Metallic industrial piping —
Part 3: Design and calculation

12 Flexibility analysis and acceptance criteria

Review of problems and open questions:

→ Alternative Stress equations for ii and io
→ Axial force
→ Corrosion allowances
→ Sectional modulus
→ Factor Ec/Eh gives strange results for cryo-piping

including solution proposals

Stress Equations

Problem:

Chap.12 describes stress equations and appendix H1 describes the stress intensification factors (similar to FDBR/ASMEB31.1 CODETI)

12.3.2 Stress due to sustained loads

The sum of primary stresses σ_1, due to
other sustained mechanical loads shall s

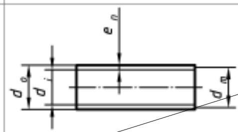
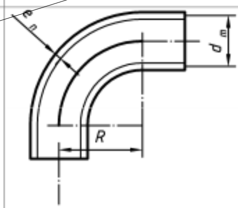
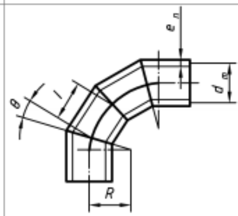
$$\sigma_1 = \frac{p_c d_o}{4 e_n} + \frac{0{,}75\, i\, M_A}{Z} \leq f_f$$

Annex H
(normative)

Flexibility characteristics, flexibility and stress intensification factors and section moduli of piping components and geometrical discontinuities

Piping component and geometrical disconuities characteristics for general cases, particular connections, and out of plane and in plane bending of the piping system shall be in accordance with Tables H.1 to H.3.

Table H.1 — Flexibility characteristics, flexibility and stress intensification factors and section moduli for general cases

N°	Designation	Sketch	Flexibility characteristic h	Flexibility factor k_B [a]	Stress intensification factor i	Section modulus Z
1	straight pipe		1	1	1	
2	plain bend		$\frac{4Re_n}{d_m^2}$	$\frac{1{,}65}{h}$	$\frac{0{,}9}{h^{2/3}}$ b c	$\frac{\pi}{32}\frac{d_o^4-d_i^4}{d_o}$
3	Closely spaced mitre bend $l < r(1+\tan\theta)$ $(l = 2R\tan\theta)$		$\frac{4Re_n}{d_m^2}$ with $R = \frac{l\cot\theta}{2}$	$\frac{1{,}52}{h^{5/6}}$	$\frac{0{,}9}{h^{2/3}}$ b c	

(to be continued)

EN 13480-3 ed.2012

Alternative Equations

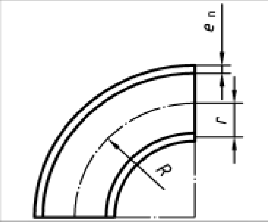
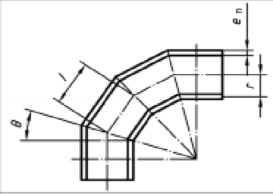
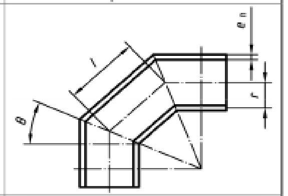
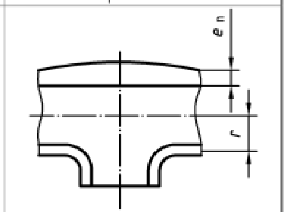
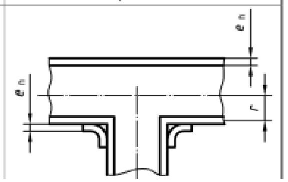
Problem:

Appendix H3 describes alternative stress equations (similar to ASME B31.3), but no equations is given in chapter 12

12.3.2 Stress due to sustained loads

The sum of primary stresses σ_1, due to
other sustained mechanical loads shall s

$$\sigma_1 = \frac{p_c d_o}{4e_n} + \frac{0,75\, i\, M_A}{Z} \leq f_f$$

Component description	Out-of-plane i_o	In-plane i_i	Flexibility characteristic	Sketch
Welding elbow or pipe bend	$\frac{0,75}{h^{2/3}}$ a b c	$\frac{0,9}{h^{2/3}}$ a b c	$\frac{e_n R}{r^2}$	
Closely spaced mitre bend $l < r(1 + \tan\theta)$ ($l = 2R\tan\theta$)	$\frac{0,9}{h^{2/3}}$ a b c	$\frac{0,9}{h^{2/3}}$ a b c	$\frac{\cot\theta}{2}\,\frac{e_n l}{r^2}$	
Single mitre bend or widely spaced mitre bend $l \geq r(1 + \tan\theta)$	$\frac{0,9}{h^{2/3}}$ a b c	$\frac{0,9}{h^{2/3}}$ a b c	$\frac{e_n}{r}\left(\frac{1+\cot\theta}{2}\right)$	
Forged tee to be welded, designed with a burst pressure greater than or equal to the burst pressure of the connected pipes	$\frac{0,9}{h^{2/3}}$ a e f g i	$0,75 i_o + 0,25$ a e f g i	$\frac{4,4e_n}{r}$	
Reinforced fabricated tee with pad or saddle	$\frac{0,9}{h^{2/3}}$ a d e i	$0,75 i_o + 0,25$ a d e i	$\frac{(e_n + 0,5e_r)^{5/2}}{r(e_n)^{3/2}}$	

Alternative Equations , Solution

Include Stress equations for alternative SIF:

or alternatively using the stress intensification factor from table H3:

$$\sigma_1' = \sqrt{\left(\frac{i_{QA} Q_x}{A_c} + \frac{\sqrt{(0{,}75 \cdot i_i \cdot M_{iA})^2 + (0{,}75 \cdot i_o \cdot M_{oA})^2}}{Z_c}\right)^2 + \left(\frac{i_t M_{tA}}{Z_c}\right)^2} \leq f_f$$

where

M_{iA} is the in-plane moment from the sustained mechanical loads

M_{oA} is the out-of-plane moment from the sustained mechanical loads

M_{tA} is the torsional moment from the sustained mechanical loads

i_t is the stress intensification factor for torsional moments. Unless more precise information is available $i_t = 1.0$

Same modifications for the other equations:

ROHR2

Alternative Equations , Solution for Range

Include Stress equations for alternating loads:

$$\sigma_3' = \sqrt{\left(\frac{i_{QC} Q_{xC}}{A} + \frac{\sqrt{(0{,}75 \cdot i_i \cdot M_{iC})^2 + (0{,}75 \cdot i_o \cdot M_{oC})^2}}{Z}\right)^2 + \left(\frac{i_t M_{tC}}{Z}\right)^2} \leq f_a$$

i_{QC} is the stress intensification factor for axial forces for alternating loads.
Unless more precise information is available i_{QC} = 1.0

As in ASME B31.3: use nominal thickness for Z for secondary loads.

Alternative Equations , Range with pressure stiffness

in cases where the stress intensification factor is load case dependant (e.g. pressure stiffening of bends), the stress range is the maximum difference between all pairs (j,k) of thermal expansion or alternating load cases calculated in the following way:

$$\sigma_3'=\max\left(\sqrt{\left(\frac{i_{Qj}Q_{xCj}-i_{Qk}Q_{xCk}}{A}+\frac{\sqrt{(i_{ij}\cdot M_{iCj}-i_{ik}\cdot M_{iCk})^2+(i_{oj}\cdot M_{oCj}-i_{ok}\cdot M_{oCk})^2}}{Z}\right)^2+\left(\frac{i_{tj}M_{tCj}-i_{tk}M_{tCk}}{Z}\right)^2}\right)_{j=1,N,k=1,N}\leq f_a$$

(Basically replace moment rang by calculation stress range directly over all load case combinations)

Alternative Equations

Similar as in ASME B31.3 2014 we introduce SIF's for axial force and torsional moment which are set to 1.0. This allows replacing the factors with more precise data if available:

$$\sigma_3' = \max\left(\sqrt{\left(\frac{i_{Qj} Q_{xCj} - i_{Qk} Q_{xCk}}{A} + \frac{\sqrt{(i_{ij}\cdot M_{iCj} - i_{ik}\cdot M_{iCk})^2 + (i_{oj}\cdot M_{oCj} - i_{ok}\cdot M_{oCk})^2}}{Z}\right)^2 + \left(\frac{i_{tj} M_{tCj} - i_{tk} M_{tCk}}{Z}\right)^2}\right)_{j=1,N,k=1,N} \leq f_a$$

i_{QL} is the stress intensification factor for axial forces in the load case L. Unless more precise information is available $i_{QL} = 1.0$

i_{tL} is the stress intensification factor for torsional moments in the load case L. Unless more precise information is available $i_{tL} = 1.0$

Axial force

Problem:

The stress equations in chap.12 do not consider axial force (other than that due to internal pressure):

$$\sigma_1 = \frac{p_c d_o}{4 e_c} + \frac{0.75 \cdot i \cdot M_A}{Z_c} \leq f_f$$

The stress analysis cannot be used where axial force from other sources is relevant:

- buried pipes
- axial restrained pipes
- pipes for supporting structures (e.g. in water boilers etc)

Axial force, Solution

Include axial force into stress equations:

$$\sigma_1 = i_{QA} \frac{Q_x}{A_c} + \frac{0.75 \cdot i \cdot M_A}{Z_c} \leq f_f$$

where:

$$Q_x = MAX\left(\left|\frac{p_c \pi d_o^2}{4} + Q_{xA}\right|, \left|Q_{xA}\right|\right)$$

Q_{xS} is the axial force from the sustained mechanical loads

d_i is the inner diameter of the corroded pipe

A_c is the cross section of the pipe (reduced by the corrosion allowances)

i_{QA} is the stress intensification factor for axial forces for sustained loads.
Unless more precise information is available i_{QA} = 1.0

