PRESENT STATUS AND FUTURE DEVELOPMENT

FOR THE DESIGN AND CONSTRUCTION

OF DOUBLE HULLS TANKERS

PRESENTED BY:
MITSUBISHI HEAVY INDUSTRIES, LTD.

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ABSTRACT

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7 years have past since the first Double Hulls VLCC (D/H VLCC) of our shipyard was entered into service and, at present, basic design of hull structure of D/H VLCC is considered generally to be established by each shipyard.

Advanced structural analysis method has been progressed rapidly to become applicable at design stage and these are providing useful indexes to the designers in association with appropriate verification by enormous actual service results which has been accumulated for a long time.

In this paper, present status of D/H VLCC is explained in its outline of the structural design, detail design with consideration to HT steel and application of advanced analysis method, enhanced construction tolerance standard and recent study or development in progress in view of sufficient service life.

Eventually as future development, it is concluded that synthetic consideration that is design, construction, condition survey with engineering interpretation and its reflection on the design procedure should also be more important for further improvement of structural reliability with economical efficiency, then this would result in interactive relation among the owner, the classification society and shipyards.

Table of Contents

1. INTRODUCTION

2. STRUCTURAL DESIGN

2.1 General
2.1 Inspection and Access

3. FATIGUE ASPECTS AND STRUCTURAL DETAIL

3.1 Fatigue design in structural detail
3.2 Fatigue assessment technology
3.3 Fabrication and enhanced construction tolerances

4. SHIPS CONDITION MONITORING STATUS

5. CONCLUSION

REFERENCE

1. INTRODUCTION

Regulation 13F of Annex I of MARPOL 73/78 was adopted for the prevention of oil pollution in case of grounding or collision of oil tankers. Double Hulls or Mid-Deck design became mandatory for the construction of new oil tankers on or after 6 July 1993.

7 years have past since the first Double Hulls VLCC (D/H VLCC) of our shipyard was entered into service and, at present, basic design of hull structure of D/H VLCC is considered generally to be established by each shipyard.

On the other hand importance of fatigue assessment at design stage has become strongly recognized among the owners, for the sake of saving costs of damage repair and deficit during docking period. Fatigue assessment procedure becomes available at design stage mainly according to the progress of advanced structural analysis technology, and at the same time, the subject, which shall be solved for the improvement of the accurate fatigue assessment procedure, is clarified.

In this report present status of structural design is outlined. Up to date fatigue assessment procedures which can be used at design stage together with the importance of the verification by accumulated actual service data and, their future subject and related investigation is also detailed. The reason of the importance of interactive relation among the owner, the classification society and the shipyard for the purpose of structural reliability is explained.

2. STRUCTURAL DESIGN

2.1 General

Main hull of cargo tank region of Double Hulls VLCC (D/H VLCC) is consist of side double hull, double bottom and hopper tanks and these compartments are used as ballast tanks. Two inner longitudinal bulkheads divide cargo tank part into center cargo tank and side cargo tanks and transverse bulkheads divides cargo tanks into about 5 to 6 tanks in longitudinal direction. Outer shell, upper deck, longitudinal bulkheads and inner bottom are generally longitudinally stiffened and transverse girders are provided about 4 to 6 meter space as main supporting members.

Typical transverse section of Single Hull VLCC (S/H VLCC) and D/H VLCC are shown in Fig.1. Although there are many common points in the arrangement of structural member in both types of VLCC, the number of discontinuous points of main supporting members, i.e., transverse girders, in the structure of D/H VLCC is more than that in S/H VLCC therefore fatigue strength of those points is very important in D/H VLCC.

The position of Cross Tie is in side cargo tanks (TYPE-1) or in center cargo tank (TYPE-2) and each shipyard chooses the type respectively. TYPE-1 is the same with conventional S/H VLCC. Our shipyard applies TYPE-2 and this type is enabled because the double side structure is rigid enough.

As for another structural key point being concerned from the beginning of the design of D/H VLCC, that is the structure of the corner of hopper tanks, structural types are classified normally into the welding joint type and the plate bending type as shown in Fig.2. In both types, structural care in design and construction to be considered is different respectively because of the difference of the important part in view of fatigue aspects.

In the welding joint type,

(1) Stress concentrated part consists of load carrying cruciform joint and fatigue strength in axial direction shall be taken care of.

(2) Structural mis-alignment between member A and B affects fatigue strength and then quality control of the alignment at this part is an important subject.

In the plate bending type, as the inner hull, consisting of longitudinal bulkhead, hopper sloping plate and inner bottom plate, is not the cruciform joint, the point where structural care to be considered is different from welding joint type.

(1) The local plate bending stress in direction of perpendicular to transverse web plate at the corner should be taken care of for this type.

(2) For the improvement of fatigue strength, provision of brackets close to the transverse web or longitudinal stiffener at the center of radius are normally effective.

Application of higher tensile steel (HT) is practicably necessary considering the size of VLCC. Extent of the use of HT strongly depends on the consideration of the owner and the weight rate of HT is approximately from 20 % to 70 % in each project. Typical extent of HT is shown in Fig.3.

Extensive technical study has been carried out to resolve the fatigue problem experienced in the HT side longitudinal of 2nd generation S/H VLCC. Eventually the fatigue assessment procedure for side longitudinal is established and it is found that HT shall be applicable in association with the improvement of the structure.

The fatigue assessment procedure consists of correct distribution of wave induced fluctuating load, introduction of stress component induced by relative deflection of transverse girder, stress concentration factor considering profile of longitudinal and allowable stress which is obtained from the actual damage data of side longitudinal. Typical resultant structures applied in the area where fluctuating load is concerned are,

(1) Structural improvement at the connection to the transverse girder (Fig.4)

(2) Application of T profile to the side longitudinal (Fig.4)

Fatigue assessment procedure, which has extensively progressed through the study of side longitudinal problem, is described later in detail.

In addition to the above mentioned fatigue consideration to the side longitudinal, net scantling concept is, and going to be applied in some classification rules then it can be said that the difference between MS and HT is not exist in terms of general corrosion.

2.2 Inspection and Access

It would be recognized among the ship operator as a experience that there is a wide difference of the condition of hull in each ship depending on the condition of maintenance and actual operation, although the ship is carefully designed, applied good specification of painting and constructed under the sufficient quality control. According to this situation, the inspection and the discreet repair of ships after delivery are highly recognized of its importance in view of the safety operation during long life of the ship.

