# Design Experience on CSR VLCC

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## ABSTRACT

Since its coming into force on 1st April 2006, Common Structural Rules for Double Hull Oil Tankers (CSR) have brought some changes and made improvements on the structural design of DH oil tankers. Research institutes, shipyards and design offices in China have completed studies on CSR and developed a series of CSR Tankers.
In the present paper, a brief introduction of a new design of 308,000DWT VLCC is introduced, mainly on the scantling increases due to CSR. To minimize the poor details for construction, a simplified method based on a concept of fatigue factor is adopted for fatigue assessment on the details in upper deck region. To increase hull girder shear strength capacity, by differential method, the sensitivity analysis on the shear flow and shear capacity are carried out. Furthermore, some new ideas and arrangement of cross tie are discussed based on FE analysis.

## 1. Introduction

With the IACS Common Structural Rules for tankers and bulk carriers taken effect on 1st April 2006, it has been found that the steel weight of new tankers and bulk carriers is increased. As a consequence, the deadweight of such vessels is decreased and their main general performance level is impacted, especially the economic performance. Therefore, researches on new type of tankers and bulk carriers with CSR requirement are of great importance. Research institutes, shipyards and design offices in China have completed studies on CSR and developed a series of CSR tankers and bulk carriers.

In this paper, we focus on CSR VLCC. A typical example is a new design of 308,000DWT VLCC applied with CSR, designed by MARIC based on so-called *ESE* (Economy, Safety and Environmental) design concept and firstly delivered from CSSC Guangzhou Long Xue Shipyard in January 2010. Design experience, mainly on scantling increases, fatigue evaluation, hull girder shear strength and cross tie, will be discussed.

## 2. CSR impact on a 308,000DWT VLCC

In 2006 China Shipping development Co. Ltd tanker company placed four DH VLCC contracts in CSSC Guangzhou Long Xue shipyard. All four vessels had to comply with CSR and with dual class of CCS and DNV.

As we all known, CSR gave the stricter requirement. The new key features are:

- Net thickness approach
- New load model for strength calculation based on North Atlantic environments
- Increased design fatigue standard of 25 years North Atlantic
- Coating performance standard
- Enhanced strength assessments:
    - Hull girder ultimate strength
    - Local fine mesh FE analysis
    - Advanced buckling analysis

Two main challenges are existing all along in our design process. One is how to meet the stricter requirement of CSR, while the other is how to control the steel weight. The initial information of the steel weight increase is from the Consequence Assessment by IACS[1] for a VLCC2 with the breadth of 60m. But after the whole design process, it is found that more steel weight will be increased. Meanwhile, the steel weight increases from the forward part, machinery space and aft end cannot be neglectable.

Reference [2] also gave an introduction of the development of the 308,000DWT VLCC, including the impact on loading condition, midship section design, and etc. by CSR. Here, a brief statistics of scantling and weight increases of such VLCC due to CSR is listed in Table 1. In midship area, the changes of bottom plating, inner bottom plating/stiffener, upper deck plating, inner hull BHD plating/stiffener, longitudinal BHD plating/stiffener, transverse watertight BHD plating/stiffener in center tank and ballast tank are similar to the conclusion in the Assessment[1].

The change shown for plating is noted as the range of difference of plate thickness, in mm, between the CSR required gross thickness and the as-built plate thickness for the plating area i.e. -0.5 or +1.0.

The change shown for stiffeners is expressed as a percentage of the gross cross sectional area, in $cm^2$, required by the CSR compared to the as-built cross sectional area, e.g. +36. The cross sectional area of stiffeners excludes the attached plate.

From the brief statistics, it could be found that:

- Beam sea load cases (5a) and harbour load case (A12) are dominant for advanced buckling check and yielding check for most structural members.
- FEM buckling, FEM yielding (coarse mesh or fine mesh) and fatigue evaluation are the key factors for increasing the steel weight in cargo hold area due to CSR.
- The weight increment in reference [1] for VLCC is small, while in real design, more steel weight will be increased.
- For fore end, aft end and ER or PR area, the local scantlings will be increased due to CSR minimum thickness requirement, local pressure and green sea load.

