Shipyard Experience in Structural Design of Double Hull Tankers -Past, Present and Future-

Satoshi Yamamoto

Universal Shipbuilding Corporation, Japan, yamamoto-satoshi@u-zosen.co.jp

Abstract

The first double hull VLCC complying with MARPOL requirements was delivered in 1992. Up to now more than three hundred VLCCs have already been delivered worldwide. Adding Suez-Max and Afra-Max Tankers to this, approximately one thousand large double hull tankers are now in operation. The oldest one would be fifteen years old.

In the design stage of double hull tankers from the early 1990s, the fatigue problem in young single hull VLCCs had been already found and investigated. And many classification societies developed new rules to solve these problems. Most of all double hull tankers have been designed and constructed according to these rules.

In this presentation, the service experience and the damage ratio of double hull VLCCs have been investigated and compared with those of single hull VLCCs. The results indicate that fatigue damage to side longitudinal connections, which was observed in single hull VLCCs, has not been found in double hull VLCCs.

Several years ago, however, fatigue damage was found at connections between longitudinal bulkhead and transverse bulkhead of a few double hull VLCCs having struts in center cargo tanks. These had never been observed before. In the present design, therefore, backing brackets are provided in positions designed to prevent the damage. Judging from the results, double hull VLCCs are generally more robust than single hull VLCCs.

In addition to the study on existing double hull VLCCs, future design for double hull VLCCs complying with CSR has been discussed.

1 PREFACE

On April 1st 2006 Common Structure Rules (CSR) for double hull tankers and bulk carriers which had been developed by International Association of Classification Societies (IACS), entered into force. Before the CSR, there were many classification rules related to hull structures, which created some confusion among related industries. This issue has been solved by implementation of the CSR. Moreover the CSR has the further aim of achieving more robust and safer ships.

On the other hand, International Maritime Organization (IMO) adopted Performance Standard for Protective Coatings (PSPC) at MSC82 in 2006. This standard affects not only coating practice of shipyards but also structural design of ships since according to it all free edges of hull structure should be ground smooth.

Taking this opportunity, service experience of single hull VLCCs and double hull VLCCs up to now has been reviewed. Based on its results, future structural design of VLCCs complying with the CSR and the PSPC is discussed.

2 SINGLE HULL VLCC

2.1 Structural design

The first single hull VLCC was developed in the 1960's. In the structural design, high tensile strength steel of HT32 was used only to upper and lower parts of hull girders. Also, struts supporting side structures were arranged in wing cargo tanks.

In the early 1980's, Thermo Mechanical Control Process (TMCP) steel was developed in Japan. Since the TMCP steel does not need additional work in the building stage of shipyards, such as pre-heating and post-heating, the use of TMCP steel expanded in Japanese shipbuilders.

As a result, the second generation VLCCs built in the late 1980's were designed using high tensile strength steel of HT36 and/or HT40, in which HT36 was used not only to hull girder strength members but also to longitudinals and transverse members to increase cargo deadweight by reducing hull steel weight. The HT steel ratio of the second generation VLCCs increased to approximately 70-80 % from 30 %.

In the second generation VLCCs, however, the concept of structural design was almost identical to that of the first generation. Difference between them lies only in materials used to hull structure. The scantlings were determined in accordance with classification societies' rules based entirely on yielding criteria. As a result, the scantlings of hull structural members were reduced. And the working stresses in the structural members increased. It caused many fatigue problems in hull structure, especially in side longitudinals.

2.2 Service experience

Service experience of the second generation VLCCs was well summarized in ClassNK(1998). According to the report, a lot of structural damage occurred at a very early stage after their delivery, as shown in Fig. 1.