Guideline of survey adopted as IMO Resolution A.744 (18) in 1993 defines the extent and application item to be surveyed. As the hull structure is a construction of welded thin steel plate, the survey focuses on the detection of the surface defect, such as cracks or excessive corrosion, and then visual inspection and measurement of plate thickness are denoted as the item to be carried out. And reporting of “CONDITION EVALUATION REPORT” shall be made by the class to submit to the owner for the purpose of common recognition of the data. This actual ship’s data is also useful for the verification of design value and complete data will results in the progress of the design criteria.

Access means for the survey is illustrated in MSC Circular A272&A333 and fig.5 shows an example of the application in an actual ship.

3. FATIGUE ASPECTS AND STRUCTURAL DETAIL

3.1 Fatigue Design in Structural Detail

Design approach to the fatigue life in hull structure has been mainly practical solutions by the improvement of detail design at the damaged part, as illustrated in TSC or in LRS ShipRight level-1, until the side longitudinal problem in S/H VLCC described in Sec.2 is experienced, and the design of ships has been progressing by the accumulation of these kinds of design improvement for long time.

As damages in hull structure are caused mainly by the insufficient design consideration of detail design, the design improvements in detail design are the appropriate solution in most of the case. This approach is simple and effective way for the case like hull structure, of which condition is varied in each vessel as the results of suffering from indefinite element, such as wave condition or actual operated condition. And also this could be an effective approach for some cases even from now on.

3.2 Fatigue Assessment Technology

As described in Sec.3.1 it is no doubt structural improvement based on the past experienced damage is still an effective method for the countermeasure against fatigue damages.

On the other hand fatigue assessment by analysis has come to be widely applied because of the progress of structural analysis software in association with the hardware, which enables extensive structural analysis at design stage. In addition to the above, fatigue assessment at design stage tends to be requested by the owner occasionally, at the beginning of the technical discussion, for the sake of saving costs of damage repair and deficit during docking period.

In case of the VLCC, fatigue assessment is classified into 2 structural parts according to their feature of structural modeling,

(1) Connection of longitudinal to transverse girder
(2) Discontinuous points of main supporting members

Theoretical structure of fatigue assessment procedure is almost established, that consists of,

(a) Definition of load
(b) Calculation of reference stress
(c) Definition of available criteria

3.2.1 Connection of longitudinal to transverse girder

After the experience of the fatigue damage in side longitudinal, investigation was mostly focused on the mode of fracture in longitudinal, and non-linear distribution of fluctuating wave load as lateral load, additional stress induced by relative deflection of main supporting transverse girders and precise feature of stress distribution in L profile longitudinal using solid element FEA were deeply studied to be clarified.

Although accuracy of the evaluation for deck and bottom longitudinal in which longitudinal stress component is dominant still needs to be studied, many classification societies nowadays provide their standards and these seem to give practicable results to evaluate the fatigue damages in the past for side longitudinals.

This can be done because of the following reasons,

(1) Modeling of the subjected structure is relatively simple and then each stress component can be obtained easily,((a), (b))

(2) As many damaged data of the member of similar stress condition are available, definition of stress criteria that is verified by the actual damaged data with sufficient accuracy can be accomplished. ((c))

3.2.2 Discontinuous points of main supporting members

As many different types of structures are to be the object about captioned points and structural response against various loads is complicated for the subjected points, relatively simplified method using the representative reference load has been applied for the relative evaluation, however this method is also effective in a certain extent. A precise fatigue assessment of the discontinuous points of main supporting members taking account of the combination of various loads has been applied only for research or damage analysis, as the large size and extensive structural modeling of FEA with the combination of calculation of loads are necessary to obtain reference stress ((b)), but progress in software and hardware enables the analysis to be carried out at design stage.

Stresses in a ship structure are caused by the combination of the load components of wave load and cargo load. Those load components have the phase difference in time and then it is necessary for the estimation of stress range that time-step simulation of the stress variation for each load component and their combination shall be calculated.

DISAM (DIScrete Analysis Method) was developed in 1986 by MHI for the above-mentioned purpose. Fig.6 shows the diagram of the method. In the method, stress response obtained for the each discrete unit load are calculated and then the stresses are combined by linear theory in conjunction with each value of loads, and resultant stresses in irregular wave condition can be obtained with the consideration of phase difference of the each loads component. Example of the results of DISAM is shown in Fig.7. It can be seen that stress caused by internal cargo pressure and outer wave pressure is not the simple summation but combination with some phase difference.

Rather simplified methods for fatigue assessment considering load combination in certain extent are also proposed, for example, correlation factor method [1] and design wave method [2] based on the intensive research work, instead of precise method such as DISAM which require a costly huge amount of structural analysis.

As mentioned above, on account of the progress in analysis environment it is possible nowadays to set,

(a) Definition of load : consideration of phase difference

(b) Calculation of reference stress : large structural modeling

In terms of (c) definition of available criteria, verification by actual data is the next subject because of the wide variation of the structural configuration in case of the primary supporting structure. Generally fatigue assessment process proceeds to obtain reference stress by detail FEA based on the calculation of the above mentioned global stresses, and to be followed by the calculation of cumulative damage factor using design S-N curve and Miner's linear cumulative rule, and to be assessed by the comparison with defined criteria.

However, damage factor according to Miner's linear cumulative rule cannot be defined as a physical value that indicates fatigue life quantitatively, therefore it should be noted that the calculated damage factor is an index for the evaluation which explains fatigue strength qualitatively [3][4]. In this meaning, the appropriate criteria verified by many actual data shall be important in order to gain the accuracy of fatigue assessment.

Recently, explicit figures of fatigue life is often specified in the design requirement by the purchaser owing to the strong demand for safety and economical protection against damage, and the requirement is expected to be indicated simply by the results of the generally used fatigue analysis program.

However, as explained above, proper judgment based on the accurate criteria, which is verified by accumulated data for long time, can only be useful for this purpose, otherwise incorrect results might propose unreasonable over or under scantling.

MHI as well as Japanese shipyards had been deeply investigating the fatigue assessment in addition to the development of structural analysis method and have sufficient experience for this field.

In addition to the study focused on analysis method, there are a lot of investigations about basic phenomena of hull structural fatigue in Japan. Fatigue assessment based on "storm model fatigue test" which is the load modeling based on analyzed ship's encounter sea state is studied in order to solve the limitation of Minor's rule [3][5]. Fatigue damage in corrosive environment is experimentally investigated to evaluate old ships in which corrosion and fatigue damage appear simultaneously. In conjunction with the considerable progress of accuracy of the stress analysis, discussions are also arising even for appropriate definition of design sea condition [2].

3.3 Fabrication and Enhanced Construction Tolerances

The most important factor at construction stage, which affects fatigue life of the structure, especially for discontinuous part of main supporting members, is a misalignment of cruciform joints. Construction standard such as JSQS or IACS standard is generally applied for the structural alignment and in addition to them, strict tolerances are applied for the important part by the shipyard as the further consideration to the fatigue strength as shown in Fig.8.

