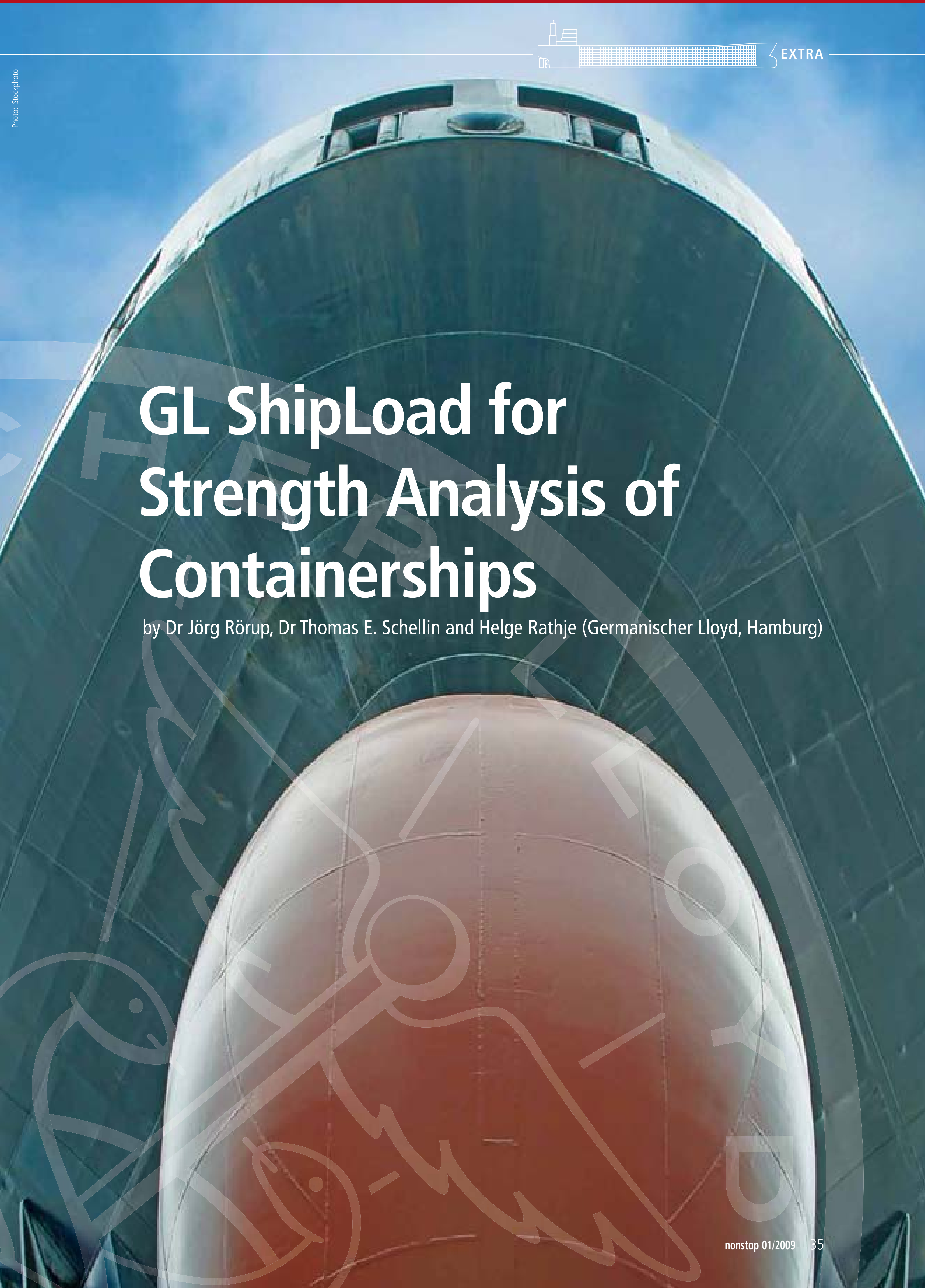

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GL ShipLoad for Strength Analysis of Containerships

by Dr Jörg Rörup, Dr Thomas E. Schellin and Helge Rathje (Germanischer Lloyd, Hamburg)

For several years now, the dimensioning of complex ship structures has been based on finite element (FE) analyses of the entire ship [1–3]. Unlike the traditional rule-and-formula-based design, this method aims to reflect the actual loads computed for the ship.

