PIP PNC00004
Piping Stress Analysis Criteria for ASME B31.3 Metallic Piping
PURPOSE AND USE OF PROCESS INDUSTRY PRACTICES

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1. Scope

This Practice describes the minimum requirements for piping flexibility analysis parameters and applications, and documentation requirements.

2. References

Applicable parts of the following Practices and industry codes and standards shall be considered an integral part of this Practice. The edition in effect on the date of contract award shall be used, except as otherwise noted. Short titles will be used herein where appropriate.

2.1 Process Industry Practices (PIP)
- PIP PNFS0001 - Miscellaneous Pipe Support Details
- PIP RECE002 - Design of Piping Loads on Rotating Machinery Nozzles

2.2 Industry Codes and Standards

- American Petroleum Institute (API)
  - API 560 - Fired Heaters for General Refinery Service
  - API 610 - Centrifugal Pumps for Petroleum, Petrochemical and Natural Gas Industries
  - API 618 - Reciprocating Compressors for Petroleum, Chemical, and Gas Industry Services
  - API 650 - Welded Tanks for Oil Storage
  - API 661 - Air-Cooled Heat Exchangers for General Refinery Services

- American Society of Civil Engineers (ASCE)
  - ASCE 7 - Minimum Design Loads for Buildings and Other Structures

- American Society of Mechanical Engineers (ASME)
  - ASME Boiler and Pressure Vessel Code Section VIII - Pressure Vessels
  - ASME B31.1 - Power Piping
  - ASME B31.3 - Process Piping
  - ASME B31E - Standard for the Seismic Design and Retrofit of Above-Ground Piping Systems
  - ASME B31J - Stress Intensification Factors (i-Factors), Flexibility Factors (k-Factors), and their Determination for Metallic Piping Components

- Welding Research Council (WRC)
  - WRC 107 (see WRC 537)
  - WRC 537 - Precision equations and enhanced diagrams for local stresses in spherical and cylindrical shells due to external loadings for implementation of WRC Bulletin 107
  - WRC 297 - Local Stresses in Cylindrical Shells Due to External Loadings on Nozzles (Supplement to WRC 107)
3. Requirements

3.1 General

3.1.1 All piping systems shall be evaluated and, if appropriate, analyzed for applicable conditions in accordance with ASME B31.3 and this Practice. The designer shall be qualified in accordance with the ASME B31.3 Paragraph 301.1.

3.1.2 The most severe, anticipated, coincident pressure and temperature conditions shall be considered to evaluate the flexibility and sustained load analyses for each anticipated operating condition. Design conditions (pressure and temperature) shall be set in accordance with ASME B31.3 Paragraphs 301.2 and 301.3 with consideration to approved variations above same as set forth in ASME B31.3 Paragraph 302.2.4. The sole uses for design conditions shall be in accordance with ASME B31.3 Appendix S, Example 1.

3.1.3 The flexibility analysis can require the combination of more than one load case to determine the total displacement stress range.

3.1.4 Any computerized pipe flexibility calculations shall be performed using owner-approved software. Software shall use appropriate code year for analysis.

3.1.5 Piping systems shall be analyzed for expansion, contraction, differential settlement, relief valve reactions, and effects due to weight, wind, seismic, vibration, and other mechanical loading in accordance with ASME B31.3, B31E, and B31J.

3.1.6 Expansion joints shall not be permitted unless approved by owner.

3.1.7 Special consideration shall be taken when piping system is identified as severe cyclic condition as set forth in ASME B31.3. Severe cyclic conditions typically cause failures at small branch connections that are attached to main piping runs. The Energy Institute, Gas Machinery Research Council, Pipeline Research Council International, and Southwest Research Institute have published guidelines for the avoidance of severe cyclic failures.

3.2 Analysis Parameters

3.2.1 Displacement Strains

3.2.1.1 The flexibility analysis for each stress range to be evaluated for each anticipated operating condition shall be based on the maximum operating temperature for that condition unless calculations are supplied to and approved by the owner that better predict the pipe metal temperature for the condition.

3.2.1.2 Climatic effects shall be considered in determining the maximum differential temperature.

3.2.1.3 The metal temperature from the effect of solar radiation in the summer and the winter dry bulb design temperature should be considered.

3.2.1.4 When more than one stress range is anticipated for a piping system with multiple operating conditions, as stated in Section 3.1.3 of this Practice, it may be necessary to determine the difference between displacement stress ranges. See ASME B31.3 Appendix S Example 3.
Comment: Cold branch includes cases dealing with parallel lines where at least one line (not always the same one) may be cold at any time. An example is three parallel pumps where one pump (not always the same one) is usually not in service.

3.2.2 Pressure, Weight, and Other Sustained Loads

3.2.2.1 The weight of piping, piping components, refractory lining, piping insulation, fluid transported, and fluid used for testing shall be considered.

