Safety at Speed - S@S

IMPLEMENTATION OF MODELS
SEAKEEPING AND AVAILABILTY MODELS
DELIVERABLE NO. D2.3.2

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DISCLAIMER

CONTENTS

1. EXECUTIVE SUMMARY SUITABLE FOR PUBLICATION

The present report corresponds to deliverable 2.3.2 of Work Package 2 – Ship Motions Hazards of safety At Speed (S@S). It presents the works carried out in Sub-tasks 2.3.2 and 2.3.3 for the implementation of risk and cost models for hull design and operational practice respectively. The risk model associated with broaching phenomenon is dealt with in the separate deliverable D2.3.3.

In this frame, basic seakeeping models and a cost model predicting the ship availability with respect to expected encountered sea states, and giving the installation and the through life costs of active stabilisation, have been implemented and are presented.

The basic seakeeping models give short term analysis of ship motions, acceleration, vertical bending moment, slamming (number of slams) and water on deck (number of occurrences), and long term analysis of vertical bending moment (VBM) at midship. The short term analysis model has been integrated in the comfort and workability model implemented within Sub-task 2.3.1, and partly integrated in the 'Availability' cost model. The long term analysis of VBM is used in WP3 to provide loading input data.

The three models have been implemented in three separate Excel worksheets and coded in Visual Basic, and are joint to the present deliverable 2.3.2 for integration in the Project Tool.

Works in Sub-task 2.3.3 also included the implementation of a risk model for the prediction of broaching. This model and its description are presented in a separate deliverable D2.3.3.

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2. INTRODUCTION

The present report corresponds to deliverable 2.3.2 of Work Package 2 – Ship Motions Hazards of Safety at Speed (S@S). It presents the works carried out in Sub-tasks 2.3.2 and 2.3.3 for the implementation of risk and cost models for hull design and operational practice respectively. The risk model associated with broaching phenomenon is dealt with in the separate deliverable D2.3.3.

The description of WP2 activities described in the work programme considers separately models related to hull design (Sub-task 2.3.2) and to operational practice (Sub-task 2.3.3), with corresponding separate deliverables (respectively D2.3.2 and D2.3.3). Since the various models of risks and costs related to ship motion hazards simultaneously involve both hull design and operational practice parameters, the activities of both sub-tasks are performed in common and this separation is not relevant. On another hand, since some delays are encountered for the implementation of the risk model associated with broaching, the latter will be presented in a separate deliverable D2.3.3.

WP2 deals with hazards associated to ship motions. The works performed in the work package allowed however to draw the following conclusions:

- The major impact of ship motions concerns comfort of passengers and crew and workability of crew. Discomfort does not represent a risk for passengers. It may represent an indirect risk for the crew, by inducing fatigue for instance. However such indirect effects are very difficult to model. Discomfort can also have an influence on costs, either by the costs due to small accidents of passengers or crew members on board, or by reducing progressively the number of passengers. Again, these effects are very difficult to model: loss of balance can be estimated, but its effect is unpredictable. Besides, the effect of discomfort on the passenger turnover will also strongly depend on external factors such as the existence of other passenger ships available on the same route, the existence of other means of transportation, the duration of the voyage with other means of transportation compared to the duration with the 'uncomfortable' ship… According to this, it has been decided not to convert comfort and workability in risks and costs, but rather to display these figures together with risks and costs figures.
- The risks associated with ship motions are mainly related to broaching, which can cause large sudden horizontal and vertical acceleration, with effects on human onboard, and even ship capsize, which is considered as a catastrophic event.
- Costs associated with ship motions correspond mainly to building costs (associated with the ship dimensions which influence the ship behaviour on waves) and to exploitation costs related to ship availability (or unavailability). As a matter of fact, fast ships sail only when the weather and waves are such that some ship motion related criteria (usually horizontal accelerations in passenger and crew areas, vertical acceleration at CG) will not exceed specified thresholds. The ship availability then refers to the time period during which the ship can sail, divided by the total service time.
- It is further considered that, when the ship is allowed to sail, it sails to its service speed, without voluntary speed reduction. It is possible that, close to the limits for

