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CSR기반 좌굴 두께 요건을 고려한 이중선체유조선의 종방향 구조부재의 최적설계 연구

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Optimum Design for Longitudinal Strength Members of Double Hull Tankers with Central Long'l Bulkhead considering Buckling Thickness Requirement of Plate Panels based on Common Structural Rules

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Abstract

The buckling assessment of plate panels described in common structural rules (CSR) is to be determined according to the buckling utilization factor with hull girder stresses calculated on net hull girder sectional properties. As the thickness requirement for the buckling assessment of plate panels is not explicitly given in CSR, a lot of time is spent to find the proper thickness of plate panels until reaching to an allowable buckling utilization factor. In this study, in order to reduce time and cost, the thickness requirement of plate panels satisfying buckling assessment was derived. The structural design system included with the thickness requirement for buckling assessment was developed. The system is called as Oil-tanker Automated Structural Investigation System (OASIS). The design result of longitudinal strength members using OASIS was verified by Nauticus Hull which is the rule scantling software of DNV. Finally, optimum design of a double hull tanker for the minimum weight using OASIS was presented.

Keywords : Common structural rules, structural design, oil-tanker; buckling assessment, OASIS, B : moulded breadth, D : moulded depth, L or L_s : rule length, s : stiffener spacing, T_{bal} : the minimum design ballast draught, T_{sc} : the maximum design draught for the scantling, $z_{NA-net50}$: distance from the baseline to the horizontal neutral axis, σ_{yd} : yield stress of the material

1. Introduction

Common structural rules (CSR) applies to double hull oil tankers of 150m length and upward classed with the society and contracted for construction after 1st April 2006 (IACS, 2008). CSR is established by IACS (International Association of Classification Societies) in order to archive the goals of more robust and safer ships. Comparing with the rules of the classification societies before CSR (Table 1), the scantling requirements of CSR are more stringent and its procedures are more complex. The severe scantling requirements cause the increase of hull weight. The complexity of procedure causes the increase of man-hour for structural design.

Table 1 Comparison of CSR and pre-CSR

	CSR	Pre-CSR
Design life	25 years	20 years
Wave environment	North Atlantic	World Wide
Corrosion margin	2.5~4.5mm	0~3.0mm
Load cases	Over 20	Below 15

In design for longitudinal strength members of double hull tankers, the requirements except buckling assessment are expressed as the thickness requirement of plate panels. However, the buckling assessment is expressed as whether the buckling utilization factor is lesser than the allowable buckling utilization factor. The buckling utilization factor is calculated from hull girder bending stress and slenderness

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factor which are obtained from the net thickness of plate panel. If thickness of plate panels doesn't satisfy with buckling assessment, the following procedures of buckling assessment are repeated until buckling assessment of plate panels is satisfied by the proper thickness of plate panel.

- To assume the net thickness of plate panels
- To estimate hull girder bending stress and slenderness factor
- To calculate buckling utilization factor

In this paper, the thickness requirement of plate panels satisfying buckling assessment was derived. Due to the direct calculation of plate thickness to satisfy buckling assessment, time and cost for the structural design for CSR was reduced. The CSR requirements of plate panels are also included in the system. The system is called as OASIS (Oil-tanker Automated Structural Investigation System). The result of structural design for the 73K panamax tanker using OASIS was verified by Nauticus Hull which is the software for the rule scantling of DNV. Optimum structural design for the minimum hull weight using OASIS was presented.

2. Scantling Requirements for Plate Panels of CSR

2.1 Corrosion margin and net thickness approach

CSR provides the corrosion margin, t_{corr}, for typical structural elements in the cargo tank region as shown in Fig. 1.

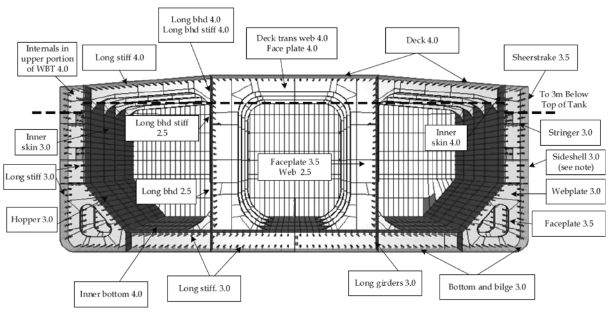

Fig. 1 Corrosion margin for typical structural elements within the cargo tank

In order to assure sufficient strength during the designed life of the ship, the net thickness approach is used. The net thickness approach distinguishes between local and global corrosion. Local corrosion is defined as the uniform corrosion of the local structural elements, such as a single plate or a stiffener. Global corrosion is defined as the overall average corrosion of large areas such as the hull girder.

