

ISESO Project 7 and 8: Grounding and Collision
**USER MANUAL FOR GRACAT –
GROUNDING AND COLLISION ANALYSIS
TOOLBOX:**
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1. BACKGROUND

To quantify the grounding and collision risks involved in vessel traffic, rational criteria for prediction and evaluation of grounding and collision accidents have to be developed. This implies that probabilities as well as the inherent consequences have to be analysed and assessed. The computer program GRACAT facilitates these types of analyses and further provides rational tools for evaluating and comparing the grounding and collision risk for the analysed alternatives.

Grounding (Project 7) and collisions (Project 8) are among the most common causes for ship disasters. As a consequence there is a growing interest to apply the method of formal safety assessment in the shipbuilding and shipping environment. In the summer of 1996 IMO published "Draft Guidelines for Application of Formal Safety Assessment (FSA) to the IMO rule-making process". The high-speed craft rules require risk analysis to be performed and new non-standard tanker designs require detailed oil out-flow analysis. Thus administrations, ship owners, shipyards, consultants, and educational institutions are now facing the situation where they have to apply FSA-methods in ship designs. At present very limited quantitative data exists for application of risk-based models. Therefore, it is the objective of Projects 7 and 8 to develop rational tools for assisting in applying FSA methods.

Using the software the probability of collision or grounding may be evaluated for a vessel operating on a specified route. Given a collision or grounding has taken place the spatial distribution of the damages may further be calculated. Results are presented in terms of probability distributions, for indentation depth, length and height of the holes and for their location. The main benefit of the formulated procedure is that it allows comparisons of various navigational routes by assessing the relative frequencies of collisions. The derived procedure is applied to a typical Ro-Ro passenger vessel routes. Whenever possible, results of the modelling has been compared to registered data and good agreement was found in all cases. This constitutes the validation of the software for frequency and damage distribution estimation.

The stand-alone application GRACAT of Project 7 and 8: Grounding and Collision contains the following four tasks:

- Task 1: Frequency estimation – estimation of the grounding and collision probability.
- Task 2: Collision damage – establishment of models for calculating the resulting grounding and collision damage.
- Task 3: Consequence estimation – analysis of the conditions of the damaged vessel.
- Task 4: Mitigation – identification and evaluation of remedial measures for the considered consequences.

A detailed description of these tasks is given in the document ISESO ID I107.00.02.052.002, ID I108.00.02.052.002, ID I107.00.02.052.003, ID I108.00.02.052.003, ID I107.00.02.052.004, ID I108.00.02.052.004, ID I107/I108.00.02.052.004.

2. INSTALLATION OF THE SOFTWARE

Insert the CD rom, run the setup.exe and follow the instructions.

3. GETTING STARTED

When the program is started the following window appears:

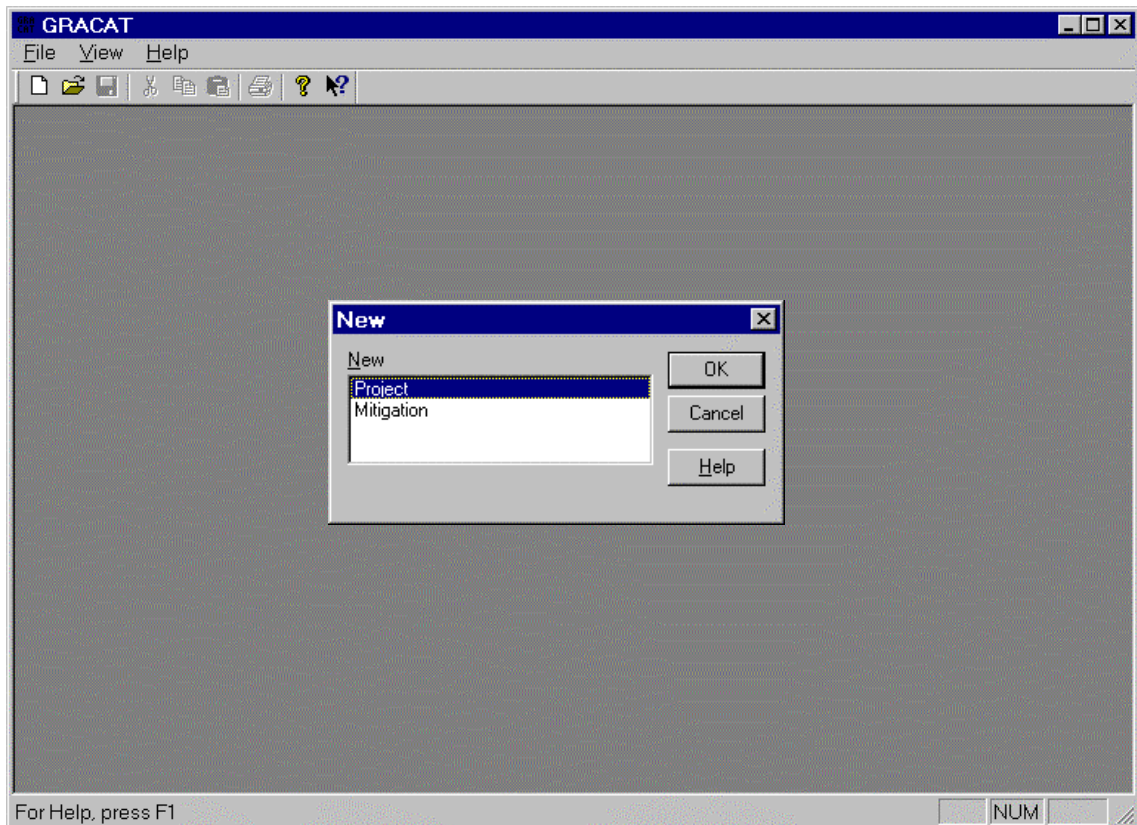


Figure 1 Window at start up.

By selecting **File New**, the user is offered two options (shown in the inserted window), either to start a **Project**, or to start a **Mitigation** analysis. The Project file contain all data and analysis results of the grounding or collision analysis, whereas the Mitigation file allows the user to perform a risk evaluations and to compare the risk results of several project files.

In the following layout of the project window and the mitigation window will be described. The subsequent chapter provides a full description of the usage of the program.

3.1 The Project Window

After selecting **Project** as the new file type, the window shown in Figure 2 is seen.

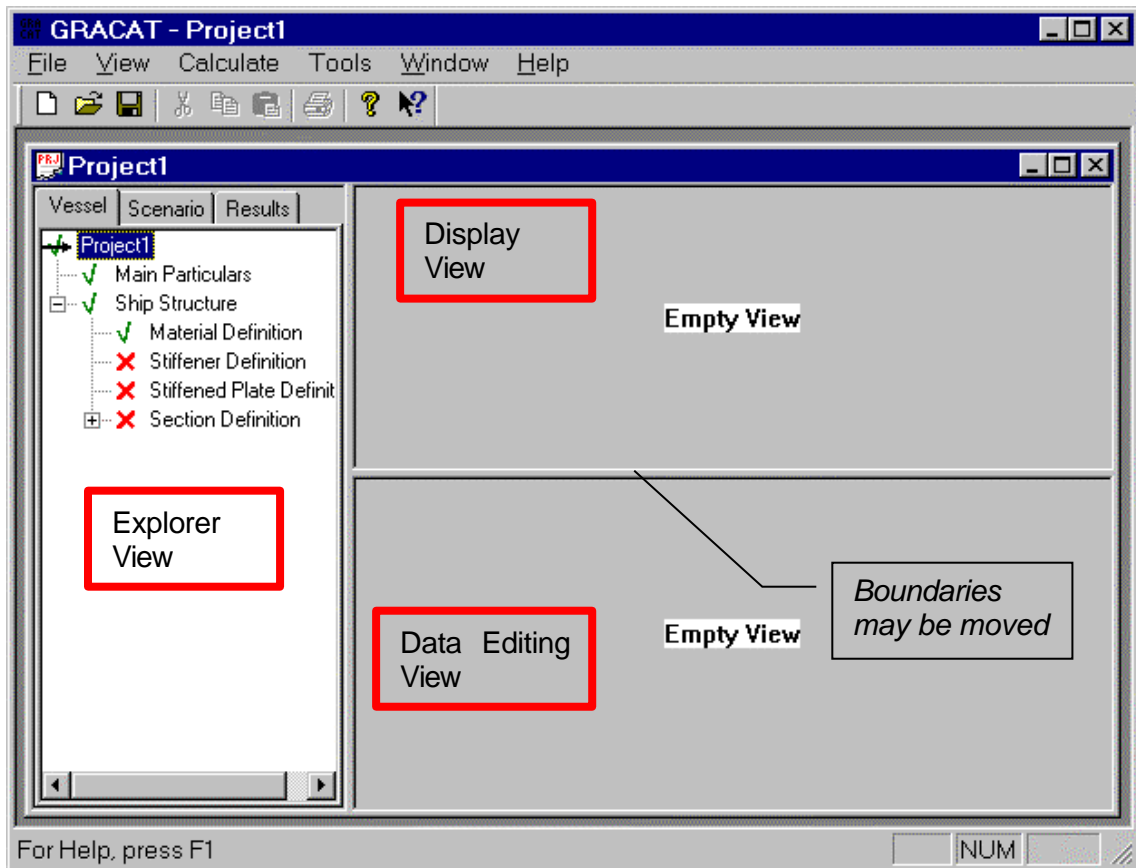


Figure 2 The Project Window.

It is noted that the main menu has changed so that **Calculate** and **Tools** have been added. Under the **Calculate** item the type of analysis to be performed is selected and calculations are started. Under the **Tools** menu the user may import or export a ship structure definition or a definition of the geographical area. This facility assures easy reuse of data among different projects. The use of the facilities will be described later.

In the left part of the main window the Explorer view is located. In the Explorer View, the user selects the type of data that should be edited or results that should be inspected. The items that may be selected are dependent on the amount of data already entered. The items that the user currently may select are clearly identified by a green check mark, whereas the non-selectable are marked with a red cross. The Explorer View contains three selectable tabs: Vessel, Scenario, and Result. By selecting these tabs the user may either define the vessel data, describe the scenario that should be analysed, or select the type of results that should be inspected. The content of all these tabs will be described later. The desired type of analysis is specified through the main menu.

To the right of Explorer View two windows are located, namely: a Display View and a Data Editing View. It might be necessary to move the boundary above the Data Editing View to see the Display View. The user can freely move the boundaries between these three windows.

In the Data Editing View Window, the user enters all the data. The Display View Window will display the data that has been entered or it will provide a help sketch that illustrates the type of data to be entered.

When the Result tap in the Explorer view has been selected, then the Display View will display the selected result.

3.2 The Mitigation Window

After selecting **Mitigation** as the new file type, the window shown in Figure 3 is seen.

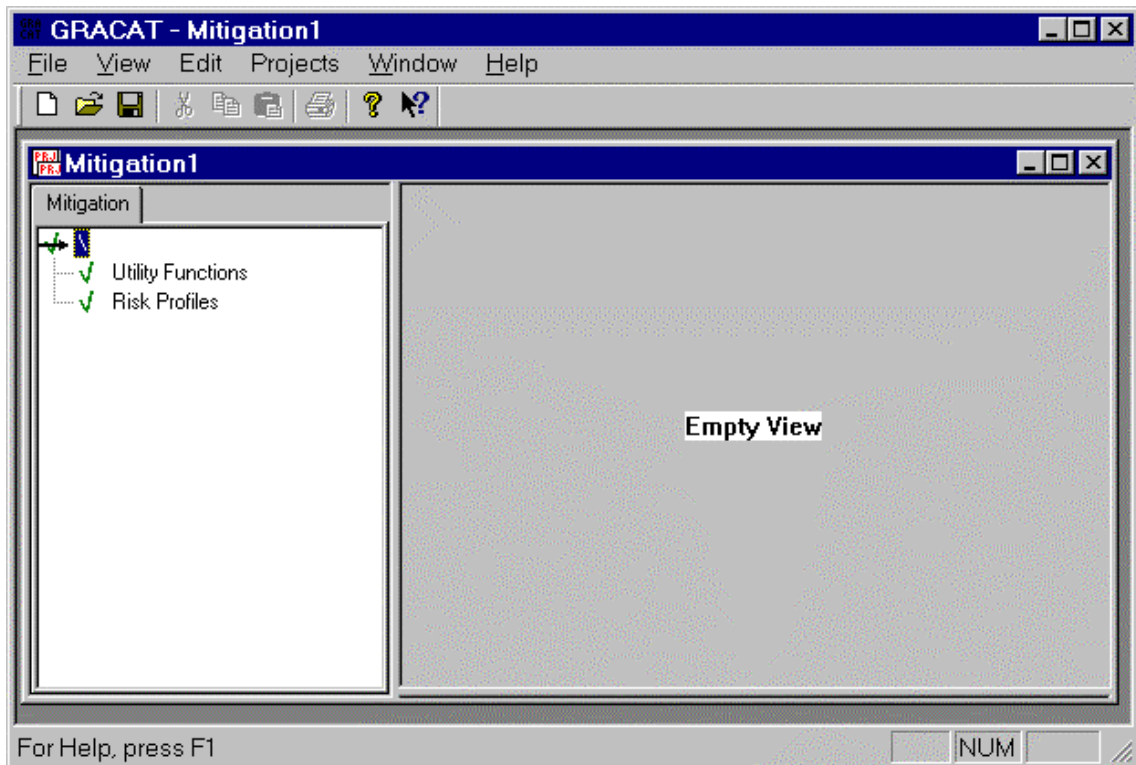


Figure 3 The Mitigation Window.

Again, the main menu is seen to have changed. The object of the mitigation module is to allow the user to compare the resulting consequences as calculated from different projects. The comparison is performed in terms of calculated risk profiles for the selected projects (via the main menu) where the loss associated to the different consequences are defined through utility functions. The usage mitigation module is described in Section 9.

The layout of the main view is similar to that of the project view, that is, an Explorer View, a Display View, and a Data Editing View. It is noted that the boundary between the Display View and a Data Editing is moved so much down that only the Display View is seen.

4. DEFINING A PROJECT

The specification of a project involves first a specification of the particular vessel that is the subject of the analysis. This specification is performed under the Vessel tab in the explorer view. The second step is to define the particular scenario that must be analysed. The user may specify a "Geographic scenario", a "Collision scenario", a "Grounding scenario", or a "Consequence scenario". The type of scenario that shall be defined is dependent on the type of analysis the user is interested in performing, see Figure 4.

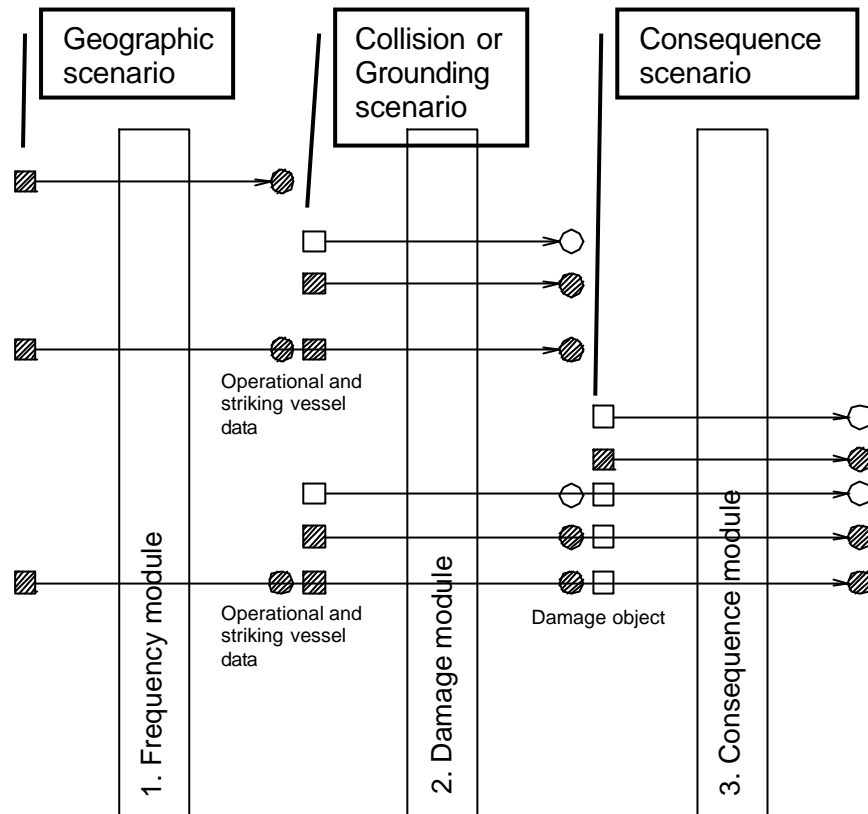


Figure 4 Overview of the various analyses that can be performed. A horizontal line illustrates each type of analysis. A box illustrates user input and a circle illustrates results to the user. An empty box or circle symbolises a deterministic analysis. A hatched box or circle illustrates an analysis where at least one input parameter is defined stochastic and results thereby becomes stochastic.

If the user is interested in performing a frequency analysis of collision or grounding in a defined area, then the user must specify a Geographic scenario. As illustrated in Figure 4 this analysis may, if requested, be continued through a damage analysis and a consequence analysis. A geographic analysis is always probabilistic.

If the user is interested in an evaluation of the resulting damages following a collision or grounding (and possibly also the related consequences) then the user must specify a Collision scenario or a Grounding scenario. A Collision scenario or a Grounding scenario may be either deterministic or probabilistic.

Finally, if the user is interested only in evaluating the consequences that follows a given damage, then the user must specify a Consequence scenario, which either may be deterministic or probabilistic.

It is noted that the scenario definition only has impact on where an analysis may be started. The end level of the analysis is defined under the Calculate→Options item that is found in the main menu.

When a calculation has been completed the user may inspect the relevant results under the Result tab. The following three sections describe the content of these tabs.

5. INPUT OF VESSEL DATA

First, the Vessel tap in the explorer view window must be activated such that the vessel data may be entered. The window shown in Figure 2 will be present.

5.1 Main particulars

After having selected main particulars from the explorer view, the data view display the window shown in Figure 5. It is noted that an arrow in the Explorer View indicates the selection of Main Particulars. Move the boundaries such that the input form is fully viewable. The data to be entered covers four aspects: I-ship compartment definition, main particulars, loading condition, and specification of the operational aspects, such as number of trips and vigilance of the bridge, as shown in Figure 5 to Figure 9. In the following sections, the four windows will first be described in overview form together with an explanation of certain non-dimensional coefficients and then separately.

5.1.1 Overview of the Input Parameters

Data is entered under four tabs, see Figure 6:

1. **Load I-Ship.** If the ship is defined in I-Ship, data from this model can be directly transferred to GRACAT. Simply click the Load I-Ship button and follow the standard Windows procedure. Note that it is necessary to load an I-Ship model if a consequence analysis is required.
2. **Main Data.** Under this item the ship size, speed, bow shape and bow geometry can be defined. If the I-ship model was loaded as described above, some of the numbers will be defined. The bow shape is only used for a soft grounding analysis, for which it is most important to model the lower part of the bow accurately. The definition of the hydrodynamic coefficients is explained below in this section.
3. **Loading Conditions.** A ship may travel in various loading conditions, for example ballast and full load. If an I-Ship model has been loaded, all the defined loading conditions are transferred to GRACAT. One loading condition has to be selected from the list. If an I-Ship model has not been loaded, data has to be entered manually. The draught is measured amidships, the trip is the draught at AP minus the draught at FP, LCF is longitudinal centre of flotation, GMT is the transverse metacentre height, GML is the longitudinal metacentre height, LCG is the longitudinal position of the centre of gravity, and the radius of inertia, r_i , is made non-dimensional with the ship length and is for both yaw and pitch.
4. **Causation Factors.** These are necessary for the analysis of probabilities of grounding or collision accidents along a route. The meaning and use of causation factors is described in a previous ISESO document, Ref. [5]. In short, causation factors are a measure of how often a ship on a collision course will actually experience an accident. Unless a detailed study has been performed, it is recommended to use the default values given by GRACAT. These values are based on previous studies and represent an average fleet. The field "Trips/year" in Figure 9 defines the number of trips per year that the vessel is expected to operate on the specified route. The field "Sec. Btw. Check" defines the average number of seconds that it takes the Officer on the watch to perform a full visual check and check of radar. This number used in the grounding frequency analysis. The number is, among other things, a function of the number of officers on the bridge and the bridge equipment and layout.

5.1.2 Load I-ship

In the consequence module, column 3 in Figure 4, hydrodynamic calculations are performed on the basis of a defined I-ship model. Therefore, whenever it is desired to calculate consequences (cargo outflow, time to capsize, trim angle, etc.) then it is necessary to establish reference to an I-ship file of the definition of the ship hull including definition of compartments, their content, and the load cases. Within the I-ship package, it is possible to load a NAPA file, and thereby generate major parts of the geometrical definition. For further information on these aspects and the use of I-ship contact J. Juncher Jensen, DTU, (+45) 4525 1384.

Note that neither the frequency analysis nor the damage analysis requires the presence of an I-ship file. Therefore, the item **Load I-ship** file may be omitted for such analyses.

In the GRACAT program the I-ship file can be loaded through the menu form shown in Figure 5. When the **Load I-Ship** button is pressed a standard file handler window is opened. Upon loading GRACAT extracts as many of the required parameters as possible and inserts these under the **Main Data** tap and the **Loading Condition** tap. By default the values that have been extracted from I-ship are not editable, but by unchecking the **Use I-ship** box in the form, the loaded values may then be modified.

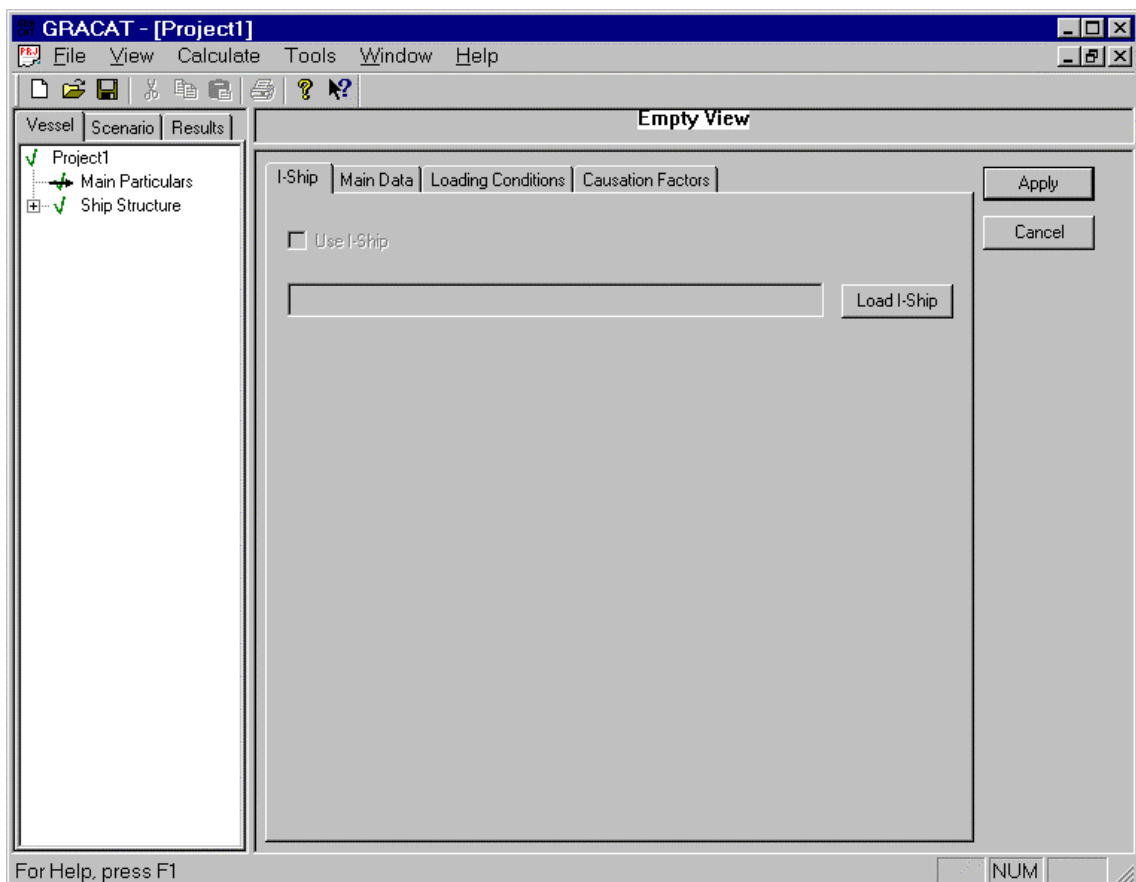


Figure 5 Loading the I-ship ship definition

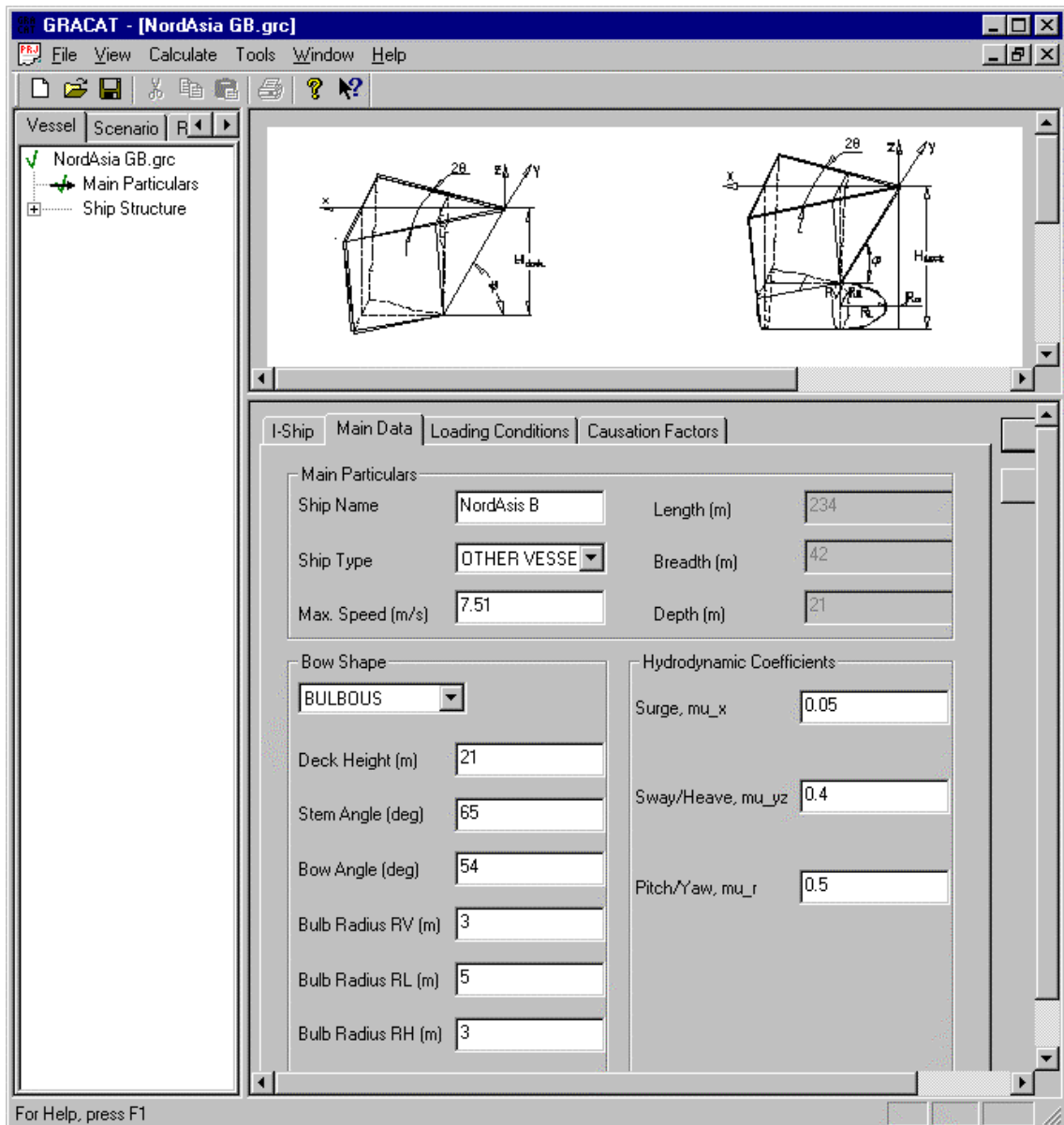


Figure 6 Main Data.

5.1.3 Main Data

The required main data are shown in Figure 6. Some of these data are self-explanatory, but the Bow Shape parameters and Hydrodynamic Coefficients will be described further.

5.1.3.1 Bow Shape

Either a conventional or a bulbous bow may be defined. The simplification of these bow types are sketched in Figure 7. The bow shape definition is only used for soft grounding analyses, for which it is most important to model the lower part of the bow accurately.

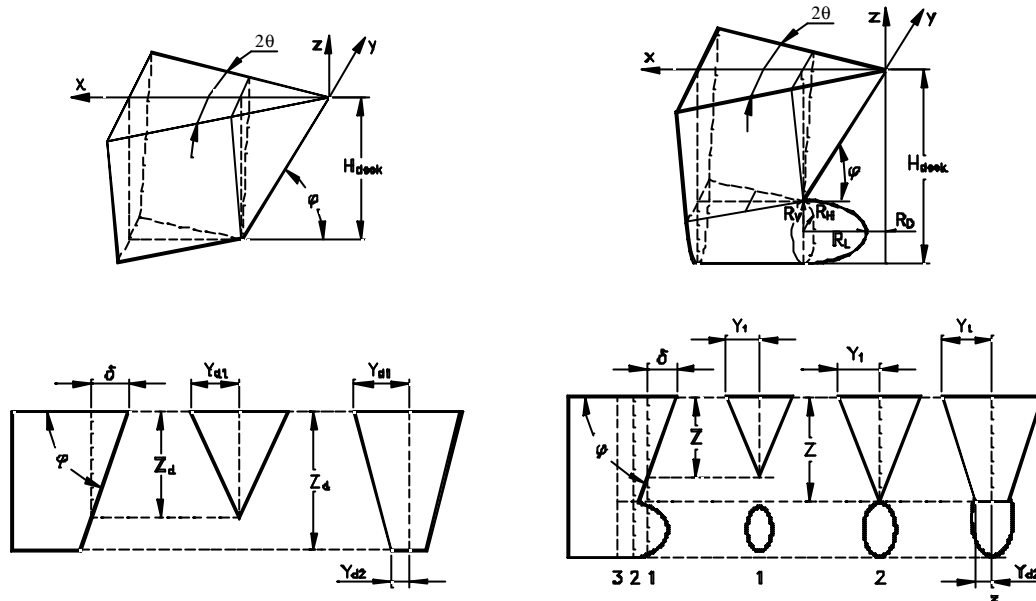


Figure 7 Simplified bow shapes. Left a conventional bow; right a bulbous bow.