Axial force, Solution Alternative Equations

Include axial force into alternative stress equations:

$$\sigma_1' = \sqrt{\left(\frac{i_{QA} Q_x}{A_c} + \frac{\sqrt{(0{,}75 \cdot i_i \cdot M_{iA})^2 + (0{,}75 \cdot i_o \cdot M_{oA})^2}}{Z_c}\right)^2 + \left(\frac{i_t M_{tA}}{Z_c}\right)^2} \leq f_f$$

where:

$$Q_x = MAX\left(\left|\frac{p_c \pi d_o^2}{4} + Q_{xA}\right|, \left|Q_{xA}\right|\right)$$

Axial force

For occasional loads

$$\sigma_2 = \frac{i_{QA} Q_x}{A_c} + \frac{0.75 \cdot i \cdot M_A + 0.75 \cdot i \cdot M_B}{Z_c} \le k \cdot f_f$$

Axial force must include:

- Pressure effect (acting or not)
- Sustained loads QxA (acting all the time)
- Occasional loads QxB (acting or not, reversing or not)

for reversing loads :

$$Q_x = MAX\left(\left|\frac{p_c \pi d_o^2}{4} + Q_{xA}\right| + \left|Q_B\right|, \left|Q_{xA}\right| + \left|Q_B\right|\right)$$

non reversing:

$$Q_x = MAX\left(\left|\frac{p_c \pi d_o^2}{4} + Q_{xA}\right|, \left|Q_{xA}\right|, \left|\frac{p_c \pi d_o^2}{4} + Q_{xA} + Q_B\right|, \left|Q_{xA} + Q_B\right|\right)$$

Corrosion allowances

Problem:

The internal pressure design considers corrosion and erosion but stress equations in chap.12 is not clear about it:

Stresses shall be determined for nominal thickness.

NOTE Wall thickness reductions, allowed by the technical conditions of delivery for seamless and welded pipes are covered by the stress limits.

First look: Manufacturing tolerance + Corrosion allowance does not need to be considered

Second look: Normal manufacturing tolerance does not need to be considered.

So what about corrosion?

Corrosion allowances

How it is done in other codes:

FDBR: Calculation of stiffness using nominal thickness
calculation of SIF using nominal thickness
calculation of stresses using corroded thickness

Codeti: Calculation of stiffness using nominal thickness
calculation of SIF using corroded thickness
calculation of stresses using corroded thickness

ASME B31.3: calculation of stiffness using nominal thickness
calculation of SIF using nominal thickness
calculation of primary stresses using corroded thickness
calculation of secondary stresses using nominal thickness

Corrosion allowances

Solution:

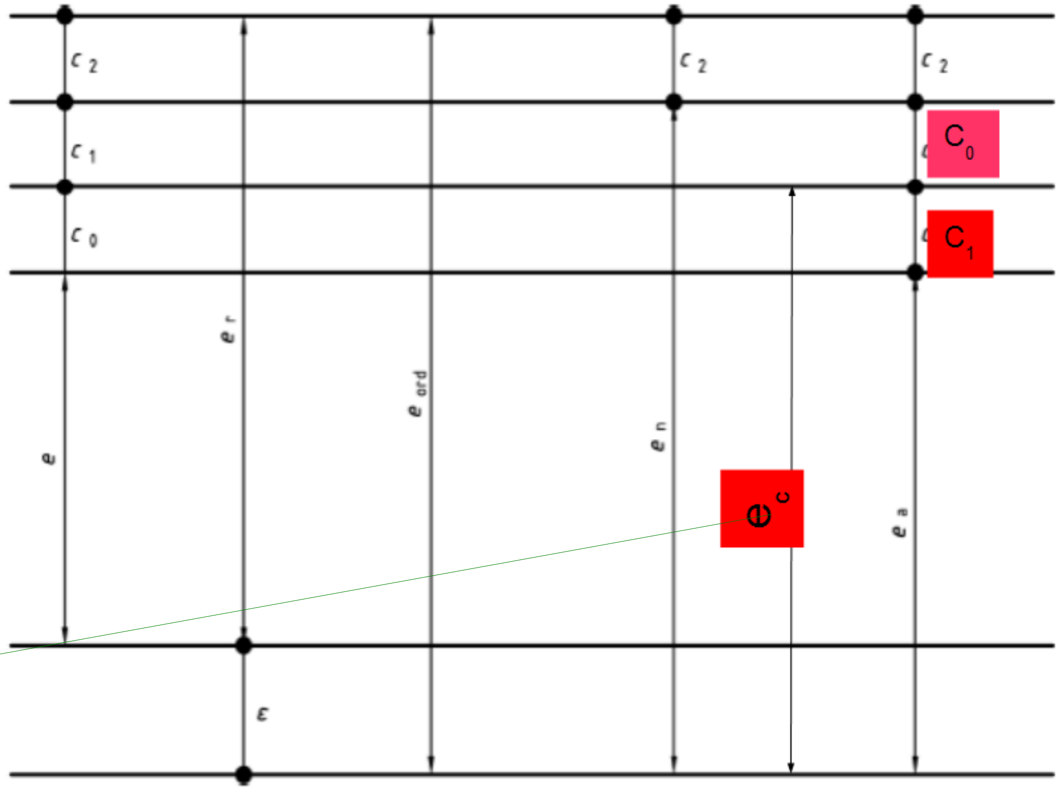
Define calculation thickness e_c

Define nominal sectional modulus:

$$Z = \frac{\pi}{32} \frac{d_o^4 - d_i^4}{d_o}$$

and corroded sectional modulus:

$$Z_c = \frac{\pi}{32} \frac{d_o^4 - (d_o - 2e_c)^4}{d_o}$$



Use nominal thickness for forces, moments and stiffness

Use corroded sectional modulus for stress analysis

Corrosion allowances

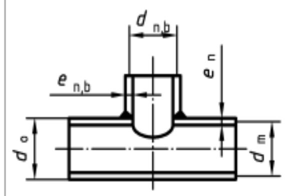
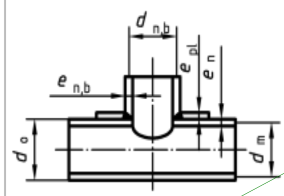
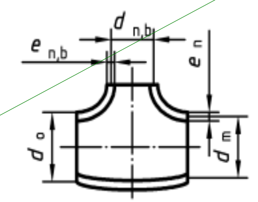
In order to avoid confusion about corroded or non corroded thickness in calculation of sectional modulus, all sectional modulus are calculated using the thick wall formula in 12.3.1

$$Z=\frac{\pi}{32}\frac{d_o^4-d_i^4}{d_o}$$

$$Z_c=\frac{\pi}{32}\frac{d_o^4-(d_o-2e_c)^4}{d_o}$$

The stress intensification factors are corrected so that the thick-wall formula can be used everywhere.

No need to have Z in table H1-H3 any more.

6	tee with welded-on, welded-in or extruded nozzle		$\frac{2e_n}{d_m}$	1	$\frac{0,9}{h^{2/3}}$ b e	Header $\frac{\pi}{32}\frac{d_o^4-d_i^4}{d_o}$
7	as above, however, with additional reinforcing ring		$\frac{2(e_n+0,5e_{pl})^{5/2}}{d_m e_n^{3/2}}$ with $e_{pl} \le e_n$	1	$\frac{0,9}{h^{2/3}}$ b e	Nozzle $\frac{\pi}{4}d_{m,b}^2 e_x$
8	forged welded-in tee with e_n and $e_{n,b}$ as connecting wall thickness		$\frac{8,8e_n}{d_m}$	1	$\frac{0,9}{h^{2/3}}$ b g	with e_x as smaller value of $e_{x1}=e_n$ and $e_{x2}=i\,e_{n,b}$ resp.

Sectional Modulus and Stress Intensification

Problem:

Appendix H1 gives SIF and sectional modulus Z. But for Tees Z is modified for the branch.

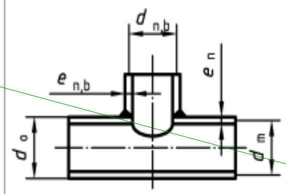
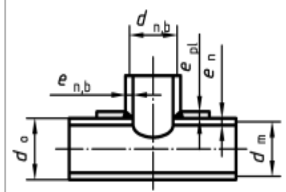
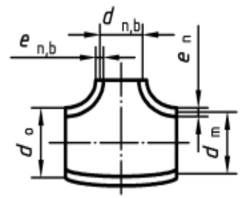
So for the run:

$$\sigma_1 = S_{lp} + \frac{0.75 \cdot i \cdot M_A}{Z_{run}}$$

and for the branch

$$\sigma_1 = S_{lp} + \frac{0.75 \cdot i \cdot M_A}{\pi/4\, d_{m,b}^2 \mathrm{MIN}(e_n, i e_{n,b})}$$

$$\sigma_1 = S_{lp} + \mathrm{MAX}\left(\frac{0.75 \cdot M_A}{\pi/4\, d_{m,b}^2 e_{n,b}}, \frac{0.75 \cdot i \cdot M_A}{\pi/4\, d_{m,b}^2 e_n} \right)$$

6	tee with welded-on, welded-in or extruded nozzle		$\frac{2e_n}{d_m}$	1	$\frac{0,9}{h^{2/3}}$ b e	Header $\frac{\pi}{32}\frac{d_o^4-d_i^4}{d_o}$
7	as above, however, with additional reinforcing ring		$\frac{2(e_n+0,5e_{pl})^{5/2}}{d_m e_n^{3/2}}$ with $e_{pl} \le e_n$	1	$\frac{0,9}{h^{2/3}}$ b e	Nozzle $\frac{\pi}{4} d_{m,b}^2 e_x$
8	forged welded-in tee with e_n and $e_{n,b}$ as connecting wall thickness		$\frac{8,8e_n}{d_m}$	1	$\frac{0,9}{h^{2/3}}$ b g	with e_x as smaller value of $e_{x1} = e_n$ and $e_{x2} = i\, e_{n,b}$ resp.