2.2 Minimum thickness requirement, t_{min}

Minimum thickness, which is independent of material and load, is based on service experience and is typically given in Table 2.

Table 2 Minimum net thickness for plating in the cargo tank region

Scantling location		Net thickness (mm)
Hull envelope up to T_{sc}+4.6m	Keel plating	5.5+0.03L_2
	Bottom shell/bilge/side shell	3.5+0.03L_2
Hull envelope above T_{sc}+4.6m	Side shell/upper deck	4.5+0.02L_2
Hull internal structure	Hull internal tank boundaries	4.5+0.02L_2
	Non-tight bulkheads, bulkheads between dry spaces and other plates in general	4.5+0.01L_2

2.3 Proportions of plate panels, t_{prop}

This requirement is non-stress based requirement. The requirement was typically defined as maximum allowable slenderness ratio. The thickness requirement is expressed as Eq. 1.

$$t_{prop} \geq \frac{s}{C}\sqrt{\frac{\sigma_{yd}}{235}} \tag{1}$$

where, C is slenderness coefficients.

2.4 Contact with q_{uay}, tquay (side shell)

This requirement applies to the side shell plates in contact with quay. It is to be applied to the extent of the side shell plating as shown in Fig. 2. Longitudinal extent is between a section aft of amidships where the breadth at the waterline exceeds 0.9B, and a section forward of amidships where the breadth at the waterline exceeds 0.6B. Vertical extent is between 0.3m below the minimum design ballast waterline, T_{bal}, amidships to 0.25T_{sc} or 2.2m, whichever is greater, above the draught T_{sc}.

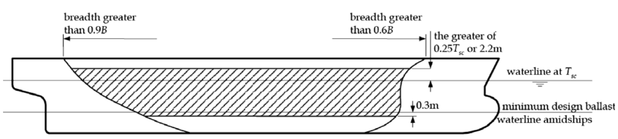

Fig. 2 Extent of side shell plating

The thickness requirement is given in Eq. 2.

$$t_{quay} \geq 26\left(\frac{s}{1000}+0.7\right)\left(\frac{BT_{sc}}{\sigma_{yd}^2}\right)^{0.25} \tag{2}$$

2.5 Requirement considering local pressure, t_{local}

This requirement is for preventing the yielding of plate panels from local pressure, P, for design load set being considered. The thickness requirement is expressed as Eq. 3.

$$t_{local} \geq 0.0158\alpha_p s\sqrt{\frac{|P|}{C_a\sigma_{yd}}} \tag{3}$$

Permissible bending stress coefficient, C_a, and hull girder bending stress coefficient, σ_{hg}, for the design load set being considered is expressed as follows.

$$C_a = \beta_a - \alpha_a\frac{|\sigma_{hg}|}{\sigma_{yd}} \tag{4}$$

$$\sigma_{hg} = \left(\frac{(z-z_{NA-net50})M_{v-total}}{I_{v-net50}} - \frac{yM_{h-total}}{I_{h-net50}}\right)10^{-3} \tag{5}$$

Where,

a_p : correction factor for the panel aspect ratio
z : vertical coordinate of load calculation point
y : transverse coordinate of load calculation point
$M_{v-total}$: design vertical bending moment
$M_{h-total}$: design horizontal bending moment
$I_{v-net50}$: net vertical hull girder moment of inertia
$I_{h-net50}$: net horizontal hull girder moment of inertia

P, C_a and σ_{hg} are dependent on the design load set. Thus, the maximum thickness due to the local pressures is not induced at the maximum pressure, but induced by the combination of P, C_a and σ_{hg} as shown in Table 3.

2.6 Requirement for sloshing pressure, t_{slh}

This requirement is similar to the requirement for the local pressure, but the sloshing pressure is used instead of the local pressure. The thickness requirement is expressed as follows.

$$t_{slh} \geq 0.0158\alpha_p s\sqrt{\frac{P_{slh}}{C_a\sigma_{yd}}} \tag{6}$$

Table 3 Example of the scantling requirement for the local pressures at the bottom plating on ballast condition (spacing, s=830mm)

Wave case	Pressure (kN/m^2)	σ_{hg} (MPa)	C_a	t_{local} (mm)
1	93.92	−168.1	0.78	11.09
2	205.81	154.0	0.81	14.81
3	117.43	−110.2	0.88	11.56
4a	170.37	91.3	0.91	13.14
4b	169.72	95.5	0.9	13.16
5a	188.67	60.9	0.95	13.41
5b	145.86	61.2	0.95	12.16
6a	208.99(max)	69.3	0.94	14.02
6b	155.53	69.0	0.94	12.50
7a	203.28	69.5	0.94	13.87
7b	176.31	68.8	0.94	13.12
Harbor	206.80	−100.7	0.74	15.35(max)

2.7 Requirement for buckling assessment

This requirement applies to the plate panels subject to axial hull girder compressive stress and it needs to meet the following criteria.

$$\eta \leq \eta_{allow} \tag{7}$$

Allowable buckling utilization factor, η_{allow}, is 1.0 for the plate panels at or above 0.5D and 0.9 for the plate panels below 0.5D.

