# "MHI DILAM", the most sophisticated Fatigue Design methodology developed by MHI

- Application of MHI DILAM to the latest design of a Malaccamax VLCC –

Kazuhiro HIROTA <kazuhiro_hirota@mhi.co.jp>
Mitsubishi Heavy Industry, Ltd. Nagasaki, Japan

## Abstract

Mitsubishi Heavy Industries, Ltd. (MHI) has completed the development of the latest Malaccamax VLCC complying with Common Structural Rules of IACS (CSR). Since MHI has built a lot of VLCCs from 1960s, considerable experience, expertise and advanced technology for the design and construction are incorporated into the development of the latest Malaccamax VLCC.

In particular, full consideration to the fatigue design, has been given in order to enhance the structural reliability. State-of-the-art structural analysis with Direct Loading Analysis Method (DILAM) developed by MHI has been applied for the fatigue strength assessment of structural members of the latest design and construction of the Malaccamax VLCC. DILAM is an analysis method based on full spectral direct analysis, where wave load derived from ship motion analysis is applied directly to finite element structural model through interface system for the calculation of the response amplitude operator (RAO) of stress.

In this paper, technical overview and feature of DILAM is presented. The advantage of this technology is demonstrated showing the example of fatigue assessment by DILAM applied to the latest Malaccamax VLCC with a view to introducing shipbuilder's efforts to significantly enhance the fatigue strength and structural reliability.

## 1 Introduction

MHI has developed State-of-the-art structural analysis with Direct Loading Analysis Method (DILAM) on purpose to assess fatigue strength of special vessels such as LNGC, LPGC, etc. This paper shows the result of fatigue study by DILAM for the latest Mallaccamax VLCC, which conforms to the CSRs, is currently under construction. The main particulars of the VLCC are shown in Table-1. Also the general arrangement plan is shown on Figure1.

Table 1 The main characteristics of the latest Malaccamax VLCC

| | |
|---|---|
| Overall length (m) | Approx. 333.0 |
| Length between perpendiculars (m) | 324.0 |
| Breadth (m) | 60.0 |
| Depth (m) | 29.1 |
| Draught (m) | 20.50 |
| Deadweight tonnage (t) | Approx. 298,500 |
| Cargo tank capacity (m3) | Approx. 355,000 |
| Gross tonnage (t) | Approx. 160,300 |
| Main engine | Mitsubishi UE 7UEC85LS II |
| Main engine output (kW) | 27,020 |
| Speed (kt) | Approx. 15.5 |

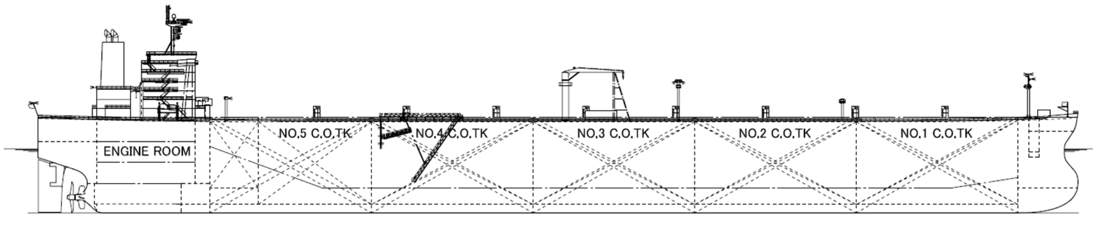


Figure 1 General Arrangement plan

## 2. Requirement of Fatigue Design Methodology by CSR for Tanker

CSR for oil tanker requires a fatigue assessment with the conditions, such as, North Atlantic wave, 25 years design life and net thickness approach.
The dynamic loads for fatigue assessment are based on a $10^{-4}$ probability level, including components such as, vertical wave bending moment, horizontal wave bending moment, dynamic wave pressure, and dynamic tank pressure. The above calculation shall be carried out for the target structures specified in the rule.

In addition, the rule gives standard detail design, for example, hopper knuckle connection, which is partly shown on Figure 2.

