KC#634

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):

$$\sigma_{CR1} = \frac{\Phi_s \sigma_{C1s} A_{Stif} + \Phi_p \sigma_{C1p} \cdot 10 b_E t_p}{A_{Stif} + 10 s t_p}$$

where:

Φ_s : Edge function defined in [2.2.3], for ordinary stiffener

Φ_p : Edge function defined in [2.2.3], for attached plate

R_{eHs} : Minimum yield stress, in N/mm2, of the material of the stiffener

R_{eHp} : Minimum yield stress, in N/mm2, of the material of attached plate

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

σ_{C1s} : Critical stress for the stiffener with its material of R_{eHs}, in N/mm^2, equal to:

$$\sigma_{C1s} = \frac{\sigma_{E1}}{\varepsilon_s} \qquad \text{for } \sigma_{E1} \le \frac{R_{eHs}}{2}\varepsilon_s$$

$$\sigma_{C1s} = R_{eHs}\left(1 - \frac{R_{eHs}\,\varepsilon_s}{4\sigma_{E1}}\right) \qquad \text{for } \sigma_{E1} > \frac{R_{eHs}}{2}\varepsilon_s$$

ε_s : Relative strain of the material of the stiffener, equal to:

$$\varepsilon_s = \frac{\varepsilon_E}{\varepsilon_{Ys}}$$

ε_{Ys} : Strain at yield stress of the material of the stiffener, equal to:

$$\varepsilon_{Ys} = \frac{R_{eHs}}{E}$$

ε_E : Element strain

σ_{C1p} : Critical stress for the stiffener with the material of R_{eHp}, in N/mm^2, equal to:

$$\sigma_{C1p} = \frac{\sigma_{E1}}{\varepsilon_p} \quad \text{for } \sigma_{E1} \le \frac{R_{eHp}}{2}\varepsilon_p$$

$$\sigma_{C1p} = R_{eHp}\left(1 - \frac{R_{eHp}\varepsilon_p}{4\sigma_{E1}}\right) \quad \text{for } \sigma_{E1} > \frac{R_{eHp}}{2}\varepsilon_p$$

ε_p : Relative strain of the material of attached plate, equal to:

$$\varepsilon_p = \frac{\varepsilon_E}{\varepsilon_{Yp}}$$

ε_{Yp} : Strain at yield stress of the material of attached plate, equal to:

$$\varepsilon_{Yp} = \frac{R_{eHp}}{E}$$

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:

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

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

$$\beta_E = 10^3 \frac{s}{t_p}\sqrt{\varepsilon_E}$$

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).

$$\sigma_{CR2} = \frac{\Phi_s A_{Stif}\sigma_{C2} + \Phi_p \cdot 10 s t_p \sigma_{CP}}{A_{Stif} + 10 s t_p}$$

where:

Φ_s : Edge function defined in [2.2.4]

Φ_p : Edge function defined in [2.2.4]

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

R_{eHs} : Minimum yield stress, in N/mm2, defined in [2.2.4]

R_{eHp} : Minimum yield stress, in N/mm2, defined in [2.2.4]

ε_s : Relative strain for the material of ordinary stiffener, defined in [2.2.4]

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

$$\sigma_{C2} = \frac{\sigma_{E2}}{\varepsilon_s} \qquad \text{for } \sigma_{E2} \le \frac{R_{eHs}}{2}\varepsilon_s$$

$$\sigma_{C2} = R_{eHs}\left(1 - \frac{R_{eHs}\,\varepsilon_s}{4\sigma_{E2}}\right) \qquad \text{for } \sigma_{E2} > \frac{R_{eHs}}{2}\varepsilon_s$$

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

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

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

$$\sigma_{CP} = R_{eHp} \qquad \text{for } \beta_E \le 1.25$$

β_E : Coefficient defined in [2.2.4]

2.2.6 Web local buckling of ordinary stiffeners made of flanged profiles

The equation describing the load-end shortening curve σ_{CR3}-ε for the web local buckling of flanged ordinary stiffeners composing the hull girder transverse section is to be obtained from the following formula:

$$\sigma_{CR3} = \frac{\Phi_p R_{eHp} \cdot 10^3 b_E t_P + \Phi_s R_{eHs}(h_{we} t_w + b_f t_f)}{10^3 s t_p + h_w t_w + b_f t_f}$$

where:

Φ_s : Edge function defined in [2.2.4]

Φ_p : Edge function defined in [2.2.4]

R_{eHs} : Minimum yield stress, in N/mm2, defined in [2.2.4]

R_{eHp} : Minimum yield stress, in N/mm2, defined in [2.2.4]

b_E : Effective width, in m, of the attached shell plating, defined in [2.2.4]

h_{we} : Effective height, in mm, of the web, equal to:

$$h_{we} = \left(\frac{2.25}{\beta_w} - \frac{1.25}{\beta_w^2}\right) h_w \qquad \text{for } \beta_w > 1.25$$

$$h_{we} = h_w \qquad \text{for } \beta_w \le 1.25$$

$$\beta_w = \frac{h_w}{t_w}\sqrt{\varepsilon_E}$$

ε_E : Element strain

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):

$$\sigma_{CR4} = \frac{\Phi_p \cdot 10 s t_P \sigma_{CP} + \Phi_s A_{Stif} \sigma_{C4}}{A_{Stif} + 10 s t_P}$$

where:

Φ_s : Edge function defined in [2.2.4]

Φ_p : Edge function defined in [2.2.4]

R_{eHs} : Minimum yield stress, in N/mm2, defined in [2.2.4]

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:

$$\sigma_{C4} = \frac{\sigma_{E4}}{\varepsilon_s} \qquad \text{for } \sigma_{E4} \le \frac{R_{eHs}}{2}\varepsilon_s$$

$$\sigma_{C4} = R_{eHs}\left(1 - \frac{R_{eHs}\,\varepsilon_s}{4\sigma_{E4}}\right) \qquad \text{for } \sigma_{E4} > \frac{R_{eHs}}{2}\varepsilon_s$$

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

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

ε_s : Relative strain for the material of ordinary stiffener, defined in [2.2.4]

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:

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

where:

Φ_p : Edge function defined in [2.2.4].

R_{eHs} : Minimum yield stress, in N/mm2, defined in [2.2.4]

β_E : Coefficient defined in [2.2.4].