3.2.2.2 Snow and ice loads shall be considered if specified by owner.

3.2.2.3 If piping lifts off a support during an ambient to operating condition flexibility (stress range) evaluation, the support shall either be removed for sustained load calculations or spring supports shall be considered. See *ASME B31.3* Appendix S Example 2 for the potentially multiple sustained load analyses required by ASME B31.3 for each anticipated operating condition.

3.2.3 Friction

3.2.3.1 The frictional resistance to thermal movement of the pipe shall be considered. The greater loads of those evaluated with friction and those evaluated without friction shall be used for reaction loads, flexibility based stress range analyses, and sustained load analyses and shall be documented.

3.2.3.2 Frictionless unrestrained movement of the piping system shall be assumed only if the entire system is supported by means of rod or spring hangers.

3.2.3.3 When pipe thermal movement is greater than \( \frac{1}{2} \) in. on F-type spring cans, consideration should be given to the use of low friction slide plates to avoid imposing bending on the spring column

3.2.4 Wind

The wind loads on piping systems shall be determined in accordance with the procedure outlined in *ASCE 7* or as specified by owner.

3.2.5 Seismic

If specified by owner or required by jurisdiction, seismic loads on piping systems shall be considered.

3.2.6 Vibration

Piping shall be supported and designed to eliminate excessive vibration that is caused by two phase flows, turbulent flow vortices, wind, acoustically induced, etc. Guidelines on vibration is given in Energy Institute Guidelines.

3.2.7 Pressure Relief Systems

3.2.7.1 Pressure relief discharge piping shall be restrained to contain the thrust loads.

3.2.7.2 Forces and moments due to relief valve discharge may be calculated by any method approved by owner.
Comment: ASME B31.1, Appendix II is an example of a calculation method for an open system

### 3.2.8 Impact Loading

3.2.8.1 Piping systems subject to water hammer shall be considered.

3.2.8.2 Forces due to water hammer shall be determined and suitable pipe restraints shall be provided.

3.2.8.3 Piping systems subject to slugging shall be considered.

### 3.2.8 Equipment and Support Settlement

3.2.9.1 Long term settlement of equipment, steel and supports shall be considered based on the soil conditions and Geotech report.

3.2.9.2 Load cases shall be modified to include displacement resulting from long term settlement. Stresses in the piping due to settlement shall be considered primary stresses (Sustained).

3.2.9.3 Piping connecting to equipment and steel experiencing settlement shall have adequate flexibility and may require the use of spring cans or expansion joints, depending on space constraints in the area.

### 3.2.9 Flanges

3.2.9.1 External bending moments on flanges shall be considered.

3.2.9.2 External loads may be analyzed by the equivalent pressure method or other methods approved by owner.

3.2.9.3 Acceptance criteria shall be in accordance with owner’s requirements.

### 3.2.10 Maximum Pipe Spans and Deflections

3.2.10.1 For determining pipe spans, maximum sag deflections shall be limited to 16 mm (5/8 in).

3.2.10.2 Any deviations to Section 3.2.10.1 shall be approved by owner.

### 3.2.11 Refractory

3.2.11.1 The increased stiffness of a piping systems caused by a refractory lining shall be considered when determining reaction loads.

3.2.11.2 To protect a piping system against collapse due to creep, the increased stiffness due to a refractory lining shall not be included in the span calculations, any sustained load analysis, and flexibility analysis.

### 3.2.12 Piping Fittings

3.2.12.1 Reduced flexibility shall be considered where attachments exist on welded ells or within two pipe diameters of the welds of an ell.

1. In the absence of better information, decreased flexibility may be simulated (in a computer analysis) by placing a flange pair at the nearest weld.
2. Although not addressed directly by *ASME B31.3*, Appendix D, 45-degree ells shall have their flexibility reduced (in a computer analysis) by placing a flange pair at each end.

3.2.12.2 In the absence of applicable data or rigorous analysis, branches at angles other than 90 degrees may be modeled by doubling the default stress intensification factor for unreinforced fabricated tees.

*Comment:* Branches at angles other than 90 degrees are not addressed by *ASME B31.3*, Appendix D. For flexibility purposes, testing has shown that these branches act like unreinforced connections.

3.2.11.3 The stress intensification factor for tees with aspect ratios of 3:4 shall be increased by 25%.

*Comment:* The *ASME B31.3* Appendix D Stress Intensification Factors for tees with this aspect ratio have been found to be non-conservative.

### 3.2.13 Other Parameters

3.2.13.1 Large diameter thin wall (D/T > 100) lines shall be analyzed for crushing loads at local stress points and reinforced as necessary. Consideration shall be given to the use of partial re-pads or saddle type supports for D/T >100 to minimize bearing stress.

