

## VLCC Structural Design - Past, Present and Future

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### Abstract

Daewoo Shipbuilding and Marine Engineering Co., Ltd. (DSME) is one of the most experienced shipyards in VLCC design and construction and has delivered more than eighty(80) VLCCs. The development of VLCC structural design was made not only to comply with the new regulatory requirements such as double hull, PMA, CSR and etc., but also to enhance the structural reliability. In the present paper, DSME's past experiences, current status and future development proposals in VLCC structural design are addressed.

## 1 INTRODUCTION

Since delivering its first VLCC in 1988, DSME has delivered or been constructing more than 120 VLCCs. They are briefly categorized into several midship configuration types as shown in Table 1. Type I single hull VLCC has cargo tanks that are directly bounded by outer hull. Type II has double sides with single bottom. Finally, Type III has cargo tanks which are surrounded by double hull except the deck area. For your reference, it should be noted that this is not official categorization by DSME, instead it is used voluntarily only for this presentation.

Table 1 Category of DSME VLCCs

Type		Year of delivery	No. of ships	Deadweight ton	Dimensions L <sub>bp</sub> / B / D / T <sub>s</sub> m
I (Single hull)	I-a	1988 ~ 1989	3	254,000	310/56.0/29.5/21.0
	I-b	1989 ~ 1995	23	280,000	315/57.2/30.4/20.8
II (Double side)		1992 ~ 1993	4	300,000	320/58.0/31.0/22.0
III (Double hull)	III-a	1993 ~ 2007	58		
	III-b	2004 ~ 2009	22	320,000	320/60.0/30.5/22.5
	III-c (CSR)	2010 ~	> 10		

There have been two major apparent motivations in these design developments - i.e., increase in capacity and compliance with the new regulatory requirements. Around 15 years ago there was

a big change in tanker structures due to the MARPOL double hull requirements, and Type III VLCCs has emerged as the result. Recently, there has been another major change to tanker structures with the development and adoption of Common Structural Rules for tankers and bulk carriers by International Association of Classification Societies (IACS CSR). Accordingly, DSME has developed a new CSR VLCC type III-c.

In the ensuing sections, the followings will be presented in detail:

- Past changes in midship configuration
- Past changes in hull steel weight and HT (higher tensile) steel portions
- Present - CSR and its impacts
- Future developments

## 2 CHANGES IN THE PAST

### 2.1 *Type I-a*

This type of VLCC has comparatively wide center tanks. So, centerline girders are fitted to support bottom and deck transverse web frames and to reduce transverse sloshing pressures. Type I-a VLCCs disappeared quickly as soon as Type I-b emerged. DSME delivered only 3 vessels in a series.

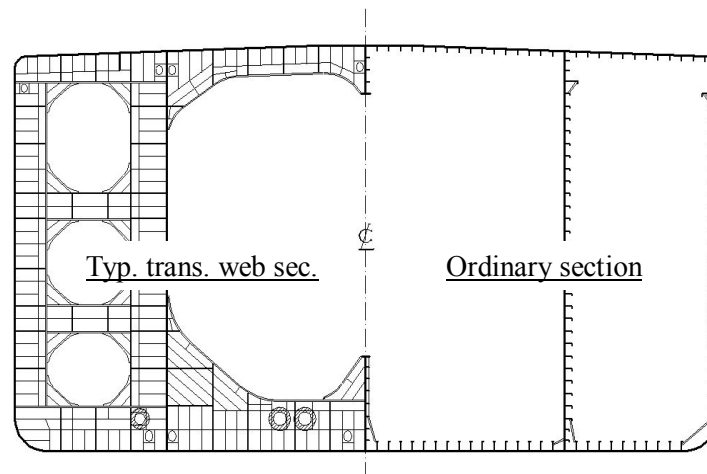


Fig. 1 Midship section of type I-a

### 2.2 *Type I-b*

This type is the DSME's typical single hull VLCC. The width of the center tank is reduced compared with the previous type; therefore, no centerline girders are arranged. Only the bottom longitudinal stiffener at the centerline has somewhat increased depth for the preparation of docking. Two rows of cross ties are arranged in side tanks. Some of side tanks are used for both cargo and ballast.

