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Voorbeeld
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I_f is the second moment of area of the flange about its centroïd;

I_s is the second moment of area of the stiffener cross-section about the axis passing through the centroid parallel to the cylinder axis;

I_w is the second moment of area of web about its centroïd;

L is the unsupported length of the shell;

L_{cyl} is the cylinder length between tangent lines;

L_{con} is the axial length of a cone, see Figure 8.5-2;

L_e is the effective length of shell acting with a light stiffener, see equation (8.5.3-34);

L_{eH} is the effective length of shell acting with a heavy stiffener given in 8.5.3.7;

L_H is the distance between heavy stiffeners, see Table 8.5-1;

L'_H , L''_H ,… are individual lengths between heavy stiffeners, see Figure 8.5-7;

L_s is mean length of the two bays of shell adjacent to a light stiffener, see Table 8.5-1;

L_{sH} is mean length of the two bays of shell adjacent to a heavy stiffener, see Table 8.5-1;

L'_s , L''_s ,… are individual lengths between light stiffeners, see Figures 8.5-6 and 8.5-8;

N is a parameter in the interstiffener collapse calculation, see equation (8.5.3-21) and Table 8.5-2;

n is the number of circumferential waves for a stiffened cylinder;

n_{cyl} is the number of circumferential waves for an unstiffened part of a cylinder, see 8.5.2.2;

P is the required external design pressure

P_C is the design pressure in a heating/cooling channel, as used in 8.5.3.5

P_g is the theoretical elastic instability pressure of a stiffener on a cylinder, see equation (8.5.3-24) or on a cone, see equation (8.6.4-1);

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P_{H}	is the theoretical elastic instability pressure for a heavy stiffener, see equation (8.5.3-51);
P_{m}	is the theoretical elastic instability pressure for collapse of a perfect cylindrical, conical or spherical shell, see equations (8.5.2-5), (8.6.3-2) and (8.7.1-2);
P_{r}	is the calculated lower bound collapse pressure obtained from Figure 8.5-5;
P_{y}	is the pressure at which mean circumferential stress in a cylindrical or conical shell midway between stiffeners, or in a spherical shell, reaches yield point, see equations (8.5.2-4), (8.6.3-1) and (8.7.1-1);
P_{ys}	is the pressure causing circumferential yield in a stiffener on a cylinder, see equation (8.5.3-47), or on a cone, see equation (8.6.4-6);
R	is the mean radius of a cylindrical or spherical shell, or mean crown radius of a torispherical end;
R_{f}	is the radius to the part of the stiffener furthest from the shell (see Figures 8.5-14 to 8.5-17);
R_{s}	is the radius of the centroid of the stiffener cross-section;
$R_{\mathrm{p}0,2/t,\mathrm{s}}$	is the minimum 0,2 % proof strength at temperature *t* for a stiffener;
r_{i}	is the radius of the point on the stiffener web closest to the shell about which rotation is assumed in stiffener tripping (see Figures 8.5-14 to 8.5-17);
S	is the safety factor applied in this clause, see equation (8.4.4-1);
S_{f}	factor depending on method of fabrication of stiffener - equations (8.5.3-32) and (8.5.3-33);
u	parameter used in calculation of L_{e}, see equations (8.5.3-36)
w_{i}	is the total width of stiffener i in contact with the shell, see equation (8.5.3-48) and (see Figures 8.5-14 to 8.5-17);
w_{f}	is the projecting width of flange of stiffener (see Figures 8.5-14 to 8.5-17);
w'_i, w''_i	are part widths of stiffener *i* in contact with the shell (see Figure 8.5-8);
X_{e}	is a parameter in the calculation for overall collapse, see equation (8.5.3-27);
X_{eH}	is a parameter in the calculation for overall collapse, see equation (8.5.3-53);
Y_1, Y_2, Y_3	are coefficients used in calculation of L_{e}, see 8.5.3.6.3;

