joints

Flex joint	Stiffness rotation along local X-axis (Nm/degree)	Stiffness rotation along local Y-axis (Nm/degree)	Stiffness rotation along local Z-axis (Nm/degree)
Lower Flex joint	1×10^6	1×10^3	1×10^3
Upper flex joint	1×10^5	1.5×10^4	1.5×10^4

The maximum upper and lower flex joint angles for the designed drilling riser with 0.037 riser wall thickness is presented in Table 6.5. See section 5.4 for the flex joint angles limitation and calculation procedure.

Table 6.5 - Upper and lower flex joint angles

Flex joint	Mean (degree)	Max (degree)
Upper flex joint	0.51	2.90
Lower flex joint	0.71	3.36

6.6 Telescopic joint (Slip Joint)

Telescopic joint which compensates for the relative translational movements between the drilling vessel and the drilling riser consists of outer barrel, inner barrel and tensioner ring. The telescopic joint is modelled by one line with two different cross sections. One of the cross sections has larger external area to represent the outer barrel and it is connected to the drilling riser while the inner barrel has smaller external area and it is connected to the drilling vessel. The tensioner ring which transmits tension loads from the tensioner system to the outer barrel of the riser is modelled by a nodal body with a high weight equal to 3.676×10^4 Kg.

6.7 Tensioner system

In principle, two different tensioner systems are utilized in drilling risers:

1. Conventional riser tensioner cylinder
2. Direct acting tensioner cylinder

The latter tensioner system is used to apply the required top tension. Four tensioner lines attached to the tensioner ring are modelled by bar elements. These tensioner lines are pre-stressed by being stretched from a stress free length to a non-stress free length. The top tension is then applied using the axial force-strain curve.

By using this method for modelling the tensioner lines, a nearly constant axial tension to the riser is provided while the floating drilling vessel moves vertically and laterally in response to the environmental loads.

Regarding the tensioner lines boundary condition, the lower end of all tensioner lines are slaved to the upper end of the telescopic joint outer barrel while the upper end of all tensioner lines are fixed to the drilling vessel in 4 degrees of freedom; all three transitions degrees of freedom and one rotational degree of freedom about global Z-axis. However they are free to rotate in global X and Y axes.

6.7.1 Applied top tension

The required top tension depends largely on the riser effective weight and it is calculated according to the procedure explained in the section 5.2. The calculated effective weight as well as the top tension that each tensioner cylinder should provide are presented in Table 6.6.

Table 6.6 - The required top tension for each tensioner line

The effective weight of the riser system, W_E (KN)	1985.74
The required top tension force = W_E + 50% W_E (KN)	2978.61
The required tension for each tensioner line (KN)	992.87
Number of tensioner cylinders	4
Number of tensioner cylinders that can be failed	1

Finally, with reference to the Figure 6.2, tension force provided by each tensioner cylinder is transmitted through the tensioner ring to the pipe wall of the telescopic joint outer barrel and subsequently through the couplings and pipe walls of the riser joints to provide the required tension force along the drilling riser.

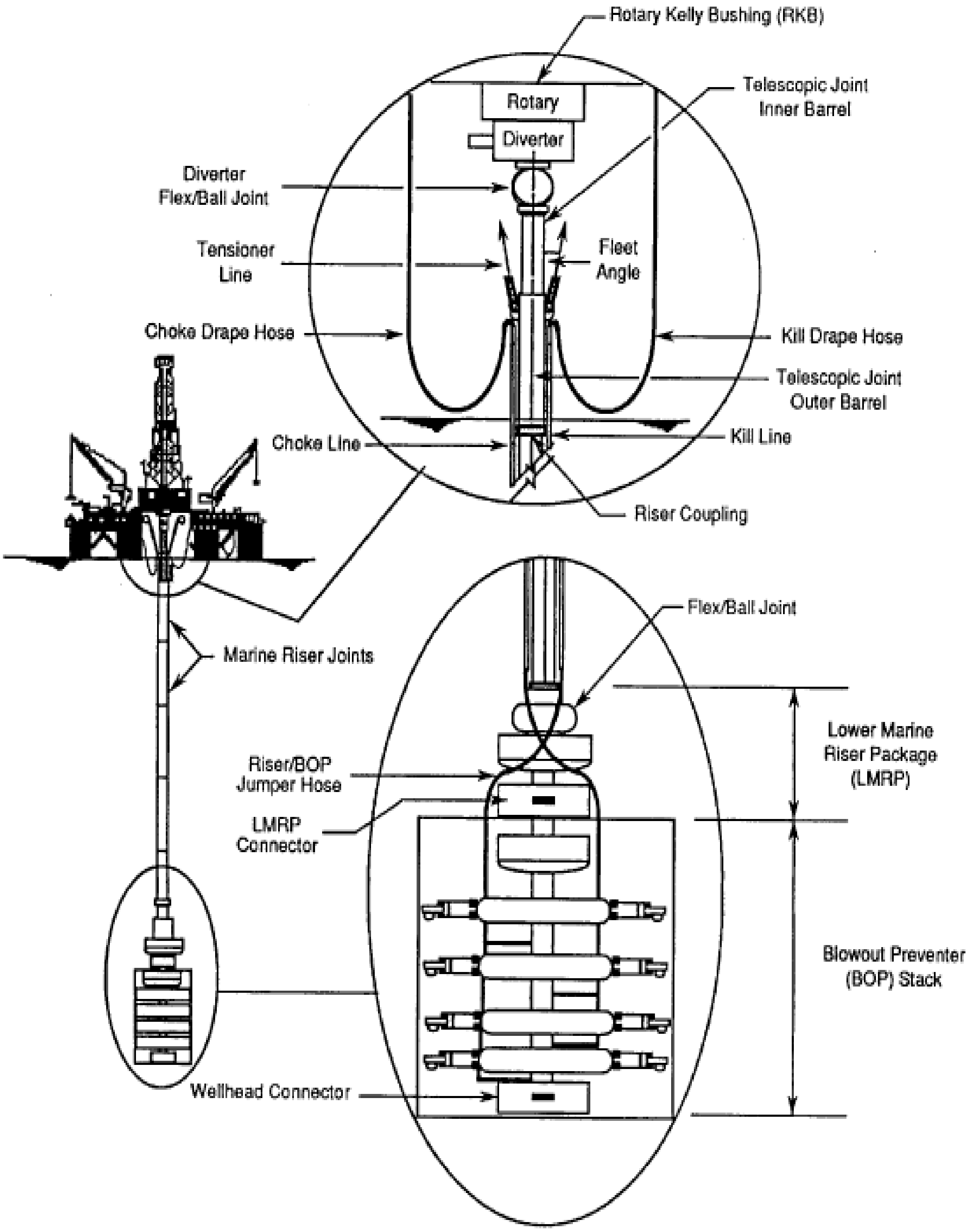

Figure 6.2 - Marine riser system and associated equipment (API-RP-16Q, 2001)

6.8 Drilling vessel

Since no information regarding the vessel type was provided in the preliminary model, literature studies is conducted to compare different type of drilling vessels with respects to their transfer functions and their natural periods. Finally, it was assumed that the drilling vessel is a semi-submersible. In order to support this assumption, some reasons are mentioned in the following.

According to DNV-RP-F205 (2010), the natural period of a semi-submersible in the heave mode varies from 20 to 50 seconds. The selected vessel has a natural period of 24 seconds in heave, and it is well located in the heave natural periods range of semi-submersibles.

Moreover, by comparing Figure 6.3 and Figure 6.4, it is seen that the heave transfer function of the drilling vessel in the SIMA is very similar to the heave transfer function for a typical semi-submersible.

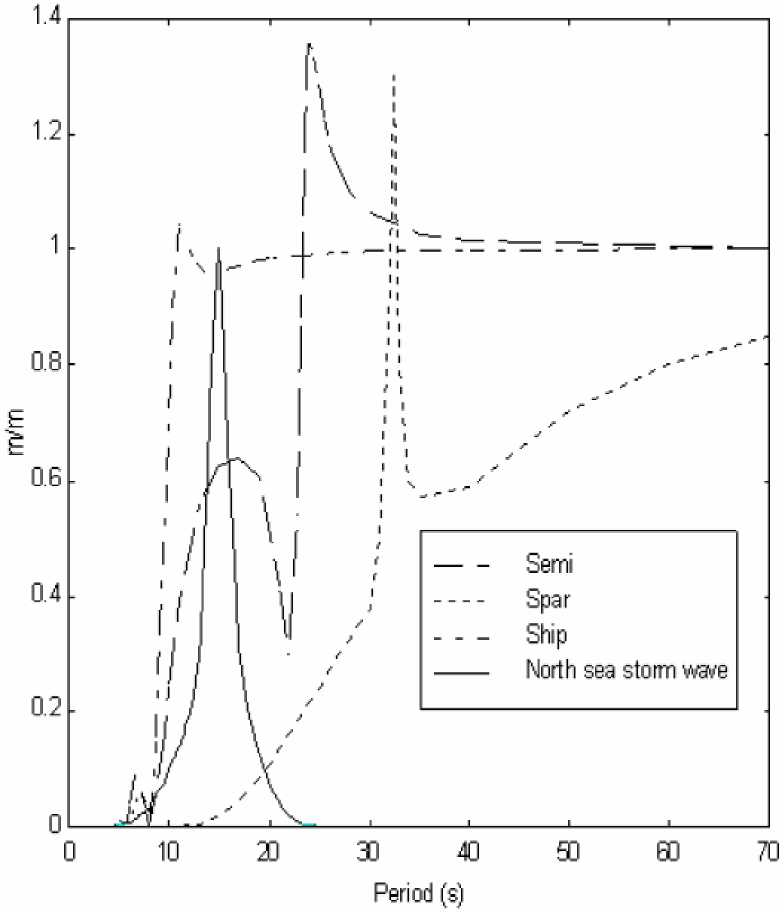

Figure 6.3 - Heave transfer functions for different floaters and storm wave spectrum (DNV-RP-F205, 2010)

A characteristic of semi-submersibles is that their natural periods in the surge, sway and yaw modes are generally larger than 100 seconds. Considering the fact that the ocean waves contain first harmonic wave energy in the period range of 5-25 seconds, it can be concluded that the semi-submersibles are very soft in the horizontal plane.

The other advantage of using a semi-submersible is it`s high natural periods in the vertical plane; heave, roll and pitch. With reference to Table 6.7, it is seen that all the natural periods of semi-submersible in the vertical plane are above the 20 seconds. This range is usually outside the range of wave periods except for some extreme sea states.

Table 6.7 - Typical natural periods of semi-submersible, taken from DNV-RP-F205 (2010)

Mode	Typical Natural period for semi-submersible
Surge	>100
Sway	>100
Heave	20-50
Roll	30-60
Pitch	30-60
Yaw	>100

The semi-submersible motions are spilt into wave frequency (WF) and low frequency (LF) motion components. In addition, wave in deck loads and slamming loads are important hydrodynamic effects for semi-submersibles and are taken into account by performing the time domain analysis. Compared to the frequency domain analysis, time domain analysis can capture higher order load effects and can predict the maximum response without making assumptions regarding the response distribution (DNV-RP-F205, 2010).

6.9 Vessel motion

The vessel motions are described by using response amplitude operator (RAO). The RAOs can be established either by a separate analysis of the drilling vessel response in waves or by performing model tests. The same transfer functions for the preliminary model are utilized. These are given as a set of tables and they provide information regarding the amplitude of the vessel response relative to the wave amplitude as a function of wave periods. Moreover, the phase angle of the response relative to the wave crest are described as a function of wave period. The transfer functions are provided in 9 different directions. For more illustration, the transfer function for the heave in 0 degree direction is presented in Figure 6.4.

With reference to Figure 6.4, it is seen that the maximum heave response amplitude at wave periods below the resonance period is about 0.6 times the wave amplitude. The full information regarding the transfer functions for the other degrees of freedom and wave propagation directions are presented in Appendix C.1.

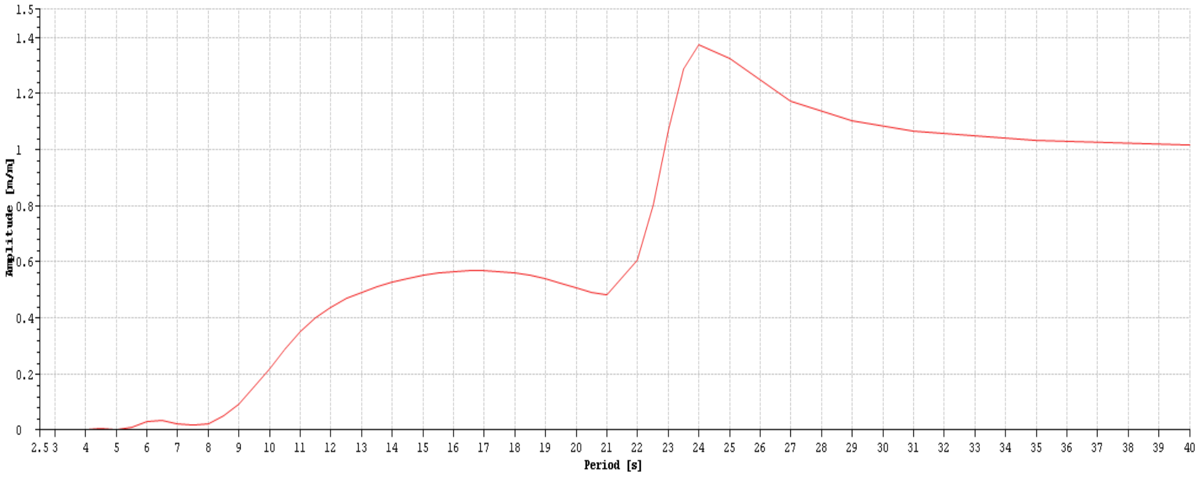

Figure 6.4 - Transfer function for heave in head sea (screen shot from SIMA)

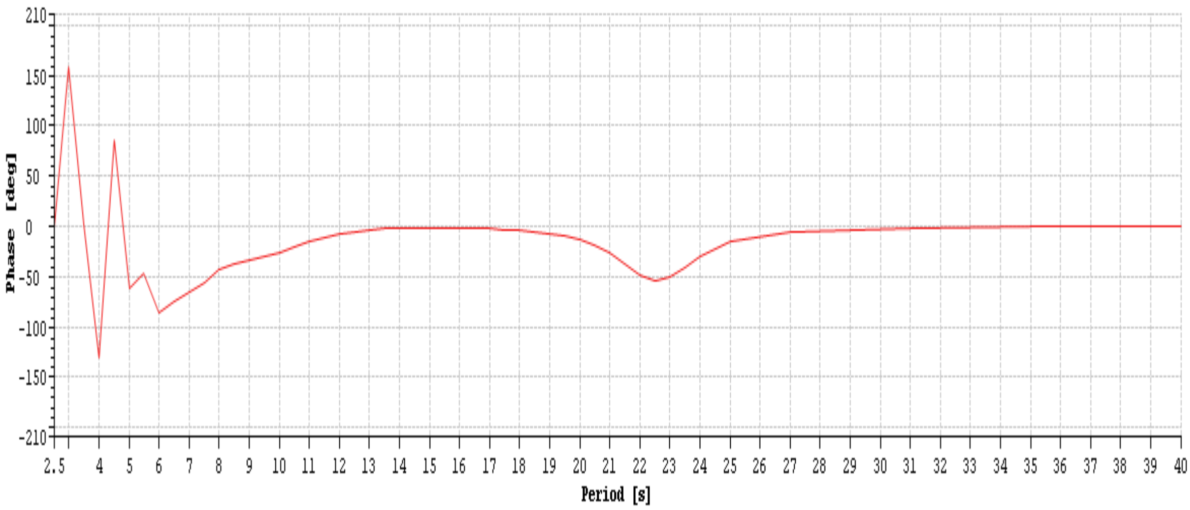

Figure 6.5 - Phase angle for heave in head sea (screen shot from SIMA)

CHAPTER 7 Static and Dynamic Analyses Result

The static and dynamic response of the drilling riser exposed to the 0.63-probability sea state with 11.8 meters significant wave height and 16.1 seconds spectral peak period and linear current profile (see Table 5.2) are presented in the following sub sections.

7.1 Effective tension curve along the riser

With reference to Figure 7.1 and Table 7.1, it is seen that the dynamic effective tension curve consist of the applied static tension by the tensioner lines, the tension force by current loads, and the dynamic tension form the wave loads. However, a large part of it is originated from the static effective tension. Hence, it can be concluded that the dynamic loads has small influence on varying the effective tension along the riser line.

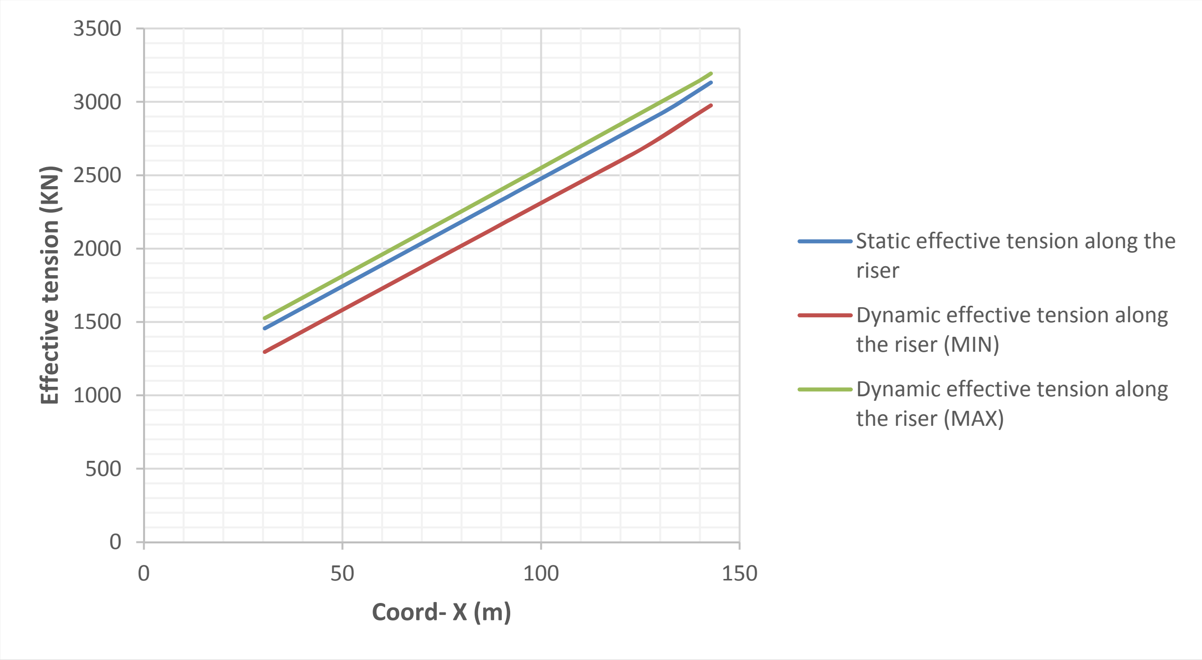

Figure 7.1 - Static and Dynamic effective tension curve along the riser

Table 7.1 - Maximum and minimum static and dynamic effective tension along the riser

Static effective tension (KN)		Dynamic effective tension (KN)	
Min	Max	Min	Max
1456.18	3131.44	1296	3193

7.2 Dynamic bending moment curve along the riser

Dynamic bending moment along the riser line has it`s maximum value close to the wave zone at the water depth equal to 98.43 meters, i.e. 34.57 meters distance from the see surface. This shows the high influence of the wave force on the dynamic bending moment. The reason that the maximum bending moment does not occur closer to the sea surface is because the region close to the sea surface is located near to the tensioner system. Correspondingly, the tension force is very high and makes the riser very stiff to bend.

With reference to Figure 7.2, it is observed that the dynamic bending moment increases from the lower part of the drilling riser to the point located 34.57 meters below the see surface, and then decreases significantly at upper part of the drilling riser. Maximum dynamic bending moment on the drilling riser is 3225 KN.m, and the dynamic bending moment on the upper end of the riser is 1176 KN.m.

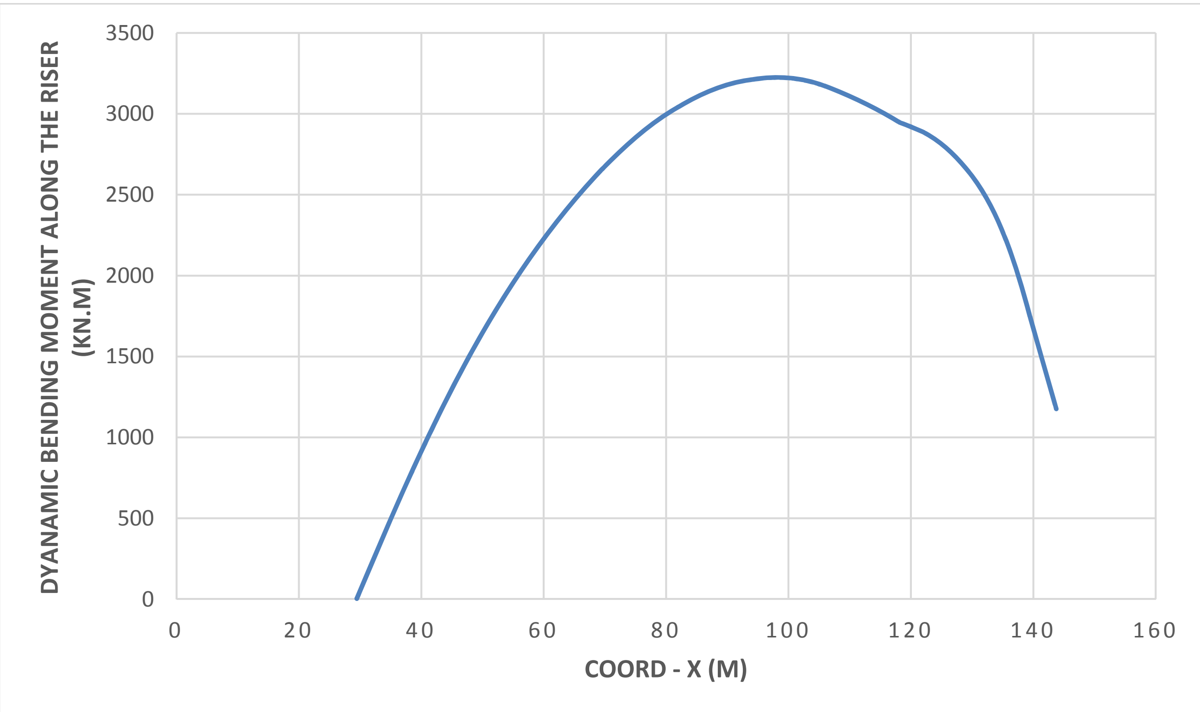

Figure 7.2 - Dynamic bending moment curve along the riser

The reduction of the dynamic bending moment on the upper region of the riser is again due to the high applied tension force by the tensioner lines. In addition, the upper point on the drilling riser is located 11.7 meters above the see surface, and the effect of dynamic loads from the wave is very low in this point. Moreover, the effect of the wind load on the system is neglected in this project, and this assumption causes underestimation in the dynamic bending moment at 11.7 meters above the sea surface.

7.3 Dynamic bending moment along BOP and LMRP

Dynamic bending moment along the BOP and LMRP are negative; see Figure 7.3. It becomes zero at the upper end of LMRP and increases from zero to 3225 KN.m along the riser.

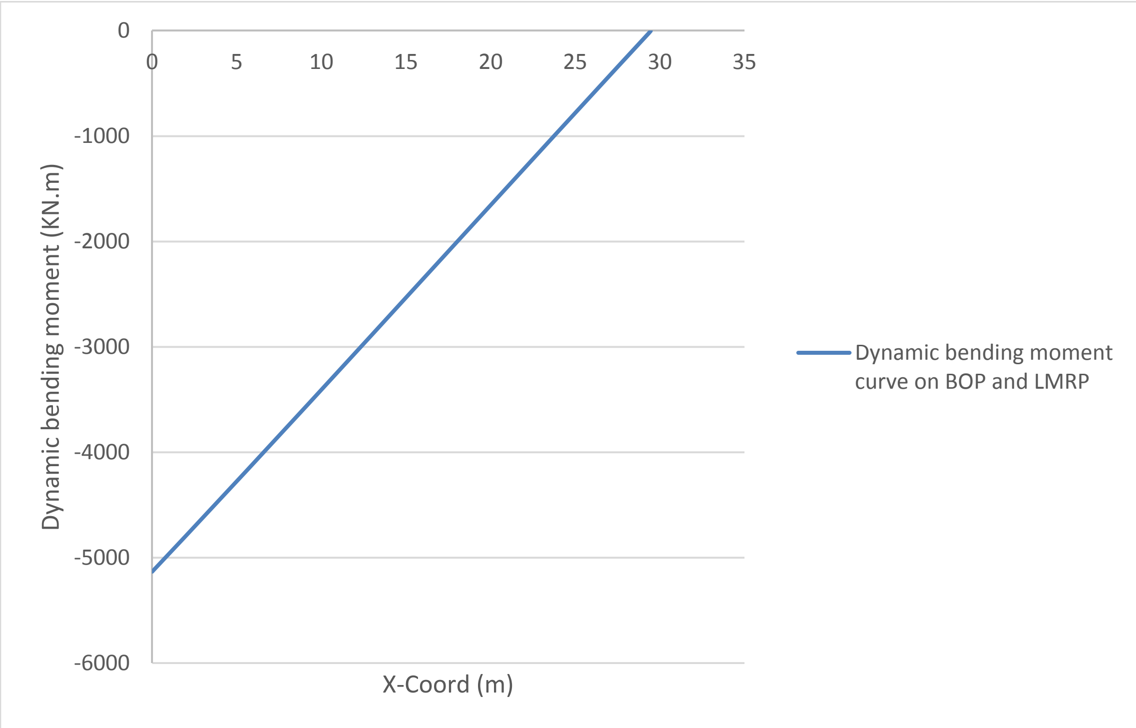

Figure 7.3 - Dynamic bending moment curve along BOP and LMRP

7.4 Axial force curve along BOP and LMRP

Figure 7.4 shows the minimum and maximum dynamic axial forces along the BOP and LMRP. It is seen that there is high compression force on the lower part of the BOP; from lower end of the BOP to approximately 15 meters above that. The axial force increases from the lower end of the BOP to the upper end of the LMRP and it continues the same trend along the riser line.

In principle, an extremely large tension force is required to avoid compression force on the BOP. This is due to the high dry weight of the BOP and LMRP. As a result, this high compression force is acceptable if the combined loading criteria is fulfilled.

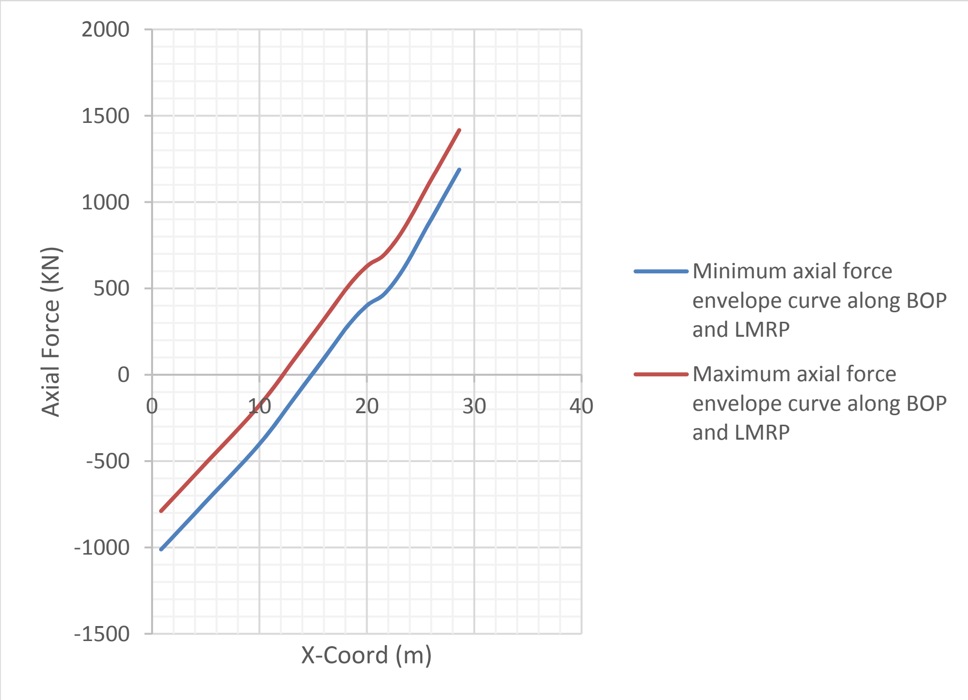

Figure 7.4 - Dynamic axial force envelope curve along BOP and LMRP

7.5 Combined loading criteria for BOP

Table 7.2 shows the functional, static and dynamic loads on the lower end of the BOP line. By inserting the functional and dynamic loads in the combined loading criteria, 0.0177 is given as the result which is below 1. Therefore, it is concluded that the compression force on the BOP does not cause Buckling and the system is stable under this compression force.

