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# ESTIMATION OF EXTREME RESPONSE AND FATIGUE DAMAGE FOR COLLIDING RISERS

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## ABSTRACT

For design of deep-water riser arrays, consideration must be made of the possibility for mechanical contact between the different riser pipes. Both the anticipated frequency of collision and the resulting stresses in the pipes need to be estimated. Such an assessment need to cover a certain range of conditions regarding environmental loading and surface floater motions. The present paper outlines a procedure which admits the most "critical" conditions to be identified based on an iterative approach. For each "load case", which corresponds to a certain combination of environmental actions and surface floater motion, the corresponding contact stresses are computed. Furthermore, the accumulated damage for each load case (referred to a certain duration) is estimated.

The numerical procedure for external load calculation is based on Computational Fluid Dynamics (CFD). For a given riser spacing, interpolation is performed during the response simulation in a pre-established data base. 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.

By assembling the response and accumulated damage which correspond to all the different load cases, the long-term probability distributions and weighted damage can be calculated. The procedure is applied to a particular example riser configuration. The effect of varying current direction (relative to the symmetry axis of the floater and riser configuration) on fatigue damage is focused upon in particular

## INTRODUCTION

The collision frequency for pipes within a riser array is influenced both by the current magnitude, its depth variation and direction. In addition, top end motions may have strong effects. The probabilistic combination of current magnitude, direction and amplitude of surface floater motion is accordingly identified as a highly important issue in the present context. Furthermore, the interaction between current velocity and top end motion in relation to collision frequencies and stresses is generally of a highly nonlinear character.

The joint modeling of current and floater motion is in the present study based on their respective long-term distribution functions. The primary response quantity is the pipe stress associated with each collision. Furthermore, the corresponding fatigue damage induced by repeated collisions need to be estimated. The response analysis is performed in the time domain. The current is presently modeled in terms of a given (planar) profile which is scaled by the surface magnitude. The direction of this current relative to the symmetry axis of the surface vessel is also varied.

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
- Algorithm to identify contact between the pipes and the resulting pipe deformations once contact has occurred.

In the Finite Element Module, see e.g. ref [1], a general 3D beam element is applied. A nonlinear analysis approach is applied primarily due to the geometric nonlinearities (i.e lateral stiffness due to tension) and the contact algorithm. The latter leads to rapid stiffness changes for the integrated riser system. The floater motion is represented in terms of prescribed displacements (harmonic motion) of the riser top end.

At present, one pair of adjacent risers in the array is analysed at a time. This implies that a number of such pairs need to analysed in order to identify the most critical combination of risers. A screening of the most relevant combinations can possibly be achieved by simplified methods.

## 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 , refs. [2,4]]. If the risers are located close to each other, the flow pattern will be "disturbed" relative to the flow around a single cylinder. The load model accounts for these effects in terms of pre-defined coefficient tables.

These tables 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 (transversal) flow conditions along the risers, which corresponds to application of strip theory. It must be noted that the structural model which is applied is fully three-dimensional.

The database applied for computation of excitation coefficients contain forces at the vortex shedding frequency. This frequency depends on the relative position, i.e. it contains interaction effects. This force produces response associated with VIV. However, a true fluid structure interaction is not fully represented.

## Search algorithm for 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 (vii) Compute stresses in the pipes.

Multiple contacts at the same cross-sections for each "interference event" are also represented. This may occur if the resulting flow-field produces an enduring contact force.

At present, only the relative velocity component normal to the pipe axes is applied. However, the tangential component is also available as part of the computation and can be recorded if required. This component can be of relevance e.g. in relation to abrasion and wear of external pipe coating.

## Verification

The methodology for dynamic simulation of interacting risers has been compared with measurements in model scale in both 2D and 3D. The promising results from 2D were the basis for implementation in 3D. However, in 3D a fully detailed comparison is very difficult due the achievable accuracy for the small scale models which are applied. Tests have been performed on long risers where the collision intensity was measured in terms of impulse. The measurements were somewhat crude, but still the computations gave promising results.

In the referred investigations, it was found that impulse was not a good parameter for assessing the severity of the collisions. Instead, the relative velocity between the risers at hit was found to be the parameter to pursue. There exist plans for designing a model test where the motions and the relative velocity can be monitored. If such a test can be performed, validation cases for the present methodology will be available.

