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Hull Structural Design of A 300,000 DWT Double Hull VLCC

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Abstract

The enactment of OPA90 (Oil Pollution Act of 1990) in the USA and the consequent moves by IMO(International Maritime Organization) to introduce new Regulations for the design of oil tankers led the oil transportation industry to undergo a period of big change. This resulted in the introduction of double hull tankers.

This paper introduces the design for the 300,000 DWT double hull VLCC of World-Wide Shipping Agency Pte Ltd. in Hong Kong, which is the first of this type constructed by Daewoo Shipbuilding & Heavy Machinery Ltd.(DSHM). The characteristics of the compartment and structural arrangement of this vessel are briefly described, and the scope of structural analysis is illustrated.

In addition, the merits/demerits of different crosstie arrangements are described in the appendices.

1 Introduction

As oil tankers increased in size, the merits of carrying large quantities of crude oil with the consequent reduction in transportion cost soon became apparent. This led to the introduction of the very large crude oil carriers (VLCCs) in the early 1970's.

Since the grounding incident of EXXON VALDEZ in March 1989, the concern about marine pollution has universally increased. This prompted compulsorily regulations for the double hull tanker by "The Oil Pollution Act of 1990 (OPA90)" of the United States of America followed by "The Marine Environmental Protection Committee (MEPC)" of "The International Maritime Organization(IMO)".

This was further reinforced by more recent successive grounding and collision incidents of oil tankers (See Table 1 [4]) which emphasized the necessity to develop the double hull tanker design.

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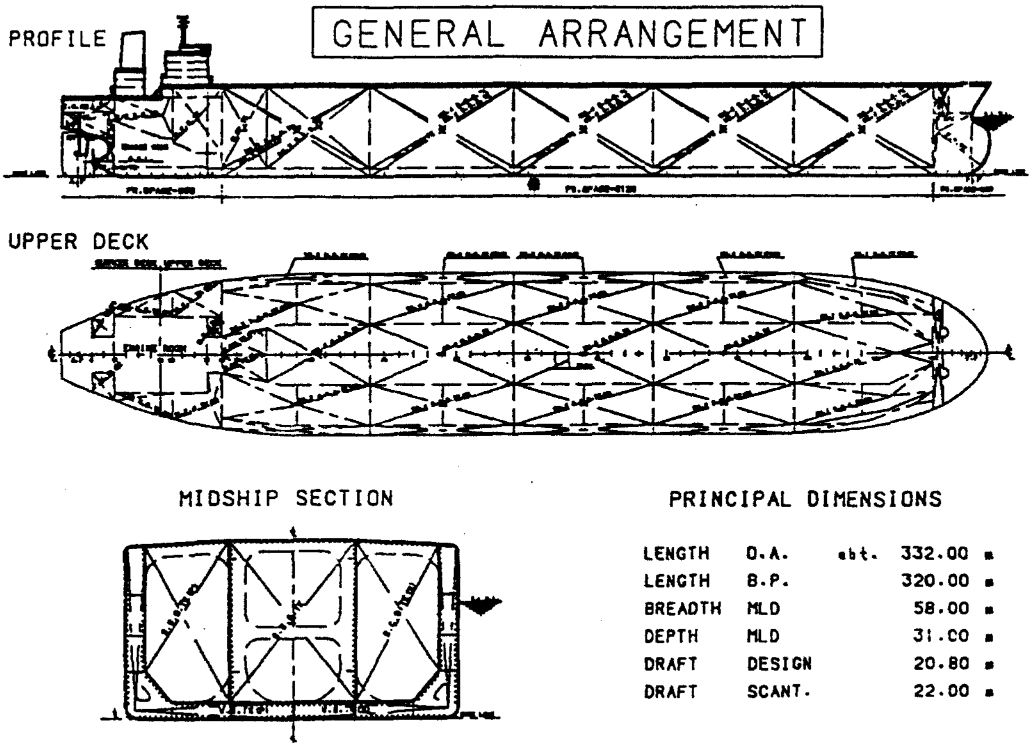
Table 1: Accidents of grounding or collision of tankers

YEAR	SHIP NAME	DWT x 1000	LEAK Q'TY (kl)	LOCATION OF ACCIDENT	CAUSE OF ACCIDENT
1967	TORREY CANYON				
1976	URQUIOLA		11.4	SPAIN	
1978	ANDROS PATRIA		50		
1978	AMOCO CADIZ	237	221	ATLANTIC FRANCE	EXPLOSION
1979	ATLANTIC EMPRESS	293	257	WEST INDIES	COLLISION
1979	INDEPENDENTA	152	95	TURKEY	"
1979	BURMAH AGATE	63	41	AMERICA	"
1980	IRENES SERENADE	105	82	GREECE	FIRE
1983	PERICLES G.C	59	44	QATAR	FIRE , EXPLOSION
1983	ASSIMI	59	50	OMAN	"
1983	CASTILLO DE BELLVER	272	239	SOUTH AFRICA	"
1985	NOVA	239	68	PERSIAN GULF OF IRAN	COLLISION
1988	ODYSSEY	138	132	ATLANTIC OCEAN	FIRE, COLLISION
1989	EXXON VALDEZ	215	36	ALASKA	GROUNDING
1989	KHARK-5	285	76	MOROCCO	FIRE, EXPLOSION
1990	NAUTILAS	70	1	NEW-ZEALAND	GROUNDING
1991	AGIP ABRVZZO	186	5	ITALY	COLLISION
1991	HAVEN	232	140	ITALY GENOVA	FIRE, EXPLOSION
1992	MT AEGEAN SEA	54	9.5	SPAIN LA CORUNA	COLLISION GROUNDING
1993	M/T BRAER	88	1.4	SCOTLAND SHETLANDS	ENGINE TROUBLE, COLLISION



LENGTH	O.A.	abt.	332.00 m
LENGTH	B.P.		320.00 m
BREADTH	MLD		58.00 m
DEPTH	MLD		31.00 m
DRAFT	DESIGN		20.80 m
DRAFT	SCANT.		22.00 m

Figure 1: General arrangement

2 Characteristics of Double Hull VLCC

The double hull should be composed of double sides and double bottom structure in order to isolate the cargo oil tanks from the sea. This means that the distance between outer shell and inner wall is to be sufficient for the protection of inner wall when the outer shell is damaged by grounding or collision.

The minimum distance is 2.0 m as required by IMO MARPOL regulations for medium and large size tanker. The captioned vessel has fifteen (15) cargo tanks, five (5) pairs of ballast tanks and one (1) pair of slop tanks in cargo hold region as shown in following Fig. 1(General Arrangement).
Each ballast tank is symmetrical about ship center line and the shape is 'L' type.
These ballast tanks are satisfactory with the above regulation for the protection from the marine pollution.

