Refining the Rules

Wei Biao (Bill) Shi* examines the critical design issues posed by the increased size of ultra-large containerships

Ultra-large containerships with a carrying capacity in excess of 10 000 TEU pose challenging design issues that cannot be adequately addressed by traditional, prescriptive classification society rules or simplified structural analysis methods. ABS has applied the knowledge gained from first principles engineering analyses and extensive in-service experience of large container carriers to establish scantling requirements for ultra-large containerships that maintain the overall level of structural integrity and further improve the durability of critical structural details.

Although developed specifically for ultra-large containerships, the new rules provide a more rational approach to the establishment of appropriate strength requirements for containerships of 250m in length and greater. Application of the latest rules will result in steel being effectively distributed to critical areas that are prone to yielding, buckling and fatigue.

Previous rule requirements were developed for container carriers of 130-350m in length. With rapid expansion of the global container trade, some container carriers being designed have already exceeded the upper length limit. It is therefore necessary to broaden the application envelope of the current rule requirements to cover container carriers up to 450m in length.

The technical basis for such an extension is the first principles engineering analyses carried out for a number of ultra-large container carriers. These encompass non-linear sea load prediction, full ship Dynamic Loading Approach (DLA) finite element analysis, and analysis of spectral fatigue, bow flare slamming, springing, whipping, green water and vibration.

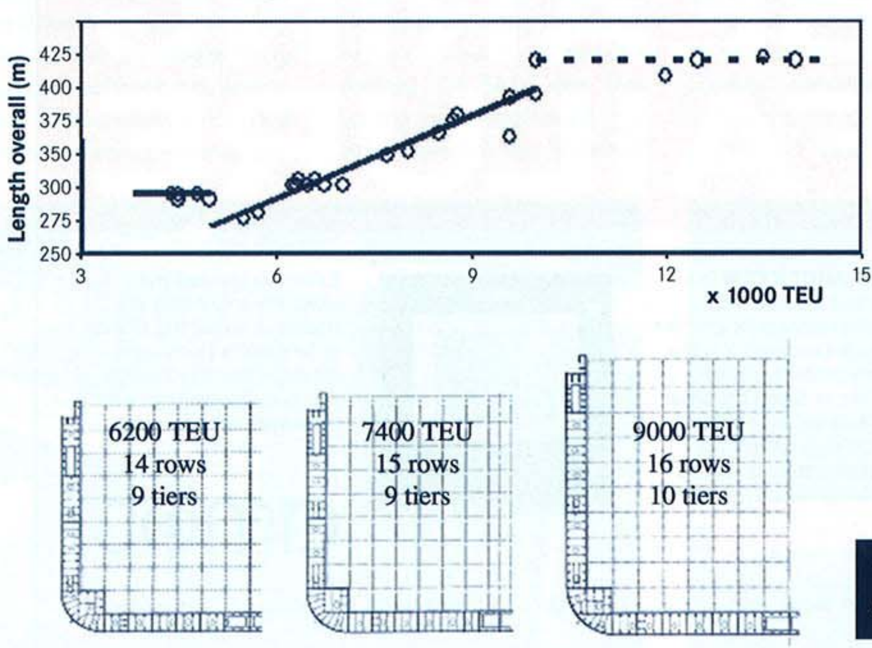


Fig 1: Design trend of ultra-large containerships

The latest rules include the following aspects of the scantling requirements:-

- ***Refined torsional strength requirements***

For post-Panamax or super post-Panamax container carriers, it is imperative that torsional response and critical structural details beyond 0.4L amidships be evaluated with desired accuracy using full ship finite element models.

For this reason, the latest rules mandate a full ship finite element analysis for container carriers over 250m in length and require compliance with the requirements of the Dynamic Loading Approach for container carriers over 350m in length.

- ***Enhanced strength requirements***

It is known that significant cyclic warping stresses in side shell/bilge longitudinals can be induced by wave torsional moment. The new fatigue strength requirements improve the connection details. The requirements are applicable to side shell/bilge longitudinals below the scantling draught. Furthermore, forebody hull structures are strengthened against buckling in the upper deck region and against shear buckling of longitudinal bulkheads due to whipping.

- ***Non-linear sea loads***

Container carriers, having large bow flare and a pronounced overhanging stern, tend to experience significant non-linear sea loads. Deviations between wave-induced sagging bending moment and hogging bending moment, and between wave-induced positive shear force and negative shear force are noticeable.

