대한조선학회 특별논문집
2005 년 6 월

Special Issue of the Society of Naval Architect of Korea
pp. 76-83, June 2005

LNG 선박의 트렁크 갑판과 거주구 연결 부위의 설계해석

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Strength Analysis for Transition Structure Design in way of Trunk Deck and Deckhouse on LNGC

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Abstract

Membrane type LNG Carriers are characterized by their special structures such as trunk deck above upper deck. It is necessary to introduce an appropriate structure arrangement taking into account transition of the trunk deck to the upper deck or deckhouse in fore and aft parts. The transition area at aft part —from trunk deck to the deckhouse – is to be specially considered because of high longitudinal stresses applied at the area. This study has been carried out to tackle the transitional structure problem in design stage. This paper deals with not only mesh size of FE models for scantling evaluation and fatigue assessment but also technical issues regarding fatigue assessment

※Keywords : Scarfing bracket(스카핑 브라켓), Trunk deck(트렁크 갑판), LR SDA(구조설계해석), LR FDA(피로설계해석), LNGC(천연액화가스 운반선)

1. Introduction

Analyses have been conducted to verify structural strength of trunk deck scarfing arrangement, deckhouse and engine room for an LNG Carrier. Yield and buckling strength have been reviewed in accordance with ShipRight SDA procedure for Primary Structure of Membrane Tank LNG Ships (LR 1999)[1]; fatigue strength has been evaluated according to ShipRight SDA procedure for Primary Structure of Passenger Ships (LR 2001)[2].

Two 3-D finite element models for the aft parts in full breadth – one for yield and buckling strength evaluation and the other for fatigue strength assessment – have been prepared extending from the transom to the middle of No.4 cargo hold. Three types of elements – elastic shell, 3-D elastic beam and rod elements

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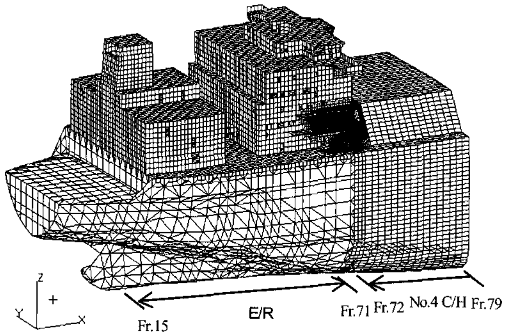

Fig. 1 FE model for the structural analyses

Table 1 Boundary condition at each position

POSITION	Translations			Rotations		
	X	Y	Z	RX	RY	RZ
Longi. member of Fr.79 Sec	1	0	0	0	1	1
Vertical line of shell & inner hull at Fr.79	0	0	1	0	0	0
Center line at fr.15, 79	0	1	0	0	0	0

where, 0 : free and 1 : fixed

– were used to represent structural members to be evaluated. In addition, line elements with small sectional area – so called, fictitious elements – were employed at free edge corners in way of openings as a means to obtain local stress for the fatigue strength evaluation. The extent of an FE model is shown in Fig. 1.

2. FE Analysis

The dimension of structural members, including plate thickness and sectional properties of profiles, is reflected into the FE models as appropriate. Mesh size was determined to meet two requirements of general scantling and fatigue.

For yield and buckling check, the size of meshes of structural details subjected to high stress is approximately 150 mm. These areas include the scarfing brackets and first deckhouse level above the trunk deck. Subsequent evaluations were carried out based on the averaged stress of area sized by 150x150 mm. For fatigue analysis, standard element size of fatigue-prone details is 15x15mm or $t \times t$, where t is the thickness of the details.

To obtain the response of the hull structure, the boundary conditions for the application of

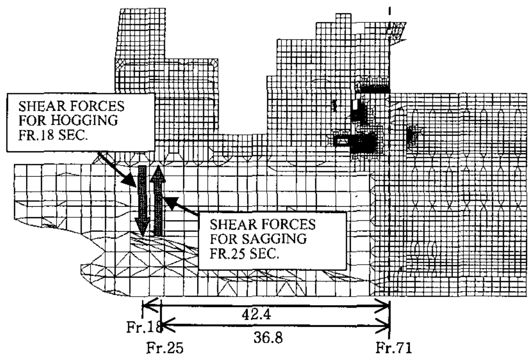

Fig. 2 Applied loading details

global loads were applied as shown in Table 1.

