Second Revised Response to Request for Additional Information – ANP-10264NP “U.S. EPR Piping Analysis and Pipe Support Design Topical Report” (TAC No. MD3128)

RAI EPR-8: *Independent Support Motion Method*

The current staff position for the Independent Support Motion (ISM) method of analysis is presented in Volume 4, Section 2 of NUREG-1061, "Report of the US NRC Piping Review Committee. "Some differences (e.g., modal combinations per RG 1.92 for uniform support motion (USM) only) were noted between the ISM method of response combinations (both methods and their sequence) presented in the TR Section 4.2.2.2.2, and the method given in NUREG-1061. Indicate whether all of the provisions (for groups, modes, spatial and inertial and SAM combination methods) contained in NUREG-1061 for the ISM method of analysis will be followed or provide the technical justification for any alternatives or methods described in the TR.

Response 8:

All of the provisions of NUREG-1061 for the ISM method of analysis will be followed. The following revisions to the TR will be made for clarification:

Section 4.2.2.2.1, the 2nd paragraph will be revised as follows:

> "The combinations of modal responses and spatial components for systems analyzed using USM are performed consistent with the guidance provided in RG 1.92. The modal and directional responses are combined as discussed in Sections ...."

Section 4.2.2.2.2 will be revised to include a reference to NUREG-1061, Volume 4 as follows:

> “The combinations of modal responses and spatial components for systems analyzed using ISM are performed consistent with the recommendations in NUREG-1061, Volume 4. Additionally, when using independent support motion, the seismic response of each mode is calculated by combining the responses of all support groups into one by using absolute summation method per the recommendations of NUREG-1061.”

Section 4.2.2.3 will be revised as a result of the revised response to RAI EPR-27 regarding the use of Regulatory Guide 1.92, Revision 2. The following changes will be included in Attachment B to this response.

- New paragraphs (third and fourth) will be added to Section 4.2.2.3 to state that modal response combinations will be per the guidance of RG 1.92 as discussed in Sections 4.2.2.3.1 through 4.2.2.3.4 for USM analyses and per NUREG-1061 as discussed in Section 4.2.2.3.5 below for ISM analyses.
- Section 4.2.2.3.1, first sentence, will be revised as follows:

> “RG 1.92 provides guidance on combining the individual periodic modal results due to each response spectrum in a dynamic analysis performed using USM.”

~~and the following text will be added to the end of this section:~~

> ~~“For piping systems analyzed using ISM methods, modal results are combined without the consideration of closely spaced modes, per NUREG-1061. Therefore, for these systems, modal results are combined by the SRSS method presented above.”~~ (Note: the deleted text has been moved to new section 4.2.2.3.5)

- Sections 4.2.2.3.1 through 4.2.2.3.4: These sections will be revised or added to add clarification for modal response combination methods used for USM analyses, which will be performed using the methodologies provided in Regulatory Guide 1.92 Revision 2. See RAI EPR-27 and Attachment B to this response for details.

- Section 4.2.2.3.5: This section will be added to clarify the modal response combination methods for ISM analyses.

Section 4.2.2.5 will be revised to read as follows:

> “The analysis of these seismic anchor motions (SAM) will be performed as a static analysis with all dynamic supports active. The results of this analysis shall be combined with the piping system seismic inertia analysis results by absolute summation when an enveloped uniform support motion is used for the dynamic analysis, per SRP 3.7.3. When independent support motion is used in the inertial analysis, the responses due to the relative displacements and those due to inertia are combined by the SRSS method, per NUREG-1061.”

RAI EPR-15: *Buried Piping*

TR Section 3.10 did not give details on the analysis method and how the criteria are to be applied in the design of buried piping.

A. Based on the criteria presented in the TR, describe the analysis method and design requirements that will be used for buried piping design (including buried pipe tunnel if used in the design). Explain how these methods compare to the analytical methods referenced in the recently published NRC Standard Review Plan 3.7.3, Rev. 3, (i.e., ASCE Standard 4-98, ASCE Report - Seismic Response of Buried Pipes and Structural Components, and NUREG/CR-1161).

B. Why doesn’t TR Section 3.10 include consideration of ground-water effects and soil arching effects which could increase or decrease the stresses in the pipe due to the overlying soil plus the ground surface loads?