GL ShipLoad was developed as a user-friendly software tool for efficient generation of realistic loads to enable a reliable global FE analysis of containerships [4, 5]. Based on the design-wave approach, this software identifies the most relevant load combinations for dimensioning a ship's structure. By performing first-principle hydrodynamic computations for regular waves, GL ShipLoad determines wave-induced pressure and ship acceleration values.

Structural loads result from the acceleration of masses (inertial loads) and from external (wave-induced) pressure. GL ShipLoad models the mass distribution of a ship and its cargo, computes hydrostatic and hydrodynamic wave-induced pressures, and combines both load types to generate balanced, quasi-static load cases.

User-defined selection criteria, such as the maximum total vertical bending moment or maximum torsional moment, specify the waves used for global strength analysis. By choosing loads specified by the Guidelines for Strength Analyses for Ship Structures with the Finite Element Method [2], the tool can create rule-based envelope curves of global sectional loads by approximation. A large number of wave situations must be analysed to identify the design waves needed. Roll contributes significantly to the initial torsional moment in the fore holds [6] and must be accounted for when analysing aspects such as hatch cover deflection and the corresponding hatch corner stresses.

Performing a structural analysis on this basis involves several tasks [5]:

1. **generating an FE mesh, capturing the structural properties of the hull**
2. **selecting two critical loading conditions for structural analysis, usually the maximum and minimum hogging moments in still water**
3. **adding grouped masses to the FE model, representing loads related to cargo and consumables**
4. **establishing hydrostatic balance for this loading condition**
5. **performing a linear calculation of ship motions and accelerations**
6. **computing wave-induced pressures acting on the ship's hull, accounting for non-linear adjustments**
7. **generating dynamic balance for the FE model**
8. **performing a systematic analysis of different wave situations**
9. **selecting the critical design load cases**
10. **performing the structural analysis.**

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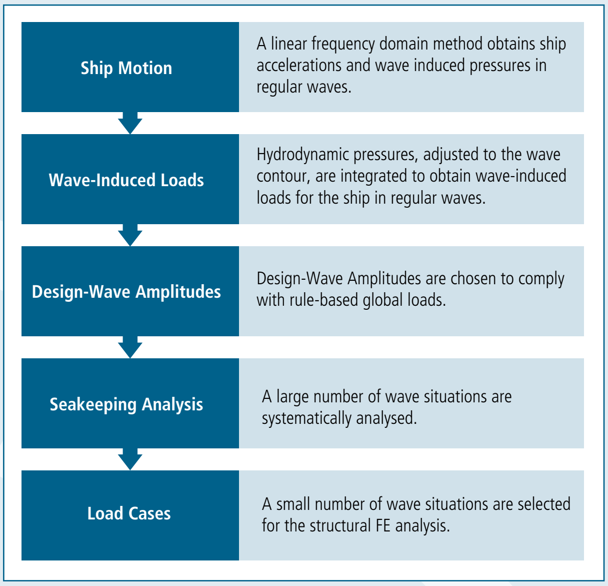
Process Descriptions

GL ShipLoad was developed to provide a convenient software tool for performing all necessary steps of the load case generation process without requiring expert knowledge in hydrodynamics.

The hydrodynamic part of the processing cycle in GL ShipLoad, schematically represented in Fig. 1, begins with the application of a linear frequency domain strip theory to calculate ship accelerations and wave-induced pressures for the ship advancing at constant forward speed in an environment of regular, unit-amplitude waves of different lengths and directions. Hydrodynamic pressures are then adjusted to the wave contour of finite amplitude waves to account for effects of extreme bow flare and strong stern overhang, yielding non-linearly corrected (pseudo) transfer functions of wave-induced pressures in waves of various heights. Next, these pressures are inte-

CONTAINERSHIP. Typical excessive bow flare and stern overhang.



