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MARINTEK REPORT

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Riser Interference and Contact.
Methodology for Prediction

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ABSTRACT

Model for prediction of forces acting on pairs of risers exposed to current has been developed by Norsk Hydro, (1998-2002). The force model, (HYBER), has been implemented in an existing, general 3D mechanical response tool, (finite element approach). The response tool is able to predict and handle eventual contact (collision) between the interfering risers and give estimates on local damage on the risers.

The simulation tool covers a number of actual environmental conditions, such as uniform current, shear current, depth varying current direction, floater motion and more. Smooth risers as well as risers with strakes for "any" configuration are handled.

Specialised graphical tools based on GLVIEW have been developed by Ceetron ASA in order to present and process a large number of data in an efficient and user-friendly manner.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Marine Technology	Marinteknikk
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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 mean to accept that the risers may come in contact for some environmental conditions.

If the impact energy is low, such impacts could 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 (collision impulse, impact forces, local pipe wall stresses etc).

The most important parameters influencing the collision process are in brief:

- ❑ Riser spacing
- ❑ Riser tension
- ❑ Pipe surface (f ex with or without ‘strakes’)
- ❑ Ocean current (velocity, direction, profile)
- ❑ Floater Motion

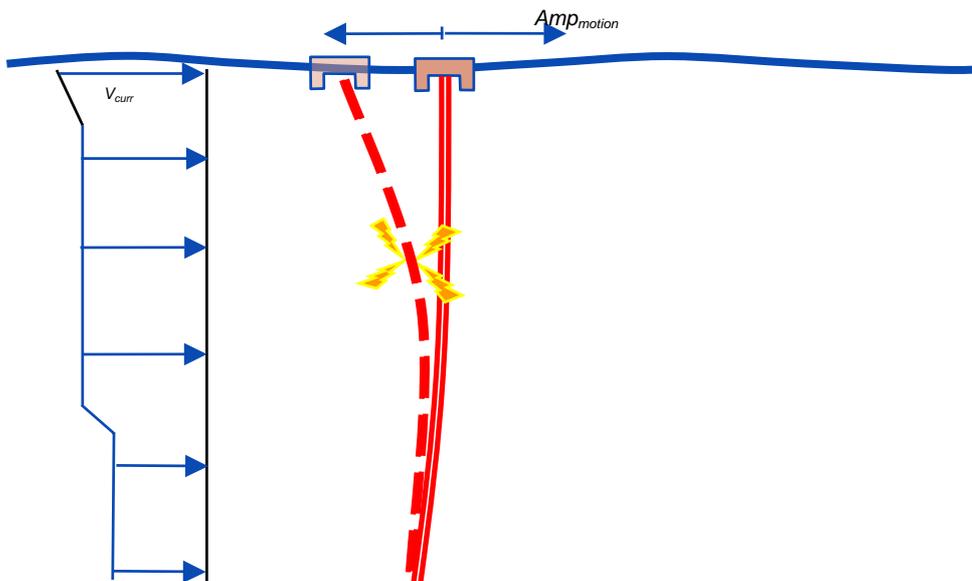


Figure 1-1 Colliding Deep Water Risers

Substantial research effort has been expended in order to increase the knowledge about the physics (laboratory tests, field measurements etc) and to develop computer tools for the designers.

2. The Concept

The complete solution of the riser interference problem would require a full fluid structure interaction formulation (FSI). However, mainly due to extreme computation time, such methods are not available for practical use for decade(s).

The actual simulation technique (HYBER) is based on pre defined tables (database), where the hydro dynamic forces acting on the interfering risers are stored for various relative positions of the risers. These pre calculated forces (coefficients) are used during the time domain simulation, where the instantaneous relative position is used to find the actual drag- and lift coefficients from the database.

The coefficient database is a pure 2D solution and is based on:

- Numerical simulation using a fluid solver (NAVSIM)
- Laboratory tests

The mechanical system is simulated using a conventional FE solver, where the risers are modelled using beam elements.

3. Environmental- and Boundary Conditions

3.1 Tension and Stiffness

Since an ordinary FE solution is used for the mechanical system, “any” riser configuration is possible. The top tension is applied using concentrated forces at the top riser nodes. (Individual forces between the risers are possible). The pre processor (preHyber) computes the actual top tension forces based on the TTF (Top Tension Factor).

The flexibility of the riser top support is modelled using spring elements. The pre processor computes the spring stiffness based on the TSF (Top Spring Factor).

3.2 Floater Motion

The technique of prescribe displacement is used for the simulation of the riser top (floater) motion. The motion is predefined typically in terms of harmonic (sine) functions, but any (irregular) function could be used as well.

Two different options are employed for modelling of the floater motion. These may be described as follows:

- (i) Fixed-amplitude motion with a given period
- (ii) Long-term distribution of floater amplitude

Further details are given in the two following sections.

3.2.1. Fixed-amplitude floater motions

For this option 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 (expected value of the arbitrary point-in-time amplitude)
- (ii) The expected largest amplitude within a single sea state. The extreme-value distribution itself 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.

Obviously, Alternative (iii) is the most conservative of the three. This is proposed as the primary option, unless it is found that the results differ by an unreasonable amount from the other two alternatives.

3.2.2 Long-term distribution of floater motion amplitude

Due to the generally different characteristic time scales for the current and sea state conditions, a similar distinction arises as for the first option 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) 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. This distribution is obtained from the long-term distribution by exponentiation
- (iii) The probability distribution for the extreme motion 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 case (ii) above

For this case, the long-term distribution of the floater motion amplitude is applied, which corresponds to option (i) in this list. The selected distribution function is discretized into a finite number of intervals corresponding to the "response" analysis cases which are applied.

3.3 Current

The surface current velocity is represented in terms of the long-term distribution. Furthermore, the duration of each stationary current condition (i.e. the period for which the current is considered as being constant) need to be specified.

The variation of the current velocity with depth is given by the analyst, and is assumed to be deterministic. Accordingly, the surface velocity scales the current velocity throughout the water depth.

In addition, the current direction need not being constant throughout the entire water depth. Any offset from the surface current direction could be specified.

4. Hydrodynamic Models

4.1 General

The HYBER concept was originally developed for 2D analyses by Norsk Hydro, /1/. The theory has been taken over to 3D analyses assuming piecewise constant conditions along the risers (“strip theory”). The mechanical system ensures interaction between the different 2D “layers”.

In the finite element representation of the riser system, each finite element is treated individually with respect to the HYBER load calculations. A coarse FE mesh results in a coarse hydrodynamic representation and vice versa.

The HYBER module core operation is calculation of drag- and lift coefficients, (both mean and fluctuating), based on the instantaneous relative position between the risers.

The normalised coefficients are read from a separate file, and for each analysis time step, the actual distance (dX and dY) between the risers are calculated, and interpolated coefficients are used.

