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History Sheet

Rev	Date	Reason for revision	Revised by
0	07/23/01	Issued for Project Use	Jack Shen
1	01/16/02	Revised per New Procedure and Incorporated DRN Comments	Dick Huang/Jack Shen
2	09/10/03	Revised per Safety Evaluation Number 24590-WTP-SE-ENS-03-704 Rev.0, Extended Span and Support Loads, and Nozzle Tables from 16”ϕ Pipe to 24”ϕ Pipe	Jack Shen
3	05/13/04	Revised per Safety Evaluation Number 24590-WTP-SE-ENS-03-962 Rev.0, pressure vessel nozzle load combination per Reference 8-22, and piping with D_o/t_c greater than 50	Dick Huang
4	10/18/04	Consideration of ASME B31.3 Mechanical / Corrosion / Erosion Allowances per PIR GPI-6BEB-00401-000, CCN069183 and 24590-WTP-CAR-QA-04-120, add SAM Criteria, Removed Rotary Equipment Nozzle Load Tables	Jack Shen
5	08/23/06	Extensive revision; changes not tracked, except on the cover sheet. Revised to Incorporate the Considerations from CCN 115252, Safety Evaluation 24590-WTP-SE-ENS-05-0128 Rev. 1, and the Discipline Directions Specified in CCNs 085280, 109336, 114910, 130111, 130571 and 134128; SC-III(Non-Chem) & SC-IV Span Tables for Every DW and Every Other DW Span, and Criteria of Critical Piping; Delete Tables 3-1, 3-2,2.1, 2.3, 3.1.1, 3.3.1, Appendices 4, 5 and 6; delete Section 4.3.2., Seismic mode combination per Ref. 8.56, Revised section 3.1 valve qualification, Revised Section 4.6 Wind load. Changed titles of Appendix 3, Tables 3.2.1 and 3.4.1.	Joseph Sasson
6	01/15/08	Revised to Incorporate the Considerations from CCN 143512, Safety Evaluation 24590-WTP-SE-ENS-06-0153 Rev. 0, “Evaluation of WTP Piping and Supports Qualified to SC I, SC II, SC III, and SC IV Requirements,” which was approved in US DOE ORP letter 06-WTP-198 and incorporated into Revision 2b of the PSAR (Ref, 8.38); added Section 5 and Table 1-1 & 1-2 to Appendix 1; added Appendix 10 to address Washington Dept. of Ecology Issue 35, “Stress Limits for SC-III(Non-Chem) and SC-IV Piping and Supports”	Joseph Sasson
7	05/24/11	Revised to incorporate General Document Change Notices (GDCN) A and B for Rev 6 of the criteria. Incorporate 24590-WTP-CRPT-QA-08-0214-B ACTION 06. Incorporate 24590-WTP-ATS-QAIS-09-0431. Revised to remove reference to ITS, replace with safety. Revised to incorporate the considerations specified in CCN 144225, Plant Design Discipline Direction - Wind Load Analysis. Documented flange loads requirements per Ref 8.64. Incorporate requirements for piping class IIIE per 24590-WTP-BODCN-ENG-09-0020. Incorporate requirements for HPAV loads in stress analysis per 24590-WTP-BODCN-ENG-10-0001. Incorporate requirements for piping interface with flexible equipment per 24590-WTP-RPT-ENG-09-040.	Joseph Sasson

7A	**11/21/2011**	**Revised to incorporate 24590-WTP-PIER-MGT-09-1179-C Action 26, by revising Section 4.3.3 & 3.1 to address environmental room temperature**	**Joseph Sasson**

Contents

Tables

Acronyms

AISC ASD	American Institute of Steel Construction, Allowable Stress Design
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
C.S.	Carbon Steel
CIS	Component Information System
CQC	Complete Quadratic Combination
CS&A	Civil, Structural & Architectural
DOE	Department Of Energy
DW	Deadweight
EGS	Engineering Group Supervisor
HPAV	Hydrogen in Pipes And Ancillary Vessels
HVAC	**Heating, Ventilation, and Air-Conditioning**
ISO	Isometric
ME101	Bechtel computer program for the linear elastic analysis of piping systems (LEAP)
NPH	Natural Phenomena Hazards
PDSA	Preliminary Documented Safety Analysis
QA	Quality Assurance
RPP-WTP	River Protection Project – Waste Treatment and Immobilization Plant
SAM	Seismic Anchor Movement
SC	Safety Class or Seismic Category
SC-I	Seismic Category I
SC-II	Seismic Category II
SC-III	Seismic Category III
SC-III(Chem)	SC-III piping containing a significant Chemical release hazard
SC-III(Non-Chem)	SC-III piping not containing a significant Chemical release hazard, other than SC-III(Chem)
SC-IIIE	Seismic Category III Enhanced.
SC-IV	Seismic Category IV
SRSS	Square Root of the Sum of the Square
SS	Safety Significant
SSC	Systems, Structures & Components

S.S.	Stainless Steel
SRD	Safety Requirements Document
UBC	Uniform Building Code

1 Purpose

The “Pipe Stress Design Criteria” is developed to establish the design basis for the pipe stress analysis of RPP-WTP piping systems and to demonstrate that the piping systems meet both ASME B31.3 Code and DOE seismic design requirements in DOE-STD-1020-94.

The purpose of the design criteria is also to provide uniform guidance and acceptance criteria for performing pipe stress analysis for different pipe categories of this project.

2 Scope

The Pipe Stress Design Criteria is applicable to the pipe categories identified in Section 3.2. All pipe stress analysis shall be performed based on the analysis procedures provided in this Design Criteria and project engineering calculation procedure 24590-WTP-3DP-G04B-00037 [Ref 8.3]. Generic calculations are also performed to generate the “Span and Support Load Tables” using the simplified pipe design methods, based on the analysis procedures provided in this Design Criteria. This Design Criteria is the analysis basis and the analysis procedure for the pipe stress analysis of RPP-WTP in accordance with the ASME B31.3 Code and the DOE seismic design requirements in DOE-STD-1020-94.

3 Design Requirements and Criteria

3.1 Design Codes and Requirements

The design Code of RPP-WTP is ASME B31.3, Process Piping [Ref 8.1]. This project is also required to meet the DOE seismic requirements as specified in DOE-STD-1020-94 [Ref 8.2]. Due to the stringent seismic requirements for different levels of seismic safety protections, a more realistic seismic analysis methodology provided in ASME Section III Code [Ref 8.4] may serve as a model for the details missing from ASME B31.3.

In compliance with seismic requirements as specified in Reference 8.2, either the response spectrum method or the UBC static method is used for the seismic analysis of the piping systems. A 5% continuous damping, as specified in Table 2-3 of the Preliminary Safety Analysis Report [Ref 8.38], shall be used when performing piping analysis using a response spectrum method.

- ASME B31.3 Code – Process Piping

This Code provides the basic design principles and formulas for the design of Chemical plants and petroleum refinery piping. The Code defines the pressure, temperature, and forces applicable to the design of piping, and states the considerations that shall be given to various effects and their consequent loadings. Those loadings are due to weight effects, dynamic effects (such as earthquake or wind effects), thermal expansion and contraction effects, etc. The Code also specifies stress criteria such as limits of calculated stresses due to sustained loads and displacement stress range, and limits of calculated stresses due to occasional loads, etc.

- Uniform Building Code (UBC)

  The UBC [Ref 8.5] provides the design earthquake loads, and the design rules for the design of buildings and other structural systems that are regulated by this Uniform Building Code. The UBC has treated piping systems similar to other mechanical equipment. The UBC is commonly used and is accepted in the design of fossil power plants, petro-chemical and other industrial facilities and is the required standard by DOE-1020-94 [Ref 8.2] for PC-1 and PC-2 SSCs. Therefore, those RPP-WTP piping systems that are SC-III, including SC-III(Chem), SC-III(Non-Chem), and SC-IIIE, or SC-IV will be designed using the UBC to calculate the static loads.

- ASCE 7-98 - Minimum Design Loads for Buildings and Other Structures (ASCE)

  The ASCE [Ref 8.9] provides the design rules and method required for evaluation of wind loads. The ASCE is commonly used and is accepted in the design of fossil power plants, petro-chemical and other industrial facilities and is the required standard by Safety Requirements Document 24590-WTP-SRD-ESH-01-001-02 [Ref 8.19]. Therefore, those RPP-WTP piping systems that are exposed to wind loads will be designed using the ASCE to calculate the wind loads.

- ASME B16.5 Pipe Flanges and Flanged Fittings

  Flanges may be designed per ASME B16.5 [Ref 8.6], or the flange joint may be evaluated in accordance with the design rules of ASME B31.3 Code for this project.
  In order to prevent leakage at flanged joint due to excessive bending the following equations B5 and B6 of Ref. 8.64 may be used:

  Deadweight + Thermal * $\leq$ $M_{fs} \leq 3125 \cdot (S_y/36000)\, C \cdot A_b$ [Ref 8.64]
  Deadweight+Thermal+Seismic * $\leq$ $M_{fd} \leq 6250 \cdot (S_y/36000)\, C \cdot A_b$ [Ref 8.64]
  * Maximum of Bending or Torsional Moments at the flange [in·lbf]
  S_y = Yield Strength of Flange material at **maximum metal temperature** [psi]
  Note: $S_y/36000 \leq 1$
  C = Diameter of Bolt Circle [in]
  A_b = Total Cross –Sectional Area of bolts at root of thread or section of least diameter under stress (stress area) [in^2]
  M_{fs}, M_{fd} = Allowed moment on the flanged joint

- Valve/In-Line Component/Instrumentation Qualifications

  The design and analysis of piping systems shall be performed so that non-hand-wheel valves and in-line components that are important to safety are subjected to seismic/dynamic acceleration less than:

  - 4.54g for SC-I & II valves and in-line components. This value is a resultant acceleration of X, Y & Z (SRSS) directions and is equivalent to a test or analysis done to 4.5g biaxial in accordance with IEEE-382 [Ref 8.60] with a 1.4 margin as required by DOE-1020-94 [Ref 8.2].
  - 5.78g for SC-III & IV valves and in-line components. This value is a resultant acceleration of X, Y & Z (SRSS) directions and is equivalent to a test or analysis done to 4.5g biaxial in accordance with IEEE-382 [Ref 8.60] with a 1.1 margin as required by DOE-1020-94 [Ref 8.2]. Note that the above value applies for dynamically analyzed systems. SC-III and SC-IV systems utilizing the UBC static analysis method will automatically meet the 5.78g limit (see Section 4.5.2(a)).

  Notes:

  1. When operator weight and location is provided, model the valve with operator weight and location in ME101 computer model.
  2. When valve CG location is not available, use 2/3 of valve assembly overall height as CG location.
  3. For the valves w/o automatic operator, valve qualification is governed by the stress check at the valve ends in the ME101 detailed analysis.
  4. The acceleration shall include the effects of all modes, including the “residual response” mode; ME101 automatically includes the acceleration from the “residual response” mode, since the “residual response” mode is treated like any other mode. The user is cautioned that other Programs used for analysis may not do this automatically.

3.2 Pipe Classifications

The design Code for the piping systems of RPP-WTP is ASME B31.3 Code. Piping systems shall be designed for pressure effects, weight effects, thermal expansion or contraction effects, and dynamic effects, etc., in accordance with the design rules of ASME B31.3 Code.

The piping classified by seismic categories along with their seismic analysis methods and acceptance criteria are provided in Table 2-6 of the Preliminary Safety Analysis Report [Ref 8.38].

Note that SC-III(Chem) is listed in the line list (CIS data base) as “SC-III Q” and SC-III(Non-Chem) is listed as “SC-III CM”.

Piping classified as SC-IIIE is defined in Reference 8.66; its acceptance criteria are the same as SC-III(Chem) but with a different coefficient of C_a [Ref 8.67].

3.3 Load Combinations and Acceptance Criteria

According to ASME B31.3 Code, in addition to internal pressure and external pressure loads, the applicable loadings considered in the pipe design shall be classified as sustained loads, displacement strains, and occasional loads. This is required because the design criteria for sustained loads, displacement strains, and occasional loads are different. They are defined as follows:

Sustained Loads -	These loads include the weight of piping components, insulation, and other superimposed permanent loads supported by the pipe. The weight of the medium transported or the medium used for the test is also considered as a sustained load.
Displacement strains -	These loads include thrusts and moments that arise when the free thermal expansion and contraction of the piping system is prevented by the restraints or anchors. The effects of movements of piping supports, anchors, and connected equipment shall be considered as this category as well.
Occasional loads -	Earthquake loads, wind loads and the dynamic fluid transient loads due to the excitation of the contained fluid.

The following are the load combinations considered in the design of ASME B31.3 Piping:

1. Internal Pressure Stress

   Hoop stresses due to internal pressure are considered safe when the wall thickness of the piping component including any reinforcement, meets the requirement of the Code [Ref 8.1]. The compliance to meet these requirements has been established by the piping group. Longitudinal stress due to internal pressure is included in the Code stress calculation.

2. Longitudinal Stresses S_L

   The sum of longitudinal stresses in any piping component due to pressure, weight, and other applicable sustained loads shall not exceed S_h. Longitudinal stresses shall be based on the nominal outside diameter and the end-of-life (corroded) thickness, as required by ASME B31.3 [Ref 8.1, Para. 302.3.5].

   For SC-III(Non-Chem) and SC-IV piping, the weight plus pressure stress is limited to $0.8S_h$, based on Appendix 10. This limitation may be exceeded (but not to exceed $1.0S_h$) if it can be shown that the sum of seismic, weight, and pressure stresses meet $1.33S_h$ when the seismic stresses are determined using the strict UBC limitations, as explained in Appendix 10. When the SC-III(Non-Chem) and SC-IV piping weight plus pressure stresses exceed $0.8S_h$, the approval of the Stress EGS is required.

3. Allowable Displacement Stress Range S_A

The computed displacement stress range S_E in a piping system shall not exceed the following displacement stress range S_A. In compliance with ASME B31.3 [Ref 8.1, Paragraph 319.3.5], the analysis and stresses shall be based on nominal outside diameter and thickness.

$S_A = f\,(1.25\ S_c + 0.25\ S_h)$, as defined in Equation (1a) of Reference 8.1.

$S_A = f\,[1.25\ (S_c + S_h) - S_L]$, as defined in Equation (1b) of Reference 8.1, where

f = stress range reduction factor, as defined in Equation (1c) of Reference 8.1
S_h = basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis, from Table A-1 of ASME B31.3 Code.
S_c = basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis, from Table A-1 of ASME B31.3 Code.

4. Limits of Calculated Stresses due to Occasional Loads

a) SC-I, SC-II, SC-III Piping containing a significant Chemical release hazard (SC-III(Chem)), SC-IIIE, or any Black Cell piping

The sum of the longitudinal stresses due to pressure, weight, other sustained loads (S_L) and the stresses produced by occasional loads (S_{oc}), such as wind, earthquake, or fluid transient, shall not exceed $1.33S_h$ per ASME B31.3 Code. Longitudinal stresses shall be based on the nominal outside diameter and the end-of-life (corroded) thickness, as required by ASME B31.3 [Ref 8.1]. Earthquake loads for SC-I, SC-II and any piping located in the Black cells are calculated using Response Spectrum methods with 5% continuous damping and the Complete Quadratic Combination (CQC) for modal combination [Section 3.2.7 of Ref 8.56] using nominal dimensions. The converted response spectra are documented in References 8.31 and 8.32 for the HLW and PTF facilities, respectively. The occasional loads should be combined by the square root of sum of squares (SRSS) method. Earthquake loads need not be considered as acting concurrently with wind or HPAV.

SC-IIIE is subject to the same requirements as SC-III(Chem) except for the C_a coefficient which is 0.312 (horizontal) for SC-IIIE [Ref 8.67] and 0.24 (horizontal) for SC-III(Non-Chem) and SC-IV.

b) SC-III piping without containing a significant Chemical release hazard (SC-III(Non-Chem)) and SC-IV piping

The sum of the longitudinal stresses due to pressure, weight, other sustained loads (S_L) and the stresses produced by occasional seismic loads (S_{oc}) shall be less than or equal to $3.0S_h$, but not greater than $2.0S_y$ as specified in Reference 8.38, where

S_h is as defined above, and

S_y = yield strength at design temperature. ASME B31.3 Code par. 302.3.2(e) refers the user to ASME Section II part D Table Y-1 [Ref 8.4] for the yield strength at temperature.

For SC-III, including SC-III(Chem), SC-III(Non-Chem), and SC-IIIE, and SC-IV piping, earthquake loads are established based on Uniform Building Code (UBC) Formula 32-2 and the pipe stresses are calculated using the UBC static method, using nominal dimensions for load calculation and the end-of-life (corroded) thickness for stress calculation.

The sum of the longitudinal stresses due to pressure, weight, other sustained loads S_L and the occasional stresses S_{oc} produced by occasional loads such as wind or fluid transient shall not exceed 1.33 S_h (per ASME B31.3 [Ref 8.1]). Longitudinal stresses shall be based on the nominal outside diameter and the end-of-life (corroded) thickness, as required by ASME B31.3. The occasional loads are combined by the square root of the sum of the squares method. However, earthquakes need not be considered as acting concurrently with wind or HPAV.

4 Pipe Stress Analysis

4.1 Analysis Methods

For the purposes of this criteria document, the following definitions apply:
Critical Piping is that which requires a formal ME101 computer analysis, see Appendix 8.
Non Critical Piping is that which does not require a formal ME101 computer analysis.

Piping systems shall be designed to prevent the effects of temperatures, pressures, weight, and dynamic loads from causing the following failures:

a) Failure of piping or supports from overstress or fatigue due to pressure cycling and thermal cycling;
b) Leakage at joints; or
c) Detrimental stresses or distortion in piping and valves or in connected equipment resulting from excessive thrusts and moments in the piping

To demonstrate a piping system meets Code stress criteria, the following analysis approaches may be used:

1. No Formal Analysis

   a) Duplicates, or replaces without significant change, a piping system operating with a successful service record

b) A piping system can readily be judged adequate by comparison with previous analyzed systems.

c) A piping system determined to be non-critical and judged to be free from design concerns such as deflection, clearance, thermal expansion/contraction, critical nozzle allowable, etc. Critical piping may be identified using the list in Appendix 8.

2. Formal Analysis

a) **Simplified or approximate method** may be applied only if used within the range of configurations, similar boundary conditions and load patterns for which their design adequacies have been demonstrated. This is normally shown by a generic calculation. Using "Span and Support Load Tables" may be considered as this approach.

b) **Acceptable comprehensive methods** of analysis include analytical and chart methods that provide an evaluation of the forces, moments, and stresses due to various load effects. This is usually performed by a manual calculation using existing analytical equations or charts on an individual case. This is not cost effective for mass production.

c) **Comprehensive analysis** for all piping components in the piping system. This is performed based on the most realistic design condition by taking into account stress intensification factors for any piping component. It is performed for all the stress evaluations to meet the stress criteria as specified in Section 4.9, Computer Analysis Using ME101, under various load considerations.

In summary, comprehensive analysis using ME101 shall be performed for SC-I, SC-II, SC-III(Chem), and SC-IIIE piping and critical piping as identified in Appendix 8, and simplified analysis using "Span and Support Load Tables" should be performed for SC-III(Non-Chem) and SC-IV piping. A comprehensive analysis for a pipeline should also be performed to qualify:

- A group of pipelines with similar pipe layout, if it is judged to be technically justifiable.
- The pipe design of a SC-III(Non-Chem) or SC-IV pipeline that deviates significantly from the design permitted by Span Tables.

In case of a piping system interaction with two different seismic category (SC) pipe classes, the piping shall be designed to the seismic design with the lowest SC number, if it is not feasible or practical to isolate them. The technical approach shall comply with the criteria for the piping of the lowest SC number. For instance, SC-III piping with respect to SC-I piping shall be designed using the more stringent analysis approach and design criteria required for SC-I piping. The model of pipe stress analysis shall be extended up to the first anchor or overlap supports on the SC-III piping. Two rigid supports in each global direction and one change in direction of the pipe are considered sufficient to isolate the piping for overlap.

4.2 Pressure Design

The compliance of pressure design required per Section 304 of ASME B31.3 is demonstrated in the pipe design for determining required pipe thickness [Ref 8.53 & 8.54].

4.3 Flexibility Analysis

Piping systems shall have sufficient flexibility to allow for thermal expansion or contraction or movements of piping supports and terminals. To accept the piping flexibility, a pipe flexibility analysis (formal analysis as provided in 4.1.2) or an engineering judgment (no formal analysis as provided in 4.1.1) is required to demonstrate that the stress criterion specified in Section 4.9.2 has been met. For specific guidance regarding when a formal flexibility analysis is required, see Section 4.3.4.

1. Design input for flexibility analysis

   a) Properties of piping materials such expansion coefficient, modulus of elasticity, allowable stress.

   b) Pipe ISO to show pipe configuration, pipe sizes and pipe schedule, support and anchor locations, types of supports, etc.

   c) Temperatures of various operating modes and corresponding imposed movements from support/anchors to determine the displacement stress ranges.

2. Deleted

3. Comprehensive analysis - using computer program ME101

   Input 3-D pipe mathematical model including all pipe dimensions, pipe material properties, piping component types and temperatures into computer program ME101 to determine the dimensional change of the piping system due to the change in temperature. As the piping system is constrained from free expansion or contraction by the connected equipment and restraints, it will be displaced from its unrestrained position. The stress ranges proportional to the total displacement strains are then determined at any piping component, with stress intensification factors per Appendix D of the ASME B31.3 Code. If an SIF is not available in ASME B31.3, use of a suitable SIF shall be justified.

   By Code, the stress range S_E is calculated between the maximum metal temperature and the minimum metal temperature for the thermal cycle under analysis. If no minimum operating temperature is below the ambient temperature 70^{o}F, the temperature range shall be determined between the maximum metal temperature and the ambient temperature 70^{o}F. For most piping systems, analyzing for the **pipe maximum metal** temperature may be the most critical case for the design of the piping system. However, some piping systems may have more than one operating temperature including temperature below ambient. It is imperative that the pipe stress engineer determines the worst thermal condition for which the flexibility analysis should be performed. In cases where it is not possible to determine the worst case by engineering judgment, it is necessary to perform flexibility analysis for each of the significant thermal modes.

Note 1: **Maximum pipe temperature may be controlled by the room environment temperature provided in WTP facility-specific room environment data sheet, See Section 2.4.13.1 of References 8.38. For those rooms for which environment temperatures are not provided use Table 12-1 of 24590-WTP-DB-ENG-01-001 [Ref 8.48].**
The Environment room temperatures provided in the facility data sheet are as follows:

Normal Temperatures:	**generally are based on summer maximum temperature listed in Table 12-1 of 24590-WTP-DB-ENG-01-001 [Ref 8.48]**
Abnormal temperatures:	**are due to an anticipated eight hour loss of HVAC cooling event conservatively postulated to occur once per year. Abnormal temperatures are not the result of an accident. Abnormal environment room temperature need not be considered concurrent with seismic event [Ref 8.74].**
Post DBE temperatures:	**are due to an anticipated loss of HVAC cooling event following seismic event per 24590-WTP-RPT-M-09-006 [Ref 8.75]. Post DBE environment room temperature need not be considered concurrent with seismic event [Ref 8.74].**

Environment temperature due to Steam line Break:
For rooms subject to steam line break identified in WTP facility-specific room environment data sheet, See Section 2.4.13.1 of References 8.38

Note 2: **Report 24590-WTP-RPT-ENG-11-153 [Ref 8.75], Section 7.4.2, concludes that rooms with environment temperature of 160°F and lower do not require formal flexibility analysis due to environmental room temperature.**

4. Analysis Approaches

Per the ASME B31.3 Code requirements, all piping, regardless of classification, is required to meet the flexibility requirements whether by using formal analysis or by engineering judgment. Based on the previous experience of piping systems with successful service, the analysis approaches are provided as follows [Ref 8.38]:

a) For piping systems with the maximum operating temperature not greater than 150°F, no formal flexibility analysis is required. However, pipe stress engineer reviews and ensures that there are no significant externally imposed displacements such as movements due to anchor or nozzle displacements, connected piping, or building settlements.

b) For piping systems with the maximum operating temperature not greater than 250°F and properly routed with adequate flexibility, formal flexibility analysis is also not required. However, where the piping systems are SC-I/SC-II, connected to major/sensitive equipment, or will have significant externally imposed displacements, a formal flexibility analysis is required.

c) For piping systems with the maximum operating temperature above 250°F, formal flexibility analysis is required.

d) Per Reference 8.19, for piping systems that contain welds that are to be vacuum box leak tested and have design temperatures greater than or equal to 150°F, a comprehensive flexibility analysis shall be performed in accordance with ASME B31.3.