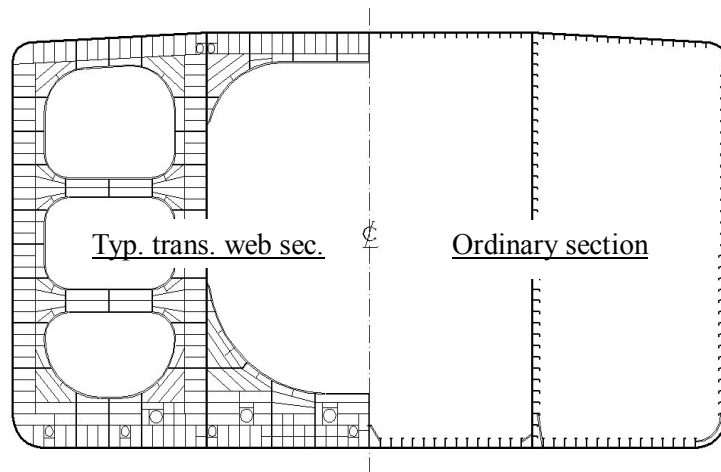


Fig. 2 Midship section of type I-b

### 2.3 Type II

Type II has a very unique midship configuration. It has only one longitudinal bulkhead at centerline like Suezmax or Aframax tankers. All wing tanks are used exclusively for ballast. Type II also disappeared from the market soon due to the MARPOL double hull requirements. Only 4 vessels in a series were delivered by DSME.

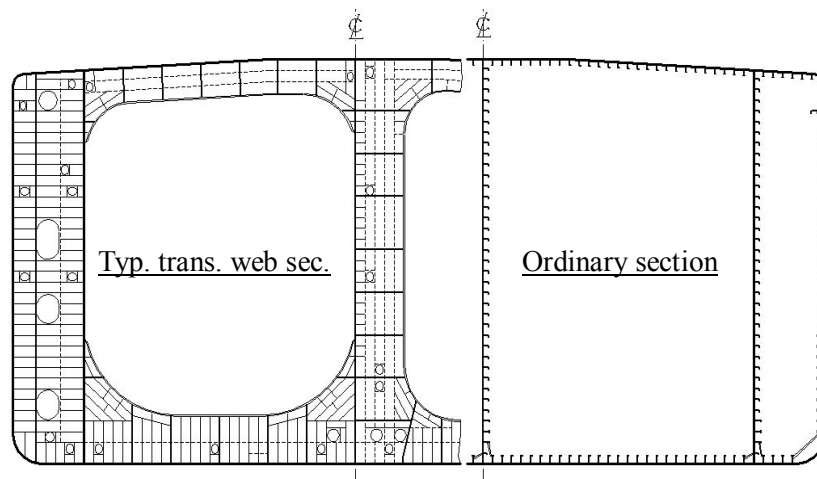


Fig. 3 Midship section of Type II

### 2.4 Type III

This type is the present DSME's typical double hull VLCC. All subcategories - 'a', 'b' and 'c' - have the same midship configuration. One row of cross tie is arranged in center tanks. Double hull spaces are composed of double bottom, double side and hopper. They are used exclusively for ballast tanks and divided into port and starboard tanks by a double bottom centerline watertight girder.

In the double sides, originally 3 longitudinal stringers were arranged aligned with the stringers on transverse bulkheads. Recently, their locations were adjusted and an additional stringer was provided as a means to comply with SOLAS PMA requirements. Also some longitudinal stiffeners were enlarged for the PMA use.

Besides the changes mentioned above, the following improvements have been introduced to increase structural reliability:

- To improve fatigue strength:
  - (1) The use of mild steel was maximized for longitudinal stiffeners on the dynamic wave wetted zone at side.
  - (2) The use of T shape profile for longitudinal stiffeners was maximized replacing L shape profiles.
  - (3) Double brackets were fitted at transverse bulkhead areas for the longitudinal stiffeners on outer hull, inner hull longitudinal bulkheads and inner bottom.
  - (4) Bent type hopper upper knuckles were implemented.
  - (5) Backing brackets were fitted at No.1 and 2 stringer levels between transverse bulkheads and inner hull longitudinal bulkheads.
- To increase hull girder stiffness, the steel grade of longitudinal strength members at deck and bottom areas was changed to HT32 steel from HT36 steel.
- To improve local strength around cut-out for longitudinal stiffeners passing through web frames, the use of slit type construction was maximized instead of lapped collar plate connection.

