Structural Design Challenges
of Ultra Large Containerships

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ABSTRACT
The size range for the largest containerships is expected to increase significantly in the near future, as economies of scale remain the dominant operational factor driving efficient transport. The largest containerships currently in service are in the 7000 teu range. Many leading shipyards, however, have developed designs for vessels with additional container rows, tiers and holds that increase the main dimensions of the vessels and increase the capacity to as much as 10,000 teu. In the future, the carrying capacity of containerships is expected to increase to 12,000 teu and above.

The trend towards increased size of containerships presents unique challenges for owners, designers, operational managers and classification societies. There are several significant issues that must be addressed by designers as they develop the next generation of ULCS (Ultra Large Containerships). Reaching beyond purely technical considerations associated with the vessel’s construction, these challenges extend into machinery limitations for higher service speeds, port crane capabilities, draft restrictions, container stack height limitations, on-land transportation infrastructure, and hub/spoke operation.

At ABS, rational structural criteria analysis is applied to large containership designs through its dynamic-based ABS SH system (SafeHull), SH-DLA analysis (SafeHull Dynamic Load Approach), LAMP (Large Amplitude Motion Program). These evaluate a vessel’s strength and identify the most critical structural elements within a design. This paper discusses the ABS SH, SH-DLA, LAMP process, the associated structural design issues and the approach ABS has taken in assuring structural safety of ULCS.

INTRODUCTION
The increase in size and use of higher strength steels, and changes of arrangement lead to ships which can fall outside the experience base on which traditional prescriptive, semi-empirical Rules are based. ABS had initiated in the early 1990’s a programme called Rules 2000 which looked at a new and more scientific approach based on engineering first principles to design and review ship structures. After a trial period as a Guide, this new approach, which is known as SafeHull, has become embodied in ABS Rules for Building and Classing Steel Vessels. SafeHull for Containerships (130 meters to 350 meters in length) was introduced into the Rules in 1998.

Large containership structural performance has, in general, been very positive. However, the trends of ever increasing size, capacity, speed and innovative design require detailed design criteria that are not available using traditional rules. The trend towards continuous increase in container carrying capacity has also been achieved by changes in design; e.g. increasing ship breadth, eliminating deck girders, narrowing width of side structure. Containership owners have recognized the importance of a rational approach to design and
the strength criteria outlined by ABS SafeHull. The objective of the SafeHull is to use the restated strength requirements to replace the traditional criteria contained in the ABS Rules.

**ABS SAFEHULL**
A ULCS designed and built to ABS class will meet the Rule requirements contained within ABS SafeHull. SafeHull provides a dynamic load based approach that considers corrosion as well as the dominant failure modes — yielding, buckling and fatigue. Shipowners recognize that ships designed to meet SafeHull criteria are demonstrably stronger and therefore safer, more durable ships and that these vessels are less susceptible to in-service, structural failure and require fewer repairs.

The ABS SafeHull System was conceived as a complete technical resource comprising two criteria—the *Guide for Dynamic-Based Design and Structural Evaluation* and *Guide for Fatigue Assessment*, as well as a comprehensive suite of software applications programs, technical support services, and related technical documentation and guidance.

ABS SafeHull for containerships incorporates a number of elements for design and evaluation by analysis.

This system is divided into two parts. During the design process, or Phase A, the general arrangement passes through a refining process beginning with an automated generation of the Hull Configuration. Next, calculations determining the dynamic loads assess the reaction of the designed vessel against specific criteria. This is followed by a determination of the structural components, compliance with strength criteria and fatigue assessment.

Evaluation of the design is the next step in the process. Commonly referred to as Phase B, this stage generates a Finite Element Model (FEM) that again runs through a calculation of dynamic loads. Following 3-D global Finite Element Analysis, the design runs through an assessment of Failure Modes. Such an evaluation of the design confirms its structural integrity. This process verifies a design with a lifetime performance able to withstand all relevant failure modes.