## GENERATION OF ENVIRONMENTAL AND VESSEL MOTION DATA

### Background

In the present analysis, the current is modeled in terms of a given (planar) velocity profile scaled by the surface magnitude. The effects of dynamic wave-induced water particle motion is neglected, since these are of little importance for deep-water risers. Combination of current (both magnitude and direction) and surface floater motion is identified as a highly relevant issue. This 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 relevant.

### Statistical modeling of current velocity and floater motion

The current velocity is here represented in terms of a long-term distribution of the Weibull type. The same applies to the floater surge motion. The shape of the current profile is for simplicity taken to be the same for all cases, but with the surface velocity acting as a scaling factor. The same factor is applied for all levels of the profile. More complex representations of both the current and the floater motion can easily be envisaged. However, in order to illustrate the basic steps of the procedure, this modeling is sufficiently general. Furthermore, it is assumed that the floater motion and the current velocity refer to the same basic duration, which here is taken as 12 hours.

Each of the long-term distributions can now be discretised into a number of intervals. For each of the intervals, the corresponding probability content can be computed as the difference between the values of the cumulative distribution function at the two interval limits. A particularly convenient scheme is to apply intervals with equal probability contents. This implies that the length of each interval (both for the current and for the floater motion) will vary.

The joint probability of each interval for the current velocity and each interval for the floater motion is now equal to the product of each of the separate probabilities (by assuming independence between the floater motion and the current velocity). For each combination of intervals, a response analysis should now be performed. This is illustrated in Figure 1 below.

Response time series are post-processed to yield probability distributions of stresses and accumulated fatigue damage. The long-term distributions of the same response quantities and the total fatigue damage may in principle be obtained by a proper weighting and summation of all the corresponding distributions.

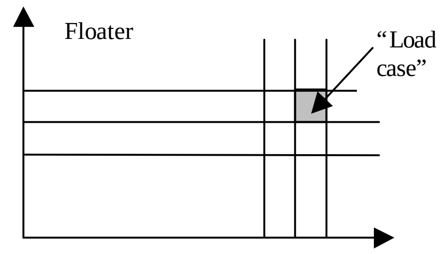


FIGURE 1. “LOAD CASES” CORRESPONDING TO COMBINATION OF CURRENT VELOCITY AND FLOATER MOTION

In addition to the current magnitude (given a specific current profile), the direction of this current relative to the riser array can also be anticipated to have a strong influence on collision frequency and magnitude. Accordingly, a third dimension representing this direction should also in reality be included in Figure 1. A parametric variation of this direction is performed in relation to the Case study below to investigate this effect.

## CASE STUDY: RISERS SUSPENDED FROM TLP

### General

The case study platform is a Tension Leg Platform (TLP). The spacing between the risers is 4m throughout the waterdepth, which is equal to 1000 m. The riser diameter is 245mm, and the wall thickness is 14mm. The riser top tension is 1.5 times the submerged weight (i.e. Top Tension Ratio (TTR) equal to 1.5).

For the case study, two production risers with identical diameter were selected. Both currents acting in-plane (which corresponda to 0° in the FE-model) and at angles to the symmetry axis are considered.

### 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 4000. The floater motion is applied to the riser top nodes as prescribed time-harmonic displacements.

The risers are modeled from the TLP to the seabed, giving a total length slightly above 1000m. As mentioned above, a TTR of 1.5 is applied in the present analysis. This is done in order to obtain more collisions for the case study purpose.

The time increment in the analysis is 5 ms, and the analysis time is 600 seconds (i.e. 4 floater periods). The time consumption is approximately 10 times the real time (1.7 hours *cpu* for 600s on a PC).

The floater motion represents a substantial fraction of the total speed which is experienced by the riser. This motion accordingly modifies the constant ocean current (a reduced correction is applied 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.

## PARAMETRIC STUDY OF CURRENT DIRECTION

Response analyses are first performed for four different current directions with a fixed floater amplitude equal to 18m.

The current velocities obtained from the long term distribution
which correspond to return periods of 10 years and 100 years are given as 0.90 m/s and 1.0 m/s, respectively. For the present analysis the applied current velocity is equal to 1.0 m/s. For the base case floater surge motion, a harmonic motion with an amplitude of 18m is applied. This is a rather extreme motion amplitude, and the resulting response hence represents an upper bound. In order to investigate the influence from motion amplitude, a reduced value of 9m is also applied. A period of 150 seconds is employed for the harmonic floater motion independent of motion amplitude.