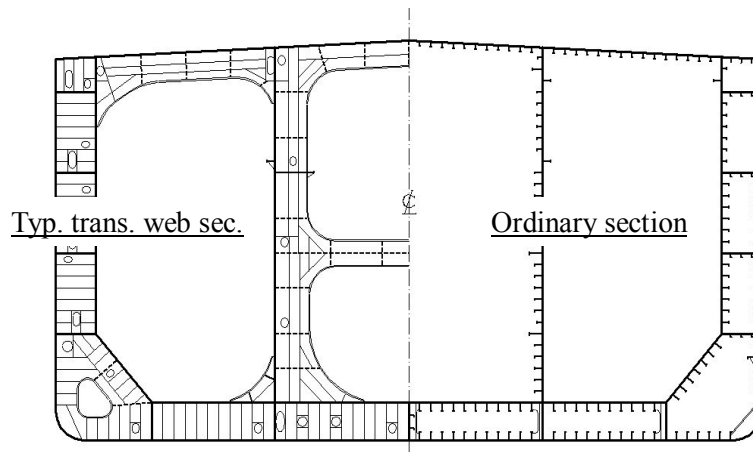


Fig. 4 Midship section of Type III

## ***2.5 Hull steel weight and HT steel portion***

Hull steel weight is one of the main parameters to evaluate economic aspects. In general, as the technology is developed, the economic efficiency of product is likely to improve. However, in case of VLCCs, the hull steel weight has been continuously increased as shown in Table 2, since design development has been focused on safety rather than efficiency.

The hull steel weight is greatly affected by the HT steel usage ratio. In early stage, HT steels had been widely used to reduce hull steel weight. However their use was significantly reduced later as mentioned in Subsection 2.4. Table 3 shows two typical cases.

Table 2 Comparison of hull steel weight

Type	HT steel portion	Hull steel weight	Dimension L*B*D	Remarks
I-b	70 %	1 (reference)	1 (reference)	Single Hull
	30 %	1.103		
III-a	70 %	1.138	1.123	Double Hull
	30 %	1.241		
III-b	30 %	1.276	1.143	
III-c (CSR)	30 %	1.345		
	45 %	1.310		

Table 3 Use of HT steel

Type (HT steel portion)		I-b (70 %)	III-a (30 %)
Longitudinal members	Deck & Bottom	HT36	HT32
	Others	HT32	Mild
Transverse members		HT32	Mild
Portion	Mild	30 %	70 %
	HT32	45 %	30 %
	HT36	25 %	-

### 3 CSR AND ITS IMPACTS

#### 3.1 What is CSR

IACS CSR for double hull oil tankers and bulk carriers came into effect from 1 April 2006. The CSR development committee reported the objectives of the development of the new unified rules as follows:

- To eliminate competition between class societies with regard to structural requirements and standards.
- To employ the combined experience and resources of all IACS societies to develop a set of unified Rules.
- To ensure that a vessel meeting these new standards will be recognized by industry as being at least as safe and robust as would have been required by any of the existing Rules.
- To fully embrace the intentions of the anticipated IMO requirements for goal based new ship construction standards.

The following design concepts characterized the CSR in line with the proposed objectives mentioned above:

- North Atlantic environment as basis for loads and fatigue standard
- 25 years design life
- Net thickness approach

- Enhanced strength assessments:
  - (1) Hull girder ultimate strength
  - (2) Local fine mesh analysis to check repeated yield
  - (3) Advanced buckling analysis

Now more than one year has passed since the CSR has come into effect. Even though there are some debates, it is sure that the overall safety levels, structural reliability and operational flexibility could be much improved due to the CSR. Nevertheless, the CSR requirements would result in scantling increases to some extent, as expected and such increases will be presented in the following subsections.

