A Probabilistic Design Approach for Riser Collision based on Time-Domain Response Analysis

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Keywords: Riser collision, time-domain simulation, probabilistic design

ABSTRACT: The present paper is concerned with probabilistic modeling of current magnitude and surface floater motions within the context of riser collision analysis. Furthermore, response statistics obtained as a result of time domain simulation is described. Application in relation to estimation of extreme response and fatigue lifetime is also addressed. A specific Spar Buoy Riser Case study is considered.

1 INTRODUCTION

Depending on riser spacing and tension, deep water risers may collide during operation. Preventing collision completely is costly, and the 'optimum' solution may in practice imply that the risers are allowed to get into contact for some environmental conditions. If the impact energy is low, such impacts might be acceptable, and it is therefore of interest to be able to estimate conditions causing impacts, the collision frequency and the "magnitude" of the impacts.

A general FE code, ref/1/ is extended to handle riser collision problems, where the load model, ref/2/ is the primary building block. The collision frequency of two riser pipes is influenced both by the current magnitude and its depth variation, in addition to top end motions. The current is presently modeled in terms of a given (planar) profile scaled by the surface magnitude. Combination of current magnitude and amplitude of surface floater motion is identified as the most important issue in the present context. The interactions between forces due to these effects are in general of a highly nonlinear character.

Typical input data to the analysis is a long-term distribution of current and long-term distribution of floater motion amplitudes. However, other options are also possible. Three alternatives of increasing complexity can be summarized as:

(i) Point Estimation of floater motion amplitude and long-term distribution of current
(ii) Modeling of floater motion amplitude and current magnitude by two separate long-term probability distributions
(iii) Long-term modeling of combined current magnitude and floater motions based on response analysis for each sea state.

The former of these alternatives is here employed as a base case approach. The primary response quantity is presently taken to be the collision impact magnitude. It is illustrated how the long-term response distribution of impact magnitude is obtained based on the input distribution of current velocity, combined with numerical response simulation in the time domain. The numerical procedure is based on Computational Fluid Dynamics (CFD). Interpolation in a pre-established data base is performed during the response simulation. Contact between pipes is checked at each time step by looping through the nodal coordinates of the Finite Element Mesh representing the pipes.

Within the framework and accuracy of present state-of- the-art methods for numerical response calculations, application of a fixed amplitude for the surface floater motion is considered to be adequate. However, as the computational tools become more refined, increasingly accurate probabilistic modelling of the input parameters is required.

A specific model for a case study is established based on the “Vøring SPAR buoy”,ref/3/. Different global results are considered, such as collision speed, collision angle and impulse. The most important parameters influencing the collision process in general are briefly: Riser spacing, riser tension, nature of pipe surface (e.g. with or without ‘strakes’), ocean current (velocity, direction, profile) and floater motion characteristics.

2. COMPUTER TOOLS FOR LOAD AND RESPONSE ANALYSIS

2.1 Background

In connection with riser collision, a 3D Finite Element Program is employed for analysis of riser response, ref/1/. This program is briefly characterised by: (i)General non linear dynamics in 3D (ii) Cables, beams and shell elements, (iii) Geometric and material non linearities, (iv) Efficient implicit equation solver (SPARSE technology).

A general 3D beam element which accounts for large rotations and non- linear material behaviour is used. The floater motion is represented in terms of prescribed displacements (harmonic motion) of the riser top end. For the hydrodynamic load calculation and for handling of contact between risers, specialized modules are employed.

2.2 Hydrodynamic load model

An efficient model for calculation of forces on deep water risers exposed to ambient flow has been developed , ref/2/. If the risers are located close to each other, the ideal flow will be “disturbed”, which will influence the forces on all the relevant risers. The load model accounts for these effects in terms of pre-defined coefficient tables. These are generated on basis of CFD calculations with extensive parametric studies for different flow regimes.

The concept was originally developed for 2D analyses. The theory has been taken over to 3D analyses assuming piecewise constant conditions along the risers. The different ‘layers’ are connected by the riser model, and movement of the riser in one layer will be transferred to the neighbour layers.

In the finite element representation of the riser system, each finite element is treated individually with respect to the hydrodynamic load calculations. A coarse FE mesh results in a coarse hydrodynamic representation and vice versa. The hydrodynamic module calculates drag- and lift coefficients based on the instantaneous relative position between the risers. The mean value, amplitude and characteristic frequency of the hydrodynamic force is subsequently stored. For each analysis time step, the actual distance (dX and dY) between the risers is calculated by the Finite Element analyses, and interpolated coefficients are used.