Table 7.2 - Combined loading criteria for BOP

Functional loads		Static		Dynamic		Combined loading critera
T_{eff} (KN)	M_b (KN.m)	T_{eff} (KN)	M_b (KN.m)	T_{eff} (KN)	M_b (KN.m)	
-854.81	0	-854.85	-521.30	-1011	-5132	0.0177

CHAPTER 8 Estimating the 0.63-probability Extreme Response by Contour Line Method

8.1 Selecting the worst sea state

A narrow part of the contour line with high values of Hs is selected. It is assumed that the worst sea state is located in this narrow area along the contour. The region is highlighted with red colour in Figure 8.1.

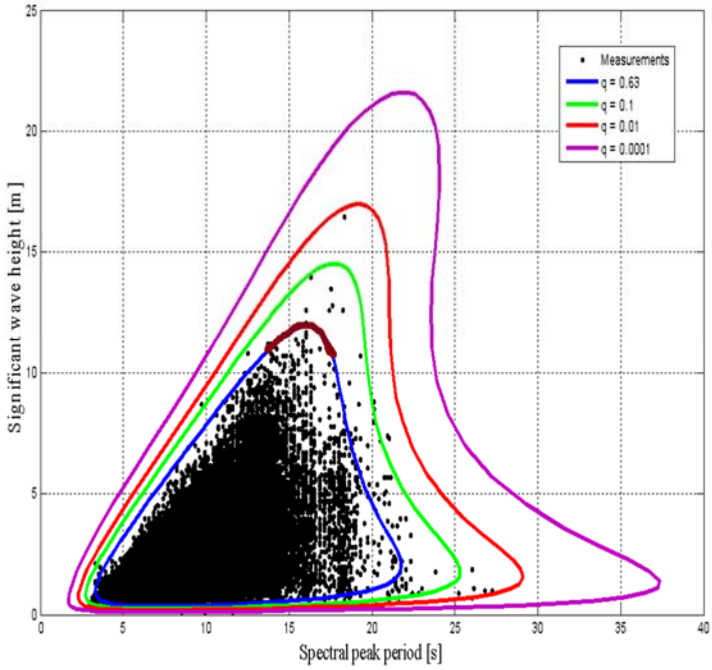

Figure 8.1 - The selected region in which the worst sea state is located

Five different sea states in the selected narrow region are chosen. The non-linear time domain analysis is performed for all five different sea states with six different random seeds. The selected sea states and random seeds are given in Table 8.1.

Table 8.1 - The maximum bending moment on the drilling riser for 5 different sea states with 6 different random seeds

Sea states	H_S	T_P	H_S	T_P	H_S	T_P	H_S	T_P	H_S	T_P
Units	(m)	(s)	(m)	(s)	(m)	(s)	(m)	(s)	(m)	(s)
Value	11.8	16.1	11.3	14.4	11.3	17.3	10.6	13.1	10.6	17.7
Seed	$M_{b(max)}$ on the riser (KN.m)		$M_{b(max)}$ on the riser (KN.m)		$M_{b(max)}$ on the riser (KN.m)		$M_{b(max)}$ on the riser (KN.m)		$M_{b(max)}$ on the riser (KN.m)	
1	3249		3234		3084		3195		3080	
30	3629		3513		3432		4109		3353	
50	3557		3749		3430		3657		3328	
100	3583		3564		3525		3831		3590	
120	4039		3916		3054		3839		3049	
800	3416		3076		3128		3158		3069	
Average value	3579		3509		3276		3632		3245	
STD[1]	264.60		312.85		208.85		381.11		216.42	

In order to perform the screening analysis and finding the worst sea state, the average value of the 6 different estimation of the maximum bending moment on the drilling riser is calculated. The average value of the maximum bending moment on the riser and the standard deviation of the response for each sea state are shown in Table 8.1.

Finally, the worst sea state along the contour line is assumed to be the sea state no.4 with 10.6 meters significant wave height and 13.1 second spectral peak period.

Assuming the proper effective fetch, f_e, equal to 370 km, Equation (2.2) gives $T_{p_0} = 6.6H_S^{\frac{1}{3}}$. Inserting H_S = 10.6 meters, it is observed that the sea state is governed by the wind sea.

[1] Standard deviation

8.2 Establishing the 3-hour extreme value distribution

In order to establish the short-term distribution of the extreme bending moment on the drilling riser more sample data are required. Therefore, the time domain analysis with more random seeds are executed for the worst sea state. The results are shown in Table 8.2.

Table 8.2 - Maximum bending moment on the riser for the worst sea state with 26 different random seeds

Seed no.	Seed	$M_{b(max)}$ (KN.m)
1	1	3195
2	30	4109
3	50	3657
4	100	3831
5	120	3839
6	800	3158
7	890	3982
8	899	3419
9	926	3137
10	1000	3466
11	1258	3606
12	1333	3944
13	1350	3905
14	1360	3621
15	1450	3816
16	1500	3214
17	1800	3548
18	1809	3420
19	1860	3430

20	1900	3306
21	2500	3833
22	2673	3098
23	2674	4162
24	2675	3437
25	2680	3575
26	5000	3190

Next steps are to order the available sample of size 26 in increasing order and plot the empirical distribution function of the estimated maximum bending moment on the drilling riser.

The most commonly used empirical distribution function is:

$$\hat{F}_X(x_k) = \frac{k}{N+1} \tag{8.1}$$

Where:

N: total number of the data which is equal to 26 in this case

Inserting the data (the estimated maximum bending moments on the drilling riser) into the Equation (8.1), the empirical distribution function is obtained. See Figure 8.2 and Table 8.3.

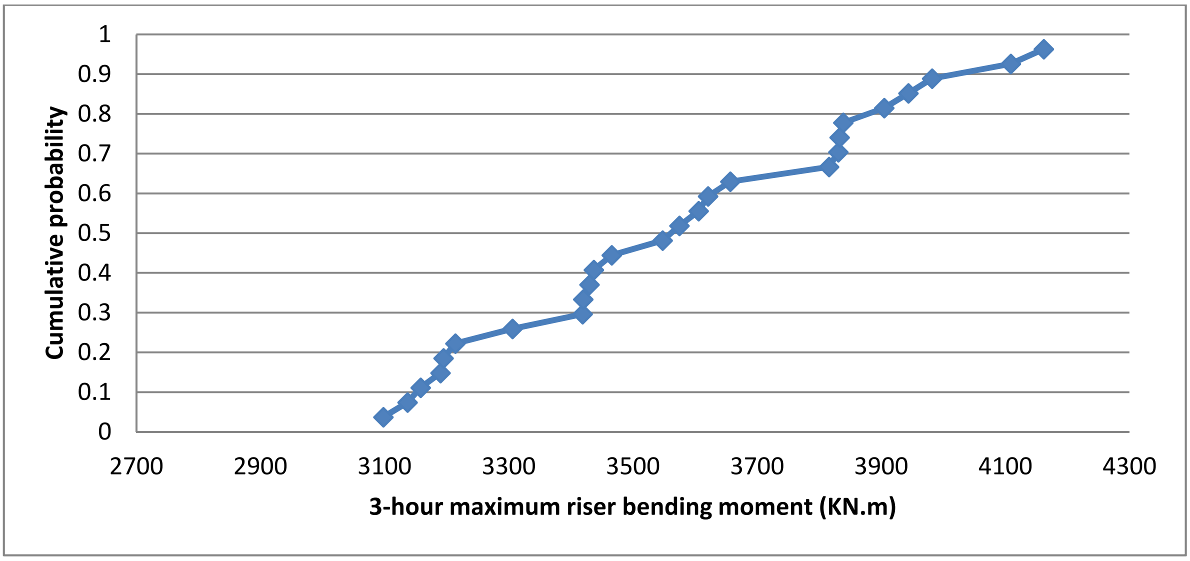

Figure 8.2 - The linear plot empirical distribution function for 3-hours maximum riser bending moments

It is assumed that the 3-hour maximum bending moment on the drilling riser is Gumbel distributed and the short-term extreme value distribution function of the response can be found by fitting the sample data to the Gumbel model. In order to make sure whether the proposed model seems reasonable or not, the observations are plotted in a constructed Gumbel probability paper.

Table 8.3 - The empirical distribution function of the maximum bending moment

No.	Data	Empirical distribution function
1	3098	0.037
2	3137	0.074
3	3158	0.111
4	3190	0.148
5	3195	0.185
6	3214	0.222
7	3306	0.259
8	3419	0.296
9	3420	0.333
10	3430	0.370
11	3437	0.407
12	3466	0.444
13	3548	0.481
14	3575	0.518
15	3606	0.555
16	3621	0.592
17	3657	0.629
18	3816	0.666
19	3831	0.704

20	3833	0.741
21	3839	0.777
22	3905	0.815
23	3944	0.852
24	3982	0.888
25	4109	0.926
26	4162	0.963

8.3 Plotting the Gumbel probability paper

The Gumbel probability paper is constructed based on the method explained in section 5.8.3.

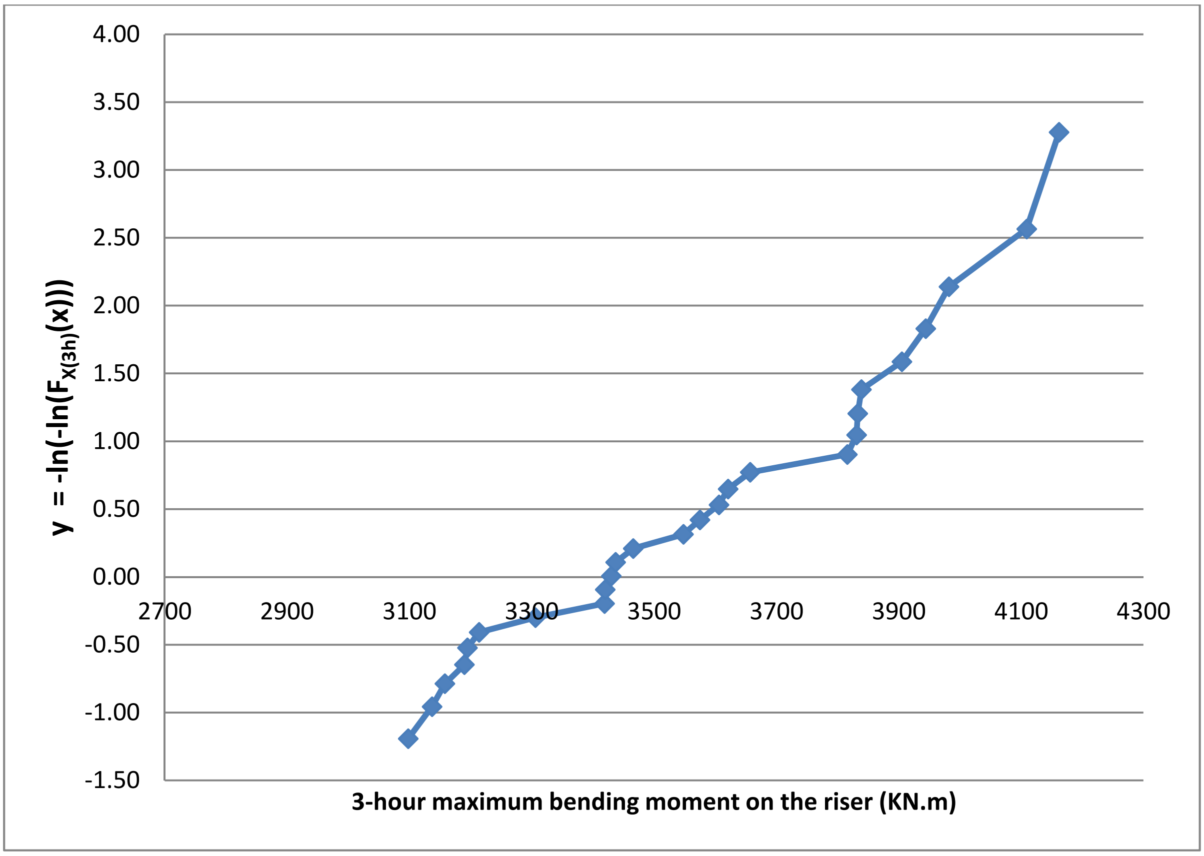

Figure 8.3 - Gumbel probability paper plot of 3-hour maximum bending moment on the riser

The results are shown in Figure 8.3 and Table 8.4.

Here Y is:

$$y = -ln\left\{-ln\{\hat{F}_X(x_k)\}\right\} \quad (8.2)$$

And $\widehat{F}_X(x_k)$ is calculated from Equation (8.1).

With reference to Figure 8.3, it is observed that the curve is more or less a straight line, therefore, it can be concluded that the Gumbel model is an adequate model for the data.

Table 8.4 - Data needed to plot the Gumbel propability paper

Data No.	data, x (KN.m)	$\hat{F}_X(x_k)$	y
1	3098	0.04	-1.19
2	3137	0.07	-0.96
3	3158	0.11	-0.79
4	3190	0.15	-0.65
5	3195	0.19	-0.52
6	3214	0.22	-0.41
7	3306	0.26	-0.30
8	3419	0.30	-0.20
9	3420	0.33	-0.09
10	3430	0.37	0.01
11	3437	0.41	0.11
12	3466	0.44	0.21
13	3548	0.48	0.31
14	3575	0.52	0.42
15	3606	0.56	0.53
16	3621	0.59	0.65
17	3657	0.63	0.77
18	3816	0.67	0.90

19	3831	0.70	1.05
20	3833	0.74	1.20
21	3839	0.78	1.38
22	3905	0.81	1.59
23	3944	0.85	1.83
24	3982	0.89	2.14
25	4109	0.93	2.56
26	4162	0.96	3.28

8.4 Method of moments

Applying the method of moments, the Gumbel parameters; $\hat{\alpha}$ and $\hat{\beta}$, are estimated and the results are shown in Table 8.5.

Table 8.5 - The estimated Gumbel parameters and the sample mean and standard deviation

σ	$[E]$	$\hat{\alpha}$	$\hat{\beta}$
316.20	3573	3430.82	246.32

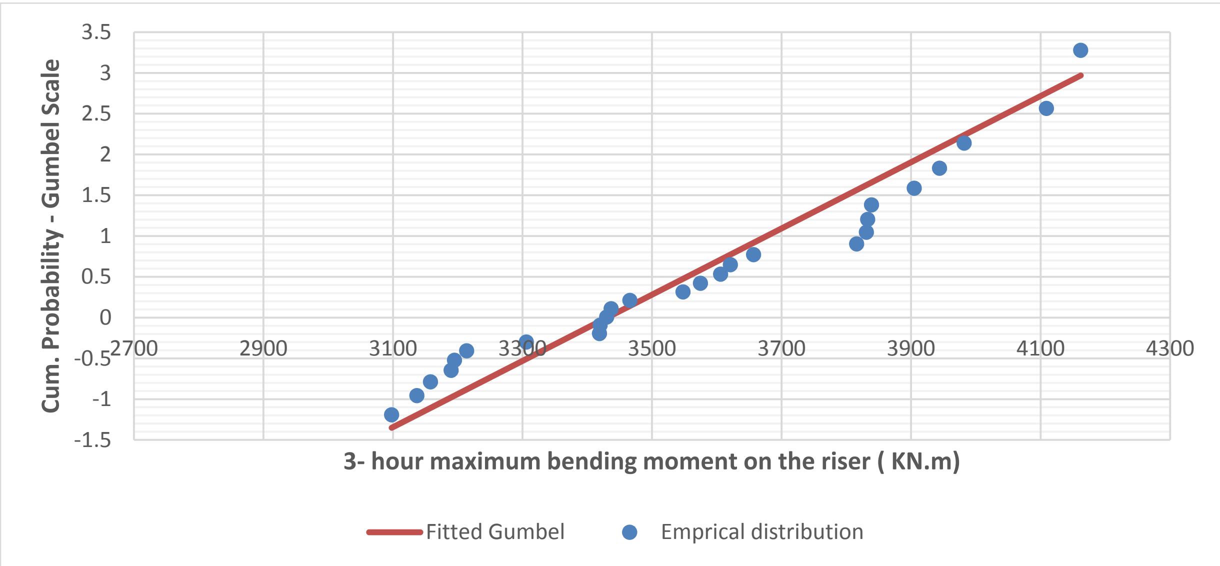

Figure 8.4 - The fitted Gumbel model and the empirical distribution function

Moreover, the fitted Gumbel model is plotted in the same figure with the empirical distribution function. See Figure 8.4. It is seen that two observations are located above the required percentile, i.e. α = 90 which corresponds to the Y=2.5, as a result, the number of observation are adequate to estimate the 0.63-probability response.

Finally, the Gumbel distribution function of the 3-hour extreme bending moment on the riser for the assumed worst sea state along the 0.63-probability contour line can be established as:

$$F(x) = exp\left\{-exp\left(-\frac{x-3430.82}{246.32}\right)\right\} \tag{8.3}$$

An estimation of the 0.63-probability extreme bending moment on the drilling riser can be found by α-percentile of the Gumbel distribution function of the 3-hour extreme bending moment for the worst sea state. Moreover, the percentile level must be higher than the median in order to take in to account the short-term variability.

With reference to NORSOK-N-003 (2007), α is varied in the range of (0.85-0.90), to study the high influence of this percentile in the estimated response. The results are presented in Table 8.6.

Table 8.6 - The 0.63-probability extreme bending moment on the riser

α	The estimated 0.63-probability extreme bending moment (KN.m) from the fitted Gumbel
0.85	3878.38
0.87	3916.42
0.90	3985.13

It is seen that by increasing α from 0.85 to 0.90 the estimated response increases by 2.75%. As a result, it is observed that the selected percentile affects the estimated response considerably.

8.5 Monte Carlo simulation

In principle, Monte Carlo is a method for assessment of uncertainties. In this project, Monte Carlo is utilized as a tool for assessment of the uncertainty in the estimated Gumbel parameters from the limited amount of observations, i.e. one sample of size 26. It is obvious that uncertainty in the estimated Gumbel parameters causes uncertainty in the estimated 0.63-probability extreme bending moment.

Firstly, it is assumed that the Gumbel distribution for the 3-hour extreme response in Equation (8.3) is the true Gumbel distribution function. Moreover, it is assumed that the 3-hour extremes for different simulations are statistically independent; this is almost an accurate assumption. As a result, adopting Equation (8.3) as the true model, 25 samples of size 26 are generated by Monte Carlo simulation. The corresponding empirical distribution functions for all generated samples are shown in Figure 8.5.

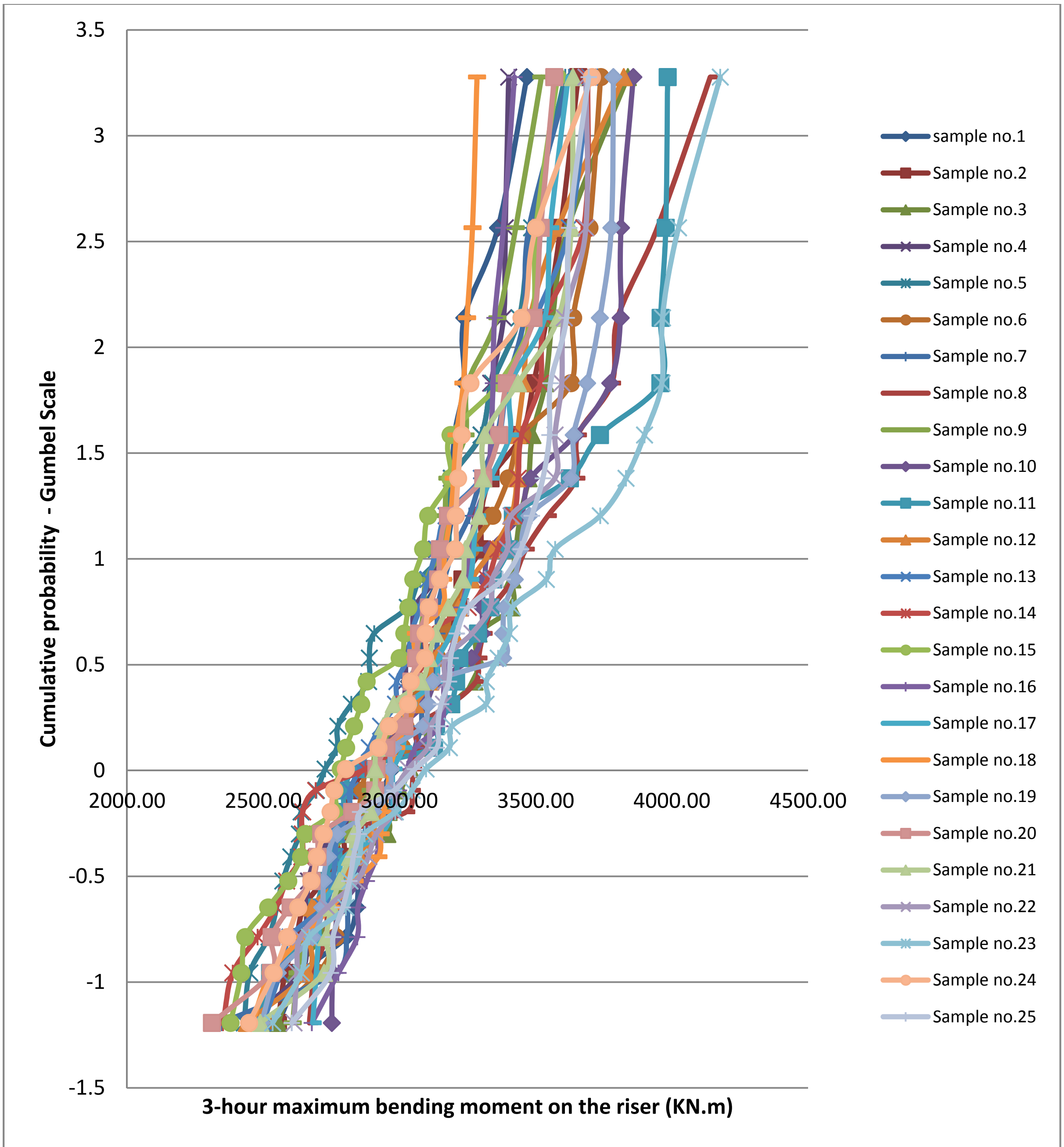

Figure 8.5 - Empirical distribution functions for 25 different generated samples of size 26 from the assumed true Gumbel model

The Gumbel parameters, $\hat{\alpha}$ and $\hat{\beta}$, for all generated samples are estimated and the results are shown in Table 8.7.

Table 8.7 - The estimated Gumbel parameters for all generated samples by Monte Carlo

Sample No.	$\hat{\alpha}$	$\hat{\beta}$
1	2935.11	162.72
2	2913.34	258.08
3	3027.16	265.01
4	2869.62	206.03
5	2757.73	265.91
6	2961.43	261.00
7	2964.98	212.12
8	3049.10	328.52
9	2893.71	193.48
10	3025.21	285.72
11	2980.16	366.66
12	2952.24	259.70
13	2872.65	247.81
14	2843.45	322.94
15	2768.72	262.67
16	3020.50	162.63
17	2975.80	218.59
18	2910.30	172.60
19	2991.32	318.46
20	2856.22	256.95
21	2935.35	235.32
22	3019.13	262.18
23	3101.96	371.50

24	2848.93	247.65
25	3024.59	252.87
Average value	2939.95	255.88

8.6 Estimating the 0.63 - probability extreme bending moment

Figure 8.6 shows the 25 Gumbel models which are fitted to the generated samples. It is observed that a large uncertainty band is associated with the estimated 0.63-probability extreme bending moment. For instance, assuming the adequate percentile level to be α = 0.9 which corresponds to 2.25 in the Gumbel scale, the estimated 0.63-probability value varies from 3298.72 (KN.m) to 3937.97 (KN.m).

With reference to Table 8.8, it is seen that the 0.63-probability extreme bending moment estimated from the assumed true Gumbel model is equal to 3985.13 (KN.m) which is higher than the upper band of the uncertainty range found by Monte Carlo. Hence, it can be concluded that the assumed true Gumbel model overestimates the 0.63-probability extreme bending moment by approximately 1.2% and it is safe to use it for the design purpose.

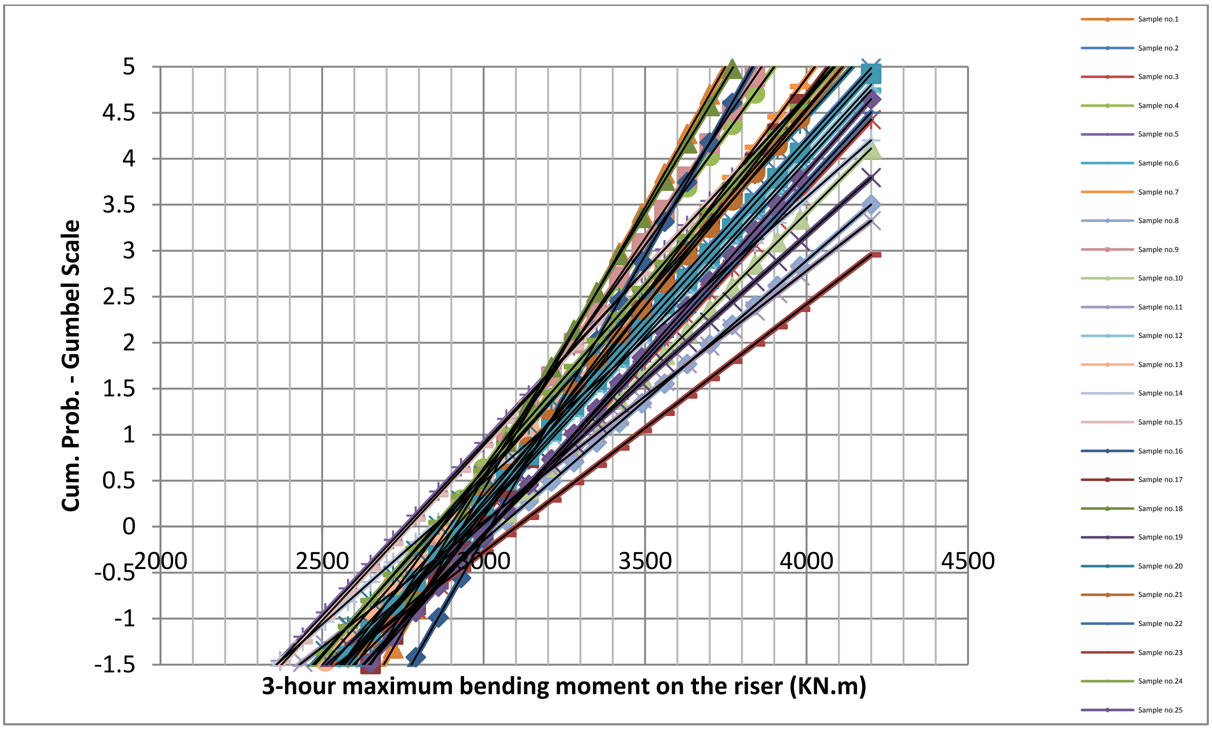

Figure 8.6 - Gumbel models fitted to the generated samples

Table 8.8 - The estimated response from different percentile level

Percentile level, α	Gumbel Scale ,Y	Uncertainty range	From eq. (8-3)
0.85	1.82	(3223.91 - 3776.96)	3878.38
0.87	1.97	(3250.57 - 3834.33)	3916.42
0.9	2.25	(3298.72 -3937.97)	3985.13

CHAPTER 9 Sensitivity studies

According to DNV-OS-F201 (2010) the numerical models of the drilling risers represent two different types of approximations to the physical drilling risers:

1. Theoretical models
2. Numerical approximations

The theoretical models represent the assumptions regarding the idealized models for the physical riser. Examples of theoretical idealizations are environmental models, load models and models for structural behavior.

Moreover, the numerical approximations are applied to represent the spatial discretization of the structure into a finite number of elements as well as time and/or frequency discretization of the dynamic loading.

In order to ensure that the theoretical models and numerical approximations represent the real physical behavior of the drilling riser system, verification of the computer model is required. One part of the verification of the computer model is performing the sensitivity study.

In general, there are many parameters that must be verified by performing sensitivity studies. Some of those parameters include:

1. Static offset of the drilling vessel
2. Static top tension provided by the tensioner system
3. Mesh size
4. Flex joint stiffness, including sensitivity to deflection, rate of deflection and temperature
5. Sea bed stiffness and soil/riser interaction effects
6. Current directionality
7. Drag coefficients
8. Marine growth
9. Vessel motion (draught and mass distribution dependence)
10. Structural damping

Among these parameters, sensitivity study with respect to:

1. Drilling riser material
2. Static offset of the drilling vessel
3. Static top tension provided by the tensioner system

are performed and the results are presented in the following.

