锥形变截面应力计算技术规程

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目录

1.圆锥过渡中的等效轴向应力

依据 ISO／FDIS19902-2020 中的第 13.6.2.1 节中规定，圆锥体内任意截面 s-s 的等效轴向应力可通过下列公式确定。

13.6.2 Design stresses

13.6.2.1 Equivalent axial stress in conical transitions

The equivalent axial stress (meridional stress) at any section s-s within a cone (see Figure 13.6-1) can be determined from Formula (13.6-1):

$$\sigma_{a,eq} = \frac{\sigma_{a,c} + \sigma_{b,c}}{\cos\alpha} \tag{13.6-1}$$

where

$\sigma_{a,eq}$ is the equivalent axial stress at section s-s;

σ_{ac} is the axial stress at section s-s due to global axial forces from factored actions;

$$\sigma_{a,c} = \frac{P_s}{\pi\left(D_s - \frac{t_c}{\cos\alpha}\right)t_c} \tag{13.6-2}$$

$\sigma_{b,c}$ is the bending stress at section s-s due to global bending moments from factored actions;

$$\sigma_{b,c} = \frac{4M_s}{\pi\left(D_s - \frac{t_c}{\cos\alpha}\right)^2 t_c} \tag{13.6-3}$$

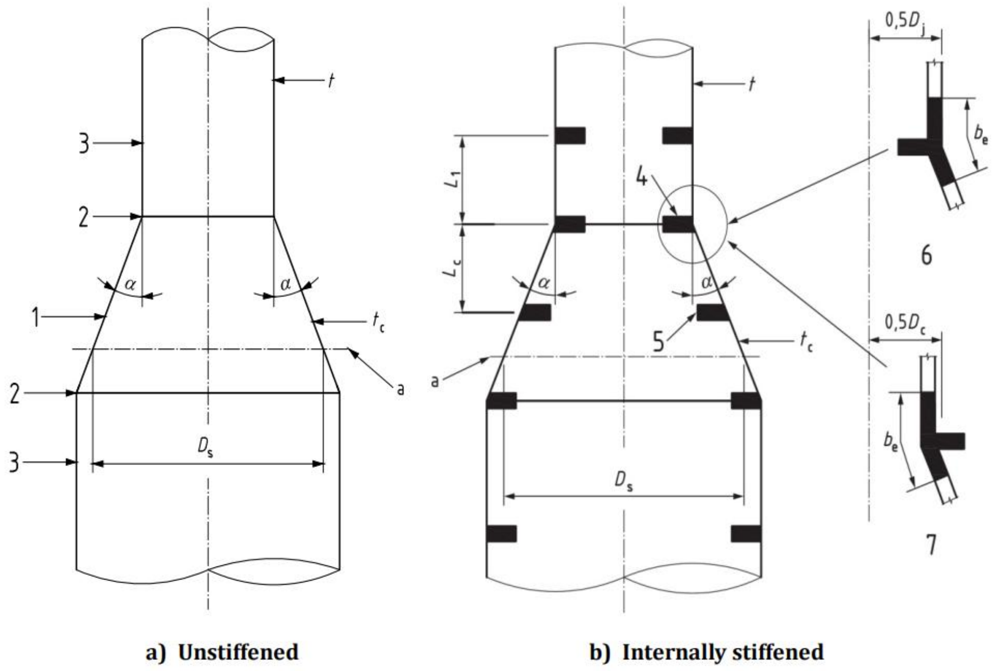
D_s is the outer diameter of the cone at section s-s;

t_c is the thickness of the cone at section s-s;

α is the slope angle of the cone (see Figure 13.6-1);

P_s is the axial force at section s-s due to factored actions;

M_s is the bending moment at section s-s due to factored actions.



Key

1 cone
2 junction between tubular and conical section
3 tubular
4 junction stiffener
5 intermediate stiffener
6 typical internal junction stiffener
7 alternative external junction stiffener

α slope angle of cone
b_e effective shell width (acting with stiffener)
D_c diameter to centroid of composite external ring section
D_j outer diameter at junction
D_s outer cone diameter at section s-s
L_1 distance from junction to first ring stiffener in tubular member
L_c distance from junction to first ring stiffener in cone section
t tubular member thickness at the junction
t_c cone thickness

[a] Section s-s under consideration.