For each time step the load calculation is carried out as follows: (i)Transform position of all finite elements into the co ordinate system defined by the direction of the current (which may vary from 0 to 360°) (ii) For each finite element along the riser, find the nearest (other) element on the second riser (iii) Find (among the two) which of them is located first in the current (iv) Select hydrodynamic coefficients and calculate drag and lift forces in the current co-ordinate system (v) Transform forces to the system’s global co-ordinate system and add forces to the system load vector.

2.3 Surface-surface contact

The contact formulation is based on a general surface-surface {contact search}/{contact force} technique. The calculations are divided into the following main steps: (i) Coarse contact search (beam/beam search) (ii) Re-meshing of beams to surface elements (if beams are close), see Figure 1 (iii) Detailed 3D surface– surface contact search (iv) Establish appropriate stiffness of the pipe surface (v) Calculate interface force (if contact) on pipe surface and re-track to beam system for further adding to the system load vector (vi) Record impulse, impact velocity, and angle between risers (see figures below).

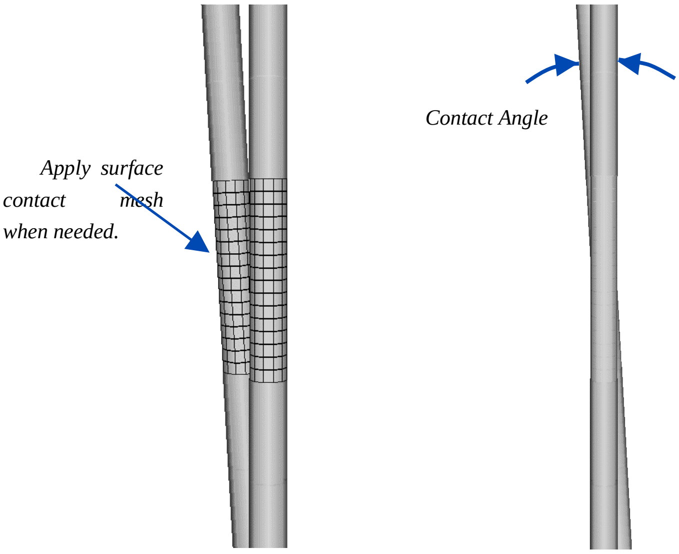

Figure 1 Automatic Surface-Surface contact in FEM model

3.1 GENERATION OF ENVIRONMENTAL DATA

3.1Background

The present paper is concerned with modeling of input parameters for current magnitude and surface floater motions within the context of riser collision analysis. The current is here modeled in terms of a given (planar) velocity profile scaled by the surface magnitude. Combination of current magnitude and surface Spar motion amplitude is identified as a highly relevant modeling issue. The interaction between forces due to current and prescribed top end motions is in general of a highly nonlinear character.

According to the background Spar buoy Case study report, the characteristic time scale for the current (i.e. for which the current magnitude is kept constant) is 12 hours. However, the characteristic time scale for the Spar motion will generally correspond to the duration of a stationary sea state. This is typically taken to be in the range of 3-4 hours. Given these different reference periods, various options for how they should be combined are available.

3.2 Interaction between input parameter generator and load/response analysis

A number of input files are generated by a preprocessor. Each of these files corresponds to a specific combination of current velocity and vessel motion amplitude. For each of the input files, a corresponding result file is generated by load and response analysis programs. Response time series are post-processed to yield distributions of impact, normal velocity and relative angle at contact. Long-term distributions of the same response quantities can be obtained by a proper weighting and summation of all the corresponding distributions.

As discussed in the next two sections, the total number of input files depends on the type of representation for the floater motion. Two different options are outlined. A third and more complete joint representation of the current velocity and floater motion was discussed earlier. However, this approach was considered as being too detailed for the present purpose and is hence not pursued any further.

Once the long-term distribution of the impact energy has been obtained, this can be employed for design purposes by specification of a proper return period. This is achieved by converting the return period into expected number of impacts corresponding to that specific period (i.e. 10 years).

3.3 Alternative methods for combination of current magnitude and SPAR motion amplitude

3.3.1 Option 1: Point Estimation of Spar Motion Amplitude

This is the simplest option, where focus is set on the value of the current magnitude to be applied. Maximum and minimum values of the current to be applied in the analysis is specified by the analyst (in terms of current magnitudes or alternatively in terms of return periods). Furthermore, the number of velocity intervals to be applied for discretizing the current magnitude distribution is given.