For each time step the load calculation is carried out as follows:

- 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°)
- For each finite element along the riser, find the nearest (other) element on the second riser
- Find (among the two) which of them is located first in the current
- Select HYBER coefficients and calculate drag and lift forces in the current co-ordinate system
- Transform forces to the system’s global co-ordinate system and add forces to the system load vector

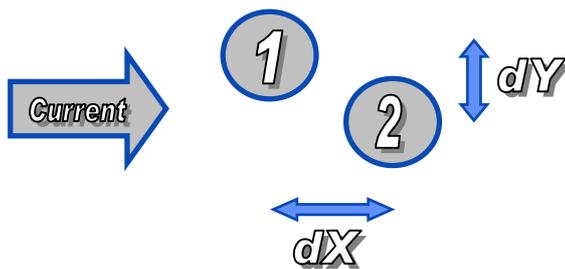


Figure 4-1 Coefficients are based on relative position

4.2 Coefficient Database

The coefficient databases are produced either by computations with CFD program or by model tests. As the program is based on a quasi-static assumption, the database consists of forces and frequencies as fixed numbers for each relative position. The database for one particular case, as for instance two smooth cylinders with equal diameter, may be illustrated by 3D function

representation or colour “maps”. For one particular case, there will be 12 such maps, see table below:

Cylinder 1	Cylinder 27
Mean drag coefficient	Mean drag coefficient
Frequency of oscillating drag	Frequency of oscillating drag
Standard deviation of oscillating drag	Standard deviation of oscillating drag
Mean lift coefficient	Mean lift coefficient
Frequency of oscillating lift	Frequency of oscillating lift
Standard deviation of oscillating lift	Standard deviation of oscillating lift

Table 4-1 Actual data per relative position

As examples, two colour maps are shown below.

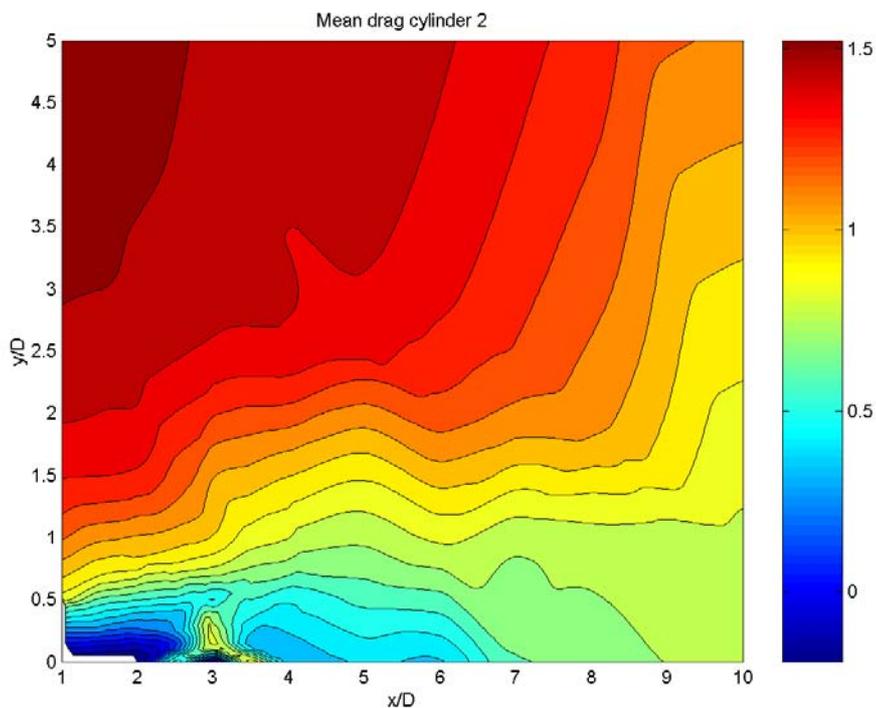


Figure 4-2 Contour plot of mean drag on cylinder 2 (in the wake of cylinder 1) as a function of relative position based on computed results with Navsim. Cylinder 1 is in the origin of the coordinate system. The relative distance is measured in number of diameters

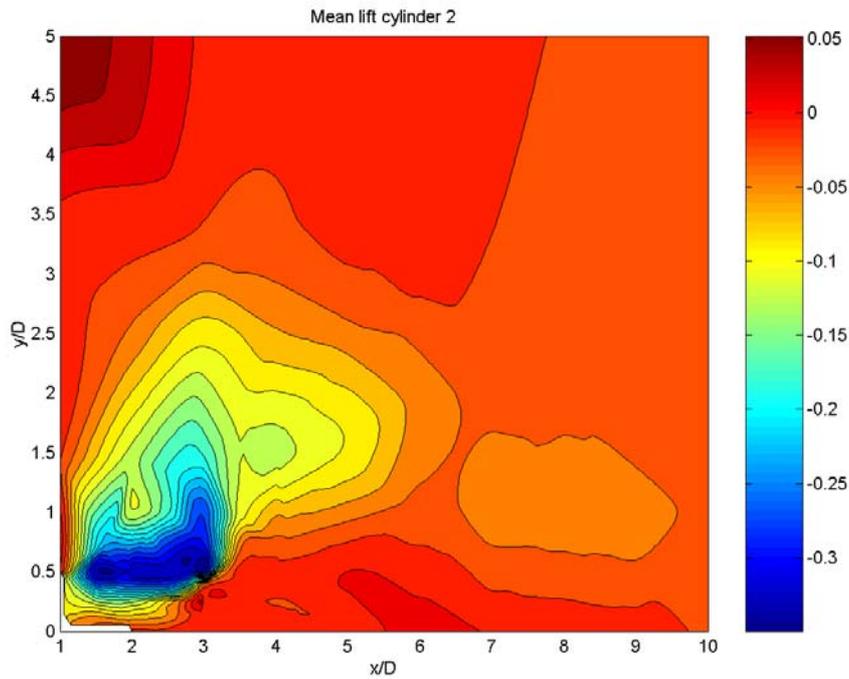


Figure 4-3 Contour plot of mean lift on cylinder 2 (in the wake of cylinder 1) as a function of relative position based on computed results with NAVSIM. Cylinder 1 is in the origin of the coordinate system. The relative distance is measured in number of diameters.

At present, the following cases are given its databases:

Relation between diameters	Smooth/strakes	Source
1:1	Smooth	CFD
1:1	Smooth	Model tests
1:1	Strakes, h=0.25 D, P=17.5D	Model tests
1:1	Strakes, h=0.15 D, P=10D	Model tests
2:1	Smooth	CFD
2:1	Smooth	Model tests
4:1	Smooth	CFD
4:1	Smooth	Model tests

Table 4-2 Available Databases

4.3 Force Model

HYBER is based on pre-established interaction coefficients. Interaction effects are present for all relevant parameters, mean as well as dynamic forces. The model is described by showing the transverse force for cylinder 1.

$$F_L^1 = \frac{1}{2} \rho D U^2 (C_{L_mean}^1 + C_{L_osc}^1) + F_{L_damp}^1 \quad (0.1)$$

$$C_{L_mean}^1 = C_{L_mean}^1(x, y) \quad (0.2)$$

$$C_{L_osc}^1 = \sqrt{2} \sigma_{C_L}^1(x, y) \sin\left(2\pi \frac{f_{C_L}^1(x, y) U}{D} t\right) \quad (0.3)$$

The sine function is given as follows:

$$\sin \theta \quad (0.4)$$

Where

$$\theta = \int_0^t \omega(t') dt' \quad (0.5)$$

The practical implementation is as follows:

$$\theta_{(n+1)} = \theta_n + 2\pi \frac{f_{C_L}^1(x, y)_n U}{D} dt \quad (0.6)$$