The main items [8] to be considered in the arrangement of cargo hold area are as follows.

(1) The cargo volume is to be sufficient to hold more than 2 million barrels.

(2) The ballast volume is to be sufficient to keep the ballast draft.

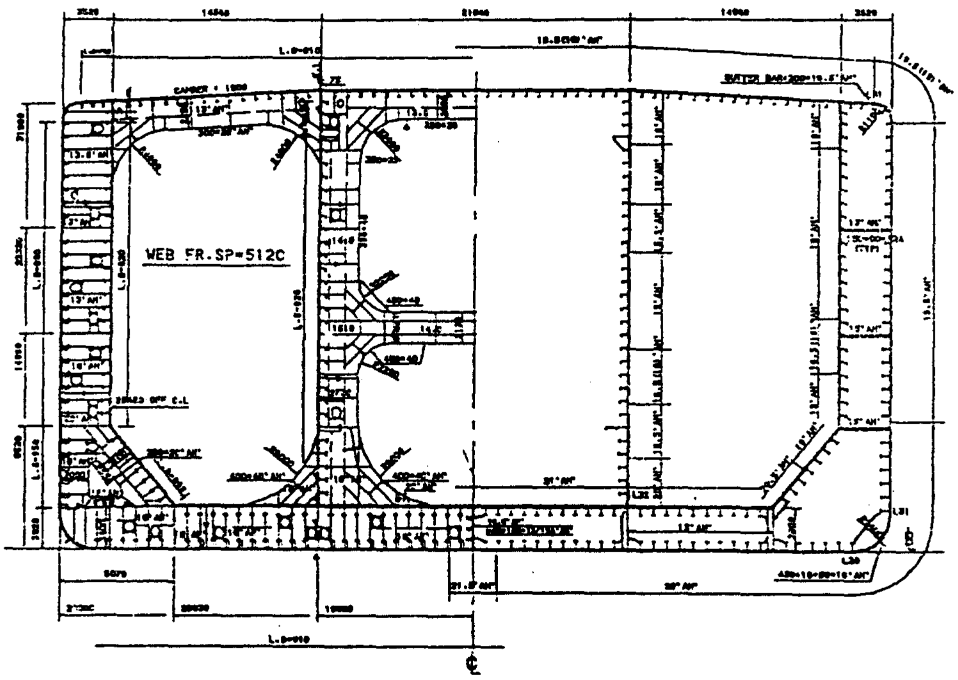


Figure 2: Midship section

(3) The oil outflow is to be minimized in case of grounding or collision of vessel.

(4) The breadth of double side and the height of double bottom are to be more than 2.0 m as mentioned in MARPOL regulations.

More detailed design particulars are shown in Table 2.

3 Main Features of Structural Arrangement

This vessel is likely to have very effective features for the low energy groundings or collisions and many items were considered to improve the structural strength and stability.

3.1 Configuration of Mid-Ship Section

For the configuration of mid-ship, see Fig. 2.

3.1.1 Number of Longitudinal Bulkheads

In case of three (3) longitudinal bulkhead ship, there are several disadvantages, such as, the increase of hull weight, the excessive concentration of hull girder shear force at center longitudinal bulkhead, the difficulty in securing of transverse strength for lack of cross tie and the increase of work-amount due to the asymmetric shape of midship section. Therefore, the four (4) longitudinal bulkhead type was chosen for this vessel.

3.1.2 Depths of Double Bottom and Double Side

According to the new regulation of IMO, the depth of double hull structure is to be more than 2 m in order to keep the stability of ship in case of grounding or collision. At first, the depth of double hull structure had been considered by 2.5m for the painting work without staging.

However, in this case, the still water bending moment is sharply increased and the passage way throughout double bottom is very narrow due to the installation of main ballast pipes inside double bottom. So, the depths of double bottom and of double side were finally determined by 3.0 m and 3.52 m respectively.

3.1.3 Hopper Structure

Although there are some difficuties in fabrication, the hopper structure has the merits of the good connections with other structures in cargo hold forward and aft area and the good security of transverse strength. Therefore, the hopper structure was adopted in this vessel.

3.1.4 Arrangement of Cross-Ties

It is in the field of the structural reliability of the new generation tankers that owners and charterers are genuinely concerned.

In this respect consideration must be given to the position and arrangement of cross-ties in cargo tanks and to this end the following aspects must be addressed.

(1) The function of transverse cross-ties: To connect two longitudinal structures at a position which reduces the end bending moments. Cross-ties are most effective when the two structures to be tied together are of a similar arrangement. Therefore by positioning the cross-ties in the centre cargo tanks and joining two similar structures the optimum arrangement can be achieved.

(2) stability : The greatest fear of owners or charterers is of leakage from the cargo tanks into the double hull space, leading to a hazardous and possibly explosive atmosphere, contamination of clean ballast water and difficulty in cleaning the ballast tanks.

Generally, the end points of cross-ties connecting other structures are regarded as critical points containing the risk of cracking. The number of these critical points are decreased when the cross-ties are fitted in centre tanks.

Table 2: Main items in arr't of ship division/structure

	ITEM	DESCRIPTION	REMARK
SHIP DIVISION	CARGO VOLUME	2 millon barrel(abt.318,000 m^3) in case of 95% loading – Actual 346,717 m^3 (100% full) 339,782 m^3 (98% full)	Spec. 345,000 m^3
	BALLAST VOLUME	Sufficient volume for ballast draft – Actual 104,419 m^3 (100% full)	Spec.: 104,000 m^3 (including peak tanks)
	TRIM CONDITION	Keeping trim by stern	
	HYPOTHETIC OIL OUTFLOW	Maximum 30,000 m^3 –Actual 28,554 m^3	bottom damage
	MARPOL REGULATION	Breadth of double bottom, Height of double bottom-2.0m	3.52 m 3.0 m
STRUCTURAL ARR'T	STRUCTURAL STABILITY	* C/H length, numbers	51.2*5EA
		* L.BHD position, numbers	4EA
		* Size of D/S , D/B	3.52m,3m
		* Primary member arr't	Center cross-tie
		* Fatigue strength	'T'type longitud'l
	HULL WEIGHT	* Weight increase under 30% in comparison with S/H	
	PRODUCTIVITY IMPROVEMENT	* NSC:New Shipbuild'g Concept - Grand huge blocks up to 800 tonnes - Pre-erection of main deck athwart the whole breadth - No scaffolding - Pre-outfitting in block assembly stage - Protection of paint damage	
		* Minimization of work contents:the number of pieces, joint length	
ETC.	INCREASE OF DESIGN PERFORMANCE	* Stronger hull * Easy maintenance * Easy access * Safety increase	Three(3) segregation loading type

Morevoer, it is less dangerous for the cross-tie to be positioned in center tanks because these critical points are then mainly located in the same cargo tanks.