The basic data for describing the conventional bow are:

- q = Half angle of bow
- j = Stem angle (Raked angle)
- H_{deck} = Uppermost deck height
- B = Breadth of the ship

The bulbous bow is divided into two parts, the upper part, which is similar to the conventional bow, and the lower part, which is the bulb and is assumed to have form of elliptic parabola. The basic data for describing the assumed bulbous bow are as followings:

- q = Half angle of bow
- j = Stem angle (Raked angle)
- H_{deck} = Uppermost deck height
- B = Breadth of the ship

and

- R_L = Bulb length
- R_V = Vertical radius of bulb
- R_H = Horizontal radius of bulb

On the basis of a world fleet analysis, Reardon and Sprung [8] suggested for the conventional bow shape the following ranges for the half bow angle q and stem angle j for the following four vessel classes:

- $q = 28 \sim 38$ and $j = 74$ degrees for Tankers and bulk carriers
- $q = 20$ and $j = 76$ degrees for General cargo ships
- $q = 17$ and $j = 63$ degrees for Container vessels
- $q = 17$ and $j = 54$ degrees for Passenger vessels

For the bulbous bow the three radii of the bulb are assumed be proportioned to the height (H_{deck}) of uppermost deck. The proportionality can be expressed as:

$$\begin{aligned}R_L &= I_L \cdot H_{deck} \\R_V &= I_V \cdot H_{deck} \\R_H &= I_H \cdot H_{deck}\end{aligned}$$

where I_L , I_V and I_H are constants. Based on statistics of existing ships and design guidance for bulbs the following values have been found to represent reasonable values:

$$\begin{aligned}I_L &= 0.300 \\I_V &= 0.125 \\I_H &= 0.050\end{aligned}$$

The distance R_D , between bulb tip and forward perpendicular, can be calculated from

$$R_D = \frac{H_{deck} - 2R_V}{\tan j} - R_L$$

5.1.3.2 Hydrodynamic Coefficients

Inertia properties of the vessel are calculated in the following way. The basic quantity is the vessel displacement, V (m^3), which is given under "Loading Conditions". The vessel mass, M , is calculated by assuming that the water density is $1025 \text{ kg}/m^3$. The ship moment of inertia in pitch and yaw is calculated by use of the ship length and non-dimensional radius of inertia, r_i (also given under "Loading Conditions"):

The ship moment of inertia for yaw or pitch is calculated as

$$I = M(r_i \cdot L)^2$$

Since the ship has to displace and accelerate the water around it when it accelerates itself, its apparent, effective inertia will be larger than its own inertia. The actual, apparent vessel mass used in dynamic analyses is calculated by use of the hydrodynamic coefficients for surge, sway, heave, pitch and yaw. The pitch and yaw coefficients, μ_r , are entered in one field just as the sway and heave coefficients, μ_{yz} , are entered in one field. The hydrodynamic coefficient for surge is denoted μ_x . The coefficients are defined in the following way:

$$\mu_x = \frac{\text{Total inertia in surge direction}}{M} - 1$$

This means, of course, that

$$\text{Total inertia in surge direction} = M (1 + \mu_x)$$

Similarly, the sway and heave coefficient is defined as:

$$\mu_{yz} = \frac{\text{Total inertia in sway or heave motion}}{M} - 1$$

The pitch and yaw coefficient is defined as:

$$\mu_r = \frac{\text{Total moment of inertia in pitch or yaw motion}}{I} - 1$$

Reasonable default values are:

Yaw: $\mu_r = 0.5$

Sway: $\mu_{yz} = 0.4$

Surge: $\mu_x = 0.05$

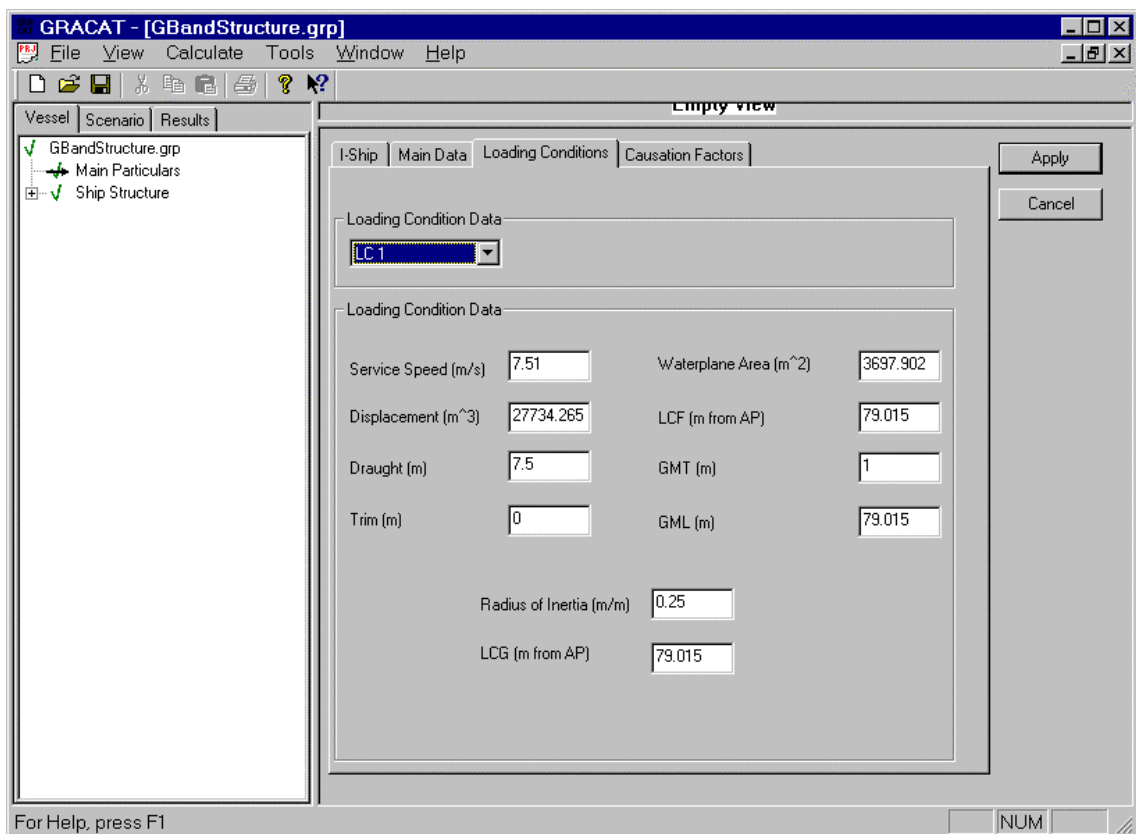


Figure 8 Loading Condition.

5.1.3.3 Loading Conditions

A ship may travel in various loading conditions, for example ballast and full load. If an I-Ship model has been loaded, all the defined loading conditions are transferred to GRACAT. One loading condition has to be selected from the list. If an I-Ship model has not been loaded, data has to be entered manually. It is then possible to enter data for two load cases, see Figure 8. The draught is measured amidships, the trip is the draught at AP minus the draught at FP, LCF is longitudinal centre of flotation, GMT is the transverse metacentre height, GML is the longitudinal metacentre height, LCG is the longitudinal position of the centre of gravity, and the radius of inertia, r_i , is made non-dimensional with the ship length and is for both yaw and pitch.

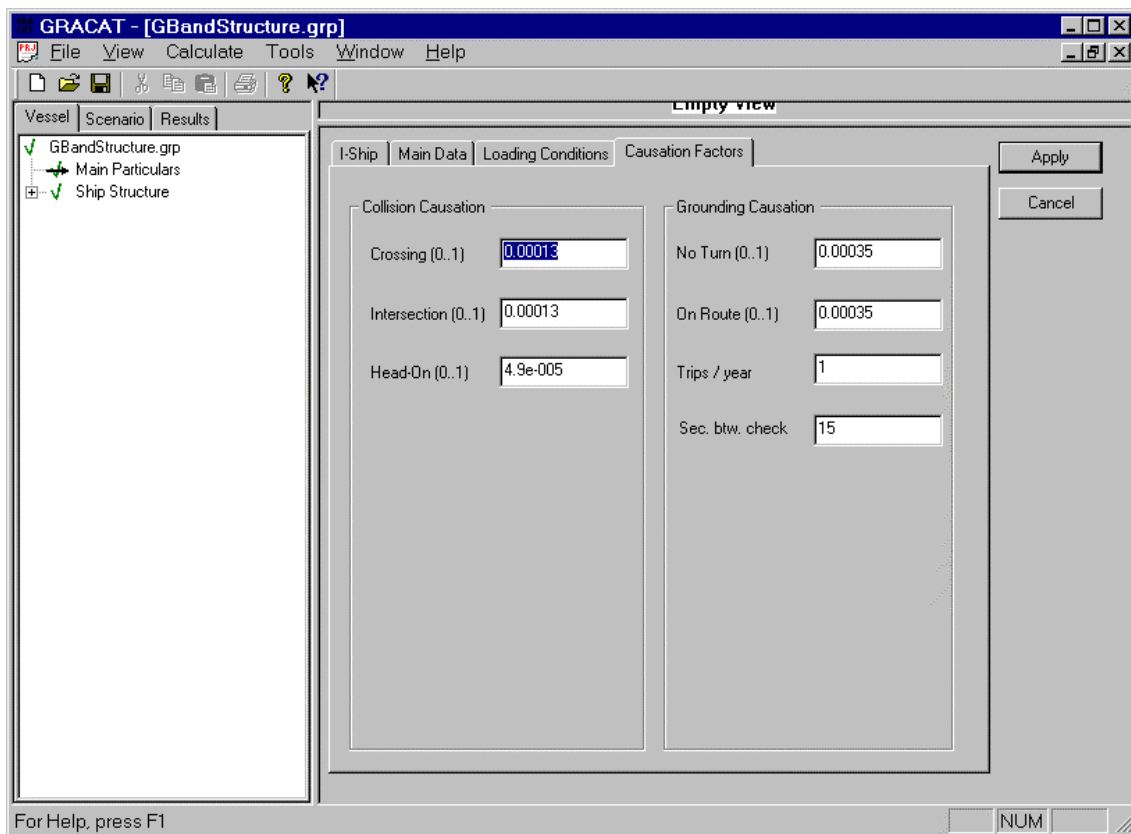


Figure 9 Specification of causation factors.

5.1.3.4 Causation factors

The causation factors are needed for both grounding and collision frequency analysis. A thorough description of the causation factors may be found in ISESO document ID I107/I108.00.02.052.004. The causation factor describes the probability that the navigating officer will react in the event that a critical situation has occurred.

The field “Trips/year” in Figure 9 defines the number of trips per year that the vessel is expected to operate on the specified route. The number of trips must be given both for collision and for grounding analysis. The field “Sec. Btw. Check” defines the average number of seconds that it takes the Officer on the watch to perform a full visual check and check of radar. This number used in the grounding frequency analysis. The number is, among other things, a function of the number of officers on the bridge and the bridge equipment and layout, see ISESO document ID I107/I108.00.02.052.004, Ref. [5].

5.2 Structural layout

In any type of analysis that requires the calculation of *structural damage*, it is necessary to define the structural layout.

The following subsections describe the overall modelling principles and the detailed procedures of entering data.

5.2.1 Overall Modelling Principles

Theoretical modelling of ship crashes is a discipline that was first reported in 1959 in a famous paper by V.U. Minorsky, Ref. [1]. Minorsky proposed a method that has been widely used since then for prediction of structural damage ship-ship collision accidents. The method is based on dividing the impact problem into the external dynamics (the global ship motions) and the internal mechanics (the crushing mechanics). By first considering the impact velocities, masses etc. in the external dynamics, it can be calculated how much energy that should be dissipated by the structural deformations. Then the theoretical model for the internal mechanics (the structural crushing process) will determine the extent of damage that corresponds to this energy. Based on a study of observed damages, Minorsky proposed that the bow can be considered rigid and that the energy absorbed by the side structure is a linear function of the volume of deformed steel in the side structure. This is remarkable because it suggests that the energy absorption in a crash scenario is not sensitive to small details but can be captured at a reasonably accurate level by a rather crude description of the structure that leaves out small details.

The methodology implemented in GRACAT is orders of magnitude more complicated than the Minorsky method but it is still based on the assumption of a rigid bow and on a simplified, idealised description of the structure that leaves out details that are not of primary importance for crash modelling.

The theoretical methods for prediction of collision and grounding damages are described in Refs. [2], [3] and [4]. It is assumed that hard grounds as well as penetrating bows are infinitely rigid. Therefore, it is only necessary to define the structure of 'own ship', i.e. the bottom and side structures.

In the modelling of the side structure the following aspects are important:

1. The hull is modelled as one box (a so-called hull-section) in which all the longitudinal members are prismatic. Several hull-sections can be defined but calculations can only be carried out on one section at the time. It should be noted that a section is not truly prismatic, since transverse members (frames, floors and bulkheads) can be defined individually. This means that a particularly strong part of the hull can be modelled by defining stronger or more densely spaced transverse members in this part.
2. The structural components are all oriented in vertical or horizontal planes. Their position are defined in a Cartesian coordinate system where the x-axis coincides with the base line, points forward and has origin at the aft perpendicular (AP). The y-axis points towards the port side and the z-axis points upwards.

3. The following components can be defined in GRACAT: side, inner side, decks (extending from the side shell), bottom, inner bottom, transverse and longitudinal bulkheads (extending from bottom shell to upper deck), girders, floors, web frames, plate stiffeners. With these members, tankers and similar relatively simple structures can easily be defined. However, a number of components seen in various ships cannot immediately be defined, for example inclined wall sides in bulk carrier hopper tanks or transverse bulkheads not extending all the way from bottom shell to upper deck. The analysis of such structures is not straightforward since the user has to select a representative equivalent structure. Some guidance is given below, but there is no general rule of thumb for defining such an equivalent structure; the user has to combine engineering judgement and parameter studies to arrive at reliable results.
4. For modelling/idealising the structure it is of help to know what is governing the crash mechanics. As mentioned above, the volume of deformed steel is a primary parameter. This means that if the ship under consideration deviates significantly from what can be modelled in GRACAT, it is important to make a GRACAT structure that has the same amount of steel in the deformed area. For example, manholes in a double bottom floor can be taken into account by decreasing the plate thickness. Likewise, a bulb profile can be approximated by an L-stiffener that has the same cross-sectional area. Often, the bottom- and side plating will absorb a significant portion of the energy so it is important that these members are accurately represented. GRACAT assumes that the plate thickness, material and stiffener configuration does not vary over the height of the shipside or over the breadth of the bottom. Therefore, some representative average thickness and material has to be selected for side and bottom respectively. GRACAT assumes that the shell- and bottom plating deforms to the first set of stiffeners outside the imprint of the bow. This means that it is also important to include the positions of horizontal and longitudinal components attached to the side- and bottom plating.
5. The structure is not assumed to be fully symmetric. Longitudinal bulkheads and longitudinal girders have to be defined on both sides of the symmetry plane.

5.2.2 Typical Sequence of Input

The sequence of steps required in the definition of the necessary structural data would normally be:

1. Define a library of materials. Each material is specified by its Young's modulus, yield strength, ultimate tensile strength, critical strain to fracture and fracture toughness
2. Define a library of stiffeners. Each stiffener is defined by its geometry and a material. The material is selected from the library built under Step 2 above.
3. Define a library of stiffened plates. Each stiffened plate is defined by the base plate thickness, the base plate material (selected from the material library), the type of stiffeners (selected from the library of stiffeners) and the spacing between stiffeners.
4. Define a hull section. It is assumed that all longitudinal members within that section are prismatic. The hull section is defined by its boundaries in the longitudinal direction, its width and its depth. More hull sections can be defined but GRACAT can only analyse one section at the time (one hull section has to be selected for further analysis).

- The structure of the hull is now defined by assigning a stiffened plate to sides, longitudinal bulkheads, transverse bulkheads, girders, floors, stringers, decks etc. For each of those main structural elements in the hull, the appropriate stiffened plate is selected from the library defined under Step 4 and the orientation of stiffeners is given.

5.2.3 Definition of Materials, Stiffeners and Stiffened Plates

As described in the previous section, the basic idea of the structure definition is to start defining building blocks (stiffeners and stiffened plates) and then finally select those building blocks to form the structure.

First, however, materials have to be defined. Figure 10 shows the input screen for the definition of materials. A material is inserted into the library in the following way:

- Select a row by clicking a number - or the upper cell as shown in Figure 10 - in the first column
- Click the mouse bottom to the right (right-click)
- Click the “Add” (or another appropriate option, such as delete)
- A line is now added to the table and the data can be modified by selecting a cell by use of the mouse and by keying in data. Note that a name should be assigned to each material in the second column “ID”. Typical names are “Mild Steel”, “HTS” or “Al5083”.
- Press Apply when all material data is defined

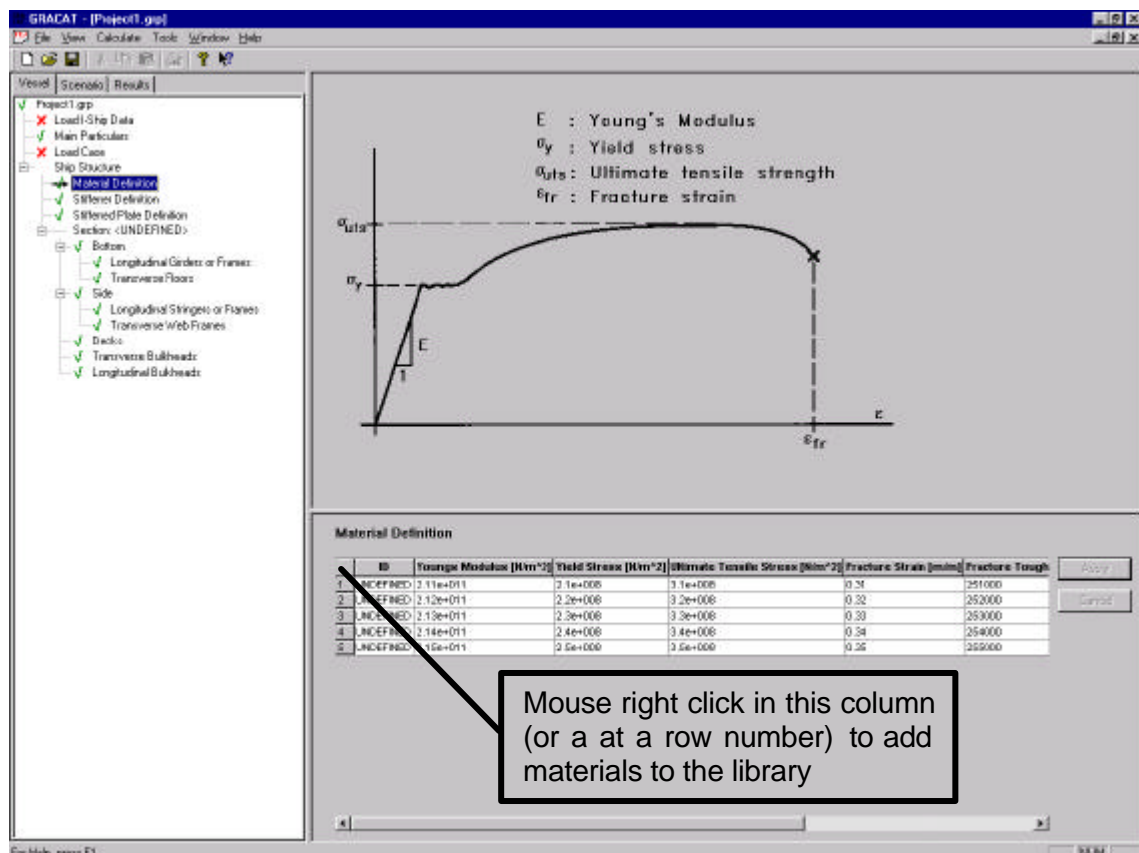


Figure 10 Definition of a library of materials. These materials are used later for definition of plates and stiffeners.

Figure 11 shows the input screen for definition of stiffeners. A stiffener is added to the list in the same way as described for materials above. Type a name for each stiffener. This name is used later for reference to the stiffener. When a cell in the “Material” is clicked, a list of the names of all defined materials is displayed. Select a material from this list by clicking the name. Press **Apply** when all data is defined. Note that only T- and L-stiffeners can be defined directly. In order to model another type of stiffener - for example a bulb profile - an equivalent T- or L-stiffener has to be defined. According to previous sections, it is important that the stiffener in GRACAT is defined such that it has the same cross-sectional area as the real stiffener. Moreover, it should be chosen such that the plastic moment is also approximately the same. This is obtained automatically, if it is chosen such that it looks similar to the real stiffener. For example, if a bulb profile is modelled, it is recommended that it is modelled with a L-stiffener. The height and thickness of the web are chosen to be the same as for the bulb stiffener and the width and thickness of the top flange of the L are chosen such that the two stiffeners look alike and so that the cross-sectional area in GRACAT is the same as for the real stiffener. This procedure will guarantee that the plastic moment will be correctly represented in GRACAT and that the idealisation does not cause modelling errors.

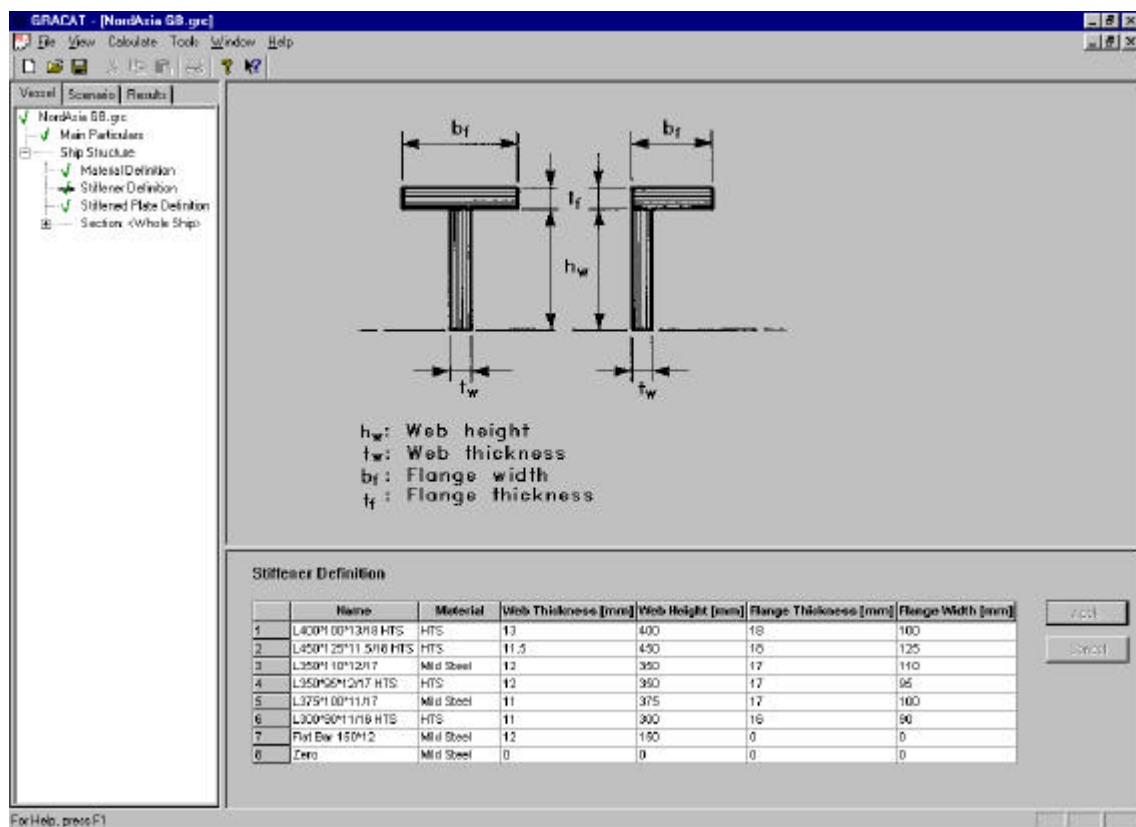


Figure 11 Definition of a library of stiffeners.

Figure 12 shows the input screen for definition of stiffened plates. In order to define a stiffened plate a base plate material must be selected from the defined library and the thickness of the base plate must be given. Furthermore, a stiffener must be selected from the defined library and a stiffener spacing must be keyed in. Press Apply when all data is defined. Note that an unstiffened plate has been defined by use of a ‘zero’-stiffener. Alternatively, one can define an unstiffened plate by use of a very large stiffener spacing (also shown for the same plate).

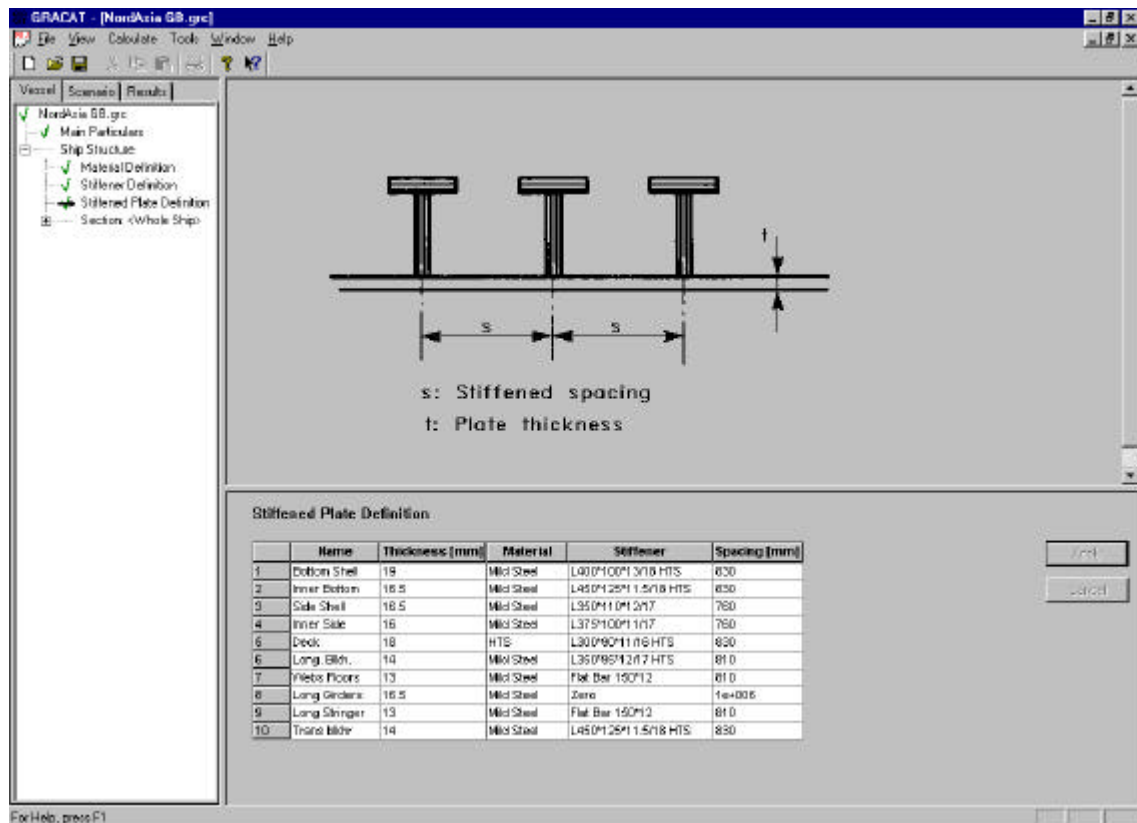


Figure 12 Definition of a library of stiffened plates. The stiffened plates are used later for definition of all major structural components, such as the hull side, bottom shell, bulkheads, girders, floors, decks etc.

5.2.4 Definition of the Structure of Hull Sections

Figure 13 shows the input screen for definition of a hull section. The figure also shows the xyz-coordinate system. Note that the transverse section is seen from the fore end towards the aft end. Transverse sections shown later are also seen in this direction.

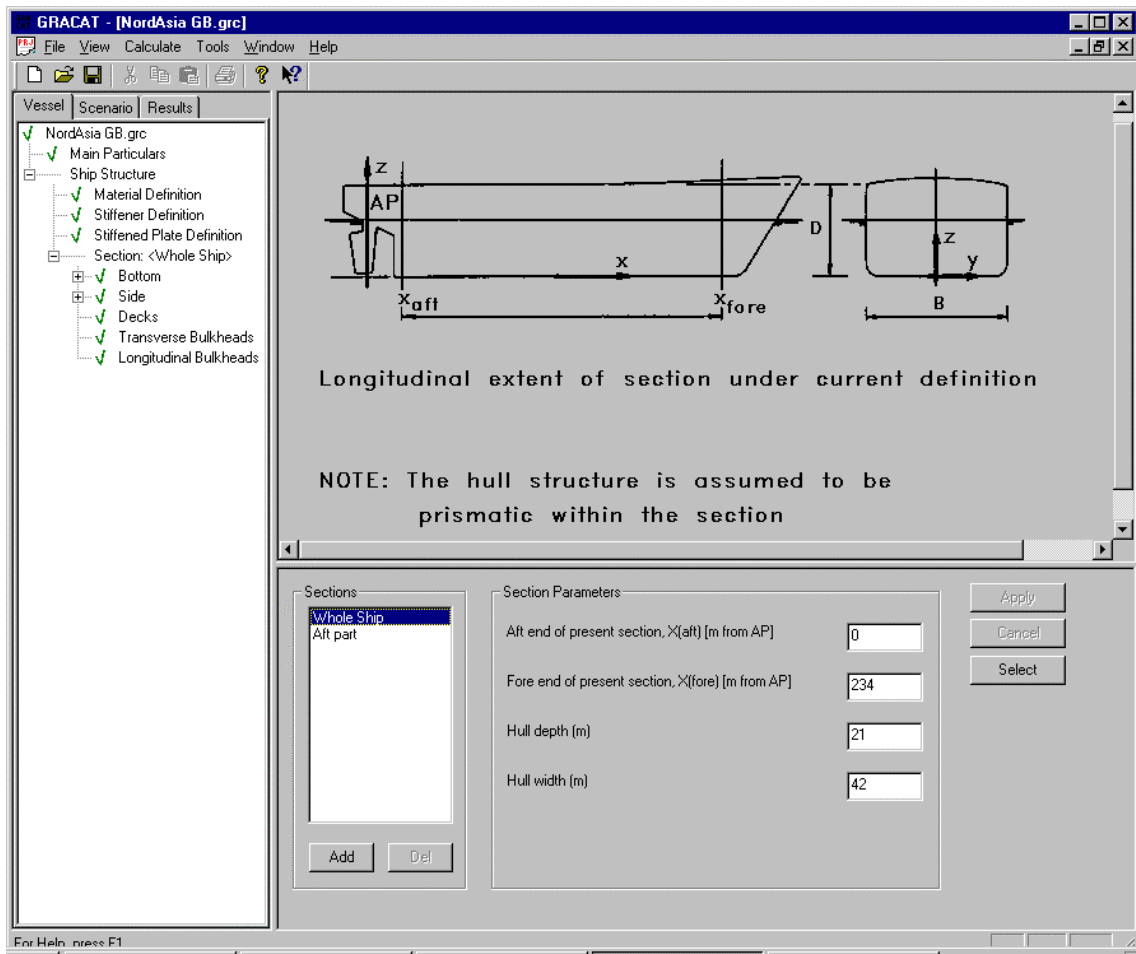


Figure 13 Definition of a hull section. Within this hull section all longitudinal members are considered to be prismatic. Several sections can be defined but one particular hull section has to be selected for further analysis.

Figure 14 - Figure 19 show the input screens for definition of the structure within one hull section. The basic idea is that the main structure is built out of the defined stiffened plates and stiffeners. Note that since stiffened plates are the main building block, the user does not have to input the location of individual stiffeners - the program distributes these stiffeners automatically according the defined spacing. From now on, the user therefore only has to define major components, such as bottom, inner bottom, decks, bulkheads etc. Each of these major components has to be defined by its position, the stiffened plate and the orientation of the stiffeners. The following section does not describe all input screens as there is great similarity between input screens for the bottom and for the side.

5.2.4.1 Bottom

Figure 14 shows the input screen for definition of the bottom. The user first selects between single and double bottom. If a double bottom is selected - as in Figure 14 - the user has to select a stiffened plate for inner and outer bottom, the stiffener orientation (longitudinal or transverse) and the double bottom spacing. By going to the submenu *Longitudinal Girders* the input screen shown in Figure 15 will appear. Longitudinal girders can now be added to the list (which is initially empty) the same way as materials were added to the material library. Note that it is possible to add many components at the same time (mouse right click on a row: select Add->Multiple). This is particularly convenient for transverse frames as these typically occur in a large number. After input is completed, press Apply and go to the next item in the explorer tree.

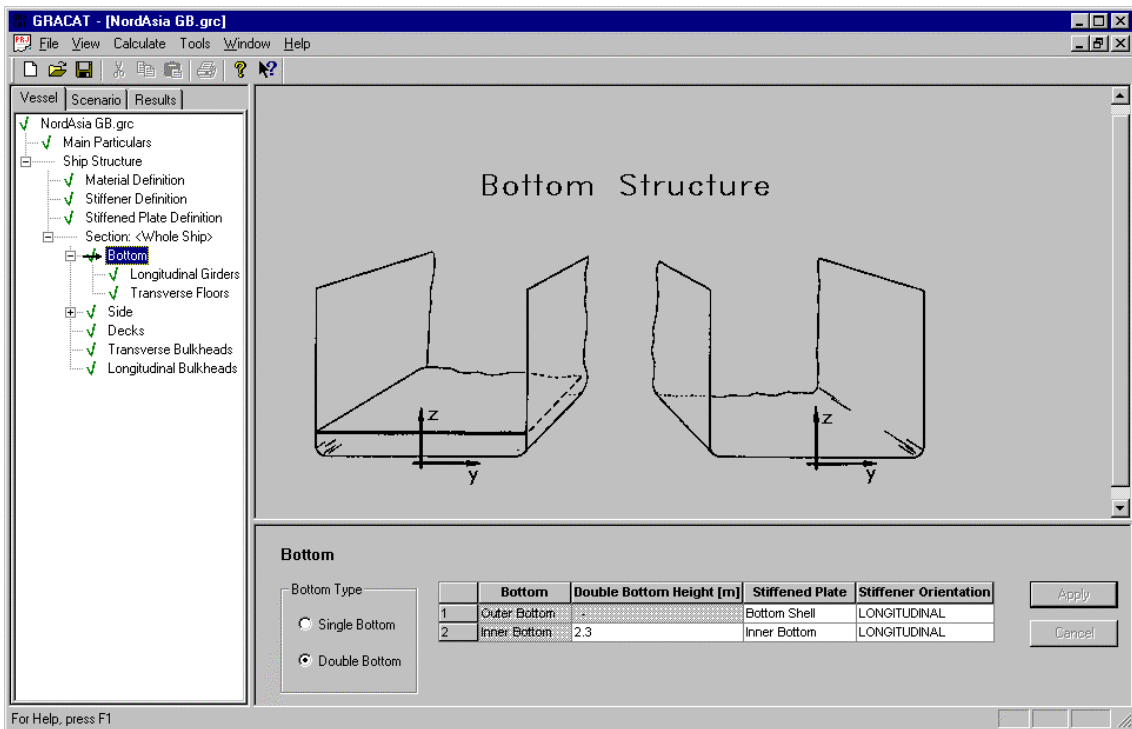


Figure 14 Selection between single and double bottom and definition of data.

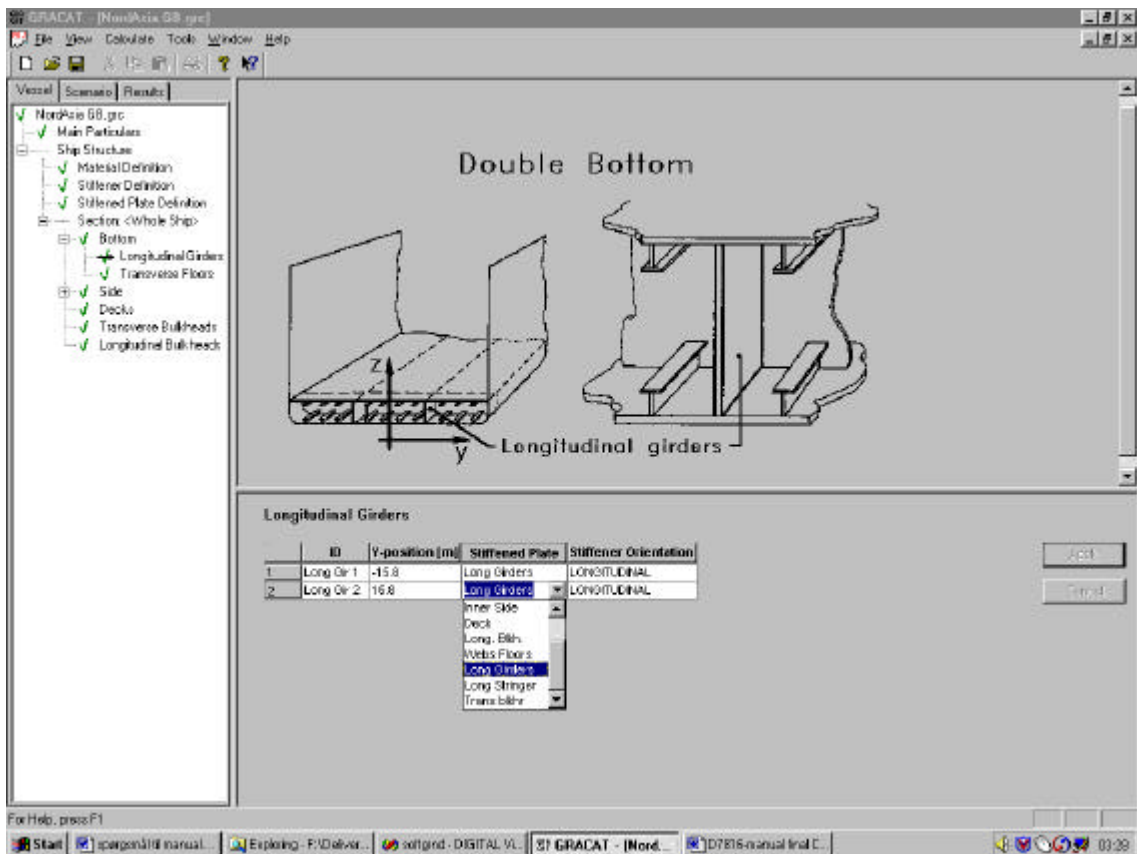


Figure 15 Definition of data for a double bottom. The figure is captured during definition of a stiffened plate.

