STRESS ANALYSIS OF PIPING SYSTEMS

A thesis submitted in partial fulfilment of the requirements for the Degree of
Master of Technology
(Pipeline Engineering)

Submitted by:

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College of Engineering Studies

University of Petroleum and Energy Studies

Dehradun

May 2015

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By

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May, 2015

BONAFIDE CERTIFICATE

This is to certify that the work contained in this thesis title **STRESS ANALYSIS OF PIPING SYSTEMS** has been carried out by Ajo Jacob under my/our supervision and has not been submitted elsewhere for a degree.

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ABSTRACT

Pipe stress analysis is the process of evaluating the mechanical behavior of piping under regular, occasional and intermittent loads. The process utilizes a specialized finite element pipe stress analysis computer program to analyze the thermal expansion and contraction of the system as well as the static and dynamic loading involved. It verifies that the routing, loads and supports are selected and placed in a manner such that stress acting does not exceed under different loads such as sustained loads, operating loads and pressure testing loads as stipulated by the ASME B31.3.

The thesis is an attempt to investigate and establish the methods and steps involved in the stress analysis of an actual piping system involving a pig launcher unit of a city gas distribution facility according to actual industry practices. Improper understanding of stress analysis and its practices can lead to problems such as pipe rupture due to over pressure, bending failures and fatigue failures due to cyclic loading. The modeling and analysis of the unit in CAESAR and its corresponding mathematical analysis using numerical methods paves the way to understanding stress conditions and the nature of load balance for particular operating and environmental conditions. Stress analysis is an integral part of process piping but a separate operating entity involve the services and select skills of a stress engineer. The work demonstrates the adherence to requirements of the code as per ASME B 31.3 for standard piping analysis which involves

1. Stresses due to sustained loads
2. Stresses due to thermal expansion loads
3. Stresses due to occasional loads

ACKNOWLEDGEMENTS

I thank and appreciate Engineering Design and Power Training Institute, Delhi for the opportunity to undertake the course on Stress Analysis of Pipelines and thus work on the project of Stress Analysis of Piping Systems

My sincere gratitude to **Mr. Santhosh Kumar Kurre** , Asst Professor, Mechanical Department at **University of Petroleum and Energy Studies**, Dehradun for his support and guidance for the project.

I am grateful to my guide **Mr. Girish Mallik**, EDPTI, Delhi for his valuable guidance for the duration of the course of the and the preparation of the reports.

I would also like to express my gratitude for support and input provided by Mr. Vishwanath Sharma, HR Manager, EDPTI throughout the course of the internship.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

F - Stress range reduction factor

S_c -Basic allowable stress at minimum metal temperature

S_h - Basic allowable stress at metal temperature (ASME 13.3-2012, table A1)

S_t - torsional Stress

S_b - resulting bending stress due to thermal expansion

M_t - torsional moment

i_i -in-plane Stress intensification Factor

i_o - out-plane Stress intensification Factor

M_i - in-plane bending moment

M_o - out-plane bending moment

ΔL -Change in length (in)

L_o - Initial length of pipe (in)

a - Coefficient of thermal expansion (in/in-°F)

T_2 - End temperature (°F)

T_1 - Starting temperature (°F)

E - *Young's Modulus (psi)*

ε	- Strain (in/in)
F	- Force (lb_f-can be negative or positive)
A	- Area (square inches)
Δ	- Expansion in the line (inch) (ASME 31.3, table C1)
L	- Leg required in the perpendicular direction
S_A	- Basic allowable stress range
E_C	- Cold modulus of elasticity at ambient temperature (ASME 31.3, Table C6)
D_O	- Pipe outside diameter in inches
t	-calculated pipe wall thickness in inches
P	-internal pressure in psi
D_o	-outside dia of pipe in inches
S	-Basic allowable Stress in psi (ASME B31.3, tableA1)
E	-longitudinal weld joint quality factor (table A1B of code)
W	-Weld joint strength reduction factor (table 302.3.5)
Y	-co-eff of material (table 304.1.1)
T_m	-min wall thickness (inches)
A	-sum of allowances (corrosion allowance + thread depth allowance)

$\bar{T}$	-Nominal wall thickness required
S_b	-bending moment due to weight
l	-span length (feet)
Z	-section modulus ($inch^3$)
W	-total weight
W_p	-weight of pipe
W_f	-weight of fluid
W_{ins}	-weight of insulation
I	-Moment of Inertia
W	-Total Weight

CHAPTER 1

1. INTRODUCTION

Pipes are the most intricate and delicate components in any process plant. It is very important to take note of all potential loads that a piping system would encounter during operation as well as during other stages in the life cycle of a process plant. A common practice for piping layout is to route piping by considering mainly space, process and flow conditions and other parameters arising from constructability, operability and maintenance. Pipe stress analysis requirements are often not sufficiently considered while routing and supporting piping systems, especially in providing adequate flexibility to absorb expansion/contraction of pipes due to action of primary and secondary loads. Ignoring any such load while designing, erecting, hydro-testing, start-up shut-down, normal operation, maintenance etc. can lead to inadequate design and engineering of a piping system. The system may fail on the first occurrence of a case of excessive stress due to overlooked load conditions. Failure of a piping system may trigger a Domino effect and cause damage in other systems.

The varying design iterations between layout and stress departments continue until a suitable layout and support plan is arrived at, resulting in significant increase in project execution time and also project costs.

The current operating conditions involving increased operating pressures and temperatures in order to increase plant output requires thicker pipe walls, which consequently further increase piping stiffness. Such increased operating conditions applied on “stiffer” systems increase pipe thermal stresses and support loads. Thus it is important to make the piping layout flexible at the time of process planning and routing. Softwares such as AutoCAD, CATIA, CAESAR, Autoplant, PDMS, and others, directly address these issues.

The report aims to provide a glimpse of the actual methodology and practices involved in stress analysis of plant piping design. The study and practice of Pipeline Engineering places a limit on the exposure and knowledge of practices involved plant piping. The work aims to provide an introduction to piping stresses using numerical methods and also to the use of analysis software in validating corresponding plant designs.

1.1 Objectives of Pipe Stress Analysis

1. To ensure that piping stresses in the system are within the allowable limits of code

2. To ensure that piping end reactions (forces and movements acting on equipment nozzles) are within allowable range.

3. To ensure that piping systems are properly supported

Provision of safe design to the piping systems through the above steps is the goal of the quantification and analysis of the stresses involved.

The scope of the research aims to validate the numerical procedures of stress analysis process according to requirements of ASME B 31.3 as give below:

1. Stresses due to sustained loads

- Internal pressure stresses
- External pressure stresses

The pipe is considered to be safe if the wall thickness of the and its components including any reinforcements meets the requirements of the code from P304.

- Sustained load stresses

The sum of longitudinal stresses due to sustained loads (SL) due to pressure and weight of any piping component or system shall not exceed (SH) the basic allowable stress at metal temperature.

2. Stresses due to thermal expansion loads

The computed displacement stress range in a piping system in a piping system (SE) shall not exceed the allowable displacement stress range (SA).

3. Stresses due to occasional loads

The sum of longitudinal stresses(Sl) due to sustained loads such as pressure and weight and of stresses produced by occasional loads such as wind or earthquake may be as much as 1.33xbasic allowable stress as per table A1 of code.

The methodology involves use of individual scenarios relating to different plant conditions to investigate:

- Allowable thermal expansion stress range
- Span calculations based on limitation of stress
- Span calculations based on limitation of deflection
- Span reduction factor
- Flexibility analysis
- Nozzle thermal expansion

- Expansion loop

The combination of these conditions provides a comprehensive methodology for the evaluation of stresses and subsequent provision of supports in the system. The investigations contained in the report aims to underline the importance of stress analysis and good piping practices as a whole in an aspect separate from pipeline engineering.

CHAPTER 2

2. LITERATURE REVIEW

The analysis of piping under pressure, weight and thermal expansion is complex. This complexity can be understood by knowledge of Principal Axis System.

Stress is considered as the ratio of Force to Area. To find the stress in the small element, say cube of a piece of pipe, construct a three-dimensional, mutually perpendicular principal axis system with each axis perpendicular to the face of the cube it intersects.

Each force, acting on the cube can be resolved into force components, acting along each of the axis. Each force, acting on the face of the cube divided by area of the cube face is called the principal stress.

The principal stress acting along the centerline of the pipe is called longitudinal principal stress. This stress is caused by longitudinal bending, axial force loading or pressure.

Radial principal stress acts on a line from a radial line from center of pipe through the pipe wall. This stress is compressive stress acting on pipe inside diameter caused by internal pressure or a tensile stress caused by vacuum pressure.

Circumferential principal stress, sometimes called Hoop or tangential stress, acts along the circumference of the pipe. This stress tends to open-up the pipe wall and is caused by internal pressure.

When two or more principal stresses act at a point on a pipe, a shear stress will be generated.

Longitudinal Principal stress, LPS = PD/4T

Circumferential Principal stress, CPS (Hoop) = PD/2T

Radial Principal stress, RPS = P

The B31.3 Code provides design guidance for primary & secondary stresses. The basic characteristic of a primary stress is that it is not self-limiting. As long as the load is applied, the stress will be present & will not diminish with time or as deformation takes place. The failure mode of primary stress is gross deformation progressing to rupture. Examples of a primary stress are circumferential stresses due to internal pressure & longitudinal bending stresses due to gravity. The basic characteristic of a secondary stress is that it is self- limiting. The stress will diminish with time and strain. The failure mode of a secondary stress is small crack leading to leakage. Secondary stresses are due to cyclic thermal expansion and contraction.

The proper provision of supports is essential in limiting primary and secondary stresses in piping systems. The support locations are determined by the guidance of the maximum allowable span and the support types are selected by the expected vertical thermal displacement. (***Peng 1970, The Art of Designing Piping Support Systems, L.C Peng)***

Piping is used to convey a certain amount of fluid from one point to another. Shorter the pipe used, lesser is the capital expenditure. The longer pipe may generate excessive pressure drop. However, the shortest layout is not acceptable for absorbing thermal expansion.

When one end is connected and the other end is loose, the expansion is given by Δ = eL. If the other end is connected to piping, it creates stresses of the order of S = E(Δ/L) (***Peng, 1970, Quick Check on piping flexibility,)***

Flexibility can be provided by adding expansion loops or expansion joints. The traditional piping design procedure depends heavily on the stress engineer to check piping flexibility. With the availability of quick methods in checking the flexibility, the designer can now plan the layout with sufficient flexibility at the very beginning. This reduces the number of iterations required between the piping engineer and the stress engineer. (***Peng PE, 1970 Quick Check on piping flexibility***)

Simple beam theories which can be applied to straight pipe may not be able to reflect true behavior of the piping fittings due to varying cross sections, thickness, curvatures etc. Hence it is essential to consider additional stresses at the fittings by introducing Stress Intensification Factor (SIF). ASME B31code equations for SIF.

Considering the example of bend under moment, the ovalization of pipe generates bending on the pipe wall which creates a high circumferential bending stress on the pipe wall. Since the pipe is oval at the bend and not circular, there cannot be direct comparison with non-ovalized bend. Hence the binding stress at bend is compared with the circular cross section of pipe.

The theoretical SIF‟s for circumferential stresses are ici = 1.8 / h2/3 for in-plane bending (6) ico = 1.5 / h2/3 for out-plane bending (7) Markl and others observed that the theoretical SIF‟s are consistent with the test data. But the test performed on commercial pipe implied theoretical SIF of 2.0 against polished pipe which is mainly due to three factors – girth welds (welded or grinded), clamping - supporting effects and defects, surface roughness. Hence, in attempt of simplifying the analysis the SIF of commercial girth weld had been considered as unity modifying equations of SIFs in B31 codes as ii = 0.9 / h2/3 for in-plane bending io = 0.75 / h2/3 for out-plane bending.(***, Gaurav Bhende1 , Girish Tembhare, 2013, Stress Intensification & Flexibility in Pipe Stress Analysis***)

CHAPTER 3

3. THEORITICAL DEVELOPMENT

3.1 TYPES OF LOADS

3.1.1 Primary loads

Loads caused by forces acting on the system due to process parameters and operating conditions causing tension, compression and torsion.

a. Sustained loads:

These mainly consist of internal pressure and dead-weight. Dead-weight is from the weight of pipes, fittings, components such as valves, operating fluid or test fluid, insulation, cladding, lining,etc.

Internal design or operating pressure causes uniform circumferential stresses in the pipe wall, based on which a pipe wall thickness is determined during the process P&ID stage of plant design. Additionally, internal pressure gives rise to axial stresses in the pipe wall. Since these axial pressure stresses vary only with pressure, pipe diameter and wall thickness (all three of which are preset at the P&ID stage), these stresses cannot be altered by changing the piping layout or the support scheme.

A pipe's deadweight causes the pipe to bend (generally downward) between supports and nozzles, producing axial stresses in the pipe wall (also called "bending stresses") which vary linearly across the pipe cross-section, being tensile at either the top or bottom surface and compressive at the other surface. If the piping system is not supported in the vertical direction (i.e., in the gravity direction) excepting equipment nozzles, bending of the pipe due to deadweight may develop excessive stresses in the pipe and impose large loads on equipment nozzles, thereby increasing its susceptibility to "failure by collapse."

Various international piping standards/codes impose stress limits, also called "allowable stresses for sustained loads," on these axial stresses generated by deadweight and pressure in order to avoid "failure by collapse."

For the calculated actual stresses to be below such allowable stresses for sustained loads, it may be necessary to support the piping system vertically. Typical vertical supports to carry deadweight are:

- Variable spring hangers
- Constant support hangers
- Rod hangers
- Resting steel supports

Rod hangers and resting steel supports fully restrain downward pipe movement but permit pipe to lift up.

b. Occasional loads

This third type of loads is imposed on piping systems by occasional events such as earthquake, wind or a fluid hammer. To protect piping from wind and/or earthquake (which normally occur in a horizontal plane), it is normal practice to attach "lateral supports" to piping systems (instead of "axial restraints"). On the other hand, to protect piping for water/steam hammer loads, both "lateral supports" and "axial restraints" may be required.

3.1.2 Secondary loads

These are due to the displacement in piping systems

i. Thermal loads:

These refer to the “cyclic” thermal expansion or contraction of piping as it goes from one thermal state to another (for example, from “shut-down” to “normal operation” and then back to “shut-down”). If the piping system is not restrained in the thermal growth/contraction directions (for example, in the axial direction of pipe), then, for such cyclic thermal load, the pipe expands/contracts freely; in this case, no internal forces, moments and resulting stresses and strains are generated in the piping system. If, on the other hand, the pipe is “restrained” in the directions it wants to thermally deform (such as at equipment nozzles and pipe supports), such constraint on free thermal deformation generates cyclic thermal stresses and strains throughout the system as the system goes from one thermal state to another. When such calculated thermal stress ranges exceed the “allowable thermal stress range” specified by various international piping standards/codes, then the system is susceptible to “failure by fatigue.” So, in order to avoid “fatigue” failure due to cyclic thermal loads, the piping system should be made flexible (and not stiff).

This is normally accomplished as follows:

i. Introduce bends/elbows in the layout, as bends/ elbows “ovalize” when bent by end-moments, which increases piping flexibility.
ii. Introduce as much “offset” as possible between equipment nozzles (which are normally modeled as anchors in pipe stress analyses).

For example, if two equipment nozzles (which are to be connected by piping) are in line, then the straight pipe connecting these nozzles will be “very stiff”. If, on the other hand, the two equipment are located with an “offset,” then their nozzles will have to be connected by an “L-shaped” pipeline which includes a bend/elbow; such “L-shaped” pipeline is much more flexible than the straight pipeline mentioned above.

iii. Introduce expansion loops (with each loop consisting of four bends/elbows) to absorb thermal growth/contraction.

iv. Lastly, introduce expansion joints such as bellows, slip joints, etc., if warranted.

In addition to generating thermal stress ranges in the piping system, cyclic thermal loads impose loads on static and rotating equipment nozzles. By following one or more of the steps from (a) to (d) given above and steps (e) and (f) given below, such nozzle loads can be reduced.

v. Introduce “axial restraints” (which restrain pipe in its axial direction) at appropriate locations such that thermal growth/contraction is directed away from nozzles.

vi. Introduce “intermediate anchors” (which restrain pipe movement in the three translational and three rotational directions) at appropriate locations such that thermal deformation is absorbed by regions (such as expansion loops) away from equipment nozzles.

ii. Equipment foundation settlement.

A soil shear failure can result in excessive building distortion and even collapse. Excessive settlements can result in structural damage to a building frame nuisances such as sticking doors and windows, cracks in tile and plaster, and excessive wear or equipment failure from misalignment resulting from foundation settlements.

It is necessary to investigate both base shear resistance (ultimate bearing capacity) and settlements for any structure. In many cases settlement criteria will control the allowable bearing capacity.

Except for occasional happy coincidences, soil settlement computations are only best estimates of the deformation to expect when a load is applied.

3.2 TYPES OF STRESS

3.2.1 PRIMARY STRESS

These are due to the primary loads and act on the piping system with no respect of time. Failure here is total deformation of piping leading to rupture or exposure. These are developed by the imposed loading and are necessary to satisfy the equilibrium between external

and internal forces and moments of the piping system. Primary stresses are not self-limiting.

- Hoop Stress: PD/2t
- Longitudinal Stress: PD/4t
- Radial Stress: P

The three stresses are mutually perpendicular to each other.

Where t = (₸ x 0.875) – (allowance)

D= O.D

P= internal pressure

3.2.2 SECONDARY STRESS

These are developed by the constraint of displacements of a structure. These displacements can be caused either by thermal expansion or by outwardly imposed restraint and anchor point movements. Secondary stresses are self-limiting. These are often cyclic but not always creating fatigue I the piping system.

Failure here is bending or deformation of the piping system leading to leakage at joints.

3.3 MODES OF FAILURE

There are various failure modes, which could affect a piping system. The piping engineers can provide protection against some of these failure modes by performing stress analysis according to piping codes.

i. Failure by general yielding: Failure is due to excessive plastic deformation.
ii. Yielding at Sub Elevated temperatures: Body undergoes plastic deformation under slip action of grains.
iii. Yielding at Elevated temperature: After slippage, material re-crystallizes and hence yielding continues without increasing load. This phenomenon is known as creep.
iv. Failure by Fracture: Body fails without undergoing yielding.
v. Brittle fracture: Occurs in brittle materials.
vi. Fatigue: Due to cyclic loading initially a small crack is developed which grows after each cycle and results in sudden failure.

3.4 CRITICAL LINE

It is a line for which flexibility review is required by the stress engineer.

3.4.1 Critical line list criteria:

- Lines NPS 3 and larger connected to rotating equipments
- Lines NPS 3 and larger with temperatures less than 20°F
- Lines NPS 6 or larger with 250°F and more
- Lines with temperature 600°F and more
- Line with NPS 16 or larger
- Alloy Steel lines
- High Pressure lines as per chapter 9 of code
- Lines with expansion joints
- Lines connected to upstream and downstream of relief valve
- Underground process lines

3.4.2 Information required for stress analysis:

- Line size and thickness
- Design temp and pressure
- Material
- Insulation and its density
- Specific gravity of fluid
- Corrosion allowance of pipe material

- Flange and valve ratings
- Standard weight of valves and special components
- Type of branch connection
- Nozzle initial movement (Initial Reaction)
- Pipe Stress isometrics

3.5 REQUIREMENTS OF ASME B31.3 FOR STRESS ANALYSIS

3.5.1 STRESS DUE TO THERMAL LOADS

The computed displacement stress range in a piping system (S_E) shall not exceed the allowable displacement stress range (S_A). i.e $S_E \leq S_A$.

$$S_A = f(1.25\, S_c + 0.25\, S_h) \quad \text{(ASME 13.3, para302.3.5, (1a))}$$

f - Stress range reduction factor

S_c - Basic allowable stress at minimum metal temperature- (cold stress at ambient temperature-70°F) from table A1 of code(basic allowable stresses for tension for metals- ASME B 13.3-2012.

S_h - Basic allowable stress at metal temperature (ASME 13.3-2012, table A1)

$$S_E = \sqrt{(S_b)^2 + (2S_t)^2}$$

From (ASME 13.3-2012, table A1)

S_t - torsional Stress

S_b - resulting bending stress due to thermal expansion

$$S_t = \frac{Mt}{2Z}$$

M_t - torsional moment

$$Sb = \sqrt{\frac{(i_i Mi)^2 + (i_o Mo)^2}{2}}$$

i_i -in-plane Stress intensification Factor (ASME 13.3-2012, Appendix D)

i_o - out-plane Stress intensification Factor

M_i - in-plane bending moment

M_o - out-plane bending moment

Scenario 1

-Pipe supplying steam in 4hr cycle

-Pipe material is *A335(5Cr ½ Mo)*

-Steam temperature is 200°F

-Design life of 12 years

Solution:

Allowable thermal expansion: $S_{A=}$ f(1.25 S_c + 0.25 S_h)

Number of cycles = $\frac{\text{no. of days in years x hours in a day x no. of year}}{\text{One cycle time}}$

$$N = \frac{365x24x12}{4} = 26280$$

(from ASME B31.3-2012 fig302.3.5)

Stress range factor, f=0.78 corresponding to N

$S_{A\,=}$ 0.78(1.25x 20000 + 0.25x 18100)

$S_{A\,=}$ 23029.5psi

20000 + 0.25x 18100)

$S_{A\,=}$ 23029.5psi

3.5.1.1 STRESSES INDUCED BY THERMAL EXPANSION

If the object is a straight bar or pipe:

$$\Delta L = a \times Lo(T2 - T1)$$

ΔL	-Change in length (in)
L_o	- Initial length of pipe (in)
a	- Coefficient of thermal expansion (in/in-°F)
T_2	- End temperature (°F)
T_1	- Starting temperature (°F)

Scenario:

Consider a 6 in diameter steel (ASTM A53) pipe, 100 ft long, anchored at one end. The pipe is empty, and the inside is at atmospheric pressure. The temperature is increased to 200 deg F above ambient. The expansion of the pipe from equation (2) is:

a	- 6.33 x 10^{-6} in/in-°F
L_o	- 1,200 in
T_2	- 270 deg F
T_1	- 70 deg F

$$\Delta \mathrm{L} = (6.33 \times 1\ 0 - 6\ \mathrm{in/in} - {}^\circ\mathrm{F}) \times (1{,}200\ \mathrm{in}) \times (270^\circ\mathrm{F} - 70^\circ\mathrm{F})$$

$$= 1.52\ in$$

If the pipe is installed at an ambient temperature of 70 deg F, and the temperature of the pipe increases to 270 deg F, we can expect about 1.5 in of expansion in the 100 ft unanchored run. Assuming the pipe is properly supported along its length, the stresses will remain well below the yield point of the steel.

