Tutorial on Pressure Design of Pipe and Pipe Fittings according to EN 13480-3 (2017)

Pressure Design of Pipe and Pipe Fittings can be performed using the modules built into CAEPIPE which are independent of the flexibility analysis.

These modules can be launched through Layout frame > Misc > Internal Pressure Design: EN 13480-3 and Layout frame > Misc > External Pressure Design: EN 13480-3 respectively.

Note:

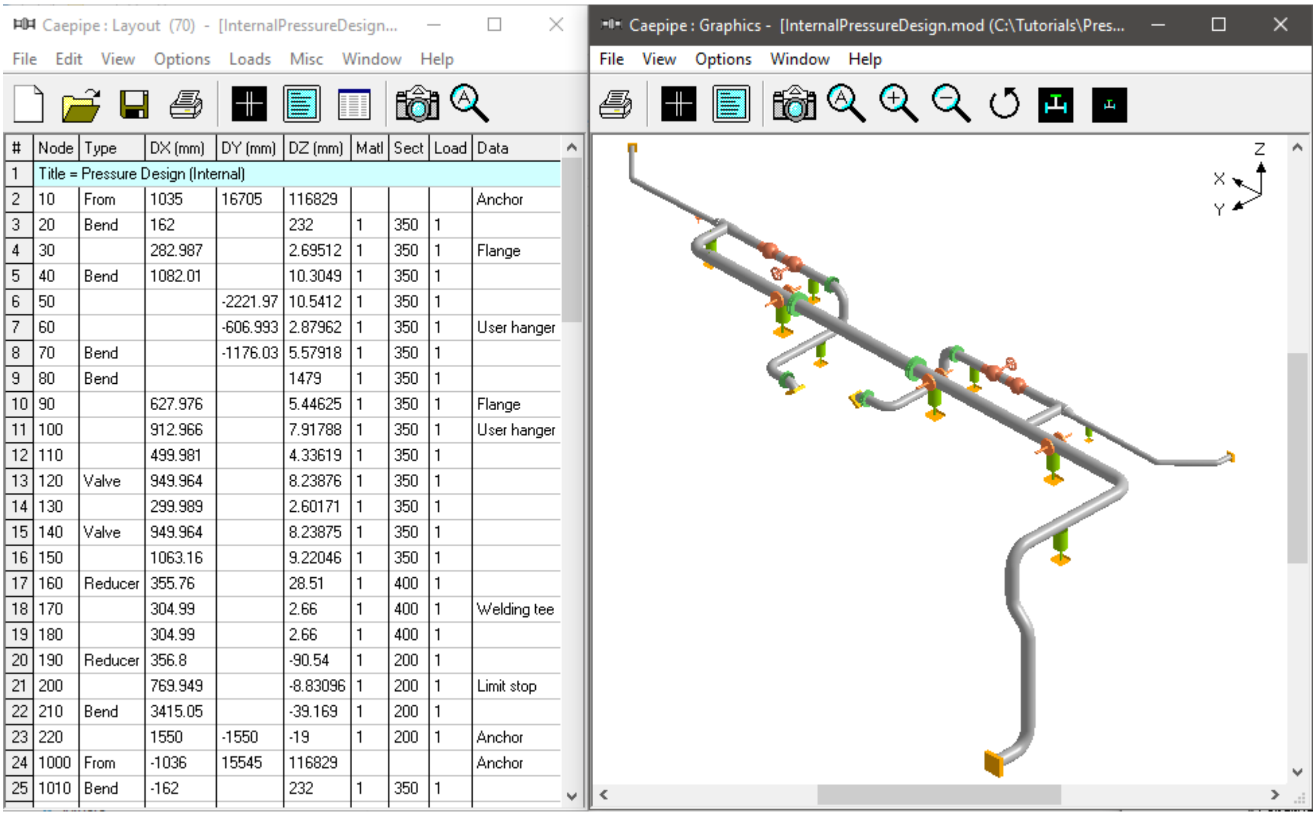
These modules perform Pressure Design of Pipe and Pipe Fittings ONLY using the equations given in the EN 13480-3 (2017) Code irrespective of the Analysis Code selected for flexibility analysis in CAEPIPE.

In case the flexibility analysis is performed with an Analysis Code other than EN 13480-3 (2017), the Pressure Design modules will use the material allowable stresses corresponding to the maximum temperature T1 through T10 entered in the CAEPIPE stress model.

Tutorial on Internal Pressure Design of Pipe and Pipe Fittings

Step 1:

Snap shots shown below present a sample stress model developed to show the Internal Pressure Design calculations performed by CAEPIPE.



#	Node	Type	DX (mm)	DY (mm)	DZ (mm)	Matl	Sect	Load	Data
1	Title = Pressure Design (Internal)								
2	10	From	1035	16705	116829				Anchor
3	20	Bend	162		232	1	350	1	
4	30		282.987		2.69512	1	350	1	Flange
5	40	Bend	1082.01		10.3049	1	350	1	
6	50			-2221.97	10.5412	1	350	1	
7	60			-606.993	2.87962	1	350	1	User hanger
8	70	Bend		-1176.03	5.57918	1	350	1	
9	80	Bend			1479	1	350	1	
10	90		627.976		5.44625	1	350	1	Flange
11	100		912.966		7.91788	1	350	1	User hanger
12	110		499.981		4.33619	1	350	1	
13	120	Valve	949.964		8.23876	1	350	1	
14	130		299.989		2.60171	1	350	1	
15	140	Valve	949.964		8.23875	1	350	1	
16	150		1063.16		9.22046	1	350	1	
17	160	Reducer	355.76		28.51	1	400	1	
18	170		304.99		2.66	1	400	1	Welding tee
19	180		304.99		2.66	1	400	1	
20	190	Reducer	356.8		-90.54	1	200	1	
21	200		769.949		-8.83096	1	200	1	Limit stop
22	210	Bend	3415.05		-39.169	1	200	1	
23	220		1550	-1550	-19	1	200	1	Anchor
24	1000	From	-1036	15545	116829				Anchor
25	1010	Bend	-162		232	1	350	1	

Caepipe : Materials (1) - [InternalPressureDesign.mod (C:\Tutorials\PressureDesign)]

File Edit Options Help

#	Name	Description	Type	Density (kg/m3)	Nu	Joint factor	Tensile (N/mm2)
1	1	EN 10216-2 10CrMo9-10 Seamless	CS	7850	0.3	0.80	229.8
2							

#	Temp (C)	E (kN/mm2)	Alpha (mm/mm/C)	f (N/mm2)	fCR (N/mm2)
1	20	211	11.51E-6	137.1	
2	50	209	11.78E-6	136.9	
3	100	206	12.10E-6	136.5	
4	150	203	12.43E-6	132.8	
5	200	199	12.75E-6	132.8	
6	250	196	13.08E-6	132.8	
7	300	192	13.22E-6	132.8	

Caepipe : Pipe Sections (8) - [InternalPressureDesign.mod (C:\Tutorials\PressureDesign)]

File Edit Options Help

#	Name	Nom Dia	Sch	OD (mm)	Thk (mm)	Cor.Al (mm)	M.Tol (%)	Ins.Dens (kg/m3)	Ins.Thk (mm)	Lin.Dens (kg/m3)	Lin.Thk (mm)	Soil
1	25	25	3	33.7	2.6	1	12.5					
2	50	50	3	60.3	2.9	1	12.5					
3	150	150	3	168.3	4.5	1	12.5	150	100	2700	1	
4	200	200	3	219.1	6.3	1	12.5	150	120	2700	1	
5	300	300	3	323.9	7.1	1	12.5	150	140	2700	1	
6	350	350	3	355.6	8	1	12.5	150	140	2700	1	
7	400	400	3	406.4	8.8	1	12.5	150	140	2700	1	
8	500	500	3	508	11	1	12.5	200	140	2700	1	

Caepipe : Loads (1) - [InternalPressureDesign.mod (C:\Tutorials\02_Press...