Buckling utilization factor, η, is obtained as follows.

$$\eta = \frac{\sigma_{hg-net50}}{\sigma_{cr}} \tag{8}$$

Hull girder compressive stress, $\sigma_{hg-net50}$, due to bending for the buckling assessment is to be calculated using the net hull girder sectional properties and is to be taken as the greater of the following.

$$\sigma_{hg-net50} = \left(\frac{(z-z_{NA-net50})(M_{sw-perm-sea}+M_{wv-v})}{I_{v-net50}}\right)10^{-3} \tag{9}$$

$$\sigma_{hg-net50} = \frac{30}{k} \tag{10}$$

Where,

$M_{sw-perm-sea}$: permissible still water bending moment for seagoing operation
M_{w-v} : vertical wave bending moments
k : higher strength steel factor

The critical stress of plate panels subject to compression is given as Eq. 11.

$$\sigma_{cr} = C_x \sigma_{yd} \tag{11}$$

In the case that hull girder compressive stress is applied to plate panels as shown in Fig. 3, buckling factor, K, and reduction factor, C_x, are given as Eq. 12 and 13, respectively.

$$K = \frac{8.4}{\Psi + 1.1} \tag{12}$$

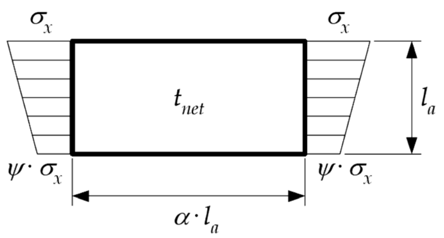

Fig. 3 Plate penal subjected to compressive stress

$$C_x = c\left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2}\right) \tag{13}$$

Where, l_a is stiffener spacing, α is aspect ratio and ψ is stress ratio.

Reference degree of slenderness, λ, is given as Eq. 14.

$$\lambda = \sqrt{\frac{\sigma_{yd}}{K\sigma_E}} \tag{14}$$

σ_E is reference stress including net thickness of plate panel.

$$\sigma_E = 0.9E\left(\frac{t_{net}}{l_a}\right)^2 \tag{15}$$

In order to assess buckling of plate panels by CSR, the procedure to calculate buckling utilization factor is summarized as follows. First, the net thickness of plate panel, t_{net}, is determined by the former requirements. Subsequently, reference stress, σ_E, and hull girder compressive stress, $\sigma_{hg-net50}$ are calculated according to the net thickness. In addition, buckling factor, K, is calculated by the geometry of plate panel and hull girder compressive stress distribution. Reference degree of slenderness, λ, is also calculated according to reference stress and buckling factor. Finally, buckling utilization factor, η, is obtained according to critical stress which is calculated by reduction factor, C_x.

If the buckling utilization factor calculated by the former procedure is greater than the allowable buckling utilization factor, the procedure is repeated until buckling utilization factor satisfy buckling assessment. In other words, the net thickness of plate panels which satisfy buckling assessment is not directly obtained.

2.8 Derivation of thickness requirement for buckling assessment, t_{buck}

The thickness requirement of plate panel for buckling assessment is derived and suggested in following process.

Eq. 16 is obtained by combining Eqs. 7, 8 and 11.

$$\sigma_{hg-net50} \leq \eta_{allow} C_x \sigma_{yd} \tag{16}$$

Substitute Eq. 13 for C_x in Eq. 16, and multiply λ^2 to both sides. It becomes a second order inequality equation as follows.

$$\sigma_{hg-net50}\lambda^2 - \eta_{allow}\sigma_{yd}c\lambda + 0.22\eta_{allow}\sigma_{yd}c \leq 0 \tag{17}$$

Let $b = \eta_{allow}\sigma_{yd}c$, then Eq. 17 becomes

$$\sigma_{hg-net50}\lambda^2 - b\lambda + 0.22b \leq 0 \tag{18}$$

Solve the second order inequality equation, and obtain Eq. 19.

$$\frac{b - \sqrt{b^2 - 0.88\sigma_{hg-net50}b}}{2\sigma_{hg-net50}} \leq \lambda \leq \frac{b + \sqrt{b^2 - 0.88\sigma_{hg-net50}b}}{2\sigma_{hg-net50}} \tag{19}$$

Using Eqs. 14 and 15, the equation of thickness requirement for buckling assessment is derived as follows.

$$t_{buck} \geq l_a \sqrt{\frac{\sigma_{yd}}{0.9EK}} \frac{2\sigma_{ht-net50}}{b + \sqrt{b^2 - 0.88\sigma_{hg-net}b}} \tag{20}$$

2.9 Determination of net thickness, t_{net}

Steel plate for shipbuilding is typically produced by the 0.5mm. Thus, the required net thickness is determined by rounding the estimated thickness as follows.

