Common Structural Rules for Bulk Carriers, January 2006

Rule Change Notice No. 1
November 2007

Notes: This rule change is to be implemented by IACS Members on ships contracted for construction from a date not later than 1 April 2008.

For technical background for Rule Changes in this present document, reference is made to separate document Technical Background for Rule Change Notice No.1.

CHAPTER 5 – HULL GIRDER STRENGTH

APPENDIX 1 HULL GIRDER ULTIMATE STRENGTH

2. Criteria for the calculation of the curve M-χ

2.2 Load-end shortening curve σ-ε

2.2.4 Beam column buckling

The equation describing the load-end shortening curve σ_{CR1}-ε for the beam column buckling of ordinary stiffeners composing the hull girder transverse section is to be obtained from the following formula (see Fig 3):

$$\sigma_{CR1} = \Phi \sigma_{C1} \frac{A_{Stif} + 10 b_E t_p}{A_{Stif} + 10 s t_p}$$

where:

Φ : Edge function defined in [2.2.3]

A_{Stif} : Net sectional area of the stiffener, in cm^2, without attached plating

σ_{C1} : Critical stress, in N/mm^2, equal to:

$$\sigma_{C1} = \frac{\sigma_{E1}}{\varepsilon} \qquad \text{for } \sigma_{E1} \le \frac{R_{eH}}{2} \varepsilon$$

$$\cancel{\sigma_{C1} = R_{eH}\left(1 - \frac{\Phi R_{eH}\,\varepsilon}{4\sigma_{E1}}\right)} \qquad \underline{\sigma_{C1} = R_{eH}\left(1 - \frac{R_{eH}\,\varepsilon}{4\sigma_{E1}}\right)} \qquad \text{for } \sigma_{E1} > \frac{R_{eH}}{2} \varepsilon$$

ε : Relative strain defined in [2.2.3]

σ_{E1} : Euler column buckling stress, in N/mm^2, equal to:

$$\sigma_{E1} = \pi^2 E \frac{I_E}{A_E l^2} 10^{-4}$$

I_E : Net moment of inertia of ordinary stiffeners, in cm^4, with attached shell plating of width b_{E1}

b_{E1} : Effective width, in m, of the attached shell plating, equal to:

$$b_{E1} = \frac{s}{\beta_E} \qquad \text{for } \beta_E > 1.0$$

$$b_{E1} = s \qquad \text{for } \beta_E \le 1.0$$

$$\beta_E = 10^3 \frac{s}{t_p} \sqrt{\frac{\varepsilon R_{eH}}{E}}$$

A_E : Net sectional area, in cm^2, of ordinary stiffeners with attached shell plating of width b_E

b_E : Effective width, in m, of the attached shell plating, equal to:

$$b_E = \left(\frac{2.25}{\beta_E} - \frac{1.25}{\beta_E^2}\right)s \quad \text{for } \beta_E > 1.25$$

$$b_E = s \quad \text{for } \beta_E \le 1.25$$

2.2.5 Torsional buckling

The equation describing the load-end shortening curve σ_{CR2}-ε for the flexural-torsional buckling of ordinary stiffeners composing the hull girder transverse section is to be obtained according to the following formula (see Fig 4).

$$\sigma_{CR2} = \Phi \frac{A_{Stif}\sigma_{C2} + 10st_p\sigma_{CP}}{A_{Stif} + 10st_p}$$

where:

Φ : Edge function defined in [2.2.3]

A_{Stif} : Net sectional area of the stiffener, in cm^2, without attached plating

σ_{C2} : Critical stress, in N/mm^2, equal to:

$$\sigma_{C2} = \frac{\sigma_{E2}}{\varepsilon} \quad \text{for } \sigma_{E2} \le \frac{R_{eH}}{2}\varepsilon$$

$$\cancel{\sigma_{C2} = R_{eH}\left(1 - \frac{\Phi R_{eH}\,\varepsilon}{4\sigma_{E2}}\right)} \quad \underline{\sigma_{C2} = R_{eH}\left(1 - \frac{R_{eH}\,\varepsilon}{4\sigma_{E2}}\right)} \quad \text{for } \sigma_{E2} > \frac{R_{eH}}{2}\varepsilon$$

