APPENDIX A - PROPOSED SEISMIC STANDARD

PROPOSED STANDARD
FOR THE SEISMIC DESIGN AND RETROFIT OF PIPING SYSTEMS
(DRAFT)

S100 – PURPOSE

This standard establishes alternate requirements for the seismic design of piping systems in the scope of the ASME B31 pressure piping codes. The standard applies to the seismic design of new piping systems as well as the seismic retrofit of existing piping systems.

S101 – SCOPE

This standard applies to above ground, metallic and non-metallic piping systems in the scope of the ASME B31 pressure piping codes (B31.1, B31.3, B31.4, B31.5, B31.8, B31.9, B31.11). Except for seismic design, the piping system in the scope of this standard must comply with the materials, design, fabrication, examination and testing requirements of the applicable ASME B31 code.

S102 – DEFINITIONS

Active components: Components that must perform an active function, involving moving parts or controls during or following the earthquake (e.g. valve actuators, pumps, compressors that must operate during or following the design earthquake).

Critical piping: Piping system that must remain leak tight or operable (deliver, control or shut-off flow) during or following the earthquake. A piping system may be classified by the owner or designee as critical, if it contains toxic or flammable materials, operates at high pressure (above 6000 psi), high temperature (above 750^{o}F), or must operate (deliver, control or shut-off flow) during or after the design earthquake.

Design earthquake: The level of earthquake for which the system must be designed.

Free field seismic input: The seismic input (typically static acceleration coefficients or seismic response spectra) in the free field, at the facility location. It may be obtained from the applicable standard (such as ASCE-7), or may be developed specifically for the site.

In-structure seismic response spectra: The seismic excitation (typically static acceleration coefficients or seismic response spectra) within a building or structure, at the elevation of the equipment attachments to the building or structure. The in-structure response spectra may be obtained (a) by amplification of the free field seismic input as described in the applicable standard (such as ASCE-7), or (b) by dynamic analysis of a specific building, structure or equipment.

Lateral restraint: A brace that restrains a pipe horizontally, in a direction lateral to its axis.

Leak tightness: The ability of a piping system to remain leak tight, typically defined as (a) no visible leak in liquid service and (b) bubble solution tight in gas service.

Longitudinal restraint: A brace that restrains the pipe along the pipe axis.

Operability: The ability of a piping system to deliver, control or shut-off flow during or after the design earthquake.

Peak ground acceleration: The maximum ground acceleration at the facility.

Peak spectral acceleration: The 5% damped maximum acceleration value input to the pipe, including in-structure amplification. It is the peak of the response spectrum.

Position retention: The ability of a piping system not to fall or collapse in case of design earthquake.

Seismic design: The activities necessary to demonstrate that the system can perform its seismic function in case of design earthquake. Seismic design may be achieved by rules, static or dynamic analysis, testing, or comparison to the documented performance of similar components in earthquakes.

Seismic function: A function to be specified by the owner or designee either as position retention, leak tightness, or operability.

Seismic interactions: Spatial interactions or system that could affect the seismic function of the piping system. An example of spatial interaction is the fall of overhead components, ceilings or structures on the piping system. Examples of system interactions include seismically induced spurious signals that would cause a valve actuator to close unintentionally, or loss of contents through the rupture of an un-isolable branch line. Credible interactions are interactions likely to take place, such as the collapse of an unreinforced masonry wall. Significant interactions are interactions that, should they occur, would affect the seismic function of the piping system, for example the fall of a small instrument on a large pipe may be credible but not significant, while the fall of a block wall on the same pipe would be significant. The impact of insulated adjacent pipe runs may be credible but not significant.

Seismic response spectra: A plot or table of accelerations, velocities or displacements versus frequencies or periods, for each of three orthogonal directions (typically east-west, north-south, vertical).

Seismic restraint: A brace that constrains the pipe against movement in case of earthquake. Seismic restraints. It includes rigid struts, mechanical or hydraulic snubbers, and steel frames.

Seismic retrofit: The activities involved in evaluating the seismic adequacy of an existing piping system and identifying the changes or upgrades required to seismically qualify the system.

Seismic static coefficient: Acceleration values to be applied to the piping system in each of three directions (typically two horizontal directions, east-west and north-south, and the vertical direction).

Static component: Mechanical component that does not perform an active function (involving moving parts) during or following the design earthquake. For example pressure vessels, tanks, strainers, manual valves that do not need to change position.

Vertical restraint: A brace that restrains the pipe in the vertical direction.

S103 – OWNER'S RESPONSIBILITY

The owner or designee shall specify:

(a) The scope and boundaries of piping systems to be seismically designed or retrofitted.
(b) The applicable ASME B31 code.
(c) The classification of piping as critical or non-critical, and the corresponding seismic function (position retention for non-critical systems; leak tightness or operability for critical systems).
(d) The free field seismic input for the design earthquake.
(e) The responsibility for developing the in-structure seismic response spectra, where required.
(f) The operating conditions concurrent with the seismic load.
(g) The responsibility for qualification of static and active components, including the operability of active components where required
(h) The responsibility for the evaluation of seismic interactions.
(i) The responsibility for as-built reconciliation of construction deviations from the design drawings.

S200 – MATERIALS

S201 – APPLICABILITY

The standard applies to piping with metallic or non-metallic materials that conform to the applicable ASME B31 code, with an elongation at rupture of at least 10% at the operating temperature.

S202 – RETROFIT

The seismic retrofit of existing piping systems shall take into account the material condition of the system. The Designer shall evaluate the condition of the piping system to identify and account for material or component degradation or lack of quality that could prevent the piping system from performing its seismic function.

S300 – DESIGN

S301 - SEISMIC INPUT

The seismic input excitation may be defined as horizontal and vertical seismic static coefficients, or as horizontal and vertical seismic response spectra. The seismic input is to be specified by the owner or designee by reference to the applicable standard (e.g. ASCE-7) or to site-specific input.

The seismic input shall be specified for each of three orthogonal directions: east-west, north-south and vertical. The seismic design may be based on either
(a) The resultant (square root sum of the squares) of the east-west plus vertical or north-south plus vertical loads, whichever is larger, or
(b) The resultant (square root sum of the squares) of the east-west plus north-south plus vertical loads concurrently.

The seismic input to piping systems inside buildings or structures shall account for the in-structure amplification of the free field accelerations by the structure. The in-structure amplification may be determined based on existing consensus standards, (such as the in-structure seismic coefficient in ASCE-7), or by a facility specific dynamic evaluation.

The damping for the seismic static coefficient or response spectra to be used as input for static or dynamic analysis of the piping system shall be 5%.

S302 – DESIGN METHOD

The method of seismic design and the applicable sections are given in Table S302-1. The method of seismic design depends on (a) the classification of the piping system (critical or non-critical), (b) the magnitude of the seismic input, and (c) the pipe size.

In all cases, the designer may select to seismically design the pipe by analysis, in accordance with S304 or S305.

a	Non-Critical Piping			Critical Piping	
	NPS ≤ 2”	2” < NPS < 6”	NPS ≥ 6”	NPS ≤ 2”	NPS > 2”
< 0.2 g	NR S400	NR S400	NR S400	NR S400	NR S400
0.2 g to 0.3 g	NR S400	NR S400	NR S307 S308 S400	DR S303 S306 S307 S308 S400	DR S303 S306 S307 S308 S400
> 0.3 g	NR S400	DR S303 S306 S307 S308 S400	DR S303 S306 S307 S308 S400	DR S303 S306 S307 S308 S400	DA S304/305 S306 S307 S308 S400

Nomenclature:
a = Maximum value of the peak spectral acceleration or seismic coefficient, g
NPS = Nominal pipe size, inches
NR = Not required. Explicit seismic design is not required, provided the piping system complies with the provisions of the applicable ASME B31 code, including design for loading other than seismic.
DR = Design by rule.
DA = Design by analysis.