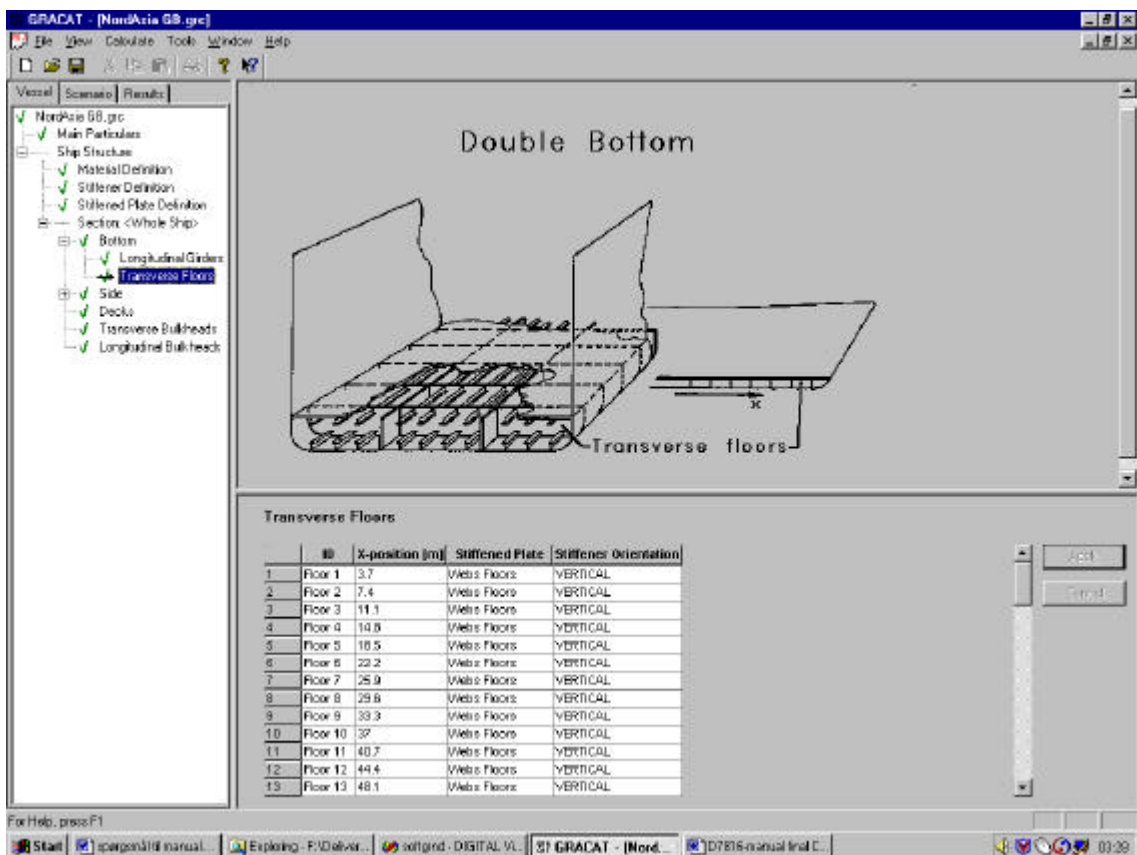


Figure 16 Definition of transverse floors in a double bottom.

5.2.4.2 Sides

The sides are defined similarly to the definition of bottom. Note the sides must be defined in order to run a hard ground analysis.

5.2.4.3 Decks

Figure 17 shows the input screen for definition of decks. Decks always extend from the side shell but not necessarily all the way to the other side shell. If the width of the deck is input as being larger than half of the ship width GRACAT automatically assumes that the deck is extending continuously from one shell to the other. Decks that do not extend to the side shells cannot be input. Often decks in ships are carried by transverse beams. GRACAT assumes that the transverse web frames defined for the side are continuing under the decks as horizontal, transverse beams. This may be a rather crude approximation, which requires care from the modeller. Note that stringer decks on a side can be modelled either under the present deck definition or under the Side submenu "Longitudinal stringers".

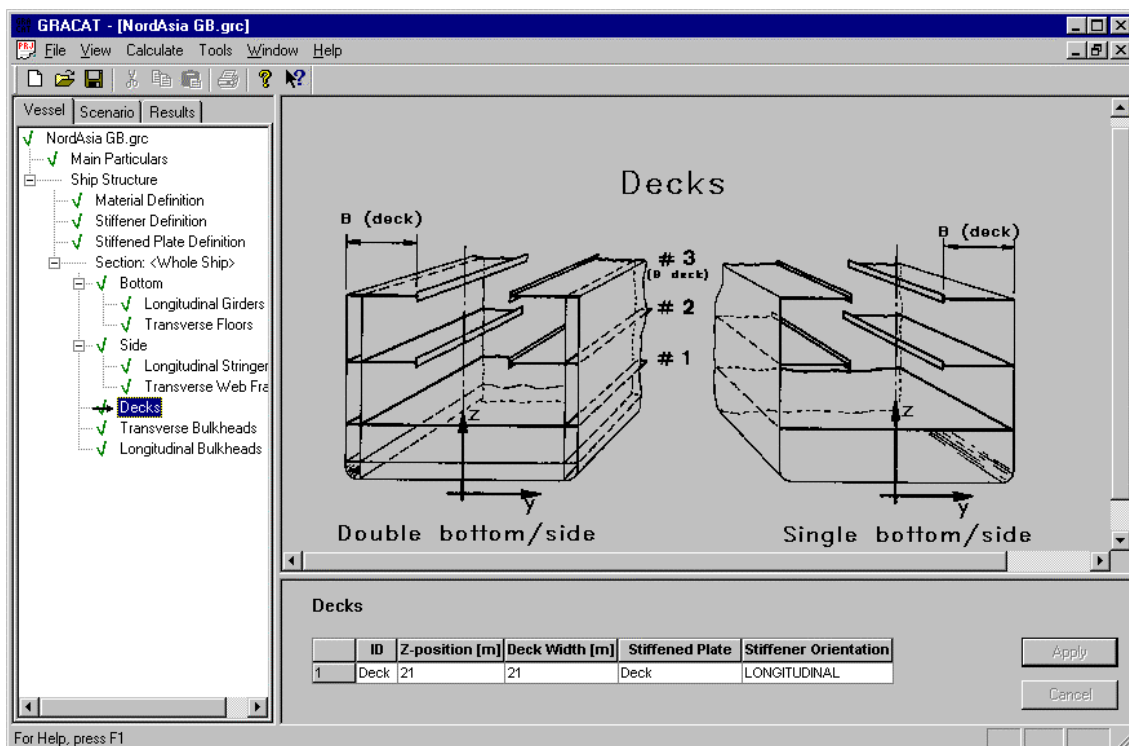


Figure 17 Definition of decks. Decks always extend in one direction to the shell but not necessarily in the full ship width from shell to shell. If the width of the deck is input as larger than the half width of the hull, GRACAT automatically assumes that the deck extends continuously between the shells in the full ship width.

5.2.4.4 Bulkheads

Figure 18 and Figure 19 show the input screens for definition of longitudinal and transverse bulkheads. Longitudinal bulkheads extend from the bottom shell to the upper deck. A longitudinal bottom girder should therefore not be located at the position of a longitudinal bulkhead, as structure will then be taken into account twice in GRACAT.

Transverse bulkheads extend from the bottom shell to the upper deck and from side shell to side shell. A bottom floor should therefore not be located at the position of a transverse bulkhead.

As for the side and bottom, a bulkhead is defined by a single stiffened plate so that the plate thickness cannot vary over the height; a representative thickness has to be selected.

Note that transverse bulkheads in side tanks can be defined as Side -> Web Frames in a double side structure.

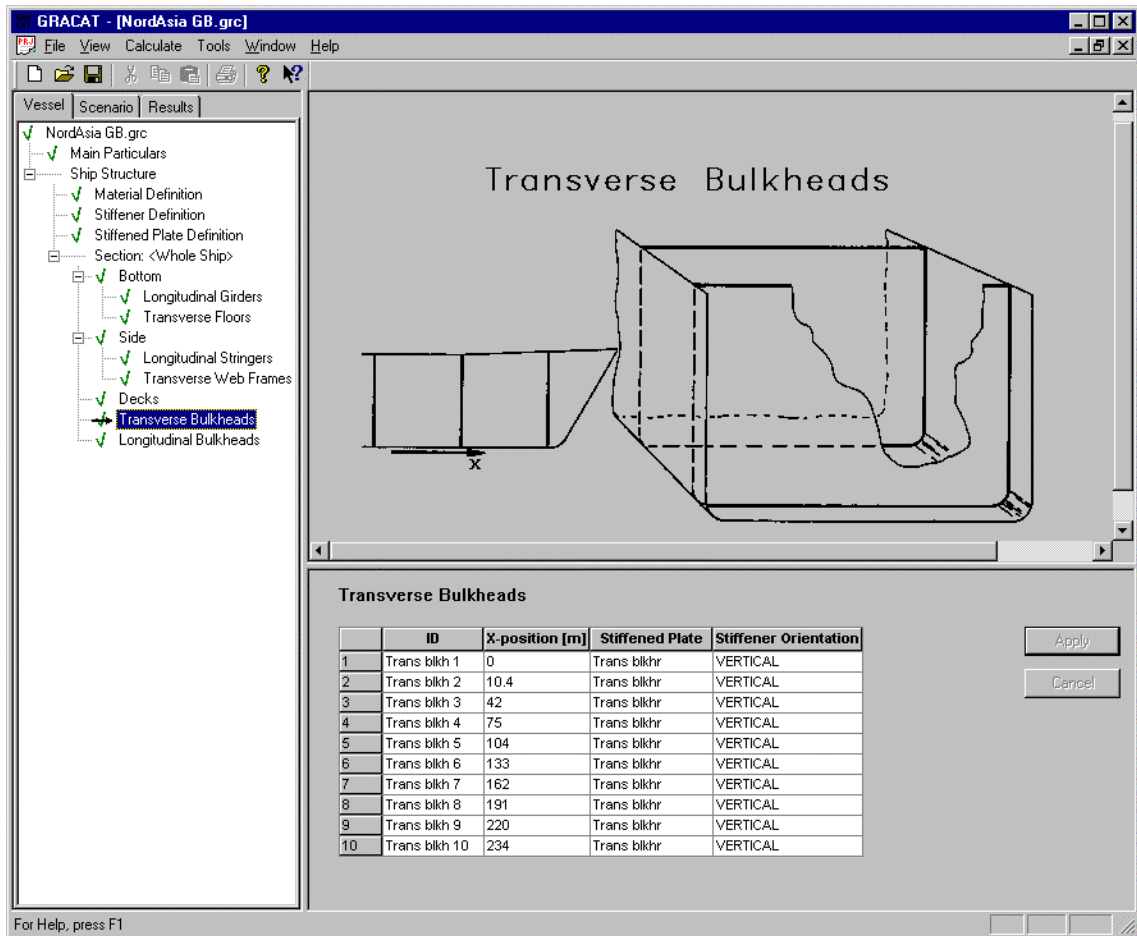


Figure 18 Definition of transverse bulkheads. Transverse bulkheads extend from the bottom shell to the upper deck and from side shell to side shell.

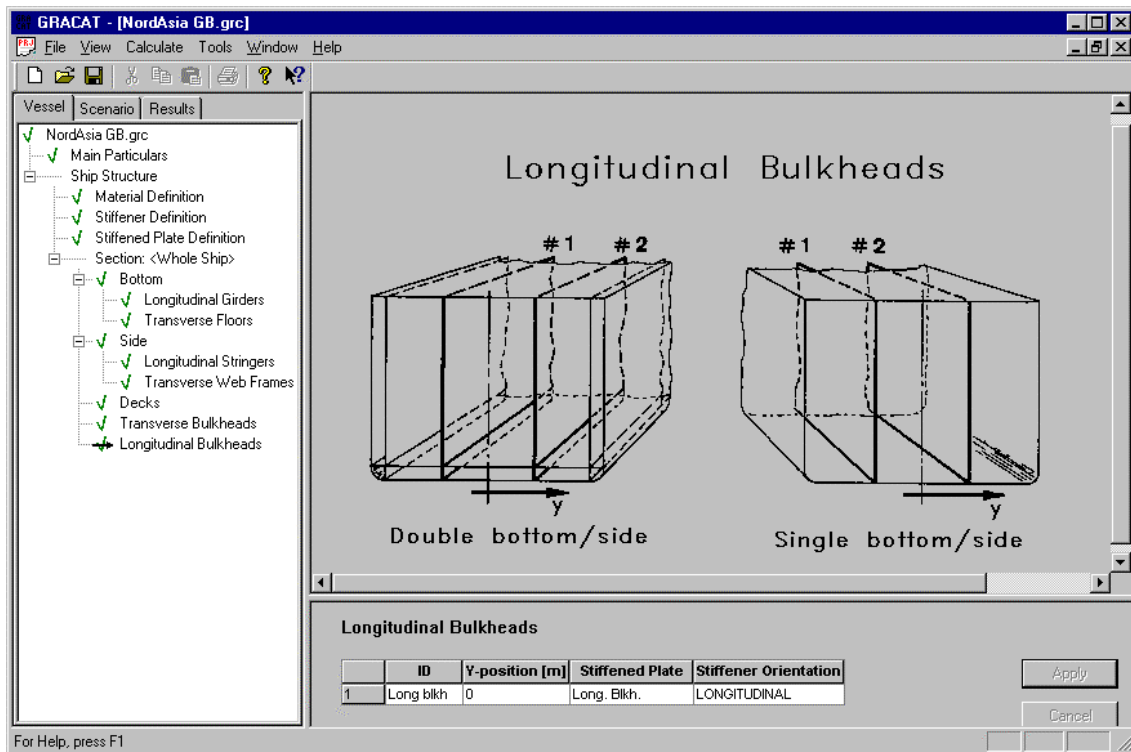


Figure 19 Definition of longitudinal bulkheads. Longitudinal bulkheads extend from bottom shell to upper deck.

5.3 Exporting or Importing the structural definition

The structural definition may be exported to or imported from a file. This facility assures an easy reuse of data in other projects.

5.3.1 Exporting the structural data to a file

The procedure for exporting data is as follows. First select one of the items under the structure definition – this can for instance be the **Material Definition** – and mouse click on one of the fields, which will assure that the entire structural definition becomes active. Next, from the main menu select **Tools® Structure® Export** and a standard File Save window will appear. The structural data can now be saved to any file. It is a good idea to choose an easy recognisable extension, for example “STRUCT”.

5.3.2 Importing the structural data from a file

The procedure for importing data follows a scheme similar to the above described. First, select the **Material Definition** and mouse click the square field to the left of the heading field “ID”. Next, from the main menu select **Tools® Structure® Import** and a standard File Open window will appear. Select the file that contain the structural definition, and press Ok. Although not visible, the data has now been loaded. To load the data into the form you must exit and re-enter the form. Therefore, click once the **Ship Structure** or the **Main Particulars** item, and then again on the **Material Definition** and the data are now visible.

6. INPUT OF A SCENARIO

The implication of the different scenarios that may be defined is described in connection with Figure 4 and will not be repeated here. In this section we will describe what type of data is needed for defining the different scenarios and how this data must be entered into the program. Scenario is selected by clicking the Scenario tab in the Explorer View.

6.1 Geographic Scenario

The geographic scenario must be specified whenever the user desires to investigate collision or grounding frequencies in a given area. By expanding the **Geographic scenario** leaf and the **Area** leaf in the Explorer View, the window shown in Figure 20 appears.

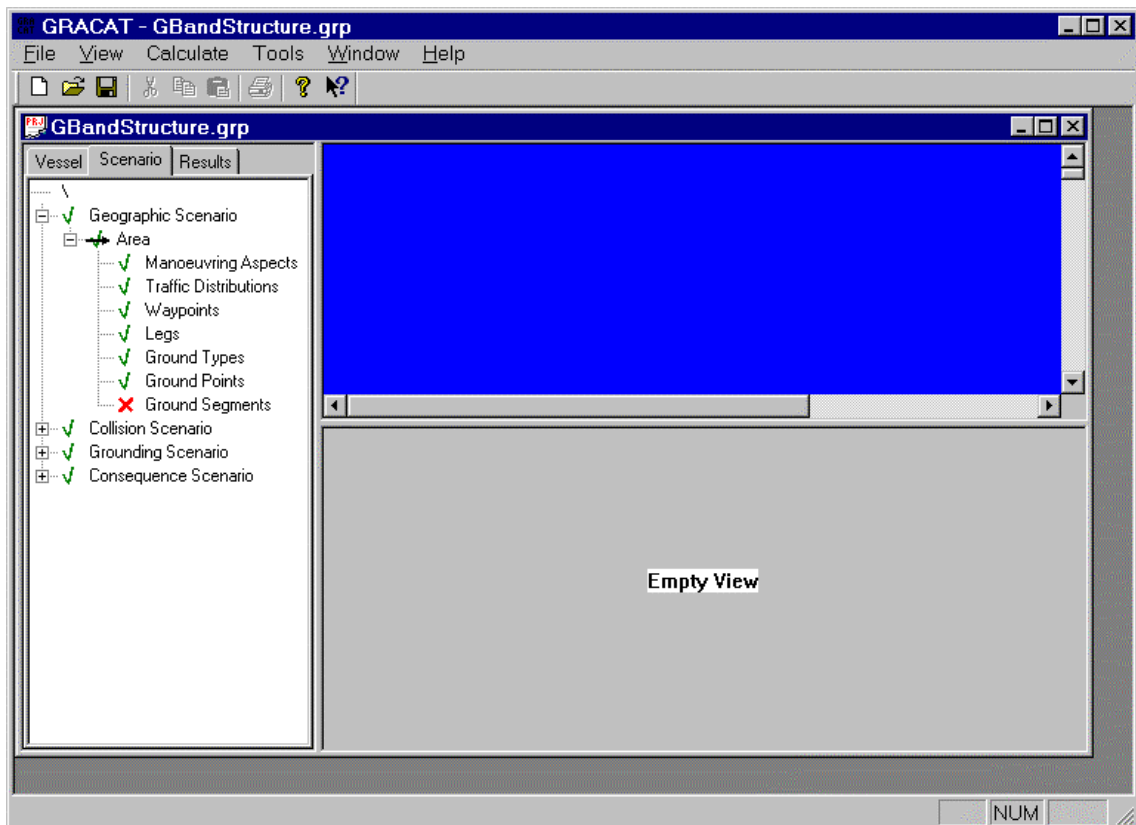


Figure 20 Geographic Scenario.

Basically, a geographic scenario consists of a series of sailing routes that are defined in terms of waypoints that are connected with legs. Similarly, the grounds are specified by ground points, which in turn are connected with ground segments. Further information that is needed in the specification of the geographic scenario is information on how the vessels are sailing along the specified route (Manoeuvring Aspects), which also includes speed restrictions and other aspects that impact on the operation safety (e.g. requirements of having pilot on board). Moreover, for a collision analysis the traffic composition (Traffic Distribution) on the different segments must be specified. Similarly for the grounding analysis, a specification of the bathymetry (Ground Types, Ground Points, and Ground Segments) must be given.

It is noted that it is not necessary to specify the bathymetry for performing a collision frequency analysis. Likewise, it is not necessary to specify the traffic composition for performing a grounding frequency analysis.

When all required data has been entered, then the user must define the route on which the vessel operates. We will revert to this later. By following the order shown in Figure 20 we will describe how the input must be entered and defined. It should be noted only relevant data need to be specified before an analysis is performed. For instance, a collision frequency analysis does neither need a definition of the structure nor the definition of the grounds. Similar, a grounding frequency analysis may be performed without specifying the general traffic distributions in the area – only a dummy traffic distribution needs to be defined so that an unused reference can be established.

6.1.1 Manoeuvring Aspects

Figure 21 shows the data that must be filled out to define the manoeuvring aspects. The manoeuvring aspect is identified by a name. By clicking the **Add** button a new “Manoeuvring Aspects” may be defined. Later, when the manoeuvring aspects are linked with a specific leg, reference is made to the particular name. A specification of the manoeuvring aspects may therefore be reused at several legs. The given name may be edited by double clicking on the name.

The first part of the input defines how the vessel is sailing along a leg segment. In the present case it is defined that the vessel is sailing with a mean distance of 125 m and a standard deviation of 25 m away from the direct line between the waypoints. The max velocity of 45 m/s indicates that there is no speed limit along the particular leg. The second part that specifies “multiplication factor on the causation factor” identifies whether higher vigilance is present along a given leg. If vigilance in a specific area is twice as good as the overall vigilance defined by the causation factor under **Vessel® Main Particulars->Causation Factors**, then a multiplication factor of 0.5 must be given. The present manoeuvring aspects is seen to be relevant for the average vigilance.

When data has been entered the apply button must be clicked.

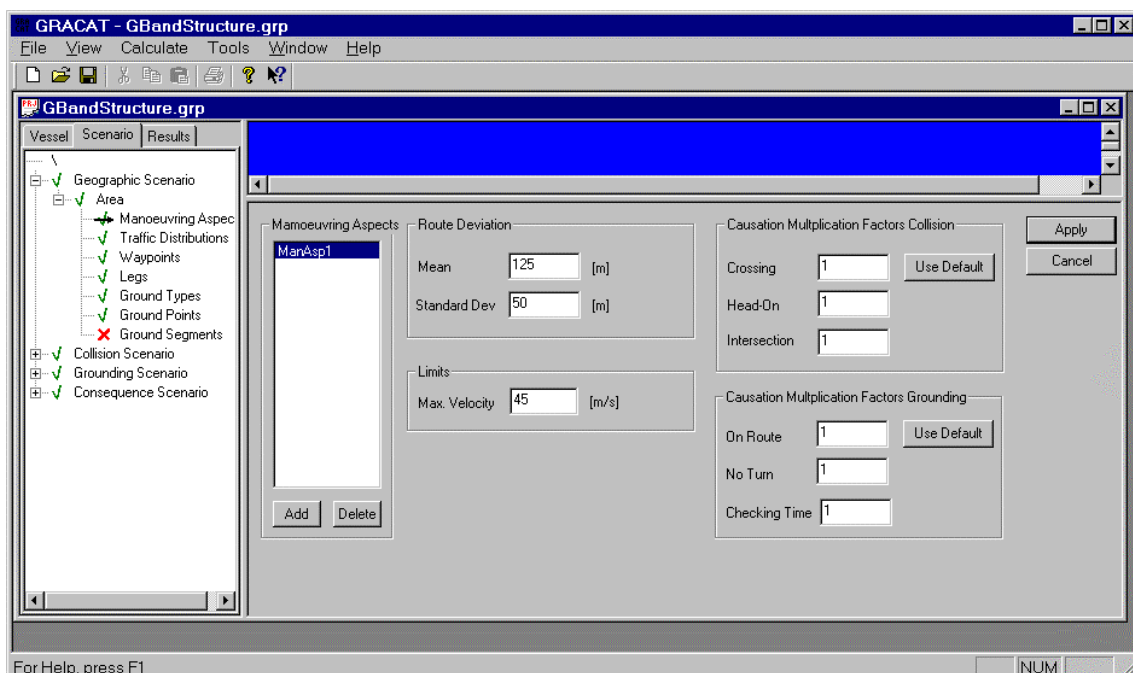


Figure 21 Manoeuvring Aspects.

6.1.2 Traffic Distribution

Figure 22 shows the specification of the traffic distribution. Again, a traffic distribution is referenced by a name, which later is used as reference when the traffic distribution is linked to a given leg. By clicking the **Add** button a new traffic distribution may be defined. A traffic distribution defines the annual number of vessels that operates at a given leg. The vessels are divided into ship types (Bulk Carriers, Chemical Tankers, etc.) and each of these also into a size category. By moving the cursor over one of the categories, a “tool tip” will show the average size of vessel in the selected category. This is shown in Figure 22 (L = 175, B=32, T=10). The annual number of vessels operating on the route is given in the field **Frequency**. The data is stored in the database when the return button is pressed.

The figure to the right displays the frequency distribution of the current ship type. When a full distribution has been entered, the Apply button (further to the right – not shown in the figure) must be clicked.

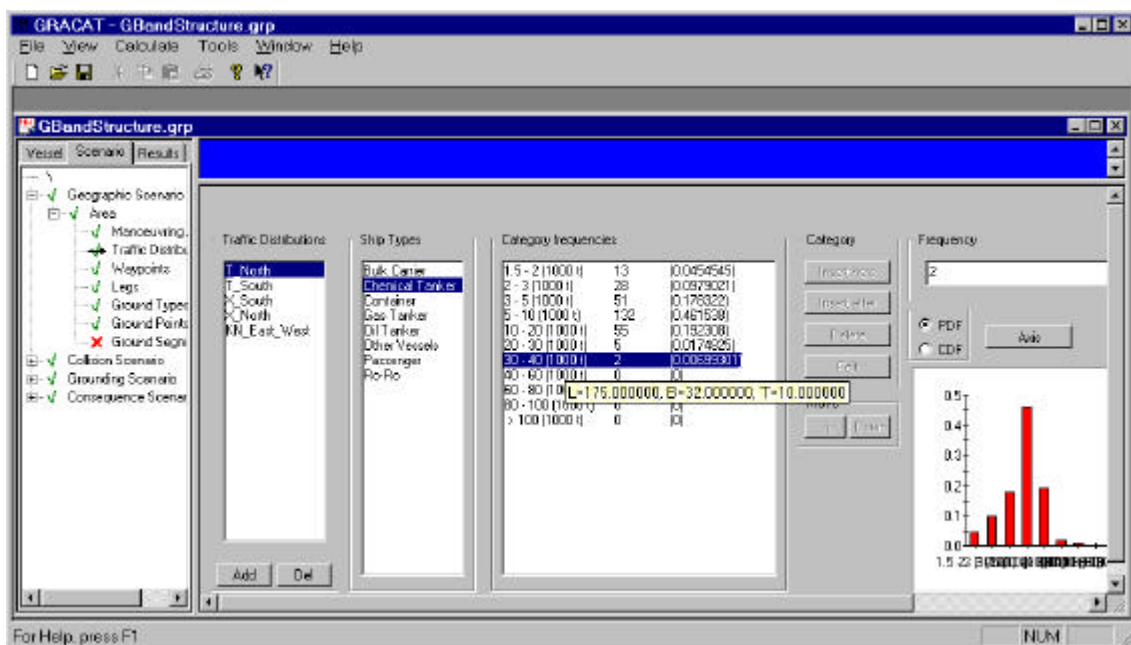


Figure 22 Specification of traffic distributions.

6.1.3 Waypoints

Waypoints are given by definition of latitude and longitude. By right clicking the mouse as indicated in Figure 23 a new window appears. The user is offered the choice of either adding a single input, or adding a multiple input, i.e. generating the data. The ID field is user for later reference. Do not forget to activate the Apply button when the input has been completed.

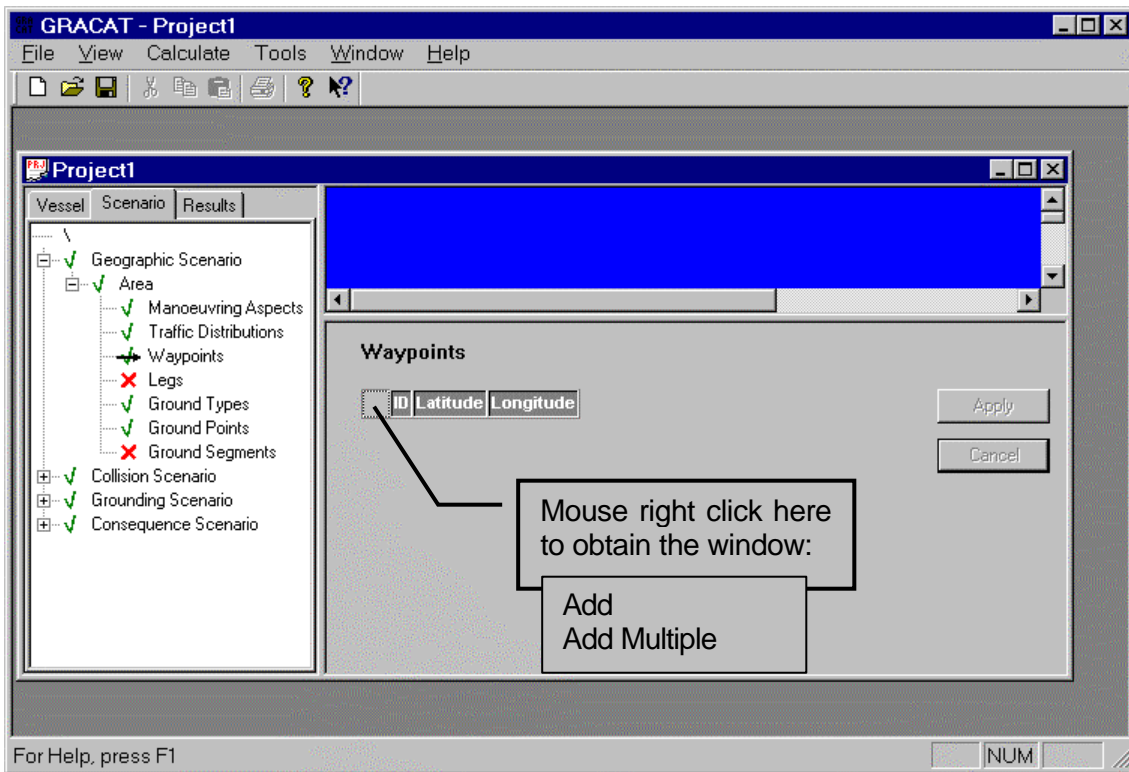


Figure 23 Entering Waypoints.

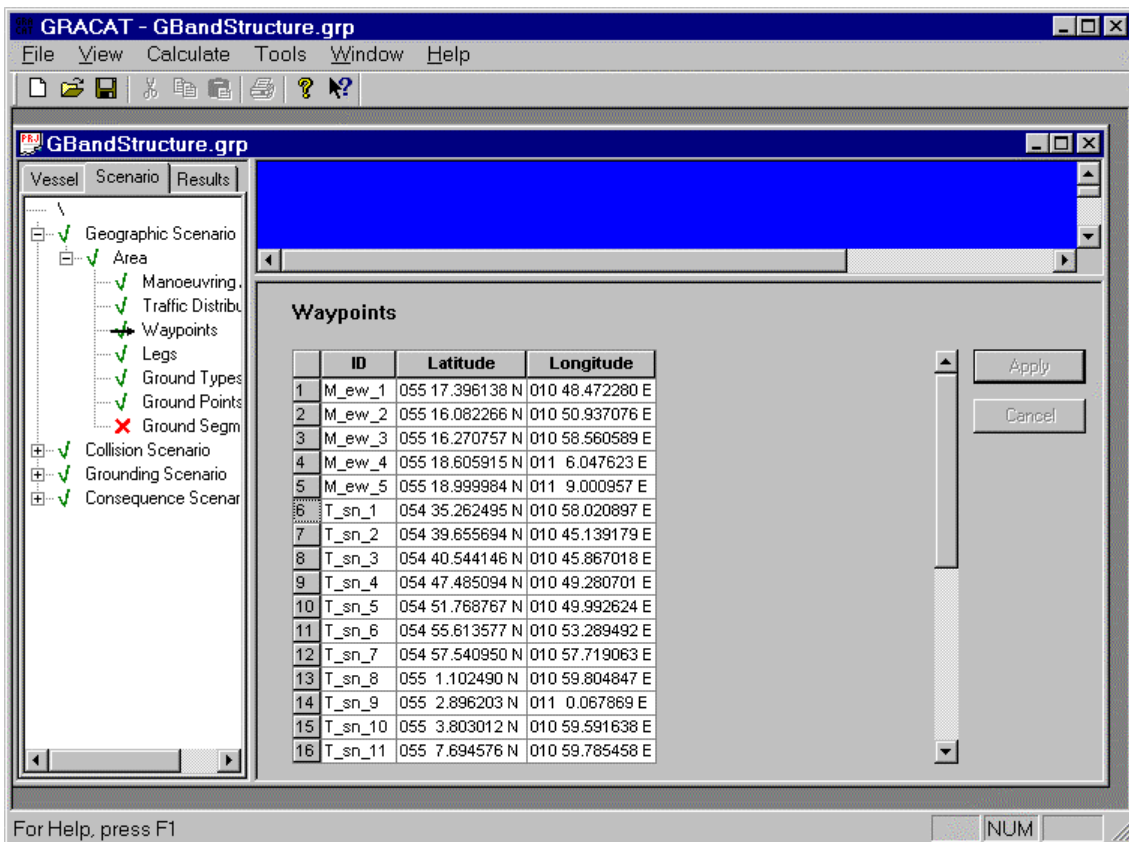


Figure 24 Waypoints entered.

Figure 24 shows a series of waypoints that have been entered. A waypoint may be deleted by right clicking the row number, and then subsequently selecting Delete in the window that appears.