4.4 Damping Formulations

The damping may be handled in different ways. There exist relative velocity forcing formulations where the damping is treated implicitly. We have chosen to use explicit damping formulations. One is given by the following relation:

$$F_{xDamp} = B\rho DU \dot{x}$$

$$F_{yDamp} = B\rho DU \dot{y}$$

The factor B is quantified with support of Venugopal (1996) /6/ and Vikestad et al. (2000)/7/. On this basis, a value of 0.2 is used. When used in a VIV prediction program, the given damping model will act in a surrounding where the excitation (e.g. lift coefficient) is given as a function of response (cross-flow) amplitude. The present program has excitation and is able to predict VIV in in-line as well as cross-flow direction. The excitation is not, however, a function of amplitude. The excitation is fixed, and merely a function of relative position between the risers. Due to this, we have been seeking a damping formulation that can take into account the response amplitude in some way. With reference to Halvor Lie (Marintek) and Mike Triantfyllou (MIT), we have adapted the following damping formulation:

$$F_{L_damp}^1 = \frac{1}{2} \rho D C_{L_osc}^1 U^2 \frac{1}{A_{0_L}^1 2\pi f_{C_L}^1(x, y)} \quad (0.7)$$

$C_{L_osc}^1$ is the amplitude of the oscillating part of the force in the actual degree of freedom and actual riser. $A_{0_IL}^1$ is a limiting amplitude where the excitation should be reduced to zero according to the self-limiting tendency of lock-in VIV. In in-line direction, the limiting amplitude is set to $0.35 D$, and in cross-flow direction it is set to $1.1 D$.

A drag amplification due to the cross-flow motions will be implemented according to Sarpkaya, with the general form as follows:

$$C_{D_mod}^1 = C_{D_mean}^1(x, y) \left(1 + 2 \frac{A_{0_L}^1}{D} \right) \quad (0.8)$$

4.5 VIV

The present tool is not made to be a precise VIV prediction tool. VIV prediction tools use empirical data for the force amplitude in cross-flow direction as a function of the response amplitude.

The resulting response is found as an equilibrium condition between excitation zones and damping zones along the riser. This is done in frequency domain, and the result is considered stationary in a short time condition. These programs do not attempt to predict in-line VIV. The present program models the excitation in in-line as well as cross-flow direction, for both the modeled risers.

The program does the computations in time domain, so that the excitation can be altered according to the relative position between the risers from time step to time step. Except for the influence from damping model two above, it is the structural model that will decide the VIV response.

The excitation is imposed according to the vortex shedding frequency. The structure will respond in this frequency, possibly in a combination with a closely positioned natural frequency. The actual natural frequency may dominate the picture, similarly to a lock-in situation. However, there is no fluid structure interaction modeling in the program, thus it is the properties of the structure, in combination with the influence from damping model two that decide the VIV response.

According to experience gained so far, the VIV response is under predicted by HYBER. Certain ideas to improve this tendency will be pursued.

4.6 Handling of Relative Motion

The coefficients in the database are based on fixed cylinders in a constant flow (current). For risers fixed at both the top and the bottom, the incoming current should be used in connection with the force calculations. However, if the top end of the riser is moving up- and down stream due to the floater motion, the current speed will vary, (order of ± 0.2 m/s at the surface), during the floater period. This oscillating current has to be accounted for.

This floater motion induced velocity is computed using a low pass filtering technique of the riser movement. (The high frequency movement caused by riser impact etc. should not be included in the relative velocity).

In Figure 4-4 the in line velocity at one point of the riser is plotted with solid (black) line. The dotted (red) curve is the predicted slow varying velocity, which is induced by the floater motion.

The velocity used in connection with the force calculation (database coefficients) is adjusted for this slow varying, harmonic velocity

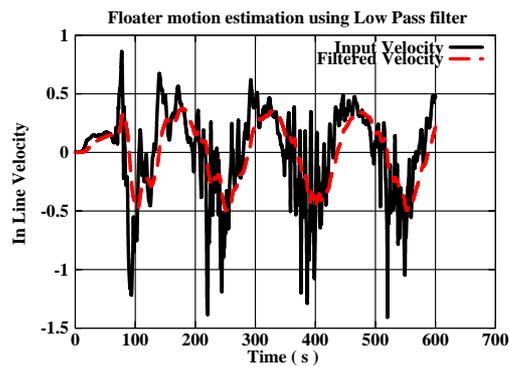


Figure 4-4 Estimation of floater motion induced velocity

5. Mechanical System

5.1 Non linear Finite Element Tool

A computer program for dynamic non-linear analysis of structural systems forms the basic building block. In connection with riser collision, the following requirements to the tool exist:

- ❑ General non linear dynamics in 3D
- ❑ Beams, cables, springs
- ❑ Geometric non linearity
- ❑ Efficient implicit equation solver (SPARSE technology)
- ❑ Prescribed motion

For the hydrodynamic load calculation and for handling of contact between risers, new modules had to be developed and implemented in the basic version of the tool.

5.2 Contact between Risers

The contact formulation implemented in connection with the riser collision problem is based on a general surface-surface {contact search}/{contact force} technique. Collision search between an arbitrarily number of risers is possible, but for the present purpose, only two risers are involved. The collision calculations are divided into the following main steps:

- ❑ Coarse contact search (beam/beam search)
- ❑ Re-meshing of beams to surface elements (if beams are close), see
- ❑ Detailed 3D surface– surface contact search
- ❑ Establish appropriate stiffness of the pipe surface
- ❑ Calculate interface force (if contact) on pipe surface and re-track to beam system for further adding to the system load vector
- ❑ Record impulse, impact velocity, and angle between risers (see figures below).

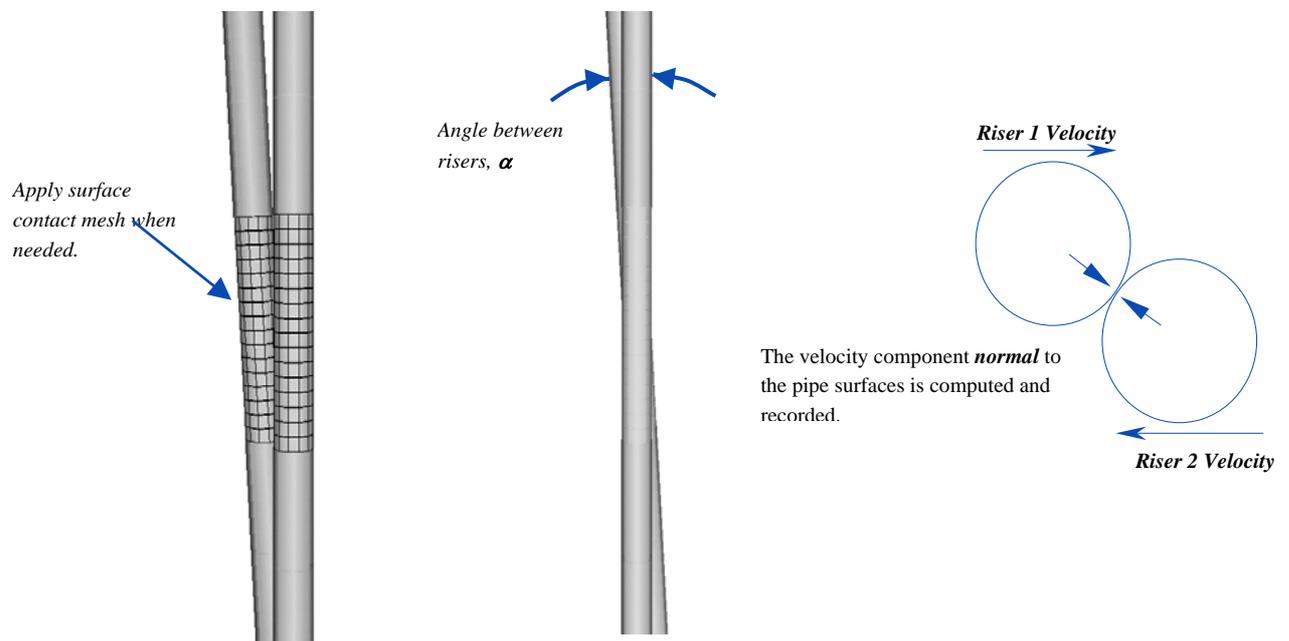


Figure 5-1 Automatic Surface-Surface contact search

The contact search procedure for beam/beam impact is divided into several steps.