3.2.13.2 Piping systems supported primarily by rod hangers shall accommodate the rod’s rotation and the consequent load impact on nearby equipment nozzles. Rod hanger lengths shall be modeled in the piping stress analysis. The rotation of the rod hanger shall be checked and shall not exceed 5 degrees during any of the operating, upset, relieving, etc., conditions. External Loads on Equipment shall be considered for impact due to support rod rotation.

3.2.13.3 Unless otherwise approved by owner, use of cold spring for piping systems that connect to rotating machinery (compressors, turbines, pumps) shall not be permitted.

3.2.13.4 If the use of cold spring is approved for use in a piping system by the Owner Engineer experienced in stress analysis, the piping shall be analyzed. No credit shall be taken for cold spring in the fatigue based flexibility evaluation(s) at operating conditions (i.e., when computing $S_{t}$). Reaction load evaluation(s) may reflect the use of cold spring at the more severe of either any anticipated operating conditions, B31.3 para. 302.2.4 approved variations, or design condition(s).

### 3.3 External Load Limits on Equipment

3.3.1 Unless otherwise approved by owner, loads imposed on equipment by the piping shall not exceed the lesser of that allowed by the equipment manufacturer or that listed in the applicable references in this Practice.

3.3.2 Allowable nozzle loads for rotating machinery shall be in accordance with *PIP RESE002*. 
3.3.3 Reciprocating compressor piping shall be analyzed in accordance with *API 618*.

3.3.4 Unless otherwise specified by owner, loads on air cooled heat exchanger nozzles shall be in accordance with the load criteria of *API 661*.

3.3.5 For pressure vessels and heat exchangers:

   a. If the vessel/nozzle aspect ratios are within limits of the bulletins, *WRC 107* and *WRC 297* may be used in the evaluation unless otherwise specified by the owner.

   b. If the nozzle/vessel geometry is outside the limit of *WRC 107* or *WRC 297*, other owner-approved local stress analysis methods shall be used. Extrapolation of the curves in *WRC 107* or *WRC 297* shall not be permitted.

   c. If applicable, allowable stresses shall be based on *Boiler and Pressure Vessel Code*, Section VIII, Division 1 or 2.

3.3.6 Tank nozzle loads shall be evaluated in accordance with the owner’s requirements.

3.4 **Analysis Applications**

3.4.1 A formal flexibility analysis shall be performed on all of the following piping systems (reference *ASME B31.3*, Paragraph 319.4.2):

   a. Piping connected to load/stress-sensitive equipment

   b. Process, regeneration, and decoking piping to and from steam generators and fired heaters

   c. Process piping to and from centrifugal compressors, turbo-expanders, and blowers

   d. Working fluid piping to and from turbines

   e. Suction and discharge piping to and from reciprocating pumps and compressors

   f. Piping NPS 3 and larger to and from centrifugal pump nozzles

   g. Piping NPS 4 and larger to air cooled heat exchangers

   h. Relief systems, whether closed or relieving to atmosphere, with considerations for attached or detached tail pipes

   i. Piping requiring proprietary expansion devices (e.g., bellows expansion joints)

   j. Piping NPS 3 and larger subject to stresses from significant differential settlement of associated vessels, tanks, equipment, or supports

   k. NPS 3 and larger piping subjected to mixed phase flow (liquid and vapor)

   l. NPS 3 and larger piping subject to slug flow

   m. Piping identified as severe cyclic or vibrating service

   n. Jacketed piping systems

   o. Piping as required by applicable codes and standards (e.g., *ASME B31.3 Category M*)

   p. Plastic lined piping systems
q. Piping that requires support for occasional loadings (e.g., seismic, wind, steam out, steam tracing)

3.4.2 All piping systems shall be reviewed to identify those systems that are outside the requirements of Section 3.4.1 but may still require flexibility analysis.

3.4.3 In addition to the requirements in Section 3.4.1, flexibility analysis for carbon, low and intermediate alloy, and stainless steel piping systems shall be performed in accordance with Figures 1 and 2.

3.4.4 Flexibility analysis shall be performed for other piping materials in accordance with owner’s requirements.

3.5 Documentation

3.5.1 Calculation numbers shall be assigned to identify each analysis and the flexibility analysis files shall be stored.

3.5.2 Upon project completion, all stress calculations and documentation shall be provided in accordance with the owner’s requirements.
Notes:
1. Visual Analysis: Piping in this category may be analyzed by the use of engineering experience or approximate methods.
2. Formal Analysis: Piping in this category requires formal analysis. Analysis may be performed by approximate, comprehensive, or computer methods. Documentation is required.
3. Comprehensive Analysis: Piping in this category requires a comprehensive analysis (typically by computer). Other methods may be used with owner’s approval. Documentation is required.