D. TR Table 3-4 provides the design conditions, load combinations and acceptance criteria for Class 2/3 buried piping. Explain clearly the term non-repeated anchor movement, Equation 9U (vs 9), and Equation 9E (vs 9). While the intent may be interpreted, it is important that these terms be clearly defined in the TR. For Equations 10M and 11M, which are identified as “modified to include axial friction forces,” provide the equations to show how they are modified.

F. Confirm that Note 5 in the TR Table is applicable to all cases cited in TR Table 3-4 since it is not referenced in the Table like the other notes are. Also, explain how the criteria of

NC/ND-3133 of the ASME Code (Note 5 in the Table) will be implemented in conjunction with meeting the loads and loading conditions specified in Table 3-4.

Response 15:

A. Section 3.10 of the TR will be revised to include analysis methods and design requirements for buried piping, as shown in Attachment B to this response.

The methods developed for the U.S. EPR buried piping meet requirements in SRP 3.7.3, Rev. 3, ASCE Standard 4-98 and ASCE Report-Seismic Response of Buried Pipes and Structural Components.

The revised Attachment B also includes Tables 3-5 and 3-6 that are referred to in Section 3.10.1.4 of the TR.

B. Section 3.10 of the TR will be revised as shown in Attachment B to include buoyancy forces from ground-water, overburden, and surface traffic from trucks, rail and construction equipment, as shown in Attachment B to this response.

D. Non-repeated anchor movements, in the case of buried pipe, refers to building settlement at the point where the buried pipe enters the building. Equations 9U and 9F refer to upset and faulted respectively. These designations are used to distinguish the differences in plant events that occur during the upset or faulted plant conditions and must be combined per equation 9 and meet the allowable stresses as noted in the various section of NC/ND 3650.

The TR will be revised as shown in Attachment B to provide revised equations 10M and 11M and define the terms in these equations.

F. Note 5 will be added to Table 3-4 as appropriate. As shown in Attachment B, the external pressure of the soil overburden defined in NC/ND-3133 will be added to the discussion in 3.10. Note 5 applies to the equations that include a pressure term. The TR will be revised to include this term.

<u>RAI EPR-18:</u> *Piping Model Structural Boundaries*

TR Sections 5.4.1.2 and 5.4.1.3 describe two alternate approaches of separating a piping analysis model using an elbow or a tee within the piping model. While these approaches may be technically sound, no references or technical justifications are provided for each of these methods. Provide technical justifications and limitations (if any) for these two methods of establishing piping model terminations. Also, discuss the basis for selecting the dimensions of L1 and L2 in TR Figure 5-1 for a restrained elbow and Figure 5-2 for a restrained tee.

Response 18:

The TR will be revised as shown in Attachment B to delete sections 5.4.1.2 and 5.4.1.3 including Figures 5-1 and 5-2.

RAI EPR-25: *Piping Load Combinations*

The staff needs clarification of several items associated with TR Section 3.3 and Tables 3-1 and 3-2.

C. Note 8 to TR Table 3-1 states that the earthquake inertial load used in the Level D Primary Stress (Equation 9F) calculations shall be taken as the peak SSE inertial load. The earthquake anchor motion load used in the Level D Primary Stress (Equation 9F) calculations shall be taken as the peak SSE anchor motion load. The staff position on the use of a single-earthquake design in SECY-93-087 states that the effects of anchor displacements in the piping caused by an SSE be considered with the Service Level D limits. For simplified elastic-plastic discontinuity analysis, if Eq. 10 cannot be satisfied for all pairs of load sets, then the alternative analysis per NB-3653.6 for Service Level D should be followed. In addition, the combined moment range for either the resultant thermal expansion and thermal anchor movements plus ½ the SSE seismic anchor motion or the resultant moment due to the full SSE anchor motion alone, whichever is greater must satisfy the equation (known as Eq. 12a) given in NB-3656(b)(4). Clarify if this is applicable to EPR piping design. Also, justify why this anchor motion stress is categorized as a primary stress in the TR Table 3-1 for the faulted condition.

