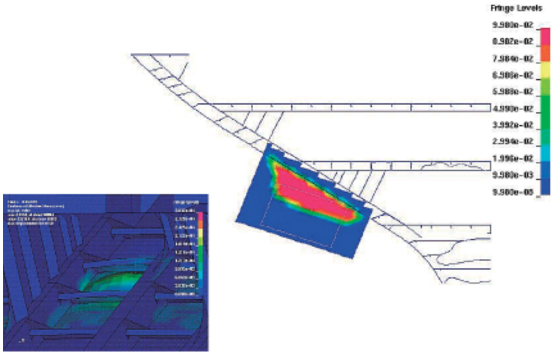

Numerical Design Approach against Bow Flare Wave Impacts

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The structural design against bow flare wave impacts has long employed semi-empirical calculations that were established by the results of model tests and actual damage records. This design method, however, relied very much on the assumptions on which the approximate equations were established. Thanks to the recent development and improvement in numerical analysis techniques, a bow flare wave impact phenomenon can be calculated more directly using the numerical simulation of fluid-structure interaction. Recently, Mitsubishi Heavy Industries, Ltd. (MHI) has established a more direct method of structural design against bow flare wave impacts by applying the latest simulation techniques instead of the semi-empirical methods. This design method was then applied to the structural design of new large-scale container carriers.

1. Introduction

Bow flare wave impacts have been an issue since around 1965 when a lot of damage was reported with bluff bows that rapidly became large and voluminous. Accordingly MHI, the Classification Society and other research and development institutes have undertaken various studies and have proposed a good many new design methods so far. Most of these studies, however, were still semi-empirical in nature where theoretical equations were approximated by adjusting and supplementing them with the results of model tests or the actual damage records at that time. While these methods are practical for actual design work and therefore effective, they still require further and intensive study from the viewpoint of theoretical accuracy.

Meanwhile, recent developments in numerical analysis codes and the rapid and greatly advanced performance of computers are creating an environment that enables the complicated phenomenon of bow flare wave impact problems to be analyzed more directly. To improve the structural reliability of products, MHI recently started a program to apply the latest numerical simulation of fluid-structure interaction techniques to the structural design against bow flare wave impacts.

2. History of bow flare wave impact problems and MHI's contribution

This section outlines the major studies in Japan on the problems of bow flare wave impact which MHI and others have undertaken to the present.

2.1 Damages and countermeasures for large, voluminous ships

With low-speed ships, mainly VLCCs (very large crude oil carriers), rapidly becoming larger and more voluminous in around 1965, many cases of damage to bluff bows due to bow flare wave impacts started to be reported, which, until that time, had hardly been heard of. The West-Japan Society of Naval Architects organized a subcommittee with participants from universities and shipyards which established a structural design guideline based on experiments, theoretical studies and many cases of damage(1). Although the number of cases of damage to large, voluminous ships has been reduced dramatically ever since, the guidelines had a limited range of application in terms of hull form, ship speed and other parameters because they had a significant reliance on approximation based on inverse analysis of actual damage records. Under these circumstances, MHI solved the behavioral mechanism between the impact pressure and the structural response by drop impact experiments with bow flare structural models. As a result, MHI proposed a design method based on the concept of extreme equivalent hydrostatic pressure that corresponds to the allowable exceedance probability level(2).

2.2 Damage to and countermeasures for ships with large bow flares

Over the period from around 1975 to 1985, reports again began to arise on damage of mid- to high-speed ships such as container carriers and pure car carriers that had large flares at their bows. The West-Japan Society of Naval Architects organized the New Bow Flare Damage Sub-committee (NBFD) that later on established new structural design guidelines that were also applicable to container carriers and pure car carriers(3). At that time, MHI was also carrying out research on and studying(4) ships with large flares, whose main purpose was to closely and precisely examine the conditions of wave impacts based on the results of the ship motion analysis and model tests. Therefore, the empirical approach based on the equivalent hydrostatic pressures and an inverse analysis based on actual damage records was still used.