6.1.4 Legs

The definition of the legs is done by a reference to a first and second waypoint. Moreover, reference must also be given to the traffic distribution and manoeuvring aspects that are applicable in direction from first to second waypoint and similarly for the opposite direction. All defined waypoints, traffic distributions, and manoeuvring aspects are available in a look-up in the relevant field in the form.

Figure 25 shows the input form for entering the legs. Similarly to the definition of waypoints, legs are as indicated entered by right clicking the mouse. If “Add Multiple” is selected the window shown in Figure 26 will appear. Selecting this type of input allows fast generation of the area topology.

If Waypoints are defined as “pearls on a string” for all routes in the area, then it can be a time saving act to generate all legs in one run. This, of course, will require that the generated non-existing legs must be deleted, i.e. legs between independent routes.

When the Apply button is pressed the defined topology will be displayed in the Display View Window.

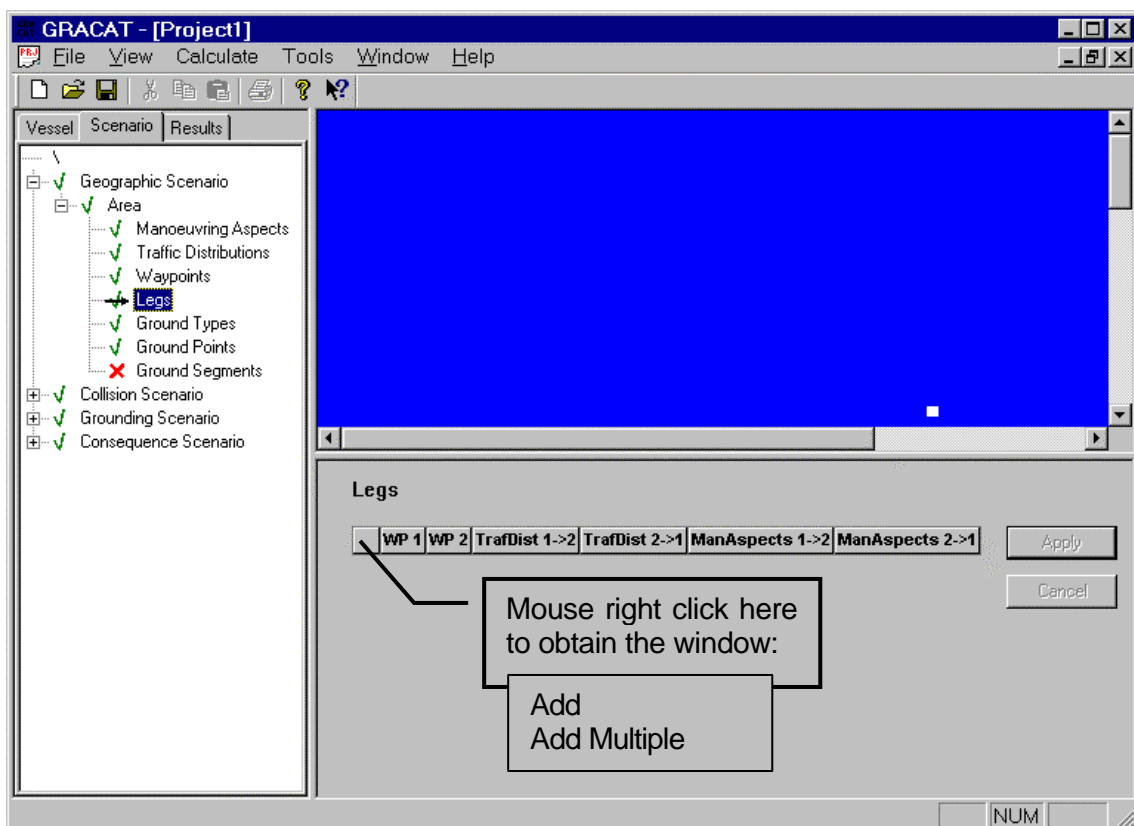


Figure 25 Defining Legs.

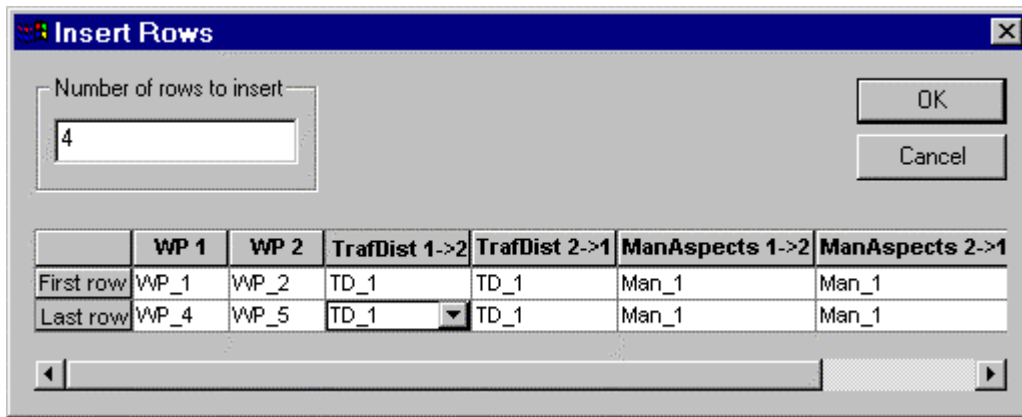


Figure 26 Adding multiple records.

Definition of route and zooming the displayed Area

The displayed area may be zoomed out by holding down the Shift-key and right-clicking the mouse. Zooming in is performed by holding down the Shift-key and dragging an area with the mouse while holding down the left mouse button, see Figure 27.

When zooming in and out it can happen that one “get lost” in the process. Therefore, to let GRACAT rescale the display, exit and re-enter the area definition by first clicking the **Geographic Scenario** and then again the **Area**.

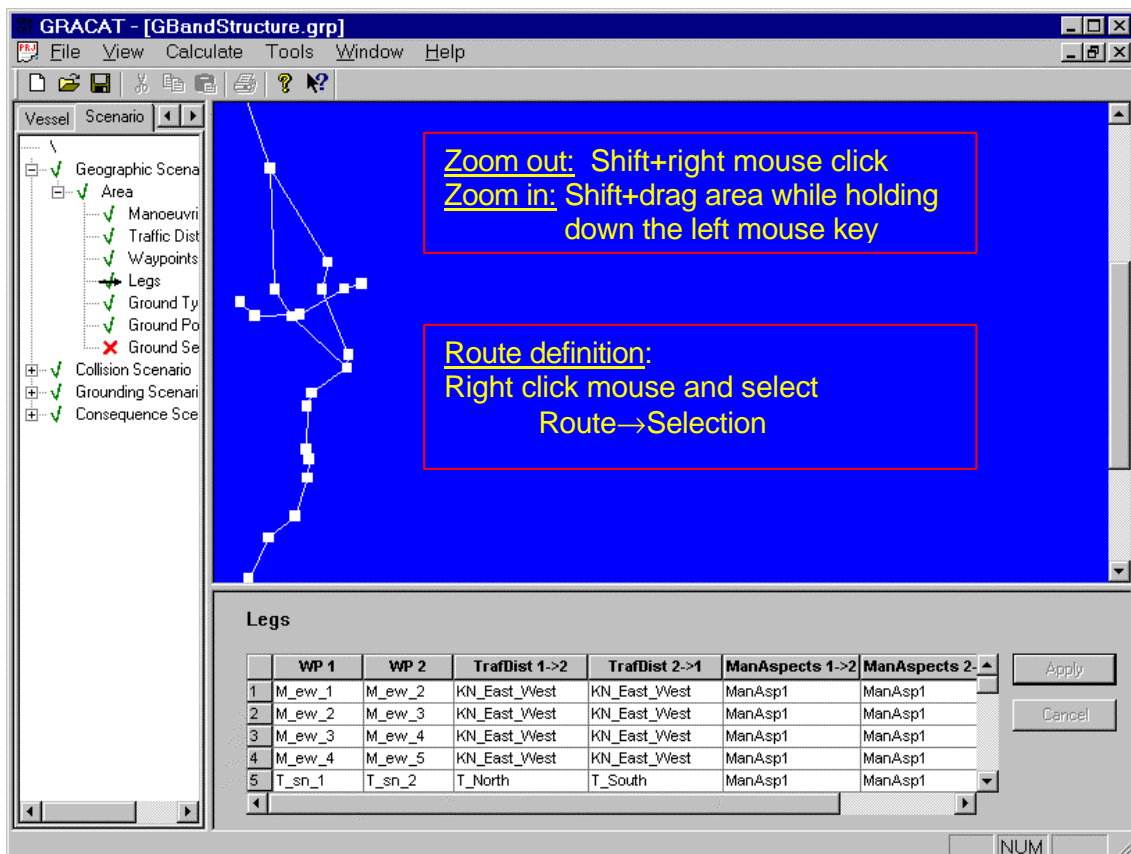


Figure 27 Manipulating the Area Display View.

The route that the vessel is operating is defined by first right clicking the mouse and then select **Route® Selection**. Thereafter the route is selected by clicking on legs. The order in which the legs are given defines the sailing direction called **UP**. The program will suggest a next leg segment on the route. This segment can be accepted by hitting the Return key. Remember to deselect route selection when the route has been defined. This is done by right-clicking the mouse, and then by deactivating the route selection. When the route has been selected Red legs will indicate the selected route. A check mark on **Selection** indicates that selection is active.

By moving the mouse pointer over the legs or the waypoint will result in the appearance of a cross-hair. In the bottom of the mainframe window relevant information of the waypoint or leg will be displayed, see Figure 28.

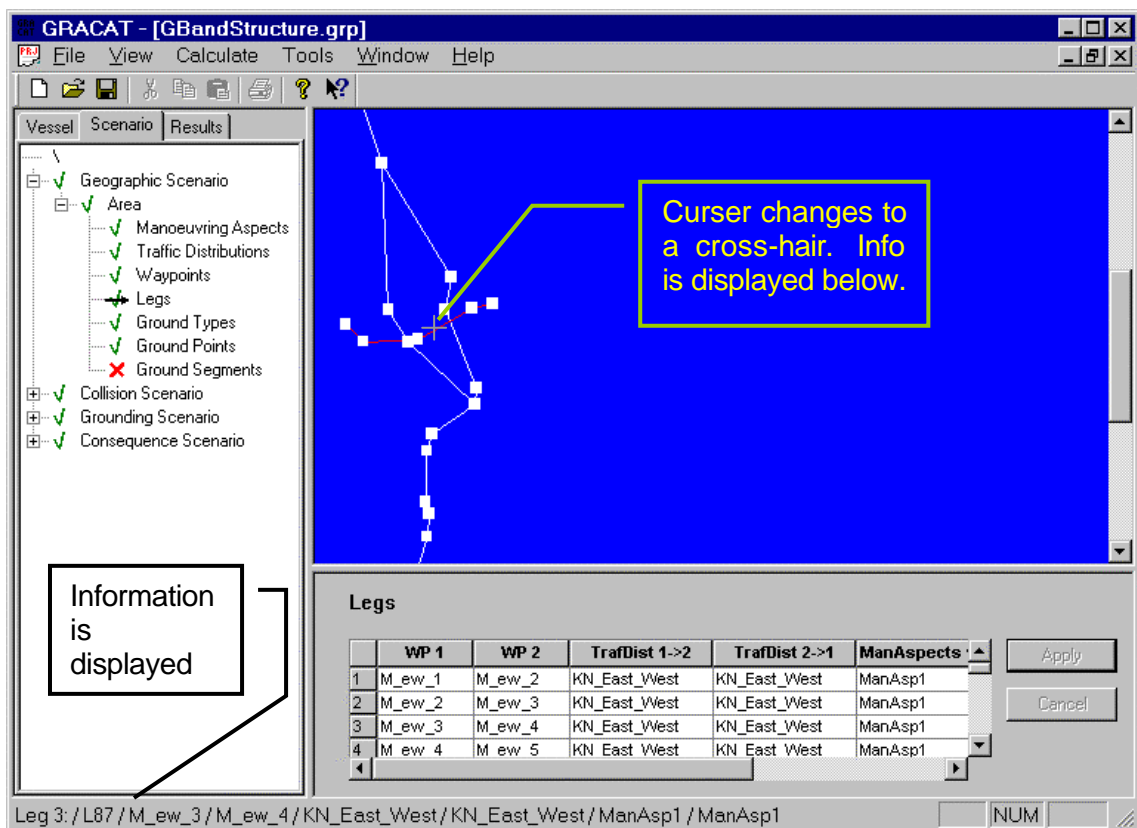


Figure 28 Obtaining information by placing the mouse cursor over a leg or a waypoint.

6.1.5 Ground Types

Two different ground types may be specified. These are soft grounds and hard grounds and the required data is shown in Figure 29.

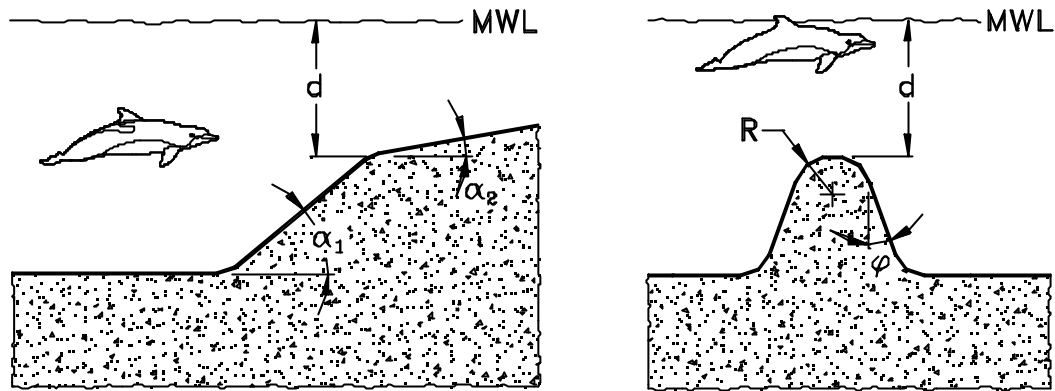


Figure 29 Data definition of soft ground (left) and hard ground (right).

The specification of ground data is given by probability distributions, see Figure 30. A description of all probability distributions is given in the Appendix, Section 12.1. A new ground is first added and named followed by a selection of the ground being a soft or a hard ground. The variable to be defined is selected in the Variable field as shown in the figure. A series of distributions are built-in into the program, one of which may be selected for the variable. The type of distribution parameters to be given is selected in the subsequent column. The parameter column shows the defined distribution parameters. Remember to hit return when new values are entered – this will cause an update of the values in the parameter window.

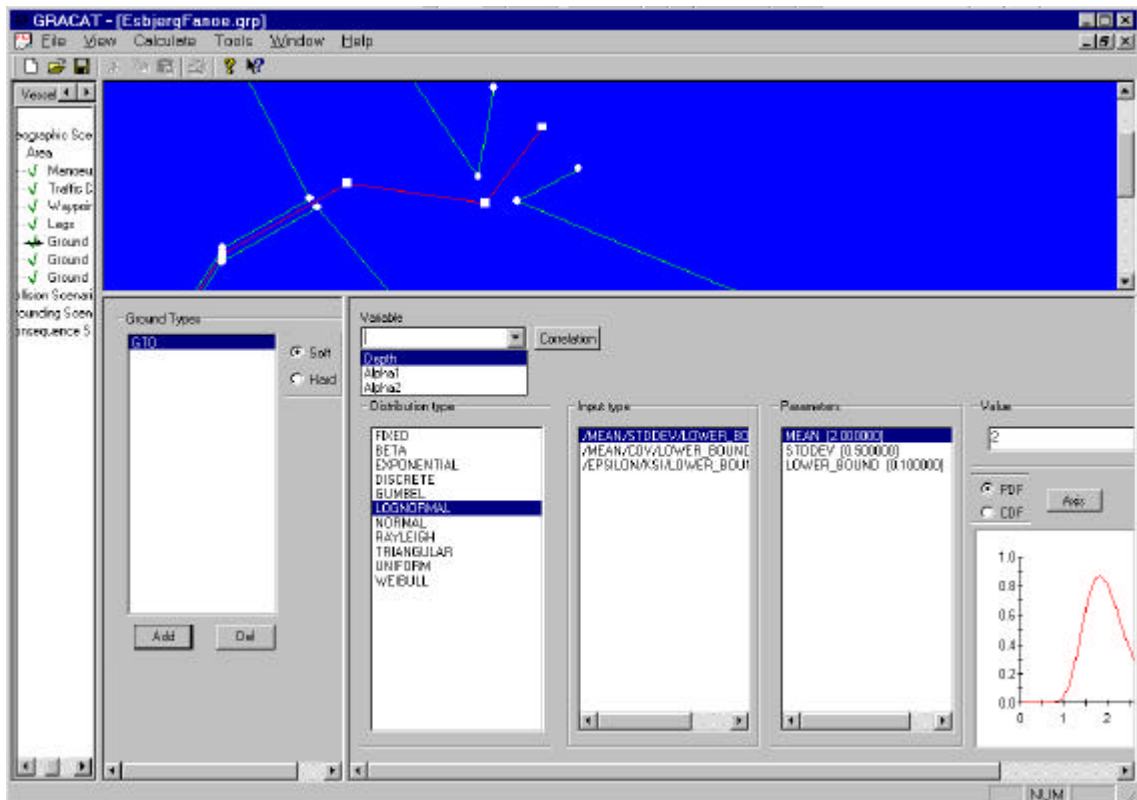


Figure 30 Definition of Hard ground types.

Reference is left to Section 6.3.1 and Section 6.3.3 for a description of the parameters that describes the hard and soft grounds.

6.1.6 Ground Points

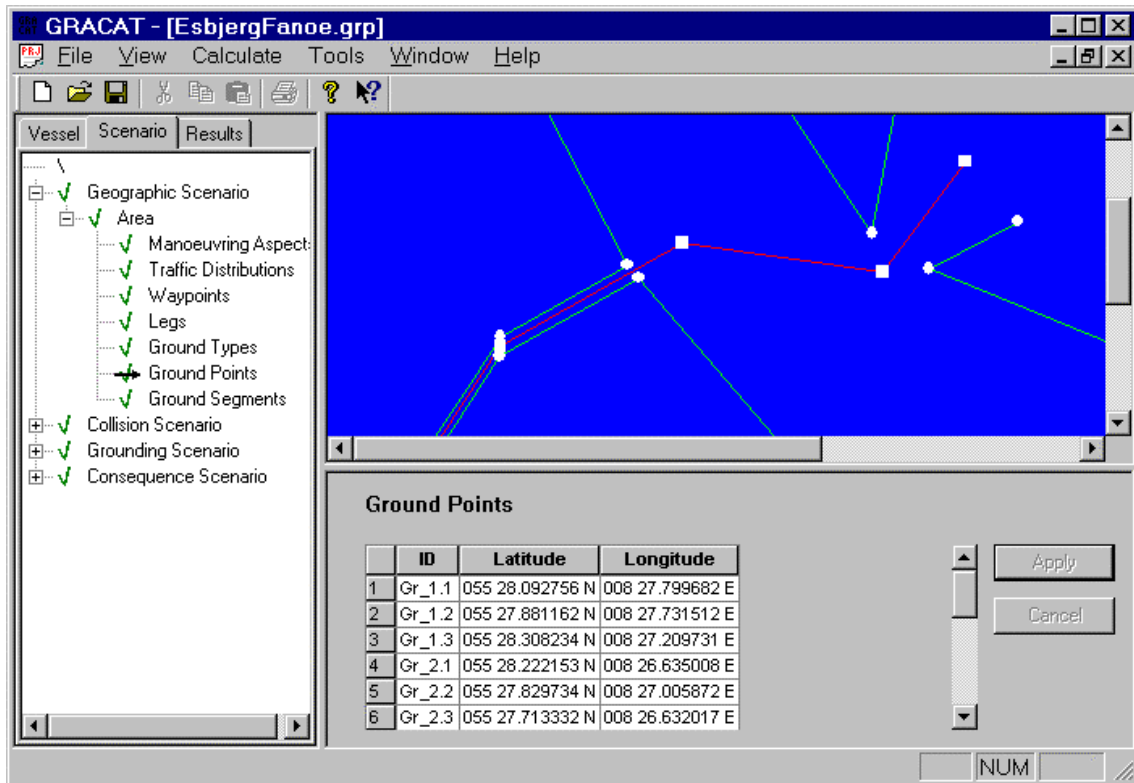


Figure 31 Specification of ground points.

Ground points are specified in a similar manner to waypoints, and the procedure will therefore not be repeated here.

6.1.7 Ground Segments

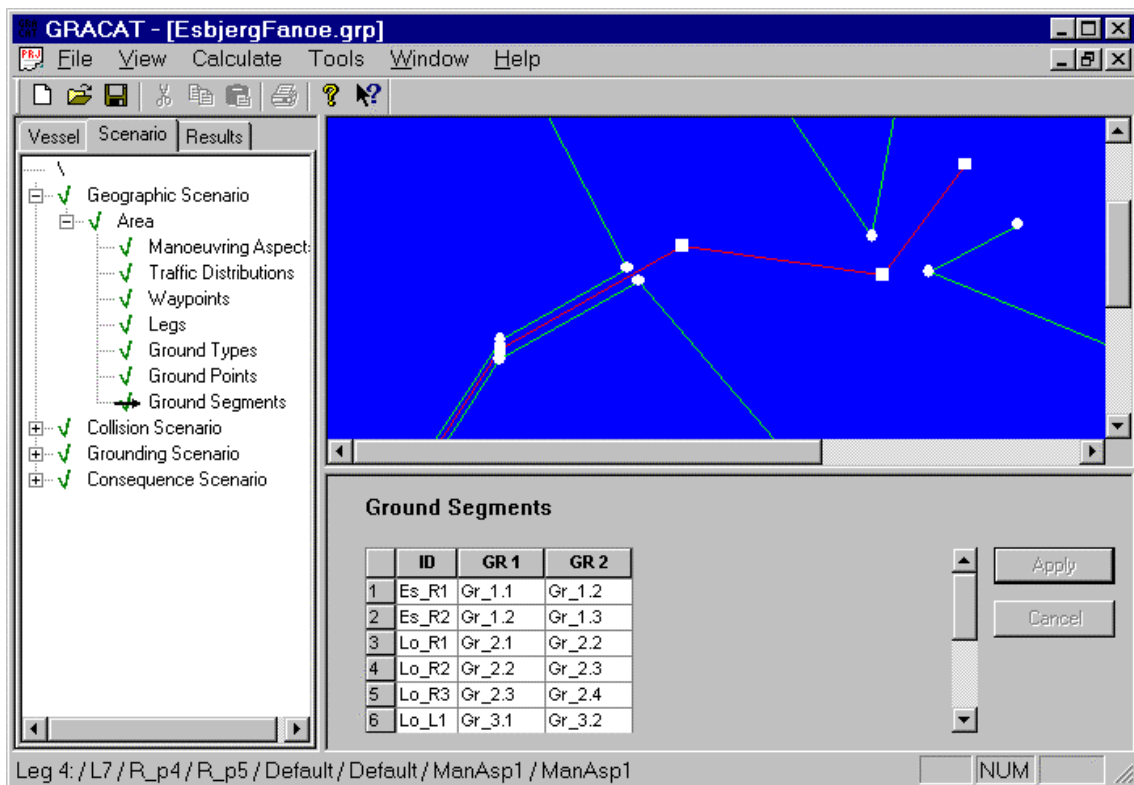


Figure 32 Specification of ground segments.

Ground segments are defined similarly to legs by reference to ground points and to ground type specification.

6.1.8 Exporting or Importing the area definition

The area definition may be exported to or imported from a file. This facility assures an easy reuse of data in other projects.

6.1.8.1 Exporting the area data to a file

The procedure for exporting data is as follows. First select one of the items under the area definition – this can for instance be the **Waypoints** – and mouse click on one of the fields, which will assure that the area definition becomes active. Next, from the main menu select **Tools® Area® Export** and a standard File Save window will appear. The structural data can now be saved to any file. It is a good idea to choose an easy recognisable extension, for example “AREA”.

6.1.8.2 Importing the area data from a file

The procedure for importing data follows a scheme similar to the above described. First, select the **Waypoints** and mouse click the square field to the left of the heading field “ID”. Next, from the main menu select **Tools® Area® Import** and a standard File Open window will appear. Select the file that contain the area definition, and press Ok. Although not visible, the data has now been loaded. To load the data into the form you must exit and re-enter the form. Therefore, click once the **Geographic Scenario** item, and then again on the **Waypoints** and the data are now visible.

6.2 Collision Scenario

A collision scenario is specified when the user wants to perform a probabilistic or a deterministic collision damage analysis. In order to define a collision analysis the user must specify the speed of own vessel at the collision impact, the longitudinal location and angle of impact, and finally the main particulars and bow shape of the striking ship. Some of these parameters can be specified both as single values (deterministic analysis) or as probability distributions (probabilistic analysis). A deterministic analysis is based on just a single impact calculation whereas the probabilistic calculation requires stochastic simulation of many impacts.

The underlying mathematical model for the collision analysis is described in Ref. [4]. Some of the basic assumptions/limitations are:

1. The bow of the striking ship is rigid.
2. Only a side collision can be analysed, i.e. only the side of the struck ship deforms. The theoretical model is based on a perpendicular impact, and is then modified for non-perpendicular impact angles. This means that the deviation of the impact angle from perpendicular should most reasonably be in the interval between -45 and 45 degrees.
3. The forward velocity of the struck ship is not taken into account in the calculation of the damage.

4. The bow is approximated by planes for the ship sides and the bottom and by an ellipsoid for the bulb. It is assumed that the tip of the bulb is at the same longitudinal location as the tip of the raked bow idealisation of the bow. Since a part of the bow is approximated by planes, it may be a crude representation of a bow with a large radius of curvature at the front edge. Analysis of such bows requires careful modelling. Again, a good rule of thumb is that the volume of deformed steel is a governing parameter for the resistance.
5. The theoretical model is based on an accurate analysis of the interaction between the penetrating bow and the structural elements in the shipside. Therefore the model captures the dependence on the impact location (longitudinal and vertical position) at a detailed level, see for example Figure 33. The response may be quite sensitive to the impact location, as - for example - there is a great difference between hitting right at a bulkhead or just missing it. If the impact location is uncertain, the user should therefore be careful to make either a probabilistic analysis with stochastic impact location or at least a deterministic analysis with a comprehensive parameter study.

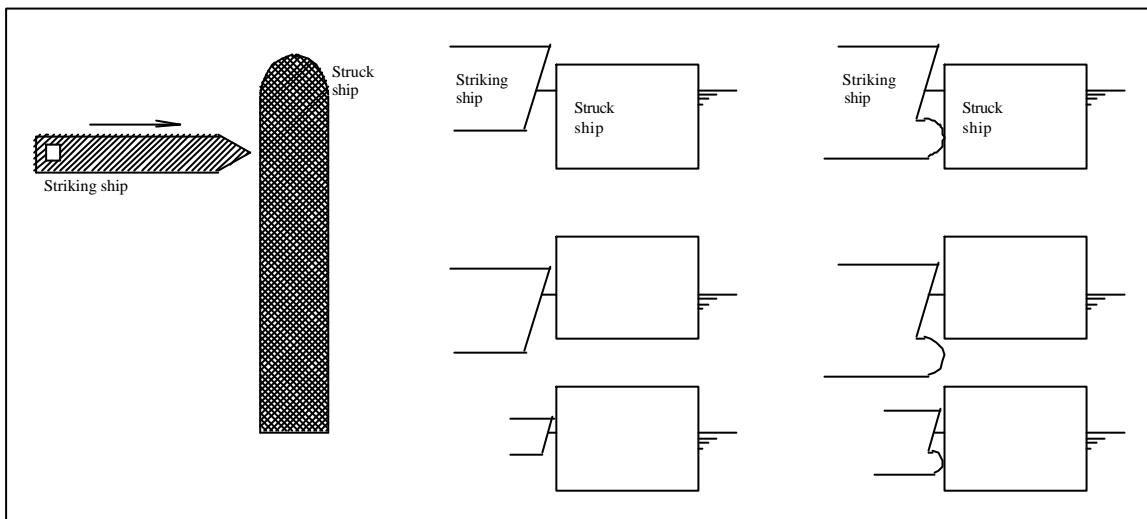


Figure 33 GRACAT takes into account the impact location at a detailed level so the user should take care to make sure that both vertical and longitudinal impact location is correct.

6.2.1 Deterministic collision scenario

When a deterministic collision analysis is desired, the required data is entered in the data window shown in . It is seen that the analysis requires input data for

1. Own vessel speed (only a pure forward speed can be considered).
2. Impact conditions for the global ship dynamics, that is the impact location on the struck ship and the angle between the ships. Note that the impact location (x-coordinate) is made non-dimensional with the length of the ship. This means that a number between 0 and 1 should be entered.
3. Main particulars and speed of striking ship
4. Bow shape of striking ship.

For general information it may be noted that the program will – from the defined deterministic data – generate a “probabilistic” collision scenario where all variables, however, are assigned a “fixed” distribution type. The next section describes how a probabilistic analysis be carried out by assigning probability distribution functions to some of the input parameters. Figure 34 shows the input screen for definition of a deterministic collision scenario. The definition sketch for the bow shape is shown in Figure 6.

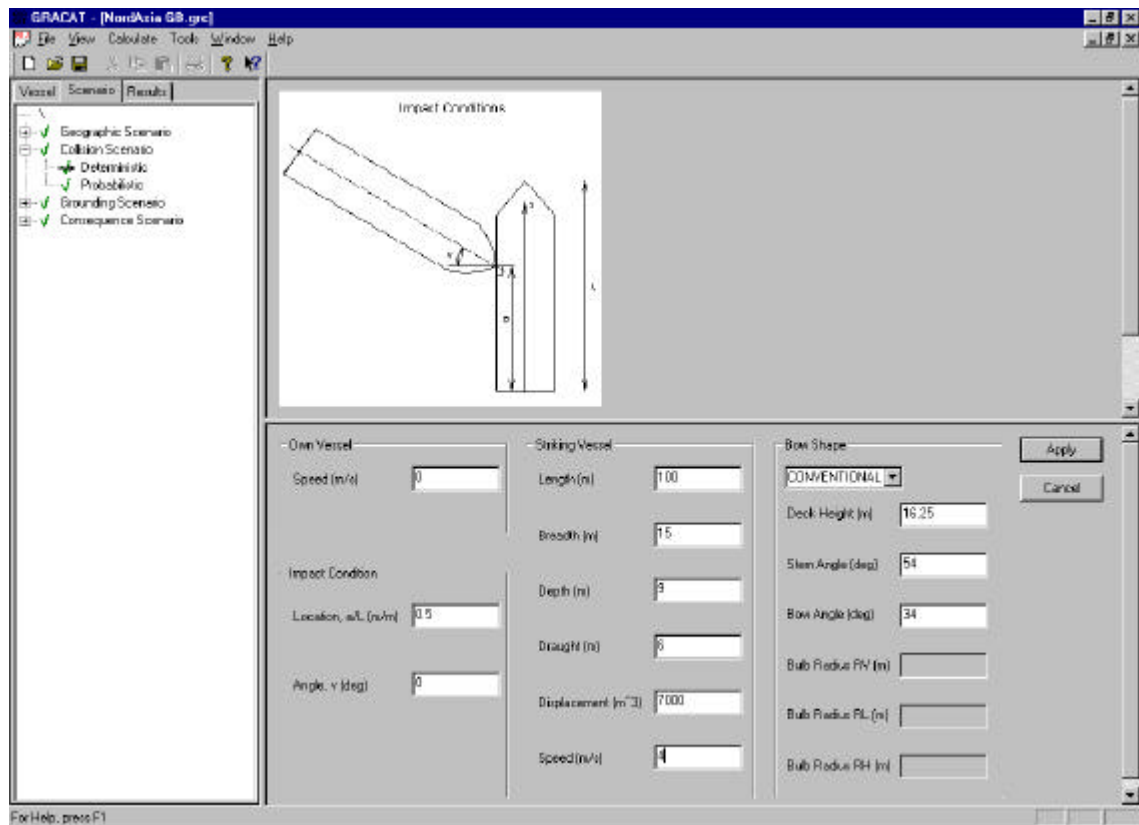


Figure 34 The specification of a deterministic collision scenario.

6.2.2 Probabilistic collision scenario

In Figure 35 it is seen that a probabilistic collision scenario consists of three data groups – OwnShip, Impact Condition, and Striking Ships. Each of these groups consists of a minimum one “Scenario item” (indicated by an S), which contains the random variables. Each group may contain several Scenario items where the likelihood of occurrence of each of these scenario items is given in the group definition. Each Scenario item may besides random variables also contain group definitions. This will be exemplified in the following.

First, the random definition of the variables is edited by double clicking on the actual variable. A window as shown in Figure 36 will be opened, where the user may enter the distribution data. The distributions are described in the Appendix, Section 12.1.