### 3.2 Scantling Increases

Comprehensive study carried out by DSME reveals that scantling increases for each structural member due to the CSR are prominent as shown in Figs. 5~6. The main reason behind the scantling increases is a conservative combination of extreme conditions - North Atlantic 25 year extreme sea state, assumed extreme loading, fully corroded state, materials of marginal properties, full initial imperfections, etc.

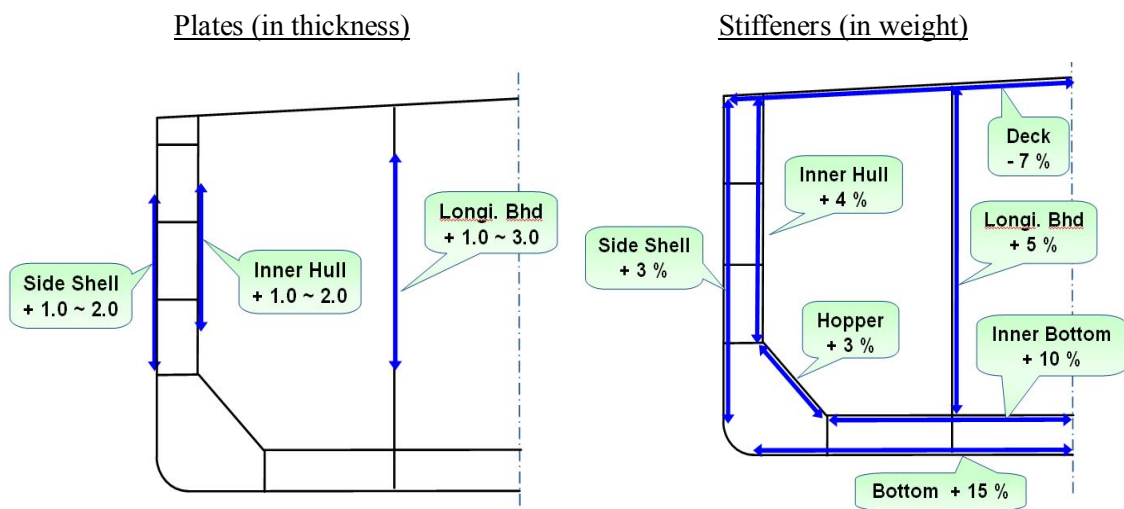


Fig. 5 Scantling increases - longitudinal members

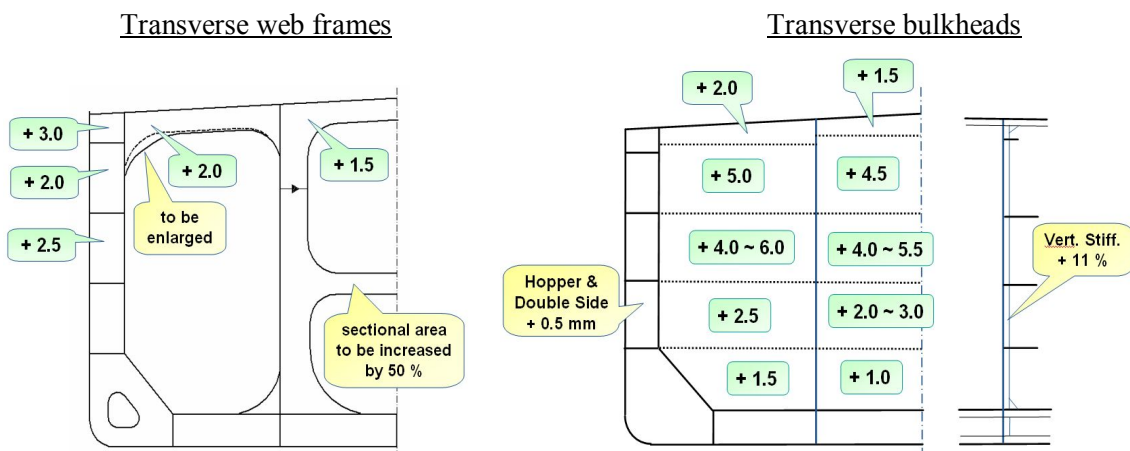


Fig. 6 Scantling increases - transverse members

### **3.3 Bottom slamming**

In particular, the CSR requirements for bottom slamming are estimated to be much more severe than the previous rules. The CSR requirements for bottom slamming were found to cause the scantling increases as shown in Table 4..