First, maximum thickness, t_{max5}, except buckling assessment is obtained by Eq. 21.

$$t_{\max 5} = \max(t_{\min},\ t_{prop},\ t_{quay},\ t_{local},\ t_{slh}) \tag{21}$$

Next, the net thickness, t_{net5}, except buckling assessment is given by rounding the calculated net thickness to the nearest half millimeter. For example:

(a) For $10.75 \leq t_{max5} < 11.25$ mm the net thickness, t_{net5}, is 11.00 mm

(b) For $11.25 \leq t_{max5} < 11.75$ mm the net thickness, t_{net5}, is 11.50 mm

The net thickness, t_{netb}, for buckling assessment is given by rounding the thickness requirement for buckling assessment, t_{buck}, to higher half millimeter. For example:

(a) For $10.00 < t_{buck} \leq 10.50$ mm the net thickness, t_{netb}, is 10.50 mm

(b) For $10.50 < t_{buck} \leq 11.00$ mm the net thickness, t_{netb}, is 11.00 mm

Finally, the required net thickness, t_{net}, is obtained as the larger value of t_{net5} and t_{netb}.

$$t_{net} = \max(t_{net5},\ t_{netb}) \tag{22}$$

3. Estimation of Cargo Tank Weight

The cargo tank weight, W_{tank}, is the sum of the weight of longitudinals, $W_{longi.}$, and the weight of transverse structural members, $W_{trans.}$.

$$W_{tank} = W_{longi.} + W_{trans.} \tag{23}$$

3.1 Weight of longitudinal structural members

The gross thickness, t_{gros}, is obtained by adding the net thickness, t_{net}, and the corrosion margin, t_{corr}. The sectional area of the mid-ship section, A_{gros}, is calculated based on the gross thickness. The weight of longitudinal members is obtained using the steel density, ρ_{steel}, and the cargo tank length, L_{tank}.

$$t_{gros} = t_{net} + t_{corr} \tag{24}$$

$$W_{longi.} = \rho_{steel} A_{gros} L_{tank} \tag{25}$$

3.2 Weight of transverse structural members

Weight of transverse structural members, W_{trans}, which consists of transverse web frames, W_{web}, transverse bulkhead, W_{BHD} and horizontal stringer, W_{str}, as Eq. 26 was calculated by following estimation formula based on data of existing ships.

$$W_{trans.} = n_{web} W_{web} + W_{BHD} + W_{str.} \tag{26}$$

Weight of web frames is sum of weight of double bottom floors, side transverse, vertical transverse on longitudinal bulkhead and deck transverse.

$$W_{web} = W_{D/B} + W_{D/S} + W_{vert.} + W_{deck} \tag{27}$$

$$W_{D/B} = 9.42\sqrt{L}\,B h_{D/B} \times 10^{-3} \tag{28}$$

$$W_{D/S} = 18.84\sqrt{L}\,D b_{D/S} \times 10^{-3} \tag{29}$$

$$W_{vert.} = 1.413\sqrt{L}\,(D - h_{D/B}) D \times 10^{-3} \tag{30}$$

$$W_{deck} = 0.4288\sqrt{L-50}\,(B - b_{D/S}) B \times 10^{-3} \tag{31}$$

$$W_{BHD} = 12.56BD\left(3 + 0.0158 s_{bot.}\sqrt{0.04(D+1)}\right) \times 10^{-3} \tag{32}$$

$$W_{str.} = 2.6B(B - 2b_{D/S})\sqrt{L} \times 10^{-3} \tag{33}$$

Where,

$h_{D/B}$: height of double bottom floor

$b_{D/S}$: breadth of double side transverse

s_{bot} : long'l spacing in bottom plate

n_{web} : number of web frames in cargo hold region

4. Oil-tanker Automated Structural Investigation System (OASIS)

4.1 Introduction

OASIS is developed for the structural design of the longitudinal members to comply with the requirement of CSR. Fig. 4 shows the main frame of OASIS. This system includes the scantling requirements of CSR and the thickness requirement for buckling assessment.

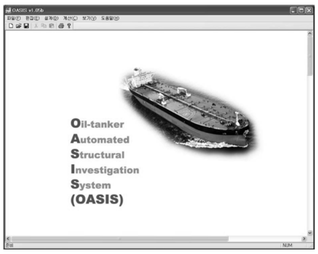

Fig. 4 Main frame of OASIS

4.2 Input data

Data input for the CSR scantling in OASIS is handled by several dialog boxes. Fig. 5 shows the dialog box for the main dimension input.