Response 25:

C. At the time that the Topical Report was written, portions of Section III NB-3600 in the 2004 Edition of the ASME Boiler and Pressure Code were not endorsed by the NRC, per the version of 10CFR50.55a in effect at that time. The proposed draft of 10CFR50.55a which was published in spring of 2007 indicates that restrictions on the use of the rules involving seismic loading have been removed. AREVA will therefore reference the equations from NB-3656(b)(4) for the treatment of SSE anchor motions. TR Table 3-1 will be revised as shown in Attachment B to provide further clarification of the Class 1 load combinations.

RAI EPR-26: *Piping Damping Values*

In TR Section 4.2.5, it is identified that Rev. 0 of the RG 1.61 values of damping will be used in the seismic analysis of structures, systems, and components (SSCs) using ISM response spectrum analysis or time history analysis. However, for piping systems analyzed using USM response spectrum analysis, 5% damping will be used provided that the system is not susceptible to stress corrosion cracking. Five percent damping will not be used for analyzing the dynamic response of piping systems using supports designed to dissipate energy by yielding.

B. For piping systems analyzed using uniform support motion response spectrum analysis and 5% damping, verify that all of the limitations specified in RG 1.84 for ASME Code Case N-411 (or RG 1.61, Rev.1) will be met.

Response 26:

TR Section 4.2.5 will be revised as shown in Attachment B to this response, to specify that RG 1.61, Revision 1, damping values will be used for USM, ISM, and time-history analysis.

RAI EPR-27: *Modal Combinations*

In TR Section 4.2.2.3.1, it is stated that for the response spectrum method of analysis, the modal contributions to the inertial responses are normally combined by the SRSS method. If some or all of the modes are closely spaced, any one of the methods (Grouping method, 10% method, and Double Sum method, as well as the less conservative methods in revision 2 of the RG 1.92) is applicable for the combination of modal responses. This combination method is applicable to both USM and ISM methods of analysis.

A. If guidance given in Revision 2 of the RG 1.92 is used for the EPR piping design, then Revision 2 of the RG no longer recognizes the Grouping method, 10% method and Double Sum method for closely spaced modes. These methods are renamed and AREVA should identify them as noted in the RG.

B. TR states that for closely spaced modes AREVA may use less conservative methods discussed in the RG. Please identify which methods are less conservative methods and explain why they are less conservative with respect to the other method(s).

Response 27:

A. AREVA NP will use RG 1.92, Revision 2, methods of modal combination for piping analyzed using USM (Note: RAI EPR-8 addresses ISM method of analysis). TR Sections 4.2.2.3 and 4.2.5 will be revised as shown in Attachment B to this response.

B. See the response to item A above.

RAI EPR-37: *Inclusion of Support Self-Weight Excitation*

In TR Section 6.8, AREVA did not indicate if the criteria presented is also applicable to other dynamic loads and did not discuss how the damping value will be used in the response spectrum analysis.

A. Clarify whether the criterion presented in the TR is also applicable to other dynamic loads. If not, provide technical justification.

B. Since the piping and support structure damping value may be different per RG 1.61, discuss what damping value will be used in the response spectrum analysis when the support structure is also modeled as part of the piping analysis. See also RAI EPR-32.

Response 37:

A. Section 6.8 of the TR will be revised as shown in Attachment B to address other dynamic loads.

B. In most cases, Revision 1 of RG 1.61 calls for 4 percent damping for the piping analysis. Similarly, the RG allows for 4 percent damping for welded steel or bolted steel with friction connections and 7 percent for bolted steel with bearing connections, which would be applicable for the supports. If frequency dependent damping values are used in the piping analysis, the support structure will still utilize the 4 percent or 7 percent damping values.

In those analyses where the support\restraint stiffnesses are explicitly represented in the analysis model and where the support damping is judged to be different than the piping damping, one of two approaches may be taken: 1) the lower of the support\restraint and piping damping may be applied to both support\restraints and piping, or 2) composite modal damping (as described in AREVA response to RAI EPR-32) may be used.

