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PROBABILISTIC MODELLING AND ANALYSIS OF RISER COLLISION

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ABSTRACT

Analysis and design of deep-water riser arrays requires that both collision frequency and resulting stresses in the pipes are addressed. Within a probabilistic context, the joint modelling of the current magnitude and surface floater motions must be taken into account. The present paper gives an outline of the general analysis setup, and response statistics obtained as a result of time domain simulation are described. Utilization of the analysis is also discussed in relation to estimation of extreme response and fatigue lifetime. As an example of application, a specific Spar buoy riser configuration at a waterdepth of 900m is considered.

INTRODUCTION

The collision frequency for pipes within a riser array is influenced both by the current magnitude and its depth variation. In addition, top end motions may have strong effects. The probabilistic combination of current magnitude and amplitude of surface floater motion is accordingly identified as a highly important issue in the present context. This interaction between current and top end motion in relation to collision frequencies and stresses is 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, various simplifications are also highly relevant. Three alternatives of increasing complexity can be summarized as:

(i) Single value of floater motion amplitude and long-term distribution of current
(ii) Separate long-term probability distributions are applied for representation of floater motion amplitude and current magnitude
(iii) Long-term modeling of combined current magnitude and floater motions based on scatter diagram and subsequent 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 pipe stresses associated with each collision. It is illustrated how the long-term response distribution of stress can be obtained based on the input distribution of current velocity, combined with numerical response simulation in the time domain. The current is presently modeled in terms of a given (planar) profile which is scaled by the surface magnitude.

Calculation of hydrodynamic forces is based on results obtained by Computational Fluid Dynamics (CFD). These results are stored in a data base on non-dimensional form. Force parameters are subsequently evaluated by interpolation in this pre-established data base during the response simulation. Contact between pipes is checked at each time step by looping through the nodal coordinates of the Finite Element Mesh which represents the pipe geometry.

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

A specific Case study is performed in relation to a platform and riser configuration which is proposed for production in the Northern North Sea. Results for collision between a pair of riser pipes are presented, such as stress time series, distribution of impact velocity as function of depth, probability density function of stresses caused by collision , and relative accumulated damage as a function of depth. The most important parameters influencing the collision process are in general found to be: Riser spacing, riser tension, nature of pipe surface (e.g. with or without connectors or flanges), ocean current (velocity, direction, profile) and floater motion characteristics.

COMPUTER TOOLS FOR LOAD AND RESPONSE ANALYSIS

Background

The collision analysis is performed by the integrated program system HYBER, which comprises the following modules:

- Calculation of hydrodynamic forces for the riser pipes
- Response calculation based on 3D Finite Element Models of the riser pipes
- Contact search to identify contact between the pipes and pipe deformations

In the Finite Element Module, see e.g. ref/1/, a general 3D beam element is applied, which accounts for large rotations and non- linear material behaviour. The floater motion is represented in terms of prescribed displacements (harmonic motion) of the riser top end.

Hydrodynamic load model

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

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 flow pattern characteristic for a single cylinder 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 relative positions. 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.

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 neighbor layers.

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 modification of the system load vector (vi) Record impulse, impact velocity, and angle between risers (see figures below) (vii) Compute stresses in the pipes.

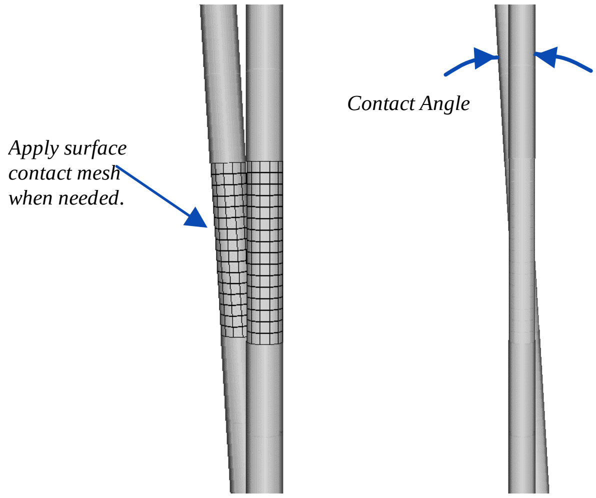

Figure 1 Surface-Surface contact search in FEM model

GENERATION OF ENVIRONMENTAL AND VESSEL MOTION DATA

Background

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.