Table 1 A brief statistics of scantling/weight increases of 308K_VLCC due to CSR

| Structural members | Dominant Load case | Criteria or Brief statement | Comparison with Consequence assessment[1] | Change |
|---|---|---|---|---|
| **Midship C/H Area** | | | | |
| **Bottom** | | | | |
| Stiffener (%) | | Local press, Rule buckling, fatigue | Not only adding soft toe but adding soft back brackets. | +15 |
| **Inner Bottom** | | | | |
| Plating (mm) | | Local press, FEM fatigue | +3.5 is only for one small strake at the hopper knuckle due to FEM fatigue. | +1 to +3.5 |
| **Upper Deck** | | | | |
| Stiffener (%) | | HG fatigue | May be dominant for sectional modulus. | Increasing |
| **Horizontal Girders in Wing Ballast Tank** | | | | |
| Plating (mm) | A4-1 | FEM buckling, Fine mesh | More increasing than [1] only at the area near trans. w.t. BHD. | 0 to +5.5 |
| Stiffener (%) | | buckling slender | e.g. FB250x14.5,FB275x18AH. | Increasing |
| **Transverse W.T. BHD in Wing C/H** | | | | |
| Plating (mm) | A1-5a, A5-5a | FEM yielding, FEM buckling | More increasing than [1]. | 0 to +4 |
| **Horizontal Girders on Transverse W.T. BHD in Wing C/H** | | | | |
| Plating (mm) | A1-5a, A12 | FEM yielding, FEM buckling | No results in [1]. Faceplate increment at end areas. | 0 to +3 |
| Faceplate (%) | | | | Increasing |
| **Horizontal Girders on Transverse W.T. BHD in Center C/H** | | | | |
| Plating (mm) | A2-5a, A10 | FEM yielding, FEM buckling | No results in [1]. Faceplate increment at end areas. | 0 to +4 |
| Faceplate (%) | | | | Increasing |
| **Transverse Swash BHD in Wing C/H** | | | | |
| Plating (mm) | A1-5a | FEM buckling FEM yielding | No results in [1]. Buckling carling increment. | 0 to +2 |
| Faceplate (%) | | | | -16 to +32 |
| **Horizontal Girders on Transverse Swash BHD in Wing C/H** | | | | |
| Plating (mm) | A12 | FEM yielding, FEM buckling | No results in [1]. | +0.5 to +2.5 |
| Faceplate (%) | | | | Increasing |
| **N.W.T. Floors** | | | | |
| Plating (mm) | A1-5a | Rule shear, FEM buckling | More increasing than [1]. | -1.5 to 2.5 |
| **N.W.T. Hopper Web Plate** | | | | |
| Plating (mm) | A1-5a, A2-1, A12 | FEM buckling, FEM yielding | No results in [1]. Faceplate increment due to curved shape. | 0 to +4 |
| Faceplate (%) | | | | +40 to +59 |
| **Side Transverse** | | | | |
| Plating (mm) | A1-5a | FEM buckling, fine mesh | More increasing than [1]. | 0 to +4.5 |

| Structural members | Dominant Load case | Criteria or Brief statement | Comparison with Consequence assessment[1] | Change |
|---|---|---|---|---|
| **Deck Transverse in Wing C/H** | | | | |
| Plating (mm) | A1-5a | FEM yielding, FEM buckling, Rule Min. | More increasing than [1]. Faceplate at end area near inner hull increment and HT32 used. | +1.5 to +2.5 |
| Faceplate (%) | | | | -31 to +36 |
| **Deck Transverse in Center C/H** | | | | |
| Plating (mm) | A2-5a | FEM buckling, Rule Min. | Min. thickness increment, while faceplate could be decreased. | +1.5 |
| Faceplate (%) | | | | -24 |
| **Upper Portion of Vertical Transverse** | | | | |
| Plating (mm) | A1-5a, A12 | FEM buckling, Rule Min. | Web plating increment due to FEM buckling, while faceplate could be decreased. | 0 to +2 |
| Faceplate (%) | | | | -10 to +20 |
| **Lower Portion of Vertical Transverse** | | | | |
| Plating (mm) | A10, A12 | FEM buckling, FEM yielding, fine mesh | More increasing than [1]. | -1 to +3 |
| Faceplate (%) | | | | 0 to +18 |
| **Cross Tie** | | | | |
| Plating (mm) | A4-5a, A12 | Rule buckling, FEM buckling | Different type or section and arrangement. RCN 1 to July 2008 version for utilization factor and end constraint factor | -2 to +2 |
| Faceplate (%) | | | | Increasing |
| Type/Section | | | | Different |
| **End Brackets at the Lower Portion of Vertical Transverse** | | | | |
| Plating (mm) | A12 | FEM yielding | Enlarge the size and scantling due to FEM yielding. | -1 to +1 |
| Faceplate (%) | | | | Increasing |
| **FWD C/H (similar to Midship area except as shown)** | | | | |
| **Bottom** | | | | |
| Plating (mm) | | Bottom slamming | Design slamming draft forward is equal 6.11m (DB tank empty) | 0 to +1 |
| Stiffener (%) | | | | Increasing |
| **Side Shell** | | | | |
| Plating (mm) | | Bow impact | More increasing than [1]. Back brackets are added for side longitudinals. | -1 to +2 |
| Stiffener (%) | | | | Increasing |
| **Inner Bottom** | | | | |
| Plating (mm) | | Local press | Similar to [1]. | +1 to +2 |
| **N.W.T. Floors** | | | | |
| Plating (mm) | | Bottom slamming | More increasing than [1]. HT32 steel instead of MS is used. | 0 to +5 |
| **Transverse Swash BHD in Center/Wing C/H** | | | | |
| Plating (mm) | | Local press | | 0 to +2.5 |
| **Deck Transverse in Center/Wing C/H** | | | | |
| Plating (mm) | | Green sea load | No results in [1]. HT32 steel is used for end area. | HT32 used |
| Faceplate (%) | | | | HT32 used |