The motion of the Spar buoy is represented in terms of a single representative amplitude value. The magnitude of the single amplitude can be selected as one of the following:

(i) The expected value of the long-term-distribution

(ii) The expected largest amplitude within a single sea state. The extreme-value distribution within each sea state is obtained from the long-term distribution by exponentiation.

(iii) The expected largest amplitude within a duration of 12 hours. The extreme value distribution is obtained by exponentiation also for this case, but with the exponent being multiplied by a factor of three relative to Alternative (ii) above. (Due to the ratio 12hrs/4hrs being equal to three)

Obviously, Alternative (iii) is the most conservative of the three. In the Case study described below, 50% of the 100 year motion amplitude for the SPAR buoy is employed in order to provoke collision. This must be taken into account in the subsequent post-processing of the result files.

3.3.2 Option 2: Modelling of Spar Motion Amplitude and Current Magnitude by Separate Long-term Probability Distributions

The representation of the current magnitude and the corresponding input required for this case is identical to Option 1. Presently, the probability distribution of the Spar motion amplitude is also discretized in a similar way. Lower and upper bounds for the amplitudes to be applied are given explicitly or in terms of return periods.

Due to the generally different characteristic time scales for the current and sea state conditions, a similar distinction arises as for Option 1 with respect to choice of representative motion amplitude to be applied. However, the different possibilities are now given in terms of different choices of probability distribution function to be applied rather than single point values,i.e.:

(i) Direct application of the long-term-distribution of floater motion amplitude

(ii) The probability distribution for the extreme motion amplitude within a single sea-state.

(iii) The probability distribution for the extreme motion amplitude within a duration of 12 hours. The extreme value distribution is obtained as explained above.

Also for this case, it is proposed that the third Option (i.e. probability distribution of the 12 hour extreme value) is applied. The selected distribution function is discretized into a finite number of intervals for subsequent "response" analysis.

4 CASE STUDY: RISERS SUSPENDED FROM "VØRING" SPAR BUOY

4.1 General

The case study is based on ref/3/, and an overview of the layout is shown in Figure 2. The spacing between the risers is approx. 3.5 m at the SPAR and 12m at the well. The horizontal distance between top and bottom of each riser is approx. 50m, which results in almost vertical risers (~87°).

In the design, it is suggested to use a relatively high top tension (2.2) in order to avoid riser collision. The riser outer casing has a diameter of 273mm, and thickness 11.4mm, with tubing 178/9mm. For the case study, two risers were selected, (see Figure 1) with the current in the Y direction (0° in the local FE-model).

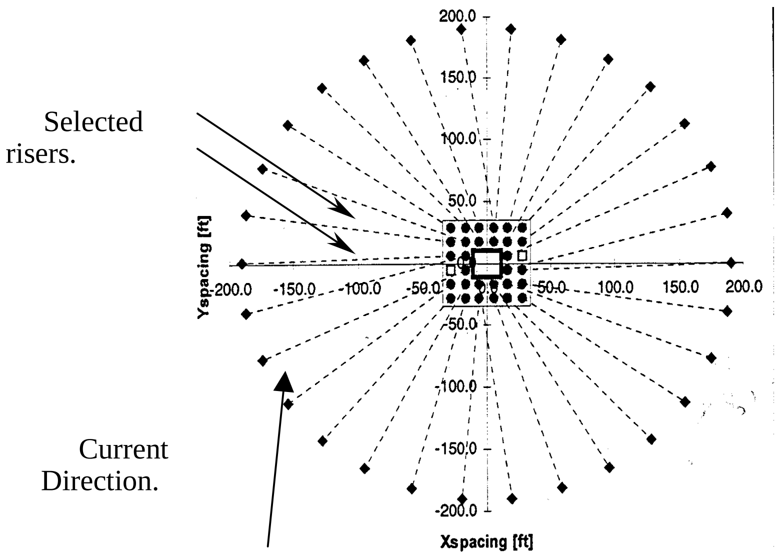

Figure 2 Case study riser configuration (horizontal projection). Riser connection between the well and the SPAR is illustrated with dashed lines.

4.2 Modelling of surface current velocity and SPAR surge motion

The parameters for the long term distribution of the surface current velocity are determined such that they represent the given numbers for the 1-year and 100-year velocities. These velocities are given as 0.7 m/s and 0.9 m/s, respectively. The corresponding parameters of the long-term Weibull distribution are computed as a scale parameter of 0.3 and a shape parameter of 2.25. This defines the distribution function based on which the discretized velocity intervals are computed. These numbers are given as input to the preprocessor which generates input files to USFOS-TRICE. For the SPAR surge motion (at keel level), a harmonic motion with an amplitude of ~8 m and a period of ~400 seconds is employed. This corresponds to about half the 100 year value as given in the Case study report, see Ref/3/. As discussed above, this represents a conservative choice which is made in order to provoke more collisions.