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 platform 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.

Generation of input data for load and response analysis

Sets of analysis parameters are generated by a preprocessor. Each of these sets corresponds to a specific combination of current velocity and vessel motion amplitude. For each of the sets, corresponding result statistics are generated by the load and response analysis programs. Response time series are post-processed to yield probability distributions of stresses, number of impacts as a function of depth, and accumulated fatigue damage. The long-term distributions of the same response quantities may subsequently be obtained by a proper weighting and summation of all the corresponding distributions.

As discussed in the next two sections, the total number of analysis sets depends on the type of representation for the floater motion. Two different options are outlined. A third and more complete joint probabilistic representation of the current velocity and floater motion has already been pointed at. 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).

Alternative methods for combination of current magnitude and platform motion amplitude

Option 1: Point Estimation of Platform 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 in the analysis must be specified.

The motion of the platform is represented in terms of a single representative amplitude value. The magnitude of the single amplitude can e.g. 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
(iii) The expected largest amplitude within the duration of a stationary current condition which is equal to 12 hrs.

iv)

The extreme-value distribution within each sea state is obtained from the long-term distribution by exponentiation. The extreme value distribution within a duration of 12 hrs is also obtained by exponentiation, 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, a motion amplitude of 10 m (of the order of the 100 year motion amplitude) is employed as a base case in order to provoke collision. This is an extremely high value, and this must be taken into account in the subsequent statistical post-processing of the results.

Option 2: Modelling of Platform Motion Amplitude and Current Magnitude by Separate 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 discretised 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 the respective probability distribution functions rather than single point values. The selected distribution function must subsequently be discretised into a finite number of intervals for which "response" analysis is performed.

CASE STUDY: RISERS SUSPENDED FROM SPAR BUOY

General

The case study platform is a Spar buoy with a trusswork at the lower part. The diameter of the upper cylindrical part of the platform is 40m. An overview of the layout is shown in Figure 2. The spacing between the risers is 15 diameters at the platform (within the moonpool), and 40 diameters at the seabed. This implies that the risers are almost vertical for the present waterdepth of 900m.

It is found that a top tension of 2.2 times the submerged weight (i.e. Top Tension Ratio (TTR) equal to 2.2) will imply negligible collision frequencies. However, in the present analysis, a reduced TTR of 1.8 is applied as a base case value in order to provoke collisions.

For the case study, two production risers with identical diameter were selected. The current is acting in-plane, which corresponds to 0° in the FE-model.

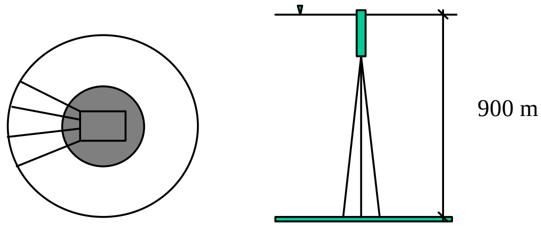

Figure 2 Case study riser configuration.

Modelling of surface current velocity and Spar surge motion

The current velocities obtained from the long term distribution which corresponding to return periods of 1 year and 100 years are given as 1.25 m/s and 1.7 m/s, respectively. However, for the present analysis the lowest current velocity applied is taken as 1.3 m/s. The highest velocity applied corresponds to the 100 year value of 1.7 m/s. For the Spar surge motion (at keel level), a harmonic motion with amplitudes of both 5 and 10 m have been investigated to show the effect of varying platform offset. A period of 150 seconds is employed.