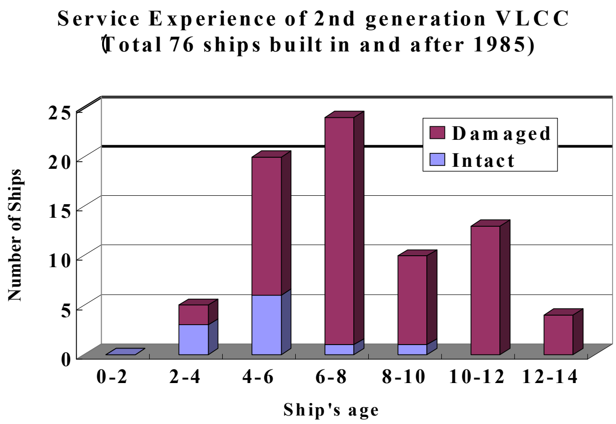


Fig. 1 Service experience of 2nd generation S/H VLCCs

ClassNK(1998) reviewed the structural damage in each ship's age. The results are shown in Fig. 2. In the figure, the solid line shows the total amount of damage for each area (ratio to the cumulative total number of damage). The line has two peaks at ship's ages of 4-6 and 8-10 years old. Since the ages correspond to 1st and 2nd Special Survey, the structural damage was probably found during the special survey.

Fig. 2 shows that almost all structural damage occurred in side and bottom areas. The structural damage of side area began to occur at an earlier stage than any other areas. Two years later, structural damage of bottom area began to occur.

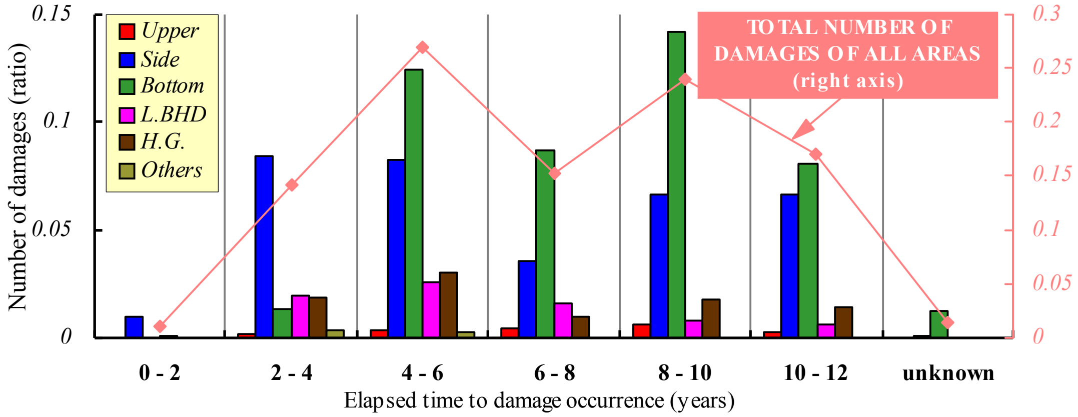


Fig. 2 Frequency distribution of damage based on elapsed time to damage occurrence of S/H VLCCs, ClassNK(1998)

The type of the structural damage in side area is mainly fatigue crack which occurs at connections of side longitudinals and web stiffeners fitted on transverse webs or transverse bulkheads. On the other hand, the type of the structural damage in bottom area is mainly fatigue crack which occurs around slot openings for bottom longitudinals.

Photos of fatigue cracks occurred in second generation VLCCs are shown in Fig. 3. Left hand photo shows the fatigue crack occurred at the connection between side longitudinal and web stiffener. Right hand photo shows the fatigue crack occurred around slot opening of bottom transverse.