Description of Changes to the Piping Topical Report

Page number	Section	Description of Change
Att. B, pages 2 and 3	Table 1-1 and section 2.3	Based on discussion with NRC, the term "as-built" was changed to "as-designed" for the COL action item regarding development of design specifications and design reports.
Att. B, pages 4 through 11, pages 17 through 19, and page 25	Section 3.10 and Tables 3.4 through 3.6	Changed to reflect the revised response to RAI EPR-15.
Att. B, pages 12 through 16	Table 3-1	Changed to reflect the revised response to RAI EPR-25C.
Att. B, pages 20 through 24	Section 4.2.2.3	Changed to reflect the revised responses to RAI EPR-27 and RAI EPR-8.
Att. B, page 25 and 30	Section 4.2.5 and References	Changed to reflect the revised responses to RAI EPR-26 and RAI EPR-27. This section also includes the changes in response to RAI EPR-32.
Att. B, pages 26 through 28	Sections 5.4.1.2 and 5.4.1.3, Figures 5-1 and 5-2	Deleted sections 5.4.1.2 and 5.4.1.3, Figures 5-1 and 5-2 per the revised response to RAI EPR-18
Att. B, page 29	Section 6.8	Changed to reflect the revised response to RAI EPR-37.

Table 1-1: Analysis and Design Responsibilities for COL Applicants

ITEM	COL Applicant Responsibility	Applicable Section
1	COL applicant will identify any additional Code Cases used that are not listed in this Topical Report for piping not included in the scope of the U.S. EPR Design Certification.	2.2
2	The COL applicant will develop the design specification and the design reports using requirements outlined in the Code and demonstrate and document that as-~~built~~ designed piping and support configurations adhere to the requirements of the design specification.	2.3
3	Should the COL applicant find it necessary to route Class 1, 2 and 3 piping not included in the U.S. EPR Design Certification in such a manner that it is exposed to wind and/or tornadoes, it must be designed to withstand the plant design basis loads for this event	3.3.1.6
4	The COL applicant will confirm that thermal deflections do not create adverse conditions on the pressurizer surge line during hot functional testing.	3.7.2
5	A review of the impact of contributing mass of supports on the piping analysis will need to be performed by the COL applicant(s) following the final support design to confirm that the mass of the support is no more than 10% of the mass of the adjacent pipe span.	5.2
6	Pipe stress and support analysis will be performed by the COL applicant(s). A COL applicant choosing to use a piping analysis program other than those listed in Section 5.1 will implement the U. S EPR benchmark program using models specifically selected for the U.S. EPR.	5.3
7	The COL Applicant will verify proper installation and operation of snubbers utilizing visual inspections, hot and cold position measurements, and observance of thermal movements during plant startup.	6.6

- ASME Code Case N-318-5, ‘Procedure for Evaluation of the Design of Rectangular Cross Section Attachments on Class 2 or 3 Piping, Section III, Division 1.’
- ASME Code Case N-319-3, ‘Alternate Procedure for Evaluation of Stresses in Butt Welding Elbows in Class 1 Piping Section III, Division 1.’
- ASME Code Case N-391-2, ‘Procedure for Evaluation of the Design of Hollow Circular Cross Section Welded Attachments on Class 1 Piping, Section III, Division 1.’
- ASME Code Case N-392-3, ‘Procedure for Evaluation of the Design of Hollow Circular Cross Section Welded Attachments on Class 2 and 3 Piping, Section III, Division 1.’

Other ASME Code Cases may be used in the Design Certification if they are either conditionally or unconditionally approved in Regulatory Guide (RG) 1.84[4]. In addition, new Code Cases may be used by the Combined Construction Permit and Operating License (COL) applicant if they are included in RG 1.84[4].

2.3 Design Specification

A design specification is required by Section III of the ASME Code[2] for ASME Class 1, 2 and 3 piping. In addition, the ASME Code requires design reports for all Class 1, 2 and 3 piping demonstrating and documenting that as-designed~~built~~ piping and support configurations adhere to the requirements of the design specification. It is the responsibility of the COL applicant or his agent to develop the design specification and the design reports using requirements outlined in the ASME Code.

3.10 *Seismic Category I Buried Pipe*

Class 2 and 3 Seismic Category I buried piping systems in the U.S. EPR will be analyzed for pressure, weight, thermal expansion and seismic loads using dynamic or equivalent static load methods. The acceptance criteria for buried piping systems are described in Table 3-4.

3.10.1 *Static Loads and Load Combinations for Buried Pipe*

Loads and Loading Conditions are similar to those outlined in 3.3 but are modified for additional considerations of strains and stresses induced by the motion of the pipe in the surrounding soil mass. Thermal loads are impacted by the friction between the pipe and soil due to expansion and contraction of the pipe per the guidance in Reference 13.