Sectional Modulus and Stress Intensification

Problem:

for branches with big wall thickness

$$\sigma_1 = S_{lp} + \frac{0.75 \cdot i \cdot M_A}{\pi / 4\, d_{m,b}^2\, e_n}$$

with constant outer diameter:

$$d_{m,b}^2 = d_{o,b} - e_{n,b}$$

this leads to higher stresses for bigger wall thickness $e_{n,b}$

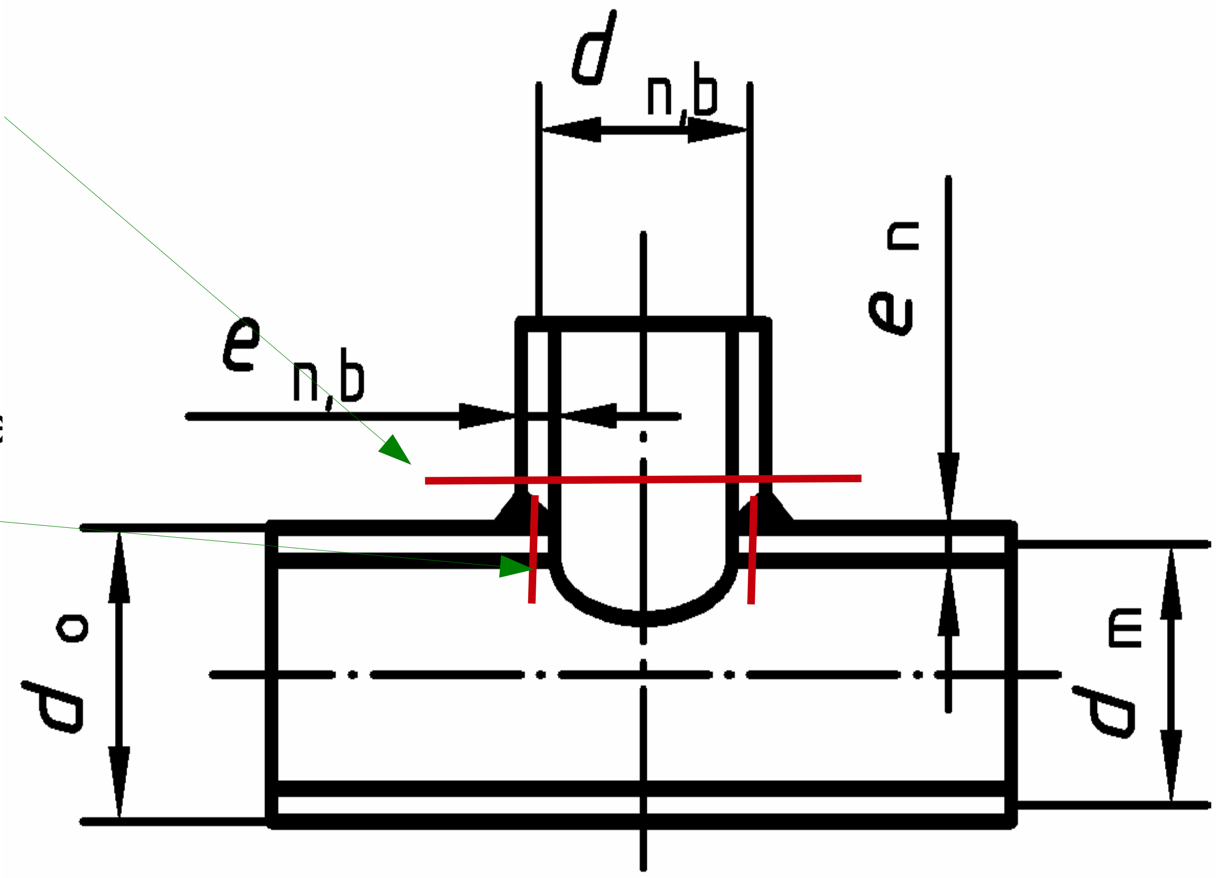
$$\sigma_1 = S_{lp} + \frac{0.75 \cdot i \cdot M_A}{\pi / 4 \left(d_{o,b}^2 - e_{n,b} \right) e_n}$$

Sectional Modulus and Stress Intensification

Stress verification for the branch is done at two sections:

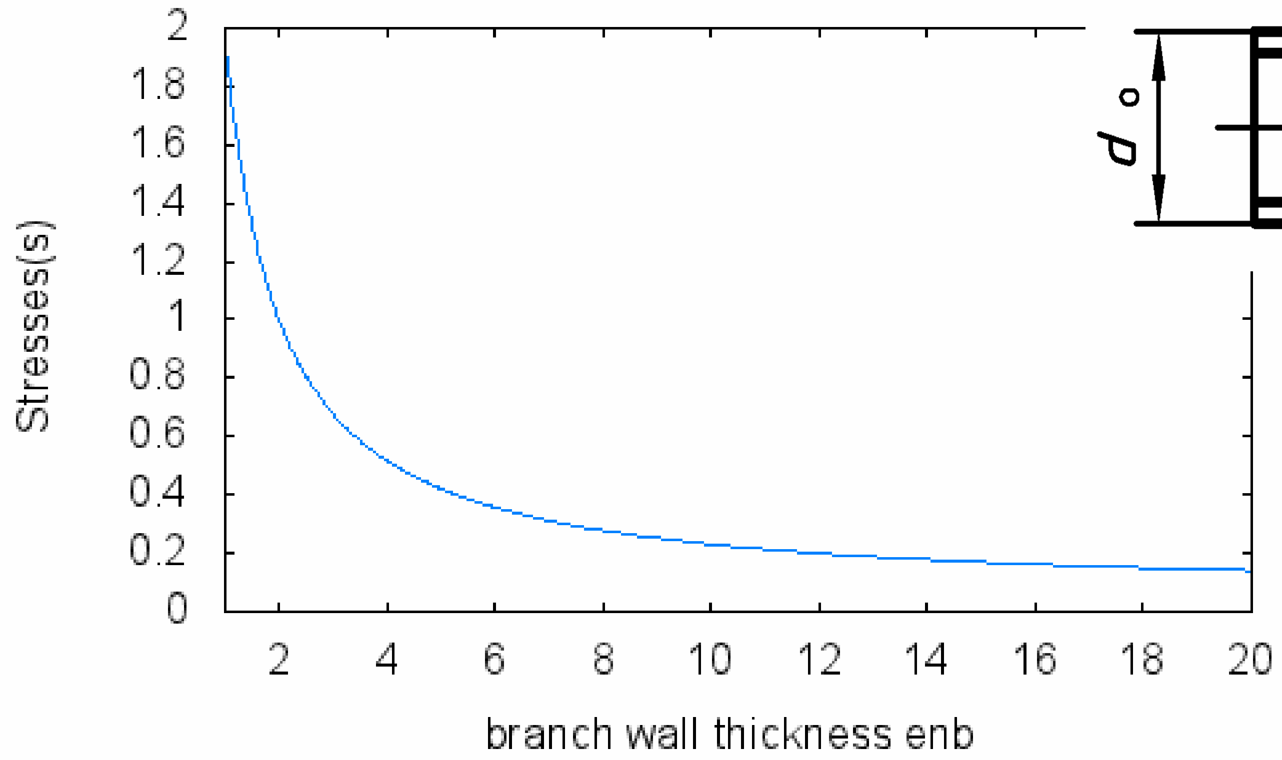
At the branch itself without SIF

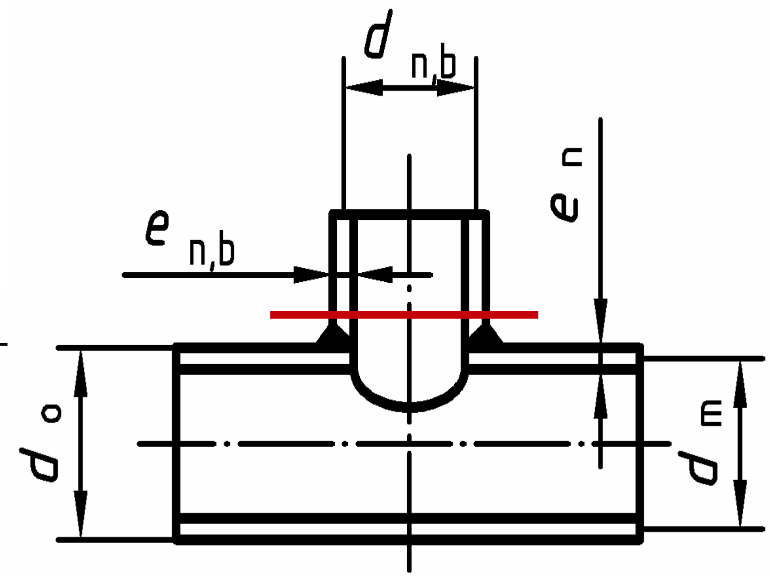
In the shell of the run at the average diameter of the branch including SIF



Sectional Modulus and Stress Intensification

Stresses calculated at the branch
as function of branch wall thickness
(OD constant)