4.4 Weight Analysis

1. General Requirements of Weight Analysis

Sustained loads include weight loads, such as the weight of the piping, piping components, insulation, contents, and other superimposed permanent loads, and live loads such as snow load of 15 lb/ft^2, volcanic ash loads of 12.5 lb/ft^2 for SC-I & SC-II piping, and snow load of 15 lb/ft^2, volcanic ash loads of 5 lb/ft^2 for SC-III (Chem and Non-Chem) & SC-IV piping [Tables 4-1 & 4-2 of Ref 8.19]. Note that snow and volcanic ash loads apply only to exposed piping outside the buildings; therefore these loads do not apply to SC-IIIE piping, which is exclusively inside the facilities. These additional loads apply only to weight analysis and are not required to be combined with seismic per section 1612.3.1 of UBC [Ref 8.5]. In addition, it is reasonable to assume that the snow and volcanic ash will not remain on the pipe during seismic or wind events.

One of the characteristics of snow or volcanic ash is that it is like powder. Buildup of a powder-like substance on a round surface such as a pipe will result in accumulation in the shape of a triangle and not a rectangle, which is common for a flat surface. Hence, any excess of snow or volcanic ash will fall off. In addition, since snow loads envelope volcanic ash live loads, qualifying the pipe for live loads of 15 lb/ft^2 addresses the requirements for both snow and volcanic ash.

The main purpose of weight analysis is to support the piping system to meet the criterion specified in Section 4.9.1, and to limit the piping sag to 1/4” or less. This is to avoid creating low points (pockets) in the piping between supports if no slope is taken into consideration, and to avoid system drainage problems.

For development of Span and Support Load Tables for RPP-WTP piping, sag is limited to 0.25 inch, or the pipe stress due to weight load is limited as specified in Appendix 1, whichever provides the shortest span length.

Rigid vertical supports should be provided to the piping system based on the weight analysis where possible. If the piping system is operating at higher temperature, spring hangers may be required at locations near equipment or a connected header due to large differential movements.

2. Analysis Approaches

In general, a formal analysis is required to determine the piping sag and the pipe stresses.

a) “Span and Support Load Tables”, provided in Appendix 2, may be used for SC-III(Non-Chem) and SC-IV piping. Using spans less than or equal to the weight span specified in the Span Tables for SC-III(Non-Chem) and SC-IV piping indicates that the sustained load requirement of ASME B31.3 is met and will also ensure that the lower $0.8S_h$ limit is met, due to the limitations on pressure stresses.

b) Comprehensive analysis using ME101 is required for SC-I, SC-II, SC-III(Chem), and SC-IIIE piping, and for critical piping as identified in Appendix 8 in order to perform the Code check for sustained load.

4.5 Seismic Analysis

1. Code Requirements of Seismic Analysis

ASME B31.3 Code requires piping systems be designed for occasional loads such as earthquake to meet the design criteria specified in Section 4.9.3, to ensure that the piping systems will be able to perform their seismic safety function.

2. Seismic Analysis Techniques

Seismic analysis is performed using static methods or dynamic methods. Each method consists of several steps such as seismic load determination, methods of applied loads, pipe model selections, and methods of determining the pipe responses, etc. For RPP-WTP, the static method based on the Uniform Building Code is used for SC-III(Chem), SC-III(Non-Chem), SC-IIIE and SC-IV piping except for black cell piping. The response spectrum method is used for dynamic seismic analysis of SC-I and SC-II piping and all black cell piping. These methods are described as follows:

a) Static Method Using the Uniform Building Code

This method establishes the lateral seismic force, F_p, on piping systems using the nominal pipe wall thickness for defining loads as detailed in Section 4.9 and is based on Equations 32-2 and 32-3 and Zone 2B of UBC [Ref 8.5] as follows:

$$0.7C_a I_p W_p \leq F_p = \frac{a_p C_a I_p}{R_p}\left(1 + 3\frac{h_x}{h_r}\right)W_p \leq 4C_a I_p W_p$$

where

- C_a = Seismic Coefficient, as set forth in UBC Table 16-Q, taken as 0.24 for WTP (see below) except for SC-IIIE, for which C_a is taken as 0.312 [Ref 8.67]
- I_P = Importance Factor specified in UBC Table 16-K, taken as 1.50 for SC-III piping and 1.0 for SC-IV piping for WTP
- W_P = The weight of an element or component
- F_p = Total design lateral seismic force (as defined in UBC 1632.2)
- a_p = In-structure Component Amplification Factor from UBC Table 16-O
- R_p = Component Response Modification Factor from UBC Table 16-O
- h_x = Element or Component elevation with respect to grade, not less than 0.0
- h_r = Structure roof elevation with respect to grade

The following list indicates the requirements that are used to develop loads for SC III/IV piping and supports:

- Lateral and vertical seismic loading, with the vertical force, F_v, equal to 2/3 the lateral force, which is consistent with typical Nuclear Power Plant (NPP) requirements
- Lateral force applied in both horizontal directions consistent with typical NPP requirements
- The three directions of force (both horizontals and the vertical) combined SRSS
- No reduction factor applied to the earthquake load
- a_p = 2.5 for piping (UBC Table 16-O, maximum possible value)
- R_p = 3.0 (UBC Table 16-O, Item 3B) for piping and for supports that don't use Concrete Expansion Anchors (CEAs) or have a buckling issue
- R_p = 1.5 for non-ductile failure modes based on Table 16-O, Item 4B (buckling, CEA pullout)

Determination of the seismic coefficient, C_a, is described in section 8.1.6, 1997 Uniform Building Code Soil Profile Type, of the WTP geotechnical investigation report (Shannon & Wilson 2000) [Ref 8.61]. The coefficient is based upon the soil profile type and the UBC Seismic Zone 2B classification.

F_p and F_v shall be distributed in proportion to the mass distribution of the piping system. To determine the pipe stresses and support loads using static methods, either of the following two approaches may be used:

- Simplified or approximate method

  This method uses the single span beam with the assumed end conditions as the pipe mathematical model, and applying the lateral and vertical seismic forces (F_p and F_v) to the model to determine the pipe stresses and support loads. This method is used to develop the "Span and Support Load Tables" for earthquake load as provided in Appendix 1, Span Method Criteria.

- Comprehensive Static Analysis using ME101

  This method applies UBC static lateral and vertical seismic loads to the mass distribution of the piping system model to determine the pipe stresses and support loads. The piping system model is the same as that for comprehensive ME101 flexibility analysis and comprehensive ME101 weight analysis. This analysis will provide more realistic results than those from the "Span and Support load Tables" using a single span beam model. When using ME101, F_p is applied in both horizontal directions with F_v in the vertical, and the results are combined by SRSS.

- In-line Component Accelerations Based on UBC Static Methods

  <u>SC-III(Chem), SC-III(Non-Chem) or SC-IV</u>
  With C_a = 0.24, and I_p conservatively = 1.5, and considering both horizontal directions of load and 2/3 the horizontal for the vertical, the resultant maximum acceleration for a valve or any in-line component is:

$$A_{res} = \sqrt{(4 \cdot 0.24 \cdot 1.5)^2 + (4 \cdot 0.24 \cdot 1.5)^2 + \left(\frac{2}{3} \cdot 4 \cdot 0.24 \cdot 1.5\right)^2} = 2.25g$$

  Applying the 1.1 factor required in DOE-1020-94, page 2-20 (assuming the equipment is tested):

  A_{res} (test) = 2.48g peak

  <u>SC-IIIE</u>
  With C_a = 0.312, and I_p = 1.5 [Ref 8.66 & 8.67], and considering both horizontal directions of load and 2/3 the horizontal for the vertical, the resultant maximum acceleration for a valve or any in-line component is:

$$A_{res} = \sqrt{(4 \cdot 0.312 \cdot 1.5)^2 + (4 \cdot 0.312 \cdot 1.5)^2 + \left(\frac{2}{3} \cdot 4 \cdot 0.312 \cdot 1.5\right)^2} = 2.93g$$

  Applying the 1.1 factor required in DOE-1020-94, page 2-20 (assuming the equipment is tested):

A_{res} (test) = 3.22g peak

Since these are lower than the value cited in Section 3.1 for SC-III in-line components, in-line devices tested as described in Section 3.1 will automatically meet UBC maximum static accelerations.

b) Dynamic Seismic Analysis – Response Spectrum Method with 5% Damping

Response Spectrum Method is the most common dynamic seismic analysis method for piping systems used by the nuclear industry.

Facility Structures are approximated by mathematical models to permit analysis of responses due to earthquake motions. For piping systems or equipment that are not analyzed as part of the building structural model, the Stress EGS should consult with CS&A for the use of floor response spectra curves. Both horizontal and vertical floor response spectra are computed from time history motions of the structure at various floor elevations or other support locations of interest.

A comprehensive dynamic seismic analysis using in-structure response spectra required per Reference 8.2 is performed using ME101 for SC-I, SC-II piping and all black cell piping to ensure meeting the occasional load requirement. In the response spectrum analysis, the piping system shall be modeled in accordance with Section 7.2.2.2.2 (b) of the Seismic Analysis and Design Criteria [Ref 8.7]. The peak values of particular responses of interest are determined for each mode. The total response may be obtained by combining the peak modal responses by the CQC modal combination method. Reference 8.56 approves CQC as a method for considering closely spaced modal effects. The residual rigid response is then combined with the modal response, again in compliance with Reference 8.56. In combining the effects due to tri-axial excitations, the natural frequencies, mode shapes, and the loads for each mode of the piping system are first determined. The load for each mode for unit-generalized response is the product of the stiffness matrix, the mode shapes, and the mode participation factors. When this product is multiplied by the generalized response determined from spectrum curves, the load for each natural mode results. The combined earthquake-induced response is then computed by the SRSS method of the three earthquake components [Ref 8.56].

Motions in a piping system dissipate energy from the system. The phenomenon of this kind of energy loss is called damping. For the WTP project, the damping value of 5% is used for piping [Ref 8.2].

The following Inelastic Energy Absorption Coefficients (F_{μ}) shall be used in piping stress analysis for SC-I and SC-II piping [Table 2-6a, Ref 8.38]:

Component	F_{μ} Value
Butt Joined Groove Welded Pipe	1.50

Socket Welded Pipe	1.25
Threaded Pipe	1.15
Equipment and Pipe Supports	1.50

However, Inelastic Energy Absorption Coefficients (F_{μ}) shall remain equal to 1.0 for the following:

- Calculating piping displacements
- Calculating loads and/or accelerations on active equipment that must function during and after the seismic event
- Calculating loads on components that exhibit non-ductile failure modes (buckling, concrete expansion anchor pull out, cast-iron standard components)
- Calculating pipe support attachment interface loads to be used in evaluation of CS&A components

Note that Seismic analysis of piping may involve consideration of Seismic Anchor Movement (SAM) loads; see section 4.9.5 for details.

3. Analysis Approaches

The earthquake loads are different from facility to facility, and the response spectra curves are different from elevation to elevation. Therefore, seismic analysis shall be performed by Formal Analysis approach using either the simplified approximate method or comprehensive computer analysis.

"Span and Support Load Tables" are developed based on simplified or approximate methods and UBC requirements for SC-III(Non-Chem) and SC-IV piping. The detailed design basis is provided in Appendix 1. Using spans less than or equal to the seismic span specified in "Span and Support Load Tables" in Appendix 2 indicates that the occasional load requirement of ASME B31.3 is met for piping design of SC-III(Non-Chem) and SC-IV piping.

"Formal Analysis – response spectrum analysis" always provides more realistic results and the results are less conservative than those using simplified or approximate methods. Therefore, if the support span of a SC-III(Non-Chem) or SC-IV piping system deviates from that specified in the span and support tables and can not be justified, the piping system will be qualified using "Formal Analysis" by ME101 for weight, flexibility and/or seismic analysis to reduce the conservatism.

In case the actual support span is less than that specified in "Span and Support Load Tables", the support load may be adjusted to the actual support span by interpolation. Appendix 2 provides span load tables at maximum span with lateral support at every DW support, every other DW support and every third DW support for this purpose.

4.6 Analysis for Wind Loads – For Exposed Piping Only

ASME B31.3 Code requires that the effect of wind loading be considered in the design of exposed piping. ASME Code B31.3 Paragraph 301.5.2 states that the method of analysis may be as described in ASCE 7 [Ref 8.9], Minimum Design Loads for Buildings and Other Structures, or the Uniform Building Code [Ref 8.5]. The ASCE 7-98 [Ref 8.9] is used as the basis for wind load analysis for the RPP-WTP project [Ref 8.19].

For wind load analysis, the design wind pressures are determined per ASCE and applied to the pipe in any horizontal direction using static analysis. The design wind pressures per Equation 6-20 of ASCE 7-98 are determined for any height in accordance with the following formula:

$$F = q_z G C_f A_f$$

where

F = design wind force (lb)
q_z = wind velocity pressure evaluated at height z above ground (lb/ft^2)
{I_w = wind importance factor as set forth in Table 4-1 and 4-2 of Ref 8.19 (Note 1)}
G = gust effect factor (Note 2)
C_f = force coefficient (Note 3)
A_f = pipe projected area normal to the wind direction (ft^2)

Per Tables 4-1 and 4-2 of Reference 8.19, the straight wind speed is 91 miles per hour, 3-second gust, at 33 ft above ground for SSCs without NPH Safety Functions SC-III & SC-IV, and 111 miles per hour, 3-second gust, at 33 ft above ground for SSCs with NPH Safety Functions SC-I & SC-II.

Notes:

1) Use I_w = 1.00 (part of q_z)
2) G should be 0.85 for piping, per ASCE 7-98 Section 6.5.8 [Ref 8.9]
3) C_f is force coefficient taken as 0.7, per ASCE 7-98 Table 6-10.
4) It is recommended to use exposure category "C" [Ref 8.9, Section 6.5.6].

The wind analysis is to be performed using static method assuming the wind to come from any horizontal direction. For piping with segments mostly in global directions, enveloping the results of global x-wind and global z-wind is acceptable. For piping with global as well as skewed segments, SRSS of the results of global x-wind and global z-wind is acceptable.

Wind loads and seismic loads do not have to be taken concurrently. Wind loads are also considered as occasional loads and are considered as S_{oc} in Section 4.9.3 as required by seismic category of the piping. However, wind loads are kept to 1.33 S_h in all seismic category piping.

Since only a few piping systems may require analysis for wind loads, no simplified or approximate methods such as Span Tables are provided here. If required, ME101 has the capability to perform the above analysis as required by the B31.3 Code and ASCE 7-98.

Note 1: Wind data (profile) for use in ME101 analysis in accordance with ASCE 7-98 [Ref 8.9] is provided by calculation 24590-WTP-P6C-P40T-00015 [Ref 8.62]

Note 2: In order to meet the 1Hz frequency requirement of ASCE 7-98, deflection due to wind load is limited to 10" [Ref: 8.62]. In addition, Attachment 5 of the Stress calculation lists all piping movement above 1.0" as part of the Interference Clearance Deviation Evaluation [Ref 8.57].

4.7 Simplified Methods

In order to simplify the analysis process, a simple pipe mathematical model has to be established. The simple pipe model usually consists of a single span of one or two dimension pipe layout with conservative end conditions and simple loading conditions.

a) Simplified Methods for Flexibility Analysis

Simplified Methods for flexibility analysis are effective for piping with simple layout and end conditions. The main purpose of simplified method is to determine the offset length or expansion loop to absorb the expansion/contraction movements imposed by its connected pipe or equipment. If necessary, a comprehensive analysis using a computer program such as ME101 may be used to obtain realistic results from thermal expansion/contraction and imposed thermal anchor movements.

b) Simplified Methods for Weight and Seismic Analyses – Span Tables

As weight analysis is a simple static analysis with gravity load only, a simplified weight analysis in general provides a reasonably accurate result in comparison to the result of a comprehensive computer analysis. Therefore, the "Span and Support Load Tables" for weight loads, generated based on the simplified method provided in Appendix 1, Span Method Criteria, should be used for SC-III(Non-Chem) and SC-IV piping.

The "Span and Support Load Tables" were developed for straight insulated pipe with and without water content. Piping with different insulation materials and specific gravities than those used in developing the span tables should be accounted for when applying the Span and Support Load Tables into the design of SC-III(Non-Chem) and SC-IV piping.

The span tables were originally developed based on nominal wall thickness. In addition, a calculation [Ref 8.27] was prepared to justify the span tables to account for mechanical, corrosion, and erosion allowance in accordance with ASME B31.3 Code. The guidelines for using the span tables are specified in Section 4.10.2.

The static seismic analysis based on UBC is used to develop the span and support load tables for SC-III(Non-Chem) and SC-IV piping. Design of SC-III(Non-Chem) and SC-IV piping by fully applying the "Span and Support Load Tables" is considered as meeting the Code requirements for occasional load, and no further analysis is required.

Separate analysis to document the design of non-critical SC-III(Non-Chem) and SC-IV piping systems is not required when Span Tables are used, provided that the design is consistent with the limitations for using the Span Tables as described in Engineering Design Guide for Pipe Stress [Ref 8.57], and the supports are designed with the loads specified in Span Tables, as allowed per project procedures [Ref 8.3 & 8.41]. The signature of the stress engineer on the piping isometric signifies that the design meets the span and flexibility requirements.

c) Simplified Methods - Study Run

Pipe support loads for a straight pipe per the Span Tables have proven to be approximately the same as those from ME101 analysis per Reference 8.15. For a complicated three-dimensional piping routing with concentrated weight, in-line equipment, and more turns, the support loads from an ME101 study run may be more realistic than those from the Span Tables; loads from the study run for non-critical SC-III(Non-Chem) and SC-IV piping systems may be used for pipe support design provided that ME101 input and the requested results are documented as an attachment to the support calculation.

Separate analysis to document the design of non-critical SC-III(Non-Chem) and SC-IV piping systems is not required when Span Tables are used, provided that the design is consistent with the limitations for using the Span Tables as described in Engineering Design Guide for Pipe Stress [Ref 8.57], and the supports are designed with the loads specified in Span Tables, as allowed per project procedures [Ref 8.3 & 8.41]. The signature of the stress engineer on the piping isometric signifies that the design meets the span and flexibility requirements.

4.8 Deleted

4.9 Computer Analysis Using ME101

ME101, Linear Elastic Analysis of Piping Program, is a family of computer programs that performs design analysis of piping systems, does various Code compliance checks, and produces complete calculation packages excluding project required manually attached information. The program is based on the finite pipe element method to calculate the response of piping systems subjected to a variety of loading conditions. Static analysis is performed for weight loading, thermal expansion loading, wind loading, seismic anchor-movement loading, building settlement, and static seismic loading such as UBC earthquake loading, etc. Dynamic analysis is performed for earthquake events using response spectrum methods or time history methods. Transient events, such as water hammer loads, can also be analyzed with modal time history or direct integration methods.

ME101 input keyword "CODE=B31399" meets all Code requirements of B31.3, 1996 and is acceptable for use on the WTP project per Reference 8.43.

Note that paragraphs 1 through 5 below describe how ME101 calculates applicable stresses. Since WTP uses a mixture of nominal thickness (loads, displacement stresses) and end-of-life thickness (sustained and occasional stresses), the ME101 analysis is run using nominal dimensions. The resulting stresses are then corrected as explained in Section 4.10 to account for the end-of-life thickness.

1. Longitudinal Stresses S_L

$$S_L = \frac{PD}{4t_n} + S_s \le S_h \qquad \text{[Ref 8.1, Paragraph 302.3.5(c)]}$$

The longitudinal pressure stress of $\frac{PD}{4t_n}$ may be determined by the equation of

$$S_{lp} = \frac{Pd^2}{D^2 - d^2}$$

where

S_s = the longitudinal stress due to weight and other sustained loads.
S_{lp} = the longitudinal pressure stress.
P = design pressure
D = pipe outside diameter
t_n = nominal thickness of pipe; for corrosion/erosion and mechanical allowance consideration see Section 4.10
d = pipe inside diameter; for corrosion/erosion and mechanical allowance consideration see Section 4.10

2. Displacement Stress Range S_E – used as the criteria in the design of piping for flexibility

$$S_E \le S_A$$

where

S_E is the displacement stress range due to thermal displacements (constrained from free expansion or contraction), reaction displacements and externally imposed displacements such as seismic anchor movements, see paragraph 319.4.4 of Reference 8.1.

$$S_A = f\left(1.25S_c + 0.25S_h\right)$$

where

f = stress range reduction factor defined in equation (1c) ASME B31.3.

= 1 if the equivalent number of full displacement cycles during the expected service life of the piping system is less than 7,000.

f may be taken as unity for the initial design of RPP-WTP piping systems. However, the Pipe Stress EGS should consult with Mechanical Systems for service life system operation thermal cycles. If the expected number of thermal cycles in the service life of any piping system exceeds 7,000 cycles, Equations (1c) and (1d), or the Stress-Range Reduction Factors *f* in Table 302.3.5 in ASME B31.3 shall be applied.

3. Longitudinal Stresses due to Pressure, Sustained loads, and Occasional loads

3.1. For SC-I, SC-II, SC-III piping containing a significant Chemical release hazard (SC-III(Chem)), and SC-IIIE or any piping in black cells

$$S_L = \frac{PD}{4t_n} + S_s + S_{oc} \le 1.33 S_h \quad \text{[Ref 8.1, Paragraph 302.3.6(a)]}$$

3.2. For SC-III without containing a significant Chemical release hazard (SC-III(Non-Chem)) and SC-IV Piping

$$S_L = \frac{PD}{4t_n} + S_s + S_{oc} \le 3.0 S_h \text{, but not greater than 2.0 } S_y \quad \text{[Ref 8.38, Table 2-6]}$$

where

S_{oc} is the longitudinal stress produced by occasional seismic loads.

For S_{oc} based on wind or fluid transient loads for SC-III(Non-Chem) & SC-IV piping:

$$S_L = \frac{PD}{4t_n} + S_s + S_{oc} \le 1.33 S_h \quad \text{[Ref 8.1, Paragraph 302.3.6(a)]}$$

4. The pipe stresses S_s, $S_{oc,}$ and S_E shall be calculated from the bending moments and torsional moment at the piping component in the piping system as follows:

$$S_s, S_{oc,} S_E = \sqrt{S_b^2 + 4S_t^2}$$

where

$$S_b = \frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z} = \text{resultant bending stress}$$

S_t = torsional stress, $\frac{M_t}{2Z}$

M_t = torsional moment

M_i = in-plane bending moment

M_o = out-of-plane bending moment

i_i = in-plane stress intensification factor

i_o = out-of-plane stress intensification factor

Z = section modulus of pipe

The three moment components (M_t, M_i, M_o) are calculated at the same location of a piping component in the piping system due to sustained load, occasional load and displacement strains, respectively.

In performing pipe stress analysis for sustained and occasional loads using ME101, the longitudinal and occasional stress checks shall be performed per Section 4.10.1 below to meet Para. 302.3.5 (c) and 302.3.6 (a) of ASME B31.3 Code [Ref 8.1].