| Structural members | Dominant Load case | Criteria or Brief statement | Comparison with Consequence assessment[1] | Change |
|---|---|---|---|---|
| **AFT C/H (similar to Midship area except as shown)** | | | | |
| **W.T. boundary** | | | | |
| Plating (mm) | | Local press | Similar to [1]. Especially for side shell, inner hull BHD and longitudinal BHD. | 0 to +2.5 |
| Stiffener (%) | | | | 0 to +50 |
| | | | **Total Weight increase in Cargo Area due to CSR** | +1610t |
| | | | | |
| | | Criteria | Regions | Change |
| **Fore End Area (Comparison to MARIC's another design of VLCC, not CSR)** | | | | |
| | | Rule Min. | PSM, W.T. boundaries | ↑↑↑ |
| ↑↑↑ | -- Increasing more | Local press | Collision BHD, tank boundaries | ↑↑↑ |
| ↑↑ | -- Increasing less | Bow impact | Side shell | ↑↑ |
| ↑ | -- Increasing little | Bottom slamming | Bottom | ↑ |
| | | Green sea load | Upper deck region | ↑ |
| | | | **Total Weight increase in Fore End Area due to CSR** | +95t |
| **Aft End Area (Comparison to MARIC's another design of VLCC, not CSR)** | | | | |
| ↑↑↑ | -- Increasing more | Rule Min. | PSM, W.T. boundaries | ↑↑↑ |
| ↑↑ | -- Increasing less | Local press | Aft peak, Fresh tank, side shell | ↑↑ |
| ↑ | -- Increasing little | Green sea load | Upper deck region | ↑↑ |
| | | | **Total Weight increase in Aft End Area due to CSR** | +108t |
| **Engine Room and Pump Room (Comparison to MARIC's another design of VLCC, not CSR)** | | | | |
| ↑↑↑ | -- Increasing more | Rule Min. | PSM, W.T. boundaries | ↑↑↑ |
| ↑↑ | -- Increasing less | Local press | Tanks | ↑↑ |
| ↑ | -- Increasing little | Green sea load | Upper deck region | ↑ |
| | | | **Total Weight increase in E/R & P/R Area due to CSR** | +177t |
| | | | | |
| **Total steel weight increase due to CSR** | | | | +1990t |

# 3. Design experience on CSR VLCC

## 3.1 Fatigue evaluation on upper deck structure

The recently published statistics indicate a number of defects, especially fractures, occurring in tankers less than 10 years old[3,4]. In such damages, it is found that cracks for the upper deck and stiffeners are greater than that for either side shell or transverse bulkhead plate and stiffeners. Such defects reported for the upper deck plate and stiffeners are due to details. To avoid such failures, the shipyard should check and confirm the suitable structural details during construction. On the other hand, things will be better if an appropriate design standard or criterion can be provided for the outfit staffs.

MARIC introduces a simplified method based on a concept of fatigue factor for fatigue assessment on the details in upper/strength deck region. Such method is derived from our design experience on FPSO.

It is well known that the notch stress range governs the fatigue life of a detail. For components other than smooth specimens the notch stress is obtained by multiplication of the nominal stress by K-factors or stress concentration factors. In different stress approach, different stress ranges and different S-N curves are to be used. In CSR, nominal stress approach and hot spot stress approach are provided.

In MARIC's simplified method, the nominal stress approach is used because it is based on beam theory and easy to use. The so-called fatigue factor [K] only for deck structure, arising from different causes, geometry or welding or etc., is defined as:

$$[K] = \frac{\Delta\sigma_{perm-nominal}}{\Delta\sigma_{actual-nominal}} \qquad (1)$$

Where,

$\Delta\sigma_{perm-nominal}$ is the maximum permissible nominal stress range for deck structure calculated by nominal stress fatigue analysis when fatigue damage DM=1

$\Delta\sigma_{actual-nominal}$ is the actual nominal stress range for deck structure calculated by empirical formula shown in CSR

For upper deck region, the nominal stress response of longitudinal and transverse frames due to dynamic wave pressure and dynamic tank pressure loads is nearly to zero. That is to say, only the global stress components induced by hull girder wave bending moments are to be considered. Such vertical or horizontal wave bending moments can be calculated based on the CSR formulas or hydrodynamic analysis with a probability of exceedance of $10^{-4}$ in North Atlantic condition. Then, the actual nominal stress range can be derived. For different region of upper deck, a diagram of fatigue factor [K] can be achieved. In construction, the shipyard can check or confirm whether the stress concentration factor calculated from the selected detail is less than the fatigue factor [K]. If not, modification will be carried out to improve the details.