Table S302-1 Seismic Design Requirements, Applicable Sections

S303 – DESIGN BY RULE

Where design by rule permitted in Table S302-1, the seismic qualification of piping systems may be established by providing lateral and vertical seismic restraints at a maximum spacing given by

$$L_{max} = \min\{1.94\ L_T / a^{0.25}\ ;\ 0.0175\ L_T\ (S_Y / a)^{0.5}\}$$

L_{max} = maximum permitted pipe span between lateral and vertical seismic restraints, ft
L_T = recommended span between weight supports, from ASME B31.1 (reproduced in Table S303-1), ft
a = maximum acceleration input to the pipe, g
S_Y = material yield stress at normal operating temperature, psi

Pipe Size NPS (in)	Water Service (ft)	Steam, Gas or Air Service (ft)
1	7	9
2	10	13
3	12	15
4	14	17
6	17	21
8	19	24
12	23	30
16	27	35
20	30	39
24	32	42

Table S301-1 ASME B31.1 Suggested Pipe Support Spacing (L_T) [ASME B31.1 Table 121.5]

In addition, straight pipe runs longer than three times the span of Table S303-1 should be restrained longitudinally.

The distance between lateral and vertical restraints should be reduced for pipe spans that contain heavy in-line components (with a total component weight in excess of 10% of the weight of the tabulated pipe span).

Unrestrained cantilevered pipe must be evaluated case-by-case.

The effect of seismic restraints on the flexibility (expansion or contraction) of the piping system must be verified in accordance with the design rules of the applicable ASME B31 code.

S304 - DESIGN BY ANALYSIS

Where design by analysis is required in Table S302-1, or where it is used as an alternative to the rules of section S303, the elastically calculated longitudinal stresses due to the design earthquake (calculated by static or dynamic analysis) shall comply with equation S304-1

$$i\,(M_i^2 + M_a^2)^{0.5} / Z < S_S \qquad \text{(S304-1)}$$

S_S = 16 ksi carbon and low alloy steel
S_S = 19 ksi austenitic stainless steel

i = stress intensification factor (from the applicable ASME B31 Code)
M_i = resultant moment amplitude due to inertia, in-lb (1)
M_a = resultant moment amplitude due to relative anchor motion, in-lb (1)
Z = pipe section modulus, in^3
S_S = allowable seismic stress at -20^oF to 100^oF , psi

Note:

(1) The resultant moment at a point may be the square root sum of the square of the three moment components at that point. Alternatively, the in-plane, out-of-plane and torsional moments may be multiplied by their respective stress intensification factor, then combined to obtain a resultant moment, where permitted in the applicable ASME B31 code.

S305 – ALTERNATIVE DESIGN METHODS

Where equation S304-1 cannot be met, the piping system may be qualified by more detailed analysis techniques, including fatigue, plastic or limit load analysis.

S306 – MECHANICAL JOINTS

For critical piping systems, the movements (rotations, displacements) and loads (forces, moments) at mechanical joints (non-welded joints unlisted in an ASME B16 standard) must remain within the limits specified by the joint manufacturer.

S307 – SEISMIC RESTRAINTS

The seismic load on seismic restraints and their attachment to building structures and anchorage to concrete, shall be calculated by static or dynamic analysis. The seismic adequacy of seismic restraints and their attachments must be determined in accordance with the applicable design code, such as MSS-SP-69 for standard support components, AISC or AISI for steel members, and ACI for concrete anchor bolts. A total gap equal to the pipe radius for 2” nominal pipe size (NPS) and smaller pipe, and 2” for pipe larger than 2” NPS, is permitted in the restrained direction, provided the seismic load, calculated on the basis of zero gap, is multiplied by an impact factor of 2.

S308 - COMPONENTS

The seismic and concurrent loads applied by the pipe at component nozzles must be determined as part of the seismic design of the piping system. The owner or designee is to determine the responsibility for qualification of the components, including the operability of active components where required.

S400 - INTERACTIONS

Piping systems shall be evaluated for seismic interactions. Credible and significant interactions shall be identified and resolved by analysis, testing or hardware modification.

S500 - DOCUMENTATION

The designer shall submit to the owner documentation of the seismic design, to include, as a minimum:

(a) Drawing showing the scope of work.
(b) Arrangement of pipe supports and restraints.

(c) Calculations showing design input and calculation results to show compliance with this standard and the owner's requirements.
(d) Drawings for new or modified supports, with dimensions, weld and anchor bolt details, bill of materials, and sufficient information for procurement and construction.

S600 – MAINTENANCE

The Owner is responsible for maintaining the configuration of the seismically qualified piping system. In particular, changes to layout, supports, components or function, as well as material degradation in service must be evaluated to verify the continued seismic adequacy of the system.

S700 - REFERENCES

ACI 318 Building Code Requirements for Reinforced Concrete, American Concrete Institute.

AISC, Manual of Steel Construction, American Institute of Steel Construction.

AISI, Specification for the Design of Cold-Formed Steel Structural Members, American Iron and Steel Institute, Washington D.C..

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

ASME B31.1, Power Piping, American Society of Mechanical Engineers, New York, NY.

ASME B31.3, Process Piping, American Society of Mechanical Engineers, New York, NY.

ASME B31.4, Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids, American Society of Mechanical Engineers, New York, NY.

ASME B31.5, Refrigerant Piping and Heat Transfer Components, American Society of Mechanical Engineers, New York, NY.

ASME B31.8, Gas Transmission and Distribution Piping Systems, American Society of Mechanical Engineers, New York, NY.

ASME B31.9, Building Services Piping, American Society of Mechanical Engineers, New York, NY.

ASME B31.11, Slurry Transportation Piping, American Society of Mechanical Engineers, New York, NY.

ICBO AC156, Acceptance Criteria for the Seismic Qualification Testing of Nonstructural Components, International Conference of Building Officials, Whittier, CA.

MSS-SP-69, Pipe Hangers and Supports – Selection and Application.

APPENDIX B – COMMENTARY TO PROPOSED STANDARD

S100C – PURPOSE

Currently, the ASME B31 codes require consideration of all design loads, including earthquakes where applicable. The B31 codes treat earthquake as an occasional load, the longitudinal seismic stress being added to the longitudinal stresses due to pressure and sustained loads. ASME B31.1 provides an explicit equation for computing the longitudinal stress. The code allowable stress for seismic plus sustained stresses is 1.2S for ASME B31.1 and 1.33S for ASME B31.3, where S is the code allowable stress. This standard provides an alternate approach for the seismic design of pressure piping systems, and is applicable to all the ASME B31 codes.

S101C – SCOPE

The standard applies to piping systems and pipelines designed and constructed to one of the ASME B31 codes. Code compliance provides a level of design and construction quality necessary for the application of the rules in this standard. The ASME B31 Pressure Piping codes are:

ASME B31.1, Power Piping
ASME B31.3, Process Piping
ASME B31.4, Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids
ASME B31.5, Refrigerant Piping and Heat Transfer Components
ASME B31.8, Gas Transmission and Distribution Piping Systems
ASME B31.9, Building Services Piping
ASME B31.11, Slurry Transportation Piping

S102C – DEFINITIONS

Active components: Note that a manual or actuated valve that does not need to change its position during or following the earthquake is not considered to be an “active” component.

Critical piping: The definition of high pressure is based on B31.3, which defines high pressure as a B16.5 pressure rating of 2500, which corresponds to approximately 6000 psi for steel at ambient temperature.

The limit of 750^{o}F provides an upper limit for steel, beyond which the mechanical properties are significantly affected by temperature.

The definition of material content in critical piping can also be based on OSHA regulation 19 CFR 1910 or rules of the National Fire Protection Association (NFPA).

The piping must be classified “critical” if its function or leak tightness is required by regulation.

An owner may also classify a piping system as critical for economic reasons, if loss of system function or leaks would be too costly.

Design earthquake: A design earthquake may be specified by regulation or building codes.