σ_{E2} : Euler torsional buckling stress, in N/mm^2, defined in Ch 6, Sec 3, [4.3]

ε : Relative strain defined in [2.2.3]

σ_{CP} : Buckling stress of the attached plating, in N/mm^2, equal to:

$$\sigma_{CP} = \left(\frac{2.25}{\beta_E} - \frac{1.25}{\beta_E^2}\right)R_{eH} \quad \text{for } \beta_E > 1.25$$

$$\sigma_{CP} = R_{eH} \quad \text{for } \beta_E \le 1.25$$

β_E : Coefficient defined in [2.2.4]

2.2.7 Web local buckling of ordinary stiffeners made of flat bars

The equation describing the load-end shortening curve σ_{CR4}-ε for the web local buckling of flat bar ordinary stiffeners composing the hull girder transverse section is to be obtained from the following formula (see Fig 5):

$$\sigma_{CR4} = \Phi \frac{10st_P\sigma_{CP} + A_{Stif}\sigma_{C4}}{A_{Stif} + 10st_P}$$

where:

Φ : Edge function defined in [2.2.3]

A_{Stif} : Net sectional area of the stiffener, in cm^2, without attached plating

σ_{CP} : Buckling stress of the attached plating, in N/mm^2, defined in [2.2.5]

σ_{C4} : Critical stress, in N/mm^2, equal to:

$$\sigma_{C4} = \frac{\sigma_{E4}}{\varepsilon} \qquad \text{for } \sigma_{E4} \le \frac{R_{eH}}{2}\varepsilon$$

$$\cancel{\sigma_{C4} = R_{eH}\left(1 - \frac{\Phi\, R_{eH}\, \varepsilon}{4\sigma_{E4}}\right)} \qquad \underline{\sigma_{C4} = R_{eH}\left(1 - \frac{R_{eH}\, \varepsilon}{4\sigma_{E4}}\right)} \qquad \text{for } \sigma_{E4} > \frac{R_{eH}}{2}\varepsilon$$

σ_{E4} : Local Euler buckling stress, in N/mm^2, equal to:

$$\sigma_{E4} = 160000\left(\frac{t_w}{h_w}\right)^2$$

ε : Relative strain defined in [2.2.3].

2.2.8 Plate buckling

The equation describing the load-end shortening curve σ_{CR5}-ε for the buckling of transversely stiffened panels composing the hull girder transverse section is to be obtained from the following formula:

$$\cancel{\sigma_{CR5} = \min\begin{cases} R_{eH}\,\Phi \\ R_{eH}\left[\frac{s}{\ell}\left(\frac{2.25}{\beta_E} - \frac{1.25}{\beta_E^2}\right) + 0.1\left(1 - \frac{s}{\ell}\right)\left(1 + \frac{1}{\beta_E^2}\right)^2\right] \end{cases}}$$

$$\underline{\sigma_{CR5} = \min\begin{cases} R_{eH}\,\Phi \\ \Phi R_{eH}\left[\frac{s}{\ell}\left(\frac{2.25}{\beta_E} - \frac{1.25}{\beta_E^2}\right) + 0.1\left(1 - \frac{s}{\ell}\right)\left(1 + \frac{1}{\beta_E^2}\right)^2\right] \end{cases}}$$

where:

Φ : Edge function defined in [2.2.3].

β_E : Coefficient defined in [2.2.4].

Common Structural Rules for Bulk Carriers, January 2006

Technical Background for Rule Change Notice No. 1, November 2007

Technical Background for the Changes in:

Chapter 5/Appendix 1

1. Reason for the Rule Change:

The original formulae in Appendix 1 of Chapter 5 which are the determination of the load-end shortening curve are some class Rules, however, some formulae is not consistent with the assumption of the method adopted in CSR. This rule change proposal is made to fix the inconsistency.

