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Thickness an Mitre Calculations for Pipe: A Case Study

Divyesh Satishkumar Mistry

Student, Dr. S.&S.S. Gandhy Government Engineering College

Abstract
In various industries, such as oil and gas production, chemical processing, and water distribution, pipeline integrity and safety are of utmost importance. It is essential to ensure that pipes are thick enough to withstand internal pressures, external loads, as well as environmental conditions. The paper aims to enhance the practical skills and knowledge in computer-aided design while contributing to real-world projects within the field of engineering. We have used AutoCAD, a widely used software in the industry, to serve as the primary tool for creating precise and detailed technical drawings.
Initially, thickness is calculated based on internal gauge pressure and then it is verified by different methods for different conditions. The ambient conditions play a major role in determining the pipe thickness. In this paper, we are going to discuss and get an overall observation on thickness calculation for a pipe using internal gauge pressure and also discuss the steps to perform necessary calculations to get our desired outcome. In this paper, a comprehensive analysis of pipe thickness calculations is presented to provide engineers and practitioners with a robust methodology for determining the thickness of pipes accurately.

Overview
Pipelines, offshore and onshore, are subjected to combinations of various loads, such as internal or external pressure, surrounding soil, bending, normal force, shear force and sometimes torsion and local loading, e.g. due to support reactions. Some dynamic effects which the pipe needs to sustain are Impact and wind. Earthquake, Vibration, Discharge Reactions. The purpose of this study was to determine the minimum number of bends required to sustain design pressure in which different formulas were utilised to get the accurate figure. The details of experimental specimens are highlighted, with a view to these perhaps providing useful verification data for any future finite element analysis for example.

Thickness calculation based on internal gauge pressure

- The required thickness of straight sections of pipe shall be determined by the following equation. tm=t + c
- The minimum thickness, t, for the pipe selected, considering the manufacturer's minus tolerance, shall be not less than tm, to make the pipe safe also in the worst condition.
- The equation for thickness for internally pressurized pipe is:
  t = PD/2(SEW+PY)
  Where:
- c = sum of the mechanical allowances (thread or groove depth) plus corrosion and erosion allowances. For threaded components, the nominal thread depth (dimension h of ASME B1.20.1, or equivalent)

shall apply. For machined surfaces or grooves where the tolerance is not specified, the tolerance shall be assumed to be 0.5 mm (0.02 in.) in addition to the specified depth of the cut.

- D = outside diameter of pipe as listed in tables of standards or specifications or as measured
- d = inside diameter of pipe. For pressure design calculation, the inside diameter of the pipe is the maximum value allowable under the purchase specification.
- E = quality factor from Table A-1A or A-1B. It depends on the material and the method of manufacturing.
- P = internal design gage pressure
- S = stress value for material from Table A-1
- T = pipe wall thickness (measured or minimum by the purchase specification)
- t = pressure design thickness, as calculated by para. 304.1.2 of ASME 31.3 for internal pressure or as determined by para. 304.1.3 of ASME 31.3 for external pressure
- tm = minimum required thickness, including mechanical, corrosion, and erosion allowances
- W = weld joint strength reduction factor by para. 302.3.5(e) of ASME 31.3
- Y = coefficient from Table 304.1.1, valid for t < D/6 and for materials shown.
- The above formula is only valid for t<D/6, or thin pipes. For thick pipes or P/SE>0.385, the calculation of pressure design thickness for straight pipe requires special consideration of factors such as theory of failure, effects of fatigue, and thermal stress.
- To find the thickness ASME B 31.3, the piping process code in table 304.1.1 gives the formula of the thickness.

Tm = T + C
Where T = PD / 2(SE + PY)
Where P = inter pressure gauge (kg/mm2g)
D = outside diameter of pipe (mm)
S = allowable stress (kg/mm2)
(Taken from ASME B 31.3 TABLE A-1A)
E = Joint quality factor
(Taken from ASME B 31.3 TABLE A-1B)
W = Weld Joint Reduction Factor
(Taken from ASME B 31.3 TABLE 302.3.5)
Y = Co-efficient factor
(Taken from ASME B 31.3 TABLE 304.1.1)
C1 = Corrosion Allowance
Tm = (PD / 2(SEW + PY) + C1

STEP 1:

- For all the above temperatures find the allowable stress value from Table A-1 in ASME B31.3
- Now calculate the P/SE ratio for each of the above combinations.
- The combination, for which the P/S ratio is maximum, indicates the worst extreme condition.