Figure 13.6-1 — Typical unstiffened and stiffened conical transitions

2.圆锥过渡节点处的局部应力

圆柱体与锥体之间的纵向力传递在接合处产生径向和轴分量，其产生：

a）管状体和锥体的局部弯曲应力；

b）管状结构和锥形结构的环向应力。

2.1 弯曲应力

依据 ISO / FDIS19902-2020 中的第 13.6.2.2 节中规定，圆柱体与圆锥连接处的局部弯曲应力应根据下列规定计算：

Bending stresses

In lieu of a detailed analysis, the local bending stress at an unstiffened tubular-cone junction may be estimated from Formula (13.6-4):

$$\sigma_{b,j} = 0{,}85\sqrt{\frac{D_j}{t}}\left(\sigma_{a,t} + \sigma_{b,t}\right)\tan\alpha \tag{13.6-4}$$

where

$\sigma_{b,j}$ is the local bending stress at the junction;

D_j is the outer diameter at the junction (see Figure 13.6-1);

t is the wall thickness of the tubular member at the junction;

$\sigma_{a,t}$ is the axial stress in the tubular section at the junction due to global axial forces from factored actions;

$\sigma_{b,t}$ is the bending stress in the tubular section at the junction due to global bending moments from factored actions;

α is the slope angle of the cone.

2.2 环向应力

依据 ISO / FDIS19902-2020 中的第 13.6.2.2 节中规定，圆柱体与圆锥连接处的局部环向应力应根据下列规定计算：

Hoop stresses

The hoop stresses at an unstiffened tubular-cone junction due to unbalanced radial line forces may be estimated using Formulae (13.6-6) and (13.6-7):

$$\sigma_{h,t} = 0{,}45\sqrt{\frac{D_j}{t}}\left(\sigma_{a,t} + \sigma_{b,t}\right)\tan\alpha \tag{13.6-6}$$

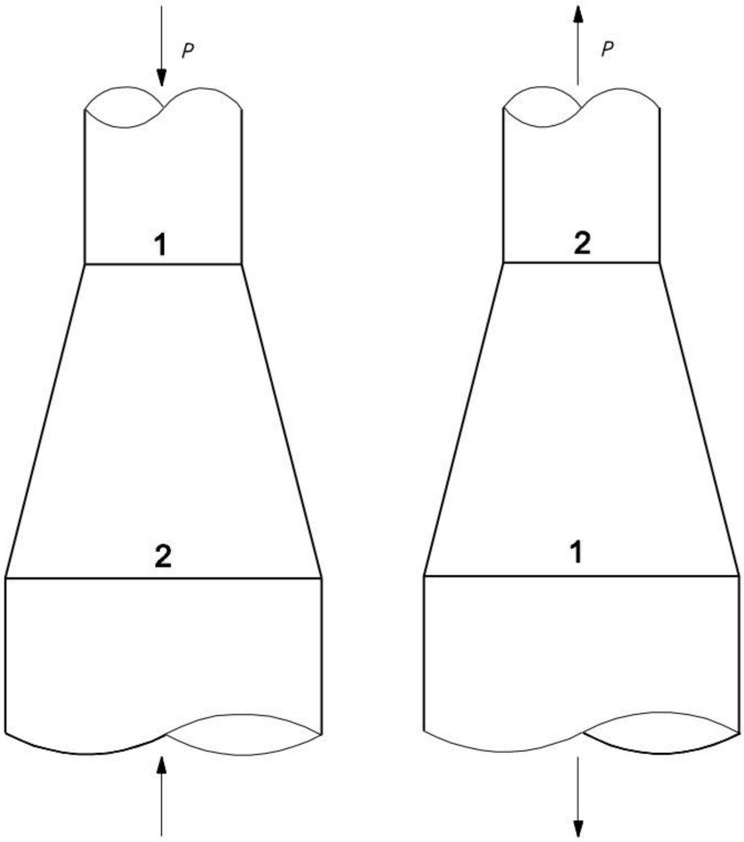
$$\sigma_{h,c} = 0{,}45\sqrt{\frac{D_j}{t_c}}\left(\sigma_{a,t} + \sigma_{b,t}\right)\tan\alpha \tag{13.6-7}$$

where, in addition to previous variables,

$\sigma_{h,t}$ is the hoop stress at the tubular side of the junction;

$\sigma_{h,c}$ is the hoop stress at the cone side of the junction.