5.2.1 1: Point - Line Search

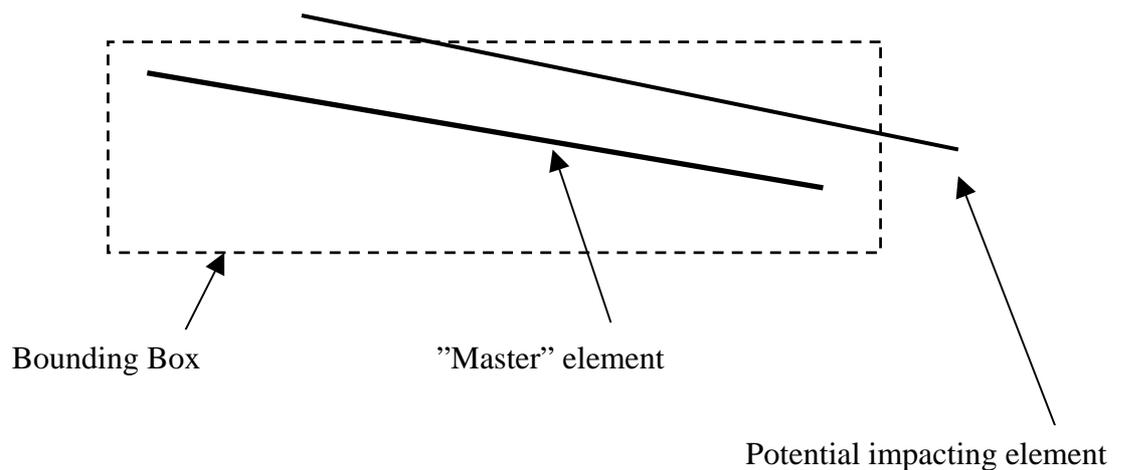


Figure 5-2 Step 1 search. Bounding box around master element

A “Bounding box” (which is 3D) is placed around all master elements, one by one. The size of the bounding box reflects the size of the beam cross section (pipe diameter, box width/height etc.). If one or more “slave” elements are crossing the box boundary, further checking of these elements will be performed.

5.2.2 Step 2: Surface Mesh Generation

Beam elements are (in the “FE world”), lines between points and have thus no physical volume. It is then necessary to “dress” the line with the correct physical surface. A new FE-model is established, consisting of quadrilateral “shell” elements, see Figure 5-3 and Figure 5-4. Depending on the actual cross section type, a corresponding mesh is created.

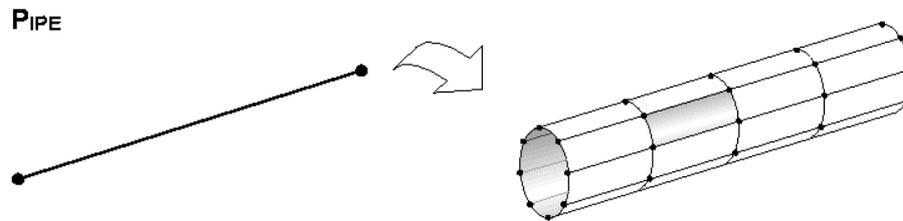


Figure 5-3 Automatic transition from line to surface. Pipe cross section

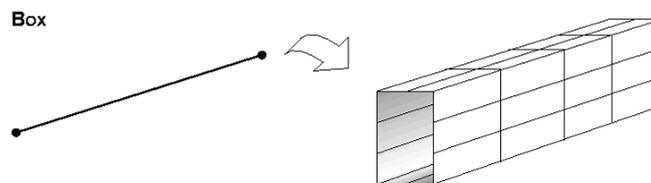


Figure 5-4 Automatic transition from line to surface. Box cross section

All elements (both ”masters” and “slaves”) involved from step 2 are transferred to shell elements.

5.2.3 Step 3: Surface to Surface Contact

All elements in question from this step are represented with 2D elements. (Step 3 is also the starting point for FE plate and shell elements). The further checking is based on *node-surface* contact.

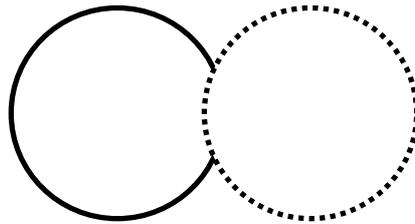


Figure 5-5 Node - Surface contact

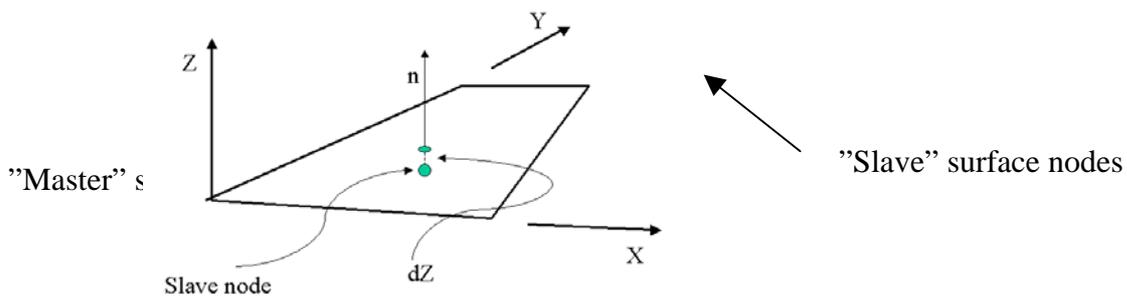


Figure 5-6 Slave node - Master surface penetration

Both master surfaces and slave surfaces are represented with nodes and quadrilateral elements (as an ordinary FE shell model). In order to avoid excessive time consumption, a 3D grid approach is used to determine which slave nodes are potential hitting the different master surfaces. Further, for every master (surface shell) element, a local co ordinate system is established (see figure 2.3-6). The actual slave node co-ordinates are transferred into this local master system.

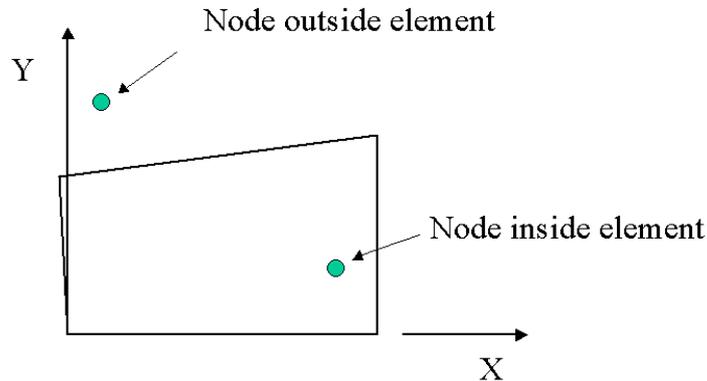


Figure 5-7 Slave node location in master element plane.