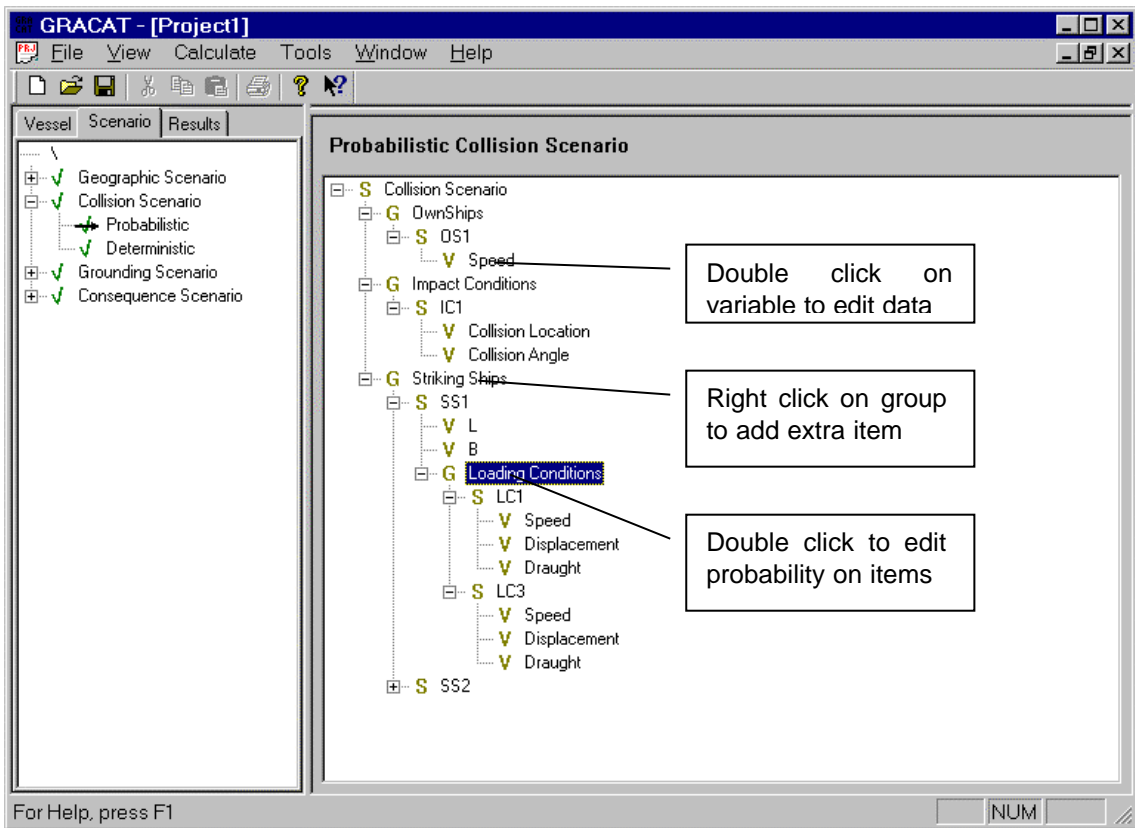


Figure 35 Probabilistic collision scenario.

The following units are used, see also Section 6.2.1:

- Speed is given in m/s
- Collision Location is defined from aft and is given relative to Lpp.
- Collision Angle is given in degrees
- Vessel Length, Breadth, and Draught in m
- Displacement in m³

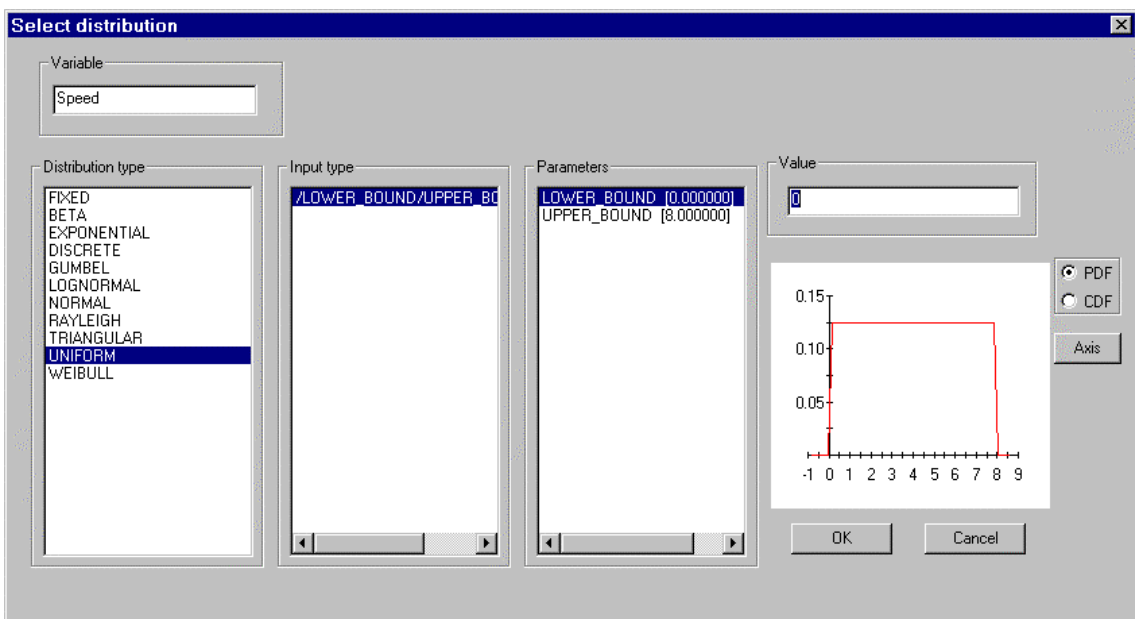


Figure 36 Entering the distribution information of the random variable.

By right clicking on a group definition, additional scenario items may be added. As an example it is seen in Figure 35 that two striking vessels (SS1 and SS2) have been added. It is also seen that striking vessel SS1 has two loading conditions defined (LC1 and LC3). The probability of occurrence of the striking vessels or their loading conditions is defined by double clicking on the group. As an example Figure 37 shows the definition of the probability of occurrence the loading conditions after the loading condition group has been double clicked, as shown in Figure 35.

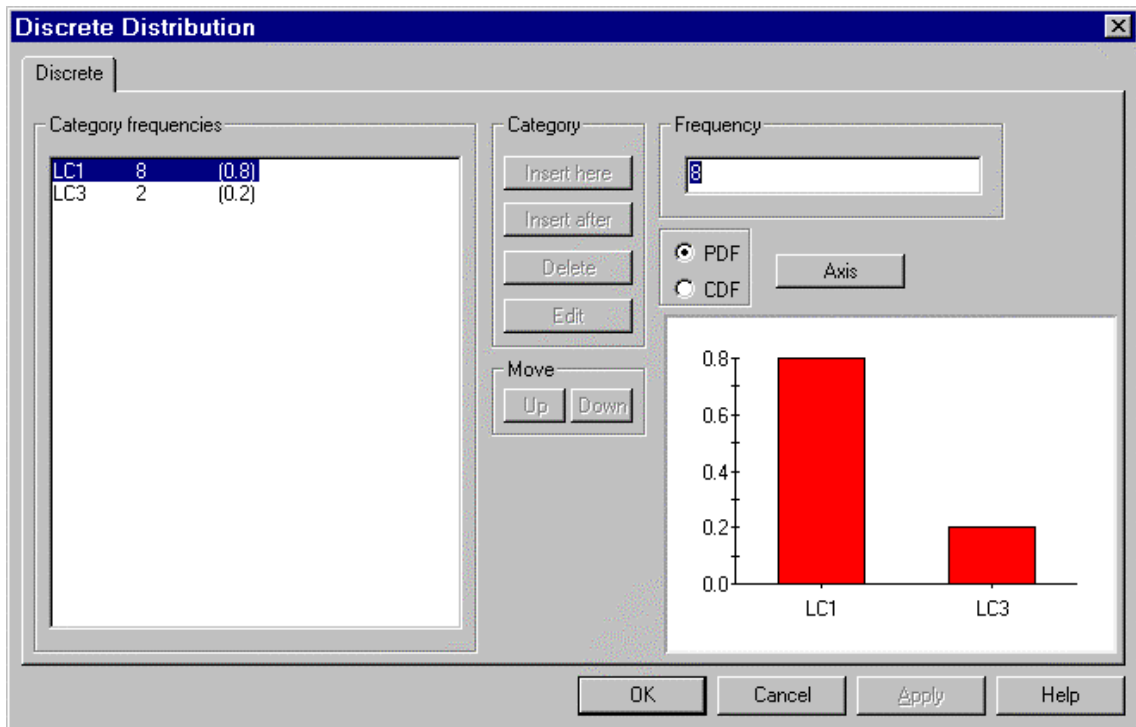


Figure 37 Entering probability of occurrence of the defined loading conditions.

6.3 Grounding Scenarios

GRACAT allows for analyses of a ship running aground on both hard and soft ground:

- The soft grounding event is the type of grounding that would occur in most areas around Denmark, where a ship runs onto a sand bar or a beach. GRACAT assumes in this case that no structural damage occurs - all the deformation takes place in the ground. The theoretical model is described in Ref. [6].
- In the hard grounding event the ship is running onto a rigid rock. In this case, all the deformation takes place in the ship structure. The theoretical model is described in Refs. [2] and [3].

6.3.1 Deterministic hard ground scenario

The input screen for definition of a deterministic hard ground scenario is shown in Figure 38.

The most important assumptions/limitations of the model are:

1. The rock is rigid.
2. The rock is idealised by a cone with a rounded tip. The geometry is defined by the tip radius and the cone semi-apex angle.

3. The position of the rock is defined by the depth, D , from the water surface to the rock tip and by the rock eccentricity, $e=a/B$, see Figure 38. The eccentricity, e , can only attain values between -0.5 and 0.5 (i.e. the rock tip is within the sides of the ship).
4. The rock tip radius can attain values between zero and infinity. The semi-apex angle can attain values between 25 and 60 degrees. With these large intervals, the chosen idealisation can model small cutting rocks as well as large, shallow banks.
5. The theoretical model is based on a pseudo steady-state crushing process where it is assumed that the structure is forced to 'flow' around the rock. This implies that the theoretical model can only be expected to be valid for limited rock tip penetrations, of say a few metres, so that the longitudinal damage is several times longer than the vertical penetration. For example, the model will not capture correctly the head-on impact with a high, near-vertical cylinder (semi-apex angle close to 0).

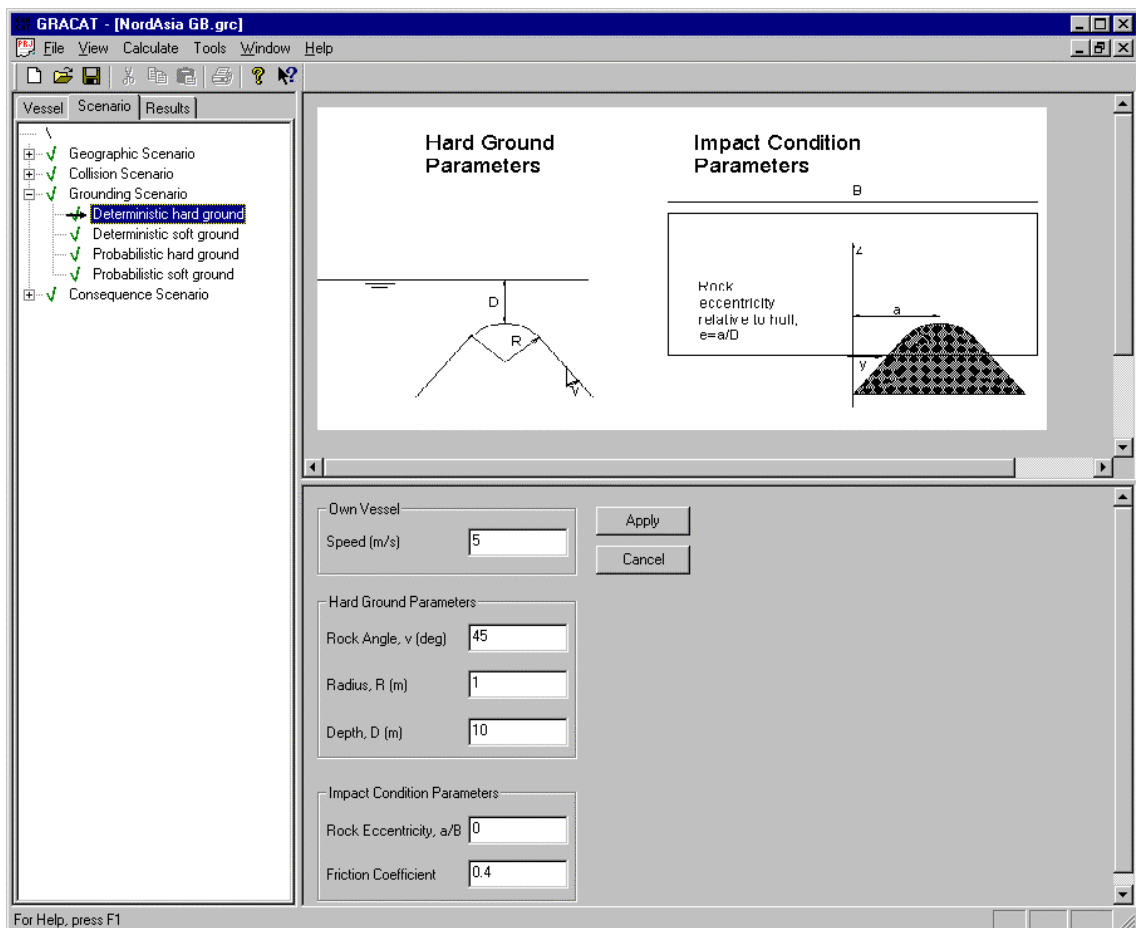


Figure 38 Specification of deterministic hard ground scenario.

6.3.2 Probabilistic hard ground scenario

The probabilistic hard ground scenario consists of two data groups – OwnShip and Hard Ground description. The scenario is build up like described in section 6.2.2, and reference is left hereto for information on manipulating the scenario. The relevant data for specification of the hard ground is given in the section about the deterministic hard grounding scenario, Section 6.3.1.

6.3.3 Deterministic soft ground scenario

Figure 39 shows the input screen for definition of a deterministic soft grounding scenario.

The theoretical model for the soft grounding analysis is described in Ref. [6]. The most important assumptions/limitations of the model are:

1. The ship is rigid. This is good approximation for the ship motion, but a soft grounding event may actually induce some minor denting or scratching, which is not determined in the analysis. GRACAT does, however, calculate the maximum grounding induced shear force and bending moment in the hull girder so these loads can be compared with the hull strength in order to check if there is a risk of hull girder failure.
2. Only surge, heave and pitch motions are considered.
3. The geometry of the ground is idealised by two semi-infinite planes, see Figure 39. Individual inclinations can be assigned to the two planes. The position of the planes are described by the water depth, D , at the intersection line between the planes. Normally natural slopes in open water have an inclination not steeper than 1:6. Note that the upper slope shall be given an inclination angle, which is not steeper than the lower slope. Only positive slope angles can be input. This means that the upper slope can be horizontal (slope2 large) but it can not be inclined downwards (slope2 negative).
4. The soil is modelled by a special theory for frictional soil under partially drained conditions. This means that the model works for sand (like at Danish beaches) but not for clay, see Ref. [6].
5. The input parameters for the soil are standard geotechnical parameters, which can be determined either from soil samples from the site or from geotechnical text books or data tables.

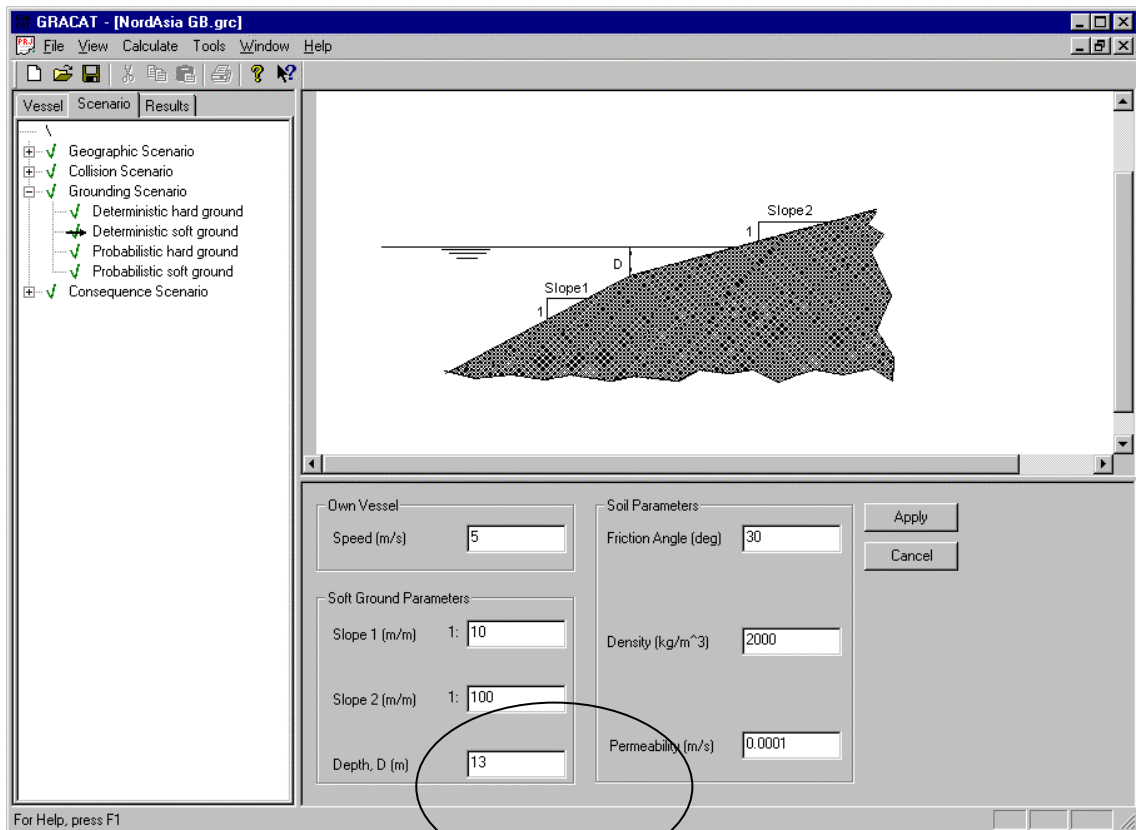


Figure 39 Specification of deterministic soft ground scenario.

6.3.4 Probabilistic soft ground scenario

The probabilistic soft ground scenario consists of two data groups – OwnShip and Soft Ground description. The scenario is build up like described in section 6.2.2 and as shown in Figure 35, and reference is left to these for information on manipulating the scenario. The relevant data for specification of the soft ground is shown in Figure 29.

The units for the data are given in the description of the deterministic soft grounding scenario, section 6.3.3.

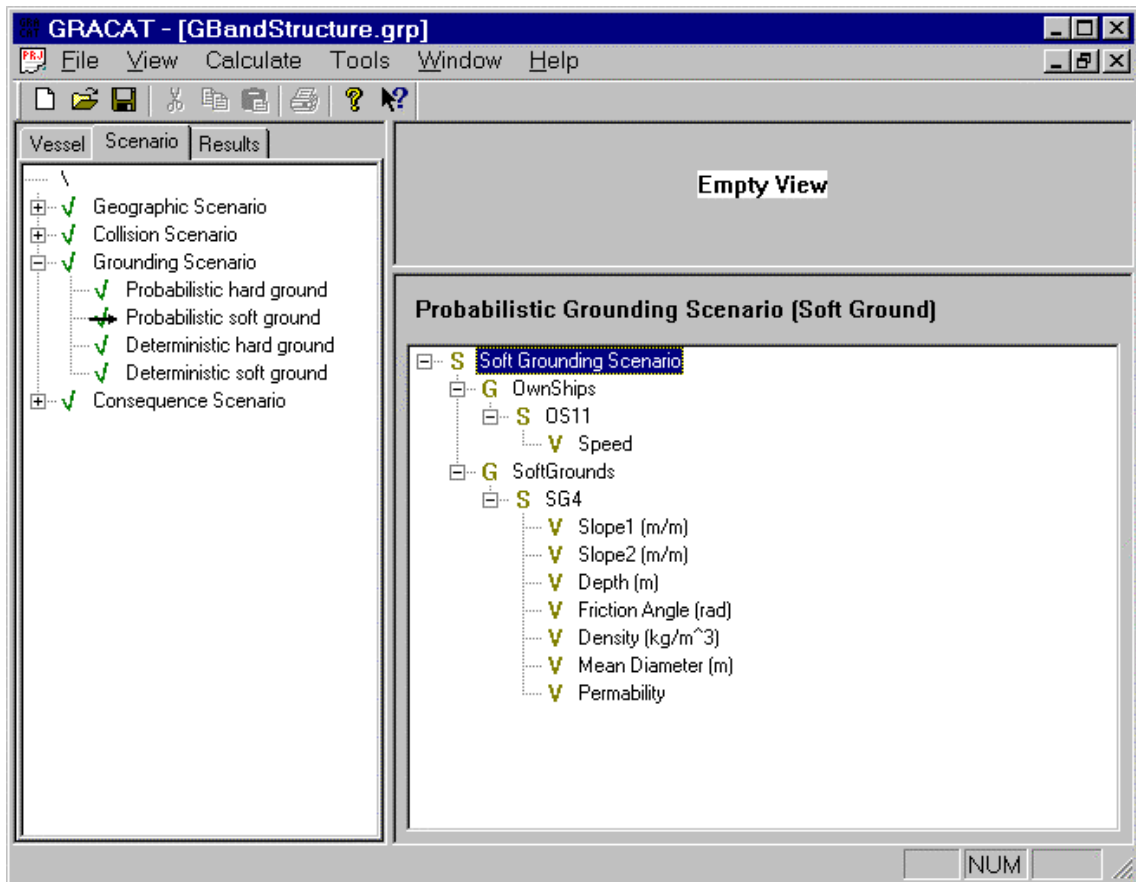


Figure 42 Specification of probabilistic soft ground scenario

6.4 Consequence Scenario

The definition of the collision scenario is established similarly to the above-defined scenarios. The sections below define the deterministic and probabilistic consequence scenario. The consequence analysis requires a definition of an I-ship file.

The most important assumptions/limitations of the model are:

1. The damage is idealised as a rectangular box-shaped object.
2. The analysis is performed as a quasi-static analysis.
3. When a tank containing oil is damaged, then all the oil in the tank is assumed spilled.

6.4.1 Deterministic consequence scenario

The input form for the deterministic consequence scenario is shown in Figure 45 that also defines the units. The center of the damage is given in terms of the longitudinal X-position, the vertical Z-position and the horizontal Y-position. These data are given in the ship coordinate system. The dimension of the box shaped damage is given in terms of its length (X), depth (Y), and height (Z).

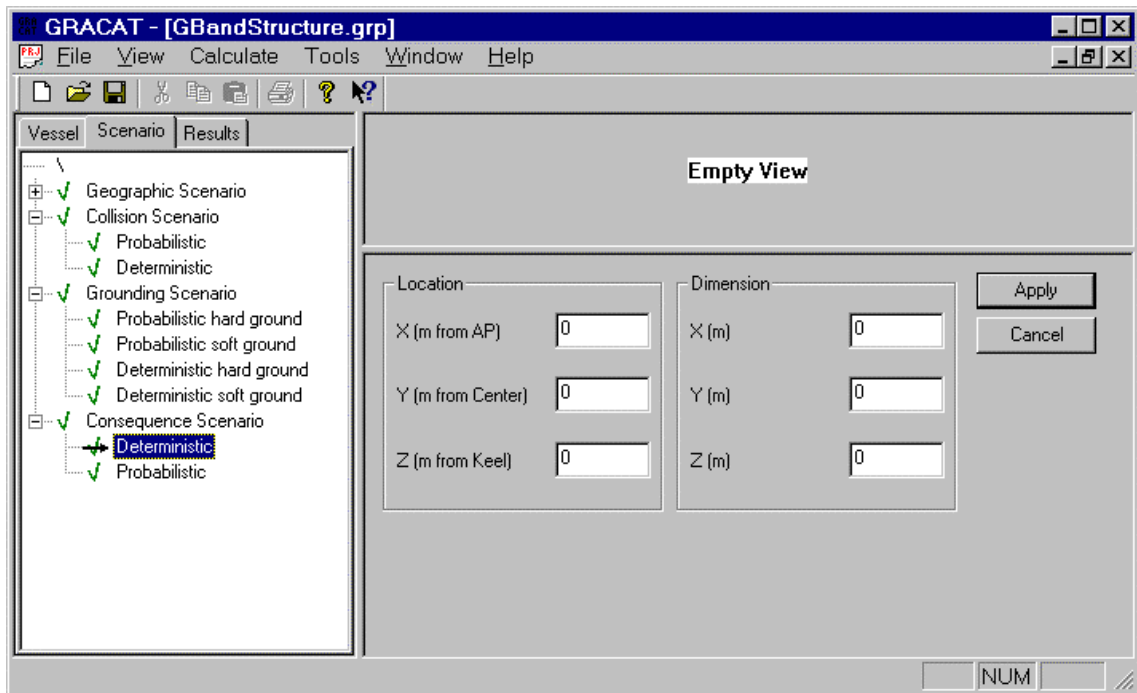


Figure 45 Deterministic consequence scenario.

6.4.2 Probabilistic consequence scenario

The input form for the deterministic consequence scenario is shown in Figure 47. The manipulation of the probabilistic scenario is similar to that defined earlier in Section 6.2.2, and will therefore not be described again.

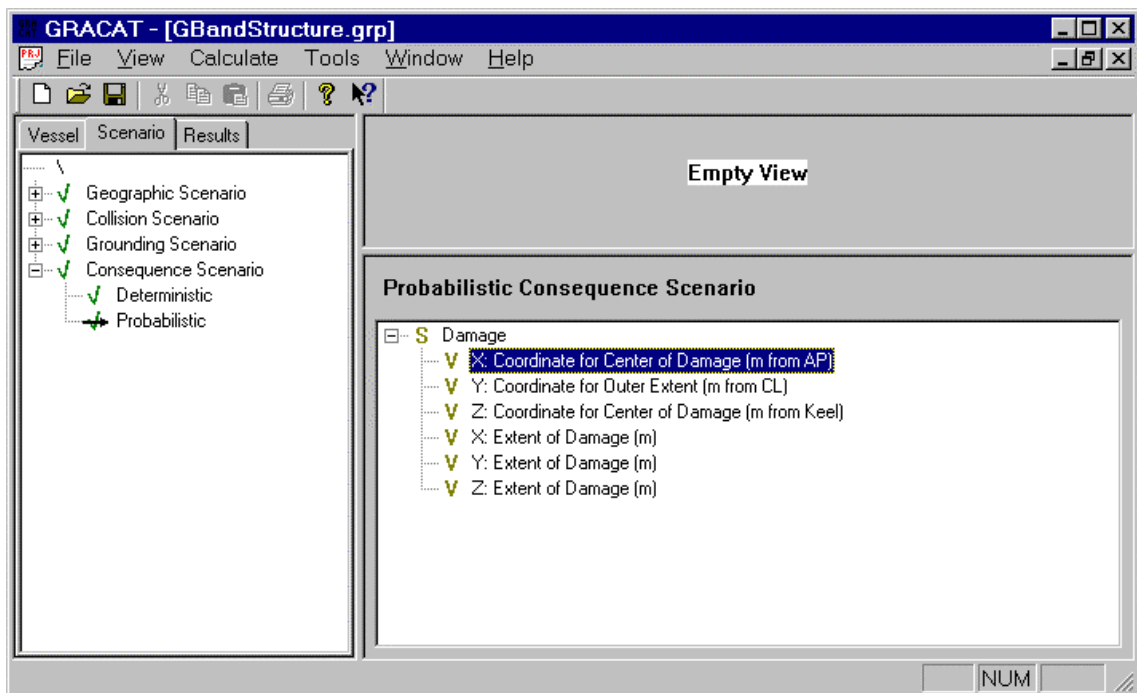


Figure 47 Probabilistic consequence scenario.

7. DEFINING THE ANALYSIS

By selecting **Calculate® Options** from the main menu the window shown in Figure 48 will appear. The purpose of this form is first of all to allow the user to specify the extent of the analysis but also to modify some parameters used in the analysis. The option

window shown in

Figure 48 defines the start level and the end level of the analysis. The window resembles the layout shown in Figure 4 (copy inserted here to the right). The user must define the start and end level of the analysis, whether a grounding or collision analysis should be performed, and the calculation and simulation type. The user is given two choices of simulation sampling methods: Monte Carlo and Latin Hypercube sampling. Both methods converge to the same result, but for smaller sample sizes Latin Hypercube is generally preferable.

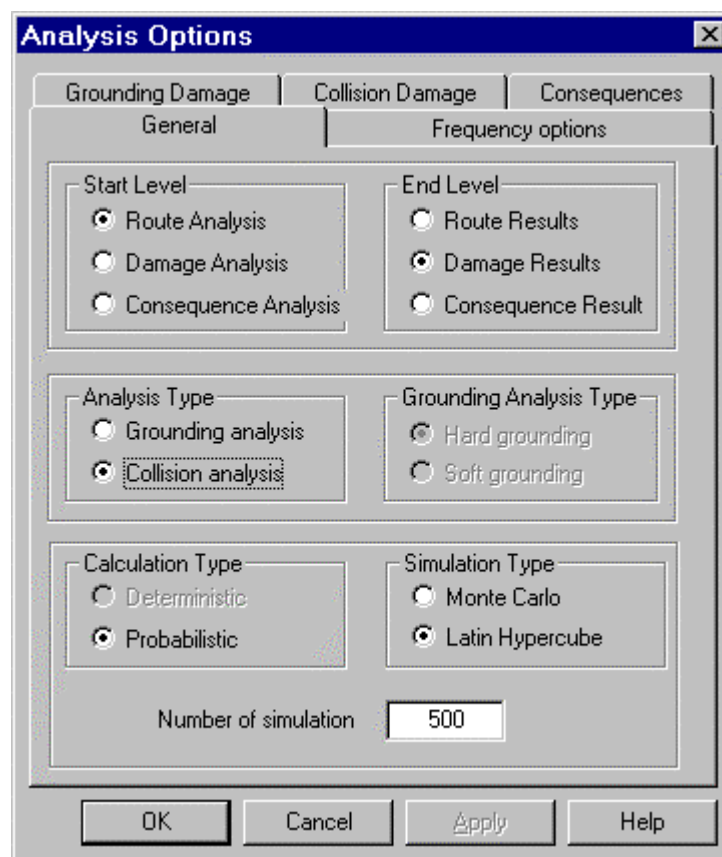
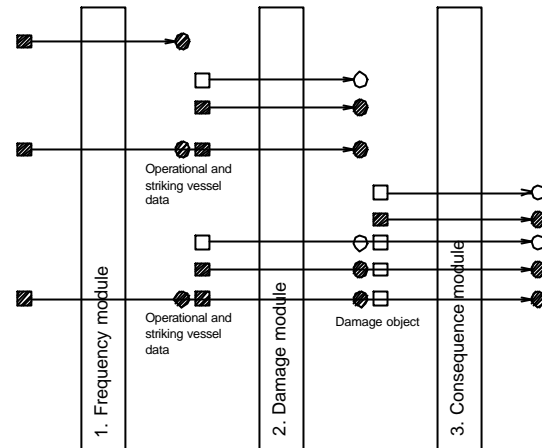


Figure 48 Defining the general analysis options.

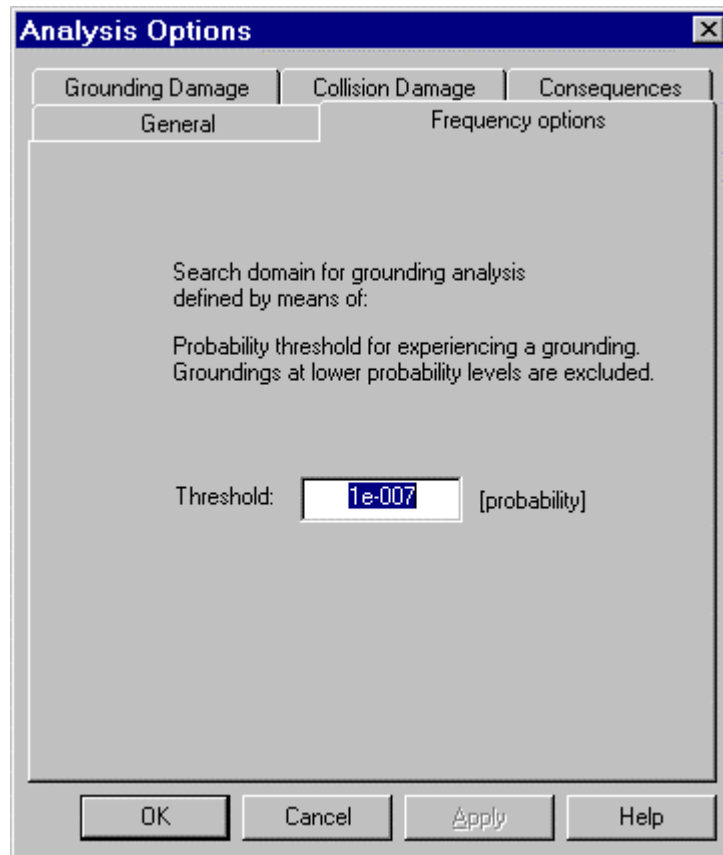


Figure 49 Defining the frequency analysis options.

Figure 49 shows the analysis options for the frequency analysis. In a grounding frequency analysis the program will search for all potential grounds where the vessel may ground. To limit the extent of this search a probability threshold value is included to specify the search domain. Although the default probability threshold level is set to 10^{-7} , the actual calculated grounding probabilities may well be lower than the threshold value. The reason for this is that geometric domain is identified prior to any the modification with the causation factor.

When the analysis options have been defined an analysis is started by selecting **Calculate** ® **Go** from the main menu.

8. VIEWING THE RESULTS

When the calculation is completed the result of the analysis may be inspected by selecting the Results tab from the Explorer Window as seen in Figure 50.