At the smaller diameter junction, the hoop stress is tensile (or compressive) when ($\sigma_{a,t}$ + $\sigma_{b,t}$) is tensile (or compressive). Similarly, the hoop stress at the larger diameter junction is tensile (or compressive) when ($\sigma_{a,t}$ + $\sigma_{b,t}$) is compressive (or tensile); see Figure 13.6-2.



Key

1 area of hoop compression

2 area of hoop tension

Figure 13.6-2 — Hoop tension and hoop compression at cone junctions due to axial forces

3.圆锥过渡内的局部屈曲

依据 ISO / FDIS19902-2020 中的第 13.6.3.2 节中规定，锥形过渡段内的局部屈曲可根据下列规定计算：

注意，其中 $\sigma_{a，eq}$可根据本技术规程第 1 节中规定进行计算

13.6.3.2 Local buckling within conical transition

For local buckling under combined axial compression and bending, the Formula (13.6-8) shall be satisfied at all sections within the cone:

$$\sigma_{a,eq} \le \frac{f_{yc}}{\gamma_{R,c}} \tag{13.6-8}$$

where

$\sigma_{a,eq}$ is the equivalent axial stress at any section s-s, see 13.6.2.1;

f_{yc} is the representative local buckling strength of a cone, in stress units;

$\gamma_{R,c}$ is the partial resistance factor for axial compressive strength (see 13.2.3.1).

For cones with slope angle $\alpha \le 30°$, f_{yc} may be determined using Formulae (13.2-8) to (13.2-10), in which f_y is the representative yield strength of the cone section being checked and t and D respectively are replaced by the wall thickness of the cone, tc, and an equivalent diameter, D_e, both at the section under consideration. D_e is given by

$$D_e = \frac{D_s}{\cos\alpha} \tag{13.6-9}$$

where D_s and α are defined in 13.6.2.1. If $\alpha > 30°$, Formula (13.6-9) is not applicable.

The utilization of a cone, U_m, under local buckling shall be calculated from Formula (13.6-10):

$$U_m = \gamma_{R,c} \frac{\sigma_{a,eq}}{f_{yc}} \tag{13.6-10}$$

4.节点屈服（圆锥过渡段，无静水压力）

依据 ISO / FDIS19902-2020 中的第 13.6.3.3 节中规定，锥形过渡段内的局部屈曲可根据下列规定计算：

注意：其中关于等效轴向应力、节点处局部弯曲应力、节点处局部环向应力的计算，根据第 1 节和第 2 节计算。

13.6.3.3 Junction yielding

The requirements for junction yielding only apply to cases where the hoop stresses $\sigma_{h,t}$ and $\sigma_{h,c}$ are tensile. Yielding at a junction shall be checked on both the tubular and the cone side of the junction using Formula (13.6-11) or Formula (13.6-12), as appropriate.

For net axial tension, i.e. when σ_{max} is tensile:

$$\sqrt{\sigma_{max}^2 + \sigma_j^2 - \sigma_j \sigma_{max}} \le \frac{f_y}{\gamma_{R,t}} \tag{13.6-11}$$

For net axial compression, i.e. when σ_{max} is compressive:

$$\sqrt{\sigma_{max}^2 + \sigma_j^2 + \sigma_j |\sigma_{max}|} \le \frac{f_y}{\gamma_{R,t}} \tag{13.6-12}$$

where

σ_{max} is the maximum axial tensile stress at the junction;

$\sigma_{max} = \sigma_{a,t} + \sigma_{b,t}$ for checking yielding on the tubular side of the junction,

$\sigma_{max} = \dfrac{\sigma_{a,c} + \sigma_{b,c}}{\cos\alpha}$ for checking yielding on the cone side of the junction,

(see 13.6.2.1 and 13.6.2.2 for definitions of the stress components),

σ_j is the hoop stress at the junction

$\sigma_j = \sigma_{h,t}$ for checking yielding on the tubular side of the junction;

$\sigma_j = \sigma_{h,c}$ for checking yielding on the cone side of the junction;

f_y is the representative yield strength of the tubular or cone section being checked;

$\gamma_{R,t}$ is the partial resistance factor for axial tensile strength (see 13.2.2).