If the slave node projection on the master element is “inside” the element boundaries, (see Figure 5-6), the *local Z-coordinate* is further investigated.

As the slave node coordinates are transformed to the local master element system, a *negative Z-coordinate* means that the node is “below” the element plane. *This is the criterion for penetration.*

A slave node “below” the master plane is illegal, and the node must be “pushed” back to a legal position. The “push” force is simply established as $F = k * dZ$, where k is an artificial stiffness. The (“penalty”) stiffness, k may be constant or follow a given (P_d) shape, see Figure 5-8 .

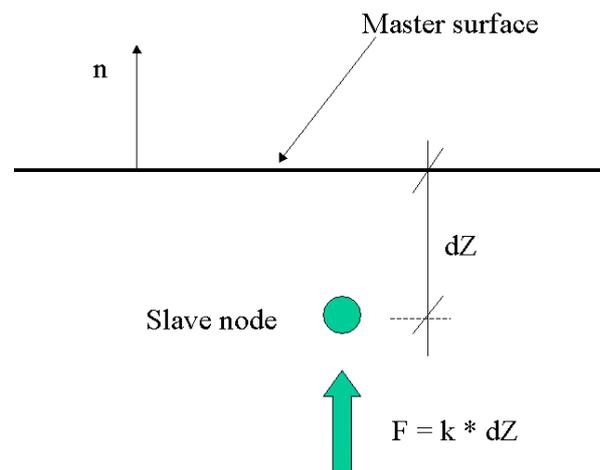


Figure 5.2-8 Slave node penetration, dZ.

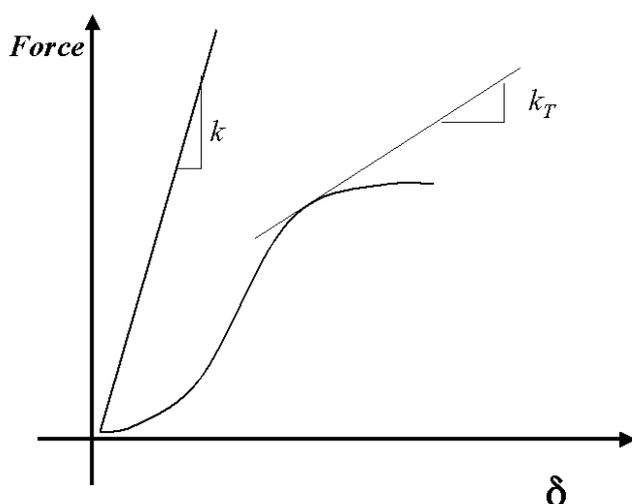


Figure 5-8 Spring characteristics used for "penalty" force calculations

5.2.4 Step 4 : Force re-tracking:

The “penalty” forces are always directed *normal* to the master surface. An opposite directed force is applied on the slave node (*actio = re actio*). The master surface force is weighted and distributed to the master surface nodes (typically to the 4 corner nodes of the quadrilateral).

For FE shell/plate structures, these nodal forces are added directly into the global load vector. For beams (which are the most actual element in connection with riser analyses), further re tracking is necessary.

The surface nodal forces are weighted and transferred to the beam element end nodes for further adding to the global load vector.

5.3 Recording of Hits

The main purpose of the simulation is to estimate number of times the risers are in contact, and to quantify the severity of the different contacts.

At present, all hits within one finite element (beam element) are collected in one “basket”. This means that all hits within an element are treated as hit at same point on the riser. In reality, the hit point will vary within the element, both in longitudinal and circumferential direction, and the above assumption is thus conservative. (Local position within one element is possible to compute, but is not implemented at the present stage of the software.)

Following data are recorded per hit and is possible to inspect in HyberPost:

- ❑ Relative Velocity between the impacting risers (normal component)
- ❑ Angle between the risers
- ❑ Duration of the contact (a short hit or a more permanent contact)
- ❑ Impulse

Based on this information, it is possible to compute the local wall stress in the risers as a post processing task. By default, a calculation of the peak stress based on elastic shell solution, /8/, is performed for two different assumptions:

- ❑ Flange hitting a smooth pipe
- ❑ Smooth pipe hitting a smooth pipe

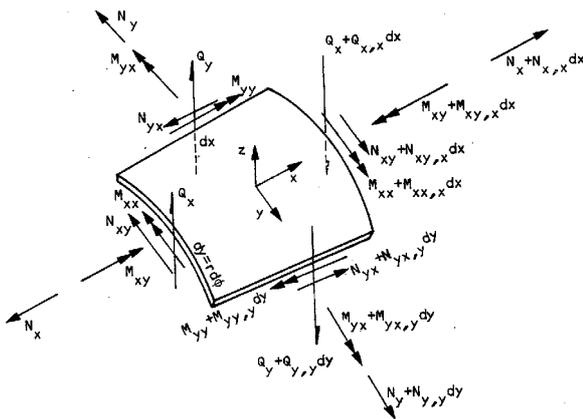


Figure 5-9 Force acting on a shell element

The “flange hit” implies that the contact area during the hit is small, with high stresses (and damages) as a result. For the case with “smooth pipe hit”, the angle between the risers during impact will influence the contact area. For parallel risers, the contact area becomes big, and the contact forces are distributed over a substantial distance along the riser. The bigger angle between risers during impact, the more concentrated is the interface force.

The default values for the contact area are:

- ❑ Flange hit : Area = thick x thick
- ❑ Smooth hit : Width = Thick, Length = Thick/Tan(φ). φ : angle between risers

If more refined (both shell and solid finite elements) calculations of the local shell stresses during impact are performed, HyberPost is able to import such data.

5.4 Estimation of Local Damage

As mentioned above, all hits within one riser finite element (beam) are treated as hit at same point.

At present, following 3 alternatives to estimate the local damage at the different “points” exist:

- ❑ Part Damage based on the default computed stresses and default SN curve.
- ❑ User defined stress vs. impact velocity and default SN curve.
- ❑ User Defined Partial Damage vs. impact velocity, (f ex from tests)

The first alternative is computed by default, and is available in HyberPost. The two other alternatives require that the user specify the relationship between the impact velocity and the local stress (curve defined through discrete points). The velocity-stress curves could be derived from finite element calculations.

The third alternative gives the user direct control with the part damage as a function of the impact velocity. Such curves could for example be a result from finite element calculations and actual SN data, or from laboratory test.

6. Simulations

6.1 Introduction

The numerical simulations are based on time domain response analysis by application of the procedures described above. The simulations are performed for a selected number of combinations of the following parameters: (i) Current velocity at the surface (ii) Floater motion amplitude and period (iii) Current direction. Each triple of such parameters is referred to as a “load case”. The number of load cases to be analysed must be sufficient to represent the variation of the collision stresses properly. At the same time, there can be a significant increase of workload associated with analysis of many load cases. Hence, a trade-off between accuracy and computational effort is typically required.