The collisions are assumed to occur at a flange, i.e. the flange on one riser hits the bare pipe of the second riser. This implies that the resulting collision stresses are much higher than for a pure pipe-pipe collision. The dominating stress components are the shell bending stresses. For the most extreme collisions, the impact stresses exceed the yield stress of the steel in the riser pipes. This implies that the resulting dent depth should be considered for such cases. However, this topic is not pursued in any more detail in the present work.

### Results for current direction equal to 0 degrees

Time series of impact velocities for all collisions that occur along the riser is shown in Figure 2 for the case that the current is acting along the symmetry axis of the surface floater (i.e. the angle of incidence is 0 degrees). This is also the direction of motion for for the TLP. Furthermore, both risers are lying in the plane of symmetry.

The impacts occur when the floater is moving towards the incoming current. This is due to the relative fluid velocity being highest for this case. The first part of the time series is not shown as transient response is present during the first 100 seconds. As observed, the maximum impact velocity is found to be 2 m/s, while most of the velocities are 1m/s and less.

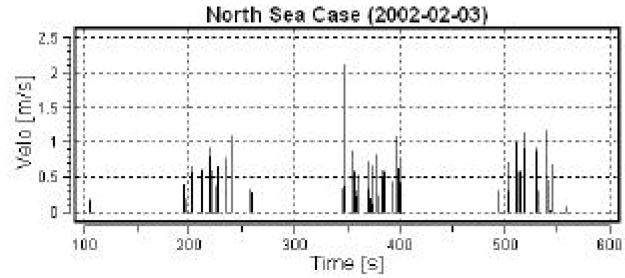


FIGURE 2 TIME SERIES OF IMPACT VELOCITES FOR CRITICAL CROSS-SECTION. DIRECTION OF CURRENT IS 0 DEGREES.

The corresponding fatigue damage (corresponding to a reference period of 1 year, i.e. assuming the given "load condition" to last for 1 year) along the riser is shown in Figure 3.

The impacts occur in a zone with length of 400 m around the upper middle part of the risers (i.e. between 200 and 600 m below the surface). The highest value of the damage occurs for a depth range from 200 to 300 m. A second peak occurs at a depth of around 500m.

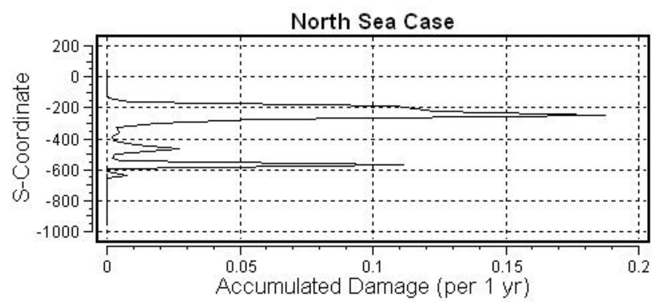


FIGURE 3 ACCUMULATED DAMAGE ALONG RISER. CURRENT DIRECTION IS 0 DEGREES (CURRENT VELOCITY IS 1.0 M/S).

### Results for current direction equal to 2.5 degrees

The time series of impact velocities for the case that the incoming current has a direction of 2.5 degrees relative to the symmetry axis is shown in Figure 4. The motion of the TLP is in the same direction as before.

The maximum impact velocity is around 1.0 m/s. The "typical level" of impact velocities is now around 0.6 m/s. The same clumping of impacts is observed as for the previous direction. This is due the combined effect of current and floater motion. The collisions occur when the combined "relative velocity" has its maximum value.

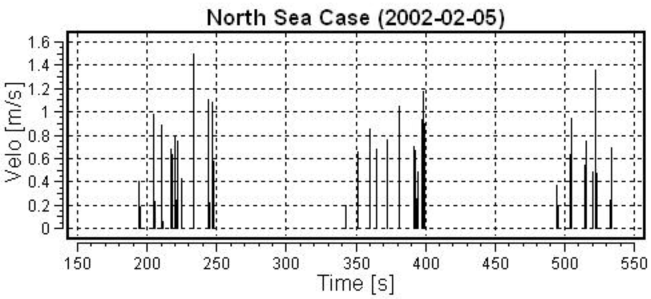


FIGURE 4 TIME SERIES OF IMPACT VELOCITIES. DIRECTION OF CURRENT IS 2.5 DEGREES.