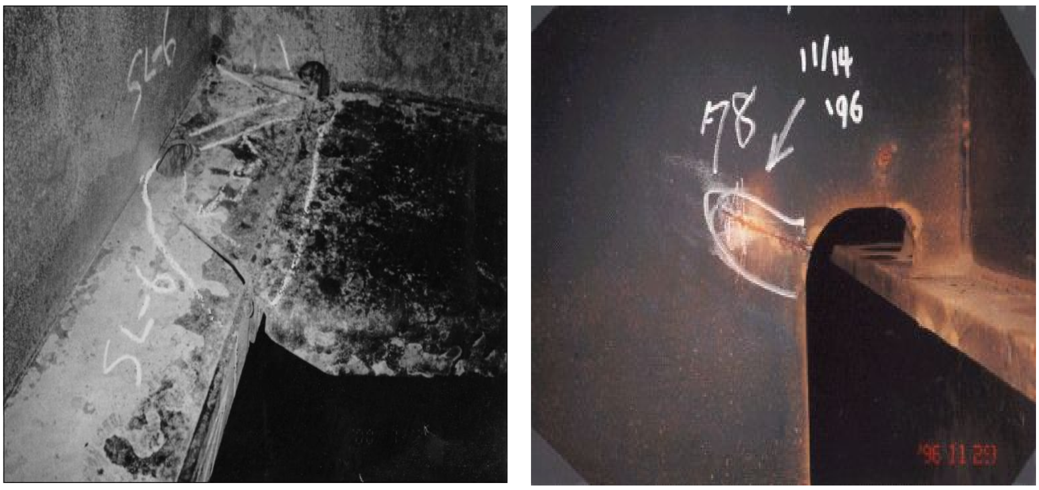


Fig. 3 Photos of fatigue cracks

2.3 Feedback to structural design

The causes of the structural damage were examined by classification societies and shipyards for several years.

[Side Area]

The structural damage in side area can be categorized into two patterns. One is a fatigue crack propagating along welded joint of side longitudinal and web stiffener. The other is a fatigue crack occurring at toe of web stiffener and propagating into side longitudinal. The latter one is very serious damage since the crack probably penetrates side shell plating. As a result, it makes oil spills and can lead to environmental pollution.

The cause of the former crack is lack of connection area of side longitudinal and transverse web. The connection area is the total area of a lug connection area of side longitudinal and transverse web and a connection area of side longitudinal and web stiffener.

In the second generation VLCCs, depth of side longitudinal was reduced. And thickness of transverse web was also reduced. Thus the lug connection area was reduced in comparison with that of the first generation VLCCs by using HT steel design. As a result, stress in the connection area of side longitudinal and web stiffener increased, which caused the fatigue crack at the connection. Taking this into account, many classification societies established their rules requiring an adequate total connection area.

- Required connection area between longitudinals and transverse web

As for the latter crack, main cause is an increase in working stress in side longitudinal. The working stress was increased due to the following causes. The first is scantling reduction of side longitudinal by using HT steel. The second is a reduction of rigidity of transverse web, which increases a relative deflection between transverse web and transverse bulkhead. The increase in relative deflection increases stresses in side longitudinal. The last is configuration of side longitudinal. Asymmetrical shape was used to side longitudinals of the first generation VLCCs. This asymmetrical shape increases working stress in side longitudinal. In the second generation VLCCs, however, the shape of side longitudinal had not been reconsidered.

Taking into account these causes, many classification societies established their rules to prevent occurrence of such types of damage.

- Required scantling of longitudinal taken into account fatigue strength
- Relative deflection to be taken into account in fatigue assessment
- Difference in shape of longitudinal to be taken into account in fatigue assessment

[Bottom Area]

The cause of the structural damage in bottom area is an increase in working stress around slot opening. The thickness of transverse web was reduced taking into account higher permissible stress for HT steel, which increased the stress around slot opening. Adequate size of collar plate was provided to the slot opening to prevent occurrence of such kind of damage.

- To provide adequate size of collar plate to slot opening

Structural designers learned how to adequately use HT steel for reliable hull structure through the service experience of second generation VLCCs.

3 DOUBLE HULL VLCC

3.1 Structural design

The first double hull VLCC complying with MARPOL requirements was delivered in 1992. Up to now more than three hundred VLCCs have already been delivered worldwide, as shown in Fig. 4. The oldest one would be fifteen years old.