2. Explanation of the modified formula

2.1 Main assumptions of the method

The hull girder is treated as a beam subjected exclusively to bending, excluding shear. It corresponds to the assumption of the cross section remaining plane during loading.
The method adopted uses the so-called "component approach" and is based on the following simplifying assumptions:

- each cross section is made of an assembly of independent elements or components (plates and stiffened plates),
- transverse cross-sections of the ship hull remain plane after deformation and perpendicular, to the neutral surface, which enables to calculate for any curvature Φ the strain ε according to the following formula : $\Phi = z\varepsilon$ (z distance from the element under consideration to the neutral axis),
- collapse occurs for panels located between two adjacent transverse primary members,
- elasto-plastic behaviour of each panel is determined under tension and compression;
- influence of shear stresses is neglected.

The method takes also advantage of the possibility to determine for each panel its load-end shortening curve σ_{CR1}-ε, as indicated hereafter.

2.2 Determination of the load-end shortening curve σ_{CR1}-ε – beam column buckling

The Euler column buckling stress is taken as:

$$\sigma_E = \pi^2 \frac{E\, I_e^{'}}{A_e\, \ell^2} 10^{-4}$$

where $I_e^{'}$: moment of inertia, in cm⁴, of the stiffener with attached plating of width b_e' taken as: $b_e^{'} = \dfrac{1.125\, b}{\beta_e} \le b$

A_e : cross sectional area, in cm², of the stiffener with an attached plating of width b_e taken as:

$$\begin{cases} b_e = \left(\dfrac{2.25}{\beta_e} - \dfrac{1.25}{\beta_e^2}\right) b & for \quad \beta_e \ge 1.25 \\ b_e = b & for \quad \beta_e < 1.25 \end{cases} \qquad \beta_e = \frac{b}{t_p}\sqrt{\frac{\sigma_{c1}}{E}}$$

t_p : thickness of attached plating

ℓ: span of stiffeners

Since the effective width b_e of attached plating may be calculated for any strain level by considering the generalized slenderness of plating $\beta_e(\bar{\varepsilon})$:

$$\begin{cases} b_e(\bar{\varepsilon}) = \left(\dfrac{2.25}{\beta_e(\bar{\varepsilon})} - \dfrac{1.25}{\beta_e^2(\bar{\varepsilon})} \right) b & for \quad \beta_e(\bar{\varepsilon}) \geq 1.25 \\ b_e(\bar{\varepsilon}) = b & for \quad \beta_e(\bar{\varepsilon}) < 1.25 \end{cases}$$

the Euler column buckling stress can be expressed as:

$$\sigma_E(\bar{\varepsilon}) = \pi^2 \frac{E\, I_e^{'}(\bar{\varepsilon})}{A_e(\bar{\varepsilon})\, \ell^2}$$

where $I_e^{'}$ = moment of inertia of the stiffener with attached plating of width $b_e^{'}(\bar{\varepsilon})$ taken as

$$b_e^{'}(\bar{\varepsilon}) = \frac{1.125\, b}{\beta_e(\bar{\varepsilon})} \leq b$$

If we assume that the Johnson-Ostenfeld correction is applicable to any edge stress the maximum stress that the stiffener with attached plate of width $b_e(\bar{\varepsilon})$ can sustain is:

$$\sigma_{\max}(\bar{\varepsilon}) = \left(1 - \frac{\sigma_e}{4\,\sigma_E(\bar{\varepsilon})}\right)\sigma_e = \Phi_e(\bar{\varepsilon})\left(1 - \Phi_e(\bar{\varepsilon})\frac{\sigma_Y}{4\,\sigma_E(\bar{\varepsilon})}\right)\sigma_Y \qquad \text{for} \quad \frac{\sigma_E(\bar{\varepsilon})}{\sigma_e} > 0.5$$

$$\sigma_{\max}(\bar{\varepsilon}) = \sigma_E(\bar{\varepsilon}) \qquad \text{for} \quad \frac{\sigma_E(\bar{\varepsilon})}{\sigma_e} \leq 0.5$$

where $\Phi_e(\bar{\varepsilon}) = \dfrac{\sigma_e}{\sigma_Y}$.