From this point of view, the design with the cross-ties in center cargo tanks and relatively clean side cargo tanks appears to be more favourable due to having less risk of oil leakage.

(3) Deflection: Double hull VLCC structure, as the single hull ships have experienced fatigue fractures.

The transverse deflection of side vertical webs is the main reason of fatigue failure in side longitudinals due to the introduction of high stresses at the ends of the side vertical webs. Fitting cross-ties in the side tanks is effectively reduces this deflection and minimises the risk of fractures.

This side web deflection, however can still be considerably reduced by controlling the depth of the double side and adequate side stringers and swash bulkheads.

(4) Production: From the production point of view the perceived merits and demerits of different cross ties arrangement differ between each shipyard. From painting aspect fitting cross ties in centre tanks is considered more beneficial.

From DSHM's Okpo shipyard production point of view, the disadvantages of having cross-ties in the side tanks are as follows.

- The number of erection units will be increased, since super blocks cannot be made for the double side structure due to the excessive weight.
- It is more difficult to join the cross-ties with other structures because this work has to be done in the dock stage.
- This kind of cross-tie arrangement results in the unbalance of work load among production shops.

Considering the aboves, the arrangement of cross-ties in center cargo tanks is more effective and suitable for DSHM.

3.2 Increase of Structural Stability

This type of vessel is very effective for the low energy grounding or collision. And the following items were considered to increase the structural stability as shown in Fig. 3.

3.2.1 Cargo Hold Area

(1) Slit sype slot: Good for structural efficiency and productivity.

(2) The application of 'T' type longitudinal on side shell: Improve the fatigue strength.

(3) Fitting the back brackets in the transverse bulkheads: Improve the fatigue strength by decreasing the relative deflection of shell longitudinals in way of transverse bulkheads.

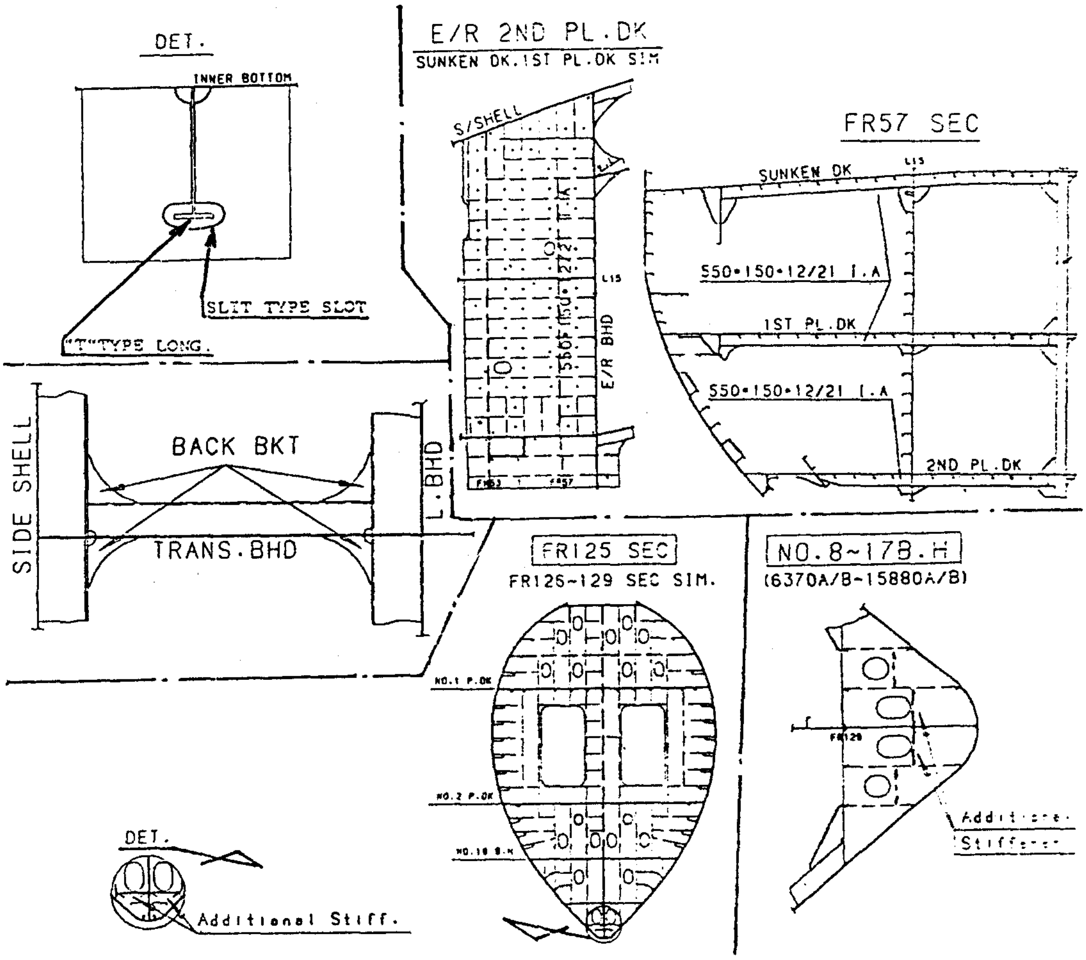


Figure 3: Increase of structural stability

3.2.2 Engine Room Area

(1) The partial webs on platform decks: After investigating the damage survey for as-built ships, the partial web frames are arranged on E/R platform decks to prevent the deformation of deck plate.

3.2.3 Fore Body Area

(1) Breast Hooks: The additional stiffeners on the edge of lightening holes and solid breast hooks are arranged.

(2) Diaphragms inside F.P.TK: The additional stiffeners on the edge of lightening holes at the diaphragms inside F.P.TK.