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3. Simulation of bow flare wave impact using techniques for numerical analysis for fluid-structure interaction

This section briefly explains the structural response mechanism in the bow flare wave impact phenomenon and compares it with the previous methods introducing the advantages of applying numerical analysis to the design. In addition, it also discusses the repeatability of the phenomenon when using numerical analysis.

3.1 Structural response mechanism and previous design methods

The bow flare wave impact phenomenon occurs when waves crash against the ship structure at the certain relative velocity and impact angle shown on **Fig. 1**. In this case, the pressure generated and the structural response characteristics are greatly different from those created by hydrostatic pressure. As shown in **Fig. 2**, a locally generated high pressure wave moves along the structure while loading and unloading for short periods of time. The structure responds dynamically to the phenomenon in a manner determined by the geometrical and structural characteristics for example, the size and thickness of the panels.

It is difficult to analyze and develop theoretically the complex phenomenon seen above with practical accuracy and convenience for designers. As described earlier, MHI's previous design method employed, as a simplified concept, design loads called "equivalent hydrostatic pressures" and applied strength criteria based on an elastic-plastic design that allowed partial yielding of the structural members which had been established from the results of inverse analysis of actual damage records. This method was used effectively for many years for practical design. It remained, however, insufficient from the viewpoint of theoretical accuracy and precision because a quantitative evaluation of the magnitude of the structural response (the amount of residual deformation, for example) was unavailable in the elastic-plastic domain although the method allowed an elastic-plastic design.

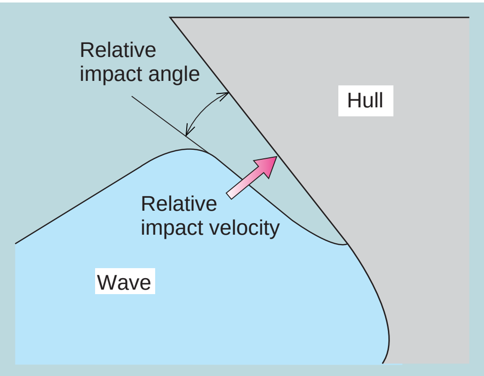

Fig. 1 Phenomenon of bow flare wave impact

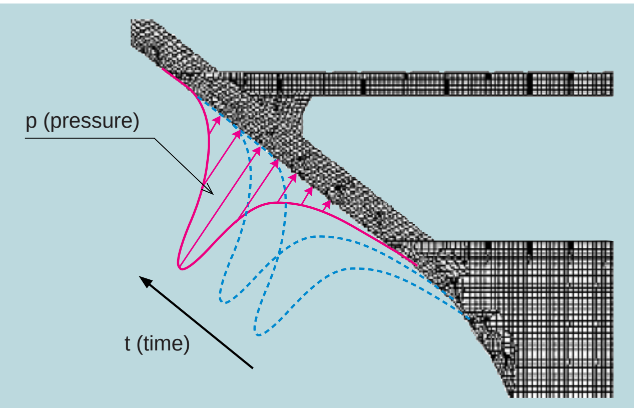

Fig. 2 Structural response mechanism
Locally generated high pressure is exerted for a short period of time while moving, causing a structural response.

3.2 Response simulation by numerical analysis

To cope with the above, MHI recently started a simulation using LS-DYNA, which is a fluid structure interaction code, to the structural design against bow flare wave impacts so that a more precise direct calculation could be introduced as the design method. LS-DYNA is a general purpose finite element analysis program developed by the US company LSTC and is presently used worldwide. The program enables dynamic elastic-plastic analysis for fluid-structure interaction problems using fluid models expressed by Eulerian elements and structural models expressed by Lagrangian elements.

Figure 3 is a sample of a time domain structural response (displacement) due to bow flare wave impact loads calculated by this analytical code. One of the features of the design method using this simulation is that the amount of residual deformation in structural members can be calculated quantitatively. In other words, by application of this analysis, designers can determine the structural scantlings with consideration of the allowable amount of residual deformation when they conduct elastic-plastic structural design against bow flare wave impacts given as statistical extreme loads.