4. SHIPS CONDITION MONITORING STATUS

"Ships condition monitoring system" is the system, which observes the stress and motion during voyage and loading, consisting of strain gauges, and acceleration sensor fixed on the hull as shown in Fig.9. Proposal was made in 1994 by IMO in MSC/Circ.646 to provide the monitoring system of stress and motion during voyage and loading, and also of announcing the dangerous condition, only for bulk carrier. Classification societies define the requisite specification for ship's condition monitoring system and are ready to give notations for conformed ship, not only for bulk carrier but also for other types of ship as shown in Table 1.

Following items are considered to be utilization of the system.

(1) Indication on monitor or alarm gives actual hull stress condition directly to the operator and the operator refer this data for the operation
(2) Record of the monitored data gives information for maintenance
(3) Record of the data may be utilized for the investigation of accident
(4) Cumulative data with additional data such as sea state, ship speed and engine data give information to ship design and voyage plan.

Regarding the information for maintenance, data base system of inspection and repair record to the assistance of ship maintenance is also provided by the classes.

Extensive research of advanced monitoring system was carried out by SR (The Shipbuilding Research Association of Japan) from 1996 to 1998. In this study, fundamental technology that formed advanced monitoring system was investigated at first, and this includes,

(1) To establish the monitoring technology of encountered wave environment
(2) To develop sensing technology of hull stress monitoring using optical fiber and sacrificial specimen method[6]
(3) To obtain relation between ship motion and structural response by the application of preparatory structural analysis and development of fatigue monitor system for the support of maintenance

The advanced monitoring system proposed in SR gives many information of hull response in actual sea condition therefore the data can be the supplement to exclude uncertainties in the assumption of design loads. Also the more accurate analysis of obtained structural response data can be made with the combination of preparatory detailed structural analysis. It is no doubt to be an effective feed back data for the design that obtained data is associated with inspection and repair record of docking.

5. CONCLUSION

Present status of the design of D/H VLCC and fatigue design using advanced structural analysis method is described.

Design approach to fatigue damage problem - the fatigue design method of ship yard in order to accomplish long operational life is composed of the design improvement in detail design based on the accumulated experience, the simplified model base fatigue assessment applied for longitudinal and the advanced fatigue assessment method using large scale structural analysis, and all of them are quite important.

However, the outcome of the fatigue analysis program solely is not adequate for proper fatigue design and it should be applicable in combination with the accurate criteria, which has been verified by accumulated actual service data in reliable shipyards who has been researching fatigue problem for long time by themselves.

Advanced ship stress monitoring system will give the important data for verification of the criteria of fatigue assessment in association with advanced structural analysis.

Improvement of structural reliability for the purpose of long and safe operational life with economical efficiency demands synthetic knowledge of design, construction and, condition survey by inspection and monitoring. In this meaning, classification societies are required to clarify the technical back ground of their rule in order to reveal the design condition and safety standard, on which structural strength are based on, to ship operators and ship builders for the safety operation.

Eventually interactive relation among the owner, the classification society and the shipyard shall be emphasized its importance.

REFERENCE

[1] Study on Strength Analysis Method for Transverse Member of Double Hulls VLCC, Transactions of The West-Japan Society of Naval Architects No.92, by Y. Kuramoto and others.

[2] Technical Guide Regarding the Strength the Evaluation of Hull Structure, NIPPON KAIJI KYOUKAI

[3] SR216, The Shipbuilding Research Association of Japan

[4] Consideration on Crack Initiation Life under Program Fatigue Test, Journal of Naval Architects of Japan No.223, by M.Matoba, H.Kumamoto

[5] Fatigue Crack Growth Behavior under Random Loading Model Simulating Real Encountered Wave Condition, Marine Structure Vol.8, by Y.Tomita, M.Matoba, H.Kawabe

[6] Development of Sacrificial Specimen for Fatigue Damage Prediction of Structures, Journal of The Kanasai Society of Naval Architects No.223, by Y.Fujimoto and others

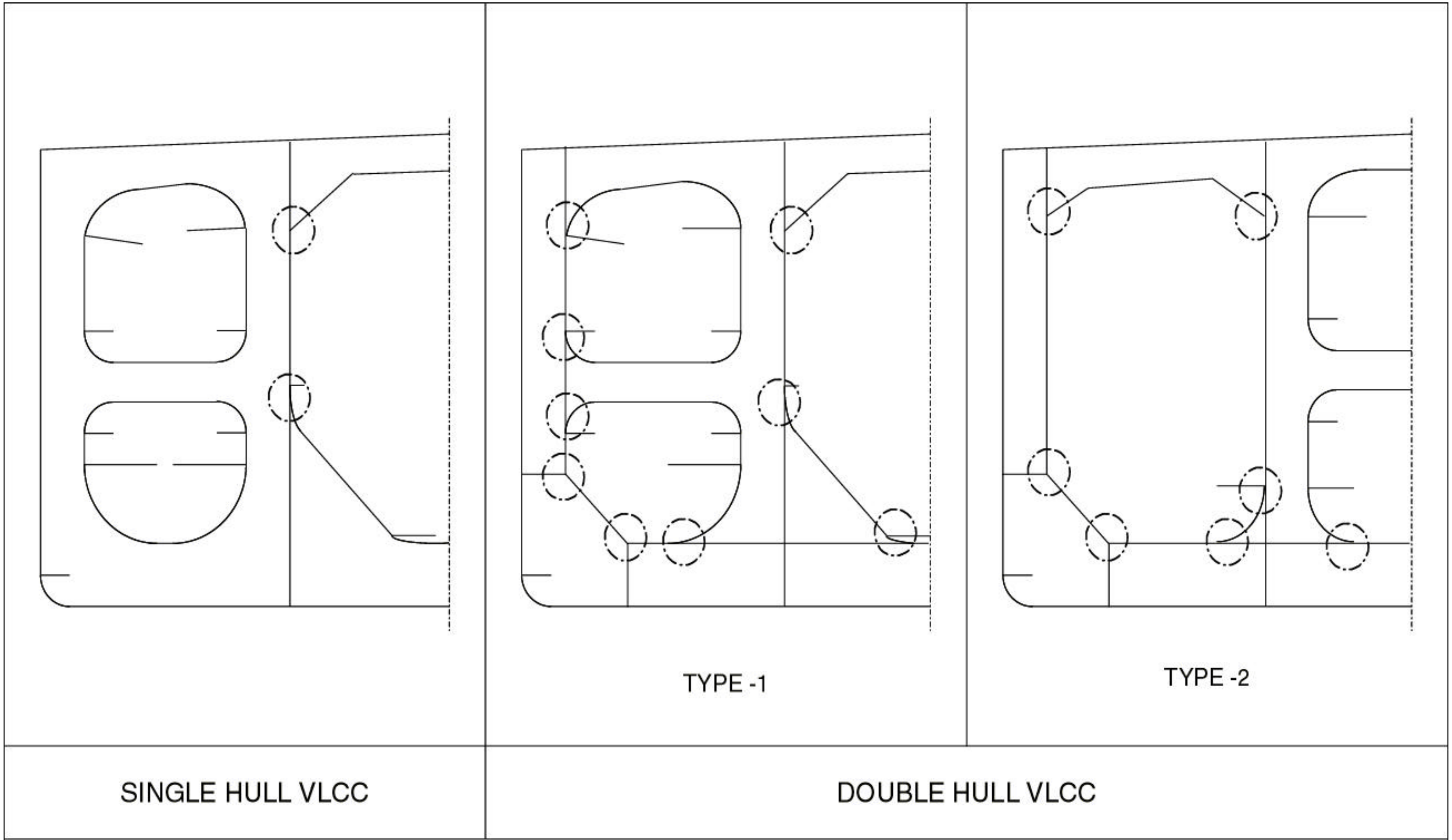
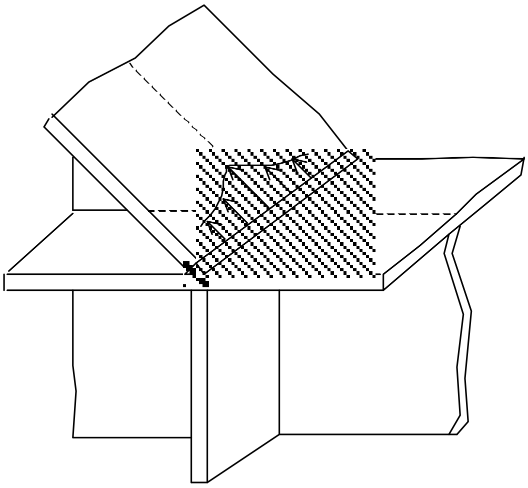