Based on the response analysis for each load case, the following response characteristics are obtained: (i) Expected fatigue damage (ii) Histogram of collision stresses (i.e. relative number versus stress level). The simulation length which is required in order to achieve stable estimates of these quantities is clearly of concern.

6.2 Analysis Procedure

A complete simulation involves following operations:

- ❑ Prepare Input (Manually or utilizing “PreHyber”, see Examples)
- ❑ Simulation (“HYBER”, the engine, running on UNIX or PC)
- ❑ Extraction/process results (“Sipost”. Binary Database -> ASCII)
- ❑ Result Inspection (“HyberPost”. Estimate damage etc, /10/)

PreHyber supports generation of a number of input files, (different “cases”), f. ex containing different current speed and directions. The “engine” simulates case by case and produces one result database (binary) per case. This result database contains general stored information from the simulation, and a specialized module (work name *sipost*) extracts the relevant data for inspection in HyberPost.

HyberPost combines the results from the different cases (f ex 10-20), and is typically used for estimation of fatigue and extreme response. In addition, it is possible to inspect single cases and investigate the local behaviour of the system.

6.3 Selecting Appropriate Cases

The analysis of riser collision is based on a certain number of “load cases”. Each load case is defined in terms of given values of the parameters specified above, which are required in order to specify the excitation levels. A load case is illustrated schematically in the figure below in relation to the current velocity and the floater motion. Furthermore, a specific depth variation of the current is given as input to the analysis together with a particular current direction.

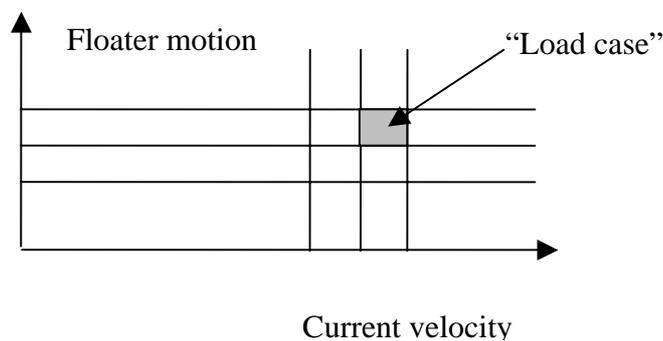


Figure 6-1 Definition of a load case with respect to current velocity and floater motion. (Current velocity profile, current direction and floater motion period are additional “load parameters”).

It is essential that the number of load cases analysed is sufficient to capture whether the response varies in a linear or nonlinear manner as a function of the basic “load parameters”. This implies that at least two analyses are required for each parameter in addition to a selected basic “reference load case”. If a significant degree of quadratic behaviour is observed based on these analyses, further load cases should be investigated to identify if the response has a cubic component and so on.

It is also important to be aware that there typically exist cut-off limits for the load parameters. This implies that below a certain current velocity and floater amplitude, no collision between the risers occur. The presence of these cut-off limits obviously implies that only load cases located above these limits need to be considered. However, identification of where these limits are located will generally require some amount of iteration.

6.4 Simulation Lengths

In order to obtain reliable results, it is essential that sufficiently long simulations are applied. It is natural to apply the duration corresponding to one floater motion period as the reference time

scale. Typically, the response recorded during the first floater period should be discarded due to initial response transients which in general are present. In order to check whether the simulation length is sufficient, a possible approach is to also perform statistical analysis for only parts of the response time series. By comparing e.g. the stress histogram for such a subsection and that for the complete time series, the stability (or possibly lack of stability) of the obtained histogram can be assessed.

7. Statistics

7.1 Introduction

Two different types of “response” are relevant when performing design and layout of the riser system. These correspond respectively to the fatigue and extreme stress design criteria (i.e. FLS and ULS limit states). Procedures for computation of these two categories of response are in both cases based on summation of contributions from a number of “short term” conditions. Each of these is characterized by a set of load case parameters as described above. For the fatigue damage, a single number (i.e. the accumulated damage for each condition) is computed for each “short-term” condition. As a basis for estimation of the extreme stress, the probability distribution of stress amplitudes is estimated for each of these conditions. A further description is given in the following for these two types of “response”.

7.2 Fatigue

The expected damage is determined by integration across the total range of the load parameters. For the case where the cut-off limits are equal to zero current velocity and zero floater amplitude, the following expression is obtained:

$$E[D] = \int_0^{\infty} \int_0^{\infty} E[D | X_1 X_2] f_{X_1 X_2}(x_1, x_2) dx_1 dx_2$$

where the variable X_1 represents the current velocity at the surface, and X_2 represents the floater motion amplitude. The expression to be integrated is the damage corresponding to a given short-term load case. For numerical evaluation of this expression, the double integral is replaced by a summation across all the load cases which are analysed. If the current direction is also included as a variable, a third integral must be inserted (or a third summation index).

If cut-off limits U_0 and A_0 are present for the current velocity and floater amplitude respectively, the modified expression becomes:

$$E[D] = \int_{U_0}^{\infty} \int_{A_0}^{\infty} E[D | X_1 X_2] f_{X_1 X_2}(x_1, x_2) dx_1 dx_2$$

In the case of independent and Weibull distributed current velocity and floater amplitude, the main contribution to this integral typically occurs from 1 to 2.5 times the scale parameter of the corresponding distributions. For the case where a cut-off limit is present, the main contributions can be expected to be shifted upwards by a distance of the order of the cut-off limit.

7.3 Extreme Response

The extreme response is estimated from the long-term distribution of the stress response.

Formally, the long-term distribution is expressed by the following integral (for the case where cut-off-limits are present):

$$1 - F_Y(y) = Q_Y(y) = \int_{A_0}^{\infty} \int_{U_0}^{\infty} w(x_1, x_2) \cdot [1 - F_{X,ST}(y)] \cdot f_{X_1}(x_1) f_{X_2}(x_2) dx_1 dx_2$$

where $F_{X,ST}(y)$ is the short term distribution of impact stresses for each load case. A slight generalization of this expression is required also for this case if the directional variation of the current (and the corresponding response variation) is taken into account. In the numerical implementation of this expression, the integral is approximated by a finite sum for both the current velocity and the floater amplitude.

For independent and Weibull distributed current velocity and floater amplitude, the main contribution to the long-term distribution typically occurs at distances between 2 to 10 Weibull scale parameters away from the origin for each of the parameters. If cut-off limits are present, the main contribution can be expected to occur at the same distance but shifted by an amount of the order of the cut-off limit.

8. Examples

The following example demonstrates how to generate input to HYBER. The preHyber module attached to the general graphical user interface, XACT is used. (For general description of XACT, see /9/).

8.1 Example 1. TLP, 850m water depth

In the following example, two vertical risers connected to a TLP should be simulated with following key data.

- Depth : 850m (distance from bottom to top end of riser)
- Spacing : 4m (same at bottom and on top)
- Outer Pipe : D = 0.340 m, T = 0.0155m.
- Inner Pipe : D = 0.178 m, T = 0.0081m.
- Fluid density : Between pipes : 1100kg/m³ . Inside tube: 200kg/m³
- Top tension : TTF = 1.4
- Top spring : k = 0.4 x Top Tension
- Simulation length : 600 sec
- Current speeds: 0.8 to 1.3m/s with increment 0.1 m/s (5 cases)
- Current dir : 0° to 10° with increment 5° (3 cases)
- Floater motion: Amp=4m, Period=142.2s, Direction 0°. (1 case)
- Depth profile : Current speed varies vs depth.
Current direction is constant vs depth.