Two(2) load cases were considered for the present evaluation. These load cases represent the maximum design bending moments and shear forces (for Hogging & Sagging Conditions) that occur at the aft end of trunk deck. The applied loading includes still water and wave bending moments and shear forces. The value of applied loads was determined to impose the required bending moment and shear force at the transverse section where the trunk deck ends (Fr.71 as shown in Fig.2).

Shear forces were applied to the shell plating at Fr.18 (hogging) and Fr.25 (sagging) of the vessel, so that the required bending moments are generated at Fr. 71. Loading details are shown in Fig.2 and Table 2. The FE models were treated as weightless and not subjected to any other load component.

3. Evaluation

Stress components resulting from the FE analysis should not exceed the values of *permissible stresses given in the SDA for Primary* Structure of Membrane Tank LNG Ships (LR 1999) as shown in Table 3.

Table 2 Load details for the FE analysis (at Fr. 71 section)

Load Case	B.M. (S.W.+Wave) [Ton-m]		S.F. (S.W.+Wave) [Ton]		X_{actual} (Dist. from Fr.71)
	Req.	App.	Req.	App.	
1 (Hog)	458970	486582	11476	11476	42.4
2 (Sag)	-360150	-378414	-10283	-10283	36.8

Note: $BM_{app.} > BM_{req.}$ for the both two cases

Table 3 Maximum permissible stresses

Structural Item	Permissible Stresses (kgf/cm^2)	
	Combined Stress σ_e	Shear Stresses τ
General	1780/k	850/k
Fine Mesh Regions		
Average combined stress, $\sigma_{average}$, and average shear stress, $\tau_{average}$, See Note	2400/k	1020/k
Individual Element	$< 1.2\ \sigma_{average}$	$< 1.2\ \tau_{average}$

Note, :
$\sigma_{average}$ And $\tau_{average}$ are the average combined stress and shear stress respectively from elements around and including the element being assessed.
k = higher tensile steel factor given in Pt 3, Ch 2, 1.2 of the *Rules for Ships*, k=0.75 for " AH32"

Elastic buckling strength of each plate panel is checked based on the procedure proposed by LR Classification. Buckling strength factors calculated should not exceed the permissible buckling factor given in the same SDA (LR 1999).

Dynamic stress ranges resulting from FE analysis are required, in general, not to exceed the values of acceptance criteria given in the SDA for Primary Structure of Passenger Ships (LR 2001) as shown in Tables 4 and 5.

Some items of Tables 4 and 5 may be modified using first principle such that LR FDA3 guide can be adopted to select an S-N curve, with the assumption of a proper long-term *distribution of applied stress ranges. In* this project, a simplified approach was adopted with the assumption that long-term distribution of stress range can be defined by the Weibull distribution with the shape parameter *1.0*.

Table 4 Stress criteria for major/minor openings, sweep brackets and side screens

Load case	Stress criterion	Allowable Stress
Hogging Wave minus Sagging Wave	Dynamic Stress Range	$600fG_2$
Symbols		

$G_2 = 0.85$

f is a criticality factor
f = 1.0 for free edges, free from welding
f = 0.7 heavy face bar welded to shell (no free weld edge)
f = 0.375 attachments to shell plating having weld endings

Table 5 Stress criteria for minor openings, such as window, door, Etc.

Load case	Stress criterion	Allowable Stress
Combined still water and wave	Average direct stress between openings	$0.8\sigma_0$ (see Notes 2 &3)
	Average shear stress between openings	$0.47\sigma_0$ (see Notes 2 &4)
	Average Von-Mises stress between openings	$0.94\sigma_0$ (see Notes 2 &3)
	Peak stress in radius	$1.5G_1\sigma_0$ (see Note 1)
Hogging wave minus Sagging wave	Dynamic stress range	$600fG_2$

Symbols

$G_1 = 1.0$

$G_2 = 1.0$

f is a criticality factor

f = 1.0 for free edges, free from welding

f = 0.7 heavy window frame welded to shell (no free weld edge)

f = 0.5 T-section type door frames

f = 0.375 attachments to shell plating having weld endings

NOTES,

1. This is a theoretical peak stress obtained from a linear elastic finite element analysis. In practice, under the extreme loading assumed, local yielding of the plate edge will occur and the actual peak stress will not be significantly greater than yield (i.e. less than $1.1\sigma_0$)
2. Average stress is to be calculated independently of the sign of the individual stress levels.
3. No single element stress in the corner plating is to exceedσ_0
4. No single element stress in the corner plating is to exceed $0.58\sigma_0$

Especially for the case of " attachments to shell plating having weld endings with *f = 0.375*" needs a special consideration, as its fatigue strength can be assessed by the combination of " *D curve of BS5400*" and local hot spot stress defined at 10^{-8} probability level with the assumed Weibull distribution.