5. Seismic Anchor Movement (SAM)

Pipe stress analysis for the effects of SAM should be evaluated as Displacement Stress Range S_E. The application of SAM to pipe supports (same building/facility) in the pipe stress analysis is simplified in the following:

(1) SLAB-WALL Joints: In-Phase in all directions and at all elevations
(2) Vertical SAM:
- If on the same slab: In-Phase
- If on different slabs:
  - (A) If on the same elevation
    - (a) If there is a vertical support on wall (i.e., penetration, etc.):
      - Supports on slabs: In-phase
      - Supports on wall: Out-of-Phase
    - (b) If no vertical support on wall:
      - Supports on slabs: Out-of-Phase
  - (B) If on different elevations: Out-of-Phase

Refer to Reference 8.29 and Reference 8.30 for the seismic displacements in HLW and PTF facilities, respectively.

Note that SAM displacement can be induced by Seismic movement of header piping, structural attachment (such as building/support) and equipment seismic movement.

The impact from seismic anchor movement may be insignificant and the analysis of SAM may not be necessary if either of the following conditions is met [Ref 8.15]

<u>Condition 1</u> (All limitations of this condition must be satisfied)

a). Relative SAM between structural elements such as wall penetration, floor box, etc. and first adjacent support is less than 1/8" in any direction, or 1/16" for first support from a nozzle

b) Pipe nominal size is 6" and smaller

c). Displacement stress range is less than 70% of thermal piping Code stress allowable S_A for piping schedules 40 & 80 and less than 65% for piping with schedule 10S

d) The distance of adjacent support from the effected SAM is not less than 80% of the weight span specified in Span Tables (Note: This is an offset span that absorbs the SAM by bending)

e) Maximum SIF for the piping subjected to SAM is 2.1

<u>Condition 2</u> (All limitations of this condition must be satisfied)

a) The piping system is analyzed utilizing ME101 (comprehensive stress analysis)

b) Relative SAM between structural elements such as wall penetration, floor box etc. and first adjacent support is less than 1/16" in any direction

c) Displacement stress range combined with pressure and longitudinal stresses (sustained) are less than 90% of the piping Code stress allowable S_A+S_h

4.10 Consideration of Mechanical, Corrosion, and Erosion Allowance

The ASME B31.3 Code requirements for mechanical, corrosion and erosion allowance shall be incorporated in pipe stress calculations as follows:

4.10.1 ME-101 Analyzed Piping

Two confirmatory longitudinal stress checks for the eroded/corroded condition, sustained and occasional, shall be performed for each pipe stress calculation. These stress checks shall be completed prior to assigning a confirmed/committed status to any of future stress calculations.

A. Sustained Stress Check, S_L = longitudinal stress due to pressure and weight,

$$S_L = \frac{PD}{4t_c} + S_s \text{, psi} \leq 1.0\, S_h \text{ (SC-I, SC-II, SC-III(Chem), SC-IIIE);}$$

$\leq 0.8\, S_h$ (SC-III(Non-Chem), SC-IV; see Section 3.3.2 for discussion)

using

1. Nominal weight for load calculations and
2. Corroded (reduced) wall properties for stress calculations

The longitudinal pressure stress $S_{lp} = \frac{PD}{4t_c}$ may also be determined by the equation of

$$S_{lp} = \frac{P(d+2c)^2}{D^2 - (d+2c)^2} \text{ or } \frac{P(D-2t_c)^2}{D^2 - (D-2t_c)^2}$$

Where

S_s = the longitudinal stress due to weight and other sustained loads, see Section 4.10.1.C below
S_{lp} = the longitudinal pressure stress
P = design pressure
D = pipe outside diameter
d = pipe inside diameter
t_c = eroded/corroded thickness of pipe, = t_n - c
t_n = nominal thickness of pipe
c = mechanical, erosion, and corrosion allowance

Longitudinal stresses [Ref 8.1, Para. 302.3.5(c)] are re-calculated based on weight moments from ME101 output with corroded section modulus plus pressure stress from design pressure with corroded wall thickness. Nominal pipe weight and pipe content are considered in the longitudinal stress calculations. The sustained load stress ratio is calculated by dividing the calculated longitudinal stresses by the Code stress allowable. The sustained load stress ratio shall be ≤ 1.0 for SC-I, SC-II, SC-III(Chem), and SC-IIIE, and ≤ 0.8 for SC-III(Non-Chem) and SC-IV (see 3.3.2 for discussion and permitted changes).

Sustained Longitudinal Stress Check due to pressure and weight under corrosion/erosion consideration shall be performed directly using the ME101 Report Writer. The standard Excel sheet/instructions in Appendix 7A may be used at the discretion of the Pipe Stress EGS.

B. Occasional Stress Check, S_L = longitudinal stress due to pressure, weight and occasional load,

$S_L = \frac{PD}{4t_c} + S_s + S_{oc}$, psi, $\leq 1.33\ S_h$ (for SC-I, SC-II, SC-III(Chem) and SC-IIIE piping)

or

$\leq 3.0\ S_h$, but not greater than $2.0\ S_y$ [for SC-III(Non-Chem) and SC-IV piping] (See Note 3 for additional restrictions)

where

S_{oc} = the longitudinal stress due to occasional load, see Section 4.10.1.C
S_h = basic allowable stress at maximum metal temperature, (psi)
S_y = yield strength at temperature, (psi) using

1. Nominal weight for load calculations
2. Corroded (reduced) wall properties for stress calculations
3. For wind and fluid transient loads the stress limit is 1.33 S_h, regardless of seismic category

Stresses due to occasional loads are re-calculated based on occasional moments from the ME101 output with corroded section modulus. Occasional stresses [Ref 8.1, Para. 302.3.6 (a)] are calculated by combining stresses due to sustained loads with stresses due to occasional loads, such as wind or earthquake loads. The occasional load stress ratio is calculated by dividing the calculated occasional stress by the allowable stress. The occasional load stress ratio shall be less than or equal to 1.0.

Longitudinal Stress Check due to pressure, weight and occasional loads under corrosion/erosion consideration shall be performed directly using the ME101 Report Writer. The standard Excel sheets/instructions in Appendix 7B may be used at the discretion of the Pipe Stress EGS.

C. The pipe stresses S_s and S_{oc} shall be calculated from the bending moments and torsional moment at the piping component in the piping system as follows:

$$S_s, S_{oc} = \sqrt{S_b^2 + 4S_t^2}$$

where

$$S_b = \frac{\sqrt{(0.75 i_i M_i)^2 + (0.75 i_o M_o)^2}}{Z_c}$$

S_t = torsional stress, $\frac{M_t}{2Z_c}$

M_t = torsional moment

M_i = in-plane bending moment

M_o = out-of-plane bending moment

i_i = in-plane stress intensification factor from Appendix D of the ASME B31.3 Code

i_o = out-of-plane stress intensification factor from Appendix D of the ASME B31.3 Code

Z_c = reduced section modulus of pipe for S_s and S_{oc} in consideration of erosion/corrosion

Per the Code interpretation 1-34 [Ref 8.44] of ASME B31.3, $0.75i_i$ or $0.75i_o$ is used in the calculation but shall not be less than 1.0. Note that Code Case 178 [Ref 8.59] issued at a later date reaffirmed Code interpretation 1-34. Axial loads, which are included in the Code Case equation, are typically small for piping and are, therefore, ignored. This treatment is in compliance with Table 2-6 of the PDSA [Ref 8.38].

4.10.2 Piping Qualified by the Span Tables [Ref. 8.27]

The current RPP-WTP Span Tables shall be used for the pipe sizes (with mechanical, corrosion, erosion allowance of up to 50% of the nominal wall thickness) listed in Tables 2.2 and 2.4, which address the majority of piping at the WTP project. The following pipe sizes with wall thinning of 50% or more shall require further review:

Table 4.1 Piping with Erosion/Corrosion Allowance 50% or Greater

Pipe Size	Schedule	E/C, c, (in)	% of E/C	Pipe Classes Requiring Further Review
1/2	80 or 80s	0.125	85%	**C.S.**: C14A, C14B; **Alloy**: N14A; **S.S.**: S14A
3/4	80 or 80s	0.125	81%	**C.S.**: C14A, C14B; **Alloy**: N14A; **S.S.**: S14A
1	80 or 80s	0.125	70%	**C.S.**: C14A, C14B; **Alloy**: N14A; **S.S.**: S14A; W32A*
1-1/2	40S	0.0937	65%	**C.S.**: None; **Alloy**: N14A; **S.S.**: W32A*
1-1/2	80 or 80s	0.125	63%	**C.S.**: C14A, C14B; **Alloy**: N14A; **S.S.**: S14A, S14E, S14F
2	40S	0.0937	61%	**C.S.**: None; **Alloy**: None; **S.S.**: W32A*
2	80 or 80S	.125	57%	**C.S.**: C14A; **Alloy**: N14A; **S.S.**: S14A, S14E
3	40 or 40s	0.125	58%	**C.S.**: C14A; **Alloy**: N14A; **S.S.**: S14A, S14E, S14F
4	40 or 40s	0.125	53%	**C.S.**: C14A; **Alloy**: N14A; **S.S.**: S14A, S14E, S14F
6	80S	0.25	58%	**C.S.**: None; **Alloy**: None; **S.S.**: S14D
8	80S	0.25	50%	**C.S.**: None; **Alloy**: None; **S.S.**: S14D

* Inner (core) pipe of jacketed pipe system (outer pipe (jacket) has corrosion = 0.0”)

Additional requirements may include a review of the existing pipe elevations and/or performance of a detailed ME101 stress analysis as follows:

A. Piping located at elevations (or below):
  +23 ft in <u>HLW</u>,
  +28 ft in <u>PTF</u>,
  +3 ft in <u>LAW</u>,
  +2 ft in <u>LAB</u>
 is acceptable per the existing Span Tables; no further analysis is required.

B. For piping located at elevations:
  +40 ft in <u>HLW</u>,
  +56 ft in <u>PTF</u>,
  +28 ft in <u>LAW</u>,
  +27 ft in <u>LAB</u>

ME-101 analysis is required for:

Pipe Size	Schedule	E/C, c, (in)	% of E/C	Pipe Classes Requiring ME-101 Analyses
1/2	80 or 80s	0.125	85%	**C.S.**: C14A, C14B; **Alloy**: N14A; **S.S.**: S14A
3/4	80 or 80s	0.125	81%	**C.S.**: C14A, C14B; **Alloy**: N14A; **S.S.**: S14A

C. For piping located at the following elevations (and above), ME-101 analysis is required for all pipe sizes and pipe classes listed in Table 4.1:
+71 ft in HLW,
+98 ft in PTF,
+48 ft in LAW,
+36 ft in LAB

5 Computer Analysis Procedures

5.1 General Procedure

A pipe mathematical model needs to be established in order to perform the pipe stress analysis using a computer program. The mathematical model shall include the pipe dimensions and geometry, pipe material, piping component types, support types and support locations, and the loading conditions.

5.2 Pipe Mathematical Model

A pipe mathematical model is used to represent the piping system and its boundaries in sufficient detail based on its pipe classification such as SC-I and SC-II, SC-III(Chem), SC-IIIE or SC-III(Non-Chem) and SC-IV in order to obtain realistic analysis results per Project design requirements.

The boundaries of a piping system are located at anchors such as equipment nozzles, penetrations, or intermediate structural support anchors, or at free ends. In some cases, the boundaries also can be at locations where the "De-couple Criteria" per Section 5.3 apply and a fictitious fixed point of the piping system may be assumed.

The model includes piping coordinates and properties such as pipe diameters, pipe wall thickness, pipe materials, support locations and support types. Pipe fittings/piping components and welded joints if necessary should be modeled as well. At each fitting/piping component or welded joint in the piping system, the stress intensification factor (SIF) per Appendix D of ASME B31.3 Code shall be specified. For anchors, a SIF of 2.1 should be specified to account for welded attachments, anchor plates, etc. For response spectrum analysis, for valves with operators offset from the valve body, the operator weight should be modeled at its center of gravity. It is preferable to model small cantilever vents and drains with the large process pipe. If the design of vents and drains are not available at the time the larger process pipe is analyzed, it is acceptable not to include them in the pipe mathematical model. However, the effects of vents and drains should be addressed later in either a revision of the stress calculation, or in a separate calculation.

5.3 De-coupled Analysis

The following de-coupled criteria may be used for de-coupling of branch pipe analysis if either of the following conditions is met:

- If the pipe moment of inertia ratio is greater than 25
- If the nominal pipe diameter ratio is greater than 3

De-coupling piping systems generally is not a significant issue for static analysis such as UBC seismic analysis, thermal expansion or weight calculations. The following are guidelines for de-coupling of the branch pipe analysis:

1) The analysis of the branch piping must include the thermal and seismic movements of the run pipe at the intersection point. If SC-III or SC-IV piping is de-coupled from SC-I and SC-II piping, the seismic displacements from SC-I and SC-II piping in terms of SAM at the decoupled point should be considered in the design of SC-III and SC-IV piping. The support loads due to the SAM case shall be considered as occasional loads (note that SAM stress is considered as secondary stress similar to thermal stress). For SC-III and SC-IV branch piping de-coupled from either SC-III or SC-IV piping, the requirement for SAM analysis is determined by the stress engineer. The analytical approach of SAM is specified in Section 4.9.5.

2) If an anchor or rigid constraint on the branch pipe significantly restrains the movement of the run pipe, this branch pipe should not be decoupled. Instead, the branch pipe up to its anchor or the nearest three-way restraint or sufficient overlap restraints should be included in the model of the run pipe.

3) The branch pipe including the mass effects such as a valve or in-line equipment close to main run should be included in the mathematical model of the run pipe if more precise magnitude of reaction is required at terminal points (i.e., equipment, penetration, etc.)

4) The connecting component such as sockolet, weldolet, latrolet, un-reinforced branch, etc., shall be appropriately specified at the branch/run intersection location to get proper stress intensification factors in both the run pipe and branch pipe during analysis.

5.4 Considerations of Support Design in Pipe Stress Analysis

1. Rigid Supports in Thermal Expansion Analysis

   A free thermal expansion analysis is initially helpful to locate rigid supports at points of zero thermal movement (inflection points).

Rigid supports for weight and seismic shall permit expansion and contraction of the piping. To accomplish this, rigid supports used as guides such as U-bolts or seismic bumpers with small gaps of 1/16" are practical. Using a support gap in analysis to reduce either the weight or thermal load should be avoided whenever possible. However, when it is necessary to use gapped supports, the analysis should follow the guidelines specified in Appendix 9. For high temperature piping, snubbers may be practical based on a design point of view. However, they are prone to premature lock-up and are costly to maintain. Therefore, snubbers are not recommended unless there is absolutely no practical alternative. Snubbers are not permitted for the piping systems in black cells.

2. Spring hangers are considered to take deadweight only and no seismic load. Snubbers are not considered as effective in weight and thermal expansion analysis. If the analysis is based on design cold loads, then it should be stated clearly in the hanger guidance in order to design the travel range of the spring hanger. Spring hangers shall not be used in the black cells.

3. Pipe Supports are to be designed for normal operating loads and occasional loads. Therefore, pipe stress analysis shall provide the following loads for each support:

Normal Operating Loads – Weight*, or
Weight* + Thermal
* If there are no temporary supports to resist hydro test load, the pipe support shall be qualified with hydro load specified in hanger guidance.
* Weight also includes live loads

Occasional Loads – Normal Operating* + Earthquake, or
Normal Operating* + Wind, or
Normal Operating* + Other Fluid Transient Load if exist.**
* Weight also includes live loads
** In some cases, a fluid transient load may occur at the same time as earthquake or wind load. In this case, SRSS may be used to combine two occasional loads. Wind and earthquake loads do not need to be considered as acting concurrently.

For pipe support load combination due to HPAV loading see Section 7.11 of this criteria.

The upward thermal and seismic load can be offset by weight for any piping. For the vertical supports on SC-III and SC-IV piping, if the maximum positive thermal load plus positive seismic load is less than the deadweight, the vertical support does not need to be double-acting. However, for the vertical supports on SC-I and SC-II piping, the vertical supports should be double-acting unless the piping is also qualified with specific vertical supports inactive in the seismic run, as defined in the hanger guidance (note that the seismic average downward loads of the adjacent supports should be added manually to this support (only downward)).

Where vertical deadweight supports in the 3D Model are designed to contact or are in close proximity (<1/8") to other support steel or CS&A steel, these vertical deadweight support points shall be analyzed per the requirements specified in the previous paragraph, identified with support numbers on the appropriate isometric, and reflected on the parent support, as applicable.

Under the following circumstances, the points in the 3D Model may not be considered as support points and no support tag number is required even though there is the possibility of lateral or upward contact with pipe support or CS&A steel:

- The point is not modeled as a support point in the piping stress analysis.
- Clearance is greater than the thermal displacement at the point.
- Piping with design temperature less than 150°F and the total thermal growth at the point is judged to be less than 1/8".

5.5 Modeling of Piping Components in ME101

To perform a pipe stress analysis, the pipe mathematical model of the pipe system, design conditions and the loading input and their combinations are required as input in ME101. ME101 data separates the data field of 80 characters into four regions. They are functional tag, node map, nodal increment, and engineering data.

Functional tag is to identify the key functions such as RUN (Load case definition), HED (General heading information), ANC (Anchor description), CMB (Load combination definition), OLA (Code compliance stress check), etc. CMB and OLA are all preset for each seismic category piping, and need not be reset for each calculation

Node map is the simple way to layout the mathematical model of a piping system. The node map is defined by a **FROM** field and a **TO** field between column 4 to 6, and 7 to 9, respectively. The finite element model is automatically created as each node is defined. A **From** field does not need to be input if the **TO** node is connected from the previous node.

Node increment is to describe the node geometry. They are divided into four individual columns, i.e., the increment of D_X (Column 10-20), D_Y (Column 21-31), D_Z (Column 32-42), and elbow radius. The format of each of these column employs engineering notation, such as feet-inch-fraction input.

Engineering data field is from column 51 to 80. It is reserved for inputting the engineering design data of this unique node point using Class-B keywords, or to the pipe segment beginning from this node point using Class-A keywords. Class-A keywords include OD (outside diameter), THICK (pipe wall thickness), TEMP (pipe temperature), LBS/FT (weight density distribution), etc. The Class-A keyword implies the properties are passed to the next node or next element until the value of same keyword is redefined. Class-B keywords include ADDWT (additional weight), TEE (tee type identification), SIF (stress intensification factor), etc. The Class-B keyword is applied to that unique node and that unique element only.

The major task of a pipe stress engineer is to follow the Stress ISO's to establish the pipe mathematical model by defining the node map and node increments, and to identify the engineering data of each node or element.

For more details, pipe stress engineers should refer to "ME101 User Manual" [Ref 8.55].

5.6 Summary of Analysis Results

The purpose of pipe stress analysis is to demonstrate that all piping components in the piping system have met the Code requirements and seismic requirements as specified in Section 4.9.

ME101 provides the stress summary for each piping component specified as a nodal point. The calculated stresses at each nodal point per criteria specified in Section 4.9 are compared with the Code allowable, respectively. The stress intensification factor for each nodal point (piping component) is also identified. In addition, the maximum calculated stress for each equation for the entire piping system is identified by the nodal point and listed in the stress summary sheet. The pipe stress engineer shall review and ensure that all piping components meet the Code requirements.

The displacements in local and global coordinates of each nodal point for each loading condition are also shown in the computer output. The pipe stress engineers should review these data to avoid pipe interference problems, ensure proper slope requirements are maintained, and to relocate the seismic supports at the zero or minimum thermal movement locations when possible.

The forces and the displacements at each support in local and global coordinates are shown in the computer output. The three forces and three moments at the nozzles are also shown in the output. The support loads and the displacements shall be given to the pipe support designer to design the support details. The forces and the moments of the nozzles shall be evaluated with the nozzle allowable specified in Reference 8.22 or per project approved data for vessel nozzles, or per Code criteria or vendor data as applicable (e.g., pumps, etc.).

5.7 Documentation of Calculation Packages

Pipe stress calculations are required to meet the applicable Quality Assurance (QA) procedures specified in Engineering Department Project Instructions. The documentation of each calculation package in engineering calculation preparation, checking, and approval shall follow the procedures specified in References 8.3, 8.20 and 8.41. The use of computer software shall be per the requirements of Reference 8.17.

ME101 Report Writer has been designed to create the calculation package in the format of a report to meet the unique requirements of the above project procedures. The Report Writer is constructed directly from the input design data and the output data stored in the ME101 master file.

6 Interface with Other Disciplines

6.1 Interface with the Layout Group

The layout group routes the pipe and transmits the stress ISO's to the Stress Group for analysis. The pipe stress engineer performs the stress analysis per Code requirements and coordinates any required routing changes with the layout group. The fabrication isometrics shall be reviewed and signed by the Pipe Stress EGS or designee.

6.2 Interface with the Pipe Support Designer

The pipe support designer is responsible for designing the pipe supports and determining the support locations based on the availability of structural steel, pipe racks, etc. The stress engineer coordinates with the pipe support designer for any changes to the original support configuration, support location, or support types.

If pipe stress analysis is done based on ME101, then the Pipe Stress Group issues the pipe support design loads table to the Pipe Support Group for the design of support details. If the pipe stress is completed based on the span method (tables), transmittal of support loads is not required.

6.3 Interface with Mechanical Systems Group

The system operating modes, pressures, temperatures, thermal cycles, specific gravity, nozzle loads, HPAV loads, fluid transient and thrust loads from relief valves are generated by the Mechanical Systems Group. The Stress Group needs to coordinate with Mechanical Systems for the timely issuance of that information, and to ensure the analysis meets those requirements.

6.4 Interface with CS&A Discipline

CS&A is responsible for generating the floor response spectrum curves for piping stress analysis. CS&A is also responsible for designing and qualifying building structural members. Coordination with CS&A regarding supporting piping from building structural members is primarily the responsibility of the Pipe Support Group.

6.5 Interface with Piping and Valve Engineering

Piping & Valve Engineering is responsible for developing the piping material classes such as piping schedules, corrosion/erosion rates and flange ratings that provide important design input data for pipe stress analysis.

6.6 Interface with the Jumper Group

The Jumper group is responsible for providing the Stress and Pipe Support group with the Jumper Frame simplified dynamic model to incorporate in ME101 pipe stress analysis. In addition, the Jumper Group is responsible for approving the loads from the ME101 piping analysis on the jumper frame.
Note: Dynamic simplified model data applies only to SC-I and SC-II Jumper Frames

6.7 Interface with Plant Equipment Group

Depending on the type of equipment and its status, the Plant Equipment Group may be responsible for providing pipe stress with the following information:

- An equipment data sheet to address operating condition such as material, pressures, temperatures and allowable nozzle loads determined by the vendor or PEQ
- Whether the equipment is considered rigid (Fundamental frequency is above 33 Hz horizontally or 50 Hz vertically) or not; if not, to provide a simplified dynamic model, if available and needed, to incorporate in ME101 pipe stress analysis.
  Note: applies only to SC-I and SC-II equipment
- Equipment seismic spectra, if available
  Note: applies only to SC-I and SC-II equipment

7 Special Stress Analysis

7.1 Pipe Local Stress Analysis at Welded Attachments

1. General Design Consideration

According to Subsection 321.3 of ASME B31.3 Code, structural attachments shall be designed so that they will not cause undue flattening of the pipe, excessive localized bending stresses, or harmful thermal gradients in the pipe wall. It is important that attachments be designed to minimize stress concentration, particularly in cyclic services.

Welded attachments are those shear lugs, shoes, saddles, stanchions, and structural anchors, etc., welded to piping systems. The use of welded attachments requires additional engineering hours and increases construction and fabrication cost. Therefore, welded attachments should be minimized on large bore pipe and not used on small-bore pipe (pipe sizes 2” and smaller) or any thinner than Sch40 pipes unless justified by stress engineer.

Welded attachments should be standardized. The design should be simple such as rectangular or circular cross section made of tube steel or pipe to facilitate analysis.

Irregular cross sections (such as channel, wide flange, cross configuration, etc.), are not recommended. To perform local stress analysis, similar welded attachments should be grouped together and the number of analyses should be kept to a minimum using engineering judgment.