3.3 Pursuit of Owner's Convenience

According to the DSHM's policy of **"The Customer's Satisfaction"**, a number of facilities are provided for easy access, maintenance and close-up survey considering the owner's

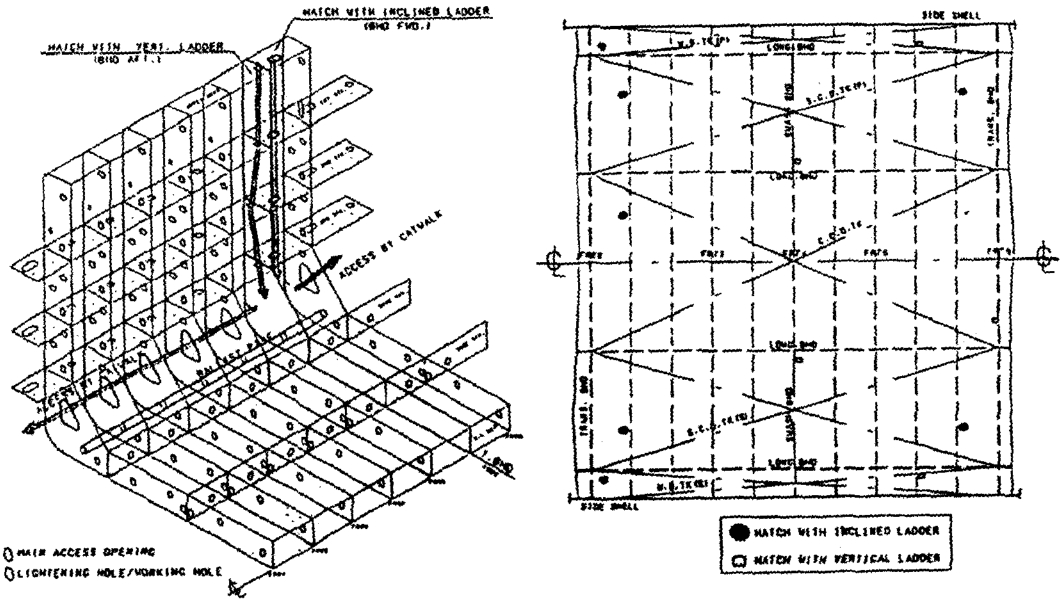


Figure 4: Access method of C/H area

convenience. For the accessibility in cargo hold area, refer to Fig. 4, and for the details, see Fig. 5 and 6.

3.3.1 Inspection platform

For easy maintenance, inspection and close-up survey. (See Fig. 5)

3.3.2 Catwalk

The catwalk is fitted in hopper for good access. (See Fig. 6)

3.3.3 Inclined ladder in wing tank

For good access.

3.3.4 Hand rail on slanted stringers

The half round bars are fitted at the longitudinals of longitudinal bulkheads above No.3 slanted stringer for safer passage. (See Fig. 6)

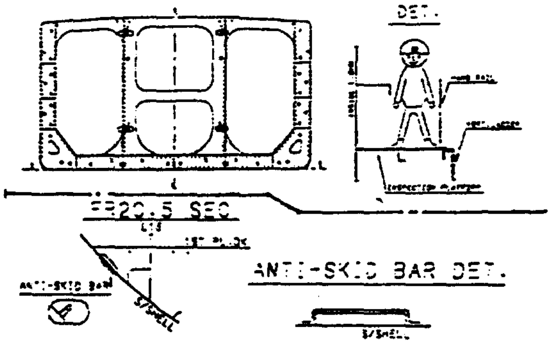


Figure 5: Access facilities (I)

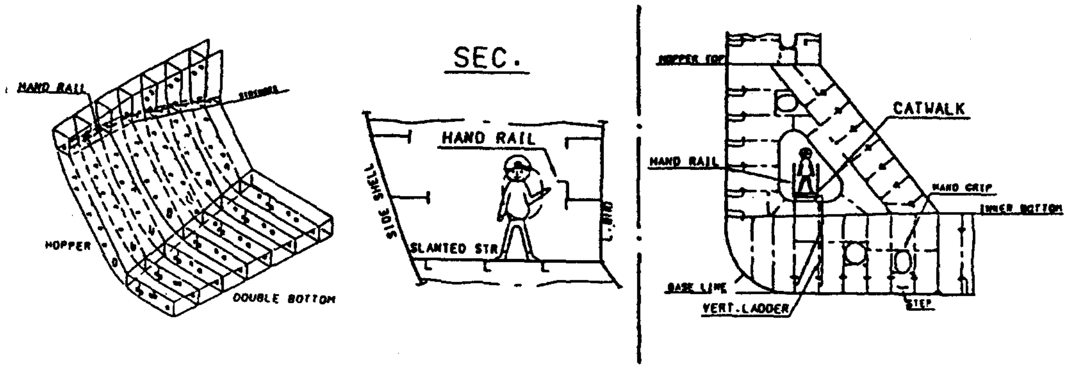


Figure 6: Access facilities (II)

3.3.5 Anti-Skid Bar

The anti-skid bars are fitted on the curved shell plate for easier access/inspection.(See Fig. 5)

3.4 Production process

The basic principle of block division is as follows:

- The large sized blocks at the assembly/erection stage.
- The maximization of work-amount at the shop stage (hull, outfitting, painting,etc.)
- The minimization of indirect work (for example, the work of staging)
- The improvement of working condition: For the minimization of overhead work and staging, the cross-ties to be fitted in the shop stage.

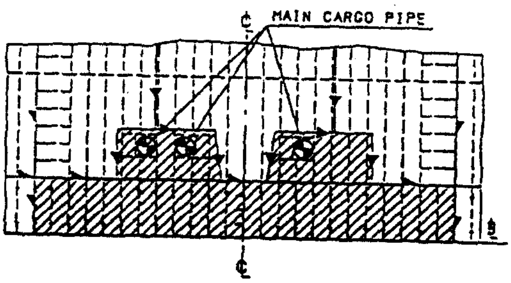


Figure 7: Pipe unit block

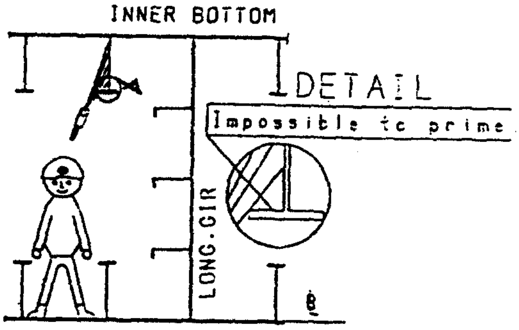


Figure 8: Shop priming

3.4.1 Pursuit of large sized pre-erection block at upright condition

Using the maximum capacity of Goliath Crane, the minimization of erection joints by the application of ring type erection of large-sized deck blocks.

3.4.2 Modification of block division

In order to install the main cargo pipes at the shop stage, the transverse bulkheads in way of main cargo pipes above inner bottom belong to the bottom blocks. (See Fig. 7)

3.4.3 Using the portable staging facilities inside the double bottom and double side, the minimization of fixed staging is pursued.

3.4.4 Built-up longitudinals are fitted after being shop-primed for better quality of painting.(See Fig. 8)

3.4.5 The shift of block-butts in way of E/R bulkhead and collision bulkhead

For the minimization of burn-damage, block joints are shifted.