FE - model

The finite element model consists of beam elements representing the two production risers. The risers are assumed to be located in the same plane. The structural system is relatively slender with a length/diameter ratio of approximately 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 slightly above 1000m. As mentioned above, a TTR of 1.8 is applied in the present analysis. This is done in order to obtain more collisions for the case study purpose. A parametric study on the effect of TTR is also performed below.

The time increment in the analysis is 5 ms, and the analysis time is 1200 seconds (8 floater periods), Time consumption: Approx. 10 times the real time (3.3 hours *cpu* for 1200s on a PC).

The floater motion represents a substantial fraction of the total speed which is experienced by the riser. This motion is accordingly applied in order to correct the constant ocean current (with a reduced correction for the lower parts of the risers). The resulting current is hence composed of a constant part + a harmonic varying part with a period of 150s.

RESULTS

General

Results for three different current velocities are presented. These are equal to 1.3 m/s, 1.5 m/s and 1.7 m/s. For all cases the riser motion caused by motion of the Spar buoy is added on top of the ocean current (as described above). The base case motion amplitude for this study is selected as 10 m in order to provoke collisions, with sensitivity analyses including results for a 5 m amplitude. The base case TTR is set to 1.8, but also results for a TTR of 2.25 are computed.

Results for current velocity equal to 1.3 m/s

The velocity at the top of the riser which is induced by a vessel motion amplitude of 10m and a period of 150 seconds is 0.42 m/s. The "total current" accordingly varies between 1.3 - 0.42 m/s = 0. 88 m/s and 1.3 + 0.42 = 1.72 m/s. As seen from Figure 3, the peak stress (assuming a homogeneous pipe) is approximately 65 MPa.

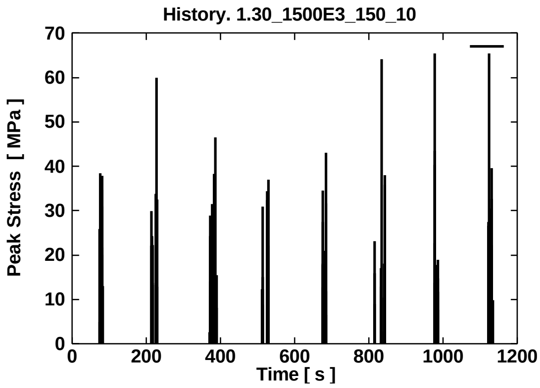

Figure 3 Stress history. Current velocity is 1.3 m/s.

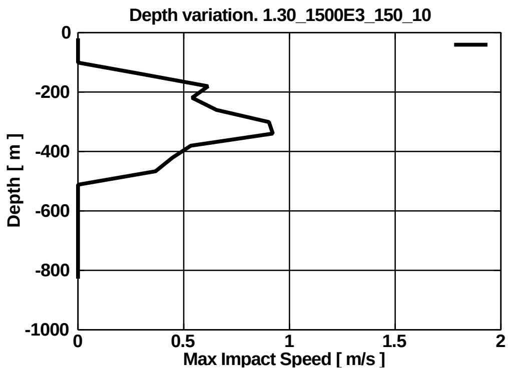

Figure 4 Max impact speed with depth.
Current velocity is 1.3 m/s.

The impacts occur in a zone with length of 400 m at the upper parts of the risers, (between 100 and 500 m), see Figure 4. The maximum impact speed is roughly 0.9 m/s which occurs at a depth of about 350m.