In CSR for tankers, stress concentration factors are not expressed clearly. But each classified detail is defined to belong to one S-N curve. This means that the stress concentration factor for the detail is included in the S-N curve. Also, such values for different details can be found in CSR for bulk carriers or other Class Rules. By Classification factor, different S-N curves can be unified as one S-N curve shown in Table 2.

Table 2 Classification Factor for S-N curves in CSR

| S-N curve | B | C | D | E | F | F2 | G |
|---|---|---|---|---|---|---|---|
| Classification Factor | 0.83 | 1.02 | 1.44 | 1.62 | 1.92 | 2.19 | 2.63 |

On the other hand, preliminary "fatigue section modulus" verification (**CSR**[5]**, Section 8/1.5.3**) is provided in CSR to control the fatigue life for deck structure. Such modulus is larger than the rule minimum hull girder section modulus (**CSR**[5]**, Section 8/1.2.2.2**) or the rule required hull girder section modulus (**CSR**[5]**, Section 8/1.2.3.2**). The greater value of section modulus at deck side, the lower nominal stress for deck structure could be found, and then the greater value of [K] could be achieved by formula (1). That is to say, the greater value of [K], the better fatigue life could be estimated.

The typical diagram of fatigue factor [K] for deck region in C.L. section of 308,000DWT VLCC is shown in Fig.1. By such diagram, how to choose, check or confirm the suitable structural details is available for the shipyard.

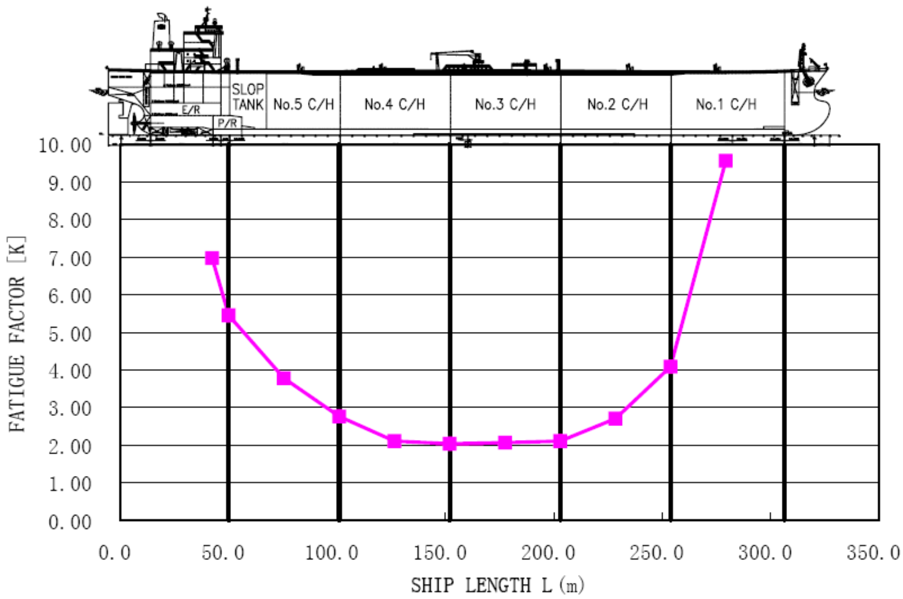



Fig.1 Typical diagram of fatigue factor [K] for deck region in C.L. section

## 3.2 Analysis on hull girder shear strength

The cross section of DH oil tankers is always subdivided into two or more closed cells by double hull, longitudinal bulkheads, tank tops, and decks. The shear flow $q_v$ ($mm^{-1}$) in such multicell sections can be expressed as according to CSR[5]:

$$q_v = f_i \left( \frac{q_{1-net50}}{I_{v-net50}} \right) \cdot 10^{-9} \qquad mm^{-1} \tag{2}$$

Where,

$f_i$ shear force distribution factor for the main longitudinal hull girder shear carrying members being considered. CSR gives the formula to determine the $f_i$ for standard structural configurations.

$q_{1-net50}$ first moment of area about the horizontal neutral axis of the members between the vertical level at which the shear stress is being determined and the vertical extremely of effective shear carrying members, in $cm^3$.

$I_{v-net50}$ net vertical hull girder section moment of inertia, in $m^4$.

Based on shear flow $q_v$, the net vertical shear strength $Q_{vij-net50}$ (kN) for plate $ij$ can be achieved.

$$Q_{vij-net50} = \frac{\tau_{ij-perm} t_{ij-net50}}{1000 q_{vij}} \qquad kN \tag{3}$$

Where,

$t_{ij-net50}$ equivalent net thickness for plate $ij$, in mm.