Fig.1 Midship Section of VLCC

TYPE	TYPICAL REINFORCEMENT

WELDING JOINT TYPE



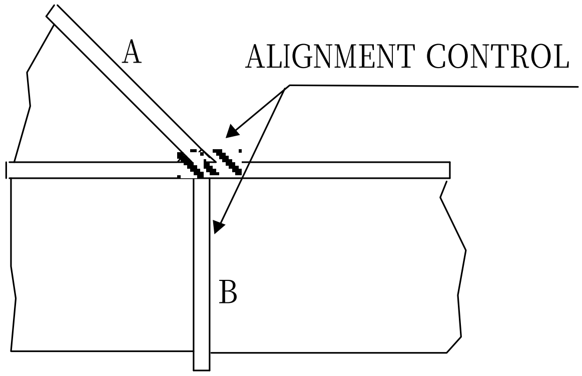
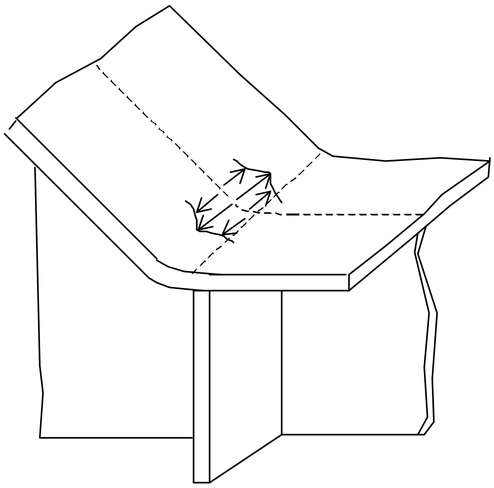
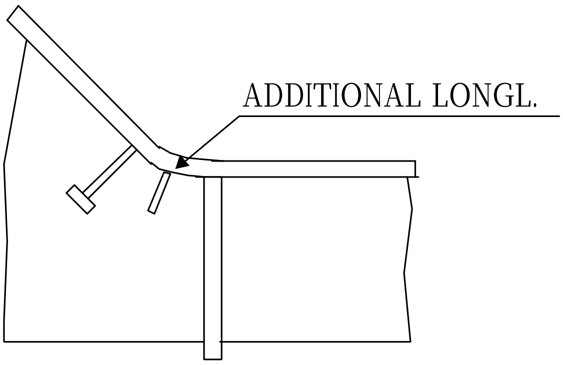


PLATE BENDING TYPE





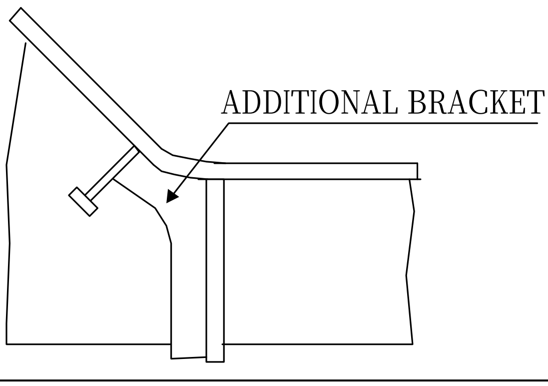
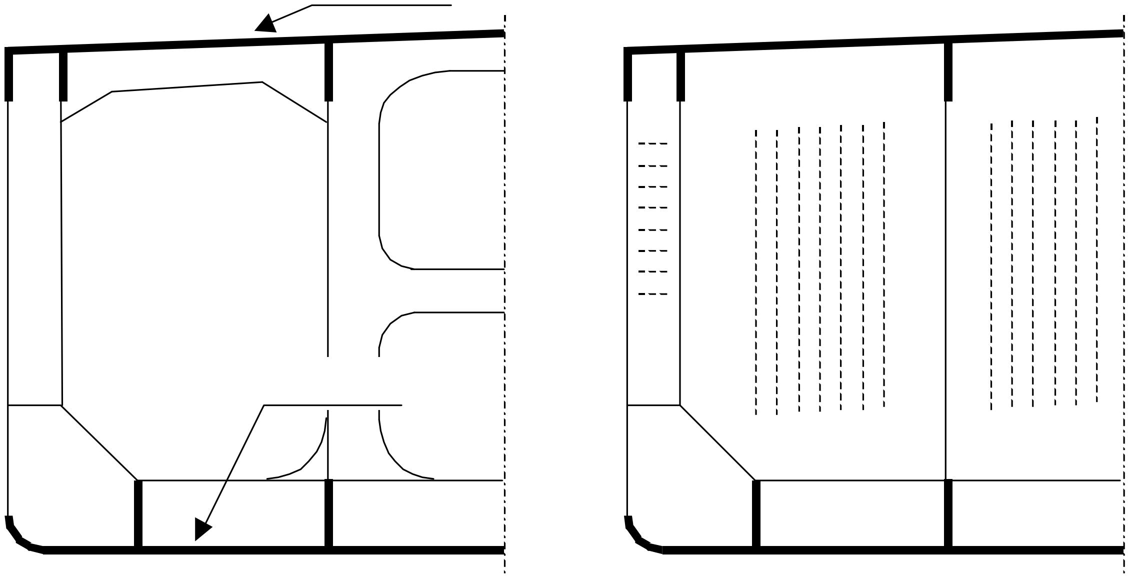