3.10.1.1 *Pressure*

Internal Design Pressure, P, is calculated as described in 3.3.1.1. However, there is an external pressure, P_V, for buried pipe associated with the overburden of soil and P_P for loads from surface loads. The allowable external pressure is calculated using the methods and formula in NC/ND-3133.

3.10.1.2 *Deadweight*

For buried pipe, deadweight loads must include the weight of the soil overburden. It must also include live loads from surface traffic such as trucks, rail and construction equipment.

3.10.1.3 *Soil Overburden*

Soil overburden pressure is dependent on the diameter of buried pipe as well as the burial depth relative to the ground water table. Buried pipes are designed for soil load corresponding to weight of the overlying soil prism.

$P_v = \gamma H$ This equation applies to pipes buried above the groundwater table.

Where P_v = overburden pressure on pipe due to soil, psi

γ = dry unit weight of backfill material, lbs/in^3

H = burial depth to top of pipe, inches

In the case where the pipe is located below ground water table or where seasonal change in ground water table is significant, the effect of buoyancy and increased weight of water should be considered. For such condition, soil pressure should be computed as follows:

$$P_v = \gamma H - 0.33\gamma h + \gamma_w h$$

Where h = depth of groundwater above pipe, inches

γ_w = unit weight of water, lbs/in^3

3.10.1.4 *Surface Loads*

Live loads such as those imposed by trucks, rail, and construction equipment or other construction conditions should be considered in the analysis and design. The pressure transmitted to the buried pipe under these loads may be computed as follows:

$$P_p = 0.48 \frac{P_s}{H^2\left[1+\left(\frac{d}{H}\right)^2\right]^{2.5}}$$

Where P_p = surface load transmitted to the buried pipe, psi

d = offset distance from the surface load to buried pipe, inches

H = thickness of soil cover above the pipe, inches

P_s = concentrated surface load, lbs

The magnitude of P_p above is multiplied by an impact factor which is dependent on the soil cover and type of surface load. Table 3-5 shows some recommended values of impact factors. The magnitude of P_p may be taken from Table 3-6 which is based on AASHTO HS-20 Truck and Copper E-80 railroad loads [13]. The values reported in Table 3-6 include an impact factor of 1.50.

COL applicants should perform detailed geotechnical engineering analysis to determine if the surface load will cause lateral and/or vertical displacement of bearing soil for the piping. Consideration should also be given to the effect of wide and extra heavy loads when evaluating the buried utility.

3.10.1.5 *Bouyancy Force*

For utilities buried below groundwater table, vertical force due to buoyancy should be considered and may be evaluated as follows:

$$F_b = W_w - W_p - P_v D + \gamma_w hD$$

The above equation conservatively assumes that the pipe is empty.

Where F_b = buoyancy force per unit length of pipe, lb/in

D = outside diameter of the pipe, inches

P_v = γH = overburden pressure due to soil, psi

W_w = weight of water displaced by pipe per unit length, lb/in

W_p = self weight of pipe per unit length, lb/in

The corresponding buoyancy stress on the utility may be computed as follows:

$$\sigma_b = \frac{F_b L^2}{10Z}$$

Where L = length of the utility in the buoyancy zone, inches

Z = section modulus of the utility, in^3

3.10.1.6 *Pipe Ovalization*

Under combined dead and live loads, buried pipes tend to ovalize thereby causing through-wall bending stresses. The allowable ovalization (Ref. [13]) of the pipe diameter may be evaluated using the following equation:

$$\text{Pipe ovality} = \frac{\Delta}{D} = \frac{D'KP}{\left[\frac{(E_{sct} I)_{eq}}{R^3} + 0.061E'\right]}$$

$$\sigma_b = 4E_{sct}\frac{\Delta}{D}\frac{t}{D}$$

Where

E' = modulus of soil reaction, psi

K = bedding constant (typically taken to be 0.1)

R = outside radius of pipe, inches

Δ = vertical deflection of the utility/pipe, inches

P = pressure due to soil overburden, surface loads, flooding, and snow load, psi

$(E_{sct}\ I)_{eq}$ = equivalent pipe wall stiffness per unit length of pipe, $lb\text{-}in^2/in$~~in./lb~~