2. Analysis Approach

The industry practice to ensure the attachment designs meet the ASME B31.3 Code requirements is to perform the pipe local stress analysis based on Welding Research Council Bulletin No. 107 [Ref 8.21] or by using stress intensification factor methods (SIF methods).

a) ME101/LS is written based on WRC Bulletin No.107 [Ref 8.21], and is used to determine local stresses at welded attachments. Local stresses should be added to the pipe stresses calculated per equations provided in Section 4.10.1 and compared with the appropriate allowable stresses as specified in Sections 7.1.1 and 7.1.2. In the local stress analysis, the additional loading due to friction (normal case and live loads conditions only) needs to be considered.

b) SIF Methods

This method is to apply an appropriate SIF value at the welded attachment to intensify the general pipe stress to determine the total pipe stress that is equivalent to the general pipe plus local stress. The following are recommended SIF values:

- When a stanchion is directly welded to the pipe, SIF of reinforced tee (RTEE) may be used to calculate the pipe stress including local stress. In this case, the stanchion should be included in the pipe model to represent the branch side of the pipe.

- When a welded attachment consists of a stanchion and a partial wrapper plate ($\leq 180^o$ around the pipe circumference), SIF of RTEE may be used except that the wrapper plate thickness can also be considered as reinforcement thickness in the RTEE SIF calculation. Local stresses at the pipe/wrapper plate can be calculated using ME101/LS.

- Welded attachment with 360^o wrapper plate, the stresses due to attachment are no longer local in nature as the plate is not a pressure boundary any more. The interface weld between wrapper plate and the pipe should be analyzed using a fillet weld SIF = 1.3 or that per note 14 in Appendix D of B31.3 in the pipe stress analysis.

- Standard welded attachments AP (anchor plate), AW (axial stop), and ZL (riser clamps - lugs) may be analyzed using SIF = 2.1, provided that the following conditions are met:

  - The support is modeled and evaluated in strict compliance with the loading and eccentricity limitations of the Engineering Design Guide for Pipe Support [Ref 8.46].
  - Pipe schedule is limited to schedule STD and higher
  - Allowed loads and associated local stresses are listed for lugs AW or ZL in Reference 8.58, including the limitations.

- Welded attachments on fittings such as elbows, tees, etc., should be avoided.

- Welded attachments should be avoided on thin-wall pipe. Local stress analysis utilizing ME101 local stress module (LS or FE), shall be performed for welded attachments on 5S, 10S, or other thin-wall pipe.

- For standard supports on insulated lines, it is recommended to use SIF = 2.1 to account for saddles, shoes, etc. This will conservatively cover the support whether a welded attachment is used or not. This does not apply for stanchions, which should be addressed as noted previously.

3. Acceptance Criteria

ASME B31.3 Code does not provide the stress criteria for local stress analysis. The following Criteria are established based on the Code Cases N318 (rectangular) or N392 (hollow circular) of ASME Section III [Ref 8.49 and 8.50], ASME Section VIII Code (Fig 4-130.1) [Ref 8.4] and industry practice.

7.1.1 For SC-I, SC-II, SC-III(Chem), and SC-IIIE Piping

a) Primary membrane stress check

$$S_{SL} = \frac{PD}{4t_c} + S_s + S_{oc} + S_{ml} \leq 1.8S_h$$

Note: S_{oc} is a stress due to DBE seismic load, or to wind or fluid transient load.

Where

S_{ml} = local primary membrane stress due to weight and occasional loads such as earthquake or wind or fluid transient load

P, D, t_c, S_s, S_{oc} and S_h are defined in Section 4.10.

b) Primary plus secondary stress check

$$\frac{PD}{4t_c} + S_s + S_{oc} + S_E + S_{nl} \leq 3.0S_h$$

Where

S_{nl} = the local primary plus secondary stress due to weight, occasional loads, plus secondary loads such as thermal expansion load

P, D, t_c, S_s, S_{oc}, and S_h are defined in Section 4.10, and S_E is defined in Section 4.9.

7.1.2 For SC-III(Non-Chem) and SC-IV Piping

Only primary membrane stress check with occasional loads is required for piping.

$$\frac{PD}{4t_c} + S_s + S_{oc} + S_{ml} \le 3.0S_h \text{, but not} > 2.0\ S_y \text{ (seismic)}$$

$$\le 1.8S_h \text{ (wind, fluid transient)}$$

Note: Stress limits of the above equation are the same limits that apply to piping without local stress (see section 4.9.3.2).

Where

S_{ml} = local primary membrane stress due to weight and occasional loads such as earthquake, wind, fluid transient

P, D, t_c, S_s, S_{oc} and S_h are defined in Section 4.10.

b) Primary plus secondary stress check

Primary plus Secondary stress check (without seismic) is not required, since gross pressure boundary integrity is all that is required for SC-III & SC-IV piping. Hence, local stress evaluation check for secondary stress (through - wall bending) is not required.

All piping stresses evaluated per Sections 7.1.1 and 7.1.2 are combined by absolute sum method.

7.2 Nozzle and Anchor Qualifications

An anchor is a rigid restraint to provide essentially complete fixation (i.e., ideally provide full constraint against three deflections and three rotations of the pipe on any of three reference axes). An equipment nozzle is not primarily designed as an anchor for the pipe and may not be designed as rigid as a structural anchor. However, it provides significant constraint in three deflections and three rotations on the pipe. Since in general the flexibility of the nozzle is not provided by the vendor, a nozzle may be considered as an anchor in the pipe stress analysis (see also Section 7.2.1.c).

A structural anchor is primarily designed to provide six way restraint. Therefore, it meets the definition of a pipe anchor in pipe stress analysis. Structural anchors are very often designed to analytically separate the pipeline from each side of the anchor. This type of anchor is called an intermediate structural anchor. The loading from both sides of the anchor shall be combined per paragraphs a) thru c) in Section 7.2.2 and applied to the design of the anchor.

7.2.1 Nozzle Qualification

a) Nozzle Load Consideration

Nozzle loads on equipment are one of the controlling parameters in the design of a piping system. Nozzle reactions are a function of the piping routing, support configuration, and operating conditions.

For vessel nozzle qualification, pipe stress engineers shall perform pipe stress analysis to demonstrate that the pipe reactions at the vessel nozzle are below the nozzle allowable loads specified in Reference 8.22 or project approved data. Nozzle load qualification for rotary equipment, such as API610/API685 pumps, shall follow their governing Codes or project approved vendor nozzle data.

b) Nozzle Load Evaluation

Pipe reaction loads are generally tabulated in the Hanger Guidance as individual weight, thermal and seismic loads and as combined design loads.

For SC-I, SC-II, SC-III(Chem) and SC-IIIE piping, the calculated pipe reaction loads shown in the Hanger Guidance should be compared with the nozzle loads provided in Reference 8.22 or project approved data, or sent to the Vessel Group for approval via Correspondence Control Number (CCN).

The nozzle loads on pressure vessels should be qualified based on the following two cases:

1. Weight + Seismic
2. Weight + Seismic + Thermal

This load combination is consistent with the WRC 107 [Ref. 8.21] method of qualifying local stresses in the vicinity of the nozzle to shell interface for primary and primary plus secondary stress. Per Engineering Specification for Pressure Vessel Design and Fabrication, 24590-WTP-3PS-MV00-T0001 [Ref. 8.22], “Seller shall design nozzles according to the methods of WRC-107, WRC-297, or finite element analysis as applicable.”

Individual weight evaluation on pressure vessels may be performed if needed.

Seismic should include seismic inertia, seismic anchor movement and dynamic transient loads, as applicable, and they may be combined by the square root of sum of squares (SRSS) per Paragraph (4) below. Per Section 3.7.5 of Reference 8.22, if the maximum operating temperature is less than 350F, the thermal loads on Table A1 thru Table A4 of Reference 8.22 must be reduced by a scale factor of |(X-70)/(350-70)|, in which X is the maximum operating temperature of the vessel. The vessel maximum operating temperature is specified on the vessel data sheet, and should be used to calculate the reduction, unless otherwise noted. In addition, each individual nozzle load (e.g. F_x, F_y, F_z, M_x, M_y, and M_z) from the analysis shall satisfy its corresponding nozzle allowable load instead of qualification by SRSS of nozzle loads, unless approved by the Pipe Stress EGS on case-by-case basis.

For non-critical SC-III(Non-Chem) and SC-IV piping with no thermal expansion/contraction and external thermal anchor movement concerns, connecting to any non-safety vessels or sumps, routed and supported per the "Span and Support Load Tables", and accepted by a pipe stress engineer, the nozzles may be considered as acceptable.

If the pipe reactions do not meet the nozzle allowable, the following are some approaches to reduce the nozzle loads:

(1) Using pipe maximum operating temperature to qualify the nozzle load instead of the design temperature.

(2) Consider nozzle flexibility in ME101. This is to include the vessel shell stiffness to reduce the rigidity of the anchor and, therefore, reduce the nozzle loads. Nozzle stiffness values may be obtained from WTP Mechanical Vessel Group or utilizing ME101 capability to extract the vessel shell stiffness.

(3) Using expansion joints to reduce nozzle loads. However, expansion joints are not suitable for all service conditions. In some cases, it is more desirable to add an expansion loop or modify the support types and/or support locations. Expansion joints may be used only in accessible areas (not in Black Cells, for example).

(4) The pipe reaction loads with signs such as due to weight and thermal expansion should be combined algebraically. The loads due to seismic inertia, seismic anchor movement and dynamic transient loads should be combined by the square root of sum of squares (SRSS) first, then combined absolutely with the loads with signs.

(5) The nozzle thermal loads can be reduced by the use of hot modulus of elasticity (E_h) as ME101 loads are calculated based on the cold modulus of elasticity (E_c).

(6) Reduce thermal load by modeling the first dead weight support inactive in hot condition if the net movement (thermal plus weight) is upward. It may be necessary to run two weight cases: one for cold condition in which all gravity supports are active, and another case for hot condition in which any gravity

supports with net upward movement are considered inactive. The enveloped results of these two weight cases will be used for Code compliance.

(7) If the calculated nozzle loads are still above the nozzle allowable, the loads should be submitted to the Mechanical Vessel Group via CCN for review and approval.

c) Interface with Flexible Equipment

SC-I and SC-II piping is analyzed using in-structure response spectra from the building. However, if the equipment to which the piping is attached is flexible, then the equipment itself will also amplify the seismic motion. Equipment is considered flexible if the fundamental frequency is less than 33Hz (horizontal) or 50 Hz (vertical) This amplification has to be addressed in the piping stress analysis (Section 3.2.3.1 and 3.1.7.1 of Ref. 8.56, Section 7.2.2.2.2 of Ref 8.7, and Ref 8.65).

For SC-I and SC-II piping attached to flexible equipment one of the following approaches should be used (Ref. 8.19, Appendix L 4.3):

1. A simplified model of the equipment, provided by the Plant Equipment Group, may be included in the ME101 model. The simplified model should approximate the dynamic characteristics of the equipment.
2. If spectra are available at the attachment point (nozzle) of the piping to the equipment, then those spectra may be used with the building spectra.
3. If the fundamental frequency is not available, then assume that the equipment is flexible, and follow the guidance in Design Guide 24590-WTP-GPG-ENG-0144 Ref. 8.69 for flexible equipment and document it as an assumption in Section 6 of the stress calculation. The assumption that the fundamental frequency is less than 33 Hz (horizontal) or 50 Hz (vertical) is conservative.
4. If the equipment is considered flexible, but neither a simplified model nor equipment spectra are available, then follow the guidance provided in Design Guide 24590-WTP-GPG-ENG-0144 Ref. 8.69

Note that for piping analyzed in accordance with SC-III or SC-IV, there is no need to address the equipment as flexible. The piping seismic loads and stresses are analyzed in accordance with UBC Code (static seismic), which considers only the building seismic motion.

7.2.2 Anchor Qualifications

The main purpose of an anchor is to provide a complete fixation for the pipe system. Therefore, it shall be designed to meet the specified pipe reaction loads as required.

An intermediate anchor has the pipe reaction loads from both sides of the anchor; therefore, the loading combination for the intermediate anchor is determined as follows:

a) The pipe reaction loads with signs such as due to weight and thermal effects from both sides of the anchor may be combined algebraically for the design of anchor structure.

b) The pipe reaction loads without signs due to seismic inertia, seismic anchor movement and dynamic transient loads may be combined by the square root of sum of the squares (SRSS) from both sides. These loads are then combined by absolute sum with the other pipe reaction loads with signs for the design of anchor structure.

c) All the above combinations should be performed on the force component and moment component levels.

d). Intermediate anchors for SC-III(Non-Chem) and SC-IV piping may be designed based on the nozzle load tables specified in Appendix 3, multiplying the loads by two.

e). For an intermediate anchor that has analyzed loads from one side and the other side is non-analyzed pipe, the loading combination is determined in one of the following three ways:

- To obtain non-analyzed pipe reaction load, use nozzle load table specified in Appendix 3 and follow the provisions of a) thru c) of Section 7.2.2 to combine the loads with analyzed side loads.
- Include portion of the non-analyzed pipe as overlap in the analysis and qualify overlapped supports for greater of analyzed/Span table loads. The overlap portion should include at least two supports in each direction of restraint, i.e., X, Y and Z direction restraints.
- For non-analyzed pipe use the same reaction loads as the analyzed side pipe and follow the provisions of a) thru c) of Section 7.2.2 to combine the loads if judged acceptable by Pipe Stress and Support EGS.

7.3 Dynamic Transient Forces on Closed Discharge Piping Systems

Pipe loads may be caused by the events due to transient fluid flow in closed discharge piping systems. A fluid flow transient is often initiated by intentional actuation of some flow control device (pump, valve, or rupture disc). The pipe stress engineer should pay attention to the following three types of fluid transient forces if applicable:

(1) Transient unbalanced thrust load along the pipe run axis, tending to forcibly displace the pipe and to set up pipe vibrations.

(2) Continually oscillating periodic force along any surface of the pipe tending to set up steady state resonance vibrations.

(3) Transient pressure change tending to either burst or collapse the pipe.

Of these three forces, the first type is by far the most common dynamic problem for design, and the attention of this Subsection will be directed toward that problem. The piping systems that have this type of transient unbalanced thrust load are required to be identified by Mechanical Systems engineers. Design calculations of dynamic transient forcing functions normally are required to be generated by qualified fluid transient analysts using specialized computer programs. The time history fluid dynamic transient forcing functions are then provided to the pipe stress analysts for piping structural analysis using ME101. The pipe stresses due to fluid dynamic transient forcing functions shall be combined with earthquake load or wind load using SRSS method and considered as S_{oc} per Section 4.9.3.

7.4 Welding Tee

Either ASME B16.9-1986 welding tees that meet the requirements of ASME B31.3-1996 or ASME B16.9-1993 welding tees that meet the requirements of ASME B31.3-2002 are permitted in the RPP-WTP project per Appendix C, Section 26.0 of the SRD [Ref 8.19]. The SRD also provides the requirements to meet the stress limits in accordance with the ASME B16.9 welding tees specified in ASME B31.3-2002 [Ref 8.42]. Per the SRD, the flexibility characteristic and stress intensification factors for ASME B16.9 welding tees shall be per Table D300 of the ASME B31.3-2002 Code [Ref 8.42]. A pipe stress engineer may either manually input the SIF based on the flexibility characteristic, or use TEE=EXTEE, and specify RX=2.1r_2, where r_2 is the mean radius of the run pipe.

If $r_x \geq 1/8D_b$ and $T_c \geq 1.5T$, a flexibility characteristic of $4.4T/r_2$ may be used in accordance with ASME B31.3-2002, where T is the nominal wall thickness of the matching pipe; r_2 is mean radius of matching pipe; r_x is radius of curvature of external contoured portion of outlet, measured in the plane containing the axes of the header and branch; T_c is the crotch thickness of tees; D_b is outside diameter of branch.

7.5 Piping with $D_o/t_c > 50$

For B31.3 piping with outside diameter to thickness ratio (D_o/t_c) greater than 50, the eroded/corroded section modulus Z_c used to calculate bending stresses, M/Z_c shall be replaced by $(1.3\text{-}0.006\ D_o/t_c)Z_c$, where D_o is outside diameter and t_c is the pipe eroded/corroded thickness. In order to fulfill this requirement for the pipe with D_o/t_c greater than 50, the pipe stress engineer should either calculate the bending stresses with $(1.3\text{-}0.006\ D_o/t_c)Z_c$ or conservatively adjust the stress ratio from ME101 output by a factor of $1/(1.3\text{-}0.006\ D_o/t_c)$.

7.6 Black Cell / Hard-to-Reach Piping Systems

Piping within the black cells and Hard-to-Reach areas shall be analyzed to Seismic category I (SC-I) requirements, per the Basis of Design [Ref 8.48, Section 16.4.2.7].

Black Cell Piping – All piping and tubing within the black cell up to the first weld outside the black cell. (See Figure 1.) The room numbers of the black cells, located in the PT and HLW facilities are:

Room Numbers P-0102, P-0102A, P-0104, P-0106, P-0108, P-0108A, P-0108B, P-0108C, P-0109, P-0111, P-0112, P-0113, P-0114, P-0117, and P-0117A in the PT Building

Room numbers H-B005, H-B014, and H-B021 in the HLW Building

Hard-to-Reach Areas – Facility areas located in the rooms listed below where piping and equipment is not designed for manual or remote access, replacement, or repair.

PTF Facility Rooms P-B001, P-B001A, P-B002, P-B003, P-B004, P-0123 (piping out to jumper nozzles), P-0123 (components above crane), P-0123A (components above crane), P-0335 (components out of reach of crane and below the filter deck), and P-0335A (components out of reach of crane and below the filter deck).

HLW Facility Rooms H-B005A, H-B032, H-B015, HCH14, HCH15, H-0104 (components out of reach of crane and below filter deck), H-0115, H-0121, H-0136 (components out of reach of crane or below canister racks or weld table), and H-0302, H-0308.

All-welded construction shall be used for piping. With the exception of socket welded thermowell nozzle connections, socket welded branch fittings on outer jacket pipe drains used in dual containment piping systems, and the threaded black cell liner spray nozzle connections, which will be tack welded or mechanically secured so that they will not back out, there shall be no flanged, socket welded or threaded connections in the black cells. For black cell and hard-to-reach components, there shall be no non-removable soft or non-metallic parts that could be affected by high radiation doses.

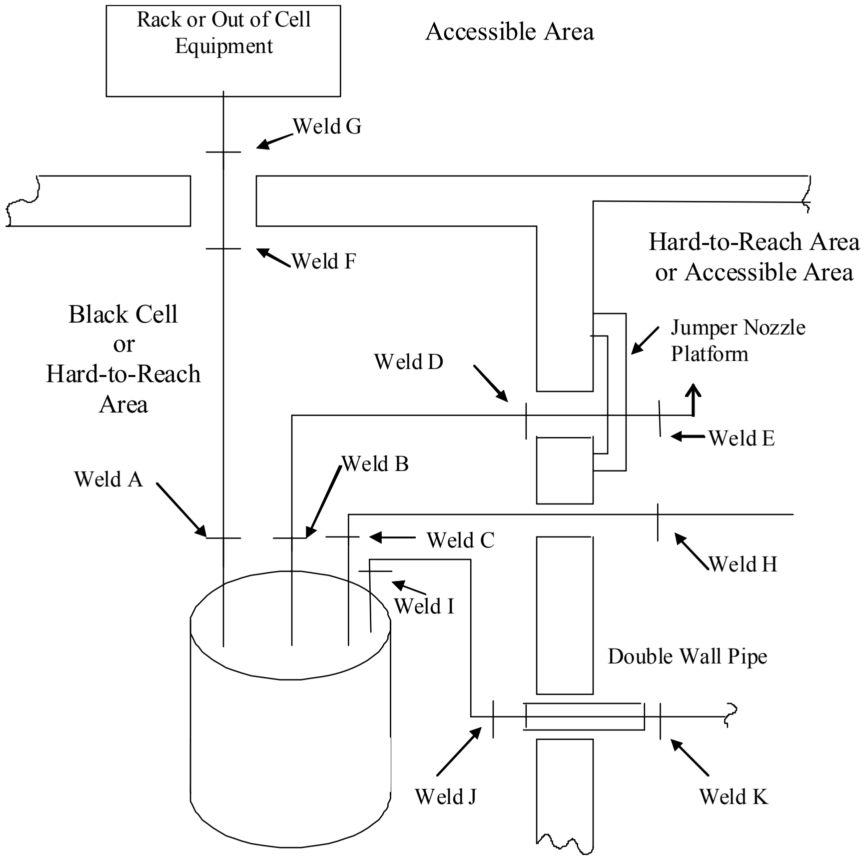

Figure 1: Example of Black Cell and Component Piping

Black cell piping extends between termination welds. Examples include the piping and welds extending from Weld A to Weld G, from Weld B to Weld E, from Weld C to Weld H, and Weld I to Weld K.

The piping procured as part of equipment and penetrating the black cell or hard-to-reach area walls shall meet the same design, fabrication, construction, testing, and inspection requirements as the black cell piping to which it attaches out to the first weld outside of a black cell or a hard-to-reach area. An example is the component piping between Weld F and Weld G, and Weld J to K.

The piping procured as part of a jumper platform (Frame) and penetrating the black cell wall shall meet the same design, fabrication, construction, testing, and inspection requirements as the black cell or hard-to-reach piping to which it attaches out to the first weld outside of the black cell or hard-to-reach area. An example of this is the piping between Weld D and Weld E.

Hard-to-reach piping includes pipe spools extending from a field weld inside the hard-to-reach area across a wall or slab out to the first accessible field weld out in an R2/R3 area; see Table 5-1 of 24590-WTP-DB-ENG-01-001 [Ref 8.48] for definition of R1 through R5. Examples include the piping and welds extending from Weld A to Weld G and Weld C to Weld H.

7.7 Piping Two over One Protection

The requirements for seismic interaction analysis/classification are provided in Reference 8.19, safety criterion 4.1-3.

Piping shall be analyzed to the minimum seismic requirement above when a two over one protection issue is identified via hazards reviews.

7.8 Jumpers

The jumper piping system design shall comply with the requirements of Jumper Stress Design Criteria, 24590-WTP-DC-PS-03-001 [Ref 8.70].

Note that a "Jumper" is a remotely removable assembly consisting of piping, dunnage, remote end connectors and in some cases in-line components such as valves or instruments.

7.9 Pipe Break (To be determined)

7.10 Wind Missile (To be determined)

7.11 Hydrogen In Pipes And Ancillary Vessels (HPAV)

1. The design requirements and acceptance criteria to qualify the pipe stress for HPAV (Hydrogen in Piping and Ancillary Vessels) loading are provided in 24590-WTP-BODCN-ENG-10-0001 [Ref 8.71].

2. HPAV - Stress Analysis Design Guide 24590-WTP-GPG-ENG-0143 [Ref 8.72] provides specific guidance for pipe stress analysts to model and qualify piping.

   Note: At the present time the above documents address the piping located in the pretreatment facility (PT). Design requirements for the HLW facility are to be determined.