The dimensions of the mid-ship section in the cargo tank region are inserted in the dialog box as shown in Fig. 6. In the long'l spacing dialog box shown in Fig. 7, the number of longitudinal stiffeners is determined. When data input is completed, the configuration of the mid-ship section is displayed as shown in Fig. 8.

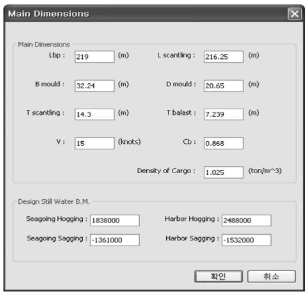

Fig. 5 Main dimension dialog box

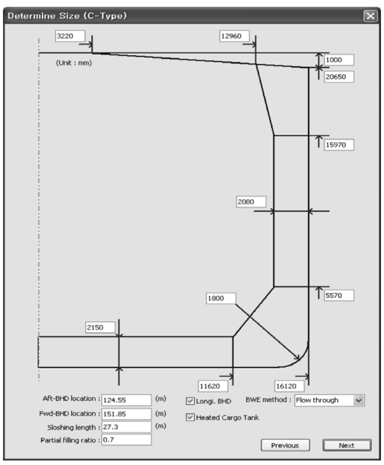

Fig. 6 Dialog box for the dimensions of the mid-ship section

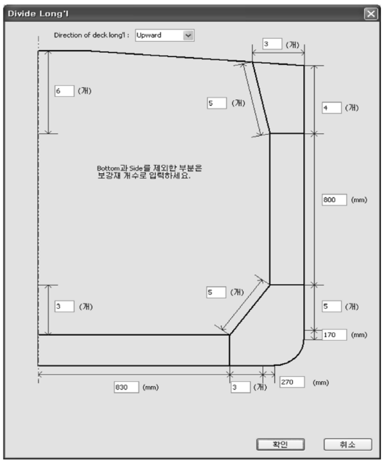

Fig. 7 Long'l spacing dialog box

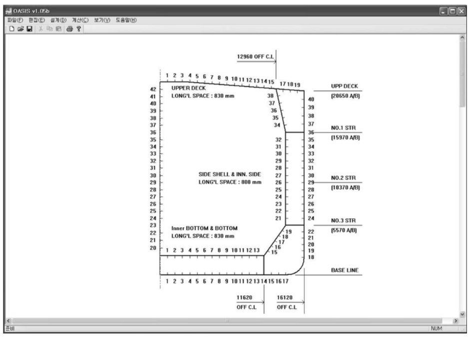

Fig. 8 Display mid-ship section by inputted data

4.3 Estimate CSR requirements

After data input, the estimation of longitudinal structural members is performed based on CSR. The estimation procedure is shown as Fig. 9.

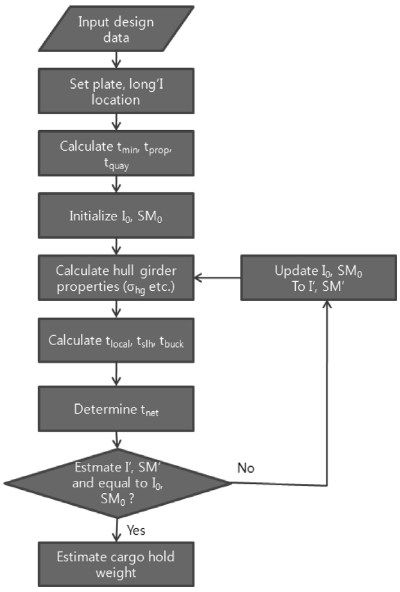

Fig. 9 Procedure of calculate CSR requirements in OASIS

4.4 Display design results

Upon completing the calculation of CSR requirements using OASIS, the design result of longitudinal structural members is displayed on the mid-ship section with the thickness of plate panels (Fig. 10).

OASIS supports GUI. When the left button is clicked on the plate panel, the pop-up window including the detail results of CSR scantling appears as shown in Fig. 11. Similarly, when the left button is clicked on the interested longitudinal stiffener, the pop-up window for the detail results of the stiffener appears as shown in Fig. 12.

Fig. 13 shows the hull girder properties such as cross sectional area, moment of inertia, section modulus and so on. OASIS presents the plating and the stiffening calculation sheets as shown in Figs. 14 and 15.