Free field seismic input: Free field seismic input is ground motion, unaffected by the proximity of structures. Seismic maps provide free field seismic input. The free field input may also be obtained from seismic maps, United States Geological Survey (USGS) regional data, or they may be developed based on explicit geotechnical and seismological studies of a given site, in which case it is referred to as "site specific".

In-structure seismic response spectra: The seismic excitation at ground level is amplified with elevation in a structure. For example, the acceleration atop a pipe rack will be larger than at ground level. If the piping system is supported within a structure, its input excitation is therefore larger than if it was supported at ground level. There are two common methods to obtain the amplified spectra in a structure: (a) A finite element analysis of the structure, in which the ground excitation is the input and the accelerations at various floor elevations are obtained as output. (b) An approximate multiplier applied to the ground acceleration, for example $1 + 2z/h$, where z is the elevation of the floor in the structure and h is the total height of the structure. In this case, the largest in-structure amplification of ground accelerations will therefore be 3 at roof level ($z = h$). For a piping system, the elevation to consider (z) is the highest elevation of pipe restraint attachment points to the building structure.

Lateral restraint: For example, an east-west brace provides lateral restrain to a north-south run of pipe. A horizontal brace provides lateral restrain to a vertical pipe riser.

Leak tightness: Leak tightness, as used here, is the ability of the piping system to prevent its contents from leaking out of the system, within a level of tightness specified by the owner. In most industrial applications, leak tightness will correspond to a lack of visible leakage for liquids and bubble-solution tightness for gases. Leak tightness does not apply to valve through-seat leakage, which falls under the definition of operability (delivery, control and shutoff of flow). For example, as defined here, a leak tight valve may not leak out through flange or packing, but may leak through its seat.

Longitudinal restraint: For example, an east-west brace provides longitudinal restrain to an east-west run of pipe. A vertical brace provides longitudinal restrain to a vertical pipe riser. A restraint placed within 12" of a bend may be considered to act as a longitudinal restraint to the run of pipe upstream of the bend, in the direction of the restraint. For example, an east-west brace on a north-south run, 12" from the east-west / north-south bend, acts as a longitudinal restraint to the east-west run.

Operability: Where operability is required, it will be necessary to specify what components need to operate and the required function. For example, an air operated valve actuator may have to open or close a gate valve or throttle flow through a globe valve. A manual valve may have to be closed by an operator following the earthquake to isolate a potential spill, a pump may have to start-up or shutdown. The owner, or designee, needs to consider the failure mode of active components, such as valve actuators on loss of power or loss of air (common in large earthquakes unless the power supply or plant air systems have been seismically qualified). In defining what component needs to remain operable, keep in mind the following post-earthquake conditions:

(a) Normal offsite and non-qualified emergency power may be lost for several days (for example 3 days).
(b) If operators are required to take actions, they must have access to the equipment and the equipment needs to be qualified.
(c) Non-qualified piping systems may leak or rupture causing loss of function, flooding, etc.
(d) The earthquake may cause fires.

Peak ground acceleration: It is the highest value of the seismic response spectrum at ground level. It is typically the value of the ground-level seismic static coefficient calculated following a building code practice, not including in-structure amplification (e.g. not including the term 1 + 2 z/h).

Peak spectral acceleration: It is the peak of the response spectrum, or the maximum value of the static coefficient including in-structure amplification (i.e.. including the term 1 + 2 z/h).

Position retention: A piping system may leak and not operate (control, shut-off or maintain flow) yet maintain its position, by not falling.

Seismic function: No seismic design should proceed without an understanding of the desired system function. For piping systems and pipelines, there are three possible functions:
(a) Position retention means that the pipe will not fall (collapse), and injure workers or the public.
(b) Leak tightness means that the pipe should not leak to the environment (a typical requirement for toxic or flammable fluids). Through-leakage of valve seats should be considered an operability requirement.
(c) Operability means that the system must deliver, shut-off or throttle flow.

Seismic response spectra: Typically, for piping design, response spectra are specified as acceleration (in g's) versus frequency (in Hz). They can be obtained from building codes or from site-specific analyses. The maximum value (or "peak") of the in-structure response spectra is the value "a" used in Table S302-1

Seismic restraint: Note that a seismic restraint may also be provided by a wall penetration or a hard interference with the pipe. The restraint should have sufficient stiffness and strength to restrict the pipe movement. Spring hangers are not seismic restraints, rod hangers that can only act in tension (they would buckle under compressive loads) may be considered seismic restraints only if the vertical acceleration is smaller than the pipe weight (i.e. the pipe will not tend to uplift and compress the rod hanger).

Seismic interactions: The evaluation of seismic interactions starts in the field. The designer should use judgment and calculations, as necessary, to determine which nearby or overhead structures, systems or components could adversely affect the pipe function. The pipe being seismically designed is the "target" of interactions. The structures, systems and components that can affect the pipe are the "sources" of interaction. Credible sources of interactions include the building itself, block walls, suspended ceilings, large unanchored equipment that could slide or overturn, or poorly anchored overhead ducts or cable trays. Significant interactions include impact of valve actuators against adjacent walls where operability is required, fall of ceiling panels on top of pipes, overturning of tall equipment onto pipes.

Seismic static coefficient: The value of the seismic static coefficient is typically obtained from building codes (such as the International Building Code) or standards (such as ASCE-7).

S103C – OWNER'S RESPONSIBILITY

The success of a seismic design or retrofit effort depends on the clarity and completeness of the purpose, scope and input. To that end, the owner may rely on an expert individual (consultant) or engineering firm (the designee).

S200C – MATERIALS

S201C – APPLICABILITY

For process and power plant applications, at least 10% elongation at rupture is a reasonable measure of ductility of the material. For pipelines, operating at pressure induced hoop stresses close to 72% yield, a ductility is better measured by a minimum shear area in a drop weight tear test (DWTT) or Charpy V-notch test (CVN). This ductility permits the material to yield if overloaded and redistribute the seismic load, prior to rupture. The rules of this standard are based on analyses, tests and earthquake experience with ductile materials.

S202C – RETROFIT

The seismic retrofit of an existing piping system is similar to the seismic design of a new piping system, with one added advantage and one added difficulty. The advantage is that the system has been in operation and its weaknesses, if any, are known through its performance and maintenance records (for example, a persistently leaking joint would require particular attention in seismic design). The difficulty is that components may be corroded or otherwise degraded, which would be the source of leaks or ruptures in case of earthquake. A visual inspection, supplemented with internal or volumetric inspections (such as ultrasonic examination) may be in order where degradation is suspected.

S300C – DESIGN

Where design by rule is permitted in Table S302-1, the seismic qualification of piping systems may be established by providing lateral and vertical seismic restraints at a maximum spacing (distance between supports) given by

$$L_{max} = \min\{1.94\ L_T / a^{0.25}\ ;\ 0.0175\ L_T\ (S_Y / a)^{0.5}\}$$

L_{max} = maximum permitted pipe span between lateral and vertical seismic restraints, ft
L_T = recommended span between weight supports, from ASME B31.1 (reproduced in Table S303-1), ft
a = maximum acceleration input to the pipe, g
S_Y = material yield stress at operating temperature, psi

This equation for L_{max} stems from the following considerations. For a given span of pipe (given linear weight, Young's modulus and moment of inertia of the cross section)

$$\Delta / (a\ L^4) = \text{constant}$$

$$\sigma / (a\ L^2) = \text{constant}$$

Δ = deflection at mid-span, in
a = lateral uniform acceleration, g's
L = length of pipe span, in
σ = maximum bending stress, psi

The span lengths in Table S301-1 are based on

$$\Delta = 0.1"$$

$$\sigma = 2300 \text{ psi}$$

$$a = 1 \text{ (gravity = 1g)}$$

To limit the mid-span deflection to 2" under a uniform seismic acceleration "a" applied concurrently to the pipe in two lateral directions (resultant 1.414a) it is necessary that

$$2" / (1.414a \times L^4) = 0.1" / (1 \times L_T^4)$$

L = span length that will deflect 2" under resultant acceleration 1.414a, in
L_T = span length from ASME B31.1 Table 121.5

or

$$L \leq 1.94\ L_T / a^{0.25}$$

To limit the maximum bending stress to 0.5 S_Y under a uniform seismic acceleration "a" applied concurrently to the pipe in two lateral directions (resultant 1.414a) it is necessary that

$$L \leq 0.0175\ L_T\ (S_Y / a)^{0.5}$$

S_Y = material yield stress at operating temperature, psi (ref. ASME B&PV Section II Part D, Table Y-1).