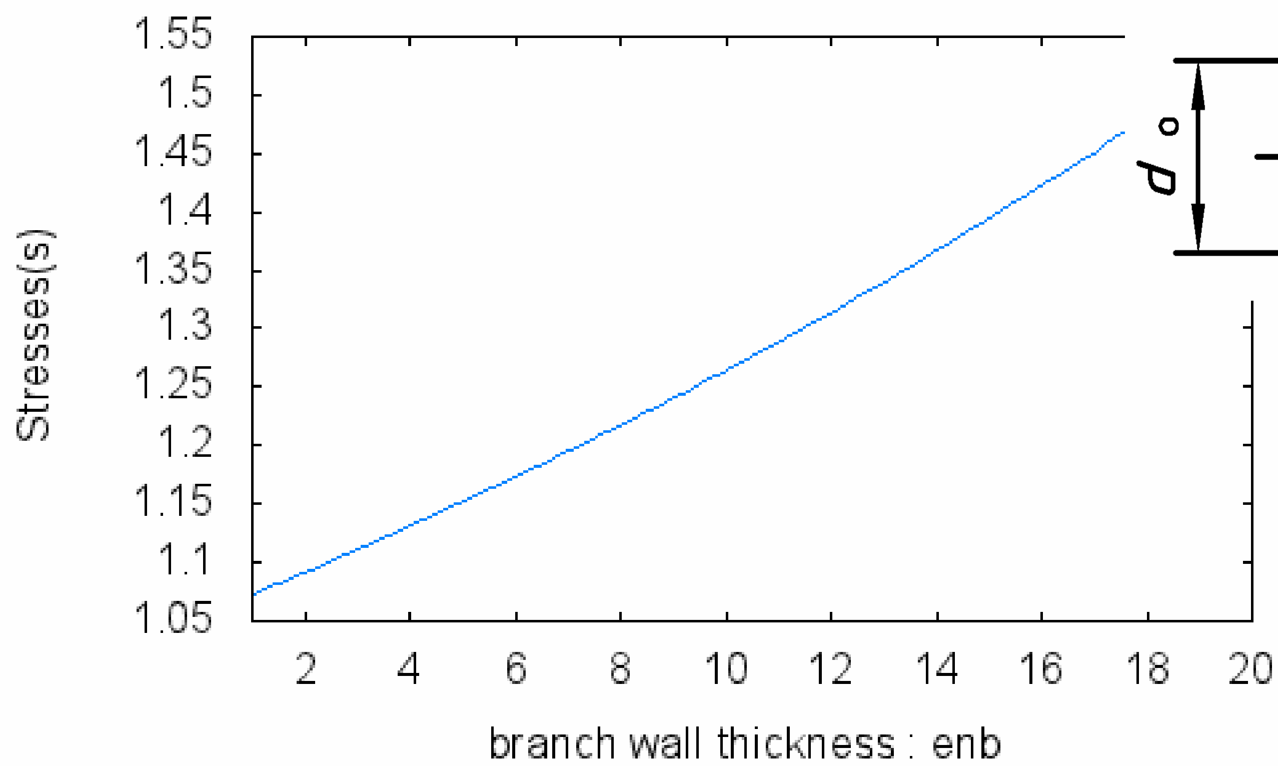


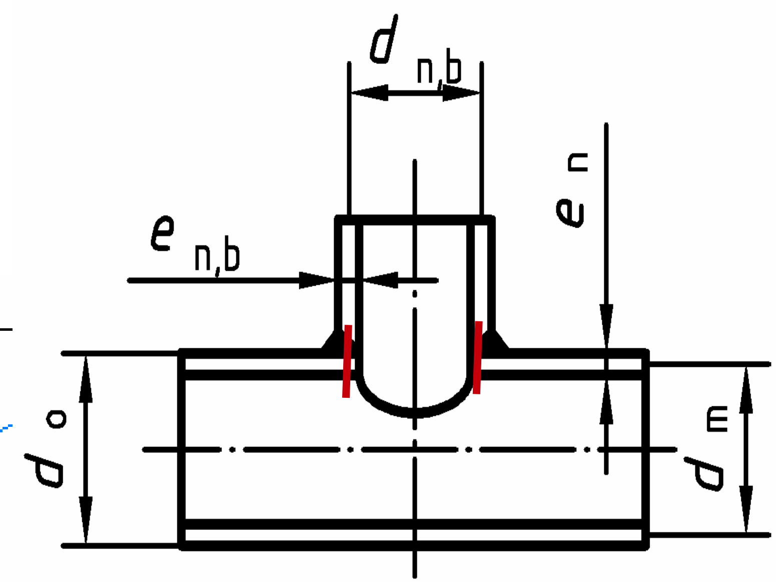


$e_{n,b}$

Sectional Modulus and Stress Intensification

Stresses calculated at the run shell
as function of branch wall thickness
(OD constant)