To activate PreHyber, use the graphical user interface XACT. The Analysis is selected from the menu, and select “HYBER Analysis Setup”.



Figure 8-1 Selecting Analysis Set-up from Xact

An empty worksheet appears (see Figure 8-2), and following options exist:

- Start from scratch. Fill in the different data types.
- Load an existing setup file, and modify
- Load an existing setup file and use directly

As the different sheets are filled in, a green tag is inserted. By default, the boundary conditions are filled in (default values exist). As soon as any sheet is modified, the “Save...” button, (see Figure 8-3), becomes active, indicating that the sheets are not saved on file.

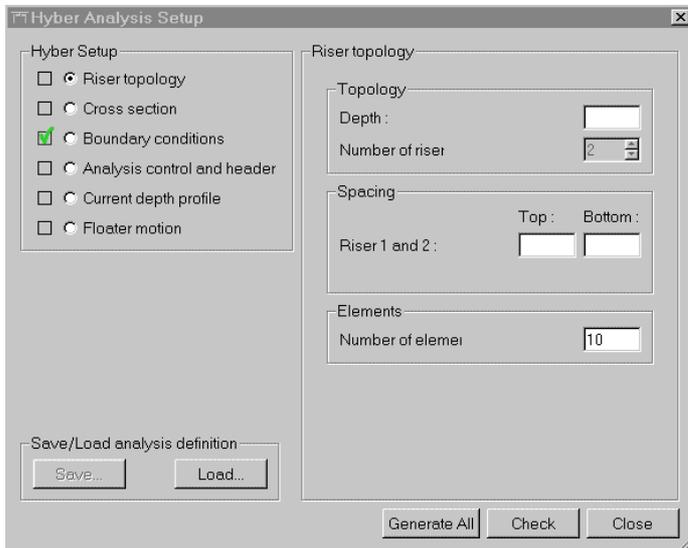


Figure 8-2 Hyber Analysis Setup. Opening of empty window

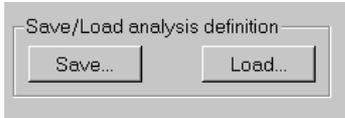


Figure 8-3 Save / Load analysis set-up file.

In Figure 8-4 the Riser topology (depth and spacing) is defined. In the FE simulations, 20 elements are used per riser.

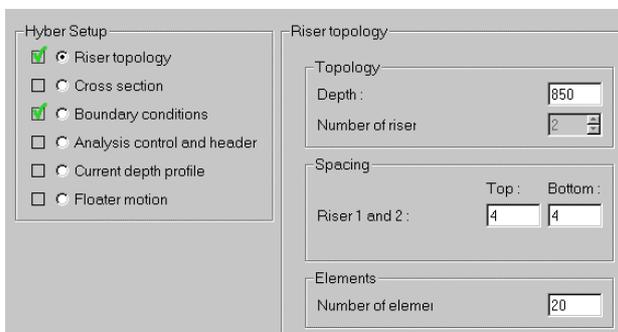


Figure 8-4 Hyber Analysis Set-up. Definition of Riser Topology

Figure 8-5 shows dialogues for definition of riser cross section and boundary conditions. The riser consists of two pipes (number of pipes is selected to 2). The fluid density for the Outer Pipe is used for the annulus between the outer pipe and the tubing. Based on the data, an equivalent cross section is computed where the outer diameter and total cross section area are kept. The material density is artificially scaled in order to get correct dry mass per length unit of the pipe. (Added mass is accounted for separately in HYBER).

The top tension is specified through the top tension factor ($\text{Tension} = \text{TTF} \times \text{Submerged weight}$). Flexibility of the top riser support is specified relative to the top tension, ($k = \text{Tension} \times \text{TSF}$).

Figure 8-5 Hyber Analysis Set-up. Definition of Cross Section and Boundary Conditions

Figure 8-6 Hyber Analysis Set-up. Definition of Simulation and Current.

Figure 8-6 describes the simulation and current sheets. Simulation length is specified in seconds. Heading, which will appear on the different results are typed in, (max 3 lines of text).

The current is specified as follows:

- ❑ Surface speed and direction
- ❑ Depth profile for speed (product of surface speed and curve value gives the actual speed).
- ❑ Depth profile for direction offset, (relative to the surface direction).

In Figure 8-6, it is specified 5 different surface speeds and 3 different surface directions, (which gives totally 15 different analysis cases in HYBER).

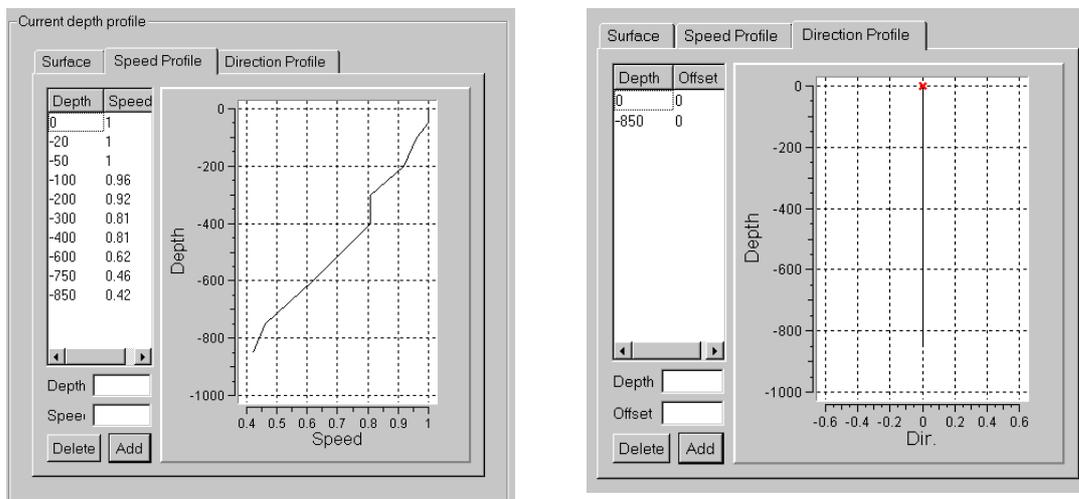


Figure 8-7 Hyber Analysis Set-up. Definition of Depth Profiles for Current.

The depth variation of the current speed and direction is specified in separate sheets (see Figure 8-7). The current speed used in at given depth is the *product* of the surface speed and the curve value at the actual depth. The “Speed Profile” is then a scaling curve, which typically is kept constant for varying surface speed.

The ocean current direction is seldom (never) constant over the entire water depth. Significant changes in direction may occur for the different water levels. The *direction offset* from the surface current direction is specified as a depth profile. The depth curve is specified in degrees [°], and both positive and negative direction offset could be specified. The current direction in at a given depth is then the *sum* of the surface direction and the curve value at the actual depth.

Direction = 0° is along global X-axis.

The motion of the top end of the risers could be prescribed using a harmonic function (sine), and the amplitude and period are specified. In addition, the direction of the floater motion could be specified.

In the actual demo example shown in Figure 8-8, only one amplitude motion is specified. As for the current, it is possible to generate a series of combinations of the 3 parameters.