MHI malaccamax VLCC is designed with a bent-type hopper knuckle in accordance with the rule requirement. In addition, assessment by MHI-DILAM has been carried out in addition to the rule requirement, which is explained later in this paper.

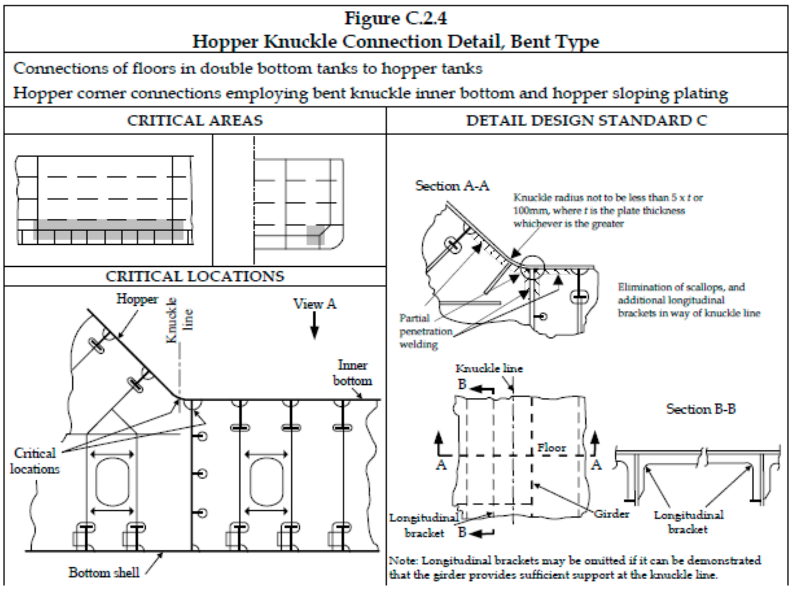


Figure 2　Example of standard design of primary member by CSR for tanker (from IACS website)

## 3. MHI-DILAM: Latest fatigue analysis method by direct wave load

### 3.1 History of MHI's development of fatigue analysis method

Mitsubishi Heavy Industries, Ltd. (MHI) has been continuously developing a simulation method extending from estimation of wave loads to structural responses and put to practical use in tandem with continuing improvements in computers and the increasing sophistication of structural designs.
MHI has been consistently at the forefront of research and development in this field since the 1970s. The company developed an analysis technique known as the MHI Discrete Analysis Method (MHI-DISAM) in the 1980s, and applied it to the design of side longitudinal stiffeners for large oil tankers. This gave momentum to the practical application of structural analysis methods based on the quantitative evaluation of physical phenomena, in addition to designs based on prescriptive rules.
Furthermore, MHI developed a new analysis technique known as the MHI Direct Loading Analysis Method (MHI-DILAM) around 2000, and its reliability as a design tool has been enhanced via numerous applications since then.
Today, the main targets of MHI-DILAM are the ships with novel design or offshore structures, where direct fatigue design shall be preferably carried out in addition to the rule. In this paper, we apply MHI-DILAM to the fatigue assessment of primary member of VLCC to confirm the rule requirement is in line with the result of direct fatigue assessment.
Before introducing particular application, the following sections outline the features of MHI-DILAM.

### 3.2 Concept of MHI-DILAM

Because ships and offshore structures are large-scale constructions floating on complex ocean waves, complex loads must be efficiently processed during structural analysis to improve the accuracy of the results. Thus far, the structural design of ships has often been carried out using simplified “design wave loads,” as shown in Figure 3. In practice, the use of design wave loads is effective for a relative comparison with existing structures. However, for the development of a new type of structure, or when manufacturing a product that exceeds the scope of conventional services (e.g., a ship of unusually large size), an analysis technique that can faithfully simulate the complexity of the loads should be adopted in combination.