The $\phi_e(\bar{\varepsilon})$ is defined as $\phi_e(\bar{\varepsilon}) = \dfrac{\sigma_E(\bar{\varepsilon})}{\sigma_e}$, then the above formulae can be expressed as follows.

$$\sigma_{\max}(\bar{\varepsilon}) = \Phi_e(\bar{\varepsilon})\left(1 - \frac{1}{4\,\phi_e(\bar{\varepsilon})}\right)\sigma_Y \qquad \text{for} \quad \phi_e(\bar{\varepsilon}) > 0.5$$

$$\sigma_{\max}(\bar{\varepsilon}) = \phi_e(\bar{\varepsilon})\,\Phi_e(\bar{\varepsilon})\,\sigma_Y \qquad \text{for} \quad \phi_e(\bar{\varepsilon}) \leq 0.5$$

where $\phi_e(\bar{\varepsilon}) = \dfrac{\sigma_E(\bar{\varepsilon})}{\sigma_e}$

For any relative strain $\bar{\varepsilon}$, the average stress σ_{av} in the stiffener with attached plate of width $b_e(\bar{\varepsilon})$ is given by

$$\left(A_{Stif} + b\,t_p\right)\sigma_{av} = \left(A_{Stif} + b_e(\bar{\varepsilon})\,t_p\right)\sigma_{\max}(\bar{\varepsilon})$$

$$\sigma_{av} = \Phi_e(\bar{\varepsilon})\;\frac{A_{Stif} + \Phi_w(\bar{\varepsilon})\,b\,t_p}{A_{Stif} + b\,t_p}\left(1 - \frac{1}{4\,\phi_e(\bar{\varepsilon})}\right)\sigma_Y \qquad \text{for} \quad \phi_e(\bar{\varepsilon}) > 0.5$$

$$\sigma_{av} = \phi_e(\bar{\varepsilon})\;\Phi_e(\bar{\varepsilon})\;\frac{A_{Stif} + \Phi_w(\bar{\varepsilon})\,b\,t_p}{A_{Stif} + b\,t_p}\,\sigma_Y \qquad \text{for} \quad \phi_e(\bar{\varepsilon}) \leq 0.5$$

CSR for Bulk Carriers, $\sigma_{av} = \sigma_{CR1}$ and $\sigma_y = R_{eH}$, so the formulae are as follows:

$$\sigma_{CR1} = \Phi_e(\bar{\varepsilon})\;\frac{A_{Stif} + \Phi_w(\bar{\varepsilon})\,b\,t_p}{A_{Stif} + b\,t_p}\left(1 - \frac{1}{4\,\phi_e(\bar{\varepsilon})}\right)R_{eH} \qquad \text{for} \quad \phi_e(\bar{\varepsilon}) > 0.5$$

$$\sigma_{CR1} = \Phi_e(\bar{\varepsilon}) \frac{A_{Stif} + b_e(\bar{\varepsilon})\, t_p}{A_{Stif} + b\, t_p} \left(1 - \frac{\sigma_e}{4\,\sigma_E(\bar{\varepsilon})}\right) R_{eH} \qquad \text{for} \quad \frac{\sigma_E(\bar{\varepsilon})}{\sigma_e} > 0.5$$

$$\sigma_{CR1} = \Phi_e(\bar{\varepsilon})\, \sigma_{C1} \frac{A_{Stif} + b_e(\bar{\varepsilon})\, t_p}{A_{Stif} + b\, t_p} \qquad \text{for} \quad \frac{\sigma_E(\bar{\varepsilon})}{\sigma_e} > 0.5$$

where $\sigma_{C1} = R_{eH} \left(1 - \frac{\sigma_e}{4\,\sigma_E(\bar{\varepsilon})}\right)$ and $\sigma_e = R_{eH}\,\varepsilon$

$$\sigma_{CR1} = \Phi_e(\bar{\varepsilon})\, \sigma_{C1} \frac{A_{Stif} + b_e(\bar{\varepsilon})\, t_p}{A_{Stif} + b\, t_p} \qquad \text{for} \quad \sigma_E(\bar{\varepsilon}) > \frac{R_{eH}\,\varepsilon}{2}$$

where $\sigma_{C1} = R_{eH} \left(1 - \frac{R_{eH}\,\varepsilon}{4\,\sigma_E(\bar{\varepsilon})}\right)$ for $\sigma_E(\bar{\varepsilon}) > \frac{R_{eH}\,\varepsilon}{2}$