If the pipe is now anchored at both ends and subjected to the same conditions, the stresses in the pipe will significantly increase. The anchors will prevent the pipe from expanding during the temperature rise. The result will likely be failed anchors, a buckled pipe or both.

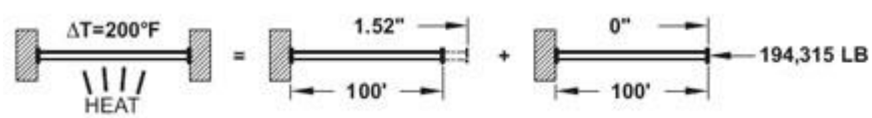


Figure 1: Pipe Expansion

S - Eε

- F/A

- Stress (psi-can be negative or positive)

E - *Young's Modulus (psi)*

ε - Strain (in/in)

F - Force (lb_f-can be negative or positive)

A - Area (square inches)

Strain is defined as a percentage or ratio of a change of length divided by the original length:

$$\varepsilon \ = \ a\ (T2 - T1)$$

ε - strain (in/in)

a = Coefficient of thermal expansion (in/in-°F)

T_2 = End temperature (°F)

T_1 = Starting temperature (°F)

F = AEa (T_2-T_1)

Notice that the initial length and change in length do not matter in calculating the stresses and forces. For our 6 in diameter, 100 ft pipe restrained by the anchors:

A = 5.581 in^2

E = 27.5 x 10^6 lb_f/in^2a = 6.33 x 10^{-6} in/in-°F

T_2 = 270 deg F

T_1 = 70 deg F

The stress along the longitudinal axis of the pipe is then:

$$S \ = \ Ea\ (T2 - T1)$$

$$S \ = \ (27.5 \ \times \ 106\ lbf/in^2)(6.33 \ \times \ 10^{-6}\ in/in - °F)(270°F - 70°F)$$

$$S = \ 194{,}315\ lbf/\ 5.581\ in^2$$

$$\therefore S = 34{,}815\ psi$$

The force in the anchors is:

F = stress *x* pipe area

$$F = (5.581\ in^2) \times (34{,}815\ lbf/in^2)$$

$$\therefore F = 194{,}315\ lbf\ (anchor\ load)$$

3.5.2 FLEXIBILITY ANALYSIS

It is the term applied to the process involved which addresses thermal expansion and contraction in a piping system. Piping systems should have sufficient flexibility so that the thermal expansion and contraction of piping or the movement of terminal points will not cause

- Failure of pipe from overstress
- Leakage at joints

(Young, 1989)

3.5.2.1 EXPANSION LOOP

Expansion loop provides the necessary leg to the piping system in a perpendicular direction to absorb thermal expansion of a particular line. They are provided to accommodate the thermal stresses when there are anchor points on the line.

Anchor points are points of restraints on the line where degree of freedom is zero.

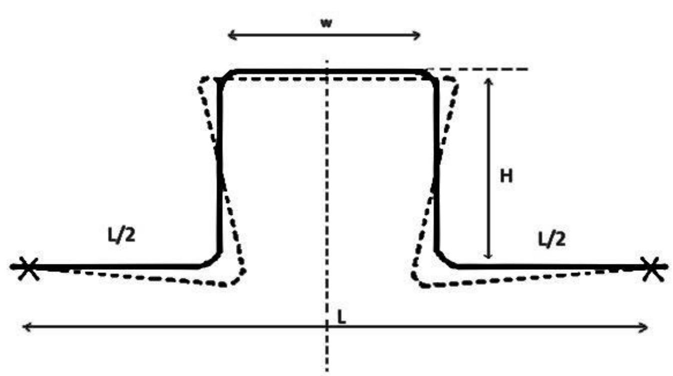


Figure 2: Expansion loop

Guidelines for sizing expansion loops:

a) Locate anchors such that the maximum allowable movement (thermal expansion) between them is 12”

b) 5” shall be the maximum expansion at a point of change in direction near the anchor

c) Width of the loop is approximately 20’ for pipes of sizes from NPS 3 to NPS 20

d) Width of the loop is approximately 30’ for pipe sizes greater than NPS 20

e) Height : width ratio is generally 1:1

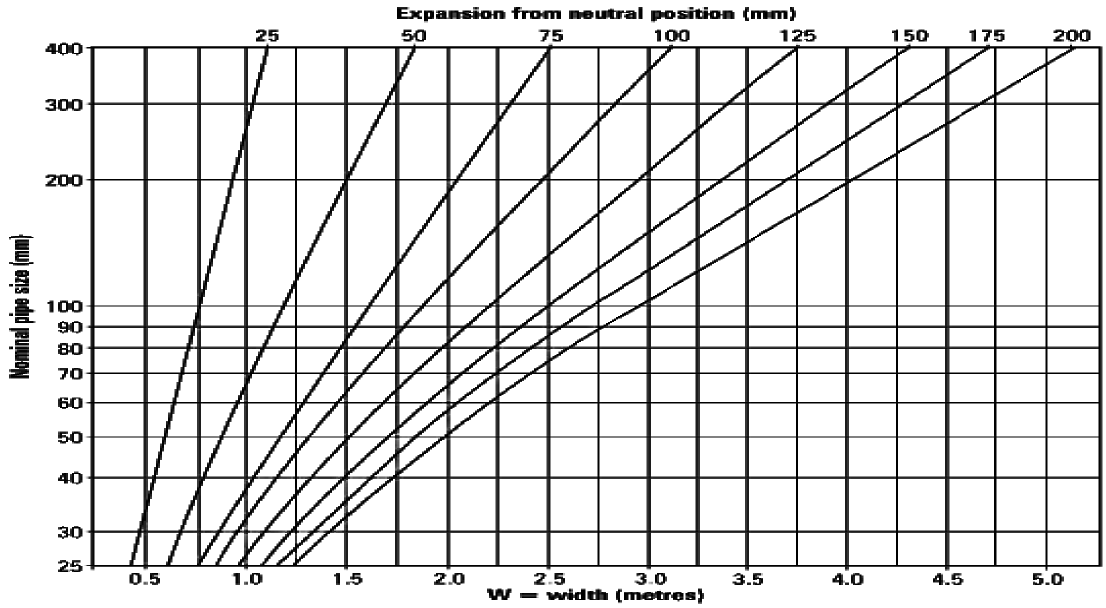


Figure 3: Determination of width

3.5.2.2 GUIDED CANTILEVER METHORD

Leg required in the perpendicular direction to absorb thermal expansion of the pipe in a system is calculated by the following method:

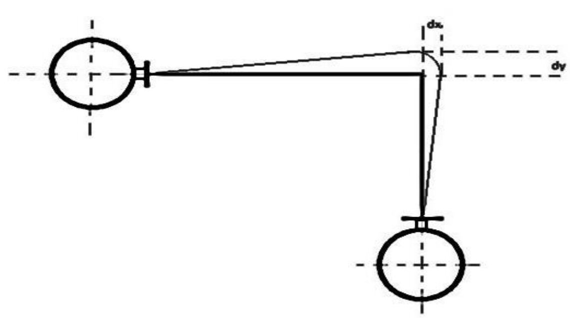


Figure 4: Perpendicular Leg

$$\Delta = \frac{144 \text{ x } L^2 \text{ x } S_A}{3 \text{ x } E_c \text{ x } D_o}$$

Δ - Expansion in the line (inch) (ASME 31.3, table C1)

L - Leg required in the perpendicular direction

S_A - Basic allowable stress range

$$\boldsymbol{SA = f(1.25\, Sc + 0.25\, Sh)}$$

E_C - Cold modulus of elasticity at ambient temperature (ASME 31.3, Table C6)

D_O - Pipe outside diameter in inches

Scenario

Sizing of horizontal and 3D expansion loop

Line NPS 10

Material A335 g P11

Temp: 1000°f

Initial length of pipe is 500’

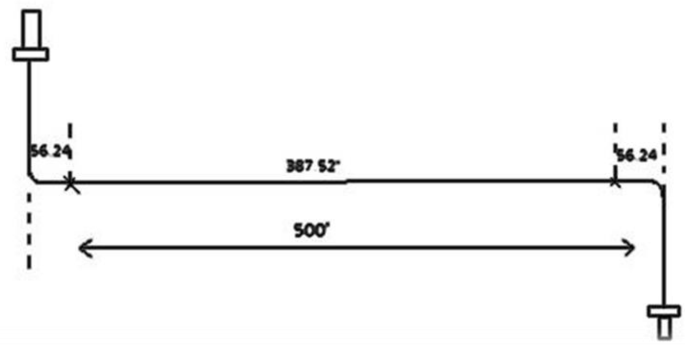


Figure: 5: Anchor distance from bends

Total expansion allowed for the length of line: Δ

From ASME 31.3, table C1(total thermal expansion for metals), corresponding to

carbon steel (carbon-moly-low-chrome), foe 1000°f, linear thermal expansion per 100ft is 8.89".

$$\Delta = \left(\frac{8.89}{100}\right) \times 500 = 44.45''$$

According to the condition, 5" should be the expansion from the bend. Therefore a suitable length has to be calculated to place the anchor from the bend for corresponding 5" expansion.

8.89"- 100' therefore for 5": (100/8.89) x 5 = 56.24'

Anchor points can be placed at a distance of 56.24' from the bends

Distance between the anchor points; 500 – (56.24 x 2) = 387.52'

The distance between anchor points should correspond to only a max of 12" expansion. Therefore more anchor points are required between the distances of 387.52'

Calculating the length corresponding to 12” expansion:

$$\left(\frac{100}{8.89}\right) \times 12 \; = \; 134.98'$$

Hence more than two anchor points. (there should be an anchor point for every 134.98’ to comply with code)

387.52’ – 134.98’ = 252.54’ (position of second anchor)

252.54’ – 134.98’ = 117.56’ (position of third anchor)

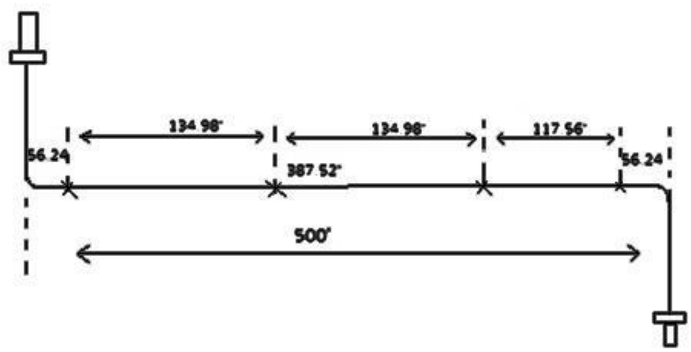


Figure 6: Distancing of anchor points

The values of the sections are rounded off as follows: 56.54 as 55’, 134.98 as 130, 117.56 as 130.

For length L = 130, calculating the balancing leg.

100’ – 8.89”

$$1' = \frac{8.89}{100}$$

$$\text{for } 130' \rightarrow \Delta = \frac{8.89}{100} \times 130 = 11.557''$$

from (ASME B31.3, Table A1),

$S_C = 20\text{ksi} = 20 \times 10^3\text{psi}$, $S_H = 6.3\text{ksi} = 6.3 \times 10^3\text{psi}$

Allowable thermal expansion: $S_A = f(1.25\ S_C + 0.25\ S_H)$

$S_A = 1(1.25 \times 20 \times 10^3 + 0.25 \times 6.3 \times 10^3) = 26575$ psi

Δ = (144 x L^2 x S_A)/(3 x Ec x Do)

$$11.567 = \frac{144 \times L^2 \times 26575}{3 \times 29.7 \times 10^6 \times 10.75}$$

$L^2 = 2892.647$

L = 53.78 = 54’

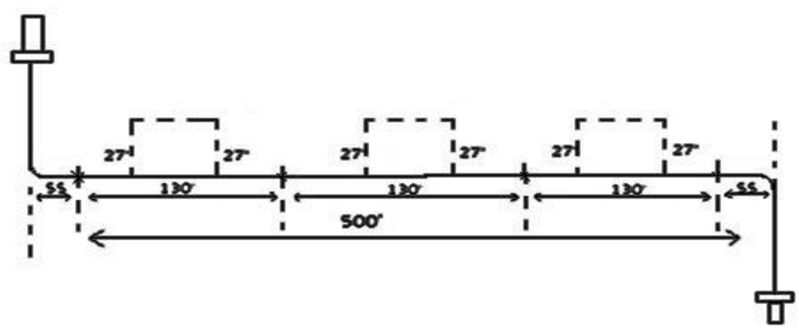


Figure 7: Loop modelling

Therefor it can be split into two legs of 27’ each in a direction perpendicular to the main line.

3.5.2.3 FLEXIBILITY ANALYSIS FOR VESSEL PIPING USING NOMOGRAPH

Complex piping layouts interconnecting vessels in a plant can be analyzed for sufficient thermal expansion and contraction allowance and available flexibility using a nomograph.

Scenario:

-Pipe material: A53 g B

-Line size: NPS 30

-Temperature: 100°f

-Max allowable stress on the vessel nozzle: 14000psi

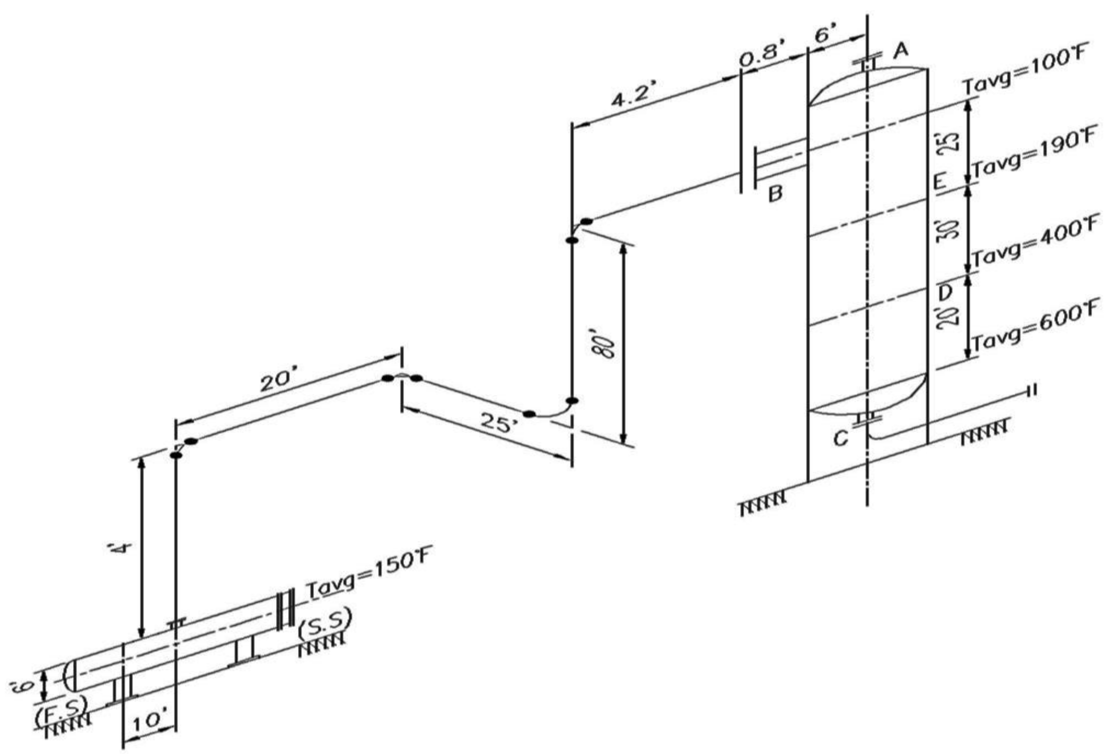


Figure: 8: Isometric

Note1: thermal growth of the vessels should be considered in flexibility calculations but vessels are not absorbing legs and are capable of absorbing thermal growth of perpendicular lines.

Note2: expansion of heat exchangers should be considered from anchor support in flexibility calculations

N-S DIRECTION

Expansion of piping

Total length: 20’ + 4’-2” = 24’ – 2”

Δ = 0.23/100ft   (ASME B31.3, Table C1)

Δ = (0.23/100ft) x 24.166’ = 0.0555”

Expansion in vessel

6’ + 10’ = 6’-10” = 6.833’

- Note: nozzle length thumb rule

If the dimensions of nozzles are not given in the isometrics, it can be assumes as the following:

1. Upto NPS 6: length 6”
2. Above NPS 6: length 10”

Taking higher temperature at the point of separation of sections in the vessels,

Δ = (0.61/150) x 6.833 = 0.0461”

Expansion in exchanger

At temp T = 150°f, Δ = 0.61/100ft (table C1)

Total length considered in N-S direction from fixed support is 10'

Δ = (0.61/100) x 10' = 0.061'

Total expansion in N-S direction: 0.0555 + 0.0461 + 0.061 = 0.158"

Procedure for determining absorbing leg on vessel piping using nomograph

- Corresponding to the 'total thermal expansion', 0.158" is marked on the scale
- Corresponding to 'pipe stress', 14000psi is marked on the scale
- Join the two points, intersecting the pivot line at a point
- On the 'nominal diameter' scale, mark the diameter as NPS30
- Join the NPS point with the intersection point on the pivot line
- The point where this line intersects the 'pipe length' scale is 18' and gives the total leg required to accommodate the thermal expansion.

Length of pipe leg require in perpendicular direction = 18'

The available leg in the perpendicular direction: 80' + 25' + 4' = 109'

Therefore, available leg is more than sufficient to accommodate expansion.

E-W Direction

Expansion in piping

Total length: 25’

Δ = 0.23”/100’ (ASME B31.3, table C1)

Δ = (0.23/100) x 25’ = 0.0575”

Expansion in vessel

Δ = 0 (The expansion of the vessel in the E-W direction does not affect the E-W pipe)

Expansion in exchange

Δ = 0

Total expansion in E-W direction = 0.0575”

Corresponding leg required = 9’ (from nomograph)

Available leg: 80’ + 20’ + 4’ + 4’-2” = 108.16’

Therefore, available leg is more than sufficient to accommodate expansion.

U-D Direction

Expansion in piping

Total length: 80’ + 4’ = 84’

Δ = 0.23”/100’ (ASME B31.3, table C1)

Δ = (0.23”/100’) x 84’ = 0.193”

Expansion in vessel

(4.60/100) x 20’ + (2.70/100) x 30’ + (0.61/100) x 25’ = 1.88”

Expansion in exchanger

Δ = 0.61”/100’   (ASME B31.3, table C1)

Δ = (0.61”/100’) x 6’ = 0.0366”

Total expansion: Δ = ΔV – ΔP – ΔE = 1.88 – 0.193 – 0.0366 = 1.65”

Corresponding leg required: 50’ (from nomograph)

Leg Available: 20’ + 25’ + 4’-2” = 49’-2”

The available leg is shorter than the leg require by 10”, therefore 10” has to be increased in any of the other directions.

3.5.2.4 NOZZLE THERMAL EXPANSION

Nozzle loads are the net forces and moments exerted on equipment nozzles from the weight and thermal expansion of connected piping and equipment. The loads exerted on equipment are directly related to how the equipment and piping are supported. Increased nozzle loads are a cause of misalignment and increased wear and vibration rates in pumps.

Nozzle thermal movements should also be accounted for flexibility calculations, as they expand due to the thermal expansion properties of their materials, which in turn adds more displacement to the connected piping. Nozzle movements are also due to the expansion, contraction or other movements of the equipments to which they are connected such as vessels, heat exchangers, pumps etc.

Scenario:

Expansions in nozzles A,B,C and support D

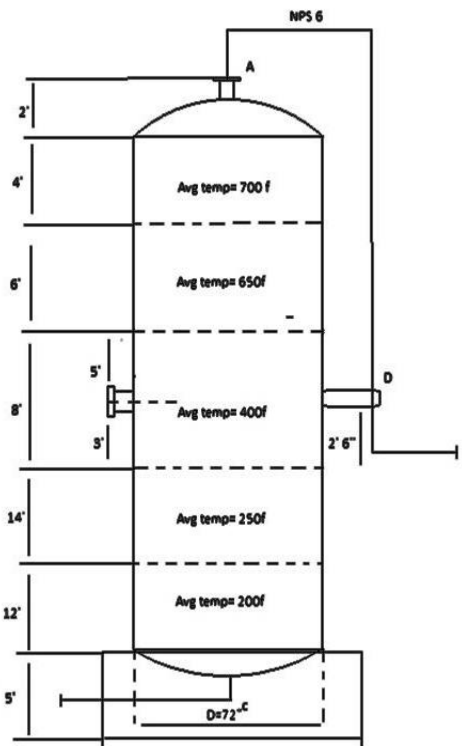


Figure 9: Plant column

Nozzle A

$\Delta x = 0$

From ASME B31.3, Table C1, the expansion rate of the different sections at different temperatures are calculated for the size of the section.