Furthermore, when this analysis is applied to the inverse analysis of damaged ships, the bow flare wave impact load which occurred on a ship can be estimated accurately based on the amount of residual deformation.

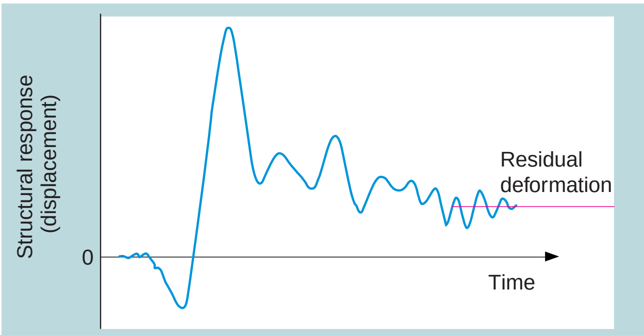

Fig. 3 An example of results of time domain response analyzed by LS-DYNA
The amount of residual deformation generated in the structure can be quantitatively calculated.

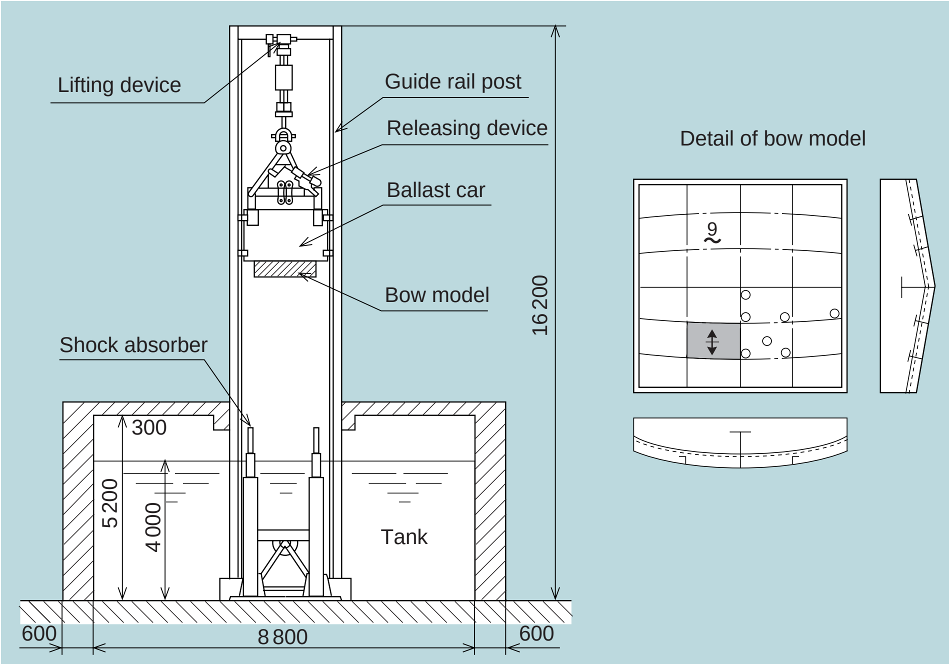

Fig. 4 Drop impact test of bow model
Experimental model falls onto water surface in tank to measure pressures generated and time-history structural response.

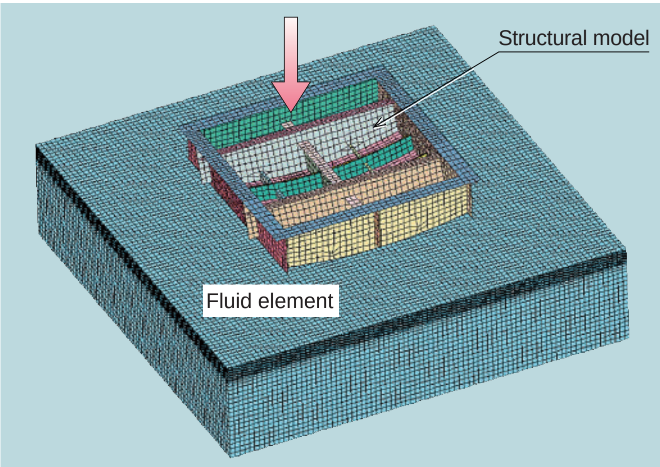

Fig. 5 Numerical analysis model corresponding to model drop test
Given drop speed, structural simulation model hits surface of still water.