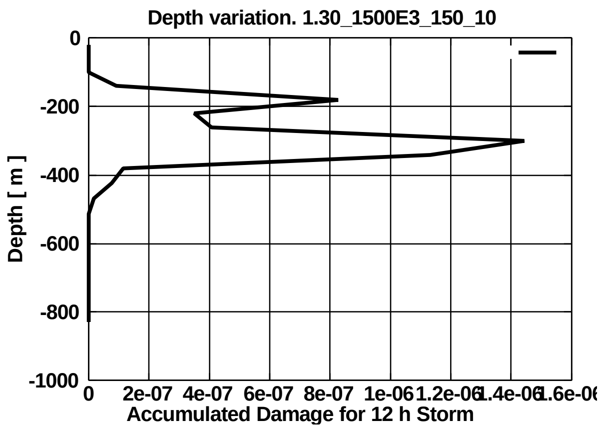

Figure 5 Accumulated damage along riser.
Current velocity is 1.3 m/s.

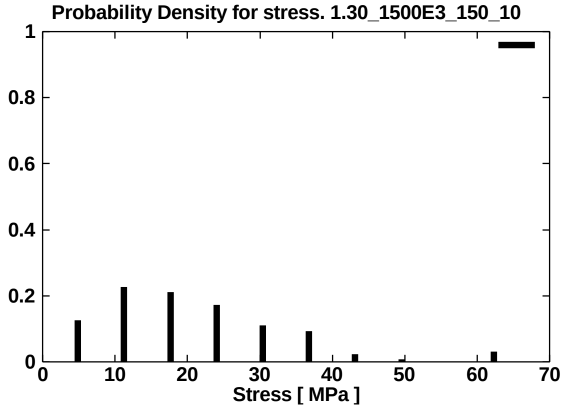

Figure 6 Probability density of impact stress.
Current velocity is 1.3m/s

Based on the stresses occuring within a given riser segement, the accumulated damage which corresponds to a given duration can be computed. The damage along the riser, which is computed for a duration of 12 hours, is shown in 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 150 to 350 m. Two distinct peaks occur at rougly the same locations as for the maximum impact speed.

The contact stress probability density is shown in Figure 6 (corresponding to all the collisions along the riser). It is observed that around 80% of the contact stresses are less than or equal to 30 MPa. The peak of the density funciton is found between 10 and 20 MPa.

Results for current velocity equal to 1.5 m/s

The "total current" now varies between 1.5 - 0.42 m/s = 1.08 m/s and 1.5 + 0.42 = 1.92 m/s. As seen from Figure 7, the peak stress (assuming a homogeneous pipe) is approximately 105 MPa.

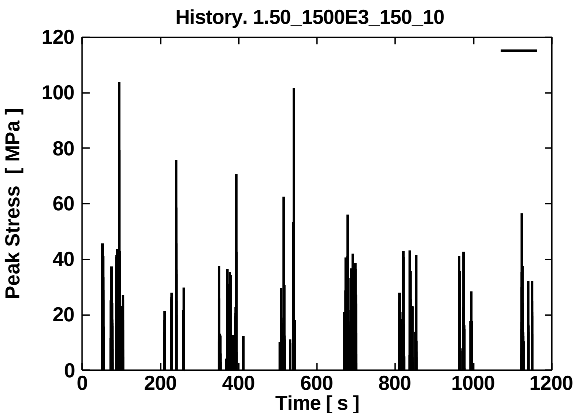

Figure 7 Stress history. Current velocity is 1.5 m/s.

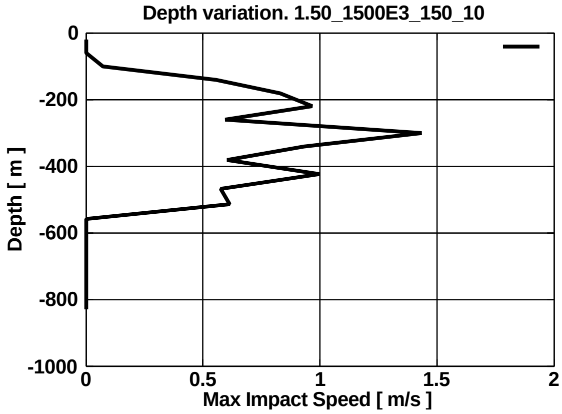

Figure 8 Max impact speed with depth.
Current velocity is 1.5 m/s.

