

## GL.ShipLoad: An Integrated Load Generation Tool for FE Analysis

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### Abstract

*With GL.ShipLoad, Germanischer Lloyd provides a user friendly computer application for the efficient load generation for global FE analyses of ship structures. The graphical user interface facilitates the convenient application of ship and cargo masses to the FE model. Hydrostatic and hydrodynamic computations are integrated into the program. GL.ShipLoad supports the generation of loads from first principles (realistic inertia and wave loads for user supplied wave parameters), but the program also aids in the selection of relevant wave situations for the global strength assessment based on bending moments and shear forces according to GL's rules. The result is a small number of balanced load cases that are sufficient for the dimensioning of the hull structure.*

### 1. Introduction

The reliable computation of loads is crucial for an accurate global FE analysis of a ship. In its "Guideline for the global strength analysis for container vessels" (*Germanischer Lloyd (2006)*), Germanischer Lloyd uses the design wave approach (see e.g. *FOLSO et. al. (2003)*) to find those load combinations which are most relevant for the dimensioning of the structure. In contrast to the loading approaches in the common structural rules for bulkers and tankers (*IACS (2006)*), the hydromechanic pressure and the ship accelerations are here taken from first principle hydrodynamic computations for regular waves. As an aid in applying the loading procedure, the software GL.ShipLoad has been developed by Germanischer Lloyd.

Loads on the structure result from acceleration of masses (inertial loads) and from external loads (mainly pressures). GL.ShipLoad provides support for modeling the mass distribution of ship and cargo as well as for computing static and hydrodynamic pressures due to waves, and for the combination of both types of loads into balanced quasi-static load cases.

For finding the most relevant regular waves, GL.ShipLoad analyzes a large number of wave situations. With an easy to use mechanism for defining selection criteria (e.g. "maximum total vertical bending moment" or "maximum wave torsional moment"), the user can specify which waves shall be chosen for the global strength analysis. By choosing the loads as specified in the guideline (*Germanischer Lloyd (2006)*), the rule envelope curves for sectional moments and forces are approximated. For any chosen load case, the longitudinal distribution of sectional forces and moments is immediately displayed.

The GL.ShipLoad program can easily be applied in a typical design environment, as e.g. at a shipyard, since it only requires a global FE model of the ship as input, and its output consists of nodal forces which can be applied in any standard FE program. In the implementation, nodal loads have been given preference over surface loads, since for global analysis they yield sufficient accuracy and their application is straightforward in any FE code.

The following main steps of a typical program run will be described in detail in this paper:

1. Import of the FE model
2. Modeling of the mass distribution (steel weight, equipment and accommodation, bunkering, ballast, cargo)
3. Computation of the still water floating position

4. Computation of hydrodynamic potentials by a strip method
5. Computation of reference wave amplitudes from prescribed (rule-)bending moments
6. Specification of the scan range of wave parameters
7. Computation of pressures/section loads for this scan range
8. Selection of load cases (manually or automatically by section load extrema)
9. Generation of balanced nodal load cases

Since – even with good software support – the definition of a realistic mass distribution of the ship for different loading conditions is a laborious task, GL.ShipLoad has been designed such that all mass definitions can also be used for a finite element vibration analysis at a later stage.

From the software engineering point of view, the aims in developing GL.ShipLoad were:

- Convenience (clear layout, re-use of data from other programs, copy and paste)
- Objectivity (reproducible results independent of the person at work and according to the GL guideline for global FE analysis)
- Reliability (assessment of results by graphical feedback)
- Efficiency (easy to use and fast to apply)

In particular these goals are met by the following features of the program

- Any user inputs into the software are stored in an XML file. In this way, data input is transparent to other developers and GL.ShipLoad can be integrated into other environments.
- For the internal storage of hydrodynamic results, a data model has been developed, which is independent of the hydrodynamic method. The corresponding files use HDF5 (*NCSA (2005)*) as an efficient binary exchange format. Because of this approach, the current strip method can easily be replaced by more detailed approaches at a later stage.
- Using copy and paste, data can be exchanged with e.g. spreadsheet programs, and any prior inputs to Germanischer Lloyd's scantling software POSEIDON (e.g. container input) can be reused.
- If desired, the global strength analysis can immediately be performed with the integrated FE solver GLFRAME.
- Users acquainted with POSEIDON will quickly get accustomed to GL.ShipLoad because of the familiar look and feel.

## 2. General remarks

Apart from the major tasks of defining masses and selecting hydrodynamic load cases, some more general input is required. Most prominently, input and output files must be specified. GL.ShipLoad deals with files for reading information (FE model, hull description), writing results (loads), storing user input data, and for communicating with external programs (hydrodynamics, export for e.g. NASTRAN).

GL.ShipLoad operates on the basis of nodes, elements, and materials as used in any standard FE program. This data is loaded from a finite element model in Germanischer Lloyd's BMF file format. Converters between NASTRAN and ANSYS formats and BMF are available. The resulting nodal loads (representing inertial loads that result from acceleration of the mass distribution, and static and dynamic pressures) are either appended to the FE model file or are directly output as ANSYS or NASTRAN nodal loads.