$\tau_{ij-perm}$ permissible hull girder shear stress for plate $ij$, in $N/mm^2$.

The net hull girder vertical shear strength, $Q_{v-net50}$, is to be taken as the minimum for all plate elements that contribute to the hull girder shear capacity. The shear flow of continuous longitudinal bulkheads will be altered by changing the bulkhead plate thickness.

By differential method, the sensitivity coefficients for shear flow and shear capacity are discussed in reference [6]. Such coefficients can be expressed in the following:

$$\frac{dq_v}{q_v} = \frac{df_i}{f_i} + \frac{dq_{1-net50}}{q_{1-net50}} - \frac{dI_{v-net50}}{I_{v-net50}} \tag{4}$$

$$\frac{dQ_{vij-net50}}{Q_{vij-net50}} = \frac{d\tau_{ij-perm}}{\tau_{ij-perm}} + \frac{dt_{ij-net50}}{t_{ij-net50}} - \frac{dq_{vij}}{q_{vij}} \tag{5}$$

From the numerical results, it is found that if the plate thickness of longitudinal bulkheads between cargo tanks is increased, the alternation of shear flow due to $df_i$ is larger than that due to $dq_{1\text{-}net50}$ and $dI_{v\text{-}net50}$. That is to say, with the increasing of bulkhead plate thickness, the whole shear flow of the bulkhead is increased, so that more shear force will be taken by the longitudinal bulkheads.

From the formula (5), it could be found:

**Case 1:** No changes for plate thickness, but increase the permissible shear stress of the plate *ij*. The sensitivity coefficient of $Q_{vij\text{-}net50}$ can be expressed as:

$$\frac{dQ_{vij-net50}}{Q_{vij-net50}} = \frac{d\tau_{ij-perm}}{\tau_{ij-perm}} \tag{6}$$

**Case 2**: Only increase the plate thickness for plate *ij*, no changes for the materials. For plate *ij*, the sensitivity coefficient of $Q_{vij\text{-}net50}$ can be expressed as:

$$\frac{dQ_{vij-net50}}{Q_{vij-net50}} = \frac{dt_{ij-net50}}{t_{ij-net50}} - \frac{dq_{vij}}{q_{vij}} \tag{7}$$

For other bulkhead plate, e.g. plate *gh*, the sensitivity coefficient of $Q_{vij\text{-}net50}$ can be expressed as:

$$\frac{dQ_{vgh-net50}}{Q_{vgh-net50}} = -\frac{dq_{vgh}}{q_{vgh}} \tag{8}$$

From the formula (6)~(8), it can be found that for case 1, the vertical shear capacity will be increased, while for case 2 things will be different. If increasing the plate thickness for plate *ij*, the whole shear flow for the bulkhead will be increased as mentioned above. Therefore, for plate *gh*, the vertical shear capacity will be decreased from formula (8). Using higher strength steels is the most effective method to increase the vertical shear capacity for the longitudinal bulkheads between cargo tanks.

More attention should be paid to where shear capacity is significantly changing due to variation of scantling or arrangement in longitudinal bulkhead. Such areas are usually at the locations just outside the reinforced region 2 frames aft or forward from the transverse bulkhead due to the changing of plate thickness or the locations near the engine room forward bulkhead due to double hull transmitted to single hull.

## 3.3 Cross ties

Cross ties are large transverse structural members joining longitudinal bulkheads and used to support them against hydrostatic and hydrodynamic loads. According to the designer, it is both accepted that cross tie is arranged in wing cargo tanks or center cargo tank[7]. But for improving shipyard technology and owner's convenience to tank wash, the current trend is to set the cross tie in center cargo tank.

According to the requirement of Technical Provisions for Means of Access for Inspection (i.e. PMA)[8], for ships having cross ties which are 6m or more above tank bottom, a transverse PMA on the cross ties providing inspection of the tie flaring brackets at both sides of the tank, with access from one of the longitudinal PMA.

According to buckling requirement of CSR, not only the column buckling mode, but also the torsional buckling mode and the interaction between them are to be checked. From our analysis, it is found that it's too difficult to meet the torsional buckling requirement for the section of cross tie where the centroid and the shear center do not coincide. Besides three axial symmetric cross sections provided by CSR[5], MARIC pays attention to a new centrosymmetric cross section type as shown in Fig.2. The cross sectional properties are as follows:

$$I_{sv-net50} = \frac{1}{3}\left(b_{f1}t_{f1-net50}^3 + 2b_{f2}t_{f2-net50}^3 + 2b_{f3}t_{f3-net50}^3 + d_{wt}t_{w-net50}^3\right)10^{-4} \quad \text{cm}^4$$

$$y_0 = 0 \quad \text{cm}$$

$$z_0 = 0 \quad \text{cm}$$

$$C_{warp} = \frac{b_{f1}^2 b_{f2}^3 t_{f2-net50} + d_{wt}^2 b_{f3}^3 t_{f3-net50}}{24} 10^{-6} \quad \text{cm}^6$$