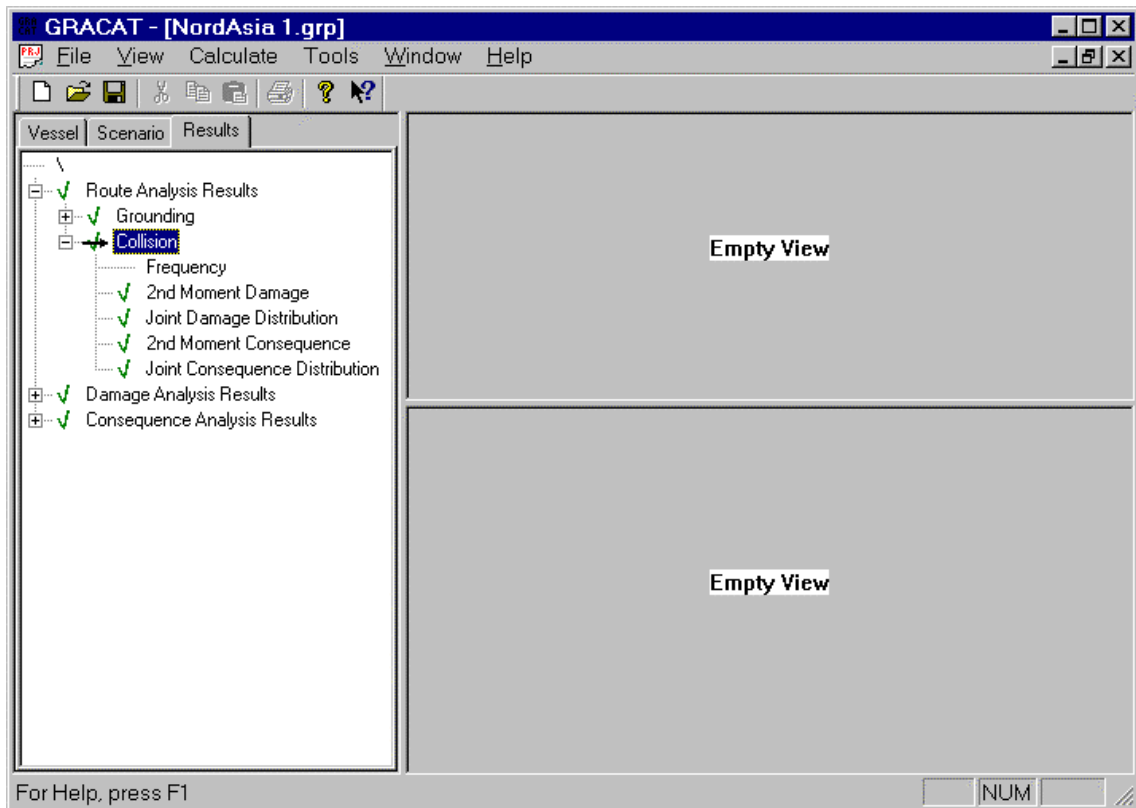


Figure 50 The result window.

Results are grouped according to the type of analysis that has been completed. The main groups are Route Analysis Results, Damage Analysis Results, and finally Consequence Analysis Results. The set of results that will be available is dependent on the start level and level defined under **Calculate® Options**. The results from a route analysis will be probabilistic only, whereas an analysis started at either the damage or the consequence level may be specified to be deterministic or probabilistic, dependent on the defined input.

As mentioned, the available results from the route analysis are depended on the selected end level of the analysis. Whatever type of route analysis performed the frequency results will always be available. If the structural layout has been defined and the end level was selected as Damage Results, then also 2^d moment and joint distribution results will be available. Finally, if further reference is made to an I-ship compartment file and end level is defined as Consequence Results, then also the statistical description of the consequences will be available.

An analysis initiated at the damage analysis level will always produce damage results. If reference is made to an I-ship compartment file and end level is defined as Consequence Results, then also the consequence results will be available. Dependent on the user selection, the results may be either probabilistic or deterministic. Similarly, a consequence analysis produces consequence results, which may be either deterministic or probabilistic.

Since results produced at a given end level are similar and independent on the start level of the analysis, the description of the results will not be repeated for the different types of analysis. The description of results will be given related to the result type as follows:

- Section 8.1 Route Analysis Results presents the frequency results for grounding and collision,
- Section 1.1 Damage Analysis Results presents the deterministic and the probabilistic damage results.
- Finally, Section 8.3 Consequence Analysis Results presents the deterministic and probabilistic consequence results.

8.1 Route analysis results

In this section the frequency results of a grounding and collision analysis are presented.

8.1.1 Grounding frequency

Figure 51 shows the grounding frequency results. Results are presented for annual number of grounding and the corresponding annual probability of grounding.

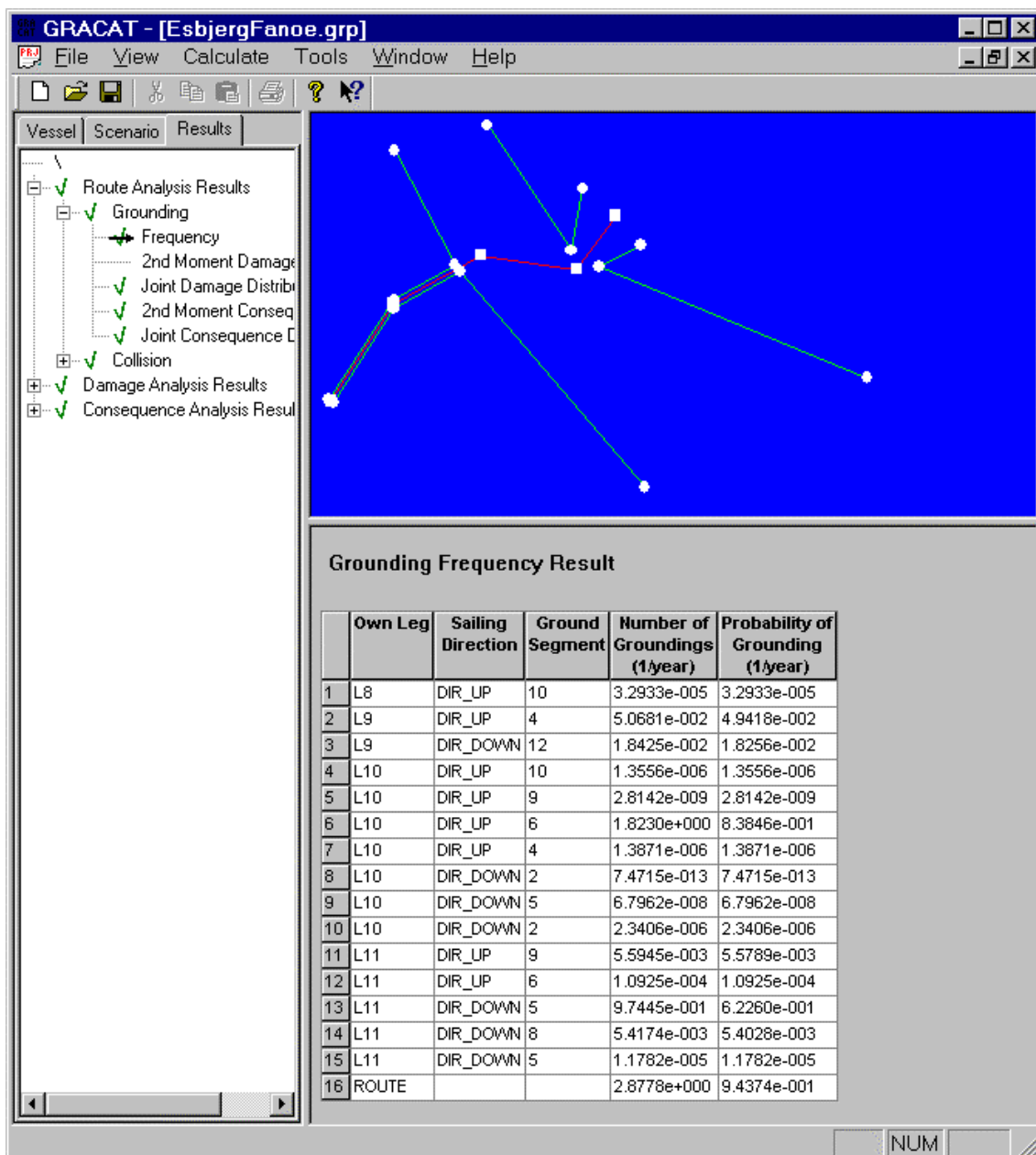


Figure 51 Grounding frequency results.

In the end of the list in Figure 51 the final result of the grounding probabilities for the analysed route is given. In general grounding probability results are presented for each identified item along the route. The grounding item is identified in terms of the leg number on the route, the sailing direction, and the ground segment at which the grounding occurs.

Mouse clicking one of the column headers result in a sorting of the rows in decreasing or increasing order.

8.1.2 Collision frequency

Figure 52 shows the collision frequency results. Results are presented for annual probability of collision, annual number of struck collision, and the corresponding annual probability of struck collision.

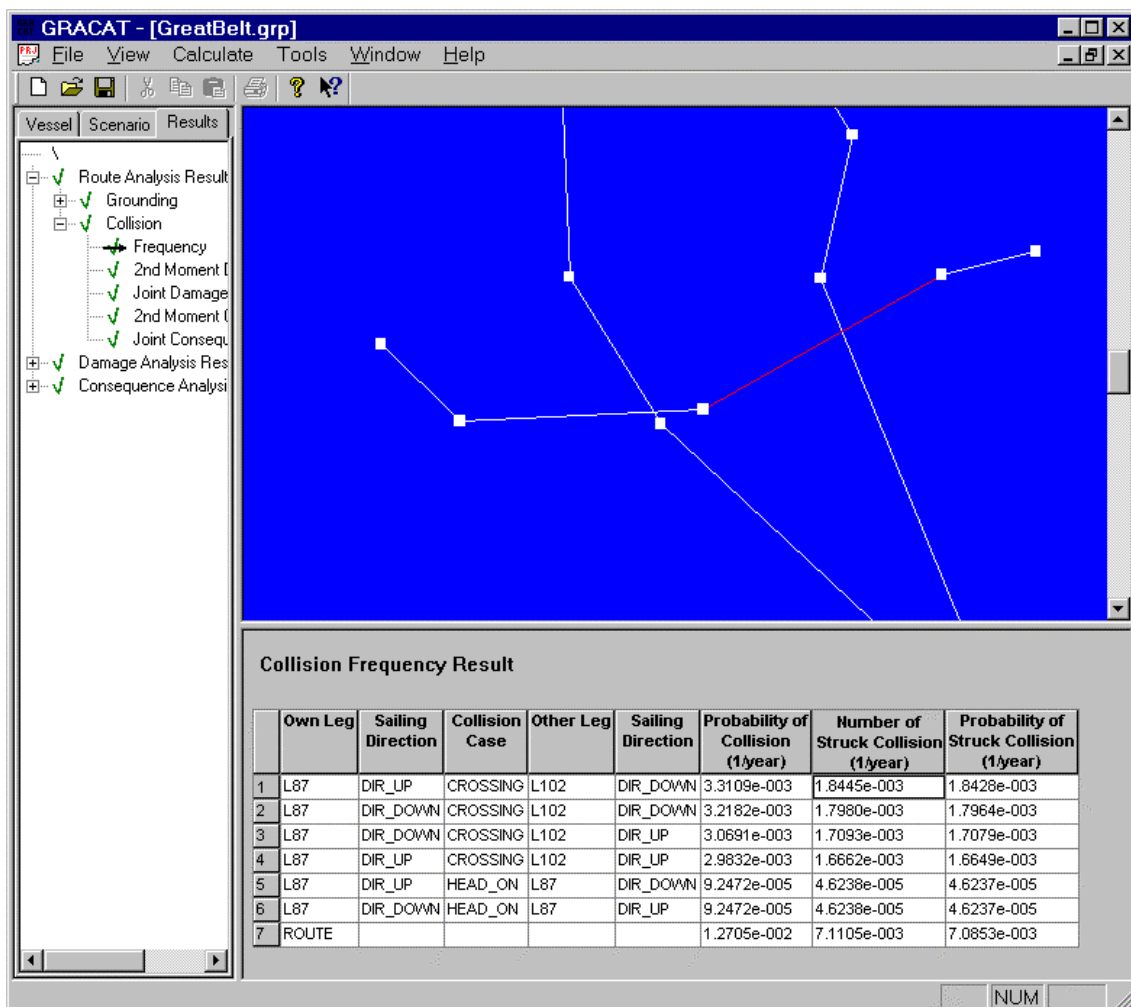


Figure 52 Collision frequency results.

Results in Figure 52 are presented for each identified collision item, that is, the leg and direction own vessel is sailing at, the type of collision, and finally the leg and direction that the striking vessel is sailing.

Rows may be sorted in decreasing or increasing order by mouse clicking the header of a selected column.

8.2 Damage analysis results

Damage results may be presented for hard and soft grounding and for ship-ship collision. Dependent on the selected type of analysis, the results may be deterministic or probabilistic. A deterministic result is typically the development of a parameter - for example the ship velocity or the absorbed energy as a function of time. These results are viewed as two-dimensional xy-graphs. The probabilistic results are probability distributions for single parameters (ex. the damage length) and these may be view as 2- or 3-dimensional plots.

The basic idea of the viewer for the deterministic results is that in a time series where there are several calculated quantities at each time step, every quantity can be plotted against every other quantity.

8.2.1 Hard Grounding

8.2.1.1 Deterministic

Figure 53 shows an example of a deterministic grounding damage. The ship is 234m long, the double bottom height is 2.3m and it ran aground on a rock that was approximately 4 m above baseline (amidships). The trim was 0. The figure shows the rock tip penetration into inner and outer bottom respectively. It is seen that the damage starts at the fore end of the ship (x=234m), that the damage has maximum penetration around midship and that the damage ends at approximately x=75m.

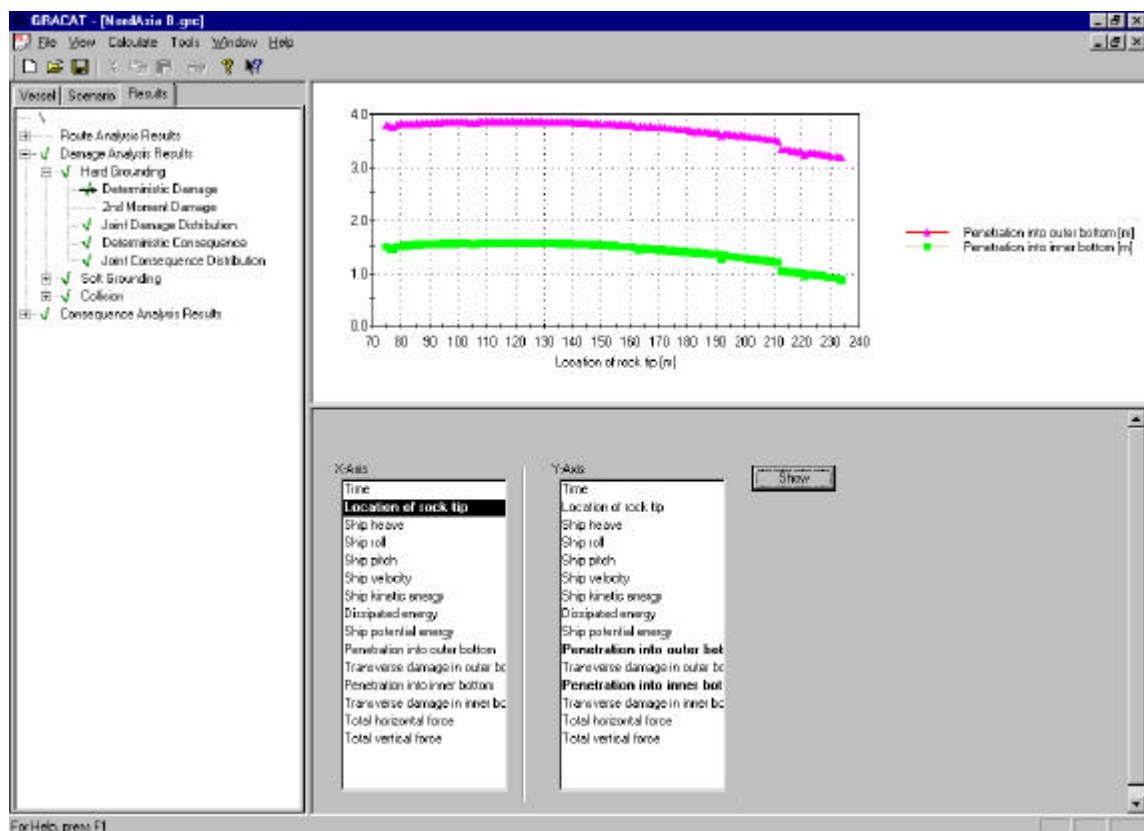


Figure 53 Deterministic grounding damage.

The parameters that can be viewed after a deterministic hard ground analysis are:

1. Time [s]: the time from the initial impact.

2. Location of rock tip [m]. The position of the rock tip in the x-coordinate system of the ship (origin at AP). The first and last point on the plot of Time vs. Location at rock tip shows the total damage length.
3. Ship heave [m]. This is the change in ship heave from equilibrium measured amidships.
4. Ship roll [deg]. The change in roll angle from equilibrium. The ship will only roll, if a rock eccentricity has been defined for the scenario.
5. Ship pitch [deg]. The change in pitch angle from equilibrium.
6. Ship velocity [m/s]. The forward ship speed. This should be seen to decrease to zero, otherwise the ship rides completely over the rock.
7. Ship kinetic energy [J]. The remaining ship kinetic energy.
8. Dissipated energy [J]. The total energy dissipated by structural deformations.
9. Ship potential energy [J]. As the ship is lifted and rotated,
10. Penetration into outer bottom [m]. The penetration of the rock tip into the outer bottom. A plot of Item 10 (this) vs. Item 2 shows a horizontal view of the damage envelope in the bottom.
11. Transverse damage in outer bottom [m]. The width of the damage at the position of the rock tip. A plot of Item 11 (this) vs. Item 2 shows a vertical view of the damage envelope in the shell plating.
12. Penetration into inner bottom [m]. The penetration of the rock tip into the outer bottom.
13. Transverse damage in inner bottom [m].
14. Total horizontal force [N]. This is the total horizontal reaction force acting from the rock on the ship.
15. Total vertical force [N]. This is the total vertical reaction force acting from the rock on the ship.

8.2.1.2 Probabilistic

If a route analysis has been continued through a damage analysis, then joint probability distributions for the resulting damage will be available. Figure 54 and presents respectively, joint and marginal distribution functions of the calculated damage.

It is possible to modify the view of figure by right clicking the mouse when located in the Data View Window. Selecting Chart Properties from the lookup will show the window in . An extensive on-line, printable, help facility is associated with the Chart Control Properties, and we will not describe this further here.

Holding down the shift key and the left mouse key while dragging the mouse performs zooming.

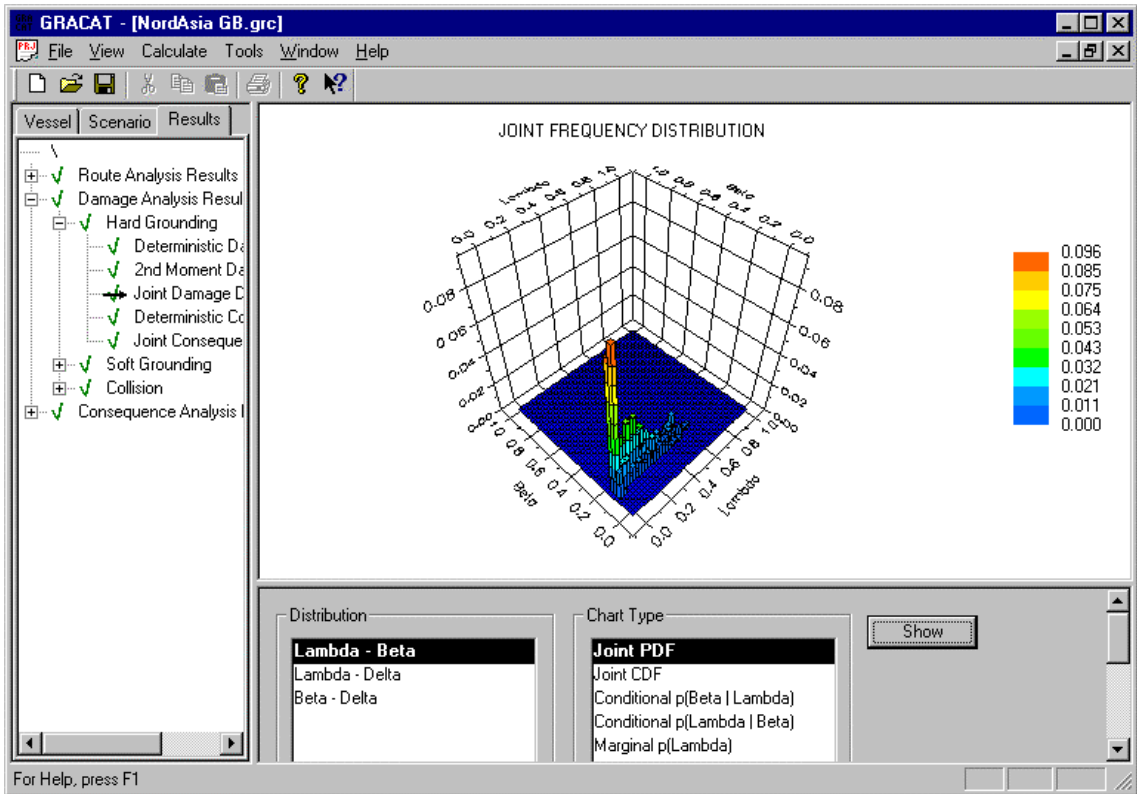


Figure 54 Joint distribution of damage.

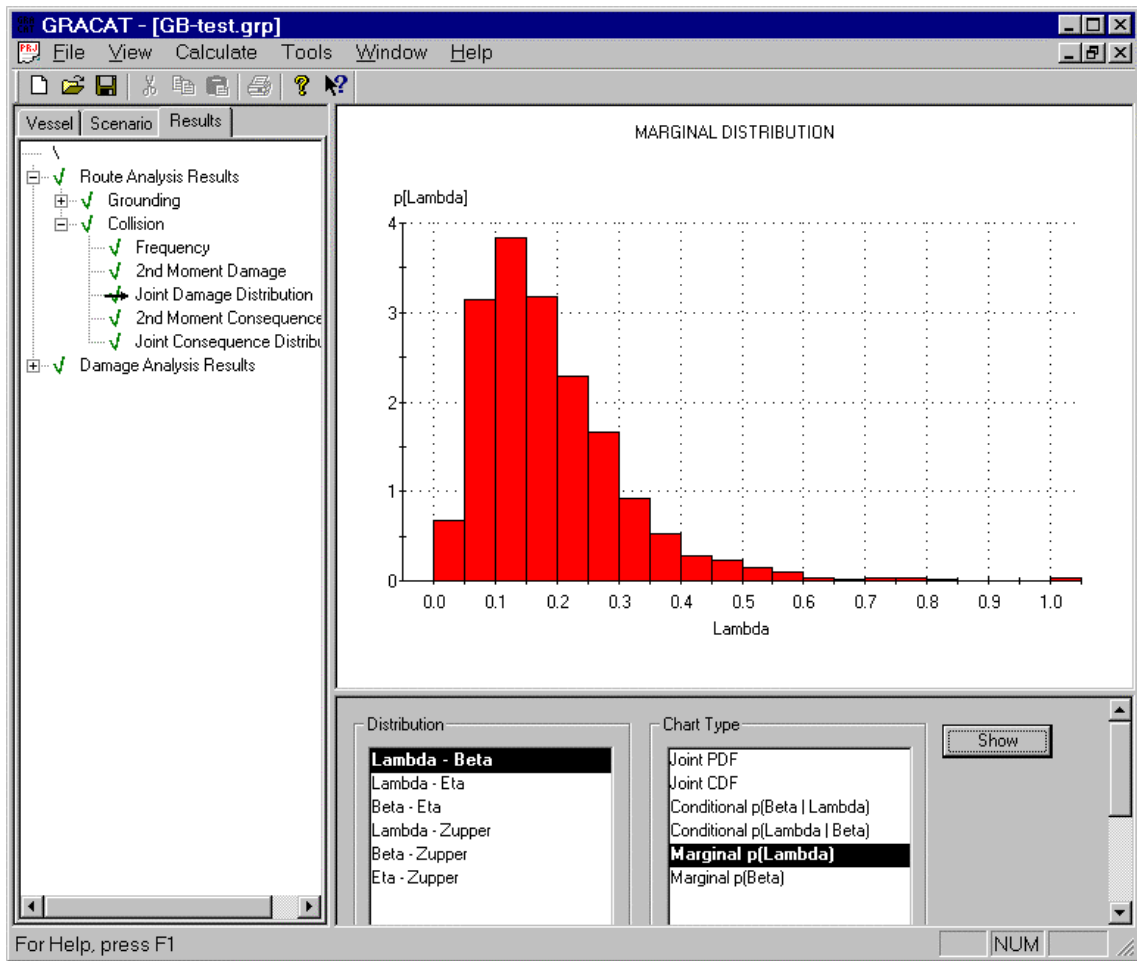


Figure 55 Marginal distribution for normalized damage length.

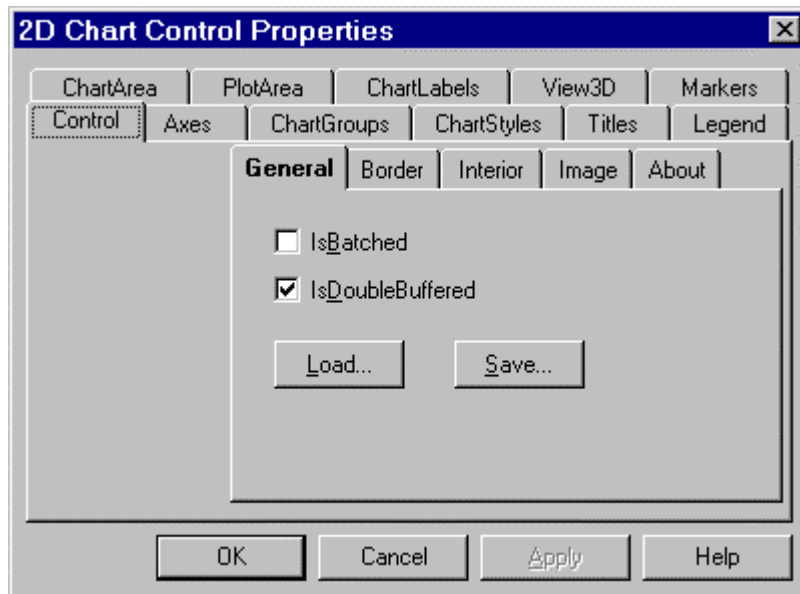


Figure 56 Chart control Properties.

8.2.2 Soft Grounding

8.2.2.1 Deterministic

Figure 57 shows an example of a deterministic soft grounding analysis. The plot shows the original underwater slope and the bottom of the furrow generated by the bow plotted against an x-axis for the ground.

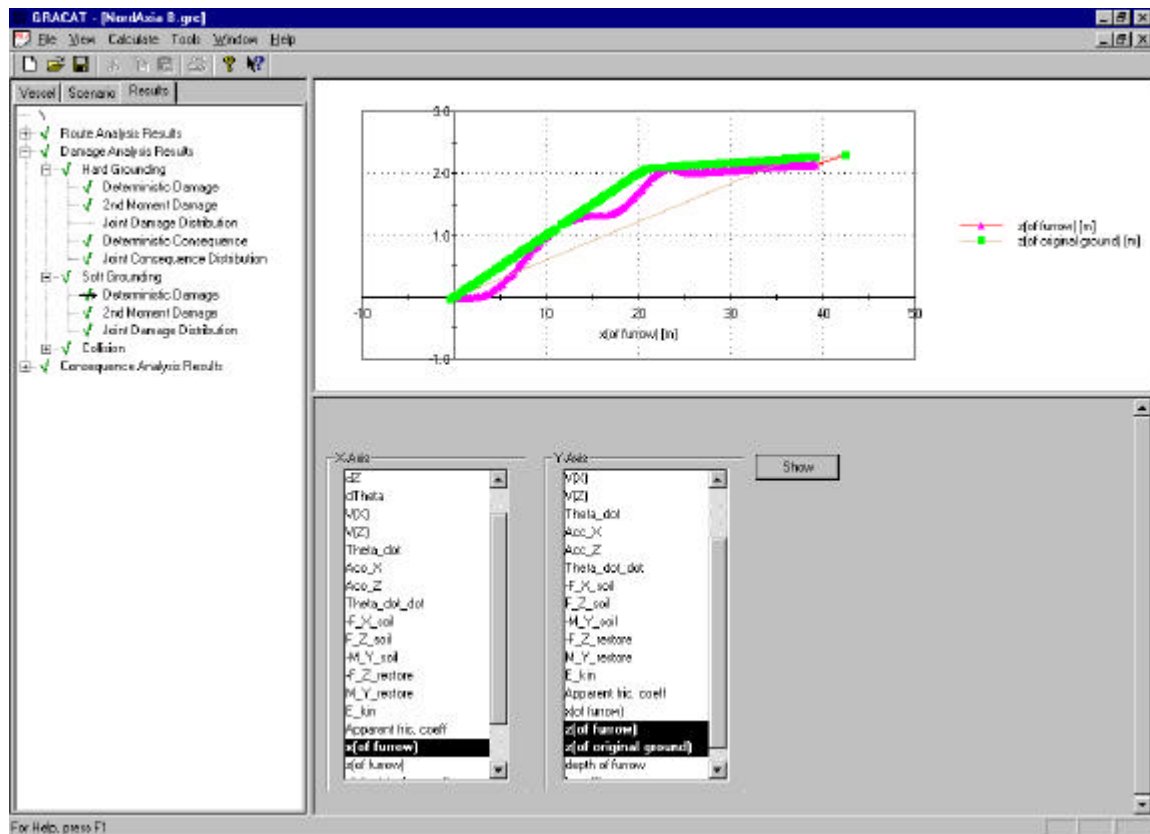


Figure 57 Deterministic soft ground results: the original ground and the ground deformed by the penetrating ship bow.

The parameters that can be viewed after a soft grounding analysis are:

1. Time [s]. The independent parameter: time after initial impact.
2. dX [m]. Change in the ship horizontal position after impact.
3. dZ [m]. Change in the ship heave after impact.
4. dTheta [rad]. Change in the ship pitch angle after impact.
5. V(x) [m/s]. Forward ship surge velocity.
6. V(Z) [m/s]. Upward ship heave velocity.
7. Theta_dot [rad/s]. Rate of pitch rotation.
8. Acc_X [m/s²]. Ship acceleration in surge direction.
9. Acc_Z [m/s²]. Ship acceleration in heave direction.
10. Theta_dot_dot [rad/s/s]. Angular acceleration of pitch angle.
11. -F_X_soil [N]. Horizontal soil reaction force.
12. F_Z_soil [N]. Vertical soil reaction force.
13. -M_Y_soil [Nm]. Moment on ship generated by soil reaction.
14. -F_Z_restore [N]. Restoring force generated by the ship weight and the buoyancy.

15. $M_Y_restore$ [Nm]. Restoring moment on ship generated by the ship weight and the buoyancy.
16. E_kin [J]. Remaining kinetic energy of the ship.
17. Apparent fric. Coeff. [1]. Effective coefficient of friction, defined as the ratio between the soil reaction force in the direction of motion of the bow and the soil reaction force in the perpendicular direction. Since the bow plows into the soil, this effective coefficient of friction may be much higher than for steel-sand sliding alone.
18. $x(of\ furrow)$ [m]. A x-coordinate of the ground.
19. $z(of\ furrow)$ [m]. A z-coordinate of the bottom of the furrow generated by the ship bow. Should be plotted against Item 18 to show the furrow profile.
20. $z(of\ original\ ground)$. A z-coordinate of the original, undisturbed slope. Should be plotted together with Item 19 against Item 18 to show the furrow profile.
21. depth of furrow [m]. Vertical distance from the original slope to the bottom of the furrow.
22. Bowlift [m]. Total lift of bow due to the grounding.

8.2.2.2 Probabilistic

The calculated probabilistic values are:

1. Sliding distance [m]. This is the stopping length.
2. Non-dim Moment at Midship (IACCS). This is the hull girder strength according to IACCS (waveload) divided by the grounding induced hull girder bending moment around amidships.
3. Non-dim Shearforce at Load Point (IACCS). This is the hull girder strength according to IACCS (waveload) divided by the grounding induced shear force at the point of contact with the ground.

For details refer to Ref. [7].

8.2.3 Collision

8.2.3.1 Deterministic

Figure 58 shows an example of a collision damage analysis. The plot shows the energy absorbed by the structural deformations in the shipside, as a function of the bow penetration into the side. The energy dissipation has been calculated by two different methods.

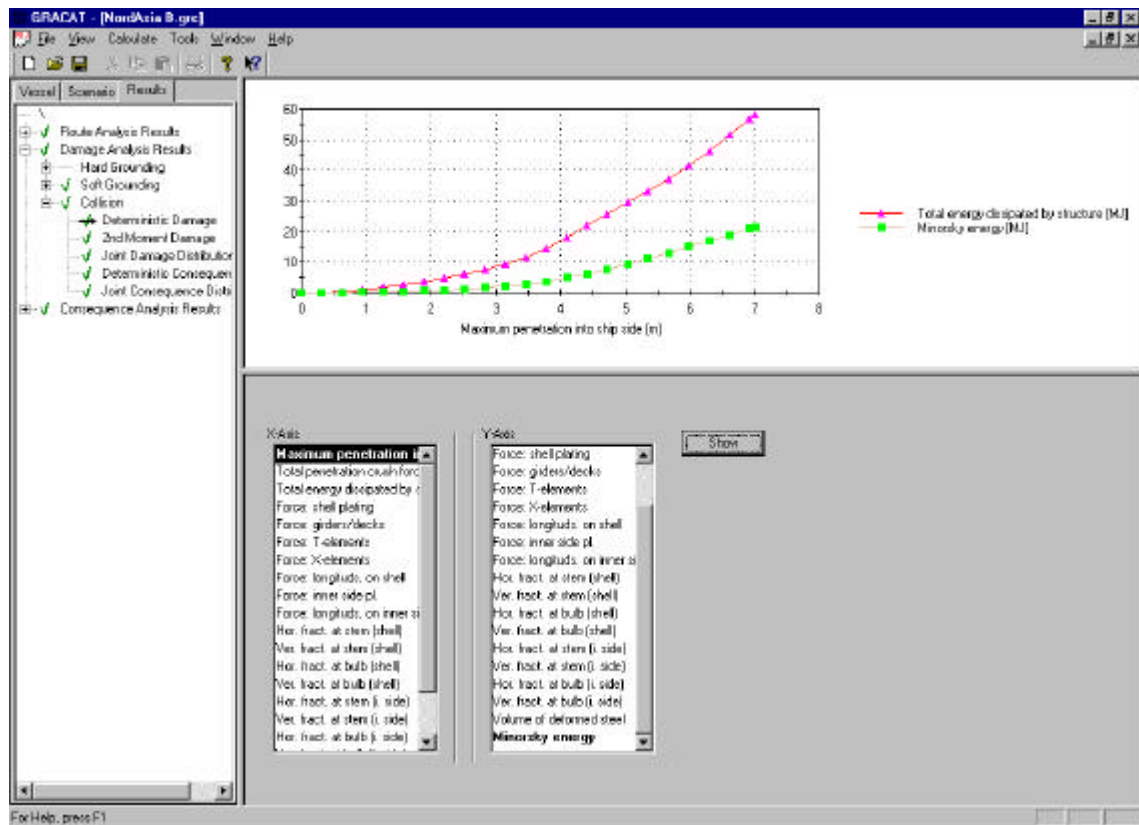


Figure 58 Deterministic collision damage results: the energy absorption is plotted as a function of the bow penetration in the ship side. Both the ISESO collision damage model and the Minorsky method have been used to predict the energy dissipation.