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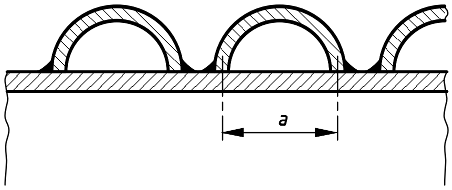

Figure 8.5-11 – Heating/cooling channels (hemi-coil)

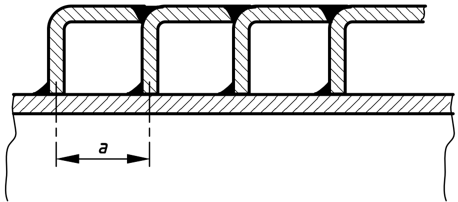

Figure 8.5-12 – Heating/cooling channels (overlapping construction)

8.5.3.6 Design of light stiffeners

8.5.3.6.1 General

To resist overall collapse, the design of light stiffeners shall be in accordance with the procedures in subclauses 8.5.3.6.2, 8.5.3.6.3 and 8.5.3.6.4.

8.5.3.6.2 Design against elastic instability

Calculate P_g for n = 2 to n = 6 using:

$$P_{\mathrm{g}} = \frac{E \cdot e_{\mathrm{a}} \cdot \beta}{R} + \frac{\left(n^2 - 1\right)}{R^3 \cdot L_{\mathrm{s}}} E \cdot I_{\mathrm{e}} \qquad (8.5.3\text{-}24)$$

where β is either obtained from Figure 8.5-13, or calculated from:

$$\beta = \frac{1}{\left[n^2 - 1 + \frac{1}{2}\left(\frac{\pi R}{L_{\mathrm{H}}}\right)^2\right]\left[n^2\left(\frac{L_{\mathrm{H}}}{\pi R}\right)^2 + 1\right]^2} \qquad (8.5.3\text{-}25)$$

NOTE Figure 8.5-13 is plotted from equation (8.5.3-25).

L_{s} and L_{H} are obtained from Table 8.5-1.

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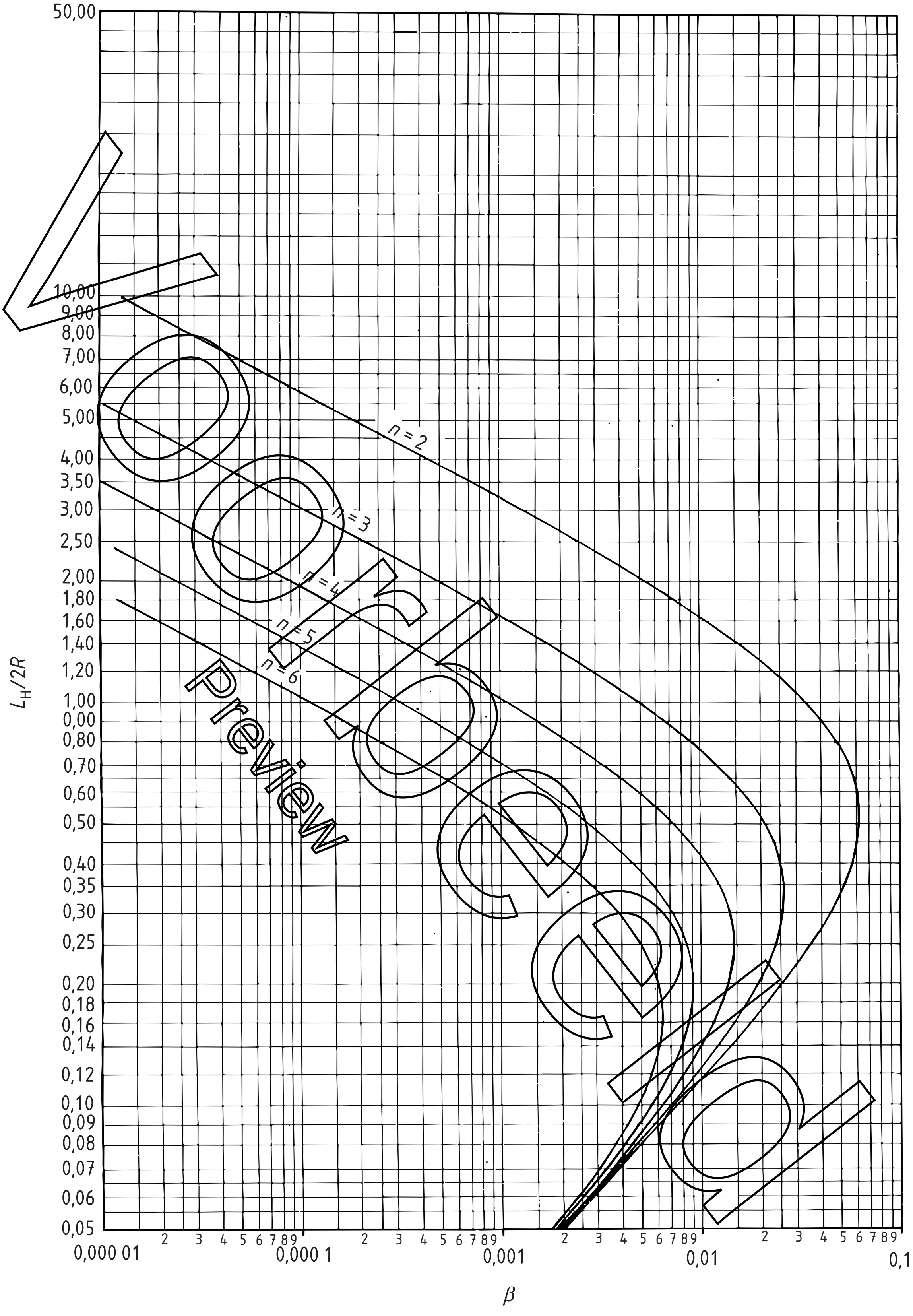