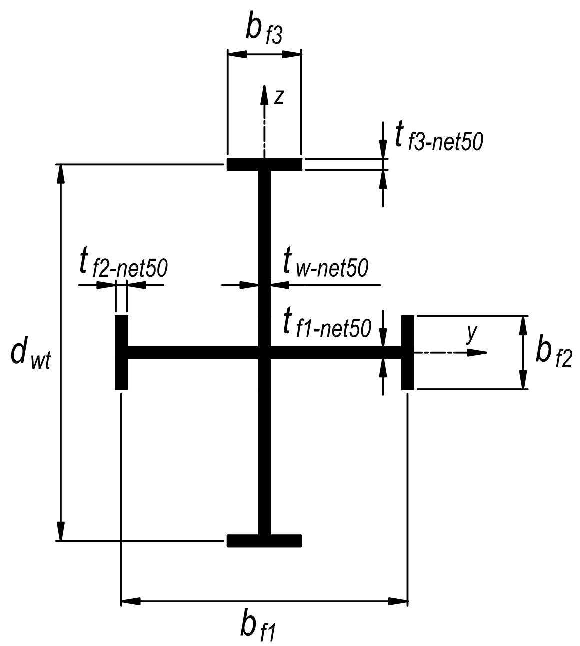



Fig.2 Centrosymmetric cross section

### 3.3.1 Conventional arrangement

The conventional arrangement of cross ties in center cargo tank is shown in Fig.3. The omitted cross tie is due to the horizontal stringer on the transverse watertight bulkhead. The longitudinal PMA may be integrated in the structural members or not.

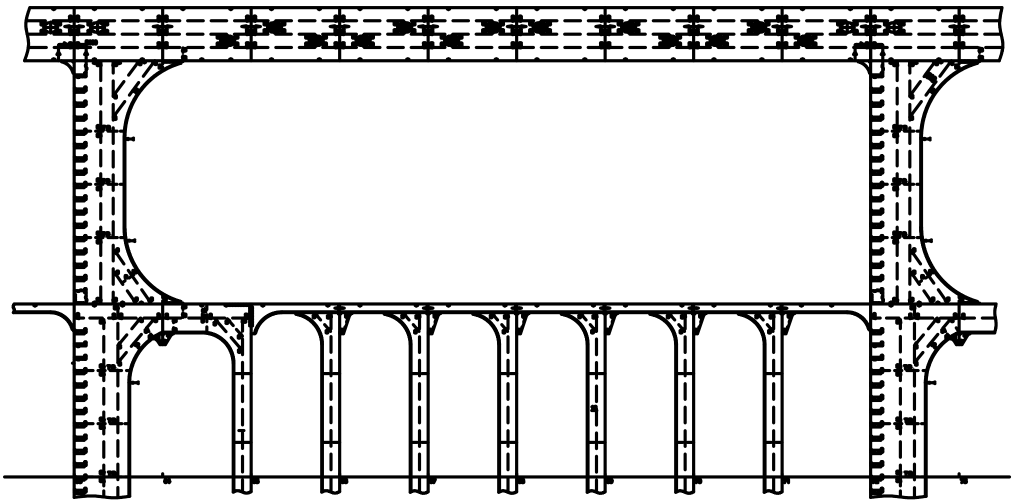


Fig.3 The conventional arrangement of cross ties in center C/H

### 3.3.2 Current typical arrangement

The current typical arrangement of cross ties in center cargo tank is shown in Fig.4. One more cross tie is omitted in way of transverse swash bulkhead arranged in wing cargo tanks. In this case, the horizontal stringers on swash bulkhead are to be designed carefully. The longitudinal PMA may be integrated in the structural members or not.