ABS SafeHull embodies the “net ship” concept by taking into account, at the design stage, the future effects of deterioration. SafeHull vessels are designed to meet requirements after
20 years of assumed wastage. During Structure Modeling, SafeHull uses a partial FEM to determine structure interaction and whether the area is a high or low stress area. This is needed for determining plate thickness, stiffeners and the local structure.

ABS SafeHull places an emphasis on both hull girder strength and local strength established in conjunction with specified load and failure criteria to address the use of higher tensile steels commonly found in current designs. Because of this, the failure modes of buckling and fatigue receive appropriate close attention, and in some cases they are the governing failure modes that determine the design. This distinction is a valuable feature of the SafeHull approach.

**Loads and Strength Assessment**

To obtain the combined load effects, a comprehensive set of design load cases has been developed to ensure that the maximum response has been considered by analyzing the Hydrodynamic Loads, Impact Loads, Ballast Loads, Container Loads, and Operational Loads. Loading cases are used to determine the effect of green water on deck and on hatch covers. Loads are calculated to determine the proper scantlings in a rational manner for the forebody.

The torsional strength of the hull and high stress concentrations at the hatch corners are of paramount concern. Oblique sea conditions are applied to impose maximum torsional loads at the forward and aft ends of the mid-ship cargo hold and to check the fatigue strength of the structures immediately forward of the engine room where there is an abrupt change in torsional rigidity.

ABS SafeHull encompasses a strength assessment to verify the suitability of the initial design, against the specified failure criteria. A series of load cases are specified to determine the scantlings against yielding strength, buckling and ultimate strength, and fatigue strength of the material.

Of particular importance to containerships is the design of hatch openings concerning associated loads, stresses and distortions. The large deck openings, the strong warping restraint of the engine room, and the non-prismatic hull structure of containerships cause significant torsion-induced longitudinal warping stresses along the strength deck.

Certain structural details have been identified as particularly vulnerable to fatigue. Special attention in the development of the SafeHull criteria has been given to the following fatigue sensitive areas:

- Hatch corners on the main and second decks, and top of continuous hatchside coamings
- Connections of longitudinal deck girders to transverse bulkheads, and side longitudinals to webs and transverse bulkheads
- End connections for the hatch side coaming, including coaming stays and hatch end coamings
- Cutouts in the longitudinal bulkheads, longitudinal deck girders, hatch end coamings and cross deck beams

Transverse structures, hatch openings and hatch corners must be considered together as any distortion and stress to one point influences the entire structure. As the size of
containerships continue to increase, the transverse structures become more critical with increasing ship breadth or decreasing width of the double side structures.

The result of these analyses is a vessel that meets load requirements, while avoiding sometimes overly conservative safety factors. SafeHull provides the exact knowledge of what areas need more or less consideration and answers the question of where reinforcement with filler plates best strengthens the structure and prevents cracking.

**SH-DLA (DYNAMIC LOADING APPROACH)**

The ABS SafeHull program relies on the engineering principles established in the SH-DLA program. SH-DLA was first introduced in 1991 as an engineering approach to determine the expected dynamic loads and permissible stresses acting on a vessel in a seaway, replacing the traditional semi-empirical approach. While SafeHull looks at a portion of the vessel and then makes a global comparison, SH-DLA enhances the analysis provided by SafeHull by examining the entire ship's surface in a variety of loading cases to determine where any additional reinforcements or scantlings are needed.

For containerships, SH-DLA is not a requirement for class; however, many existing ABS-classed post-panamax vessels use both SafeHull and SH-DLA to identify critical areas. SafeHull for containerships is a comprehensive approach to design verification, but as ABS' clients order larger vessels, they increasingly turn to SH-DLA to focus on all areas of critical importance, such as torsional strength analysis, to ensure vessel structural strength.

As the loads acting on a vessel come from a variety of sources, both internal and external, the motions experienced by the vessel at sea are simulated by SH-DLA to determine bending moments, sheer forces and external wave pressure acting on the hull.