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Figure 8.5-13 — Values of β

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$$I_\mathrm{e} = \frac{e_\mathrm{a}^3 \cdot L_\mathrm{e}}{3} + I_\mathrm{s} + A_\mathrm{s}\left[\frac{e_\mathrm{a}}{2} + \lambda\left(R - R_\mathrm{s}\right)\right]^2 - A_\mathrm{e} \cdot X_\mathrm{e}^2 \qquad (8.5.3\text{-}26)$$

in which

$$X_\mathrm{e} = \frac{\left\{\left(\dfrac{e_\mathrm{a}^2}{2}\right)L_\mathrm{e} + A_\mathrm{s}\left[\dfrac{e_\mathrm{a}}{2} + \lambda\left(R - R_\mathrm{s}\right)\right]\right\}}{A_\mathrm{e}} \qquad (8.5.3\text{-}27)$$

where for internal stiffeners:

$$\lambda = +1 \qquad (8.5.3\text{-}28)$$

and for external stiffeners:

$$\lambda = -1 \qquad (8.5.3\text{-}29)$$

$$A_\mathrm{e} = A_\mathrm{s} + e_\mathrm{a} \cdot L_\mathrm{e} \qquad (8.5.3\text{-}30)$$

L_e is determined from 8.5.3.6.3.

For n = 2, 3, 4, 5 and 6:

$$P \le \frac{P_\mathrm{g}}{S_\mathrm{f} \cdot \mathrm{S}} \qquad (8.5.3\text{-}31)$$

where for fabricated or hot-formed stiffeners (i.e. with low residual stresses):

$$S_\mathrm{f} = 1{,}20 \qquad (8.5.3\text{-}32)$$

and for cold bent stiffeners (i.e. with high residual stresses):

$$S_\mathrm{f} = 1{,}33 \qquad (8.5.3\text{-}33)$$

If equation (8.5.3-31) is not met, additional light stiffening or heavy stiffening shall be provided, or the shell thickness increased.