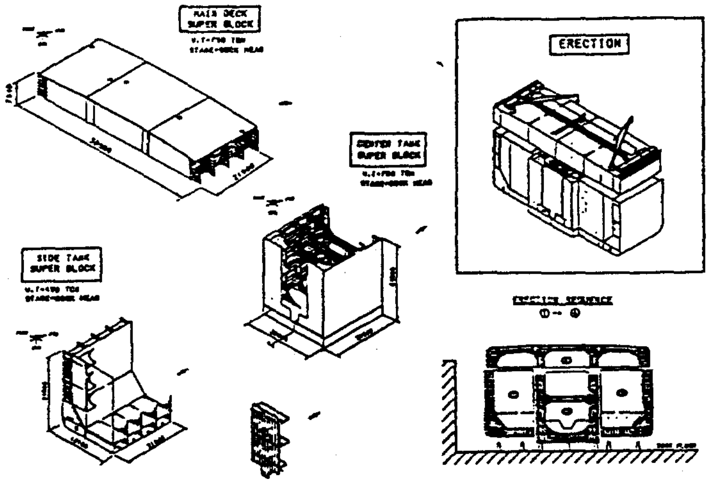


Figure 9: Process of block fabrication

3.4.6 Characteristics of block division at each zone.

(1) Cargo hold: Super blocks with complete pre-outfitting to be made at pre-erection stage. The process of block-fabrication is shown in Fig. 9.

- The bisection of pre-erection block for the vertical direction → pursuit of pre-erection at upright condition.
- The pre-erection of main deck block across the full breadth.
- The cross-ties are arranged in center cargo tanks.

(2) E/R and Aft Body

- Sunken deck and upper deck: Erection by one unit.
- Below 3rd deck: the full breadth pre-erection of each deck.
- The E/R equipment is installed at the shop assembly stage owing to the large-sized pre-erection of E/R blocks at up-right condition. → The minimization of staging for erection work.
- Fore Body: The pre-erection at upright condition, dividing five units for the vertical direction.

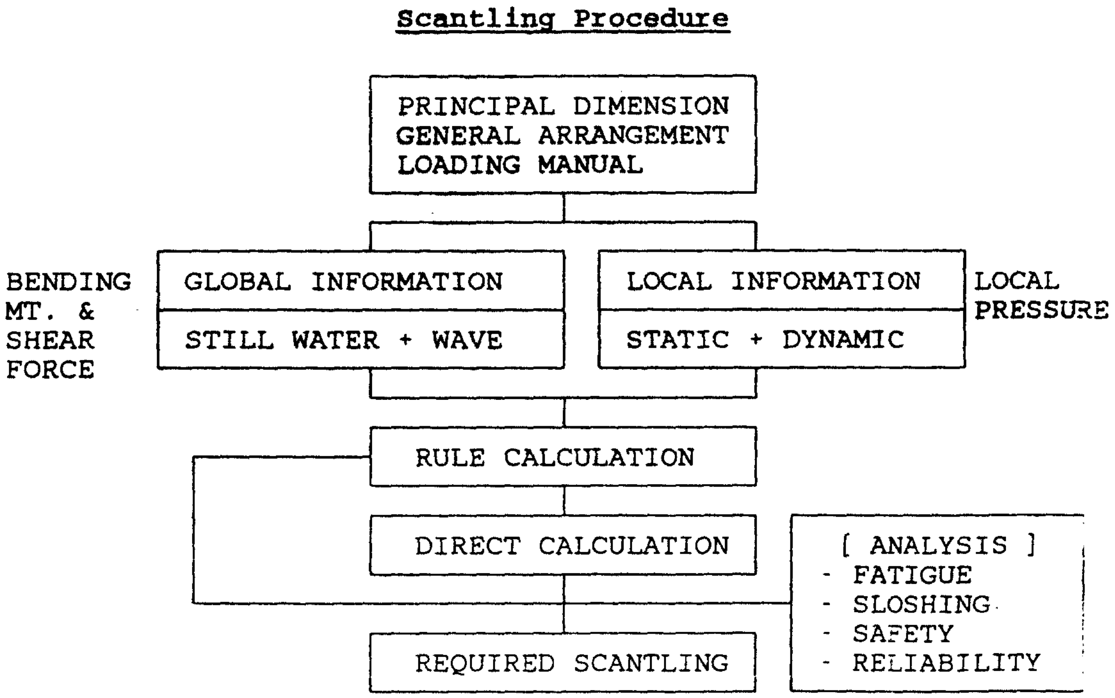
3.5 Cargo Pipes and Ballast Pipes

Pipes are isolated for the minimization of marine pollution according to new regulation of IMO MARPOL.

4 Scantling of Hull Structure

4.1 General

The scantling procedure of DSHM is as follows.



4.2 Direct Calculation for Cargo Hold Midpart

The direct calculation method is as follows.

- STEP 1: 2D CARGO SPACE GRILLAGE (BEAM MODEL)
- STEP 2: 3D COARSE MESH FEM
- STEP 3: 2D FINE MESH FEM

- STEP 4: BUCKLING STRENGTH ANALYSIS

- STEP 5: FATIGUE ANALYSIS

Some samples of structural analysis for this vessel are shown in Fig. 10 and Fig. 11.

4.2.1 STEP 1: 2D-Cargo Space Grillage Analysis

The grillage analysis using the beam analysis method was carried out from E/R bulkhead to collision bulkhead for the boundary condition of 3D course mesh FEM analysis.

4.2.2 STEP 2: 3D-Coarse Mesh FEM Analysis

The 3-dimensional coarse mesh FEM analysis was carried out for the middle part of cargo hold, and the model extent, boundary condition, loading condition, the model and the result of analysis are shown in Fig. 10 and Fig. 11.

4.2.3 STEP 3: 2D-Fine Mesh FEM Analysis

Using the boundary condition which is obtained in the 3D-coarse mesh FEM analysis of step2, 2-dimensional fine mesh FEM analysis was carried out for the typical web frame, adjacent web frame, bulkheads, stringers, buttress structure including the secondary members (typical longitudinals).

4.2.4 STEP 4: Buckling Strength Analysis

On the basis of the result of 3D-coarse mesh FEM analysis and 2D-fine mesh FEM analysis, the buckling strength analysis was carried out for bottom shell, inner bottom, bulkheads, transverse web frames, stringers, etc.

4.2.5 STEP 5: Fatigue Analysis

The fatigue analysis for the side shell longitudinals, the structure in way of slot hole and hopper structure, etc. which can anticipate the possibility of fatigue failure was carried out.

4.3 Cargo Hold Aft/Forward Area (No.5 Hold & No.1 Hold)

Since the hopper structure of cargo holds aft or forward is much longer due to the hull form compared with mid-part, the strength of these parts should be checked apart from that of mid-part. So, the FEM analysis was also carried out to verify the stability of those structures.

4.4 Fore Peak Tank Area/ Engine Room Area

The direct structural analysis using 3D-beam analysis method was carried out to verify the strength of the transverse webs and girders in these areas.