SR. NO.	PRESSURE (kg/mm²g)	STRESS (N/mm²)	P / SE	TEMP (`C)	MATERIAL
1.	2203.3	140613.9	0.015669148	38	A106(B)
2.	1778.7	140613.9	0.012649532	149	
3.	965.8	121631.0372	0.007940407	343	
4.	850.3	117412.6197	0.007241981	371	
1	1762.2	152566.0987	0.011550403	38	A672 GR B65 class22
2	1423.4	144814.6174	0.009829118	149	
3	772.2	121675.961	0.006346365	343	
4	679.8	117412.6197	0.005789838	371	

Table 1

- From the above readings we can say that the worst condition or the condition of maximum thickness is at 38`c.
- Therefore, we will use the temperature and pressure at 38`c to find the resultant thickness of the pipe.

STEP 2:

- Now from Table 302.3.5 in ASME B31.3 based on temp and material select the weld joint strength reduction factor W.
- Here for given parameters W = 1

DIAMETER	O.D	P	STRESS	C3	C	Tm	Total Thickness	Material
NPS(in)	mm	(kg/mm²g)	(N/mm²)	mm	mm	mm	tm+c mm	
0.5	21.3	10405	112517.58	0.5	2	0.165837016	2.16583702	A106(B)
6	168.3	9582	112517.58	0.5	2	1.310345996	3.310346	
24	610	9210	112517.58	0.593	2.09	4.749322981	6.84298835	
42	1067	8472	112517.58	0.3	1.8	6.133801115	7.93380111	A672 GR B65 class22
56	1422	7452	112517.58	0.3	1.8	8.174569058	9.97456906	
64	1626	5800	112517.58	0.3	1.8	9.347292045	11.147292	

Table 2

STEP 3:

- Now from table A1-A or A1-B in ASME B31.3 select the weld quality factor E based on material specification.
- Here for the given material specification E = 1

STEP 4:

- Now from Table 304.1.1 in ASME B31.3 select the Y coefficient based on material and temperature.
- Here for the given case Y = 0.4

STEP 5:

- Now put all the selected values given equation for the given outside dia. D:
  t = PD/2(SEW+PY)

STEP 6:

- Now add the corrosion allowance and milling tolerance in the calculated to get tm • Here, C.A. = 1.5 mm (As per given in PMS), And the milling tolerance is 12.5%
- We get the thickness of the pipe at 38`c as seen below:
- Some values which are constant for all diameters are:

E=1 (quality factor)
Y=0.4 (coefficient)
W= 1 (Weld Joint factor)
C1=0.6 (corrosion allowance)
C2=0 (thread allowance)
C3= mill tolerance
Overall c= c1+c2+c3
Total thickness= tm +c
P= internal pressure ((kg/mm2g)) S= Allowable stresses(s) (kg/mm2)

STEP 7:

- Now we will select the standard thickness concerning the total thickness found out.
- Usually, the procured thickness is very high for the standard thickness because of various reasons. Some of these reasons are discussed later in the report
- We can see that the difference between the procured thickness and the total thickness increases with an increase in diameter. This is because, with an increase in dia, the stress caused due to various effects increases significantly.
- Some of these factors which affect the thickness are:
- External pressure verification
- Underground thickness calculation
- Thread Check
- Bend check
- Hydro test calculation
- Indian boiler regulation (IBR)
- Let's go through some important factors

Bend check

The minimum required thickness tm of a bend, after bending, in its finished form, shall be determined by the following equations.

t = PD/2[(SEW/I) + PY]

Where at the intrados (inside bend radius)

I = (4(R1/D) - 1)/(4(R1/D) - 2)

And at the extrados (outside bend radius)

I = (4(R1/D) + 1)/(4(R1/D) + 2)