Non-linear correction factors are introduced into the IACS wave-induced hull girder loads formulations, which were developed for full-formed ship types such as tankers and bulk carriers, to account for the unique hull form of these large containerships.

Design challenges

Containerships inherently possess low torsional rigidity due to their open deck structural configuration. More pronounced than other ship types such as tankers and bulk carriers, some of the structural failure mechanisms for containerships are caused by wave torsional moment in combination with other load components in oblique seas.

For ultra-large containerships, the structural design issues associated with low torsional rigidity cannot be resolved by relying on prescriptive classification society rules or simplified engineering analysis methods which were calibrated to the service experience of mostly smaller containerships of less than 6000 TEU capacity.

The design features of these ultra-large containerships can be characterised by the principal dimensions (length overall, breadth, depth and draught) and are driven primarily by the growth in container trade and continual expansion of port facilities. Containerships of 10 000 TEU or greater are now under consideration or construction at most major shipyards in the world.

Fig 1 shows ship length overall plotted against design TEU capacity, together with typical cross sections of post-Panamax container carriers. With improved port infrastructures, the next frontier of the containership design technology could be 18 000 TEU containerships.

The positioning of the deckhouse is greatly influenced by ship length in order to meet the SOLAS visibility requirements. For an ultra-large containership, the deckhouse is likely to be placed closer to the midship region. However, the torsional strength requirements in classification society rules were primarily developed for containerships with deckhouses situated much closer to the stern.

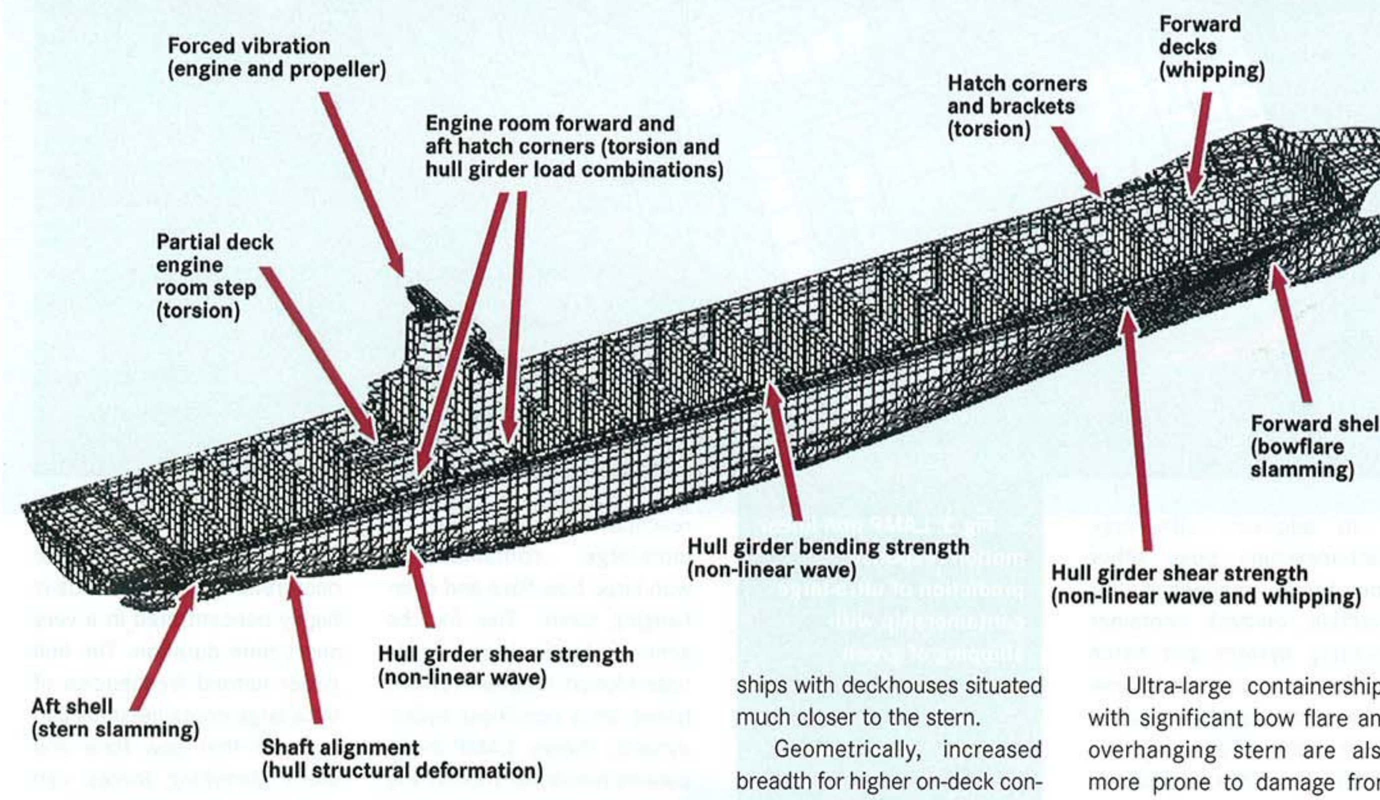
Geometrically, increased breadth for higher on-deck container capacity can result in significant bow flare and overhanging stern, which are the contributing factors for non-linear motions and sea loads. Also with increased breadth, the double bottom structure becomes a greater load bearing member, and the outboard portion of double bottom floors can be critically stressed.