sailing, involuntary speed reduction occurs (particularly with large significant wave height and head or oblique seas). Such a speed reduction may have an influence on exploitation costs due to longer ship voyages (the fuel consumption rate can be considered constant as the power engines are used at 90% of their maximum power). However, the literature tends to indicate that involuntary speed reduction is small (about 2%) before the captain decides to reduce voluntarily the speed. Such voluntary speed reduction is not considered here, since the ship should not be allowed to sail if environmental conditions are such that it becomes necessary. Besides, fast ships often have short voyages with regular (e.g. daily) stand by periods in harbours at night for instance (periods used for maintenance). Delays associated to involuntary speed reduction are then small, and without influence on the number of trips per day. Finally, involuntary speed reduction results from combined effects of different phenomena (added resistance, reduced propulsion efficiency) which cannot be modelled simply enough for use in the project tool, and accurately enough to allow to differentiate different ship designs from this speed reduction point of view. Consequently, it has been decided not to model involuntary speed reduction.

According to the above conclusions, the following models have been developed within workpackage 2:

- Comfort and workability models, providing criteria for the effect on human of: ship motions (sea sickness, workability), low frequency (whipping) vibrations, high frequency vibrations, noise and indoor climate. These models are implemented within Sub-task 2.3.1, and are reported in the deliverable D2.3.1.
- Risk model associated with broaching (large sudden horizontal and vertical acceleration, capsizing). This model is implemented within Sub-task 2.3.3, and is reported in the deliverable D2.3.3.
- Cost model related to ship availability. This model is implemented commonly within Sub-tasks 2.3.2 and 2.3.3 and is reported in the present document (D2.3.2).
- Basic seakeeping models for the determination of the response amplitude operators (RAOs) of the ship motions, the accelerations and the midship vertical bending moment (VBM). Based on the RAOs, models are made for calculating the short term most probable maximum values, and the long term prediction of VBM. These models are used partially by the above comfort, workability, risk and cost models developed in WP2. The long term VBM prediction model is also used in WP3 for the determination of loading. The basic seakeeping models are implemented commonly within Sub-tasks 2.3.2 and 2.3.3 and are also reported in the present document.

The cost model related to ship availability and the basic seakeeping models implemented in Excel worksheets are joined to the present report.

3. BASIC SEAKEEPING MODELS

Basic seakeeping models for the determination of ship motions, accelerations, relative motion and velocity, midship vertical bending moment (VBM) RAOs and short term most probable maximum values and for long term prediction of VBM have been developed and implemented.

The models are formulated as closed-form expressions (CFE), hence the calculations are fast and they can be made in a spreadsheet. The formulation was made in Sub-tasks 2.2.2 and 2.2.3 ([1]). The models have been validated against strip theory calculations ([2]), performed for variations of ship dimensions, wave heading and ship speed, and against model test results. The experiments were performed with a scale model in head sea with regular waves and at a corresponding full scale speed of 40 kn ([3]). The comparison between these results is presented in [4]. The main results of the comparison can be summarised as follows:

- Heave motions:
  - At low speed (5 kn), a good agreement is obtained between CFE and strip theory results, except for beam seas for which CFE give a dynamic amplification not predicted by strip theory.
  - At large speed (40 kn), good agreement with strip theory is obtained for following to beam seas. For beam to head seas, CFE give a dynamic amplification not predicted by strip theory, but obtained in model tests for head sea. CFE heave motion predictions are closer to model tests results for head sea than strip theory ones, and are conservative.

- Pitch motions:
  - At low speed (5 kn), a good agreement is obtained between CFE and strip theory results.
  - At large speed (40 kn), good agreement with strip theory is obtained for following to beam seas. For beam to head seas, CFE give a dynamic amplification not predicted by strip theory nor by model tests in head sea. CFE pitch motion predictions overestimate pitch motions by a factor up to 2 at the peak RAO.

- Roll motions:
  - For both low and high speed, good agreements are obtained between strip theory results and CFE ones using 10 to 15% added damping.

- Vertical bending moment (VBM) at midship:
  - For following to beam seas, CFE predictions are lower than the strip theory ones, which however seem unrealistically large and unreliable.
  - For beam to head seas, strip theory and CFE results are close and in good agreement with model tests ones for head sea, in particular at large speed.