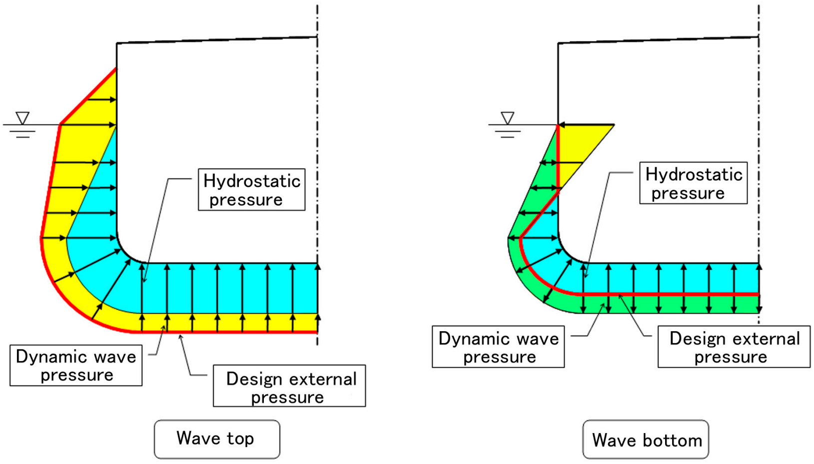


Figure 3 Example of existing design wave loads

Although actual ocean waves are “irregular waves” with complex shapes, an irregular wave can be represented as a set of “regular waves,” as illustrated in Figure 4. The typical number of regular waves that make up an irregular wave is shown in Figure 4 (i.e., 12 wave directions and about 20 wavelengths). Accordingly, MHI-DILAM divides the wave cycle into 12 steps, and automatically generates an approximate total of 3,000 load cases (12 wave directions x approximately 20 wavelengths x 12 time steps) to obtain the history of the ever-changing wave loads. MHI-DILAM carries out the structural analysis of ships by processing these complex loads with the enhanced efficiency enabled by a specialized program.

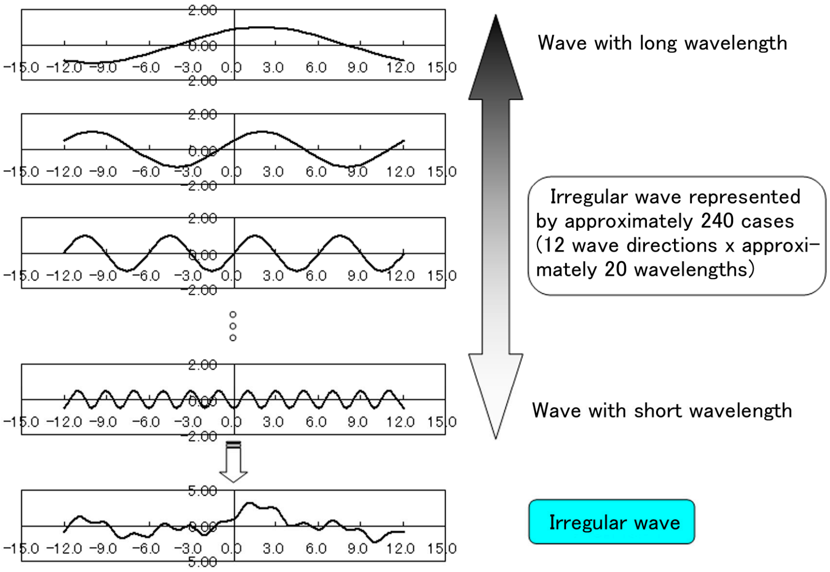


Figure 4 Image of an irregular wave

### 3.3 System configuration

Figure 5 shows a flowchart of MHI-DILAM. The following modules are used to efficiently process the complex load information.

(1) Automatic load-generation module

The automatic load-generation module processes the output files of a ship's motion analysis, and automatically generates load information data in the format used by the structural analysis program (NASTRAN).

(2) Global load-check module

The global load balance should be checked prior to structural analysis, because a load imbalance may cause defects (for example, an unnatural restraint in the analysis). The global load-check module reads the previously generated load information data, sums up the local loads, and checks the sums of the loads and moments.