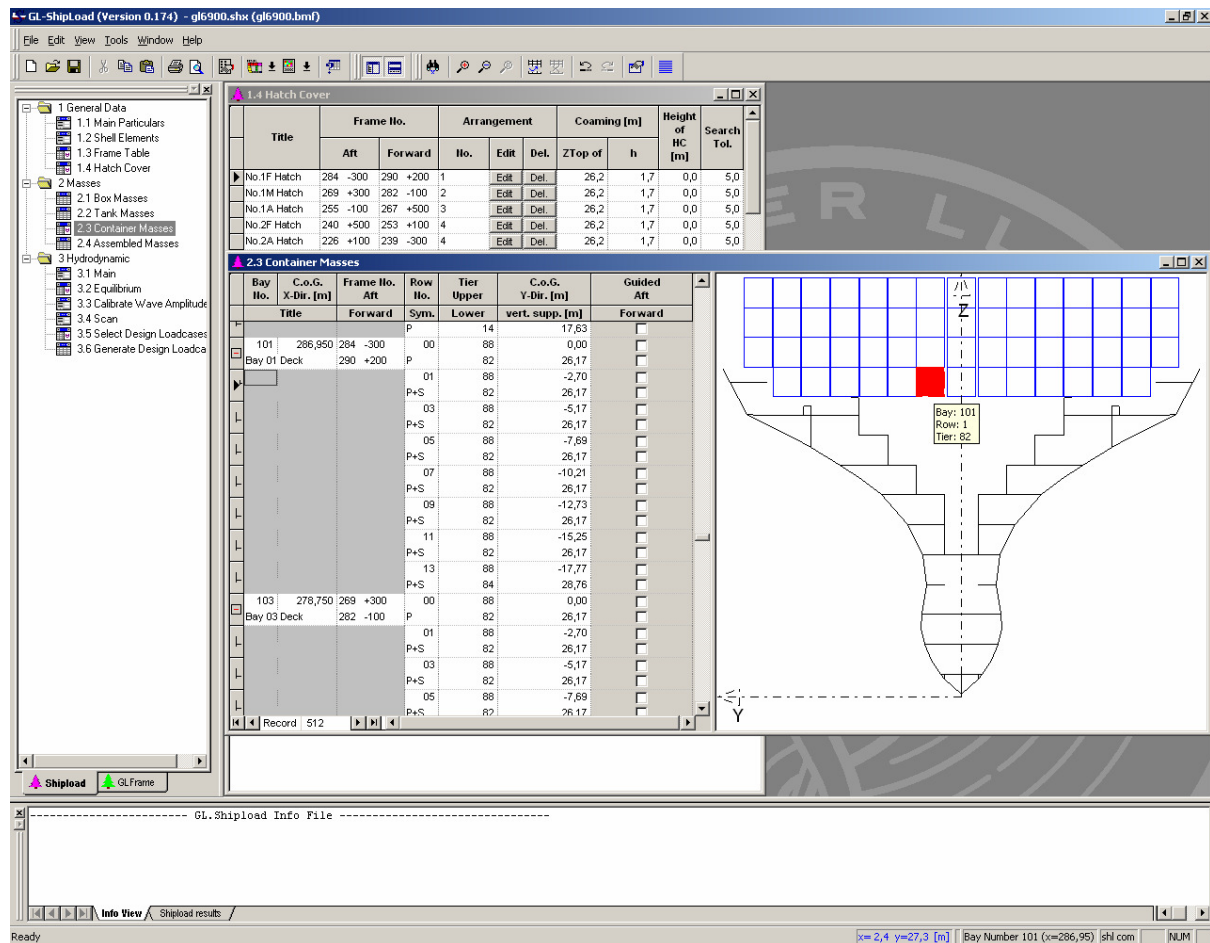


Fig. 1: The graphical user interface is divided into the areas “tree” (on the left), “output” (at the bottom), and “workspace”. User input windows are opened in the workspace by clicking on the tree items (additional symbols for actions that are specific to the active window may appear in the toolbar). Some windows have a “preview” for graphical feedback of the user input in the white input fields. (The figure above shows a section of the FE model and the current container bay – a tool tip displays information about the object at the mouse position.) The items of the tree are arranged in such a way that, by proceeding from the top to the bottom, the user is guided through all required steps from the input of the principal dimensions to the generation of FE loads. A progress bar indicates the progress of longer computations. Information, warning, and error messages are written to the output area as a persistent log of the program run.

Apart from the detailed geometrical information contained in the FE model, some principal dimensions have to be entered (mainly for the computation of bending moment rule values). A frame table can be specified that allows the addressing of longitudinal positions by frame number rather than by coordinate value.

Normally, hatch covers are not explicitly modeled by finite elements (as they must not contribute to the overall stiffness of the model). Hence, hatch cover definitions have to be entered in GL.ShipLoad as they are required for the load application of deck containers.

For the computation of trim and for the conversion of hydrodynamic pressures to nodal loads, the elements of the FE model that represent the shell have to be specified. This can be done automatically by specifying the height up to which the FE model is water tight (in this case, starting with the bottom-most element, all elements below this height that are connected via common edges are selected), or one or more element groups of the FE model can be specified. In either case, a procedure that ensures consistent orientation of the elements is invoked automatically.

Additionally, a shell representation of (open) polygons at cross-sections of the hull is required for hydrodynamic computations; these polygons can be imported from a (e.g. NAPA-generated) XML file or can be derived from the FE model. From these polygons, linear and non-linear shell representations for strip method and non-linear pressure extrapolation are generated by the program.

## 2.1. Load groups

GL.ShipLoad uses an efficient concept for defining nodal loads. Any *load case*, which is later applied to the finite element model, is a linear combination of so called *load groups*. Since in particular the inertial loads of the ship are always a linear combination of the same six load groups (corresponding to three translational and three rotational accelerations of the rigid ship), this approach leads to a much more efficient storage of the loads in the case of many different wave situations. The array of factors connecting load groups to load cases is also output by the program, an example is shown in Fig. 2