- Vertical acceleration at CG and FP:
  - Important differences are observed at high speed for beam to head seas with CFE predictions larger than strip theory ones, which seem very low. For head sea, the agreement between CFE and model tests results is good, which would

mean that vertical accelerations predicted by strip theory are strongly underestimated, and that CFE vertical accelerations are more accurate.

According to these results, it has been concluded that the CFE where accurate enough for use in early design stage and ready for implementation in models.

Then further complements have been made in order to calculate longitudinal and transverse accelerations due to pitch, roll motions and lever arms with respect to CG, and to calculate phases between motions, accelerations and waves.

The final CFE have been implemented in two forms:

- Short term analysis including calculations of RAOs and of most probable peak values, for a given reference period and for given ship speed, wave height (Hs), period (Tz) and heading. The short term analysis model is not used directly, but parts have been implemented in the comfort and workability model (deliv. D2.3.1) and in the availability model later described in the present report (§ 4).
- Long term analysis for calculation of VBM distribution of probability for user defined operational and wave scatter diagram. The loading long term analysis model is used in WP3 to define the loading input.

After the presentation of the basic seakeeping model in Genoa on 03/09/2003, it has been requested by the Consortium to account for active stabilisation systems. The active stabilisation effect has then been accounted for on roll and pitch motions:

- For roll, the active stabilisation effect is accounted for by increasing the added damping factor.
- For pitch motion, the effect of active stabilisation is modelled by a reduction in the pitch excitating moment expressed as:

  $$1\text{-cstDamp}*\exp[-4*(\omega/\omega_0\text{-}1)^2]$$

  where ω is the encounter frequency and $\omega_0 = (0.5*g/T)^{1/2}$ is the pitch resonance frequency. 'cstDamp' is given as input and is either 0, i.e. no pitch damping, or 0.5 if there is a stabilisation system. Hence with a stabilisation system the excitating moment is halved at the resonance frequency and for high and low frequencies the moment is almost not reduced.

The values of the added damping factor for roll and of the damping coefficient for pitch when the active stabilisation is active have been determined by DTU from sea trial data collected on SuperSeacCat I (ref. [6]), made available by SEA after the Genoa meeting, and from other results available at DTU.

The sea trial data from [6] also showed that the basic seakeeping models overestimated the roll motion without active stabilisation obtained with an added damping factor of 0.15. Consequently, this value has been increased. The final set of roll and pitch damping is:

	Pitch damping	Roll damping
No active stabilisation	0	1
Active stabilisation	0.5	2

The implementation of both basic seakeeping models is briefly described in § 3.1 and 3.2 hereafter.

3.1 Short term analysis seakeeping model

The short term seakeeping model has been implemented in the Excel file S@S_WP2_short_term_analysis_v*i.ii*.xls and coded in Visual Basic. The file contains two worksheets:

- Short_term_stat: this worksheet contains the input parameter which have to be defined by the operator, and displays the main results (most probable peak values).
- RAO: this worksheet contains intermediate calculated parameters and motions, accelerations and VBM RAOs.

The color code used is as follows:

- Light green cells: input data – to be entered by operator.
- Yellow cell: result of the model

Some 'input' cells present comments defining their contents and their default values, in blue characters, when applicable.

After modification of the input parameters, calculations must be launched manually (F9) to update the results.

3.1.1 Worksheet 'Short_term_stat'

This worksheet contains fields to enter the input parameters values. When applicable, default values corresponding to the SuperSeaCat 3 values are indicated in blue characters.

The worksheet also displays the main results corresponding to the maximum expected value, in the input reference period, of:

- Heave motion (at user selected location)
- Pitch and roll angles
- Vertical, longitudinal and transverse accelerations (at user selected location)
- Relative motion and velocity (at user selected location)
- Vertical bending moment at midship
- Number of slams and water on deck in the reference period
- Motion Sickness Incidence value (according to formula presented in 'Seakeeping: ship behaviour in rough weather' by A.R. Lloyd)

The units of these parameters are displayed.