The local bending stresses, $\sigma_{b,jt}$ and $\sigma_{b,jc}$, at the junction shall be limited to the plastic moment capacities of the tubular member and conical transition wall thicknesses, respectively, in accordance with Formulae (13.6-12a) and (13.6-12b)

$$\sigma_{b,jt} \leq 1.5\frac{f_y}{\gamma_{R,t}}\left(1 - \frac{\sigma_{max}{}^2}{f_y{}^2}\right) \quad \text{for checking on the tubular side of the junction} \qquad (13.6\text{-}12a)$$

$$\sigma_{b,jc} \leq 1.5\frac{f_y}{\gamma_{R,t}}\left(1 - \frac{\sigma_{max}{}^2}{f_y{}^2}\right) \quad \text{for checking on the cone side of the junction} \qquad (13.6\text{-}12b)$$

The utilization of a junction of a conical transition, U_m, for junction yielding shall be calculated from Formula (13.6-13) or Formula (13.6-14), as appropriate:

$$U_m = \gamma_{R,t}\frac{\sqrt{\sigma_{max}{}^2 + (\sigma_j)^2 - \sigma_j \cdot \sigma_{max}}}{f_y} \quad \text{when } \sigma_{max} \text{ is tensile} \qquad (13.6\text{-}13)$$

$$U_m = \gamma_{R,t}\frac{\sqrt{\sigma_{max}{}^2 + (\sigma_j)^2 + \sigma_j \cdot |\sigma_{max}|}}{f_y} \quad \text{when } \sigma_{max} \text{ is compressive} \qquad (13.6\text{-}14)$$

The utilization of a junction of a conical transition, U_m, for local bending plastification shall be calculated from Formula (13.6-14a) or Formula (13.6-14b), as appropriate:

$$U_m = \gamma_{R,t}\frac{\sigma_{b,jt}}{1.5f_y\left(1 - \dfrac{\sigma_{max}{}^2}{f_y{}^2}\right)} \quad \text{for checking on the tubular side of the junction} \qquad (13.6\text{-}14a)$$

$$U_m = \gamma_{R,t}\frac{\sigma_{b,jc}}{1.5f_y\left(1 - \dfrac{\sigma_{max}{}^2}{f_y{}^2}\right)} \quad \text{for checking on the cone side of the junction} \qquad (13.6\text{-}14b)$$

5.节点屈曲（圆锥过渡段，无静水压力）

依据 ISO / FDIS19902-2020 中的第 13.6.3.4 节中规定，锥形过渡段内的节点屈曲可根据下列规定计算：

13.6.3.4 Junction buckling

The requirements for junction buckling only apply to cases where the hoop stress, σ_j, is compressive, and shall be checked on both the tubular and the cone side of the junction using Formula (13.6-15) or Formulae (13.6-19) and (13.6 20), as appropriate.

For net axial tension, i.e. when σ_{max} is tensile, the following requirement shall be satisfied:

$$A^2 + B^{2\eta} + 2\nu A B \le 1{,}0 \qquad (13.6\text{-}15)$$

where, in addition to the definitions given in 13.6.3.3,

$$A = \frac{\gamma_{R,t}\,\sigma_{max}}{f_y} \qquad (13.6\text{-}16)$$

$$B = \frac{\gamma_{R,h}\sigma_j}{f_h} \qquad (13.6\text{-}17)$$

$\gamma_{R,h}$ is the partial resistance factor for hoop buckling strength (see 13.2.6.2);

f_h is the representative hoop buckling strength, in stress units, calculated using Formulae (13.2-25) to (13.2-27), with $f_{he} = 0{,}4\,E\,t/D_j$;

σ_j is the positive absolute value of the hoop compression;

ν is Poisson's ratio, $\nu = 0{,}3$;

η is as defined in Formula (13.4-11);

The utilization of a junction of a conical transition, U_m, for junction buckling when σ_{max} is tensile shall be calculated from Formula (13.6-18):

$$U_m = A^2 + B^{2\eta} + 2\nu AB \qquad (13.6\text{-}18)$$

For net axial compression, i.e. when σ_{max} is compressive, the following requirements shall be satisfied:

$$\sigma_{max} \le \frac{f_{yc}}{\gamma_{R,c}} \qquad (13.6\text{-}19)$$

and

$$\sigma_j \le \frac{f_h}{\gamma_{R,h}} \qquad (13.6\text{-}20)$$

where

f_{yc} is the representative local buckling strength of the section being checked, in stress units (see 13.2.3.3); for cones with slope angle $\alpha \leq 30°$, f_{yc} may be calculated in accordance with 13.6.3.2;

$\gamma_{R,c}$ is the partial resistance factor for axial compressive strength (see 13.2.3.1);

f_h is the representative hoop buckling strength, in stress units, calculated using Formulae (13.2-25) to (13.2-27), with $f_{he} = 0{,}4\ E\ t/D_j$;

σ_j is the positive absolute value of the hoop compression.