σ_b = through-wall bending stress, psi

~~D = diameter of the pipe~~

t = thickness of the pipe, inches

E_{sct} = secant Modulus of the pipe material, psi (Note: E_{sct} = E if pipe is fabricated from steel)

D' = deflection lag factor (typically taken to be between 1.0 and 1.50)

I = $t^3/12$ = moment of inertia, in^4/in~~, in^4~~

Pipe must be buried deep enough such that crushing of side wall of the pipe is eliminated. Soil, surface, and other credible event loads must not be excessive so as to cause buckling of the pipe. To avert ring buckling, the magnitude of the total vertical pressure should be limited to equation below.

$$P(\textit{as defined for ovality}) \le \frac{1}{FS}\sqrt{32R_w B'E'\frac{(E_{sct}I)_{eq}}{D^3}}$$

FS = factor of safety with value dependent on relative magnitude of thickness of cover soil, H and external pipe diameter, D. For $H/D < 2.0$, FS = 3.0 and for $H/D \ge 2$, FS = 2.5

R_W = water buoyancy factor with magnitude $1 - 0.33h/H$ (0<h<H)

h = height of ground water table above the top of the buried utility, inches

B' = dimensionless empirical coefficient of elastic support.

$$B' = \frac{1}{1 + 4e^{\left(-0.065\frac{H}{D}\right)}}$$

All the other parameters in above equation have been defined previously.

The effects of pressure (P, P_P, P_v), dead and live loads and loads from the effects of ovality must meet the requirements of Table 3-4 as follows for Equation 8:

$$S_{SL} = \frac{B_1 PD}{2t_n} + \frac{B_2 M_A}{Z} + \frac{F_b L^2}{10Z} + 4E_{sct}\frac{\Delta}{D}\frac{t}{D} \le 1.5S_h$$

Where S_{SL} = Stress from sustained loads, psi

P = Internal pressure + ABS Sum (P_P +P_V), psi

B_1, B_2 = Stress indices

~~D_O = Pipe outside diameter~~

t_n = Pipe nominal wall thickness, inches

M_A = Moment due to weight, in-lbs

S_h = Allowable stress (hot), psi

3.10.2 *Thermal Expansion and Contraction*

Depending on the relative temperature of the soil in which the pipe is buried and the temperature of the fluid contained in the pipe, a pipe that is fully restrained by the surrounding soil may experience contraction or expansion. This thermal-induced stress (due to friction between the pipe and soil) should be considered and may be evaluated as follows:

$$\sigma_A = E_{sct}\alpha(T_2 - T_1)$$

Where

σ_A = axial compressive stress, psi, in fully restrained pipe due to difference in temperature between soil and pipe content.

α = coefficient of thermal expansion of the pipe, in/in/°F

T_2 = maximum operating temperature of fluid in the pipe, °F

T_1 = burial installation temperature, °F

The effects of restrained thermal expansion/contraction forces in buried pipe are evaluated against the requirements of NC/ND-3653.2(a) by using a modified Equation 10 or NC/ND-3653.2(c) by using a modified Equation 11. From Reference 2, the equations are as follows:

$$S_E = \frac{iM_C}{Z} + E_{sct}\alpha(T_2 - T_1) \le S_a \qquad \text{Equation 10M}$$

Where S_a = Allowable stress range for thermal expansion, psi

M_C = range of resultant bending moment due to restrained thermal expansion, in-lb

Or

$$S_{TE} = \frac{PD}{4t_n} + 0.75i\frac{M_A}{Z} + i\frac{M_C}{Z} + E_{sct}\alpha(T_2 - T_1) \le (S_h + S_a) \qquad \text{Equation 11M}$$

Where S_E = Stress from restrained thermal expansion, psi

S_{TE} = Stress from pressure, weight and thermal expansion, psi

3.10.3 *Seismic Loads*

Seismic-induced damage to buried piping is largely due to wave propagation or permanent ground deformation resulting from fault movement, landslide, and liquefaction-induced lateral spread. Where buried piping enters a structure, the seismic anchor movements of the structure must be accounted for in the design of the piping. Other forms of damage related to ground movement such as elastic and consolidation settlement (total and differential), freeze-thaw induced settlement, and seismic-induced settlement due to soil compaction and rearrangement should be considered on a case-by-case basis. For the case of piping anchored to an adjacent building, strain development in the utility due to settlement of the building should be evaluated. The seismic effects on buried piping are self limiting in that strains are limited by the surrounding soil. Therefore the stresses due to these strains are secondary in nature.