The peak values are derived from the variance σ^2 by: Peak = σ x $[2Ln(N)]^{1/2}$, where N corresponds to the number of waves encountered, and is estimated by Reference_period / Tz.

3.1.2 Worksheet 'RAO'

This worksheet presents calculated RAOs of:

- Heave amplitude
- Pitch amplitude (divided by effective wave number ke)
- Phases of heave and pitch:
  - ε_exi and ε_rsp correspond respectively to the phase angle between the excitation force/moment and the wave, and to the phase angle between heave/pitch responses and the excitation force/moment. Thus, the phase angle between the heave/pitch motions and the wave is ε_exi + ε_rsp.
  - ε_exi and ε_rsp are the same for heave an pitch. However, pitch and heave must be kept out of phase by 90° ($\phi_{heave/wave}=\phi_{pitch/wave}-90°$).
- Roll: amplitude and phases ε_exi and ε_rsp (see heave and pitch)
- Vertical motion at selected point (resulting from heave at CG, pitch, roll angles and lever arms):
  - Amplitude RAO.
  - Phase angle between vertical motion and wave
  - Acceleration amplitude (the phase of acceleration w.r.t. motion is then 180°)
- Longitudinal (horizontal) motion at selected point (resulting from pitch motion and z position of user selected location above CG):
  - Amplitude RAO.
  - Phase angle between longitudinal motion and wave
  - Acceleration amplitude (the phase of acceleration w.r.t. motion is then 180°)
- Transverse (horizontal) motion at selected point (resulting from roll motion and z position of user selected location above CG):
  - Amplitude RAO.
  - Phase angle between transverse motion and wave
  - Acceleration amplitude (the phase of acceleration w.r.t. motion is then 180°)
- Relative motion and velocity
- VBM at midship: amplitude

This worksheet also contains some intermediate calculated parameters used for RAO calculations.

3.2 Long term analysis of VBM model

The long term analysis of VBM model has been implemented in the Excel file S@S_WP2_long_term_loading_v*i.ii*.xls and coded in Visual Basic. The file contains one worksheet:

- Long term VBM: this worksheet contains the input parameters, auxiliary results and the main results. With the spreadsheet it is possible to get the most probable largest VBM both in a linear and non-linear formulation, and the whipping bending moment can be included.

The colour code used is as follows:

- Light green cells: input
- Rose and orange cells: comments
- Green and grey cells: auxiliary calculations
- Turquoise cells: auxiliary results
- Yellow cells: main results

After modification of the input parameters, calculations must be launched manually by pressing 'shift+ctrl+a' to update the results. During the calculations the Excel Solver function is used and it is necessary to decide if the found solution should be kept or not before the calculations are continued.

3.2.1 Worksheet 'Long term VBM'

This worksheet contains both the input parameters and the results of the calculations. When applicable, default values corresponding to the SuperSeaCat 3 values are indicated in blue characters.

The calculations of the long term VBM at midship is made in accordance with the method described in [5].

The input parameters are:

- ➢ Main dimensions: ship length between perpendiculars, waterline breadth, draught and block coefficient
- ➢ Operational diagram:
  - Four different speeds, for which the heading is varied in five steps from 0° to 180°
  - For the three Hs intervals the probabilities of sailing with the given heading and speed. For each Hs interval the sum should be one.
  - Operational time in years
- ➢ Scatter diagram:
  - Weather routing factor.
- ➢ Bow flare coefficient according to the DNV definition
- ➢ Relative number of peaks with whipping
- ➢ Standard deviation for whipping
- ➢ Input for the short term analysis used as an indication of the long term results:
  - Significant wave height (Hs)
  - Zero up-crossing period (Tz)
  - Ship speed
- ➢ Max linear peak value. This value corresponds to the highest peak VBM in the calculations

The worksheet contains many results. Only the most useful ones are mentioned here:

- Standard deviation of the VBM for two headings
- The probability that the individual long tem peaks (P[individual peak > xxxx MNm]) as function of Tz are higher than a specified value. Each long term peak corresponds to a Hs, Tz combination in the scatter diagram.
- The probability that an individual long term peak (P[individual]) is higher than the peak VBM (Peak)
- The Weibull approximation (Weibull appr.) of P[individual]
- The probability that the maximum peak value in the operational time (P[max]) is higher than the peak VBM value (Peak)

4. COST MODEL: SHIP AVAILABILITY AND ACTIVE STABILISATION SYSTEM COSTS

4.1 General description of the model

Ship availability refers to the period during which the encountered sea state allow the ship to operate. An availability of 1 means that the ship can sail all the sea state conditions.