File Edit View Options Misc Window Help

#	Name	T1 (C)	P1 (bar)	T2 (C)	P2 (bar)	Desg.T (C)	Desg.Pr. (bar)	Specific gravity	Add.Wgt. (kg/m)	Wind Load 1	Wind Load 2	Wind Load 3	Wind Load 4
1	1	221	22.6	20	-1.00	221	22.6	0.003					
2													

Caepipe : Bends (17) - [InternalPressureDesign.mod (C:\Tutorials\PressureDesign)]

File Edit Options Help

#	Bend Node	Radius (mm)	Rad. Type	Thk (mm)	Bend Matl	Flex.F	In Pln SIF	Out Pln SIF	Int. Node	Angle (deg)	Int. Node	Angle (deg)
1	20	356	Short									
2	40	533	Long									
3	70	533	Long									
4	80	533	Long									
5	210	305	Long									
6	1010	356	Short									
7	1030	533	Long									
8	1060	533	Long									
9	1070	533	Long									

Caepipe : Reducers (5) - [InternalPressureDesign.mod (C:\Tutorials\PressureDesign)]

File Edit Options Help

#	From	To	OD1 (mm)	Thk1 (mm)	OD2 (mm)	Thk2 (mm)	Cone angle (deg)
1	150	160	355.6	8	406.4	8.8	8
2	180	190	406.4	8.8	219.1	6.3	46
3	1140	1150	355.6	8	406.4	8.8	8
4	1170	1180	406.4	8.8	219.1	6.3	46
5	1620	1800	406.4	8.8	508	11	18

Step 2:

Internal pressure design calculations of pipe and pipe fittings according to EN 13480-3 are independent of lengths of elements defined in the CAEPIPE stress model. Hence, these calculations can be performed directly from the existing stress model developed for flexibility analysis. *Equations used for performing Internal Pressure Design as per EN 13480-3 (2017) are provided at the end of this tutorial for reference*.

Once the layout of the stress model as shown in the above snap shots is completed, the internal pressure design is performed through Layout window > Misc > Internal Pressure Design: EN 13480-3.

When executed, CAEPIPE automatically performs the pressure design calculations for Pipes, Elbows, Miters, Bends and Reducers for the entire stress model and displays the results as shown below.

It is observed that the ratios Uf1 and Uf2 are all less than 1.0, confirming that the Internal Pressure Design requirements of EN 13480-3 (2017) code are met for this stress model.

Caepipe : Internal Pressure Design: EN 13480-3 (2017) (74) - [InternalPressureDesign.mod (C:\Tutorials\PressureDesign)]

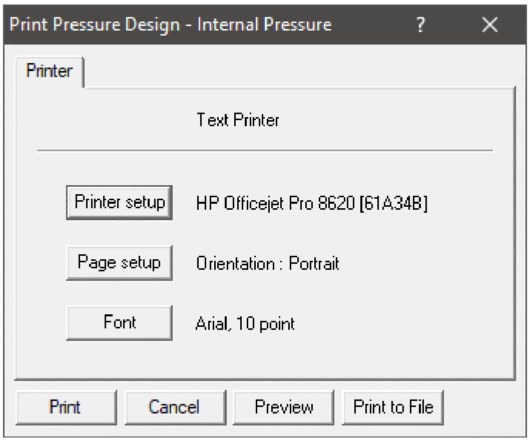
File Options Window Help

#	From	To	Element Type	Des.Temp (C)	Des.Press (bar)	All.Stress (N/mm2)	OD1 (mm)	OD2 (mm)	Cor.All (mm)	Radius (mm)	Cone Angle (deg)	ea1 (mm)	ea2 (mm)	ep1 (mm)	ep2 (mm)	Uf1 (ep1/ea1)	Uf2 (ep2/ea2)
1	10	20	Elbow	221	22.6	132.8	355.6	355.6	1	356		6	6	4.4417	4.4417	0.74	0.74
2			Bend	221	22.6	132.8	355.6	355.6	1	356		6	6	4.4824	2.4943	0.75	0.42
3	20	30	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
4	30	40	Elbow	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7316	3.7316	0.62	0.62
5			Bend	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7468	2.6225	0.62	0.44
6	40	50	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
7	50	60	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
8	60	70	Elbow	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7316	3.7316	0.62	0.62
9			Bend	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7468	2.6225	0.62	0.44
10	70	80	Elbow	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7316	3.7316	0.62	0.62
11			Bend	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7468	2.6225	0.62	0.44
12	80	90	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
13	90	100	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
14	100	110	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
15	120	130	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
16	140	150	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
17	150	160	Reducer	221	22.6	132.8	406.4	355.6	1		8	6.7	6	3.4289	3.0003	0.51	0.50
18	160	170	Pipe	221	22.6	132.8	406.4	406.4	1			6.7	6.7	3.4289	3.4289	0.51	0.51
19	170	180	Pipe	221	22.6	132.8	406.4	406.4	1			6.7	6.7	3.4289	3.4289	0.51	0.51
20	180	190	Reducer	221	22.6	132.8	406.4	219.1	1		46	6.7	4.5125	4.4882	2.9294	0.67	0.65
21	190	200	Pipe	221	22.6	132.8	219.1	219.1	1			4.5125	4.5125	1.8486	1.8486	0.41	0.41

See the attached model "InternalPressureDesign.mod" for more details.

Step 3:

The results shown above can also be printed to the printer or to a file using the option File > Print.



Internal Pressure Design: EN 13480-3 (2017) (74)

From	To	Element Type	Des.Temp (C)	Des.Press (bar)	All.Stress (N/mm2)	OD1 (mm)	OD2 (mm)	Cor.All (mm)	Radius (mm)	Cone Angle (deg)	ea1 (mm)	ea2 (mm)	ep1 (mm)	ep2 (mm)	Uf1 (ep1/ea1)	Uf2 (ep2/ea2)
10	20	Elbow	221	22.6	132.8	355.6	355.6	1	356		6	6	4.4417	4.4417	0.74	0.74
		Bend	221	22.6	132.8	355.6	355.6	1	356		6	6	4.4824	2.4943	0.75	0.42
20	30	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
30	40	Elbow	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7316	3.7316	0.62	0.62
		Bend	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7468	2.6225	0.62	0.44
40	50	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
50	60	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
60	70	Elbow	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7316	3.7316	0.62	0.62
		Bend	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7468	2.6225	0.62	0.44
70	80	Elbow	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7316	3.7316	0.62	0.62
		Bend	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7468	2.6225	0.62	0.44
80	90	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
90	100	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
100	110	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
120	130	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
140	150	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
150	160	Reducer	221	22.6	132.8	406.4	355.6	1		8	6.7	6	3.4289	3.0003	0.51	0.50
160	170	Pipe	221	22.6	132.8	406.4	406.4	1			6.7	6.7	3.4289	3.4289	0.51	0.51
170	180	Pipe	221	22.6	132.8	406.4	406.4	1			6.7	6.7	3.4289	3.4289	0.51	0.51
180	190	Reducer	221	22.6	132.8	406.4	219.1	1		46	6.7	4.5125	4.4882	2.9294	0.67	0.65
190	200	Pipe	221	22.6	132.8	219.1	219.1	1			4.5125	4.5125	1.8486	1.8486	0.41	0.41
200	210	Elbow	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3525	2.3525	0.52	0.52
		Bend	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3634	1.6025	0.52	0.36
210	220	Pipe	221	22.6	132.8	219.1	219.1	1			4.5125	4.5125	1.8486	1.8486	0.41	0.41
1000	1010	Elbow	221	22.6	132.8	355.6	355.6	1	356		6	6	4.4417	4.4417	0.74	0.74
		Bend	221	22.6	132.8	355.6	355.6	1	356		6	6	4.4824	2.4943	0.75	0.42
1010	1020	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
1020	1030	Elbow	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7316	3.7316	0.62	0.62
		Bend	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7468	2.6225	0.62	0.44
1030	1040	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50