Ship Motion	A linear frequency domain method obtains ship accelerations and wave induced pressures in regular waves.
Wave-Induced Loads	Hydrodynamic pressures, adjusted to the wave contour, are integrated to obtain wave-induced loads for the ship in regular waves.
Design-Wave Amplitudes	Design-Wave Amplitudes are chosen to comply with rule-based global loads.
Seakeeping Analysis	A large number of wave situations are systematically analysed.
Load Cases	A small number of wave situations are selected for the structural FE analysis.

FIGURE 1. Key steps of hydrodynamic load generation.

grated and combined with the inertial forces to obtain the global loads acting on the ship structure.

Design-wave amplitudes are chosen to comply with rule-based bending moments. From a large number of wave situations characterized by systematic variations of wave heights, wave lengths, and wave headings, a smaller number of regular design waves are selected to subject the hull girder to the required maximum loads.

Imbalances between pressure and inertial forces caused by non-linear corrections are compensated by adjusting the ship's accelerations. This ensures balanced global loading of the structural finite element model.

Load Groups

Any load case processed for the FE model is a combination of specific load groups. This approach provides an efficient repertoire of loads for many different wave conditions. All loads are assigned to one of the following load groups:

1. **hydrostatic buoyancy loads**
2. **static weight loads**
3. **static tank loads**
4. **six inertial unit load groups resulting from the three translational and three rotational rigid body accelerations of all masses except the tanks**
5. **six inertial unit load groups resulting from the three translational and three rotational rigid body accelerations of the tanks**
6. **one hydrodynamic load group for each selected wave pressure distribution.**

Combining the first three load groups produces balanced hydrostatic load cases. Inertial load groups must be multiplied by the accelerations relevant for the respective load case. Balanced dynamic load cases are then obtained by combining the results with the hydrodynamic load distribution.

Mass Distributions

For a containership, components of a mass distribution are typically grouped into assembled mass items that define reusable building blocks. These mass items comprise the steel weight of the hull, the equipment and accommodations (lightship weight), fuel oil, fresh

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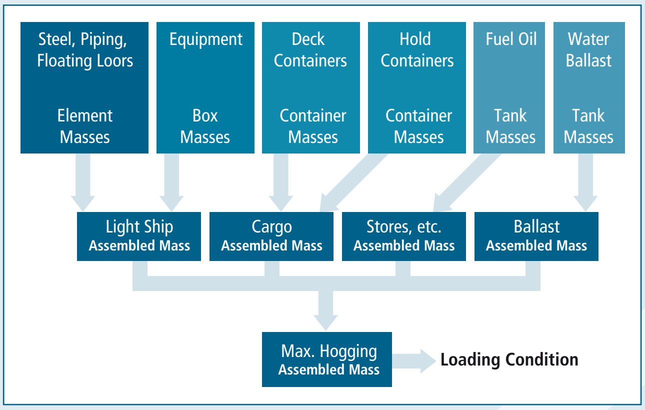


FIGURE 2. Typical masses grouped into assembled mass items.

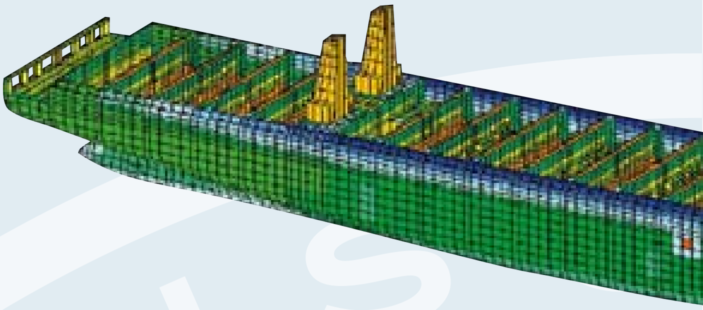


FIGURE 3. Global FE model.