The HSC code, Annexes 3 and 9, define limits for normal operation and for worst intended conditions, as maximum horizontal and vertical peak accelerations expected for a given period (5 minutes).

In the developed model, the operating and sea state conditions that will be encountered by the ship are defined as a probability distribution of wave incidences with respect to the ship and by a wave scatter diagram (probability distribution of (Tz, Hs), Tz – zero up-crossing period, Hs – significant wave height). The ship speed is considered constant for all these conditions (ship speed input by operator). Wave incidence and sea state (Tz, Hs) are considered to be independent variables.

Then, for each condition wave_incidence(i), and wave characteristics Tz(j), Hs(i), the maximum horizontal and vertical acceleration expected in the selected reference period are calculated using simplified seakeeping models also developed in WP2. For each condition, the availability Γ(i) equals 1 if maximum horizontal and vertical accelerations are lower or equal to the limit (HSC) ones, and equals 0 otherwise. The total availability is then given by:

$$\sum_i \sum_j P(wave\_incidence(i)) \times P(Tz(j), Hs(j)) \times \Gamma(i, j)$$

Accelerations can be calculated in several user defined locations (defined by their coordinates X, Y, Z in meters with respect to the ship aft perpendicular, centreline and baseline), corresponding to passenger and crew locations for instance. Different locations can be defined for horizontal accelerations calculation and for vertical ones. Then the maximum horizontal (resp. vertical) accelerations obtained over the selected locations are compared to the limit values.

The seakeeping models used are closed form expressions. They have been developed within WP2 for the calculation of heave, pitch, roll, vertical acceleration, longitudinal acceleration, transverse acceleration and vertical bending moment RAOs and variance. Since availability criteria are based on acceleration levels, only models for predicting the variance of vertical, longitudinal and transverse accelerations are used in the availability model. These accelerations result from heave, roll and pitch motions and the lever arms between the calculation locations and the ship CG.

The variance of horizontal acceleration is calculated as the sum of the variances of longitudinal and transverse accelerations.

The peak values are derived from the variance σ^2 by: Peak = σ x $[2Ln(N)]^{1/2}$, where N corresponds to the number of waves encountered, and is estimated by Reference_period / Tz for each considered sea state.

4.2 Implementation of the model

The availability model has been implemented in the Excel file S@S_WP2_availability_v*i.ii*.xls and coded in Visual Basic. The file contains six worksheets:

- Main: where the design parameters and speed are input by the operator, the availability calculation is run and the results displayed.
- Locations: where the co-ordinates of the locations where horizontal and vertical accelerations have to be calculated. The locations are defined separately for horizontal and vertical accelerations.
- Scatter diag.: where the wave scatter diagram is input.
- Incidence distrib.: where the wave incidence distribution with respect to the ship is input.
- Class criteria: where criteria for defining availability are defined. The criteria correspond to a reference period of peak value occurrence, limit horizontal acceleration and limit vertical acceleration. Several values can be defined, corresponding to different Classification Societies for instance.
- Cost Data: in which equipment, labour, overheads and maintenance cost information for active stabilisation are given.

4.3 Use of the model

The colour code used is as follows:

- Light green cells: input data – to be entered by operator.
- Yellow cell: result of the model
- Grey cells: intermediate data calculated by the model.
- Green cells: information for guiding the operator.

Some 'input' cells present comments defining their contents and their default values when applicable.