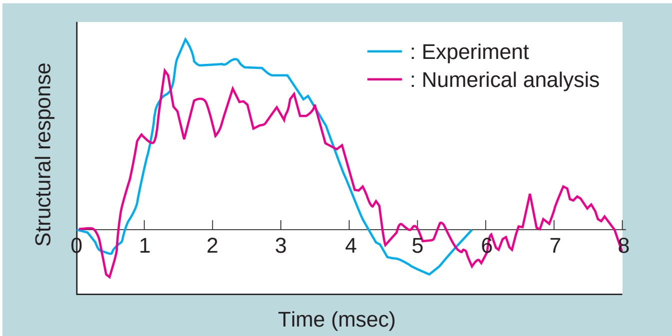

Fig. 6 Comparison of structural response between experiment and numerical analysis
Numerical analysis simulates experimental values with sufficient accuracy.

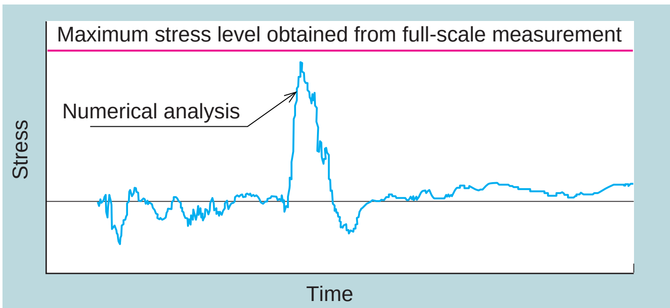

Fig. 7 Comparison of structural response between full-scale measurement and numerical analysis
Numerical analysis simulates well stress level measured on actual ship.

3.3 Verification of accuracy of simulation

Before applying this analysis code to design, the results of the previous drop impact tests with the bow flare model were simulated in order to verify the accuracy of the numerical calculations.

In the drop impact test, as shown on **Fig. 4**, an experimental model partially simulating a bow flare structure was dropped from various heights onto the surface of water in a tank to measure the generated pressures and structural response.

Figure 5 shows the analytical model corresponding to this experiment. The analysis was conducted giving the structural model the same impact speed to the water surface as the drop experiment in order to simulate the experiment.

Figure 6 compares the time domain structural response between the experiment and the analysis. As is evident, it is confirmed that the analysis simulated the experiment results with a sufficient level of accuracy.

The results of full-scale measurement on an pure car carrier also verified the accuracy of this simulation. **Figure 7** compares the actual stress of the outer shell obtained from the measurement and the structural response calculated on the corresponding panel by loading the design load of the bow flare wave impact (based on the condition given by the NBFD method as mentioned above). As seen from the figure, the analysis simulates well the stress levels measured on the actual ship.

As discussed above, this numerical analysis demonstrated a sufficient level of accuracy to the actual phenomenon of a bow flare wave impact that it can be applied to the structural design of ships.

4. Application to newly-built container carriers

Having verified the applicability of the numerical bow flare wave impact simulation to design, it was used in the structural design of the bow flare of the latest container carriers built in MHI's Nagasaki Shipyard and Machinery Works. This section describes how it was used.

4.1 An example of structural design by direct calculation

Figure 8 shows an analysis model partially simulating the bow flare structure of the subject ships. The design conditions of impact velocities and impact angles were calculated by the NBFD method, a typical method for estimating design loads. As an example of the calculation results, **Fig. 9** shows the stress distribution at a representative time.

As described above, since this analysis enables a quantitative calculation of the amount of residual deformation in the subject structure, the structural dimensions can be so determined as to satisfy the allowable amount of residual deformation that is prepared for each structure separately.

For the actual structural design of the new ship, however, it is not practical to apply this direct calculation to all structural members from viewpoint of the calculation costs and design period, since the design load and structural layout are different for each one. Therefore, a more simplified design method based on the results of the numerical analysis was devised and applied during the design of the subject ships.