The reason for performing the sensitivity study with respect to the riser material is not to validate the computer model. The purpose of this sensitivity study is to study how much the required riser wall thickness is decreased by selecting higher strength steels.

9.1 Drilling riser material

Selection of the riser material has a significant influence on the riser wall thickness. As the material tensile and yield strength increases, the required riser thickness decreases considerably. This reduction in the riser wall thickness has different impacts such as:

1. Reducing the construction cost
2. Increasing the required top tension by the tensioner system
3. Reducing the external riser area

Three high strength steels are considered, and the riser wall thickness is calculated according to the DNV-OS-F201 (2010). The mechanical properties of these steels are presented in Table 9.1. The second high strength steel in this table, X80, is the selected material in the base model. Moreover, the environmental condition in all analyses are same as the base model; see section 5.1.

Table 9.1 - Mechanical properties of X65, X80 and X100

Steel grade	Yield strength (MPa)	Tensile strength (MPa)
X65	448-600	531-758
X80	555-750	621-827
X100	690-840	760-990

With reference to Table 9.2, it seen that as the yield and tensile strength of the steel increases, the required riser wall thickness that can fulfils the combined loading criteria is decreased. This reduction in the riser wall thickness reduces external area of the riser pipe, A_o, which increases the effective weight of the riser; see Equation (5.1) regarding how to calculate the effective weight of the riser.

Accordingly, the required top tension is increased by reducing the riser wall thickness. However, it is seen that the increase in the required top tension force by the tensioner system is insignificant, and there is no need to improve the tensioner system.

It must be noted that the required riser thicknesses presented in Table 9.2 are the initial riser wall thicknesses. Hence, in the base model (with X80 as the riser material) the riser wall thickness is increased by a safety factor to 0.037 meters to ensure a safe design.

Table 9.2 - The influence of different steel grades on the riser design

Parameters	Steel grade	t[1]	M_E	T_E	M_F	T_F	H[2]	T_{App}[3]	Combined loading criteria
Unit	-	m	KN.m	KN	KN.m	KN	m	KN	
Value	X65	0.0418	3244	2515	0	2441.8	98.43	992.83	0.99
Value	X80	0.0354	3219	2511	0	2438	98.43	992.88	0.99
Value	X100	0.0289	3193	2507	0	2434.3	98.43	992.94	0.99

In addition, it is seen as the riser wall thickness decreases, the functional and the environmental loads decreases. However, the applied top tension increases.

With reference to Table 9.3, by using higher strength steel, the dynamic lower and upper flex joint angles decrease. This is because the riser becomes stiffer and can withstand more environmental forces while having less deformation.

Table 9.3 - Dynamic lower and upper flex joint angles for different steel grades

Steel Grade	LFJ angle (degree)		UFJ angle (degree)	
	Median	Max	Median	Max
X65	0.72	3.39	0.53	2.92
X80	0.71	3.36	0.52	2.90
X100	0.70	3.34	0.51	2.88

[1] Required riser wall thickness that fulfills the combined loading criteria formula
[2] The water depth in which the maximum bending moment on the drilling riser is occurred
[3] The applied tension force on each tensioner line in the SIMA (allowing one tensioner line to be failed)

Moreover, it is observed by using higher strength steel the design riser wall thickness decreases. However, this increase in the riser slenderness does not cause more deformation. This is due to the capability of the higher strength steels to keep their configuration. Therefore, it can be concluded that, by using higher strength steel, the flex joint angles reduce while the riser design wall thickness decreases considerably.

9.1.1 Conclusion

It is observed that by using higher strength steel, the environmental and functional axial force (tension force), the environmental bending moment and the flex joint angles are decreased due to the high strength and stiffness of the steel grade. Therefore, one may conclude that, it is better to use the steel grade with highest strength; X100.

On the contrary, X100 and the other high strength steels are very susceptible to the brittle fracture. Due to their high strength level, they are susceptible to both hydrogen embrittlement and stress corrosion cracking that can cause suddenly brittle failure (Campbell, 2006).

In conclude, among three steel grade studied, X80 is selected as the best choice to fulfil stability between cost saving and avoiding suddenly brittle failure.

9.2 Static offset of the drilling vessel

The static offset is varied in 4 different cases in which the case with zero static offset is the base case. According to (Faltinsen, 1999), the maximum allowable static offset of the drilling vessel relative to the connection point of the riser to the sea floor must be less than 10% of the water depth. Correspondingly, the maximum static offset is set to 13 meters.

In SIMA, the static offset is increased in 10 different increment steps with 1 meter offset increment in each step. The case studies are presented in Table 9.4. All other parameters remained unchanged in the static offset variation study.

Table 9.4 - Case studies for static offset variation in x-direction

Case No.	Static offset variation in X-direction (m)
1	0
2	5
3	10
4	13

For illustrative purpose, the drilling riser and the drilling vessel (the red box) with static offset in positive x-direction is shown in Figure 9.1. It is seen that the drilling vessel`s static offset is in line with the wave and current loads.

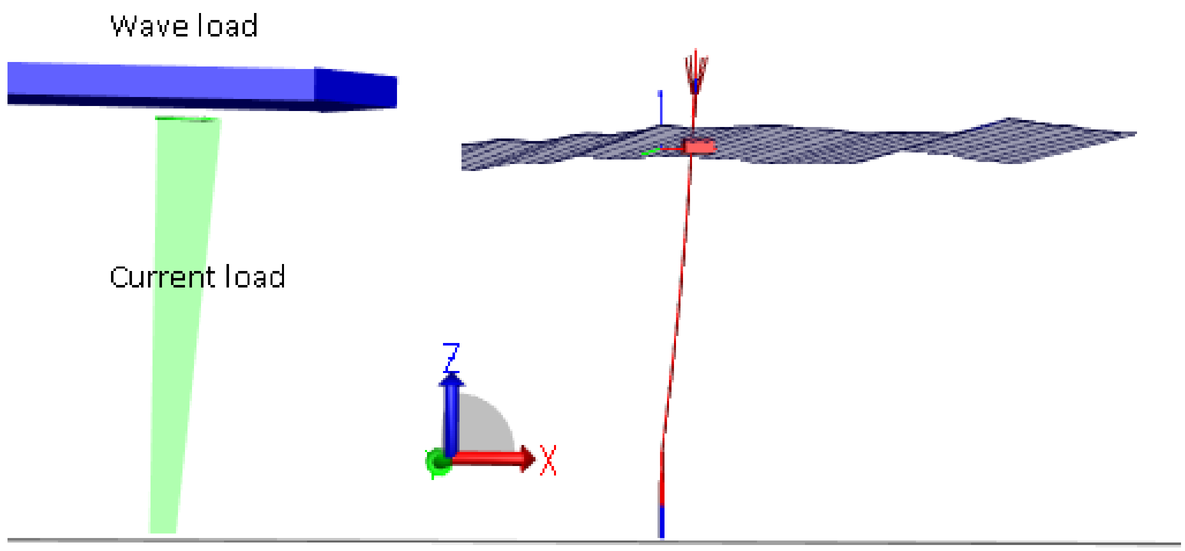

Figure 9.1 - Static offset in x direction; in line with wave and current loads (Screen shot from SIMA)

Figure 9.2 shows the dynamic bending moment curve along the riser with different static offsets. It is observed that as the static offset increases, the maximum value of the dynamic bending moment on the riser increases significantly.

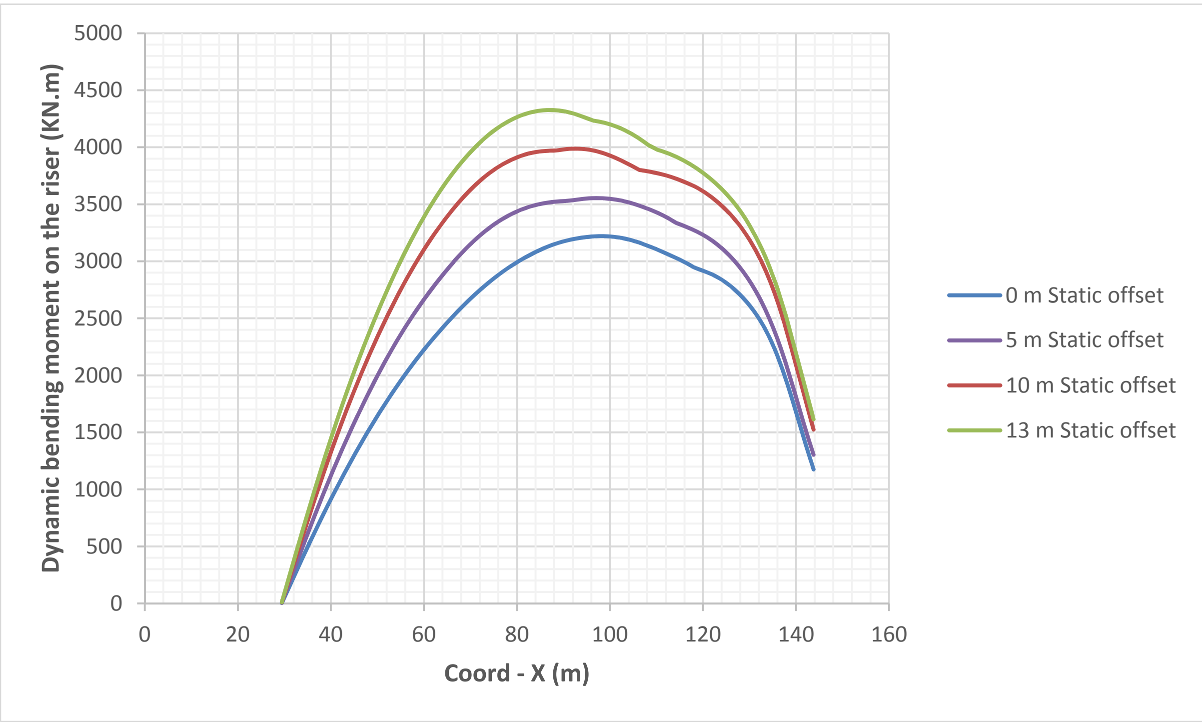

Figure 9.2 - Dynamic bending moment curve along the riser with different static offset in x-direction

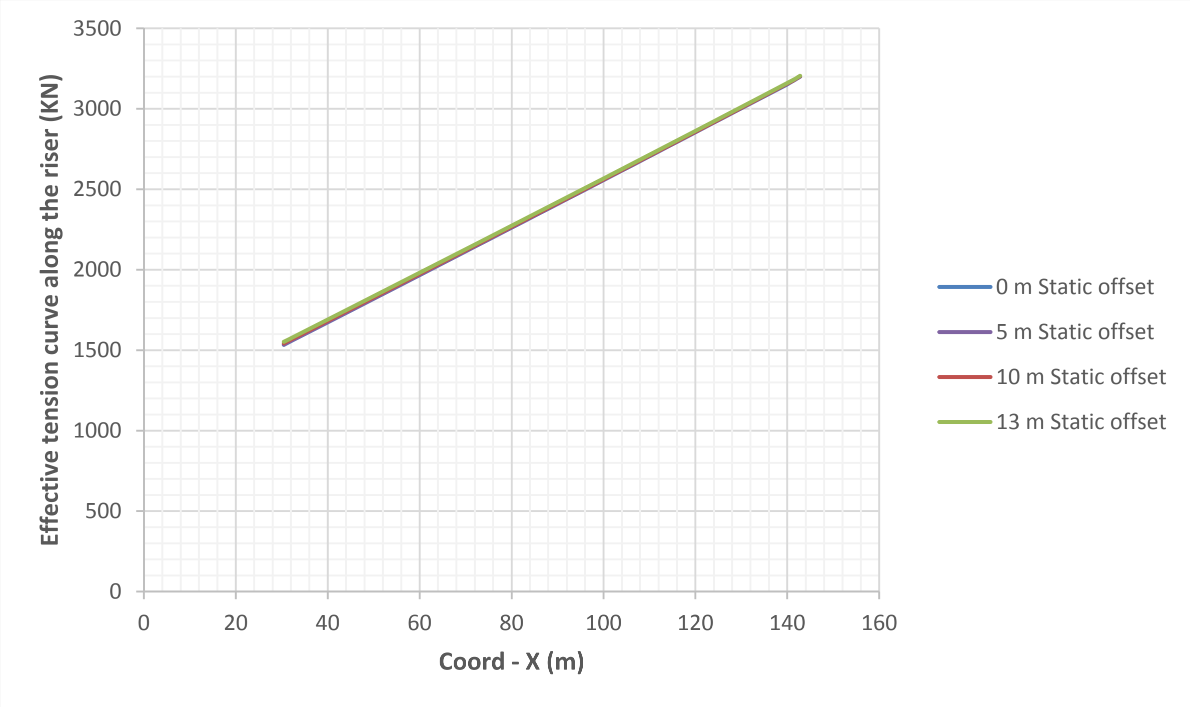

Figure 9.3 - Dynamic effective tension curve along the riser with different static offset in x-direction

With reference to Figure 9.3 and Table 9.5, it is observed that the dynamic effective tension along the riser is almost constant for all four case studies and there is only minor increase in the dynamic effective tension as the static offset increases. It can be concluded that the tensioner system is well modelled to provide approximately constant axial tension to the riser while the drilling vessel moves horizontally in response to the environmental loads.

Table 9.5 - Dynamic bending moment and effective tension statistics

Case No.	Maximum dynamic bending moment (KN.m)	Maximum dynamic effective tension (KN)	Minimum dynamic effective tension (KN)
1	3221	3200	1298
2	3554	3200	1307
3	3988	3203	1333
4	4327	3205	1354

In addition, the dynamic lower and upper flex joint angles are calculated and the results are presented in Table 9.6. It is observed that by increasing the static offset, both the maximum dynamic lower and upper flex joint angles exceed the maximum limitation for drilling operation according to API-RP-16Q (2001); see section 5.4 regarding the flex joint angle limitation for drilling operation.

Accordingly, it is concluded that for drilling operation, the static offset of the drilling vessel must be set to zero meter in the positive X-direction.

Table 9.6 - Dynamic Lower and Upper flex joint angle for three case studies with different static offset

Case No.	Static offset in positive X-direction (m)	LFJ angle (degree)		UFJ angle (degree)	
		Median	Max	Median	Max
1	0	0.71	3.36	0.51	2.90
2	5	2.95	5.87	1.05	3.76
3	10	5.52	8.35	1.95	4.68
4	13	7.06	9.82	2.46	5.09

9.3 Static top tension provided by the tensioner system

Due to high importance of the applied top tension on the static and dynamic behaviour of the drilling riser, this parameter is varied and it`s effect is studies in this section.

As mentioned earlier, the applied top tension for drilling riser is specified in terms of excess over the effective weight of the riser, i.e. in the typical range of 30-60% of the effective weight of the riser.

Three different cases are studied in which the case number 3 is the base case. The required top tension and the tension force applied on each tensioner lines are listed in Table 9.7. All the other parameters are constants and same as the base case, i.e. zero static offset and the same environmental condition as the base case.

Table 9.7 - Required tension force for each case study

Case No.	Top tension (KN)		Tension force applied on each tensioner line (KN)
1	$W_E + 30\% W_E$	2581.46	860.49
2	$W_E + 40\% W_E$	2780.04	926.68
3	$W_E + 50\% W_E$	2978.61	992.87

It is assumed that one tensioner line can be failed while sufficient tension force is provided by the other 3 tensioner lines to keep the riser stable. As a result, in order to calculate the tension force to be applied on each tensioner line, the total required top tension is divided by 3.

Table 9.8 presents the static and dynamic results for three case studies. Functional loads are estimated by performing the time domain analysis on the drilling riser when no environmental loads are applied. Static loads are estimated by executing the time domain analysis of the riser when it is exposed to the current loads. And finally, the dynamic loads are estimated by performing the time domain analysis of the riser when it is exposed to both current and wave loads. The dynamic loads also contain the static results.

Moreover, all responses are estimated for the point on the riser which gives the highest dynamic bending moment. The point is described by its water depth; H in the table.

Table 9.8 - Static and dynamic results for the drilling riser

Case No.	Functional load	Static load	Dynamic load		
	T_{eff} (KN)	T_{eff} (KN)	T_{eff} (KN)	M_b (KN.m)	H[4] (m)
1	1869.22	1869.22	1934	3608	94.49
2	2166.95	2159.22	2231	3402	96.46
3	2439	2439.01	2512	3249	98.43

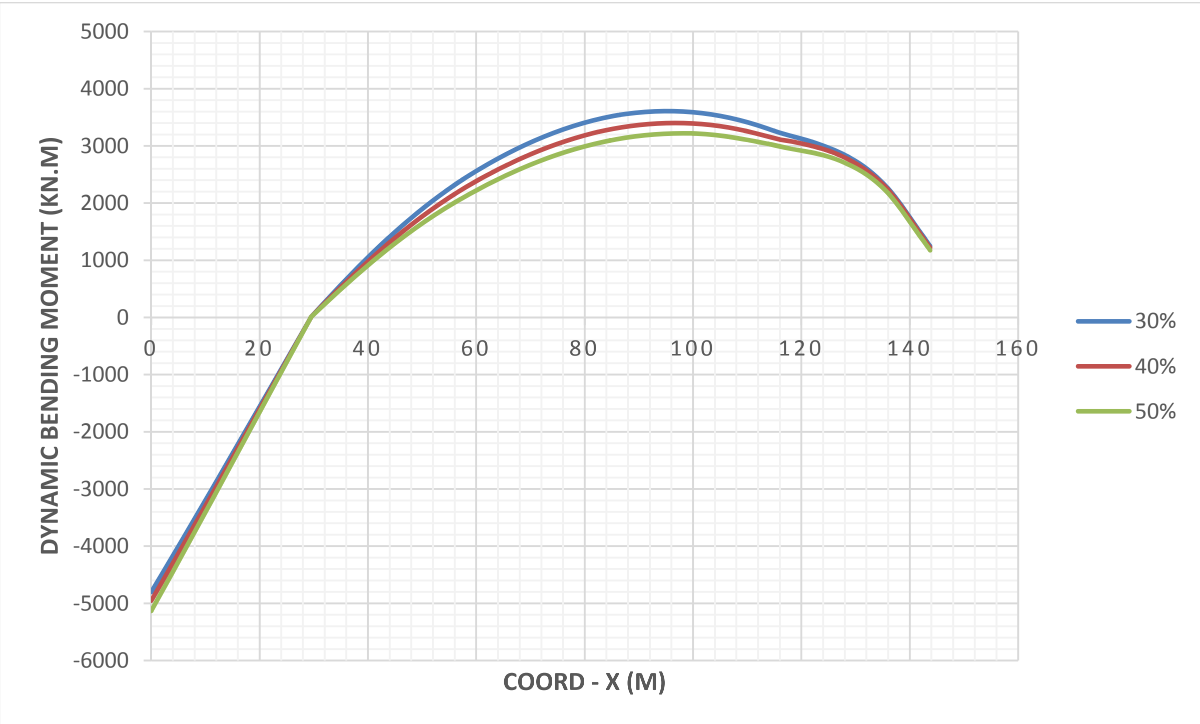

Figure 9.4 - Dynamic bending moment curve along the BOP, LMRP and riser

[4] The water depth in which the loads are estimated

With reference to Table 9.8, it is seen as the applied static top tension increases, the functional effective tension, the static effective tension and the dynamic effective tension increases.

However, with reference to Table 9.8 and Figure 9.4 it is observed the dynamic bending moment on the riser decreases as the applied static top tension increases. This is because, the riser is stiffer and more difficult to bend when a higher static top tension is applied.

Table 9.9 - Static and dynamic results for the lower end of BOP

Case No.	Functional loads		Static		Dynamic	
	T_{eff} (KN)	M_b (KN.m)	T_{eff} (KN)	M_b (KN.m)	T_{eff} (KN)	M_b (KN.m)
1	-1366.78	0	-1366.82	-513.90	-1503	-4801
2	-1097.96	0	-1105.73	-517.90	-1255	-4955
3	-854.81	0	-854.85	-521.30	-1011	-5132

When decreasing the static top tension, the area close to the see bottom; BOP and LMRP, might face compression load. Due to the high weight of these two equipment, compression is acceptable in this area if it does not cause buckling. In order to check that, the functional and environmental loads on the BOP are estimated for three cases and the results are inserted in the combined loading criteria. With reference to Table 9.10, it is seen that the compression loads on the BOP do no cause buckling and instability in the model.

Table 9.10 - The results for the combined loading criteria formula, for the BOP and riser

Case No.	Combined loading criteria	
	Lower end of BOP	Drilling riser
1	0.0165	1.0314
2	0.0170	0.9809
3	0.0177	0.9456

In addition, it is seen as the static top tension increases the absolute value of the static and dynamic bending moment on the lower end of the BOP, wellhead, increases too; see Table 9.9 and Figure 9.4.

This is because, as the riser inclined (either due to the vessel`s offset or due to the environment loads), the horizontal component of the effective tension, F_H, increases, too. F_H contributes in the total wellhead bending moment. When it comes to a drilling riser with flex joint, the rotational stiffness of the flex joint also contributes in the bending moment on the wellhead. Finally, wellhead bending moment reads:

$$M_{Wellhead} = (F_{horizontal} \times y) + (K_{\theta flexjoint} \times \theta) \quad (9.1)$$

Where:

$F_{horizontal}$: the horizontal component of the effective tension

Y: the distance from point of attack of the horizontal load component to the wellhead

K: the rotational stiffness of the flex joint

θ: the flex joint angle

Correspondingly, it is reasonable to have higher bending moment (the absolute value) on the wellhead when the static top tension increases.

The combined loading criteria for the point on the drilling riser that is exposed to the maximum dynamic bending moment is calculated and the results are presented in Table 9.10. It is observed that applying 30% excess over the effective weight of the riser as the static top tension is not adequate for this drilling riser. In addition, applying 40% excess over the effective weight of the riser gives a result very close to the upper limit; 1. Therefore, in order to ensure a safe design it is better to apply higher top tension than case number 2. Finally, it is concluded that the provided static top tension in the base model is quite good. In this case, even if the riser is exposed to the higher sea state than the one used in this sensitivity studies, the combined loading criteria can be fulfilled for at least a few higher sea states.

Table 9.11 - Lower and Upper flex joint angles for the riser with different top tension

Case No.	LFJ angle (degree)		UFJ angle (degree)	
	Median	Max	Median	Max
1	0.79	3.71	0.59	3.15
2	0.74	3.52	0.54	3.05
3	0.71	3.36	0.51	2.90

Moreover, the dynamic lower and upper flex joint angles are calculated for three different cases and the results are presented in Table 9.11. A common characteristic of all calculated angles is that, the angles decreases as the static top tension increases that is one of the tasks that the tensioner system is used for. In principle, the tensioner system can be used to limit the flex joint angles by applying higher top tension.

All the flex joint angles are well located below the upper limitation of the lower and upper flex joint angles provided by API-RP-16Q (2001).

Conclusion

The aim of this master thesis was to an extent redesign a preliminary drilling riser model according to the standards and to estimate the long-term extreme bending moment on the drilling riser when it is exposed to the assumed worst sea state along the 0.63-probability contour line.

The contour line method was utilized to estimate the 0.63-probability extreme bending moment on the riser. The screening analysis on the 0.63-probability contour line showed that the worst sea state along the 0.63-probability contour has 10.6 meters significant wave height and 13.1 seconds spectral peak period.

After plotting the data in a Gumbel probability paper, it was observed that the 3-hour extreme bending moments on the drilling riser were Gumbel distributed. Applying the method of moments, the Gumbel distribution of the 3-hour extreme bending moment on the riser for the assumed worst sea state along the 0.63-probability contour line was established.

Afterward, a first estimate of the 0.63-probability extreme bending moment on the riser was found by the α-percentile of the Gumbel distribution of the 3-hour extreme bending moment for the worst sea state.

Moreover, due to the high uncertainty associated with the estimated 0.63-probability extreme bending moment from the established Gumbel distribution, Monte Carlo method was utilized for the assessment of the uncertainty. Adopting the established Gumbel model for the 3-hour extreme bending moment on the riser as the true model, 25 samples of size 26 were generated by Monte Carlo simulation. With reference to Table 1, it was observed that the 0.63-probability response estimated from the assumed true Gumbel model was higher than the uncertainty range found by Monte Carlo simulation.

Correspondingly, it was concluded that the assumed true Gumbel distribution function gives the 0.63-probability extreme bending Moment on the upper side. Therefore, it is safe to estimate the design bending moment on the riser by the assumed true Gumbel distribution function.

Table 1 - The estimated 0.63-probability extreme bending moment on the riser

Percentile level, α	Gumbel scale ,Y	Uncertainty range	From the assumed true Gumbel model
0.85	1.82	(3223.91 - 3776.96)	3878.38
0.87	1.97	(3250.57 - 3834.33)	3916.42
0.9	2.25	(3298.72 - 3937.97)	3985.13

Moreover, the sensitivity study with respect to drilling riser material, static offset of the drilling vessel and the static top tension provided by the tensioner system were performed in order to study the influence of each parameter on the global static and dynamic results of the riser.

Regarding the drilling riser material, X80 was selected as the best drilling riser material that provides stability between cost saving and avoiding suddenly brittle failure.

Regarding the static offset of the drilling vessel, it was concluded that the static offset of the drilling vessel must be set to zero meter in the positive X-direction to have the lower and upper flex joint angles within the limitation provided by API-RP-16Q (2001).

And finally, the required static top tension was varied to find the minimum tension force to be provided by the tensioner system to fulfill the combined loading criteria. It was observed that applying 50% excess over the effective weight of the riser is the best choice to have a safe riser as well as avoiding not necessarily high static top tension.

Recommendation for Further Work

Due to the non-availability of the wind information, the influence of the wind loads on the drilling semi-submersible was neglected. However, the wind load has a significant contribution on the semi-submersible`s motions. As a result, it is recommended to redo the analysis with more specific data regarding the environmental condition and especially the wind loads.

Regarding the riser wall thickness selection, since it was a preliminary design of the drilling riser, a constant wall thickness was applied for the whole drilling riser. However, in order to save construction cost and decreasing the loads on the riser, it is recommended to apply the combined loading criteria formula for many water depth along the riser, and estimate the associated riser wall thickness which is suitable for each water depth.

The worst sea state was selected among a limited number of the sea states along the 0.63-probability contour line. As a result, it is recommended to do the screening analyses with more random seeds and on more sea states along the contour line to make a stronger decision regarding the worst sea state.

It was observed that the worst sea state (H_S =10.6 m and T_P =13.1 s) has a significant wave height less than the maximum significant wave height on the 0.63-probability contour line; 11.8 meters. The reason might be due to the high influence of the wave period in this sea state. The drilling riser might experience resonance at 13.1 seconds spectral wave period, i.e. the wave period may catch one of the natural periods of the drilling riser. However, the exact information regarding the natural periods of the riser can be obtained by performing the Eigen value analysis.

In order to verify the uncertainty associated with the percentile level, α, to estimate the long-term extreme bending moment on the riser from the short-term 3-hour extreme bending moment on the riser, 25 samples of size 26 were generated by Monte Carlo simulation. However, it is recommended to perform time domain simulations for simulating the required amount of sample data. In addition, the uncertainty band will be reduced when the Gumbel models are fitted to more simulated samples.

And last but not least, the contour line method utilized to estimate the long-term extreme bending moment on the drilling riser is a short-term approach. Correspondingly, the estimate found by this method must be verified by a full long-term analysis. The results of the full long-term analysis can be used to verify the selected percentile level in the contour line method.

Bibliography

API-RP-16Q. (2001). Recommended practice for design, selection, operation and maintenance of marine drilling riser systems. Washington: American Petroleum Institute.

Baarholm, G. S., Haver, S., & Økland, O. D. (2010). Combining Contour of Significant wave height and peak period with platform response distributions for predicting design response. *ELSEVIER*, 147-163.

Baarholm, G. S., & Moan, T. (2001). Application of Contour line method to estimate extreme ship hull loads considering operational restrictions. *Journal of ship research, 45*, 228-240.

Campbell, F. C. (2006). *Manufacturing Technology for Aerospace Structural Materials*: Elsevier.

Chakrabarti, S. (2005). *Handbook of Offshore Engineering* (Vol. 1): Elsevier.

DNV-OS-F201. (2010). Dynamic risers. Norway: DNV.

DNV-RP-C205. (2010). environmental conditions and environmental loads. Norway: DNV.

DNV-RP-F205. (2010). Global performance analysis of deep water floating structures. Norway: DNV.

Faltinsen, O. M. (1999). *Sea loads on ships and offshore strucures*. United Kingdom: Cambridge university press.