Internal Pressure Design: EN 13480-3 (2017) (74)																
From	To	Element Type	Des.Temp (C)	Des.Press (bar)	All.Stress (N/mm2)	OD1 (mm)	OD2 (mm)	Cor.All (mm)	Radius (mm)	Cone Angle (deg)	ea1 (mm)	ea2 (mm)	ep1 (mm)	ep2 (mm)	Uf1 (ep1/ea1)	Uf2 (ep2/ea2)
1040	1050	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
1050	1060	Elbow	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7316	3.7316	0.62	0.62
		Bend	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7468	2.6225	0.62	0.44
1060	1070	Elbow	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7316	3.7316	0.62	0.62
		Bend	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7468	2.6225	0.62	0.44
1070	1080	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
1080	1090	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
1090	1100	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
1110	1120	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
1130	1140	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
1140	1150	Reducer	221	22.6	132.8	406.4	355.6	1		8	6.7	6	3.4289	3.0003	0.51	0.50
1150	1160	Pipe	221	22.6	132.8	406.4	406.4	1			6.7	6.7	3.4289	3.4289	0.51	0.51
1160	1170	Pipe	221	22.6	132.8	406.4	406.4	1			6.7	6.7	3.4289	3.4289	0.51	0.51
1170	1180	Reducer	221	22.6	132.8	406.4	219.1	1		46	6.7	4.5125	4.4882	2.9294	0.67	0.65
1180	1190	Pipe	221	22.6	132.8	219.1	219.1	1			4.5125	4.5125	1.8486	1.8486	0.41	0.41
1190	1200	Elbow	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3525	2.3525	0.52	0.52
		Bend	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3634	1.6025	0.52	0.36
1200	1210	Elbow	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3525	2.3525	0.52	0.52
		Bend	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3634	1.6025	0.52	0.36
1210	1220	Pipe	221	22.6	132.8	219.1	219.1	1			4.5125	4.5125	1.8486	1.8486	0.41	0.41
170	1600	Pipe	221	22.6	132.8	406.4	406.4	1			6.7	6.7	3.4289	3.4289	0.51	0.51
1600	1610	Elbow	221	22.6	132.8	406.4	406.4	1	610		6.7	6.7	4.2629	4.2629	0.64	0.64
		Bend	221	22.6	132.8	406.4	406.4	1	610		6.7	6.7	4.2803	2.9976	0.64	0.45
1610	1620	Pipe	221	22.6	132.8	406.4	406.4	1			6.7	6.7	3.4289	3.4289	0.51	0.51
1160	1850	Pipe	221	22.6	132.8	406.4	406.4	1			6.7	6.7	3.4289	3.4289	0.51	0.51
1620	1800	Reducer	221	22.6	132.8	508	406.4	1		18	8.625	6.7	4.2861	3.7079	0.50	0.55
1800	1810	Pipe	221	22.6	132.8	508	508	1			8.625	8.625	4.2861	4.2861	0.50	0.50
1810	1820	Pipe	221	22.6	132.8	508	508	1			8.625	8.625	4.2861	4.2861	0.50	0.50
1820	1830	Pipe	221	22.6	132.8	508	508	1			8.625	8.625	4.2861	4.2861	0.50	0.50
1830	1840	Pipe	221	22.6	132.8	508	508	1			8.625	8.625	4.2861	4.2861	0.50	0.50

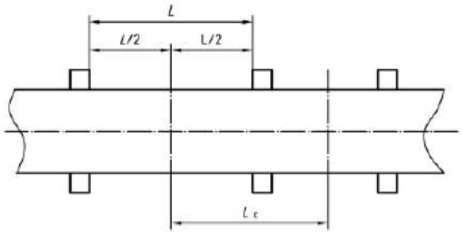
Internal Pressure Design: EN 13480-3 (2017) (74)																
From	To	Element Type	Des.Temp (C)	Des.Press (bar)	All.Stress (N/mm2)	OD1 (mm)	OD2 (mm)	Cor.All (mm)	Radius (mm)	Cone Angle (deg)	ea1 (mm)	ea2 (mm)	ep1 (mm)	ep2 (mm)	Uf1 (ep1/ea1)	Uf2 (ep2/ea2)
1840	1850	Pipe	221	22.6	132.8	508	508	1			8.625	8.625	4.2861	4.2861	0.50	0.50
1850	1860	Pipe	221	22.6	132.8	508	508	1			8.625	8.625	4.2861	4.2861	0.50	0.50
1860	1870	Elbow	221	22.6	132.8	508	508	1	762		8.625	8.625	5.3297	5.3297	0.62	0.62
		Bend	221	22.6	132.8	508	508	1	762		8.625	8.625	5.3514	3.7467	0.62	0.43
1870	1880	Pipe	221	22.6	132.8	508	508	1			8.625	8.625	4.2861	4.2861	0.50	0.50
1880	1890	Elbow	221	22.6	132.8	508	508	1	762		8.625	8.625	5.3297	5.3297	0.62	0.62
		Bend	221	22.6	132.8	508	508	1	762		8.625	8.625	5.3514	3.7467	0.62	0.43
1890	1900	Elbow	221	22.6	132.8	508	508	1	762		8.625	8.625	5.3297	5.3297	0.62	0.62
		Bend	221	22.6	132.8	508	508	1	762		8.625	8.625	5.3514	3.7467	0.62	0.43
1900	1910	Elbow	221	22.6	132.8	508	508	1	762		8.625	8.625	5.3297	5.3297	0.62	0.62
		Bend	221	22.6	132.8	508	508	1	762		8.625	8.625	5.3514	3.7467	0.62	0.43
1910	1920	Elbow	221	22.6	132.8	508	508	1	762		8.625	8.625	5.3297	5.3297	0.62	0.62
		Bend	221	22.6	132.8	508	508	1	762		8.625	8.625	5.3514	3.7467	0.62	0.43
1920	1930	Pipe	221	22.6	132.8	508	508	1			8.625	8.625	4.2861	4.2861	0.50	0.50

Tutorial on External Pressure Design of Pipe and Pipe Fittings

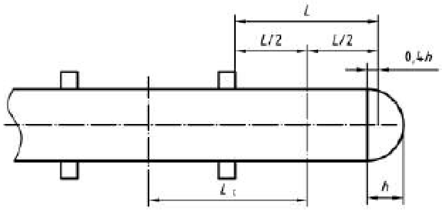
External Pressure Design module will function ONLY when the stress layout is defined with negative pressure (such as vacuum pressure).

This module first calculates collapse pressure (same as buckling pressure), which is a function of span length "L" between the stiffeners placed on the piping (shown in figures below). Since the collapse (buckling) mode of deformation for a pipe element between two adjacent stiffeners is restrained by these stiffeners, shorter the span length L between the stiffeners, higher the collapse (buckling) pressure.

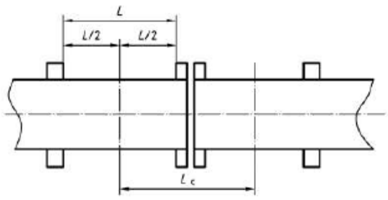
The External Pressure Design module assumes that a stiffener is located at each node of the CAEPIPE model. Hence, ensure that nodes are defined in CAEPIPE model only at locations where the stiffeners are attached to the piping. Even nodes where flanges or certain types of supports that restrain the collapse (buckling) mode of deformation should be included as "stiffener locations". All other nodes at which the collapse (buckling) mode of deformation is not restrained (such as resting supports) should not be included in the CAEPIPE model for external pressure design calculations. In other words, the CAEPIPE stress model (that was developed for flexibility analysis) needs to be edited before performing the external pressure design.