4.2 Simplified design method based on numerical analysis

Figure 10 is a schematic flow of the simplified design method devised based on the results of numerical analysis and applied to the design of the ship. The following paragraphs discuss an outline of the design method and its advantages compared with the previous semi-empirical one.

- The previous design method has the technical problem that it cannot evaluate the structural response in the elastic-plastic domain. This is because while the amount of elastic-plastic response depends on the time duration and area of water pressure, the mass of impacting water and the vibration characteristics of structural members, and so on, such parameters could not be considered in the previous method.
- To alleviate this, these parameters are divided into several representative types and the relationship between the loads and elastic-plastic response is prepared by numerical analysis for each type in advance in the new simplified design method
- In a step in the actual design, the scantlings of structural members are determine by applying their design loads and the amount of allowable residual deformation to the relationship between the loads and the elastic-plastic response whose type corresponds to the members under consideration.

Figure 11 shows an example of the relationship between these loads and the response in the elastic-plastic domain.

The use of the simplified method based on numerical analysis in addition to direct calculation realizes a more reliable structural design of the bow flare of this ship.

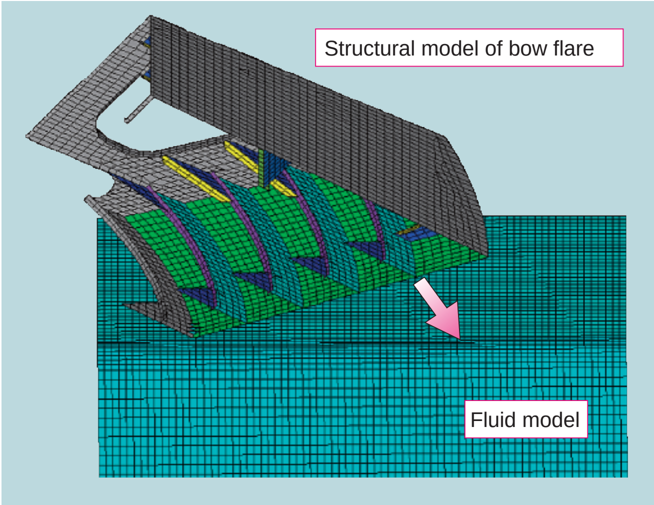

Fig. 8 Analysis model of bow flare for newly-built container carrier
Bow flare wave impact simulation was used in new container carrier.

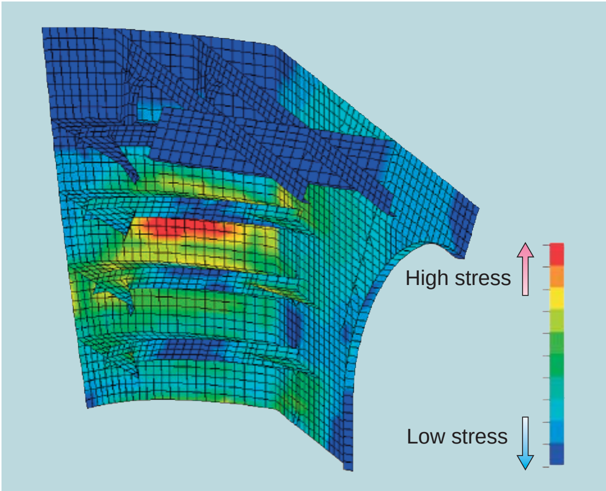

Fig. 9 Stress distribution at representative time
Applying this analysis enables the time domain stress distribution to be analyzed.