LG No	names	Factor for load groups in global load case (GLC)					
		1	2	3	4	5	6
1	C004 B	1,0000	1,0000	1,0000	1,0000	1,0000	0,0000
2	C004 T	1,0000	1,0000	1,0000	1,0000	1,0000	0,0000
3	C004 T X	0,3199	-0,3997	-0,2815	0,0479	0,0000	0,0000
4	C004 T Y	-0,0008	0,0009	1,2838	-3,0362	0,0000	0,0000
5	C004 T Z	-1,7015	2,3712	2,3279	1,2603	0,0000	0,0000
6	C004 T XX	0,0000	0,0000	0,0126	0,0291	0,0000	0,0000
7	C004 T YY	-0,0172	0,0215	0,0151	-0,0026	0,0000	0,0000
8	C004 T ZZ	0,0000	0,0000	-0,0103	-0,0011	0,0000	0,0000
9	C004 W	1,0000	1,0000	1,0000	1,0000	1,0000	0,0000
10	C004 W X	0,3199	-0,3997	-0,2815	0,0479	0,0000	0,0000
11	C004 W Y	-0,0008	0,0009	1,2838	-3,0362	0,0000	0,0000
12	C004 W Z	-1,7015	2,3712	2,3279	1,2603	0,0000	0,0000
13	C004 W XX	0,0000	0,0000	0,0126	0,0291	0,0000	0,0000
14	C004 W YY	-0,0172	0,0215	0,0151	-0,0026	0,0000	0,0000
15	C004 W ZZ	0,0000	0,0000	-0,0103	-0,0011	0,0000	0,0000
16	Max. V. Bend	1,0000	0,0000	0,0000	0,0000	0,0000	0,0000
17	Min. V. Bend	0,0000	1,0000	0,0000	0,0000	0,0000	0,0000
18	Max. H. Bend	0,0000	0,0000	1,0000	0,0000	0,0000	0,0000
19	Max. Tors.	0,0000	0,0000	0,0000	1,0000	0,0000	0,0000
20	Stillwater	0,0000	0,0000	0,0000	0,0000	1,0000	0,0000
20	Stillwater	0,0000	0,0000	0,0000	0,0000	1,0000	0,0000

Fig. 2: Load cases as linear combinations of load groups.

The following load groups are created by GL.ShipLoad for each loading condition of the ship:

1. hydrostatic buoyancy loads
2. static weight loads
3. static tank loads
4. 6 unit load groups that result from the 3 translational and the 3 rotational rigid body accelerations of all masses except for the tanks
5. 6 unit load groups that result from the 3 translational and the 3 rotational rigid body accelerations of the tanks
6. one hydrodynamic load group per selected wave

The combination of the first three types of load groups (with factor 1.) results in the balanced (no residual forces or moments) *hydrostatic* load case (load groups 1, 2, and 9 in Fig. 2). In order to get balanced *hydrodynamic* load cases, the factors for the unit load groups are computed from the condition that no residual forces and moments shall result from the linear combination with the hydrodynamic load group – the factors are then equivalent to the rigid body accelerations.

All mass definitions entered into GL.ShipLoad can be used not only for load generation for the quasi-static analysis, but can later be exported as masses for a dynamic analysis. This feature will be available in a future release.

### 3. Mass distribution

Typical components of a mass distribution (e.g. of a container vessel) are: steel weight, equipment and accommodation (resulting in the light ship weight), bunkering, water ballast, and cargo. While some components differ for different loading conditions (e.g. bunkering for departure and arrival conditions), some loading conditions share the same components (e.g. light ship weight is the same for all loading conditions). For this reason, GL.ShipLoad supports the assembly of basic mass items (e.g. a single storage tank) to assembled mass items (e.g. departure bunkering) in order to facilitate the convenient access to and re-use of the “building blocks” of typical loading conditions.

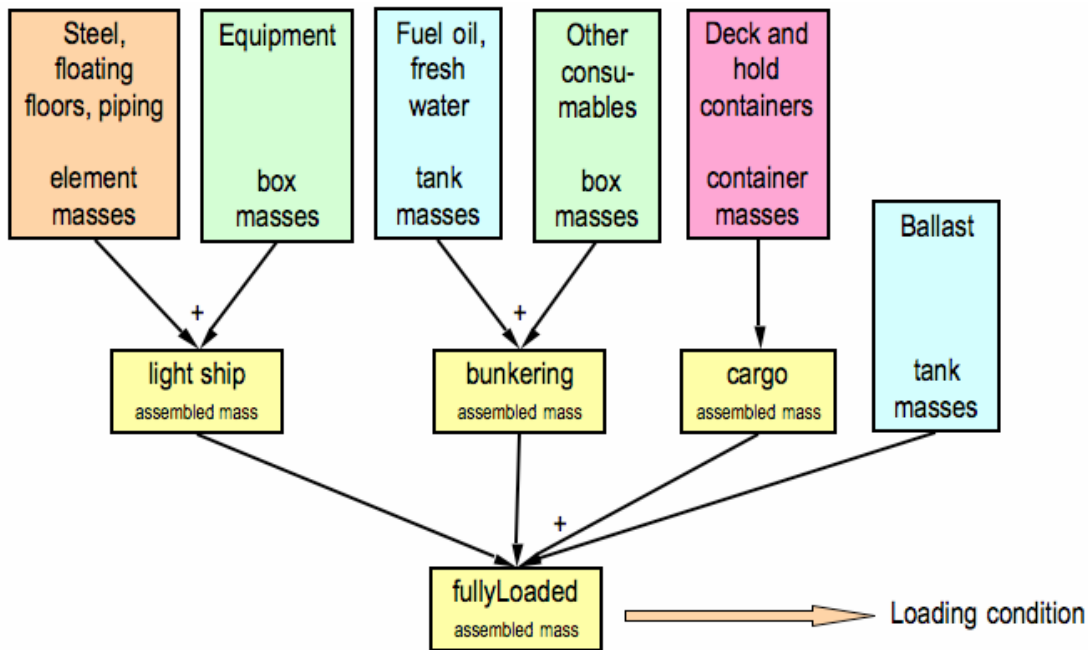


Fig. 3: Making use of assembled mass items for definition of reusable “building blocks” of a typical container vessel loading condition.