➔ water and other consumables (bunkering), water ballast and cargo.

While some mass components differ for each loading condition, such as bunkering masses at departure and arrival, other mass components remain the same for each loading condition, such as lightship weight. For ease of use and reuse in typical loading situations, the basic mass components are grouped into assembled mass items as represented in Fig. 2.

Basic and assembled mass items form a so-called mass matrix. A mass matrix assigns nodal loads to nodal accelerations derived from computed rigid body accelerations. Translational accelerations are directly applied to all nodes; rotational accelerations are converted into translational accelerations. The lightship weight of the hull is obtained by applying a material density to finite elements. It is common practice to scale element masses to account for structural components not included in the model, such as brackets. To meet a centre of gravity position specification for the weight of the hull structure, different material densities can be used for individual element groups.

The remainder of the lightship weight (machinery, hatch covers and outfitting) and the consumables are represented by a distribution of nodal masses in relevant regions according to their locations and centres of gravity using so-called box masses. Box masses distribute a prescribed total mass within a spatial region that is described by one rectangular box or by a combination of rectangular boxes.

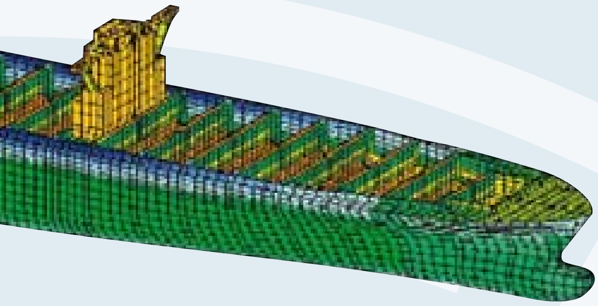
The mass within each box, specified by two diagonally opposing points, is distributed as homogeneously as possible. A given centre of gravity may be entered. User-defined box masses are also used to define tank geometries. Topologically closed regions in the finite element model, so-called closed cells, are used to identify tank loads. The tank masses are distributed among the relevant nodes of the tank based on a hydrostatic pressure distribution scheme that accounts for the fluid level and density.

The location of each container is pinpointed by defining the locations of container bays and container tiers. An interactive graphical representation of the relevant ship cross-section and the containers to be accommodated ensures continuous visual control of the process. While the procedure for transferring container masses to the ship's structure is the same for hold and deck containers, they differ in terms of nodal degrees of freedom.

In the case of hold containers, all lateral loads in the longitudinal and transverse directions are applied to the fore and aft transverse bulkheads, while the vertical forces are transmitted through the corner fittings of 20' or 40'containers onto the inner floor of the hull or a deck supporting the containers. For deck containers, hatch cover specifications determine which nodes are subject to container loads. Vertical loads are applied to the fore and aft hatch coamings through the corner fittings of a 40' container, while horizontal loads act upon the stopper locations.

Hydrostatics

The ship's hydrostatic equilibrium in calm water determines its trim and heel. To achieve hydrostatic equilibrium, GL ShipLoad relies on a Newton iteration of draft, trim, and heel until



buoyancy forces and moments are in balance with the mass distribution, whereby a finite difference scheme computes the Jacobian matrix required for the Newton iteration.

Then, integration of hydrostatic pressures over shell elements idealizing the hull yields buoyancy forces, and multiplying distributed masses with the gravity vector (in ship coordinates) determines gravity forces.

Hydrodynamics

Excessive bow flare and stern overhang are common features of modern containerships. For large ship motions that do not involve bow emergence or water on deck, the non-vertical sides at the ends cause non-linear ship response.

Accounting for these non-linear effects can lead to significant differences compared to linear wave-induced loads. Hachmann [7] formulated a computationally efficient method that extrapolates hydrodynamic pressures above the calm water level. This method is implemented in GL ShipLoad to obtain non-linearly corrected pressure predictions that extend up to the wave contour.