Farnes, k.-A., & Moan, T. (1993, 6-11 June 1993). *Extreme Response of a flexible riser system using a complete nonlinear long-term approach.* Paper presented at the Proceedings of the third International offshore and polar engineering Singapore.

Haver, S., & Kleiven, G. (2004). *Environmental Contour Lines For Design Purposes-Why and When?* Paper presented at the 23rd International Conference on Offshore Mechanics and Arctic Engineering, Vancouver, British Columbia, Canada.

Haver, S., & Winterstein, S. R. (2009). *Environmental contour lines: A method for estimating long term extremes by a short term analysis*. Paper presented at the Transactions, Society of Naval Architects and Marine Engineers.

Haver, S. K. (2011). *Prediction of Characteristic Response for Design Purposes*. Department of Marine Technology, NTNU. Lecture notes for special topic: Design of offshore structures.

J. Leira, B. (Ed.). (2010). *Analyse av usikkerhet*. Norway: NTNU.

Langen, I., & Sigbjörnsson, R. (1979). *Dynamisk analyse av konstruksjoner*. Norway: SiT Tapir.

Larsen, C. M. (2005). *Drag forces in dynamic analysis*. Lecture note for special topic: Dynamic analysis of marine structures. Department of marine technology, NTNU.

Myrhaug, D., & Lian, W. (2009). *Marine Dynamics Lecture notes*. Trondheim, Norway: Norwegian University of science and Technology.

NORSOK-N-003. (2007). Actions and action effects. Norway: NORSOK.

RIFLEX. (2012). RIFLEX Theory Manual (Version 4.0v0). Trondheim, Norway: Marintek.

Torsethaugen, K., & Haver, S. (2004). *Simplified double peak spectral model for ocean waves*. Paper presented at the JSC.

Winterstein, S. R., Ude, T. C., Cornell, C. A., Bjerager, P., & Haver, S. (1993, 9-13 August). *Environmental parameters for extreme response: Inverse form with omission factors.* Paper presented at the ICOSSAR, Austria.

APPENDIX A **Metocean Data**

The following information are part of the metocean data defined for a typical location in the Norwegian Sea. In the following, design values for waves for a typical Norwegian Sea deep water field are presented.

A.1 Waves

Figure A.1 shows the (annual) wave rose, i.e. the sample direction distribution of significant wave height, at the chosen location in the Norwegian Sea. Figure A.2 shows q-probability contour lines of Hs-Tp for q = 0.63, 10^{-1}, 10^{-2} and 10^{-4} for omni-directional waves. Table A.1 shows omni-directional extreme significant wave heights and corresponding spectral peak periods.

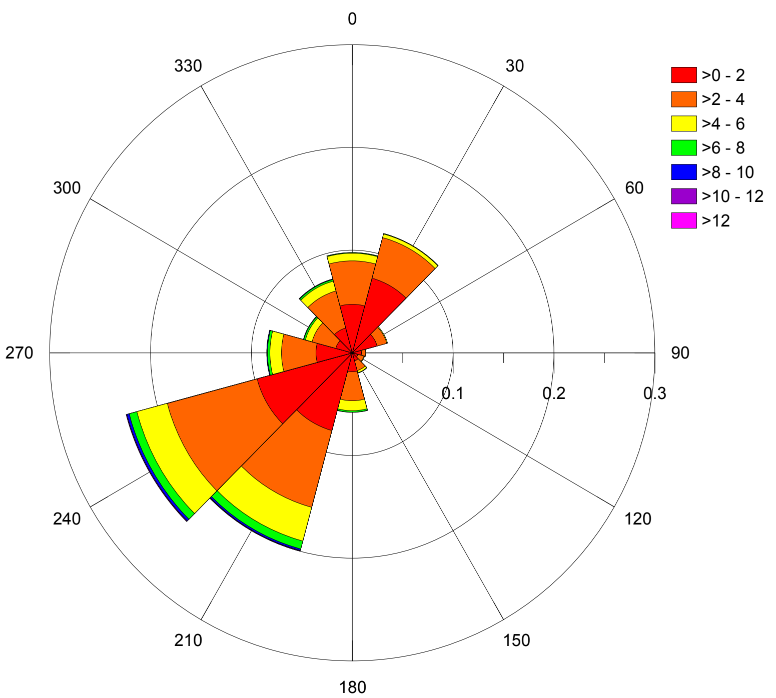

Figure A.1 - Annual wave rose

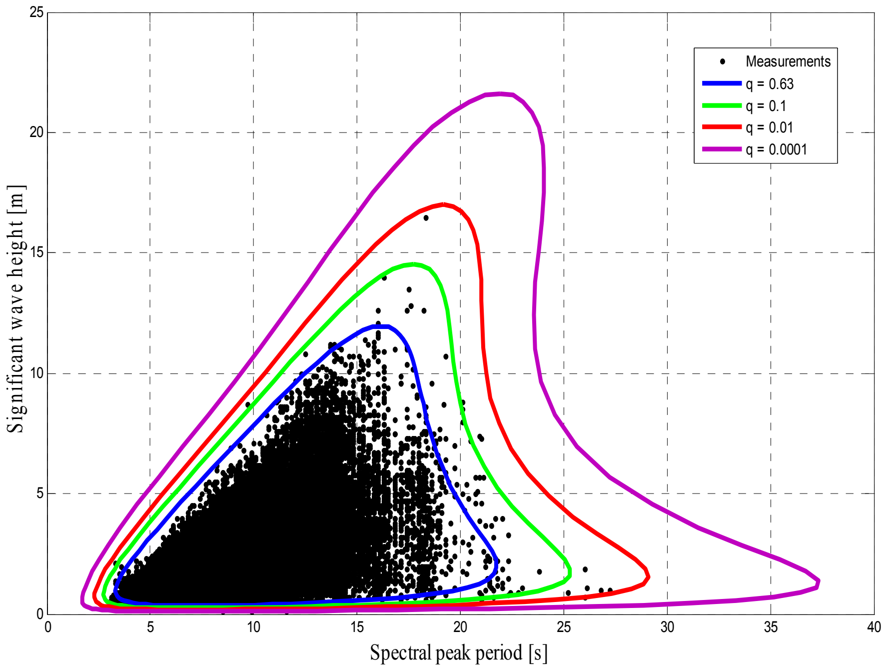

Figure A.2 - The q-probability contour lines of H_s-T_p for q=0.63, 10^{-1}, 10^{-2} and 10^{-4} for omni-directonal waves. Duration of sea state is 3 hours

Table A.1 - Omni-directional extreme significant wave heights and corresponding spectral peak periods; mean values

Annual probability of exceedance	Significant wave height H_S [m]	Spectral peak period T_P [s]
0.63	11.8	16.1
10^{-1}	14.5	17.7
10^{-2}	17.0	19.2
10^{-4}	21.9	22.1

APPENDIX B MATLAB Code for Combined Loading Criteria

```
% ULS - Combined Loading Criteria (Subjected to Net Internal Overpressure,
Bending Moment & Effective Tension) (DNV-OS-F201 Dynamic Risers,
October2010, Section 5)
% at 133 m Water depth
ID=0.495; % Riser Internal Diameter (m)
ro1=1600; % Density of drilling mud (kg/m3)
ro2=1025; % Density of water (kg/m3)
h=34.57; % Height difference between the actual point and the internal
pressure reference point (m)
g=9.81; % Acceleration of gravity (m/s2)
gamaf=1.1; % Functional Load Effect Factor (ULS)
gamae=1.3; % Environmental Load Effect Factor (ULS)
gamasc=1.14; % Safety class resistance factor (normal)
gamam=1.15; % Material resistance factor
fy=555; % Material Yield strength (MPa)
fu=621; % Material Tensile strength (MPa)
Md=(0*gamaf)+(3.249*gamae); %
Md=(M_functional*gamaf)+(M_environmental*gamae); Design Bending Moment
(MN.m)
Ted=(2.439*gamaf)+(2.512*gamae); % Design Effective Tension (MN)
P0=0.101325; % Atmosphere pressure (MPa)
Pd=0; % Design pressure (MPa)
Pld=Pd+(0.000001*(ro1*g*h)); % local internal design pressure (MPa)
Pe=P0+(0.000001*(ro2*g*h)); % External pressure (MPa)
%for Thickness=0:0.0001:0.1 % Riser thickness (m)
for Thickness=0.037 % thickness (m)
    OD=ID+(2*Thickness); % Outer diameter (m)
    Pb=(2/sqrt(3))*((2*Thickness)/(OD-Thickness))*min(fy,(fu/1.15)); % The
resistance against buckling propagation (MPa)
    if        Pld>Pe
              qh=((Pld-Pe)/Pb)*(2/sqrt(3));
    else
              qh=0;
    end
    if        (OD/Thickness)<15
              beta=0.4+qh;
    elseif    (OD/Thickness)>15 && (OD/Thickness)<60
              beta=((0.4+qh)*(60-(OD/Thickness)))/45;
    else
```

```
             beta=0;
    end
    alphac=(1-beta)+(beta*(fu/fy)); % Strain Hardening Factor
    Mk=fy*alphac*((OD-Thickness)^2)*Thickness;%Plastic Bending Moment
Resistance (MN.m)
    Tk=fy*alphac*pi*(OD-Thickness)*Thickness;%Plastic Axial Force
Resistance (MN)
%if(((gamasc*gamam)*(((abs(Md)/Mk)*(sqrt(1-(((Pld-Pe)/Pb)^2))))+
((Ted/Tk)^2)))+(((Pld-Pe)/Pb)^2))<=1
    %Thickness
    %break
    %end
((gamasc*gamam)*(((abs(Md)/Mk)*(sqrt(1-(((Pld-Pe)/Pb)^2))))+((Ted/Tk)^2)))
+(((Pld-Pe)/Pb)^2)
end
```

APPENDIX C RIFLEX Files for the designed Drilling Riser

C.1 RIFLEX Inpmod.inp file

```
'***********************************************************************
 INPMOD IDENTIFICATION TEXT 4.0.0
'-----------------------------------------------------------------------
 UNIT NAMES SPECIFICATION
'-----------------------------------------------------------------------
'ut ul um uf grav gcons
 s  m  Mg kN /    1.0000000
'***********************************************************************
 NEW SINGLE RISER
'***********************************************************************
'atyps idris
 AR    ARSYS
'***********************************************************************
 ARBITRARY SYSTEM AR
'***********************************************************************
'nsnod nlin nsnfix nves nricon nspr nack
 14    9    6      1    4      0    0
'ibtang zbot          ibot3d
 0      -133          0
'B 6.5: LINE TOPOLOGY DEFINITION
'lineid    lintyp-id  snod1-id  snod2-id
 bop_line  bop_a4     well36     bop_end2
 lmrp80    lmrp95     bop_end2   lmrp63
 join98    join21     lmrp63     join7b
 pup1de    pup19e     join7b     pup1c0
 tens70    tens1      tensaf     tensb0
 tens71    tens2      tens87     tens88
 tens72    tens3      tens60     tens61
 tens73    tens4      tens39     tens3a
 slipa7    slip42     pup1c0     uppe0c
'FIXED NODES
'snod-id ipos ix iy iz irx iry irz chcoo  chupro
 well36  0    1  1  1  1   1   1   GLOBAL NO
'x0         y0         z0            x1         y1         z1            rot        dir
 0          0          -132          0          0          -132          0          0
'snod-id ipos ix iy iz irx iry irz chcoo  chupro
 tensb0  1    1  1  1  0   0   1   GLOBAL NO
'x0          y0         z0          x1          y1         z1          rot         dir
 -3          2.642      30.589      -3          2.642      30.589      0           0
'snod-id ipos ix iy iz irx iry irz chcoo  chupro
```

```
 tens88  1    1  1  1  0   0   1   GLOBAL NO
'x0          y0          z0          x1          y1          z1          rot        dir
 -3.0000000  -2.6420000  30.5890000  -3.0000000  -2.6420000  30.5890000  0.0000000
0.0000000
'snod-id ipos ix iy iz irx iry irz chcoo  chupro
 tens61  1    1  1  1  0   0   1   GLOBAL NO
'x0         y0          z0          x1          y1          z1          rot        dir
 3          -2.642      30.589      3           -2.642      30.589      0          0
'snod-id ipos ix iy iz irx iry irz chcoo  chupro
 tens3a  1    1  1  1  0   0   1   GLOBAL NO
'x0         y0         z0          x1         y1         z1          rot        dir
 3.0000000 2.6420000 30.5890000 3.0000000 2.6420000 30.5890000 0.0000000 0.0000000
'snod-id ipos ix iy iz irx iry irz chcoo  chupro
 uppe0c  1    1  1  1  0   0   1   GLOBAL NO
'x0         y0         z0          x1         y1         z1          rot        dir
 0.0000000 0.0000000 33.0000000 0.0000000 0.0000000 33.0000000 0.0000000 0.0000000
'FREE NODES
'snod-id      x0         y0         z0
 bop_end2     0.0000000 0.0000000 -112.6410000
 lmrp63       0.0000000 0.0000000 -102.5410000
 join7b       0.0000000 0.0000000 11.7590000
 pup1c0       0.0000000 0.0000000 19.7590000
 tensaf      -0.8350000 0.7760000 19.7590000
 tens87      -0.8350000 -0.7760000 19.7590000
 tens60       0.8350000 -0.7760000 19.7590000
 tens39       0.8350000 0.7760000 19.7590000
'ives idwftr xg         yg         zg         dirx
 1    rig1   0.0000000 0.0000000 0.0000000 0.0000000
'chmast chslave
 pup1c0 tensaf
 pup1c0 tens87
 pup1c0 tens60
 pup1c0 tens39
'B.10 Line and segment specification
'**********************************************************************
 NEW LINE DATA
'**********************************************************************
'lintyp-id nseg ncmpty2 flutyp iaddtwi
 bop_a4    2    0       0      0
'crstyp   ncmpty1 exwtyp nelseg slgth      nstrps nstrpd slgth0     isoity
 bop_cs1 0        0      6      10.1000000 3      5      10.1000000 0
 bop_cs2 0        0      5      9.2590000  3      5      9.2590000  0
'**********************************************************************
 NEW LINE DATA
'**********************************************************************
'lintyp-id nseg ncmpty2 flutyp iaddtwi
 lmrp95    3    lowef4  0      0
'crstyp    ncmpty1 exwtyp nelseg slgth     nstrps nstrpd slgth0    isoity
 lmrp_cs1 0        0      2      3.0000000 3      5      3.0000000 0
 lmrp_cs2 0        0      1      2.0000000 3      5      2.0000000 0
 lmrp_cs3 0        0      3      5.1000000 3      5      5.1000000 0
'**********************************************************************
 NEW LINE DATA
'**********************************************************************
'lintyp-id nseg ncmpty2 flutyp iaddtwi
 join21    1    0       fluid  0
'crstyp ncmpty1 exwtyp nelseg slgth       nstrps nstrpd slgth0      isoity
 join2a 0       0      58     114.3000000 3      5      114.3000000 0
'**********************************************************************
 NEW LINE DATA
'**********************************************************************
'lintyp-id nseg ncmpty2 flutyp iaddtwi
 pup19e    1    tensad  fluid  0
'crstyp  ncmpty1 exwtyp nelseg slgth     nstrps nstrpd slgth0    isoity
```

```
 pup1_cs 0       0      4      8.0000000 3      5      8.0000000 0
'*********************************************************************
 NEW LINE DATA
'*********************************************************************
'lintyp-id nseg ncmpty2 flutyp iaddtwi
 tens1     1    0       0      0
'crstyp ncmpty1 exwtyp nelseg slgth      nstrps nstrpd slgth0    isoity
 tense8 0       0      1      11.2008072 3      5      5.6004036 0
'*********************************************************************
 NEW LINE DATA
'*********************************************************************
'lintyp-id nseg ncmpty2 flutyp iaddtwi
 tens2     1    0       0      0
'crstyp ncmpty1 exwtyp nelseg slgth      nstrps nstrpd slgth0    isoity
 tense8 0       0      1      11.2008072 3      5      5.6004036 0
'*********************************************************************
 NEW LINE DATA
'*********************************************************************
'lintyp-id nseg ncmpty2 flutyp iaddtwi
 tens3     1    0       0      0
'crstyp ncmpty1 exwtyp nelseg slgth      nstrps nstrpd slgth0    isoity
 tense8 0       0      1      11.2008072 3      5      5.6004036 0
'*********************************************************************
 NEW LINE DATA
'*********************************************************************
'lintyp-id nseg ncmpty2 flutyp iaddtwi
 tens4     1    0       0      0
'crstyp ncmpty1 exwtyp nelseg slgth      nstrps nstrpd slgth0    isoity
 tense8 0       0      1      11.2008072 3      5      5.6004036 0
'*********************************************************************
 NEW LINE DATA
'*********************************************************************
'lintyp-id nseg ncmpty2 flutyp iaddtwi
 slip42    2    0       0      0
'crstyp ncmpty1 exwtyp nelseg slgth     nstrps nstrpd slgth0    isoity
 outecb 0       0      5      5.0000000 3      5      5.0000000 0
 inne61 ufj     0      1      8.2410000 3      5      2.1205000 0
'*********************************************************************
 NEW COMPONENT CRS1
'*********************************************************************
'cmptyp-id temp alpha     beta
 bop_cs1   /    0.0000000 0.0000000
'ams       ae        ai             rgyr      ast wst dst thst rextcnt rintcnt
 9.4700000 2.6490000 3.7700000e-02 0.0000000 /   /   /   /    /       /
'iea iej igt ipress imf harpar
 1   1   1   0      0   0.0000000
'ea
 1.0000000e+08
'ei            gas
 1.0000000e+08 0.0000000
'gtminus
 1.0000000e+08
'cqx       cqy       cax       cay       clx       cly       icode d
 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 2     1.8365216
'tb        ycurmx
 0.0000000 0.0000000
'*********************************************************************
 NEW COMPONENT CRS1
'*********************************************************************
'cmptyp-id temp alpha     beta
 bop_cs2   /    0.0000000 0.0000000
'ams        ae        ai             rgyr      ast wst dst thst rextcnt rintcnt
 11.2700000 2.6490000 3.7700000e-02 0.0000000 /   /   /   /    /       /
'iea iej igt ipress imf harpar
```

```
 1   1   1   0      0   0.0000000
'ea
 1.0000000e+08
'ei             gas
 1.0000000e+08 0.0000000
'gtminus
 1.0000000e+08
'cqx       cqy       cax       cay       clx       cly       icode d
 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 2     1.8365216
'tb        ycurmx
 0.0000000 0.0000000
'*********************************************************************
 NEW COMPONENT CRS1
'*********************************************************************
'cmptyp-id temp alpha     beta
 lmrp_cs1  /    0.0000000 0.0000000
'ams       ae        ai            rgyr      ast wst dst thst rextcnt rintcnt
 5.3330000 1.1772358 3.7700000e-02 0.0000000 /   /   /   /    /       /
'iea iej igt ipress imf harpar
 1   1   1   0      0   0.0000000
'ea
 1.0000000e+08
'ei             gas
 1.0000000e+08 0.0000000
'gtminus
 1.0000000e+08
'cqx       cqy       cax       cay       clx       cly       icode d
 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 2     1.2241744
'tb        ycurmx
 0.0000000 0.0000000
'*********************************************************************
 NEW COMPONENT CRS1
'*********************************************************************
'cmptyp-id temp alpha     beta
 lmrp_cs2  /    0.0000000 0.0000000
'ams        ae        ai            rgyr      ast wst dst thst rextcnt rintcnt
 12.0000000 0.6320000 3.7700000e-02 0.0000000 /   /   /   /    /       /
'iea iej igt ipress imf harpar
 1   1   1   0      0   0.0000000
'ea
 1.0000000e+08
'ei             gas
 1.0000000e+08 0.0000000
'gtminus
 1.0000000e+08
'cqx       cqy       cax       cay       clx       cly       icode d
 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 2     0.8970437
'tb        ycurmx
 0.0000000 0.0000000
'*********************************************************************
 NEW COMPONENT CRS1
'*********************************************************************
'cmptyp-id temp alpha     beta
 lmrp_cs3  /    0.0000000 0.0000000
'ams        ae        ai            rgyr      ast wst dst thst rextcnt rintcnt
 12.0000000 0.7520000 3.7700000e-02 0.0000000 /   /   /   /    /       /
'iea iej igt ipress imf harpar
 1   1   1   0      0   0.0000000
'ea
 1.0000000e+08
'ei             gas
 1.0000000e+08 0.0000000
'gtminus
 1.0000000e+08
```

```
'cqx       cqy       cax       cay       clx       cly       icode d
 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 2     0.9785071
'tb        ycurmx
 0.0000000 0.0000000
'***********************************************************************
 NEW COMPONENT CRS1
'***********************************************************************
'cmptyp-id temp alpha     beta
 join2a    /    0.0000000 0.0000000
'ams       ae        ai        rgyr      ast wst dst thst rextcnt rintcnt
 1.4480000 0.2542813 0.1924422 0.0000000 /   /   /   /    /       /
'iea iej igt ipress imf harpar
 1   1   1   0      0   0.0000000
'ea
 8.1277658e+07
'ei              gas
 3211533.5771172 0.0000000
'gtminus
 2483784.6690775
'cqx       cqy       cax       cay       clx       cly       icode d
 0.0000000 2.0000000 0.0000000 2.0000000 0.0000000 0.0000000 2     0.5690000
'tb        ycurmx
 0.0000000 0.0000000
'***********************************************************************
 NEW COMPONENT CRS1
'***********************************************************************
'cmptyp-id temp alpha     beta
 pup1_cs   /    0.0000000 0.0000000
'ams       ae        ai            rgyr      ast wst dst thst rextcnt rintcnt
 4.1220000 0.7300897 5.4800000e-02 0.0000000 /   /   /   /    /       /
'iea iej igt ipress imf harpar
 1   1   1   0      0   0.0000000
'ea
 8.1277658e+07
'ei              gas
 3211533.5771172 0.0000000
'gtminus
 2483784.6690775
'cqx       cqy       cax       cay       clx       cly       icode d
 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 2     1.2640263
'tb        ycurmx
 0.0000000 0.0000000
'***********************************************************************
 NEW COMPONENT CRS1
'***********************************************************************
'cmptyp-id temp alpha     beta
 tense8    /    0.0000000 0.0000000
'ams       ae            ai        rgyr      ast wst dst thst rextcnt rintcnt
 0.0000000 3.1415927e-02 0.0000000 0.0000000 /   /   /   /    /       /
'iea iej igt ipress imf harpar
 4   0   0   0      0   0.0000000
'EAF(i)        ELONG(i)
-8.0000000     -1.0000000  &
 992.8702025   0.0000000   &
 992.8703000   1.0000000   &
 992.8704000   2.0000000
'cqx       cqy       cax       cay       clx       cly       icode d
 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 1     /
'tb        ycurmx
 0.0000000 0.0000000
'***********************************************************************
 NEW COMPONENT CRS1
'***********************************************************************
'cmptyp-id temp alpha     beta
```

```
 outecb    /    0.0000000 0.0000000
'ams             ae         ai         rgyr      ast wst dst thst rextcnt rintcnt
 1.1111111e-02 0.7853982 0.0000000 0.0000000 /   /   /   /    /       /
'iea iej igt ipress imf harpar
 1   1   1   0      0   0.0000000
'ea
 6990000.0000000
'ei             gas
 699000.0000000 0.0000000
'gtminus
 69900.0000000
'cqx       cqy       cax       cay       clx       cly       icode d
 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 1     /
'tb        ycurmx
 0.0000000 0.0000000
'*********************************************************************
 NEW COMPONENT CRS1
'*********************************************************************
'cmptyp-id temp alpha     beta
 inne61    /    0.0000000 0.0000000
'ams             ae         ai         rgyr      ast wst dst thst rextcnt rintcnt
 2.3579344e-02 0.2827433 0.0000000 0.0000000 /   /   /   /    /       /
'iea iej igt ipress imf harpar
 1   1   1   0      0   0.0000000
'ea
 0.1000000
'ei             gas
 699000.0000000 0.0000000
'gtminus
 69900.0000000
'cqx       cqy       cax       cay       clx       cly       icode d
 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 1     /
'tb        ycurmx
 0.0000000 0.0000000
'*********************************************************************
 NEW COMPONENT BODY
'*********************************************************************
'cmptyp-id
 tensad
'am         ae
 36.7630000 0.0000000
'icoo   cdx       cdy       cdz       amx       amy       amz
 GLOBAL 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000
'*********************************************************************
 NEW COMPONENT FLEX
'*********************************************************************
'cmptyp-id
 lowef4
'am        ae        rgx       rgy       rgz       crx       cry       crz
 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000
'cdx       cdy       cdz       amx       amy       amz       amxrot    amyrot    amzrot
 0.0000000  0.0000000  0.0000000  0.0000000  0.0000000  0.0000000  0.0000000  0.0000000
0.0000000
'idof ibound raydmp
 IRX  1      0.0000000
'idof ibound raydmp
 IRY  1      0.0000000
'idof ibound raydmp
 IRZ  1      0.0000000
'stiffrx
 1000.0000000
'stiffry
 1.0000000
'stiffrz
```

```
 1.0000000
'**********************************************************************
 NEW COMPONENT FLEX
'**********************************************************************
'cmptyp-id
 ufj
'am        ae        rgx       rgy       rgz       crx       cry       crz
 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000
'cdx       cdy       cdz       amx       amy       amz       amxrot    amyrot    amzrot
 0.0000000  0.0000000  0.0000000  0.0000000  0.0000000  0.0000000  0.0000000  0.0000000
0.0000000
'idof ibound raydmp
 IRX  1      0.0000000
'idof ibound raydmp
 IRY  1      0.0000000
'idof ibound raydmp
 IRZ  1      0.0000000
'stiffrx
 100.0000000
'stiffry
 15.0000000
'stiffrz
 15.0000000
'**********************************************************************
 NEW COMPONENT FLUID
'**********************************************************************
'cmptyp-id
 fluid
'rhoi      vveli     pressi    dpress    idir
 1.6000000 0.0000000 0.0000000 0.0000000 1
'**********************************************************************
 SUPPORT VESSEL IDENTIFICATION
'**********************************************************************

'idhftr
 rig1
'----------------------------------------------------------------------
 HFTRANSFER REFERENCE POSITION
'----------------------------------------------------------------------
'zg
 0.0000000
'----------------------------------------------------------------------
 HFTRANSFER CONTROL DATA
'----------------------------------------------------------------------
'ndhftr nwhftr isymhf itypin
 9      49     1      2
'----------------------------------------------------------------------
 WAVE DIRECTIONS
'----------------------------------------------------------------------
'ihead head
 1     0.0000000
 2     22.5000000
 3     45.0000000
 4     67.5000000
 5     90.0000000
 6     112.5000000
 7     135.0000000
 8     157.5000000
 9     180.0000000
'----------------------------------------------------------------------
 WAVE FREQUENCIES
'----------------------------------------------------------------------
'ifreq whftr
 1     0.1570800
```

```
 2     0.1795200
 3     0.2026830
 4     0.2166620
 5     0.2327110
 6     0.2513270
 7     0.2617990
 8     0.2673700
 9     0.2731820
 10    0.2792530
 11    0.2855990
 12    0.2991990
 13    0.3064970
 14    0.3141590
 15    0.3222150
 16    0.3306940
 17    0.3396320
 18    0.3490660
 19    0.3590390
 20    0.3695990
 21    0.3807990
 22    0.3926990
 23    0.4053670
 24    0.4188790
 25    0.4333230
 26    0.4487990
 27    0.4654210
 28    0.4833220
 29    0.5026550
 30    0.5235990
 31    0.5463640
 32    0.5711990
 33    0.5983990
 34    0.6283190
 35    0.6613880
 36    0.6981320
 37    0.7391980
 38    0.7853980
 39    0.8377580
 40    0.8975980
 41    0.9666440
 42    1.0471980
 43    1.1423970
 44    1.2566370
 45    1.3962630
 46    1.5707960
 47    1.7951960
 48    2.0943950
 49    2.5132740
'----------------------------------------------------------------------
 HFTRANSFER FUNCTION SURGE
'----------------------------------------------------------------------
'idir ifreq amplitude phase[deg]
 1    1     1.0770000 -89.9800000
 1    2     1.0040000 -89.9800000
 1    3     0.9553000 -89.9700000
 1    4     0.9339000 -89.9700000
 1    5     0.9135000 -89.9700000
 1    6     0.8926000 -89.9600000
 1    7     0.8812000 -89.9500000
 1    8     0.8751000 -89.9400000
 1    9     0.8687000 -89.9400000
 1    10    0.8619000 -89.9300000
 1    11    0.8546000 -89.9200000
 1    12    0.8384000 -89.9000000
```

```
1     13    0.8293000 -89.8900000
1     14    0.8195000 -89.8800000
1     15    0.8089000 -89.8600000
1     16    0.7972000 -89.8400000
1     17    0.7845000 -89.8100000
1     18    0.7707000 -89.7800000
1     19    0.7554000 -89.7400000
1     20    0.7387000 -89.6900000
1     21    0.7202000 -89.6400000
1     22    0.6999000 -89.5700000
1     23    0.6775000 -89.4800000
1     24    0.6526000 -89.3800000
1     25    0.6250000 -89.2500000
1     26    0.5945000 -89.1000000
1     27    0.5605000 -88.9100000
1     28    0.5228000 -88.6900000
1     29    0.4808000 -88.4200000
1     30    0.4341000 -88.1200000
1     31    0.3822000 -87.7900000
1     32    0.3245000 -87.4800000
1     33    0.2602000 -87.2700000
1     34    0.1882000 -87.4400000
1     35    0.1065000 -88.5100000
1     36    1.4120000e-02 -92.2500000
1     37    8.3210000e-02 86.1200000
1     38    0.1731000 82.3300000
1     39    0.2422000 77.5800000
1     40    0.2639000 70.8100000
1     41    0.2154000 64.9700000
1     42    0.1226000 62.4300000
1     43    1.9730000e-02 71.0500000
1     44    4.0050000e-02 -108.1600000
1     45    3.7680000e-02 -78.7400000
1     46    1.0750000e-02 96.7000000
1     47    4.6900000e-03 174.1400000
1     48    2.6300000e-03 -159.8500000
1     49    2.5300000e-03 -63.0000000
2     1     0.9955000 -89.9800000
2     2     0.9279000 -89.9800000
2     3     0.8828000 -89.9700000
2     4     0.8630000 -89.9700000
2     5     0.8442000 -89.9700000
2     6     0.8250000 -89.9600000
2     7     0.8145000 -89.9500000
2     8     0.8090000 -89.9400000
2     9     0.8031000 -89.9400000
2     10    0.7968000 -89.9300000
2     11    0.7901000 -89.9300000
2     12    0.7753000 -89.9100000
2     13    0.7670000 -89.8900000
2     14    0.7580000 -89.8800000
2     15    0.7483000 -89.8600000
2     16    0.7377000 -89.8400000
2     17    0.7261000 -89.8100000
2     18    0.7134000 -89.7800000
2     19    0.6996000 -89.7500000
2     20    0.6844000 -89.7000000
2     21    0.6676000 -89.6500000
2     22    0.6492000 -89.5800000
2     23    0.6289000 -89.5000000
2     24    0.6065000 -89.4100000
2     25    0.5817000 -89.2900000
2     26    0.5543000 -89.1600000
2     27    0.5240000 -89.0100000
```

```
2     28     0.4904000 -88.8400000
2     29     0.4532000 -88.6700000
2     30     0.4121000 -88.5200000
2     31     0.3665000 -88.4500000
2     32     0.3158000 -88.5600000
2     33     0.2593000 -89.1000000
2     34     0.1955000 -90.4600000
2     35     0.1228000 -93.1700000
2     36     4.2940000e-02 -96.2200000
2     37     3.1990000e-02 72.0600000
2     38     8.6470000e-02 71.9500000
2     39     0.1166000 70.9200000
2     40     0.1156000 68.1500000
2     41     7.9120000e-02 65.4000000
2     42     2.8380000e-02 68.3800000
2     43     1.7200000e-03 123.2400000
2     44     6.5100000e-03 50.2100000
2     45     1.8500000e-02 95.5100000
2     46     8.0700000e-03 147.2900000
2     47     7.3100000e-03 -0.6400000
2     48     3.6700000e-03 72.1400000
2     49     4.4000000e-04 22.6600000
3     1      0.7620000 -89.9800000
3     2      0.7104000 -89.9800000
3     3      0.6759000 -89.9800000
3     4      0.6608000 -89.9700000
3     5      0.6466000 -89.9700000
3     6      0.6320000 -89.9600000
3     7      0.6241000 -89.9500000
3     8      0.6199000 -89.9500000
3     9      0.6155000 -89.9400000
3     10     0.6108000 -89.9300000
3     11     0.6058000 -89.9300000
3     12     0.5946000 -89.9100000
3     13     0.5884000 -89.9000000
3     14     0.5817000 -89.8800000
3     15     0.5744000 -89.8700000
3     16     0.5665000 -89.8500000
3     17     0.5578000 -89.8200000
3     18     0.5484000 -89.7900000
3     19     0.5381000 -89.7600000
3     20     0.5268000 -89.7200000
3     21     0.5145000 -89.6700000
3     22     0.5009000 -89.6100000
3     23     0.4860000 -89.5500000
3     24     0.4695000 -89.4800000
3     25     0.4515000 -89.4000000
3     26     0.4316000 -89.3200000
3     27     0.4096000 -89.2500000
3     28     0.3855000 -89.2100000
3     29     0.3589000 -89.2500000
3     30     0.3295000 -89.4300000
3     31     0.2968000 -89.9200000
3     32     0.2602000 -90.9600000
3     33     0.2184000 -93.0200000
3     34     0.1692000 -96.8200000
3     35     0.1102000 -102.8700000
3     36     4.4500000e-02 -106.0000000
3     37     1.9180000e-02 -1.8600000
3     38     4.1280000e-02 3.0100000
3     39     3.8180000e-02 -29.1100000
3     40     4.3050000e-02 -88.6000000
3     41     6.6950000e-02 -117.3100000
3     42     8.2080000e-02 -117.7200000
```

```
3    43    7.8030000e-02 -107.8300000
3    44    4.2350000e-02 -97.6500000
3    45    1.7900000e-03 -95.9600000
3    46    2.0670000e-02 -92.8100000
3    47    1.3900000e-03 -51.2700000
3    48    1.8400000e-03 28.8500000
3    49    4.8000000e-04 62.8600000
4    1     0.4125000 -89.9800000
4    2     0.3845000 -89.9800000
4    3     0.3659000 -89.9800000
4    4     0.3578000 -89.9700000
4    5     0.3502000 -89.9700000
4    6     0.3424000 -89.9600000
4    7     0.3381000 -89.9500000
4    8     0.3359000 -89.9500000
4    9     0.3335000 -89.9400000
4    10    0.3310000 -89.9400000
4    11    0.3283000 -89.9300000
4    12    0.3224000 -89.9100000
4    13    0.3191000 -89.9000000
4    14    0.3155000 -89.8900000
4    15    0.3116000 -89.8700000
4    16    0.3074000 -89.8500000
4    17    0.3028000 -89.8300000
4    18    0.2978000 -89.8000000
4    19    0.2924000 -89.7700000
4    20    0.2864000 -89.7400000
4    21    0.2798000 -89.6900000
4    22    0.2726000 -89.6500000
4    23    0.2647000 -89.6000000
4    24    0.2560000 -89.5500000
4    25    0.2465000 -89.5000000
4    26    0.2359000 -89.4700000
4    27    0.2243000 -89.4800000
4    28    0.2114000 -89.5700000
4    29    0.1971000 -89.8100000
4    30    0.1811000 -90.3300000
4    31    0.1630000 -91.3900000
4    32    0.1420000 -93.4400000
4    33    0.1170000 -97.3500000
4    34    8.5930000e-02 -105.0100000
4    35    4.7150000e-02 -122.2000000
4    36    1.4500000e-02 145.8900000
4    37    4.2620000e-02 64.1400000
4    38    5.6250000e-02 43.6500000
4    39    4.6340000e-02 34.6800000
4    40    2.3290000e-02 41.7700000
4    41    1.1850000e-02 123.7400000
4    42    2.1720000e-02 166.0100000
4    43    1.6120000e-02 156.3500000
4    44    4.1800000e-03 92.4300000
4    45    1.6890000e-02 100.6000000
4    46    7.2500000e-03 77.8700000
4    47    4.9200000e-03 -52.1100000
4    48    4.1000000e-04 27.2500000
4    49    3.3000000e-04 143.9900000
5    1     0.0000000 180.0000000
5    2     0.0000000 0.0000000
5    3     0.0000000 0.0000000
5    4     0.0000000 0.0000000
5    5     0.0000000 180.0000000
5    6     0.0000000 180.0000000
5    7     0.0000000 180.0000000
5    8     0.0000000 180.0000000
```