The extension and location of the impact zone is roughly the same as for the 1.3 m/s case. The maximum impact speed is now increased to roughly 1.4 m/s, at a depth of about 300m.

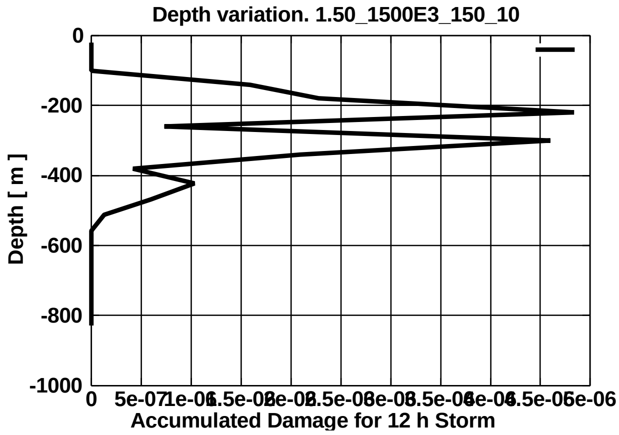

Figure 9 Accumulated damage along riser.
Current velocity is 1.5 m/s.

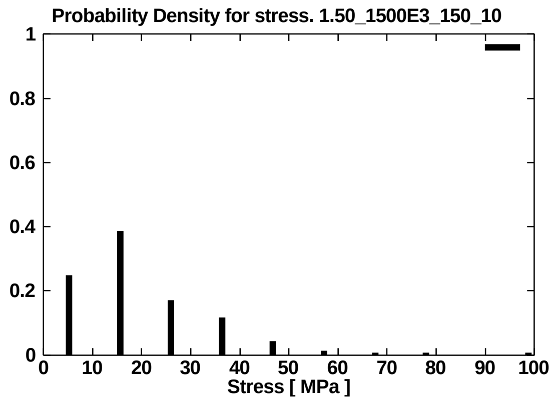

Figure 10 Probability density of impact stress
Current velocity is 1.5m/s

The damage along the riser is shown in Figure 9. The highest values occur at depths of about 200 and 300m. The two distinct peaks occur as the same locations as for the maximum impact speed. However, the third peak for the impact speed is much less pronounced for the accumulated damage.

The stress probability density is shown in Figure 10. Also for this case, around 80% of the contact stresses are less than 30 MPa. However, the peak between 10 and 20 Mpa is now much higher than for the current velocity of 1.3 m/s.

Results for current velocity equal to 1.7 m/s

For the 100 year current ((1.7 m/s), the total current velocity varies between 1.7 - 0.42 = 1.28 m/s and 1.7 + 0.42 = 2.12 m/s by including the floater motion. As seen from Figure 11, the peak stress is about 120 MPa, which is of the order of 25 % of the yield stress for the riser pipe.

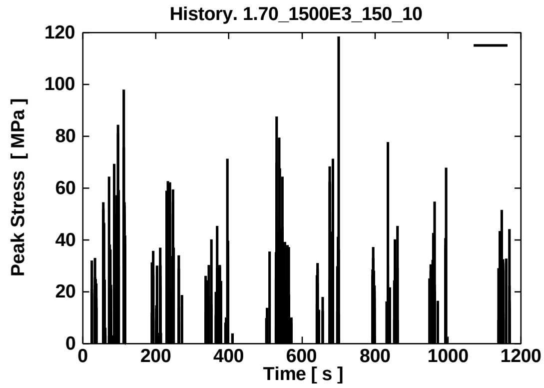

Figure 11 Stress History. Current velocity is 1.7 m/s

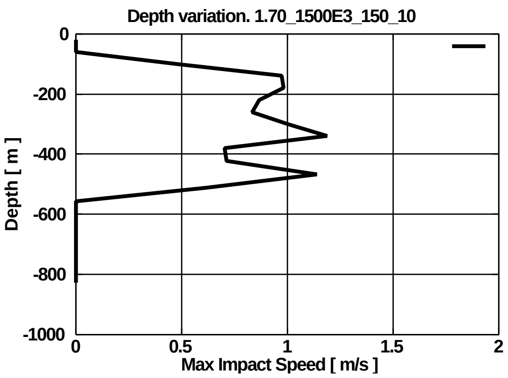

Figure 12 Maximum impact velocity with depth.
Current velocity is 1.7 m/s.