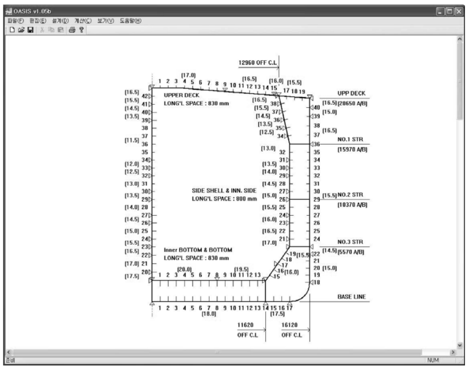

Fig. 10 Display design result in midship section

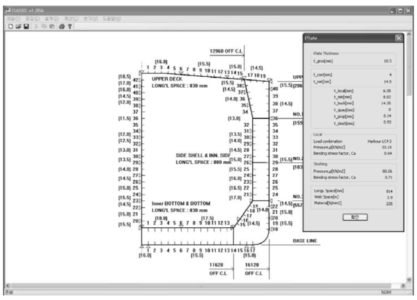

Fig. 11 Display plating requirements

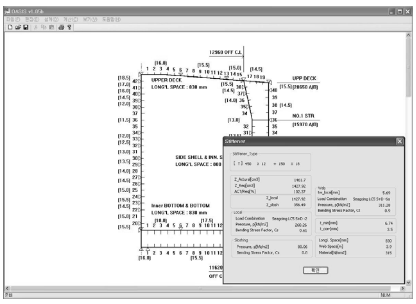

Fig. 12 Display long'l stiffener requirements

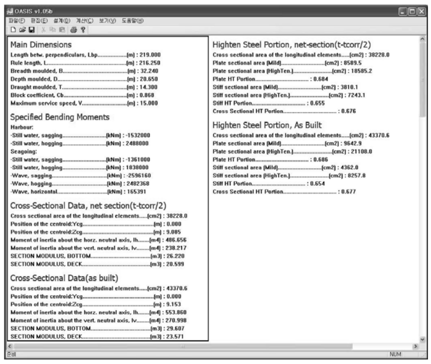

Fig. 13 Display hull girder properties calculation sheets

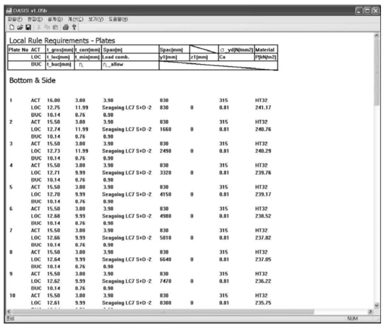

Fig. 14 Display plate calculation sheet

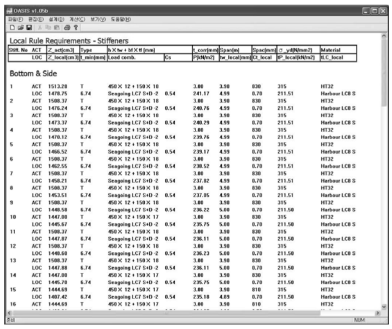

Fig. 15 Display stiffener calculation sheet

5. Design Results using OASIS

5.1 Target vessel

In order to verify the proposed thickness requirement and OASIS, the structural design of the longitudinal structural members for the 73K panamax product/crude oil tanker is performed. Main dimensions of the vessel are shown in Table 4.

Table 4 Main dimensions of the 73K panamax tanker

Item	Dimension	Item	Dimension
L_S(m)	216.25	T_{SC}(m)	14.30
B(m)	32.24	T_{bal}(m)	7.24
D(m)	20.65	V(knots)	15.00

5.2 Verification

The structural design results from OASIS are verified by the rule scantling of Nauticus Hull. Table 5 shows verification of design results without buckling assessment. Table 6 shows verification of design results with buckling assessment. Whether the buckling assessment is considered or not, the OASIS results are virtually identical to the Nauticus ones. Therefore OASIS is a fully capable tool to carry out the CSR scantling design.

Note that, in some cases, OASIS outperforms Nauticus, resulting in a better optimized scantling results shown as 1~2 mm less thickness around the deck panels when buckling assessment is not considered. The reason is that Nauticus isn't able to consider the change of hull girder properties such as cross sectional area, moment of inertia and section modulus due to the change of plate panel thickness, while OASIS is able to consider the change of hull girder properties due to the change of plate panel thickness.