Therefore, to limit the mid-span deflection to 2" and the maximum bending stress to 0.5 S_Y, it is necessary limit the span length to

$$L_{max} = \min\{1.94\ L_T / a^{0.25}\ ;\ 0.0175\ L_T\ (S_Y / a)^{0.5}\}$$

Repeating this calculation for a series of pipe sizes and accelerations, we obtain the maximum spacing of lateral and vertical seismic restraints in 70^{o}F service shown in the following table

NPS	ASME-B31.1 Table 121.5	0.1g	1.0g	2.0g	3.0g
1	7	24	13	11	9
2	10	34	19	16	13
3	12	41	23	19	15
4	14	48	27	22	18
6	17	58	32	27	22
8	19	65	36	30	25
12	23	79	44	37	30
16	27	93	52	44	35
20	30	103	58	48	39
24	32	110	62	52	42

In design by analysis, equation S304-1 is based on the relationship between applied reversing stress amplitude S and fatigue cycles to failure N

$$i\,S = C / N^{0.2}$$

i = stress intensification factor
S = applied stress amplitude, psi
N = cycles to failure
C = material coefficient = 122,000 for carbon steel (245,000 stress range / 2)
= 140,000 for austenitic stainless steel (281,000 stress range / 2)

Allowing the seismic load to cause an incremental stress of 1/3 (=0.33) in 100 cycles of maximum applied seismic load, the stress equation becomes

$$iS = 0.33\ C / 100^{0.2} = 0.13\ C = 16.2 \text{ ksi carbon steel} \sim 16 \text{ ksi and } 18.6 \text{ ksi SS} \sim 19 \text{ ksi}$$

S305C – ALTERNATIVE DESIGN METHODS

Where equation S304-1 cannot be met, the piping system may be qualified by more detailed analysis techniques, including fatigue, plastic or limit load analysis. Welding Research Council Bulletin WRC 379, Alternative Methods for the Seismic Analysis of Piping Systems, February 1993, provides an overview of various alternate seismic design methods [ASME, New York].

For passive equipment (vessel and heat exchanger) the forces and moments at equipment nozzles are evaluated by comparison to vendor allowable limits. For pressure vessels, if vendor allowable nozzle loads are not available, the nozzle loads may be evaluated by calculations. Applicable references for nozzle load evaluation include:

(a) ASME Boiler and Pressure Vessel Code section VIII Pressure Vessels [ASME New York.
(b) The Standard of the Tubular Heat Exchangers manufacturers Association [TEMA, Tarrytown, NY].
(c) WRC 107 [Welding Research Council Bulletin 107, Local Stresses in Spherical and Cylindrical Shells Due to External Loadings, March 1979, ASME, New York].
(d) WRC 297 [Welding Research Council Bulletin 297, Local Stress in Cylindrical Shells Due to External Loadings and Nozzles, September 1987, ASME, New York].

S400C - INTERACTIONS

Piping systems shall be evaluated for seismic interactions. Credible and significant interactions shall be identified and resolved by analysis, testing or hardware modification.

S500C - DOCUMENTATION

The designer shall submit to the owner documentation of the seismic design. The documentation shall include, as a minimum:

(a) Drawing showing the scope of work.
(b) Arrangement of pipe supports and restraints.
(c) Calculations showing design input and calculation results to show compliance with this standard and the owner's requirements.

(d) Drawings for new or modified supports, with dimensions, weld and anchor bolt details, bill of materials, and sufficient information for procurement and construction.

S600 – MAINTENANCE

The Owner is responsible for maintaining the configuration of the seismically qualified piping system. In particular, changes to layout, supports, components or function, as well as material degradation in service must be evaluated to verify the continued seismic adequacy of the system.

APPENDIX C - SEISMIC DESIGN EXAMPLE

S100 – PURPOSE

To illustrate the application of ASME B31S to a new process steam line, from a vertical vessel to a heat exchanger (Figure C-1).

S101 – SCOPE

The scope of work includes the steam piping from the vertical vessel to the heat exchanger, including the 2” branch line to the isolation valve and excluding the vessel and heat exchanger, Figure C-1 and C-2.

The piping has been designed for normal operating loads (pressure, temperature, weight) in accordance with the ASME B31.3 Process Piping Code. The pipe is ASTM A 106 Grade B, size 6” schedule 40, with a 2” schedule 40 branch line.

The piping is to be constructed (materials, welding, NDE and hydrostatic testing) in accordance with ASME B31.3 Process Piping.

S103 – SPECIFIED REQUIREMENTS

(a) The scope and boundaries of piping system to be seismically qualified is shown in Figure C-2, it consists of the 6” piping from the vertical vessel to the heat exchanger, and the 2” branch to the first anchor point past the isolation valve. The scope of work does not include the design of the heat exchanger, or the design of the pressure vessel.
(b) The applicable code is ASME B31.3.
(c) The pipe is considered “critical”. The system is required to operate following the earthquake.
(d) The free field seismic input is to be obtained from IBC-2000. The system is Seismic Use Group III, with an importance factor I = 1.5. The soil is very dense with soft rock, and has a shear wave velocity v_S estimated at 2,000 ft/sec.
(e) The in-structure seismic response spectra is to be obtained from IBC-2000 (1 + 2z/h amplification factor for elevation).
(f) The operating and design conditions concurrent with the seismic load are:
Design Pressure: 450 psi.
Design Temperature: 460^{o}F
Ambient temperature: 100^{o}F max, 40^{o}F min.
Operating Pressure: 350 psi
Operating Temperature: 435^{o}F max., 70^{o}F min.
Design Life: 52 cycles per year for 30 years
Dead Load: Fluid density = 0.
Live loads: None.
Wind: None (indoor).
(g) Seismic interactions review is excluded from this scope of work.
(h) As-built reconciliation of the installed system is excluded from this review.

S200 - MATERIALS

Piping: ASTM A 106 Grade B.
Valves: cast steel body.
Pressure vessel and heat exchanger shell: ASME BPV II, SA XXX.
Insulation: 1" thick, 1.83 lb/ft.
Fluid: steam
Corrosion Allowance: 1/16" =0.06".
Joints: Welded in all places.

S201 – APPLICABILITY

The pipe and joints are metallic, ductile at operating conditions.

S202 – RETROFIT

This section is not applicable.

S300 – DESIGN

S301 – SEISMIC INPUT

S301.1 – SEISMIC INPUT AT GRADE

Step-1: The site ground motion will be selected from the IBC seismic maps, and not from a site-specific seismicity study.

Step-2: To obtain the IBC site ground motion, the facility location is first placed on the IBC map (IBC Figures F1615(1) to (10)), and the mapped maximum considered earthquake spectral response acceleration (MCESRA) is read from the contour intervals as, for example:

$$S_S = 50\%\ g = 0.50\ g$$
$$S_1 = 25\%\ g = 0.25\ g$$

S_S = MCESRA at short period, and 5% damping in a site class B.
S_1 = MCESRA at 1 sec, and 5% damping in a site class B.
$g = 32.2\ ft/sec^2 = 386\ in/sec^2$ = gravity

Step-3: At the facility, the soil is very dense with soft rock, and has a shear wave velocity v_S estimated at 2,000 ft/sec.