As seen from Figure 12, the impact zone has roughly the same extension as for the previous case. Surprisingly, the highest impact speed is somewhat reduced as compared to the 1.5 m/s current, now with a maximum value of 1.2 m/s.

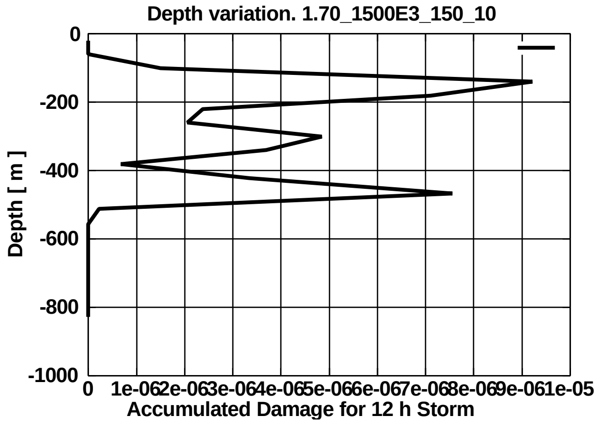

Figure 13 Accumulated damage versus depth
Current velocity is 1.7 m/s.

For the accumulated damage shown in Figure 13, the locations of the maximum values are shifted upwards to about 150m. The maximum value is also increased as compared to the two previous cases as expected.

As seen from Figure 14, about 80 % of the stresses are less than 40 MPa.

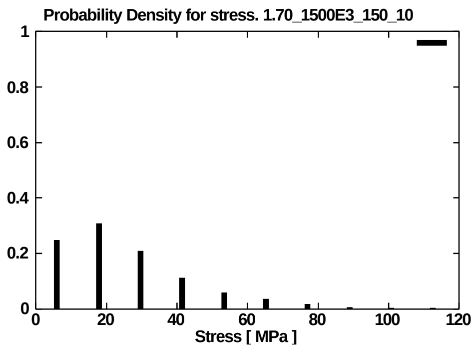

Figure 14 Probability density of stress.
Current velocity is 1.7 m/s

Effect of increasing top tension level (TTR) to 2.25

In order to study the sensitivity with respect to the top tension level, a second value of 1.8 MN is selected. The current velocity is 1.7 m/s also for this case, and the motion amplitude is 10m. As seen from Figure 15, the peak stress is now reduced to approximately 85 MPa.

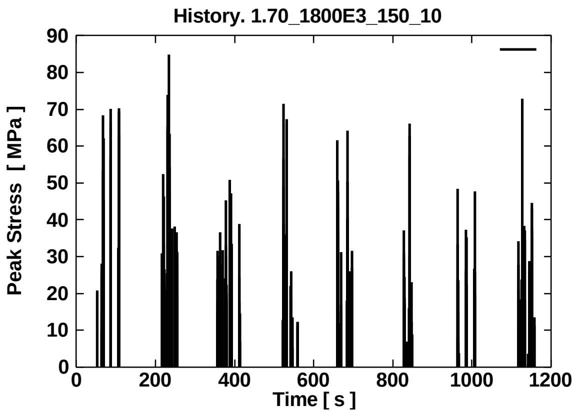

Figure 15 Stress History. Top tension is 1.8 MN. Current velocity is 1.7 m/s

As observed from Figure 16, the impacts still occur within the same zone as before, with a maximum impact speed of 1 m/s, i.e. a reduction as compared to the TTR of 1.8.