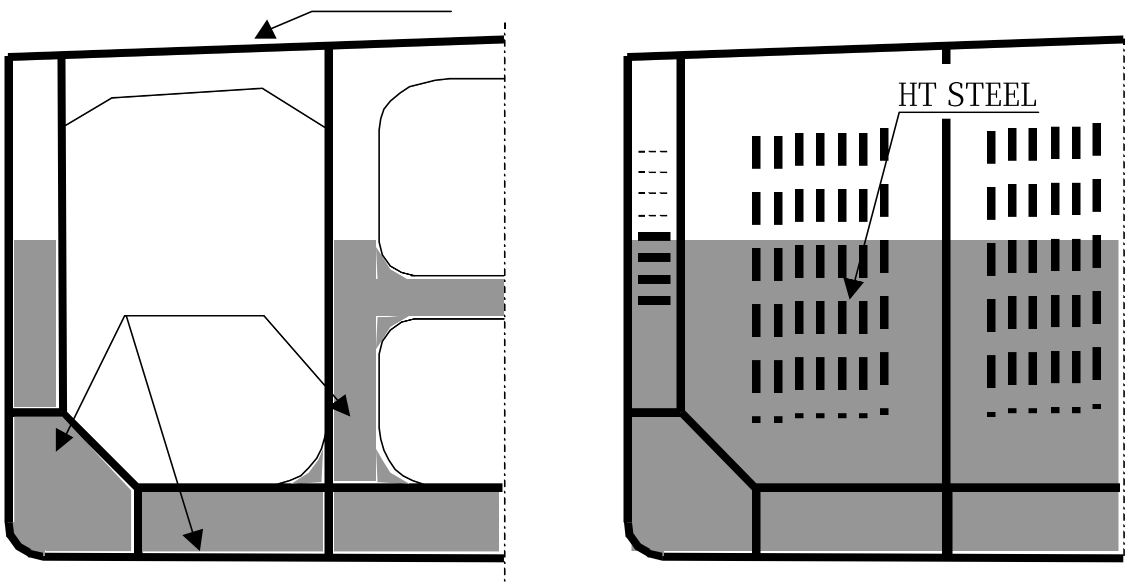
Fig.2 Detail Structure of Hopper Tank Corner