The resulting fatigue damage is shown in Figure 5. As observed, the damage is much more localized than for the previous current direction. The largest peak occurs at a depth of around 250m. A much smaller peak occurs at a depth of roughly 400 m. The maximum value of the damage is furthermore a factor of four higher than for the previous case. This is due to the higher average value of the impact velocities even if the extreme velocity is significantly smaller than for the current direction of 0 degrees.

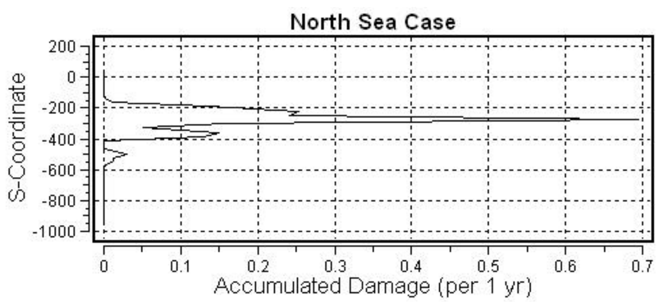


FIGURE 5 ACCUMULATED DAMAGE VERSUS DEPTH. DIRECTION OF CURRENT IS 2.5 DEGREES.

**Results for current direction equal to 5 degrees**

From the impact velocity time series corresponding to a current direction of 5 degrees, which is displayed in Figure 6, it is seen that the maximum velocity now is around 1.8 m/s. The average velocity is of the order of 0.5 m/s and less.

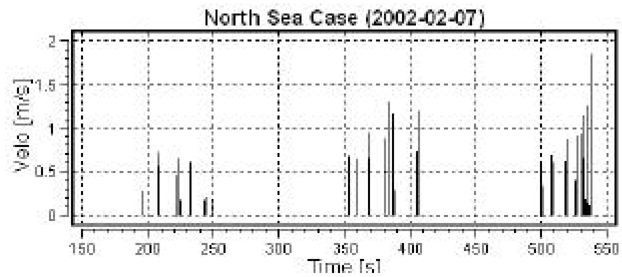


FIGURE 6 TIME SERIES OF IMPACT VELOCITIES. DIRECTION OF CURRENT IS 5 DEGREES.

As seen from Figure 7, the highest value of the fatigue damage is now of the order of 0.1, which occurs at a depth of around 300m. This is quite close to the location of the critical cross-section for the previous current direction.

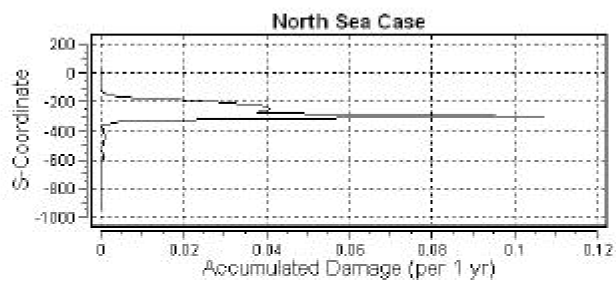


FIGURE 7 ACCUMULATED DAMAGE ALONG RISER. CURRENT DIRECTION IS 5 DEGREES.

**Results for current direction equal to 10 degrees**

The impact velocity time series for a current angle of 10 degrees is shown in Figure 8. The maximum velocity is still of the same order as before, i.e. 1.8 m/s. The average level is also now of the order of 0.5 m/s and less. However, now it is seen that the total number of collisions is significantly reduced as compared to the previous cases.

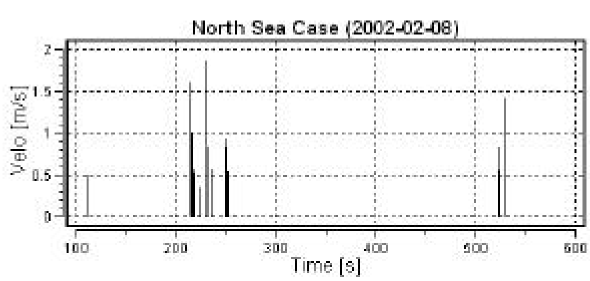


FIGURE 8 TIME SERIES OF IMPACT VELOCITY. DIRECTION OF CURRENT IS 10 DEGREES.

The damage along the riser is shown in Figure 9. The peak of the diagram is now located at depths between 200 and 250 m. Furthermore, it seen that the magnitude of the peak now is significantly reduced as compared to the previous cases. The maximum value is of the order of 0.01 which is only one tenth of the value for 5 degrees.