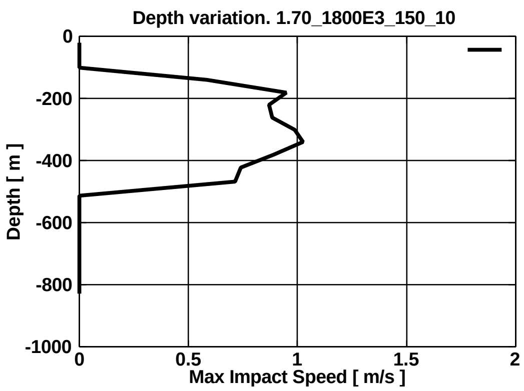

Figure 16 Max impact speed with depth

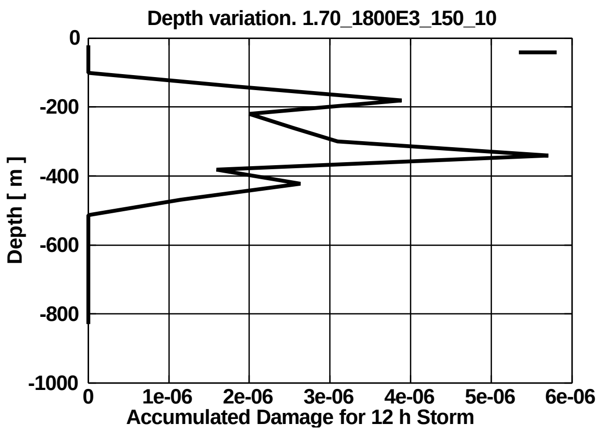

Figure 17 Accumulated damage along the riser

The accumulated damage is shown in Figure 17. The maximum peak occurs at a depth of 350 m, and the damage is reduced as compared to the TTR of 1.8 by roughly 40%.

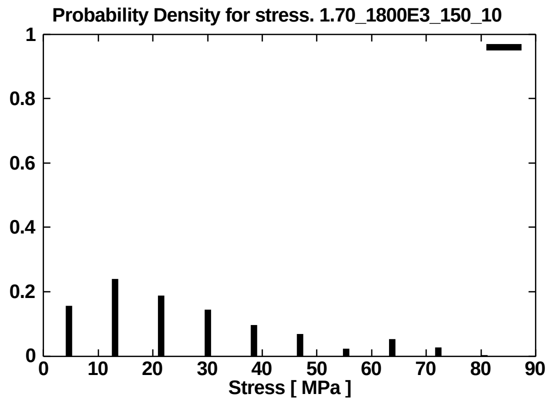

Figure 18 Probability density of maximum stress. TTR is 2.25

The contact stress probability density is shown in Figure 18. It is observed that around 80% of the contact stresses are less than 35 MPa.

Effect of reducing floater motion amplitude

The amplitude of the floater motion is subsequently reduced from 10 to 5m. The TTR is equal to the base case value of 1.8, and the current velocity is 1.7 m/s. As seen from Figure 19, the peak stress is now approximately 130 MPa.