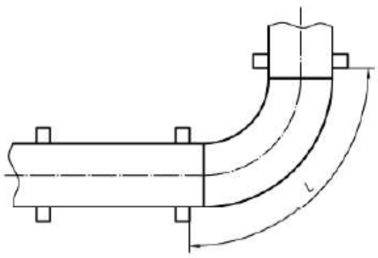
Single Pipe



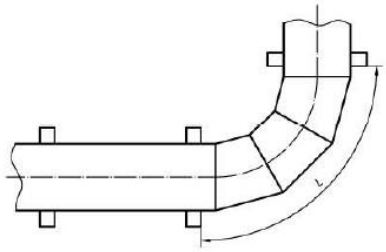
Pipe with bend



Pipe with flange connections



Pipe with bend or elbow with 'L' measured on extrados



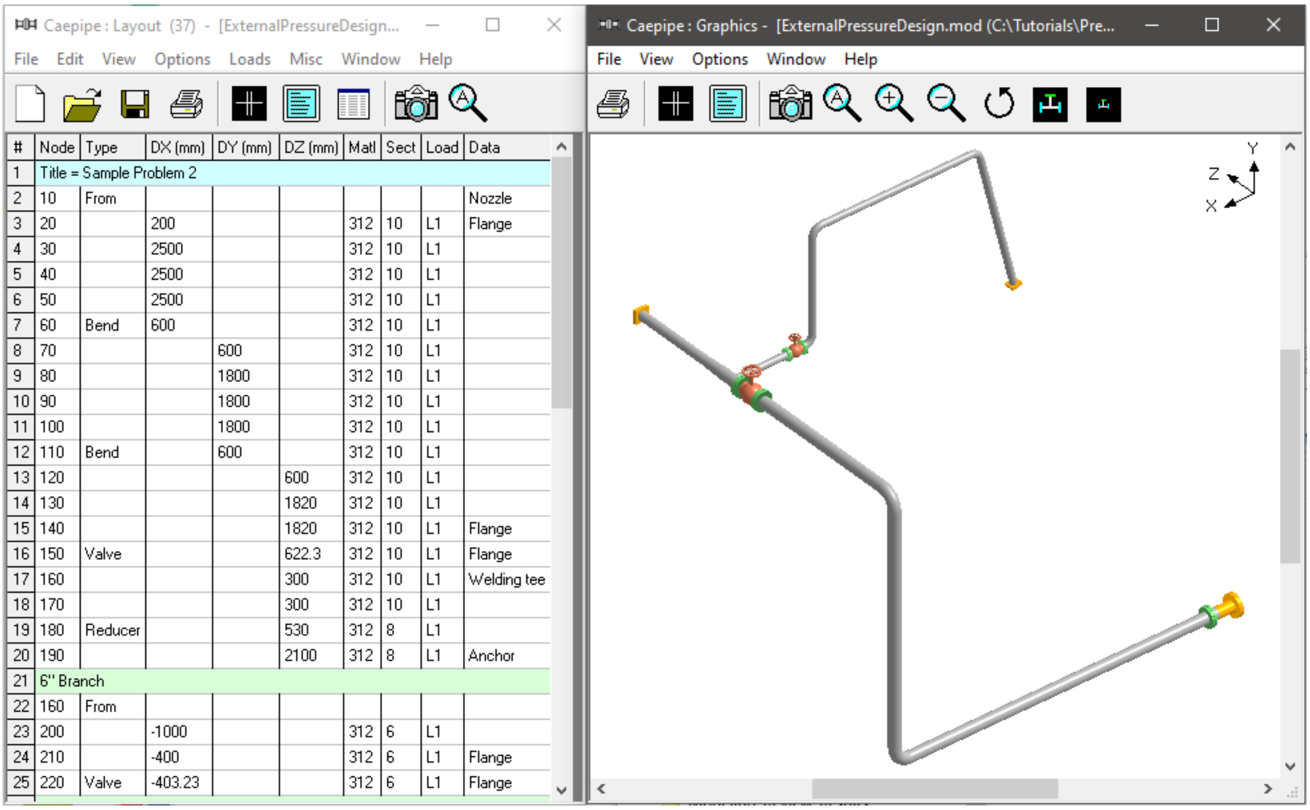
Pipe with mitre with 'L' measured on extrados

Step 1:

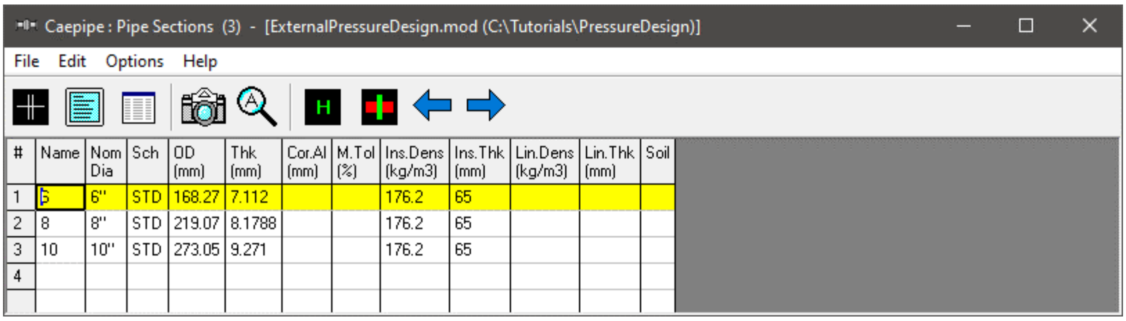
The procedure given below will help in retaining ONLY those nodes of the CAEPIPE stress model (originally developed for flexibility analysis) prior to External Pressure Design calculations.

- Create a copy of the existing CAEPIPE stress model (developed for flexibility analysis).
- At whichever node the collapse (buckling) mode of deformation is NOT restrained, navigate to that element node in the layout window and use the option "Combine…" through Layout window > Edit. This action will remove that node by combining the two adjacent elements.
- Repeat Step 2 above and remove all other nodes where there are NO stiffeners or flanges or supports [that restrain the collapse (buckling) mode] defined.
- Upon completion, save the model.

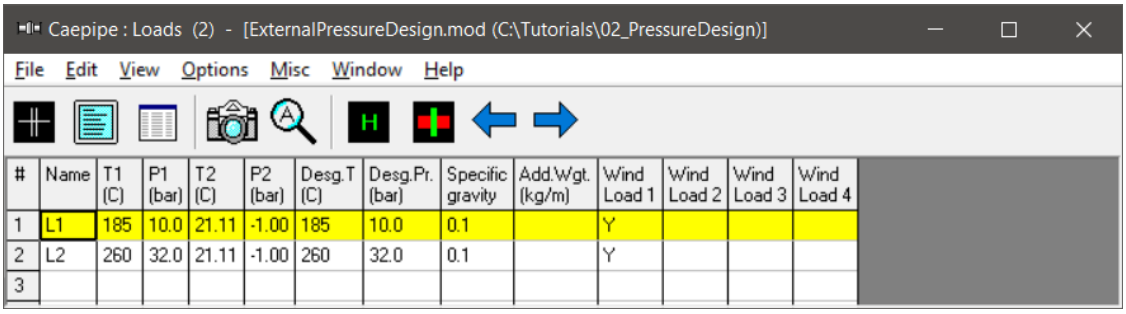
Snap shots shown below present a sample model developed to show the External Pressure Design calculations performed by CAEPIPE. As stated above, a copy of the original stress model was made and the model has been edited to include only those nodes on pipe where stiffeners, flanges and supports (that are equivalent to stiffeners from the point of view of restraining collapse mode of deformation) are attached.