TRANS SECTION

TRANS. BULKHEAD

(A) SECTION OF 25% HT VLCC

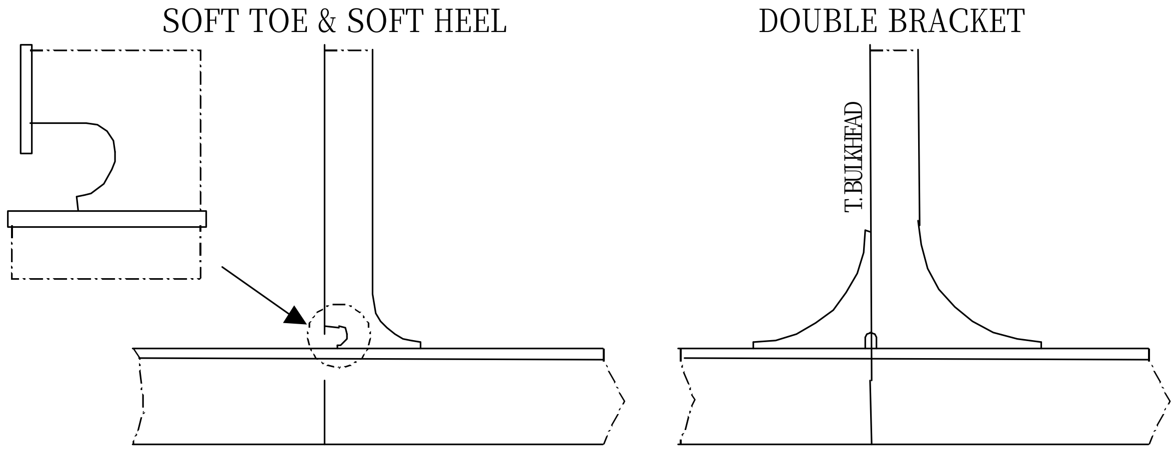


TRANS SECTION

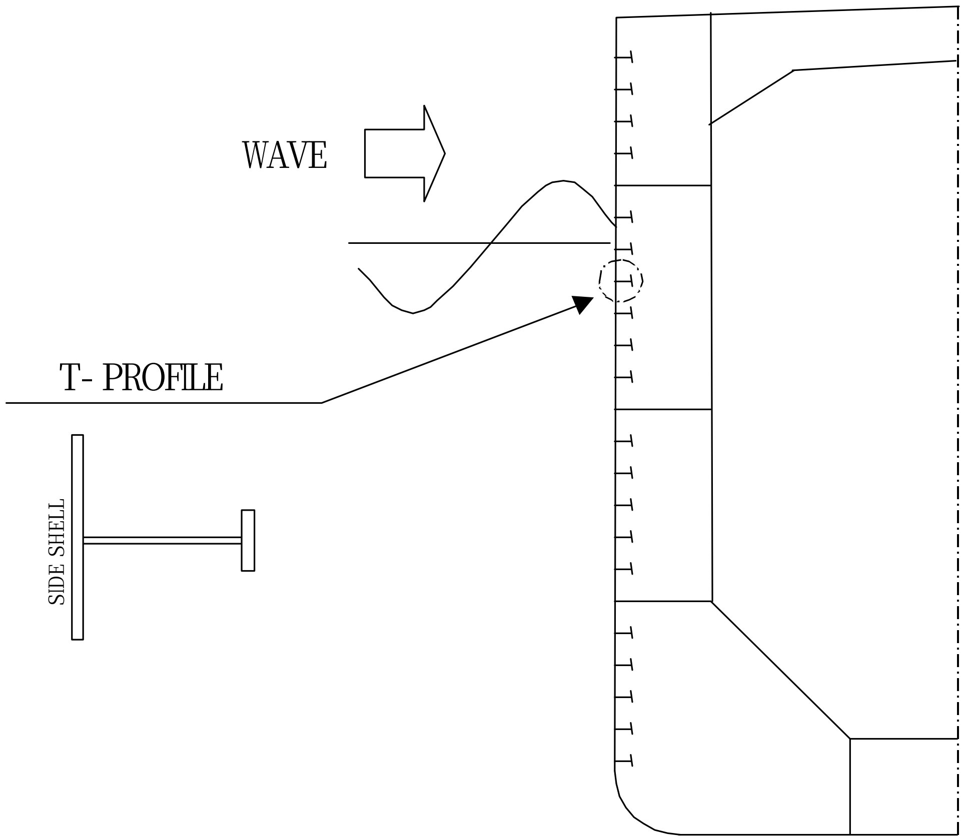
TRANS. BULKHEAD

(B) SECTION OF 70% HT VLCC

Fig.3 Extent of Higher Tensile Steel



(A) LONGITUDINAL STIFFENER CONNECTION

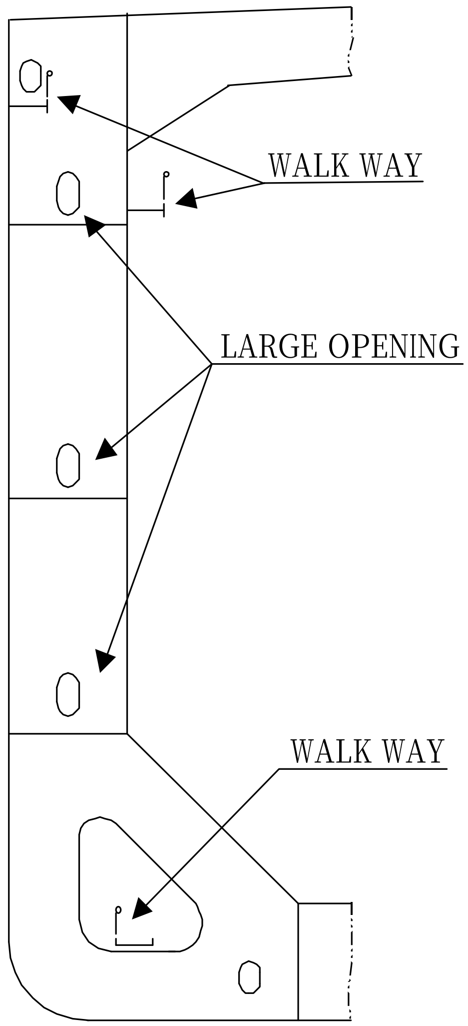


(B) T-PROFILE FOR SIDE LONGITUDINALS

Fig.4 Detail Structure for HT VLCC

LONGITUDINAL DIRECTION

TRANSVERSE BULKHEAD



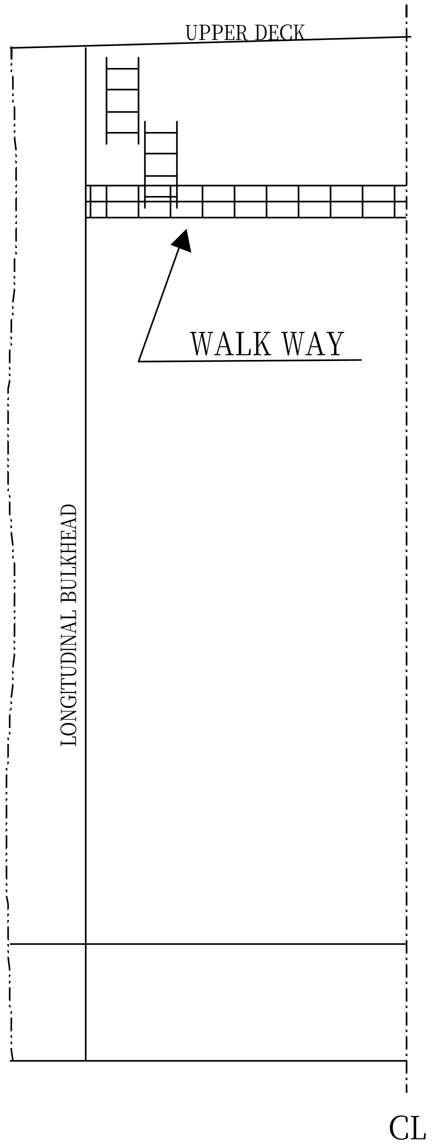