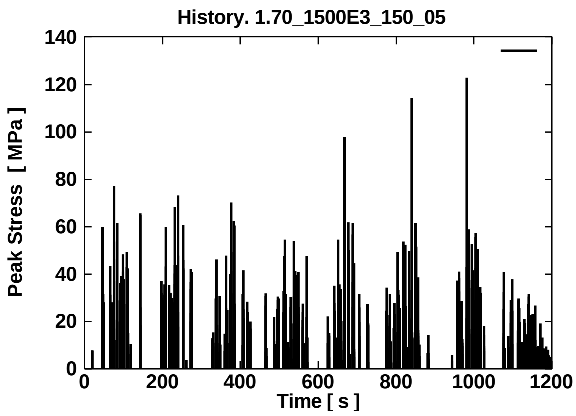

Figure 19 Stress History. Motion amplitude is 5m

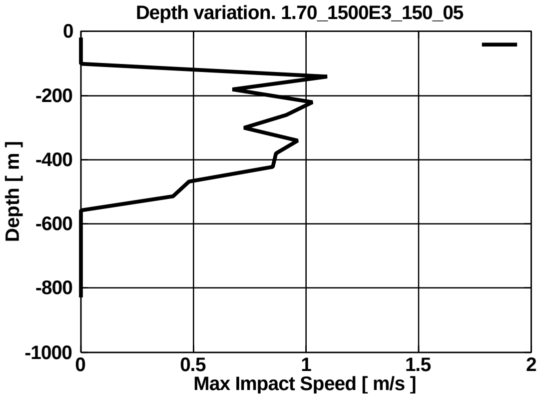

Figure 20 Max impact speed with depth.
Motion amplitude is 5m

The impacts still occur within the same zone as before, with the maximum velocity now being roughly 1 m/s. This is somewhat smaller than for the 10m motion amplitude.

The maximum damage occurs according to Figure 21 at the same depth of 150 m as for the 10m amplitude. However, the peak damage is surprisingly increased by a factor of 2 compared to that case, even if the other peaks are somewhat reduced.

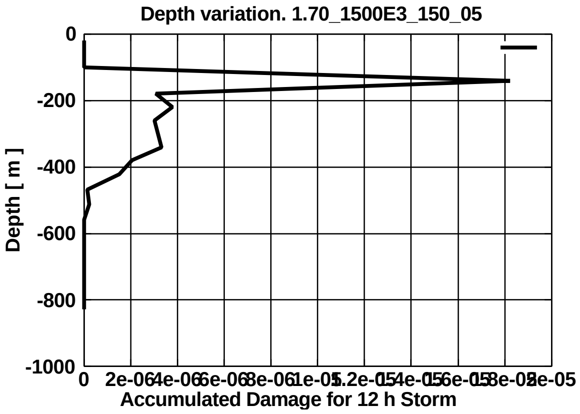

Figure 21 Accumulated damage along the riser.
Motion amplitude is 5m.

The probability density in Figure 22 shows that 80% of the stresses are less than 40 MPa. However, for this case the peak probability density occurs for a much smaller value (less than 10 MPa) than for the 10m amplitude (for which the peak occurs close to 20 MPa)

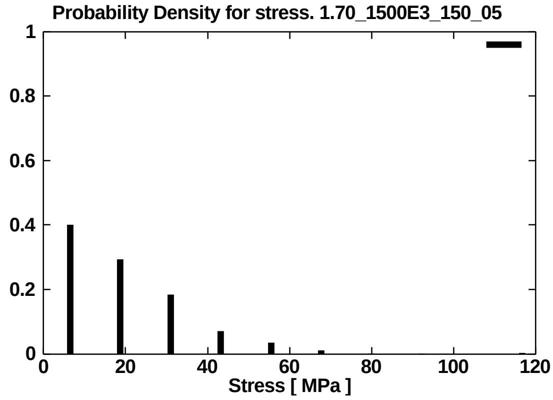

Figure 22 Probability density of maximum stress.
Motion amplitude is 5m

SUMMARY AND CONCLUSIONS

A procedure for assessing the severity of collision problems for deep-water riser arrays is described A specific Case study is performed in order to illustrate the methodology. The surface current velocities are in the range between the 1-year and 100-year extreme values. The following observations of key response quantities are made:

- Peak stresses of the order of 130 MPa are observed. These stress levels are relevant for uniform pipes and will be much increased for cases with a connector on one the risers.
- The extension and location of the zone where impacts occur seem to be quite stable.
- The top tension influences the impact statistics considerably.
- Increasing vessel motion amplitudes seem to increase the avarege stress level, but the tendency is not so clear.

Further studies on the simulation lengths required to obtain stable response statistics should obviously be performed.

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