Δy = (0.99/100)x12 + (1.40/100) x 14 + (2.70/100) x 8 + (4.11/100) x 6 + (5.63/100) x 6 = 1.115”

Nozzle B

Δx =

From Table C1, corresponding to temp 400°f, Δ = 2.70/100ft

Total distance from center line to the end of nozzle = 6” + 36” = 42” = 3.5’

Δx = (2.70/100) x 3.5

Δx = 0.0945”

Δy = (0.99/100) x 12 + (1.4/100) x 14 + (2.7/100) x 3

Δy = 0.3958”

Nozzle C

Δx = 0

Δy = 0

Since they are both beneath the thermal growth line

Support D

Δx =(2.7/100) x 3’   (36” = 3’)

Δx = 0.081”

Δy = (0.99/100) x 12 + (1.4/100) x 14 + (2.7/100) x 2.5

$\Delta y = 3823"$

3.5.3 STRESSES DUE TO SUSTAINED LOADS

a. Internal Pressure stresses

b. External Pressure Stresses

c. Sustained Load Stresses

3.5.3.1 PIPE WALL THICKNESS DUE TO INTERNAL PRESSURE STRESSES

(ASME B31.3, Para 304.1.2)

For $t \leq D/6$, the thickness required is given by:

$$t = \frac{P \times D_o}{2(S.E.W + P.Y)}$$

$t_m = t + A$

$\bar{T} = (t_m / 0.875)$

t = calculated pipe wall thickness in inches

P = internal pressure in psi

D_o = outside dia of pipe in inches

S = Basic allowable Stress in psi (ASME B31.3, tableA1)

E = longitudinal weld joint quality factor (table A1B of code)

W = Weld joint strength reduction factor (table 302.3.5)

Y = co-eff of material (table 304.1.1)

T_m = min wall thickness (inches)

A = sum of allowances (corrosion allowance + thread depth allowance)

$\bar{T}$ = Nominal wall thickness required

3.5.3.2 PIPE WALL THICKNESS DUE TO EXTERNAL PRESSURE STRESSES

To determine wall thickness and stiffening requirements for straight pipe under external pressure, the procedure outlined in the PBV code, section VIII, Division1, UG28 through UG30 shall be followed, using as the design length L, the running centerline length between any two sections stiffened in accordance with UG29.

Pipe is considered to be safe if the wall thickness of the and its components including any reinforcements meet the requirements of ASME B 31.3-Para304.

3.5.3.3 Sustained Load Stresses

The sum of the longitudinal loads due to sustained loads(S_l), due to pressure and weight of piping component or system shall not exceed (S_h), where S_h is the basic allowable stress at metal temperature from table A1 of ASME B31.3.

i.e, $S_l \leq S_h$

Sum of Longitudinal Stress due to sustained loads = Longitudinal Stress+ Bending Moment

$$S_l = \frac{PD}{4t} + Sb$$

S_b is the bending moment due to weight

$$Sb = \frac{M_b}{Z} = \frac{Resultant\ Bending\ Moment}{\text{Section Modulus of Pipe}}$$

$$Z = \pi r^2 \bar{T}$$

Where

$\bar{T}$ = Nominal Wall Thickness

r = mean radius = $\frac{O.D - \bar{T}}{2}$

O.D = Outer Diameter

Scenario:

To verify Sustained Stress Requirement of the code:

- NPS 14, sh 80, Material A335 g P11

- length between equipments : 80ft

- Design Temperature : 650°F

- Design Pressure : 1380psi

- Corrosion Allowance: 0.0625"

Solution:

From requirements of ASME B31.3, verify $S_l \leq S_h$

The system is considered as a Uniformly Distributed Load, having a bending moment:

$$M_b = \frac{WL^2}{12}$$

W = uniform load(lb/ft)

L = span(ft)

The density is not given, hence from the Standard for Welded Seamless Wrought Steel Pipe (ASME 36.10), corresponding to NPS14, sh 80, plain end weight is 106.13 lb/ft

$$M_b = \frac{WL^2}{12} = \frac{106.13 \times 80^2}{12}$$

= 56602.66 lb.ft

Wall thickness corresponding to NPS14, Sh 80 from Standard ASME B36.10, $\bar{T}$= 0.75" r = mean radius

$$r = \frac{O.D - \overline{T}}{2}$$

$$r = \frac{14 - 0.75}{2} = 6.625''$$

$$Z = \pi r^2 \overline{T}$$

$$Z = \pi \times 6.625^2 \times 0.75$$

$$Z = 103.36\ in^3$$

Bending stress due to weight $S_b = \frac{M_b}{Z}$

$$S_b = \frac{56602.66}{103.36} \quad (lb.ft/in^3)$$

$$= \frac{56602.66}{103.36} \times 12\ lb/in^2$$

$$= 547.62 \times 12 = 6571.44\ psi$$

Sum of longitudinal stresses, $S_l = \frac{PD}{4t} + S_b$

$$t = (\overline{T} \times 0.875) - Allowance$$

$$t = (0.75 \times 0.875) - 0.0625$$

$$t = 0.5937$$

$$S_l = \frac{1380 \times 14}{4 \times 0.5937} + 6571.44$$

$$= 14706.86 \text{ psi}$$

From table A1 of code ASME B13.3, corresponding to material A335 p 11, S_h = 16.2 ksi at 650°F. i.e,16200psi.

Thus, $S_l \leq S_h$ and code is verified.

In conditions where the code is not verified, the stress engineer can revert the plan back to the layout department. The following changes can be brought about:

Provision of supports

3.5.6 STRESSES DUE TO OCASSIONAL LOADS

The sum of the longitudinal stresses(SL), due to sustained loads such as pressure and weight and of the stresses produced by the occasional loads such as wind or earthquake is calculated as 1.33 x basic allowable stress given in table A1

3.6 PROVISION OF SUPPORTS AND SPAN CALCULATIONS

Span can be provided based on:

a) Limitation of stresses

$$I = \sqrt{\frac{0.4 \text{ x Z x Sh}}{\text{W}}}$$

l = span length (feet)

Z = section modulus ($inch^3$)

S_h = basic allowable stress at metal temperature from table A1 of ASME B31.3.

W = total weight

$W = W_p + W_f + W_{ins}$

W_p = weight of pipe

W_f = weight of fluid

W_{ins} = weight of insulation

b) Limitation of deflection

$$I = \sqrt[4]{\frac{\Delta \text{ x Eh x I}}{13.5 \text{ x W}}}$$

Δ = Deflection of pipe in inches

Eh = Modulus of Elasticity (ASME B3.3 table C6) in psi

I = Moment of Inertia ($inch^4$) = $\frac{\pi}{64}(\mathrm{O.D}^4 - \mathrm{I.D}^4)$

W = Total Weight

The two cases are compared and the span of the lesser value is selected.

Scenario:

Pipe Material –A106gB (c% ≤ 0.3)

Pipe material Density: 0.283 lb/in^3

Line- NPS10, std

Max deflection allowed: 5/8”

Operating temperature: 400°f

Fluid: crude oil

Density: 62.4 lb/ft^3

Insulation thickness: 2”

Insulation density: 11 lb/ft^3

<u>**Span based on limitation of stresses**</u>

$$I = \sqrt{\frac{0.4 \text{ x Z x Sh}}{\text{W}}}$$

Z = $\pi\, r^2$₸

From Standard ASME B 36.10 table 2, for NPS 10, std size, ₸ = 0.365

r = mean radius = $\frac{O.D - \bar{T}}{2} = \frac{10 - 0.365}{2} = 5.19''$

$Z = 3.14 \times 5.19^2 \times 0.365$

$= 30.902\ in^3$

$S_h = 19.9 \times 10^3 psi$ (ASME B31.3, table A1)

W = total weight

$\mathbf{W = W_p + W_f + W_{ins}}$

$W_p = \frac{\pi}{4}(O.D^2 - I.D^2) \times \rho$

$W_p = \frac{\pi}{4}(10.75^2 - 10.02^2) \times 0.283 \quad (in^2 \times lb/in^3)$

$W_p = 3.370\ lb/in = 3.370 \times 12 = 40.44 lb/ft$

$W_f = \frac{\pi}{4}(I.D^2) \times \rho_f$

$= \frac{\pi}{4}(10.02^2) \times 62.4$

$= 4921.145 \quad (in^2 \times lb/ft^3) = (lb/ft \times 1/144)$

$W_f = 34.174\ lb/ft$

$W_{ins} = \frac{\pi}{4}(O.D^2 - I.D^2) \times \rho$

$W_{ins} = \frac{\pi}{4}(14.75^2 - 10.75^2) \times 11$ ($in^2 \times lb/in^3$)

W_{ins} = 6.120 lb/ft

W = 40.44 + 34.174 + 6.102 = 80.74lb/ft

$$I = \sqrt{\frac{0.4 \text{ x } 30.92 \text{ x } 19.9\text{x}10^3}{80.74}} = 35.211'$$

Span based on limitation of deflection

$$I = \sqrt[4]{\frac{\Delta \text{ x Eh x I}}{13.5 \text{ x W}}}$$

Δ = 5/8"

$E_h = 27.7 \times 10^6$ psi (ASME B31.3 Table C6)

$I = \frac{\pi}{64}(O.D^4 - I.D^4) = \frac{\pi}{64}(10.75^4 - 10.02^4) = 160.775 \text{ inch}^4$

$$I = \sqrt[4]{\frac{\frac{5}{8} \text{x } 27.7\text{x } 10^6 \text{x } 160.775}{13.5 \text{ x } 80.74}} = 39.973"$$

Thus length of span taken is based on limitation of stress, **l = 35.211'**

3.7 PIPE SUPPORTS

3.7.1 Pipe supports classification as per general detail

A pipe line needs to be supported from a foundation or a structure. The piping loads will be acting on these foundations / structures. Since these foundations / structures are built on ground, they will exert an equal and opposite reaction, while supporting the pipe.

In a pipe support, there will be some parts of support arrangement which is directly attached to the pipeline and there will be some other parts which shall be directly attached to the foundation / structure supporting the pipe.

As per this general detail the support is classified as:

3.7.1.1 Primary Supports

It is the parts of support assembly which is directly connected to the pipe.

3.7.1.2 Secondary Supports

It is the parts of support assembly which is directly connected to the foundation / structure and is supporting the primary support attached to the pipe line.

a) Pipe Supports Classification as per Construction

- Rigid Supports

This type of support arrangement is generally very simple and has maximum use in piping. It does not have adjustability to the erection tolerances. It will directly rest on foundation or structure which is supporting the pipe. Common type of RIGID SUPPORTS are shoe type (welded), shoe type (with clamp) Trunnion type, valve holder type, support brackets (Secondary Support). These are described under the topic 'Supports Generally used'.

- Elastic Supports:

This type of support is commonly used for supporting hot piping. It shall be able to support pipes even when the pipe is moving up or down at support point.

Common types of elastic supports are variable type spring supports, constant type spring supports. These are described under the topic 'Supports generally used '.

- Adjustable Supports:

This type of support is Rigid type in construction but is has few nuts and bolts arrangements for adjusting the supports with respect to the actual erected condition of pipe. The support can be adjusted for the erection tolerances in the piping. These are required for a better supporting need at critical locations of pipe supports.

Mostly all type of rigid supports can be modified by using certain type of nuts and bolts arrangement, to make it as an Adjustable support.

b) Pipe supports classification as per function (i.e. purpose)

This may change based on project.

Pipe supports classified as per functions are summarized in the Table at FIG.7. These are shown along with its basic construction, the symbols generally used and type of restraints it offers to the piping system.

The supports classified as per function are further described as follows:

- Loose Support:

This is most commonly used support meant for supporting only the pipe weight vertically. It allows pipe to move in axial as well as transverse direction but restricts only the vertical downward movement.

- Longitudinal Guide:

This type of support is used to restrict the movement of pipe in transverse direction i.e. perpendicular to length of pipe but allow movement in longitudinal direction. This is also a commonly used type of support. Generally it is used along with loose support.

- Transverse Guide:

This type of support is used to restrict the movement of pipe in longitudinal (axial) direction but allows the pipe to move in transverse direction. This is also referred as 'AXIAL STOP'. This type is less used as compared to above two types. Generally it is used along with Loose support.

- Fixed point/Anchor:

This type of support is used to restrict movements in all three directions. ANCHOR type of support is used to restrict movement in all three directions and rotation also in these three directions.

- Non-Welded Type (Fix Point):

This can be considered as a combination of longitudinal and transverse guide. This type resists only the linear movements in all directions but not the rotational movements. This avoids heavy loading of support as well as pipe. Therefore this type of support is preferred over welded type.

- Welded Type (Anchor)

This type of support prevents total movements i.e. linear as well as rotational. This type of support is used when it is absolutely essential to prevent any moment/force being transferred further. It causes heavy loading on support as well as pipe.

- Limit Stop:

As name itself indicates it allows pipe movement freely upto a certain limit and restricts any further movement. This is useful when total stops causes excessive loading on piping and support or nozzle.

This type of support should be used selectively, because of stringent and complicated requirements of design, erection and operation.

- Special Supports:

When we need a pipe support whose construction or functional details are different from the available details, then a special support detail sketch is prepared. The functions of this support can be any combination of above functions.

3.8 SPAN REDUCTION FACTOR

$L_{ft} = f \times l$

The presence of components such as valves and the presence of elbows between piping between two points alters the support span length by a factor called the span reduction factor

a) For an elbow places between supports, f=0.76

b) For concentrated loads,

$$f = \sqrt{\frac{1}{1 + 12 \propto \text{x}\,\beta\,(1-\beta)^2}}$$

$$\alpha = \frac{Wc}{w(a+b)} \qquad \beta = \frac{a}{l}$$

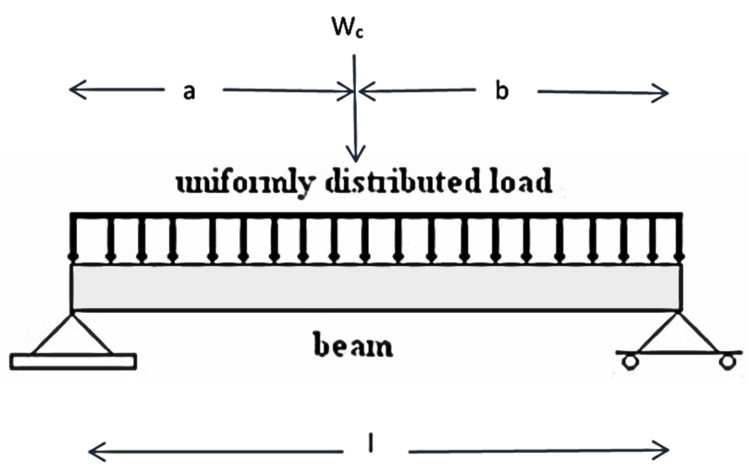


Figure 10: Point load on a pipe

W_c = weight of the component

W = total weight of the pipe

3.9 STRESS INTENSIFICATION FACTOR

It is defined as the ratio of max stress intensity to normal stress acting on a component. It is applied to bends and branch connections where the concentration of stresses is more and the possibility of fatigue failure is high.

SIF of a bend or elbow can be described as the ratio of bending stress of an elbow to that of straight pipe of same diameter and thickness when subjected to same bending moment. Whenever the same bending moment is applied to a bend because of ovalization the bending stress of the elbow will be much higher than that of strainght pipe. That is why the SIF value will always be greater than or equal to 1.0 (for straight pipe).

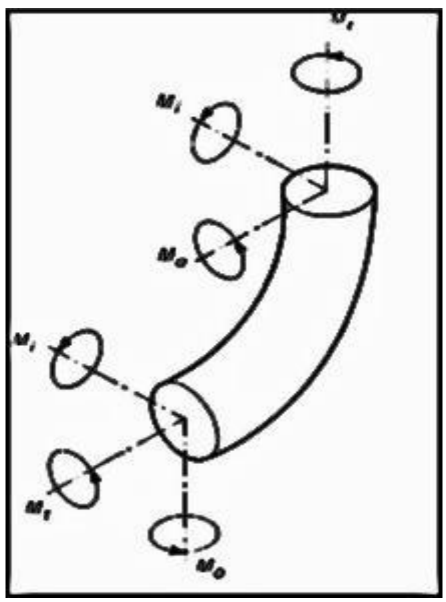


Figure 11: Planes of Movement

The inplane and outplane concept for a bend can be obtained from the attached figure from code or in layman’s language the same can be explained as follows:

The in-plane bending moment is the bending moment which causes elbow to close or open in the plane formed by two limbs of elbow.

In a similar way the out plane bending moment can be defined as the bending moment which causes one limb of elbow to move out of the plane keeping other limb steady.

A stress intensification factor is a multiplier on nominal stress for typically bend and intersection components so that the effect of geometry and welding can be considered in a beam analysis.

Stress Intensification Factors (SIFs) form the basis of most stress analysis of piping systems.

The stress intensification factor is used in a pipe stress analysis as shown in the equation below:

(Beam Stress)(SIF) < (Allowable Stress) (***Basavaraju, C., Lee, R.L., and Kalavar, S.R.,1992,***)

Flexibility factor: (k)

It denotes the flexibility of piping bends and branch connections as compared to that of straight pipe. It is used as a multiplier to determine flexibility in comparison to a straight pipe.

Scenario

Comparison of CIF and flexibility factor (k) for different types of branch connections

i. NPS 8, Sh40 fabricated T (unreinforced)

ASME B31.3, APPENDIX-D

k = 1

Flexible characteristic, $h = \frac{\bar{T}}{r_2}$

$\overline{T}$ = 0.322, for NPS8, sh40 (from Standard ASME B36.10)

r_2 = (O.D - $\overline{T}$)/2 = (8.625 – 0.322)/2 = 4.151"

$$h = \frac{\overline{T}}{h} \rightarrow \frac{0.322}{4.151} = 0.077$$

Out plane SIF: $i_O = \frac{0.9}{h^{2/3}}$ = 4.96

In plane SIF: i_I = ¾ I_o + ¼ = 3.97

ii. NPS 8, Sh40 fabricated T (reinforced)

$$h = \frac{(\overline{T} + \frac{1}{2}\overline{T}r)^{2.5}}{\overline{T}^{1.5} x\, r^2} \rightarrow \frac{(0.322 + \frac{1}{2}0.322)^{2.5}}{0.322^{1.5} x\, 4.151}$$

$$\therefore h = 0.231$$

Out plane SIF: $i_O = \frac{0.9}{h^{2/3}}$ = 2.52

In plane SIF: i_I = ¾ I_o + ¼ = 2.14

iii. NPS 8, Sh40 welded T

$$h = 3.1\frac{\overline{T}}{r^2} \rightarrow 3.1\frac{0.322}{4.151} = 0.240$$

Out plane SIF: $i_O = \frac{0.9}{h^{2/3}} = 2.311$

In plane SIF: $i_I = \frac{3}{4} I_o + \frac{1}{4} = 1.998$

Stress concentration: **welded T< Fabricated T (reinforced)< fabricated T (unreinforced)**

3.10 EXPANSION JOINTS

Expansion joints are used in piping systems An expansion joint or movement joint is an assembly designed to safely absorb the heat-induced expansion and contraction of construction materials, to absorb vibration, to hold parts together, or to allow movement due to ground settlement or earthquakes. Expansion joints can absorb axial movements, lateral movements and angular/torsional movements.

There are two main categories:

1. Slip expansion joint

These are sometimes used because they take up little room, but it is essential that the pipeline is rigidly anchored and guided in strict accordance with the manufacturers' instructions; otherwise steam pressure acting on the cross sectional area of the sleeve part of the joint tends to blow the joint apart in opposition to the forces produced by the expanding pipework Misalignment will cause the sliding sleeve to bend, while regular maintenance of the gland packing may also be needed.

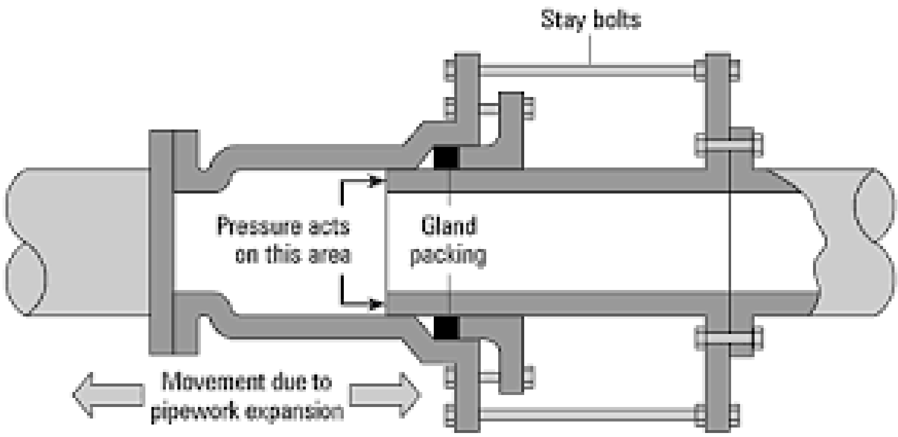


Figure 12: Slip expansion joint

2. Bellow expansion joint

An expansion bellows, has the advantage that it requires no packing (as does the sliding joint type). But it does have the same disadvantages as the sliding joint in that pressure inside tends to extend the fitting, consequently, anchors and guides must be able to withstand this force.

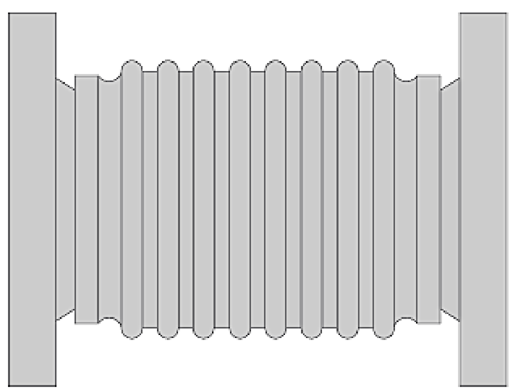


Figure 13: Bellow

Bellows may incorporate limit rods, which limit over-compression and over-extension of the element. These may have little function under normal operating conditions, as most simple bellows assemblies are able to withstand small lateral and angular movement. However, in the event of anchor failure, they behave as tie rods and contain the pressure thrust forces, preventing damage to the unit whilst reducing the possibility of further damage to piping, equipment and personnel. Where larger forces are expected, some form of additional mechanical reinforcement should be built into the device, such as hinged stay bars.