In assessing hydrodynamic loads, it is necessary to consider a range of sea conditions and headings that produce a critical response of the structure. For containerships, the following three global sectional loads are usually identified as critical loads:

1. **vertical bending moment (VBM)**
2. **horizontal bending moment (HBM)**
3. **torsional moment (TM).**

Additional load parameters may be specified. For example, if slamming loads affect the design, vertical accelerations at the ship's ends must be considered as critical load parameters.

Numerous wave situations are analysed by systematically varying wave length, wave crest position (phase angle of the wave), and wave heading. For every loading condition, about 20 load cases are finally selected for the FE analysis. Waves required for the strength analysis may also be selected manually by specifying the height, length, heading, and phase angle of the wave along with the ship's speed. Based on the global sectional loads listed above, GL ShipLoad facilitates an automatic selection of wave parameters. ➔

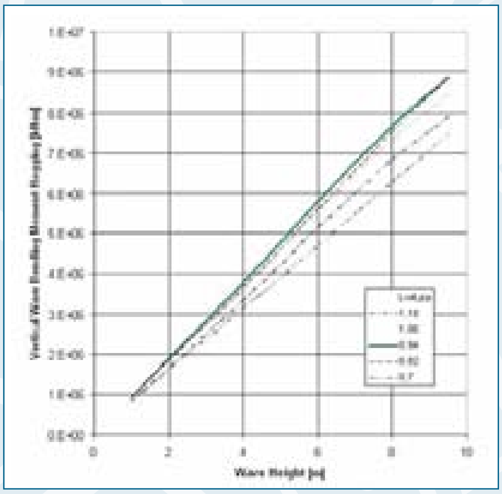


FIGURE 4. Vertical wave bending moment hogging vs. wave height (Lw = wave length, Lpp = ship length between perpendiculars).

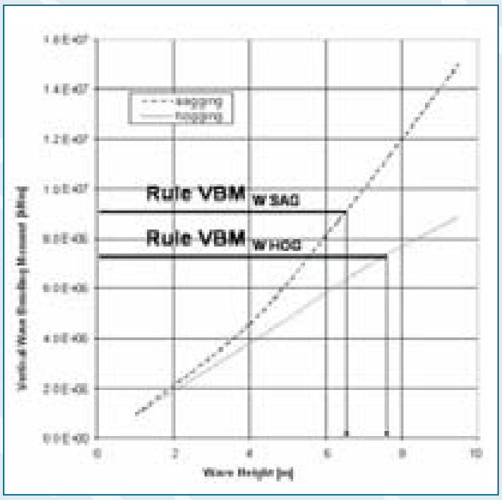


FIGURE 5. Selection of the design wave height.