In GL.ShipLoad, both basic and assembled mass items are represented internally by (sparse) *mass matrices*. A mass matrix relates nodal loads to nodal accelerations (via  $f = Ma$ ). Nodal accelerations are derived from the computed hydrodynamic rigid body accelerations (translational rigid body acceleration is directly applied to all nodes, whereas rotational rigid body acceleration is converted to translational nodal accelerations that depend on the distance from the axis of rotation). Generally, all mass matrices couple the nodes to which they are connected. Nodal masses (encountered for element group masses and box masses, see below) are represented by diagonal mass matrices. Container mass matrices actually couple the bearing nodes in the FE model. A physically correct representation of tank masses (e.g. loads perpendicular to tank walls) would couple all wet nodes within the tank and requires a more complex computation. Since this coupling has only a minor effect on the global strength examination, static tank masses are excluded from the mass matrix approach, and dynamic tank masses are treated as nodal masses.

#### 3.1. Element group masses

The elements of the FE model are partitioned into *element groups*. Each element of the FE model belongs to one and only one element group, and all elements of a specific element group have the same element type (truss, beam, plain stress, shell, boundary). Normally, elements in an element group share some property (e. g. represent the same structural member, such as main deck). Structural masses are therefore represented by *element group mass items*. They are computed from the element geometry and the associated material density without further user input, but can be

manipulated by factors in the *assembled mass item* (see below). Typically element group mass items are used to model e.g. outfitting. At the load generation step, nodal loads are generated from element group mass items (as element loads are not supported by GL.ShipLoad).

### 3.2 Box masses

The purpose of mass boxes is the distribution of a prescribed total mass to a spatial region which is described by either a single coordinate “box” (a rectangular region specified by two diagonally opposing points) or a combination of coordinate boxes.

Without further restriction, the mass is distributed as homogeneously as possible. In this way, nodes in regions of higher nodal density (number of nodes per unit volume) will get less mass per node than nodes in regions of lower nodal density. The distribution of mass is also affected by a prescribing a center of gravity (or individual components thereof). Obviously, there are certain restrictions for this center of gravity: e.g., since no negative nodal masses are allowed, only a center of gravity within the box under consideration can be achieved.

In addition to the distribution of the prescribed mass to all nodes in the region, it is possible to limit its distribution to “hard nodes”. This type of nodes is defined as nodes which are connected to a membrane (in case of 2D elements) or axial stiffness (for 1D elements) in all three space directions. In this way local effects of masses or load distributions (e. g. overly large deflections of inner nodes of a plate) are avoided, as a global FE model of a ship typically would not represent them correctly.

Deck floorings are a special application of mass boxes: in this case, the mass per unit area is prescribed, and nodes are selected by the choice of an element group (the geometrical selection by region is still active as a secondary criterion), and mass is distributed to the nodes according to the element geometry (so, the center of gravity cannot be prescribed).

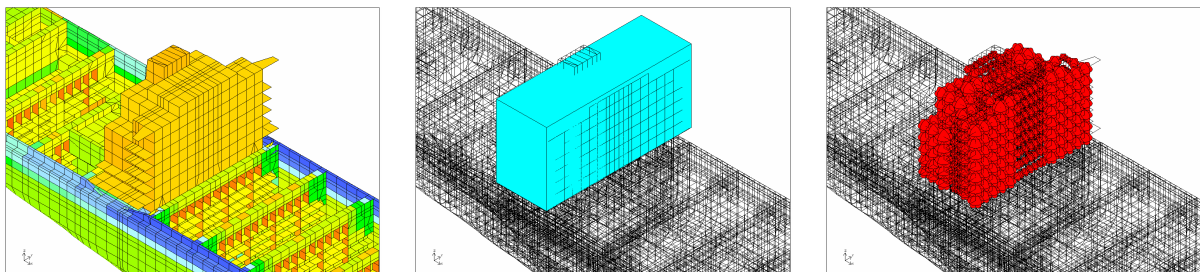


Fig. 4: Superstructure, mass box, nodal masses. Note that “weak” nodes are excluded from the mass distribution and mass per node depends on nodal density.

### 3.3. Tanks

GL.ShipLoad aids in applying tank loads by automatically identifying (topologically) closed regions in the FE model. These closed regions are also called *closed cells* in the following.

Tanks are defined by (optionally composite) boxes (analogous to mass boxes), either as *surrounding boxes* or as *enclosed boxes*. In the case of a surrounding box, the combination of all closed cells that lie completely inside the box constitutes the tank; in the case of an enclosed box, the smallest closed region that completely encloses the box constitutes the tank.

Often, the volume of a tank found in this way differs somewhat from its designated volume (as e. g. specified by the loading manual). The reason is that normally the FE model does not perfectly represent the actual ship geometry. Therefore, if the designated tank volume is prescribed by the user, the computed tank volume is scaled accordingly in the computation of nodal masses/pressures.



In the program, the tank geometry is defined independently from its actual *fill level* and *fluid density*. These latter two parameters are defined when referring to the tanks in describing an assembled mass item. This has the significant advantage, that the same tank can be used for different loading conditions by referring to the same tank geometry but specifying different fill levels and fluid densities.

The actual mass distribution within a tank is computed by finding the position of its free surface in the still water floating position of the ship. The resulting *hydrostatic* pressure is correctly transferred to the FE model by forces that are perpendicular to the tank walls and increase linearly with the distance from the free surface. The *dynamic* tank pressure (resulting from the ship's acceleration minus gravity) is transferred to the model as nodal masses (see page 5 for more detail). Here, the mass box approach as described above is used, but with a further limitation to nodes at tank wall elements below (or directly above) the tank's free surface.