Step-4: According to IBC Table 1615.1.1 this soil is classified as class C. Since the soil is "softer" than a class B (rock) soil, we can expect that the spectral accelerations will be larger than the IBC map values, which apply to a class B soil. This adjustment of accelerations with soil is achieved through the "site coefficients" F_a and F_V in step 5.

Step-5: From IBC Tables 1615.1.2(1) and (2), given the site class C and the MCESRA values S_S = 0.5g, S_1 = 0.25g we read:

$$F_a = 1.20$$
$$F_V = 1.55$$

F_A and F_V = site coefficients

Step-6: Following the IBC procedure, we calculate the maximum considered earthquake spectral response acceleration (MCESRA)

$$S_{MS} = F_a\ S_S = 1.20 \text{ x } 0.50g = 0.60 \text{ g}$$
$$S_{M1} = F_V\ S_1 = 1.55 \text{ x } 0.25g = 0.39 \text{ g}$$

S_{MS} = mapped spectral acceleration for short period
S_{M1} = mapped spectral acceleration for 1-second period

Step-7: The design seismic response accelerations (DSRA) are

$$S_{DS} = (2/3)\ S_{MS} = 2/3 \text{ x } 0.60g = 0.40 \text{ g}$$
$$S_{D1} = (2/3)\ S_{M1} = 2/3 \text{ x } 0.39g = 0.26 \text{ g}$$

S_{DS} = Design spectral acceleration for short period
S_{D1} = Design spectral acceleration for 1-second period

Step-8: Two reference spectral periods are defined as

$$T_o = 0.2\ S_{D1}/S_{DS} = 0.2\ (0.26/0.40) = 0.13 \text{ sec (7.7 Hz)}$$
$$T_S = S_{D1}/S_{DS} = 0.26/0.40 = 0.65 \text{ sec (1.5 Hz)}$$

Step-9: The design response spectrum (DRS) of the facility, at 5% damping, can now be traced. It consists of three regions:

Period Range T(sec)	Spectral Acceleration S(g)
0 to T_o	0.6 (S_{DS}/T_o) T + 0.4 S_{DS}
T_o to T_S	S_{DS}
T_S to infinite	S_{D1} / T

Period Range T(sec)	Frequency Range f(Hz)	Spectral Acceleration S(g)
0 to 0.13 sec	infinite to 7.7 Hz	S = 1.85 T + 0.16 S = 0.16 + 1.85 / f
0.13 to 0.65 sec	7.7 to 1.5 Hz	S = 0.40
0.65 to infinite	1.5 to 0 Hz	S = 0.26 / T S = 0.26 f

S301.2 – SEISMIC EXCITATION IN-STRUCTURE

Step – 1: Based on the consequence of failure of the system (failure effect), the system is assigned a Seismic Use Group I, II or III (IBC 1616.2), and an importance factor I = 1.0 or 1.5 (IBC 1621.1.6). The example facility is Seismic Use Group III, with an importance factor I = 1.5.

Step – 2: Given the Seismic Use Group (SUG I, II or III) and the values of S_{DS}, $S_{D1}$and S_1, the system is assigned a Seismic Design Category (SDC) A to F (IBC 1616.3). The extent of seismic design and qualification will increase from SDC A to SDC F. Since S_{DS} = 0.40g, S_{D1} = 0.26g and I = 1.5, the assigned SDC is D.

Step – 3: The system is not to be exempted from seismic qualification.

Step – 4: The horizontal seismic load applies separately in the longitudinal and lateral directions, it is given by F_P where (IBC 1621.1.4)

$$0.3\ S_{DS}\ I\ W \leq F_P = [0.4\ a_P\ S_{DS}\ W\ I / R_P]\ (1 + 2\ z/h) \leq 1.6\ S_{DS}\ I\ W$$

S_{DS} = Project Specificationtral acceleration for short period
I = importance factor (1.0 or 1.5)
W = weight
F_P = horizontal load
a_P = component amplification factor (1.0 to 2.5)
a_P = 1.0 for any piping system
R_P = component response modification factor (1.0 to 5.0)
R_P = 1.25 for low deformability piping systems, 2.5 for limited deformability piping system, 3.5 for high deformability piping systems
z = height of attachment to structure
h = height of structure

With,
S_{DS} = 0.40 g
I = 1.5
W = distributed weight of piping system
a_P = 1.0
R_P = 2.5 because the piping is welded steel (high deformability) but the 2” line is joined by swage mechanical fittings (medium deformability)
z /h = 1 because the pipe may be supported from the building roof (z = h).

$$F_P = (0.4 \times 1.0 \times 0.40 \times W \times 1.5 / 2.5)(1 + 2 \times 1) = 0.3\ W$$

The horizontal load is verified to be larger than 0.3 S_{Ds} I W = 0.3 x 0.40 x 1.5 x W = 0.18 W
And it need not be larger than 1.6 S_{DS} I W = 1.6 x 0.40 x 1.5 x W = 0.96 W

Step – 5: The effect of the horizontal seismic load F_P (applied separately in the lateral and longitudinal direction) is added to the effect of the vertical seismic load F_V given by (IBC 1617.1.1, 1621.1.4)

$$F_V = 0.2\ S_{DS}\ W$$

F_P = vertical component of seismic load

In this case,

$$F_V = 0.2 \times 0.40 \times W = 0.08\ W = 8\%$$

The total seismic load is therefore the horizontal load F_P plus the vertical load F_V. This is a vectorial addition, in other words, the effects of the horizontal load are added to the effects of the vertical load to obtain the total seismic effect on the system (IBC 1617.1.1, 1621.1.4)

$$E = F_P + F_V = 0.30\ W\ \text{(lateral)} + 0.08\ W\ \text{(vertical)}$$

In summary, the system will have to be seismically designed to resist a horizontal force equal to 30% of its weight ($F_P = 0.3$ W), applied separately in the lateral direction (for example east-west), and the longitudinal direction (for example north-south). In addition, and concurrent with either the lateral or the longitudinal force, the system will have to sustain a vertical force (upward or downward) equal to 8% of its weight ($F_V = 0.08$ W).

Step – 6: The total load is the sum of the seismic load E and the weight W. If the allowable stress design method (also called working stress design method) is used to qualify the piping system, as is common practice, then the seismic load E should be divided by 1.4 (IBC 1605.3.2). The total load is therefore

$$F_T = W + E/1.4$$

In this case, this leads to

$$F_T = [W]_{\text{vertical down weight}} + [0.3/1.4\ W]_{\text{horizontal EW or NS}} + [0.08/1.4\ W]_{\text{vertical up or down}}$$

$$F_T = [1\ (\text{+or-})\ 0.06]\ W_{\text{vertical down}} + 0.21\ W_{\text{EW or NS}}$$

S302 – DESIGN METHOD

Given that (a) the piping is 6” and 2”, (b) the lateral acceleration is 0.21g, and (c) the piping system is critical, then – according to table S302-1 – the piping system may be qualified by design rules. However, for the purpose of illustration, the system will be qualified by analysis, with notes (2) and (3) from Table S302-1:

Note (2) Detailed seismic design of braces is required for critical piping systems, and will be addressed in section S306.
Note (3) Operability is required, and will be addressed in section S308.

S303 – DESIGN BY RULE

This section is not applicable.

S304 - DESIGN BY ANALYSIS

S304.1 – PIPING MODEL INPUT

P&ID: Figure C-2,enclosed.

Isometric: Figure C-3.

Piping:
Pipe size and schedule: 6" NPS, with a 2" NPS, schedule 40.
Pipe material specification and grade: ASTM A 106 Grade B carbon steel.
Joints: Welded.
Linear weight of pipe contents and insulation:
Contents = steam = 0 lb/ft.
Insulation = 1" calcium silicate.
Valves:
Two 6" manual gate valves. Make ABC,model ABC, Class 300.
Weight: 320 lb each, center of gravity approximately at pipe centerline.
One 2" manual gate valve. Make DEF, model DEF, Class 300.
Weight: 74 lb, center of gravity approximately at pipe centerline.