Therefore, the formula for σ_{C1} for $\sigma_{E1} > \frac{R_{eH}}{2}\varepsilon$ is modified to $\sigma_{C1} = R_{eH} \left(1 - \frac{R_{eH}\,\varepsilon}{4\,\sigma_E(\bar{\varepsilon})}\right)$ from $\sigma_{C1} = R_{eH} \left(1 - \frac{\Phi R_{eH}\,\varepsilon}{4\,\sigma_E(\bar{\varepsilon})}\right)$

The formula for σ_{C1} for $\sigma_{E1} \le \frac{R_{eH}}{2}\varepsilon$ is obtained as follows in the same manner.

$$\sigma_{CR1} = \phi_e(\bar{\varepsilon})\ \Phi_e(\bar{\varepsilon}) \frac{A_S + \Phi_w(\bar{\varepsilon})\, b\, t_p}{A_S + b\, t_p}\ \sigma_Y \qquad \text{for} \quad \phi_e(\bar{\varepsilon}) \le 0.5$$

$$\sigma_{CR1} = \frac{\sigma_E(\bar{\varepsilon})}{\sigma_e}\ \Phi_e(\bar{\varepsilon}) \frac{A_S + b_e(\bar{\varepsilon})\, t_p}{A_S + b\, t_p}\ R_{eH} \qquad \text{for} \quad \frac{\sigma_E(\bar{\varepsilon})}{\sigma_e} \le 0.5$$

$$\sigma_{CR1} = \frac{\sigma_E(\bar{\varepsilon})}{R_{eH}\,\varepsilon}\ \Phi_e(\bar{\varepsilon}) \frac{A_S + b_e(\bar{\varepsilon})\, t_p}{A_S + b\, t_p}\ R_{eH} \qquad \text{for} \quad \sigma_E(\bar{\varepsilon}) \le \frac{R_{eH}\,\varepsilon}{2}$$

$$\sigma_{CR1} = \frac{\sigma_E(\bar{\varepsilon})}{\varepsilon}\ \Phi_e(\bar{\varepsilon}) \frac{A_S + b_e(\bar{\varepsilon})\, t_p}{A_S + b\, t_p} \qquad \text{for} \quad \sigma_E(\bar{\varepsilon}) \le \frac{R_{eH}\,\varepsilon}{2}$$

$$\sigma_{CR1} = \Phi_e(\bar{\varepsilon})\, \sigma_{C1} \frac{A_S + b_e(\bar{\varepsilon})\, t_p}{A_S + b\, t_p} \qquad \text{for} \quad \sigma_E(\bar{\varepsilon}) \le \frac{R_{eH}\,\varepsilon}{2}$$

where $\sigma_{C1} = \frac{\sigma_E(\bar{\varepsilon})}{\varepsilon}$ for $\sigma_E(\bar{\varepsilon}) \le \frac{R_{eH}\,\varepsilon}{2}$

Therefore, the modification of formula for σ_{C1} for $\sigma_{E1} \le \frac{R_{eH}}{2}\varepsilon$ is not necessary.

The proposed modification of the formula for the load-end shortening curve of torsional buckling and web local buckling of ordinary stiffeners made of flat bars can be obtained by the same manner mentioned above.

2.3 Determination of the load-end shortening curve σ_{CR1}-ε – plate buckling

The ultimate strength for plate panel element is approximated by the following formula.

$$\sigma_{cr} = \left[\frac{b}{a} \left(\frac{2.25}{\beta_0} - \frac{1.25}{\beta_0^2} \right) + 0.1 \left(1 - \frac{b}{a} \right) \left(1 + \frac{1}{\beta_0^2} \right)^2 \right] \sigma_Y$$

where $\beta_0 = \frac{b}{t}\sqrt{\frac{\sigma_Y}{E}}$

As for transversely_stiffened panels, the above equation can be generalised to any edge stress σ_e according to:

$$\sigma_{\max}(\bar{\varepsilon}) = \Phi_w(\bar{\varepsilon})\,\sigma_e = \Phi_e(\bar{\varepsilon})\,\Phi_w(\bar{\varepsilon})\,\sigma_Y$$

where $\Phi_w(\bar{\varepsilon}) = \frac{b}{a}\left(\frac{2.25}{\beta_e(\bar{\varepsilon})} - \frac{1.25}{\beta_e^2(\bar{\varepsilon})} \right) + 0.1\left(1 - \frac{b}{a} \right)\left(1 + \frac{1}{\beta_e^2(\bar{\varepsilon})} \right)^2$

$$\beta_e(\bar{\varepsilon}) = \beta_0\sqrt{\bar{\varepsilon}}$$

$$\sigma_e = \Phi_e(\varepsilon)\sigma_y$$

In CSR for Bulk Carriers, $\sigma_{max} = \sigma_{CR5}$ and $\sigma_y = R_{eH}$,, a = ℓ and b = s, so the formula is as follows:

$$\sigma_{CR5}(\bar{\varepsilon}) = \Phi_e(\bar{\varepsilon}) \left[\frac{s}{\ell}\left(\frac{2.25}{\beta_e(\bar{\varepsilon})} - \frac{1.25}{\beta_e^2(\bar{\varepsilon})} \right) + 0.1\left(1 - \frac{s}{\ell} \right)\left(1 + \frac{1}{\beta_e^2(\bar{\varepsilon})} \right)^2 \right] R_{eH}$$

In addition, ultimate strength of transversely stiffened panels is controlled by the yielding stress of the material.

Therefore, σ_{CR5} is modified to $\sigma_{CR5} = \min\begin{cases} \{R_{eH}\,\Phi \\ \{R_{eH}\,\underline{\Phi}\left[\frac{s}{l}\left(\frac{2.25}{\beta_E} - \frac{1.25}{\beta_E{}^2} \right) + 0.1\left(1 - \frac{s}{l} \right)\left(1 + \frac{1}{\beta_E{}^2} \right)^2 \right] \end{cases}$

from $\sigma_{CR5} = \min\begin{cases} \{R_{eH}\,\Phi \\ \{R_{eH}\left[\frac{s}{l}\left(\frac{2.25}{\beta_E} - \frac{1.25}{\beta_E{}^2} \right) + 0.1\left(1 - \frac{s}{l} \right)\left(1 + \frac{1}{\beta_E{}^2} \right)^2 \right] \end{cases}$

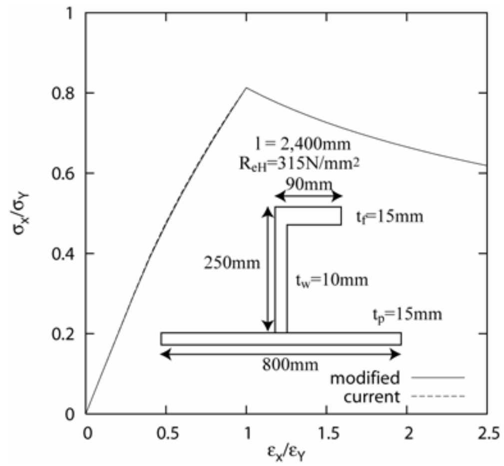
3. Impact on Scantling

3.1 The effect due to the modification of formula

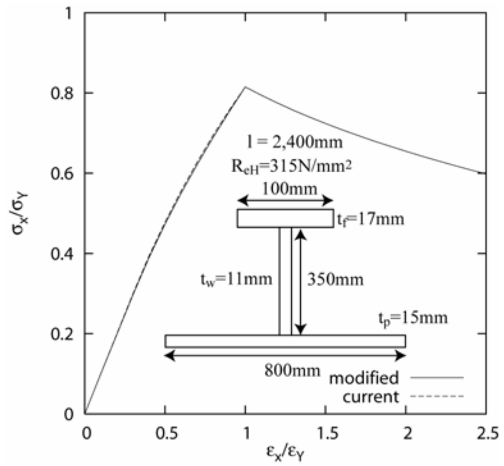
At first, the investigation was carried out how this modification of the formula affects the load-end shortening curve.
The load-shortening curve was calculated for the following stiffened panel and plate.
The material of all plates and stiffeners is HT32.