COL applicants shall carry out site investigation to assess the best route for the underground piping. During this field investigation, sites that are vulnerable to fault movement and liquefaction-induced landslide and lateral spread should be avoided. If a pipe must be buried in loose saturated cohesionless soil susceptible to liquefaction, rigorous linear and non-linear pipe-soil interaction analysis should be carried out to evaluate the integrity of the pipe under settlement and lateral spread conditions that may be caused by the liquefiable soil. If the result of the soil-pipe interaction is not acceptable, any of the following options recommended in Reference [14] may be adopted:

(1) Re-route the pipe to avoid areas of liquefiable loose saturated cohesionless soils;

(2) Modify the strength of the soil by using appropriate stabilizing agent;

(3) Excavate liquefiable soil and replace with competent structural fill materials; or

(4) Support the pipe in soil that is not susceptible to failure.

3.10.3.1 *Axial and Bending Strains Due to Propagation of Seismic Waves*

Typically, the magnitude of axial and bending strains on buried piping due to propagation of seismic wave is dependent on several factors such as the buried material and soil properties and pipe-soil interfacial properties. Conservatively, axial and bending strains on the buried piping are taken to be the same as those of the seismic wave if there is no site specific field instrumentation to measure the strain level experienced by the buried piping. Based on the axial and bending strains developed in the buried piping assuming long, linear runs remote from anchors or bends, the corresponding axial load and bending stress can be computed as follows:

$$F_a = \varepsilon_a A E_{sct}$$

$$M_b = \sigma_b Z$$

Where $\sigma_b = \varepsilon_b E_{sct}$

In above equations,

E_{SCT} = Secant modulus of the buried piping, psi

ε_a = Axial strain in the buried piping due to wave propagation

ε_b = Bending strain in the buried piping due to wave propagation

Z = Section modulus of the buried piping, in^3

A = Cross-sectional area of the pipe, in^2

For the computation of loads developed at elbows, the simplified procedures outlined in reference [14] are recommended for flexible and rigid conditions. At site locations where the differential settlement is significant, flexible anchors may be used in lieu of rigid anchors. All support structures (anchors) should be designed to resist the resulting axial loads and bending stresses.

The general axial and bending strains due to seismic wave propagation may be found as follows:

$$\varepsilon_a = \pm \frac{V}{\alpha_\varepsilon c}$$

$$\varepsilon_b = \pm \frac{Ra}{(\alpha_k c)^2}$$

Where V = maximum velocity of the soil layer (particle) in which the piping is embedded, ft/sec

a = maximum acceleration of the soil layer (particle) in which the piping is embedded, ft/sec^2

c = apparent velocity relative to ground surface, ft/sec

R = radius of the pipe, ft

ε_b = bending strain

ε_a = axial strain

α_e = wave velocity axial coefficient (compression & rayleigh=1.0, shear=2.0)

α_k = wave velocity bending coefficient (compression = 1.6, shear & rayleigh = 1.0)

In reference [15], it is noted that axial and bending strains are a result of three types of seismic waves, (1) compression, (2) shear and (3) surface or Rayleigh. The strain for each wave is calculated using the general form for axial and bending noted above.

As noted in Table 3-2 for above ground piping, the effects of seismic loads on above ground piping must meet the requirements of NC/ND-3655. As further indicated in Table 3-2, and in compliance with the guidance in SECY-93-087, page 23, the effect of SSE seismic anchor displacements (which produce secondary stresses) together with normal loads would be evaluated to a Service Level D limit. This has been done for above ground piping in the secondary stress equation shown in Table 3-2 for Level D. Since the seismic effects in buried pipe produce secondary stresses, to be consistent with Table 3-2 and the guidance provided, the two equations shown below for buried pipe must be evaluated and the worse of the two met. The use of the two equations allows for two possible cases: thermal expansion plus the amplitude of the buried pipe SSE effects or the range (= twice the amplitude) of the buried pipe SSE effects, whichever is larger. The use of the larger of the two results is consistent with the methodology in the example provided in Reference 14, Appendix 3, pages 45 and 46.