The SH-DLA procedure investigates a vessel's movements through a series of dynamic evaluations. SH-DLA considers the structure of the vessel and its intended environment to consider the appropriate wave environment and the dynamic response of the vessel. Taking these two things into account, SH-DLA then applies the combined dynamic and static loads in the structural analysis, along with the distribution of the external hydrostatic and hydrodynamic pressures over the hull.

Structural response of the vessel is examined through a FEM. The results of the 3D FEM analysis generate the hull girder's overall response and are used as input for the subsequent fine mesh FEM analysis (zooming analysis). The fine mesh FEM analysis is then used to determine the more detailed local stresses, including transverse web frames, longitudinal girders, and all horizontal stringers.

These FEM results are then used to examine the stresses and deflections in the structure to ensure they fall within the prescribed limits of the failure modes of yield and buckling. The greater detail of SH-DLA provides further assurance to a robust design with a long service life.

SH-DLA represents a consistent and rational approach that employs a direct linear analysis of the containership. This reduces the "modeling uncertainties" that may be introduced when using rule scantling equations. Rule equations have necessarily relied on
simplifications to account for the applied loads, structural response and strength. The comprehensive SH-DLA analysis does not rely on these modeling simplifications and produces more reliable answers for structural components.

Just as SH-DLA can be used to further verify specific load cases, ABS employs a variety of other analyses to refine designs against known influences.

**MORE ANALYTICAL TOOLS**

Owners need a vessel that has a large capacity and the ability to move at a rapid speed. These two considerations create complex design considerations and require enhanced technical evaluations to verify structural integrity. In addition to ABS SafeHull and SH-DLA, ABS offers several analyses to guide the structural design.

**DYSOS (Dynamic Stress Analysis of Open Ships)**

As an early design stage screening tool for evaluating many different designs and identifying critical cases for detailed FEM analysis, DYSOS (Dynamic Stress Analysis of Open Ships) uses a simplified non-prismatic box beam model to obtain a full length torsional analysis. This system relies on the ABS/SHIPMOTION program and structural beam theory to provide an assessment of the torsional responses of the containership and the impact of some design alterations. These assessments are then used as guidance for the shipyard's structural design.
As the width of hatch openings increase with the ULCS, undesirable stresses (at the transition from the torsionally weak open sections to the relatively stiff closed sections) due to twist and warping occur and become one of the major design concerns. Calculations are performed to screen proposed designs for deck stress and hatch opening distortion caused by global load of vertical, horizontal and torsional moments.

SHIPMOTION is used to calculate the vertical bending moment, horizontal bending moment, torsional moment, vertical shear force and horizontal shear force, which are due to the wave pressure, vessel's motions and the inertial loads for a range of wave headings and periods. These loads are applied to the containership using beam theory. By using a non-prismatic beam model for a containership, this analysis is more efficient requiring limited modeling time but provides abundance of information of structural response. Critical wave conditions for FEM analysis can be more accurately determined based on the structural response rather than a traditional load based approach.

DYSOS can easily consider over 20 to 30 design variations in determining the global effects of torsion in a short time period. The simplified but very efficient modeling makes it well suited to perform comparative studies—resulting in an ideal preliminary design tool.

**Nonlinear Analysis by LAMP-NASTRAN System**

Compared to traditional linear theory, nonlinear theory is needed to accurately calculate the dynamic loads for modern, ultra-large containerships. The nonlinear analysis consists of two main parts: nonlinear motion and loads by LAMP (Large Amplitude Motion Program) and structure analysis by NASTRAN for the critical load cases determined from the linear seakeeping analysis or DYSOS analysis.

LAMP incorporates nonlinear motion and load theories to calculate the pressure distribution over the instantaneous actual wetted surface of the vessel in waves. The nonlinear load structural FEM analysis is performed using NASTRAN. This advanced direct calculation approach provides more realistic load and structural responses than traditional linear SH-DLA in that it accounts for nonlinear motion and loads. Nonlinear analysis results in improved design and optimized scantling for extreme sea conditions that govern the design.