3. Load Combinations for Pipe Supports due to HPAV loading

   If the total number of deflagrations $N \geq 1000$
   Normal Operating Loads: Larger of (Weight or Weight plus Thermal) plus Abs(Fdef)
   Occasional Loads – Normal Operating + Abs(Fdet)

   If the total number of deflagrations $N < 1000$
   Normal Operating Loads: Larger of (Weight or Weight plus Thermal)
   Occasional Loads – Normal Operating + Abs(Fdef) or
   Occasional Loads – Normal Operating + Abs(Fdet)

Notes:

1 That for the Occasional loads. The loading is an "OR". That is, neither deflagration nor detonation loads are considered concurrent with either earthquake, wind, or other fluid transient loads, nor are they concurrent with each other.
2. Abs(Fdef) Absolute loads due to deflagration
3. Abs(Fdet) Absolute loads due to detonation/R-DDT load
4. Vertical supports on HPAV affected piping must be designed as double-acting, regardless of whether the HPAV load overcomes the deadweight.
5. See Stress Analysis Design Guide 24590-WTP-GPG-ENG-0143 [Ref 8.72] for more details and definition of deflagration and detonation/R-DDT load

7.12 Buried Pipe

For the analysis of buried pipe, the recommendations of ASCE 4-98 Section 3.5.2 [Ref 8.56] will be followed

8 References

8.1. ASME B31.3 Code, Process Piping, 1996 Edition, ASME Code For Pressure Piping, B31 An American National Standard, The American Society of Mechanical Engineers, New York, NY

8.2. DOE-STD-1020-94 including Change Notice #1 dated January 1996, Natural Phenomena Hazards and Evaluation Criteria for Department of Energy Facilities, U.S. Department of Energy, Washington, DC

8.3. Engineering Calculations, 24590-WTP-3DP-G04B-00037, Rev. 18

8.4. ASME Boiler and Pressure Vessel Code: Section II Part D, 1995 Edition; Section III Division 1, 1995 Edition, Rules for Construction of Nuclear Facility Components, Subsection NC; Section VIII Division 2, 1995 Edition, The American Society of Mechanical Engineers, New York, NY

8.5. Uniform Building Code (UBC), 1997 Edition, International Conference of Building Officials, Whittier, CA

8.6. ASME B16.5 1988 Edition, Pipe Flanges and Flanged Fittings, The American Society of Mechanical Engineers, New York, NY

8.7. Seismic Analysis and Design Criteria, 24590-WTP-DC-ST-04-001, Rev. 3A

8.8. Not used

8.9. ASCE 7-98, Minimum Design Loads for Buildings and Other Structures

8.10. Not used

8.11. Not used

8.12. Not Used

8.13. Not Used

8.14. Not Used

8.15. Pipe Stress Backup Calculation, 24590-WTP-P6C-P40T-00001, Rev. 0. (including ECCN: 24590-WTP-P6E-P40T-00001)

8.16. Manual of Steel Construction, Allowable Stress Design, AISC ASD, Ninth Edition, American Institute of Steel Construction, Inc., Chicago, IL

8.17. Development and Management of Levels A, B, C, and D Software for Plant, 24590-WTP-GPP-SQP-202, Rev 0

8.18. Not used

8.19. Safety Requirements Document Volume II, 24590-WTP-SRD-ESH-01-001-02, Rev. 5aa

8.20. Automation Work Process for Pipe Stress Analysis and Support Design, 24590-WTP-GPG-ENG-034, Rev. 5

8.21. WRC-107, Local Stresses in Spherical and Cylindrical Shells due to External Loadings, Welding Research Council Bulletin 107, March 1979 Revision, New York, NY; WRC-297, Local Stresses in Cylindrical Shells Due to External Loadings on Nozzles Supplement to WRC Bulletin No. 107, August 1984 revised September 1987, New York, NY

8.22. Engineering Specification for Pressure Vessel Design and Fabrication, 24590-WTP-3PS-MV00-T0001, Rev 4
8.23. Not used
8.24. Not used
8.25. Not used
8.26. Not used
8.27. Sustained and Occasional Stress Checks of Span Tables for (1) Reduced Weight and Reduced Wall Thickness and (2) Nominal Weight and Reduced Wall Thickness, 24590-WTP-P6C-P40T-00008, Rev. A
8.28. Not used
8.29. HLW Vitrification Building Seismic Analysis: Seismic Displacements, 24590-HLW-S0C-S15T-00029, Rev. C
8.30. Pretreatment Facility Seismic Analysis: Seismic Displacements, 24590-PTF-S0C-S15T-00040, Rev. C
8.31. HLW In-Structure Response Spectra (ISRS) Conversion, 24590-HLW-P6C-P40T-00003, Rev. C. (including ECCN: 24590-HLW-P6E-P40T-00001)
8.32. PTF In-Structure Response Spectra (ISRS) Conversion, 24590-PTF-P6C-P40-00001, Rev. B
8.33. Not Used
8.34. Not Used
8.35. Not Used
8.36. Not Used
8.37. Not Used
8.38. Preliminary Documented Safety Analysis to Support Construction Authorization; General Information, 24590-WTP-PSAR-ESH-01-002-01, Rev **4R**
8.39. Not Used
8.40. Not Used
8.41. Isometric Drawings and Associated Calculations, 24590-WTP-3DP-G04T-00906, Rev. 8
8.42. ASME B31.3 Code, Process Piping, 2002 Edition, American Society of Mechanical Engineers, New York, NY
8.43. CCN 085280, ME101 Input CODE
8.44. Interpretations No. 1 to ANSI/ASME B31.3, Interpretation 1-34, "Appendix D on Stress Intensification Factors", Interpretations Issued January 1, 1980 through December 31, 1982, The American Society of Mechanical Engineers, New York, NY
8.45. Not Used
8.46. Design Guide: Pipe Support, 24590-WTP-GPG-ENG-005, Rev 4E
8.47. Not Used
8.48. Basis of Design, 24590-WTP-DB-ENG-01-001, Rev **1Q**
8.49. N-392-3, Procedure for Evaluation of the Design of Hollow Circular Cross Section Welded Attachments on Classes 2 and 3 Piping, Section III, Division 1, The American Society of Mechanical Engineers, New York, NY
8.50. N-318-5, Procedure for Evaluation of the Design of Rectangular Cross Section Welded Attachments on Class 2 or 3 Piping, Section III, Division 1, The American Society of Mechanical Engineers, New York, NY
8.51. Not Used
8.52. Not Used

8.53. Piping Wall Thickness Calculation, 24590-WTP-P0C-50-00001, Rev D
8.54. Calculation To Verify Adequacy Of Pipe Wall Under External Pressure, 24590-WTP-P0C-50-00002, Rev C. (including ECCN: 24590-WTP-P0E-50-00002)
8.55. ME101 Linear Elastic Analysis of Piping, Version N8
8.56. ASCE 4-98, Seismic Analysis of Safety - Related Nuclear Structures and Commentary.
8.57. Design Guide: Pipe Stress, Pipe Layout and Support Spacing, 24590-WTP-GPG-ENG-004, Rev 2A
8.58. Pipe Stress- Lug Local Stress Evaluation - Backup Calculation, 24590-WTP-P6C-P40T-00013, Rev 0
8.59. B31 Case 178, Providing an Equation for Longitudinal Stress for Sustained Loads in ASME B31.3 Construction, approved May 6th, 2005, American Society of Mechanical Engineers, New York, NY
8.60. IEEE 382-1996, IEEE Standard for Qualification of Actuators for Power-Operated Valve Assemblies With Safety-Related Functions for Nuclear Power Plants
8.61. Final Report Geotechnical Investigation River Protection Project – Waste Treatment Plant, Shannon & Wilson, Inc., May, 2000, WTSC99-1036-42-17, Rev C
8.62. ME101 Wind load design parameter - Backup Calculation, 24590-WTP-P6C-P40T-00015, Rev. 0
8.63. Not Used
8.64. Evaluation Of The Bolting And Flanges Of ANSI B16.5 Flanged Joint – ASME Design Rules, E. C. Rodabaugh and S.E. Moore, ORNL/Sub/2913-3, Septmeber 30, 1976
8.65. Seismic Classification and Evaluation for the Pretreatment Facility Piping and Vessels, 24590-WTP-RPT-ENG-09-040, Rev 0
8.66. Alignment of Piping Design Requirements With PDSA Addendum Revision For Seismic Changes, Basis of Design Change Notice 24590-WTP-BODCN-ENG-09-0020
8.67. SC-IIIE Piping - Stress Analysis Design Guide, 24590-WTP-GPG-ENG-0145, Rev 0
8.68. Comparison of HLW to PTF Vessel Characteristics for Dynamic Analysis, 24590-HLW-ES-PEQ-10-001, Rev 0
8.69. Piping Interface with Flexible Equipment -Stress Analysis Design Guide, 24590-WTP-GPG-ENG-0144, Rev 0
8.70. Jumper Stress Design Criteria, 24590-WTP-DC-PS-03-001, Rev 1
8.71. HPAV Analysis and Design Criteria, 24590-WTP-BODCN-ENG-10-0001
8.72. HPAV-Stress Analysis Design Guide, 24590-WTP-GPG-ENG-0143, Rev 0
8.73. Reduction factors for piping span due to insulation and or SPG greater than 1, 24590-WTP-P6C-P40T-00026, Rev 0
8.74. Use of Room EEQ Data for Seismic Qualification, 24590-WTP-RPT-M-09-006, Rev 0
8.75. Environmental Room Temperature Impact on Pipe Stress Analysis, 24590-WTP-RPT-ENG-11-153, Rev 0

9 Appendices

9.1 APPENDIX 1, Span Method Criteria

Design Basis of Span and Support Load Tables

DESIGN BASIS OF SPAN AND SUPPORT LOAD TABLES FOR WEIGHT AND SEISMIC LOADS

1.0 Introduction

A piping system is normally supported by a series of supports, dividing the system into a series of continuous spans. The spans of the piping system are limited by

1) Vertical supports for pipe weight; and

2) Two mutually perpendicular restraints to the pipe
- At each change of direction,
- At all concentrated masses,
- At each tee, or
- At the maximum spacing on straight runs of piping

This document is to establish the piping design criteria to meet the ASME B31.3 Code requirements and to provide the methodology to determine the maximum support spans and their support loads under such design conditions.

2.0 Weight Spans

a. General

The end condition of a pipe span for a pipe system under a series of supports is approximately between the fixed end and the simply supported end. The maximum deflection, bending moment and support load of pipe span with these end conditions under uniformly distributed load are the average of the values from equations of Case 1 [Ref 8.16, Page 2-296] and Case 15 [Ref 8.16, Page 2-301] and expressed below:

Deflection (Δ) = $\frac{1}{2}\left[(5wL^4/384EI) + (wL^4/384EI)\right] = 3wL^4/384EI$

Moment load (M) = $\frac{1}{2}\left[(wL^2/8) + (wL^2/12)\right] = 5wL^2/48$

Support load (R) = wL

Where
w = pipe weight per unit length
L = maximum pipe span between two supports
I = moment of inertia of the pipe
E = modulus of elasticity

b. Criteria

The following is the basic criteria to develop the weight spans for SC-III(Non-Chem), and SC-IV piping components:

1. Limit the maximum deflection of a pipe span ≤ ¼ inch, or limit the pipe stress due to weight load to σ_w whichever provides the shortest span length.

   $\Delta = 3wL^4/384EI \le$ ¼ inch, or

   $M = 5wL^2/48 \le \sigma_w Z/i$ (or $iM/Z \le \sigma_w$, psi)

   Where
   σ_w = Pipe stress due to weight load
   Z = Section Modulus

   in which, σ_w ranges from 2,600 psi to 3,550 psi for carbon steel pipe, and 2,000 psi to 2,950 psi for stainless pipe. A lateral seismic restraint is required at every, every second, or every third dead weight support.

   Refer to Section 4.10.2 of this criteria for considering the mechanical / erosion / corrosion allowances.

2. Limit the internal pressure to 400 psi for pipe schedules 40 and 80, and 200 psi for schedules 10 and 20.

3. Stress intensification factor (SIF or *i*) per ASME B31.3 Code as follows:

   SIF (or *i*) = 1.3 for fillet welds for pipe sizes 2" and below. (*)

   SIF (or *i*) = 1.0 for butt welds for pipe sizes above 2 inch.

   (*) Per Appendix D of B31.3 Code[Ref 8.1], for fillet weld joint, or socket weld flange or fitting, *i*=2.1 (SIF) or $i = 2.1 \cdot T / C_x$ but not less than 1.3. C_x is the fillet weld length identified in paragraph 328.5.2C of [Ref 8.1], and is $1.25 \cdot T$ minimum but not less than 1/8″. For longitudinal stress by sustained loads and occasional loads, the use of $0.75 \cdot i$ is acceptable [Ref 8.44]. Therefore, $i = 0.75 \cdot 2.1 \cdot (T / 1.25 \cdot T) = 1.26$, use 1.3.

4. The weight spans and support loads in the Span and Support Load Tables are determined as follows:

   Weight Span, L is equal to the lesser of $L_1 = ({}^1/_4 \cdot 384EI/3w)^{1/4}$ or $L_2 = (\sigma_w \cdot 48Z/5iw)^{1/2}$
   Support Load due to weight, $R = wL$

3.0 Deleted

4.0 Seismic Spans based on the Uniform Building Code (SC-III(Non-Chem) and SC-IV Piping components)

For SC-III without containing a significant Chemical release hazard (SC-III(Non- Chem)) and SC-IV piping components, the seismic spans are developed based on Section 7.3.4 of Seismic Analysis and Design Criteria [Ref 8.7]. The lateral seismic force on systems and piping components, F_p, is calculated per Formula (32-1) of the UBC Code, i.e.,

$$F_p = 4.0\, C_a\, I_p\, W_p = 1.44\, W_p$$

For vertical seismic force, $F_v = {}^2/_3 F_p = 0.96\, W_p$

where

- W_p = the weight per unit length of piping component
- C_a = 0.24
- I_p = the importance factor, shall be taken as 1.5 for SC-III piping and 1.0 for SC-IV piping [see Section 7.3.4 of Reference 8.7].
- M_h = $5F_pL_h^2/48$ where L_h is the distance between lateral restraints
- M_v = $5F_vL_v^2/48$ where L_v is the distance between vertical restraints
- R_h = F_pL_h
- R_v = F_vL_v
- M = $(M_h^2 + M_v^2)^{1/2}$

The stress for SC-III and SC-IV piping components is calculated as follows:

$$\frac{PD}{4t_n} + \text{weight stress} + i\frac{M}{Z} \leq 3.0S_h\text{, but not greater than } 2.0S_y.$$

where

- t_n = pipe nominal wall thickness
- Z = pipe section modulus based on nominal wall thickness

The dead weight supports for SC-III(Non-Chem) or SC-IV piping are not always designed as double-acting supports. To account for that, the seismic span (L) is developed conservatively based on the same span for calculation of horizontal and vertical moments. Therefore, the seismic spans and seismic support loads for SC-III without containing a significant Chemical release hazard SC-III(Non-Chem) and SC-IV piping in Span Tables are determined as follows:

$$L \leq \sqrt{\left(3.0S_h - \frac{PD}{4t_n} - weight\_stress\right)\frac{Z}{i\sqrt{(1.44w)^2 + (0.96w)^2}}\frac{48}{5}}$$

where

weight stress, $\sigma_w = 5iwL^2/48Z$

S_h = 20,000 psi for carbon steel, and S_h =16,700 psi for stainless steel
$R_h = 1.44 W_p L$ for lateral UBC seismic loads
$R_v = 0.96 \cdot W_p L$ for vertical UBC seismic loads

1" thickness of insulation with an assumed density of 8 lb/ft^3 for pipe 1-1/2 inch and under and 2" thickness of insulation for pipe 2 inch and above has been included into pipe weight to develop the "Span and Support Load Tables". For the backup calculation for the "Span and Support Load Tables" see Reference 8.15. For pipe insulation density other than 8 lb/ft^3, the span and support load should be adjusted based on the formula specified in "limitations 5" under Tables 2.2 and 2.4. Refer to Reference 8.15 for more detailed development of "Span and Support Load Table" if needed.

Refer to Section 4.10.2 of this criteria for considering the mechanical / erosion / corrosion allowances. The span tables listed in Appendix 2 comply with project requirements for mechanical / erosion / corrosion allowances as documented in calculation 24590-WTP-P6C-P40T-00008 [Ref 8.27].

5.0 Span Tables Seismic Load Reduction Factor based on the Uniform Building Code (SC-III(Non-Chem) and SC-IV Piping components)

Section 3.3.4.b permits the use of UBC formula 32-2 for calculating the seismic loads and stresses for SC-III & SC-IV piping, which results in reduction of applied seismic acceleration on the piping and seismic support load.

Tables 2-2 and 2-4 are based on maximum horizontal acceleration of 1.44g and vertical acceleration of 0.96g based on maximum seismic acceleration [g] in Formula 32-2 of the UBC code as follow → $4C_a I_p$

Table 1-1 Seismic Load Reduction Factor for SC-III(Non-Chem) support loads, Ductile failure

Build.	Roof Elev	Floor Elev	Minimum Horizontal Accl.	Horizontal Accl.	Vertical Accl.	Reduction Factor Horizontal	Reduction Factor Vertical
	[ft]	[ft]	(1)	(2)	(3)	(4)	(5)
PTF	98	98	0.252	1.200	0.8	0.84	0.92
		77	0.252	1.007	0.68	0.7	0.86
		56	0.252	0.814	0.55	0.57	0.8
		28	0.252	0.557	0.38	0.39	0.7
		0	0.252	0.300	0.2	0.21	0.62
HLW	89	89	0.252	1.200	0.8	0.84	0.92
		72	0.252	1.028	0.69	0.72	0.87
		58	0.252	0.887	0.6	0.62	0.82
		37	0.252	0.674	0.45	0.47	0.74
		14	0.252	0.442	0.3	0.31	0.67
		0	0.252	0.300	0.2	0.21	0.62
LAW	68	68	0.252	1.200	0.8	0.84	0.92
		48	0.252	0.935	0.63	0.65	0.83
		28	0.252	0.671	0.45	0.47	0.74
		3	0.252	0.340	0.23	0.24	0.63
LAB	35	35	0.252	1.200	0.8	0.84	0.92
		17	0.252	0.737	0.5	0.52	0.77
		0	0.252	0.300	0.2	0.21	0.62

Notes:

(1) UBC Formula 32-2 minimum seismic acceleration [g] as follows: $0.7C_a I_p$

(2) UBC Formula 32-2 for seismic acceleration [g] as follows: $\frac{a_p C_a I_p}{R_p}\left(1+3\frac{h_x}{h_r}\right) \le 4C_a I_p$

Note that I_p for SC-III is 1.5 and R_p for ductile failure is 3; all other coefficients are defined in section 4.5.2

(3) Vertical seismic acceleration is 2/3 the lateral acceleration (see section 4.5.2)

(4) Horizontal seismic load reduction factor: this factor should be applied for supports design loads per Span Tables 2-2 and 2-4 of this criteria, horizontal direction only

(5) Vertical seismic load reduction factor: based on gravity + vertical seismic acceleration over 1.96g. This factor should be applied for supports design loads per Span Tables 2-2 and 2-4 of this criteria.

Table 1-2 Seismic Load Reduction Factor for SC-IV support loads, Ductile failure

Build.	Roof Elev	Floor Elev	Minimum Horizontal. Accl.	Horizontal Accl.	Vertical Accl.	Reduction Factor Horizontal	Reduction Factor Vertical
	[ft]	[ft]	(1)	(2)	(3)	(4)	(5)
PTF	98	98	0.168	0.800	0.54	0.56	0.79
		77	0.168	0.671	0.45	0.47	0.74
		56	0.168	0.543	0.37	0.38	0.7
		28	0.168	0.371	0.25	0.26	0.64
		0	0.168	0.200	0.14	0.14	0.58
HLW	89	89	0.168	0.800	0.54	0.56	0.79
		72	0.168	0.685	0.46	0.48	0.75
		58	0.168	0.591	0.4	0.41	0.72
		37	0.168	0.449	0.3	0.32	0.67
		14	0.168	0.294	0.2	0.21	0.61
		0	0.168	0.200	0.14	0.14	0.58
LAW	68	68	0.168	0.800	0.54	0.56	0.79
		48	0.168	0.624	0.42	0.44	0.73
		28	0.168	0.447	0.3	0.32	0.67
		3	0.168	0.226	0.16	0.16	0.59
LAB	35	35	0.168	0.800	0.54	0.56	0.79
		17	0.168	0.491	0.33	0.35	0.68
		0	0.168	0.200	0.14	0.14	0.58

Notes:

(1) UBC Formula 32-2 minimum seismic acceleration [*g*] as follows: $F_p \geq 0.7 C_a I_p W_p$

(2) UBC Formula 32-2 for seismic acceleration [*g*] as follows: $\frac{a_p C_a I_p}{R_p}\left(1 + 3\frac{h_x}{h_r}\right) \leq 4 C_a I_p$

Note that I_p for SC-IV is 1.0 and R_p for ductile failure is 3, all other coefficients are defined in section 4.5.2

(3) Vertical seismic acceleration is 2/3 the lateral acceleration, see section 4.5.2

(4) Horizontal seismic load reduction factor: this factor should be applied for supports design loads per Span Tables 2-2 and 2-4 of this criteria, horizontal direction only

(5) Vertical seismic load reduction factor: based on gravity + vertical seismic acceleration over 1.96*g*. This factor should be applied for vertical supports design loads per Span Tables 2-2 and 2-4 of this criteria.

9.2 APPENDIX 2, Span and Support Load Tables

1) **Table 2.1 - Deleted**
2) **Table 2.2 - Span and Support Loads for SC-III(Non-Chem) and SC-IV C. S. Piping (For Mechanical / Erosion / Corrosion Allowances ≥ 50% of The Nominal Wall Thickness, See Section 4.10.2)**
3) **Table 2.3 -Deleted**
4) **Table 2.4 - Span and Support Loads for SC-III(Non-Chem) and SC-IV S. S. Piping (For Mechanical / Erosion / Corrosion Allowances ≥ 50% of The Nominal Wall Thickness, See Section 4.10.2)**

TABLE 2. 1 – Span and Support Loads for SC-I, SC-II, and SC-III(Chem) C. S. Piping (For Reference Use)

Deleted

TABLE 2. 2 – Span and Support Loads for SC-III(Non-Chem) and SC-IV C. S. Piping
(For Mechanical / Erosion / Corrosion Allowances ≥ 50% 0f The Nominal Wall Thickness, See Section 4.10.2)

A). Lateral Seismic Support at Every Third Weight Span

pipe size	sch	Weight Span		Seismic Span		Support Loads (lbs)			
		ft	ft	ft	ft	Weight		Seismic	
		Empty	w/ water	Empty	w/ water	empty	w/ water	empty	w/ water
3/8 in	40	7.7	7.3	23.0	22.1	7	7	30	32
	80	7.8	7.6	23.4	22.8	8	9	36	37
1/2 in	40	9.2	8.7	27.7	26.3	11	11	47	50
	80	9.2	8.9	27.9	26.9	13	14	57	59
3/4 in	40	10.7	10.1	32.7	30.3	15	17	68	73
	80	10.7	10.4	32.9	31.2	19	20	85	89
1 in	40	12.1	11.3	36.7	33.9	26	28	113	122
	80	12.0	11.6	37.0	35.0	32	34	140	148
1-1/2 in	40	14.9	13.5	46.1	40.8	48	56	216	243
	80	14.8	14.1	46.5	42.6	62	69	279	303
2 in	40	15.6	13.8	46.8	41.5	83	93	358	404
	80	16.0	14.7	48.5	44.4	107	117	466	509
2-1/2 in	40	17.8	16.8	60.8	53.9	141	168	696	779
	80	17.8	17.1	62.3	57.0	175	199	881	958
3 in	40	20.1	18.7	70.2	60.5	192	239	967	1113
	80	20.1	19.1	71.6	64.3	246	289	1262	1398
4 in	40	23.1	21.2	81.3	67.9	303	395	1538	1824
	80	23.1	21.7	82.9	72.8	401	485	2068	2339
6 in	40	28.5	25.5	101.1	80.3	628	880	3211	3997
	80	28.5	26.4	103.2	88.2	903	1135	4702	5457
8 in	20	32.7	28.0	116.5	84.7	855	1360	4387	5933
	40	32.8	28.9	116.9	89.8	1061	1559	5443	6989
	80	32.8	30.1	119.1	99.5	1548	2013	8090	9599
10 in	20	36.6	29.5	130.0	89.1	1198	2024	6130	8796
	40	36.8	32.0	131.4	98.5	1664	2536	8548	11240
	80	36.8	33.5	133.9	110.7	2540	3357	13314	15963
12 in	20	40.0	30.7	141.7	92.3	1551	2759	7917	11949
	40	40.3	34.7	144.0	105.8	2375	3725	12222	16369
	80	40.2	36.5	146.7	120.5	3777	5038	19849	23941
14 in	10	42.1	31.3	149.1	94.0	1774	3269	9060	14123
	20	42.2	33.6	151.4	101.4	2160	3768	11155	16365
	40	42.4	36.3	151.8	110.6	2916	4630	15048	20315
	80	42.2	38.3	154.5	126.5	4714	6315	24829	30032
16 in	10	45.0	31.9	159.2	96.2	2171	4150	11054	18003
	20	45.2	34.4	161.8	104.1	2646	4775	13635	20839
	40	45.4	38.9	163.3	118.7	4039	6433	20910	28287
	80	45.2	41.0	165.7	135.2	6452	8696	34033	41327
18 in	10	47.8	32.6	168.6	97.8	2594	5165	13164	22321
	20	48.0	35.2	171.5	106.2	3164	5931	16263	25803
	40	48.3	41.3	173.9	126.1	5386	8610	27940	37887
	80	48.1	43.4	176.2	143.3	8535	11559	45066	54898
20 in	10	50.5	32.6	177.3	99.2	3041	6194	15382	27095
	20	50.8	38.1	182.8	115.5	4379	8090	22669	35269
	40	51.0	43.3	183.6	131.2	6648	10857	34480	47402
	80	50.7	45.8	186.1	151.0	10976	14918	58004	70824
22 in	10	53.0	33.1	185.6	100.2	3508	7405	17691	32268
	20	53.3	38.8	191.1	117.2	5077	9656	26199	41994
	30	53.5	41.9	190.3	126.7	6591	11447	33762	49880
	80	53.2	48.0	195.5	158.2	13801	18821	72969	89292
24 in	10	55.4	33.5	193.2	101.0	4003	8724	20111	37870
	20	55.8	39.4	199.7	118.8	5776	11334	29772	49168
	40	56.0	47.3	201.8	142.6	10079	16748	52328	72749
	80	55.7	50.1	204.5	165.2	16992	23245	89911	110246

Limitations:

1. For pipe content with specific gravity other than 1.0, span reduction factors specified in Attachment 4 of Reference 8.15 or Attachment A of Reference 8.73 shall be used.
2. Any concentrated weight such as valve, riser, piping component, etc., shall be located as close to support as possible, and 100% of the concentrated weight shall be added to the adjacent support.
3. For pipe with horizontal elbow, reduce by 25% the listed span for design span. A reduction factor of 0.75 is applied.
4. The every vertical support load for support design shall be the weight support load plus the vertical seismic load that is 0.96 of weight support load (i.e., 1.96*Weight Support Load).
5. Insulation density of 8 lb/ft^3 has been used to develop this Table. For insulation density other than 8 lb/ft^3, the maximum weight or seismic spans may be adjusted by the formulas below:
   For pipe without water content: $L_s' = L_s[(w_p + w_i)/(w_p + w_i')]^{1/2}$
   For pipe with water content: $L_s' = L_s[(w_p + w_i + w_w)/(w_p + w_i' + w_w)]^{1/2}$
   where, w_p, w_i, w_w see Attachment 1 of Reference 8.15; w_i'= new insulation weight, lb/ft; L_s is the span from Table, L_s' is the adjusted span due to specific insulation.
6. This Table only applies to SC-III without containing a significant Chemical release hazard (SC-III(Non-Chem)) and SC-IV piping.
7. For SC-IV piping, use the listed seismic support loads multiplied by a factor of 0.667, or use Reduction Factor provided in Table 1-2.