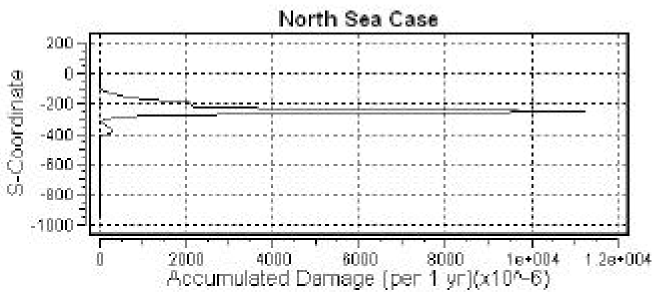


FIGURE 9 ACCUMULATED DAMAGE ALONG RISER. DIRECTION OF CURRENT IS 10 DEGREES.

### Fatigue damage weighted across all directions

The total fatigue damage is now obtained by weighting and summing the contributions from the different directions. In order to perform such a computation, the probabilities associated with the different directions is of key importance.

Presently, we assume that the probability distribution across all directions is uniform. However, the fatigue damage for incoming current directions larger than 10 degrees is found to be zero. Furthermore, the contributions from negative angles are the same as for positive contributions due to symmetry. It is also important to note that for the 180 current direction the riser response is zero due to shielding effects from other risers in the array.

The resulting weighted damage along the riser for all directions is shown in Figure 10. As observed, the peak damage is 0.011. This corresponds to total fatigue damage of around 1.1 for a duration of 100 years (or a value of 1.0 for a duration of 90 years). If we apply the damage for the 0 degree direction as a reference value, we see that the present weighted damage is more than a factor of 10 less.

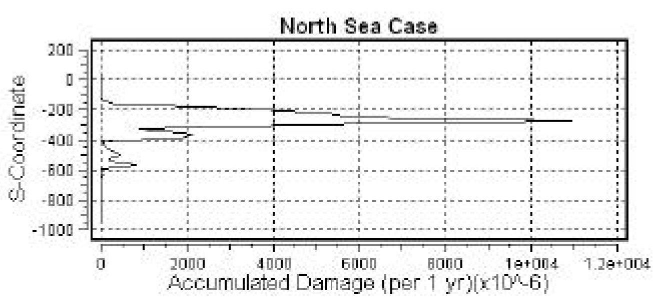


FIGURE 10 RESULTING WEIGHTED DAMAGE FOR ALL CURRENT DIRECTIONS. CURRENT VELOCITY IS 1.0 M/S. FLOATER AMPLITUDE IS 18M.

It should furthermore be kept in mind that the present damage estimates are based on high values of both the current velocity and the floater motion amplitude. Accordingly, a further weighting across the different "load cases" illustrated in Figure 1 should be performed. Presently, we illustrate below the effect of changing the motion amplitude from 18m to 9 m.

### Effect of reducing floater motion amplitude

The impact velocity time series for a current direction equal to 0 degrees for the case with a floater amplitude equal to 9m is shown in Figure 11. The maximum velocity is 1.5 m/s which is much smaller than the value of around 2 which was observed for a floater amplitude of 18m.

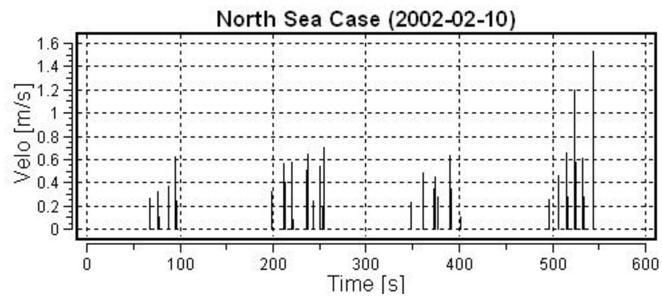


FIGURE 11 TIME SERIES OF IMPACT VELOCITY. DIRECTION OF CURRENT IS 0 DEGREES. FLOATER AMPLITUDE IS 9M.

The corresponding fatigue damage along the riser is displayed in Figure 12. This diagram should be compared with corresponding results in Figure 3. As observed, the peak value is now reduced from 0.18 to 0.02 which almost corresponds to a factor of 10. The location of the critical cross section is shifted downward from 250m to around 350m.