In the design stage of early built double hull VLCCs, in the early 1990s, the fatigue problem in young single hull VLCCs had been already found and investigated. And many classification societies developed new rules to solve the problem. Most of all double hull tankers have been designed and constructed according to these rules.

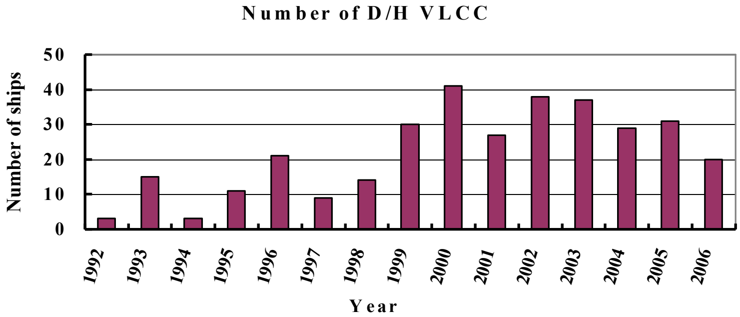


Fig. 4 Number of D/H VLCC delivered

There is one feature in the structural designs of double hull VLCCs. In single hull VLCCs, struts connecting vertical webs were arranged in wing cargo tanks. In the newly designed double hull VLCCs, however, the struts were arranged in center cargo tanks. This design focused on the increase in the rigidity of side structure due to double hull.

Comparison in configuration between them is shown in Fig. 5. Left hand and right hand are wing strut type and center strut type, respectively. In the early stage, the majority was wing strut type VLCCs. At present, however, center strut type VLCCs has become the majority.

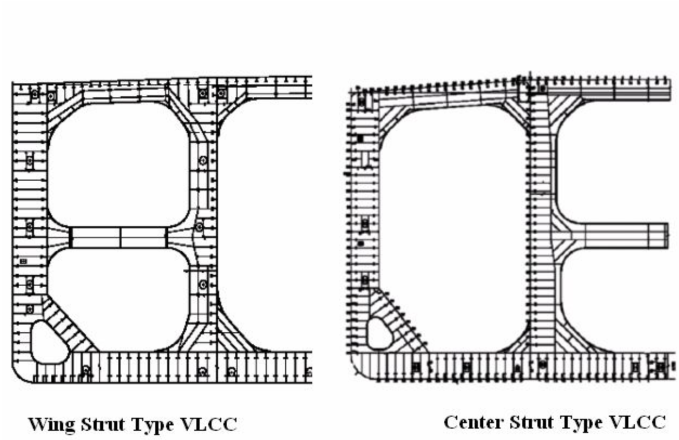


Fig. 5 Typical structural designs of D/H VLCC

3.2 *Service experience*

In the second generation VLCCs, many fatigue cracks were found by 1st special survey. In double hull VLCCs, however, fatigue damage to side longitudinal connection which was observed in single hull VLCCs, had not been found up to now.

This kind of damage problem has been solved by newly developed rules in which fatigue assessment should be carried out. Judging from the results, double hull VLCCs are generally more robust than single hull VLCCs.

Several years ago, however, new kinds of structural damage were reported. Fatigue damage was found at connections between longitudinal bulkhead and transverse bulkhead of several double hull VLCCs having struts in center cargo tanks, which had never been observed before. A sketch of the damage is shown in Fig. 6. Such kind of damage has not been found out in wing strut type VLCCs until now.