There is invariably more than one way to accommodate the relative movement between two laterally displaced pipes depending upon the relative positions of bellows anchors and guides. In terms of preference, axial displacement is better than angular, which in turn, is better than lateral. Angular and lateral movement should be avoided wherever possible.

Functions:

1) To reduce expansion stress
2) To reduce piping end reactions (forces and moments acting on equipment nozzles)
3) To isolate mechanical vibrations from piping

Types of bellow expansion joints:

1) Single Bellow Untied
2) Single Bellow Tied
3) Double Bellow untied
4) Double Bellow Tied

Guidelines for the use of expansion joints

1. When the space constraint do not permit providing adequate flexibility by expansion loop for maintaining the system stresses within acceptable limits.

2. When conventional systems such as expansion loops create unnecessary process conditions such as pressure drops.

3. At the suction and discharge nozzles of vibrating equipment's

4. On large diameter pipes and ducts operating at high temperature but low pressure

5. It is not advised to use expansion joints in the following conditions;

    - Where hazardous chemicals are involved

    - Where the service is high pressure

Guide Spacing for expansion joints

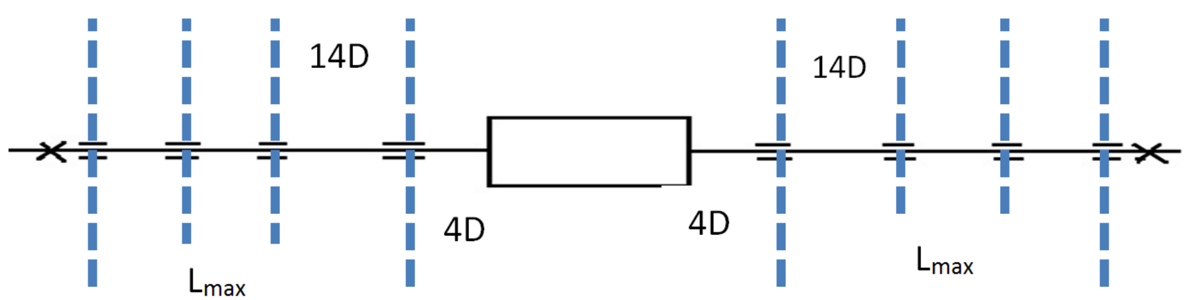


Figure 14: Guide spacing

$$L_{max} = 0.131 = \sqrt{\frac{E_h \times I}{P \times Ae \pm (f.ex)}}$$

- The first guide is place at 4D
- The second guide is placed at 14D
- All the other guides are placed at a distance not more than L_{max}
- D = O.D of the pipe (feet)
- E_h = Hot modulus of elasticity as per pipe material(psi) (table C6)
- I = Moment of Inertia
- Ae = Bellow effective pressure thrust area(inch)
- f = Bellow spring rate(lb/in)
- e_x = Axial stroke of bellow(in/convolution)
- e_x = (total expansion/number of convolution)

3.11 CAESAR

(COMPUTER AIDED ENGINEERING STRESS ANALYSIS ROUTING)

Caesar II is the name of a computer pipe stress finite element program. This program is used to model pipe systems for electric power, petrochemical, and process industries. It is written and maintained by COADE, Houston TX and was first introduced in 1984. The program accommodates standard pipe often referred to by Nominal Pipe Size. Pipe stress analysis is a subset of the field of Stress analysis. Users of the CAESAR II program must determine the specific applicable piping code requirement, i.e. ASME B31.1 or ASME B31.3 or other applicable power or process piping code.

CAESAR II is a comprehensive program for pipe stress analysis. CAESAR II has become the standard for pipe stress analysis, preferred by major corporations and engineering firms worldwide. It is the program by which all others are measured.

CAESAR II includes a full range of the latest international piping codes. It provides static and dynamic analysis of pipe and piping systems and evaluates FRP (fiber reinforced plastic); buried piping; wind, wave, and earthquake loading; expansion joints, valves, flanges and pressure vessel nozzles; pipe components; and nozzle flexibilities. The program automatically models structural steel and buried pipe and provides spectrum and time history analysis and automatic spring sizing. CAESAR II includes component databases and an extensive material database with allowable stress data. It also includes a bi-directional link to COADE's CADWorx Plant for process plant design.

The program's interactive capabilities permit rapid evaluation of input and output, a perfect match for the iterative `design and analyze` cycle, and the easy-to-use menu-driven interface makes all the needed options available at the click of the mouse or keystroke.

Used in the analysis of:

1. Piping

2. Structure Steel

3. Loads/Stresses on equipment shells due to external piping loads

Types of analysis

1. Static analysis:

In this process, the loads applied are slow enough that the piping system has time to react and internally distribute them, thus remaining in equilibrium. In equilibrium condition, the sum of forces and moments are resolved, therefore there are no pipe movements

Eg: Static stresses and thermal stresses

2. Dynamic analysis:

In this process, the loads applied are so quick that the system has no time to react and internally distribute them. So the sum of forces and moments are not resolved. This results in an unbalanced state therefore leading to unbalanced state

Eg: seismic loads and relief valve loads

CAESAR II calculations:

1. Stresses
   - Acting
   - Allowable
2. Forces and Moments acting on Restraints
3. Displacement at nodes

CAESAR II outputs:

1. Code compliance report
   - Sustained loads
   - Expansion
   - Occasional loads
2. Restraints Summary
   - Forces and moments acting on restraints
3. Displacement summary
   - Movements at nodes

- **STRESS ANALYSIS USING CAESAR:**

Using the Isometric diagram as the source the various inputs are given in the input screen of CAESAR.

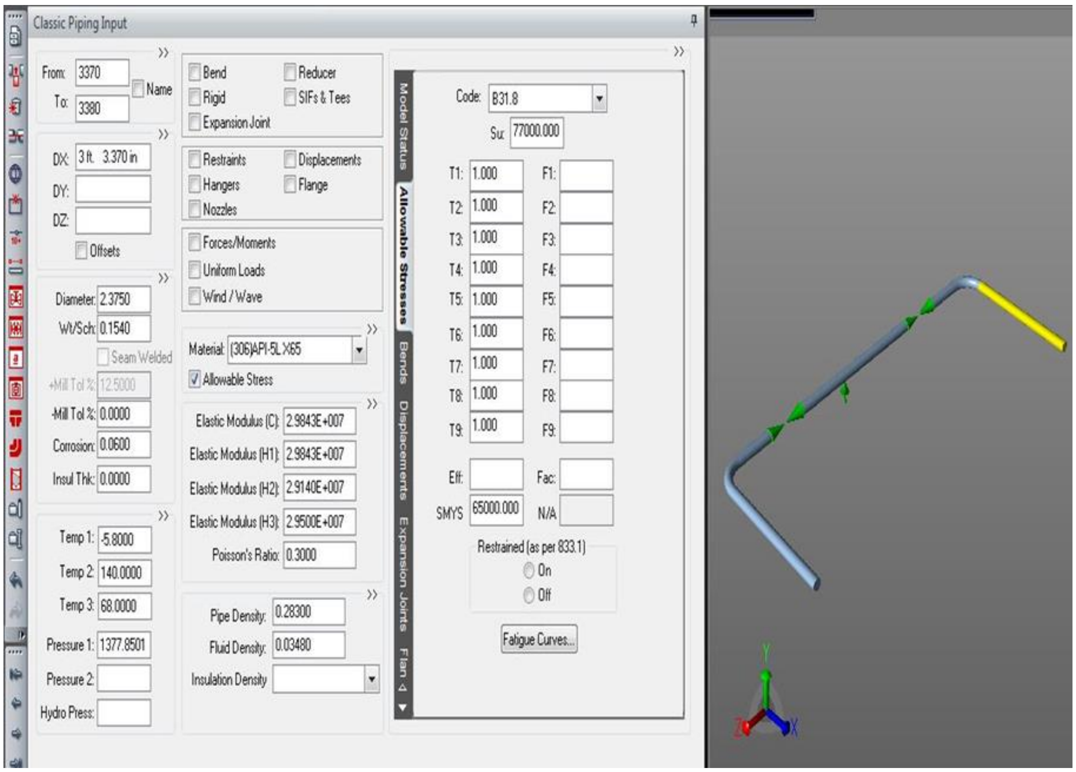
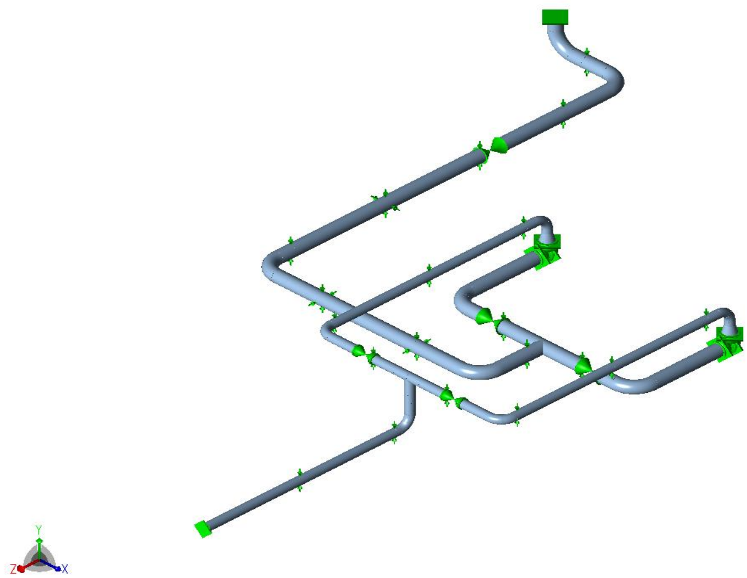


Figure 15: CAESAR input screen

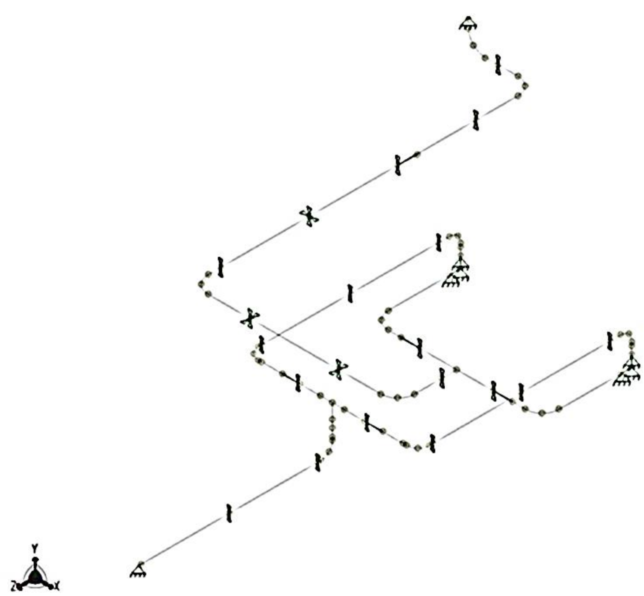
CHAPTER 4

4.1 EXPERIMENTAL RESULTS

Isometric View



Isometric View and Supports



4.2 INPUT DATA

PIPE DATA

From 10 V0401 To 20 DY= -137.000 mm

PIPE

Dia= 762.000 mm Wall= 12.700 mm Insul= .000 mm

GENERAL

T1= 100 C P1= 70.0000 kPa Mat= (106)A106 B E= 203,366 MPa v = .292

Density= 7,833.4116 kg/m³ Fluid= 999.5520020 kg/m³

RIGID Weight= 1,974.00 N

RESTRAINTS

Node 10 ANC

ALLOWABLE STRESSES

B31.3 (2004) Sc= 138 N/mm² Sh1= 138 N/mm² Sh2= 138 N/mm²

Sh3= 138 N/mm² Sh4= 138 N/mm² Sh5= 138 N/mm² Sh6= 138 N/mm²

Sh7= 138 N/mm² Sh8= 138 N/mm² Sh9= 138 N/mm²

From 20 To 30 DY= -1,680.000 mm

BEND at "TO" end

Radius= 1,143.000 mm (LONG) Bend Angle= 90.000 Angle/Node @1= 45.00 29

Angle/Node @2= .00 28

From 30 To 40 DX= 2,000.000 mm

RESTRAINTS

Node 40 Y Mu = .10

From 40 To 50 DX= 2,500.000 mm

BEND at "TO" end

Radius= 1,143.000 mm (LONG)   Bend Angle= 90.000   Angle/Node @1= 45.00 49

Angle/Node @2= .00 48

From 50 To 60 DZ= 4,000.000 mm

RESTRAINTS

Node 60 Y   Mu = .10

From 60 To 70 DZ= 4,000.000 mm

From 70 To 80 DZ= 1,295.000 mm

RIGID Weight=66,708.00 N

RESTRAINTS

Node 80 Y   Mu = .10

From 80 To 90 DZ= 6,000.000 mm

RESTRAINTS

Node 90 Y   Mu = .10

Node 90 Guide   Mu = .10

From 90 To 100 DZ= 6,000.000 mm

RESTRAINTS

Node 100 Y   Mu = .10

From 100 To 110 DZ= 2,000.000 mm

BEND at "TO" end

Radius= 1,143.000 mm (LONG) Bend Angle= 90.000 Angle/Node @1= 45.00 109

Angle/Node @2= .00 108

From 110 To 120 DX= 4,000.000 mm

RESTRAINTS

Node 120 Y Mu = .10

Node 120 Guide Mu = .10

From 120 To 125 DX= 6,000.000 mm

RESTRAINTS

Node 125 Y Mu = .10

Node 125 Guide Mu = .10

From 125 To 130 DX= 4,000.000 mm

BEND at "TO" end

Radius= 1,143.000 mm (LONG) Bend Angle= 90.000 Angle/Node @1= 45.00 129

Angle/Node @2= .00 128

From 130 To 140 DZ= -3,000.000 mm

RESTRAINTS

Node 140 Y Mu = .10

From 140 To 150 DZ= -1,000.000 mm

From 150 To 160 DX= 2,500.000 mm

RESTRAINTS

Node 160 Y Mu = .10

SIF's & TEE's

Node 150 Welding Tee

From 160 To 165 DX= 1,295.000 mm

RIGID Weight=66,708.00 N

From 150 To 170 DX= -2,500.000 mm

RESTRAINTS

Node 170 Y Mu = .10

From 170 To 175 DX= -1,295.000 mm

RIGID Weight=66,708.00 N

From 175 To 180 DX= -2,000.000 mm

BEND at "TO" end

Radius= 1,143.000 mm (LONG) Bend Angle= 90.000 Angle/Node @1= 45.00 179

Angle/Node @2= .00 178

From 180 To 190 DZ= -5,300.000 mm

From 190 To 200 DZ= -137.000 mm

RIGID Weight= 1,974.00 N

RESTRAINTS

Node 200 ANC   Cnode 201

From 165 To 210 DX= 2,000.000 mm

BEND at "TO" end

Radius= 1,143.000 mm (LONG)   Bend Angle= 90.000   Angle/Node @1= 45.00 209

Angle/Node @2= .00 208

From 210 To 220 DZ= -5,300.000 mm

From 220 To 230 DZ= -137.000 mm

RIGID Weight= 1,974.00 N

RESTRAINTS

Node 230 ANC   Cnode 231

From 231 To 240 DZ= -137.000 mm

RIGID Weight= 1,974.00 N

From 240 To 250   P1202 DZ= -500.000 mm

RIGID Weight= .20 N

RESTRAINTS

Node 250 ANC

From 250 To 260 DY= 500.000 mm

RIGID Weight= .20 N

From 260 To 270 DY= 137.000 mm

RIGID Weight= 1,974.00 N

RESTRAINTS

Node 270 ANC Cnode 271

From 271 To 280 DY= 137.000 mm

RIGID Weight= 1,974.00 N

From 280 To 290 DY= 500.000 mm

REDUCER

Diam2= 508.000 mm Wall2= 9.525 mm

From 290 To 300 DY= 1,000.000 mm

PIPE

Dia= 508.000 mm Wall= 9.525 mm Insul= .000 mm

BEND at "TO" end

Radius= 762.000 mm (LONG) Bend Angle= 90.000 Angle/Node @1= 45.00 299

Angle/Node @2= .00 298

From 300 To 310 DZ= 1,500.000 mm

RESTRAINTS

Node 310 Y Mu = .10

From 310 To 320 DZ= 6,000.000 mm

RESTRAINTS

Node 320 Y Mu = .10

From 320 To 330 DZ= 6,000.000 mm

RESTRAINTS

Node 330 Y Mu = .10

From 330 To 340 DZ= 1,000.000 mm

BEND at "TO" end

Radius= 762.000 mm (LONG) Bend Angle= 90.000 Angle/Node @1= 45.00 339

Angle/Node @2= .00 338

From 340 To 350 DX= -1,000.000 mm

From 201 To 390 DZ= -137.000 mm

RIGID Weight= 1,974.00 N

From 390 To 400 P1201 DZ= -500.000 mm

PIPE

Dia= 762.000 mm Wall= 12.700 mm Insul= .000 mm

RIGID Weight= .20 N

RESTRAINTS

Node 400 ANC

From 400 To 410 DY= 500.000 mm

RIGID Weight= .20 N

From 410 To 420 DY= 137.000 mm

RIGID Weight= 1,974.00 N

RESTRAINTS

Node 420 ANC   Cnode 421

From 421 To 430 DY= 137.000 mm

RIGID Weight= 1,974.00 N

From 430 To 440 DY= 500.000 mm

REDUCER

Diam2= 508.000 mm   Wall2= 9.525 mm

From 440 To 450 DY= 1,000.000 mm

PIPE

Dia= 508.000 mm   Wall= 9.525 mm   Insul= .000 mm

BEND at "TO" end

Radius= 762.000 mm (LONG)   Bend Angle= 90.000   Angle/Node @1= 45.00 449

Angle/Node @2= .00 448

From 450 To 460 DZ= 1,500.000 mm

RESTRAINTS

Node 460 Y   Mu = .10

From 460 To 470 DZ= 6,000.000 mm

RESTRAINTS

Node 470 Y   Mu = .10

From 470 To 480 DZ= 6,000.000 mm

RESTRAINTS

Node 480 Y   Mu = .10

From 480 To 490 DZ= 1,000.000 mm

BEND at "TO" end

Radius= 762.000 mm (LONG)   Bend Angle= 90.000   Angle/Node @1= 45.00 489

Angle/Node @2= .00 488

From 490 To 590 DX= 1,000.000 mm

From 350 To 392 DX= -1,398.000 mm

From 392 To 434 DX= -145.000 mm

RIGID Weight= 983.00 N

From 434 To 476 DX= -914.000 mm

RIGID Weight=23,642.00 N

RESTRAINTS

Node 476 Y Mu = .10

From 476 To 518 DX= -145.000 mm

RIGID Weight= 983.00 N

From 518 To 560 DX= -1,398.000 mm

From 560 To 475 DX= -795.000 mm

From 475 To 505 DX= -795.000 mm

From 505 To 522 DX= -1,398.000 mm

From 522 To 539 DX= -145.000 mm

RIGID Weight= 983.00 N

From 539 To 556 DX= -914.000 mm

RIGID Weight=23,642.00 N

RESTRAINTS

Node 539 Y Mu = .10

From 556 To 573 DX= -145.000 mm

RIGID Weight= 983.00 N

From 573 To 590 DX= -1,398.000 mm

From 475 To 600 DY= -1,000.000 mm

SIF's & TEE's

Node 475 Welding Tee

From 600 To 610 DY= -500.000 mm

From 610 To 620 DY= -500.000 mm

From 620 To 630 DY= -1,000.000 mm

BEND at "TO" end

Radius= 762.000 mm (LONG) Bend Angle= 90.000 Angle/Node @1= 45.00 629

Angle/Node @2= .00 628

From 630 To 640 DZ= 1,000.000 mm

RESTRAINTS

Node 640 Y Mu = .10

From 640 To 650 DZ= 6,000.000 mm

RESTRAINTS

Node 650 Y Mu = .10

From 650 To 660 DZ= 6,000.000 mm

From 660 To 670 U1201 DZ= 145.000 mm

RIGID Weight= 983.00 N

RESTRAINTS

Node 670 ANC

4.3 OUTPUT DATA

NODENAMES

10 20 From= V0401 To=

240 250 From= To= P1202

390 400 From= To= P1201

660 670 From= To= U1201

MATERIAL Changes:

10 V0401 20 Mat= (106)A106 B E= 203,366 MPa v = .292

Density= 7,833.4116 kg/m³

ALLOWABLE STRESS Changes

10 V0401 20 B31.3 (2004) Sc= 138 N/mm²

Sh1= 138 N/mm² Sh2= 138 N/mm²

Sh3= 138 N/mm² Sh4= 138 N/mm²

Sh5= 138 N/mm² Sh6= 138 N/mm²

Sh7= 138 N/mm² Sh8= 138 N/mm²

Sh9= 138 N/mm²

BEND ELEMENTS

20 30 Radius= 1,143.000 mm (LONG)

Bend Angle= 90.000 Angle/Node @1= 45.00 29

Angle/Node @2= .00 28

40 50 Radius= 1,143.000 mm (LONG)

Bend Angle= 90.000 Angle/Node @1= 45.00 49

Angle/Node @2= .00 48

100 110 Radius= 1,143.000 mm (LONG)

Bend Angle= 90.000 Angle/Node @1= 45.00

109 Angle/Node @2= .00 108

125 130 Radius= 1,143.000 mm (LONG)

Bend Angle= 90.000 Angle/Node @1= 45.00

129 Angle/Node @2= .00 128

175 180 Radius= 1,143.000 mm (LONG)

Bend Angle= 90.000 Angle/Node @1= 45.00

179 Angle/Node @2= .00 178

165 210 Radius= 1,143.000 mm (LONG)