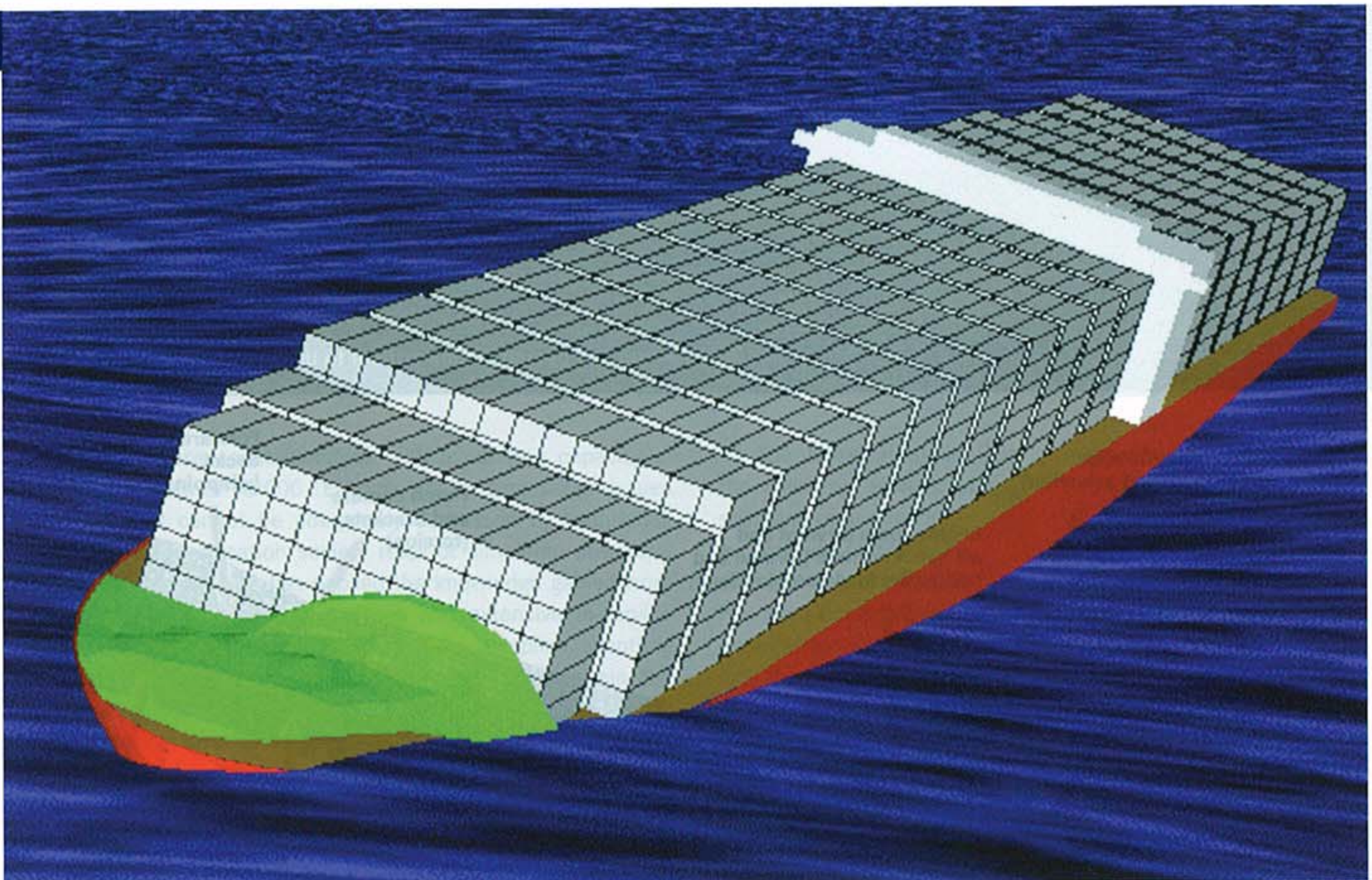
With a typical double side width less than 3m, the open deck structure of an ultra-large containership is intrinsically more flexible than its smaller counterparts, resulting in much greater hatch opening distortion. Increased forebody deck area, with large deck openings for the purpose of maximising container capacity in the forebody region can further aggravate this problem.