4.3 FE - model

The finite element model consists of beam elements representing the two risers indicated in the figure above. The risers are assumed to be located in the same planeThe structural system is relatively slender with a length/diameter ratio of approx. 3500. The floater motion is applied to the riser top nodes as prescribed time-harmonic displacements.

The risers are modelled from the SPAR buoy to the seabed, giving a total length of approx. 1000m. The top tension corresponding to 2.2 times the submerged riser weight is about 1.8 MN and applied at the top nodal points. However, the initial analyses using the proposed (high) tension resulted in *no collisions*, and the top tension was accordingly reduced to 1.5 times the riser weight (1.2MN) for the case study purpose.

Key data for the riser system are given as: Riser diameter : 273mm, Wall thickness : 23mm, Top tension : 1200 kN, Total length : 1000 m, Riser inclination : 87° , Floater motion period is 400s and amplitude is 12m (implying a peak speed of 0.2m/s), Current speed : 0.7 – 0.9 m/s

(Floater motion is added to these values), Current direction : 0°, Time increment : 5 ms, Analysis time : 2000 – 6000 s (5-15 floater periods), Time consumption: Approx. 10 times the real time (5 hours *cpu* for 2000s on a new PC)

The hydrodynamic load model is based on assuming an absolute incoming current (not the relative velocity caused by the riser movement). However, because the floater motion represents a substantial fraction of the total speed (experienced by the riser), a kind of relative velocity must be used. In the case study, the harmonic floater motion is used to correct the constant ocean current (with a reduced correction for the lower parts of the risers). The resulting current is then composed of a constant part + a harmonic varying part with period 400s.

5 RESULTS

5.1 General

Results from two cases (the 1 year and the 100 year current conditions) are presented. In both cases the riser motion caused by the motion of the SPAR buoy is added on top of the ocean current (as described above). The top tension is set to 1200 kN, which corresponds to 1.5 times the riser weight.

5.2 Results for 1- year current

The 1-year surface current velocity is estimated as 0.7m/s, and including the floater motion (T=400s) the current varies between 0.7-0.19=0.51 m/s and 0.7+0.19=0.89 m/s. As seen from Figure 3, the peak stress (assuming a homogeneous pipe) is approximately 80MPa.

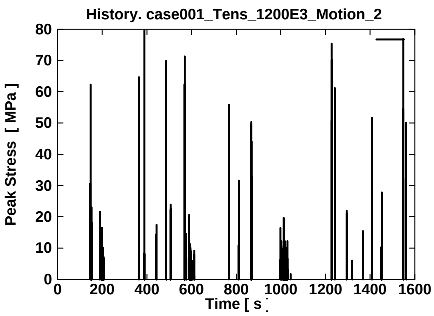

Figure 3 Stress History, 1 year current.

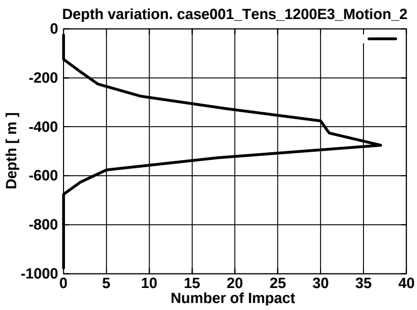

Figure 4 Number of impacts with depth

The impacts occur in a zone with length 400m in the middle section of the risers, (between –200 and-600m), see Figure 4

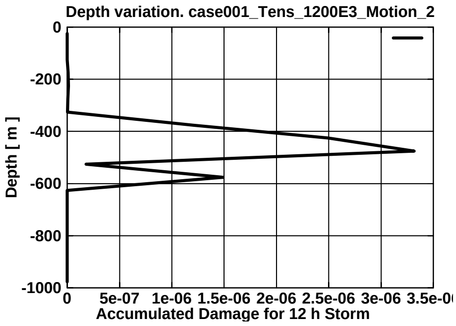

Figure 5 Accumulated damage along the riser

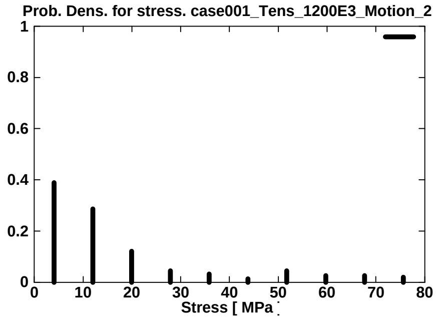

Figure 6 Probability density of maximum stress along the riser. 1 year current

It is important to note that the highest stresses do not necessarily occur for the sections with the highest number of impacts. Accordingly, it is relevant to compute the relative “accumulated” damage at each section (referred e.g. to a 12 hours storm) for comparison purposes, see Figure 5. This quantity accounts for the product of stress level and the number of impacts at that particular level. The highest value occurs for a depth range from 400 to 500 m.