Allowable stress of details corresponding to D curve is calculated from the Palmgren-Minor rule, which defines damage ratio cumulatively using S-N curve and long-term distribution of stress range. Allowable stress is defined by a stress that gives the cumulative damage ratio 1.0, having 10^{-8} probability level especially in this report.

Two loading conditions were taken into account in the SDA analysis. It is clear that LC1 (Hogging Moment) governs scantling in the allowable stress assessment and LC2 (Sagging Moment) is dominant in the buckling strength assessment.

The results of LC1 and LC2 were employed for fatigue strength assessment, as fatigue strength evaluation requires dynamic stress range defined by the difference between maximum and minimum dynamic stresses.

Design shear force is given by the sum of still water shear force selected from loading conditions and wave shear force defined by the rule. In this analysis uniform shear force was applied to simulate design wave bending moment at FR71. Therefore shear stresses obtained from SDA are to be adjusted using proper shear correction factors defined by the ratio of the required shear force to the applied shear force. Calculation details of shear force correction factor are given in Fig.3:

From the FE analysis results, all structural members including trunk deck scarfing arrangement, D/H, and E/R have been evaluated in terms of yield and buckling strength. Obtained shear stresses have been corrected using the shear correction factors calculated above and equivalent stresses are also subject to the correction. Figs.4 and 5 show examples of allowable stress evaluation.

Some examples of yielding strength evaluation results and buckling strength evaluation results are shown in Table 6 and 7 respectively. These evaluation results were used to modify original drawings.

Fatigue strength should be evaluated based on stress range, that is, the difference between the

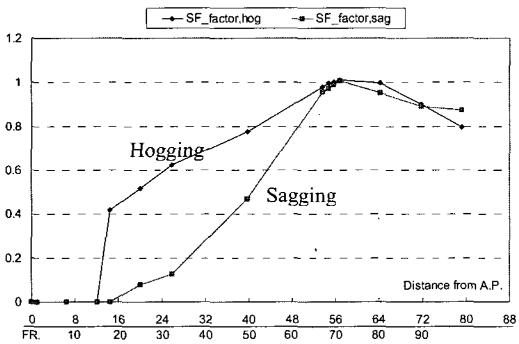

Fig. 3 Shear force correction factor distribution along ship length

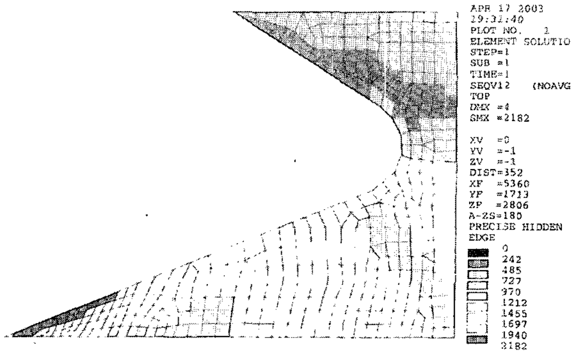

Fig. 4 Equivalent stress distribution of scarfing BKT (hogging, port side) (unit : kgf/cm^2)

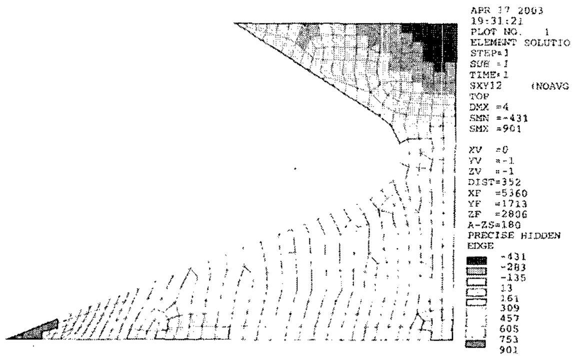

Fig. 5 Shear stress distribution of scarfing BKT (hogging, port side) (unit : kgf/cm^2)

maximum and minimum applied dynamic stresses at details. For fatigue analysis (FDA) in this report, the same loading as in SDA was used except the FE model, which includes finer meshes to obtain local concentrated stress at the target details. The scheme shown in Table 8 was used to calculate dynamic stress range. And some examples of fatigue strength results are shown in Table 9.