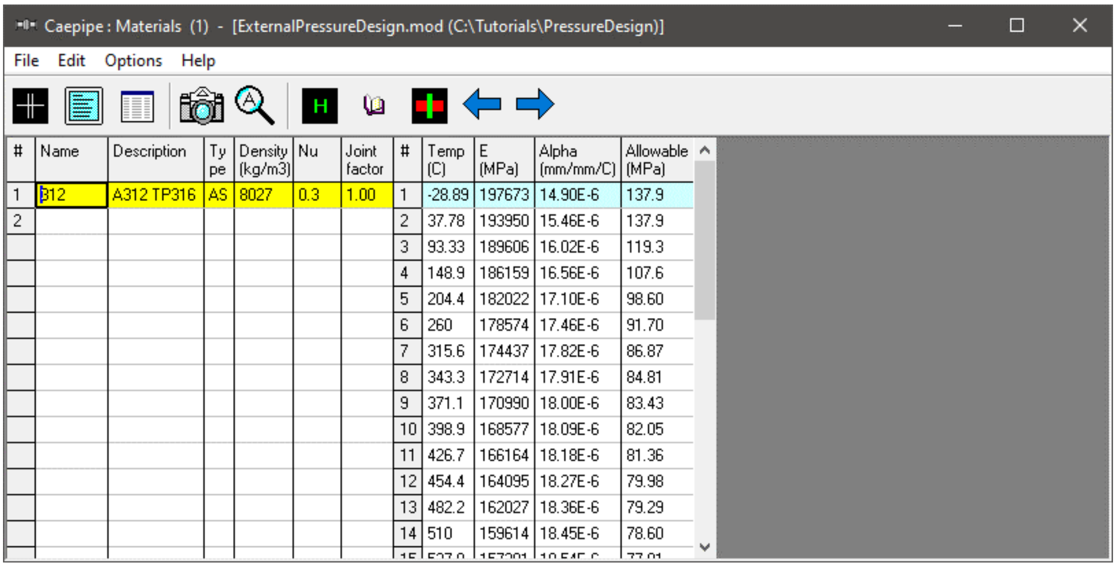
#	Node	Type	DX (mm)	DY (mm)	DZ (mm)	Matl	Sect	Load	Data
1	Title = Sample Problem 2								
2	10	From							Nozzle
3	20		200			312	10	L1	Flange
4	30		2500			312	10	L1	
5	40		2500			312	10	L1	
6	50		2500			312	10	L1	
7	60	Bend	600			312	10	L1	
8	70			600		312	10	L1	
9	80			1800		312	10	L1	
10	90			1800		312	10	L1	
11	100			1800		312	10	L1	
12	110	Bend		600		312	10	L1	
13	120				600	312	10	L1	
14	130				1820	312	10	L1	
15	140				1820	312	10	L1	Flange
16	150	Valve			622.3	312	10	L1	Flange
17	160				300	312	10	L1	Welding tee
18	170				300	312	10	L1	
19	180	Reducer			530	312	8	L1	
20	190				2100	312	8	L1	Anchor
21	6" Branch								
22	160	From							
23	200		-1000			312	6	L1	
24	210		-400			312	6	L1	Flange
25	220	Valve	-403.23			312	6	L1	Flange



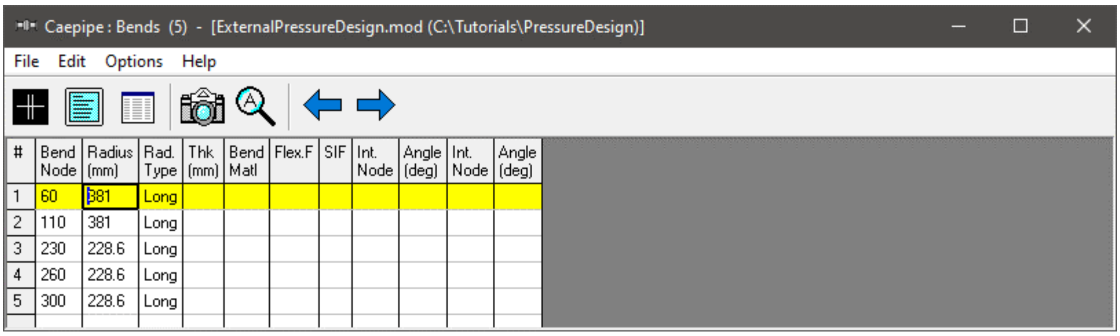
#	Name	Nom Dia	Sch	OD (mm)	Thk (mm)	Cor.Al (mm)	M.Tol (%)	Ins.Dens (kg/m3)	Ins.Thk (mm)	Lin.Dens (kg/m3)	Lin.Thk (mm)	Soil
1	6	6"	STD	168.27	7.112			176.2	65			
2	8	8"	STD	219.07	8.1788			176.2	65			
3	10	10"	STD	273.05	9.271			176.2	65			
4												



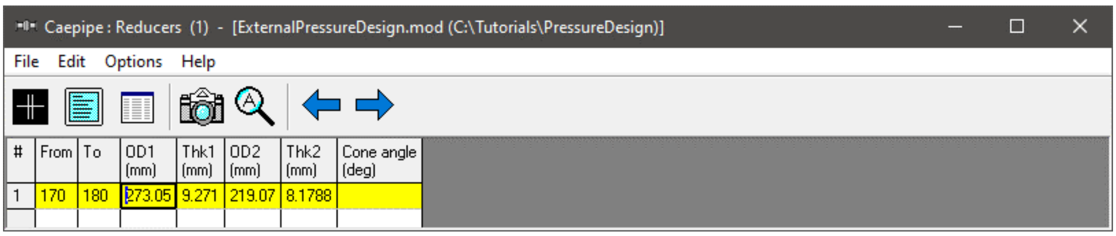
#	Name	T1 (C)	P1 (bar)	T2 (C)	P2 (bar)	Desg.T (C)	Desg.Pr. (bar)	Specific gravity	Add.Wgt. (kg/m)	Wind Load 1	Wind Load 2	Wind Load 3	Wind Load 4
1	L1	185	10.0	21.11	-1.00	185	10.0	0.1		Y			
2	L2	260	32.0	21.11	-1.00	260	32.0	0.1		Y			
3													



#	Name	Description	Type	Density (kg/m3)	Nu	Joint factor	#	Temp (C)	E (MPa)	Alpha (mm/mm/C)	Allowable (MPa)
1	312	A312 TP316	AS	8027	0.3	1.00	1	-28.89	197673	14.90E-6	137.9
2							2	37.78	193950	15.46E-6	137.9
							3	93.33	189606	16.02E-6	119.3
							4	148.9	186159	16.56E-6	107.6
							5	204.4	182022	17.10E-6	98.60
							6	260	178574	17.46E-6	91.70
							7	315.6	174437	17.82E-6	86.87
							8	343.3	172714	17.91E-6	84.81
							9	371.1	170990	18.00E-6	83.43
							10	398.9	168577	18.09E-6	82.05
							11	426.7	166164	18.18E-6	81.36
							12	454.4	164095	18.27E-6	79.98
							13	482.2	162027	18.36E-6	79.29
							14	510	159614	18.45E-6	78.60
							15	[illegible]	[illegible]	[illegible]	[illegible]



#	Bend Node	Radius (mm)	Rad. Type	Thk (mm)	Bend Matl	Flex.F	SIF	Int. Node	Angle (deg)	Int. Node	Angle (deg)
1	60	381	Long								
2	110	381	Long								
3	230	228.6	Long								
4	260	228.6	Long								
5	300	228.6	Long								



#	From	To	OD1 (mm)	Thk1 (mm)	OD2 (mm)	Thk2 (mm)	Cone angle (deg)
1	170	180	273.05	9.271	219.07	8.1788	

Step 2:

Once the layout of the stress model as shown in the above snap shots is completed, the external pressure design is performed through Layout window > Misc > External Pressure Design: EN 13480-3.

When executed, CAEPIPE automatically performs the external pressure design calculations for Pipes, Miters, Elbows, Bends and Reducers for the entire stress model and displays the results as shown below.

It is observed that the ratio [$P_r/(KP_c)$] is much higher than 1.0 throughout the stress model, confirming that the collapse (buckling) pressures P_r calculated for all segments of the stress model are much higher than the corresponding peak negative pressures specified in the CAEPIPE model. In other words, the potential for any segment of this piping system to collapse (buckle) is very minimal.