Bend Angle= 90.000 Angle/Node @1= 45.00

209 Angle/Node @2= .00 208

290 300 Radius= 762.000 mm (LONG)

Bend Angle= 90.000 Angle/Node @1= 45.00

299 Angle/Node @2= .00 298

330 340 Radius= 762.000 mm (LONG)

Bend Angle= 90.000 Angle/Node @1= 45.00

339 Angle/Node @2= .00 338

440 450 Radius= 762.000 mm (LONG)

Bend Angle= 90.000 Angle/Node @1= 45.00

449 Angle/Node @2= .00 448

480 490 Radius= 762.000 mm (LONG)

Bend Angle= 90.000 Angle/Node @1= 45.00

489 Angle/Node @2= .00 488

620 630 Radius= 762.000 mm (LONG)

Bend Angle= 90.000 Angle/Node @1= 45.00

629 Angle/Node @2= .00 628

RIGIDS

10 V0401 20 RIGID Weight= 1,974.00 N

70 80 RIGID Weight=66,708.00 N

160 165 RIGID Weight=66,708.00 N

170 175 RIGID Weight=66,708.00 N

190 200 RIGID Weight= 1,974.00 N

220 230 RIGID Weight= 1,974.00 N

231 240 RIGID Weight= 1,974.00 N

240 250 P1202 RIGID Weight= .20 N

250 260 RIGID Weight= .20 N

260 270 RIGID Weight= 1,974.00 N

271 280 RIGID Weight= 1,974.00 N

201 390 RIGID Weight= 1,974.00 N

390 400 P1201 RIGID Weight= .20 N

400 410 RIGID Weight= .20 N

410 420 RIGID Weight= 1,974.00 N

421	430	RIGID Weight= 1,974.00 N
392	434	RIGID Weight= 983.00 N
434	476	RIGID Weight=23,642.00 N
476	518	RIGID Weight= 983.00 N
522	539	RIGID Weight= 983.00 N
539	556	RIGID Weight=23,642.00 N
556	573	RIGID Weight= 983.00 N
660	670 U1201	RIGID Weight= 983.00 N

SIF's & TEE's

150	160	Node 150 Welding Tee
475	600	Node 475 Welding Tee

REDUCERS

280	290	Diam2= 508.000 mm Wall2= 9.525 mm
430	440	Diam2= 508.000 mm Wall2= 9.525 mm

RESTRAINTS Len MU

GAP YIELD Dir

NODE TYPE CNODE STIF1 STIF2 FORCE Vectors

-------+-------+------+----------+----------+----------+---------------------

10	ANC			.000	.000	.000
40	Y		.10	.000	1.000	.000
60	Y		.10	.000	1.000	.000
80	Y		.10	.000	1.000	.000
90	Y		.10	.000	1.000	.000
90	Guide		.10	.000	.000	.000
100	Y		.10	.000	1.000	.000
120	Y		.10	.000	1.000	.000
120	Guide		.10	.000	.000	.000
125	Y		.10	.000	1.000	.000
125	Guide		.10	.000	.000	.000
140	Y		.10	.000	1.000	.000
160	Y		.10	.000	1.000	.000
170	Y		.10	.000	1.000	.000
200	ANC	201		.000	.000	.000
230	ANC	231		.000	.000	.000
250	ANC			.000	.000	.000
270	ANC	271		.000	.000	.000
310	Y		.10	.000	1.000	.000
320	Y		.10	.000	1.000	.000
330	Y		.10	.000	1.000	.000
400	ANC			.000	.000	.000
420	ANC	421		.000	.000	.000
460	Y		.10	.000	1.000	.000

470	Y	.10	.000	1.000	.000
480	Y	.10	.000	1.000	.000
476	Y	.10	.000	1.000	.000
539	Y	.10	.000	1.000	.000
640	Y	.10	.000	1.000	.000
650	Y	.10	.000	1.000	.000
670	ANC		.000	.000	.000

INPUT UNITS USED...

UNITS= Foster W NOM/SCH INPUT= ON

LENGTH	inches	x	25.400	=	mm
FORCE	pounds	x	4.448	=	N
MASS(dynamics)	pounds	x	0.454	=	kg
MOMENTS(INPUT)	inch-pounds	x	0.113	=	Nm
MOMENTS(OUTPUT)	inch-pounds	x	0.113	=	Nm
STRESS	lbs./sq.in.	x	0.007	=	N/mm²
TEMP. SCALE	degrees F.	x	0.556	=	C
PRESSURE	psig	x	6.895	=	kPa
ELASTIC MODULUS	lbs./sq.in.	x	0.007	=	MPa
PIPE DENSITY	lbs./cu.in.	x	27679.900	=	kg/m³
INSULATION DENS.	lbs./cu.in.	x	27679.900	=	kg/m³
FLUID DENSITY	lbs./cu.in.	x	27679.900	=	kg/m³
TRANSL. STIF	lbs./in.	x	1.751	=	N/cm
ROTATIONAL STIF	in.lb./deg.	x	0.113	=	Nm/deg

UNIFORM LOAD	lb./in.	x	1.751	=	N/cm
G LOAD	g's	x	1.000	=	g's
WIND LOAD	lbs./sq.in.	x	6.895	=	kPa
ELEVATION	inches	x	0.025	=	m
COMPOUND LENGTH	inches	x	25.400	=	mm
DIAMETER	inches	x	25.400	=	mm
WALL THICKNESS	inches	x	25.400	=	mm

EXECUTION CONTROL PARAMETERS

Rigid/ExpJt Print Flag 1.000

Bourdon Option .... .000

Loop Closure Flag .... .000

Thermal Bowing Delta Temp .. .000 C

Liberal Allowable Flag 1.000

Uniform Load Option .... .000

Ambient Temperature .... 22.000 C

Plastic (FRP) Alpha 21.598

Plastic (FRP) GMOD/EMODa ... .250

Plastic (FRP) Laminate Type. 3.000

Eqn Optimizer .... .000

Node Selection .... .000

Eqn Ordering .... .000

Collins .... .000

Degree Determination .... .000

User Eqn Control .... .000

COORDINATE REPORT

/--------------------(mm)----------------------/

NODE	X	Y	Z
10	.0000	.0000	.0000
20	.0000	-137.0000	.0000
30	.0000	-1817.0000	.0000
40	2000.0000	-1817.0000	.0000
50	4500.0000	-1817.0000	.0000
60	4500.0000	-1817.0000	4000.0000
70	4500.0000	-1817.0000	8000.0000
80	4500.0000	-1817.0000	9295.0000
90	4500.0000	-1817.0000	15295.0000
100	4500.0000	-1817.0000	21295.0000
110	4500.0000	-1817.0000	23295.0000
120	8500.0000	-1817.0000	23295.0000
125	14500.0000	-1817.0000	23295.0000
130	18500.0000	-1817.0000	23295.0000
140	18500.0000	-1817.0000	20295.0000
150	18500.0000	-1817.0000	19295.0000
160	21000.0000	-1817.0000	19295.0000
165	22295.0000	-1817.0000	19295.0000
150	18500.0000	-1817.0000	19295.0000

170	16000.0000	-1817.0000	19295.0000
175	14705.0000	-1817.0000	19295.0000
180	12705.0000	-1817.0000	19295.0000
190	12705.0000	-1817.0000	13995.0000
200	12705.0000	-1817.0000	13858.0000
165	22295.0000	-1817.0000	19295.0000
210	24295.0000	-1817.0000	19295.0000
220	24295.0000	-1817.0000	13995.0000
230	24295.0000	-1817.0000	13858.0000
240	24295.0000	-1817.0000	13721.0000
250	24295.0000	-1817.0000	13221.0000
260	24295.0000	-1317.0000	13221.0000
270	24295.0000	-1180.0000	13221.0000
280	24295.0000	-1043.0000	13221.0000
290	24295.0000	-543.0000	13221.0000
300	24295.0000	457.0000	13221.0000
310	24295.0000	457.0000	14721.0000
320	24295.0000	457.0000	20721.0000
330	24295.0000	457.0000	26721.0000
340	24295.0000	457.0000	27721.0000
350	23295.0000	457.0000	27721.0000
200	12705.0000	-1817.0000	13858.0000
390	12705.0000	-1817.0000	13721.0000
400	12705.0000	-1817.0000	13221.0000
410	12705.0000	-1317.0000	13221.0000

420	12705.0000	-1180.0000	13221.0000
430	12705.0000	-1043.0000	13221.0000
440	12705.0000	-543.0000	13221.0000
450	12705.0000	457.0000	13221.0000
460	12705.0000	457.0000	14721.0000
470	12705.0000	457.0000	20721.0000
480	12705.0000	457.0000	26721.0000
490	12705.0000	457.0000	27721.0000
590	13705.0000	457.0000	27721.0000
350	23295.0000	457.0000	27721.0000
392	21897.0000	457.0000	27721.0000
434	21752.0000	457.0000	27721.0000
476	20838.0000	457.0000	27721.0000
518	20693.0000	457.0000	27721.0000
560	19295.0000	457.0000	27721.0000
475	18500.0000	457.0000	27721.0000
505	17705.0000	457.0000	27721.0000
522	16307.0000	457.0000	27721.0000
539	16162.0000	457.0000	27721.0000
556	15248.0000	457.0000	27721.0000
573	15103.0000	457.0000	27721.0000
590	13705.0000	457.0000	27721.0000
475	18500.0000	457.0000	27721.0000
600	18500.0000	-543.0000	27721.0000
610	18500.0000	-1043.0000	27721.0000

620	18500.0000	-1543.0000	27721.0000
630	18500.0000	-2543.0000	27721.0000
640	18500.0000	-2543.0000	28721.0000
650	18500.0000	-2543.0000	34721.0000
660	18500.0000	-2543.0000	40721.0000
670	18500.0000	-2543.0000	40866.0000

Table 1 : DISPLACEMENTS REPORT: CASE 1 (OPE) W+T1+P1

NODE	DX mm	DY mm	DZ mm	RX deg.	RY deg.	RZ deg.
10	0	0	0	0	0	0
20	0	-0.123	0	0	0.0002	0
28	0.003	-0.605	-0.029	0.0015	0.0126	0.0013
29	0.579	-1.171	-0.635	0.061	0.0649	0.0387
30	1.581	-0.767	-3.059	0.1059	0.2078	0.0505
40	2.352	0	-6.261	0.1	0.2154	0.0479
48	3.572	1.052	-11.476	0.0908	0.2182	0.0429
49	5.337	1.061	-13.884	0.0797	0.1452	0.0405
50	6.798	0.605	-13.783	0.0196	0.0211	0.058
60	7.225	0	-11.235	0.0077	-0.0028	0.052
70	6.04	-0.122	-7.669	-0.0052	-0.03	0.0434
80	5.356	0	-6.505	-0.0051	-0.0305	0.0432
90	0	0	-1.165	0.0008	-0.0762	0.0305
100	-9.508	0	4.169	0.0015	-0.0887	0.0177
108	-10.811	-0.056	4.931	0.0037	-0.083	0.0158
109	-10.894	-0.159	5.674	0.0177	0.0343	0.0094
110	-9.78	-0.192	4.837	0.0198	0.1035	0.0038
120	-7.22	0	0	0.0182	0.0725	0.0028
125	-1.851	0	0	0.0147	-0.0759	-0.0092
128	0.699	-0.812	5.192	0.0131	-0.113	-0.0177
129	1.93	-0.937	6.277	0.016	-0.062	-0.0099
130	2.464	-0.709	5.751	0.0217	0.0185	-0.0055
140	1.778	0	4.101	0.0208	0.0162	-0.0023
150	1.533	0.354	3.213	0.0189	0.0067	-0.0006
160	3.745	0	4.213	0.0149	-0.0415	-0.0191
165	4.908	-0.443	5.163	0.0148	-0.042	-0.0195
170	-0.696	0	4.214	0.0149	0.0336	0.0195
175	-1.861	-0.451	4.982	0.0148	0.034	0.0199
178	-2.625	-0.762	5.513	0.0134	0.0333	0.0201
179	-3.343	-0.913	5.36	0.0149	-0.0204	0.0119
180	-2.997	-0.762	4.415	0.0136	-0.0567	0.0092
190	-0.016	-0.006	0.696	0.0007	-0.0022	0.0002
200	-0.01	-0.004	0.573	0.0007	-0.002	0.0002
201	-0.01	-0.004	0.573	0.0007	-0.002	0.0002
208	5.667	-0.749	5.83	0.0134	-0.0409	-0.0197
209	6.291	-0.896	5.566	0.0148	0.0484	-0.0116
210	5.344	-0.746	4.399	0.0134	0.1027	-0.0091
220	0.023	-0.005	0.696	0.0005	0.0026	-0.0001

230	0.016	-0.004	0.573	0.0004	0.0022	-0.0001
231	0.016	-0.004	0.573	0.0004	0.0022	-0.0001
240	0.011	-0.003	0.45	0.0003	0.0017	-0.0001
250	0	0	0	0	0	0
260	0	0.449	-0.002	-0.0002	0	0
270	0	0.573	-0.003	-0.0002	0	0
271	0	0.573	-0.003	-0.0002	0	0
280	0	0.696	-0.004	-0.0002	0	0
290	0.001	1.139	-0.034	-0.0016	0.0007	-0.0003
298	0.003	1.348	-0.056	-0.0013	0.0013	-0.0007
299	0.1	1.675	0.369	0.0618	0.0098	-0.0171
300	0.371	1.062	1.16	0.0822	0.0297	-0.0262
310	0.764	0	1.815	0.0689	0.0315	-0.028
320	4.414	0	7.152	-0.0278	0.0332	-0.0424
330	6.29	0	12.493	0.0468	-0.0073	-0.0568
338	6.256	-0.215	12.705	0.0529	-0.0101	-0.0574
339	5.514	-1.336	12.888	0.1932	-0.1061	-0.0158
340	4.523	-2.063	11.772	0.2142	-0.1548	-0.0261
350	4.309	-1.955	11.118	0.219	-0.1546	-0.0287
390	-0.006	-0.003	0.45	0.0003	-0.001	0.0001
392	3.053	-1.01	7.456	0.2472	-0.1349	-0.0539
400	0	0	0	0	0	0
410	0	0.449	-0.002	-0.0002	0	0
420	0	0.573	-0.003	-0.0002	0	0
421	0	0.573	-0.003	-0.0002	0	0
430	0	0.696	-0.004	-0.0002	0	0
434	2.922	-0.874	7.114	0.2474	-0.1347	-0.0541
440	-0.001	1.139	-0.034	-0.0016	-0.0007	0.0003
448	-0.003	1.348	-0.056	-0.0013	-0.0013	0.0007
449	-0.1	1.675	0.369	0.0618	-0.0098	0.0171
450	-0.371	1.062	1.16	0.0822	-0.0297	0.0262
460	-0.764	0	1.815	0.0689	-0.0315	0.028
470	-4.414	0	7.152	-0.0278	-0.0332	0.0424
475	0	2.054	1.805	0.2929	0	0
476	2.1	0	4.976	0.2485	-0.1328	-0.0554
480	-6.29	0	12.493	0.0468	0.0073	0.0568
488	-6.256	-0.215	12.705	0.0529	0.0101	0.0574
489	-5.514	-1.336	12.888	0.1932	0.1061	0.0158
490	-4.523	-2.063	11.772	0.2142	0.1548	0.0261
505	-0.714	1.641	2.233	0.2768	0.0558	0.0422
518	1.969	0.142	4.64	0.2487	-0.1324	-0.0556

522	-1.969	0.142	4.64	0.2487	0.1324	0.0556
539	-2.1	0	4.976	0.2485	0.1328	0.0554
556	-2.922	-0.874	7.114	0.2474	0.1347	0.0541
560	0.714	1.641	2.233	0.2768	-0.0558	-0.0422
573	-3.053	-1.01	7.456	0.2472	0.1349	0.0539
590	-4.309	-1.955	11.118	0.219	0.1546	0.0287
600	0	1.2	-3.576	0.31	0	0
610	0	0.773	-6.317	0.3081	0	0
620	0	0.347	-9.011	0.2991	0	0
628	0	0.144	-10.259	0.2924	0	0
629	0	-0.714	-11.549	0.0151	0	0
630	0	-0.294	-10.89	-0.059	0	0
640	0	0	-10.679	-0.0531	0	0
650	0	0	-5.404	0.0128	0	0
660	0	0	-0.13	-0.0001	0	0
670	0	0	0	0	0	0

Table 2 : RESTRAINT SUMMARY REPORT: Various Load Cases

LOAD CASE DEFINITION KEY							
CASE 1 (OPE) W+T1+P1							
CASE 2 (SUS) W+P1							
CASE 3 (EXP) L3=L1-L2							
NODE	Load	FX N	FY N	FZ N	MX Nm	MY Nm	MZ Nm
	Case						
10		Rigid ANC					
	1 (OPE)	-6796	16416	-42638	38156	133543	14997
	2 (SUS)	-3873	-2806	-246	-61	420	-2380
	3 (EXP)	-2923	19223	-42392	38217	133123	17377
	MAX	6796/ 1	19223/ 3	42638/ 1	38217/ 3	133543/ 1	17377/ 3
40		Rigid Y					
	1 (OPE)	2052	-58353	-5463	0	0	0
	2 (SUS)	3650	-38107	183	0	0	0
	3 (EXP)	-1598	-20246	-5646	0	0	0
	MAX	3650/ 2	58353/ 1	5646/ 3	0/ 1	0/ 1	0/ 1
60		Rigid Y					
	1 (OPE)	1906	-35230	-2963	0	0	0
	2 (SUS)	358	-46528	22	0	0	0
	3 (EXP)	1547	11298	-2985	0	0	0
	MAX	1906/ 1	46528/ 2	2985/ 3	0/ 1	0/ 1	0/ 1
80		Rigid Y					
	1 (OPE)	6809	-107125	-8270	0	0	0
	2 (SUS)	-145	-94304	17	0	0	0
	3 (EXP)	6955	-12821	-8287	0	0	0
	MAX	6955/ 3	107125/ 1	8287/ 3	0/ 1	0/ 1	0/ 1
90		Rigid Y; Rigid GUI					
	1 (OPE)	-23343	-31500	-5484	0	0	0
	2 (SUS)	10	-35516	13	0	0	0
	3 (EXP)	-23353	4016	-5498	0	0	0
	MAX	23353/ 3	35516/ 2	5498/ 3	0/ 1	0/ 1	0/ 1

100		Rigid Y					
	1 (OPE)	-4066	-44401	1783	0	0	0
	2 (SUS)	0	-38512	11	0	0	0
	3 (EXP)	-4066	-5888	1772	0	0	0
	MAX	4066/ 1	44401/ 1	1783/ 1	0/ 1	0/ 1	0/ 1
120		Rigid Y; Rigid GUI					
	1 (OPE)	-8626	-25577	60683	0	0	0
	2 (SUS)	0	-31245	1	0	0	0
	3 (EXP)	-8626	5668	60682	0	0	0
	MAX	8626/ 3	31245/ 2	60683/ 1	0/ 1	0/ 1	0/ 1
125		Rigid Y; Rigid GUI					
	1 (OPE)	-12894	-55938	72998	0	0	0
	2 (SUS)	0	-53353	-1	0	0	0
	3 (EXP)	-12894	-2585	72998	0	0	0
	MAX	12894/ 3	55938/ 1	72998/ 3	0/ 1	0/ 1	0/ 1
140		Rigid Y					
	1 (OPE)	369	-9286	852	0	0	0
	2 (SUS)	0	-10785	0	0	0	0
	3 (EXP)	369	1499	852	0	0	0
	MAX	369/ 3	10785/ 2	852/ 1	0/ 1	0/ 1	0/ 1
160		Rigid Y					
	1 (OPE)	7463	-112336	8396	0	0	0
	2 (SUS)	0	-111754	0	0	0	0
	3 (EXP)	7463	-583	8396	0	0	0
	MAX	7463/ 1	112336/ 1	8396/ 1	0/ 1	0/ 1	0/ 1
170		Rigid Y					
	1 (OPE)	-1769	-108475	10702	0	0	0
	2 (SUS)	0	-108892	0	0	0	0
	3 (EXP)	-1769	417	10702	0	0	0
	MAX	1769/ 1	108892/ 2	10702/ 1	0/ 1	0/ 1	0/ 1
200		Rigid ANC					
	1 (OPE)	-48035	-29457	-32833	64172	-203985	12541
	2 (SUS)	0	-29441	0	64125	0	12559
	3 (EXP)	-48035	-16	-32833	47	-203985	-18
	MAX	48035/ 1	29457/ 1	32833/ 1	64172/ 1	203985/ 1	12559/ 2
230		Rigid ANC					
	1 (OPE)	85470	-29492	-54971	64376	368727	-12432
	2 (SUS)	0	-29508	0	64476	0	-12452
	3 (EXP)	85470	16	-54971	-99	368727	20
	MAX	85470/ 1	29508/ 2	54971/ 1	64476/ 2	368727/ 1	12452/ 2
250		Rigid ANC					