Ultra-large containerships with significant bow flare and overhanging stern are also more prone to damage from wave impact loads and the subsequent transient responses. Therefore, bow flare and stern slamming pressures, as well as whipping induced hull girder loads, have to be explicitly considered for these ships. Final resolution of these design issues has to rely on direct wave impact analysis.

A slender deckhouse sitting on a flexible hull structure is more likely to resonate under vibratory forces from the main engine that provides the necessary shaft power to maintain the service speed of these large ships. Hence, forced vibration analysis should be an integral part of the engineering assessment. Fig 2 highlights the structural design areas that are critical to these large container carriers.

Fig 2: Structural design issues critical to ultra-large containerships





■ Fig 3: LAMP non-linear motion response prediction of ultra-large containership with shipping of green water on deck

In addition, ultra-large containerships pose other operational challenges, for example, on-deck container securing system and hatch cover design under extensive movements between hatch cover and hatch coaming, loss of containers due to parametric roll and excessive vibratory levels in substructures. The Dynamic Loading Approach (DLA) pioneered by ABS, represents an efficient and reliable way to address these critical design issues for ultra-large containerships.

First principles analysis

The ABS Dynamic Loading Approach represents a first principles systematic dynamic loads and strength assessment procedure to evaluate ship structural strength under realistic dynamic load conditions.

This approach has been successfully applied to many ship types such as tankers, containerships, bulk carriers, FPSOs and large LNG/LPG carriers. Central to this approach is the full ship finite element analysis, integrated with large amplitude seakeeping analysis.

Unlike other ship types, hull structural responses in oblique seas are difficult to be approximated by a closed-form solution or by carrying out a finite element model analysis of a portion of the hull structure. The difficulty stems from the open deck structural configuration of the cargo hold block that is supported by relatively rigid substructures such as engine room, deckhouse, forepeak structure and fuel oil tanks. Therefore it is essential to carry out a full ship finite element analysis.

One critical component of the ABS DLA is accurate representation of wave loads on ultra-large containerships with large bow flare and overhanging stern. This can be achieved by the Large Amplitude Motion Program (LAMP) based on a non-linear hydrodynamic theory. LAMP incorporates non-linear motion and load concepts to calculate the pressure distribution over the instantaneous actual wetted surface of the ship's hull in extreme waves.

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 shipping of green water on deck, a consistent analysis of non-linear motion, acceleration and hydrodynamic pressure is essential for the full ship finite element analysis (see Fig 3).

Speed requirements, hull form and increased ship size are contributing factors that make ultra-large containerships susceptible to bow flare and stern slamming impact. The impact forces may result in local structural damage.

For these ships, the occurrence of impact loads is highly concentrated in a very short time duration. The hull girder natural frequencies of ultra-large containerships can be such that bow flare and stern slamming forces can also accentuate structural vibration throughout the hull structure. At ABS, the LAMP system is effectively applied to predict the slamming pressures on upper bow flare and flat stern regions.

The next generation of large containerships poses some engineering challenges to the maritime industry. Proper and responsible classification assessment requires that a first principles based methodology be used to rationalise the structural response of a dynamic nature. The ABS Dynamic Loading Approach, introduced above, offers a rational design philosophy for this ship type. □

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