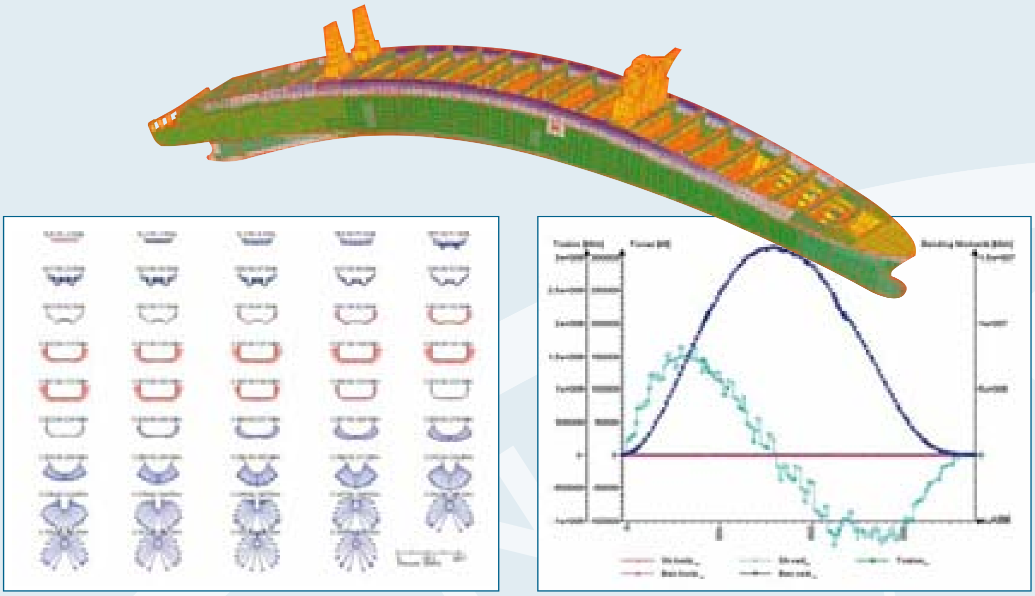


FIGURE 6. Hydrodynamic pressures, sectional loads, and hull deformation for the maximum bending moment.

➔ Obviously, the wave height must be excluded from the variable parameters when searching for sectional load extremes since there would be no upper bound on hydrodynamic forces if the wave height were allowed to become arbitrarily large.

Instead, so-called reference wave amplitudes are derived from rule-based bending moments, shear forces, or torsional moments. The applied wave height is thus a function of the reference wave amplitudes for each wave length and phase angle.

Equivalent Design-Wave Approach

The equivalent design-wave approach is a compromise between the rule-based load approach and the physical-load approach. The underlying assumption is that if the ship is designed to resist loading caused by selected design waves, it will resist all loads expected during its lifetime.

The software tool GL ShipLoad implements this approach by selecting design waves that represent load combinations relevant for dimensioning the structure from a set of harmonic waves. Amplitudes of design waves are scaled such that only one wave causes the design load while none of the other waves cause larger loads.

Generally, these computations are extensive. Therefore, to expedite calculations, one or more so-called dominant load parameters (DLPs) may be specified by the classification society. Based on previous experience with similar ships, such load cases represent critical wave loading conditions.

Analysis of a Sample Containership

We performed a global FE strength analysis for a 13,000-TEU containership. Table 1 lists its principle particulars; Fig. 3 shows our global FE model.

Loads applied to the FE model were broken down into appropriate load groups, such as deck containers, cargo hold containers, ballast and fuel oil, etc., and distributed among the nodes of the FE model based on the loading case under investigation.

A strip-theory-based code solved the linear problem of a ship advancing at constant speed in waves. We added viscous roll damping according to Blume [8] and corrected for non-linear hydrodynamic pressures in finite amplitude waves according to Hachmann [7].

To determine the design-wave amplitude, the first step was to establish the critical wave length that resulted in the maximum vertical bending moment at a given amplitude. The DLP according to [7] was the midship vertical bending moment in hogging under head and following sea conditions. In this case, the critical wave length was 0.94 times the ship's length (Fig. 4).

Length between perpendiculars	366,0 m
Molded breadth	54,2 m
Molded depthe	27,7 m
Molded scantling draft	15,0 m
Design speed	26,0 kn

TABLE 1. Principal particulars.

FIGURE 7. Typical hatch-corner crack damage.

According to [2], the smallest wave height resulting in the maximum required wave bending moment (VBMWH) had to be selected as the design-wave height. For the ship under investigation, VBMWH values were 7.38 · 10^6 in hogging and 8.93 · 10^6 in sagging, and the corresponding design-wave heights turned out to be 7.82 and 6.34 m for the hogging and sagging conditions, respectively; see Fig. 5.

Wave lengths that were analysed to obtain global loads in regular waves ranged from 0.35 to 1.2 times the ship's length. Wave headings ranged from 0 to 180 degrees at 30-degree intervals. For each combination of wave length and wave heading, 50 equidistant wave-crest positions over the ship's length were considered.