Table 4 Summary of bottom slamming evaluation

ITEM	DNV	CSR
Slamming draft	6.6 m	6.6 m
Slamming pressure	926 kPa	947 kPa
Web size of bottom longitudinal	635*15.0 AH	700*20.5 AH
Floor thickness	18.0 MILD	25.0 AH

### **3.4 Ballast water exchange**

Generally two(2) methods are adopted for ballast water exchange - i.e., sequential filling and flow through. In case of the sequential filling, the CSR requires that the design slamming draft is not to be greater than the minimum draft during any seagoing operations including ballast exchange. DSME has been applying the same design concept to many pre-CSR VLCCs. So, no impacts would be added to those mentioned in Subsection 3.3.

Meanwhile, in case of the flow through, design pressures in seagoing condition for the ballast tanks will be increased by about 35 kPa and the scantlings of structures will also be increased consequently. The increase in steel weight is expected to be about 400 ton for VLCC. So, the flow through method is not adopted in DSME standard design.

### **3.5 Cargo tank heating**

It is well known that the high temperature would increase the corrosion rates in ballast tanks. So, the CSR requires an increased corrosion addition of 0.5 mm for the plate boundaries between heated cargo tanks and ballast tanks and the stiffeners attached on them from ballast tank side. In case of VLCC, normally cargo tank heating is not adopted. However, if heating is applied to all cargo tanks, steel weight will be increased by about 200 ton.

### **3.6 Other enhancements**

In addition to the above, many other enhancements could be achieved according to the CSR requirements as follows:

- Minimum still water shear forces for seagoing and harbour operations
- Loading conditions mandatorily included in loading manual:
  - (1) Homogeneous loading conditions at the scantling draft without filling of any ballast tanks
  - (2) A heavy ballast condition in which the fore peak tank is full
- Web shear area requirements for stiffeners
- Prescriptive web depth requirements for primary support members.
- Increased plate thickness in areas likely to be subjected to contact with anchors and chain cables during anchor handling

- Strict prescriptive requirements for stiffness and proportions regardless of stress levels

### 3.7 Summary of hull steel weight increase

According to DSME's study, the total hull steel weight increase due to the CSR is 5 to 10 %, depending on the ship type, higher tensile steel portion, pre-CSR classification society, method of ballast water exchange, etc. An example is summarized in Table 5.

Table 5 Hull steel weight increase due to CSR

Structural member		Weight increase, ton
Cargo area	Longitudinal member	700
	Transversal member	650
	Slamming, sloshing, etc.	300
Outside cargo area		300
Total		1,950
<p><u>Note:</u></p> <p>The weight increases were estimated based on the following conditions:</p> <ul style="list-style-type: none"> <li>- ship type: DSME standard VLCC with 60 m beam</li> <li>- higher tensile steel portion: 35 %</li> <li>- classification society: DNV or LR</li> <li>- method of water ballast exchange: only sequential filling</li> <li>- cargo tank heating: generally not applied</li> </ul>		

## 4 FUTURE DEVELOPMENTS

### 4.1 Rule change proposals to CSR

Even though the CSR is generally well organized, technically improved and consistent, there are still some irrational requirements as described in the previous section. The following items are proposed to be reinvestigated:

- Transverse buckling: Many comparison studies showed that most of steel weight increases are concentrated on the structures around neutral axis and above except deck area due to FE buckling. Normally, it is well known fact that those areas are less critical in strength point of view.
- Cross tie: The CSR requires about 50 % increase in cross sectional areas for cross ties compared with the previous rules because the utilization factor for FE pillar buckling is far less than that for prescriptive requirement. The utilization factor should be increased considering that acceptance criteria for FE analysis are normally greater than those for prescriptive requirements as stated in the CSR.
- Bottom slamming: The CSR also require about 50 % increase in shear areas for longitudinal stiffeners and floors in bottom slamming zone compared with the previous rules whereas the calculated slamming pressure is the same. This is thought to be quite abnormal considering the total steel weight increase is 5 to 10 %.