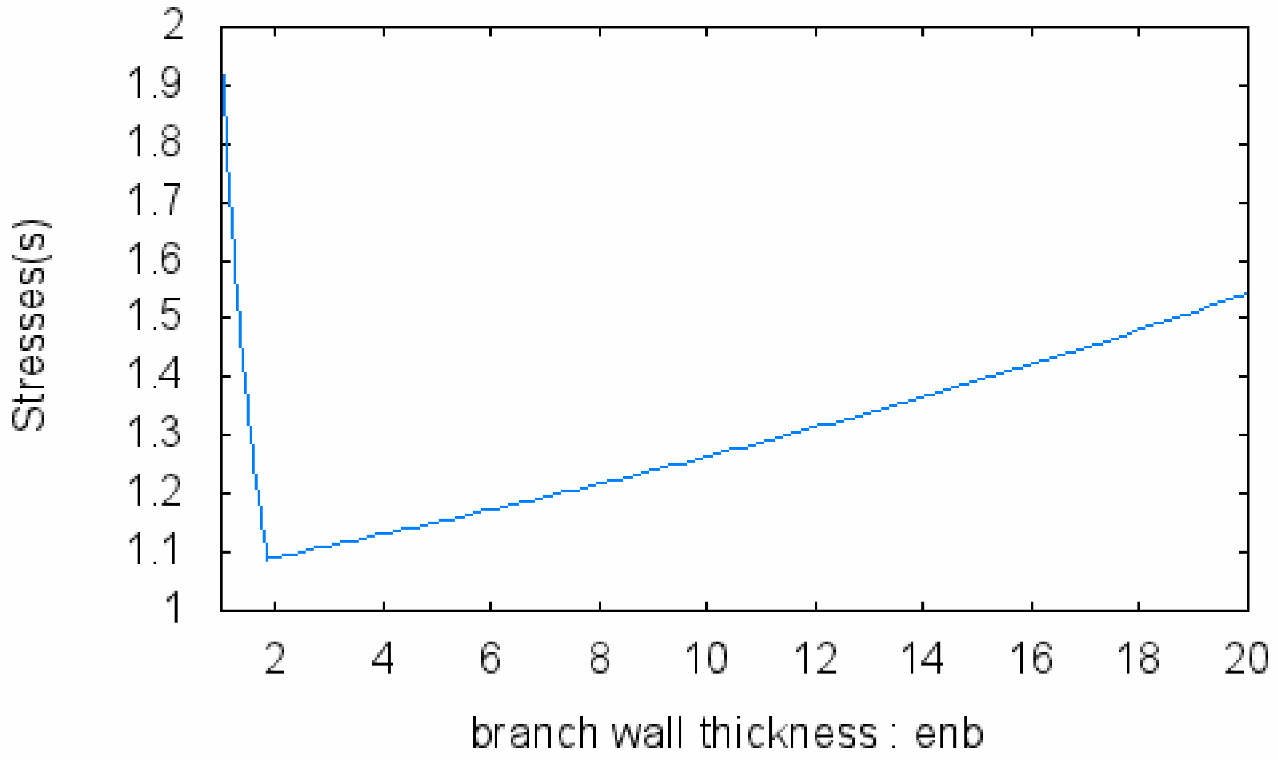


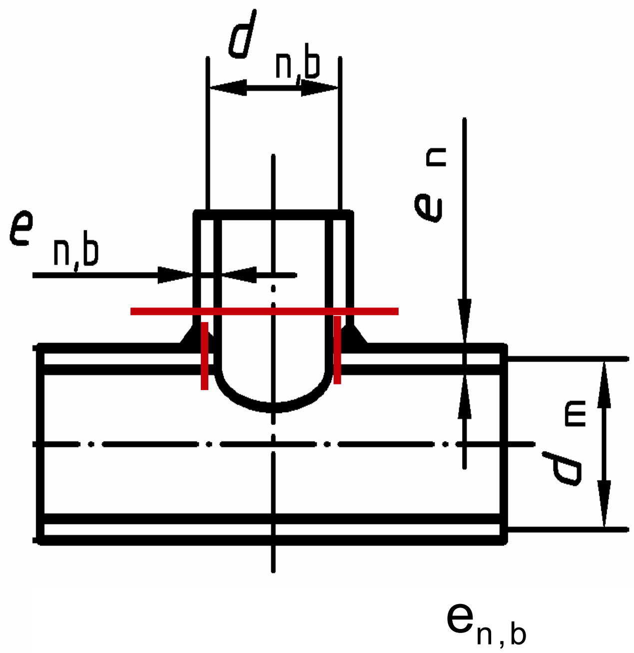


$e_{n,b}$

Sectional Modulus and Stress Intensification

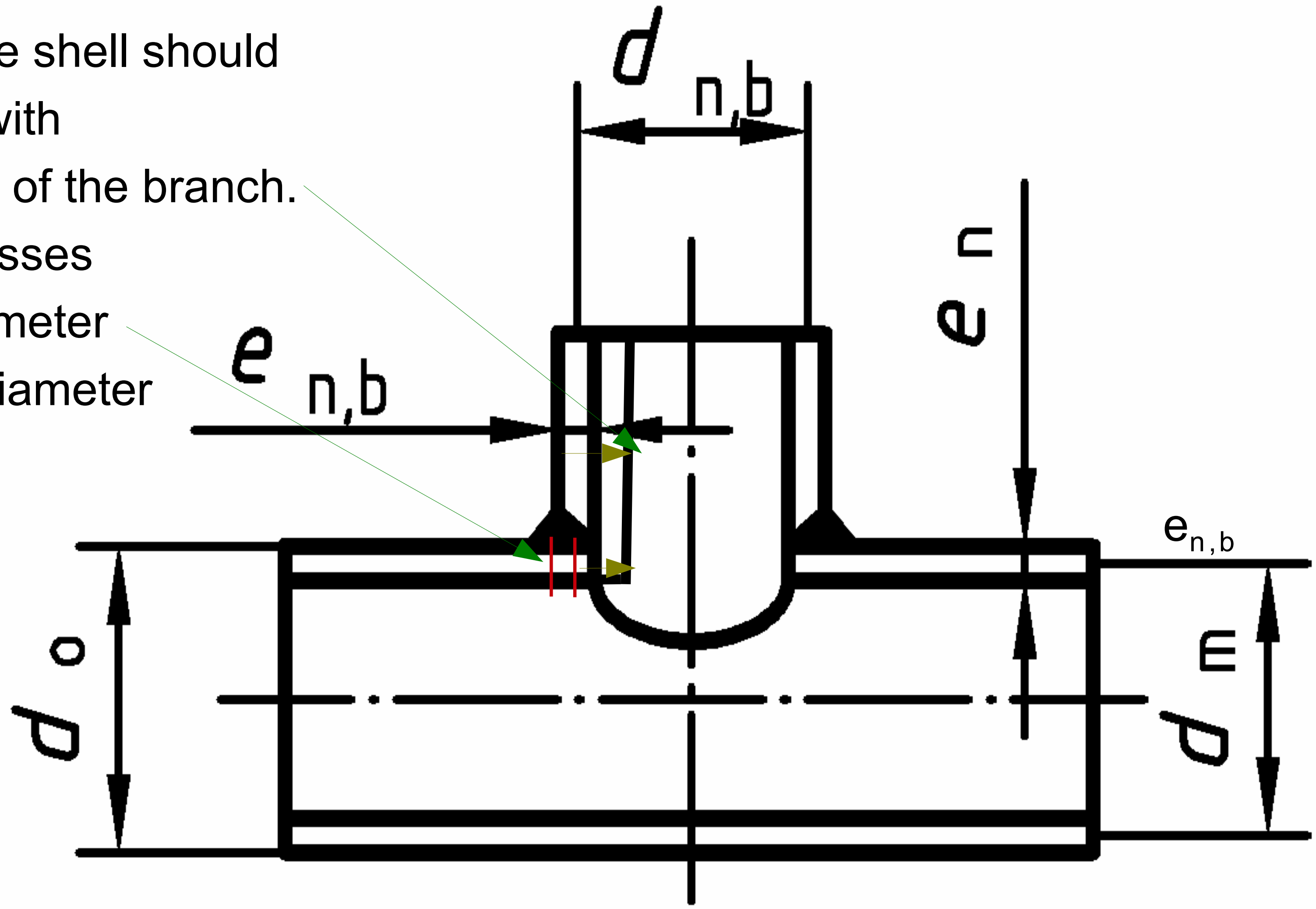
Code stresses calculated as function of branch wall thickness (OD constant)





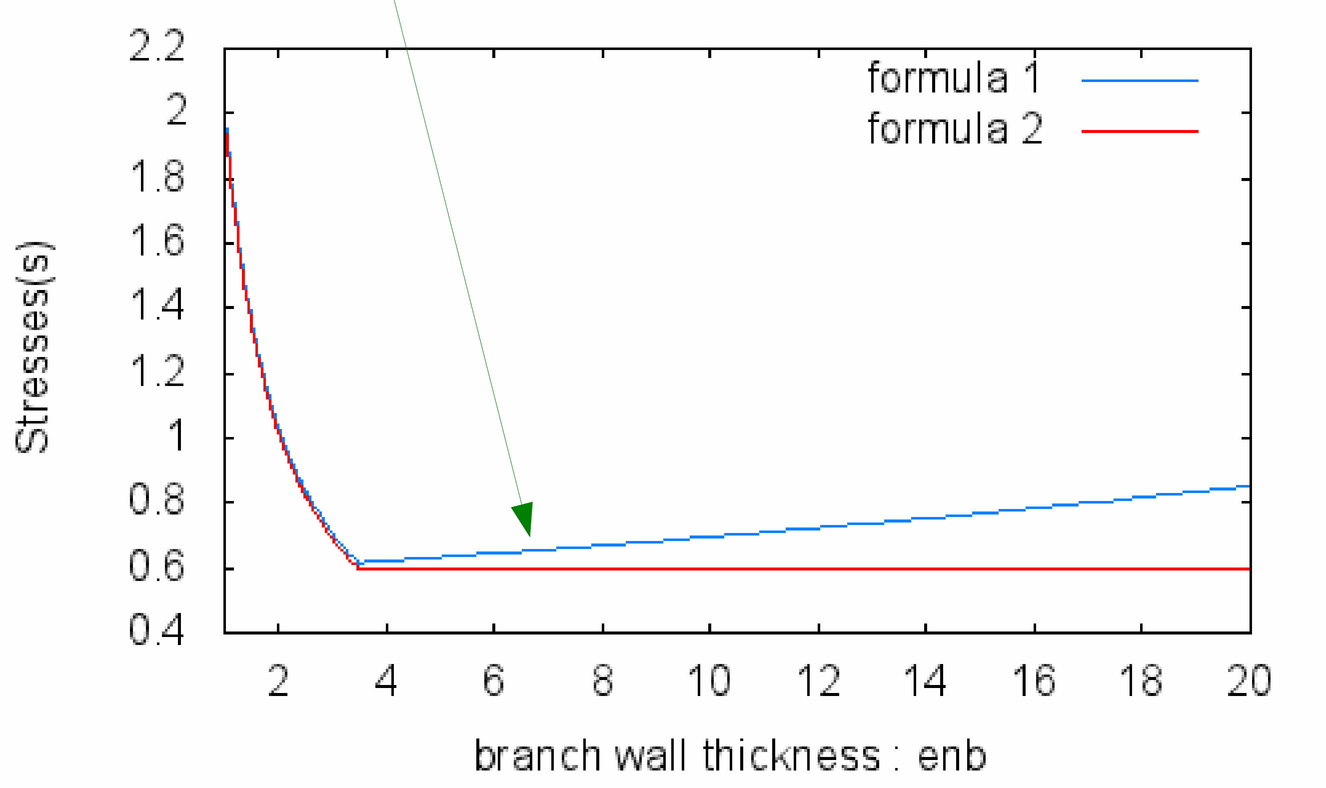
Sectional Modulus and Stress Intensification

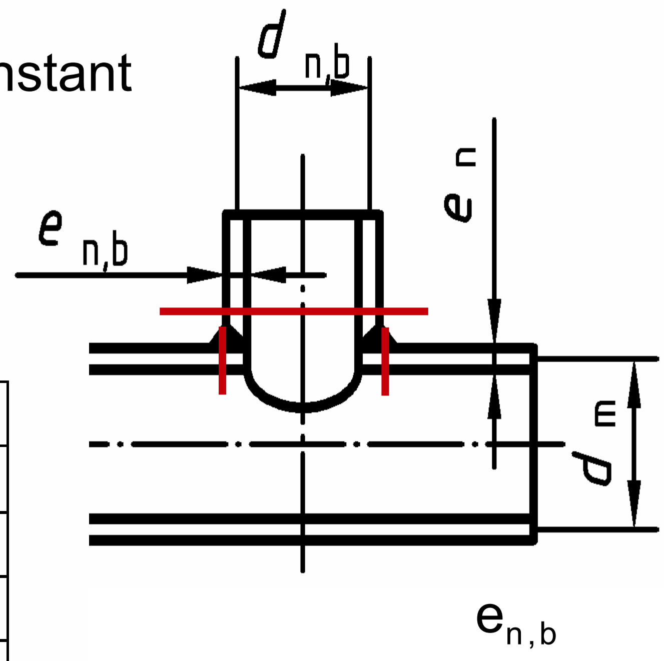
Stresses in the shell should
not increase with
wall thickness of the branch.
Calculate stresses
at outside diameter
not average diameter
of the branch



Sectional Modulus and Stress Intensification

When using outside diameter, stresses remain constant when increasing branch wall in the area where stresses are maximum in the run of the header



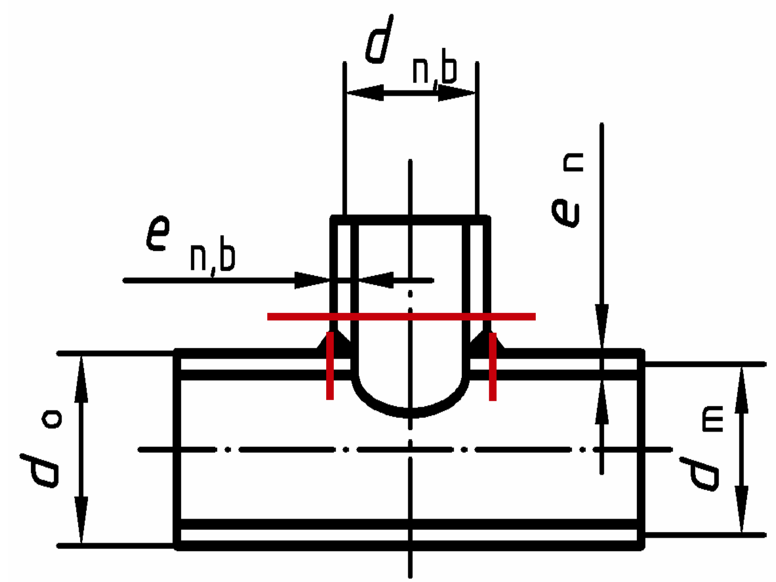


Sectional Modulus and Stress Intensification

New SIF must like old one but multiplied by
ratio of Zexact(average diameter)
and Zthin(outer diameter)

$$i_{new} = i_{old} * \frac{Z_{exact}(e_{n,b}, d_{m,b})}{Z_{thin}(e_n, d_{m,b} + e_{n,b})}$$

$$i_{new} = \frac{0{,}9}{h^{2/3}} \frac{(d_{m,b}+e_{n,b})^4 - (d_{m,b}-e_{n,b})^4}{8\,e_n \cdot (d_{m,b}+e_{n,b})^3}$$