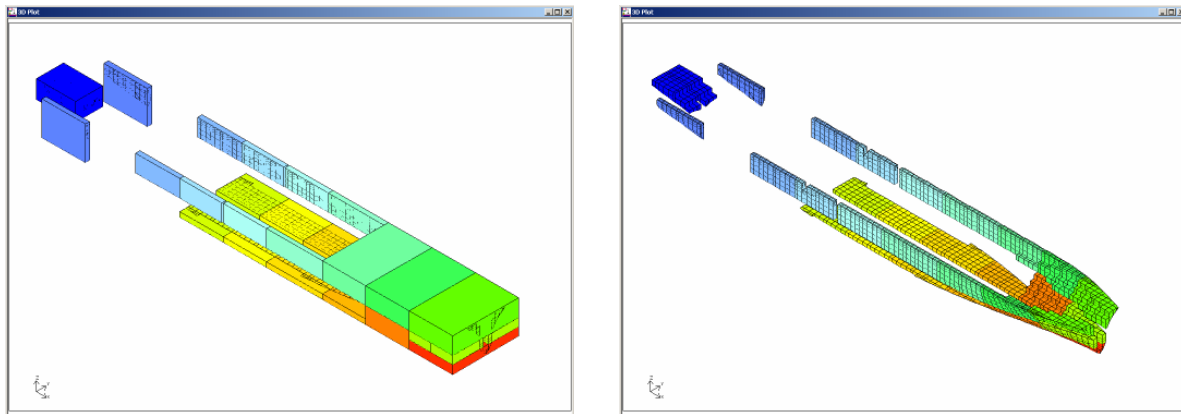


Fig. 5: Tank definition by boxes. The left hand figure shows the definitions of the boxes for a ship. On the right hand side, the tanks (closed cells in the FE model) which have been identified automatically by the program from this input are shown.

### 3.4. Container

Container mass items represent (hold or deck) container bays. At this point in the program, only the *container arrangement* is specified. The average mass per container and the vertical center of gravity are specified later, during input of the assembled mass items.

First, a container bay is defined by its longitudinal center of gravity and the aft and fore positions at which horizontal loads should be applied to the structure. GL.ShipLoad supports (ISO) standard containers of 20' and 40' length, which are denoted by their bay id (odd for 20', even for 40' container). Secondly, container stacks are defined by their lateral center of gravity, their vertical support, and their vertical extent in terms of upper and lower tier id. Deck containers are identified by a lower tier id greater than or equal to 82. Stacks that are present on portside and starboard can be marked "symmetric" and need to be entered only once.

While the general procedure for the transfer of container masses to the ship structure is the same for hold and deck containers, the involved nodal degrees of freedom differ for hold and deck containers. They will also differ for strength or vibration analysis. For hold containers for strength analysis all lateral loads are applied to the aft and fore transversal bulkheads independent of the still water floating position and the hydrodynamic acceleration. In a future program version, attributes "guided aft" and "guided fore" will determine if lateral loads for 20' container will be applied to longitudinal bulkheads at the gap between 20' containers. Longitudinal loads are applied to the fore transversal bulkhead.

For deck containers, hatch cover definitions control to which structural nodes loads are applied. Vertical loads are applied at the aft and fore edges of the hatches at the lateral positions of the corners of the container stack. Horizontal loads are applied at the stopper positions. Loads resulting from

containers that completely or partially overlap the hatch cover are applied to the nearest node on deck, as their support is generally not explicitly modeled in the FE model.

When structural nodes have been identified according to the aforementioned criteria, the stiffness matrix of an auxiliary beam model connecting the container's center of gravity and the structural nodes (all degrees of freedom) is assembled. By a first condensation, nodal degrees of freedom are released according to the designated degrees of freedom as described above. By a second condensation, the container mass matrix is computed, for which multiplication with an acceleration vector results in the same total forces and moments for the center of gravity specified.

The export of container mass matrices for a vibration analysis will be possible in a future version of GL.ShipLoad (in this case, both vertical and horizontal loads will be applied to structural nodes at the bottom of the hold container stacks). These mass matrices represent the condensed mass effect of the container, applied at the structure nodes, but with correct center of gravity. The stiffness of the structure is not changed in this approach.

### **3.5. Assembled masses**

A ship's loading condition is defined by connecting it to an assembled mass item. The purpose of assembled mass items is the assembly of element group, box, tank, and container masses to form a mass distribution. The contributions from the individual basic mass items are controlled by factors (levels and densities for tanks). An assembled mass item may reference other assembled mass items, for example, an assembled mass item "light ship" could be defined and could be re-used in all loading conditions.

Container mass items have an additional parameter to adjust the vertical center of gravity. The center of gravity of partially-filled tanks depends on the static trim displayed in the table header; the value is updated on trim computation. For a consistent trim with partially filled tanks, a (manual) iteration "computation of assembled masses/computation of trim" has to be performed.

The computation of total mass, center of gravity, and tensor of inertia for one or for all assembled mass items takes into account any dependencies on other assembled mass items and performs calculations in the correct order. If any cyclic dependencies are detected, an error message is issued. The total mass and total center of gravity can be adjusted to prescribed values by automatic manipulation of element group and box mass factors. The adjustment is achieved with the least possible change of the original factors and such that no negative factors occur. Items with factor "0." are excluded from manipulation; furthermore, individual factors can be protected from any changes.

A mass distribution represented by an assembled mass item can be exported as a list of nodal masses for a vibration analysis. Container masses are currently excluded from mass export, since in particular deck containers cannot be represented by nodal masses (there are no structure nodes that surround the center of gravity, to which the mass could be distributed with the same inertia effect.) In future versions of GL.ShipLoad, the direct export of the internal mass matrix representation will be possible (see above).