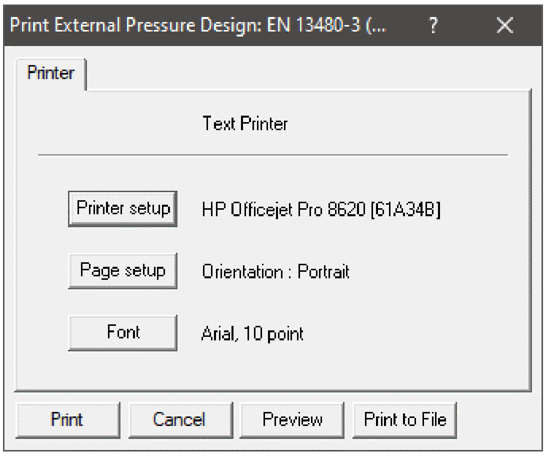
Caepipe : External Pressure Design: EN 13480-3 (2017) (35) - [ExternalPressureDesign.mod (C:\Tutorials\PressureDesign)]

File Options Window Help

#	From	To	Element Type	Temp (C)	Press (Pc) (bar)	All.Stress (MPa)	Yield (MPa)	E (MPa)	OD1 (mm)	OD2 (mm)	Thk1 (mm)	Thk2 (mm)	Cor.All (mm)	Radius (mm)	Length (mm)	Cone Angle (deg)	Pr (bar)	K.Pc (bar)	(Pr/K.Pc)	Ix (mm4)	Ixa (mm4)
1	10	20	Pipe	185	1.00	101.7	165.5	183470	273.05	273.05	9.271	9.271	0		200		111	1.50	74.33		
2	20	30	Pipe	185	1.00	101.7	165.5	183470	273.05	273.05	9.271	9.271	0		2500		79.8	1.50	53.23		
3	30	40	Pipe	185	1.00	101.7	165.5	183470	273.05	273.05	9.271	9.271	0		2500		79.8	1.50	53.23		
4	40	50	Pipe	185	1.00	101.7	165.5	183470	273.05	273.05	9.271	9.271	0		2500		79.8	1.50	53.23		
5	50	60A	Pipe	185	1.00	101.7	165.5	183470	273.05	273.05	9.271	9.271	0		219		111	1.50	74.33		
6	60A	60B	Elbow	185	1.00	101.7	165.5	183470	273.05	273.05	9.271	9.271	0	381	812.926		97.3	1.50	64.88		
7	60B	70	Pipe	185	1.00	101.7	165.5	183470	273.05	273.05	9.271	9.271	0		219		111	1.50	74.33		
8	70	80	Pipe	185	1.00	101.7	165.5	183470	273.05	273.05	9.271	9.271	0		1800		81.1	1.50	54.05		
9	80	90	Pipe	185	1.00	101.7	165.5	183470	273.05	273.05	9.271	9.271	0		1800		81.1	1.50	54.05		
10	90	100	Pipe	185	1.00	101.7	165.5	183470	273.05	273.05	9.271	9.271	0		1800		81.1	1.50	54.05		
11	100	110A	Pipe	185	1.00	101.7	165.5	183470	273.05	273.05	9.271	9.271	0		219		111	1.50	74.33		
12	110A	110B	Elbow	185	1.00	101.7	165.5	183470	273.05	273.05	9.271	9.271	0	381	812.926		97.3	1.50	64.88		
13	110B	120	Pipe	185	1.00	101.7	165.5	183470	273.05	273.05	9.271	9.271	0		219		111	1.50	74.33		
14	120	130	Pipe	185	1.00	101.7	165.5	183470	273.05	273.05	9.271	9.271	0		1820		81.0	1.50	54.00		
15	130	140	Pipe	185	1.00	101.7	165.5	183470	273.05	273.05	9.271	9.271	0		1820		81.0	1.50	54.00		
16	150	160	Pipe	185	1.00	101.7	165.5	183470	273.05	273.05	9.271	9.271	0		300		111	1.50	74.33		
17	160	170	Pipe	185	1.00	101.7	165.5	183470	273.05	273.05	9.271	9.271	0		300		111	1.50	74.33		
18	170	180	Reducer	185	1.00	101.7	165.5	183470	273.05	219.07	9.271	8.1788	0		530		129	1.50	85.97	748.545	4.0901E+6
19	180	190	Pipe	185	1.00	101.7	165.5	183470	219.07	219.07	8.1788	8.1788	0		2100		94.5	1.50	63.02		
20	160	200	Pipe	185	1.00	101.7	165.5	183470	168.27	168.27	7.112	7.112	0		1000		118	1.50	78.44		
21	200	210	Pipe	185	1.00	101.7	165.5	183470	168.27	168.27	7.112	7.112	0		400		136	1.50	90.35		
22	220	230A	Pipe	260	1.00	91.70	165.5	178574	168.27	168.27	7.112	7.112	0		26.3999		140	1.50	93.33		
23	230A	230B	Elbow	260	1.00	91.70	165.5	178574	168.27	168.27	7.112	7.112	0	228.6	491.243		128	1.50	85.43		
24	230B	240	Pipe	260	1.00	91.70	165.5	178574	168.27	168.27	7.112	7.112	0		271.4		140	1.50	93.33		
25	240	250	Pipe	260	1.00	91.70	165.5	178574	168.27	168.27	7.112	7.112	0		1800		115	1.50	76.74		
26	250	260A	Pipe	260	1.00	91.70	165.5	178574	168.27	168.27	7.112	7.112	0		271.4		140	1.50	93.33		
27	260A	260B	Elbow	260	1.00	91.70	165.5	178574	168.27	168.27	7.112	7.112	0	228.6	491.243		128	1.50	85.43		

Step 3:

The results shown above can also be printed to the printer or to a file using the option File > Print.



External Pressure Design: EN 13480-3 (2017) (35)