5 Conclusions

With the new double hull tanker concept, the traditional design criteria of optimization by life-cycle economy will take second place to the new criteria of reliability against oil spill.

We have made special efforts to improve the structural design for the conveniences of owners and crews, with sucessive activities corresponding with the motto **"Stronger-Safer-Ships"**.

The major things are as follows.

(1) The most important thing to be considered is to keep free from leakage of oil from cargo tanks into ballast tanks.
So, care is to be taken of cross-ties, and upper and lower connection of hopper tanks.

(2) In order to improve the characteristics of fatigue, the use of mild steel is to be increased up to 70 % and the 'T'-bar longitudinals are to be applied extremely and the soft type of scallops is to be adopted.

(3) Inspection platforms are to be made for the close-up inspection.

(4) In order to prevent the corrosion due to paint cracks caused by stress concentration, the arrangement of stiffeners is to be improved.

(5) The impact loads are to be taken into consideration in the fore body structure.

(6) Structural continuity is to be maintained and good scarfings to be provided.

(7) Vibration levels are to be controlled within the lower stipulated zone.

As mentioned in the introduction, the concern about marine pollution following successive incidents resulted in the introduction of new regulation of IMO MARPOL, that is, VLCCs which are contracted after July 6, 1993 are to be constructed with double hull.

As the brisk increase of double hull VLCC market is expected, DSHM will try to do its best in preparation for the future market.

DSHM promises to present the best standard of double hull VLCCs incorporating an optimum design with pride, as one of the leading groups for developing this type of vessels. The basis of our experience will enable DSHM to construct and launch two double hull VLCC's in one dock in tandem, first in the world.

References

[1] Hyon-Soo Bong, "Recent development of VLCC design and construction in DSHM," *proceeding of PRADS '92,* Vol. 2, 1992

[2] IMO, "Regulation 13F of MARPOL 73/78, annex1," *Marine Environmental Protection Committee(MEPC) 31st session,* London, 1991

[3] LR, "Inspection and maintenance of new generation double hull tankers," *Tank Structure Cooperative Forum '92,* 1992

[4] The Korea Shipbuilders' Association, "The effect of the accident of Braer on the shipbuilding market," *Journal of The Korea Shipbuilders' Association,* 1993

[5] Mitsui, "Comments from Mitsui Engineering and Shipbuilding Co, Ltd."

[6] NK, "Structural problems of recently built tankers," *Tank Structure Cooperative Forum '92,* 1992

[7] BP Shipbuilding, "Fatigue evaluation of tanker structures," *Tank Structure Cooperative Forum '92,* 1992

[8] Hyon-Soo Bong, "Hull design for 300k double hull VLCC," *Proceedings of The Society of Naval Architects of Korea,* 1992

[9] Keizom Yamazaki, "Structural design of 150 type double hull tankers," *IHI technical report,* Vol. 32-3, 1992

[10] M.G. Osborne, "An oil company's thoughts on future tanker design," *The conference of future tanker design,* 1992

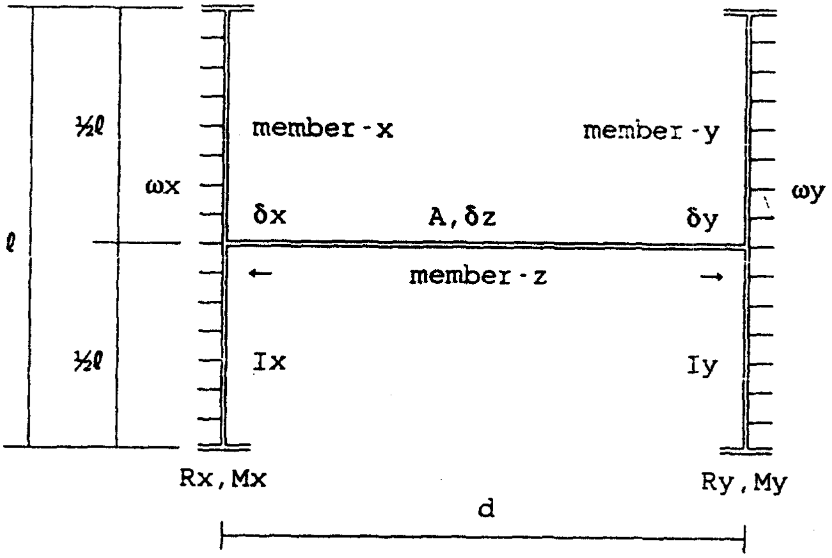
Appendix: Optimum Arrangement of Cross-Tie

A. Theoretical consideration for the cross-tie's function

1)

$$\begin{aligned} P &= K \times R_x = K \times \omega_x \times l/2 \\ K &: \text{constant} \end{aligned}$$

$$\text{Therefore} \quad K = \frac{2P}{\omega_x \times \ell} \tag{1}$$



2) Considering the deflection for members - x, y, z,
δx: the deflection of member - x due to load P,
δy: the deflection of member - y due to load P,

$$\delta x = \frac{Pl^3}{192EI_x}, \quad \delta y = \frac{Pl^3}{192EI_y}, \tag{2}$$

δz: the difference of length of member - z due to load P,

$$\delta z = \frac{Pl}{AE}, \tag{3}$$

δ: the summary of deflection for members - x,y,z due to load P,
δ': the summary of deflection for members - x,y due to ω_x, ω_y,

$$\delta = \delta' \tag{4}$$

3)

$$\delta = \delta x + \delta y + \delta z = \frac{Pl^3}{192EI_x} + \frac{Pl^3}{192EI_y} + \frac{Pl}{AE}$$

$$\delta = \frac{Pl^3}{192EI_x}(1 + \frac{I_x}{I_y} + \frac{192I_x d}{Al^3}) \tag{5}$$

$$\delta' = \frac{\omega_x(l^2)^2}{384EI_x} + \frac{\omega_y(l^2)^2}{384EI_y} \tag{6}$$

$$\delta' = \frac{\omega_x l^4}{384 E I_x}(1 + \frac{\omega_y I_x}{\omega_x I_y}) \tag{7}$$

4) Considering (5), (7) and (4)

$$\frac{P l^3}{192 E I_x}(1 + \frac{I_x}{I_y} + \frac{192 I_x d}{A \ell^3}) = \frac{\omega_x l^4}{384 E I_x}(1 + \frac{\omega_y I_x}{\omega_x I_y})$$

$$\text{therefore,} \quad \frac{2P}{\omega_x \ell} = \frac{1 + \frac{\omega_y I_x}{\omega_x I_y}}{1 + \frac{I_x}{I_y} + \frac{192 I_x d}{A \ell^3}} \tag{8}$$