5	9	0.0000000	180.0000000
5	10	0.0000000	180.0000000
5	11	0.0000000	180.0000000
5	12	0.0000000	180.0000000
5	13	0.0000000	180.0000000
5	14	0.0000000	180.0000000
5	15	0.0000000	180.0000000
5	16	0.0000000	180.0000000
5	17	0.0000000	180.0000000
5	18	0.0000000	180.0000000
5	19	0.0000000	180.0000000
5	20	0.0000000	180.0000000
5	21	0.0000000	180.0000000
5	22	0.0000000	180.0000000
5	23	0.0000000	180.0000000
5	24	0.0000000	180.0000000
5	25	0.0000000	180.0000000
5	26	0.0000000	180.0000000
5	27	0.0000000	180.0000000
5	28	0.0000000	180.0000000
5	29	0.0000000	0.0000000
5	30	0.0000000	180.0000000
5	31	0.0000000	0.0000000
5	32	0.0000000	0.0000000
5	33	0.0000000	0.0000000
5	34	0.0000000	0.0000000
5	35	0.0000000	0.0000000
5	36	0.0000000	-0.0000000
5	37	0.0000000	-180.0000000
5	38	0.0000000	-180.0000000
5	39	0.0000000	-180.0000000
5	40	0.0000000	-180.0000000
5	41	0.0000000	-180.0000000
5	42	0.0000000	-0.0000000
5	43	0.0000000	-0.0000000
5	44	0.0000000	180.0000000
5	45	0.0000000	0.0000000
5	46	0.0000000	-0.0000000
5	47	0.0000000	-0.0000000
5	48	0.0000000	-0.0000000
5	49	0.0000000	180.0000000
6	1	0.4125000	90.0200000
6	2	0.3845000	90.0200000
6	3	0.3659000	90.0300000
6	4	0.3578000	90.0300000
6	5	0.3502000	90.0300000
6	6	0.3424000	90.0400000
6	7	0.3381000	90.0500000
6	8	0.3359000	90.0500000
6	9	0.3335000	90.0600000
6	10	0.3310000	90.0700000
6	11	0.3283000	90.0700000
6	12	0.3224000	90.0900000
6	13	0.3191000	90.1000000
6	14	0.3155000	90.1200000
6	15	0.3116000	90.1300000
6	16	0.3074000	90.1500000
6	17	0.3028000	90.1700000
6	18	0.2978000	90.2000000
6	19	0.2924000	90.2300000
6	20	0.2864000	90.2700000
6	21	0.2798000	90.3100000
6	22	0.2726000	90.3500000
6	23	0.2647000	90.4000000

```
6    24    0.2560000 90.4600000
6    25    0.2465000 90.5000000
6    26    0.2359000 90.5300000
6    27    0.2243000 90.5200000
6    28    0.2114000 90.4400000
6    29    0.1971000 90.1900000
6    30    0.1811000 89.6700000
6    31    0.1630000 88.6100000
6    32    0.1420000 86.5700000
6    33    0.1170000 82.6600000
6    34    8.5930000e-02 74.9900000
6    35    4.7150000e-02 57.8000000
6    36    1.4500000e-02 -34.1100000
6    37    4.2620000e-02 -115.8600000
6    38    5.6250000e-02 -136.3500000
6    39    4.6340000e-02 -145.3200000
6    40    2.3290000e-02 -138.2300000
6    41    1.1850000e-02 -56.2600000
6    42    2.1720000e-02 -13.9900000
6    43    1.6120000e-02 -23.6500000
6    44    4.1800000e-03 -87.5700000
6    45    1.6890000e-02 -79.4000000
6    46    7.2500000e-03 -102.1300000
6    47    4.9200000e-03 127.8900000
6    48    4.1000000e-04 -152.7500000
6    49    3.3000000e-04 -36.0100000
7    1     0.7620000 90.0200000
7    2     0.7104000 90.0200000
7    3     0.6759000 90.0300000
7    4     0.6608000 90.0300000
7    5     0.6466000 90.0300000
7    6     0.6320000 90.0400000
7    7     0.6241000 90.0500000
7    8     0.6199000 90.0600000
7    9     0.6155000 90.0600000
7    10    0.6108000 90.0700000
7    11    0.6058000 90.0700000
7    12    0.5946000 90.0900000
7    13    0.5884000 90.1000000
7    14    0.5817000 90.1200000
7    15    0.5744000 90.1400000
7    16    0.5665000 90.1600000
7    17    0.5578000 90.1800000
7    18    0.5484000 90.2100000
7    19    0.5381000 90.2400000
7    20    0.5268000 90.2800000
7    21    0.5145000 90.3300000
7    22    0.5009000 90.3900000
7    23    0.4860000 90.4500000
7    24    0.4695000 90.5200000
7    25    0.4515000 90.6000000
7    26    0.4316000 90.6800000
7    27    0.4096000 90.7500000
7    28    0.3855000 90.7900000
7    29    0.3589000 90.7600000
7    30    0.3295000 90.5700000
7    31    0.2968000 90.0800000
7    32    0.2602000 89.0400000
7    33    0.2184000 86.9800000
7    34    0.1692000 83.1800000
7    35    0.1102000 77.1300000
7    36    4.4500000e-02 74.0100000
7    37    1.9180000e-02 178.1400000
7    38    4.1280000e-02 -177.0000000
```

```
7    39    3.8180000e-02 150.8900000
7    40    4.3050000e-02 91.4000000
7    41    6.6950000e-02 62.6900000
7    42    8.2080000e-02 62.2800000
7    43    7.8030000e-02 72.1700000
7    44    4.2350000e-02 82.3500000
7    45    1.7900000e-03 84.0400000
7    46    2.0670000e-02 87.1900000
7    47    1.3900000e-03 128.7300000
7    48    1.8400000e-03 -151.1500000
7    49    4.8000000e-04 -117.1500000
8    1     0.9955000 90.0300000
8    2     0.9279000 90.0200000
8    3     0.8828000 90.0300000
8    4     0.8630000 90.0300000
8    5     0.8442000 90.0300000
8    6     0.8250000 90.0400000
8    7     0.8145000 90.0500000
8    8     0.8090000 90.0600000
8    9     0.8031000 90.0600000
8    10    0.7968000 90.0700000
8    11    0.7901000 90.0800000
8    12    0.7753000 90.1000000
8    13    0.7670000 90.1100000
8    14    0.7580000 90.1200000
8    15    0.7483000 90.1400000
8    16    0.7377000 90.1600000
8    17    0.7261000 90.1900000
8    18    0.7134000 90.2200000
8    19    0.6996000 90.2600000
8    20    0.6844000 90.3000000
8    21    0.6676000 90.3500000
8    22    0.6492000 90.4200000
8    23    0.6289000 90.5000000
8    24    0.6065000 90.5900000
8    25    0.5817000 90.7100000
8    26    0.5543000 90.8400000
8    27    0.5240000 90.9900000
8    28    0.4904000 91.1600000
8    29    0.4532000 91.3300000
8    30    0.4121000 91.4800000
8    31    0.3665000 91.5500000
8    32    0.3158000 91.4400000
8    33    0.2593000 90.9100000
8    34    0.1955000 89.5500000
8    35    0.1228000 86.8300000
8    36    4.2940000e-02 83.7800000
8    37    3.1990000e-02 -107.9400000
8    38    8.6470000e-02 -108.0500000
8    39    0.1166000 -109.0800000
8    40    0.1156000 -111.8500000
8    41    7.9120000e-02 -114.6000000
8    42    2.8380000e-02 -111.6200000
8    43    1.7200000e-03 -56.7600000
8    44    6.5100000e-03 -129.7900000
8    45    1.8500000e-02 -84.4900000
8    46    8.0700000e-03 -32.7100000
8    47    7.3100000e-03 179.3600000
8    48    3.6700000e-03 -107.8600000
8    49    4.4000000e-04 -157.3500000
9    1     1.0770000 90.0300000
9    2     1.0040000 90.0200000
9    3     0.9553000 90.0300000
9    4     0.9339000 90.0300000
```

```
 9    5     0.9135000 90.0400000
 9    6     0.8926000 90.0500000
 9    7     0.8812000 90.0500000
 9    8     0.8751000 90.0600000
 9    9     0.8687000 90.0600000
 9    10    0.8619000 90.0700000
 9    11    0.8546000 90.0800000
 9    12    0.8384000 90.1000000
 9    13    0.8293000 90.1100000
 9    14    0.8195000 90.1200000
 9    15    0.8089000 90.1400000
 9    16    0.7972000 90.1600000
 9    17    0.7845000 90.1900000
 9    18    0.7707000 90.2200000
 9    19    0.7554000 90.2600000
 9    20    0.7387000 90.3100000
 9    21    0.7202000 90.3700000
 9    22    0.6999000 90.4300000
 9    23    0.6775000 90.5200000
 9    24    0.6526000 90.6200000
 9    25    0.6250000 90.7500000
 9    26    0.5945000 90.9000000
 9    27    0.5605000 91.0900000
 9    28    0.5228000 91.3100000
 9    29    0.4808000 91.5800000
 9    30    0.4341000 91.8800000
 9    31    0.3822000 92.2100000
 9    32    0.3245000 92.5200000
 9    33    0.2602000 92.7300000
 9    34    0.1882000 92.5600000
 9    35    0.1065000 91.5000000
 9    36    1.4120000e-02 87.7500000
 9    37    8.3210000e-02 -93.8800000
 9    38    0.1731000 -97.6700000
 9    39    0.2422000 -102.4200000
 9    40    0.2639000 -109.1900000
 9    41    0.2154000 -115.0300000
 9    42    0.1226000 -117.5700000
 9    43    1.9730000e-02 -108.9500000
 9    44    4.0050000e-02 71.8400000
 9    45    3.7680000e-02 101.2600000
 9    46    1.0750000e-02 -83.3000000
 9    47    4.6900000e-03 -5.8700000
 9    48    2.6300000e-03 20.1500000
 9    49    2.5300000e-03 117.0000000
'----------------------------------------------------------------------
 HFTRANSFER FUNCTION SWAY
'----------------------------------------------------------------------
'idir ifreq amplitude phase[deg]
 1    1     0.0000000 -180.0000000
 1    2     0.0000000 -180.0000000
 1    3     0.0000000 -0.0000000
 1    4     0.0000000 -180.0000000
 1    5     0.0000000 -180.0000000
 1    6     0.0000000 -180.0000000
 1    7     0.0000000 -180.0000000
 1    8     0.0000000 -180.0000000
 1    9     0.0000000 -180.0000000
 1    10    0.0000000 180.0000000
 1    11    0.0000000 180.0000000
 1    12    0.0000000 -0.0000000
 1    13    0.0000000 -180.0000000
 1    14    0.0000000 -180.0000000
 1    15    0.0000000 -180.0000000
```

```
1    16    0.0000000 0.0000000
1    17    0.0000000 -180.0000000
1    18    0.0000000 -180.0000000
1    19    0.0000000 -180.0000000
1    20    0.0000000 0.0000000
1    21    0.0000000 -0.0000000
1    22    0.0000000 -0.0000000
1    23    0.0000000 -180.0000000
1    24    0.0000000 -0.0000000
1    25    0.0000000 -0.0000000
1    26    0.0000000 -180.0000000
1    27    0.0000000 -180.0000000
1    28    0.0000000 -180.0000000
1    29    0.0000000 -0.0000000
1    30    0.0000000 -180.0000000
1    31    0.0000000 -180.0000000
1    32    0.0000000 -0.0000000
1    33    0.0000000 -0.0000000
1    34    0.0000000 180.0000000
1    35    0.0000000 -0.0000000
1    36    0.0000000 -0.0000000
1    37    0.0000000 -0.0000000
1    38    0.0000000 -0.0000000
1    39    0.0000000 0.0000000
1    40    0.0000000 -180.0000000
1    41    0.0000000 -0.0000000
1    42    0.0000000 -180.0000000
1    43    0.0000000 -180.0000000
1    44    0.0000000 0.0000000
1    45    0.0000000 0.0000000
1    46    0.0000000 180.0000000
1    47    0.0000000 -0.0000000
1    48    0.0000000 0.0000000
1    49    0.0000000 0.0000000
2    1     0.4110000 -89.8400000
2    2     0.3819000 -89.8200000
2    3     0.3620000 -89.8000000
2    4     0.3530000 -89.7900000
2    5     0.3444000 -89.7700000
2    6     0.3353000 -89.7400000
2    7     0.3304000 -89.7300000
2    8     0.3278000 -89.7200000
2    9     0.3250000 -89.7100000
2    10    0.3221000 -89.7000000
2    11    0.3190000 -89.6900000
2    12    0.3121000 -89.6600000
2    13    0.3083000 -89.6400000
2    14    0.3041000 -89.6200000
2    15    0.2997000 -89.6000000
2    16    0.2949000 -89.5700000
2    17    0.2897000 -89.5400000
2    18    0.2841000 -89.5100000
2    19    0.2779000 -89.4700000
2    20    0.2712000 -89.4200000
2    21    0.2640000 -89.3700000
2    22    0.2560000 -89.3200000
2    23    0.2474000 -89.2500000
2    24    0.2379000 -89.1900000
2    25    0.2276000 -89.1200000
2    26    0.2163000 -89.0700000
2    27    0.2039000 -89.0400000
2    28    0.1904000 -89.0900000
2    29    0.1755000 -89.2700000
2    30    0.1592000 -89.7100000
```

```
2    31    0.1409000 -90.6300000
2    32    0.1201000 -92.4700000
2    33    9.5830000e-02 -96.0400000
2    34    6.6270000e-02 -103.0900000
2    35    2.9780000e-02 -119.5000000
2    36    1.4250000e-02 83.5600000
2    37    4.6130000e-02 45.8700000
2    38    5.5440000e-02 26.5700000
2    39    4.5660000e-02 12.6000000
2    40    2.8880000e-02 -4.0000000
2    41    1.7780000e-02 -55.6200000
2    42    2.7780000e-02 -129.5900000
2    43    1.7210000e-02 168.3000000
2    44    3.0200000e-03 109.4800000
2    45    1.5690000e-02 108.5300000
2    46    2.7000000e-03 71.1200000
2    47    2.5300000e-03 -73.3400000
2    48    2.0300000e-03 97.7500000
2    49    1.5000000e-04 156.9200000
3    1     0.7594000 -89.8400000
3    2     0.7056000 -89.8200000
3    3     0.6687000 -89.8000000
3    4     0.6522000 -89.7900000
3    5     0.6362000 -89.7700000
3    6     0.6195000 -89.7500000
3    7     0.6103000 -89.7300000
3    8     0.6055000 -89.7200000
3    9     0.6003000 -89.7100000
3    10    0.5949000 -89.7000000
3    11    0.5891000 -89.6900000
3    12    0.5763000 -89.6600000
3    13    0.5692000 -89.6400000
3    14    0.5615000 -89.6200000
3    15    0.5533000 -89.6000000
3    16    0.5443000 -89.5700000
3    17    0.5346000 -89.5400000
3    18    0.5241000 -89.5100000
3    19    0.5127000 -89.4700000
3    20    0.5002000 -89.4200000
3    21    0.4866000 -89.3600000
3    22    0.4718000 -89.3000000
3    23    0.4556000 -89.2200000
3    24    0.4379000 -89.1400000
3    25    0.4185000 -89.0500000
3    26    0.3973000 -88.9500000
3    27    0.3742000 -88.8700000
3    28    0.3489000 -88.8100000
3    29    0.3213000 -88.8200000
3    30    0.2911000 -88.9800000
3    31    0.2579000 -89.4200000
3    32    0.2211000 -90.4200000
3    33    0.1796000 -92.4200000
3    34    0.1316000 -96.1200000
3    35    7.5170000e-02 -101.5300000
3    36    1.6110000e-02 -82.7000000
3    37    3.8800000e-02 20.7200000
3    38    5.5210000e-02 3.8200000
3    39    4.9330000e-02 -29.9300000
3    40    5.5370000e-02 -81.3300000
3    41    8.0340000e-02 -112.3100000
3    42    9.0250000e-02 -121.3600000
3    43    7.2270000e-02 -114.1000000
3    44    3.9560000e-02 -101.9200000
3    45    4.5700000e-03 -115.1300000
```

```
3    46    1.3700000e-02 -110.8200000
3    47    1.3500000e-03 -67.4500000
3    48    1.7200000e-03 -15.3300000
3    49    4.7000000e-04 159.0400000
4    1     0.9921000 -89.8400000
4    2     0.9218000 -89.8200000
4    3     0.8737000 -89.8000000
4    4     0.8520000 -89.7900000
4    5     0.8311000 -89.7700000
4    6     0.8091000 -89.7500000
4    7     0.7971000 -89.7300000
4    8     0.7907000 -89.7200000
4    9     0.7840000 -89.7100000
4    10    0.7768000 -89.7000000
4    11    0.7692000 -89.6900000
4    12    0.7523000 -89.6600000
4    13    0.7429000 -89.6400000
4    14    0.7328000 -89.6200000
4    15    0.7219000 -89.6000000
4    16    0.7100000 -89.5700000
4    17    0.6972000 -89.5400000
4    18    0.6832000 -89.5100000
4    19    0.6679000 -89.4600000
4    20    0.6513000 -89.4100000
4    21    0.6331000 -89.3500000
4    22    0.6132000 -89.2800000
4    23    0.5914000 -89.1900000
4    24    0.5674000 -89.0900000
4    25    0.5411000 -88.9700000
4    26    0.5122000 -88.8400000
4    27    0.4804000 -88.6800000
4    28    0.4454000 -88.5200000
4    29    0.4069000 -88.3500000
4    30    0.3645000 -88.2100000
4    31    0.3178000 -88.1700000
4    32    0.2661000 -88.3500000
4    33    0.2086000 -89.0000000
4    34    0.1440000 -90.6100000
4    35    7.1000000e-02 -93.8900000
4    36    7.3000000e-03 75.5500000
4    37    7.5200000e-02 73.6200000
4    38    0.1172000 71.5000000
4    39    0.1344000 72.6200000
4    40    0.1274000 74.3800000
4    41    9.2440000e-02 75.8000000
4    42    3.7400000e-02 82.5000000
4    43    4.6200000e-03 136.9500000
4    44    6.1900000e-03 30.4300000
4    45    2.5130000e-02 80.2400000
4    46    1.1800000e-02 135.9200000
4    47    1.0090000e-02 -37.6400000
4    48    5.0600000e-03 3.5400000
4    49    2.8000000e-04 -176.2300000
5    1     1.0740000 -89.8400000
5    2     0.9977000 -89.8200000
5    3     0.9456000 -89.8000000
5    4     0.9222000 -89.7900000
5    5     0.8994000 -89.7700000
5    6     0.8757000 -89.7500000
5    7     0.8627000 -89.7300000
5    8     0.8557000 -89.7200000
5    9     0.8483000 -89.7100000
5    10    0.8406000 -89.7000000
5    11    0.8323000 -89.6900000
```

```
5    12    0.8139000 -89.6600000
5    13    0.8037000 -89.6500000
5    14    0.7927000 -89.6200000
5    15    0.7808000 -89.6000000
5    16    0.7679000 -89.5700000
5    17    0.7538000 -89.5400000
5    18    0.7386000 -89.5000000
5    19    0.7219000 -89.4600000
5    20    0.7037000 -89.4100000
5    21    0.6837000 -89.3400000
5    22    0.6618000 -89.2700000
5    23    0.6378000 -89.1800000
5    24    0.6113000 -89.0700000
5    25    0.5822000 -88.9400000
5    26    0.5500000 -88.7900000
5    27    0.5145000 -88.6000000
5    28    0.4752000 -88.3900000
5    29    0.4318000 -88.1400000
5    30    0.3836000 -87.8700000
5    31    0.3302000 -87.5900000
5    32    0.2708000 -87.3600000
5    33    0.2046000 -87.2800000
5    34    0.1301000 -87.6200000
5    35    4.5630000e-02 -88.7600000
5    36    4.8180000e-02 87.9600000
5    37    0.1421000 84.7200000
5    38    0.2232000 82.3100000
5    39    0.2843000 80.3700000
5    40    0.3105000 77.4400000
5    41    0.2774000 73.2500000
5    42    0.1724000 67.8500000
5    43    3.9570000e-02 93.9900000
5    44    4.5890000e-02 -122.6400000
5    45    5.8550000e-02 -99.9900000
5    46    1.2860000e-02 47.6300000
5    47    5.2200000e-03 90.2000000
5    48    2.2500000e-03 174.3500000
5    49    1.7600000e-03 -164.7200000
6    1     0.9921000 -89.8400000
6    2     0.9218000 -89.8200000
6    3     0.8737000 -89.8000000
6    4     0.8520000 -89.7900000
6    5     0.8311000 -89.7700000
6    6     0.8091000 -89.7500000
6    7     0.7971000 -89.7300000
6    8     0.7907000 -89.7200000
6    9     0.7840000 -89.7100000
6    10    0.7768000 -89.7000000
6    11    0.7692000 -89.6900000
6    12    0.7523000 -89.6600000
6    13    0.7429000 -89.6400000
6    14    0.7328000 -89.6200000
6    15    0.7219000 -89.6000000
6    16    0.7100000 -89.5700000
6    17    0.6972000 -89.5400000
6    18    0.6832000 -89.5100000
6    19    0.6679000 -89.4600000
6    20    0.6513000 -89.4100000
6    21    0.6331000 -89.3500000
6    22    0.6132000 -89.2800000
6    23    0.5914000 -89.1900000
6    24    0.5674000 -89.0900000
6    25    0.5411000 -88.9700000
6    26    0.5122000 -88.8400000
```

```
6    27    0.4804000 -88.6800000
6    28    0.4454000 -88.5200000
6    29    0.4069000 -88.3500000
6    30    0.3645000 -88.2100000
6    31    0.3178000 -88.1700000
6    32    0.2661000 -88.3500000
6    33    0.2086000 -89.0000000
6    34    0.1440000 -90.6100000
6    35    7.1000000e-02 -93.8900000
6    36    7.3000000e-03 75.5500000
6    37    7.5200000e-02 73.6200000
6    38    0.1172000 71.5000000
6    39    0.1344000 72.6200000
6    40    0.1274000 74.3800000
6    41    9.2440000e-02 75.8000000
6    42    3.7400000e-02 82.5000000
6    43    4.6200000e-03 136.9500000
6    44    6.1900000e-03 30.4300000
6    45    2.5130000e-02 80.2400000
6    46    1.1800000e-02 135.9200000
6    47    1.0090000e-02 -37.6400000
6    48    5.0600000e-03 3.5400000
6    49    2.8000000e-04 -176.2300000
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7    2     0.7056000 -89.8200000
7    3     0.6687000 -89.8000000
7    4     0.6522000 -89.7900000
7    5     0.6362000 -89.7700000
7    6     0.6195000 -89.7500000
7    7     0.6103000 -89.7300000
7    8     0.6055000 -89.7200000
7    9     0.6003000 -89.7100000
7    10    0.5949000 -89.7000000
7    11    0.5891000 -89.6900000
7    12    0.5763000 -89.6600000
7    13    0.5692000 -89.6400000
7    14    0.5615000 -89.6200000
7    15    0.5533000 -89.6000000
7    16    0.5443000 -89.5700000
7    17    0.5346000 -89.5400000
7    18    0.5241000 -89.5100000
7    19    0.5127000 -89.4700000
7    20    0.5002000 -89.4200000
7    21    0.4866000 -89.3600000
7    22    0.4718000 -89.3000000
7    23    0.4556000 -89.2200000
7    24    0.4379000 -89.1400000
7    25    0.4185000 -89.0500000
7    26    0.3973000 -88.9500000
7    27    0.3742000 -88.8700000
7    28    0.3489000 -88.8100000
7    29    0.3213000 -88.8200000
7    30    0.2911000 -88.9800000
7    31    0.2579000 -89.4200000
7    32    0.2211000 -90.4200000
7    33    0.1796000 -92.4200000
7    34    0.1316000 -96.1200000
7    35    7.5170000e-02 -101.5300000
7    36    1.6110000e-02 -82.7000000
7    37    3.8800000e-02 20.7200000
7    38    5.5210000e-02 3.8200000
7    39    4.9330000e-02 -29.9300000
7    40    5.5370000e-02 -81.3300000
7    41    8.0340000e-02 -112.3100000
```

```
7    42    9.0250000e-02 -121.3600000
7    43    7.2270000e-02 -114.1000000
7    44    3.9560000e-02 -101.9200000
7    45    4.5700000e-03 -115.1300000
7    46    1.3700000e-02 -110.8200000
7    47    1.3500000e-03 -67.4500000
7    48    1.7200000e-03 -15.3300000
7    49    4.7000000e-04 159.0400000
8    1     0.4110000 -89.8400000
8    2     0.3819000 -89.8200000
8    3     0.3620000 -89.8000000
8    4     0.3530000 -89.7900000
8    5     0.3444000 -89.7700000
8    6     0.3353000 -89.7400000
8    7     0.3304000 -89.7300000
8    8     0.3278000 -89.7200000
8    9     0.3250000 -89.7100000
8    10    0.3221000 -89.7000000
8    11    0.3190000 -89.6900000
8    12    0.3121000 -89.6600000
8    13    0.3083000 -89.6400000
8    14    0.3041000 -89.6200000
8    15    0.2997000 -89.6000000
8    16    0.2949000 -89.5700000
8    17    0.2897000 -89.5400000
8    18    0.2841000 -89.5100000
8    19    0.2779000 -89.4700000
8    20    0.2712000 -89.4200000
8    21    0.2640000 -89.3700000
8    22    0.2560000 -89.3200000
8    23    0.2474000 -89.2500000
8    24    0.2379000 -89.1900000
8    25    0.2276000 -89.1200000
8    26    0.2163000 -89.0700000
8    27    0.2039000 -89.0400000
8    28    0.1904000 -89.0900000
8    29    0.1755000 -89.2700000
8    30    0.1592000 -89.7100000
8    31    0.1409000 -90.6300000
8    32    0.1201000 -92.4700000
8    33    9.5830000e-02 -96.0400000
8    34    6.6270000e-02 -103.0900000
8    35    2.9780000e-02 -119.5000000
8    36    1.4250000e-02 83.5600000
8    37    4.6130000e-02 45.8700000
8    38    5.5440000e-02 26.5700000
8    39    4.5660000e-02 12.6000000
8    40    2.8880000e-02 -4.0000000
8    41    1.7780000e-02 -55.6200000
8    42    2.7780000e-02 -129.5900000
8    43    1.7210000e-02 168.3000000
8    44    3.0200000e-03 109.4800000
8    45    1.5690000e-02 108.5300000
8    46    2.7000000e-03 71.1200000
8    47    2.5300000e-03 -73.3400000
8    48    2.0300000e-03 97.7500000
8    49    1.5000000e-04 156.9200000
9    1     0.0000000 180.0000000
9    2     0.0000000 180.0000000
9    3     0.0000000 180.0000000
9    4     0.0000000 180.0000000
9    5     0.0000000 180.0000000
9    6     0.0000000 180.0000000
9    7     0.0000000 180.0000000
```

```
 9    8     0.0000000 180.0000000
 9    9     0.0000000 180.0000000
 9    10    0.0000000 180.0000000
 9    11    0.0000000 180.0000000
 9    12    0.0000000 180.0000000
 9    13    0.0000000 180.0000000
 9    14    0.0000000 180.0000000
 9    15    0.0000000 180.0000000
 9    16    0.0000000 180.0000000
 9    17    0.0000000 180.0000000
 9    18    0.0000000 180.0000000
 9    19    0.0000000 180.0000000
 9    20    0.0000000 180.0000000
 9    21    0.0000000 180.0000000
 9    22    0.0000000 180.0000000
 9    23    0.0000000 180.0000000
 9    24    0.0000000 180.0000000
 9    25    0.0000000 180.0000000
 9    26    0.0000000 180.0000000
 9    27    0.0000000 180.0000000
 9    28    0.0000000 180.0000000
 9    29    0.0000000 180.0000000
 9    30    0.0000000 180.0000000
 9    31    0.0000000 0.0000000
 9    32    0.0000000 0.0000000
 9    33    0.0000000 0.0000000
 9    34    0.0000000 0.0000000
 9    35    0.0000000 0.0000000
 9    36    0.0000000 -180.0000000
 9    37    0.0000000 -180.0000000
 9    38    0.0000000 -180.0000000
 9    39    0.0000000 -180.0000000
 9    40    0.0000000 -180.0000000
 9    41    0.0000000 -180.0000000
 9    42    0.0000000 0.0000000
 9    43    0.0000000 -0.0000000
 9    44    0.0000000 0.0000000
 9    45    0.0000000 0.0000000
 9    46    0.0000000 -180.0000000
 9    47    0.0000000 -0.0000000
 9    48    0.0000000 180.0000000
 9    49    0.0000000 0.0000000
'-----------------------------------------------------------------------
 HFTRANSFER FUNCTION HEAVE
'-----------------------------------------------------------------------
'idir ifreq amplitude phase[deg]
 1    1     1.0180000 -0.4800000
 1    2     1.0330000 -0.8500000
 1    3     1.0660000 -1.7200000
 1    4     1.1020000 -2.8400000
 1    5     1.1740000 -5.5900000
 1    6     1.3250000 -15.1700000
 1    7     1.3750000 -29.3100000
 1    8     1.2880000 -40.2900000
 1    9     1.0690000 -50.6500000
 1    10    0.8023000 -54.6500000
 1    11    0.6044000 -49.4000000
 1    12    0.4830000 -26.7500000
 1    13    0.4904000 -18.4200000
 1    14    0.5078000 -12.9100000
 1    15    0.5258000 -9.3000000
 1    16    0.5411000 -6.8800000
 1    17    0.5530000 -5.2200000
 1    18    0.5613000 -4.0400000
```

```
1    19    0.5665000 -3.1800000
1    20    0.5686000 -2.5600000
1    21    0.5680000 -2.1100000
1    22    0.5649000 -1.8100000
1    23    0.5593000 -1.6500000
1    24    0.5513000 -1.6200000
1    25    0.5409000 -1.7600000
1    26    0.5279000 -2.1100000
1    27    0.5120000 -2.7400000
1    28    0.4926000 -3.7600000
1    29    0.4687000 -5.3300000
1    30    0.4387000 -7.6500000
1    31    0.4002000 -10.9300000
1    32    0.3507000 -15.2500000
1    33    0.2897000 -20.4300000
1    34    0.2208000 -25.8100000
1    35    0.1526000 -30.5600000
1    36    9.3830000e-02 -34.1400000
1    37    5.0370000e-02 -36.9900000
1    38    2.4430000e-02 -42.1700000
1    39    1.6510000e-02 -55.0800000
1    40    2.4480000e-02 -65.0600000
1    41    3.6730000e-02 -74.6600000
1    42    3.1370000e-02 -85.1800000
1    43    9.3500000e-03 -46.1100000
1    44    1.2800000e-03 -61.7600000
1    45    6.6000000e-03 85.6400000
1    46    6.5000000e-04 -130.4500000
1    47    3.0000000e-05 1.9200000
1    48    1.0000000e-05 158.5700000
1    49    0.0000000 0.0000000
2    1     1.0170000 -0.4700000
2    2     1.0330000 -0.8500000
2    3     1.0650000 -1.7100000
2    4     1.1010000 -2.8100000
2    5     1.1710000 -5.5400000
2    6     1.3200000 -15.0400000
2    7     1.3670000 -29.0600000
2    8     1.2790000 -39.9200000
2    9     1.0620000 -50.1000000
2    10    0.7980000 -53.8600000
2    11    0.6040000 -48.4000000
2    12    0.4880000 -25.9800000
2    13    0.4962000 -17.8700000
2    14    0.5137000 -12.5200000
2    15    0.5316000 -9.0300000
2    16    0.5468000 -6.6900000
2    17    0.5585000 -5.0700000
2    18    0.5667000 -3.9300000
2    19    0.5717000 -3.1000000
2    20    0.5737000 -2.5100000
2    21    0.5730000 -2.0800000
2    22    0.5697000 -1.8000000
2    23    0.5640000 -1.6500000
2    24    0.5558000 -1.6400000
2    25    0.5452000 -1.8000000
2    26    0.5319000 -2.1600000
2    27    0.5155000 -2.8000000
2    28    0.4955000 -3.8300000
2    29    0.4708000 -5.3900000
2    30    0.4397000 -7.6500000
2    31    0.3999000 -10.7900000
2    32    0.3491000 -14.8300000
2    33    0.2871000 -19.4600000
```

```
2    34    0.2181000 -23.8700000
2    35    0.1510000 -27.0100000
2    36    9.4100000e-02 -28.3000000
2    37    5.1550000e-02 -28.8200000
2    38    2.3210000e-02 -36.4100000
2    39    1.1380000e-02 -89.6800000
2    40    1.9090000e-02 -136.9900000
2    41    2.4800000e-02 -161.0300000
2    42    1.7500000e-02 160.1600000
2    43    5.1300000e-03 104.6900000
2    44    1.6300000e-03 22.0100000
2    45    5.0500000e-03 -63.9000000
2    46    3.6000000e-04 -21.6700000
2    47    5.0000000e-05 110.2700000
2    48    2.0000000e-05 161.5900000
2    49    0.0000000 -180.0000000
3    1     1.0160000 -0.4700000
3    2     1.0310000 -0.8300000
3    3     1.0620000 -1.6800000
3    4     1.0960000 -2.7600000
3    5     1.1640000 -5.4200000
3    6     1.3060000 -14.7100000
3    7     1.3470000 -28.4200000
3    8     1.2580000 -38.9900000
3    9     1.0440000 -48.7100000
3    10    0.7876000 -51.8500000
3    11    0.6036000 -45.8800000
3    12    0.5010000 -24.0700000
3    13    0.5110000 -16.5100000
3    14    0.5290000 -11.5600000
3    15    0.5468000 -8.3400000
3    16    0.5617000 -6.1800000
3    17    0.5731000 -4.6900000
3    18    0.5810000 -3.6400000
3    19    0.5858000 -2.8800000
3    20    0.5876000 -2.3500000
3    21    0.5868000 -1.9700000
3    22    0.5834000 -1.7400000
3    23    0.5777000 -1.6500000
3    24    0.5694000 -1.6900000
3    25    0.5587000 -1.9100000
3    26    0.5451000 -2.3400000
3    27    0.5284000 -3.0700000
3    28    0.5077000 -4.1900000
3    29    0.4818000 -5.8600000
3    30    0.4487000 -8.2300000
3    31    0.4061000 -11.4400000
3    32    0.3516000 -15.4600000
3    33    0.2851000 -19.7900000
3    34    0.2122000 -23.2800000
3    35    0.1432000 -24.2600000
3    36    8.7030000e-02 -21.2900000
3    37    4.6340000e-02 -14.2000000
3    38    1.7150000e-02 -4.6200000
3    39    6.9200000e-03 170.3700000
3    40    2.8680000e-02 167.8700000
3    41    4.1640000e-02 143.1800000
3    42    3.4450000e-02 102.2800000
3    43    1.4400000e-02 58.7300000
3    44    6.2800000e-03 172.1500000
3    45    4.8000000e-04 -167.2400000
3    46    7.7000000e-04 102.7100000
3    47    1.1000000e-04 164.3400000
3    48    3.0000000e-05 -60.2100000
```

```
3    49    0.0000000 -0.0000000
4    1     1.0160000 -0.4600000
4    2     1.0300000 -0.8200000
4    3     1.0600000 -1.6400000
4    4     1.0920000 -2.7000000
4    5     1.1570000 -5.3000000
4    6     1.2910000 -14.3700000
4    7     1.3260000 -27.7400000
4    8     1.2360000 -37.9800000
4    9     1.0250000 -47.2000000
4    10    0.7776000 -49.6800000
4    11    0.6044000 -43.2100000
4    12    0.5154000 -22.1100000
4    13    0.5273000 -15.1200000
4    14    0.5458000 -10.5700000
4    15    0.5635000 -7.6100000
4    16    0.5782000 -5.6300000
4    17    0.5894000 -4.2600000
4    18    0.5972000 -3.3100000
4    19    0.6019000 -2.6300000
4    20    0.6038000 -2.1500000
4    21    0.6032000 -1.8300000
4    22    0.6001000 -1.6600000
4    23    0.5947000 -1.6200000
4    24    0.5869000 -1.7400000
4    25    0.5766000 -2.0400000
4    26    0.5636000 -2.5900000
4    27    0.5474000 -3.4600000
4    28    0.5270000 -4.8000000
4    29    0.5009000 -6.7600000
4    30    0.4670000 -9.5800000
4    31    0.4220000 -13.4400000
4    32    0.3627000 -18.4300000
4    33    0.2886000 -24.1600000
4    34    0.2052000 -29.5800000
4    35    0.1244000 -32.8900000
4    36    5.7820000e-02 -31.1600000
4    37    1.1570000e-02 -2.4100000
4    38    2.1490000e-02 133.5200000
4    39    3.8390000e-02 150.6500000
4    40    4.8040000e-02 162.8100000
4    41    4.9400000e-02 166.8700000
4    42    3.2640000e-02 164.5700000
4    43    1.2300000e-02 174.4700000
4    44    2.2400000e-03 141.6600000
4    45    1.6400000e-03 -30.0900000
4    46    6.9000000e-04 -105.8400000
4    47    2.7000000e-04 154.1400000
4    48    0.0000000 -180.0000000
4    49    1.0000000e-05 -164.0300000
5    1     1.0150000 -0.4600000
5    2     1.0290000 -0.8100000
5    3     1.0580000 -1.6300000
5    4     1.0900000 -2.6700000
5    5     1.1540000 -5.2400000
5    6     1.2850000 -14.2200000
5    7     1.3170000 -27.4500000
5    8     1.2270000 -37.5500000
5    9     1.0180000 -46.5400000
5    10    0.7736000 -48.7300000
5    11    0.6050000 -42.0600000
5    12    0.5218000 -21.3000000
5    13    0.5345000 -14.5300000
5    14    0.5531000 -10.1500000
```

```
5    15    0.5708000 -7.2900000
5    16    0.5855000 -5.3900000
5    17    0.5966000 -4.0800000
5    18    0.6044000 -3.1600000
5    19    0.6092000 -2.5100000
5    20    0.6112000 -2.0600000
5    21    0.6107000 -1.7700000
5    22    0.6078000 -1.6200000
5    23    0.6027000 -1.6000000
5    24    0.5952000 -1.7500000
5    25    0.5854000 -2.1000000
5    26    0.5728000 -2.7000000
5    27    0.5570000 -3.6600000
5    28    0.5370000 -5.1100000
5    29    0.5112000 -7.2500000
5    30    0.4772000 -10.3300000
5    31    0.4314000 -14.6200000
5    32    0.3700000 -20.2800000
5    33    0.2921000 -27.1500000
5    34    0.2029000 -34.5800000
5    35    0.1151000 -42.0000000
5    36    4.1440000e-02 -53.1300000
5    37    1.6780000e-02 171.9800000
5    38    5.0110000e-02 153.2500000
5    39    6.8760000e-02 158.0300000
5    40    7.8950000e-02 170.3300000
5    41    9.2840000e-02 -179.8400000
5    42    8.3330000e-02 171.4900000
5    43    3.1220000e-02 155.2400000
5    44    8.2800000e-03 -34.1200000
5    45    9.3800000e-03 -11.1100000
5    46    9.9000000e-04 -2.3100000
5    47    3.6000000e-04 -162.8500000
5    48    4.0000000e-05 -159.0900000
5    49    0.0000000 0.0000000
6    1     1.0160000 -0.4600000
6    2     1.0300000 -0.8200000
6    3     1.0600000 -1.6400000
6    4     1.0920000 -2.7000000
6    5     1.1570000 -5.3000000
6    6     1.2910000 -14.3700000
6    7     1.3260000 -27.7400000
6    8     1.2360000 -37.9800000
6    9     1.0250000 -47.2000000
6    10    0.7776000 -49.6800000
6    11    0.6044000 -43.2100000
6    12    0.5154000 -22.1100000
6    13    0.5273000 -15.1200000
6    14    0.5458000 -10.5700000
6    15    0.5635000 -7.6100000
6    16    0.5782000 -5.6300000
6    17    0.5894000 -4.2600000
6    18    0.5972000 -3.3100000
6    19    0.6019000 -2.6300000
6    20    0.6038000 -2.1500000
6    21    0.6032000 -1.8300000
6    22    0.6001000 -1.6600000
6    23    0.5947000 -1.6200000
6    24    0.5869000 -1.7400000
6    25    0.5766000 -2.0400000
6    26    0.5636000 -2.5900000
6    27    0.5474000 -3.4600000
6    28    0.5270000 -4.8000000
6    29    0.5009000 -6.7600000
```

```
6     30     0.4670000 -9.5800000
6     31     0.4220000 -13.4400000
6     32     0.3627000 -18.4300000
6     33     0.2886000 -24.1600000
6     34     0.2052000 -29.5800000
6     35     0.1244000 -32.8900000
6     36     5.7820000e-02 -31.1600000
6     37     1.1570000e-02 -2.4100000
6     38     2.1490000e-02 133.5200000
6     39     3.8390000e-02 150.6500000
6     40     4.8040000e-02 162.8100000
6     41     4.9400000e-02 166.8700000
6     42     3.2640000e-02 164.5700000
6     43     1.2300000e-02 174.4700000
6     44     2.2400000e-03 141.6600000
6     45     1.6400000e-03 -30.0900000
6     46     6.9000000e-04 -105.8400000
6     47     2.7000000e-04 154.1400000
6     48     0.0000000 -180.0000000
6     49     1.0000000e-05 -164.0300000
7     1      1.0160000 -0.4700000
7     2      1.0310000 -0.8300000
7     3      1.0620000 -1.6800000
7     4      1.0960000 -2.7600000
7     5      1.1640000 -5.4200000
7     6      1.3060000 -14.7100000
7     7      1.3470000 -28.4200000
7     8      1.2580000 -38.9900000
7     9      1.0440000 -48.7100000
7     10     0.7876000 -51.8500000
7     11     0.6036000 -45.8800000
7     12     0.5010000 -24.0700000
7     13     0.5110000 -16.5100000
7     14     0.5290000 -11.5600000
7     15     0.5468000 -8.3400000
7     16     0.5617000 -6.1800000
7     17     0.5731000 -4.6900000
7     18     0.5810000 -3.6400000
7     19     0.5858000 -2.8800000
7     20     0.5876000 -2.3500000
7     21     0.5868000 -1.9700000
7     22     0.5834000 -1.7400000
7     23     0.5777000 -1.6500000
7     24     0.5694000 -1.6900000
7     25     0.5587000 -1.9100000
7     26     0.5451000 -2.3400000
7     27     0.5284000 -3.0700000
7     28     0.5077000 -4.1900000
7     29     0.4818000 -5.8600000
7     30     0.4487000 -8.2300000
7     31     0.4061000 -11.4400000
7     32     0.3516000 -15.4600000
7     33     0.2851000 -19.7900000
7     34     0.2122000 -23.2800000
7     35     0.1432000 -24.2600000
7     36     8.7030000e-02 -21.2900000
7     37     4.6340000e-02 -14.2000000
7     38     1.7150000e-02 -4.6200000
7     39     6.9200000e-03 170.3700000
7     40     2.8680000e-02 167.8700000
7     41     4.1640000e-02 143.1800000
7     42     3.4450000e-02 102.2800000
7     43     1.4400000e-02 58.7300000
7     44     6.2800000e-03 172.1500000
```

```
7    45    4.8000000e-04 -167.2400000
7    46    7.7000000e-04 102.7100000
7    47    1.1000000e-04 164.3400000
7    48    3.0000000e-05 -60.2100000
7    49    0.0000000 -0.0000000
8    1     1.0170000 -0.4700000
8    2     1.0330000 -0.8500000
8    3     1.0650000 -1.7100000
8    4     1.1010000 -2.8100000
8    5     1.1710000 -5.5400000
8    6     1.3200000 -15.0400000
8    7     1.3670000 -29.0600000
8    8     1.2790000 -39.9200000
8    9     1.0620000 -50.1000000
8    10    0.7980000 -53.8600000
8    11    0.6040000 -48.4000000
8    12    0.4880000 -25.9800000
8    13    0.4962000 -17.8700000
8    14    0.5137000 -12.5200000
8    15    0.5316000 -9.0300000
8    16    0.5468000 -6.6900000
8    17    0.5585000 -5.0700000
8    18    0.5667000 -3.9300000
8    19    0.5717000 -3.1000000
8    20    0.5737000 -2.5100000
8    21    0.5730000 -2.0800000
8    22    0.5697000 -1.8000000
8    23    0.5640000 -1.6500000
8    24    0.5558000 -1.6400000
8    25    0.5452000 -1.8000000
8    26    0.5319000 -2.1600000
8    27    0.5155000 -2.8000000
8    28    0.4955000 -3.8300000
8    29    0.4708000 -5.3900000
8    30    0.4397000 -7.6500000
8    31    0.3999000 -10.7900000
8    32    0.3491000 -14.8300000
8    33    0.2871000 -19.4600000
8    34    0.2181000 -23.8700000
8    35    0.1510000 -27.0100000
8    36    9.4100000e-02 -28.3000000
8    37    5.1550000e-02 -28.8200000
8    38    2.3210000e-02 -36.4100000
8    39    1.1380000e-02 -89.6800000
8    40    1.9090000e-02 -136.9900000
8    41    2.4800000e-02 -161.0300000
8    42    1.7500000e-02 160.1600000
8    43    5.1300000e-03 104.6900000
8    44    1.6300000e-03 22.0100000
8    45    5.0500000e-03 -63.9000000
8    46    3.6000000e-04 -21.6700000
8    47    5.0000000e-05 110.2700000
8    48    2.0000000e-05 161.5900000
8    49    0.0000000 -180.0000000
9    1     1.0180000 -0.4800000
9    2     1.0330000 -0.8500000
9    3     1.0660000 -1.7200000
9    4     1.1020000 -2.8400000
9    5     1.1740000 -5.5900000
9    6     1.3250000 -15.1700000
9    7     1.3750000 -29.3100000
9    8     1.2880000 -40.2900000
9    9     1.0690000 -50.6500000
9    10    0.8023000 -54.6500000
```

```
 9    11    0.6044000 -49.4000000
 9    12    0.4830000 -26.7500000
 9    13    0.4904000 -18.4200000
 9    14    0.5078000 -12.9100000
 9    15    0.5258000 -9.3000000
 9    16    0.5411000 -6.8800000
 9    17    0.5530000 -5.2200000
 9    18    0.5613000 -4.0400000
 9    19    0.5665000 -3.1800000
 9    20    0.5686000 -2.5600000
 9    21    0.5680000 -2.1100000
 9    22    0.5649000 -1.8100000
 9    23    0.5593000 -1.6500000
 9    24    0.5513000 -1.6200000
 9    25    0.5409000 -1.7600000
 9    26    0.5279000 -2.1100000
 9    27    0.5120000 -2.7400000
 9    28    0.4926000 -3.7600000
 9    29    0.4687000 -5.3300000
 9    30    0.4387000 -7.6500000
 9    31    0.4002000 -10.9300000
 9    32    0.3507000 -15.2500000
 9    33    0.2897000 -20.4300000
 9    34    0.2208000 -25.8100000
 9    35    0.1526000 -30.5600000
 9    36    9.3830000e-02 -34.1400000
 9    37    5.0370000e-02 -36.9900000
 9    38    2.4430000e-02 -42.1700000
 9    39    1.6510000e-02 -55.0800000
 9    40    2.4480000e-02 -65.0600000
 9    41    3.6730000e-02 -74.6600000
 9    42    3.1370000e-02 -85.1800000
 9    43    9.3500000e-03 -46.1100000
 9    44    1.2800000e-03 -61.7600000
 9    45    6.6000000e-03 85.6400000
 9    46    6.5000000e-04 -130.4500000
 9    47    3.0000000e-05 1.9200000
 9    48    1.0000000e-05 158.5700000
 9    49    0.0000000 0.0000000
'-----------------------------------------------------------------------
 HFTRANSFER FUNCTION ROLL
'-----------------------------------------------------------------------
'idir ifreq amplitude phase[deg]
 1    1     0.0000000 180.0000000
 1    2     0.0000000 180.0000000
 1    3     0.0000000 180.0000000
 1    4     0.0000000 180.0000000
 1    5     0.0000000 180.0000000
 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 180.0000000
 1    13    0.0000000 0.0000000
 1    14    0.0000000 180.0000000
 1    15    0.0000000 180.0000000
 1    16    0.0000000 -180.0000000
 1    17    0.0000000 180.0000000
 1    18    0.0000000 0.0000000
 1    19    0.0000000 0.0000000
 1    20    0.0000000 -180.0000000
 1    21    0.0000000 180.0000000
```

```
1    22    0.0000000 -180.0000000
1    23    0.0000000 180.0000000
1    24    0.0000000 180.0000000
1    25    0.0000000 180.0000000
1    26    0.0000000 180.0000000
1    27    0.0000000 180.0000000
1    28    0.0000000 0.0000000
1    29    0.0000000 180.0000000
1    30    0.0000000 180.0000000
1    31    0.0000000 180.0000000
1    32    0.0000000 180.0000000
1    33    0.0000000 -180.0000000
1    34    0.0000000 0.0000000
1    35    0.0000000 -180.0000000
1    36    0.0000000 0.0000000
1    37    0.0000000 0.0000000
1    38    0.0000000 180.0000000
1    39    0.0000000 -180.0000000
1    40    0.0000000 -0.0000000
1    41    0.0000000 -180.0000000
1    42    0.0000000 180.0000000
1    43    0.0000000 180.0000000
1    44    0.0000000 -180.0000000
1    45    0.0000000 -180.0000000
1    46    0.0000000 0.0000000
1    47    0.0000000 180.0000000
1    48    0.0000000 -180.0000000
1    49    0.0000000 -180.0000000
2    1     0.2266300 -101.5100000
2    2     0.2252600 -97.3800000
2    3     0.2232700 -95.3200000
2    4     0.2219400 -94.5500000
2    5     0.2203000 -93.8900000
2    6     0.2179900 -93.3200000
2    7     0.2164100 -93.0700000
2    8     0.2155100 -92.9400000
2    9     0.2144900 -92.8200000
2    10    0.2133500 -92.7100000
2    11    0.2120100 -92.5900000
2    12    0.2090500 -92.3600000
2    13    0.2074100 -92.2500000
2    14    0.2054000 -92.1400000
2    15    0.2033400 -92.0300000
2    16    0.2010300 -91.9100000
2    17    0.1984500 -91.8000000
2    18    0.1956000 -91.6800000
2    19    0.1925900 -91.5500000
2    20    0.1891400 -91.4200000
2    21    0.1853800 -91.2900000
2    22    0.1813100 -91.1400000
2    23    0.1768200 -90.9900000
2    24    0.1720400 -90.8300000
2    25    0.1667800 -90.6700000
2    26    0.1610800 -90.5200000
2    27    0.1550000 -90.3900000
2    28    0.1485700 -90.3100000
2    29    0.1417600 -90.3500000
2    30    0.1346500 -90.6400000
2    31    0.1272700 -91.3800000
2    32    0.1197000 -93.0100000
2    33    0.1117400 -96.2600000
2    34    0.1025700 -102.5000000
2    35    9.0260000e-02 -113.8900000
2    36    7.1350000e-02 -132.7900000
```