From	To	Element Type	Temp (C)	Press (Pc) (bar)	All.Stress (MPa)	Yield (MPa)	E (MPa)	OD1 (mm)	OD2 (mm)	Thk1 (mm)	Thk2 (mm)	Cor.All (mm)	Radius (mm)	Length (mm)	ncyl	Cone Angle (deg)	Pr (bar)	K.Pc (bar)	(Pr/K.Pc)	Ix (mm4)	Ixa (mm4)
10	20	Pipe	185	1.00	101.7	122.1	183470	273.05	273.05	9.271	9.271	0		200	4		82.3	1.50	54.83		
20	30	Pipe	185	1.00	101.7	122.1	183470	273.05	273.05	9.271	9.271	0		2500	2		65.5	1.50	43.70		
30	40	Pipe	185	1.00	101.7	122.1	183470	273.05	273.05	9.271	9.271	0		2500	2		65.5	1.50	43.70		
40	50	Pipe	185	1.00	101.7	122.1	183470	273.05	273.05	9.271	9.271	0		2500	2		65.5	1.50	43.70		
50	60A	Pipe	185	1.00	101.7	122.1	183470	273.05	273.05	9.271	9.271	0		219	4		82.3	1.50	54.83		
60A	60B	Elbow	185	1.00	101.7	122.1	183470	273.05	273.05	9.271	9.271	0	381	812.926	2		75.7	1.50	50.45		
60B	70	Pipe	185	1.00	101.7	122.1	183470	273.05	273.05	9.271	9.271	0		219	4		82.3	1.50	54.83		
70	80	Pipe	185	1.00	101.7	122.1	183470	273.05	273.05	9.271	9.271	0		1800	2		66.3	1.50	44.21		
80	90	Pipe	185	1.00	101.7	122.1	183470	273.05	273.05	9.271	9.271	0		1800	2		66.3	1.50	44.21		
90	100	Pipe	185	1.00	101.7	122.1	183470	273.05	273.05	9.271	9.271	0		1800	2		66.3	1.50	44.21		
100	110A	Pipe	185	1.00	101.7	122.1	183470	273.05	273.05	9.271	9.271	0		219	4		82.3	1.50	54.83		
110A	110B	Elbow	185	1.00	101.7	122.1	183470	273.05	273.05	9.271	9.271	0	381	812.926	2		75.7	1.50	50.45		
110B	120	Pipe	185	1.00	101.7	122.1	183470	273.05	273.05	9.271	9.271	0		219	4		82.3	1.50	54.83		
120	130	Pipe	185	1.00	101.7	122.1	183470	273.05	273.05	9.271	9.271	0		1820	2		66.3	1.50	44.18		
130	140	Pipe	185	1.00	101.7	122.1	183470	273.05	273.05	9.271	9.271	0		1820	2		66.3	1.50	44.18		
150	160	Pipe	185	1.00	101.7	122.1	183470	273.05	273.05	9.271	9.271	0		300	3		82.3	1.50	54.83		
160	170	Pipe	185	1.00	101.7	122.1	183470	273.05	273.05	9.271	9.271	0		300	3		82.3	1.50	54.83		
170	180	Reducer	185	1.00	101.7	122.1	183470	273.05	219.07	9.271	8.1788	0		530	2		97.9	1.50	65.27	748.545	4.0901E+6
180	190	Pipe	185	1.00	101.7	122.1	183470	219.07	219.07	8.1788	8.1788	0		2100	2		76.2	1.50	50.83		
160	200	Pipe	185	1.00	101.7	122.1	183470	168.27	168.27	7.112	7.112	0		1000	2		92.5	1.50	61.65		
200	210	Pipe	185	1.00	101.7	122.1	183470	168.27	168.27	7.112	7.112	0		400	2		103	1.50	68.85		
220	230A	Pipe	260	1.00	91.70	110.0	178574	168.27	168.27	7.112	7.112	0		26.3999	4		93.1	1.50	62.06		
230A	230B	Elbow	260	1.00	91.70	110.0	178574	168.27	168.27	7.112	7.112	0	228.6	491.243	2		90.6	1.50	60.43		
230B	240	Pipe	260	1.00	91.70	110.0	178574	168.27	168.27	7.112	7.112	0		271.4	3		93.1	1.50	62.06		
240	250	Pipe	260	1.00	91.70	110.0	178574	168.27	168.27	7.112	7.112	0		1800	2		83.7	1.50	55.80		
250	260A	Pipe	260	1.00	91.70	110.0	178574	168.27	168.27	7.112	7.112	0		271.4	3		93.1	1.50	62.06		
260A	260B	Elbow	260	1.00	91.70	110.0	178574	168.27	168.27	7.112	7.112	0	228.6	491.243	2		90.6	1.50	60.43		
260B	270	Pipe	260	1.00	91.70	110.0	178574	168.27	168.27	7.112	7.112	0		271.4	3		93.1	1.50	62.06		
270	280	Pipe	260	1.00	91.70	110.0	178574	168.27	168.27	7.112	7.112	0		1800	2		83.7	1.50	55.80		
280	290	Pipe	260	1.00	91.70	110.0	178574	168.27	168.27	7.112	7.112	0		1490	2		83.8	1.50	55.87		
290	300A	Pipe	260	1.00	91.70	110.0	178574	168.27	168.27	7.112	7.112	0		321.278	3		93.1	1.50	62.06		
300A	300B	Elbow	260	1.00	91.70	110.0	178574	168.27	168.27	7.112	7.112	0	228.6	415.032	2		93.1	1.50	62.06		
300B	310	Pipe	260	1.00	91.70	110.0	178574	168.27	168.27	7.112	7.112	0		321.278	3		93.1	1.50	62.06		
310	320	Pipe	260	1.00	91.70	110.0	178574	168.27	168.27	7.112	7.112	0		1635.72	2		83.7	1.50	55.83		
320	330	Pipe	260	1.00	91.70	110.0	178574	168.27	168.27	7.112	7.112	0		1635.72	2		83.7	1.50	55.83		

Design of pipe and pipe fittings under internal pressure according to EN 13480-3 (2017)

Straight Pipes

The minimum required wall thickness for a straight pipe without allowances and tolerances, ep, is calculated from equation 6.1-1 and 6.1-3 depending on the ratio between inner and outer diameter as follows:

For $D_o/D_i <= 1.7$

$$ep = \frac{P_c D_0}{2fz + P_c}$$

For $D_o/D_i > 1.7$

$$ep = \frac{D_o}{2}\left[1 - \sqrt{\frac{fz - p_c}{fz + p_c}}\right]$$

where,

D_o = outside diameter of pipe

D_i = inside diameter of pipe = Do – 2 x e_n

e_n = nominal wall thickness of pipe

f = Allowable stress for material at maximum temperature

z = weld efficiency factor = 1.0

p_c = maximum internal pressure = maximum of CAEPIPE input pressures P1 through P10

e_p = minimum required wall thickness

Elbows

The minimum required wall thickness of the intrados and the extrados of the elbow without allowances and tolerances, ep1 / ep2, is calculated from equation B.4.1-3

ep1 = ep2 = e.B

$$B = \frac{D_0}{2e} - \frac{R}{e} + \sqrt{\left[\frac{D_0}{2e} - \frac{R}{e}\right]^2 + 2\frac{R}{e} - \frac{D_0}{2e}}$$

where

D_o = outside diameter of elbow

e = minimum required wall thickness of corresponding straight pipe computed as per Eq. 6.1-1 or 6.1-3

R = radius of the elbow

ep1 = ep2 = minimum required wall thickness of the elbow

Bends (formed by cold bending of straight pipes)

Wall thickness of the intrados of the bend

The minimum required wall thickness of the intrados of the bend without allowances and tolerances, ep1, is calculated from equation B.4.1-1

ep1 = e . B_{int}

$$B_{int} = \frac{D_0}{2e} + \frac{r}{e} - \left[\frac{D_o}{2e} + \frac{r}{e} - 1\right] \sqrt{\frac{\left(\frac{r}{e}\right)^2 - \left(\frac{D_o}{2e}\right)^2}{\left(\frac{r}{e}\right)^2 - \frac{D_o}{2e}\left(\frac{D_o}{2e} - 1\right)}}$$

r/e is calculated from

$$\frac{r}{e} = \sqrt{\frac{1}{2}\left\{\left(\frac{D_o}{2e}\right)^2 + \left(\frac{R}{e}\right)^2\right\} + \sqrt{\frac{1}{4}\left(\left(\frac{D_o}{2e}\right)^2 + \left(\frac{R}{e}\right)^2\right)^2 - \frac{D_o}{2e}\left(\frac{D_o}{2e} - 1\right)\left(\frac{R}{e}\right)^2}}$$

where

D_o = outside diameter of bend

D_i = inside diameter of bend = Do – 2 x e_n

e = minimum required wall thickness of corresponding straight pipe computed as per Eq. 6.1-1 or 6.1-3

R = radius of the bend

e_{p1} = minimum required wall thickness of the intrados

Wall thickness of the extrados of the bend

The minimum required wall thickness of the extrados of the bend without allowances and tolerances, ep2, is calculated from equation B.4.1-8

$$ep2 = e \cdot B_{ext}$$

$$B_{ext} = \frac{D_0}{2e} - \frac{r}{e} - \left[\frac{D_o}{2e} - \frac{r}{e} - 1\right] \sqrt{\frac{\left(\frac{r}{e}\right)^2 - \left(\frac{D_o}{2e}\right)^2}{\left(\frac{r}{e}\right)^2 - \frac{D_o}{2e}\left(\frac{D_o}{2e} - 1\right)}}$$

r/e is calculated from

$$\frac{r}{e} = \sqrt{\frac{1}{2}\left\{\left(\frac{D_o}{2e}\right)^2 + \left(\frac{R}{e}\right)^2\right\} + \sqrt{\frac{1}{4}\left(\left(\frac{D_o}{2e}\right)^2 + \left(\frac{R}{e}\right)^2\right)^2 - \frac{D_o}{2e}\left(\frac{D_o}{2e} - 1\right)\left(\frac{R}{e}\right)^2}}$$

where

D_o = outside diameter of bend

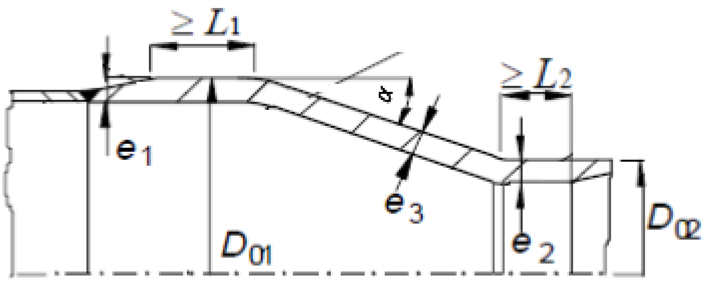
D_i = inside diameter of bend = Do – 2 x e_n

e = minimum required wall thickness of corresponding straight pipe computed as per Eq. 6.1-1 or 6.1-3