Meshes for local stress check were prepared on the basis of the mesh size ' t' x ' t' or 15 x 15mm in accordance with the FDA procedure. In addition, fictitious truss elements are employed for corner parts to obtain local stress.

Table 6 An example of yielding strength evaluation results

POSITIONS		LC	ALLOWABLE (unit : kgf/cm2) eqv.	ALLOWABLE (unit : kgf/cm2)	CALCULATED (unit : kgf/cm2) eqv.	CALCULATED (unit : kgf/cm2)	$t_{ORIGINAL}$ (Unit : mm)	$t_{REQUIRED}$ (Unit : mm)
C.L. Elev.	Plate iwo Fr.65 & Above A Dk	1	–	1020	–	1074	6.0	6.5
	Plete iwo Fr.65 & Upp. Dk~A Dk	1	2880	–	2951	–	16.0	16.5
	Plate iwo Fr.67~70 & Above Upp. Dk	1	–	850	–	1010	16.0	19.0
	Plate iwo Fr.66~67 & Under Upp. Dk	1	–	1224	–	1345	17.5	19.5
L11 Elev. (P)	Plate iwo Fr.46 & Above Upp. Dk	1	1780	850	2262	1008	10.0	12.5
	Plate iwo Fr.58~60 & Under A Dk	1	1780	850	1836	971	11.0	12.5
	Plate iwo Fr.65~68 & Above Upp. Dk	1	1780	850	2021	1158	14.0	19.0
	Plate iwo Fr.71 & Under A Dk	1	1780	850	1789	946	16.0	18.0
	plate iwo Fr.56~58 & Under B Dk	1	1780	850	1962	980	6.0	7.0
	bkt iwo Fr.58~60 & Under B Dk	1	1780	850	1841	899	6.0	6.5
	plate iwo Fr.71 & Under B Dk	1	2880	1224	3374	1768	6.0	9.0

Table 7 An example of buckling strength evaluation results

Panel ID:	Panel No. 3 @ L11 ELEV. PORT Under Upper Deck													**Unit : N-mm**	
$a=$	800	$C_{opng}=$	0	$C_a=$	1.00	$(\tau)_m=$	22.3	$\gamma_x=$	1.000	$\sigma_{yc}=$	140.8	$R_s=$	0.117	$\sigma_{ec2}=$	N/A
$b=$	5038	$d_{opng}=$	0	$C_b=$	1.21	$a/b=$	0.16	$\gamma_y=$	1.000	$\sigma_{ybc}=$	844.8	$p=$	2.00	$\sigma_{ec3}=$	N/A
$t=$	11.0	$\sigma_x=$	50.8	Hull =	O	$c/d=$	N/A	$\gamma_{sh}=$	1.000	$\tau_c=$	191.5	$k_1=$	0.01	$\sigma_{ec4}=$	N/A
$t_k=$	0.0	$\sigma_{xb}=$	0.0	$(\sigma_x)_m=$	50.8	$c/a=$	0.00	$\sigma_{ed}=$	64.89	$R_x=$	1.13	$k_2=$	1.431	$\sigma_{ec5}=$	N/A
$t_{net}=$	11.0	$\sigma_y=$	53.3	$(\sigma_{xb})_m=$	0.0	$\mu_1=$	4.00	$\alpha=$	0.16	$R_{xb}=$	0.00	$x=$	0.832	$\sigma_{ec}=$	53.99
$\sigma_o=$	235	$\sigma_{yb}=$	0.0	$(\sigma_y)_m=$	53.3	$\mu_2=$	0.70	$\sigma_{xc}=$	44.8	$R_y=$	0.38	$\sigma_{ec1a}=$	53.99	$\sigma_{ec'}=$	53.99
$\lambda_{sf}=$	1.0	$\tau=$	22.3	$(\sigma_{yb})_m=$	0.0	$\delta=$	0.00	$\sigma_{xbc}=$	55.6	$R_{yb}=$	0.00	$\sigma_{ec1b}=$	N/A	$\lambda=$	0.832
												Result		**No**	
Panel ID:	Panel No. 3 @ L11 ELEV. PORT Under Upper Deck - Modified													**Unit : N-mm**	
$a=$	800	$C_{opng}=$	0	$C_a=$	1.00	$(\tau)_m=$	22.3	$\gamma_x=$	1.000	$\sigma_{yc}=$	181.8	$R_s=$	0.090	$\sigma_{ec2}=$	N/A
$b=$	5038	$d_{opng}=$	0	$C_b=$	1.21	$a/b=$	0.16	$\gamma_y=$	1.000	$\sigma_{ybc}=$	1090.9	$p=$	2.00	$\sigma_{ec3}=$	N/A
$t=$	12.5	$\sigma_x=$	50.8	Hull =	O	$c/d=$	N/A	$\gamma_{sh}=$	1.000	$\tau_c=$	247.3	$k_1=$	0.01	$\sigma_{ec4}=$	N/A
$t_k=$	0.0	$\sigma_{xb}=$	0.0	$(\sigma_x)_m=$	50.8	$c/a=$	0.00	$\sigma_{ed}=$	64.89	$R_x=$	0.88	$k_2=$	0.858	$\sigma_{ec5}=$	N/A
$t_{net}=$	12.5	$\sigma_y=$	53.3	$(\sigma_{xb})_m=$	0.0	$\mu_1=$	4.00	$\alpha=$	0.16	$R_{xb}=$	0.00	$x=$	1.074	$\sigma_{ec}=$	69.72
$\sigma_o=$	235	$\sigma_{yb}=$	0.0	$(\sigma_y)_m=$	53.3	$\mu_2=$	0.70	$\sigma_{xc}=$	57.8	$R_y=$	0.29	$\sigma_{ec1a}=$	69.72	$\sigma_{ec'}=$	69.72
$\lambda_{sf}=$	1.0	$\tau=$	22.3	$(\sigma_{yb})_m=$	0.0	$\delta=$	0.00	$\sigma_{xbc}=$	71.8	$R_{yb}=$	0.00	$\sigma_{ec1b}=$	N/A	$\lambda=$	1.074
Actual Design Thickness		12.5										**Result**		**OK**	