TABLE 2. 2 (cont'd) –
B). Lateral Seismic Support at Every Weight Span

pipe size	sch	Weight Span		Seismic Span		Support Loads (lbs)			
		ft	ft	ft	ft	Weight		Seismic	
		Empty	w/ water	Empty	w/ water	empty	w/ water	empty	w/ water
3/8 in	40	7.7	7.3	7.7	7.3	7	7	10	10
	80	7.8	7.6	7.8	7.6	8	9	12	12
1/2 in	40	9.2	8.7	9.2	8.7	11	11	16	16
	80	9.2	8.9	9.2	8.9	13	14	19	20
3/4 in	40	10.7	10.1	10.7	10.1	15	17	22	24
	80	10.7	10.4	10.7	10.4	19	20	27	29
1 in	40	12.1	11.3	12.1	11.3	26	28	37	41
	80	12.0	11.6	12.0	11.6	32	34	45	49
1-1/2 in	40	14.9	13.5	14.9	13.5	48	56	70	81
	80	14.8	14.1	14.8	14.1	62	69	89	100
2 in	40	15.6	13.8	15.6	13.8	83	93	119	134
	80	16.0	14.7	16.0	14.7	107	117	154	168
2-1/2 in	40	17.8	16.8	17.8	16.8	141	168	203	242
	80	17.8	17.1	17.8	17.1	175	199	252	287
3 in	40	20.1	18.7	20.1	18.7	192	239	277	344
	80	20.1	19.1	20.1	19.1	246	289	355	416
4 in	40	23.1	21.2	23.1	21.2	303	395	437	568
	80	23.1	21.7	23.1	21.7	401	485	577	698
6 in	40	28.5	25.5	28.5	25.5	628	880	905	1268
	80	28.5	26.4	28.5	26.4	903	1135	1300	1634
8 in	20	32.7	28.0	32.7	28.0	855	1360	1231	1958
	40	32.8	28.9	32.8	28.9	1061	1559	1528	2245
	80	32.8	30.1	32.8	30.1	1548	2013	2229	2899
10 in	20	36.6	29.5	36.6	29.5	1198	2024	1726	2914
	40	36.8	32.0	36.8	32.0	1664	2536	2396	3653
	80	36.8	33.5	36.8	33.5	2540	3357	3658	4834
12 in	20	40.0	30.7	40.0	30.7	1551	2759	2234	3973
	40	40.3	34.7	40.3	34.7	2375	3725	3419	5364
	80	40.2	36.5	40.2	36.5	3777	5038	5439	7255
14 in	10	42.1	31.3	42.1	31.3	1774	3269	2555	4707
	20	42.2	33.6	42.2	33.6	2160	3768	3110	5426
	40	42.4	36.3	42.4	36.3	2916	4630	4199	6667
	80	42.2	38.3	42.2	38.3	4714	6315	6788	9093
16 in	10	45.0	31.9	45.0	31.9	2171	4150	3126	5976
	20	45.2	34.4	45.2	34.4	2646	4775	3810	6877
	40	45.4	38.9	45.4	38.9	4039	6433	5816	9263
	80	45.2	41.0	45.2	41.0	6452	8696	9292	12523
18 in	10	47.8	32.6	47.8	32.6	2594	5165	3735	7437
	20	48.0	35.2	48.0	35.2	3164	5931	4556	8540
	40	48.3	41.3	48.3	41.3	5386	8610	7755	12398
	80	48.1	43.4	48.1	43.4	8535	11559	12291	16645
20 in	10	50.5	32.6	50.5	32.6	3041	6194	4379	8919
	20	50.8	38.1	50.8	38.1	4379	8090	6305	11650
	40	51.0	43.3	51.0	43.3	6648	10857	9574	15634
	80	50.7	45.8	50.7	45.8	10976	14918	15805	21482
22 in	10	53.0	33.1	53.0	33.1	3508	7405	5052	10663
	20	53.3	38.8	53.3	38.8	5077	9656	7311	13905
	30	53.5	41.9	53.5	41.9	6591	11447	9491	16483
	80	53.2	48.0	53.2	48.0	13801	18821	19873	27102
24 in	10	55.4	33.5	55.4	33.5	4003	8724	5765	12563
	20	55.8	39.4	55.8	39.4	5776	11334	8318	16321
	40	56.0	47.3	56.0	47.3	10079	16748	14514	24117
	80	55.7	50.1	55.7	50.1	16992	23245	24469	33473

Limitations:
1. For pipe content with specific gravity other than 1.0, span reduction factors specified in Attachment 4 of Reference 8.15 or Attachment A of Reference 8.73 shall be used.
2. Any concentrated weight such as valve, riser, piping component, etc., shall be located as close to support as possible, and 100% of the concentrated weight shall be added to the adjacent support.
3. For pipe with horizontal elbow, reduce 25% the listed span as design span. A reduction factor of 0.75 is applied.
4. The every vertical support load for support design shall be the weight support load plus the vertical seismic load that is 0.96 of weight support load (i.e., 1.96*Weight Support Load).
5. Insulation density of 8 lb/ft^3 has been used to develop this Table. For insulation density other than 8 lb/ft^3, the maximum weight or seismic spans may be adjusted by the formulas below:
   For pipe without water content: $L_s' = L_s[(w_p + w_i)/(w_p + w_i')]^{1/2}$
   For pipe with water content: $L_s' = L_s[(w_p + w_i + w_w)/(w_p + w_i' + w_w)]^{1/2}$
   where,
   w_p, w_i, w_w see Attachment 1 of Reference 8.15; w_i'= new insulation weight, lb/ft; L_s is the span from Table, L_s' is the adjusted span due to specific insulation.
6. This Table only applies to SC-III without containing a significant Chemical release hazard (SC-III(Non-Chem)) and SC-IV piping.
7. For SC-IV piping, use the listed seismic support loads multiplied by a factor of 0.667, or use Reduction Factor provided in Table 1-2.

TABLE 2. 2 (cont'd) –
C). Lateral Seismic Support at Every Other Weight Span

pipe size	sch	Weight Span		Seismic Span		Support Loads (lbs)			
		ft	ft	ft	ft	Weight		Seismic	
		Empty	w/ water	Empty	w/ water	empty	w/ water	empty	w/ water
3/8 in	40	7.7	7.3	15.3	14.7	7	7	20	21
	80	7.8	7.6	15.5	15.1	8	9	24	25
1/2 in	40	9.2	8.7	18.4	17.5	11	11	31	33
	80	9.2	8.9	18.5	17.9	13	14	38	39
3/4 in	40	10.7	10.1	21.5	20.2	15	17	45	49
	80	10.7	10.4	21.3	20.7	19	20	55	59
1 in	40	12.1	11.3	24.1	22.5	26	28	74	81
	80	12.0	11.6	24.0	23.2	32	34	91	98
1-1/2 in	40	14.9	13.5	29.8	27.0	48	56	140	161
	80	14.8	14.1	29.7	28.2	62	69	178	200
2 in	40	15.6	13.8	31.1	27.6	83	93	238	269
	80	16.0	14.7	32.1	29.4	107	117	308	337
2-1/2 in	40	17.8	16.8	35.5	33.5	141	168	407	484
	80	17.8	17.1	35.7	34.2	175	199	505	574
3 in	40	20.1	18.7	40.2	37.4	192	239	554	687
	80	20.1	19.1	40.3	38.2	246	289	710	831
4 in	40	23.1	21.2	46.2	42.3	303	395	874	1136
	80	23.1	21.7	46.3	43.4	401	485	1155	1396
6 in	40	28.5	25.5	57.0	50.9	628	880	1810	2535
	80	28.5	26.4	57.0	52.8	903	1135	2599	3268
8 in	20	32.7	28.0	65.4	55.9	855	1360	2461	3916
	40	32.8	28.9	65.6	57.7	1061	1559	3056	4490
	80	32.8	30.1	65.6	60.1	1548	2013	4457	5797
10 in	20	36.6	29.5	73.2	59.0	1198	2024	3451	5828
	40	36.8	32.0	73.6	64.0	1664	2536	4791	7305
	80	36.8	33.5	73.6	67.1	2540	3357	7315	9669
12 in	20	40.0	30.7	80.0	61.4	1551	2759	4468	7946
	40	40.3	34.7	80.6	69.3	2375	3725	6839	10728
	80	40.2	36.5	80.4	73.1	3777	5038	10878	14511
14 in	10	42.1	31.3	84.1	62.7	1774	3269	5109	9414
	20	42.2	33.6	84.4	67.3	2160	3768	6219	10852
	40	42.4	36.3	84.7	72.6	2916	4630	8397	13335
	80	42.2	38.3	84.5	76.6	4714	6315	13576	18186
16 in	10	45.0	31.9	90.1	63.8	2171	4150	6252	11952
	20	45.2	34.4	90.4	68.7	2646	4775	7620	13753
	40	45.4	38.9	90.8	77.8	4039	6433	11631	18527
	80	45.2	41.0	90.5	81.9	6452	8696	18583	25045
18 in	10	47.8	32.6	95.7	65.2	2594	5165	7470	14875
	20	48.0	35.2	96.1	70.3	3164	5931	9111	17080
	40	48.3	41.3	96.5	82.6	5386	8610	15511	24796
	80	48.1	43.4	96.1	86.9	8535	11559	24581	33290
20 in	10	50.5	32.6	100.9	65.3	3041	6194	8758	17839
	20	50.8	38.1	101.7	76.3	4379	8090	12610	23299
	40	51.0	43.3	101.9	86.6	6648	10857	19147	31269
	80	50.7	45.8	101.4	91.6	10976	14918	31611	42965
22 in	10	53.0	33.1	106.0	66.2	3508	7405	10104	21326
	20	53.3	38.8	106.7	77.6	5077	9656	14621	27811
	30	53.5	41.9	107.0	83.7	6591	11447	18982	32966
	80	53.2	48.0	106.5	96.0	13801	18821	39746	54204
24 in	10	55.4	33.5	110.7	67.0	4003	8724	11530	25125
	20	55.8	39.4	111.6	78.9	5776	11334	16635	32642
	40	56.0	47.3	112.0	94.5	10079	16748	29029	48234
	80	55.7	50.1	111.3	100.3	16992	23245	48938	66946

Limitations:
1. For pipe content with specific gravity other than 1.0, span reduction factors specified in Attachment 4 of Reference 8.15 or Attachment A of Reference 8.73 shall be used.
2. Any concentrated weight such as valve, riser, piping component, etc., shall be located as close to support as possible, and 100% of the concentrated weight shall be added to the adjacent support.
3. For pipe with horizontal elbow, reduce by 25% the listed span as design span. A reduction factor of 0.75 is applied.
4. The every vertical support load for support design shall be the weight support load plus the vertical seismic load that is 0.96 of weight support load (i.e., 1.96*Weight Support Load).
5. Insulation density of 8 lb/ft^3 has been used to develop this Table. For insulation density other than 8 lb/ft^3, the maximum weight or seismic spans may be adjusted by the formulas below:
   For pipe without water content: $L_s' = L_s[(w_p + w_i)/(w_p + w_i')]^{1/2}$
   For pipe with water content: $L_s' = L_s[(w_p + w_i + w_w)/(w_p + w_i' + w_w)]^{1/2}$
   where,
   w_p, w_i, w_w see Attachment 1 of Reference 8.15; w_i'= new insulation weight, lb/ft; L_s is the span from Table, L_s' is the adjusted span due to specific insulation.
6. This Table only applies to SC-III without containing a significant Chemical release hazard (SC-III(Non-Chem)) and SC-IV piping.
7. For SC-IV piping, use the listed seismic support loads multiplied by a factor of 0.667., or use Reduction Factor provided in Table 1-2.

TABLE 2. 3 – Span and Support Loads for SC-I, SC-II, and SC-III(Chem) S. S. Piping (For Reference Use)

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TABLE 2. 4 – Span and Support Loads for SC-III(Non-Chem) and SC-IV S. S. Piping
(For Mechanical / Erosion / Corrosion Allowances ≥ 50% 0f The Nominal Wall Thickness, See Section 4.10.2)

A) Seismic Support at Every Third Weight Span

pipe size	sch	Weight Span		Seismic Span		Support Loads (lbs)			
		ft	ft	ft	ft	Weight		Seismic	
		Empty	w/ water	empty	w/ water	empty	w/ water	empty	w/ water
3/8 in	10s	6.7	6.3	20.3	19.1	5	5	22	24
	40s	7.0	6.7	21.0	20.1	6	7	28	29
	80s	7.1	6.9	21.4	20.8	8	8	33	34
1/2 in	10s	8.2	7.7	24.9	23.1	8	9	36	38
	40s	8.4	8.0	25.2	23.9	10	10	43	45
	80s	8.4	8.1	25.4	24.6	12	12	52	54
3/4 in	10s	9.7	8.8	29.3	26.5	11	13	49	55
	40s	9.9	9.2	29.8	27.2	14	15	62	67
	80s	9.9	9.5	29.2	27.5	18	19	77	81
1 in	10s	11.0	10.0	33.2	29.9	21	23	89	98
	40s	11.1	10.3	33.4	30.2	24	26	103	112
	80s	11.2	10.6	32.9	30.8	29	31	128	135
1-1/2 in	10s	13.7	11.7	41.2	34.1	36	42	157	183
	40s	13.9	12.3	40.6	35.3	45	51	196	221
	80s	13.9	12.8	40.1	36.5	58	63	254	276
2 in	10s	13.5	11.6	40.9	35.0	58	68	253	296
	40s	14.2	12.5	42.7	37.8	75	85	326	368
	80s	14.6	13.4	44.2	40.3	97	106	425	464
2-1/2 in	10s	17.1	14.4	51.6	43.4	97	116	423	504
	40s	17.8	16.2	55.0	48.9	142	163	631	707
	80s	17.9	17.1	56.5	50.9	176	199	799	868
3 in	10s	19.7	15.9	60.0	47.3	125	157	546	684
	40s	20.2	18.2	63.5	52.9	193	233	876	1009
	80s	20.2	19.2	63.1	55.5	247	290	1144	1267
4 in	10s	22.6	17.2	69.0	50.1	180	243	791	1052
	40s	23.2	20.5	72.1	58.2	304	383	1392	1653
	80s	23.2	21.8	71.8	61.9	402	486	1874	2119
6 in	10s	27.9	19.7	86.1	55.6	346	514	1535	2227
	40s	28.6	24.2	87.4	67.3	631	835	2905	3624
	80s	28.6	26.3	87.3	73.5	906	1129	4261	4943
8 in	10s	32.2	21.4	99.9	59.9	554	874	2472	3803
	40s	32.9	26.9	99.5	74.5	1065	1453	4921	6340
	80s	32.9	29.4	99.7	82.1	1553	1972	7329	8700
10 in	10s	36.2	23.2	111.2	64.1	848	1400	3790	6073
	40s	37.0	29.6	110.8	81.1	1670	2343	7724	10197
	80s	37.0	31.7	111.3	87.8	2198	2912	10329	12784
12 in	10s	39.7	24.7	120.8	67.5	1176	2023	5274	8746
	40s	40.4	31.2	120.2	84.7	2221	3241	10241	14033
	80s	40.4	33.5	121.0	91.8	2865	3944	13418	17240
14 in	10s	41.9	25.4	131.0	75.4	1389	2443	6256	10637
	std	42.5	31.7	135.8	93.6	2550	3795	11739	16526
	xs	42.5	34.1	137.1	101.7	3298	4612	15431	20294
16 in	10s	44.7	25.9	138.9	76.2	1708	3137	7634	13577
	std	45.5	32.7	144.6	95.8	3128	4836	14316	20928
	xs	45.6	35.4	146.2	104.9	4053	5860	18886	25671
18 in	10s	47.5	26.1	146.8	76.8	2037	3877	9056	16840
	std	48.3	33.3	152.7	97.4	3743	5942	17034	25803
	xs	48.4	36.2	154.5	107.3	4858	7184	22543	31638
20 in	10s	50.5	28.1	157.5	82.5	2702	5156	12139	22449
	std	51.0	33.7	160.1	98.7	4394	7142	19878	31130
	xs	51.1	37.4	162.3	109.4	5710	8776	26383	38097
22 in	10s	52.9	28.4	164.0	82.9	3132	6176	13981	26745
	std	53.5	34.3	166.5	99.6	5095	8525	22882	36921
	xs	53.7	38.2	169.4	111.0	6614	10449	30416	45149
24 in	5s	55.4	28.5	171.5	83.3	3542	7204	15774	31335
	std	56.0	34.5	173.2	100.4	5797	9911	25900	43082
	xs	56.2	38.6	175.4	112.5	7546	12137	34560	52710

Limitations:
1. For pipe content with specific gravity other than 1.0, span reduction factors specified in Attachment 4 of Reference 8.15 or Attachment A of Reference 8.73 shall be used.
2. Any concentrated weight such as valve, riser, piping component, etc., shall be located as close to support as possible, and 100% of the concentrated weight shall be added to the adjacent support.
3. For pipe with horizontal elbow, reduce by 25% the listed span as design span. A reduction factor of 0.75 is applied.
4. The every vertical support load for support design shall be the weight support load plus the vertical seismic load that is 0.96 of weight support load (i.e., 1.96*Weight Support Load).
5. Pipe insulation is not considered in this Table. For insulation density, the maximum weight or seismic spans may be adjusted by the formulas below:
   For pipe without water content: $L_s' = L_s[(w_p)/(w_p + w_i')]^{1/2}$
   For pipe with water content: $L_s' = L_s[(w_p + w_w)/(w_p + w_i' + w_w)]^{1/2}$
   where, w_p, w_w see Attachment 1 of Reference 8.15; w_i'= new insulation weight, lb/ft; L_s is the span from Table, L_s' is the adjusted span due to specific insulation.
6. This Table only applies to SC-III without containing a significant Chemical release hazard (SC-III(Non-Chem)) and SC-IV piping.
7. For SC-IV piping, use the listed seismic support loads multiplied by a factor of 0.667., or use Reduction Factor provided in Table 1-2.