From a total of 9,500 situations of the ship in regular waves, 20 design load cases were selected for each static loading condition. They were selected by comparing the sectional moments for the vertical and horizontal wave bending and torsional moments to approximate the envelope curves for these moments as provided by the classification society [9].

Typical results of load computations are shown in Fig. 6 for the containership subject to the DLP that defines wave loads causing maximum vertical bending. Presented are hydrodynamic pressures acting on 44 cross sections of the ship, longitudinal distributions of total sectional loads (shear forces, bending moments, and torsional moments) that also include still-water loads, and the corresponding hull deformation. The illustration shows the deformation of the FE model with vertical exaggeration.

Enforced Roll

Large open hatch areas, characteristic of modern containerships, tend to weaken the torsional strength in the fore-hold area. Fig. 7 shows typical fatigue damage at a hatch corner of a post-Panamax container carrier. High torsional moments, especially in the →

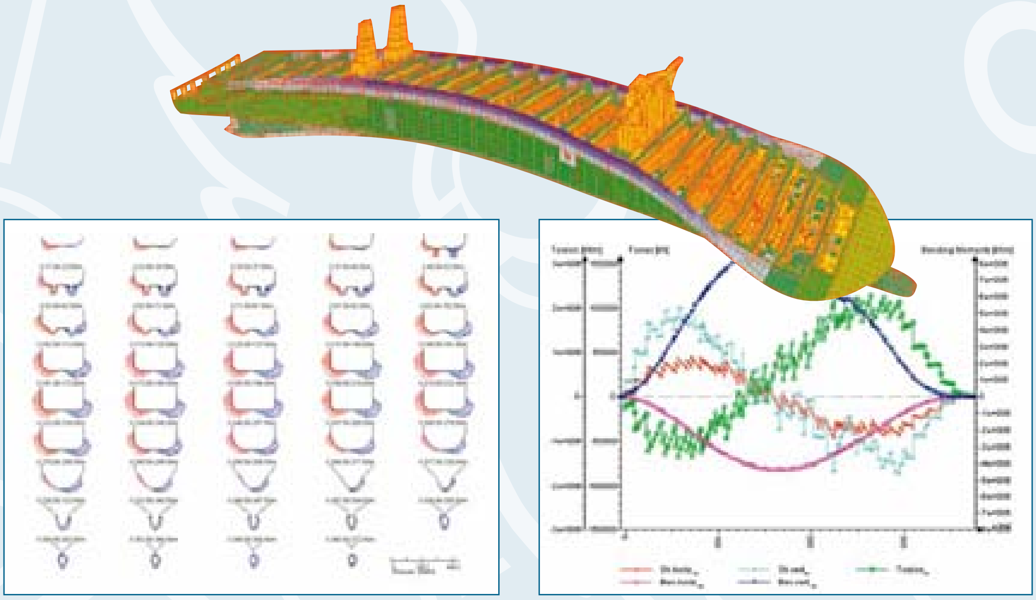


FIGURE 8. Hydrodynamic pressures, sectional loads, and hull deformation for the ship under maximum torsion and 16.0 degrees enforced roll to starboard.

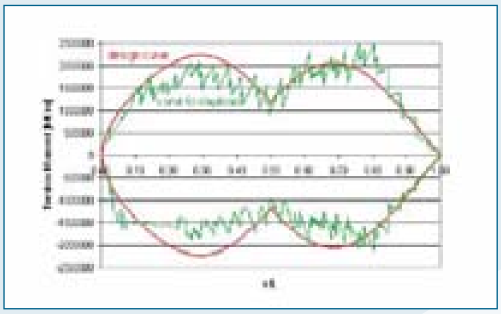


FIGURE 9. Envelope curves of torsional moments.

➔ fore-hold area, are often related to roll motions. To allow realistic simulation of the effects of an additional, roll-induced torsional moment in the fore-hold area, we specified an enforced roll angle as an additional input parameter for a subsequent FE analysis with GL ShipLoad.