The model should be used as follows:

- In 'Main' worksheet, input of design parameters values, of ship speed and of the class criteria to be used. The list available for the class criteria definition refers to the chart on 'Class criteria' worksheet.
- Check/modifications of locations for acceleration calculations ('Locations' worksheet), wave scatter diagram ('Scatter diagram.' worksheet), wave incidence probability distribution ('Incidence distrib.' worksheet).
- In 'Main' worksheet, press 'AVAILABILITY & ACTIVE STAB. COSTS:' button. The number of conditions (wave incidence, Tz, Hs) to be calculated and the progress (in %) of the calculation is displayed. Once the calculation is finished, 'Completed' appears for progress and the availability value is displayed in the yellow cell.

4.3.1 Worksheet 'Main'

This worksheet is the main interface with the user. It contains fields corresponding to input parameters, a button 'AVAILABILITY & ACTIVE STAB. COSTS :' which starts the availability and cost calculation and fields presenting the results, close to the button.

The input parameters are set to default values corresponding to the SuperSeaCat 3. The default values are indicated in comment cells which are displayed when the mouse pointer is located on the input cells.

If the roll natural period is unknown, set it to zero. The program will then estimate it from the waterline breadth and the transverse metacentric height by the IMO recommended formula:

T_N=2 x (0.373 + 0.023 x B / T - 0.043 x Lpp / 100) x B / $(GM_T)^{1/2}$.

Where Lpp is the length between perpendicular, B is the waterline breadth, T is the draught and GM_T is the transverse metacentric height.

Intermediate results are also displayed in grey cells:

- Block coefficient C_B: it is calculated from the displacement, the length between perpendicular, the waterline breadth and the draft.
- Number of calculated conditions: this corresponds to the number of wave Hs, Tz and incidence conditions for which the horizontal and vertical accelerations will be calculated at each user selected location. This number corresponds to number_Hs x number_Tz x number_wave_incidences.
- Progress: this value represents the progress of the calculation in percent. It is updated continuously during the calculation and displays 'Completed' when finished

Roll and pitch damping coefficients with and without active stabilisation are given in block N16:P17.

The duration of a calculation, with a 15x15 scatter diagram, 5 wave incidences (hence 1125 calculated conditions), two locations for horizontal acceleration calculation and one location for vertical one, is approximately 4 minutes on a Pentium II computer.

Active stabilisation costs are presented as building costs (in Euros) and maintenance costs (in Euros/year). Building costs correspond to equipment costs and labour costs for installation of the equipment. Overheads, calculated as a percentage of the labour costs, are also added. These figures are taken from the Cost_Data sheet. The maintenance cost directly corresponds to the figure given in the Cost_Data sheet.

4.3.2 Worksheet 'Locations'

In this worksheet, the operator defines the co-ordinates where the accelerations have to be calculated (for instance passengers or crew areas). The locations can be different for horizontal and vertical acceleration measurements, since the availability criteria can give limits for horizontal and vertical accelerations at different locations (e.g. horizontal acceleration in passengers and crew areas, vertical acceleration at CG).

Up to 10 locations can be defined for both horizontal and vertical accelerations. The co-ordinates have to be input in meters with respect to ship aft perpendicular, centreline and baseline. The reference frame is: X- longitudinal ship axis positive from stern to front, Y – transverse axis, positive from starboard to port, Z – vertical axis, positive up.

The lines corresponding to unused locations can be left blank, provided that the used locations are filled starting from the first line of the charts (no blank line between used locations).

Since the number of computations (and so the time) increases with the number of locations, it is recommended to consider mainly the extremities of the considered zones (most fore/back locations and most starboard/port locations). The default values are set to

- The ship centre of gravity for vertical acceleration.
- Points on the upper deck: one in the centre line on the front perpendicular and two symmetrical on port and starboard sides longitudinally at the level of CG, and transversely at +/- 0.5 x Breadth moulded.

  Note: In this case, since the positions are symmetrical with respect to the ship centre line, wave incidences between 0° and 180° only are considered, with probabilities for intermediate incidences doubled so that they correspond to waves between 0° and 360° with a uniform probability distribution. This allows to reduce the number of calculated conditions (1125 instead of 1800).

4.3.3 Worksheet 'Scatter diag.'

In this worksheet, the operator defines the scatter diagram of the waves that the ship will encounter. The scatter diagram gives the probability of occurrence of each couple Tz – zero up-crossing period, Hs – significant wave height.