2	37	4.6530000e-02	-159.1400000
2	38	2.5340000e-02	169.5900000
2	39	1.3410000e-02	136.4400000
2	40	6.6900000e-03	109.1900000
2	41	6.0000000e-04	46.4600000
2	42	5.9500000e-03	-100.7500000
2	43	4.4800000e-03	-130.9400000
2	44	1.3200000e-03	-67.2200000
2	45	1.2000000e-04	-40.7400000
2	46	3.0000000e-05	72.0600000
2	47	1.0000000e-05	67.6700000
2	48	0.0000000	-0.0000000
2	49	0.0000000	-0.0000000
3	1	0.4151700	-101.8200000
3	2	0.4125900	-97.6100000
3	3	0.4087000	-95.5200000
3	4	0.4059500	-94.7400000
3	5	0.4027900	-94.0800000
3	6	0.3981900	-93.5200000
3	7	0.3952000	-93.2600000
3	8	0.3935100	-93.1400000
3	9	0.3914000	-93.0300000
3	10	0.3892800	-92.9100000
3	11	0.3868600	-92.8000000
3	12	0.3811800	-92.5800000
3	13	0.3780100	-92.4700000
3	14	0.3743700	-92.3600000
3	15	0.3704000	-92.2600000
3	16	0.3658900	-92.1500000
3	17	0.3611400	-92.0400000
3	18	0.3557900	-91.9300000
3	19	0.3499800	-91.8100000
3	20	0.3436800	-91.6900000
3	21	0.3367500	-91.5600000
3	22	0.3291900	-91.4200000
3	23	0.3208200	-91.2700000
3	24	0.3118700	-91.1200000
3	25	0.3021000	-90.9500000
3	26	0.2914800	-90.7800000
3	27	0.2801200	-90.6100000
3	28	0.2678900	-90.4700000
3	29	0.2549300	-90.3800000
3	30	0.2411900	-90.4300000
3	31	0.2267900	-90.7600000
3	32	0.2116400	-91.6500000
3	33	0.1955200	-93.6200000
3	34	0.1772100	-97.6200000
3	35	0.1534300	-105.1600000
3	36	0.1188100	-117.4400000
3	37	7.4330000e-02	-132.4200000
3	38	3.5330000e-02	-144.6100000
3	39	1.2230000e-02	-149.8600000
3	40	3.0500000e-03	-133.2700000
3	41	1.9100000e-03	-114.4400000
3	42	1.8400000e-03	-144.2500000
3	43	6.5000000e-04	124.3000000
3	44	1.1400000e-03	14.0200000
3	45	3.3000000e-04	84.4300000
3	46	1.3000000e-04	-134.0700000
3	47	0.0000000	0.0000000
3	48	0.0000000	-180.0000000
3	49	0.0000000	-0.0000000
4	1	0.5377800	-102.1300000
4	2	0.5344700	-97.8500000

```
4    3    0.5289000 -95.7300000
4    4    0.5255900 -94.9400000
4    5    0.5207200 -94.2800000
4    6    0.5144700 -93.7200000
4    7    0.5103600 -93.4700000
4    8    0.5077600 -93.3500000
4    9    0.5052000 -93.2300000
4    10   0.5021300 -93.1200000
4    11   0.4989500 -93.0100000
4    12   0.4911600 -92.8000000
4    13   0.4868200 -92.7000000
4    14   0.4819200 -92.6000000
4    15   0.4766000 -92.5000000
4    16   0.4707900 -92.4000000
4    17   0.4644500 -92.2900000
4    18   0.4573900 -92.1900000
4    19   0.4497300 -92.0800000
4    20   0.4413200 -91.9600000
4    21   0.4321500 -91.8400000
4    22   0.4221200 -91.7100000
4    23   0.4112600 -91.5700000
4    24   0.3993100 -91.4200000
4    25   0.3864400 -91.2500000
4    26   0.3724100 -91.0700000
4    27   0.3571900 -90.8600000
4    28   0.3408200 -90.6500000
4    29   0.3233100 -90.4400000
4    30   0.3045200 -90.2600000
4    31   0.2844900 -90.1700000
4    32   0.2633300 -90.3100000
4    33   0.2407500 -90.9200000
4    34   0.2161100 -92.5200000
4    35   0.1870200 -95.8900000
4    36   0.1494800 -101.4200000
4    37   0.1042200 -106.9400000
4    38   6.3170000e-02 -108.7700000
4    39   3.3470000e-02 -107.2200000
4    40   1.3580000e-02 -104.8000000
4    41   1.8200000e-03 -100.1300000
4    42   2.5000000e-03 76.4200000
4    43   3.1200000e-03 78.2400000
4    44   7.4000000e-04 38.2100000
4    45   9.0000000e-05 77.3800000
4    46   9.0000000e-05 -145.5500000
4    47   1.0000000e-05 32.1300000
4    48   1.0000000e-05 171.0800000
4    49   0.0000000 0.0000000
5    1    0.5799700 -102.2600000
5    2    0.5764400 -97.9400000
5    3    0.5701600 -95.8100000
5    4    0.5664400 -95.0200000
5    5    0.5611900 -94.3600000
5    6    0.5543200 -93.8000000
5    7    0.5495800 -93.5500000
5    8    0.5468000 -93.4400000
5    9    0.5439700 -93.3200000
5    10   0.5405500 -93.2100000
5    11   0.5369500 -93.1000000
5    12   0.5286400 -92.9000000
5    13   0.5238200 -92.8000000
5    14   0.5185300 -92.7000000
5    15   0.5127200 -92.6000000
5    16   0.5063300 -92.5000000
5    17   0.4993300 -92.4000000
```

```
5    18    0.4916700 -92.3000000
5    19    0.4833300 -92.1900000
5    20    0.4741600 -92.0800000
5    21    0.4642700 -91.9700000
5    22    0.4533200 -91.8400000
5    23    0.4414800 -91.7000000
5    24    0.4284800 -91.5500000
5    25    0.4144400 -91.3800000
5    26    0.3991000 -91.1900000
5    27    0.3825600 -90.9800000
5    28    0.3646400 -90.7400000
5    29    0.3452600 -90.4800000
5    30    0.3245700 -90.2000000
5    31    0.3023800 -89.9400000
5    32    0.2787600 -89.7600000
5    33    0.2537500 -89.8000000
5    34    0.2270400 -90.3700000
5    35    0.1973100 -92.0500000
5    36    0.1616300 -95.3500000
5    37    0.1191700 -99.3700000
5    38    7.6830000e-02 -102.4300000
5    39    4.0400000e-02 -105.6100000
5    40    1.1590000e-02 -115.1300000
5    41    7.6600000e-03 84.9100000
5    42    1.3760000e-02 70.6100000
5    43    8.3400000e-03 88.8400000
5    44    4.8400000e-03 85.0500000
5    45    4.5000000e-04 -85.7200000
5    46    3.6000000e-04 -90.0500000
5    47    4.0000000e-05 76.7500000
5    48    1.0000000e-05 48.1900000
5    49    0.0000000 0.0000000
6    1     0.5377800 -102.1300000
6    2     0.5344700 -97.8500000
6    3     0.5289000 -95.7300000
6    4     0.5255900 -94.9400000
6    5     0.5207200 -94.2800000
6    6     0.5144700 -93.7200000
6    7     0.5103600 -93.4700000
6    8     0.5077600 -93.3500000
6    9     0.5052000 -93.2300000
6    10    0.5021300 -93.1200000
6    11    0.4989500 -93.0100000
6    12    0.4911600 -92.8000000
6    13    0.4868200 -92.7000000
6    14    0.4819200 -92.6000000
6    15    0.4766000 -92.5000000
6    16    0.4707900 -92.4000000
6    17    0.4644500 -92.2900000
6    18    0.4573900 -92.1900000
6    19    0.4497300 -92.0800000
6    20    0.4413200 -91.9600000
6    21    0.4321500 -91.8400000
6    22    0.4221200 -91.7100000
6    23    0.4112600 -91.5700000
6    24    0.3993100 -91.4200000
6    25    0.3864400 -91.2500000
6    26    0.3724100 -91.0700000
6    27    0.3571900 -90.8600000
6    28    0.3408200 -90.6500000
6    29    0.3233100 -90.4400000
6    30    0.3045200 -90.2600000
6    31    0.2844900 -90.1700000
6    32    0.2633300 -90.3100000
```

```
6    33    0.2407500 -90.9200000
6    34    0.2161100 -92.5200000
6    35    0.1870200 -95.8900000
6    36    0.1494800 -101.4200000
6    37    0.1042200 -106.9400000
6    38    6.3170000e-02 -108.7700000
6    39    3.3470000e-02 -107.2200000
6    40    1.3580000e-02 -104.8000000
6    41    1.8200000e-03 -100.1300000
6    42    2.5000000e-03 76.4200000
6    43    3.1200000e-03 78.2400000
6    44    7.4000000e-04 38.2100000
6    45    9.0000000e-05 77.3800000
6    46    9.0000000e-05 -145.5500000
6    47    1.0000000e-05 32.1300000
6    48    1.0000000e-05 171.0800000
6    49    0.0000000 0.0000000
7    1     0.4151700 -101.8200000
7    2     0.4125900 -97.6100000
7    3     0.4087000 -95.5200000
7    4     0.4059500 -94.7400000
7    5     0.4027900 -94.0800000
7    6     0.3981900 -93.5200000
7    7     0.3952000 -93.2600000
7    8     0.3935100 -93.1400000
7    9     0.3914000 -93.0300000
7    10    0.3892800 -92.9100000
7    11    0.3868600 -92.8000000
7    12    0.3811800 -92.5800000
7    13    0.3780100 -92.4700000
7    14    0.3743700 -92.3600000
7    15    0.3704000 -92.2600000
7    16    0.3658900 -92.1500000
7    17    0.3611400 -92.0400000
7    18    0.3557900 -91.9300000
7    19    0.3499800 -91.8100000
7    20    0.3436800 -91.6900000
7    21    0.3367500 -91.5600000
7    22    0.3291900 -91.4200000
7    23    0.3208200 -91.2700000
7    24    0.3118700 -91.1200000
7    25    0.3021000 -90.9500000
7    26    0.2914800 -90.7800000
7    27    0.2801200 -90.6100000
7    28    0.2678900 -90.4700000
7    29    0.2549300 -90.3800000
7    30    0.2411900 -90.4300000
7    31    0.2267900 -90.7600000
7    32    0.2116400 -91.6500000
7    33    0.1955200 -93.6200000
7    34    0.1772100 -97.6200000
7    35    0.1534300 -105.1600000
7    36    0.1188100 -117.4400000
7    37    7.4330000e-02 -132.4200000
7    38    3.5330000e-02 -144.6100000
7    39    1.2230000e-02 -149.8600000
7    40    3.0500000e-03 -133.2700000
7    41    1.9100000e-03 -114.4400000
7    42    1.8400000e-03 -144.2500000
7    43    6.5000000e-04 124.3000000
7    44    1.1400000e-03 14.0200000
7    45    3.3000000e-04 84.4300000
7    46    1.3000000e-04 -134.0700000
7    47    0.0000000 0.0000000
```

```
7    48    0.0000000 -180.0000000
7    49    0.0000000 -0.0000000
8    1     0.2266300 -101.5100000
8    2     0.2252600 -97.3800000
8    3     0.2232700 -95.3200000
8    4     0.2219400 -94.5500000
8    5     0.2203000 -93.8900000
8    6     0.2179900 -93.3200000
8    7     0.2164100 -93.0700000
8    8     0.2155100 -92.9400000
8    9     0.2144900 -92.8200000
8    10    0.2133500 -92.7100000
8    11    0.2120100 -92.5900000
8    12    0.2090500 -92.3600000
8    13    0.2074100 -92.2500000
8    14    0.2054000 -92.1400000
8    15    0.2033400 -92.0300000
8    16    0.2010300 -91.9100000
8    17    0.1984500 -91.8000000
8    18    0.1956000 -91.6800000
8    19    0.1925900 -91.5500000
8    20    0.1891400 -91.4200000
8    21    0.1853800 -91.2900000
8    22    0.1813100 -91.1400000
8    23    0.1768200 -90.9900000
8    24    0.1720400 -90.8300000
8    25    0.1667800 -90.6700000
8    26    0.1610800 -90.5200000
8    27    0.1550000 -90.3900000
8    28    0.1485700 -90.3100000
8    29    0.1417600 -90.3500000
8    30    0.1346500 -90.6400000
8    31    0.1272700 -91.3800000
8    32    0.1197000 -93.0100000
8    33    0.1117400 -96.2600000
8    34    0.1025700 -102.5000000
8    35    9.0260000e-02 -113.8900000
8    36    7.1350000e-02 -132.7900000
8    37    4.6530000e-02 -159.1400000
8    38    2.5340000e-02 169.5900000
8    39    1.3410000e-02 136.4400000
8    40    6.6900000e-03 109.1900000
8    41    6.0000000e-04 46.4600000
8    42    5.9500000e-03 -100.7500000
8    43    4.4800000e-03 -130.9400000
8    44    1.3200000e-03 -67.2200000
8    45    1.2000000e-04 -40.7400000
8    46    3.0000000e-05 72.0600000
8    47    1.0000000e-05 67.6700000
8    48    0.0000000 -0.0000000
8    49    0.0000000 -0.0000000
9    1     0.0000000 0.0000000
9    2     0.0000000 180.0000000
9    3     0.0000000 180.0000000
9    4     0.0000000 180.0000000
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 180.0000000
 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
 9    27     0.0000000 0.0000000
 9    28     0.0000000 180.0000000
 9    29     0.0000000 180.0000000
 9    30     0.0000000 0.0000000
 9    31     0.0000000 0.0000000
 9    32     0.0000000 0.0000000
 9    33     0.0000000 0.0000000
 9    34     0.0000000 0.0000000
 9    35     0.0000000 0.0000000
 9    36     0.0000000 0.0000000
 9    37     0.0000000 0.0000000
 9    38     0.0000000 -0.0000000
 9    39     0.0000000 -0.0000000
 9    40     0.0000000 -0.0000000
 9    41     0.0000000 180.0000000
 9    42     0.0000000 0.0000000
 9    43     0.0000000 0.0000000
 9    44     0.0000000 180.0000000
 9    45     0.0000000 -180.0000000
 9    46     0.0000000 0.0000000
 9    47     0.0000000 180.0000000
 9    48     0.0000000 -0.0000000
 9    49     0.0000000 -180.0000000
'----------------------------------------------------------------------
 HFTRANSFER FUNCTION PITCH
'----------------------------------------------------------------------
'idir ifreq amplitude phase[deg]
 1    1      0.5703300 68.5800000
 1    2      0.5684700 77.2200000
 1    3      0.5684900 81.1500000
 1    4      0.5668000 82.5300000
 1    5      0.5634100 83.6400000
 1    6      0.5575700 84.5400000
 1    7      0.5530800 84.9300000
 1    8      0.5501500 85.1100000
 1    9      0.5471800 85.2900000
 1    10     0.5438500 85.4600000
 1    11     0.5398900 85.6200000
 1    12     0.5309400 85.9300000
 1    13     0.5256400 86.0700000
 1    14     0.5197400 86.2200000
 1    15     0.5132100 86.3600000
 1    16     0.5060200 86.4900000
 1    17     0.4981400 86.6300000
 1    18     0.4894200 86.7700000
 1    19     0.4797500 86.9100000
 1    20     0.4692700 87.0500000
 1    21     0.4576600 87.2000000
 1    22     0.4449900 87.3600000
 1    23     0.4310600 87.5200000
 1    24     0.4158900 87.7100000
```

```
1    25    0.3992100 87.9100000
1    26    0.3810800 88.1400000
1    27    0.3613800 88.3900000
1    28    0.3400100 88.6800000
1    29    0.3168700 89.0100000
1    30    0.2919600 89.3800000
1    31    0.2653300 89.7700000
1    32    0.2370900 90.1400000
1    33    0.2072800 90.3700000
1    34    0.1759500 90.1500000
1    35    0.1424300 88.8400000
1    36    0.1052800 85.6500000
1    37    6.5080000e-02 80.5800000
1    38    2.7610000e-02 72.9000000
1    39    3.2400000e-03 -44.1900000
1    40    1.7300000e-02 -104.2300000
1    41    1.6140000e-02 -110.4000000
1    42    6.2000000e-03 -74.2100000
1    43    7.4100000e-03 -52.2700000
1    44    2.4900000e-03 68.4500000
1    45    8.5000000e-04 116.6600000
1    46    3.0000000e-05 -173.9200000
1    47    3.0000000e-05 -21.9700000
1    48    1.0000000e-05 3.2500000
1    49    0.0000000 180.0000000
2    1     0.5300100 68.9000000
2    2     0.5287800 77.4400000
2    3     0.5289000 81.3300000
2    4     0.5277800 82.6900000
2    5     0.5248300 83.7900000
2    6     0.5198900 84.6900000
2    7     0.5158600 85.0800000
2    8     0.5135100 85.2600000
2    9     0.5109300 85.4400000
2    10    0.5078400 85.6100000
2    11    0.5044100 85.7700000
2    12    0.4965100 86.0800000
2    13    0.4917400 86.2300000
2    14    0.4866100 86.3800000
2    15    0.4807200 86.5200000
2    16    0.4743900 86.6600000
2    17    0.4672700 86.8000000
2    18    0.4594900 86.9400000
2    19    0.4509200 87.0900000
2    20    0.4415700 87.2300000
2    21    0.4312100 87.3900000
2    22    0.4197900 87.5500000
2    23    0.4073000 87.7200000
2    24    0.3937400 87.9000000
2    25    0.3788700 88.1000000
2    26    0.3626300 88.3200000
2    27    0.3450900 88.5600000
2    28    0.3260200 88.8100000
2    29    0.3054200 89.0700000
2    30    0.2833500 89.3100000
2    31    0.2597700 89.4800000
2    32    0.2346800 89.4500000
2    33    0.2079000 88.9800000
2    34    0.1789400 87.6000000
2    35    0.1462700 84.6000000
2    36    0.1080200 79.6900000
2    37    6.7120000e-02 74.8200000
2    38    3.2890000e-02 73.3400000
2    39    1.0080000e-02 78.7200000
```

```
2    40    2.5300000e-03 -148.3900000
2    41    4.6000000e-03 -118.3400000
2    42    3.9300000e-03 -93.5900000
2    43    2.4700000e-03 -152.3400000
2    44    1.1800000e-03 -102.2200000
2    45    6.5000000e-04 -93.6300000
2    46    1.8000000e-04 7.4100000
2    47    5.0000000e-05 -161.1900000
2    48    1.0000000e-05 -102.6500000
2    49    0.0000000 -180.0000000
3    1     0.4114200 69.6500000
3    2     0.4111000 77.9500000
3    3     0.4118200 81.7300000
3    4     0.4114300 83.0600000
3    5     0.4097500 84.1500000
3    6     0.4065900 85.0400000
3    7     0.4041900 85.4300000
3    8     0.4026200 85.6200000
3    9     0.4008100 85.7900000
3    10    0.3987200 85.9700000
3    11    0.3965200 86.1300000
3    12    0.3911300 86.4500000
3    13    0.3878500 86.6000000
3    14    0.3842600 86.7500000
3    15    0.3801300 86.9000000
3    16    0.3757600 87.0500000
3    17    0.3707900 87.2000000
3    18    0.3652100 87.3400000
3    19    0.3591400 87.4900000
3    20    0.3524500 87.6500000
3    21    0.3451300 87.8100000
3    22    0.3369700 87.9700000
3    23    0.3281100 88.1500000
3    24    0.3184100 88.3300000
3    25    0.3077500 88.5200000
3    26    0.2962400 88.7100000
3    27    0.2837600 88.9000000
3    28    0.2701600 89.0600000
3    29    0.2556100 89.1600000
3    30    0.2400700 89.1100000
3    31    0.2234000 88.7900000
3    32    0.2054500 87.9200000
3    33    0.1858100 86.0300000
3    34    0.1631100 82.2700000
3    35    0.1346100 75.5000000
3    36    9.7130000e-02 65.2700000
3    37    5.5150000e-02 55.0200000
3    38    2.3170000e-02 54.8600000
3    39    9.4900000e-03 80.8700000
3    40    7.1300000e-03 93.3900000
3    41    6.3800000e-03 69.3700000
3    42    5.8400000e-03 55.5200000
3    43    3.8700000e-03 74.3100000
3    44    1.6000000e-03 85.5700000
3    45    1.0000000e-04 -167.8400000
3    46    3.2000000e-04 81.5200000
3    47    2.0000000e-05 -143.4300000
3    48    1.0000000e-05 -145.2700000
3    49    0.0000000 -180.0000000
4    1     0.2258000 70.3800000
4    2     0.2260100 78.4400000
4    3     0.2266500 82.1200000
4    4     0.2266100 83.4300000
4    5     0.2260900 84.4900000
```

```
4    6     0.2247900 85.3800000
4    7     0.2236800 85.7700000
4    8     0.2229800 85.9500000
4    9     0.2221800 86.1300000
4    10    0.2213200 86.3000000
4    11    0.2202000 86.4700000
4    12    0.2174600 86.7900000
4    13    0.2159800 86.9500000
4    14    0.2142500 87.1000000
4    15    0.2122400 87.2600000
4    16    0.2101100 87.4100000
4    17    0.2075100 87.5600000
4    18    0.2048800 87.7100000
4    19    0.2017500 87.8700000
4    20    0.1984100 88.0300000
4    21    0.1947000 88.1900000
4    22    0.1906300 88.3600000
4    23    0.1860900 88.5300000
4    24    0.1811100 88.7100000
4    25    0.1757100 88.8800000
4    26    0.1697500 89.0400000
4    27    0.1633800 89.1800000
4    28    0.1564100 89.2500000
4    29    0.1488800 89.1900000
4    30    0.1408300 88.8900000
4    31    0.1321500 88.1200000
4    32    0.1226400 86.4900000
4    33    0.1118400 83.3000000
4    34    9.8710000e-02 77.2800000
4    35    8.1140000e-02 66.3500000
4    36    5.7090000e-02 47.7700000
4    37    3.0720000e-02 17.4200000
4    38    1.5330000e-02 -37.4500000
4    39    1.4420000e-02 -85.6300000
4    40    1.4130000e-02 -95.2500000
4    41    1.2580000e-02 -85.0400000
4    42    1.1750000e-02 -74.8500000
4    43    5.5200000e-03 -105.1700000
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4    45    4.7000000e-04 -80.4200000
4    46    1.4000000e-04 -105.1900000
4    47    3.0000000e-05 131.4200000
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4    49    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 -180.0000000
5    8     0.0000000 -180.0000000
5    9     0.0000000 -180.0000000
5    10    0.0000000 -180.0000000
5    11    0.0000000 -0.0000000
5    12    0.0000000 -180.0000000
5    13    0.0000000 180.0000000
5    14    0.0000000 -180.0000000
5    15    0.0000000 -180.0000000
5    16    0.0000000 -180.0000000
5    17    0.0000000 -0.0000000
5    18    0.0000000 -180.0000000
5    19    0.0000000 -180.0000000
5    20    0.0000000 -180.0000000
```

```
5    21    0.0000000 -180.0000000
5    22    0.0000000 -0.0000000
5    23    0.0000000 -180.0000000
5    24    0.0000000 -180.0000000
5    25    0.0000000 -180.0000000
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5    27    0.0000000 -180.0000000
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5    29    0.0000000 -0.0000000
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5    31    0.0000000 -180.0000000
5    32    0.0000000 -180.0000000
5    33    0.0000000 -180.0000000
5    34    0.0000000 -180.0000000
5    35    0.0000000 -180.0000000
5    36    0.0000000 -180.0000000
5    37    0.0000000 180.0000000
5    38    0.0000000 180.0000000
5    39    0.0000000 0.0000000
5    40    0.0000000 0.0000000
5    41    0.0000000 180.0000000
5    42    0.0000000 180.0000000
5    43    0.0000000 0.0000000
5    44    0.0000000 -180.0000000
5    45    0.0000000 -180.0000000
5    46    0.0000000 -180.0000000
5    47    0.0000000 180.0000000
5    48    0.0000000 -180.0000000
5    49    0.0000000 -0.0000000
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6    2     0.2260100 -101.5600000
6    3     0.2266500 -97.8800000
6    4     0.2266100 -96.5700000
6    5     0.2260900 -95.5100000
6    6     0.2247900 -94.6200000
6    7     0.2236800 -94.2300000
6    8     0.2229800 -94.0500000
6    9     0.2221800 -93.8700000
6    10    0.2213200 -93.7000000
6    11    0.2202000 -93.5300000
6    12    0.2174600 -93.2100000
6    13    0.2159800 -93.0500000
6    14    0.2142500 -92.9000000
6    15    0.2122400 -92.7500000
6    16    0.2101100 -92.5900000
6    17    0.2075100 -92.4400000
6    18    0.2048800 -92.2900000
6    19    0.2017500 -92.1300000
6    20    0.1984100 -91.9700000
6    21    0.1947000 -91.8100000
6    22    0.1906300 -91.6400000
6    23    0.1860900 -91.4700000
6    24    0.1811100 -91.3000000
6    25    0.1757100 -91.1200000
6    26    0.1697500 -90.9600000
6    27    0.1633800 -90.8200000
6    28    0.1564100 -90.7500000
6    29    0.1488800 -90.8100000
6    30    0.1408300 -91.1100000
6    31    0.1321500 -91.8800000
6    32    0.1226400 -93.5100000
6    33    0.1118400 -96.7000000
6    34    9.8710000e-02 -102.7300000
6    35    8.1140000e-02 -113.6600000
```