Where higher uncertainties exist in the dynamic loads, such as relative bow motion, hull girder loads of bending moments, and torsional moments, hydrodynamic pressure, and green water on deck, a consistent analysis of nonlinear motion, loads, and hydrodynamic pressure is needed. The dynamic loads such as bending moment and wave pressure are, in general, more nonlinear than the ship motion responses. For example, hogging and sagging bending moment amidships are not equal in magnitude and are not linearly proportional to the wave height. Realistic behavior of the pressure time history is important for accurately predicting the fatigue life of the side longitudinal stiffeners located near the waterline.

Conventional linear theory does not accurately predict relative motion and velocity that are the bases for calculating bow flare impact, bottom slamming pressure and the corresponding whipping responses. Other areas of concern for containerships include the prediction of green water on deck and ingress water into open hatches or open-top ships.
To achieve a full nonlinear analysis, LAMP has been developed to be a complete analysis system starting from model generation, motions, and impact and structural loads for FEM analysis. Realistic random wave environment or a specific nonlinear wave can be modeled.

An integral part of the nonlinear analysis system is the mapping of hull pressure to the structural finite element NASTRAN model for structural analysis. A 3D FEM global model representing the hull girder structure and finer mesh models for local structures are used to examine the adequacy of the hull structure.

The nonlinear analysis by LAMP-NASTRAN considers failure modes of yielding, and buckling. The evaluation for yielding and buckling of the primary supporting structure of the vessel is based on the results of the fine mesh models where more accurate determination of local stresses is made.

Case Study
ABS has recently contributed technically to Samsung Heavy Industry’s development of a 9,000 teu container vessel design. ABS teamed with Samsung to review the concept designs for a new large post-panamax vessel. Using the initial scantling criteria (Phase A) and the FEM total strength assessment (Phase B) of the Rules specifications from SafeHull, the initial design was developed. Torsional analysis of 22 design variations using DYSOS was then performed to determine the effects of hull design parameters such as wing tank breadth, ship depth, double bottom height, scantling of coaming top flange on torsional response of the proposed structural designs.

Based on the structural responses on deck stress and distortion of hatch openings calculated by DYSOS, Samsung is refining the structure design. SHI and ABS have verified and refined the final hull design with the nonlinear hydrodynamic load using LAMP and full length FEM analysis using NASTRAN.

STRUCTURAL CONSIDERATIONS
The increase in container vessel size presents structural challenges for designers. Operational demands are pushing the designs into areas where there is little direct service experience. This means that a scientific approach, based on general hydrodynamics and engineering first principles, pioneered by ABS through innovative programs like the dynamic-based ABS SafeHull system, or as assessed through the more comprehensive SH-DLA, is required to develop the vessel strength parameters if the risk of structural failure is to be minimized. For ULCS, the most significant structural design aspects to be addressed are:

Deck Structure
Large hatches in the deck and large open areas of the holds leave very little deck area to accommodate the main hull girder strength of the vessel. In the latest ultra large containership designs this feature is particularly pronounced.

The combination of vertical and horizontal hull girder bending, and the torsional twisting of the hull, are critical issues to be addressed during the structural development of a successful design. The large containership designs incorporate a combination of structural arrangements such as hull thickness, continuous hatch coamings, inboard longitudinal girders and high strength steel material in order to resist these loads.
**Hatch Corners**

To accommodate stowage of the containers, large hatch openings are provided with the smallest corner radius as possible. However, it is at these corners, where the longitudinal and transverse structure meet, that the combination of the bending and torsionally induced longitudinal warping stresses is critical. Adding to the issue is the distortion of hatch openings, which also influences the stress distribution within this critical location.

The distortion of hatch openings at the hatch coaming top is also critical to the design of the hatch covers upon which the above deck containers will be loaded. Since the majority of hatch corner stresses are wave-induced and dynamic in nature, they will fluctuate and the corresponding fatigue strength of the hatch corners is a prime design consideration.