The operator should input the Tz (in seconds) and Hs (in meters) values, as well as the corresponding probabilities. The maximum number of Hs and Tz is 15, but it is possible to use fewer values, provided that the probabilities are always filled from the upper left corner of the chart. The sum of probabilities should be equal to 1. The actual sum is displayed in the lower right corner of the diagram. If the sum is different from one, the program will automatically divide all the probability values by the sum. This can also be done by pressing the 'Read diagram' button from the worksheet.

All the waves are assumed to correspond to the same wave spectrum type. The operator can select the gamma parameter of the wave spectrum; 1 corresponds to the Pierson-Moscowitz spectrum and 3.3 corresponds to the Jonswap spectrum.

As default, a Mediterranean Sea wave scatter diagram for extreme value calculation is used.

4.3.4 Worksheet 'Incidence distrib.'

In this worksheet, the operator defines the wave incidences that the ship will encounter. The wave incidences are defined with respect to the ship longitudinal axis and 180° is head sea.

The wave incidences are considered independent from the sea state, that is all combinations of defined wave incidences and (Tz, Hs) will be calculated.

Up to 8 incidences can be used. The operator has to input the wave incidence (in deg.) and the corresponding probability of occurrence. Less than 8 incidences can be used, provided that the chart is filled from the first left column of the chart.

The sum of probabilities should be equal to 1. The actual sum is displayed in the lower right corner of the diagram. If the sum is different from one, the program will automatically divide all the probability values by the sum. This can also be done by pressing the 'Read' button from the worksheet.

4.3.5 Worksheet 'Class criteria'

In this worksheet, the operator defines the values of the criteria for ship availability. The criteria are defined by the reference period (in seconds) for the estimation of the peak values, the limit horizontal acceleration (in g) and the limit vertical acceleration (in g). In case that the comparison with the limit values is to be made on RMS acceleration values instead of peak values, the reference period should be set to 0.

Up to 5 different values can be entered. The operator selects the values to be used from the 'Main' worksheet. Additional values can be entered by inserting lines in the chart.

4.3.6 Worksheet 'Cost_Data'

In this worksheet, the operator defines the cost information related to:

- Equipment cost (in Euros)
- Labour cost for installation of equipment (in Euros)
- Overheads associated to labour costs (in percentage of labour costs)
- Maintenance costs (in Euros/year)

The data related to equipment and installation costs have been determined from information provided by Fincantieri. The labour costs were expressed in hours (2600 hours). They have been converted in Euros with a rate of 45 Euros/h. This rate can be changed by the operator in the worksheet. The overhead rate value is the one used by WP3 in its risk-cost model.

The maintenance data have been derived from information transmitted by SEA.

4.4 RESULTS AND SENSITIVITY

Using all default values, and without stabilisation, the predicted availability is 0.999.

Around these default values, the most sensitive parameters are the length, the displacement and the transverse metacentric height (or the roll natural period). This sensitivity is low (availability of 0.997 if length divided by 2). The sensitivity of the predicted availability to the parameters can however change if the operating point is changed (ship speed, scatter diagram, incidence distribution), and if other locations for acceleration calculations are selected.

5. CONCLUSIONS

The works performed in Sub-tasks 2.3.2 and 2.3.3, presented in this document, concern the implementation of basic seakeeping models and of a cost model predicting the ship availability with respect to expected encountered sea states, and giving the building and through life costs of the active stabilisation system.

The basic seakeeping models give short term analysis of ship motions, acceleration, vertical bending moment, slamming (number of slams) and water on deck (number of occurrences), and long term analysis of vertical bending moment at midship. The short term analysis model has been integrated in the comfort and workability model implemented within Sub-task 2.3.1, and partly integrated in the 'Availability' cost model. The long term analysis of VBM is used in WP3 to provide loading input data.

The three models have been implemented in three separate Excel worksheets and coded in Visual Basic, and are joint to the present deliverable 2.3.2 for integration in the Project Tool.

Works in Sub-task 2.3.3 also included the implementation of a risk model for the prediction of broaching. This model and its description are presented in a separate deliverable D2.3.3.

6. REFERENCES

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