TABLE 2. 4 (cont'd) –

B) Seismic Support at Every Weight Span

pipe size	sch	Weight Span		Seismic Span		Support Loads (lbs)			
		ft	ft	ft	ft	Weight		Seismic	
		Empty	w/ water	empty	w/ water	empty	w/ water	empty	w/ water
3/8 in	10s	6.7	6.3	6.7	6.3	5	5	7	8
	40s	7.0	6.7	7.0	6.7	6	7	9	10
	80s	7.1	6.9	7.1	6.9	8	8	11	11
1/2 in	10s	8.2	7.7	8.2	7.7	8	9	12	13
	40s	8.4	8.0	8.4	8.0	10	10	14	15
	80s	8.4	8.1	8.4	8.1	12	12	17	18
3/4 in	10s	9.7	8.8	9.7	8.8	11	13	16	18
	40s	9.9	9.2	9.9	9.2	14	15	21	22
	80s	9.9	9.5	9.9	9.5	18	19	26	27
1 in	10s	11.0	10.0	11.0	10.0	21	23	30	33
	40s	11.1	10.3	11.1	10.3	24	26	34	37
	80s	11.2	10.6	11.2	10.6	29	31	42	45
1-1/2 in	10s	13.7	11.7	13.7	11.7	36	42	52	60
	40s	13.9	12.3	13.9	12.3	45	51	65	73
	80s	13.9	12.8	13.9	12.8	58	63	84	91
2 in	10s	13.5	11.6	13.5	11.6	58	68	84	98
	40s	14.2	12.5	14.2	12.5	75	85	108	122
	80s	14.6	13.4	14.6	13.4	97	106	140	153
2-1/2 in	10s	17.1	14.4	17.1	14.4	97	116	140	167
	40s	17.8	16.2	17.8	16.2	142	163	204	234
	80s	17.9	17.1	17.9	17.1	176	199	253	287
3 in	10s	19.7	15.9	19.7	15.9	125	157	179	227
	40s	20.2	18.2	20.2	18.2	193	233	278	335
	80s	20.2	19.2	20.2	19.2	247	290	356	417
4 in	10s	22.6	17.2	22.6	17.2	180	243	259	351
	40s	23.2	20.5	23.2	20.5	304	383	438	551
	80s	23.2	21.8	23.2	21.8	402	486	579	700
6 in	10s	27.9	19.7	27.9	19.7	346	514	498	740
	40s	28.6	24.2	28.6	24.2	631	835	908	1203
	80s	28.6	26.3	28.6	26.3	906	1129	1304	1625
8 in	10s	32.2	21.4	32.2	21.4	554	874	798	1258
	40s	32.9	26.9	32.9	26.9	1065	1453	1533	2092
	80s	32.9	29.4	32.9	29.4	1553	1972	2237	2840
10 in	10s	36.2	23.2	36.2	23.2	848	1400	1221	2017
	40s	37.0	29.6	37.0	29.6	1670	2343	2404	3374
	80s	37.0	31.7	37.0	31.7	2198	2912	3165	4193
12 in	10s	39.7	24.7	39.7	24.7	1176	2023	1694	2914
	40s	40.4	31.2	40.4	31.2	2221	3241	3199	4667
	80s	40.4	33.5	40.4	33.5	2865	3944	4126	5680
14 in	10s	41.9	25.4	41.9	25.4	1389	2443	2000	3517
	std	42.5	31.7	42.5	31.7	2550	3795	3672	5465
	xs	42.5	34.1	42.5	34.1	3298	4612	4749	6641
16 in	10s	44.7	25.9	44.7	25.9	1708	3137	2459	4517
	std	45.5	32.7	45.5	32.7	3128	4836	4504	6964
	xs	45.6	35.4	45.6	35.4	4053	5860	5836	8438
18 in	10s	47.5	26.1	47.5	26.1	2037	3877	2933	5583
	std	48.3	33.3	48.3	33.3	3743	5942	5390	8556
	xs	48.4	36.2	48.4	36.2	4858	7184	6996	10346
20 in	10s	50.5	28.1	50.5	28.1	2702	5156	3890	7425
	std	51.0	33.7	51.0	33.7	4394	7142	6328	10285
	xs	51.1	37.4	51.1	37.4	5710	8776	8222	12638
22 in	10s	52.9	28.4	52.9	28.4	3132	6176	4510	8894
	std	53.5	34.3	53.5	34.3	5095	8525	7337	12276
	xs	53.7	38.2	53.7	38.2	6614	10449	9525	15047
24 in	5s	55.4	28.5	55.4	28.5	3542	7204	5101	10374
	std	56.0	34.5	56.0	34.5	5797	9911	8347	14272
	xs	56.2	38.6	56.2	38.6	7546	12137	10867	17478

Limitations:
1. For pipe content with specific gravity other than 1.0, span reduction factors specified in Attachment 4 of Reference 8.15 or Attachment A of Reference 8.73 shall be used.
2. Any concentrated weight such as valve, riser, piping component, etc., shall be located as close to support as possible, and 100% of the concentrated weight shall be added to the adjacent support.
3. For pipe with horizontal elbow, reduce by 25% the listed span as design span. A reduction factor of 0.75 is applied.
4. The every vertical support load for support design shall be the weight support load plus the vertical seismic load that is 0.96 of weight support load (i.e., 1.96*Weight Support Load).
5. Pipe insulation is not considered in this Table. For insulation density, the maximum weight or seismic spans may be adjusted by the formulas below:
   For pipe without water content: $L_s' = L_s[(w_p)/(w_p + w_i')]^{1/2}$
   For pipe with water content: $L_s' = L_s[(w_p + w_w)/(w_p + w_i' + w_w)]^{1/2}$
   where,
   w_p, w_w see Attachment 1 of Reference 8.15; w_i'= new insulation weight, lb/ft; L_s is the span from Table, L_s' is the adjusted span due to specific insulation.
6. This Table only applies to SC-III without containing a significant Chemical release hazard (SC-III(Non-Chem)) and SC-IV piping.
7. For SC-IV piping, use the listed seismic support loads multiplied by a factor of 0.667., or use Reduction Factor provided in Table 1-2.

TABLE 2. 4 (cont'd) –

C) Seismic Support at Every Other Weight Span

pipe size	sch	Weight Span		Seismic Span		Support Loads (lbs)			
		ft	ft	ft	ft	Weight		Seismic	
		Empty	w/ water	empty	w/ water	empty	w/ water	empty	w/ water
3/8 in	10s	6.7	6.3	13.4	12.6	5	5	15	16
	40s	7.0	6.7	14.0	13.4	6	7	18	19
	80s	7.1	6.9	14.2	13.8	8	8	22	23
1/2 in	10s	8.2	7.7	16.5	15.3	8	9	24	25
	40s	8.4	8.0	16.8	15.9	10	10	29	30
	80s	8.4	8.1	16.9	16.3	12	12	34	36
3/4 in	10s	9.7	8.8	19.5	17.6	11	13	33	36
	40s	9.9	9.2	19.8	18.4	14	15	41	44
	80s	9.9	9.5	19.9	18.9	18	19	51	54
1 in	10s	11.0	10.0	22.0	20.0	21	23	59	65
	40s	11.1	10.3	22.3	20.5	24	26	69	74
	80s	11.2	10.6	22.4	21.2	29	31	85	90
1-1/2 in	10s	13.7	11.7	27.3	23.4	36	42	103	121
	40s	13.9	12.3	27.7	24.6	45	51	130	147
	80s	13.9	12.8	27.9	25.6	58	63	167	182
2 in	10s	13.5	11.6	27.0	23.1	58	68	167	196
	40s	14.2	12.5	28.3	25.1	75	85	217	244
	80s	14.6	13.4	29.2	26.7	97	106	281	306
2-1/2 in	10s	17.1	14.4	34.1	28.7	97	116	280	333
	40s	17.8	16.2	35.6	32.4	142	163	408	469
	80s	17.9	17.1	35.8	34.1	176	199	507	573
3 in	10s	19.7	15.9	39.4	31.7	125	157	359	454
	40s	20.2	18.2	40.3	36.5	193	233	556	671
	80s	20.2	19.2	40.4	38.3	247	290	712	834
4 in	10s	22.6	17.2	45.2	34.5	180	243	518	701
	40s	23.2	20.5	46.4	41.0	304	383	877	1102
	80s	23.2	21.8	46.4	43.6	402	486	1159	1401
6 in	10s	27.9	19.7	55.9	39.4	346	514	996	1480
	40s	28.6	24.2	57.2	48.3	631	835	1816	2406
	80s	28.6	26.3	57.2	52.6	906	1129	2609	3251
8 in	10s	32.2	21.4	64.5	42.8	554	874	1596	2516
	40s	32.9	26.9	65.8	53.8	1065	1453	3067	4184
	80s	32.9	29.4	65.8	58.9	1553	1972	4473	5680
10 in	10s	36.2	23.2	72.4	46.4	848	1400	2441	4033
	40s	37.0	29.6	73.9	59.1	1670	2343	4808	6748
	80s	37.0	31.7	74.0	63.5	2198	2912	6330	8386
12 in	10s	39.7	24.7	79.4	49.5	1176	2023	3388	5828
	40s	40.4	31.2	80.8	62.3	2221	3241	6397	9335
	80s	40.4	33.5	80.9	66.9	2865	3944	8252	11359
14 in	10s	41.9	25.4	83.7	50.7	1389	2443	4001	7035
	xs	42.5	31.7	84.9	63.4	2550	3795	7345	10930
	std	42.5	34.1	85.0	68.3	3298	4612	9499	13281
16 in	10s	44.7	25.9	89.5	51.8	1708	3137	4918	9034
	xs	45.5	32.7	91.0	65.4	3128	4836	9008	13928
	std	45.6	35.4	91.2	70.8	4053	5860	11672	16876
18 in	10s	47.5	26.1	95.1	52.2	2037	3877	5866	11166
	std	48.3	33.3	96.7	66.5	3743	5942	10781	17112
	xs	48.4	36.2	96.9	72.3	4858	7184	13991	20691
20 in	10s	50.5	28.1	101.0	56.1	2702	5156	7781	14851
	std	51.0	33.7	102.0	67.3	4394	7142	12655	20569
	xs	51.1	37.4	102.3	74.9	5710	8776	16445	25275
22 in	10s	52.9	28.4	105.8	56.8	3132	6176	9021	17788
	std	53.5	34.3	107.0	68.5	5095	8525	14673	24552
	xs	53.7	38.2	107.4	76.4	6614	10449	19049	30094
24 in	5s	55.4	28.5	110.9	57.0	3542	7204	10201	20747
	std	56.0	34.5	112.0	69.0	5797	9911	16695	28545
	xs	56.2	38.6	112.3	77.2	7546	12137	21733	34955

Limitations:
1. For pipe content with specific gravity other than 1.0, span reduction factors specified in Attachment 4 of Reference 8.15 or Attachment A of Reference 8.73 shall be used.
2. Any concentrated weight such as valve, riser, piping component, etc., shall be located as close to support as possible, and 100% of the concentrated weight shall be added to the adjacent support.
3. For pipe with horizontal elbow, reduce by 25% the listed span as design span. A reduction factor of 0.75 is applied.
4. The every vertical support load for support design shall be the weight support load plus the vertical seismic load that is 0.96 of weight support load (i.e., 1.96*Weight Support Load).
5. Pipe insulation is not considered in this Table. For insulation density, the maximum weight or seismic spans may be adjusted by the formulas below:
   For pipe without water content: $L_s' = L_s[(w_p)/(w_p + w_i')]^{1/2}$
   For pipe with water content: $L_s' = L_s[(w_p + w_w)/(w_p + w_i' + w_w)]^{1/2}$
   where,
   w_p, w_w see Attachment 1 of Reference 8.15; w_i'= new insulation weight, lb/ft; L_s is the span from Table, L_s' is the adjusted span due to specific insulation.
6. This Table only applies to SC-III without containing a significant Chemical release hazard (SC-III(Non-Chem)) and SC-IV piping.
7. For SC-IV piping, use the listed seismic support loads multiplied by a factor of 0.667. or use Reduction Factor provided in Table 1-2.

9.3 APPENDIX 3, SC-III and SC-IV Anchor Load Tables

1) Deleted

2) Table 3.2.1 –SC-III(Non-Chem) and SC-IV C.S. ANCHOR LOADS

3) Deleted

4) Table 3.4.1 – SC-III(Non-Chem) and SC-IV S.S. ANCHOR LOADS

TABLE 3.1. 1 – SC-I, SC-II, and SC-III(Chem) C.S. VESSEL NOZZLE LOADS

Deleted

TABLE 3.2. 1 – SC-III(Non-Chem) and SC-IV C.S. ANCHOR LOADS(1)(2)

Pipe Size	Load Type	FORCES			MOMENTS			RESULTANT	
		Fx (lbs)	Fy (lbs)	Fz (lbs)	Mx (ft-lb)	My (ft-lb)	Mz (ft-lb)	Fr (lbs)	Mr (ft-lb)
3/8 in	Weight	5	4	2	2	1	1	7	3
	Seismic	17	12	17	18	27	27	27	43
	Thermal	8	7	11	9	17	17	16	26
1/2 in	Weight	4	6	4	4	2	2	8	5
	Seismic	27	18	27	34	51	51	42	79
	Thermal	13	12	17	16	32	32	25	49
3/4 in	Weight	6	9	6	7	4	4	13	9
	Seismic	41	27	41	59	89	89	64	139
	Thermal	20	17	26	28	57	57	37	85
1 in	Weight	10	16	10	13	8	8	21	17
	Seismic	68	45	68	110	166	166	107	259
	Thermal	33	29	44	53	106	106	62	159
1-1/2 in	Weight	20	32	20	31	20	20	43	42
	Seismic	139	93	139	275	412	412	218	645
	Thermal	67	60	89	132	265	265	127	397
2 in	Weight	34	54	34	55	34	34	72	73
	Seismic	234	156	234	480	721	721	365	1,127
	Thermal	113	101	151	232	465	465	214	697
2-1/2 in	Weight	57	92	57	109	68	68	122	145
	Seismic	440	294	440	1,162	1,743	1,743	688	2,726
	Thermal	210	187	280	555	1,110	1,110	397	1,666
3 in	Weight	83	132	83	176	110	110	177	234
	Seismic	642	428	642	1,910	2,865	2,865	1,003	4,479
	Thermal	307	273	410	915	1,830	1,830	581	2,744
4 in	Weight	139	222	139	335	209	209	296	447
	Seismic	1,071	715	1,071	3,612	5,418	5,418	1,675	8,472
	Thermal	516	459	688	1,739	3,479	3,479	974	5,218
6 in	Weight	323	517	323	949	593	593	690	1,267
	Seismic	2,487	1,659	2,487	10,162	15,242	15,242	3,889	23,831
	Thermal	1,208	1,074	1,610	4,934	9,868	9,868	2,282	14,802
8 in	Weight	469	751	469	1,445	903	903	1,002	1,929
	Seismic	3,582	2,389	3,582	13,445	20,168	20,168	5,601	31,532
	Thermal	1,761	1,566	2,348	6,611	13,221	13,221	3,327	19,832
10 in	Weight	384	615	384	2,607	1,629	1,629	821	3,480
	Seismic	2,924	1,950	2,924	23,702	35,553	35,553	4,571	55,586
	Thermal	1,446	1,286	1,928	11,723	23,445	23,445	2,732	35,168
12 in	Weight	567	908	567	4,148	2,593	2,593	1,212	5,537
	Seismic	4,314	2,878	4,314	37,088	55,631	55,631	6,746	86,978
	Thermal	2,143	1,906	2,857	18,423	36,846	36,846	4,048	55,269
14 in	Weight	707	1,130	707	5,400	3,375	3,375	1,509	7,207
	Seismic	5,376	3,586	5,376	48,131	72,197	72,197	8,406	112,877
	Thermal	2,674	2,378	3,565	23,939	47,879	47,879	5,052	71,818
16 in	Weight	980	1,567	980	8,037	5,023	5,023	2,092	10,726
	Seismic	7,448	4,968	7,448	71,945	107,917	107,917	11,646	168,726
	Thermal	3,704	3,294	4,938	35,773	71,546	71,546	6,996	107,319
18 in	Weight	1,301	2,081	1,301	11,337	7,086	7,086	2,778	15,131
	Seismic	9,885	6,593	9,885	101,639	152,459	152,459	15,456	238,365
	Thermal	4,950	4,402	6,599	50,892	101,784	101,784	9,350	152,676
20 in	Weight	1,642	2,628	1,642	14,932	9,332	9,332	3,507	19,929
	Seismic	12,474	8,320	12,474	131,774	197,661	197,661	19,505	309,037
	Thermal	6,296	5,599	8,395	66,511	133,021	133,021	11,894	199,532
22 in	Weight	1,898	3,037	1,898	15,397	9,623	9,623	4,053	20,550
	Seismic	14,406	9,609	14,406	135,362	203,043	203,043	22,526	317,453
	Thermal	7,325	6,515	9,767	68,828	137,657	137,657	13,838	206,485
24 in	Weight	2,510	4,016	2,510	24,845	15,528	15,528	5,359	33,158
	Seismic	19,045	12,703	19,045	217,025	325,538	325,538	29,779	508,970
	Thermal	9,758	8,678	13,010	111,192	222,384	222,384	18,433	333,576

Notes:

1. For qualification of vessel nozzles, use Project-approved vendor nozzle allowable loads, or the nozzle load tables specified in Reference 8.22.
2. Use as Reference for structural anchor design but subject to CS&A acceptance.

TABLE 3.3. 1 – SC-I, SC-II, and SC-III(Chem) S.S. VESSEL NOZZLE LOADS

Deleted

TABLE 3.4. 1 – SC-III(Non-Chem) and SC-IV S.S. ANCHOR LOADS(1)(2)

Pipe Size	Load Type	FORCES			MOMENTS			RESULTANT	
		Fx (lbs)	Fy (lbs)	Fz (lbs)	Mx (ft-lb)	My (ft-lb)	Mz (ft-lb)	Fr (lbs)	Mr (ft-lb)
3/8 in	Weight	2	4	2	2	1	1	5	2
	Seismic	17	11	17	15	23	23	26	36
	Thermal	7	6	9	6	13	13	13	19
1/2 in	Weight	4	6	4	3	2	2	8	4
	Seismic	26	17	26	28	42	42	41	66
	Thermal	11	10	14	12	23	23	20	35
3/4 in	Weight	6	9	6	6	4	4	12	8
	Seismic	40	26	40	49	74	74	62	115
	Thermal	17	15	22	21	41	41	31	62
1 in	Weight	10	15	10	11	7	7	20	14
	Seismic	66	44	66	92	137	137	104	215
	Thermal	28	25	37	38	77	77	52	115
1-1/2 in	Weight	20	32	20	26	16	16	42	35
	Seismic	139	92	139	228	342	342	217	535
	Thermal	58	52	78	96	192	192	110	288
2 in	Weight	35	56	35	46	29	29	75	61
	Seismic	244	162	244	398	597	597	381	934
	Thermal	103	92	137	169	337	337	195	506
2-1/2 in	Weight	64	102	64	109	68	68	136	146
	Seismic	445	297	445	954	1,431	1,431	695	2,237
	Thermal	188	167	250	403	805	805	355	1,208
3 in	Weight	93	149	93	180	112	112	199	240
	Seismic	654	436	654	1,565	2,347	2,347	1,022	3,669
	Thermal	277	247	370	664	1,327	1,327	524	1,991
4 in	Weight	159	255	159	342	214	214	340	456
	Seismic	1,111	741	1,111	2,956	4,435	4,435	1,738	6,933
	Thermal	474	422	632	1,261	2,523	2,523	896	3,784
6 in	Weight	385	616	385	951	595	595	823	1,270
	Seismic	2,700	1,801	2,700	8,291	12,436	12,436	4,221	19,444
	Thermal	1,165	1,036	1,554	3,579	7,157	7,157	2,201	10,736
8 in	Weight	445	711	445	1,156	723	723	949	1,543
	Seismic	3,138	2,093	3,138	10,197	15,295	15,295	4,907	23,914
	Thermal	1,407	1,251	1,876	4,795	9,589	9,589	2,657	14,384
10 in	Weight	361	578	361	2,210	1,382	1,382	772	2,950
	Seismic	2,539	1,693	2,539	19,379	29,068	29,068	3,970	45,447
	Thermal	1,114	991	1,485	8,502	17,004	17,004	2,104	25,506
12 in	Weight	502	803	502	3,236	2,023	2,023	1,071	4,320
	Seismic	3,509	2,340	3,509	28,083	42,124	42,124	5,486	65,860
	Thermal	1,550	1,378	2,066	12,404	24,807	24,807	2,927	37,211
14 in	Weight	591	946	591	3,865	2,416	2,416	1,262	5,158
	Seismic	4,162	2,776	4,162	33,924	50,886	50,886	6,508	79,559
	Thermal	1,845	1,641	2,460	15,036	30,072	30,072	3,485	45,107
16 in	Weight	757	1,211	757	5,083	3,177	3,177	1,617	6,784
	Seismic	5,307	3,540	5,307	44,069	66,104	66,104	8,299	103,352
	Thermal	2,381	2,118	3,175	19,774	39,548	39,548	4,499	59,322
18 in	Weight	1,204	1,927	1,204	8,189	5,118	5,118	2,572	10,929
	Seismic	8,486	5,660	8,486	71,497	107,246	107,246	13,268	167,676
	Thermal	2,986	2,656	3,982	25,160	50,320	50,320	5,641	75,480
20 in	Weight	1,283	2,052	1,283	8,632	5,395	5,395	2,739	11,520
	Seismic	8,908	5,941	8,908	75,915	113,872	113,872	13,928	178,036
	Thermal	3,660	3,255	4,880	31,194	62,388	62,388	6,915	93,582
22 in	Weight	1,375	2,201	1,375	9,382	5,864	5,864	2,937	12,522
	Seismic	9,509	6,342	9,509	81,467	122,200	122,200	14,868	191,056
	Thermal	4,421	3,932	5,895	37,876	75,752	75,752	8,352	113,629
24 in	Weight	1,603	2,565	1,603	10,986	6,866	6,866	3,424	14,663
	Seismic	11,140	7,430	11,140	96,098	144,147	144,147	17,419	225,369
	Thermal	5,241	4,661	6,987	45,206	90,412	90,412	9,900	135,618

Notes:

1. For qualification of vessel nozzles, use Project-approved vendor nozzle allowable loads, or the nozzle load tables specified in Reference 8.22.
2. Use as Reference for structural anchor design but subject to CS&A acceptance.

9.4 APPENDIX 4, Deleted

9.5 APPENDIX 5, Deleted

9.6 APPENDIX 6, Deleted

9.7 APPENDIX 7, ME101 Stress Check Based on Nominal Weight and Eroded/Corroded Pipe Wall Thickness

The following is a sample calculation sheet used for performing

(1) Appendix 7A: Longitudinal and
(2) Appendix 7B: Longitudinal and Occasional

pipe stress check using ME101 output based on nominal pipe weight and eroded/corroded pipe wall thickness.

Appendix 7A

CALCULATION SHEET

ORIGINATOR: DATE:

CHECKER: DATE:

Longitudinal Pipe Stress Check Using ME101 Output Based on Nominal Weight and Eroded/Corroded Pipe Wall Thickness																	
		ME101 Input/Output For Sustained Loads									ASME B31.3 - S_L Stress Calculation						
No	Stress Calculation Number	Data Point	Pipe D_o (inch)	Nominal Pipe, t_n (inch)	SIF Value i_i	SIF Value i_o	Pressure (psig)	Torsion M_A (ft-lbs)	Bending M_B (ft-lbs)	Bending M_C (ft-lbs)	Erosion and Corrosion c (inch)	Eroded & Corroded Pipe Thickness t_C (inch)	Pipe Section Modulus Z_C (in^3)	Longitudinal Stress, S_L (Weight + Pressure) (Notes 1) (psi)	ASME B31.3 Code Stress Allowable (psi)	Pipe Stress Ratio	ASME B31.3 Code Stress Check
0	1	2	3	4	5a	5b	6	7	8	9	10	11	12	13	14	15	16
1	SAMPLE STRESS CALC. NO.	5	2.375	0.218	2.1	2.1	105	24	153	14	0.0937	0.1243	0.4945	6,325	16,700	0.379	PASS
2																	
3																	
4																	
5																	
6																	
7																	
8																	
9																	
10																	

1. The stress intensity formula of S_L is

$$\frac{p(D_o - 2t_c)^2}{D_o^2 - (D_o - 2t_c)^2} + \sqrt{S_b^2 + 4S_t^2}$$ in which $$S_b = \frac{\sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2}}{Z_c}$$ $$S_t = \frac{M_t}{2Z_c}$$

where $0.75i_i$ or $0.75i_o$ is not less than 1.0 and
S_b = Bending Stress due to weight
S_t = Torsional Stress due to weight
M_i = In-plane moment due to weight
M_o = Out-of-plane moment due to weight
M_t = Torsional moment due to weight

2. Sustained and longitudinal stresses can be calculated based on a single stress intensification which is the maximum SIF of i_i and i_o per note (3) of Appendix D of ASME B31.3

SPREADSHEET NOTES:
1. COLUMNS 2-9 & 14 ARE TAKEN FROM THE APPLICABLE ME101 STRESS CALCULATION.
2. COLUMN 10 IS TAKEN FROM THE APPLICABLE PIPING CLASS SHEET.
3. COLUMNS 11, 12, 13 & 15 ARE CALCULATED BASED ON PRE-SET EXCEL FORMULAS.

Appendix 7B

CALCULATION SHEET

ORIGINATOR: DATE:

CHECKER: DATE:

Occasional Pipe Stress Check Using ME101 Output Based on Nominal Weight and Eroded/Corroded Pipe Wall Thickness																	
No	Stress Calculation Number	ME101 Input/Output For Sustained Loads									ASME B31.3 - S_L Stress Calculation						
		Data Point	Pipe D_o (inch)	Nominal Pipe, t_n (inch)	SIF Value i_i	SIF Value i_o	Pressure (psig)	Torsion M_A (ft-lbs)	Bending M_B (ft-lbs)	Bending M_C (ft-lbs)	Erosion and Corrosion c (inch)	Eroded & Corroded Pipe Thickness t_C (inch)	Pipe Section Modulus Z_C (in^3)	Occasional Stress (S_L plus Seismic) (Notes 1 & 2) (psi)	ASME B31.3 Code Stress Allowable (psi)	Pipe Stress Ratio	ASME B31.3 Code Stress Check
0	1	2	3	4	5a	5b	6	7	8	9	10	11	12	13	14	15	16
1	SAMPLE STRESS CALC. NO.	45	2.375	0.218	2.1	2.1	105	57	195	13	0.0937	0.1243	0.4945	7,596	22,211	0.342	PASS
2																	
3																	
4																	
5																	
6																	
7																	
8																	
9																	
10																	

1. Occasional stress $S_{OCC} = S_P + S_W + S_{SEIS} = S_L + S_{SEIS}$

The stress intensity formula is

$$\frac{p(D_o - 2t_c)^2}{D_o^2 - (D_o - 2t_c)^2} + \sqrt{S_b^2 + 4S_t^2}$$

$$S_b = \frac{\sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2}}{Z_c} \qquad S_t = \frac{M_t}{2Z_c}$$

where $0.75i_i$ or $0.75i_o$ is not less than 1.0 and
S_b = Bending Stress due to weight
S_t = Torsional Stress due to weight
M_i = In-plane moment due to weight
M_o = Out-of-plane moment due to weight
M_t = Torsional moment due to weight

2. Sustained and longitudinal stresses can be calculated based on a single stress intensification which is the maximum SIF of i_i and i_o per note (3) of Appendix D of ASME B31.3

SPREADSHEET NOTES:
1. COLUMNS 2-9 & 14 ARE TAKEN FROM THE APPLICABLE ME101 STRESS CALCULATION.
2. COLUMN 10 IS TAKEN FROM THE APPLICABLE PIPING CLASS SHEET.
3. COLUMNS 11, 12, 13 & 15 ARE CALCULATED BASED ON PRE-SET EXCEL FORMULAS.