8.5.3.6.3 Determination of L_e

The following formula shall be used to obtain L_e when 0,001095 ≤ e_a/R ≤ 0,0346. When e_a/R > 0,0346 then L_e is obtained using the formula with the actual value of L_s/R, but with e_a/R = 0,0346.

$$L_e / R = \frac{Y_1\sqrt{e_a / R}}{\sqrt{Y_3 \cdot x + \sqrt{1 + Y_2 \cdot x^2}}} \qquad (8.5.3\text{-}34)$$

where

$$x = n^2\left(\frac{e_\mathrm{a}}{R}\right) \qquad (8.5.3\text{-}35)$$

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$$u = \frac{\dfrac{L_s}{R}}{\sqrt{\dfrac{e_a}{R}}} \qquad (8.5.3\text{-}36)$$

The values of Y_1, Y_2 and Y_3 are given in table 8.5-3

Table 8.5-3. Parameters for calculation of Le

For *u* =	Y_1 =	Y_2 =	Y_3 =
$u \le 1$	$u/(1/1{,}098+0{,}03u^3)$	0	$0{,}6(1-0{,}27u)u^2$
$1<u<2{,}2$		$u-1$	
$2{,}2 \le u \le 2{,}9$		1,2	
$2{,}9<u<4{,}1$	$1{,}2+1{,}642/u$		$0{,}75+1{,}0/u$
$4{,}1 \le u<5$	$1{,}556+0{,}183/u$		
$5 \le u$			$0{,}65+1{,}5/u$

8.5.3.6.4 Maximum stresses in the stiffeners

σ_s shall be calculated as follows:

$$\sigma_s = S \cdot S_f \left(\frac{P \cdot \sigma_{es}}{P_{ys}} \right) + \frac{E \cdot d \cdot 0{,}005 \left(n^2 - 1\right) P \cdot S \cdot S_f}{R \left(P_g - P \cdot S \cdot S_f\right)} \qquad (8.5.3\text{-}46)$$

where

$$P_{ys} = \frac{\sigma_{es} \cdot e_a \cdot R_f}{R^2 \left(1 - \dfrac{\nu}{2}\right)} \left[1 + \frac{A_m}{w_i \cdot e_a + \dfrac{2\,N \cdot e_a}{\delta}} \right] \qquad (8.5.3\text{-}47)$$

where

A_m is given by equation (8.5.3-17);

δ is given by equation (8.5.3-19);

N is given by equation (8.5.3-21) or Table 8.5-2;

and for each stiffener:

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$$w_i = w'_i + w''_i \qquad (8.5.3\text{-}48)$$

and

$$\bar{d} = \max\left\{\left[\lambda\left(R - R_{\mathrm{f}}\right) - X_{\mathrm{e}} + \frac{e_{\mathrm{a}}}{2}\right]; X_{\mathrm{e}}\right\} \qquad (8.5.3\text{-}49)$$

S_{f} is given by equation (8.5.3-32) or (8.5.3-33);

P_{g} is given by equation (8.5.3-24).

Throughout the calculation:

- lengths L, L_{s} shall be in accordance with Table 8.5-1;
- L_{e} is obtained from 8.5.3.6.3 for each value of n.

For n = 2, 3, 4, 5 and 6:

$$0 \leq \sigma_{\mathrm{s}} \leq \sigma_{\mathrm{es}} \qquad (8.5.3\text{-}50)$$

Additional stiffening, heavier stiffening or an increased shell thickness shall be provided if equation (8.5.3-50) is not satisfied.

NOTE The simplification $A_{\mathrm{m}} = 0$ is always permissible but will result in a larger stiffener section.