Table 8 Calculation of dynamic stress range for fatigue strength evaluation

Applied Hogging Moment Components: $LC1_H = SWBM_H + VWBM_H$
Applied Sagging Moment Components: $LC2_S = SWBM_S + VWBM_S$
Dynamic Factor: DF_H, DF_S $DF_H = \frac{VWBM_H}{LC1_H}, \quad DF_S = \frac{VWBM_S}{LC2_S}$
Dynamic stress range: $\Delta\sigma = \sigma_{LC1} \times DF_H - \sigma_{LC2} \times DF_S$ where $_{LC1}$: applied stress in LC1 (Hogging Moment) $_{LC2}$: applied stress in LC2 (Sagging Moment)

4. Discussion

As explained above, these analyses should reflect two required load cases and the applied loading scheme induces more loads than required to the hull and requires shear force factor to compensate excessively applied shear force.

It appears that shear force governs most areas being considered except the narrow area including the critical transition section. In addition the excessively applied shear force effects can not be controlled only by the shear force factor as various coupling effects may result in increase in other components stresses, e.g. the z-directional stress (σ_{zz}).

This excessive shear force is observed to have influences on local stresses – around door corners – which should be used in fatigue analysis (refer to Fig. 6).

This coupling effect makes it difficult to properly apply the shear force factor in fatigue assessment.

Therefore a new loading scheme is proposed that induces accurate loads and gives more accurate results. This scheme satisfies the two load requirements at once. The required shear force distribution, shown in Fig. 7, can be applied easily by using distributed forces. Then the resultant BM distribution can be drawn as Fig.8

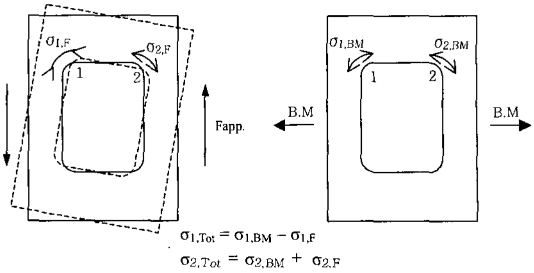

Fig. 6 Influence of shear force on local stresses

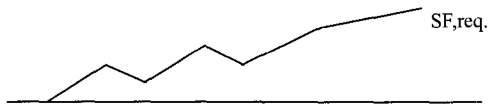

Fig. 7 Required shear force distribution

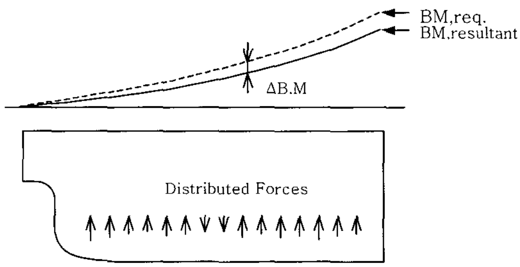

Fig. 8 Distributed forces for shear force and resultant BM distribution

Bending moment should be considered further to apply required bending moment (BM,req.) by including ' ΔBM' into the FE model. The ' ΔBM' should be compensated without affecting applied shear force and this can be achieved by bending moment couplings as Fig. 9.