Considering (1) and (8)

$$\text{therefore,} \quad K = \frac{1 + \frac{\omega_y I_x}{\omega_x I_y}}{1 + \frac{I_x}{I_y} + \frac{192 I_x d}{A \ell^3}} \tag{9}$$

5)

$$\begin{aligned} M_x &= (\text{End} - \text{moment by } \omega_x) - (\text{End} - \text{moment by } P) \\ &= \frac{\omega_x l^2}{12} - \frac{Pl}{8} \\ &= \frac{\omega_x l^2}{12}(1 - \frac{12 Pl}{8 \omega_x l^2}) \\ &= \frac{\omega_x l^2}{12}(1 - \frac{3 * 2P}{4 \omega_x l}) \\ &= \frac{\omega_x l^2}{12}(1 - \frac{3}{4}K) \\ \text{therefore,} \quad M_x &= \frac{\omega_x l^2}{12}(1 - \frac{3}{4}K) \end{aligned}$$

B. Actual verification of the cross-tie's function for actual ship

The results of verification for actual ships are shown in Table 3 and Fig. 12.

C. Comparison of cross-tie's arrangement

The example and comparison of cross-tie arrangement are shown in Table 4[5] and Fig. 13.

D. Conclusion

Considering the work process, the facilities and the yard capacity of DSHM, the arrangement of the cross-ties in center tanks is more effective in all aspects, if the transverse deflection of side vertical web frames can be controlled properly.

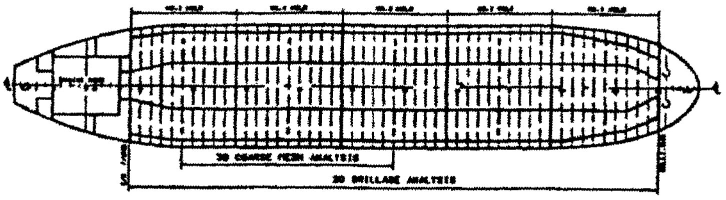
Table 3: Result of comparison with the cross tie's arr't

CASE NO.	case1: W/W (present)	case2: W/W (modify)	case3: G-proj.
C/TIE LOC.	center tank	side tank	side tank
I_x/I_y	1.000	3.636	1.392
K	0.904	0.846	0.865
M_x	0.322	0.366	0.351

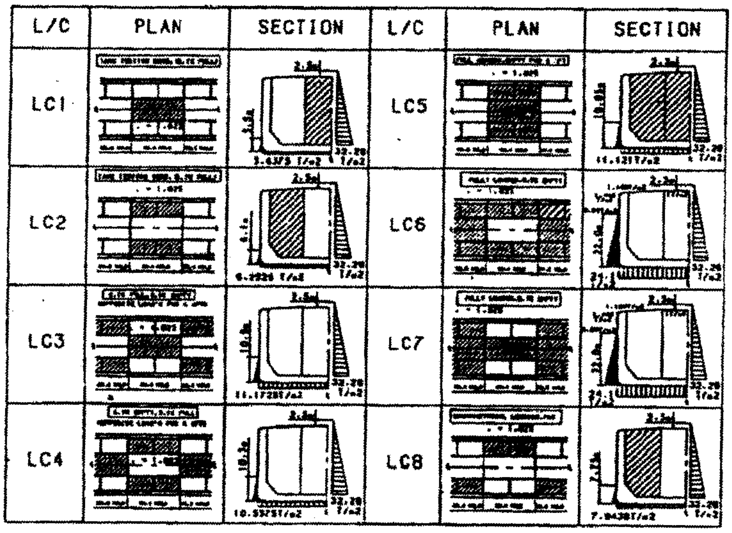
Table 4: Comparison of cross-tie's arr't

CROSS-TIE LOCATION	SIDE TANK	CENTER TANK
Effectiveness	Not so good	Good
Higher risk location along tank boundary(reliability, misalignment)	A few	None
Side D/H deformation (depend on D/S depth & number of side stringer, swash BHD)	Smaller	Larger, but feasible to design
Labour hour	Much	Less
Steel weight	Nearly same	Nearly same
Number of C/TIE	2	1
Number of swash BHD	1 (Center tank)	2 (Side tank)
Easy for construction Major problem	Difficult * Increase of joint length in erection of C/TIE * Increase of work amount at PBS	Easy * Side vertical web deformation

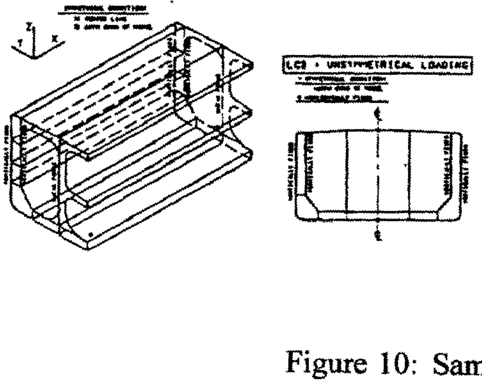
* MODEL EXTENT FOR 2D GRILLAGE/3D COARSE MESH ANALYSIS

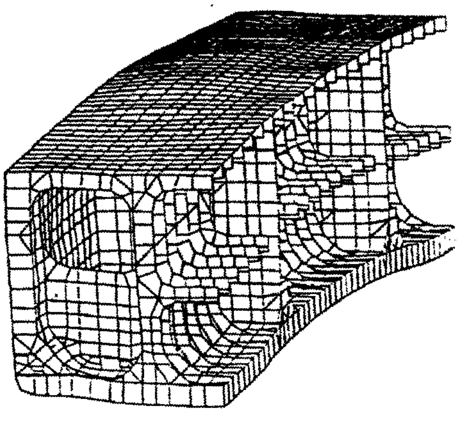


* LOAD CONDITIONS



* BOUNDARY CONDITION





DEFORMED SHAPE FOR LOAD STEP NO.7

Figure 10: Sample of Analysis(I)