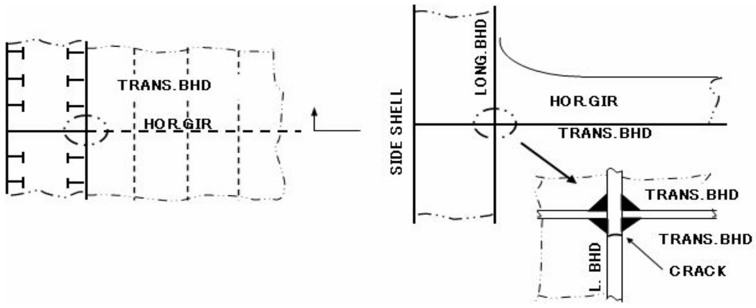


Fig. 6 Sketch of damage occurred at connection of L.BHD and T.BHD

The other type of damage was reported by SR245(2002). The damage occurred at lower hopper knuckle of a few double hull VLCCs. A sketch of the damage is shown in Fig. 7. The damaged lower hopper knuckle is of welded type. And grinding at toe of weld bead had not been carried out.

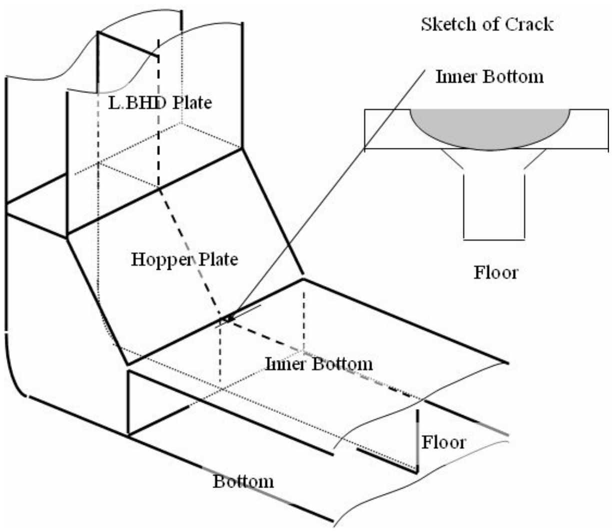


Fig. 7 Sketch of damage occurred at lower hopper knuckle

3.3 *Feedback to structural design*

The causes of the structural damage were examined by classification societies and shipyards. The results are as follows.

[L.BHD/T.BHD]

In case of center strut type VLCCs, the stresses occurring at the intersection of longitudinal bulkhead and transverse bulkhead are very high in comparison with those of wing strut type VLCCs. In case of wing strut type VLCCs, the double side structure exposed to dynamic sea loads is supported by wing struts connected to vertical webs on inner longitudinal bulkhead. Thus the stresses at the location concerned are lower than those of center strut type VLCCs.

A result of fatigue strength assessment is shown in Fig. 8. Fatigue damage factor of wing strut type VLCC is very little in comparison with that of center strut type VLCC. Under heavy weather conditions, such as the North Atlantic Ocean, fatigue damage factor of center strut type VLCC exceeds the criterion of 1.0.

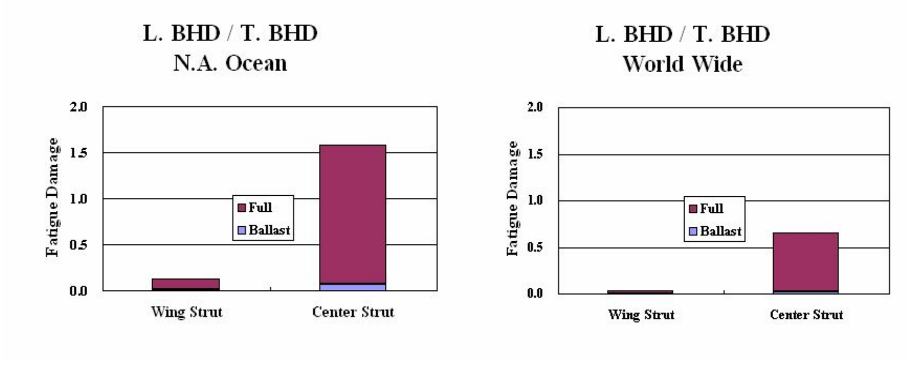


Fig. 8 Comparison in fatigue damage factor between Wing Strut and Center Strut

Since the frequency of occurrence of the damage is very little, initial defect during construction stage, such as misalignment between transverse bulkhead and transverse web in double hull, would probably be one of the causes.