Equipment flexibility: Local flexibility (nozzle, shell), and global flexibility (equipment support): to be included in the piping system model.

S304.2 – PRELIMINARY SEISMIC DESIGN

We would first place a seismic lateral support (sway brace) every forty feet. In this case, since the pipe span between vessel and heat exchanger is only 45 ft long, the preliminary design does not dictate lateral bracing. Yet, because of the heavy weight of valves V1 and V2, and because it is straightforward to make A02 a vertical (active two-way: up and down) and lateral support, we will preliminarily specify a vertical two-way (up and down) plus lateral support at A02. This will also preclude the 6" header from swaying excessively and causing an overstress in the 2" branch line, which is fixed at a floor penetration at point B04.

We may need a lateral support close to valve V2, but because of its elevation, such a support would be more difficult and costly to erect. We will therefore postpone the decision for seismic bracing valve V2 until the detailed analysis stage.

There are no large valve operators, and therefore no eccentric weights to support. The manual valves have a center of gravity close to the pipe centerline.

S304.3 - ANALYSIS MODEL

The piping system is modeled as shown in Figure C-3.
Nozzle flexibility, developed in accordance with WRC-297 (common subroutine in piping analysis software) is included at the equipment nozzle connections A00 and A13.
A02 is modeled as a rigid support.
A06 is modeled as a variable spring.
Wall penetration B04 is modeled as a full anchor.

Thermal and radial growth of the vertical vessel are applied at node A13.
The thermal growth at the heat exchanger (A00) and wall penetration (B04) are negligible.
The seismic movement at the vertical vessel (A13), the heat exchanger (A00) and the wall penetration (B04) are calculated to be negligible.

The system is analyzed for weight (W), pressure (P), thermal expansion (T) and three dimensional (X, Y and Z) seismic response spectra (S).

S304.4 – ANALYSIS OUTPUT

The analysis output consists of loads (forces and moments), displacements (translations and rotations), accelerations and ASME B31 stresses at each node point. Following is a summary of key output values, where P = pressure, W = weight, T = thermal expansion, S = seismic.

Forces (lb) and Moments (in-lb) at Nozzles and Supports

Point	Load	FX	FY	FZ	MX	MY	MZ
A00	W	-31	-87	-10	-144	4	-6
	T	-288	7	429	-145	-125	0
	S	97	31	10	280	3	5
A02	W	0	-590	64			
	T	-157	450	477			
	S	67	93	114			
A06	W	0	-646	0			
	T	0	108	0			
	S	0	3	0			
A13	W	31	-280	-18	-919	-201	-322
	T	238	172	68	390	-467	-53
	S	117	35	92	241	435	90
B04	W	0	-48	-36	-35	0	1
	T	50	-130	-946	-1422	98	-86
	S	5	7	10	13	3	8

Accelerations (g) at Valve Nozzles

Point	a_X	a_Y	a_Z
A02	0.2	0	0
A11	0.2	0.1	0
A07	4.8	1.1	4.7
A12	4.8	1.2	3.5

Points of Maximum Stress (psi)

Point	Load Case	Stress
B05	P + W	4,372
B04	T	30,568
B05	P + W + S	5,121
A03	P	4,592

S304.5 - EVALUATION

Movements: All displacements are reviewed and found to be reasonable (weight and thermal as predicted, seismic not too large) and not to lead to interference.

Support Loads: The loads at supports (A02 and A06) will be used to design and size the supports (S306).

Equipment Nozzle Loads: The forces and moments at equipment nozzles (A00 and A13) are evaluated by comparison to vendor allowable limits. For vessels, if vendor allowables are not available, the nozzle loads may be evaluated following the rules of ASME Boiler and Pressure Vessel Code section VIII Pressure Vessels, TEMA (for heat exchangers), or WRC 107, or WRC 297.

Accelerations: In many cases, valve actuators (AOV or MOV) will have acceleration limits for structural integrity or operability. These acceleration limits are usually in the order of 3g to 5g resultant (SRSS of X, Y and Z acceleration at the center of gravity of the actuator). In the case of this example, the specification imposes no acceleration limits because the valves have manual actuators (hand wheel) that are not sensitive to seismic acceleration.

Pipe Stress: The computer program automatically calculates the ASME B31 code stress, in this case the maximum stresses are

$$PD/(4t) + 0.75i\,(M_A + M_B)/Z = 5{,}121 \text{ psi}$$

P = operating pressure, psi
D = pipe outside diameter, in
t = pipe wall thickness, in
M_A = resultant moment from deadweight, in-lb
M_B = resultant moment from seismic loads, in-lb
Z = pipe section modulus, in^3

The maximum seismic stress is

$$i\,(M_i^2 + M_a^2) / Z = 749 \text{ psi} << 1.5\ S_Y = 52{,}500 \text{ psi}$$

S305 – MECHANICAL JOINTS

The system is welded, there are no mechanical joints in the system.

S306 – SEISMIC BRACING AND ANCHORAGE

Pipe and equipment supports are sized, analyzed and qualified in accordance with the following codes and standards:

Standard catalog supports: In accordance with supplier load rating.
Steel members and welds: AISC manual of Steel Construction.
Concrete anchor bolts: ACI 318 Appendix D.

S307 – STATIC EQUIPMENT

The vertical vessel and the horizontal heat exchangers are static equipment (no moving parts). Their seismic qualification is excluded from the scope of this application. Their supports have been qualified in section S306. Loads at nozzles have been developed in S304.4 and will be reported to the vessel and heat exchanger designer for approval.

S308 – ACTIVE EQUIPMENT

There is no active equipment in this application. The manual valves are cast steel, and verified to be stronger than the pipe.

S400 – INTERACTIONS

This section is excluded from the scope of work.

S500 – DOCUMENTATION

(a) Drawing showing the scope of work: Figures C-1, C-2, C-3.
(b) Final pipe support arrangement: Figure C-3.
(c) Calculations showing design input and compliance with the requirements of the Project Specification for piping, equipment, and supports: (computer analysis input-output would be enclosed).

(d) Documentation of qualification of equipment operability where applicable: Not applicable.

(e) Drawings for new or modified supports, with dimensions, weld and anchor bolt details, bill of materials, and sufficient information for material procurement and construction: (would be enclosed).

S600 – MAINTENANCE

This section does not apply.

S700 – REFERENCES

ASME B31.3 Process Piping, for design, materials, fabrication, examination and testing, latest edition.
International Building Code, latest edition.
AISC Manual of Steel Construction.
ACI 318 Appendix D Anchoring to Concrete.
ASTM A 106 Seamless Carbon Steel Pipe for High Temperature Service.
Vendor catalogs (would be listed).