8.5.3.7 Design of heavy stiffeners

8.5.3.7.1 Assessment of collapse pressure

For each heavy stiffener, calculate:

$$P_H = \frac{3}{R^3 \cdot L_{sH}} E \cdot I_{eH} \qquad (8.5.3\text{-}51)$$

where L_{sH} is in accordance with Table 8.5-1;

$$I_{\mathrm{eH}} = \frac{e_{\mathrm{a}}^3 \cdot L_{\mathrm{eH}}}{3} + I_{\mathrm{s}} + A_{\mathrm{s}}\left[\frac{e_{\mathrm{a}}}{2} + \lambda\left(R - R_{\mathrm{s}}\right)\right]^2 - A_{\mathrm{e}} \cdot X_{\mathrm{eH}}^2 \qquad (8.5.3\text{-}52)$$

where

L_{eH} is determined from equation (8.5.3-34) with $L_{\mathrm{s}} = L_{\mathrm{sH}}$ in equation (8.5.3-36);

$$X_{\mathrm{eH}} = \frac{\dfrac{e_{\mathrm{a}}^2 \cdot L_{\mathrm{eH}}}{2} + A_{\mathrm{s}}\left[\dfrac{e_{\mathrm{a}}}{2} + \lambda\left(R - R_{\mathrm{s}}\right)\right]}{A_{\mathrm{e}}} \qquad (8.5.3\text{-}53)$$

λ is from equation (8.5.3-28) or (8.5.3-29);

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$$A_{\mathrm{e}} = A_{\mathrm{s}} + e_{\mathrm{a}} \cdot L_{\mathrm{eH}} \qquad (8.5.3\text{-}54)$$

For each heavy stiffener, it is required that:

$$P \leq \frac{P_{\mathrm{H}}}{S_{\mathrm{f}} \cdot S} \qquad (8.5.3\text{-}55)$$

where S_{f} is given by equation (8.5.3-32) or (8.5.3-33).

8.5.3.7.2 Assessment of maximum stress

Calculate σ_H as follows:

$$\sigma_{\mathrm{H}} = S \cdot S_{\mathrm{f}} \frac{P \cdot \sigma_{\mathrm{s}}}{P_{\mathrm{ys}}} + \frac{E \cdot \bar{d} \cdot 0{,}015 P \cdot S \cdot S_{\mathrm{f}}}{R\left(P_{\mathrm{H}} - P \cdot S \cdot S_{\mathrm{f}}\right)} \qquad (8.5.3\text{-}56)$$

where P_{ys} is given by equation (8.5.3-47)

NOTE This is the same formula as that for σ_{s} in light stiffener design but with $n = 2$.

σ_H shall meet the requirement:

$$0 < \sigma_{\mathrm{H}} < \sigma_{\mathrm{es}} \qquad (8.5.3\text{-}57)$$

Additional stiffening, heavier stiffening or an increased shell thickness shall be provided if equation (8.5.3-57) is not satisfied.

8.5.3.8 Stiffener tripping

8.5.3.8.1 For a stiffener other than flat bar

a) σ_i shall meet the requirement:

$$\sigma_i = E \cdot C \left(\frac{P_{\mathrm{ys}}}{P} \right) > \sigma_{\mathrm{es}} \qquad (8.5.3\text{-}60)$$

For stiffeners shown in Figures 8.5-14, 8.5-15 and 8.5-17, C shall be calculated as follows:

$$C = \frac{d \cdot e_{\mathrm{w}}^3 + 8\, e_{\mathrm{f}} \cdot w_{\mathrm{f}}^3}{r_i \left[6\, d^2 \cdot e_{\mathrm{w}} + 12\, e_{\mathrm{f}} \cdot w_{\mathrm{f}} \left(2\, d + e_{\mathrm{f}} \right) \right]} \qquad (8.5.3\text{-}61)$$

and for the stiffener shown in Figure 8.5-16, C is:

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8.6 Conical shell

8.6.1 General

This subclause provides requirements for the thickness of a conical shell with $\alpha \leq 75°$.

Tolerances shall be as for cylindrical shells – see 8.5.1

NOTE The procedure is similar to that for cylindrical shells.