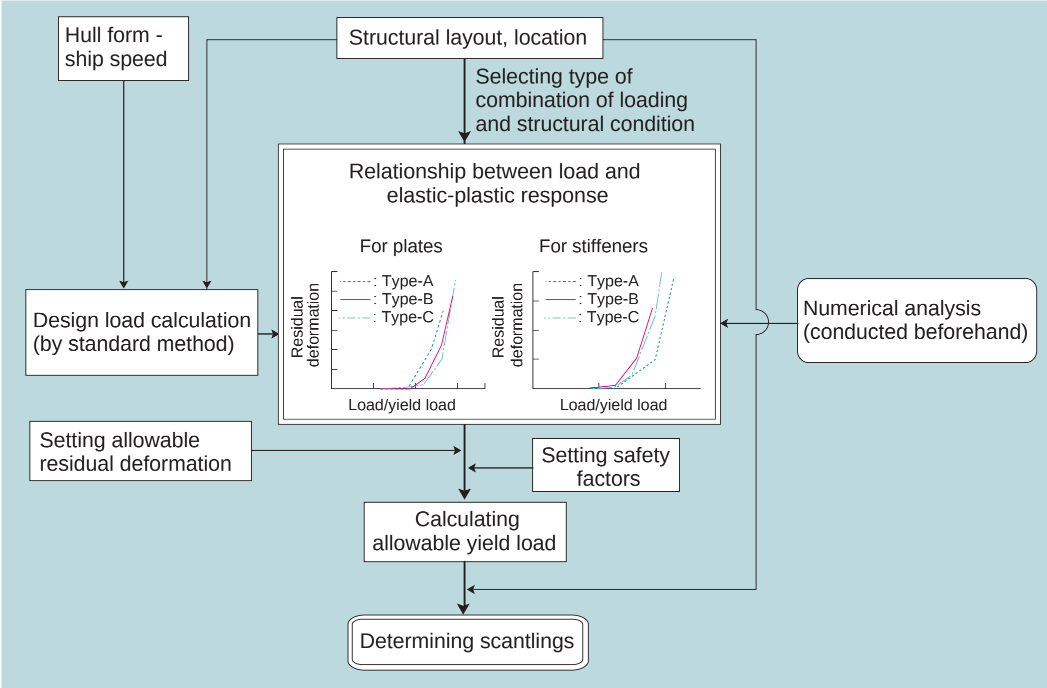

Fig. 10 Process flowchart of simplified design method based on results of numerical analysis
Scantlings are calculated accurately in simplified manner based on prepared results of numerical analysis.

5. Conclusion

Since the mechanisms from the generation of impact loads to the structural response are very complex, bow flare wave impacts are substantially a statistics problem with large variances. Therefore, while a good many studies have been conducted to propose methods of estimation, many such methods included lots of approximations with reference to actual experiences and other factors. This report has introduced a highly accurate structural design method that uses the latest simulation techniques while focusing mainly on the structural response mechanisms. On the other hand, as for the mechanism of generating bow flare wave impact loads, the assumptions used in the previous methods do not necessarily conform to the recent ships in some cases due to the recent changes hull forms and modes of transportation. Therefore, research institutes including the Classification Society and universities are continuing various studies even today. MHI is planning to put more effort into reflecting actual service conditions and to widely apply the latest analysis techniques so that ships with high structural reliability can be offered in the future as in the past.

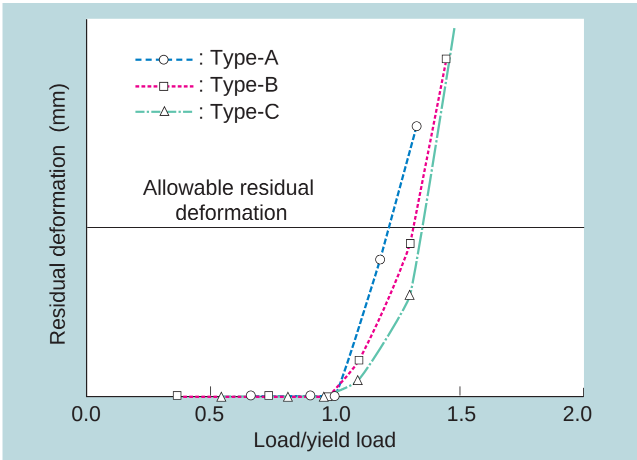

Fig. 11 Relationship between load and elastic-plastic response
Numerical analysis quantitatively estimates amount of residual deformation in member under load that partially exceeds yield stress.

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