	1 (OPE)	84740	-103767	-91572	36196	426443	-13825
	2 (SUS)	376	-42985	1619	87710	389	-12799
	3 (EXP)	84364	-60782	-93191	-51514	426052	-1027
	MAX	84740/ 1	103767/ 1	93191/ 3	87710/ 2	426443/ 1	13825/ 1
270		Rigid ANC					
	1 (OPE)	730	65005	36601	25622	-3269	1859
	2 (SUS)	-376	4207	-1619	-1436	-389	107
	3 (EXP)	1106	60798	38221	27058	-2880	1752
	MAX	1106/ 3	65005/ 1	38221/ 3	27058/ 3	3269/ 1	1859/ 1
310		Rigid Y					
	1 (OPE)	2148	55400	5107	0	0	0
	2 (SUS)	-411	-15342	-778	0	0	0
	3 (EXP)	2559	70742	5885	0	0	0
	MAX	2559/ 3	70742/ 3	5885/ 3	0/ 1	0/ 1	0/ 1
320		Rigid Y					
	1 (OPE)	1243	-23671	2014	0	0	0
	2 (SUS)	41	-19585	-487	0	0	0
	3 (EXP)	1202	-4086	2501	0	0	0
	MAX	1243/ 1	23671/ 1	2501/ 3	0/ 1	0/ 1	0/ 1
330		Rigid Y					
	1 (OPE)	1535	-34131	3048	0	0	0
	2 (SUS)	-15	-15317	-364	0	0	0
	3 (EXP)	1550	-18814	3412	0	0	0
	MAX	1550/ 3	34131/ 1	3412/ 3	0/ 1	0/ 1	0/ 1
400		Rigid ANC					
	1 (OPE)	-47305	-103412	-69434	35786	-237853	13935
	2 (SUS)	-376	-42598	1619	87134	-389	12905
	3 (EXP)	-46928	-60814	-71053	-51348	-237462	1030
	MAX	47305/ 1	103412/ 1	71053/ 3	87134/ 2	237853/ 1	13935/ 1
420		Rigid ANC					
	1 (OPE)	-730	65005	36601	25622	3269	-1859
	2 (SUS)	376	4207	-1619	-1436	389	-107
	3 (EXP)	-1106	60798	38221	27058	2880	-1752
	MAX	1106/ 3	65005/ 1	38221/ 3	27058/ 3	3269/ 1	1859/ 1
460		Rigid Y					
	1 (OPE)	-2148	55400	5107	0	0	0
	2 (SUS)	411	-15342	-778	0	0	0
	3 (EXP)	-2559	70742	5885	0	0	0
	MAX	2559/ 3	70742/ 3	5885/ 3	0/ 1	0/ 1	0/ 1
470		Rigid Y					
	1 (OPE)	-1243	-23671	2014	0	0	0

	2 (SUS)	-41	-19585	-487	0	0	0
	3 (EXP)	-1202	-4086	2501	0	0	0
	MAX	1243/ 1	23671/ 1	2501/ 3	0/ 1	0/ 1	0/ 1
476		Rigid Y					
	1 (OPE)	1746	44900	4137	0	0	0
	2 (SUS)	1	-38467	71	0	0	0
	3 (EXP)	1745	83368	4066	0	0	0
	MAX	1746/ 1	83368/ 3	4137/ 1	0/ 1	0/ 1	0/ 1
480		Rigid Y					
	1 (OPE)	-1535	-34131	3048	0	0	0
	2 (SUS)	15	-15317	-364	0	0	0
	3 (EXP)	-1550	-18814	3412	0	0	0
	MAX	1550/ 3	34131/ 1	3412/ 3	0/ 1	0/ 1	0/ 1
539		Rigid Y					
	1 (OPE)	-1746	44900	4137	0	0	0
	2 (SUS)	-1	-38467	71	0	0	0
	3 (EXP)	-1745	83368	4066	0	0	0
	MAX	1746/ 1	83368/ 3	4137/ 1	0/ 1	0/ 1	0/ 1
640		Rigid Y					
	1 (OPE)	0	-166866	-16687	0	0	0
	2 (SUS)	0	-14566	-46	0	0	0
	3 (EXP)	0	-152300	-16640	0	0	0
	MAX	0/ 1	166866/ 1	16687/ 1	0/ 1	0/ 1	0/ 1
650		Rigid Y					
	1 (OPE)	0	-4125	-413	0	0	0
	2 (SUS)	0	-19221	-20	0	0	0
	3 (EXP)	0	15096	-393	0	0	0
	MAX	0/ 1	19221/ 2	413/ 1	0/ 1	0/ 1	0/ 1
670		Rigid ANC					
	1 (OPE)	0	-13508	63350	-17199	0	0
	2 (SUS)	0	-9889	-57	-9652	0	0
	3 (EXP)	0	-3619	63407	-7547	0	0
	MAX	0/ 1	13508/ 1	63407/ 3	17199/ 1	0/ 1	0/ 1

Table 3 : STRESSES REPORT: CASE 2 (SUS) W+P1

CODE STRESS CHECK PASSED : LOADCASE 2 (SUS) W+P1							
Highest Stresses: (N/mm²)							
CodeStress Ratio: 26.5 @Node 150							
Code Stress: 36.6 Allowable: 137.9							
Axial Stress: 1.2 @Node 475							
Bending Stress: 35.6 @Node 150							
Torsion Stress: 1.1 @Node 179							
Hoop Stress: 2.0 @Node 28							
3D Max Intensity: 36.6 @Node 150							
NODE	Bending	Torsion	SIF In	SIF Out	Code	Allowable	Ratio
	Stress	Stress	Plane	Plane	Stress	Stress	%
	N/mm²	N/mm²			N/mm²	N/mm²	
10	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0
20	0.34	0.04	1	1	1.34	137.9	0.97
28	0.06	-0.04	1	1	0.95	137.9	0.69
28	0.22	0.04	4.04	3.367	1.11	137.9	0.8
29	0.73	-0.05	4.04	3.367	1.43	137.9	1.03
29	0.73	0.05	4.04	3.367	1.43	137.9	1.03
30	5.48	-0.05	4.04	3.367	6.35	137.9	4.61
30	1.36	0.05	1	1	2.23	137.9	1.61
40	4.1	-0.05	1	1	4.97	137.9	3.6
40	4.1	0.05	1	1	5.09	137.9	3.69
48	0.81	-0.05	1	1	1.8	137.9	1.31
48	2.74	0.05	4.04	3.367	3.73	137.9	2.71
49	1.19	-0.11	4.04	3.367	2.18	137.9	1.58
49	1.19	0.11	4.04	3.367	2.18	137.9	1.58
50	1.39	0.08	4.04	3.367	2.38	137.9	1.73
50	0.41	-0.08	1	1	1.41	137.9	1.02
60	5.78	0.08	1	1	6.78	137.9	4.91
60	5.78	-0.08	1	1	6.78	137.9	4.91
70	3.23	0.08	1	1	4.22	137.9	3.06
70	0	0	0	0	0	0	0

80	0	0	0	0	0	0	0
80	5.38	-0.08	1	1	6.38	137.9	4.62
90	2.96	0.08	1	1	3.96	137.9	2.87
90	2.96	-0.08	1	1	3.96	137.9	2.87
100	4.16	0.08	1	1	5.16	137.9	3.74
100	4.16	-0.08	1	1	5.16	137.9	3.74
108	1.79	0.08	1	1	2.79	137.9	2.02
108	6.03	-0.08	4.04	3.367	7.03	137.9	5.1
109	0.76	0.37	4.04	3.367	1.75	137.9	1.27
109	0.76	-0.37	4.04	3.367	1.75	137.9	1.27
110	4.08	0.04	4.04	3.367	5.07	137.9	3.68
110	1.21	-0.04	1	1	2.21	137.9	1.6
120	3.16	0.04	1	1	4.16	137.9	3.02
120	3.16	-0.04	1	1	4.16	137.9	3.02
125	9.53	0.04	1	1	10.53	137.9	7.64
125	9.53	-0.04	1	1	10.53	137.9	7.64
128	0.24	0.04	1	1	1.23	137.9	0.9
128	0.8	-0.04	4.04	3.367	1.8	137.9	1.3
129	3.99	-0.28	4.04	3.367	4.99	137.9	3.62
129	3.99	0.28	4.04	3.367	4.99	137.9	3.62
130	1.82	-0.68	4.04	3.367	2.82	137.9	2.04
130	0.54	0.68	1	1	1.54	137.9	1.12
140	2.17	-0.68	1	1	3.17	137.9	2.3
140	2.17	0.68	1	1	3.17	137.9	2.3
150	13.55	-0.68	3.281	4.042	14.55	137.9	10.55
150	30.11	0.84	3.281	4.042	31.11	137.9	22.56
160	14	-0.84	1	1	15	137.9	10.87
160	0	0	0	0	0	0	0
165	0	0	0	0	0	0	0
150	35.56	-0.84	3.281	4.042	36.56	137.9	26.51
170	14.02	0.84	1	1	15.02	137.9	10.89
170	0	0	0	0	0	0	0
175	0	0	0	0	0	0	0
175	1.5	-0.84	1	1	2.5	137.9	1.81
178	0.74	0.84	1	1	1.74	137.9	1.26
178	2.5	-0.84	4.04	3.367	3.49	137.9	2.53
179	2.01	1.15	4.04	3.367	3.01	137.9	2.18
179	2.01	-1.15	4.04	3.367	3.01	137.9	2.18
180	2.69	1.14	4.04	3.367	3.68	137.9	2.67
180	0.8	-1.14	1	1	1.8	137.9	1.3
190	10.94	1.14	1	1	11.94	137.9	8.66

190	0	0	0	0	0	0	0
200	0	0	0	0	0	0	0
165	1.5	0.84	1	1	2.49	137.9	1.81
208	0.74	-0.84	1	1	1.73	137.9	1.26
208	2.48	0.84	4.04	3.367	3.48	137.9	2.52
209	1.97	-1.14	4.04	3.367	2.97	137.9	2.15
209	1.97	1.14	4.04	3.367	2.97	137.9	2.15
210	2.72	-1.13	4.04	3.367	3.72	137.9	2.7
210	0.81	1.13	1	1	1.81	137.9	1.31
220	11	-1.13	1	1	12	137.9	8.7
220	0	0	0	0	0	0	0
230	0	0	0	0	0	0	0
231	0	0	0	0	0	0	0
240	0	0	0	0	0	0	0
240	0	0	0	0	0	0	0
250	0	0	0	0	0	0	0
250	0	0	0	0	0	0	0
260	0	0	0	0	0	0	0
260	0	0	0	0	0	0	0
270	0	0	0	0	0	0	0
271	0	0	0	0	0	0	0
280	0	0	0	0	0	0	0
280	0.22	-0.04	1	1	1.16	137.9	0.84
290	0.23	0.11	1	1	1.16	137.9	0.84
290	0.23	-0.11	1	1	1.16	137.9	0.84
298	0.12	0.11	1	1	1.1	137.9	0.79
298	0.38	-0.11	3.735	3.112	1.35	137.9	0.98
299	0.6	0.14	3.735	3.112	1.71	137.9	1.24
299	0.6	-0.14	3.735	3.112	1.71	137.9	1.24
300	3.2	0.14	3.735	3.112	4.19	137.9	3.04
300	0.86	-0.14	1	1	1.85	137.9	1.34
310	3.3	0.14	1	1	4.29	137.9	3.11
310	3.3	-0.14	1	1	4.24	137.9	3.07
320	5.8	0.14	1	1	6.74	137.9	4.89
320	5.8	-0.14	1	1	6.7	137.9	4.86
330	2.82	0.14	1	1	3.72	137.9	2.7
330	2.82	-0.14	1	1	3.7	137.9	2.68
338	1.92	0.14	1	1	2.8	137.9	2.03
338	5.96	-0.14	3.735	3.112	6.84	137.9	4.96
339	0.33	-0.22	3.735	3.112	1.21	137.9	0.88
339	0.33	0.22	3.735	3.112	1.21	137.9	0.88

340	4.69	0.14	3.735	3.112	5.57	137.9	4.04
340	1.51	-0.14	1	1	2.39	137.9	1.73
350	1.85	0.14	1	1	2.73	137.9	1.98
201	0	0	0	0	0	0	0
390	0	0	0	0	0	0	0
390	0	0	0	0	0	0	0
400	0	0	0	0	0	0	0
400	0	0	0	0	0	0	0
410	0	0	0	0	0	0	0
410	0	0	0	0	0	0	0
420	0	0	0	0	0	0	0
421	0	0	0	0	0	0	0
430	0	0	0	0	0	0	0
430	0.22	0.04	1	1	1.16	137.9	0.84
440	0.23	-0.11	1	1	1.16	137.9	0.84
440	0.23	0.11	1	1	1.16	137.9	0.84
448	0.12	-0.11	1	1	1.1	137.9	0.79
448	0.38	0.11	3.735	3.112	1.35	137.9	0.98
449	0.6	-0.14	3.735	3.112	1.71	137.9	1.24
449	0.6	0.14	3.735	3.112	1.71	137.9	1.24
450	3.2	-0.14	3.735	3.112	4.19	137.9	3.04
450	0.86	0.14	1	1	1.85	137.9	1.34
460	3.3	-0.14	1	1	4.29	137.9	3.11
460	3.3	0.14	1	1	4.24	137.9	3.07
470	5.8	-0.14	1	1	6.74	137.9	4.89
470	5.8	0.14	1	1	6.7	137.9	4.86
480	2.82	-0.14	1	1	3.72	137.9	2.7
480	2.82	0.14	1	1	3.7	137.9	2.68
488	1.92	-0.14	1	1	2.8	137.9	2.03
488	5.96	0.14	3.735	3.112	6.84	137.9	4.96
489	0.33	0.22	3.735	3.112	1.21	137.9	0.88

Table 4 : STRESSES REPORT: CASE 3 (EXP) L3=L1-L2

CODE STRESS CHECK PASSED : LOADCASE 3 (EXP) L3=L1-L2							
Highest Stresses: (N/mm²)							
CodeStress Ratio: 94.3 @Node 475							
Code Stress: 320.9 Allowable: 340.3							
Axial Stress: 9.4 @Node 600							
Bending Stress: 320.6 @Node 475							
Torsion Stress: 12.1 @Node 28							
Hoop Stress: 0.0 @Node 20							
3D Max Intensity: 321.3 @Node 475							
NODE	Bending	Torsion	SIF In	SIF Out	Code	Allowable	Ratio
	Stress	Stress	Plane	Plane	Stress	Stress	%
	N/mm²	N/mm²			N/mm²	N/mm²	
10	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0
20	6.71	12.08	1	1	25.08	343.41	7.3
28	3.92	-12.08	1	1	24.49	343.8	7.12
28	15.37	12.08	4.04	3.367	28.64	343.64	8.33
29	42.27	-9.21	4.04	3.367	46.12	343.32	13.43
29	42.27	9.21	4.04	3.367	46.12	343.32	13.43
30	51.75	-3.52	4.04	3.367	52.23	338.4	15.43
30	15.37	3.52	1	1	16.91	342.52	4.94
40	9.23	-3.52	1	1	11.61	339.78	3.42
40	9.23	3.52	1	1	11.61	339.66	3.42
48	4.16	-3.52	1	1	8.18	342.94	2.39
48	15.75	3.52	4.04	3.367	17.26	341.02	5.06
49	42.41	-3.38	4.04	3.367	42.94	342.57	12.54
49	42.41	3.38	4.04	3.367	42.94	342.57	12.54
50	56	-1.2	4.04	3.367	56.05	342.37	16.37
50	14.43	1.2	1	1	14.63	343.34	4.26
60	12.89	-1.2	1	1	13.11	337.97	3.88
60	12.89	1.2	1	1	13.11	337.97	3.88
70	8.3	-1.2	1	1	8.64	340.53	2.54
70	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0

80	7.93	1.2	1	1	8.29	338.37	2.45
90	12.94	-1.2	1	1	13.16	340.79	3.86
90	12.94	1.2	1	1	13.16	340.79	3.86
100	7.31	-1.2	1	1	7.7	339.59	2.27
100	7.31	1.2	1	1	7.7	339.59	2.27
108	10.76	-1.2	1	1	11.03	341.96	3.22
108	43.48	1.2	4.04	3.367	43.54	337.72	12.89
109	41.19	-0.9	4.04	3.367	41.23	343	12.02
109	41.19	0.9	4.04	3.367	41.23	343	12.02
110	9.68	-0.34	4.04	3.367	9.71	339.68	2.86
110	2.53	0.34	1	1	2.62	342.54	0.77
120	31.39	-0.34	1	1	31.4	340.59	9.22
120	31.39	0.34	1	1	31.4	340.59	9.22
125	35.51	-0.34	1	1	35.52	334.22	10.63
125	35.51	0.34	1	1	35.52	334.22	10.63
128	0.42	-0.34	1	1	0.81	343.51	0.24
128	1.68	0.34	4.04	3.367	1.81	342.95	0.53
129	31.95	-0.33	4.04	3.367	31.95	339.76	9.4
129	31.95	0.33	4.04	3.367	31.95	339.76	9.4
130	23.15	-0.21	4.04	3.367	23.15	341.93	6.77
130	5.73	0.21	1	1	5.75	343.21	1.68
140	8.97	-0.21	1	1	8.98	341.58	2.63
140	8.97	0.21	1	1	8.98	341.58	2.63
150	55.16	-0.21	3.281	4.042	55.16	330.2	16.71
150	120.31	0	3.281	4.042	120.31	313.64	38.36
160	15.46	0	1	1	15.46	329.75	4.69
160	0	0	0	0	0	0	0
165	0	0	0	0	0	0	0
150	65.15	0	3.281	4.042	65.15	308.19	21.14
170	9.26	0	1	1	9.26	329.73	2.81
170	0	0	0	0	0	0	0
175	0	0	0	0	0	0	0
175	1.54	0	1	1	1.54	342.25	0.45
178	3.57	0	1	1	3.57	343.01	1.04
178	14.41	0	4.04	3.367	14.41	341.25	4.22
179	22.08	0	4.04	3.367	22.08	341.74	6.46
179	22.08	0	4.04	3.367	22.08	341.74	6.46
180	1.67	0	4.04	3.367	1.67	341.06	0.49
180	0.41	0	1	1	0.41	342.95	0.12
190	35.84	0	1	1	35.84	332.81	10.77
190	0	0	0	0	0	0	0

200	0	0	0	0	0	0	0
165	2.54	0	1	1	2.54	342.26	0.74
208	6.02	0	1	1	6.02	343.02	1.75
208	24.31	0	4.04	3.367	24.31	341.27	7.12
209	35.91	0	4.04	3.367	35.91	341.78	10.51
209	35.91	0	4.04	3.367	35.91	341.78	10.51
210	1.26	0	4.04	3.367	1.26	341.03	0.37
210	0.31	0	1	1	0.31	342.94	0.09
220	64.82	0	1	1	64.82	332.75	19.48
220	0	0	0	0	0	0	0
230	0	0	0	0	0	0	0
231	0	0	0	0	0	0	0
240	0	0	0	0	0	0	0
240	0	0	0	0	0	0	0
250	0	0	0	0	0	0	0
250	0	0	0	0	0	0	0
260	0	0	0	0	0	0	0
260	0	0	0	0	0	0	0
270	0	0	0	0	0	0	0
271	0	0	0	0	0	0	0
280	0	0	0	0	0	0	0
280	3.98	-0.26	1	1	4.01	343.59	1.17
290	2.01	0.79	1	1	2.55	343.59	0.74
290	2.01	-0.79	1	1	2.55	343.59	0.74
298	3.8	0.79	1	1	4.12	343.65	1.2
298	13.87	-0.79	3.735	3.112	13.96	343.4	4.07
299	28.53	-0.04	3.735	3.112	28.53	343.04	8.32
299	28.53	0.04	3.735	3.112	28.53	343.04	8.32
300	23.04	-0.98	3.735	3.112	23.12	340.56	6.79
300	6.27	0.98	1	1	6.57	342.9	1.92
310	30.62	-0.98	1	1	30.69	340.46	9.01
310	30.62	0.98	1	1	30.69	340.51	9.01
320	2.88	-0.98	1	1	3.48	338.01	1.03
320	2.88	0.98	1	1	3.48	338.04	1.03
330	23.79	-0.98	1	1	23.87	341.03	7
330	23.79	0.98	1	1	23.87	341.05	7
338	22.52	-0.98	1	1	22.6	341.95	6.61
338	73.56	0.98	3.735	3.112	73.59	337.9	21.78
339	42.36	-6.88	3.735	3.112	44.54	343.54	12.96
339	42.36	6.88	3.735	3.112	44.54	343.54	12.96
340	23.35	-7.17	3.735	3.112	27.4	339.17	8.08

340	7.46	7.17	1	1	16.17	342.36	4.72
350	9.35	-7.17	1	1	17.12	342.02	5.01
201	0	0	0	0	0	0	0
390	0	0	0	0	0	0	0
390	0	0	0	0	0	0	0
400	0	0	0	0	0	0	0
400	0	0	0	0	0	0	0
410	0	0	0	0	0	0	0
410	0	0	0	0	0	0	0
420	0	0	0	0	0	0	0
421	0	0	0	0	0	0	0
430	0	0	0	0	0	0	0
430	3.98	0.26	1	1	4.01	343.59	1.17
440	2.01	-0.79	1	1	2.55	343.59	0.74
440	2.01	0.79	1	1	2.55	343.59	0.74
448	3.8	-0.79	1	1	4.12	343.65	1.2
448	13.87	0.79	3.735	3.112	13.96	343.4	4.07
449	28.53	0.04	3.735	3.112	28.53	343.04	8.32
449	28.53	-0.04	3.735	3.112	28.53	343.04	8.32
450	23.04	0.98	3.735	3.112	23.12	340.56	6.79
450	6.27	-0.98	1	1	6.57	342.9	1.92
460	30.62	0.98	1	1	30.69	340.46	9.01
460	30.62	-0.98	1	1	30.69	340.51	9.01
470	2.88	0.98	1	1	3.48	338.01	1.03
470	2.88	-0.98	1	1	3.48	338.04	1.03
480	23.79	0.98	1	1	23.87	341.03	7
480	23.79	-0.98	1	1	23.87	341.05	7
488	22.52	0.98	1	1	22.6	341.95	6.61
488	73.56	-0.98	3.735	3.112	73.59	337.9	21.78
489	42.36	6.88	3.735	3.112	44.54	343.54	12.96
489	42.36	-6.88	3.735	3.112	44.54	343.54	12.96

CHAPTER 5

CONCLUSION

The requirements for stress analysis per ASME B31.3 are demonstrated using numerical methods for the different conditions. The stresses developed in piping systems due to thermal loads are calculated by comparing displacement stress range in a piping system to the allowable displacement stress range as per code. In case where displacement range exceeds the allowable range, expansion loops are provided to absorb excess expansions. The use of nomograph for numerical analysis of Complex piping layouts interconnecting vessels in a plant for sufficient thermal expansion and flexibility is sufficiently demonstrated.