Item No 4		Title Fully Loaded M	Calc. Distr. Mass [t]	126237,3	CoG [m] x	145,309	y	0,002	z	18,603
			Presc. Distr. Mass [t]	AUTO	Radii of Gyr. [m] x	16,527	y	78,324	z	78,262
					CoG [m] x	AUTO	y	AUTO	z	AUTO
					Ta [m]	0,000	Tf [m]	0,000	heel [deg]	0,000

Type	No.	Mass-Item	100% Values				Param.Def.of.actual Item									
			Mass [t]	Volume [m³]	CoG-x [m]	CoG-y [m]	CoG-z [m]	Fix	Factor	Fillrate	CoG-z Para.	Density [tm³]	Actual Values			
			Mass [t]	Volume [m³]	CoG-x [m]	CoG-y [m]	CoG-z [m]	Fix	Factor	Fillrate	CoG-z Para.	Density [tm³]	Mass [t]	CoG [m]		
TA	1	NO.1 D.B.W.B.T. (	830,6	264,37	0,00	2,70			0,98		1,02	783,22	264,36	0,00	2,66	
TA	2	NO.2 D.B.W.B.T. (	2144,9	237,80	0,00	5,05			1,00		1,02	2285,40	237,80	0,00	5,05	
TA	3	NO.3 D.B.W.B.T. (	944,1	208,35	0,00	1,13			1,00		1,02	1003,00	208,35	0,00	1,13	
TA	4	NO.4 D.B.W.B.T. (	1836,4	176,56	0,00	1,02			0,98		1,02	1709,32	176,54	0,00	1,00	
TA	5	NO.5 D.B.W.B.T. (	1443,4	144,25	0,00	1,00			0,98		1,02	1333,58	144,25	0,00	0,98	
TA	6	NO.6 D.B.W.B.T. (	1394,9	115,54	0,00	1,04			0,98		1,02	1326,72	115,55	0,00	1,02	
TA	7	NO.1 L.S.W.B.T. (	1076,6	266,14	0,00	7,21			0,98		1,02	1047,62	266,14	0,00	7,16	
TA	8	NO.1 U.S.W.B.T. (	2030,8	267,32	0,00	16,48			0,43		1,02	1070,01	266,50	0,00	14,23	
TA	9	NO.2 U.S.W.B.T. (	1752,2	239,51	0,00	14,93			0,98		1,02	1705,79	239,49	0,00	14,83	
TA	10	NO.3 U.S.W.B.T. (	1382,2	210,11	0,00	14,83			1,00		1,02	1354,75	210,11	0,00	14,83	
TA	11	NO.4 U.S.W.B.T. (	1734,9	177,05	0,00	15,04			0,98		1,02	1696,19	177,05	0,00	14,93	
TA	12	NO.5 U.S.W.B.T. (	1345,2	144,23	0,00	15,02			0,98		1,02	1317,12	144,23	0,00	14,92	
TA	13	NO.6 U.S.W.B.T. (	1142,8	114,09	0,00	14,88			0,76		1,02	874,76	113,90	0,00	13,62	
TA	16	A.P.T (C)	1674,8	5,50	0,00	14,75			0,33		1,02	536,84	10,62	0,00	12,84	
AS	1	Light Ship	27817,61		123,99	0,01	15,21		1,00				27817,61	123,99	0,01	15,21
AS	2	Bunkering	8075,32		116,52	0,19	6,19		1,00				8075,32	116,52	0,19	6,19
AS	3	Cargo Max. SWB	72300,00		145,14	-0,02	23,85		1,00				72300,00	145,14	-0,02	23,85

Fig: 6: An assembled mass item is used to combine basic mass items and other assembled mass items into a mass distribution. Here, predefined assembled masses “light ship”, “bunkering”, “cargo” (specifying factors), and some water ballast tanks (specifying fill rate and density) are combined into a loading condition that will be used for the computation of hydrodynamic load cases.

#### 4. Hydrostatics

For the correct application of hydrostatic pressure and for the determination of trim and heeling angle, the floating position in still water must be found. In the case of GL.ShipLoad, static trim is computed by a Newton iteration of draught, trim angle, and heel angle until hydrostatic equilibrium is achieved, i.e. until the buoyancy forces and moments balance the gravity forces and moments of the mass distribution. Buoyancy forces are computed by integration of hydrostatic pressure over the hull described by the shell elements, gravity forces are obtained by multiplication of the mass distribution with the current gravity vector (in ship coordinates). The Jacobian matrix, which is required for the Newton iteration, is computed numerically by finite differences.

Besides output of the draught at the aft and fore perpendiculars and the heel angle, output of section loads in graphical and tabular form aid in assessing the mass distribution; if needed, adjustment of the mass distribution and re-computation of static trim is possible. Furthermore, the static load groups “buoyancy”, “weight (w/o tanks)”, and “tanks” are generated, as well as the unit load groups for masses and tanks.

On the basis of the computed trim, the hull description for the linear hydrodynamic computation is generated by clipping the polygon representation of the hull at the water plane, selecting frames, and distributing points as required by the strip method. An additional hull description with refined frame distance that extends above the water plane is generated for the non-linear pressure extrapolation.

#### 5. Hydrodynamics

Using the “linear” hull description (clipped at the waterline) from hydrostatics, hydrodynamic potentials are computed by a strip method (see e.g. *Bertram (2000)*).

The strip method is a frequency-domain method for computing hydrodynamic potentials, accelerations, and in this case also pressures for regular (harmonic) waves by dividing the hull into cross sections (strips) and thus reducing the three-dimensional computation to a series of two-

dimensional computations. The strip theory is valid for slender bodies like ships. A further simplification results from treating the wave height as infinitely small. Thus all boundary conditions can be applied with linear dependence on the wave height. Obviously, some inaccuracies result from such simplifications, but due to their superior computational efficiency and because of the availability of well validated software, strip methods are still a standard tool for seakeeping computations. In GL.ShipLoad, the computation of hydrodynamic potentials and ultimately hydrodynamic pressures is performed by a strip method. It is modularized in such a way that this method can in future easily be complemented by a more elaborate method.