8.6.2 Additional notation specific to cones

The following symbols and abbreviations apply in addition to those in 8.3.

d'	is distance to the external extremity of a stiffener, see equation (8.6.4-8);
e	is the minimum thickness over the total cone length;
I'_e	is second moment of area of the combined shell and stiffener, see equation (8.6.4-2);
$I'_{e,I}$	is the combined second moment area of stiffener i and shell at axial distance X_i from the small end of the cone and taking values for e_a separately for each bay, see equation (8.6.4-7);
L'_e, L''_e	are the effective lengths of shell adjacent to a stiffener, see Figure 8.6-1;
N_Y	is the number of bays between light stiffeners in length $L_{H;}$
R_i	is the mean radius of the thinnest section of a cone measured in the plane of stiffener i, see Figure 8.6-6;
R_{max}	is the maximum radius of conical shell for a check on interstiffener collapse, see Figures 8.6-2, 8.6-3 and 8.6-6;
$\overline{R}_{max}$	is the maximum radius of conical shell for a check of overall collapse, see Figures 8.6-4 and 8.6.-5;
R_n	is the mean radius of conical shell, for a check on interstiffener collapse, see Figures 8.6-2, 8.6-3 and 8.6-6;
$\overline{R}_n$	is the mean radius of conical shell for a check of overall collapse, see Figures 8.6-4 and 8.6.-5;
X_w	is the distance from the centroid of the web to the centroid of the combined stiffener and shell, see Figure 8.6-1;
X_f	is the distance from the centroid of the flange to the centroid of the combined stiffener and shell, see Figure 8.6-1;
X'_s, X''_s	are the distances from the centroid of the combined stiffener and shell to the centroid of the effective shell sections adjacent to the stiffener, see Figure 8.6-1;
X_i	is the axial pitch of stiffener *i*, see Figure 8.6-6;
σ_1	is the maximum hoop stress at the junction without reinforcement;
σ_2	s the maximum hoop stress in the cylinder, see equation (8.6.5-1).

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8.6.3 Interstiffener collapse

The following procedure shall be used for the design of cones in accordance with Figure 8.6-2 to guard against interstiffener collapse:

a) Estimate a value for e_a and calculate

$$P_y = \frac{e_a \, \sigma_e \cos \alpha}{R_{max}} \tag{8.6.3-1}$$

NOTE This is the same as equation (8.5.3-15) for P_y, substituting $e_a \cos\alpha$ for e_a, R_{max} for R and taking $\gamma = 0$.

b) Calculate

$$P_m = \frac{E \, e_a \, \varepsilon \cos^3 \alpha}{R_n} \tag{8.6.3-2}$$

ε shall be determined from Figure 8.5-3 using $\frac{L}{2R_n \cos \alpha}$ in place of $\frac{L}{2R}$ and $\frac{2R_n \cos\alpha}{e_a}$ in place of $\frac{2R}{e_a}$.

R_n and R_{max} shall be as defined in Figures 8.6-2 to 8.6-6.

NOTE Equation (8.6.3-2) for P_m is the same as equation (8.5.2-5) substituting $e_a \cos\alpha$ for e_a , $R_n \cos^2\alpha$ for R; $\varepsilon \cos^4\alpha$ for ε; $L \cos\alpha$ for L.

c) Calculate P_m and determine P_r from curve 1 in Figure 8.5-5.

The calculation pressure shall meet the requirement:

$$P \le \frac{Pr}{S} \tag{8.6.3-5}$$

If equation (8.6.3-5) is not met, the thickness shall be increased or the spacing between the stiffeners reduced.

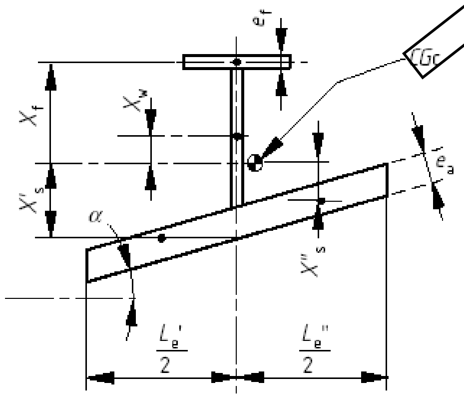

Figure 8.6-1 — Structural members

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