The parameters that can be plotted in a deterministic collision analysis are listed below. Refer to Ref. [4] for details:

1. Maximum penetration into ship side [m]. The penetration at the foremost point on the penetrating bow.
2. Total penetration crush force [kN].
3. Total energy dissipated by structure [MJ].
4. Force: shell plating [kN]. The contribution from the shell plating to the crush force.
5. Force: girders/decks [kN].
6. Force T-elements [kN].
7. Force X-elements [kN].
8. Force: longitudinals on shell [kN].
9. Force: Inner side plating [kN].
10. Force: Longitudinals on inner side plating [kN].
11. Horizontal Fracture at Stem (shell) [1/0]. Is 1 if there is a horizontal crack in the shell at the upper part of the bow
12. Vertical Fracture at Stem (shell) [1/0]. Is 1 if there is a vertical crack in the shell at the upper part of the bow
13. Horizontal Fracture at Bulb (shell) [1/0]. Is 1 if there is a horizontal crack in the shell at the bulbous bow
14. Vertical Fracture at Bulb (shell) [1/0]. Is 1 if there is a vertical crack in the shell at the bulbous bow
15. Horizontal Fracture at Stem (i. Side) [1/0]. Is 1 if there is a horizontal crack in the inner side at the upper part of the bow

16. Vertical Fracture at Stem (i. Side) [1/0]. Is 1 if there is a vertical crack in the inner side at the upper part of the bow
17. Horizontal Fracture at Bulb (i. Side) [1/0]. Is 1 if there is a horizontal crack in the inner side at the bulbous bow
18. Vertical Fracture at Bulb (i. Side) [1/0]. Is 1 if there is a vertical crack in the inner side at the bulbous bow
19. Volume of deformed steel [m^3]. The volume of side structure within the bow imprint according to Minorsky method (not shell plating or inner side plating).
20. Minorsky energy [MJ]. Energy dissipated according to the Minorsky method.

8.2.3.2 Probabilistic

The probabilistic result of the collision analysis is given in terms of the statistical description of the normalised damage object. The normalised parameters describing the damage object are illustrated in Figure 62. The normalisation values are given in the **Analysis Options**.

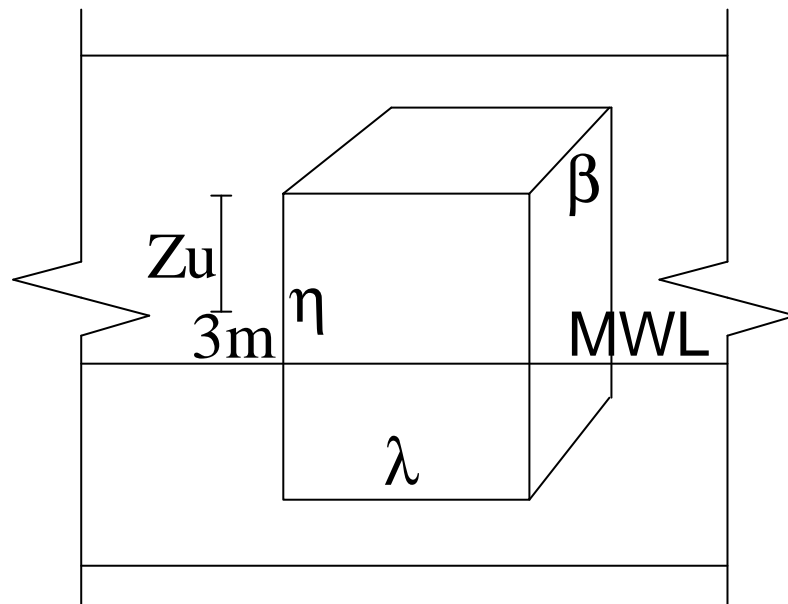


Figure 62 Parameters in the normalised damage object.

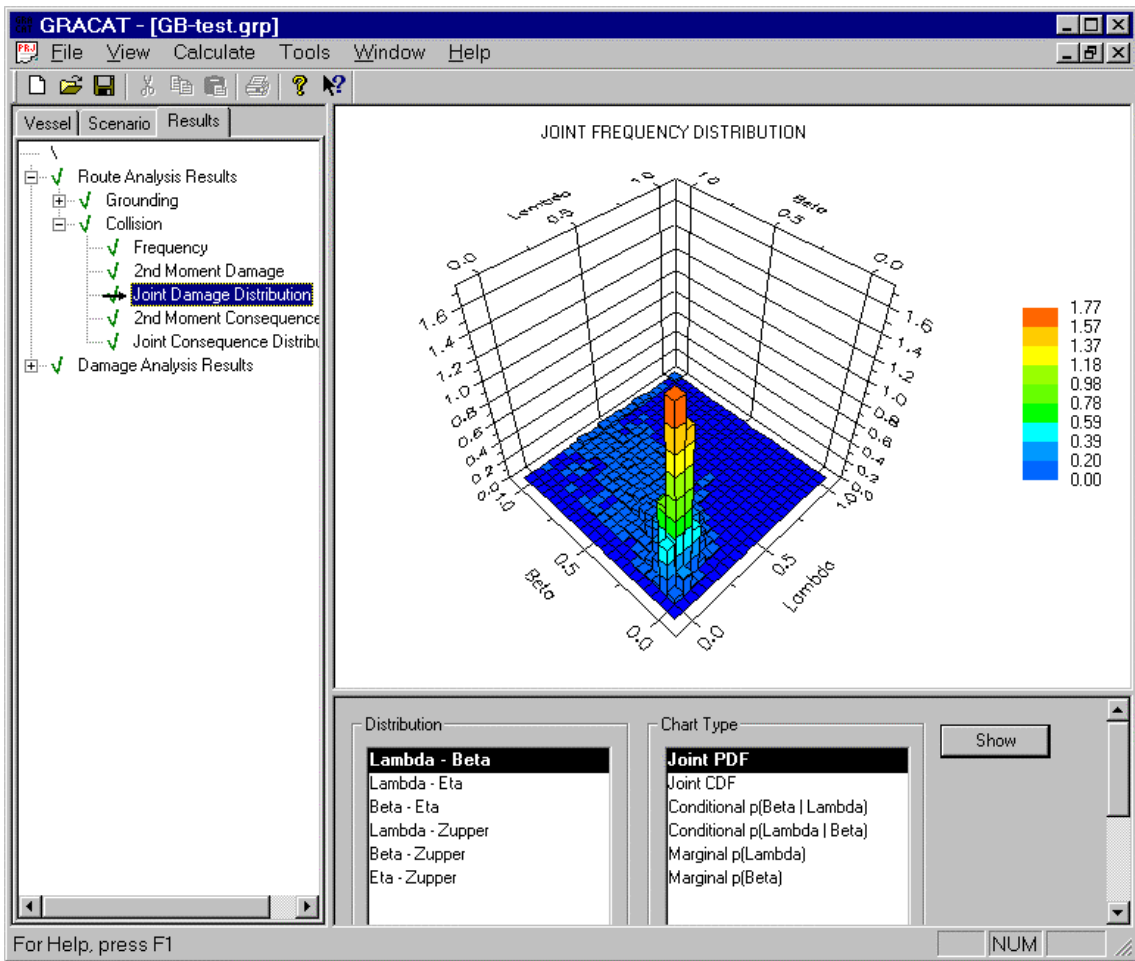


Figure 63 Probabilistic collision damage.

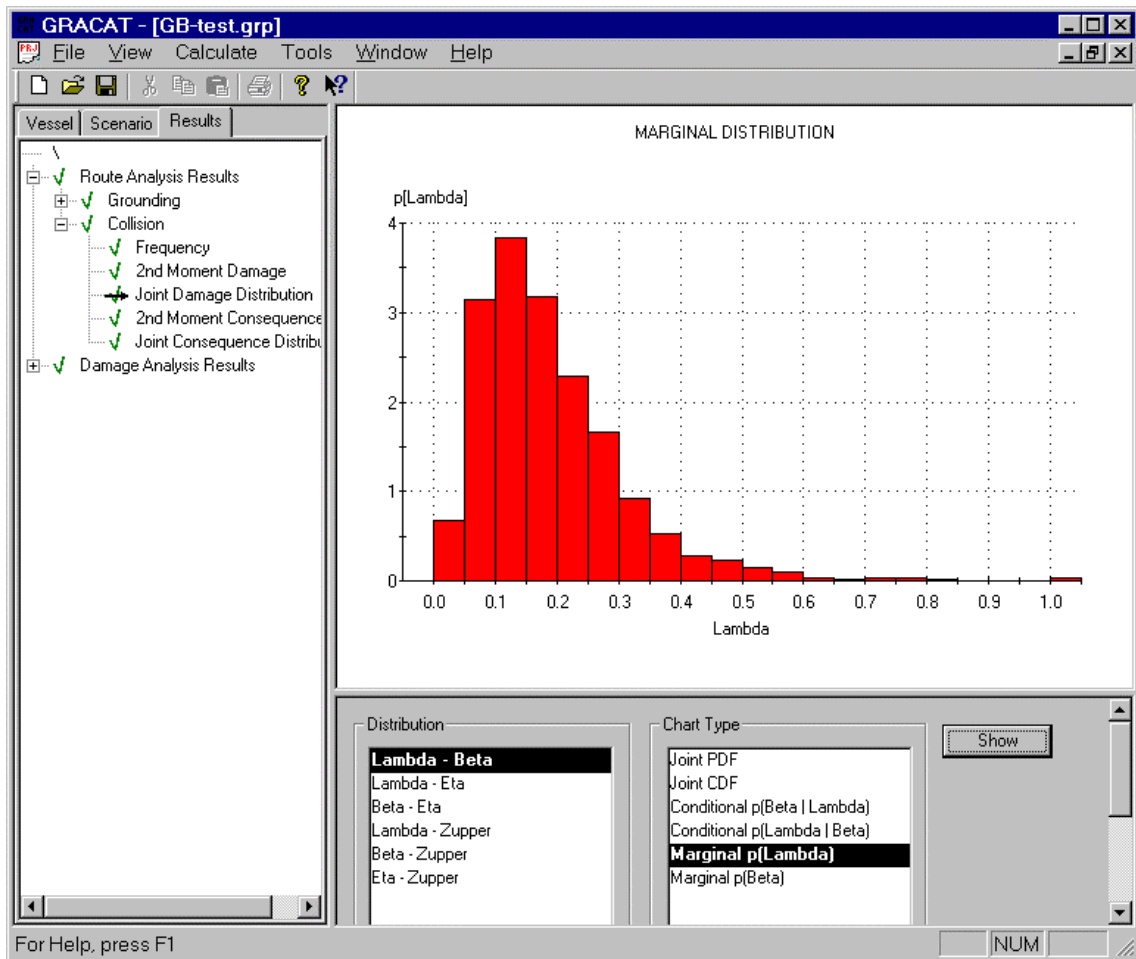


Figure 64 Marginal distribution for damage length.

8.3 Consequence analysis results

8.3.1 Deterministic

Deterministic results are presented as two-dimensional X-Y plots. The following results are available from the consequence analysis, Figure 66:

- Time from damage
- Draught amidship
- Angle of heel
- Lost buoyancy
- Distance from lower part of damage to still water level
- Bending moment at 0.25L
- Bending moment at 0.50L
- Bending moment at 0.75L
- Shear force at 0.25L
- Shear force at 0.50L
- Shear force at 0.75L
- GM corrected for free surfaces

Any consequence result may be plotted as function of the other.

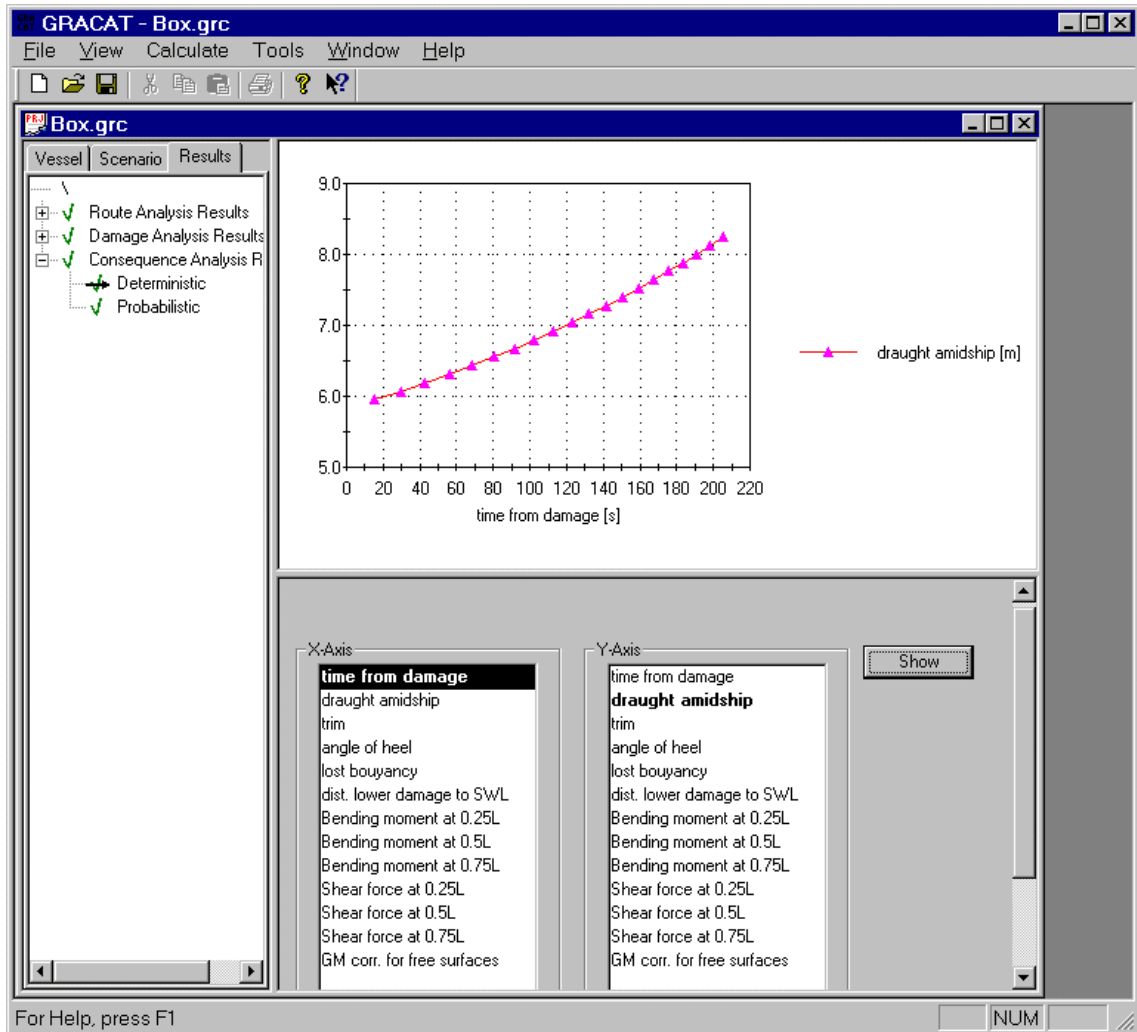


Figure 66 Results from deterministic consequence analysis.

8.3.2 Probabilistic

Figure 67 present the probabilistic consequence results. The figure shows the distribution for time to capsizes. In Figure 68 the marginal distribution for capsizes is shown. It is seen that the probability of capsizes given a damage is approximately 0.2.

Additional to the deterministic results, also oil spill is available among the joint probability distributions.

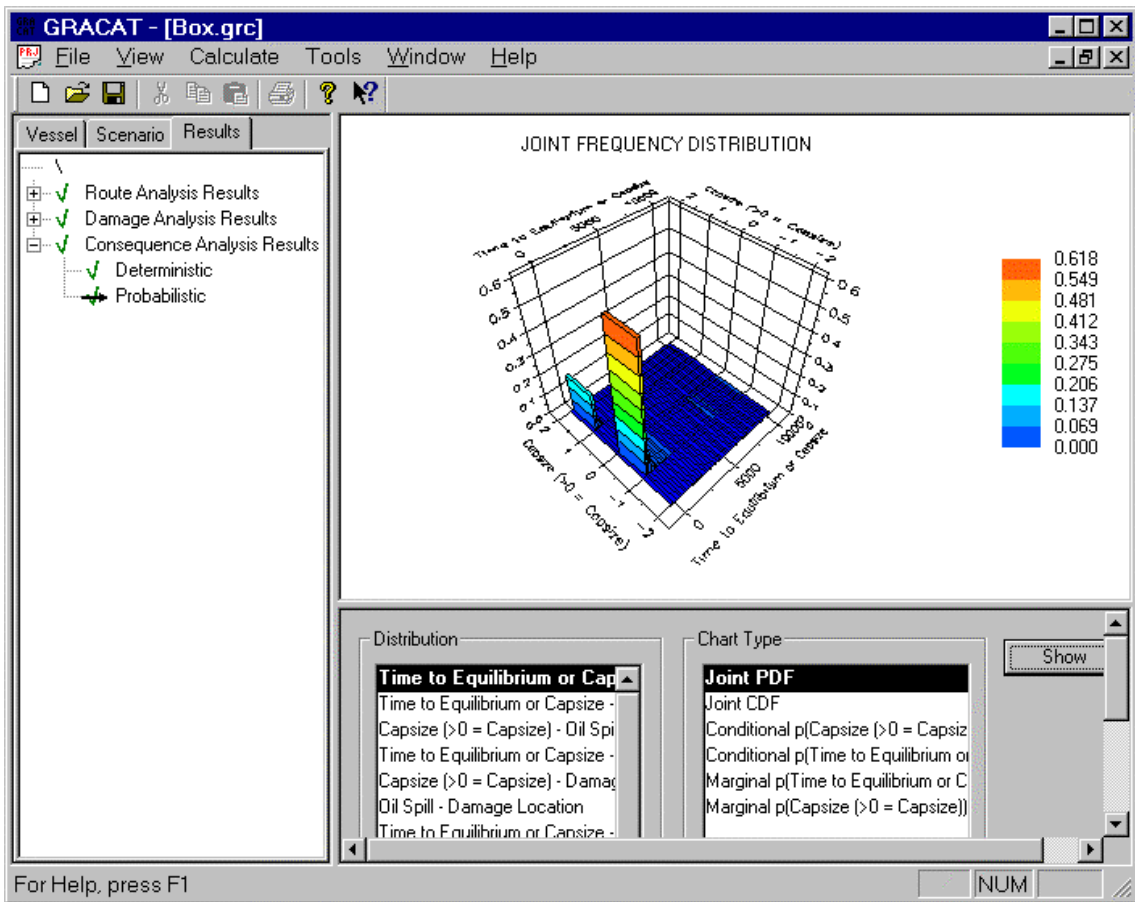


Figure 67 Probabilistic consequence results.

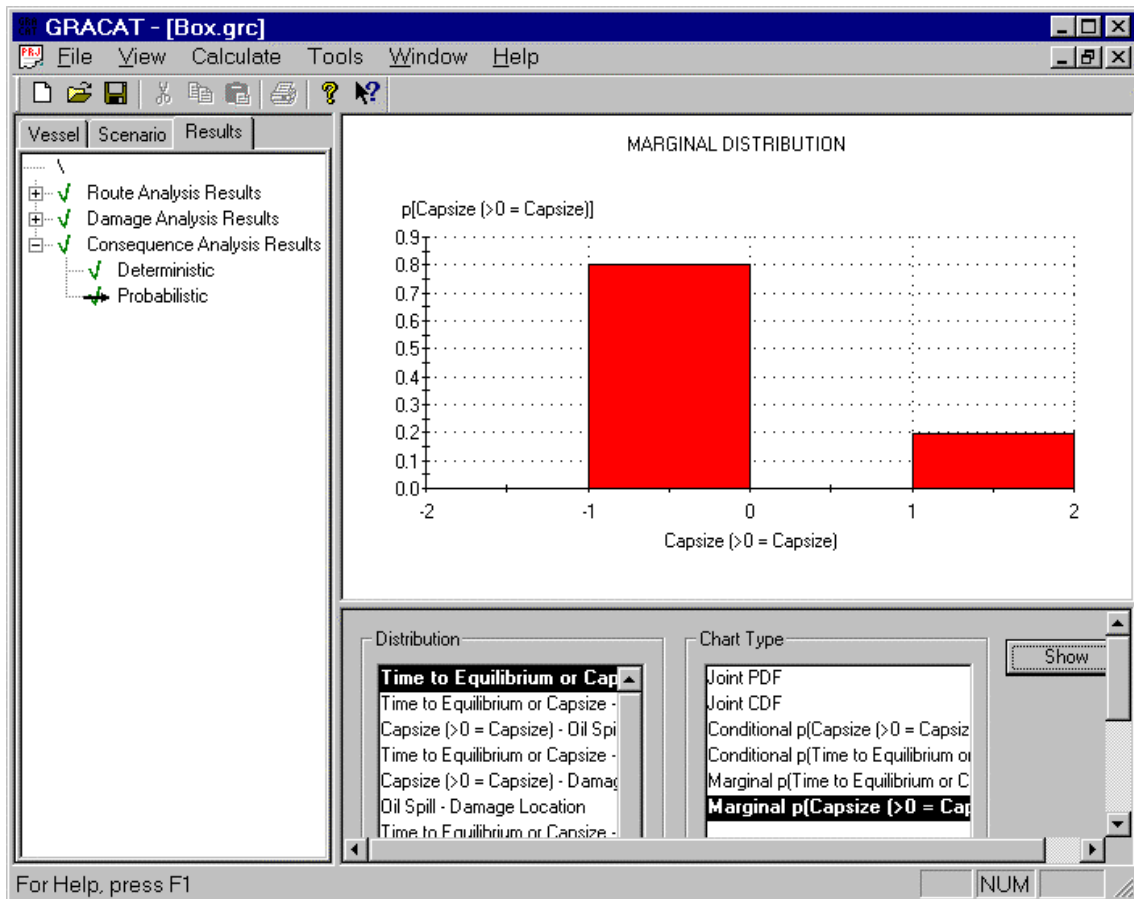


Figure 68 Marginal distribution showing time to capsizes.

9. DEFINING A MITIGATION ANALYSIS

The purpose of the mitigation module is to allow for a comparison of the resulting consequences in a risk-based framework. Several projects may be loaded and their calculated consequences included in the comparison. The comparison is performed in terms of calculated risk profiles for the selected projects (loaded via the main menu) where the loss associated to the different consequences are defined through utility functions.

In the present version of the program only the consequence results “Time to capsizes” and “Oil spill” may be mitigated.

9.1 Loading the projects

To load the projects that shall be compared first select **Projects® Add** from the main menu, which opens a standard File-Open window. The projects are added to the list that will appear under the item **Risk Profiles**.

9.2 Defining the Utility Functions

Utility functions, as used in the present analysis, define the loss associated with a consequence. Figure 69 defines a utility function for Time to capsizes. In this case the utility defines the loss of human life as a function of time to capsizes. It is seen that there are 800 persons on board the vessel that capsizes.

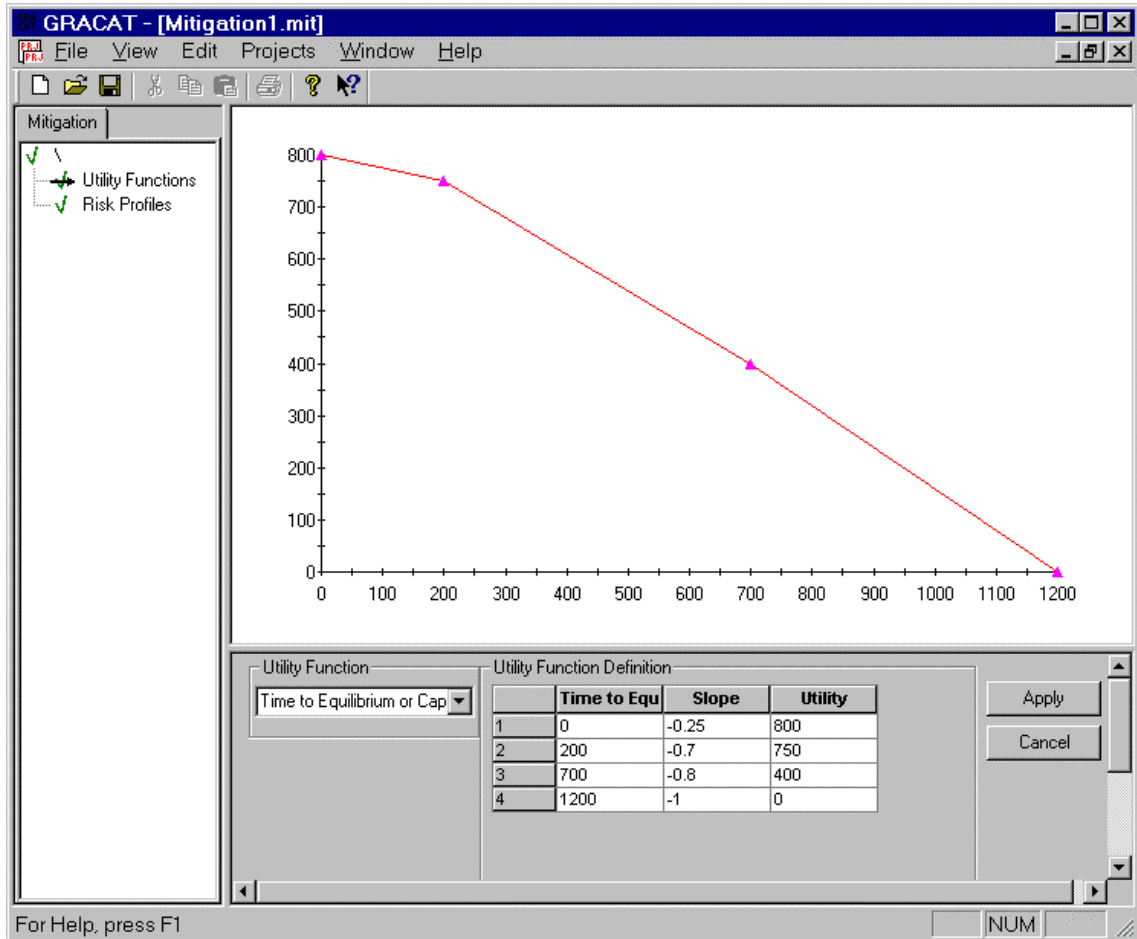


Figure 69 Utility function for time to capsizes.

Figure 70 shows a utility function for oil spill. Contrary to the utility function for time to capsizes, the loss increase with increasing amount of spilled oil.

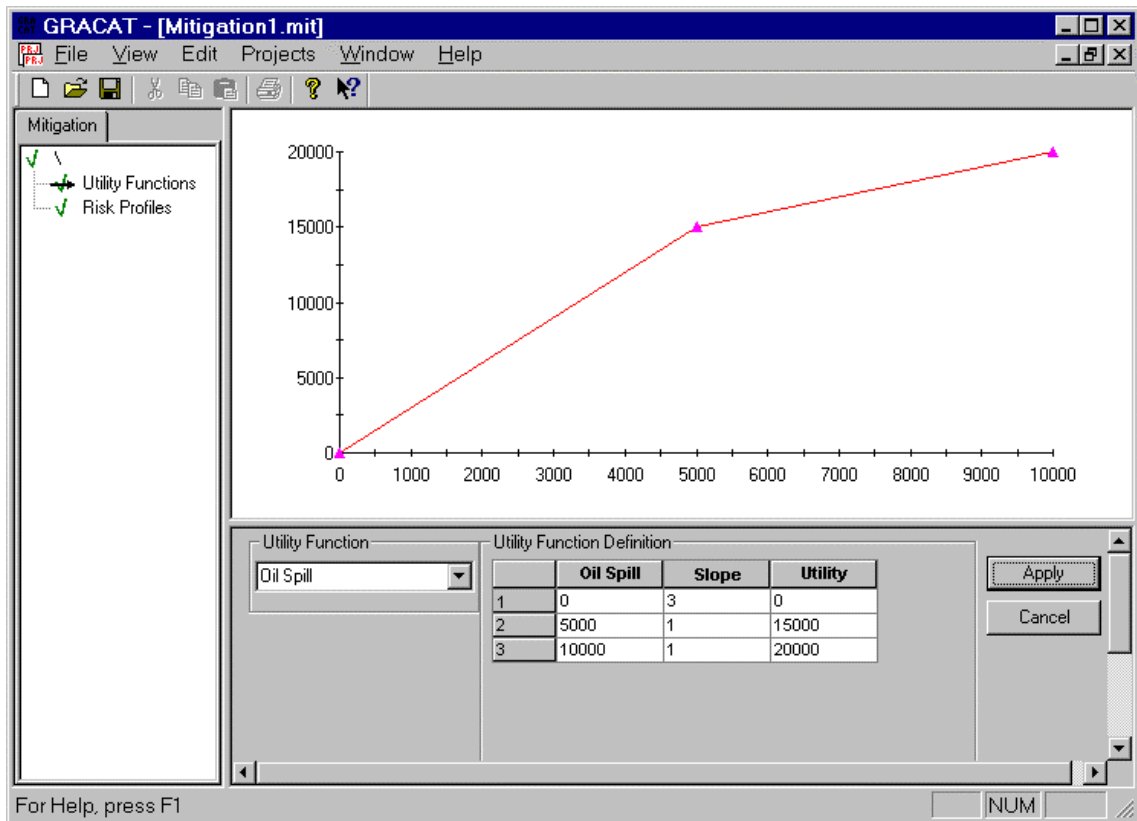


Figure 70 Utility function for oil spill.

9.3 Calculating the Risk Profiles

Figure 70 show the calculated risk profile for the “loss of human life” as calculated on the basis of consequence results “time to capsizes” as defined by the project “Box.grc”. It should be noted that the calculated risk profile is not corrected for probability experiencing the damage or the probability of capsizes.

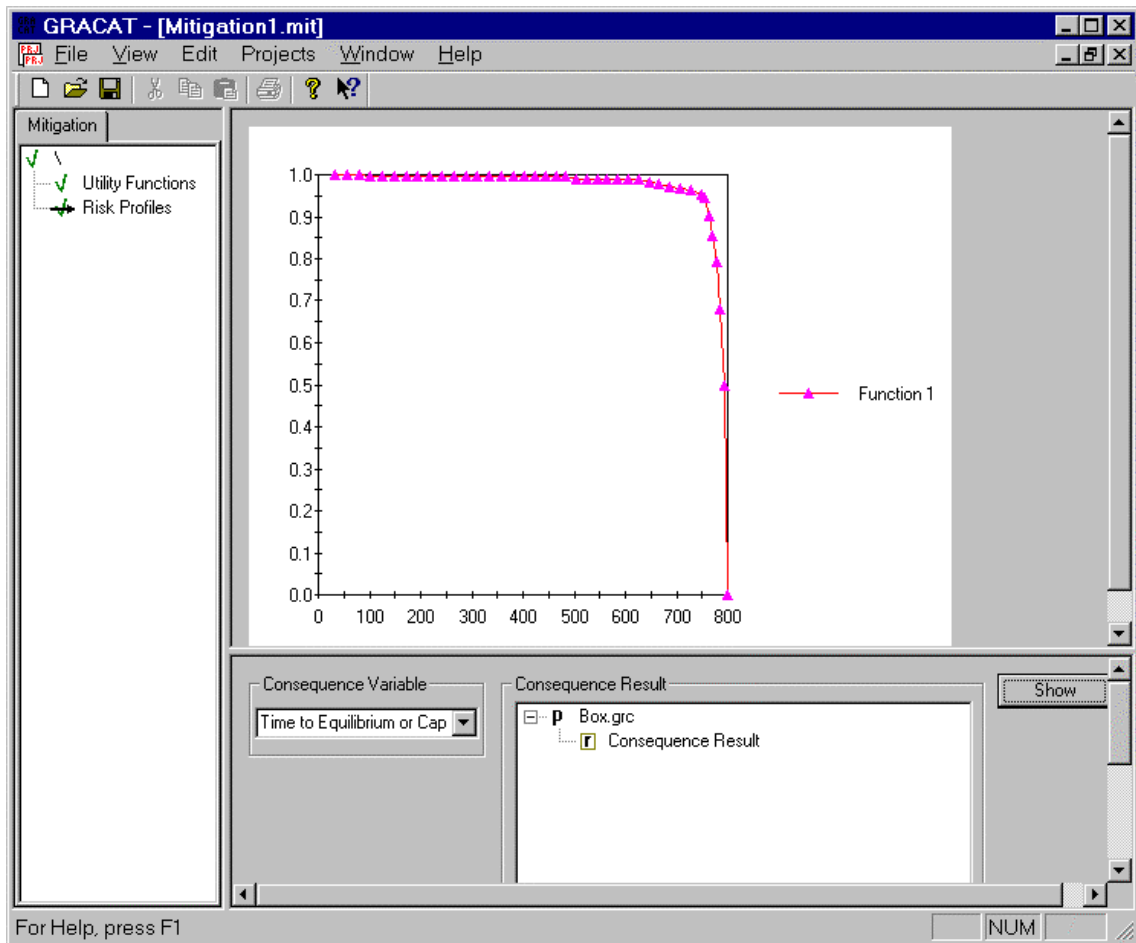


Figure 71 Risk profile for "loss of human life".

10. WORKED EXAMPLES

In this chapter we present a worked example. The example addresses a collision probability analysis of the RoRo ferries that former were operating in the Great Belt.