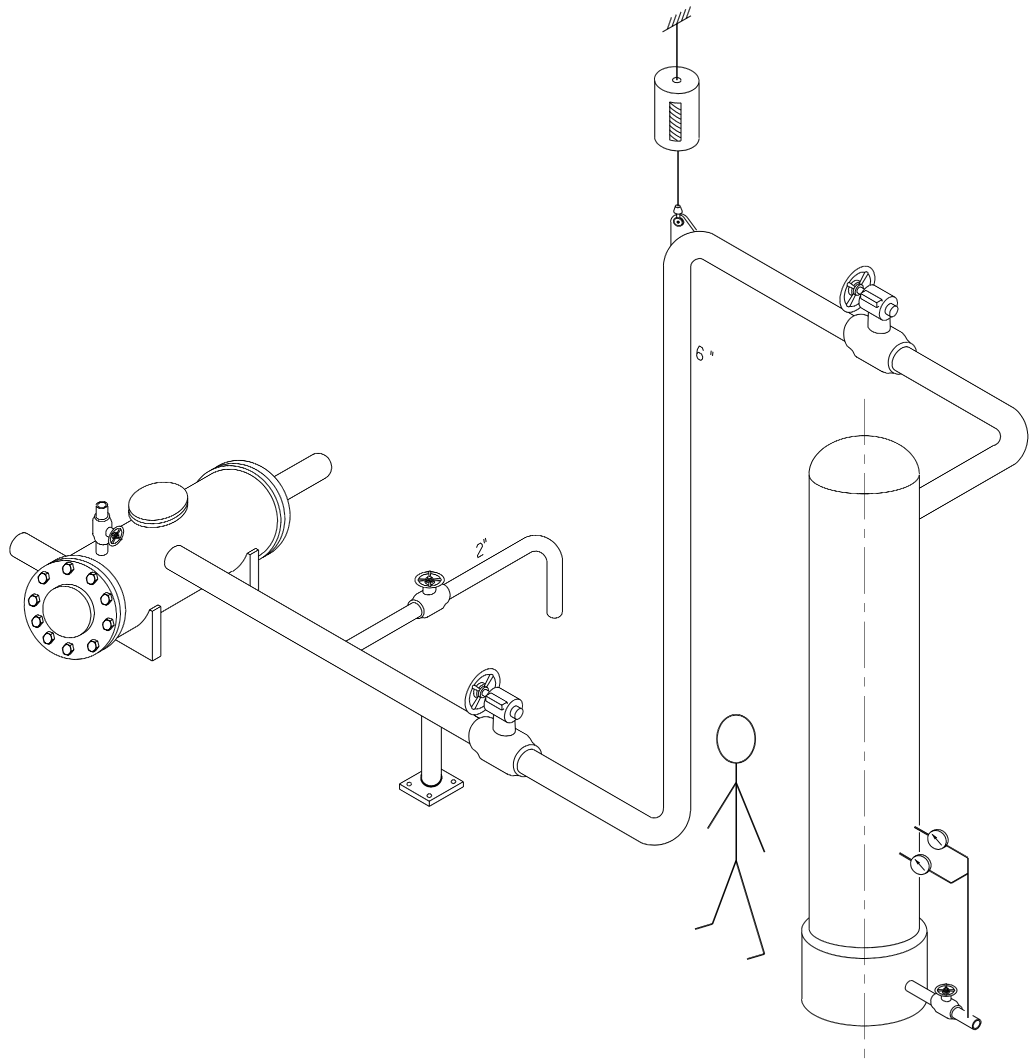

Figure C-1 Illustration of Example 1 Piping System

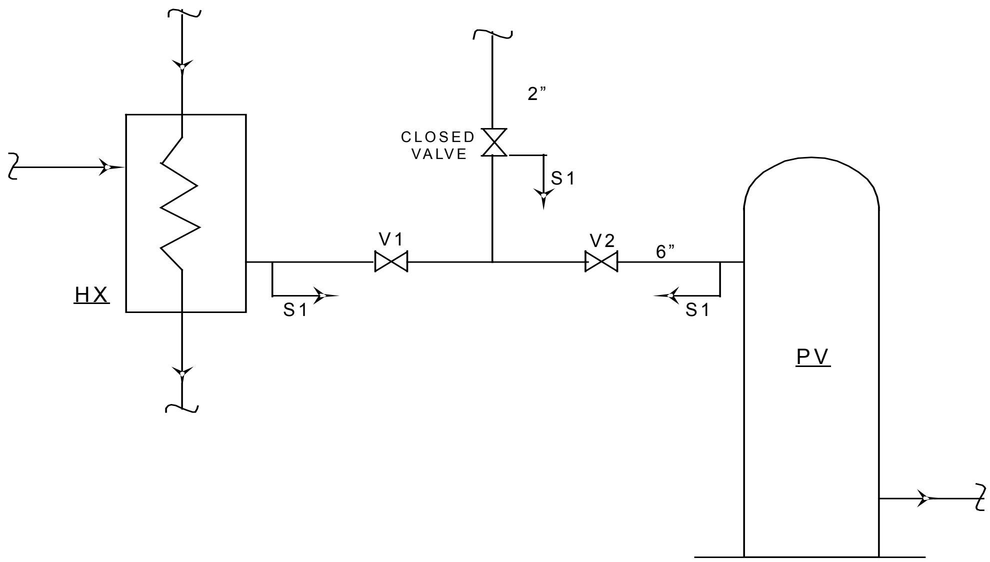

Figure C-2 P&ID Diagram pf Example 1 System

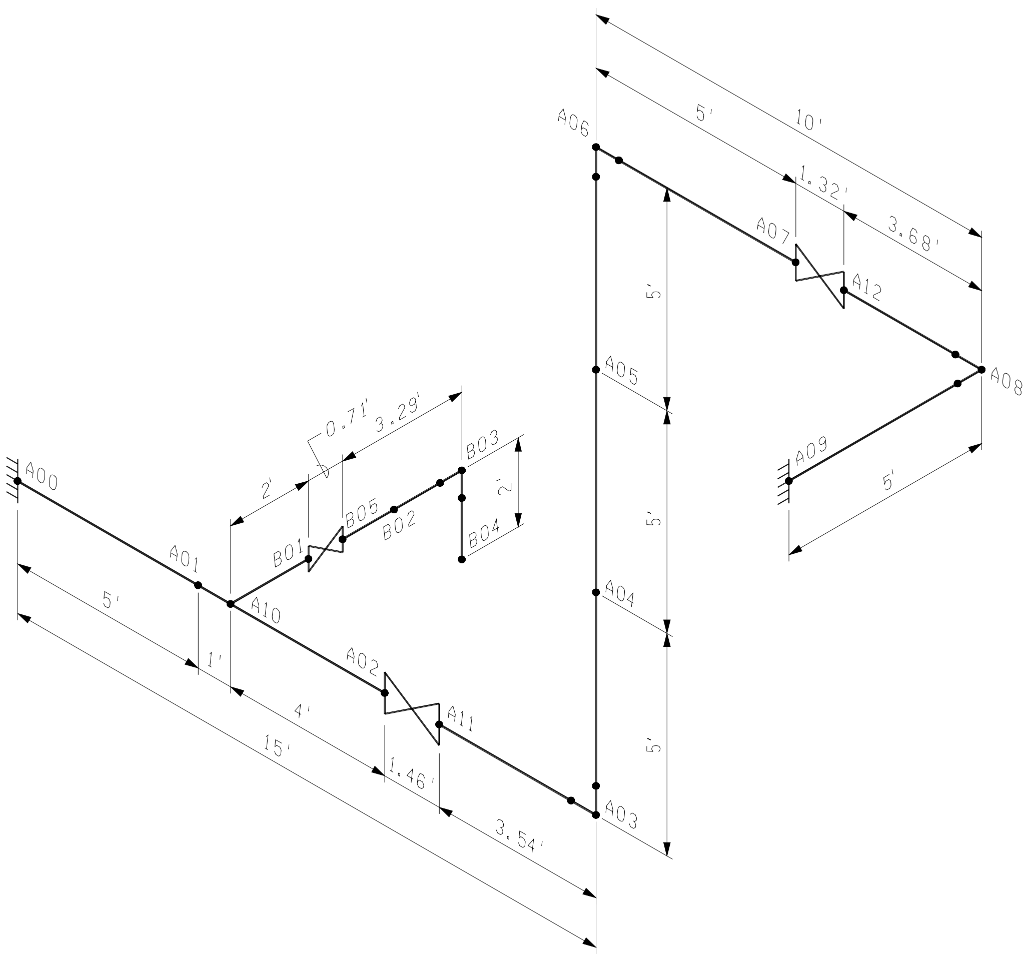

Figure C-3 Isometric of Example 1 Piping System

APPENDIX D - SESIMIC RETROFIT EXAMPLE

S100 - PURPOSE

To illustrate the application of ASME B31S to a nitrogen gas supply system. The system consists of

(1) The cryogenic, liquid nitrogen vessel.
(2) Liquid nitrogen stainless steel pipe to the vaporizer.
(3) Gas nitrogen carbon steel pipe to the building penetration.