9.8 APPENDIX 8, Criteria for Critical Piping

- Piping in black cells.
- Piping with a seismic category of SC-I, SC-II, SC-III(Chem), and SC-IIIE.
- Piping of any diameter with a design temperature above 250^{o}F.
- Piping of any diameter with a design temperature of -100^{o}F or lower.
- Piping greater than 3" in diameter with a design temperature of -50^{o}F or lower.
- Piping with a design pressure of 400 psi or greater.
- Piping greater than 6" in diameter with a design temperature of -20^{o}F or lower.
- Piping greater than 12" in diameter with a design temperature of 20^{o}F or lower.
- Piping greater than 12" in diameter with a design temperature of 150^{o}F or greater.
- Piping greater than 24" in diameter.
- Piping that is jacketed.
- Piping greater than 3" in diameter that is connected to pump and has a design temperature of 0^{o}F or lower.
- Piping greater than 6" in diameter that is connected to pump and has a design temperature of 150^{o}F or higher.
- Piping greater than 6" in diameter that is connected to pump and has a design temperature of 20^{o}F or lower.
- Piping fabricated from material other than metals, i.e. fiberglass, thermoplastic, etc.
- Piping for which the stress supervisor deems a formal analysis is required.
- Piping connected to safety pumps, vessels, heat exchangers, major/sensitive equipment, or with significant externally imposed displacements.
- Piping required to be evaluated for pipe break requirements.
- Piping with II over I issue

9.9 APPENDIX 9, ME101 Gap Options:

9.9.1 ME101 Gap Option - Generic Approach.

Whenever the first vertical rigid support adjacent to nozzles at vessels with significant upward movements generates large upward thermal loads, the GAP option may be used to reduce the thermal uplift load when the following are taken into consideration:

1. The GAP beneath the pipe is set to be equal to the calculated thermal movement of the pipe at the pipe support location. The GAP above the pipe is set equal to an arbitrary large number (greater than the thermal movement). This will require a manual iteration to first determine the vertical (upward) thermal movement of the pipe at the support point. This way, the pipe is allowed to move up during thermal condition. In weight analysis, the pipe is allowed to sag (downward displacement), and the gap will close only when the downward displacement equals or is greater than the gap.
2. Once the thermal displacement is moving upward, the support load may be shifted from the support to the adjacent nozzle and/or other vertical supports. For conservatism, two weight analyses are required:
   - Hot Condition - with the support active but with GAP equal to the upward THRM movement
   - Cold condition - with the support active and no GAP

The following are design practices when ME101 Gap option is used at the first vertical support adjacent to the nozzle to take the dead weight and also permit the upward thermal movement using:

1. Set GAP1 in THRM and WT02 (hot) load cases equal to the actual calculated thermal displacement
2. Set GAP2 in THRM and WT03 (cold) load cases to an arbitrary number larger than the actual calculated thermal displacement.
3. Envelope two weight cases for stress check as well as support/nozzle load summary:

   WT01 = SMAX(WT02,WT03), where:

   WT02: The hot condition with the support active but with GAP1 equal to the upward thermal movement.

   WT03: The cold condition with the support active and no GAP
4. Run one single SEIS case with the support inactive (i.e. no seismic load is considered for the unidirectional support) for stress check.

The above definition of GAP1 and GAP2 are based on direction cosines of -1.00 (negative 1.00) and the ME101 input example for gap option is attached below:

Appendix 9.9.1 (Cont'd)

ME101 Example for Gap Option

```
RUN                                                  LDCASE=WT02(H+A),
RUN                                                  LDCASE=WT03(C+A),
RUN                                                  LDCASE=WTHY(C+W)
RUN                                                  LDCASE=THRM01(H),
RUN                                                  LDCASE=SEISDB(A),
                                                     WT01=SMAX(WT02,WT03),

ANC     10  -0.01       0.196       0.074            OD=4"40S,
                                                     TEMP=212,
                                                     SPG=1.47,            *A
                                                     SPG=1.00,            *W

        15              8-11-15/16           3D
        20  10-0-5/8    1.4321:     0:               DTI=PWD-H90066,
RAD     20              -1                           ETI=PWD-H90066,      *C
                                                     GAP1=0.000,GAP2=1.0  *C

RAD     20              -1                           ETI=PWD-H90066,      *H
                                                     GAP1=0.202, GAP2=1.0,*H

        3010-10         1.4321:     0:               DTI=PWD-H00257,
END
```

9.9.2 ME101 Gap Option - Special Approach

Whenever the piping has significant thermal load in the opposite direction of existing steel members which is not a real restraint at that direction, for example:

1). Piping is sitting on steel member such as an undersupport which is not required to be a pipe support but has significant thermal load in upward direction, or

2). Piping interfaces with a steel structure which is not considered as a pipe support. However, CS&A needs the design loads from Plant Design for their steel design.

A special practice described below to aim at the above situations is acceptable although it may become redundant in pipe stress analysis.

Make Two ME101 Runs. One run is to include the supports with gaps, and one is to have no supports at the locations where gapped supports were modeled. The loads from the two runs should then be enveloped to design the supports. The stress summaries from both runs shall demonstrate that the Code requirements are satisfied. The stress summaries from both runs shall be included in the documented stress calculation.

It should be noted to the support designer that the support is to be designed to allow the movement in the gapped direction. The seismic load in the restraint load summary and/or the pipe support design load table is to be applied only in the restraint direction.

9.10 APPENDIX 10, Use of UBC and Alternate Stress Criteria for SC-III(Non-Chem) and SC-IV

I. Scope and Purpose

The main purpose of this Appendix is to show that the methods and criteria that are used to calculate piping stresses result in a system in verbatim compliance with B31.3 for SC-III(Non-Chem) and SC-IV piping systems. The focus of the paper is all future evaluations, using the revised methods and criteria DOE has approved in Reference 3 (References refer to those listed for this Appendix, see Section V of this Appendix). BNI will develop a calculation to determine the impact of the methods and criteria defined herein on piping and supports already designed. The scope of this paper is only SC-III(Non-Chem) and SC-IV systems.

II SC-III and SC-IV Demand

The demand on the piping system is defined by pressure, weight, thermal expansion, and seismic loading. Pressure, weight, and thermal expansion "demand" are well understood, and will not be discussed further, with the following clarification:

- B31.3 requires that the "end-of-life" thickness (nominal less corrosion or erosion allowance) be used for calculating sustained (S_L) stresses (B31.3, 302.3.5) and, by analogy, for occasional stresses, which was confirmed in Interpretation 2-15
- B31.3 provides no guidance on what thickness (nominal, end-of-life) to use to develop the forces and moments for the sustained or occasional loadings. Interpretation 4-10 implies that the simplified design methods in B31.3 would normally employ nominal thickness when calculating forces and moments and corroded thickness when calculating stresses. That approach will conservatively be used for the SC-III/IV piping, i.e., base forces and moments for weight (and seismic) on nominal dimensions and stresses on corroded dimensions.
- For thermal expansion and any displacement controlled loads (building settlement, for example), B31.3 clearly requires use of nominal dimensions for both determining loads and stresses (319.3.5, "Nominal dimensions...shall be used in flexibility calculations"). This is reiterated in Interpretation 4-10.

Seismic demand for SC-III and SC-IV piping systems is defined by the Uniform Building Code 1997 (UBC), as indicated in the SRD (Reference 1, Table 4-2) and ABAR 24590-WTP-SE-ENS-06-0022 (incorporated at Rev 4f of the SRD). UBC seismic demand is defined in Equation 32-1 (conservative maximum) and Equation 32-2 from Section 1632. BNI will use Equation 32-2 for all future evaluations:

$$0.7C_aI_pW_p \le F_p = \frac{a_pC_aI_p}{R_p}\left(1+3\frac{h_x}{h_r}\right)W_p \le 4C_aI_pW_p$$

C_a = Seismic Coefficient, as set forth in UBC Table 16-Q, taken as 0.24 for WTP
I_p = Importance Factor specified in UBC Table 16-K, taken as 1.5 for SC-III and 1.0 for SC-IV for WTP

W_p = The weight of an element or component
F_p = Total design lateral seismic force (as defined in UBC 1632.2)
a_p = In-structure component amplification factor from UBC Table 16-O
R_p = Component Response Modification Factor from UBC Table 16-O
h_x = Element or Component elevation with respect to grade, not less than 0.0
h_r = Structure roof elevation with respect to grade

The strict verbatim requirements from UBC are as follows (with appropriate paragraphs or tables referenced):

- Lateral force only (UBC 1632)
- Only one horizontal direction of load (UBC 1632)
- 1.4 reduction factor applied to the earthquake load when using allowable stress design (UBC 1612.3.2)
- a_p = 1.0 for piping (UBC Table 16-O, Item 3B)
- R_p = 3.0 (UBC Table 16-O, Item 3B) for piping and for supports that don't use Concrete Expansion Anchors (CEAs) or have a buckling issue (no change from above).
- R_p = 1.5 for non-ductile failure modes based on Table 16-O, Item 4B (buckling, CEA pullout) (no change from above).

DOE has requested that BNI use methods for SC-III(Non-Chem) and SC-IV that are more consistent with the methods chosen for SC I and SC II piping. These changes result in a much more conservative seismic loading (demand) than required by UBC. In doing so, DOE has permitted BNI relief in the allowable stresses for piping and component standard supports (capacity). The following list indicates the requirements that BNI will follow for SC-III/IV piping and supports designed to the DOE accepted criteria:

- Lateral and vertical seismic loading, with the vertical force equal to 2/3 the lateral force, which is consistent with typical Nuclear Power Plant (NPP) requirements (vertical loading not required by UBC)
- Lateral force applied in both horizontal directions (only one direction required by UBC)
- The three directions of force (both horizontals and the vertical) combined SRSS
- No reduction factor applied to the earthquake load (loss of 1.4 factor)
- a_p = 2.5 for piping (UBC Table 16-O, maximum possible value)
- R_p = 3.0 (UBC Table 16-O, Item 3B) for piping and for supports that don't use Concrete Expansion Anchors (CEAs) or have a buckling issue (same as standard UBC)
- R_p = 1.5 for non-ductile failure modes based on Table 16-O, Item 4B (buckling, CEA pullout) (same as standard UBC)

Thus, the amount of conservatism in the proposed demand can be compared easily to that from strict verbatim requirements from UBC:

Increase in earthquake load due to ignoring 1.4 factor = 1.4
Increase in earthquake load due to a_p difference = 2.5
Increase in earthquake load due to considering a vertical Earthquake equal to 2/3 horizontal = 1.2 (see below)

$$\textit{Minimum increase} = \sqrt{1.0^2 + 0.667^2} = 1.2$$

Note that the 1.2 factor is a minimum; a vertical run would be higher since the result would be the SRSS of two equal earthquakes, or a factor of 1.4. Also note that since support loads tend to be dominated by one direction of seismic load, whereas pipe stresses are an SRSS of all directions of moments, the 1.2 factor will not be applied to supports.

Total demand increase factor for stress = 2.5*1.4*1.2 = 4.2
Total demand increase factor for supports = 2.5*1.4 = 3.5

The result of the DOE/BNI/WTP requirements is that the earthquake load used to evaluate piping and supports is higher than strict verbatim compliance with UBC would require. This higher demand has been offset by a higher permitted allowable stress. As will be shown below, if the correct UBC demand were used, the B31.3 allowable stress criteria (capacity) would easily be met. That is, designing piping and supports using the conservative BNI demand and higher BNI capacity is more conservative than using the correct UBC demand and lower B31.3 capacity.

III Capacity

Prior to discussing seismic loading, the following is presented to clarify exactly how normal longitudinal stresses in piping (weight, thermal expansion/displacement) will be determined, since there has been some discussion on that issue in the past.

Pipe Stresses (Sustained and Displacement Loads)

Longitudinal Pipe Stresses for Sustained Loads will meet the Requirements of B31.3, 302.3.5. Since the 1996 B31.3 does not provide guidance concerning how the longitudinal stress is to be determined, the following equation is used based on the guidance in B31.3 Code Case 178 (Reference 2):

$$\frac{PD_O}{4t_c} + \frac{\sqrt{(0.75 i_o M_{oA})^2 + (0.75 i_i M_{iA})^2 + M_{TA}{}^2}}{Z'} \leq 1.0 S_h$$

Where:

M_{oA}, M_{iA}, M_{TA}	= out-of-plane bending, in-plane bending, and torsional moments due to Sustained Loads (typically weight), respectively.
i_o, i_i	= out-of-plane and in-plane bending stress intensification factors, respectively
D_o	= Pipe nominal outside diameter
t_c	= Nominal pipe wall thickness less corrosion/erosion allowance
Z'	= pipe section modulus based on nominal OD and corroded thickness.
S_h	= Basic Allowable Stress at maximum metal temperature from B31.3

As indicated earlier in Section II of this paper, the bending and torsional moments will be derived from an analysis based on the nominal dimensions of the pipe.

The above equation is slightly different from the Code Case, in that the Code Cases recommends including the stress due to the axial force. As this stress is typically small in well supported piping systems, and it is not used in the displacement stress equation, BNI has chosen not to consider that component of stress.

Displacement Stresses for Thermal Expansion and Displacement Controlled loads will meet the requirements of B31.3, 319.4.4:

$$\frac{\sqrt{(i_o M_{oC})^2 + (i_i M_{iC})^2 + M^2{}_{TC}}}{Z} \le S_A$$

Where:

M_{oC}, M_{iC}, M_{TC}	= out-of-plane bending, in-plane bending, and torsional moments due to Displacement Controlled Loads (typically thermal expansion), respectively.
Z	= pipe section modulus based on nominal OD and thickness.
S_A	= Allowable Displacement Stress Range, as defined in 302.3.5(d) of B31.3

As indicated earlier in Section II of this paper, the bending and torsional moments will be derived from an analysis based on the nominal dimensions of the pipe.

Pipe Stresses (Occasional Loads)

The normal limit for occasional stress in B31.3 is $1.33S_h$ (302.3.6). However, as indicated in 300(c)(3), B31.3 is based on a simplified approach to design. It permits a designer capable of a more rigorous analysis to use that approach, provided the validity is demonstrated. Based on the fact that BNI is using a higher seismic demand that the simplified approach of UBC would require, BNI will use a higher stress limit for piping than the simple approach in B31.3 allows. The proposed stress equation is provided below.

Using the same guidance as for Sustained stresses, the following equation is used:

$$\frac{PD_O}{4t_c} + \frac{\sqrt{(0.75 i_o M_{oB})^2 + (0.75 i_i M_{iB})^2 + M_{TB}{}^2}}{Z'} < lesser\ of\ k_1 S_h\ or\ k_2 S_y$$

M_{oB}, M_{iB}, M_{TB}	= out-of-plane bending, in-plane bending, and torsional moments due to Sustained plus occasional Loads (typically weight plus seismic), respectively.
i_o, i_i	= out-of-plane and in-plane bending stress intensification factors, respectively
D_o	= Pipe nominal outside diameter
t_c	= Nominal pipe wall thickness less corrosion/erosion allowance
Z'	= pipe section modulus based on nominal OD and corroded thickness.
S_h	= Basic Allowable Stress at maximum metal temperature from B31.3

S_y	= Yield stress at maximum metal temperature (from ASME Section II, Part D, since B31.3 does not define yield at temperature)
k_1	= 3.0
k_2	= 2.0

The basis for the left hand side of the equation is the same as for sustained loads. The basis for the right hand side (allowable stresses) has been discussed with and accepted by DOE (Reference 3).

In order to simplify the equations to determine demand to capacity ratios, let us look at stresses as a combination of pressure stress (PS), weight stress (WS), and seismic stress (SS) separately, using $3S_h$ as the upper BNI seismic limit and $1.33S_h$ as the upper UBC/B31.3 limit. Note that for materials limited by $2S_y$, the discussion below is conservative.

$PS + WS < S_h$
$PS + WS + SS\ (BNI) < 3S_h$
$PS + WS + SS\ (UBC) < 1.33S_h$

PS + WS can be anything between 0 and S_h. For the moment, assume PS + WS is 0. Then, in the limit

SS (BNI) = $3S_h$; SS(UBC) = $1.33S_h$
Demand (BNI) = 4.2*Demand (UBC) (from Section II)

Demand (BNI)/Capacity (BNI) = (4.2*Demand(UBC))/$3S_h$ = 1.4*Demand(UBC)/S_h
Demand (UBC)/Capacity (UBC) = (Demand (UBC))/$1.33S_h$ = 0.75*Demand (UBC)/S_h

That is, the demand to capacity ratio for the BNI method and criteria is higher (more conservative) than the standard UBC-B31.3 for PS + WS = 0, by almost a factor of 2 (1.4/0.75 = 1.87).

Clearly, as PS + WS increases, there will eventually be a point at which the demand to capacity (DC) ratio for BNI is not higher than UBC-B31.3, as shown in the following table, using the following equations:

- B31.3 SS Cap = $1.33S_h$ - S_h*(PS + WS)/S_h
- BNI SS Cap = $3S_h$ - S_h*(PS + WS)/S_h
- UBC Demand = 1.0
- BNI Demand = 4.2*UBC Demand = 4.2
- DC Ratio = [Demand (BNI)/Cap(BNI)]/[Demand (UBC)/Cap (B31.3)] = 4.2*Cap (UBC)/Cap (BNI)

For example, for (PS + WS) = $0.4S_h$

(PS + WS)/S_h	= 0.4	
B31.3 SS Cap	= $1.33S_h$ - S_h*0.4	= $0.93S_h$
BNI SS Cap	= $3S_h$ - S_h*0.4	= $2.6S_h$

DC Ratio = (4.2/2.6)/(1.0/0.93) = 1.50, as shown in the table below

(PS + WS)/Sh	B31.3 SS Cap/Sh	BNI SS Cap/Sh	DC Ratio
0	1.33	3	1.86
0.1	1.23	2.9	1.78
0.2	1.13	2.8	1.70
0.3	1.03	2.7	1.60
0.4	0.93	2.6	1.50
0.5	0.83	2.5	1.39
0.6	0.73	2.4	1.28
0.7	0.63	2.3	1.15
0.8	0.53	2.2	1.01
0.9	0.43	2.1	0.86
1	0.33	2	0.69

The cross-over point occurs at (PS + WS)/S_h = 0.8. A review of 172 of the SC-III(Non-Chem) and SC-IV piping analyses done to date shows that the maximum ratio of any line is 0.81, with well over 98% of the lines below 0.72, and many much lower. Thus, one would not expect any future lines to have PS + WS > 0.8S_h, but BNI will commit to placing this limitation on all future analyses when using the BNI seismic stress criteria.

IV. Conclusion

Based on the above work, the use of the BNI SC-III(Non-Chem)/SC-IV acceptance criteria coupled with a conservative application of UBC loading is conservative compared to strict compliance with B31.3 and UBC, subject to limiting the sustained stresses to 0.8S_h.

References for Appendix 9.10
1. BNI WTP Document 24590-WTP-SRD-ESH-01-001-02, Revision 4K, “Safety Requirements Document - Volume II”
2. B31 Case 178, “Providing an Equation for Longitudinal Stress for Sustained Loads in ASME B31.3 Construction”
3. DOE Letter 06-WTP-198 to BNI (RJ Schepens to WS Elkins) dated January 9, 2007, “Evaluation of Waste Treatment and Immobilization Plant (WTP) Piping and Supports Qualified to SC I, SC II, SC-III, and SC-IV Requirements”

Summary of BNI SC-III(Non-Chem) and SC-IV Pipe Stress Criteria

Normal Load (Weight, Pressure, Thermal Expansion) Demand:

- Forces and moments determined using nominal outside diameter and thickness
- Sustained conditions stresses determined using a thickness and section modulus based on "end-of-life" (nominal less corrosion or erosion allowance)
- Thermal expansion and any displacement controlled stresses (building settlement, for example) determined using nominal dimensions.

The resulting moments (piping) or moments and forces (supports) are then used in conjunction with pressure, weight, and thermal expansion/thermal anchor motion/seismic anchor motion results to qualify the piping and supports. The attached table shows the criteria used for pipe stress.

Table 1

SC – III(Non-Chem)/SC-IV Piping

NOTE: SC-III Importance Factor (I_p) = 1.5; SC-IV I_p = 1.0

Case	Loading	Loads	Demand	Capacity	Pipe Properties
Design	Primary - Sustained	Pressure (P)	Pressure	$\frac{PD_O}{4t_c} + \frac{\sqrt{(0.75i_o M_{oA})^2 + (0.75i_i M_{iA})^2 + M_{TA}^2}}{Z'} \le 1.0S_h$	Mass is based on the uncorroded pipe plus water plus insulation.
		Deadweight (D)	Vertical: 1g * W_P		
	Primary – Occasional	Pressure (P)	Pressure	$\frac{PD_O}{4t_c} + \frac{\sqrt{(0.75i_o M_{oB})^2 + (0.75i_i M_{iB})^2 + M_{TB}^2}}{Z'}$ $\le$ lesser of $k_1 S_h$ or $k_2 S_y$ $k_1 = 3.0$ $k_2 = 2.0$	Pipe structural properties (D_O, t_c, Z') are based on corroded pipe properties.
		Deadweight (D)	Vertical 1 g * W_P		
		Seismic-Inertial (SI)	Horizontal (E-W, N-S): F_p from equ 32-2 as defined above Vertical: 2/3 (Horizontal) Total: $(H^2_{N\text{-}S} + H^2_{E\text{-}W} + V^2)^{1/2}$		
	Secondary – Normal	Thermal (T)	$\alpha L \Delta T$	$\frac{\sqrt{(i_o M_{oC})^2 + (i_i M_{iC})^2 + M_{TC}^2}}{Z} \le S_A$	Pipe structural properties (D_O, t, Z) values are based on nominal pipe properties.
	Secondary – Occasional	Thermal (T)	$\alpha L \Delta T$	$\sqrt{\frac{(i_o M'_{oC})^2 + (i_i M'_{iC})^2 + M'^2_{TC}}{Z} \le S_A}$	Pipe structural properties (D_O, t, Z) values are based on nominal pipe properties.
		Seismic – Anchor Motion (SAM)	Displacement		

W_P = Weight of (Pipe + fluid + insulation) nominal properties.

g = acceleration of gravity (386 in//sec^2; 32.2 ft/sec^2)

M_{oA}, M_{iA}, M_{TA} = out- and in-plane bending and torsional moment due to D, respectively.

M_{oB}, M_{iB}, M_{TB} = out- and in-plane bending and torsion moment due to |D| + |SI|, respectively.

M_{oC}, M_{iC}, M_{TC} = out- and in-plane bending and torsion moment due to T, respectively.

M'_{oC}, M'_{iC}, M'_{TC} = out- and in-plane bending and torsion moment due to |T| + |SAM|, respectively.

Z = pipe section modulus based on nominal dimensions.

Z′ = pipe section modulus based on corroded dimensions.