Type of stiffener or plate	Angle	T-Bar	Flat Bar	Plate
Size of stiffener	250x90x10.0/15.0	350x11.0/100x17.0	300x17.0	-
Size of plate	2400x800x15.0	2400x800x15.0	2400x800x25.0	800x8000x15.0

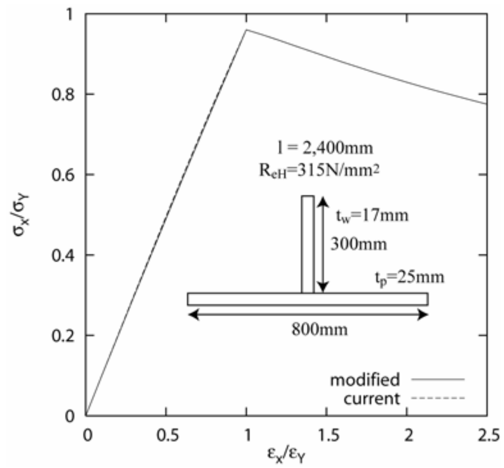
The Fig.1 shows the results of load-shortening curve. In Fig.1, the solid line is the modified one and the broken line is the current one, and vertical line means the relative stress and horizontal line means the relative strain.



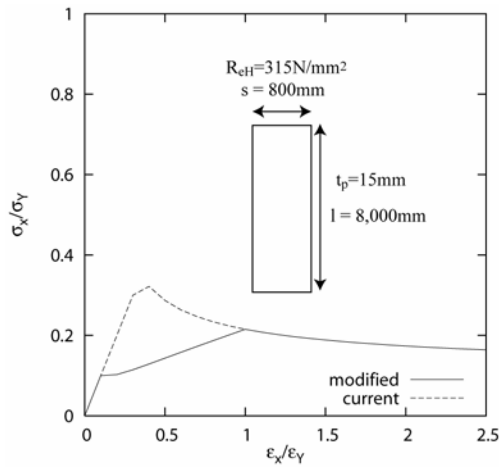
(a) Angle



(b) T-Bar



(c) Flat Bar



(d) Plate

Fig.1 The results of load-shortening curve

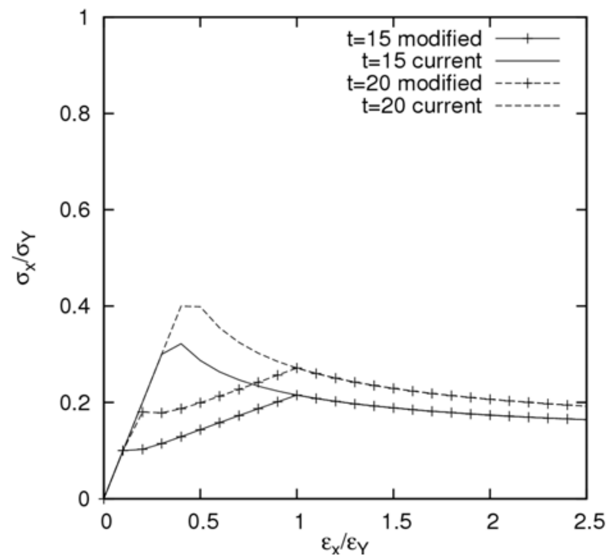
As shown in Fig. 1 (a), (b) and (c), the load-shortening curve for the longitudinal stiffened panel is not affected by this modification.

However, as shown in Fig. 1 (d), the load-shortening curve for the buckling of plate (transversely stiffened panel) is affected by this modification, especially critical stress is decreased.