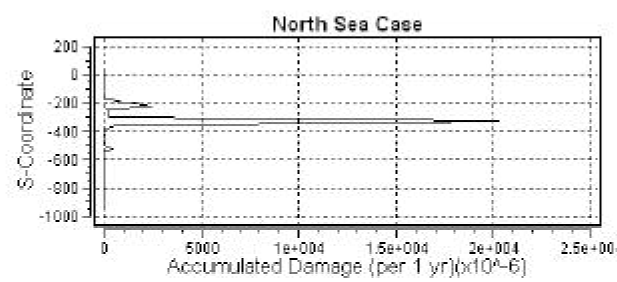


FIGURE 12 ACCUMULATED DAMAGE ALONG RISER. DIRECTION OF CURRENT IS 0 DEGREES. FLOATER AMPLITUDE IS 9M.

Similarly, the time series of impact velocity for a current direction equal to 2.5 degrees and with the reduced floater amplitude of 9m is given in Figure 13. As compared to the time series for a floater motion amplitude equal to 18m, the peak velocity is reduced from 1.8 m/s to 1 m/s. The average velocity level is also significantly reduced to a new level of less than 0.4 m/s.

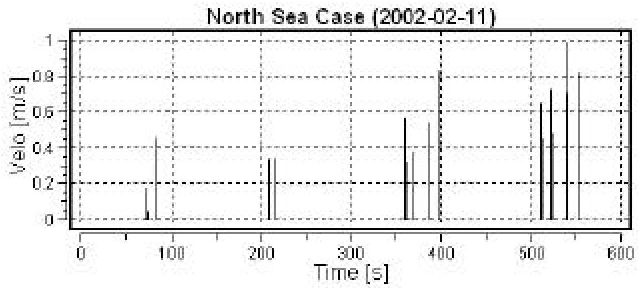


FIGURE 13 TIME SERIES OF IMPACT VELOCITY. DIRECTION OF CURRENT IS 2.5 DEGREES. FLOATER AMPLITUDE IS 9M.

The corresponding fatigue damage along the riser is given in Figure 14. As compared to the results for a floater amplitude of 18m, the peak damage is now reduced from 0.7 to 0.018 (i.e. by a factor of almost 40). Clearly, this has strong implications regarding the estimated fatigue lifetime by applying a weighting with respect to floater amplitude (multiplied by the corresponding probability).

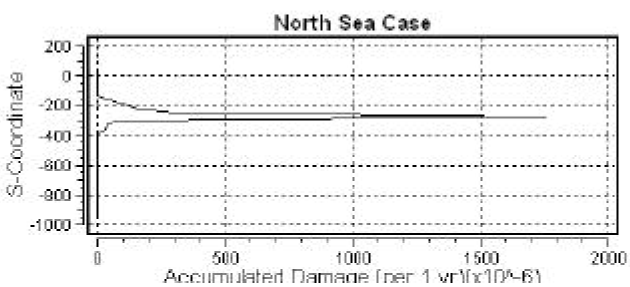


FIGURE 14 ACCUMULATED DAMAGE ALONG THE RISER. DIRECTION OF CURRENT IS 2.5 DEGREES. FLOATER AMPLITUDE IS 9M.

## SUMMARY AND CONCLUSIONS

A procedure for assessing the severity of stress levels associated with collision for deep-water riser arrays is described A specific Case study is performed in order to illustrate the methodology. The surface current velocity is of the order of the 100-year extreme value. The following observations of key response quantities are made:

- Peak impact velocities of the order of 2 m/s are observed. The corresponding stress levels relevant for a flange impacting on a uniform pipe exceeds the yield limit. Accordingy, the resulting dent depth would have to be considered.
- The direction of the incoming current relative to the symmetry axis of the surface floater is found to have a pronounced effect on the stress levels and fatigue damage induced in the risers.
- The stress level and fatigue damage decrease significantly for decreasing motion of the floater amplitude.

While the results obtained are quite case specific, the main intention of the present study is to illustrate the potential of the present method of analysis. Still, some of the issues which are to be addressed as part of future research efforts are the following:

- Further studies on the simulation lengths required to obtain stable response statistics should obviously be performed.
- Similarly, convergence studies on the number of load cases to be analysed in order to obtain stable estimates of the design values need to be performed.
- Obviously, the effect of applying more refined models for the current profile (e.g. varying current direction as a function of depth) and for the floater motion also needs to be investigated.

In addition, a number of topics related to the hydrodynamic load model also require further developments, see ref.[4] for a proper discussion.

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