Table 5 Verification of design result without buckling assessment (OAS : OASIS, NAU : Nauticus)

Plate No.	S/W	Load Comb	P (kN/m^2)	Ca	t_{local} (mm)	t_{req} (mm)	η/η_{allow}
Bottom Plating							
1	OAS	7+2 Sea	241.2	0.81	12.77	16.00 (local)	0.74/0.90
	NAU	7+2 Sea	240.5	0.81	12.76	16.00 (local)	0.75/0.90
3	OAS	7+2 (Sea)	240.3	0.81	12.75	16.00 (local)	0.77/0.90
	NAU	7+2 Sea	239.3	0.81	12.73	15.50 (local)	0.75/0.90
10	OAS	7+2 Sea	235.8	0.81	12.63	15.50 (local)	0.77/0.90
	NAU	7+2 Sea	235.0	0.81	12.62	15.50 (local)	0.77/0.90
Side Shell Plating							
31	OAS	7+5b Sea	172.4	0.95	11.11	15.50 (quay)	0.27/0.90
	NAU	7+6a Sea	160.6	0.95	10.72	15.50 (quay)	0.25/0.90
41	OAS	7+6b Sea	62.6	0.91	6.90	11.00 (prop.)	1.11/1.00
	NAU	1+7b Sea	72.5	0.90	7.48	16.50 (buck.)	1.12/1.00
Inner Bottom Plating							
2	OAS	5+6a Sea	315.8	0.95	13.47	18.00 (local)	0.55/0.90
	NAU	5+6a Sea	315.3	0.95	13.46	18.00 (local)	0.55/0.90
12	OAS	5+6a Sea	293.1	0.95	12.98	17.50 (local)	0.56/0.90
	NAU	5+6a Sea	292.5	0.95	12.97	17.50 (local)	0.56/0.90
Inner Side Plating							
23	OAS	5+6b Sea	231.9	0.95	12.88	16.50 (local)	0.16/0.90
	NAU	5+6b Sea	231.3	0.95	12.87	16.50 (local)	0.14/0.95
39	OAS	5+3 Sea	51.1	0.83	5.89	14.50 (prop.)	1.13/1.00
	NAU	5+3 Sea	54.1	0.86	5.94	16.50 (buck.)	1.14/1.00
Deck Plating							
3	OAS	1+7a Sea	34.3	0.88	4.62	13.50 (prop.)	1.26/1.00
	NAU	1+7b Sea	37.2	0.87	4.82	17.00 (buck.)	1.28/1.00
19	OAS	1+7b Sea	59.9	0.89	5.77	13.00 (prop.)	1.18/1.00
	NAU	1+7b Sea	49.3	0.89	4.26	15.50 (buck.)	1.20/1.00
Longitudinal Bulkhead Plating							
22	OAS	3+7a Sea	252.3	0.95	12.40	15.00 (local)	0.42/1.00
	NAU	3+7a Sea	251.7	0.95	12.39	15.00 (local)	0.42/1.00
30	OAS	3+7a Sea	168.9	0.95	11.00	13.50 (local)	0.21/1.00
	NAU	3+7a Sea	168.6	0.95	10.98	13.50 (local)	0.21/0.95
43	OAS	4 Harb.	33.2	0.63	6.11	13.00 (slosh)	1.51/1.00
	NAU	4 Harb.	33.2	0.62	6.13	20.00 (buck.)	1.53/1.00

Table 6 Verification of design result with buckling assessment (OAS : OASIS, NAU : Nauticus)

Plate No.	S/W	Load Comb	P (kN/m^2)	Ca	t_{local} (mm)	t_{req} (mm)	η/η_{allow}
Bottom Plating							
1	OAS	7+2 Sea	241.2	0.81	12.74	15.50 (local)	0.75/0.90
	NAU	7+2 Sea	240.5	0.81	12.73	15.50 (local)	0.76/0.90
3	OAS	7+2 (Sea)	240.3	0.81	12.72	15.50 (local)	0.75/0.90
	NAU	7+2 Sea	239.3	0.81	12.70	15.50 (local)	0.76/0.90
10	OAS	7+2 Sea	235.8	0.81	12.60	15.50 (local)	0.75/0.90
	NAU	7+2 Sea	235.0	0.81	12.58	15.50 (local)	0.76/0.90
Side Shell Plating							
31	OAS	7+5b Sea	172.4	0.95	11.11	15.50 (quay)	0.27/0.90
	NAU	7+6a Sea	160.6	0.95	10.72	15.50 (quay)	0.25/0.90
41	OAS	7+6b Sea	62.6	0.92	6.87	15.50 (buck.)	0.97/1.00
	NAU	1+7b Sea	72.5	0.91	7.44	15.50 (buck.)	0.98/1.00
Inner Bottom Plating							
2	OAS	5+6a Sea	315.8	0.95	13.47	18.00 (local)	0.54/0.90
	NAU	5+6a Sea	315.3	0.95	13.46	18.00 (local)	0.54/0.90
12	OAS	5+6a Sea	293.1	0.95	12.98	17.50 (local)	0.56/0.90
	NAU	5+6a Sea	292.5	0.95	12.97	17.50 (local)	0.56/0.90
Inner Side Plating							
23	OAS	5+6b Sea	231.9	0.95	12.88	16.50 (local)	0.16/0.90
	NAU	5+6b Sea	231.3	0.95	12.87	16.50 (local)	0.14/0.95
39	OAS	5+3 Sea	51.1	0.83	5.85	15.50 (buck.)	0.98/1.00
	NAU	5+3 Sea	54.1	0.86	5.99	15.50 (buck.)	0.98/1.00
Deck Plating							
3	OAS	1+7a Sea	34.3	0.89	4.60	16.00 (buck.)	0.97/1.00
	NAU	1+7b Sea	37.2	0.88	4.79	16.00 (buck.)	0.98/1.00
19	OAS	1+7b Sea	59.9	0.90	5.74	14.50 (buck.)	0.97/1.00
	NAU	1+7b Sea	49.3	0.90	5.23	14.50 (buck.)	0.98/1.00
Longitudinal Bulkhead Plating							
22	OAS	3+7a Sea	252.3	0.95	12.40	15.00 (local)	0.42/1.00
	NAU	3+7a Sea	251.7	0.95	12.49	15.00 (local)	0.42/1.00
30	OAS	3+7a Sea	168.9	0.95	11.00	13.50 (local)	0.21/1.00
	NAU	3+7a Sea	168.6	0.95	10.98	13.50 (local)	0.21/0.95
43	OAS	4 Harb.	33.2	0.64	6.03	18.5 (buck.)	1.00/1.00
	NAU	4 Harb.	33.2	0.64	6.04	18.5 (buck.)	0.98/1.00