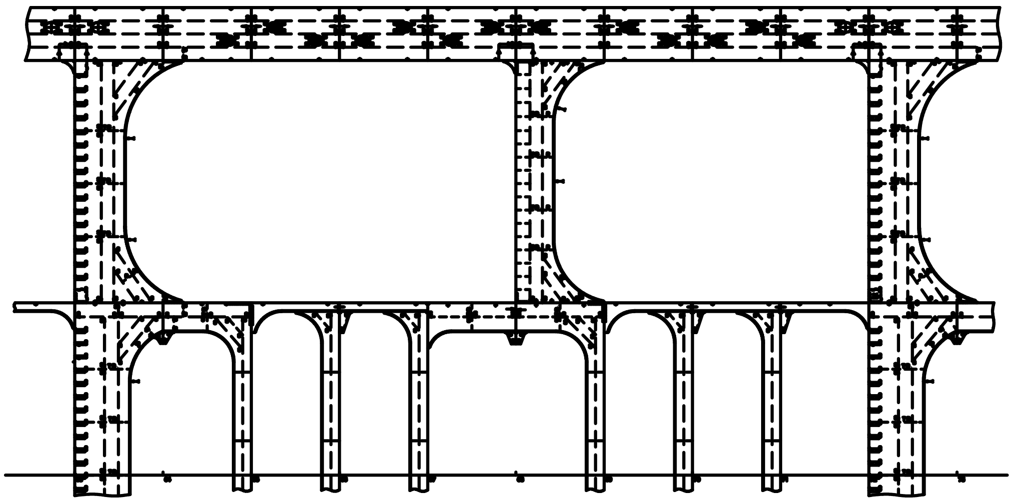


Fig.4 The current typical arrangement of cross ties in center C/H

### 3.3.3 308,000DWT arrangement

In our 308,000DWT VLCC design, another cross tie is omitted 1 frame aft or forward from the transverse bulkhead considering the enlarged longitudinal PMA stringers. Instead, the end of longitudinal PMA is enlarged and the vertical transverse where the omitted cross tie locates is reinforced. Such arrangement is shown in Fig.5. The typical FE results is shown in Fig.6. The load cases of A4-5a and A12 are dominant for cross ties. Two of the cross ties between the transverse swash bulkhead and transverse watertight bulkhead are reinforced due to Rule and FE buckling check.

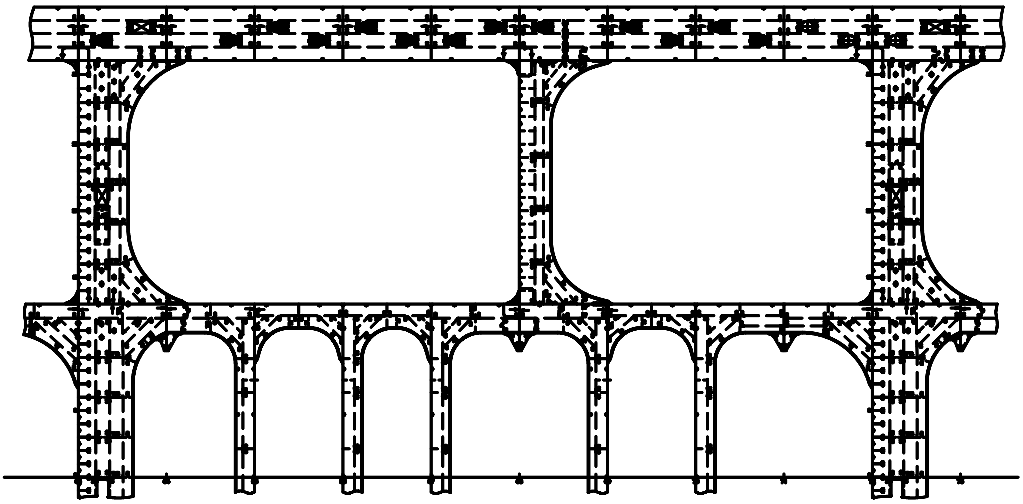
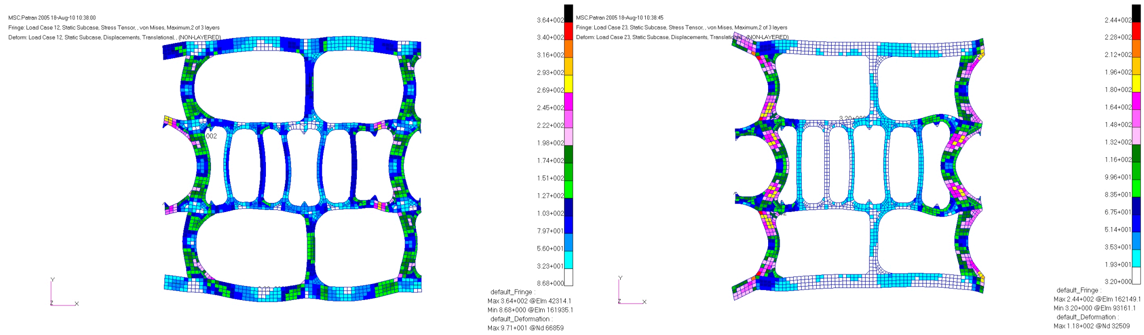


Fig.5 The arrangement of cross tie of 308,000DWT VLCC



（A4-5a） (A12)

Fig.6 Typ. FE results for the cross tie of 308,000DWT VLCC

### 3.3.4 Future new arrangement

As mentioned before, RCN 1 of CSR to July 2008 version has changed the utilization factor against buckling and end constraint factor for cross ties. Such changes give chance to optimize the arrangement and section type of cross ties.