Compliance to code for cases of internal and external pressure stresses in the calculation of stresses due to sustained loads shows the method to calculate required thickness of pipes in accordance existing process conditions. The wall thickness considerations when external stresses are present are also discussed. The sum of the longitudinal loads due to sustained loads, due to pressure and weight of piping component or system is compared to the basic allowable stress at metal temperature from table A1 of ASME B31.3. This process determines numerically, the possibility of failure due to primary and secondary stresses. The method for provision of supports and span calculations in case of failure due to sustained stresses is demonstrated.

The action of stress intensification factor at bends and tees shows the multiplication of stress at such points and compares different options of strengthening.

The use of finite element analysis software CAESAR is an indispensable tool to the modern piping industry. Complex piping systems and routings can be effectively analyzed for potentially harmful and hazardous stress concentrations.

CAESAR checks and validates a piping system's load capabilities according to the requirements of the code. It analyzes response to deadweight, thermal, and pressure loads and measures the effects of support settlement, wave and seismic loads, and wind. Additionally, It aids in the selection of proper springs for necessary support and evaluates support lift off, friction, and gap closure

The analysis of the skid which forms a part of a larger system is performed using CAESAR. The software helps to evaluate the compliance of the piping system to the requirements of code ASME B31.3. The result amply proves code compliance in the design of the piping system for the following cases:

- DISPLACEMENTS REPORT: CASE 1 (OPE) W+T1+P1
- RESTRAINT SUMMARY REPORT: Various Load Cases
- STRESSES REPORT: CASE 2 (SUS) W+P1
- STRESSES REPORT: CASE 3 (EXP) L3=L1-L2

Thus the piping design is deemed safe for use. All stresses are within the allowable limits of code and all displacements and movements at node points and restraints are within acceptable limits for the different loads under operating load case, sustained load case and expansion load case. The report thus demonstrates and validates the methods of stress analysis used in the piping industry by numerical analysis and corresponding finite element analysis using software.

CHAPTER 6

REFERENCES

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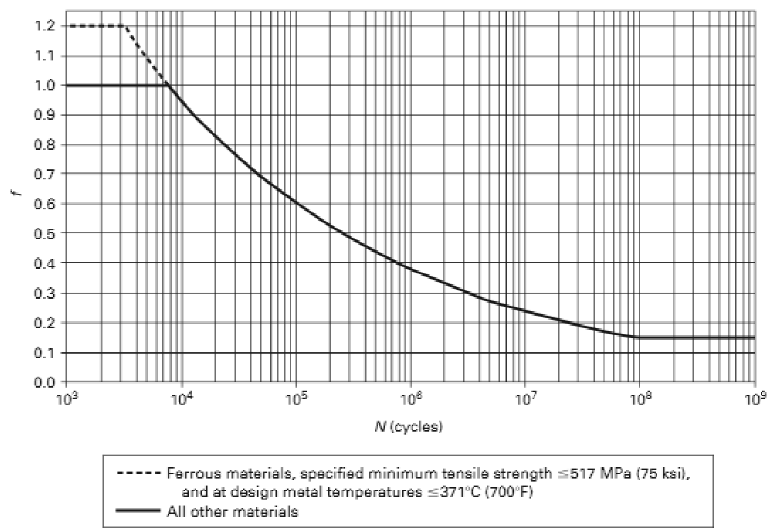
APPENDIX

- STRESS RANGE FACTOR

Fig. 302.3.5 Stress Range Factor, f



For eqs. (1a) and (1b):

f = stress range factor,[3] calculated by eq. (1c)[4]. In eqs. (1a) and (1b), S_c and S_h shall be limited to a maximum of 138 MPa (20 ksi) when using a value of $f > 1.0$.

$$f \text{ (see Fig. 302.3.5)} = 6.0(N)^{-0.2} \le f_m \qquad (1c)$$

f_m = maximum value of stress range factor; 1.2 for ferrous materials with specified minimum tensile strengths ≤ 517 MPa (75 ksi) and at metal temperatures ≤ 371°C (700°F); otherwise f_m = 1.0

N = equivalent number of full displacement cycles during the expected service life of the piping system[5]

S_c = basic allowable stress[6] at minimum metal temperature expected during the displacement cycle under analysis

S_h = basic allowable stress[6] at maximum metal temperature expected during the displacement cycle under analysis

When the computed stress range varies, whether from thermal expansion or other conditions, S_E is defined as the greatest computed displacement stress range. The value of N in such cases can be calculated by eq. (1d):

$$N = N_E + \sum(r_i^5 N_i) \text{ for } i = 1, 2, \ldots, n \qquad (1d)$$

where

N_E = number of cycles of maximum computed displacement stress range, S_E

N_i = number of cycles associated with displacement stress range, S_i

r_i = S_i/S_E

S_i = any computed displacement stress range smaller than S_E

[3] Applies to essentially noncorroded piping. Corrosion can sharply decrease cyclic life; therefore, corrosion resistant materials should be considered where a large number of major stress cycles is anticipated.

[4] The minimum value for f is 0.15, which results in an allowable displacement stress range, S_A, for an indefinitely large number of cycles.

[5] The designer is cautioned that the fatigue life of materials operated at elevated temperature may be reduced.

[6] For castings, the basic allowable stress shall be multiplied by the applicable casting quality factor, E_c. For longitudinal welds, the basic allowable stress need not be multiplied by the weld quality factor, E_j.

- BASIC ALLOWABLE STRESSES IN TENSION FOR METALS

Table A-1 Basic Allowable Stresses in Tension for Metals[1] (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Material	Spec. No.	P-No. or S-No. (5)	Grade	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi Tensile	Specified Min. Strength, ksi Yield	Min. Temp. to 100	200	300
Carbon Steel										
Pipes and Tubes (2)										
A 285 Gr. A	A 134	1	. . .	(8b)(57)	B	45	24	15.0	14.6	14.2
A 285 Gr. A	A 672	1	A45	(57)(59)(67)	B	45	24	15.0	14.6	14.2
Butt weld	API 5L	S-1	A25	(8a)	−20	45	25	15.0	15.0	14.5
Smls & ERW	API 5L	S-1	A25	(57)(59)	B	45	25	15.0	15.0	14.5
. . .	A 179	1	. . .	(57)(59)	−20	47	26	15.7	15.0	14.2
Type F	A 53	1	A	(8a)(77)	20	48	30	16.0	16.0	16.0
. . .	A 139	S-1	A	(8b)(77)	A	48	30	16.0	16.0	16.0
. . .	A 587	1	. . .	(57)(59)	−20	48	30	16.0	16.0	16.0
. . .	A 53	1	A	(57)(59)						
. . .	A 106	1	A	(57)						
. . .	A 135	1	A	(57)(59)	B	48	30	16.0	16.0	16.0
. . .	A 369	1	FPA	(57)						
. . .	API 5L	S-1	A	(57)(59)(77)						
A 285 Gr. B	A 134	1	. . .	(8b)(57)	B	50	27	16.7	16.4	16.0
A 285 Gr. B	A 672	1	A50	(57)(59)(67)	B	50	27	16.7	16.4	16.0
A 285 Gr. C	A 134	1	. . .	(8b)(57)	A	55	30	18.3	18.3	17.7
. . .	A 524	1	II	(57)	−20	55	30	18.3	18.3	17.7
. . .	A 333	1	1							
. . .	A 334	1	1	(57)(59)	−50	55	30	18.3	18.3	17.7
A 285 Gr. C	A 671	1	CA55	(59)(67)	A					
A 285 Gr. C	A 672	1	A55	(57)(59)(67)	A					
A 516 Gr. 55	A 672	1	C55	(57)(67)	C	55	30	18.3	18.3	17.7
A 516 Gr. 60	A 671	1	CC60	(57)(67)	C	60	32	20.0	19.5	18.9
A 515 Gr. 60	A 671	1	CB60							
A 515 Gr. 60	A 672	1	B60	(57)(67)	B	60	32	20.0	19.5	18.9
A 516 Gr. 60	A 672	1	C60	(57)(67)	C					
. . .	A 139	S-1	B	(8b)	A	60	35	20.0	20.0	20.0
. . .	A 135	1	B	(57)(59)	B					
. . .	A 524	1	I	(57)	−20	60	35	20.0	20.0	20.0
. . .	A 53	1	B	(57)(59)						
. . .	A 106	1	B	(57)	B					
. . .	A 333									
. . .	A 334	1	6	(57)	−50	60	35	20.0	20.0	20.0
. . .	A 369	1	FPB	(57)	−20					
. . .	A 381	S-1	Y35	. . .	A					
. . .	API 5L	S-1	B	(57)(59)(77)	B					

Table A-1 Basic Allowable Stresses in Tension for Metals[1] (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress *S*, ksi (1), at Metal Temperature, °F (7)														
400	500	600	650	700	750	800	850	900	950	1000	1050	1100	Grade	Spec. No.
														Carbon Steel Pipes and Tubes (2)
13.7	13.0	11.8	11.6	11.5	10.3	9.0	7.8	6.5	...	...	...	...	...	A 134
13.7	13.0	11.8	11.6	11.5	10.3	9.0	7.8	6.5	4.5	2.5	1.6	1.0	A45	A 672
13.8	...	...	...	...	...	...	...	...	...	...	...	...	A25	API 5L
13.8	...	...	...	...	...	...	...	...	...	...	...	...	A25	API 5L
13.5	12.8	12.1	11.8	11.5	10.6	9.2	7.9	6.5	4.5	2.5	1.6	1.0	...	A 179
16.0	...	...	...	...	...	...	...	...	...	...	...	...	A	A 53
...	...	...	...	...	...	...	...	...	...	...	...	...	A	A 139
16.0	16.0	14.8	14.5	14.4	10.7	9.3	7.9	...	...	...	...	...	...	A 587
													A	A 53
													A	A 106
16.0	16.0	14.8	14.5	14.4	10.7	9.3	7.9	6.5	4.5	2.5	1.6	1.0	A	A 135
													FPA	A 369
													A	API 5L
15.4	14.6	13.3	13.1	13.0	11.2	9.6	8.1	6.5	...	...	...	...	...	A 134
15.4	14.6	13.3	13.1	13.0	11.2	9.6	8.1	6.5	4.5	2.5	1.6	1.0	A 50	A 672
17.2	16.2	14.8	14.5	14.4	12.0	10.2	8.3	6.5	...	...	...	...	...	A 134
17.2	16.2	14.8	14.5	14.4	12.0	10.2	8.3	6.5	4.5	2.5	...	...	II	A 524
													1	A 333
17.2	16.2	14.8	14.5	14.4	12.0	10.2	8.3	6.5	4.5	2.5	1.6	1.0	1	A 334
													CA55	A 671
													A55	A 672
17.2	16.2	14.8	14.5	14.4	12.1	10.2	8.4	6.5	4.5	2.5	1.6	1.0	C55	A 672
18.3	17.3	15.8	15.5	15.4	13.0	10.8	8.7	6.5	4.5	2.5	...	...	CC60	A 671
													CB60	A 671
18.3	17.3	15.8	15.5	15.4	13.0	10.8	8.7	6.5	4.5	2.5	1.6	1.0	B60	A 672
													C60	A 672
...	...	...	...	...	...	...	...	...	...	...	...	...	B	A 139
													B	A 135
20.0	18.9	17.3	17.0	16.5	13.0	10.8	8.7	6.5	4.5	2.5	...	...	I	A 524
													B	A 53
													B	A 106
													6	A 333
20.0	18.9	17.3	17.0	16.5	13.0	10.8	8.7	6.5	4.5	2.5	1.6	1.0	6	A 334
													FPB	A 369
													Y35	A 381
													B	API 5L

Table A-1 Basic Allowable Stresses in Tension for Metals[1] (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Material	Spec. No.	P-No. or S-No. (5)	Grade	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi Tensile	Specified Min. Strength, ksi Yield	Min. Temp. to 100	200
Low and Intermediate Alloy Steel Pipes (2)									
½Cr–½Mo	A 335	3	P2	. . .	−20	55	30	18.3	18.3
½Cr–½Mo	A 691	3	½CR	(11)(67)	−20	55	33	18.3	18.3
A 387 Gr. 2 Cl. 1									
C–½Mo	A 335	3	P1						
C–½Mo	A 369	3	FP1	(58)	−20	55	30	18.3	18.3
½Cr–½Mo	A 369	3	FP2	. . .	−20	55	30	18.3	18.3
1Cr–½Mo	A 691	4	1CR	(11)(67)	−20	55	33	18.3	18.3
A 387 Gr. 12 Cl. 1									
½Cr–½Mo	A 426	3	CP2	(10)	−20	60	30	18.4	17.7
1½Si–½Mo	A 335	3	P15	. . .					
1½Si–½Mo	A 426	3	CP15	(10)	−20	60	30	18.8	18.2
1Cr–½Mo	A 426	4	CP12	(10)	−20	60	30	18.8	18.3
5Cr–½Mo–1½Si	A 426	5B	CP5b	(10)	−20	60	30	18.8	17.9
3Cr–Mo	A 426	5A	CP21	(10)	−20	60	30	18.8	18.1
¾Cr–¾Ni–Cu–Al	A 333	4	4	. . .	−150	60	35	20.0	19.1
2Cr–½Mo	A 369	4	FP3b	. . .	−20	60	30	20.0	18.5
1Cr–½Mo	A 335	4	P12						
1Cr–½Mo	A 369	4	FP12	. . .	−20	60	32	20.0	18.7
1¼Cr–½Mo	A 335	4	P11						
1¼Cr–½Mo	A 369	4	FP11	. . .	−20	60	30	20.0	18.7
1¼Cr–½Mo	A 691	4	1¼CR	(11)(67)	−20	60	35	20.0	20.0
A 387 Gr. 11 Cl. 1									
5Cr–½Mo	A 691	5B	5CR	(11)(67)	−20	60	30	20.0	18.1
A 387 Gr. 5 Cl. 1									
5Cr–½Mo	A 335	5B	P5						
5Cr–½Mo–Si	A 335	5B	P5b	. . .	−20	60	30	20.0	18.1
5Cr–½Mo–Ti	A 335	5B	P5c						
5Cr–½Mo	A 369	5B	FP5						
9Cr–1Mo	A 335	5B	P9						
9Cr–1Mo	A 369	5B	FP9	. . .	−20	60	30	20.0	18.1
9Cr–1Mo	A 691	5B	9CR						
A 387 Gr. 9 Cl. 1									
3Cr–1Mo	A 335	5A	P21						
3Cr–1Mo	A 369	5A	FP21	. . .	−20	60	30	20.0	18.7
3Cr–1Mo	A 691	5A	3CR	(11)(67)	−20	60	30	20.0	18.5
A 387 Gr. 21 Cl. 1									

Table A-1 Basic Allowable Stresses in Tension for Metals[1] (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress *S*, ksi (1), at Metal Temperature, °F (7)

300	400	500	600	650	700	750	800	850	900	950	1000	1050	1100	1150	1200	Grade	Spec. No.
																Low and Intermediate Alloy Steel Pipes (2)	
17.5	16.9	16.3	15.7	15.4	15.1	13.8	13.5	13.2	12.8	9.2	5.9	...	...	...	...	P2	A 335
18.3	18.3	17.9	17.3	16.9	16.6	13.8	13.8	13.4	12.8	9.2	5.9	...	...	...	...	½CR	A 691
17.5	16.9	16.3	15.7	15.4	15.1	13.8	13.5	13.2	12.7	8.2	4.8	4.0	2.4	...	...	P1 FP1	A 335 A 369
17.5	16.9	16.3	15.7	15.4	15.1	13.8	13.5	13.2	12.8	9.2	5.9	4.0	2.4	...	...	FP2	A 369
18.3	18.3	17.9	17.3	16.9	16.6	16.3	15.9	15.4	14.0	11.3	7.2	4.5	2.8	1.8	1.1	1CR	A 691
17.0	16.3	15.6	14.9	14.6	14.2	13.9	13.5	13.2	12.5	10.0	6.3	4.0	2.4	...	...	CP2	A 426
17.6	17.0	16.5	15.9	15.6	15.3	15.0	14.4	13.8	12.5	10.0	6.3	4.0	2.4	...	...	P15 CP15	A 335 A 426
17.6	17.1	16.5	15.9	15.7	15.4	15.1	14.8	14.2	13.1	11.3	7.2	4.5	2.8	1.8	1.1	CP12	A 426
17.1	16.2	15.4	14.5	14.1	13.7	13.3	12.8	12.4	10.9	9.0	5.5	3.5	2.5	1.8	1.2	CP5b	A 426
17.4	16.8	16.1	15.5	15.2	14.8	14.5	13.9	13.2	12.0	9.0	7.0	5.5	4.0	2.7	1.5	CP21	A 426
18.2	17.3	16.4	15.5	15.0	...	...	...	...	...	...	...	...	...	...	...	4	A 333
17.5	16.4	16.3	15.7	15.4	15.1	13.9	13.5	13.1	12.5	10.0	6.2	4.2	2.6	1.4	1.0	FP3b	A 369
18.0	17.5	17.2	16.7	16.2	15.6	15.2	15.0	14.5	12.8	11.3	7.2	4.5	2.8	1.8	1.1	P12 FP12	A 335 A 369
18.0	17.5	17.2	16.7	16.2	15.6	15.2	15.0	14.5	12.8	9.3	6.3	4.2	2.8	1.9	1.2	P11 FP11	A 335 A 369
20.0	19.7	18.9	18.3	18.0	17.6	17.3	16.8	16.3	15.0	9.9	6.3	4.2	2.8	1.9	1.2	1¼CR	A 691
17.4	17.2	17.1	16.8	16.6	16.3	13.2	12.8	12.1	10.9	8.0	5.8	4.2	2.8	2.0	1.3	5CR	A 691
17.4	17.2	17.1	16.8	16.6	16.3	13.2	12.8	12.1	10.9	8.0	5.8	4.2	2.9	1.8	1.0	P5 P5b P5c FP5	A 335 A 335 A 335 A 369
17.4	17.2	17.1	16.8	16.6	16.3	13.2	12.8	12.1	11.4	10.6	7.4	5.0	3.3	2.2	1.5	P9 FP9 9CR	A 335 A 369 A 691
18.0	17.5	17.2	16.7	16.2	15.6	15.2	15.0	14.0	12.0	9.0	7.0	5.5	4.0	2.7	1.5	P21 FP21	A 335 A 369
18.1	17.9	17.9	17.9	17.9	17.9	17.9	17.8	14.0	12.0	9.0	7.0	5.5	4.0	2.7	1.5	3CR	A 691

Table A-1 Basic Allowable Stresses in Tension for Metals[1] (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Material	Spec. No.	P-No. or S-No. (5)	Grade	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi Tensile	Specified Min. Strength, ksi Yield	Min. Temp. to 100	200	300	400	500	600
Stainless Steel (3)(4) (Cont'd)													
Bar													
18Cr–8Ni	A 479	8	304	(26)(28)(31)	–425	75	30	20.0	20.0	20.0	18.7	17.5	16.4
Castings (2)													
28Ni–20Cr–2Mo–3Cb	A 351	45	CN7M	(9)(30)	–325	62	25	16.6	...	...	...	...	...
35Ni–15Cr–Mo	A 351	S-45	HT30	(36)(39)	–325	65	28	18.6	...	...	...	...	...
25Cr–13Ni	A 351	8	CH8	(9)(31)	–325	65	28	18.6	*18.6*	*18.6*	*18.6*	*18.6*	**18.0**
25Cr–20Ni	A 351	8	CK20	(9)(27)(31)(35)(39)	–325	65	28	18.6	*18.6*	*18.6*	*18.6*	*18.6*	**18.0**
15Cr–15Ni–2Mo–Cb	A 351	S-8	CF10MC	(30)	–325	70	30	20.0	...	...	...	...	...
18Cr–8Ni	A 351	8	CF3	(9)	–425	70	30	20.0	*20.0*	**19.7**	**17.6**	**16.4**	**15.6**
17Cr–10Ni–2Mo	A 351	8	CF3M	(9)	–425	70	30	20.0	*18.0*	17.4	16.6	16.0	15.4
18Cr–8Ni	A 351	8	CF8	(9)(26)(27)(31)	–425	70	30	20.0	*20.0*	**20.0**	**18.7**	**17.4**	**16.4**
25Cr–13Ni	A 351	S-8	CH10	(27)(31)(35)									
25Cr–13Ni	A 351	8	CH20	(9)(27)(31)(35)(39)	–325	70	30	20.0	*20.0*	*20.0*	*20.0*	*20.0*	**19.2**
20Cr–10Ni–Cb	A 351	8	CF8C	(9)(27)(30)	–325	70	30	20.0	*20.0*	*20.0*	*19.3*	**18.6**	**18.5**
18Cr–10Ni–2Mo	A 351	8	CF8M	(9)(26)(27)(30)	–425	70	30	20.0	*20.0*	*20.0*	**19.4**	**18.1**	**17.1**
25Cr–20Ni	A 351	S-8	HK40	(35)(36)(39)	–325	62	35	20.6	...	...	...	...	...
25Cr–20Ni	A 351	8	HK30	(35)(39)	–325	65	35	21.6	...	...	...	...	...
18Cr–8Ni	A 351	8	CF3A	(9)(56)									
18Cr–8Ni	A 351	8	CF8A	(9)(26)(56)	–425	77	35	23.3	23.3	22.6	21.8	20.5	19.3
25Cr–10Ni–N	A 351	8	CE20N	(35)(39)	–325	80	40	26.7	26.2	24.9	23.3	22.0	21.4
12Cr	A 217	6	CA15	(35)	–20	90	65	30.0	21.5	20.8	20.0	19.3	18.8
24Cr–10Ni–Mo–N	A 351	10H	CE8MN	(9)	–60	95	65	31.7	31.6	29.3	28.2	28.2	28.2
25Cr–8Ni–3Mo–W–Cu–N	A 351	S-10H	CD3M-W-Cu-N	(9)(25)	–60	100	65	33.3	33.3	31.9	31.9	31.1	31.1
13Cr–4Ni	A 487	6	CA6NM Cl. A	(9)(35)	–20	110	80	36.7	36.7	35.4	35.0	34.4	33.7

