RPS FRP Piping

Stress Analysis Information

Table of Contents

1.0 INTRODUCTION

The purpose of this document is to provide piping data and guidelines to carry out stress analysis of RPS A-150 and P-150 FRP piping to ASME B31.1 or B31.3 using CAESAR II Pipe Stress Analysis software.

2.0 PIPE PROPERTIES

Pipe I.D. (in.)	T (in.)	Axial Mod. (Msi)	Hoop Mod. (Msi)	Shear Mod. (Msi)	CAESAR Poisson Ratio	Coef. Of Exp. (x10-5 /°F)	Density (pci)
1	0.19	1.08	1.08	0.40	0.34	1.45	0.055
1.5	0.19	1.14	1.36	0.84	0.38	1.37	0.060
2	0.19	1.14	1.36	0.84	0.38	1.37	0.060
3	0.19	1.14	1.36	0.84	0.38	1.37	0.060
4	0.20	1.16	1.39	0.88	0.38	1.37	0.060
6	0.24	1.20	1.53	0.98	0.39	1.35	0.062
8	0.28	1.23	1.64	1.05	0.41	1.34	0.062
10	0.32	1.25	1.73	1.10	0.40	1.33	0.063
12	0.37	1.27	1.82	1.15	0.41	1.33	0.063
14	0.37	1.27	1.82	1.15	0.41	1.33	0.063
16.25	0.41	1.29	1.88	1.18	0.42	1.32	0.064
18.25	0.45	1.30	1.93	1.21	0.42	1.32	0.064
20.25	0.49	1.31	1.97	1.23	0.42	1.31	0.064
24	0.56	1.32	2.02	1.26	0.42	1.31	0.065
29.53	0.67	1.34	2.08	1.30	0.43	1.30	0.065
35.43	0.79	1.35	2.12	1.33	0.43	1.30	0.065
42	0.90	1.35	2.15	1.34	0.43	1.30	0.065
48	1.01	1.36	2.17	1.36	0.43	1.30	0.066
54	1.12	1.38	2.21	1.38	0.43	1.30	0.066

Notes:
1. T includes 0.11” erosion/corrosion liner.
2. For insulated pipe, increase Coeff. of Exp. by 20%.
3. CAESAR Poisson Ratio = Poisson ratio x Axial Mod. / Hoop Mod.

3.0 FITTINGS

3.1 Elbows:

I.D. (in.)	T (in.)	Axial Mod. (Msi)	Hoop Mod. (Msi)	CAESAR Poisson ratio	SIF	k
1	0.19	1.08	1.08	0.34	1.5	1.0
1.5	0.19	1.08	1.08	0.34	1.5	1.0
2	0.19	1.14	1.14	0.34	1.5	1.0
3	0.22	1.15	1.15	0.34	2.0	1.0
4	0.26	1.16	1.16	0.34	2.0	1.0
6	0.33	1.17	1.17	0.34	2.0	1.2
8	0.28	1.52	1.98	0.22	3.0	1.7
10	0.34	1.61	1.99	0.21	3.0	1.7
12	0.38	1.58	2.09	0.21	3.0	1.9
14	0.38	1.58	2.09	0.21	3.4	2.1
16.25	0.41	1.66	2.12	0.21	3.5	2.3
18.25	0.45	1.62	2.05	0.21	3.7	2.3
20.25	0.49	1.69	2.08	0.21	3.7	2.4
24	0.59	1.70	2.24	0.20	3.8	2.4
29.53	0.68	1.70	2.17	0.20	4.0	2.5
35.43	0.78	1.75	2.27	0.20	4.1	2.6
42	0.91	1.79	2.24	0.20	4.1	2.6
48	1.06	1.76	2.36	0.19	4.1	2.6
54	1.17	1.79	2.34	0.19	4.1	2.6

Notes:

1. The thicknesses listed above apply to the elbow extrados and are the correct values to be used in the stress analysis. Intrados thicknesses range from 140% to 200% of the listed values.
2. For 45° bends, k should be reduced by 30%.
3. For flanged elbows, reduce k as recommended in ASME B31.
4. CAESAR Poisson Ratio = Poisson ratio x Axial Mod. / Hoop Mod.
5. T includes 0.11” erosion/corrosion liner.
6. To account for pressure stiffening, divide SIF and k by:

$$1 + 2.53 \times (P / Eh) \times (D / (2 \times T))^2 \times (R / T)^{1/3}$$

where: P = Design pressure
Eh = Hoop modulus
R = Bend radius

3.2 Reducers:

The thicknesses of reducers will be no less than those of the pipe. To obtain the thickness for a specific reducer, average the pipe thicknesses from Section 2.0 for the two sizes of interest. SIF = 1.3. k = 1.0.