## 4.2 Extended use of HT steel

There is no doubt that the structural safety could be greatly improved in every respect by the CSR. However, the CSR requires increase in the steel weight which may lead to initial cost increase, reduced deadweight and waste of resources. To minimize these adverse effects, extended use of HT steel is strongly proposed with careful attentions to comply with the level of safety required by the CSR.

However, it is not recommended to reduce hull girder sectional properties by use of the HT36 steel for the longitudinal members at deck areas because it would shorten fatigue lives. Also HT steels are less effective for the following areas:

- Fatigue sensitive members - i.e., side shell longitudinal stiffeners, inner bottom i.w.o. hopper corner
- Where scantlings governed by transverse buckling - i.e., bilge plate, hopper plate and middle parts of side shell/inner hull longitudinal bulkhead/longitudinal bulkhead/transverse bulkhead

In the past, especially for the tankers, it was common to specify the HT steel portion to ensure the safety level. From now, the CSR could play the role of 'invisible hand'. So, such limitations may not be necessary in the CSR design.

## 4.3 Lower hopper corner

The lower hopper corner is the most prone to fatigue in double hull tankers. The weld type corner has been widely adopted, however it is almost impossible to meet the CSR requirement without grinding the weld toe or fitting brackets inside cargo tank. Possible alternatives to eliminate such fatigue sensitive point are as follows:

- Bent type corner: DSME has applied the bent type upper hopper corner to all type of tankers and the bent type lower hopper corner to Panamax tankers without any problems. The same detail may be applied to the larger tankers too.
- Hopper-less: A self-explanatory sketch is shown on Fig. 7. Careful attentions are to be paid to the design details around toes of large brackets. The conventional hoppers may be provided to the fore and aft parts of cargo areas.
- Round hopper: A self-explanatory sketch is shown on Fig. 7. It is not recommended to arrange longitudinal stiffeners on the round hopper. For this purpose, fitting of intermediate brackets similar to round bilge may be considered. In the fore and aft parts of cargo areas, plane panels reinforced by longitudinal stiffeners may be inserted around the middle of round hopper.

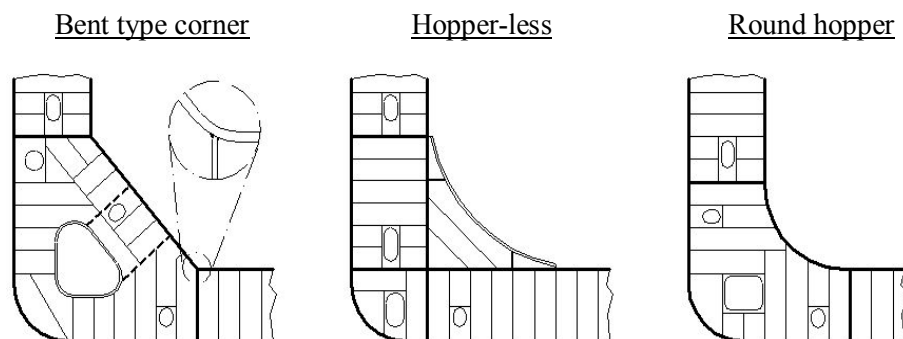


Fig. 7 Alternative hopper designs

## **5 Conclusions**

DSME has developed VLCC structural design not only to comply with the new regulatory requirements, but also to increase the structural reliability. Around 15 years ago there was a big change in tanker structures due to MARPOL double hull requirements. Another change was brought on by the development and adoption of the CSR by IACS. Although the CSR will likely improve the overall safety levels, structural reliability and operational flexibility, there are still some irrational requirements which need to be reinvestigated. In addition, extended use of HT steel is strongly proposed to minimize the adverse effects caused by the steel weight increases. Finally, all parties concerned should be cooperative more to develop more sound tanker structures.

## **6 References**

International Association of Classification Society Ltd. (2006) Common Structural Rules for Double Hull Oil Tankers