After discussion with some Classification, a new arrangement of cross tie is developed as shown in Fig.7. In such case, the longitudinal PMA is enlarged more than required, while only two cross ties are arranged between transverse swash bulkhead and transverse watertight bulkhead. The section of the cross tie is used as centrosymmetric type. Higher strength steel (HT32) is also used for the cross tie plating. The typical FE results are shown in Fig.8, which show that such arrangement of cross ties is feasible and may be better for improving shipyard technology and owner's convenience to tank wash.

For the steel weight, the difference among such choices are only a little excluding the increasing due to the integration of longitudinal PMA in the structural members.

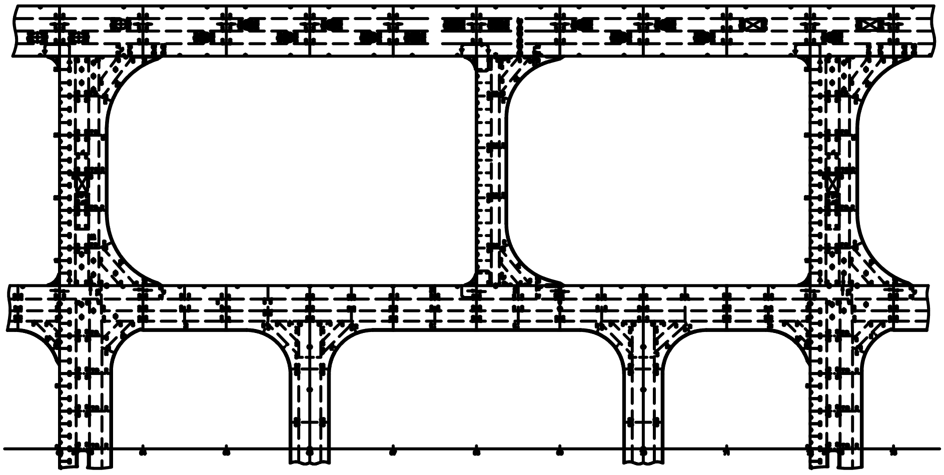
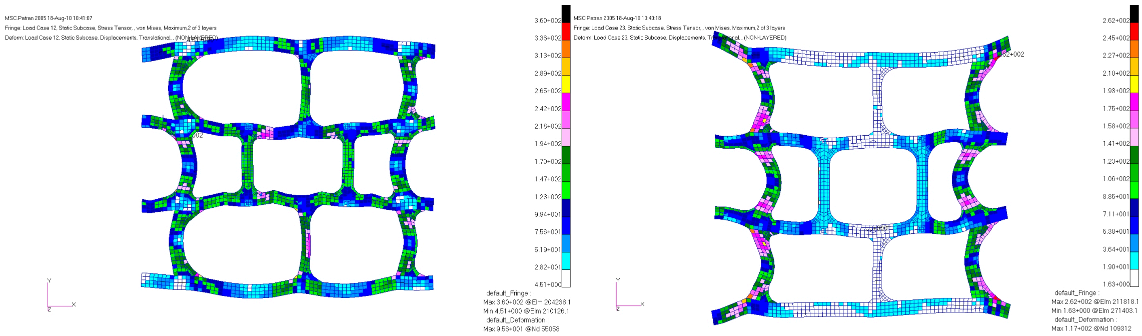


Fig.7 New arrangement of cross tie in center C/H



（A4-5a）　　　　(A12)

Fig.8 Typ. FE results for cross tie in new arrangement

## 4. Conclusion

The conclusions from our experience with the four DH VLCC complied with CSR are summarized as follows:

- Beam sea load cases (5a) and harbour load case (A12) are dominant for advanced buckling check and yielding check for most structural members, while such FE analysis and fatigue evaluation are the key factors for increasing the steel weight in cargo hold area due to CSR.
- To avoid the failures due to fatigue in upper deck region, the evaluation of maximum allowable stress range or so-called fatigue factor [K] is feasible for the shipyard to choose, check or confirm the suitable structural details during construction.
- Using the higher strength steel is the most effective method to increase the vertical shear capacity for the longitudinal bulkheads between cargo tanks. When increasing one longitudinal bulkhead plate thickness, it should be noted that the whole vertical shear capacity for the longitudinal bulkheads will be decreased

because more shear force will be taken by the bulkheads.

- When considering the enlarged longitudinal PMA girder, the arrangement and section of cross tie could be optimized for improving shipyard technology and owner's convenience to tank wash.

## 5. Acknowledgement

The author would like to thank the owner and the shipyard for their support during the design process. Thanks also to other colleagues who have participated in the project. Particular thanks are to: Dai liguang from DNV Shanghai office, Lin Li and Wang He from CCS Shanghai office, ShuJi Maruyama and Makoto Oba from ABS Pacific.

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