Table A-1 Basic Allowable Stresses in Tension for Metals[1] (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress *S*, ksi (1), at Metal Temperature, °F (7)																			
650	700	750	800	850	900	950	1000	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500	Grade	Spec. No.
																		Stainless Steel (3)(4) (Cont'd)	
																		Bar	
16.2	16.0	15.6	15.2	14.9	14.7	14.4	14.1	12.4	9.8	7.7	6.1	4.7	3.7	2.9	2.3	1.8	1.4	304	A 479
																		Castings (2)	
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	CN7M	A 351
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	HT30	A 351
18.0	17.1	16.7	16.4	12.7	12.5	11.7	10.5	8.5	6.5	5.5	3.7	2.9	2.0	1.7	1.2	0.9	0.7	CH8	A 351
17.5	17.1	16.7	16.4	12.7	12.5	11.9	11.0	9.7	8.5	7.2	6.0	4.7	3.5	2.4	1.6	1.1	0.7	CK20	A 351
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	CF10MC	A 351
15.2	15.1	14.9	14.7	...	...	...	...	...	...	...	...	...	...	...	...	...	...	CF3	A 351
15.0	14.6	14.4	14.0	13.2	...	...	...	...	...	...	...	...	...	...	...	...	...	CF3M	A 351
16.1	15.9	15.5	15.1	14.4	14.2	13.9	12.2	9.5	7.5	6.0	4.8	3.9	3.3	2.7	2.3	2.0	1.7	CF8	A 351
																		CH10	A 351
18.7	18.2	18.0	17.5	13.6	13.2	12.5	10.5	8.5	8.5	5.0	3.7	2.9	2.0	1.7	1.2	0.9	0.7	CH20	A 351
18.4	18.2	18.2	18.2	18.1	18.1	18.1	18.0	17.1	14.2	10.5	7.9	5.4	4.4	3.2	2.5	1.8	1.3	CF8C	A 351
16.7	16.2	15.7	15.6	14.7	14.5	14.0	13.1	11.5	9.4	8.0	6.7	5.2	4.0	3.0	2.4	1.9	1.5	CF8M	A 351
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	HK40	A 351
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	HK30	A 351
																		CF3A	A 351
18.9	17.6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	CF8A	A 351
21.3	21.2	21.1	21.0	20.8	20.5	...	...	...	...	...	...	...	...	...	...	...	...	CE20N	A 351
18.4	18.1	17.5	16.8	14.9	11.0	7.6	5.0	3.3	2.3	1.5	1.0	...	...	...	...	...	...	CA15	A 217
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	CE8MN	A 351
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	CD3M-W-Cu-N	A 351
33.2	32.6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	CA6NM Cl. A	A 487

- TOTAL THERMAL EXPANSION

Table C-1 Total Thermal Expansion, U.S. Units, for Metals

Total Linear Thermal Expansion Between 70°F and Indicated Temperature, in./100 ft

	Material							
Temp., °F	Carbon Steel Carbon–Moly– Low-Chrome (Through 3Cr–Mo)	5Cr–Mo Through 9Cr–Mo	Austenitic Stainless Steels 18Cr–8Ni	12Cr, 17Cr, 27Cr	25Cr–20Ni	UNS N04400 Monel 67Ni–30Cu	$3^1/_2$Ni	Copper and Copper Alloys
−450	...	...	...	...	...	...	...	−3.93
−425	...	...	...	...	...	...	...	−3.93
−400	...	...	...	...	...	...	...	−3.91
−375	...	...	...	...	...	...	...	−3.87
−350	...	...	...	...	...	...	...	−3.79
−325	−2.37	−2.22	−3.85	−2.04	...	−2.62	−2.25	−3.67
−300	−2.24	−2.10	−3.63	−1.92	...	−2.50	−2.17	−3.53
−275	−2.11	−1.98	−3.41	−1.80	...	−2.38	−2.07	−3.36
−250	−1.98	−1.86	−3.19	−1.68	...	−2.26	−1.96	−3.17
−225	−1.85	−1.74	−2.96	−1.57	...	−2.14	−1.86	−2.97
−200	−1.71	−1.62	−2.73	−1.46	...	−2.02	−1.76	−2.76
−175	−1.58	−1.50	−2.50	−1.35	...	−1.90	−1.62	−2.53
−150	−1.45	−1.37	−2.27	−1.24	...	−1.79	−1.48	−2.30
−125	−1.30	−1.23	−2.01	−1.11	...	−1.59	−1.33	−2.06
−100	−1.15	−1.08	−1.75	−0.98	...	−1.38	−1.17	−1.81
−75	−1.00	−0.94	−1.50	−0.85	...	−1.18	−1.01	−1.56
−50	−0.84	−0.79	−1.24	−0.72	...	−0.98	−0.84	−1.30
−25	−0.68	−0.63	−0.98	−0.57	...	−0.77	−0.67	−1.04
0	−0.49	−0.46	−0.72	−0.42	...	−0.57	−0.50	−0.77
25	−0.32	−0.30	−0.46	−0.27	...	−0.37	−0.32	−0.50
50	−0.14	−0.13	−0.21	−0.12	...	−0.20	−0.15	−0.22
70	0	0	0	0	0	0	0	0
100	0.23	0.22	0.34	0.20	0.32	0.28	0.23	0.34
125	0.42	0.40	0.62	0.36	0.58	0.52	0.42	0.63
150	0.61	0.58	0.90	0.53	0.84	0.75	0.61	0.91
175	0.80	0.76	1.18	0.69	1.10	0.99	0.81	1.20
200	0.99	0.94	1.46	0.86	1.37	1.22	1.01	1.49
225	1.21	1.13	1.75	1.03	1.64	1.46	1.21	1.79
250	1.40	1.33	2.03	1.21	1.91	1.71	1.42	2.09
275	1.61	1.52	2.32	1.38	2.18	1.96	1.63	2.38
300	1.82	1.71	2.61	1.56	2.45	2.21	1.84	2.68
325	2.04	1.90	2.90	1.74	2.72	2.44	2.05	2.99
350	2.26	2.10	3.20	1.93	2.99	2.68	2.26	3.29
375	2.48	2.30	3.50	2.11	3.26	2.91	2.47	3.59
400	2.70	2.50	3.80	2.30	3.53	3.25	2.69	3.90
425	2.93	2.72	4.10	2.50	3.80	3.52	2.91	4.21
450	3.16	2.93	4.41	2.69	4.07	3.79	3.13	4.51
475	3.39	3.14	4.71	2.89	4.34	4.06	3.35	4.82
500	3.62	3.35	5.01	3.08	4.61	4.33	3.58	5.14
525	3.86	3.58	5.31	3.28	4.88	4.61	3.81	5.45
550	4.11	3.80	5.62	3.49	5.15	4.90	4.04	5.76

Table C-1 Total Thermal Expansion, U.S. Units, for Metals

Total Linear Thermal Expansion Between 70°F and Indicated Temperature, in./100 ft

Material								
Aluminum	Gray Cast Iron	Bronze	Brass	70Cu–30Ni	UNS N08XXX Series Ni–Fe–Cr	UNS N06XXX Series Ni–Cr–Fe	Ductile Iron	Temp., °F
...	...	...	...	...	...	...	...	−450
...	...	...	...	...	...	...	...	−425
...	...	...	...	...	...	...	...	−400
...	...	...	...	...	...	...	...	−375
...	...	...	...	...	...	...	...	−350
−4.68	...	−3.98	−3.88	−3.15	...	...	...	−325
−4.46	...	−3.74	−3.64	−2.87	...	...	...	−300
−4.21	...	−3.50	−3.40	−2.70	...	...	...	−275
−3.97	...	−3.26	−3.16	−2.53	...	...	...	−250
−3.71	...	−3.02	−2.93	−2.36	...	...	...	−225
−3.44	...	−2.78	−2.70	−2.19	...	...	−1.51	−200
−3.16	...	−2.54	−2.47	−2.12	...	...	−1.41	−175
−2.88	...	−2.31	−2.24	−1.95	...	...	−1.29	−150
−2.57	...	−2.06	−2.00	−1.74	...	...	−1.16	−125
−2.27	...	−1.81	−1.76	−1.53	...	...	−1.04	−100
−1.97	...	−1.56	−1.52	−1.33	...	...	−0.91	−75
−1.67	...	−1.32	−1.29	−1.13	...	...	−0.77	−50
−1.32	...	−1.25	−1.02	−0.89	...	...	−0.62	−25
−0.97	...	−0.77	−0.75	−0.66	...	...	−0.46	0
−0.63	...	−0.49	−0.48	−0.42	...	...	−0.23	25
−0.28	...	−0.22	−0.21	−0.19	...	...	−0.14	50
0	0	0	0	0	0	0	0	70
0.46	0.21	0.36	0.35	0.31	0.28	0.26	0.21	100
0.85	0.38	0.66	0.64	0.56	0.52	0.48	0.39	125
1.23	0.55	0.96	0.94	0.82	0.76	0.70	0.57	150
1.62	0.73	1.26	1.23	1.07	0.99	0.92	0.76	175
2.00	0.90	1.56	1.52	1.33	1.23	1.15	0.94	200
2.41	1.08	1.86	1.83	1.59	1.49	1.38	1.13	225
2.83	1.27	2.17	2.14	1.86	1.76	1.61	1.33	250
3.24	1.45	2.48	2.45	2.13	2.03	1.85	1.53	275
3.67	1.64	2.79	2.76	2.40	2.30	2.09	1.72	300
4.09	1.83	3.11	3.08	2.68	2.59	2.32	1.93	325
4.52	2.03	3.42	3.41	2.96	2.88	2.56	2.13	350
4.95	2.22	3.74	3.73	3.24	3.18	2.80	2.36	375
5.39	2.42	4.05	4.05	3.52	3.48	3.05	2.56	400
5.83	2.62	4.37	4.38	...	3.76	3.29	2.79	425
6.28	2.83	4.69	4.72	...	4.04	3.53	3.04	450
6.72	3.03	5.01	5.06	...	4.31	3.78	3.28	475
7.17	3.24	5.33	5.40	...	4.59	4.02	3.54	500
7.63	3.46	5.65	5.75	...	4.87	4.27	3.76	525
8.10	3.67	5.98	6.10	...	5.16	4.52	3.99	550

- MODULUS OF ELASTICITY

ASME B31.3-2008

Table C-6 Modulus of Elasticity, U.S. Units, for Metals

Material	E = Modulus of Elasticity, Msi (Millions of psi), at Temperature, °F									
	−425	−400	−350	−325	−200	−100	70	200	300	400
Ferrous Metals										
Gray cast iron	...	...	...	...	...	...	13.4	13.2	12.9	12.6
Carbon steels, C ≤ 0.3%	31.9	...	...	31.4	30.8	30.2	29.5	28.8	28.3	27.7
Carbon steels, C > 0.3%	31.7	...	...	31.2	30.6	30.0	29.3	28.6	28.1	27.5
Carbon−moly steels	31.7	...	...	31.1	30.5	29.9	29.2	28.5	28.0	27.4
Nickel steels, Ni 2%−9%	30.1	...	...	29.6	29.1	28.5	27.8	27.1	26.7	26.1
Cr−Mo steels, Cr ½%−2%	32.1	...	...	31.6	31.0	30.4	29.7	29.0	28.5	27.9
Cr−Mo steels, Cr 2¼%−3%	33.1	...	...	32.6	32.0	31.4	30.6	29.8	29.4	28.8
Cr−Mo steels, Cr 5%−9%	33.4	...	...	32.9	32.3	31.7	30.9	30.1	29.7	29.0
Chromium steels, Cr 12%, 17%, 27%	31.8	...	...	31.2	30.7	30.1	29.2	28.5	27.9	27.3
Austenitic steels (TP304, 310, 316, 321, 347)	30.8	...	...	30.3	29.7	29.0	28.3	27.6	27.0	26.5
Copper and Copper Alloys (UNS Nos.)										
Comp. and leaded Sn−bronze (C83600, C92200)	...	...	...	14.8	14.6	14.4	14.0	13.7	13.4	13.2
Naval brass, Si− & Al−bronze (C46400, C65500, C95200, C95400)	...	...	...	15.9	15.6	15.4	15.0	14.6	14.4	14.1
Copper (C11000)	...	...	...	16.9	16.6	16.5	16.0	15.6	15.4	15.0
Copper, red brass, Al−bronze (C10200, C12000, C12200, C12500, C14200, C23000, C61400)	...	...	...	18.0	17.7	17.5	17.0	16.6	16.3	16.0
90Cu−10Ni (C70600)	...	...	...	19.0	18.7	18.5	18.0	17.6	17.3	16.9
Leaded Ni−bronze	...	...	...	20.1	19.8	19.6	19.0	18.5	18.2	17.9
80Cu−20Ni (C71000)	...	...	...	21.2	20.8	20.6	20.0	19.5	19.2	18.8
70Cu−30Ni (C71500)	...	...	...	23.3	22.9	22.7	22.0	21.5	21.1	20.7
Nickel and Nickel Alloys (UNS Nos.)										
Monel 400 N04400	28.3	...	...	27.8	27.3	26.8	26.0	25.4	25.0	24.7
Alloys N06007, N08320	30.3	...	...	29.5	29.2	28.6	27.8	27.1	26.7	26.4
Alloys N08800, N08810, N06002	31.1	...	...	30.5	29.9	29.4	28.5	27.8	27.4	27.1
Alloys N06455, N10276	32.5	...	...	31.6	31.3	30.6	29.8	29.1	28.6	28.3
Alloys N02200, N02201, N06625	32.7	...	...	32.1	31.5	30.9	30.0	29.3	28.8	28.5
Alloy N06600	33.8	...	...	33.2	32.6	31.9	31.0	30.2	29.9	29.5
Alloy N10001	33.9	...	...	33.3	32.7	32.0	31.1	30.3	29.9	29.5
Alloy N10665	34.2	...	...	33.3	33.0	32.3	31.4	30.6	30.1	29.8
Unalloyed Titanium										
Grades 1, 2, 3, and 7	...	...	...	...	...	...	15.5	15.0	14.6	14.0

- FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

ASME B31.3-2008

APPENDIX D
FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

Table D300[1] Flexibility Factor, *k*, and Stress Intensification Factor, *i*

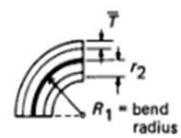
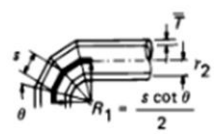
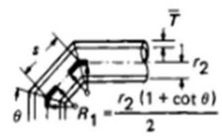
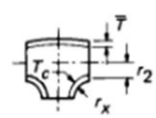
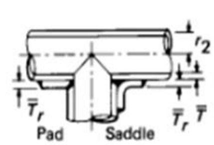
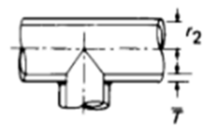
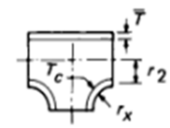
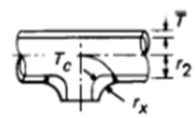
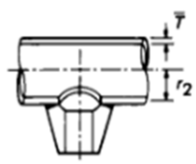
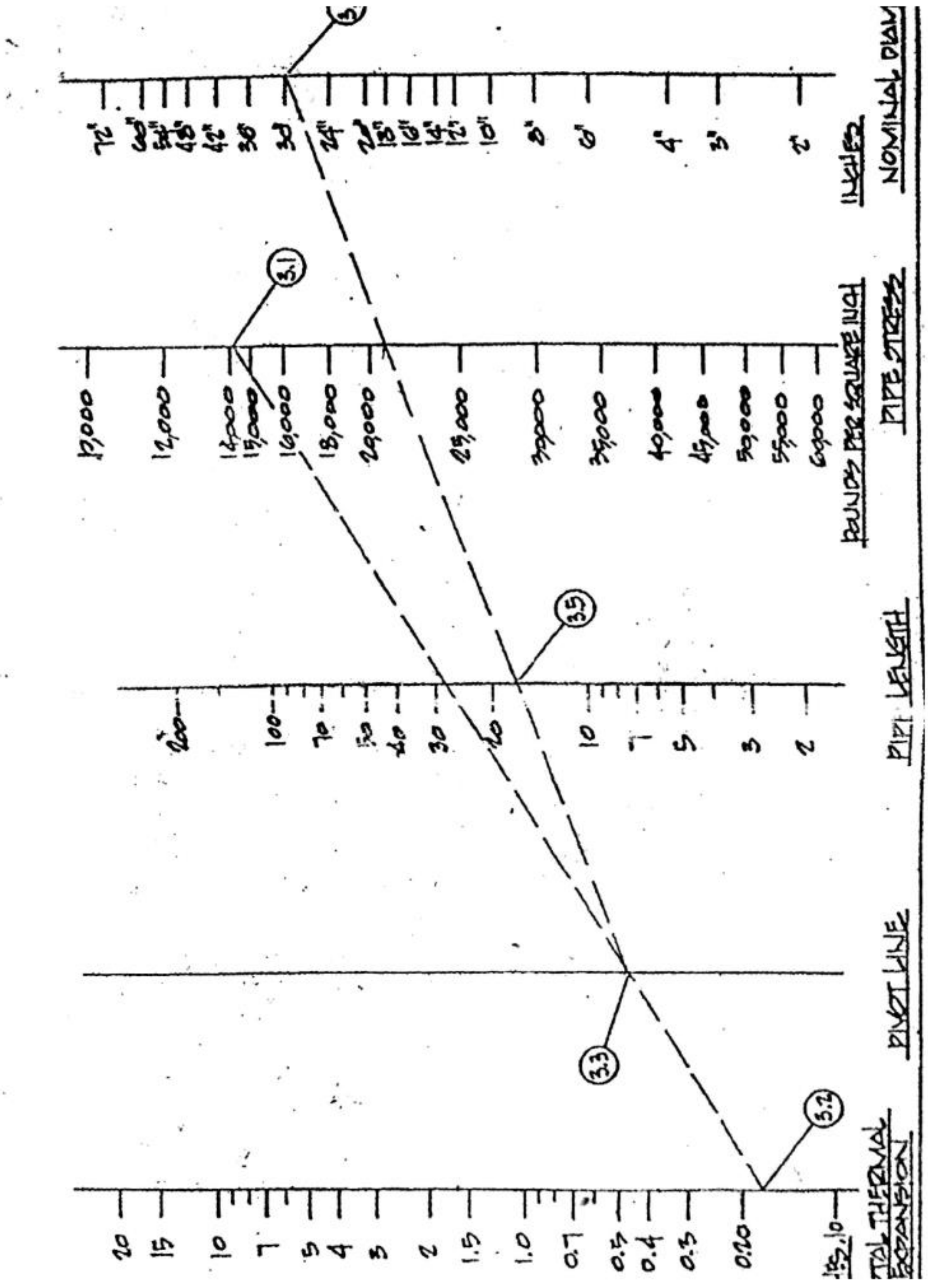
Description	Flexibility Factor, k	Stress Intensification Factor [Notes (2), (3)] Out-of-Plane, i_o	In-Plane, i_i	Flexibility Characteristic, h	Sketch
Welding elbow or pipe bend [Notes (2), (4)-(7)]	$\frac{1.65}{h}$	$\frac{0.75}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\bar{T}R_1}{r_2^2}$	
Closely spaced miter bend $s < r_2\,(1 + \tan\theta)$ [Notes (2), (4), (5), (7)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\cot\theta}{2}\left(\frac{s\bar{T}}{r_2^2}\right)$	
Single miter bend or widely spaced miter bend $s \ge r_2\,(1 + \tan\theta)$ [Notes (2), (4), (7)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{1 + \cot\theta}{2}\left(\frac{\bar{T}}{r_2}\right)$	
Welding tee per ASME B16.9 [Notes (2), (4), (6), (8), (9)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$3.1\,\frac{\bar{T}}{r_2}$	
Reinforced fabricated tee with pad or saddle [Notes (2), (4), (9), (10), (11)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$\frac{(\bar{T} + \frac{1}{2}\bar{T}_r)^{2.5}}{\bar{T}^{1.5}\,r_2}$	

Table D300[1] Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

Description	Flexibility Factor, k	Stress Intensification Factor [Notes (2), (3)] Out-of-Plane, i_o	Stress Intensification Factor [Notes (2), (3)] In-Plane, i_i	Flexibility Characteristic, h	Sketch
Unreinforced fabricated tee [Notes (2), (4), (9), (11)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$\frac{\bar{T}}{r_2}$	
Extruded welding tee with $r_x \geq 0.05\ D_b$, $T_c < 1.5\ \bar{T}$ [Notes (2), (4), (9)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$\left(1 + \frac{r_x}{r_2}\right)\frac{\bar{T}}{r_2}$	
Welded-in contour insert [Notes (2), (4), (8), (9)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$3.1\frac{\bar{T}}{r_2}$	
Branch welded-on fitting (integrally reinforced) [Notes (2), (4), (11), (12)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$3.3\frac{\bar{T}}{r_2}$	

Description	Flexibility Factor, k	Stress Intensification Factor, i [Note (1)]
Butt welded joint, reducer, or weld neck flange	1	1.0
Double-welded slip-on flange	1	1.2
Fillet welded joint, or socket weld flange or fitting	1	Note (13)
Lap joint flange (with ASME B16.9 lap joint stub)	1	1.6
Threaded pipe joint or threaded flange	1	2.3
Corrugated straight pipe, or corrugated or creased bend [Note (14)]	5	2.5

- NOMOGRAPH


NOMINAL DIAM
INCHES
PIPE STRESS
POUNDS PER SQUARE INCH
PIPE LENGTH
PIVOT LINE
3.1
3.2
3.3
3.5