Many aspects of the design, such as: the relative strength of the transverse box beam structure at the top of transverse bulkheads, whether inboard longitudinal girders are provided, whether thick insert plates in the deck are fitted, etc., can be used to control the stresses in this area. ABS programs analyze the vessel's structure to identify where design features can be modified to increase its strength.

**Location of Deckhouse and Engine Room**

As containerships become larger and the open area of the deck is expanded, the deckhouse can be relocated to a position on the ship that can help control the hatch opening distortions and stresses. This is done by separating the deckhouse and engine rooms that are typically co-located in most recent containership designs. An added benefit of separating these two spaces is that the Navigation Bridge can be brought forward to improve visibility.
**Bow and Stern Region**
Dynamic loads resulting from bow flare impact, bottom slamming and green water loads on the fore end of a containership can be substantial. These impact loads will be more pronounced for large containerships and need to be considered in the design of the local bow structure, including the breakwater protecting the forward rows of deck containers. Similarly dynamic loads resulting from stern impacts and bottom slamming on the bottom surface of the overhanging stern of ULCS can be large due to the large flat of bottom area of the stern.

ABS studies on bow flare impact loads also show that, for the full load condition, increases in dynamic bending moment can be as much as 25 percent for ships with large bow flare.

**Transverse Strength**
The vessel beam of ULCS will increase; however, the hold lengths have remained constant since hold length is governed by the standard length of cargo containers. As a result, the aspect ratio of the cargo hold double bottom is becoming skewed toward a wide section with few floors and many longitudinal girders that intersect the vertical girders of the transverse bulkheads.

Designers must ensure that the end connections and interactions of these major structural members are properly accounted for and that all relevant failure modes such as material yielding, buckling and fatigue are assessed.

**Parametric Roll**
In addition to the structural design issues, operators of modern containerships are concerned about the parametric roll which is an instability phenomenon and can be dangerous when the nonlinear resonance energy is added to the roll motion. This was recently demonstrated when a vessel lost many deck containers in November 1999 while in the North Pacific.

Parametric roll is an unusually large non-linear roll in excess of 30 to 40 degrees resulting from the wave interaction with the large overhanging vessel shape of the bow flare and/or stern flare areas. This large non-linear motion of parametric roll uniquely affects the modern containership with its sleek design below the waterline.

Owners are now considering many ways to prevent or mitigate this unstable roll. One solution to avoid or reduce the parametric roll, often used by naval ships and offshore supply vessels, is to fit the vessel with anti-roll tanks. Other options also exist to minimize
the effects of parametric roll. Some owners elect to install active fin stabilizers, similar to those installed on naval ships and cruise ships. LAMP (Large Amplitude Motion Program) can be used to predict parametric roll which occurs only for a specific range of wave and operating condition (cargo loading, metacentric height, speed, heading, wave height and period).

Figure below shows the roll amplitudes of Series 60 hull in head seas, obtained using nonlinear LAMP. Near the wave frequency 0.55 rad/sec, the large roll amplitude was observed. In the realm of linear theory, this finite roll amplitude is not observed in head waves.

CONCLUSIONS

ABS continues to provide the tools necessary to develop new generation ULCS, just as it did for the first containership almost 50 years ago. ABS has recently contributed technically to Samsung Heavy Industry’s development of a 9,000 teu container vessel design.

As described in the previous sections, advances in load determination and structural evaluation techniques available to designers and builders have opened the door to almost unlimited increases in the size of the next generation of large high-speed containerships.

Rational criteria and scientific approach as applied through the dynamic-based ABS SafeHull system, or as assessed through the more comprehensive SH-DLA, or as evaluated through the nonlinear LAMP-NASTRAN analysis will become essential tools in designing new generation ULCS.

In the design of large containerships, extra consideration should be given to deck structure, hatch corners, the location of the deckhouse and engine room, the bow and stern regions and to the transverse strength. These critical areas are all addressed through programs offered by ABS.

In addition to the structural design challenges discussed in this paper, special design consideration should be given to the safety related operational issues affecting ULCS during service such as ballast water management, green water, lashing arrangements and parametric roll.
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