From the hydrodynamic potentials and the global mass data of the selected mass distribution (total mass, center of gravity, tensor of inertia), hydrodynamic pressures can be computed for arbitrary wave parameter combinations such as wave height, wave length, wave direction, phase angle, and ship's speed. To account for finite wave height, a non-linear correction is applied: pressures are extrapolated above the waterline using the extended hull description (including hull form above still water line). Thereby, the hydrodynamic pressure is adjusted to the real wave contour. These non-linear load effects are significant, e.g. due to the characteristic hull form of container ships (pronounced bow and stern flare). The load magnitude including non-linear effects can differ considerably from the linear response.

## 6. Selection of load cases

The definition of loads is one of the most important steps in a global strength analysis for a ship. Several design sea states with different wave heights, lengths and headings have to be investigated systematically for the application of loads in a realistic way. The focus of GL.ShipLoad is the application of loads according to the GL guideline for global strength analyses. The procedure can only be summarized here, see *Germanischer Lloyd, (2006)* for more detail.

For every loading condition, the hydrodynamic pressure and ship motions are calculated for different heading angles using strip theory. First, the pressure distribution is determined according to linear analysis below the still water line. Since the ship motions are based on the results of the linear analysis, the imbalance of forces due to the non-linear correction of pressures is then compensated by adjusting the ship accelerations. Inertia forces of the ship and hydrodynamic pressure are then in equilibrium. Using this procedure, numerous wave situations are systematically analyzed with varying wave lengths, wave crest positions and headings, taking the hull shape fully into account.

From the precomputed wave situations, load cases have to be chosen which cover the vertical and horizontal wave bending and the torsional moments according to the GL Rules I 1-1, Sec.5. For every loading condition of the ship, approximately 20 load cases are finally selected for the finite element analysis.

In the program, the user can principally select the waves required for the strength analysis manually by specifying the height, length, direction, and phase angle of the wave, and the speed of the ship. In this case, the user may directly proceed with the generation of nodal loads, see below.

GL.ShipLoad also facilitates the automatic selection of wave parameters based on section load extrema as described above. Obviously, the wave height must be excluded from the parameters that are varied in the search for section load extrema, as there is no upper bound on the hydrodynamic forces if the wave height is allowed to become arbitrarily large. Instead, *reference wave amplitudes* are derived from hogging and sagging wave bending moments (which can be computed according to GL's rules by the program from the principal dimensions). The actually applied wave height will be a function of the reference wave amplitudes, wave length, direction, and phase angle.

### 6.1. Reference wave amplitude

Waves (hogging and sagging) are computed for a moderately large parameter range (ca. 1200 waves). Of all waves in the parameter range (direction 0° (following sea), 180° (head sea); phase angle between 0° and 360°; length between 0.8 L<sub>pp</sub> and 1.2 L<sub>pp</sub>; ship’s speed two thirds of the design speed), those two waves are selected, that realize the prescribed hogging and sagging wave bending moments with the *smallest amplitude*<sup>1</sup>. These amplitudes are called *design wave amplitudes*; the *reference wave amplitudes* are the corresponding amplitudes for a wave length equal to the ship’s length derived from the relation  $A/A_{ref} = \sqrt[3]{L/L_{pp}}$ . Using the reference wave amplitudes, the effective wave height can be computed for any wave parameter combination.

### 6.2. Scan of wave parameters

Using the hydrodynamic potentials, hydrodynamic pressures are computed for a large scan range (several thousand waves) of wave parameters (length, direction, phase angle, ship’s speed - the wave height is deduced from the reference wave amplitudes).

Condition		Range				Factors					Wave-Situation					value found	Info	
Title	Min/Max	X.Lpp		W-dir		Shear		Torsion	BM		W-Ampl	WL.Lpp	W-direction	W-phase	Add. heel	v/vMax		
		from	to	from	to	Horiz.	Vert.		Horiz.	Vert.								
Max. V. Bend.	Max.w.SW	0,30	0,70	0,0	180,0	0,00	0,00	0,00	0,00	1,00	4,95	0,90	0,00	350,00	0,00	0,67	10693472,27	Plot
Min. V. Bend.	Min.w.SW	0,30	0,70	0,0	180,0	0,00	0,00	0,00	0,00	1,00	4,53	1,00	180,00	170,00	0,00	0,67	-1312437,33	Plot
Max. H. Bend.	Max.w.SW	0,30	0,70	0,0	180,0	0,00	0,00	0,00	1,00	0,00	3,37	0,35	120,00	100,00	0,00	0,67	1501556,01	Plot
Max. Tors.	Max.w.SW	0,30	0,70	0,0	180,0	0,00	0,00	1,00	0,00	0,00	4,94	0,90	30,00	340,00	0,00	0,67	724235,97	Plot
Stillwater	Fix.w.SW										0,00	1,00	0,00	0,00	0,00	0,00		Plot
Stillwater	Fix.w.SW										0,00	1,00	0,00	0,00	0,00	0,00		Plot

Fig. 7: Selection of load cases. For example, by specifying “Max. w. SW”, the maximum (including the still water contribution) of the specified linear combination of shear, torsion, and bending in the specified longitudinal range for all waves in the specified wave direction range is selected – the wave parameters found are displayed in the grey (denoting output) fields. Alternatively, by specifying “Fix. W. SW”, wave parameters can be entered manually into the same (now white, denoting input) fields.

### 6.3. Selection of relevant waves

Using the hydrodynamic pressures resulting from the scan over a large wave parameter range, section loads are computed (using stored unit section loads of the mass distribution). Section loads are defined as those forces and moments that have to be applied at a cut through a formerly balanced model in order to maintain equilibrium. They are computed by summing all forces and moments (here, nodal forces due to the acceleration of the mass distribution and hydrodynamic pressures) up to the cut position for various longitudinal cut positions.