5.3 Optimum design

OASIS includes the optimum design module which utilizes the parametric search method. Using this module of OASIS, the optimum design for the minimum weight of the target ship (73K P/C tanker) is performed over the design variables. Table 7 shows the dimensions of the frame spaces for the target ship. The ranges of the design variables are shown in Table 8.

Fig. 17 shows the effect of bottom long'l spacing on the cargo hold weight. When bottom long'l spacing is 605mm, the cargo hold weight has the minimum value.

Fig. 18 shows the effect of side long'l spacing on the cargo hold weight. When side long'l spacing is 665mm, the cargo hold weight has the minimum value.

Fig. 19 shows the effect of web frame spacing on the cargo hold weight. When web frame spacing is 3.9m, that is equal to 6 web frames in a cargo hold, the cargo hold weight has minimum value.

Considering all design variables, the minimum weight design is obtained as shown in Table 9. Weight saving is 54.54 tons per cargo hold. Since the panamax tanker has 6 holds, the total weight saving is about 330 tons.

Table 7 Framing spaces of target ship

	Bottom	Side shell	Web frame
Spacing	830mm	800mm	6EA/C.H

Table 8 The ranges of design variable

Spacing	Min.	Max	Increment
Bottom	600mm	1000mm	5mm
Side shell	600mm	1000mm	5mm
Web fr.	2EA/C.H	10EA/C.H	1EA/C.H

Table 9 Result of optimum design

Design	Bottom (mm)	Side (mm)	Web (m)	Weight (ton)
Existing	830	800	3.9	1310.28
Optimum	605	665	3.9	1255.74

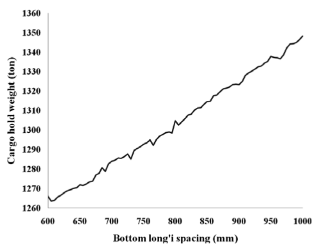

Fig. 17 The effect of BTM long'l Sp. on the C/H weight

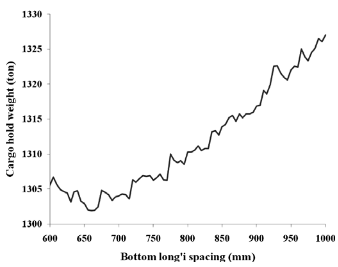

Fig. 18 The effect of side long'l Sp. on the C/H weight

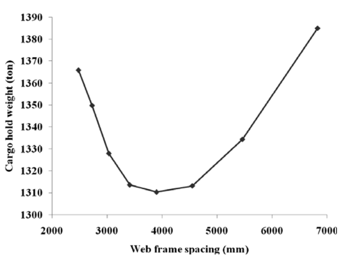

Fig. 19 The effect of web frame sp. on the C/H weight

6. Conclusions

In the present study, OASIS was developed. OASIS included the requirements of CSR and the thickness requirement for buckling assessment of plate panels.

The main conclusions of this study can be summarized as follows:

- The thickness requirement for buckling assessment of plate panels is derived. It can be applied for the structural design of double hull oil tankers according to CSR.
- OASIS, which is a structural design system for double hull oil tankers, is developed. Since the design results of OASIS are verified by Nauticus of DNV, they satisfy CSR.
- The optimum design for the minimum weight of the 73K panamax tanker was performed, resulting in the reduction of 330 tons.
- OASIS is considered to be useful for the structural design of double hull oil tankers according to CSR.

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