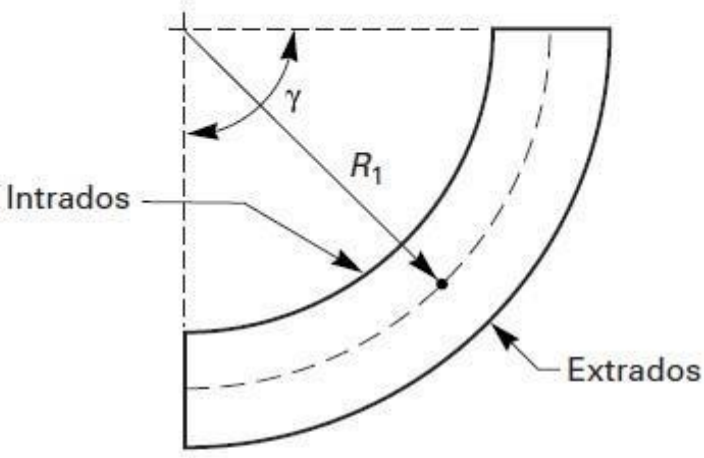

Image 1

- At the sidewall on the bend centreline radius, I = 1.0, and where R1 = bend radius of welding elbow or pipe bend
- Thickness variations from the intrados to the extrados and along the length of the bend shall be gradual.

When pipes are bent on site to achieve a curve, it becomes mandatory to check whether the pipe will be able to sustain the pressure or not because of variations in thickness at intrados and extrados of the pipe.

Hence thickness at intrados and extrados is calculated as shown below for different diameters of the pipes and the different curve radii as per the equation shown above. For all the conditions procured thickness after removing allowance at

Sr. No.	Outside Dia Meter (mm)	Bend Radius	Bend Radius (mm)	Intra Dos	Extra Dos	Tm (Extra dos) (mm)
1.	168.3	1D	168.3	1.5	0.833	1.09309
2.	168.3	3D	504.9	1.1	0.928571	1.217291
3.	168.3	6D	1009.8	1.045455	0.961538	1.26025

Table 3 the intrados and extrados are greater than the actual design thickness. Hence pipes will be able to handle the design internal pressure. Here, a pipe of thickness 6” (168.3mm O.D) is checked.

The check is done at 38`c as it is the point of worst condition or maximum thickness.

- If we want to compare it with standard thickness, we will also have to add the various tolerances to the respective intrados and extrados thickness.

- The tolerance 'C' can be obtained from previous data.

Intrados thickness will always be more than extrados thickness.

MITRE BEND ANALYSIS

DESIGN FOR MITRE THICKNESS OF 6.35 & 7.92 mm.

As per the given data, the mitre design is to be concluded.

DATA:

Sr no.	Parameters	
1	D = line size (in inch)	16
2	n = Number of mitre cuts	3
3	Number of mitres	N
4	Type of construction of pipe	Seamless
5	Pdesign = Design pressure (in psi)	290
6	S = Allowable stresses (in psi)	20000
7	E = Quality factor for longitudinal weld joints in pipes	1
8	W = Weld joints quality reduction factor	1
9	Pipe thickness (in mm)	T
10	MA = Mechanical allowance (in mm)	1.19
11	CA = Corrosion allowance (in mm)	3
12	R1 = Elbow radius	1.5D
		609.6
13	θ' = Bend angle (in degrees)	90
14	C = Sum of allowances	4.19
17	[r2 =(D-T)/2] Mean radius of pipe (in mm)	r2
18	the angle of the mitre cut	θ

Table 4

<u>Problem statement</u>: From the following data, we are required to find the allowable internal stress (Pm) and crotch length (M) that can sustain the design pressure or above for the minimum number of mitres.

Three formulas were given to verify the most reliable answers and they are given below

$$P_m = \frac{SEW(T-c)}{r_2}\left(\frac{T-c}{(T-c)+0.643\tan\theta\sqrt{r_2(T-c)}}\right)$$

------------4(A)

$$P_m = \frac{SEW(T-c)}{r_2}\left(\frac{R_1 - r_2}{R_1 - 0.5r_2}\right)$$

---------4(B)

$$P_m = \frac{SEW(T-c)}{r_2}\left(\frac{T-c}{(T-c) + 1.25\tan\theta\sqrt{r_2(T-c)}}\right)$$

----------4(C)

For multiple mitre bends (max 5), the maximum allowable internal pressure shall be the lesser value calculated from equations 4(A) and 4(B). These equations are not applicable when θ exceeds 22.5 deg.
For a single mitre bend, the maximum allowable internal pressure for a single mitre bend with angle θ not greater than 22.5 deg shall be calculated by equation 4(C).
For crotch length (M) also, two formulas were given to get the most suitable answer.