S101 - SCOPE

The piping has been designed for normal operating loads (pressure, temperature, weight) in accordance with the ASME B31.3 Process Piping code. The pipe size is 2" sch.40.

The piping has been constructed (materials, welding, NDE and hydrotesting) in accordance with ASME B31.3 Process Piping system.

S103 – OWNER'S REQUIREMENTS

(a) The scope and boundaries of piping systems to be seismically retrofitted is from the liquid nitrogen vessel, through the vaporizer J-L, to the building penetration AI, as shown in Figure 9.2-1.
(b) The applicable code is ASME B31.3.
(c) The pipe is considered "critical". The system is required to operate following the earthquake.
(d) The free field seismic input is to be obtained from IBC-2000.
(e) The in-structure seismic response spectra is to be obtained from IBC-2000 (1 + 2z/h amplification factor for elevation).
(f) The operating and design conditions concurrent with the seismic load:
The liquid pipe (vessel to vaporizer) operates at -250 ^{o}F and 250 psi.
The gas pipe (vaporizer to building penetration) operates at 80 ^{o}F and 250 psi.
(g) The seismic evaluation must address seismic interactions.
(h) The system is already installed, so there is no need for as-built reconciliation of procurement and construction deviations.

S200 – MATERIALS

S201 – APPLICABILITY

The pipe from the vessel to the vaporizer is ASTM A372 type 316, used above the minimum permitted temperature, per ASME B31.3 table A-1. The gas pipe (vaporizer to building) is carbon steel ASTM A 106 Grade B. All joints are welded, except for vaporizer inlet and outlet flanges.

S202 – RETROFIT

The piping system was walked-down and inspected for material condition. The inspection report is enclosed, in Appendix A.

S300 – DESIGN

S301 - SEISMIC INPUT

The horizontal load is developed based on IBC-2000

$F_P = (0.4\ a_P\ S_{DS}\ I\ /\ R_P)\ (1 + 2z/h)\ W$
$a_P = 1.0$
$S_{DS} = 0.8g$
$I = 1.5$
$R_P = 3.5$
$z = h/2$
Therefore, $F_P = 0.27\ W$
But F_P can not be less than $0.3\ S_{DS}\ I\ W = 0.36\ W$
The applied lateral acceleration is therefore 0.36 g.

Note that z = h/2 because part of the piping runs along mid-height of the building exterior wall.

The vertical acceleration is $0.2\ S_{DS} = 0.16$ g

S302 – DESIGN METHOD

Given that (a) the pipe is 2”, (b) the lateral acceleration is 0.36g,and (c) the piping system is critical, then – according to table S302-1 – the piping can be seismically designed by rule, with notes (2) and (3) from table S302-1:

Note (2) Detailed seismic design of braces is required for critical piping systems, and will be addressed in section S306.
Note (3) Operability is required, and will be addressed in section S308.

S303 – DESIGN BY RULE

Upstream from the vaporizer (liquid side): The longest span of pipe is 11 ft (from tie-back support E to vaporizer inlet flange J). There are two extended stem manual valves (F and G) on this 11-ft section. They weigh 10 lb each, or the equivalent of 4 ft of 2” sch 40 liquid-filled pipe (5.15 lb/ft). The total length of pipe (11 ft) plus equivalent length of the two valves (4 ft) is within the 20-ft span, well within the 20-ft guideline for liquid filled pipe.

Downstream from the vaporizer (gas side): The longest span is 9 ft (from AB to AD). The pipe spans are within the 30-ft guideline for gas pipe.

The two relief valves at location C weigh 30 lb each. The maximum unintensified bending stress at the bottom of the 3-ft riser is

$$M/Z = 30 \text{ lb x } 24\text{"} / 0.56 \text{ in}^3 = 1286 \text{ psi}$$

The seismic bending stress is well below the allowable seismic stress, acceptable.

Since we did not add seismic braces, we have not modified the flexibility of the liquid section which operates at – 250 ^oF.

S304 - DESIGN BY ANALYSIS

Stress analysis of the piping system is not required, in accordance with section S302.

S305 – MECHANICAL JOINTS

All piping joints are either welded or flanged with ASME B16.5 class 150 flanges. The pressure gage at Z is welded.

S306 – SEISMIC BRACING AND ANCHORAGE

Liquid side: The resultant load on the tie-back support at E is

$$½ \{(11 \text{ ft} + 4 \text{ ft}) \text{ x } (5.15 \text{ lb/ft}) \text{ x } [(0.36 \text{ g})^2 + (0.16 \text{ g})^2]^{0.5}\} = 15 \text{ lb}$$

The load is well within the capacity of the brace and its weld to the tank structure.

Gas side: The resultant load on each strut in regulator station Q-to-X is

$$½ \text{ x } ½ \text{ x } 30 \text{ ft x } 5.15 \text{ lb/ft x } [(0.36 \text{ g})^2 + (0.16 \text{ g})^2]^{0.5} = 15 \text{ lb}$$

The load is well within the capacity of the strut, its base plate and anchor bolts.

Gas side: The load on the finger clamps on the building wall (AB, AD, AE, AF, AH) is

$$½ \text{ x } 9 \text{ ft x } 5.15 \text{ lb/ft x } [(0.36 \text{ g})^2 + (0.16 \text{ g})^2]^{0.5} = 9 \text{ lb}$$

The load is within the catalog 100 lb load capacity of the finger clamp.

S307 - STATIC EQUIPMENT

The seismic evaluation of the vessel and of the vaporizer would be conducted in accordance with ASME and IBC codes. Their anchorage would be analyzed per ACI 318 Appendix D.

S308 - ACTIVE EQUIPMENT

Per Owner Requirement (c) in section S103, the system is to remain functional, capable of delivering gas to the building during and following the earthquake.

Pressure Regulators: There are two self-actuated pressure regulators on the gas side (U and T) which are to remain in the normal operating condition during and following the earthquake. The regulators are to remain functional (should not fail close or open). They are qualified by comparison to similar valves shake table tested per ICBO ACI 156 at an input response spectrum larger than the facility ground spectrum.

Liquid Pressure Relief Valves: There are two liquid pressure relief valves (D). They may not fail open, which would deplete the vessel contents. They are qualified by comparison to similar valves shake table tested per ICBO ACI 156 at an input response spectrum larger than the facility ground spectrum.

Gas Pressure Relief Valve: There is one gas pressure relief valve at P. It may not fail open, which would deplete the vessel contents. It is qualified by comparison to similar valves shake table tested per ICBO ACI 156 at an input response spectrum larger than the facility ground spectrum.

Manual Valves: There are two extended stem manual valves (F and G) they are to remain as-is (open). The stem and hand wheel are light weight, and the open gate valve acts as a passive component, which – if it was to fail – would fail in-place (binding).

Plug and Check Valves: Considered passive components, would fail in place (acceptable).

S400 - INTERACTIONS

As indicated in the walkdown inspection report, in Appendix A, two potentially credible and significant spatial seismic interactions have been identified:
(1) The building block wall.
(2) The second vessel.

These potential interactions must be analyzed to determine whether they could collapse on the system.

S500 - DOCUMENTATION

(a) Drawings are enclosed (Figures 1 and 2).
(b) Final pipe support arrangement is shown in Figure 2. The installed configuration is acceptable as-is.
(c) Calculations are documented in this report.
(d) Operability (here, provide documentation of operability test or analysis of valves).
(e) The installed supports are acceptable as-is. No new support drawings are required.

S600 – MAINTENANCE

All supports have been tagged to read “seismic support – do not modify”. Plant drawings have been marked to indicate “seismic system – do not modify without engineering approval”.

S700 - REFERENCES

ACI 318 Building Code Requirements for Reinforced Concrete, American Concrete Institute.

AISC, Manual of Steel Construction, American Institute of Steel Construction.

ASME B31.3, Process Piping, American Society of Mechanical Engineers, New York, NY.

IBC, International Building Code, International Code Council, Falls Church,VA.