In the present design, therefore, backing brackets are provided at the position to prevent the damage.

- To provide back brackets at the intersection of L. BHD and T. BHD
- To keep alignment between T. BHD and T. Web in double hull

[Lower Hopper Knuckle]

Figure 9 shows the result of fatigue strength assessment on lower hopper corner. Although the fatigue damage factor of lower hopper corner is less than 1.0 under world wide operation, under heavy weather conditions, such as the North Atlantic Ocean, the fatigue damage factor exceeds 1.0. Taking into account grinding effect, the fatigue damage factor can be reduced to less than 1.0.

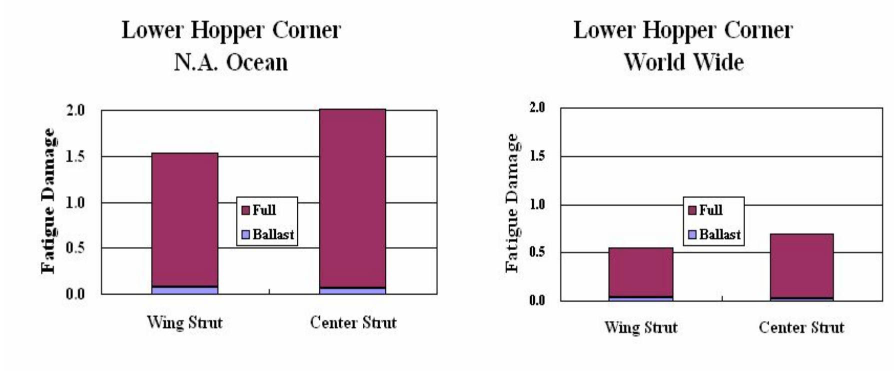


Fig. 9 Comparison in fatigue damage factor between Wing Strut and Center Strut

- Toe of weld bead of lower hopper knuckle to be ground smooth
- Centerline alignment among inner bottom, hopper plate and side girder to be kept

4 CSR VLCC DESIGN

4.1 CSR for tankers

On 1st April 2006 Common Structure Rules (CSR) for double hull tankers and bulk carriers, developed by International Association of Classification Societies (IACS), entered into force. Of course, the CSR has been developed to prevent the structural damage mentioned above. Compared with the existing rules, main features of the CSR are summarized in Table 1 in which correspondence of the CSR to IMO GBS is also listed.

Table 1 Comparison between CSR and existing rules

IMO GBS Tier II	IACS CSR	Existing Rules
Design Life	Min. 25 years	Not Explicit
Environmental Conditions	North Atlantic Ocean	Longitudinal Strength : North Atlantic Ocean Others : World Wide
Structural Strength	Yielding Buckling Ultimate Strength	Yielding Buckling No Description
Fatigue Life	Min. 25 years	Min. 20 years
Protection Against Corrosion	PSPC Corrosion Addition	Not Explicit
Construction Quality	IACS Rec. 47 or Equivalent	Not Explicit

In the CSR, main design parameters, such as design life, environmental conditions and corrosion addition, are clearly prescribed. And the CSR makes consistency among them. The most appreciated point is that the CSR makes consistency between corrosion addition in design stage and permissible diminution in operation stage. Before CSR, there was no written technical background in the determination of permissible diminution.

4.2 Structural design for CSR

Future structural designs of double hull VLCC complying with the CSR are discussed hereinafter item by item.

[HT ratio]

The existing designs of double hull VLCC can be categorized into two groups from materials viewpoint. One group is so called HT rich design. The other is MS rich design. HT rich VLCCs were mainly built in Japan to increase cargo deadweight and to reduce fuel consumption. HT ratio of the design is approximately 70-80%, almost same as the second generation single hull VLCCs. On the other hand, in the MS rich design, the use of HT steel is limited, and the HT ratio is approximately 30%.