M1 = 2.5*sqrt(r2*T) & M2 = tan(θ)(R1-r2)

❖ **ITERATION** 1.

In the first **Iteration**, mitre design was calculated for the pipe of thickness 6.35mm and below were the following results.

Sr no.	Parameters	
1	D = line size (in inch)	16
2	n = Number of mitre cuts	4
3	N = Number of mitres	5
4	Type of construction of pipe	Seamless
5	Pdesign = Design pressure (in psi)	290
6	S = Allowable stresses (in psi)	20000
7	E = Quality factor for longitudinal weld joints in pipes	1
8	W = Weld joints quality reduction factor	1
9	T = Pipe thickness (in mm)	6.35
10	MA = Mechanical allowance (in mm)	1.19
11	CA = Corrosion allowance (in mm)	3
12	R1 = Elbow radius	1.5D
		609.6
13	θ' = Bend angle (in degrees)	90
14	C = Sum of allowances	4.19
15	T-C	2.16
16	r2 = Mean radius of pipe (in mm)	200.025
17	θ = angle of mitre cut	9
18	A	216

19	Tan θ	0.15838444
20	B	4
21	Pm = allowable internal stress (in psi)	109
22	M1 (in mm)	89
23	M2 (in mm)	64

Table 5

Where, A = SEW(T-C)/r2 AND B = (T-C) + 0.643tanθ(sqrt(r2(T-C))).

The above result was calculated using equation 4(A) and we can conclude that this design will not work because here the allowable internal stress (Pm=109 psi) is less than that of design pressure (Pdesign=290 psi) for the maximum numbers of mitre i.e.5

Now with equation 4(B), the following outcomes were obtained as below.

Sr no.	Parameters	
1	D = line size (in inch)	16
2	n = Number of mitre cuts	3
3	N = Number of mitres	4
4	Type of construction of pipe	seamless
5	Pdesign = Design pressure (in psi)	290
6	S = Allowable stresses (in psi)	20000
7	E = Quality factor for longitudinal weld joints in pipes	1
8	W = Weld joints quality reduction factor	1
9	T = Pipe thickness (in mm)	6.35
10	MA = Mechanical allowance (in mm)	1.19
11	CA = Corrosion allowance (in mm)	3
12	R1 = Elbow radius	1.5D
13	Elbow Radii	609.6
14	θ' = Bend angle (in degrees)	90
15	C = Sum of allowances	4.19
16	T-C	2.16
17	r2 = Mean radius of pipe (in mm)	200.025
18	θ = angle of mitre cut	11.25
19	A	215.9730034
20	B	409.575
21	C	509.5875
22	Pm = allowable internal stress (in psi)	173.5857784
23	M1	89.09821652
24	M2	81.46953287

Table 6

Equation 4(B) does not depend on the number of mitres or the angle of the mitre cut. Rather, it depends on the mean radius and elbow radius of the mitre.

Here, A = SEW(T-C)/r2, B = R1-r2 and C = R1-0.5r2

From the above outcome, we can see that still, the allowable stress (Pm) is still less than that of the design pressure (Pdesign).

ITERATION 2.

In the second **Iteration**, mitre design was calculated for the pipe of thickness 7.92mm and below were the following results.

Sr no.	**Parameters**	
1	D = line size (in inch)	16
2	n = Number of mitre cuts	4
3	N = Number of mitres	5
4	Type of construction of pipe	Seamless
5	Pdesign = Design pressure (in psi)	290
6	S = Allowable stresses (in psi)	20000
7	E = Quality factor for longitudinal weld joints in pipes	1
8	W = Weld joints quality reduction factor	1
9	T = Pipe thickness (in mm)	7.92
10	MA = Mechanical allowance (in mm)	1.19
11	CA = Corrosion allowance (in mm)	3
12	R1 = Elbow radius	1.5D
		609.6
13	θ' = Bend angle (in degrees)	90
14	C = Sum of allowances	4.19
15	T-C	3.73
16	r2 = Mean radius of pipe (in mm)	199.24
17	θ = angle of mitre cut	9
18	A	374
19	Tan θ	0.15838444
20	B	6
21	Pm = allowable internal stress (in psi)	214
22	M1 (in mm)	99
23	M2 (in mm)	64

Table 7

Where, A = SEW(T-C)/r2 AND B = (T-C) + 0.643tanθ(sqrt(r2(T-C))).