R = radius of the bend

e_{p2} = minimum required wall thickness of the extrados

Reducers



Junction between the large end of a cone and a cylinder without a knuckle

The minimum required wall thickness (e_1) of the larger cylinder adjacent to the junction is calculated from Subsection 6.4.6.2 as the greater of e_{cyl} and e_j where e_j is determined from

$$\beta = \frac{1}{3}\sqrt{\frac{D_c}{e_j}}\frac{\tan \propto}{1+\frac{1}{\sqrt{\cos \propto}}} - 0.15 \qquad (Eq. 6.4.6-2)$$

$$e_j = \frac{p_{c\beta D_c}}{2f} \qquad (Eq. 6.4.6-1)$$

The value of e_j is acceptable, if the value given by Eq. 6.4.6-1 is not less than that assumed in Eq. 6.4.6-2

$$e_{con} = \frac{p_c D_e}{2fZ + p_c}\frac{1}{COS(\alpha)} \qquad (Eq. 6.4.4-2)$$

$$\mathrm{e_{cyl}} = \frac{\mathrm{p_c D_{01}}}{\mathrm{2fZ+p_c}}$$

$$e_1 = thickness\ of\ larger\ cylinder = max(e_j, e_{cyl})$$

$$e_3 = thickness\ of\ cone\ shell = max(e_j, e_{con})$$

where

D_e = outside diameter of the cone

D_{01} = outside diameter of the larger cylinder

D_{02} = outside diameter of the small cylinder

D_c = mean diameter of the larger cylinder at the junction with the cone = D_{01} - e_n

e_n = nominal wall thickness of the larger cylinder at the junction with the cone

$\propto$ = cone angle

e_1 = minimum required wall thickness for larger cylinder adjacent to the junction.

e_3 = minimum required wall thickness at cone.

f = Allowable stress for material at maximum temperature

p_c = maximum internal pressure = maximum of CAEPIPE input pressures P1 through P10

Z = weld efficiency factor = 1.0

Junction between the small end of a cone and a cylinder without a knuckle

The minimum required wall thickness (e_2) of the small cylinder adjacent to the junction is calculated according to Subsection 6.4.8.2 as follows.

$$s = \frac{e_3}{e_{j2}}$$

With e_3 already determined in the earlier section, assume value of e_{j2} and calculate the values of s, τ and β_H

When s < 1.0, then

$$\tau = s\sqrt{\frac{s}{cos \propto}} + \sqrt{\frac{1+s^2}{2}}$$

When s >= 1.0, then

$$\tau = 1 + \sqrt{s\frac{1+s^2}{2cos \propto}}$$

$$\beta_H = 0.4\sqrt{\frac{D_c}{e_{j2}}\frac{tan \propto}{\tau}} + 0.5 \qquad (Eq.\ 6.4.8-4)$$

$$e_{j2} = \frac{p_c D_c \beta_H}{2fZ} \qquad (Eq. 6.4.8-5)$$

The value of e_{j2} is acceptable, if the value given by Eq. 6.4.8-5 is not less than that assumed for Eq. 6.4.8-4

$$e_{cyl} = \frac{p_c D_{02}}{2fZ + p_c}$$

$$e_2 = max(e_{j2}, e_{cyl})$$

where

D_{02} = outside diameter of the small cylinder at the junction with the cone

D_c = mean diameter of the small cylinder at the junction with the cone = D_{02} - e_n

e_n = nominal wall thickness of the small cylinder at the junction with the cone

$\propto$ = cone angle

e_2 = minimum required wall thickness of the small cylinder at the junction with the cone

f = Allowable stress for material at maximum temperature

p_c = maximum internal pressure = maximum of CAEPIPE input pressures P1 through P10

Z = weld efficiency factor = 1.0

Design of pipe and pipe fittings under external pressure according to EN 13480-3 (2017)

Pipes, Elbows, Mitre Bends and Reducers

Interstiffener collapse

The thickness of the pipe within the unstiffened length L shall not be less than that determined by the following.

$$P_r \geq k.P_c$$

$$P_y = \frac{Se_a}{R_m}$$

$$P_m = \frac{E_t e_a \varepsilon}{R_m}$$

$$\varepsilon = \frac{1}{n_{cyl^2} - 1 + \frac{Z^2}{2}} \left\{ \frac{1}{\left(\frac{n_{cyl^2}}{Z^2} + 1\right)^2} + \frac{e_{a^2}}{12R_{m^2(1-v^2)}} \left(n_{cyl^2} - 1 + Z^2\right)^2 \right\}$$

$$Z = \frac{\pi R_m}{L}$$

using the calculated value of Pm/Py, Pr/Py is determined from Table 9.3.2.1 of Subsection 9.3.2

where

n_{cyl} = integer >= 2 to minimize the value of P_m

R_m = mean radius of the pipe

L = length between the stiffener, is calculated from CAEPIPE input as follows

for Pipe, L = length of pipe (= distance between the “From” and “To” node of CAEPIPE)

for Elbow and Miter bend, L = arc length measured on extrados of elbow and miter bend

for Reducer, L = Length of the reducer

E_t = Young’s modulus of material at design temperature (max of CAEPIPE Temperature T1 through T10)

e_a = analysis thickness of reducer at smaller end = e_n – corr.all – mill tolerance

e_n = nominal thickness of reducer at smaller end

k = factor = 1.5

P_c = external pressure = maximum negative CAEPIPE input pressures P1 through P10

S = elastic stress limits for pipe and stiffener

= $R_{p0.2,t}$ for non-austenitic steels

= ($R_{p0.2,t}$ / 1.25) for austenitic steels

$R_{p0.2,t}$ = minimum 0.2% proof strength at temperature of pipe

= ‘f’ for EN 13480 code and

= “Allowable stress” at temperature of pipe for other codes

Additional check for Reducers

In addition to the above, as stated in Subsection 9.4.2 of EN 13480-3, the moment of inertia, I_x taken parallel to the axis of the cylinder, of the part of the cone and cylinder with a distance of $\sqrt{D_{eq}.e}$ on either side of the junction is not less than:

$$I_x = 0.18 D_{eq} L D_s^2 \frac{p_c}{E_t} \leq I_{xa}$$

where

D_{eq} = equivalent diameter = $\dfrac{\frac{D_1+D_2}{2}}{\cos(\alpha)}$

D1 = outside diameter of larger end of reducer

D2 = outside diameter of smaller end of reducer

$\alpha =$ cone angle of reducer input in CAEPIPE

I_{xa} = moment of inertia of reducer at smaller end

Ds = diameter of the centroid of the moment of inertia of the stiffening cross section calculated as shown below

$$I_{cone} = \left(\sqrt{D_{eq} e_1}.e_1\right)\left(\frac{D_{mcon}}{2}\right)^2 = (A_{cone})\left(\frac{D_{mcon}}{2}\right)^2$$

$$I_{Cyl} = \left(\sqrt{D_{eq} e_2}.e_2\right)\left(\frac{D_{mcyl}}{2}\right)^2 = \left(A_{cyl}\right)\left(\frac{D_{mcyl}}{2}\right)^2$$

$$I_{stiff} = \left(A_{cone} + A_{cyl}\right)\left(\frac{D_s}{2}\right)^2$$

From the above,

$$I_{cone} + I_{Cyl} = I_{stiff}$$

and

$$D_s = 2\sqrt{\frac{I_{stiff}}{\left(A_{cone} + A_{cyl}\right)}}$$

e1 = analysis thickness of reducer at larger end = e_{n1} – corr.all – mill tolerance

e2 = analysis thickness of reducer at smaller end = e_{n2} – corr.all – mill tolerance

e_{n1} = nominal thickness of reducer at larger end

e_{n2} = nominal thickness of reducer at smaller end