Floater motion	
Amplitude	
Amplitude 1:	4 [m]
Increment:	0
Number of amplitudes:	1
Direction	
Direction 1:	0 [deg]
Increment:	0
Number of directions:	1
Period	
Period 1:	142.2 [s]
Increment:	0
Number of periods:	1

Figure 8-8 Hyber Analysis Set-up. Definition of Floater Motion.

When all data sheets are properly defined, all fields have a green tag. It is recommended to save the setup using the “Save” button, (ref Figure 8-3) at this stage.

Hyber Setup	
<input checked="" type="checkbox"/>	<input type="radio"/> Riser topology
<input checked="" type="checkbox"/>	<input type="radio"/> Cross section
<input checked="" type="checkbox"/>	<input type="radio"/> Boundary conditions
<input checked="" type="checkbox"/>	<input type="radio"/> Analysis control and header
<input checked="" type="checkbox"/>	<input type="radio"/> Current depth profile
<input checked="" type="checkbox"/>	<input checked="" type="radio"/> Floater motion

Buttons: Generate All, Check, Close

Figure 8-9 Hyber Analysis Set-up. Generate HYBER files / Check data.

The “Check” button creates one input file to HYBER, and the input file is presented in the *Analysis Control* dialogue, see Figure 8-10.

All input to HYBER is collected in one file, and the name convention is:

HYBER_case.fem

Since no model file is specified (included in the control file), a Warning is given when the *Run* button is activated, (answer *Yes*),

If everything is OK, the HYBER simulation starts, and some key information from the “engine” is displayed in the “Output” field. Since the analysis may take several hours, press *Abort* to terminate the simulation and to get access to the analysis results, (up to the time for abortion).

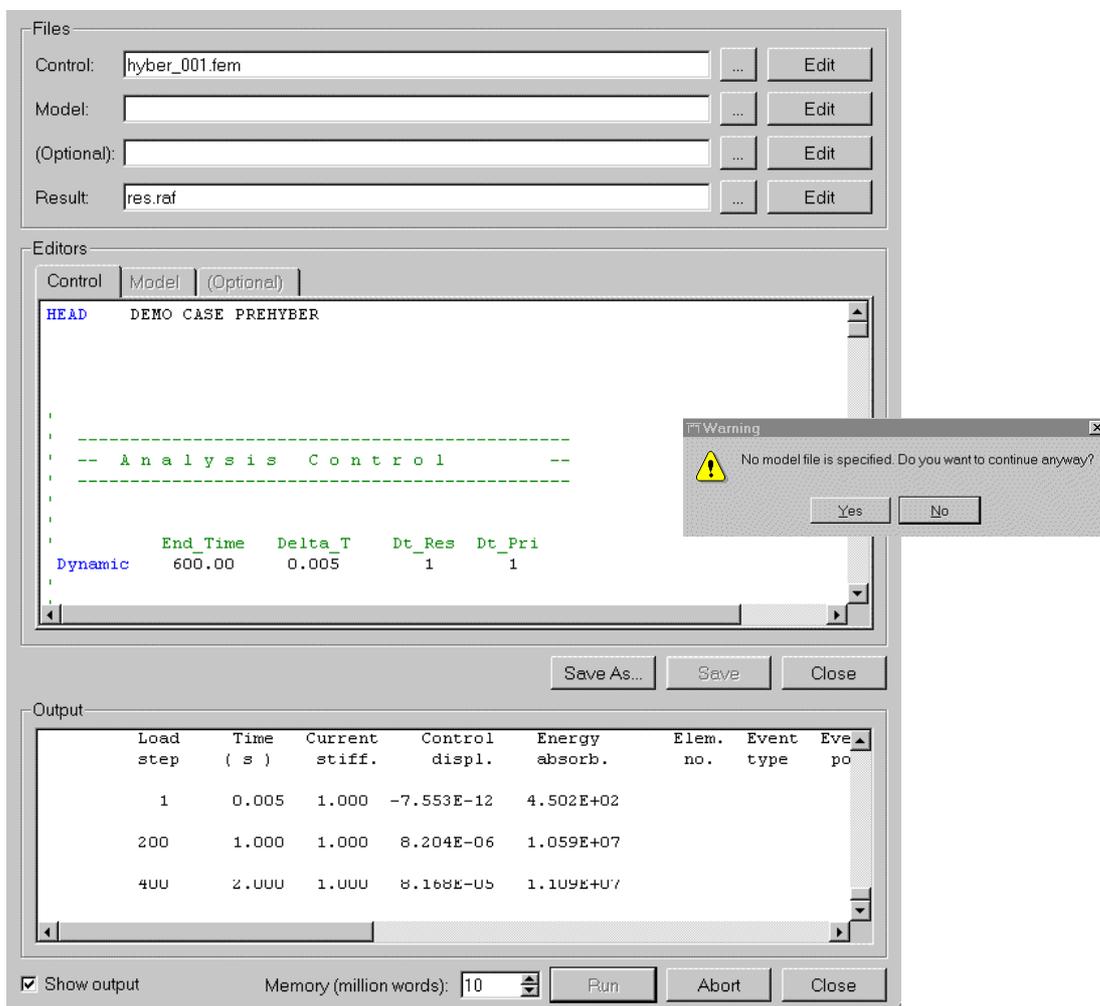


Figure 8-10 Hyber Analysis Set-up. Analysis Control.

If the model looks fine, create all input to HYBER by pressing the *Generate All* button, see Figure 8-9. In this demo example, 5 x 3 individual cases are generated.

Totally 15 HYBER input files are generated automatically ready for execution. The case number is a part of the file name, and is used to keep the individual files apart. The number will follow the case's files up to the final HYBER post processor, (HyberPost).

Name	Size	Type
head.txt	1KB	Text Document
hyber_001.fem	9KB	FEM File
hyber_002.fem	9KB	FEM File
hyber_003.fem	9KB	FEM File
hyber_004.fem	9KB	FEM File
hyber_005.fem	9KB	FEM File
hyber_006.fem	9KB	FEM File
hyber_007.fem	9KB	FEM File
hyber_008.fem	9KB	FEM File
hyber_009.fem	9KB	FEM File
hyber_010.fem	9KB	FEM File
hyber_011.fem	9KB	FEM File
hyber_012.fem	9KB	FEM File
hyber_013.fem	9KB	FEM File
hyber_014.fem	9KB	FEM File
hyber_015.fem	9KB	FEM File

Figure 8-11 Hyber Analysis Set-up. Automatic generation of 15 input files to HYBER.

Running all 15 cases could take several days (depending on computer performance), and it is recommended to utilize f ex UNIX scripts (“*run_all*”) to administrate the execution.

9. References

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- /3/ Herfjord, K., Holmås, T., Leira, B., Bryndum, M. And Hanson, T. (2002) Computation of interaction between deepwater risers. Collision statistics and stress analysis. 21st *International Conference on Offshore Mechanics and Arctic Engineering, OMAE'02*, Oslo, Norway, 23 – 28 June 2002.
- /4/ Leira, B.J., Holmås, T. and Herfjord, K. (2001) A probabilistic design approach for riser collision based on time-domain response analysis, *ICOSSAR'01*.
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- /6/ Venugopal, M. (1996) “Damping and Response Prediction of a Flexible Cylinder in a Current”, Ph.D. thesis submitted to the Department of Ocean Engineering, Massachusetts Institute of Technology.
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- /10/ HyberPost User Manual. Trondheim 2002.