Fig.5 Traffic Arrangement in Tank

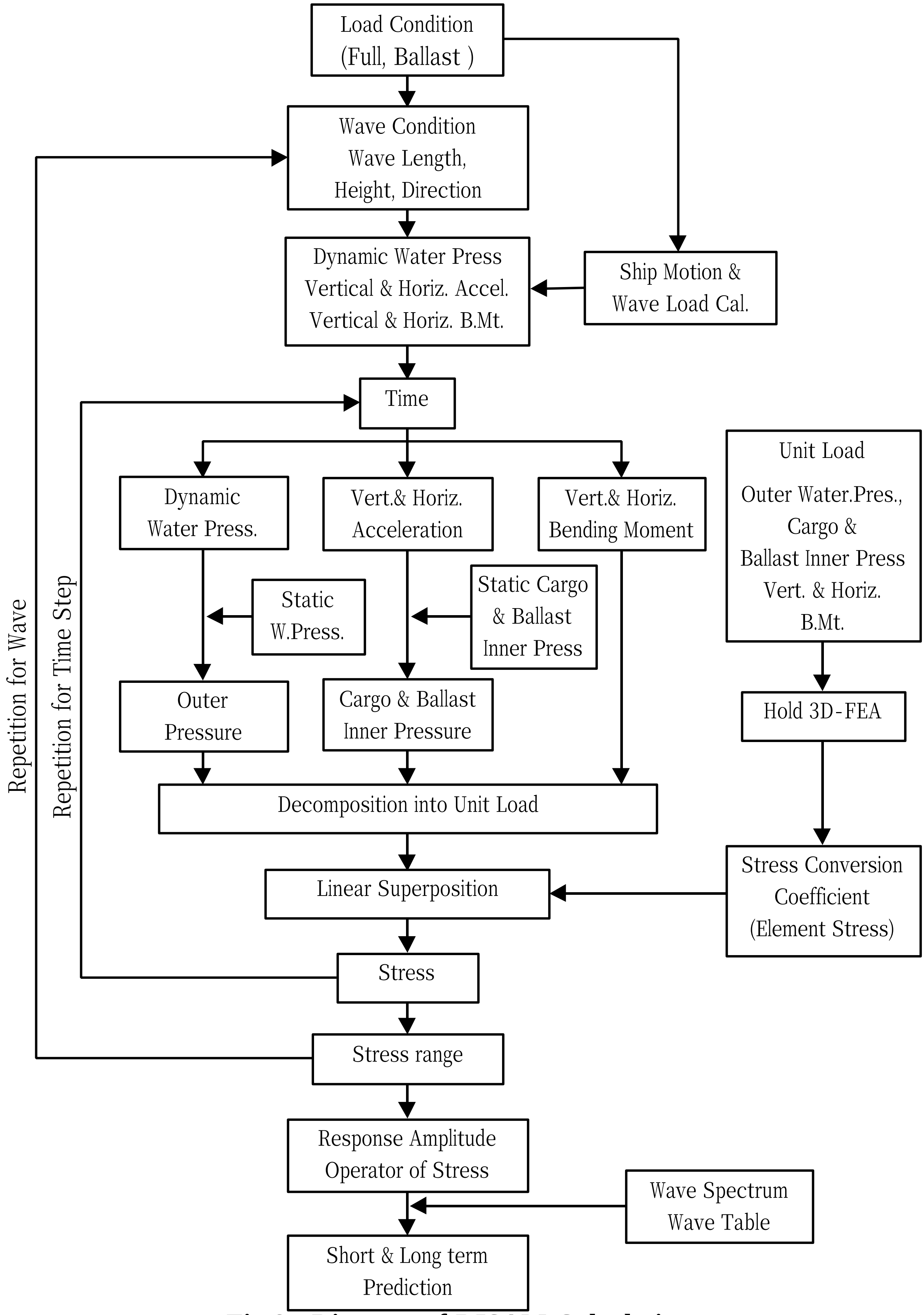


Fig.6 Diagram of DISAM Calculation

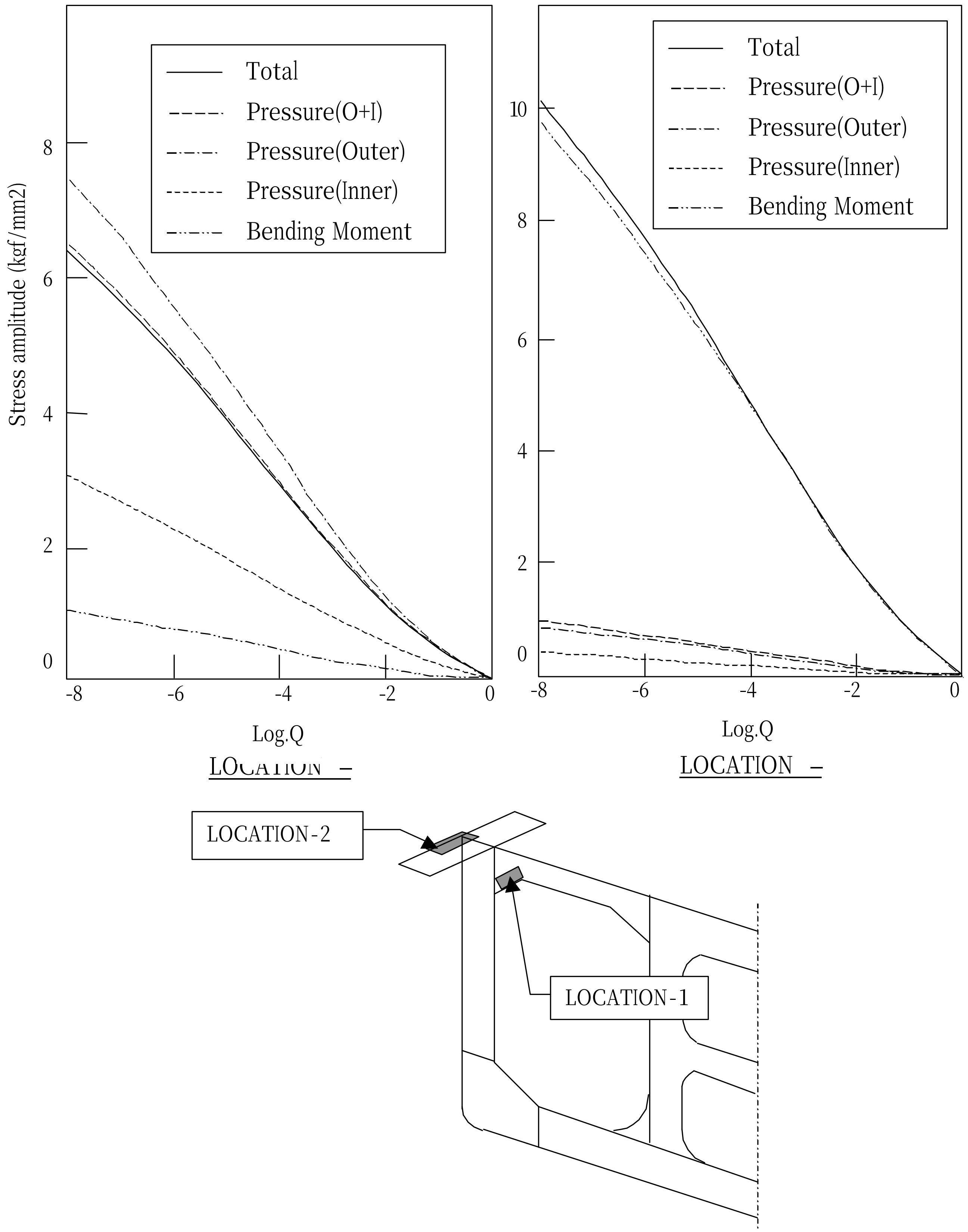
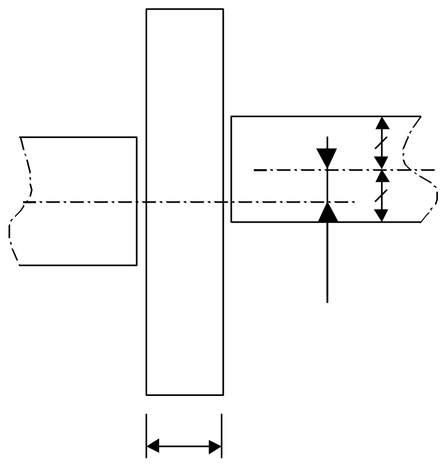


Fig.7 Results of DISAM

LOCATION	JOINT	LIMIT
CRITICAL JOINT Joint subject to higher cyclic & static stress normal to the table member. Those involve potentially high risk.		Misalignment shoud not exceed (1/3) thickness of table member on median lines of abutting members. A≦T/3