3.3 Tees and Laterals:

Tees and laterals contain significant additional reinforcement to achieve the required pressure rating, and hence can be several times thicker than pipe in local areas. However, for the purposes of the stress analysis, it is recommended that the following thicknesses be used. Note: Flexibility Factor = 1.0 for all sizes:

I.D. (in.)	T (in.)	SIF
1	0.19	1.7
1.5	0.22	1.7
2	0.22	2.3
3	0.22	2.3
4	0.22	2.3
6	0.30	2.3
8	0.41	2.3
10	0.45	2.3
12	0.49	2.3
14	0.44	2.5
16.25	0.49	2.5
18.25	0.54	2.5
20.25	0.59	2.5
24	0.67	2.5
29.53	0.81	2.5
35.43	0.96	2.5
42	1.10	2.5
48	1.24	2.5
54	1.37	2.5

Notes:
1. T includes 0.11” erosion/corrosion liner.

3.4 Reducing Branches

Reducing branches should be modelled using the appropriate tee thicknesses, and a Flexibility Factor of 1.0 for all sizes. SIF's are as follows:

d / D > 0.66:	Same as above for tees and laterals
d / D < 0.25:	1.5
0.25 ≤ d / D ≤ 0.66:	Linear interpolation.

Note: Gusseted branches can be modelled with SIF = 1.0.

3.5 Flanges

Flanges can be analyzed using SIF = 1.0 and k = 1.0. It is recommended that loads on flanges be minimized as much as possible as the actual stresses in the flanges may be higher than calculated due to less-than-ideal installation conditions.

4.0 ALLOWABLE STRESSES

4.1 Pipe

Pipe will be manufactured by filament winding. This type of construction results in an orthotropic material. The strain response of this material to applied loadings will depend upon the type of loading involved. For example, the axial strain response to a biaxial stress field such as pressure, is different than the axial strain response due to a purely axial stress such as longitudinal tension. For this reason it is necessary to select an allowable stress appropriate to the loading under consideration. The following allowable stresses apply to design pressures of 0 psi and 150 psi. For pressures between these two values, interpolation should be used.

	0 psi	150 psi
1” Diam.:	2650	2650
1.5” Diam.:	2000	2175
2” Diam.:	2000	2250
3” Diam.:	2000	2350
4” Diam.:	2000	2425
6” – 8” Diam.:	2000	2475
10” – 12” Diam.:	2000	2500
> 12” Diam.:	2000	2550

Note: These allowable stresses apply when the axial stress is tensile. If the axial stress is compressive, refer to Section 6.0 Rigidly Restrained Pipe.

4.2 Elbows

Elbows are manufactured by custom contact molding which results in quasi-isotropic behaviour, but the allowable stresses are still dependent upon the magnitude of the pressure. The following allowable stresses apply to design pressures of 0 psi and 150 psi. For pressures between these two values, interpolation should be used.

	0 psi	150 psi
1” - 3” Diam.:	1500	1500
4” – 6” Diam.:	1800	1800
8” – 14” Diam.:	2900	2800
16” – 20” Diam.:	3000	2800
24” – 54” Diam.:	3200	2600

4.3 Other Fittings

For other fittings, the same allowable stresses as for the pipe should be used.

5.0 CODE STRESS RECOMMENDATIONS

5.1 General

FRP does not yield in the same manner as a ductile material such as steel. It is therefore not recommended that higher allowable stresses be used for FRP piping when analyzing displacement-type load cases (eg. thermal load cases). Displacement load cases should be treated in the same manner as sustained loads such as pressure and weight.
For both ASME B31.1 and B31.3, it is recommended that all stress cases be analyzed as "corroded".