Table 9 An example of fatigue strength evaluation results

Fatigue Check Location	CH (kgf/cm^2)	F_{CH}	CS (kgf/cm^2)	F_{CS}	R (kgf/cm^2)	ALLOW (kgf/cm^2)	Factor		$t_{Original}$ (mm)	$t_{Required}$ (mm)	Remark	$t_{Required}$ (SDA)
							f	G_2				
1	5858	0.524	-4379	0.733	6279.40	5886	1.00	1.00	20.0	21.3	NO	24.5
2	-3939	0.524	3010	0.733	-4270.38	5886	1.00	1.00	20.0	14.5	OK	
3	6230	0.524	-4704	0.733	6712.55	5886	1.00	1.00	10.0	*11.4*	NO	10.0
4	-4055	0.524	3099	0.733	-4396.39	5886	1.00	1.00	10.0	7.5	OK	
5	-746	0.524	582	0.733	-817.51	5886	1.00	1.00	20.0	2.8	OK	
6	-5034	0.524	3804	0.733	-5426.15	5886	1.00	1.00	20.0	18.4	OK	
7	6479	0.524	-4855	0.733	6953.71	5886	1.00	1.00	8.0	*9.5*	NO	8.0
8	8743	0.524	-6599	0.733	9418.40	5886	1.00	1.00	7.0	11.2	NO	13.5
9	-4969	0.524	4154	0.733	-5648.64	5886	1.00	1.00	7.0	6.7	OK	
10	6413	0.524	-4858	0.733	6921.33	5886	1.00	1.00	7.0	8.2	NO	9.0
11	-6436	0.524	5042	0.733	-7068.25	5886	1.00	1.00	7.0	8.4	NO	9.0
12	3360	0.524	-2542	0.733	3623.93	5886	1.00	1.00	12.0	7.4	OK	
13	-3515	0.524	2729	0.733	-3842.22	5886	1.00	1.00	12.0	7.8	OK	
14	9155	0.524	-6868	0.733	9831.46	5886	1.00	1.00	7.0	11.7	NO	14.0
15	-5637	0.524	4629	0.733	-6346.85	5886	1.00	1.00	7.0	7.5	NO	14.0
16	7044	0.524	-5303	0.733	7578.16	5886	1.00	1.00	7.0	9.0	NO	9.5
17	-6312	0.524	4970	0.733	-950.50	5886	1.00	1.00	7.0	8.3	NO	9.5
22	4250	0.524	-3290	0.733	4638.57	5003	1.00	0.85	16.5	15.3	OK	
23	-1943	0.524	1627	0.733	-2210.72	5003	1.00	0.85	13.5	6.0	OK	
24	4112	0.524	-3176	0.733	4482.70	5003	1.00	0.85	16.5	14.8	OK	

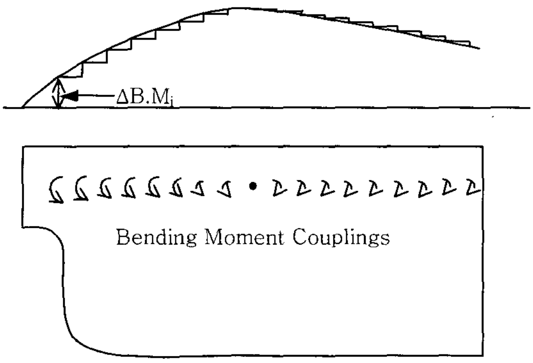

Fig. 9 Bending moment couplings to compensate required BM

This proposed new loading scheme would be used from next similar analyses.

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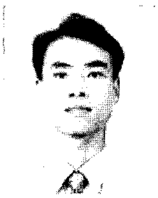
[1] LR, "ShipRight Structural Design Assessment for Primary Structure of Membrane Tank LNG Ships", August 1999, version 1.0
[2] LR, "ShipRight SDA for Primary Structure of Passenger Ships", November 2001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