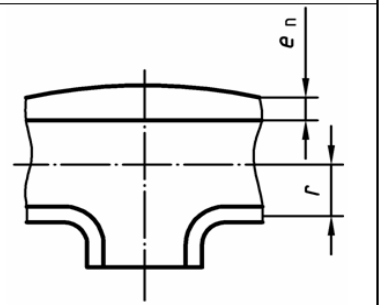
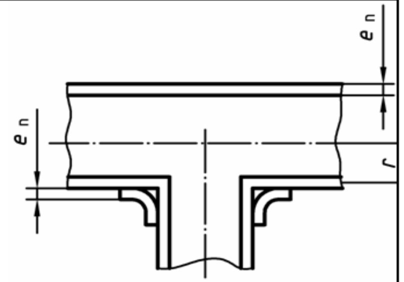
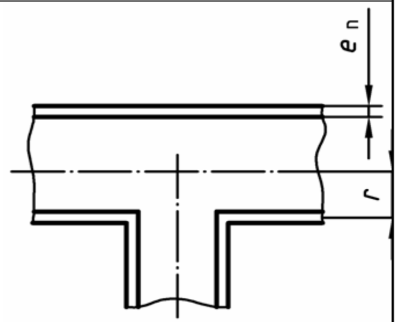
$e_{n,b}$

Sectional Modulus and Stress Intensification

Add same corrections to table H3

Previously nothing was specified about Z.

This is not needed in new version as Z is defined in chapter 12 exclusively

Forged tee to be welded, designed with a burst pressure greater than or equal to the burst pressure of the connected pipes	$\frac{0,9}{h^{2/3}} \frac{(d_{m,b}+e_{n,b})^4-(d_{m,b}-e_{n,b})^4}{8e_n\cdot(d_{m,b}+e_{n,b})^3} \geq 1$ a e f g i	$0,75 i_o + 0,25$ a e f g i	$\frac{4,4 e_n}{r}$	
Reinforced fabricated tee with pad or saddle	$\frac{0,9}{h^{2/3}} \frac{(d_{m,b}+e_{n,b})^4-(d_{m,b}-e_{n,b})^4}{8e_n\cdot(d_{m,b}+e_{n,b})^3} \geq 1$ a d e i	$0,75 i_o + 0,25$ a d e i	$\frac{(e_n + 0,5 e_r)^{5/2}}{r(e_n^{3/2})}$	
Unreinforced fabricated tee	$\frac{0,9}{h^{2/3}} \frac{(d_{m,b}+e_{n,b})^4-(d_{m,b}-e_{n,b})^4}{8e_n\cdot(d_{m,b}+e_{n,b})^3} \geq 1$ a d e i	$0,75 i_o + 0,25$ a d e i	$\frac{e_n}{r}$	

(to be continued)

Sectional Modulus and Stress Intensification

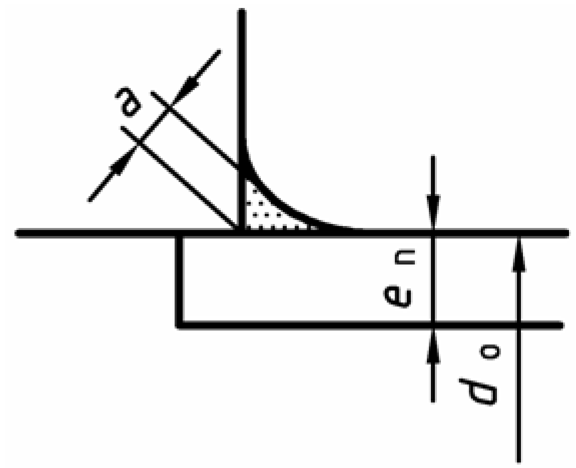
For other components where calculation was based on thin wall formula we need to change the SIF by the ratio

Zexact(average diameter) and

Zthin(average diameter).

This does not change the results.

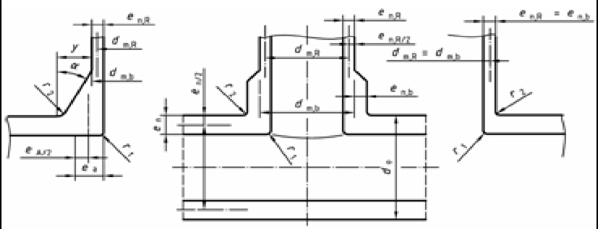
$$i_{new} = i_{old} * \frac{Z_{exact}(e_{n,b}, d_{m,b})}{Z_{thin}(e_n, d_{m,b})}$$

	concave shape with continuous transition to pipe	1	$1{,}3\left(\frac{a}{e_n}\frac{\left(\frac{e_n}{d_m}\right)^2+1}{\left(\frac{e_n}{d_m}\right)+1}\right)\geq 1$

Minor corrections:

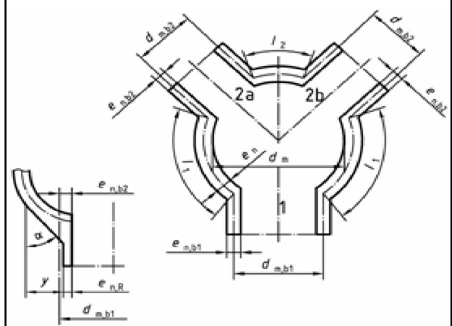
Remove bad page brake in table H2 (SIF of Tee was below heading of Y-piece):

Table H.2 — Stress intensification factors and section moduli for particular connections

Designation	Tee with special shape conditions
sketch	 $e_{\mathrm{n,b}} = e_{\mathrm{n,R}} + 2Y/3$ $d_{\mathrm{o,b}} = d_{\mathrm{m,b}} + e_{\mathrm{n,b}}$
shape conditions	$\frac{d_{\mathrm{m,R}}}{d_{\mathrm{m}}} \le 0{,}5 \quad ; \quad \frac{d}{e_{\mathrm{n}}} \le 100 \quad ; \quad 0{,}1 e_{\mathrm{n}} \le r_1 \le 0{,}5 e_{\mathrm{n}}$ $r_2 \ge \max\left(\frac{e_{\mathrm{n,b}}}{2}; \frac{e_{\mathrm{n}}}{2}\right) \qquad \alpha \le 30°$ $r_3 \ge \max\left\{\alpha \frac{d_{\mathrm{m,R}} + e_{\mathrm{n,R}}}{500}; 2\sin^3 \alpha \left(d_{\mathrm{m,b}} + e_{\mathrm{n,b}} - d_{\mathrm{m,R}} - e_{\mathrm{n,R}}\right)\right\}$ For the conditions of r_3 α shall be in deg. For branches DN < 100 the conditions for r_1 can be omitted.

(to be continued)

Table H.2 *(continued)*

Designation	Y-spherical fitting	
stress intensification factors and section moduli	for header : $i = 0{,}4\left(\frac{d_{\mathrm{m}}}{2e_{\mathrm{n}}}\right)^{\frac{2}{3}} \times \frac{d_{\mathrm{m,R}}}{d_{\mathrm{m}}}$ but at least $i = 1{,}5$ $Z = \frac{\pi}{4} d_{\mathrm{m}}^2 e_{\mathrm{n}}$	for branch : $i = 1{,}5\left(\frac{d_{\mathrm{m}}}{2e_{\mathrm{n}}}\right)^{\frac{2}{3}}\left(\frac{d_{\mathrm{m,R}}}{d_{\mathrm{m}}}\right)^{\frac{1}{2}} \times \frac{e_{\mathrm{n,R}}}{e_{\mathrm{n}}} \times \frac{d_{\mathrm{m,R}}}{d_{\mathrm{m,b}} + e_{\mathrm{n,b}}}$ $Z = \frac{\pi}{4} d_{\mathrm{Rm}}^2 e_{\mathrm{n,R}}$
sketch		$e_{\mathrm{n,b1}} = e_{\mathrm{n,R}} + 2y/3$ $d_{\mathrm{o}} = d_{\mathrm{m}} + e_{\mathrm{n}}$ $d_{\mathrm{o,b1}} = d_{\mathrm{m,b1}} + e_{\mathrm{n,b1}}$ $d_{\mathrm{o,b2}} = d_{\mathrm{m,b2}} + e_{\mathrm{n,b2}}$
factors of influence $l_{\mathrm{o}}, \lambda_1, \lambda_2$	$I_0 = 2\sqrt{d_{\mathrm{m}} e_{\mathrm{n}}}; \lambda = 1 - \sqrt{\frac{I_1}{l_{\mathrm{o}}}}; \lambda = 1 - \sqrt{\frac{I_2}{l_{\mathrm{o}}}}$ for $l_1 \ge l_{\mathrm{o}}$, $\lambda_1 = 0$ and for $l_2 \ge l_{\mathrm{o}}$, $\lambda_2 = 0$	
stress intensification factor i	$i = \frac{0{,}9}{h^{2/3}}$ with $h = \frac{2e_{\mathrm{n}}}{d_{\mathrm{m}}}$	
section moduli	Nozzle 1	Nozzle 2a and 2b
Z_1 Z_2	$Z_1 = \pi d_{\mathrm{m,b1}}^2 e_{x1}/4$ with $e_{x1} = \min(e_{\mathrm{n}}; i e_{\mathrm{n,b1}})$	$Z_2 = \pi d_{\mathrm{m,b2}}^2 e_{x2}/4$ with $e_{x2} = \min(e_{\mathrm{n}}; i e_{\mathrm{n,b2}})$

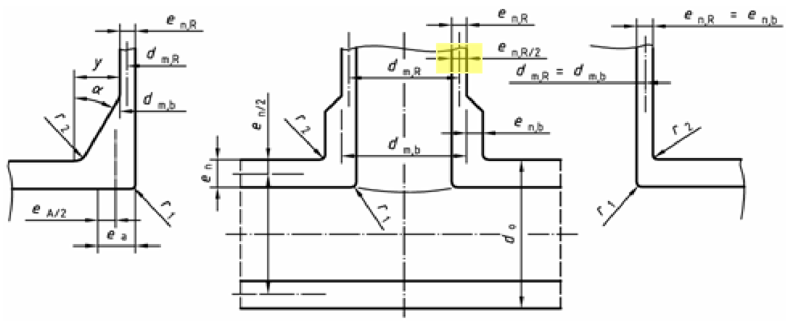
(to be continued)

Minor corrections:

New version
at new location
with new SIF and
without Z.