5.2 ASME B31.1

It is recommended that all operating loads be analyzed as either Operating or Sustained stress cases. It is not appropriate to use Expansion stress cases for FRP piping. Using Sustained stress cases is preferable to Operating stress cases as CAESAR will highlight any stresses in excess of the allowable stresses.
Occasional load cases should be analyzed using Occasional stress cases.
It is also recommended that F/A stresses be included in the code stress calculations.

5.3 ASME B31.3

It is recommended that all operating loads be analyzed as either Operating or Sustained stress cases. It is not appropriate to use Expansion stress cases for FRP piping. Using Sustained stress cases is preferable to Operating stress cases as CAESAR will highlight any stresses in excess of the allowable stresses.
Occasional load cases should be analyzed using Occasional stress cases.
It is recommended that Torsional stresses be included in the code stress equations.

5.4 Corrosion Allowance

A corrosion/erosion allowance of 0.11" should be used.

5.5 Occasional Loads

The allowable stresses listed in Section 4 are appropriate for long term loadings, i.e. sustained loads. When occasional loads such as wind or seismic are combined with the sustained (operating) loads, it has been RPS practice to increase allowable stresses by 20%.

Due to the random nature of these occasional loads, it is recommended these code stresses be combined with the operating stresses by scalar or absolute addition (i.e. not algebraic).

6.0 RIGIDLY RESTRAINED PIPE

A rigidly restrained pipe system is one that utilizes anchors along straight runs of piping to prevent thermal expansion. The restrained thermal expansion manifests itself as compressive stress in the pipe and axial thermal loads on the anchors. This type of support system is most often used for small diameter piping on pipe racks or other long straight runs. Its use is generally limited to smaller diameters of pipe as the magnitude of the thermal loads on the support structures can be excessive with larger diameter pipes. CAESAR II can be utilized to analyze this type of pipe system, but there are several additional requirements that must be borne in mind. This section will address those requirements.

6.1 Column-type Buckling

The restraint of thermal expansion of the pipe will result in compressive loads in the pipe. It is therefore necessary to ensure that the spacing between guides is adequate to prevent column-type buckling.
The thermal load is calculated as follows:

$$F_{th} = E \cdot A \cdot \alpha \cdot \Delta T$$

where:

E = Axial modulus of the pipe
A = Cross-sectional area of pipe
α = Coefficient of thermal expansion
ΔT = Change in temperature from installation temp to max operating temp.

The critical buckling load is calculated as follows:

$$F_{cr} = \frac{\pi^2 \cdot E_s \cdot I_s}{L^2}$$

where:

E_s = Axial modulus of structural layer
I_s = Moment of inertia of structural layer
L = Spacing between guides

If the critical buckling load is less than the thermal load, the spacing between guides should be reduced. A good rule of thumb is to ensure F_{cr} is at least 15% higher than F_{th}.

6.2 Allowable Stress

The allowable stresses listed in Section 4.1 apply only if the axial stress in the pipe is tensile. For compressive axial stress, the allowable code stress should be determined as follows:

$$\sigma_{allow} = \left|0.44\,\sigma_h - 3333\right|$$

where:

σ_{allow} = Allowable code stress due to combined loads of pressure, thermal, weight, etc.

$$\sigma_h = \frac{P\cdot\left(ID + T_L + Ts\right)}{2\cdot T_s}$$

P = Pressure
T_L = Thickness of liner
T_s = Thickness of structure

Note: The absolute value function is required in the above formula for the allowable stress as the code stress reported by CAESAR is a positive value even if the stress is compressive.

6.3 Pressure loads on anchors

CAESAR II includes by default, pressure elongation (or "Bourdon effect") for FRP piping. For restrained pipe systems, CAESAR II's implementation of the pressure elongation results in an understatement of the axial pressure loads on the anchors. The understatement is typically not large, particularly in comparison to the typical thermal loads on the anchors, and it can usually be ignored. If required, the actual pressure load on the anchor can be calculated from:

$$F_{anc} = P\cdot\frac{\pi}{4}\cdot\left(ID + 2\cdot T_L\right)^2 - A_t\cdot\nu_{c2}\cdot\sigma_{ph}$$

where:

P = Pressure
ID = Inside diameter of pipe
T_L = Thickness of liner
$A_{.t}$ = Cross-sectional area of total pipe wall
ν_{C2} = CAESAR Poisson ratio

$$\sigma_{ph} = \frac{P\cdot ID}{2\cdot\left(T_L + T_s\right)}$$