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6     36     5.7090000e-02 -132.2300000
6     37     3.0720000e-02 -162.5800000
6     38     1.5330000e-02 142.5500000
6     39     1.4420000e-02 94.3700000
6     40     1.4130000e-02 84.7500000
6     41     1.2580000e-02 94.9600000
6     42     1.1750000e-02 105.1500000
6     43     5.5200000e-03 74.8300000
6     44     3.6000000e-04 159.6200000
6     45     4.7000000e-04 99.5800000
6     46     1.4000000e-04 74.8100000
6     47     3.0000000e-05 -48.5800000
6     48     0.0000000 -0.0000000
6     49     0.0000000 180.0000000
7     1      0.4114200 -110.3500000
7     2      0.4111000 -102.0600000
7     3      0.4118200 -98.2700000
7     4      0.4114300 -96.9400000
7     5      0.4097500 -95.8500000
7     6      0.4065900 -94.9600000
7     7      0.4041900 -94.5700000
7     8      0.4026200 -94.3800000
7     9      0.4008100 -94.2100000
7     10     0.3987200 -94.0300000
7     11     0.3965200 -93.8700000
7     12     0.3911300 -93.5500000
7     13     0.3878500 -93.4000000
7     14     0.3842600 -93.2500000
7     15     0.3801300 -93.1000000
7     16     0.3757600 -92.9500000
7     17     0.3707900 -92.8000000
7     18     0.3652100 -92.6600000
7     19     0.3591400 -92.5100000
7     20     0.3524500 -92.3500000
7     21     0.3451300 -92.1900000
7     22     0.3369700 -92.0300000
7     23     0.3281100 -91.8500000
7     24     0.3184100 -91.6700000
7     25     0.3077500 -91.4800000
7     26     0.2962400 -91.2900000
7     27     0.2837600 -91.1000000
7     28     0.2701600 -90.9400000
7     29     0.2556100 -90.8500000
7     30     0.2400700 -90.8900000
7     31     0.2234000 -91.2100000
7     32     0.2054500 -92.0800000
7     33     0.1858100 -93.9700000
7     34     0.1631100 -97.7300000
7     35     0.1346100 -104.5000000
7     36     9.7130000e-02 -114.7300000
7     37     5.5150000e-02 -124.9800000
7     38     2.3170000e-02 -125.1400000
7     39     9.4900000e-03 -99.1300000
7     40     7.1300000e-03 -86.6100000
7     41     6.3800000e-03 -110.6300000
7     42     5.8400000e-03 -124.4800000
7     43     3.8700000e-03 -105.6900000
7     44     1.6000000e-03 -94.4300000
7     45     1.0000000e-04 12.1700000
7     46     3.2000000e-04 -98.4800000
7     47     2.0000000e-05 36.5700000
7     48     1.0000000e-05 34.7300000
7     49     0.0000000 0.0000000
8     1      0.5300100 -111.1000000
```

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8     2      0.5287800 -102.5600000
8     3      0.5289000 -98.6800000
8     4      0.5277800 -97.3100000
8     5      0.5248300 -96.2100000
8     6      0.5198900 -95.3100000
8     7      0.5158600 -94.9200000
8     8      0.5135100 -94.7400000
8     9      0.5109300 -94.5600000
8     10     0.5078400 -94.3900000
8     11     0.5044100 -94.2300000
8     12     0.4965100 -93.9200000
8     13     0.4917400 -93.7700000
8     14     0.4866100 -93.6200000
8     15     0.4807200 -93.4800000
8     16     0.4743900 -93.3400000
8     17     0.4672700 -93.2000000
8     18     0.4594900 -93.0600000
8     19     0.4509200 -92.9100000
8     20     0.4415700 -92.7700000
8     21     0.4312100 -92.6100000
8     22     0.4197900 -92.4500000
8     23     0.4073000 -92.2800000
8     24     0.3937400 -92.1000000
8     25     0.3788700 -91.9000000
8     26     0.3626300 -91.6800000
8     27     0.3450200 -91.4500000
8     28     0.3260200 -91.1900000
8     29     0.3054200 -90.9300000
8     30     0.2833500 -90.6900000
8     31     0.2597700 -90.5300000
8     32     0.2346800 -90.5500000
8     33     0.2079000 -91.0200000
8     34     0.1789400 -92.4000000
8     35     0.1462700 -95.4000000
8     36     0.1080200 -100.3100000
8     37     6.7120000e-02 -105.1800000
8     38     3.2890000e-02 -106.6600000
8     39     1.0080000e-02 -101.2800000
8     40     2.5300000e-03 31.6100000
8     41     4.6000000e-03 61.6600000
8     42     3.9300000e-03 86.4100000
8     43     2.4700000e-03 27.6600000
8     44     1.1800000e-03 77.7800000
8     45     6.5000000e-04 86.3700000
8     46     1.8000000e-04 -172.6000000
8     47     5.0000000e-05 18.8200000
8     48     1.0000000e-05 77.3500000
8     49     0.0000000 0.0000000
9     1      0.5703300 -111.4200000
9     2      0.5684700 -102.7800000
9     3      0.5684900 -98.8500000
9     4      0.5668000 -97.4700000
9     5      0.5634100 -96.3700000
9     6      0.5575700 -95.4600000
9     7      0.5530800 -95.0700000
9     8      0.5501500 -94.8900000
9     9      0.5471800 -94.7100000
9     10     0.5438500 -94.5400000
9     11     0.5398900 -94.3800000
9     12     0.5309400 -94.0800000
9     13     0.5256400 -93.9300000
9     14     0.5197400 -93.7900000
9     15     0.5132100 -93.6500000
9     16     0.5060200 -93.5100000
```