This does not change
the results.

Table H.2 — Stress intensification factors and section moduli for particular connections

Designation	Tee with special shape conditions	
sketch	 $e_{n,b} = e_{n,R} + 2Y/3$ $d_{o,b} = d_{m,b} + e_{n,b}$	
shape conditions	$\frac{d_{m,R}}{d_m} \le 0{,}5$; $\frac{d}{e_n} \le 100$; $0{,}1e_n \le r_1 \le 0{,}5e_n$ $r_2 \ge \max\left(\frac{e_{n,b}}{2};\frac{e_n}{2}\right)$ $\alpha \le 30°$ $r_3 \ge \max\left\{\alpha\frac{d_{m,R}+e_{n,R}}{500}; 2\sin^3\alpha\left(d_{m,b}+e_{n,b}-d_{m,R}-e_{n,R}\right)\right\}$ For the conditions of r_3 α shall be in deg. For branches DN < 100 the conditions for r_1 can be omitted.	
stress intensification factors	for header : $i = 0{,}4\left(\frac{d_m}{2e_n}\right)^{\frac{2}{3}} \frac{\left(\frac{e_n}{d_m}\right)^2+1}{\left(\frac{e_n}{d_m}\right)+1} \times \frac{d_{m,R}}{d_m}$ but at least $i = 1{,}5$	for branch : $i = 1{,}5\left(\frac{d_m}{2e_n}\right)^{\frac{2}{3}}\left(\frac{d_{m,R}}{d_m}\right)^{\frac{1}{2}} \frac{\left(\frac{e_{n,R}}{d_{m,R}}\right)^2+1}{\left(\frac{e_{n,R}}{d_{m,R}}\right)+1} \times \frac{e_{n,R}}{e_n} \times \frac{d_{m,R}}{d_{m,b}+e}$

(to be continued)

Sectional Modulus and Stress Intensification

Summary:

Define sectional modules once and for all in chapter 12 based on thick wall formula

advantages:

- allows to remove Z from tables H1-H3
- allows to integrate Z and Zcorroded (for equations 1-6)
- all stress intensifications now are directly visible in SIF and not hidden in different section modulus
- clarification of Z for table H3
- remove inverse effect of wall thickness of branch

Factor Ec/Eh gives strange results for cryo-piping

Problem:

The allowable stress for Stress Range is defined as:

$$f_a = U\left(1{,}25 f_c + 0{,}25 f_h\right)\frac{E_h}{E_c} \qquad (12.1.3\text{-}1)$$

where

E_c is the value of the modulus of elasticity at the minimum metal temperature consistent with the loading under consideration;

E_h is the value of the modulus of elasticity at the maximum metal temperature consistent with the loading under consideration;

For cryo piping where hot condition is „assembly temperature“ the cold condition is -200°C the thermal expansion is already calculated based on Ec but the allowable stresses are again reduced by Eh/Ec.

Factor Ec/Eh gives strange results for cryo-piping

Solution:

Change the definition of Ec in the equation (12.1.3.1)

$$f_a = U\left(1.25 f_c + 0.25 f_h\right)\frac{E_h}{E_c}$$

E_c is the value of the modulus of elasticity at the minimum metal temperature consistent with the loading under consideration. In cases where operation conditions with temperatures below assembly temperature exist, E_c may be taken as the modulus of elasticity at assembly temperature .

Mitre Bends at high pressure ?

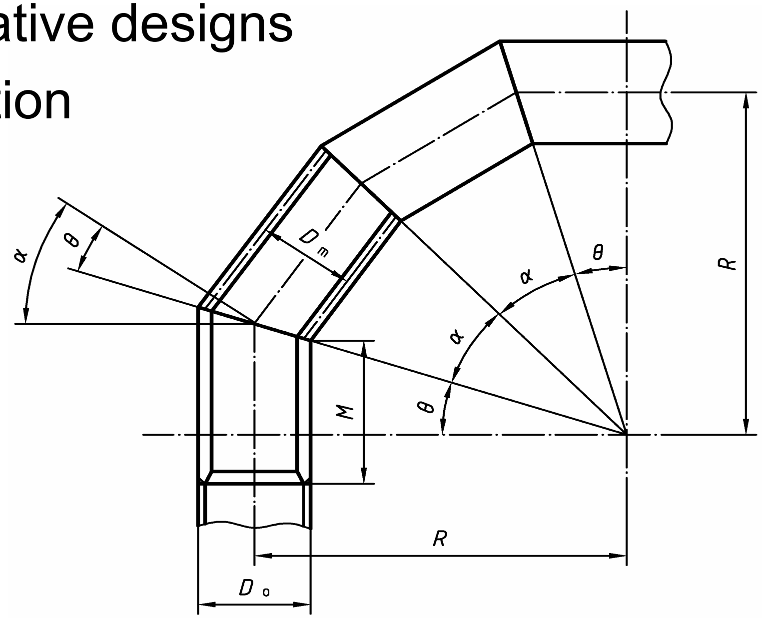
The current code limits the use of mitre bends to 20 bar :

6.3.1 ...Time independent design stress:

the calculation pressure p_c is less or equal to 20 bar (2,0 MPa);

This limitation is not given in other stress codes (FDBR, ASME B31.3). Is this limit required to prevent non-conservative designs or are the provisions for maximum pressure calculation (6.3.4 and 6.3.5) sufficient? e.g:

$$p_a = \frac{2 f z e_a}{D_m}\left(\frac{e_a}{e_a + 0.643 \tan\theta \sqrt{0,5 D_m e_a}}\right)$$

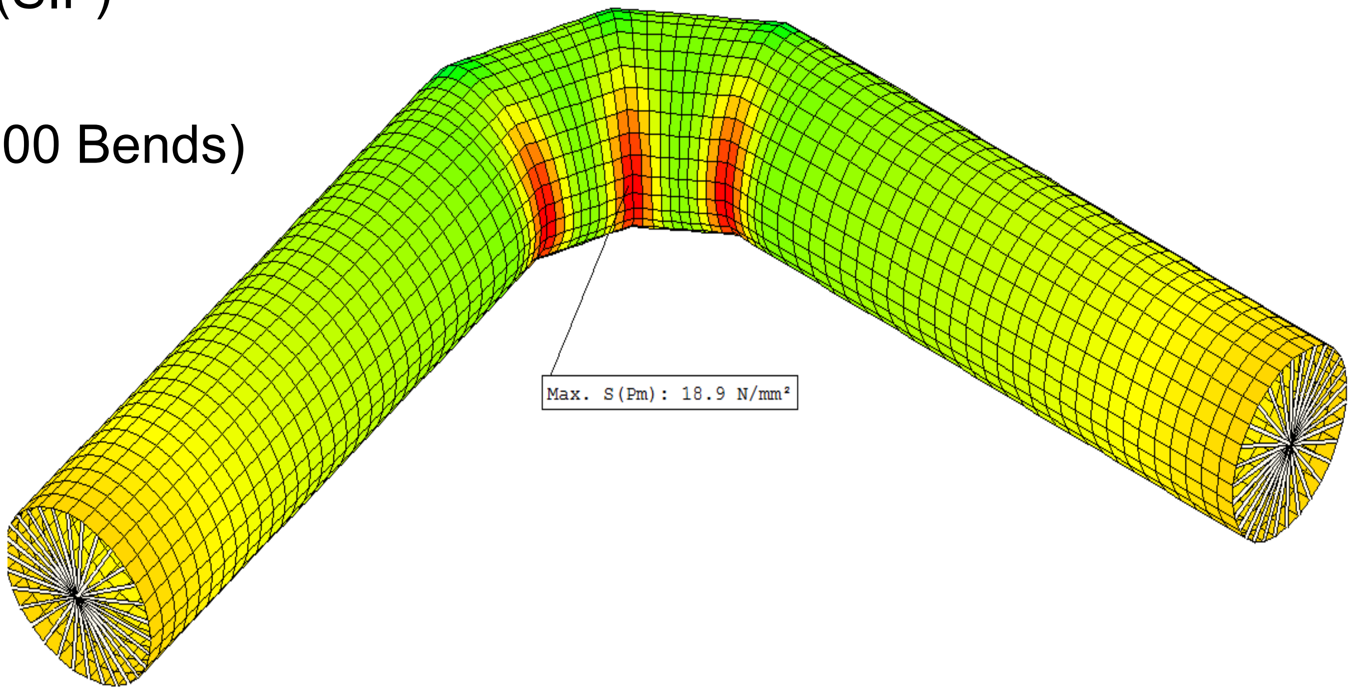


Mitre Bends at high pressure ?