The computation of section loads (and later, the generation of FE load cases) requires balanced loads, i.e. the combination of inertial loads and hydrodynamic pressures shall not result in any residual forces or moments. This may not be the case if the inertial loads are computed from the mass distribution using the acceleration resulting from hydrodynamics (e.g. because of the different shell representations). For this reason, factors for the inertia unit load groups are computed such that no

<sup>1</sup> Due to the non-linear relation between wave height and bending moment, the reference waves have to be found iteratively. The algorithm (demonstrated for a prescribed bending moment  $M$ ) is:

1. Initialize the amplitude  $A$  to some arbitrary value
2. Find (for this amplitude) the wave parameters for which  $M$  takes on the maximum  $M_{max}$
3. Scale the amplitude according to  $A \leftarrow AM_{max} / M$
4. Repeat 2. and 3. until convergence is achieved

residual forces or moments result from a linear combination with the hydrodynamic pressures, these factors are then used as “effective” acceleration components.

Waves are selected by user defined section loads extrema (optionally including static section loads, like “maximal vertical wave bending moment” or “maximal total torsional moment”). Plots of section loads and hydrodynamics pressures assist in adjusting the criteria for the automatic selection or the prescribed wave parameters for “fixed” entries. Usually, approximately 20 relevant waves are selected, each defining a finite element load case.

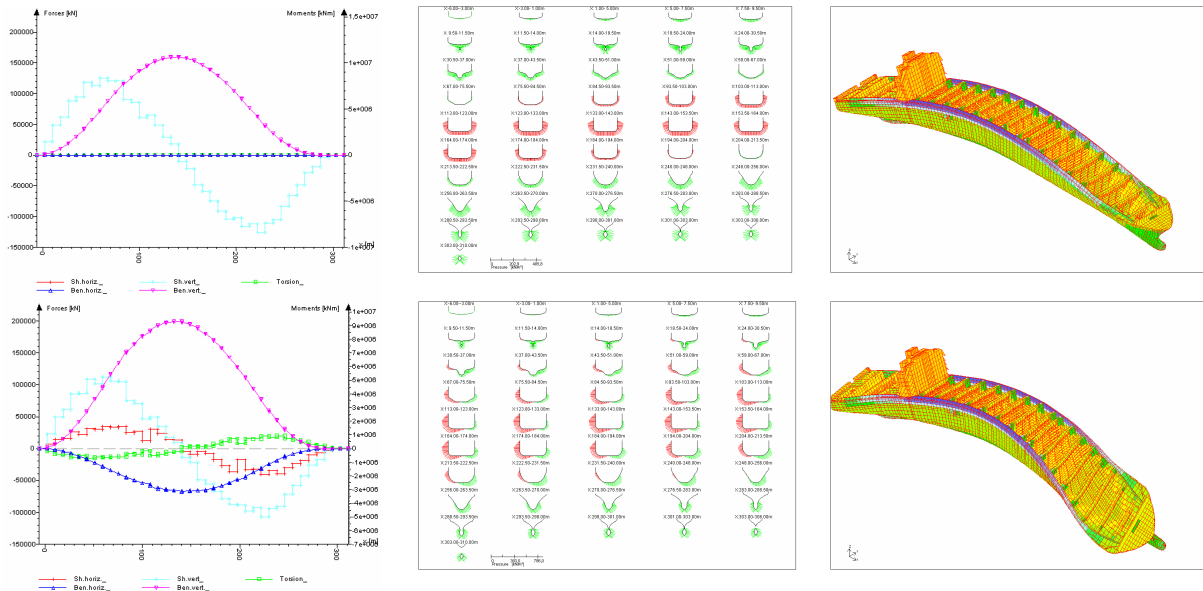


Fig. 8: Section loads, pressures and displacements (result of the FE Analysis) for the maximum vertical bending moment and the maximum torsion load cases.

### 7. Generation of nodal loads

For all selected waves, hydrodynamic pressures are converted to nodal loads acting on the shell of the FE model. These loads are combined with the unit load groups resulting from (dynamic) mass acceleration (again, the factors are computed such that no residual forces and moments result) and the static load groups (weight and buoyancy) into balanced load cases suitable for the FE analysis.

Hydrodynamic pressures (acting on the hydrodynamic shell representation) are converted to nodal loads (acting on the FE shell representation) in a way that the total forces and moments remain identical. A major problem is posed by the hydrodynamic shell description (strips) being generally much coarser than the FE shell description, such that simple interpolation of the pressure only to the nearest FE nodes leads to large localized forces (and in consequence to large displacements, rendering the results unusable for a detailed local analysis). For this reason, a more elaborate interpolation routine that distributes pressures homogeneously to FE nodes is provided with GL.ShipLoad.

Nodal loads can be appended to the FE model (in the BMF file format). They are then stored in the form of load groups and load factors. Alternatively, nodal loads can be output directly to ASCII files suitable for processing in ANSYS or NASTRAN.

### 8. Conclusions

The application of loads to a ship in regular waves is an important task in a global strength analysis with the Finite Element Method. It is fundamental for an application of the design wave approach. GL.ShipLoad integrates the necessary steps for this task such that starting from the global FE model,

all necessary input for the generation of pressure and inertial loads can be given in one environment.

Particular care has been given to an efficient and comfortable input of the mass distribution for several loading conditions. This includes cargo, outfitting, and tanks. The optional direct output of FE masses (instead of inertial loads) supports the later dynamic analysis of the ship.

Due to the use of an efficient and proven hydrodynamic method, the loads for hundreds of different wave situations can be generated in an interactive session. Non-linear correction is applied to obtain realistic pressures also above the still water line. Using section forces and moments as criteria, the most relevant waves can be selected either manually or automatically. In particular, GL.ShipLoad facilitates the application of the GL *Guidelines for Strength Analyses of Container Ship Structures*.

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