The above result was calculated using equation 4(A) and we can conclude that this design will not work because here the allowable internal stress (Pm=214 psi) is less than that of design pressure (Pdesign=290 psi) for the maximum numbers of mitre i.e.5

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Now with equation 4(B), the following outcomes were obtained as below.

Sr no.	Parameters	
1	D = line size (in inch)	16
2	n = Number of mitre cuts	3
3	N = Number of mitres	4
4	Type of construction of pipe	seamless
5	Pdesign = Design pressure (in psi)	290
6	S = Allowable stresses (in psi)	20000
7	E = Quality factor for longitudinal weld joints in pipes	1
8	W = Weld joints quality reduction factor	1
9	T = Pipe thickness (in mm)	7.92
10	MA = Mechanical allowance (in mm)	1.19
11	CA = Corrosion allowance (in mm)	3
12	R1 = Elbow radius	1.5D
13	Elbow Radii	609.6
14	θ' = Bend angle (in degrees)	90
15	C = Sum of allowances	4.19
16	T-C	3.73
17	r2 = Mean radius of pipe (in mm)	199.24
18	θ = angle of mitre cut	11.25
19	A	374
20	B	410
21	C	50
22	Pm = allowable internal stress (in psi)	301
23	M1	99
24	M2	81

Table 8

Equation 4(B) does not depend on the number of mitres or the angle of the mitre cut. Rather, it depends on the mean radius and elbow radius of the mitre.

Here, A = SEW(T-C)/r2, B = R1-r2 and C = R1-0.5r2

From the above outcome, we can see that the allowable stress (Pm) is greater than that of the design pressure (Pdesign).

Therefore, the mitre design will withstand the design pressure if it is designed as per equation 4(B) the allowable pressure is 301 psi and the crotch length is 99 mm.

Conclusion

To conclude, this analysis has shown the importance of using appropriate formulae for mitre bend by which allowable internal stresses(Pm) and the crotch length for mitre were obtained which will sustain the design pressure(Pd) for the minimum number of mitres by using trial and error method. It was found that internal pressure (Pm) is directly proportional to elbow radius (R1).

Future work

Further, I am interested in doing a fatigue test using computer software like SolidWorks for mitre bend as well as the effects of corrosion on it when exposed to the atmosphere. All these studies would help to develop an understanding of the stresses generated in mitre bends and the influence of bends on fluids.

References

1. Process Piping(ASME Code for Pressure Piping, B31)
2. "Pipeline Rules of Thumb Handbook: A Manual of Quick, Accurate Solutions to Everyday Pipeline Engineering Problems" by E.W. McAllister: This handbook offers practical guidelines and formulas for various pipeline design parameters, including thickness calculations.
3. "Process Plant Layout and Piping Design" by Ed Bausbacher and Roger Hunt: This book provides insights into plant layout and piping design principles, including considerations for pipe thickness calculations based on process requirements and industry standards.
4. "Pipe Stress Engineering" by Liang-Chuan and Tsen-Loong Peng: This textbook covers pipe stress analysis principles, including factors influencing pipe thickness calculations such as internal pressure, external loads, and temperature gradients.
5. "Pipeline Design for Installation by Horizontal Directional Drilling" by J. Ford and R. King: This publication focuses on pipeline design considerations for installation using horizontal directional drilling methods, including pipe thickness calculations for trenchless applications.
6. "Materials Selection in Mechanical Design" by Michael F. Ashby: This book discusses materials selection criteria and methodologies, which are essential for determining suitable pipe materials and thicknesses based on mechanical properties, corrosion resistance, and environmental conditions.
7. "Pipe Drafting and Design" by Roy A. Parisher and Robert A. Rhea: This book offers practical guidance on pipe drafting and design principles, including detailed explanations of thickness calculations, fabrication techniques, and piping standards.
8. "Pipeline Planning and Construction Field Manual" by E. Shashi Menon: This field manual provides practical guidance on pipeline planning, design, and construction, including detailed discussions on pipe thickness calculations and regulatory compliance.
9. "Engineering Materials: Properties and Selection" by Kenneth G. Budinski and Michael K. Budinski: This textbook covers the properties, selection criteria, and applications of engineering materials, offering insights into material selection for pipe thickness calculations.