What reasons for the limitation:

1) Internal pressure design formula?
2) Longitudinal stresses (SIF)

FE- Series Analysis (16900 Bends)
- 1-5 Segments
- 19*DN : 300-3200
- 17*s : 2-40mm
- 7* Internal pressure
(for pressure stiffening)



Mitre Bends – Internal Pressure design ?

1) Internal pressure design formula:

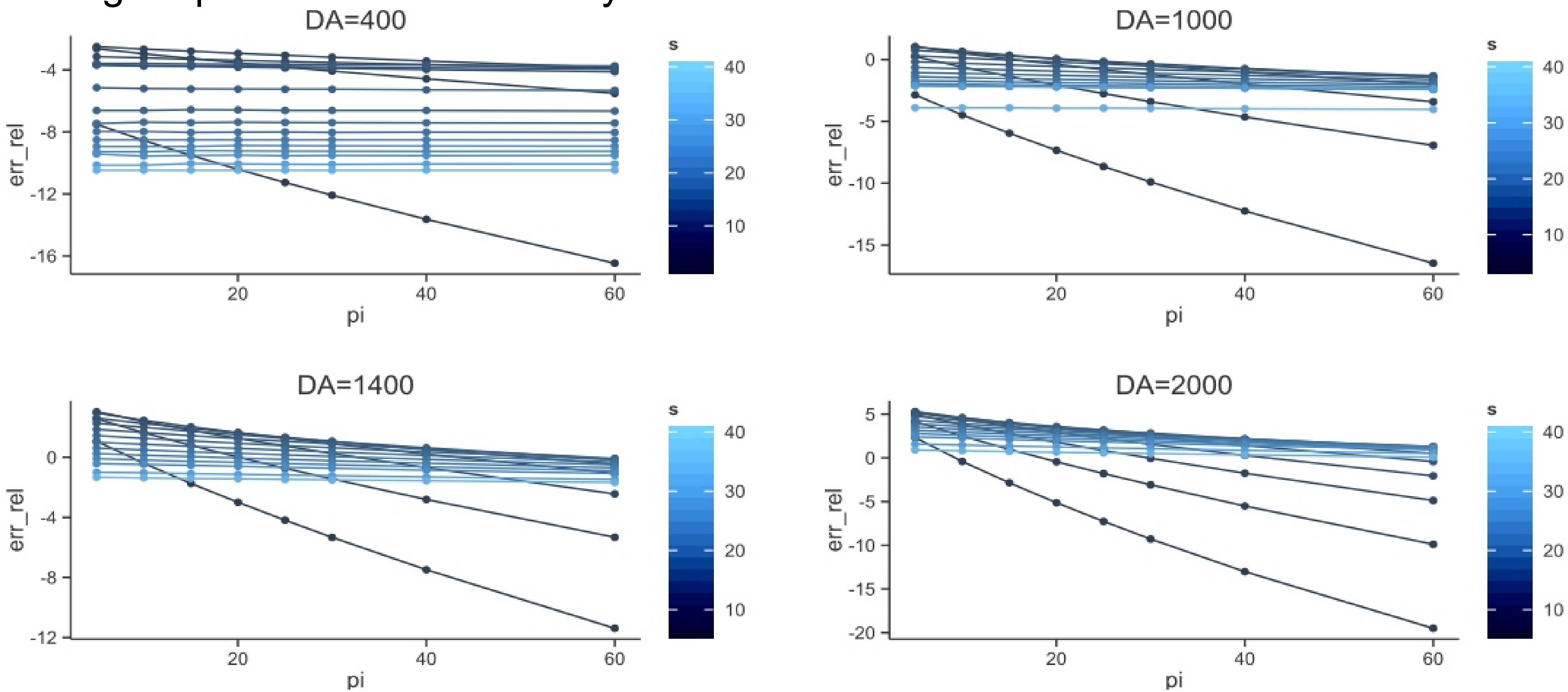
$$p_a = \frac{2 f z e_a}{D_m}\left(\frac{e_a}{e_a + 0.643 \tan\theta \sqrt{0,5 D_m e_a}}\right)$$

Stresses are proportional to pressure!

Stresses from FE Analysis are proportional with pressure unless internal pressure stiffening is considered.

Mitre Bends – Internal Pressure design ?

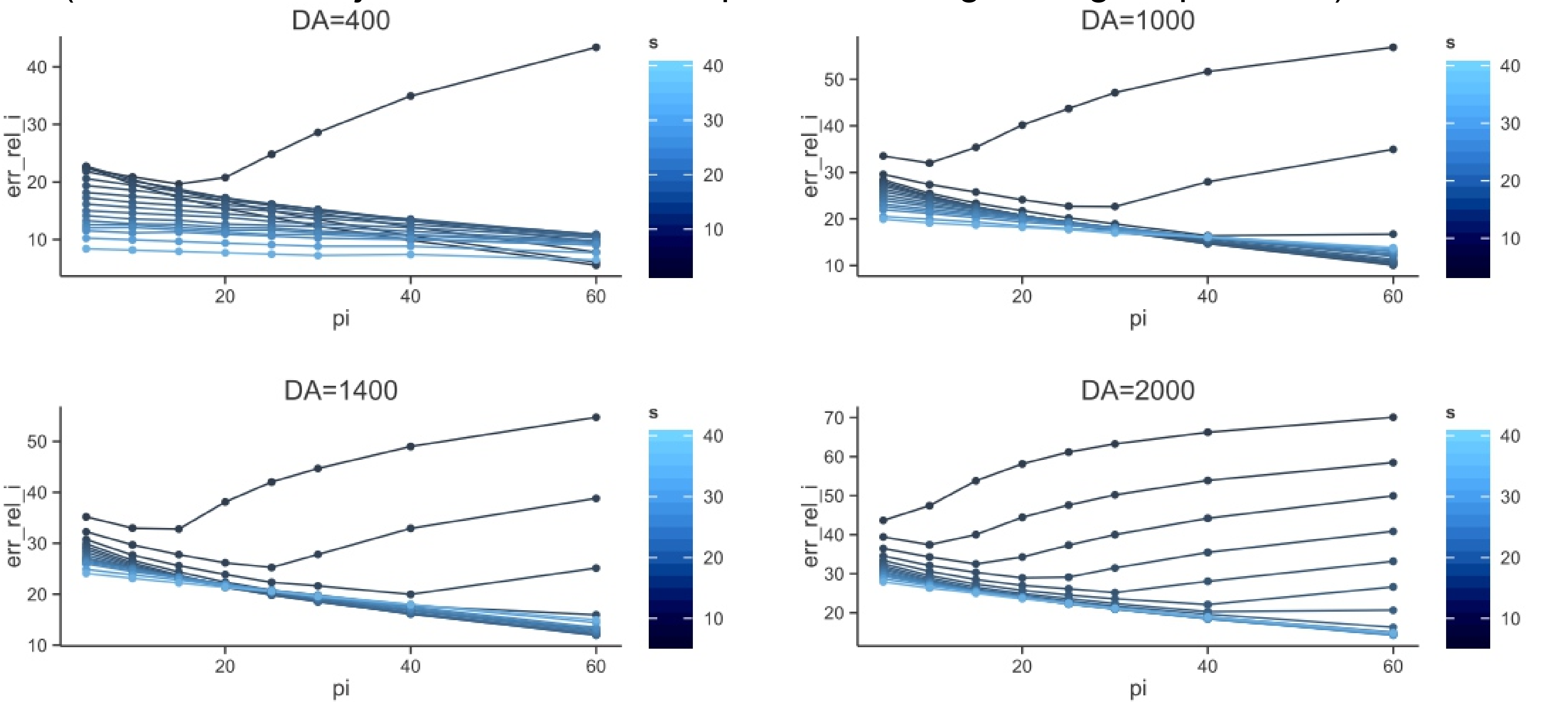
Pressure stiffening : design formulas are more conservative at higher pressure than FE-Analysis!



Mitre Bends – Longitudinal Stresses ?

SIF is less conservative at higher pressure for very thin walled bends.

(But these are rejected in the internal pressure design at higher pressure)



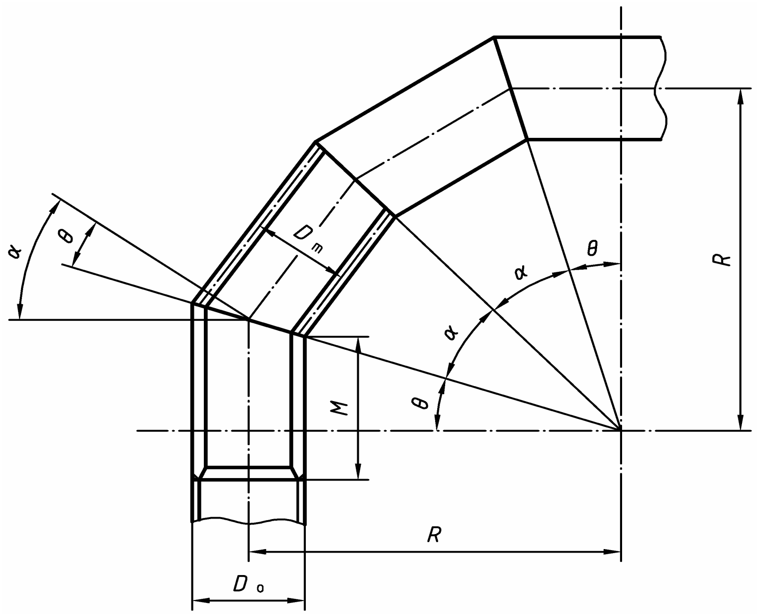
Mitre Bends at high pressure → Yes!

Conclusion:

There is not systematic limitation in the stress code which make the design process invalid above 20 bars.

The limitation:

6.3.1 ...Time independent design stress: the calculation pressure p_c is less or equal to 20 bar (2,0 MPa);



can be removed