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9    22    0.4449900 -92.6500000
9    23    0.4310600 -92.4800000
9    24    0.4158900 -92.2900000
9    25    0.3992100 -92.0900000
9    26    0.3810800 -91.8700000
9    27    0.3613800 -91.6100000
9    28    0.3400100 -91.3200000
9    29    0.3168700 -90.9900000
9    30    0.2919600 -90.6200000
9    31    0.2653300 -90.2300000
9    32    0.2370900 -89.8600000
9    33    0.2072800 -89.6300000
9    34    0.1759500 -89.8500000
9    35    0.1424300 -91.1600000
9    36    0.1052800 -94.3500000
9    37    6.5080000e-02 -99.4200000
9    38    2.7610000e-02 -107.1000000
9    39    3.2400000e-03 135.8200000
9    40    1.7300000e-02 75.7700000
9    41    1.6140000e-02 69.6000000
9    42    6.2000000e-03 105.7900000
9    43    7.4100000e-03 127.7300000
9    44    2.4900000e-03 -111.5500000
9    45    8.5000000e-04 -63.3400000
9    46    3.0000000e-05 6.0800000
9    47    3.0000000e-05 158.0300000
9    48    1.0000000e-05 -176.7500000
9    49    0.0000000 -0.0000000
'----------------------------------------------------------------------
 HFTRANSFER FUNCTION YAW
'----------------------------------------------------------------------
'idir ifreq amplitude phase[deg]
 1    1     0.0000000 -180.0000000
 1    2     0.0000000 180.0000000
 1    3     0.0000000 -180.0000000
 1    4     0.0000000 -180.0000000
 1    5     0.0000000 180.0000000
 1    6     0.0000000 -180.0000000
 1    7     0.0000000 180.0000000
 1    8     0.0000000 -180.0000000
 1    9     0.0000000 -180.0000000
 1    10    0.0000000 0.0000000
 1    11    0.0000000 -180.0000000
 1    12    0.0000000 -180.0000000
 1    13    0.0000000 -0.0000000
 1    14    0.0000000 -0.0000000
 1    15    0.0000000 180.0000000
 1    16    0.0000000 180.0000000
 1    17    0.0000000 180.0000000
 1    18    0.0000000 180.0000000
 1    19    0.0000000 180.0000000
 1    20    0.0000000 180.0000000
 1    21    0.0000000 -180.0000000
 1    22    0.0000000 -0.0000000
 1    23    0.0000000 180.0000000
 1    24    0.0000000 180.0000000
 1    25    0.0000000 180.0000000
 1    26    0.0000000 -180.0000000
 1    27    0.0000000 -180.0000000
```

```
1    28    0.0000000 -180.0000000
1    29    0.0000000 180.0000000
1    30    0.0000000 180.0000000
1    31    0.0000000 -180.0000000
1    32    0.0000000 180.0000000
1    33    0.0000000 -180.0000000
1    34    0.0000000 -180.0000000
1    35    0.0000000 -180.0000000
1    36    0.0000000 -180.0000000
1    37    0.0000000 -0.0000000
1    38    0.0000000 -0.0000000
1    39    0.0000000 -0.0000000
1    40    0.0000000 -0.0000000
1    41    0.0000000 -180.0000000
1    42    0.0000000 180.0000000
1    43    0.0000000 180.0000000
1    44    0.0000000 180.0000000
1    45    0.0000000 -180.0000000
1    46    0.0000000 -180.0000000
1    47    0.0000000 -0.0000000
1    48    0.0000000 180.0000000
1    49    0.0000000 -180.0000000
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2    2     9.0320000e-02 169.8900000
2    3     8.2440000e-02 171.0000000
2    4     7.9440000e-02 171.5600000
2    5     7.6990000e-02 172.1400000
2    6     7.4870000e-02 172.7300000
2    7     7.3870000e-02 173.0300000
2    8     7.3390000e-02 173.1800000
2    9     7.2890000e-02 173.3300000
2    10    7.2390000e-02 173.4900000
2    11    7.1870000e-02 173.6500000
2    12    7.0800000e-02 173.9600000
2    13    7.0240000e-02 174.1200000
2    14    6.9670000e-02 174.2800000
2    15    6.9070000e-02 174.4400000
2    16    6.8430000e-02 174.6100000
2    17    6.7770000e-02 174.7700000
2    18    6.7070000e-02 174.9300000
2    19    6.6360000e-02 175.0900000
2    20    6.5590000e-02 175.2600000
2    21    6.4800000e-02 175.4100000
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2    24    6.2180000e-02 175.8400000
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2    26    6.0220000e-02 176.0700000
2    27    5.9160000e-02 176.1400000
2    28    5.8030000e-02 176.2000000
2    29    5.6840000e-02 176.2400000
2    30    5.5560000e-02 176.2900000
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2    34    5.0180000e-02 177.6300000
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2    42    2.2950000e-02 155.2600000
```

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2    43    7.0800000e-03 128.0800000
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2    47    3.8000000e-04 110.9500000
2    48    2.5000000e-04 -17.6300000
2    49    8.0000000e-05 -150.1500000
3    1     0.1460700 168.5100000
3    2     0.1269800 169.8300000
3    3     0.1155700 170.9000000
3    4     0.1110600 171.4500000
3    5     0.1072100 172.0000000
3    6     0.1036800 172.5500000
3    7     0.1019200 172.8300000
3    8     0.1010300 172.9700000
3    9     0.1001000 173.1100000
3    10    9.9130000e-02 173.2500000
3    11    9.8110000e-02 173.3900000
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3    16    9.0680000e-02 174.1900000
3    17    8.9130000e-02 174.3200000
3    18    8.7440000e-02 174.4400000
3    19    8.5630000e-02 174.5600000
3    20    8.3650000e-02 174.6700000
3    21    8.1510000e-02 174.7600000
3    22    7.9160000e-02 174.8400000
3    23    7.6600000e-02 174.9100000
3    24    7.3810000e-02 174.9400000
3    25    7.0730000e-02 174.9300000
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3    29    5.4800000e-02 174.2400000
3    30    4.9640000e-02 173.8100000
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3    34    2.3620000e-02 172.0900000
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3    38    4.4000000e-04 177.5000000
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3    42    2.1300000e-03 -117.4900000
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3    47    1.8000000e-04 104.5200000
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4    5     7.4650000e-02 171.8600000
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4    7     7.0270000e-02 172.6200000
4    8     6.9480000e-02 172.7500000
```

```
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4    12    6.4860000e-02 173.3300000
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4    15    6.1220000e-02 173.6400000
4    16    5.9790000e-02 173.7200000
4    17    5.8250000e-02 173.8000000
4    18    5.6540000e-02 173.8600000
4    19    5.4680000e-02 173.9100000
4    20    5.2640000e-02 173.9300000
4    21    5.0380000e-02 173.9200000
4    22    4.7890000e-02 173.8700000
4    23    4.5120000e-02 173.7700000
4    24    4.2030000e-02 173.5800000
4    25    3.8600000e-02 173.2700000
4    26    3.4750000e-02 172.7800000
4    27    3.0430000e-02 172.0000000
4    28    2.5580000e-02 170.7100000
4    29    2.0120000e-02 168.4200000
4    30    1.4020000e-02 163.6400000
4    31    7.4300000e-03 149.1300000
4    32    3.8900000e-03 66.5400000
4    33    1.0810000e-02 16.9000000
4    34    2.0000000e-02 6.9900000
4    35    2.9880000e-02 2.7600000
4    36    3.9910000e-02 0.3000000
4    37    4.9570000e-02 -1.3300000
4    38    5.8210000e-02 -2.6400000
4    39    6.4920000e-02 -4.0600000
4    40    7.1660000e-02 -9.6400000
4    41    5.3940000e-02 -21.7200000
4    42    3.2740000e-02 -23.1900000
4    43    1.0970000e-02 -21.7100000
4    44    2.7700000e-03 59.1300000
4    45    1.5200000e-03 175.8600000
4    46    1.1400000e-03 166.1600000
4    47    8.1000000e-04 -131.9000000
4    48    3.2000000e-04 88.7600000
4    49    5.0000000e-05 9.1200000
5    1     0.0000000 -180.0000000
5    2     0.0000000 -180.0000000
5    3     0.0000000 -180.0000000
5    4     0.0000000 -180.0000000
5    5     0.0000000 -180.0000000
5    6     0.0000000 -180.0000000
5    7     0.0000000 -180.0000000
5    8     0.0000000 0.0000000
5    9     0.0000000 -180.0000000
5    10    0.0000000 180.0000000
5    11    0.0000000 -180.0000000
5    12    0.0000000 -180.0000000
5    13    0.0000000 -180.0000000
5    14    0.0000000 -0.0000000
5    15    0.0000000 180.0000000
5    16    0.0000000 -180.0000000
5    17    0.0000000 0.0000000
5    18    0.0000000 -180.0000000
5    19    0.0000000 180.0000000
5    20    0.0000000 -0.0000000
5    21    0.0000000 180.0000000
5    22    0.0000000 0.0000000
5    23    0.0000000 -0.0000000
```

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5    24    0.0000000 -0.0000000
5    25    0.0000000 -0.0000000
5    26    0.0000000 -0.0000000
5    27    0.0000000 -0.0000000
5    28    0.0000000 -0.0000000
5    29    0.0000000 -0.0000000
5    30    0.0000000 180.0000000
5    31    0.0000000 -180.0000000
5    32    0.0000000 -180.0000000
5    33    0.0000000 180.0000000
5    34    0.0000000 180.0000000
5    35    0.0000000 -180.0000000
5    36    0.0000000 180.0000000
5    37    0.0000000 180.0000000
5    38    0.0000000 180.0000000
5    39    0.0000000 180.0000000
5    40    0.0000000 180.0000000
5    41    0.0000000 180.0000000
5    42    0.0000000 180.0000000
5    43    0.0000000 180.0000000
5    44    0.0000000 -0.0000000
5    45    0.0000000 -0.0000000
5    46    0.0000000 180.0000000
5    47    0.0000000 180.0000000
5    48    0.0000000 -180.0000000
5    49    0.0000000 -0.0000000
6    1     0.1029100 -11.5400000
6    2     8.9250000e-02 -10.2400000
6    3     8.0980000e-02 -9.1900000
6    4     7.7620000e-02 -8.6700000
6    5     7.4650000e-02 -8.1400000
6    6     7.1780000e-02 -7.6300000
6    7     7.0270000e-02 -7.3800000
6    8     6.9480000e-02 -7.2500000
6    9     6.8670000e-02 -7.1300000
6    10    6.7800000e-02 -7.0100000
6    11    6.6880000e-02 -6.8900000
6    12    6.4860000e-02 -6.6700000
6    13    6.3740000e-02 -6.5600000
6    14    6.2540000e-02 -6.4600000
6    15    6.1220000e-02 -6.3700000
6    16    5.9790000e-02 -6.2800000
6    17    5.8250000e-02 -6.2000000
6    18    5.6540000e-02 -6.1400000
6    19    5.4680000e-02 -6.0900000
6    20    5.2640000e-02 -6.0700000
6    21    5.0380000e-02 -6.0800000
6    22    4.7890000e-02 -6.1300000
6    23    4.5120000e-02 -6.2300000
6    24    4.2030000e-02 -6.4200000
6    25    3.8600000e-02 -6.7300000
6    26    3.4750000e-02 -7.2200000
6    27    3.0430000e-02 -8.0000000
6    28    2.5570000e-02 -9.2900000
6    29    2.0120000e-02 -11.5800000
6    30    1.4020000e-02 -16.3600000
6    31    7.4300000e-03 -30.8700000
6    32    3.8900000e-03 -113.4600000
6    33    1.0810000e-02 -163.1000000
6    34    2.0000000e-02 -173.0100000
6    35    2.9880000e-02 -177.2500000
6    36    3.9910000e-02 -179.7000000
6    37    4.9570000e-02 178.6700000
6    38    5.8210000e-02 177.3600000
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```
6    39    6.4920000e-02 175.9500000
6    40    7.1660000e-02 170.3600000
6    41    5.3940000e-02 158.2800000
6    42    3.2740000e-02 156.8100000
6    43    1.0970000e-02 158.2900000
6    44    2.7700000e-03 -120.8700000
6    45    1.5200000e-03 -4.1400000
6    46    1.1400000e-03 -13.8400000
6    47    8.1000000e-04 48.1000000
6    48    3.2000000e-04 -91.2400000
6    49    5.0000000e-05 -170.8800000
7    1     0.1460700 -11.4900000
7    2     0.1269800 -10.1800000
7    3     0.1155700 -9.1000000
7    4     0.1110600 -8.5500000
7    5     0.1072100 -8.0000000
7    6     0.1036800 -7.4500000
7    7     0.1019200 -7.1700000
7    8     0.1010300 -7.0300000
7    9     0.1001000 -6.8900000
7    10    9.9130000e-02 -6.7500000
7    11    9.8110000e-02 -6.6100000
7    12    9.5940000e-02 -6.3400000
7    13    9.4760000e-02 -6.2000000
7    14    9.3490000e-02 -6.0700000
7    15    9.2140000e-02 -5.9400000
7    16    9.0680000e-02 -5.8100000
7    17    8.9130000e-02 -5.6800000
7    18    8.7440000e-02 -5.5600000
7    19    8.5630000e-02 -5.4400000
7    20    8.3650000e-02 -5.3300000
7    21    8.1510000e-02 -5.2400000
7    22    7.9160000e-02 -5.1600000
7    23    7.6600000e-02 -5.1000000
7    24    7.3810000e-02 -5.0600000
7    25    7.0730000e-02 -5.0700000
7    26    6.7340000e-02 -5.1300000
7    27    6.3590000e-02 -5.2500000
7    28    5.9430000e-02 -5.4500000
7    29    5.4800000e-02 -5.7700000
7    30    4.9640000e-02 -6.1900000
7    31    4.3900000e-02 -6.7300000
7    32    3.7580000e-02 -7.3300000
7    33    3.0750000e-02 -7.8300000
7    34    2.3620000e-02 -7.9100000
7    35    1.6580000e-02 -7.0000000
7    36    1.0120000e-02 -4.1800000
7    37    4.7100000e-03 1.5900000
7    38    4.4000000e-04 -2.5000000
7    39    3.9800000e-03 -150.8200000
7    40    1.2920000e-02 -176.7900000
7    41    7.3400000e-03 120.5100000
7    42    2.1300000e-03 62.5100000
7    43    2.3600000e-03 -10.1100000
7    44    2.5000000e-03 -24.2700000
7    45    1.3500000e-03 -95.2400000
7    46    5.2000000e-04 23.8600000
7    47    1.8000000e-04 -75.4800000
7    48    1.2000000e-04 33.4000000
7    49    1.0000000e-05 89.4000000
8    1     0.1036700 -11.4400000
8    2     9.0320000e-02 -10.1100000
8    3     8.2440000e-02 -9.0000000
8    4     7.9440000e-02 -8.4400000
```

```
8	5	7.6990000e-02 -7.8600000
8	6	7.4870000e-02 -7.2700000
8	7	7.3870000e-02 -6.9700000
8	8	7.3390000e-02 -6.8200000
8	9	7.2890000e-02 -6.6700000
8	10	7.2390000e-02 -6.5100000
8	11	7.1870000e-02 -6.3600000
8	12	7.0800000e-02 -6.0400000
8	13	7.0240000e-02 -5.8800000
8	14	6.9670000e-02 -5.7200000
8	15	6.9070000e-02 -5.5600000
8	16	6.8430000e-02 -5.4000000
8	17	6.7770000e-02 -5.2300000
8	18	6.7070000e-02 -5.0700000
8	19	6.6360000e-02 -4.9100000
8	20	6.5590000e-02 -4.7500000
8	21	6.4800000e-02 -4.5900000
8	22	6.3960000e-02 -4.4300000
8	23	6.3090000e-02 -4.2900000
8	24	6.2180000e-02 -4.1600000
8	25	6.1220000e-02 -4.0400000
8	26	6.0220000e-02 -3.9400000
8	27	5.9160000e-02 -3.8600000
8	28	5.8030000e-02 -3.8000000
8	29	5.6840000e-02 -3.7600000
8	30	5.5560000e-02 -3.7100000
8	31	5.4210000e-02 -3.6300000
8	32	5.2790000e-02 -3.4300000
8	33	5.1400000e-02 -3.0300000
8	34	5.0180000e-02 -2.3700000
8	35	4.9360000e-02 -1.5300000
8	36	4.9150000e-02 -0.8900000
8	37	4.9480000e-02 -1.1500000
8	38	4.9680000e-02 -3.4500000
8	39	4.7420000e-02 -9.4500000
8	40	3.4640000e-02 -11.9000000
8	41	3.5360000e-02 -10.6700000
8	42	2.2950000e-02 -24.7400000
8	43	7.0800000e-03 -51.9200000
8	44	1.6700000e-03 138.2700000
8	45	1.4800000e-03 175.4200000
8	46	7.9000000e-04 157.9100000
8	47	3.8000000e-04 -69.0500000
8	48	2.5000000e-04 162.3700000
8	49	8.0000000e-05 29.8500000
9	1	0.0000000 0.0000000
9	2	0.0000000 0.0000000
9	3	0.0000000 180.0000000
9	4	0.0000000 180.0000000
9	5	0.0000000 180.0000000
9	6	0.0000000 180.0000000
9	7	0.0000000 180.0000000
9	8	0.0000000 180.0000000
9	9	0.0000000 180.0000000
9	10	0.0000000 180.0000000
9	11	0.0000000 180.0000000
9	12	0.0000000 180.0000000
9	13	0.0000000 180.0000000
9	14	0.0000000 180.0000000
9	15	0.0000000 180.0000000
9	16	0.0000000 180.0000000
9	17	0.0000000 180.0000000
9	18	0.0000000 180.0000000
9	19	0.0000000 180.0000000
```

```
 9    20    0.0000000 180.0000000
 9    21    0.0000000 180.0000000
 9    22    0.0000000 180.0000000
 9    23    0.0000000 180.0000000
 9    24    0.0000000 180.0000000
 9    25    0.0000000 180.0000000
 9    26    0.0000000 180.0000000
 9    27    0.0000000 180.0000000
 9    28    0.0000000 180.0000000
 9    29    0.0000000 180.0000000
 9    30    0.0000000 180.0000000
 9    31    0.0000000 180.0000000
 9    32    0.0000000 180.0000000
 9    33    0.0000000 180.0000000
 9    34    0.0000000 180.0000000
 9    35    0.0000000 180.0000000
 9    36    0.0000000 180.0000000
 9    37    0.0000000 180.0000000
 9    38    0.0000000 180.0000000
 9    39    0.0000000 180.0000000
 9    40    0.0000000 180.0000000
 9    41    0.0000000 180.0000000
 9    42    0.0000000 180.0000000
 9    43    0.0000000 0.0000000
 9    44    0.0000000 -0.0000000
 9    45    0.0000000 0.0000000
 9    46    0.0000000 -180.0000000
 9    47    0.0000000 -0.0000000
 9    48    0.0000000 -0.0000000
 9    49    0.0000000 0.0000000
'**********************************************************************
 ENVIRONMENT IDENTIFICATION
'**********************************************************************

'idenv
 env
'----------------------------------------------------------------------
 WATERDEPTH AND WAVETYPE
'----------------------------------------------------------------------
'wdepth      noirw norw ncusta nwista
 133.0000000 1     0    1      0
'----------------------------------------------------------------------
 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     0      0      0
'----------------------------------------------------------------------
 WAVE SPECTRUM WIND
'----------------------------------------------------------------------
'siwahe     tpeak
 11.8000000 16.1000000
'----------------------------------------------------------------------
 DIRECTION PARAMETERS
'----------------------------------------------------------------------
'wadr1     expo1
 0.0000000 2.0000000
'----------------------------------------------------------------------
 NEW CURRENT STATE
'----------------------------------------------------------------------
```

```
'icusta nculev l_ext
 1      2      0
'curlev        curdir    curvel
 0.0000000     0.0000000 1.0000000
 -133.0000000 0.0000000 0.4000000
'**********************************************************************
 END
'**********************************************************************
```

C.2 RIFLEX Stamod. Inp file

```
'A1    STAMOD IDENTIFICATION TEXT
'**********************************************************************
 STAMOD CONTROL INFORMATION 4.0.7
'**********************************************************************
'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
 env
'----------------------------------------------------------------------
 STORE VISUALISATION RESPONSES
'----------------------------------------------------------------------
'option chresp       chilin
 STORE  EFF-AX-FORCE ALL
'**********************************************************************
 STATIC CONDITION INPUT
'**********************************************************************
'lcomp icurin curfac    iwindin
 0     1      1.0000000 0
'lcons isolvr
 0     1
'**********************************************************************
 COMPUTATIONAL PROCEDURE
'**********************************************************************
'ameth
 FEM
'----------------------------------------------------------------------
 FEM ANALYSIS PARAMETERS
'----------------------------------------------------------------------
'......................................................................
 LOAD GROUP DATA
'......................................................................
'nstep maxit racu
 10    10    1.0000000e-06
'lotype ispec
 VOLU   0
'lotype ispec
 DISP   0
'......................................................................
 LOAD GROUP DATA
'......................................................................
'nstep maxit racu
 10    10    1.0000000e-06
```

```
'lotype ispec
 ISTR   0
'.......................................................................
 LOAD GROUP DATA
'.......................................................................
'nstep maxit racu
 10    10    1.0000000e-06
'lotype ispec
 CURR   0
'***********************************************************************
 END
'***********************************************************************
```

C.3 RIFLEX Dynmod.inp file

```
'A1    DYNMOD CONTROL INFORMATION
'***********************************************************************
 DYNMOD CONTROL INFORMATION 4.0.7
'***********************************************************************
'irunco ianal     idris idenv idstat idirr idres
 ANAL   IRREGULAR ARSYS env   SIMA   XX    SIMA
'**********************************************************************
'
'           DATA GROUP D, IRREGULAR RESPONSE ANALYSIS
'
'***********************************************************************
 IRREGULAR TIMESERIES PARAMETERS
'***********************************************************************
'irand timgen       dtgen     chmeth iopamp nfrewi nfresw
 1     2048.0000000 1.0000000 COS    1      100    10
'-----------------------------------------------------------------------
 IRREGULAR RESPONSE ANALYSIS
'-----------------------------------------------------------------------
'ircno time         dt        chwav chmot chlmf tbeg      iscale
 1     1080.0000000 0.1000000 NEW   STAT  NONE  0.0000000 0
'-----------------------------------------------------------------------
 IRREGULAR WAVE PROCEDURE
'-----------------------------------------------------------------------
'iuppos icosim kinoff chstep nodstp zlower zupper iopdif
 1      3      0      NODE   1      /      /      0
'**********************************************************************
'
'           DATA GROUP E
' Time domain procedure and file storage parameters
'
'***********************************************************************
 TIME DOMAIN PROCEDURE
'***********************************************************************
'itdmet inewil
 2      1
'E1.3   TIME INTEGRATION
'betin     gamma     theta     a1        a2             a1t       a1to      a1b
a2t       a2t0      a2b
 4.0000000 0.5000000 1.0000000 0.0000000 1.0000000e-03 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      3      5      1.0000000e-02 10.0000000 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
 1     4      -1
'line-id iseg inod
 slipa7  2    1
 slipa7  2    2
 slipa7  1    5
 slipa7  1    6
'----------------------------------------------------------------------
 FORCE RESPONSE STORAGE
'----------------------------------------------------------------------
'ifor noforc iforfm ieltfm
 1    14     -2     -2
'line-id  iseg iel
 bop_line 1    1
 bop_line 2    3
 lmrp80   1    1
 lmrp80   3    1
 join98   1    1
 join98   1    58
 slipa7   2    1
 slipa7   1    1
 tens70   1    1
 tens71   1    1
 tens72   1    1
 tens73   1    1
 pup1de   1    1
 pup1de   1    4
'----------------------------------------------------------------------
 SUMFORCE RESPONSE STORAGE
'----------------------------------------------------------------------
'isfor nosfor isfofm
 1     9      -2
'line-id  iseg iel
 bop_line 1    1
 slipa7   2    1
 tens70   1    1
 tens71   1    1
 tens72   1    1
 tens73   1    1
 slipa7   1    1
 pup1de   1    1
 pup1de   1    4
'----------------------------------------------------------------------
 ENVELOPE CURVE SPECIFICATION
'----------------------------------------------------------------------
'ienvd ienvf ienvc tenvs     tenve         nprend npren f nprenc ifilmp
 1     1     1     0.0000000 1.0000000e+07 1      1      1      2
'----------------------------------------------------------------------
 STORE VISUALISATION RESPONSES
'----------------------------------------------------------------------
'tconds    tconde      delt      chform
 0.0000000 500.0000000 0.5000000 VIS
'**********************************************************************
 END
'*********************************************************************
```