The utilization of a junction of a conical transition, U_m, for junction buckling when σ_{max} is compressive shall be the larger value calculated from Formulae (13.6-21) and (13.6-22):

$$U_m = \frac{\sigma_{max}}{f_{yc}/\gamma_{R,c}} \tag{13.6-21}$$

$$U_m = \frac{\sigma_j}{f_h/\gamma_{R,h}} \tag{13.6-22}$$

As in the case of junction yielding (see 13.6.3.3), plastification under local bending shall be checked using Formulae (13.6-14a) or (13.6-14b), as appropriate.

$\gamma_{R,h}$ is the partial resistance factor for hoop buckling strength, $\gamma_{R,h} = 1{,}25$.

$$\eta = 5 - 4\frac{f_h}{f_y} \tag{13.4-11}$$

其中f_h的计算依据 ISO／FDIS19902-2020 中 13.2.6.2 节进行计算。

For tubular members satisfying the out-of-roundness tolerances given in Annex G, f_h shall be determined from:

$$f_h = f_y \quad \text{for } f_{he} > 2{,}44\, f_y \tag{13.2-25}$$

$$f_h = 0{,}7\left(f_{he}/f_y\right)^{0{,}4} f_y \leq f_y \quad \text{for } 0{,}55\, f_y < f_{he} \leq 2{,}44\, f_y \tag{13.2-26}$$

$$f_h = f_{he} \quad \text{for } f_{he} \leq 0{,}55\, f_y \tag{13.2-27}$$

where

f_y is the representative yield strength, in stress units;

f_{he} is the representative elastic critical hoop buckling strength, in stress units

$$f_{he} = 2C_h Et/D \tag{13.2-28}$$

where the elastic critical hoop buckling coefficient C_h is:

$$C_h = 0{,}44\ t/D \quad \text{for } \mu \leq 1{,}6\ D/t \tag{13.2-29}$$

$$C_h = 0{,}44\ t/D + 0{,}21\ (D/t)^3/\mu^4 \quad \text{for } 0{,}825\ D/t \leq \mu < 1{,}6\ D/t \tag{13.2-30}$$

$$C_h = 0{,}737/(\mu - 0{,}579) \quad \text{for } 1{,}5 \leq \mu < 0{,}825\ D/t \tag{13.2-31}$$

$$C_h = 0{,}80 \quad \text{for } \mu < 1{,}5 \tag{13.2-32}$$

where μ is a geometric parameter and

$$\mu = \frac{L_r}{D}\sqrt{\frac{2D}{t}}$$

where L_r is the length of tubular between stiffening rings, diaphragms, or end connections.

其中f_{yc}的计算依据 ISO / FDIS19902-2020 中 13.2.3.3 节进行计算。

13.2.3.3 Local buckling

The representative local buckling strength, f_{yc}, in 13.2.3.2 shall be determined from Formula (13.2-8) to Formula (13.2-10):

$$f_{yc} = f_y \qquad \text{for } \frac{f_y}{f_{xe}} \leq 0{,}170 \tag{13.2-8}$$

$$f_{yc} = \left(1{,}047 - 0{,}274\frac{f_y}{f_{xe}}\right) f_y \qquad \text{for } 0{,}170 > \frac{f_y}{f_{xe}} \tag{13.2-9}$$

and

$$f_{xe} = 2\,C_x E t / D \tag{13.2-10}$$

where

f_y is the representative yield strength, in stress units;

f_{xe} is the representative elastic local buckling strength, in stress units;

C_x is the elastic critical buckling coefficient, see below;

E is Young's modulus of elasticity;

D is the outside diameter of the member;

t is the wall thickness of the member.

The theoretical value of C_x for an ideal tubular is 0,6. However, a reduced value of C_x = 0,3 should be used in Formula (13.2-10) to account for the effect of initial geometric imperfections within the tolerance limits given in Clause 21. A reduced value of C_x = 0,3 is implicit in the value of f_{xe} used in Formulae (13.2-8) and (13.2-9).