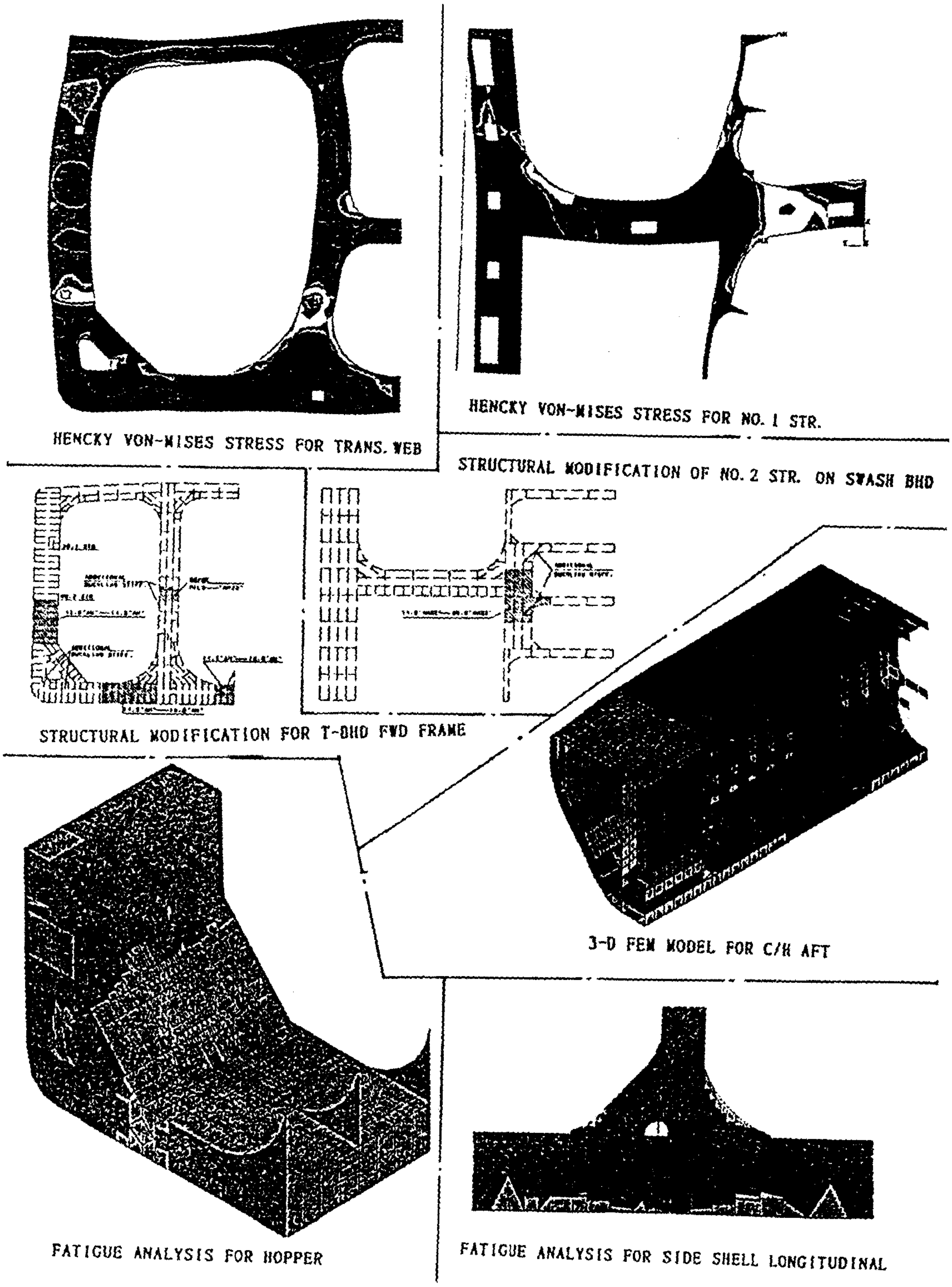
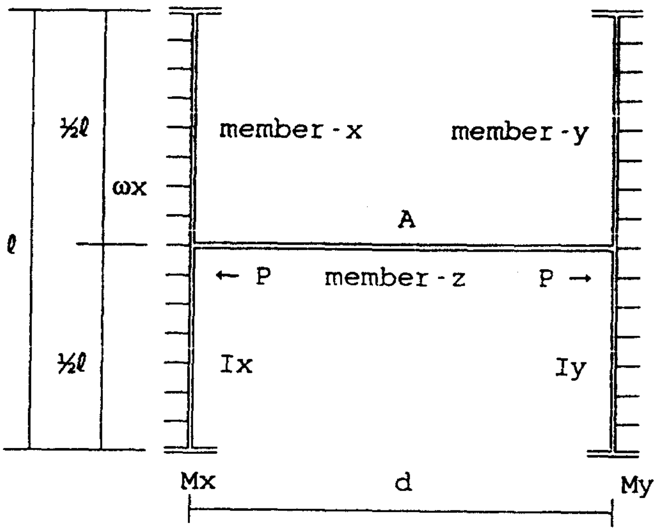


Figure 11: Sample of Analysis(II)



$$K = \frac{1 + \frac{\omega_y I_x}{\omega_x I_y}}{1 + \frac{I_x}{I_y} + \frac{192 I_x d}{A \ell^3}}$$

$$M_x = \frac{\omega_x l^2}{12}(1 - \frac{3}{4}K)$$

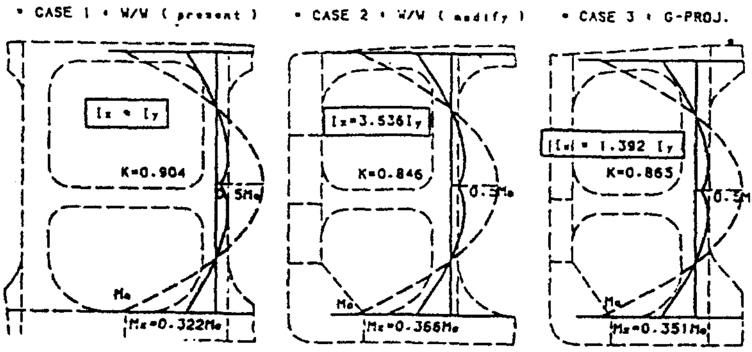


Figure 12: Result of verification of cross-tie's function

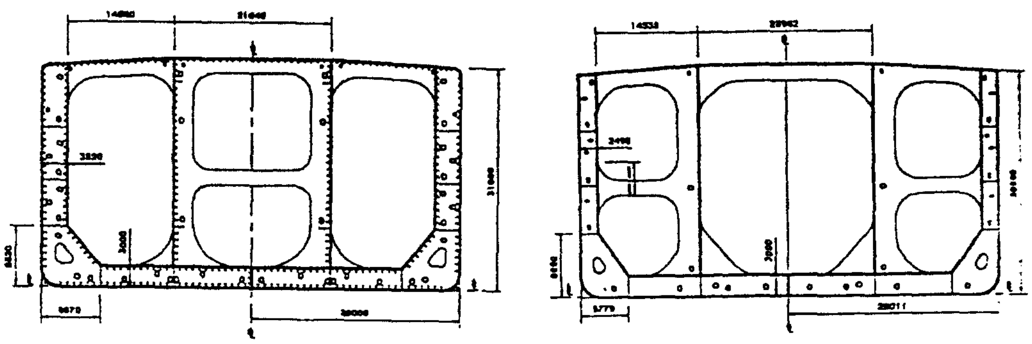


Figure 13: Example of cross-tie's arrangement