10.1 Collision analysis in the Great Belt

As an example we consider the former Danish Great Belt ferry route between Nyborg on Funen and Korsør on Zealand before the construction of the Great Belt Link. This route is modeled as consisting of four straight waterway segments, see Figure 72. The total annual traffic between the two destinations Korsør and Nyborg is around 57000 voyages. The ship traffic composition is such that the mean ship length overall is 116.0 m and the mean breadth $B = 18.7$ m.

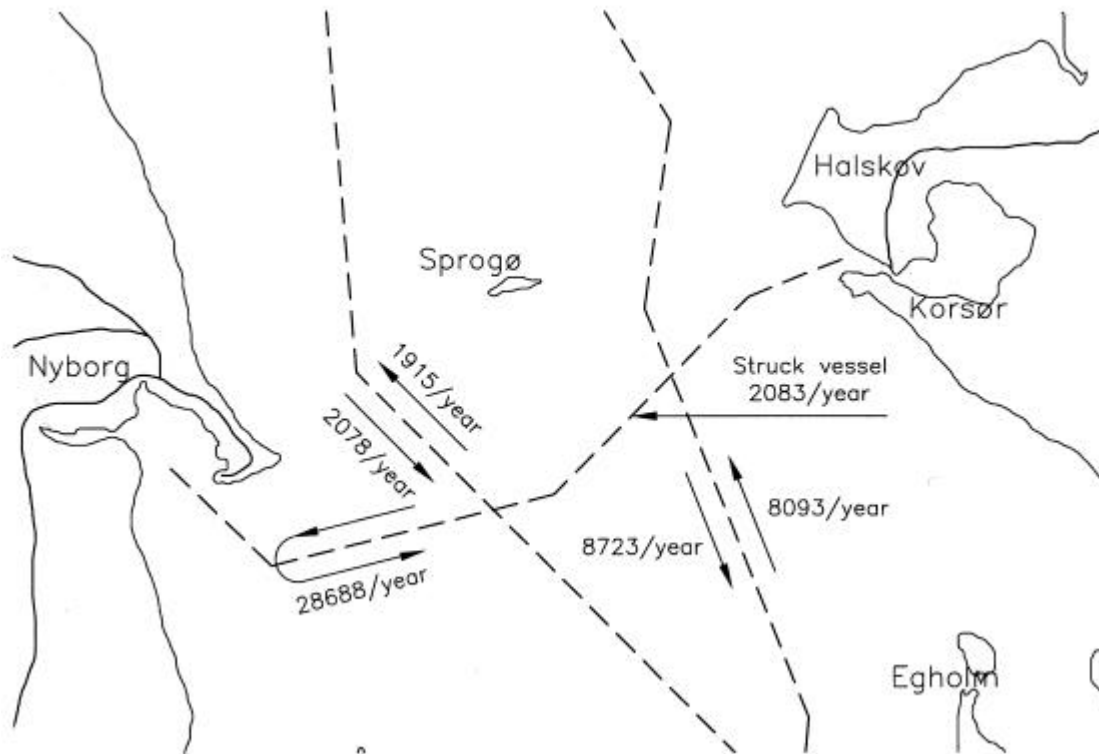


Figure 72 The total traffic distribution in the Great Belt.

We consider one specific Ro-Ro vessel with the following principal dimensions:

Length	158.03	m
Breadth	23.4	m
Depth	15.00	m
Speed	14.60	knots
Draught	7.47	m
Displacement	22722	m ³
Height of bulb	3.6	m
Height of deck	17.2	m
Traffic intensity	2083	trips/year

The east-west Ro-Ro route is crossed by two waterways. The eastern north-south route between the island Sprogø and Nyborg has about 4000 passages a year and due to draft limitation this route is only used by smaller ships. The mean overall length of these vessels is 61.0 m and the mean breadth is 11.1 m. Finally, the Ro-Ro route is crossed by the north-south T route, which is the deep-water route to the Baltic. This route passes between Sprogø and Korsør and has about 17000 passages annually with a ship size distribution such that the average overall length is 118.2 m and the average breadth is 18.2 m.

Further relevant coefficients for specification of the required main particulars are:

Stem angle	34	deg
Bow angle	54	deg
Yaw coefficient	0.5	
Sway coefficient	0.4	

Surge coefficient	0.05	
Radius of inertia	0.25	m/m
LCG (from AP)	79.015	m
Waterplane coef.	0.6	
LCF (from AP)	79.015	m
GMT	1	m
GML	150.03	m

The applied causation factors for collision are:

Crossing	$1.3 \cdot 10^{-4}$
Intersection	$1.3 \cdot 10^{-4}$
Head-On	$0.49 \cdot 10^{-4}$

10.1.1 Defining the Navigational Area: Scenario ® Area

Manoeuvring aspects:

There are no special manoeuvring aspects related to the route. Vessels are sailing with a mean offset of 125m from the specified route, and with a standard deviation of 25m.

A new Manoeuvring aspect, say: "ManAsp1", can be defined with these parameters under Area in the scenario definition. →

Traffic distribution:

We must specify 5 different traffic distributions to describe the relevant traffic composition for the considered area; two for the eastern route, two for the western route, and one for the ferry route.

ROUTE: T-North

Category 1000 t	Bulk carriers	Chem. Tanker	Container	Gas Tanker	Oil Tanker	Other Vessels	Passenge r Vessel	Roro Vessels
0 – 0.5	0	–	–	–	0	0	0	–
0.5 – 1.0	843	–	0	0	24	193	0	–
1.0 – 1.5	107	–	6	2	70	45	0	–
1.5 – 2.0	73	13	11	2	66	124	0	0
2 – 3	427	28	38	21	123	41	0	0
3 – 5	694	51	116	21	208	298	0	0
5 – 10	1027	132	82	47	307	24	0	0
10 – 20	646	55	48	22	265	10	0	0
20 – 30	234	5	24	5	217	15	0	0
30 – 40	255	2	2	2	217	0	0	0
40 – 60	108	0	0	0	270	0	0	0
60 – 80	85	0	0	0	7	0	0	0
80 – 100	7	0	–	0	22	0	0	0
100 – 150	63	0	–	–	36	0	0	0
150 – 200	–	–	–	–	2	–	0	0
200 – 250	–	–	–	–	1	–	0	0
> 250	–	–	–	–	2	–	0	0

ROUTE: T-South

Category 1000 t	Bulk carriers	Chem. Tanker	Container	Gas Tanker	Oil Tanker	Other Vessels	Passenge r Vessel	Roro Vessels
0 – 0.5	0	–	–	–	0	0	0	–
0.5 – 1.0	907	–	0	0	26	207	0	–
1.0 – 1.5	115	–	6	3	75	49	0	–
1.5 – 2.0	78	15	12	3	71	132	0	0
2 – 3	473	31	41	23	135	46	0	0
3 – 5	746	55	127	22	224	321	0	0
5 – 10	1104	142	304	51	330	25	0	0
10 – 20	694	60	127	23	285	10	0	0
20 – 30	261	5	304	5	233	15	0	0
30 – 40	275	3	52	3	233	0	0	0
40 – 60	117	0	26	0	290	0	0	0
60 – 80	90	0	3	0	8	0	0	0
80 – 100	8	0	–	0	23	0	0	0
100 – 150	67	0	–	–	39	0	0	0
150 – 200	–	–	–	–	3	–	0	0
200 – 250	–	–	–	–	1	–	0	0
> 250	–	–	–	–	2	–	0	0

ROUTE: X-North

Category 1000 t	Bulk carriers	Chem. Tanker	Container	Gas Tanker	Oil Tanker	Other Vessels	Passenge r Vessel	Roro Vessels
0 – 0.5	0	–	–	–	0	0	0	–
0.5 – 1.0	840	–	0	0	24	192	0	–
1.0 – 1.5	114	–	6	2	74	48	0	–
1.5 – 2.0	86	15	13	2	78	146	0	0
2 – 3	113	8	10	5	32	11	0	0
3 – 5	29	2	5	1	9	13	0	0
5 – 10	21	3	6	1	6	0	0	0
10 – 20	0	0	0	0	0	0	0	0
20 – 30	0	0	0	0	0	0	0	0
30 – 40	0	0	0	0	0	0	0	0
40 – 60	0	0	0	0	0	0	0	0
60 – 80	0	0	0	0	0	0	0	0
80 – 100	0	0	–	0	0	0	0	0
100 – 150	0	0	–	–	0	0	0	0
150 – 200	–	–	–	–	0	–	0	0
200 – 250	–	–	–	–	0	–	0	0
> 250	–	–	–	–	0	–	0	0

ROUTE: X-South

Category 1000 t	Bulk carriers	Chem. Tanker	Container	Gas Tanker	Oil Tanker	Other Vessels	Passenge r Vessel	Roro Vessels
0 – 0.5	0	–	–	–	0	0	0	–
0.5 – 1.0	910	–	0	0	26	208	0	–
1.0 – 1.5	124	–	7	3	81	53	0	–
1.5 – 2.0	93	17	14	3	85	158	0	0
2 – 3	122	8	11	6	35	12	0	0
3 – 5	31	2	5	1	9	13	0	0
5 – 10	23	3	6	1	7	1	0	0
10 – 20	0	0	0	0	0	0	0	0
20 – 30	0	0	0	0	0	0	0	0
30 – 40	0	0	0	0	0	0	0	0
40 – 60	0	0	0	0	0	0	0	0
60 – 80	0	0	0	0	0	0	0	0
80 – 100	0	0	–	0	0	0	0	0
100 – 150	0	0	–	–	0	0	0	0
150 – 200	–	–	–	–	0	–	0	0
200 – 250	–	–	–	–	0	–	0	0
> 250	–	–	–	–	0	–	0	0

ROUTE: KN-East-West

Category 1000 t	Bulk carriers	Chem. Tanker	Container	Gas Tanker	Oil Tanker	Other Vessels	Passenge r Vessel	Roro Vessels
0 – 0.5	0	–	–	–	0	0	0	–
0.5 – 1.0	0	–	0	0	0	0	0	–
1.0 – 1.5	0	–	0	0	0	0	0	–
1.5 – 2.0	0	0	0	0	0	0	0	0
2 – 3	0	0	0	0	0	0	0	0
3 – 5	0	0	0	0	0	0	0	0
5 – 10	0	0	0	0	0	0	0	0
10 – 20	0	0	0	0	0	0	4093	2093
20 – 30	0	0	0	0	0	0	1041	1041
30 – 40	0	0	0	0	0	0	5419	5419
40 – 60	0	0	0	0	0	0	3791	3791
60 – 80	0	0	0	0	0	0	0	0
80 – 100	0	0	–	0	0	0	0	0
100 – 150	0	0	–	–	0	0	0	0
150 – 200	–	–	–	–	0	–	0	0
200 – 250	–	–	–	–	0	–	0	0
> 250	–	–	–	–	0	–	0	0

Waypoints are specified in terms of their latitude and their longitude. For the Great Belt route the following waypoints are relevant:

Waypoints:

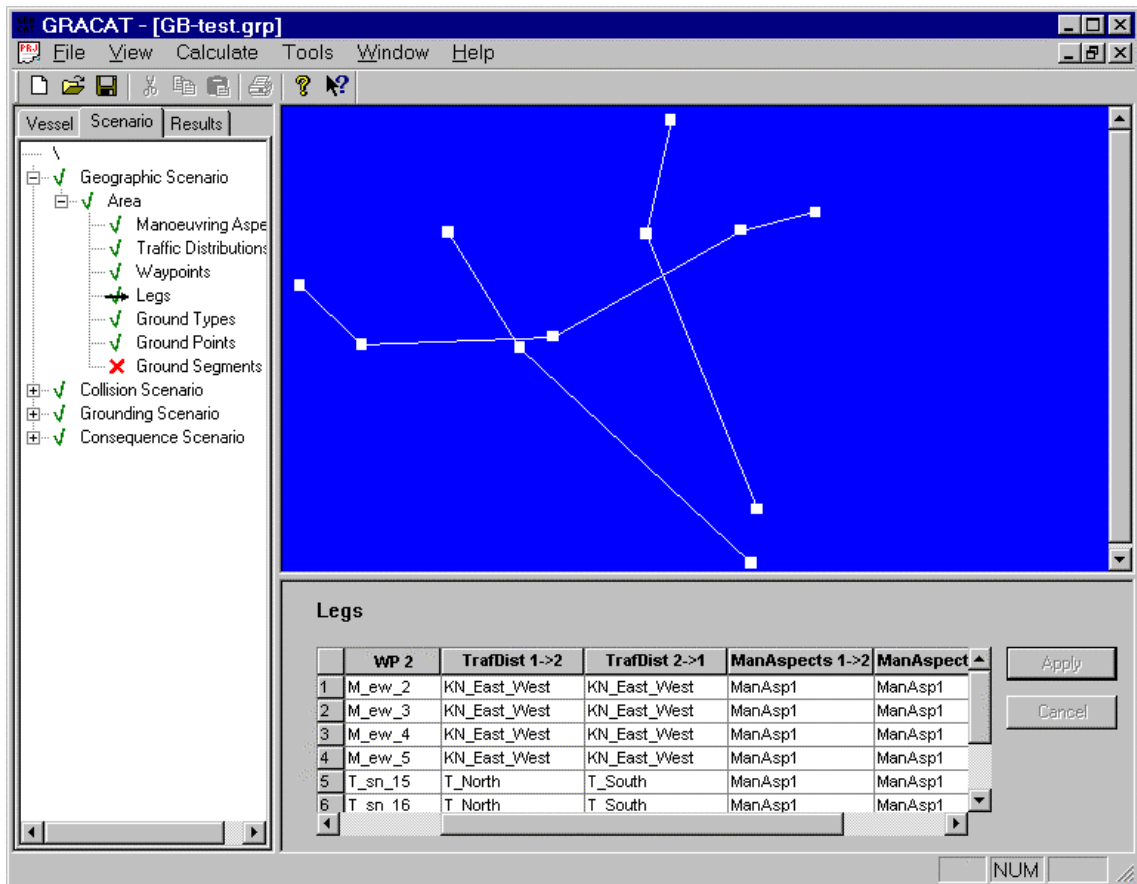
#	ID	Latitude	Longitude
1	M_ew_1	055 17.396 N	010 48.472 E
2	M_ew_2	055 16.082 N	010 50.937 E
3	M_ew_3	055 16.271 N	010 58.561 E
4	M_ew_4	055 18.606 N	011 6.048 E
5	M_ew_5	055 19.000 N	011 9.000 E
6	T_sn_13	055 11.279 N	011 6.423 E
7	T_sn_14	055 12.473 N	011 6.661 E
8	T_sn_15	055 18.540 N	011 2.256 E
9	T_sn_16	055 21.020 N	011 3.259 E
10	X_sn_1	055 11.279 N	011 6.423 E
11	X_sn_2	055 16.026 N	010 57.229 E
12	X_sn_3	055 18.568 N	010 54.378 E

The legs connect the waypoint to define the topology of the sailing area. Besides the connection between waypoint legs are also associated with traffic distributions and special manoeuvring aspects. The leg assignment is:

Legs:

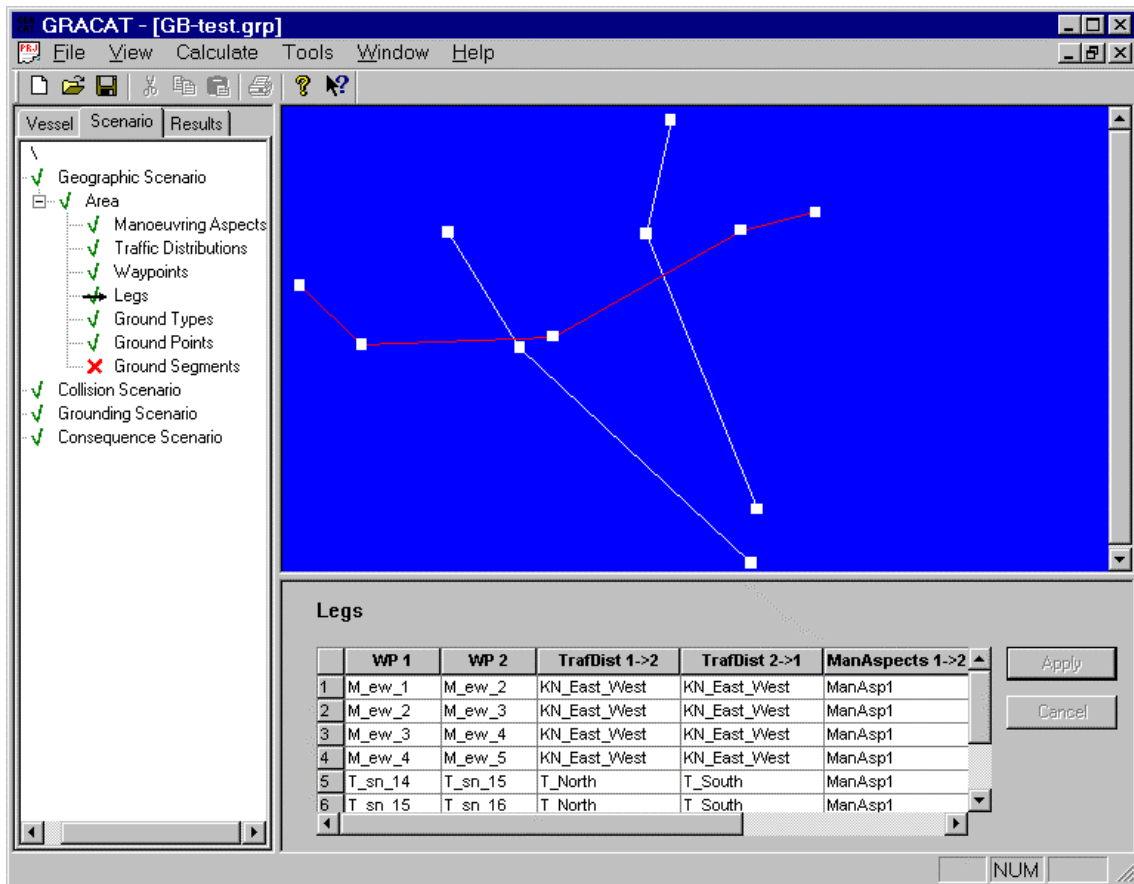
#	WP1	WP2	Trf 1→2	Trf 2→1	Man 1→2	Man 2→1
1	M_ew_1	M_ew_2	KN_East_West	KN_East_West	ManAsp1	ManAsp1
2	M_ew_2	M_ew_3	KN_East_West	KN_East_West	ManAsp1	ManAsp1
3	M_ew_3	M_ew_4	KN_East_West	KN_East_West	ManAsp1	ManAsp1
4	M_ew_4	M_ew_5	KN_East_West	KN_East_West	ManAsp1	ManAsp1
5	T_sn_13	T_sn_14	T_North	T_South	ManAsp1	ManAsp1
6	T_sn_14	T_sn_15	T_North	T_South	ManAsp1	ManAsp1
7	T_sn_15	T_sn_16	T_North	T_South	ManAsp1	ManAsp1
8	X_sn_1	X_sn_2	X_North	X_South	ManAsp1	ManAsp1
9	X_sn_2	X_sn_3	X_North	X_South	ManAsp1	ManAsp1

Having entered all these data the resulting area that has been defined should be like shown below:



The final task is to select the route that the ferry is sailing along. Right-click the mouse in the Display View, and select Own Route → Selection. Click on the horizontal leg most to the right (Korsør side), and then click on the connected leg to the left of it. The program will suggest the following legs of the route. Accept these by hitting return. Finally, uncheck Own Route → Selection.

The selected route becomes red, as shown in the figure below.



10.1.2 Starting the collision frequency analysis

First we will the collision frequencies only since this analysis is fast, and will allow us to test that everything is entered properly. But first, if you have not done so, it is a good idea to save the data into a file.

Select Calculate→Options from the main menu, and then select Start level as Route Analysis, End Level as Route results, and finally Analysis type as Collision analysis. Press OK, then select Calculate→Go. The analysis is quickly completed, press OK again, click the Result tab in the Explorer View, expand the Route Analysis and Collision analysis branches, and click at the frequency item.

At the end of the table in the Data View, it is seen that the probability of experiencing a collision that own vessel is involved in is 1.6375e-002, the probability of having a struck collision is 9.357e-002.

By clicking on the header Number of Struck Collisions the table is sorted according to increasing order (or decreasing by clicking once more). It is now quickly identified that the most critical collision points are the crossing of ferry route with the T-route. Most critical are the cases for traffic on the T-route sailing from north to south. The next critical location that can be identified is the crossing of the X-route.

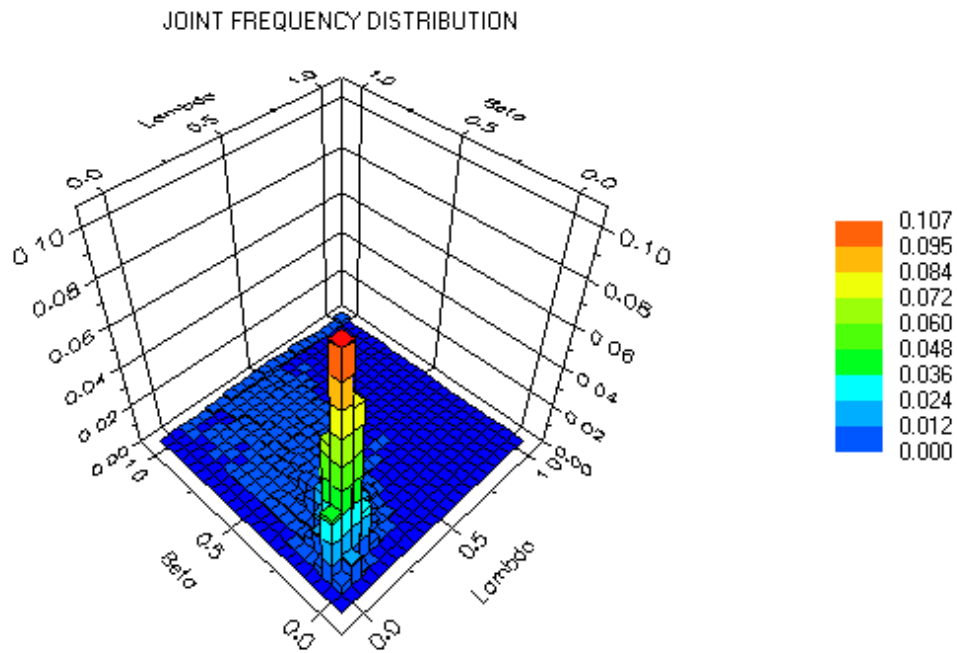
10.1.3 Starting the collision damage analysis

Next select that the end level of the analysis now should be a damage analysis. Select number of simulation and simulation method. Then start the analysis and go get a cup of coffee.

When the analysis is completed we can inspect the normalised joint damage distributions. The normalisation of the damage length L_D is given by

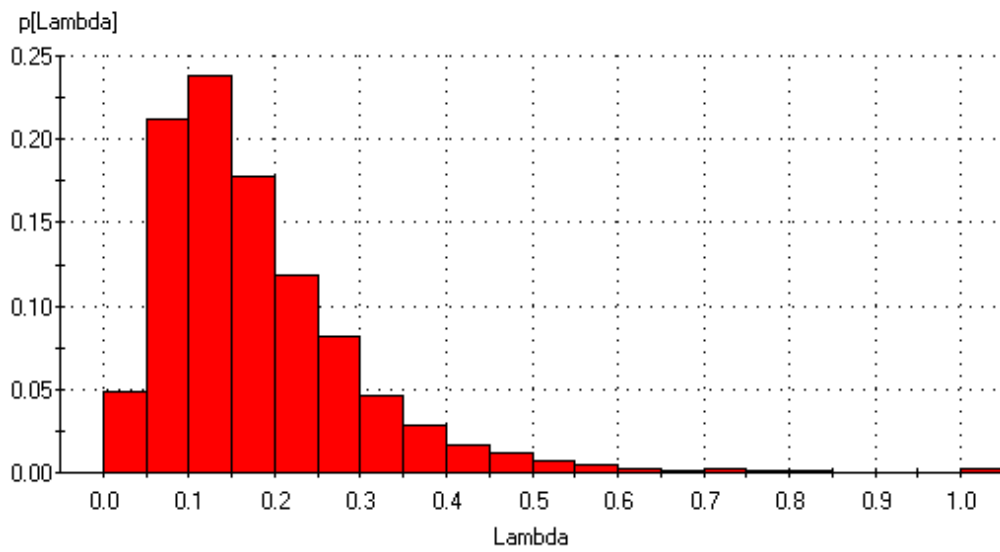
$$I = \frac{L_D}{0.4 \cdot L_{pp}} \quad \text{and the normalisation of the damage depth } D_D \text{ is } \mathbf{b} = \frac{D_D}{0.5 \cdot B}.$$

The joint distribution is shown below (recall that you can select to copy the figure to the clipboard by right clicking the mouse).

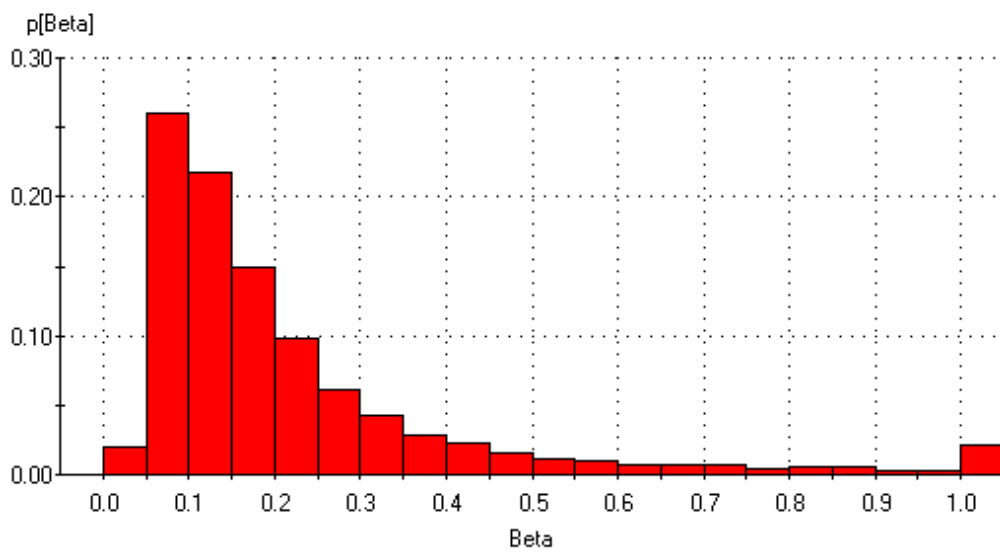


Below you see the normalised marginal distributions.

MARGINAL DISTRIBUTION



MARGINAL DISTRIBUTION



11. REFERENCES

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- [5] P. Friis Hansen, ISESO document ID I107/I108.00.02.052.004
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12. APPENDIX

12.1 Probability Distributions

The following probability distributions are implemented into the program.

12.1.1 BETA

	Description
Input name	BETA
Density (PDF)	$f(x) = \frac{1}{(b-a)^{t-1} B(r,t-r)} (x-a)^{r-1} (b-x)^{t-r-1}$
Cumulative (CDF)	$F(x) = \frac{1}{(b-a)^{t-1} B(r,t-r)} \int_a^x (v-a)^{r-1} (b-v)^{t-r-1} dv$
Restrictions	$a < x < b ; r > 0 ; t \geq r$
Mean value	;
Standard deviation	$s = (b-a) \frac{r}{t} \sqrt{\frac{t-r}{r(t+1)}}$
	Input parameters
MEAN-STD	$m ; s ; a ; b$
MEAN-COV	$m ; s / m ; a ; b$
PARAM	$r ; t ; a ; b$

a is the lower bound. b is the upper bound. $B(r,s) = \int_0^1 r^{t-1} (1-t)^{s-1} dt$.

12.1.2 EXPONENTIAL

	Description
Input name	EXPONENTIAL
Density (PDF)	$f(x) = I \exp[-I(x - g)]$
Cumulative (CDF)	$F(x) = 1 - \exp[-I(x - g)]$
Restrictions	$x > g, I > 0$
Mean value	$m = I^{-1} + g$
Standard deviation	$s = I^{-1}$
	Input parameters
MEAN-STD	$m ; s$
MEAN-COV	$m ; s / \mu$
PARAMS	$I ; g$

? is the lower bound.

12.1.3 GAMMA

	Description
Input name	GAMMA
Density (PDF)	$f(x) = \frac{I}{\Gamma(k)} (I(x - g))^{k-1} \exp[-I(x - g)]$
Cumulative (CDF)	$F(x) = \frac{g(k, I(x - g))}{\Gamma(k)}$
Restrictions	$x \geq g, k > 0, g > 0$
Mean value	$m = kI^{-1} + g$
Standard deviation	$s = I^{-1} \sqrt{k}$
	Input parameters
MEAN-STD	$m ; s ; g$
MEAN-COV	$m ; s / m ; g$
PARAM	$k ; I g$

? is the lower bound. $\Gamma(a) = \int_0^{\infty} s^{a-1} e^{-s} ds$ is the Gamma function.

$g(a, x) = \int_0^x s^{a-1} e^{-s} ds$ is the incomplete Gamma function.

12.1.4 GUMBEL

	Description
Input name	GUMBEL
Density (PDF)	$f(x) = a \exp\{-a(x - b) - \exp[-a(x - b)]\}$

Cumulative (CDF)	$F(x) = \exp\{-\exp[-a(x-b)]\}$
Restrictions	$a > 0$
Mean value	$m = \frac{g_e}{a_p} + b$
Standard deviation	$s = \frac{p}{\sqrt{6a}}$
	Input parameters
MEAN-STD	$m ; s$
MEAN-COV	$m ; s / m$
PARAMS	$a ; b$

$g_e = 0.577215664..$ is the Euler constant.

12.1.5 LOG-NORMAL

	Description
Input name	LOG-NORMAL
Density (PDF)	$f(x) = \frac{1}{\sqrt{2pe}} \exp\left[-\frac{1}{2}\left(\frac{\ln(x-g)-x}{e}\right)^2\right] \frac{1}{x-g}$
Cumulative (CDF)	$F(x) = \int_g^{\infty} f(s)ds$
Restrictions	$x \geq g, e > 0$
Mean value	$m = \exp\left[\frac{1}{2}e^2 + x\right] + g$
Standard deviation	$s = \exp\left[\frac{1}{2}e^2 + x\right] \sqrt{\exp[e^2] - 1}$
	Input parameters
MEAN-STD	$m ; s ; g$
MEAN-COV	$m ; s / m ; g$
PARAM	$e ; x ; g$

G is the lower bound.

12.1.6 NORMAL

	Description
Input name	NORMAL
Density (PDF)	$f(x) = \frac{1}{\sqrt{2ps}} \exp\left[-\frac{1}{2}\left(\frac{x-m}{s}\right)^2\right]$
Cumulative (CDF)	$F(x) = \int_{-\infty}^x f(s)ds$
Restrictions	$s > 0$

Mean value	μ
Standard deviation	$\mu ; s$
	Input parameters
MEAN-STD	$m ; s$
MEAN-COV	$m ; s / m$
PARAM	$m ; s$

12.1.7 RAYLEIGH

	Description
Input name	RAYLEIGH
Density (PDF)	$f(x) = \frac{x-g}{q^2} \exp\left[-\frac{(x-g)^2}{2q^2}\right]$
Cumulative (CDF)	$F(x) = 1 - \exp\left[-\frac{(x-g)^2}{2q^2}\right]$
Restrictions	
Mean value	$m = \sqrt{\frac{p}{2}}q + g$
Standard deviation	$s = q\sqrt{2(1-p/4)}$
	Input parameters
MEAN-STD	$m ; s$
MEAN-COV	$m ; s / m$
PARAM	$q ; g$

G is the lower bound.

12.1.8 TRUNCATED NORMAL

	Description
Input name	TRUNC- NORM
Density (PDF)	$f(x) = \frac{\frac{1}{s} f\left(\frac{x-m}{s}\right)}{\Phi\left(\frac{b-m}{s}\right) - \Phi\left(\frac{a-m}{s}\right)}$
Cumulative (CDF)	$F(x) = \frac{\Phi\left(\frac{x-m}{s}\right) - \Phi\left(\frac{a-m}{s}\right)}{\Phi\left(\frac{b-m}{s}\right) - \Phi\left(\frac{a-m}{s}\right)}$
Restrictions	$a \leq x \leq b, s > 0$

Mean value	??
Standard deviation	??
	Input parameters
MEAN-STD	$m ; s ; a ; b$
MEAN-COV	$m ; s / m ; a ; b$
PARAM	$m ; s ; a ; b$

m and s are the mean and standard deviation of the underlying normal distribution. a and b are lower and upper bound respectively.

12.1.9 UNIFORM

	Description
Input name	UNIFORM
Density (PDF)	$f(x) = \frac{1}{b-a}$
Cumulative (CDF)	$F(x) = \frac{x-a}{b-a}$
Restrictions	
Mean value	$m = a + b^2$
Standard deviation	$s = b - a2\sqrt{3}$
	Input parameters
MEAN-STD	$m ; s$
MEAN-COV	$m ; s / m$
PARAM	$a ; b$

12.1.10 WEIBULL

	Description
Input name	WEIBULL
Density (PDF)	$f(x) = db(x-g)^{b-1} \exp[-d(x-g)^b]$
Cumulative (CDF)	$F(x) = 1 - \exp\left[-\frac{(x-g)^2}{2q^2}\right]$
Restrictions	$x \geq g, d > 0, b > 0$
Mean value	$m = d^{-1/b} \Gamma\left(1 + \frac{1}{b}\right) + g$
Standard deviation	$s = d^{-1/b} \left[\Gamma\left(1 + \frac{2}{b}\right) - \Gamma\left(1 + \frac{1}{b}\right)^2 \right]^{1/2}$
	Input parameters
MEAN-STD	$m ; s ; g$

MEAN-COV	m ; s / m ; g
PARAMS	d ; b ; g

? is the lower bound. Parameters are found by a Newton-Rapson scheme when MEAN-COV is given.