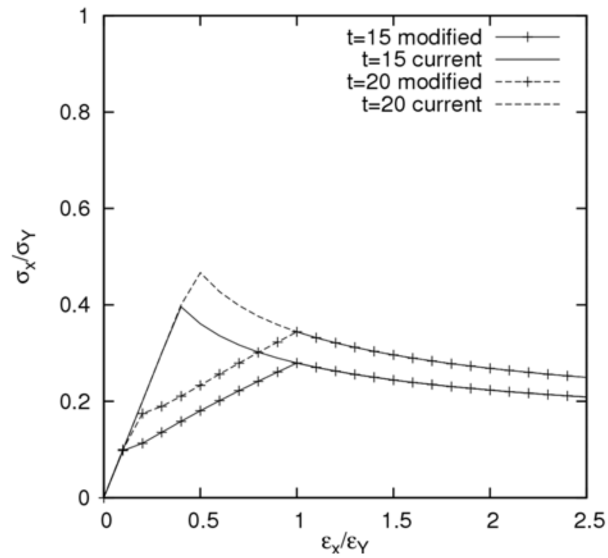
In order to investigate a large decrease in critical stress for the plate due to the modification of the formulae, additional calculation of the load-shortening curve of the plate with different aspect ratio and thickness as given in the table below is carried out.

Aspect ratio = 3	Aspect ratio = 5	Aspect ratio = 10
2400 * 800*15.0, HT32	4000 * 800*15.0, HT32	8000 * 800*15.0, HT32
2400 * 800*20.0, HT32	4000 * 800*20.0, HT32	8000 * 800*20.0, HT32

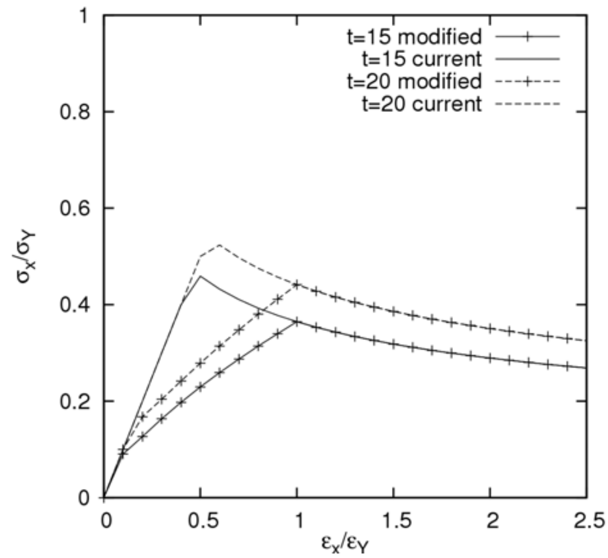
The comparisons on load-shortening curves of plates with 3 different aspect ratio subjected to transverse thrust are shown in Fig.2.



(a) Aspect ratio = 10 (8000*800)



(b) Aspect ratio = 5 (4000*800)



(c) Aspect ratio = 3 (2400*800)

Fig.2 The comparison results on load-shortening curves of plates with 3 different aspect ratio

From Fig. 2, it is found that the load-shortening curve for buckling of plate decrease due to the modification of the formulae.
From these results, it is obvious that this modification does not give the impact for Double side skin BC with longitudinal framing system.

3.2 Scantling impact due to this modification

According to the results specified in 3.1, it was found that this modification affects the scantling of ships with transversely framing system. Then the scantling impact calculation was carried out for the following three kinds of single side skin BCs, i.e., Handy Max, Panamax and Cape size. In addition, the scantling impact calculation was carried out for one double side skin BC for reference.

The ultimate bending moment capacities obtained by the modified formula were compared with those of the current one as given in the table below.

The scantling impact due to this modification was calculated based on the following assumption.

(1) The ultimate bending moment capacity of each ship calculated according to the current formula is equal to the required value.
(2) In order to satisfy with the required ultimate bending moment capacity, only the thickness of upper deck plating is increased. Because as the deck plating is located apart from the neutral axis of transverse section, increasing the thickness of deck plating is very effective to improve the ultimate hull girder bending capacity.
(3) The scantling calculation is calculated based on the increase of the transverse section area within 0.4 L amidships.

The scantling increase due to this modification was also given in the table.

	Ratio (=Modification/ current)	Difference of ultimate bending moment capacities	Scantling increase
SSS Handy max	96.1 %	-3.9%	0.82 %
SSS Panamax	97.6%	-2.4%	0.68%
SSS Cape size	98.4%	-1.6%	0.58%
DSS Cape size	100.0%	0.0%	0.0%

***** End *****