(3) Post-processing module

The stress response to regular waves, processed from the analysis results of approximately 3,000 cases, is stochastically evaluated via statistical processing (spectral analysis). In addition to the statistically estimated values thus obtained, this module makes it possible to access the response results of the respective regular waves that have been broken down.

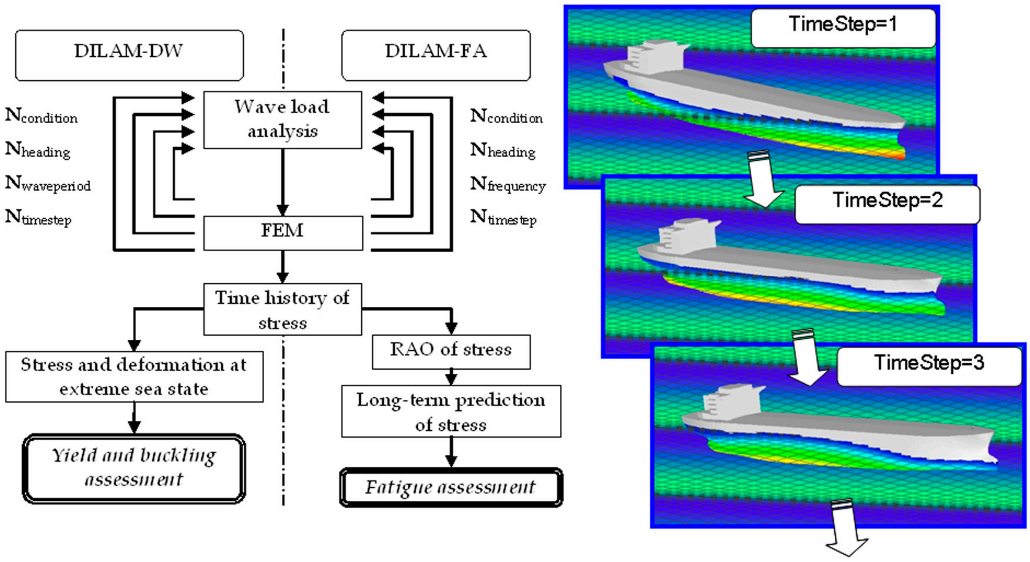


Figure 5 Illustration of MHI-DILAM

### 3.4 Evaluation of analysis results

Recently, there has been a growing demand for a longer service life and better maintainability of ship structures, and hence the importance of advanced fatigue analysis (a component technology that helps fulfill this demand) has likewise been increasing. To evaluate the fatigue limit state (FLS), a program called DILAM-Fatigue Analysis (DILAM-FA) is applied. DILAM-FA determines stress distribution of an arbitrary structure based on its response to the regular waves mentioned above, while taking into account the wave-scatter diagram of a specific ocean area. Figure 6 illustrates the technique for calculating the long-term stress distribution, which is required for the evaluation of fatigue strength.

To assess the so-called ultimate limit state (ULS), which indicates whether or not a ship structure can withstand the maximum load, DILAM-Design Wave (DILAM-DW) using "equivalent regular waves" or DILAM-Design Irregular Wave (DILAM-DIW) using "Design Irregular Wave" is applied. Design Irregular Wave is one of the latest theoretical concepts in the field of ship structural analysis. It is determined by extracting the valid components for the structural response from the wave components that constitute an irregular wave (represented by a set of independent regular waves), so that the combination of the extracted components may result in the maximum ship response.