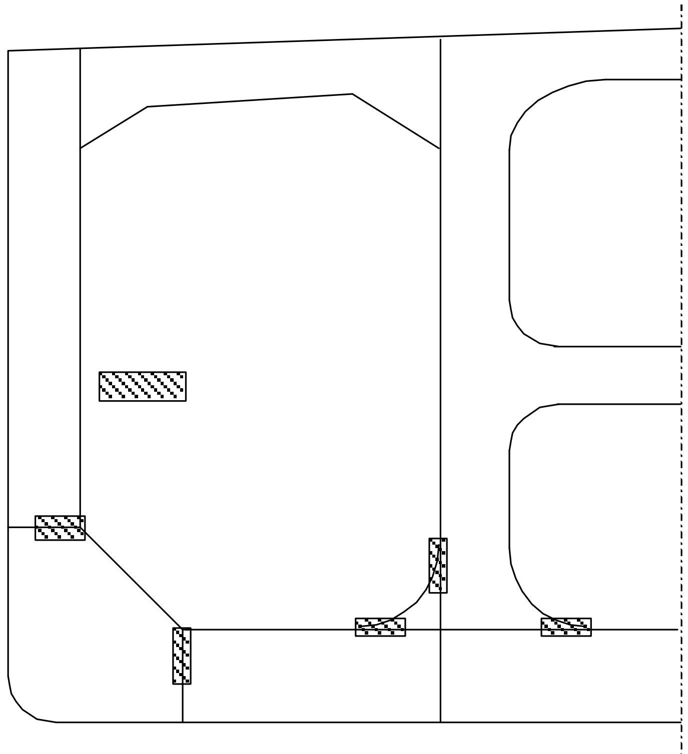


Fig.8 Enhanced Construction Tolerance

Location of sensors

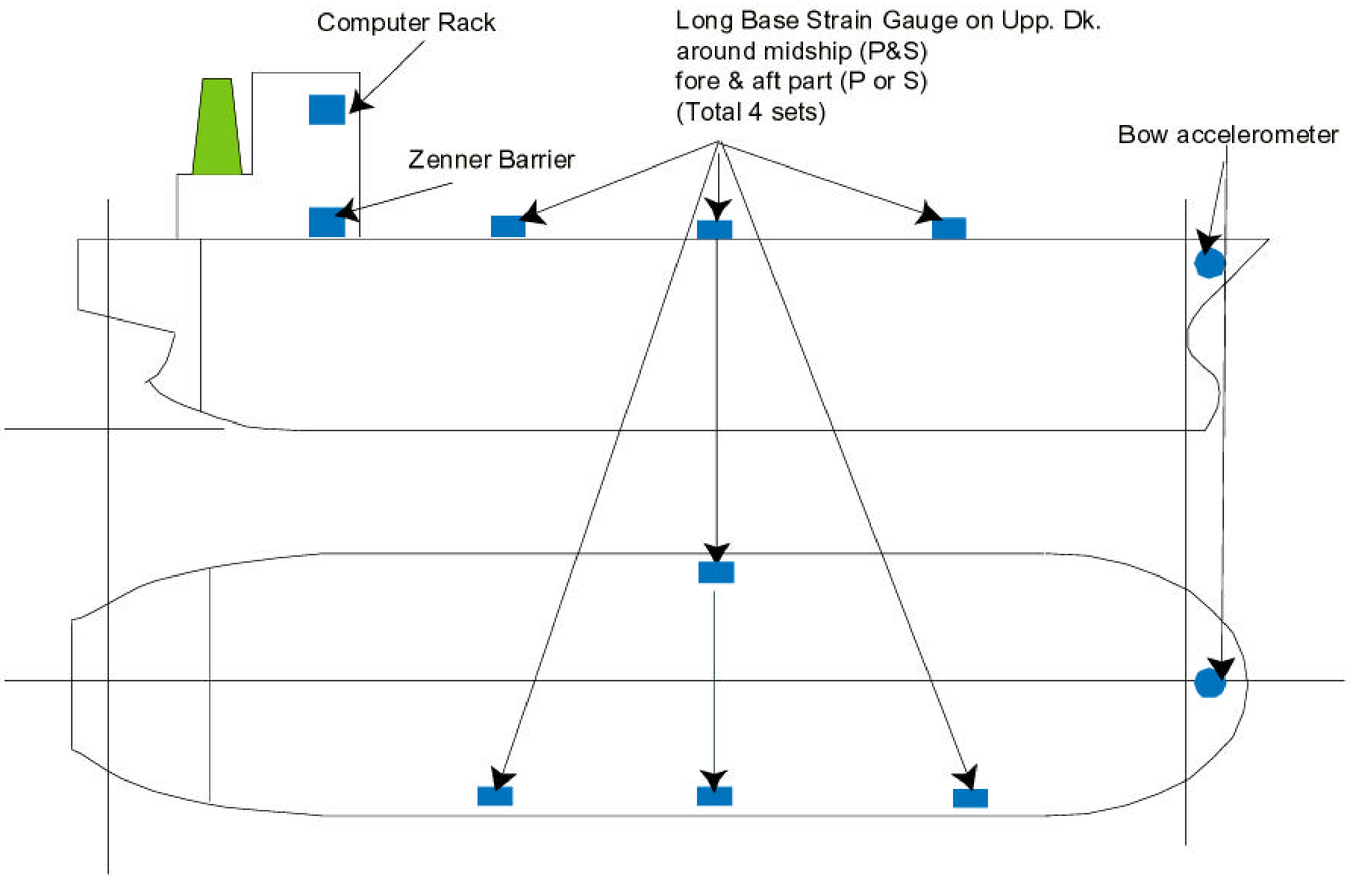


Fig.9 Ships Condition Monitoring System

Table 1 Hull Monitoring System of Classification Societies

	ABS	DNV	LRS
Title	Guide for Hull Condition Monitoring System	Rules for Classification of Ships Special Equipment and Systems Additional Classes PART 6 CHAPTER 11 Hull Monitoring System	ShipRight Procedures and Provisional Rules for the Classification of Ship Event Analysis Systems
Purpose	The reason for fitting hull monitoring systems is to acquire, display and/or record information and then use the information as a basis for making decisions that will improve operational efficiency and/or safety.	The monitoring system will give warning when stress levels and the frequency and magnitude of ship accelerations approach levels which require corrective action.	A hull surveillance system that monitors the hull girder stresses and motions of the ship and warns the ship's personnel that these levels or the frequency and magnitude of slamming motions are approaching a level where corrective action is advisable.
Class Notation	HM1 HM2 HM3 & +R	HMOM-1 HMOM-2	SEA(HSS-n) SEA(VDR)