To obtain design-relevant load cases, we assumed that extreme roll angles and a maximum vertical bending moment do not occur simultaneously. For the enforced roll cases we therefore analysed the ship in reduced-amplitude waves according to the Guidelines for FE Strength Analyses [2]. We performed the analysis for the two enforced roll angles of 9.2 and 16.0 degrees to both port and starboard. For these roll angles, the wave amplitude was reduced to 86 and 50 per cent of the design-wave amplitude, respectively.

Fig. 8 shows results for an enforced roll angle of 16.0 degrees to starboard. In the fore-hold area, the torsional moment (green curve) reached its maximum value. Fig. 9 depicts envelope curves of the longitudinal torsional moment distribution. The jagged (green) curve represents GL Ship Load results; the smooth (red) curve, rule-based design values. These curves show that torsional moments generated using GL ShipLoad closely approximated the envelope curve of torsion according to classification-society rules.

Concluding Remarks

A reliable computation of loads based on the design-wave approach requires the selection of load combinations that are relevant for the dimensions of the hull structure. The GL ShipLoad software package was developed to generate design loads for a global structural FE strength analysis of seagoing displacement ships.

For large containerships, FE analyses with a global structural model are generally performed to confirm adequate structural properties while minimizing design uncertainties.

To account for all critical load combinations, the relevant design-load cases have been laid down in the applicable directive [2]. GL ShipLoad offers a convenient tool that enables users without expert knowledge in hydrodynamics to perform all steps necessary for comprehensive load case generation.

References

[1] Payer, H.G. and Fricke, W., Rational Dimensioning and Analysis of Complex Ship Structures. SNAME Trans., Vol. 102, 1994, pp. 395–417.

[2] Germanischer Lloyd, Rules for Classification and Construction V – Analysis Techniques, Part 1 – Strength and Stability, Chapter 1 – Guidelines for Strength Analyses for Ship Structures with the Finite Element Method, Section 2 – Global Strength Analysis for Containership Structures, Hamburg, 2007.

[3] Shi, B.; Liu, D.; and Wiernicki, C., Dynamic Loading Approach for Structural Evaluation of Ultra Large Container Carriers. SNAME Trans., Vol. 113, 2005, pp. 402–417.

[4] Cabos, C.; Eisen, H.; and Krömer, M., GL ShipLoad: An Integrated Load Generation Tool for FE Analysis. Proc. 5th Int. Conf. on Computer Application and Information Technology in the Maritime Industries (COMPIT), Grimmelius, H.T. (ed.), Delft University of Technology, Oegstgeest, The Netherlands, 2006, pp. 199–210.

[5] Eisen, H. and Cabos, C., Efficient Generation of CFD-Based Loads for the FEM-Analysis of Ship Structures, Proc. Int. Conf. on Applications in Shipbuilding (ICCAS), Vol. II, Portsmouth, UK, 2007, pp. 91–98.

[6] Ryu, H.R.; Jung, B.H.; Probst, J.-O.; Rörup, J.; and Priebe, T., Advanced Structural Analysis for 8000 TEU Class Container Carrier by Wave Load Analysis Method Combined with Roll Motion. Proc. 9th Symp. on Practical Design of Ships and Other Floating Structures, Lübeck-Travemünde, Germany, 2004, Schiffbautechnische Gesellschaft, 2004, pp. 87–92.

[7] Hachmann, D., Calculation of Pressures on a Ship's Hull in Waves. J. Ship Tech. Res., Vol. 38, 1991, pp. 11–132.

[8] Blume, P., Experimentally Determined Coefficients for Effective Roll Damping and Application to Estimate Extreme Roll Angles. J. Ship Tech. Res., Vol. 26, 1979, pp. 3-23 (in German).

[9] Germanischer Lloyd, Rules for Classification and Construction I – Ship Technology, Part 1 – Sea-Going Ships, Chapter 1– Hull Structures, Hamburg, 2007.