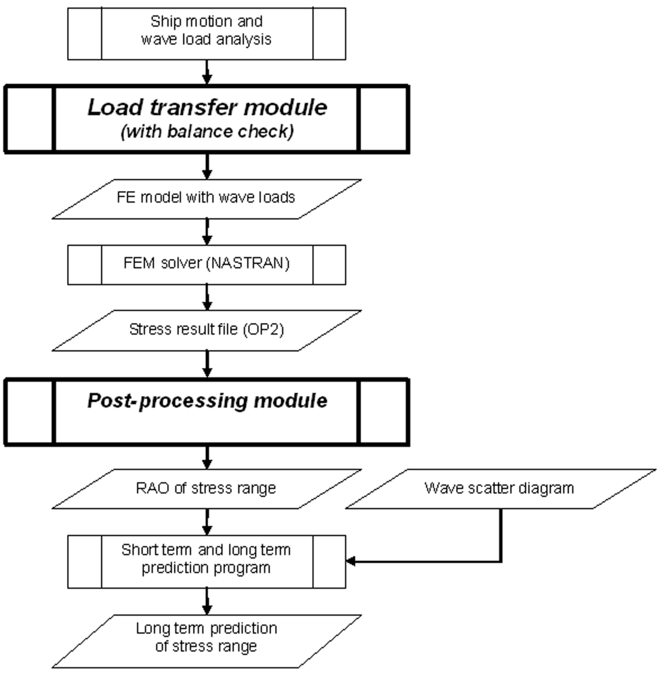


Figure 6　Flowchart of MHI-DILAM

## 4. Application of DILAM to primary member of Mallaccamax VLCC

In addition to the CSR requirement shown on Figure 2, fatigue assessment has been carried out for bent-type hopper knuckle structure as shown on Figure 7. The fatigue analysis using fine-mesh F.E.model and based on full-spectral approach confirms suitability of applied detail design. MHI-DILAM gives detailed information to the designer as explained in section 3.4, therefore they can consider structural optimization referring output from DILAM. This is one of the benefit of the MHI-DILAM as design tool.

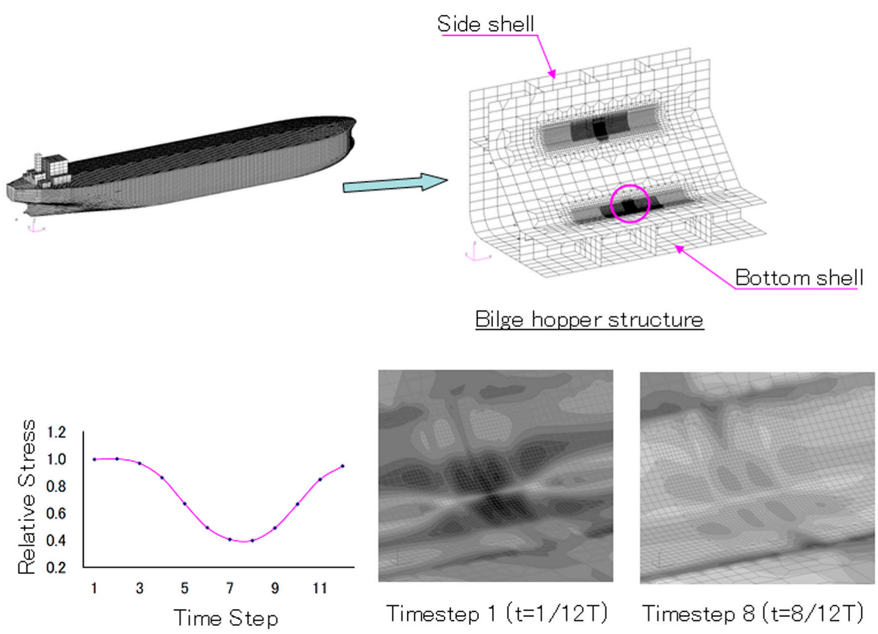


Figure 7 Stress distribution of hopper structure

## 5 Conclusion

In this paper, the technical overview and feature of DILAM is presented with the example of fatigue assessment applied to the latest Malaccamax VLCC. With considerable experience and expertise of VLCC and the new rules based on sound technical grounds, advanced technology has been adopted to significantly enhance the fatigue strength and structural reliability.

Another feature of MHI-DILAM is its technical maturity, achieved through down-to-earth efforts. Comparative study with actual service experience is continuing to enhance the evaluation technology of fatigue strength. From a historical angle in shipbuilding industries, we believe that simultaneous blending among experience, rules and new technology is the very nature of an advancement of the reliability and safety of ship structure.