The contact stress probability density is shown in Figure 6. It is observed that around 40% of the contact stresses are less than 10 MPa (at the segment where the highest stresses occur).

5.3 Results for100 year current

For the 100 year current ((approx. 0.9m/s), and including the floater motion (T=400s), the current varies between 0.87-0.19=0.68 m/s and 0.87+0.19=1.06 m/s.

As seen from Figure 7, the peak stress is about 200 MPa, which is almost 50% of the yield stress for the riser pipe.

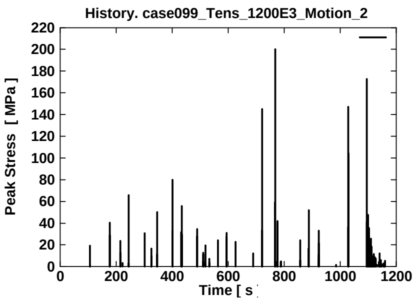

Figure 7 Stress History. 100 year current

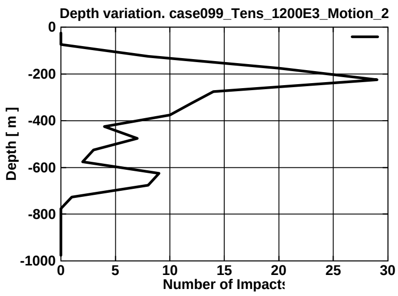

Figure 8 Number of impacts with depth

The highest number of impacts is less localized than for the 1-year case, see Figure 8. The zone now extends from about –100m to –800m. However, a pronounced peak occurs around -200m. The reason for this distribution is most likely the particular riser modes which are activated.

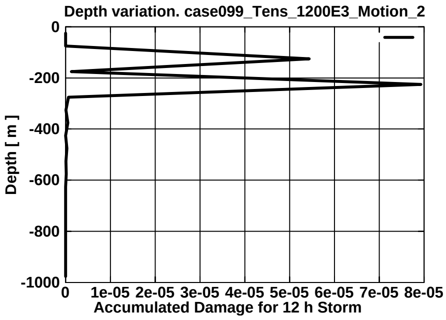

Figure 9 Accumulated damage versus depth

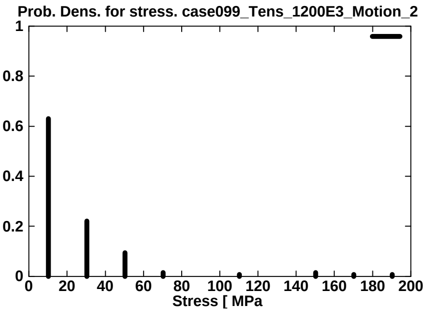

Figure 10 Probability density of stress. 100 year current

Considering again the “accumulated damage” versus depth given in Figure 9, the maximum value also occurs at a depth of about -200m. This is due to the contact stresses also being quite high at this location.

As seen from Figure 10, about 60% of the stresses (at the section with the highest stresses are less than 20 MPa.

6. SUMMARY AND CONCLUSIONS

Computer programs relevant for riser collision problems are briefly described A model for the case study is established based on the Vøring SPAR.Top tension of the risers is reduced from the original design tension in order to provoke collisions. Current corresponding to 1 year conditions and up to 100 year conditions are applied. Floater motion (derived from 100 year surge) is included and is and important parameter in the riser collision analysis. Response levels are found to stabilise after 3-5 floater motion cycles. The following observations of key response quantities were made:

- Peak stress : 110 MPa for 1 yr current / 470 MPa for 100yr current
  The maximum cumulative damage will generally occur for a different segment than where the number of collisions is highest
- The extension and location of the zone with the highest number of impacts vary as functions of the current velocity.

The drag damping coefficient, C_{dd} used in the load calculations is set equal to 1.0, but this may result in a too high hydrodynamic damping implying possibly an underestimation of the contact stresses. Further development of the computational tools and the probabilistic modelling is seen to be highly relevant.

7 REFERENCES

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