In future, however, the two designs would probably converge in one design in which the HT ratio is around 50 % for the following reasons.

Since the buckling assessment of the CSR is very severe in comparison with that of the existing rules, working stresses in structural members exposed to compression loads should be reduced. Higher permissible stresses obtained by using HT steel are not necessary for the members. Thus adding HT steel to the members is meaningless.

On the contrary, due to an increase in dynamic sea loads and the severe loading patterns adopted by the CSR, tensile working stresses become higher in certain structural members. In such cases, using HT steel is effective to reduce the increase of steel hull weight.

As a result, in case of the existing HT rich design, the HT ratio would be probably reduced. And the HT ratio of the existing MS rich design would increase.

[Transverse Spacing / Longitudinal spacing]

Since the dynamic loads prescribed in the CSR are very large, transverse spacing and longitudinal spacing in future designs would become shorter than those of the existing design. It means an increase in the number of structural members.

On the contrary, taking into consideration the requirements of the PSPC, it is better to reduce the number of structural members having free edges to be ground smooth.

This contradiction is a big issue for structural designs.

[Arrangement of strut]

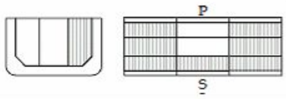
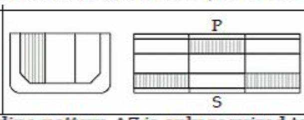
According to the CSR, the asymmetrical loading patterns which are used in strength assessment are only required for center strut type VLCCs, as shown in Table 2. In case of wing strut type VLCCs, there is no additional requirement related to asymmetrical loadings.

It is a disadvantage to the center strut design which is majority of the existing ones. If ship owners require asymmetrical loadings under ocean going conditions, wing strut design is probably suitable for the purpose.

Structural designers have to decide which one is preferable for both ship owners and shipbuilders.

Table 2 Loading pattern to be only required for center strut type VLCC

Table B.2.3 (Continued)
FE Load Cases for Tankers with Two Oil-tight Longitudinal Bulkheads

Loading Pattern	Figure	Still Water Loads			Dynamic load cases		
		Draught	Perm. SWBM(2)	Perm. SWSF(2)	Strength assessment (1a)	Strength assessment against hull girder shear loads (1b)	
					Midship region	Forward region	Midship and aft regions
A7(8)		T_{LC}	100% (hog)	100% (-ve fwd) See note 4	5a	\	\
Design load combination S (Harbour and tank testing load cases)							
A12(10,13)		$1/3T_{sc}$	See note 10	See note 10	Only applicable to strength assessment of midship region (see note 1(a))		

8. Loading pattern A7 is only required to be analysed for tankers with a cross tie arrangement in the centre cargo tanks if the ship's loading manual includes a non-symmetrical loading condition with only one of the wing tanks filled. The actual draught from the loading manual for the condition is to be used in the analysis, see *Table B.2.5*.

5 CONCLUSION

Structural designers learned how to adequately use HT steel for reliable hull structure through the service experience of the second generation single hull VLCCs. Moreover they knew critical areas of double hull VLCCs to be thoroughly designed through the service experience of over 15 years.

In the CSR, main design parameters, such as design life, environmental conditions and corrosion addition, are clearly prescribed. And the CSR makes consistency among them. The most appreciated point is that the CSR shows consistency between corrosion addition in design stage and permissible diminution in operation stage.

Although the CSR is the advanced rule, as a result, the CSR increases hull steel weight and building man-hours. It has a big impact on shipbuilding industries.

By using the knowledge obtained from the service experience, structural designers have to study optimal structural design for industries.

6 REFRENCES

ClassNK (1998) Casualty Review, Comprehensive damage review of 2^{nd} Generation VLCCs
SR245(2002) Japanese Ship Research Project No.245: Study of Fatigue Life Monitoring System
IACS (2006) Common Structural Rules for Double Hull Oil Tankers