$$S_{NSSE} = \frac{iM_C}{Z} + \frac{iM_{SSE}}{Z} + \varepsilon_b E_{sct} + \varepsilon_a E_{sct} + E_{sct}\alpha(T_2 - T_1) \le 3.0S_h \text{ but not > than } 2.0S_y$$

$$S_{SSE} = \frac{2iM_{SSE}}{Z} + 2\varepsilon_a E_{sct} + 2\varepsilon_b E_{sct} \le 3S_h \text{ but not > than } 2.0S_y$$

Where S_{NSSE} = buried pipe stress due to normal plus the amplitude of SSE loads

S_{SSE} = buried pipe stress due to the range of SSE loads

M_{SSE} = amplitude of moments due to earthquake moment loading and anchor movements; earthquake moment loading is induced in the pipe near bends, intersections, and anchor points as described in Reference 15, Section 3.5.2.2(b)

S_y = yield stress

The allowable stress, $3.0S_h$ or $2.0S_Y$, is based on service level D limits due to the fact that only SSE load case is evaluated in the piping design for the U.S. EPR.

The value of M_{SSE}, ε_b and ε_a represent the amplitude of the seismic moment and seismic strains.

~~. In addition to the above equation, the following equation, which checks the range of seismic motion, shall also be evaluated:~~

~~$S_{OL} = \frac{2iM_{SSE}}{Z} + 2\varepsilon_a E_{sct} + 2\varepsilon_b E_{sct} \le 3S_h$ but not>than 2.0S_y~~

Table 3-1: Load Combinations and Acceptance Criteria for ASME Class 1 Piping

Service Condition	Service Level	Category	Loading or Stress Component	Acceptance Criteria[1]
Design	-	Primary Stress	Design Pressure, Deadweight, Steady State Flow Load and Dynamic Fluid Load[2] specified as Level A	Eq 9N NB-3652
Normal	A	Primary plus Second-ary Stress Intensity Range (S.I.R.)	Range of Level A: Service Pressure, Steady State Flow Load, Dynamic Fluid Load[2], Thermal Expansion Load[3], Thermal Expansion Anchor Motion Load[3], Cyclic Thermal Load[4], Material Discontinuity Stress	Eq 10N NB-3653.1
		Peak S.I.R.	Range of Level A: Service Pressure, Steady State Flow Load, Dynamic Fluid Load[2], Thermal Expansion Load[3], Thermal Expansion Anchor Motion Load[3], Cyclic Thermal Load[4], Material Discontinuity Stress,~~Same as for Level A Primary plus Secondary S.I.R. plus Range of Level A~~ Thermal Radial Gradient Stress (linear and non-linear)	Eq 11N NB-3653.2
		Thermal S.I.R.[5]	Range of Level A: Thermal Expansion Load[3], Thermal Expansion Anchor Motion Load[3], Cyclic Thermal Load[4]	Eq 12N NB-3653.6(a)
		Primary plus Second-ary Membrane plus Bending S.I.R.[5]	Range of Level A: Service Pressure, Steady State Flow Load, Dynamic Fluid Load[2], Material Discontinuity Stress~~Same as for Level A Primary plus Secondary S.I.R. except Range of Level A Thermal Expansion Load[3], Thermal Expansion Anchor Motion Load[3] and Cyclic Thermal Load[4] is not Considered~~	Eq 13N NB-3653.6(b)
		Alternating Stress Intensity (S.I.) (Fatigue Usage)[6]	Range of Level A: Service Pressure, Steady State Flow Load, Dynamic Fluid Load[2], Thermal Expansion Load[3], Thermal Expansion Anchor Motion Load[3], Cyclic Thermal Load[4], Material Discontinuity Stress, Thermal Radial Gradient Stress (linear and non-linear)~~Same as for Level A Peak S.I.R.~~	Eq 14N NB-3653.6(c)
		Thermal Stress Ratchet	Range of Level A Linear Thermal Radial Gradient	NB-3653.7

Table 3-1: Load Combinations and Acceptance Criteria for ASME Class 1 Piping

Service Condition	Service Level	Category	Loading or Stress Component	Acceptance Criteria[1]
Upset	B	Permissible Pressure	Maximum Level B Service Pressure	NB-3654.1
		Primary Stress	Coincident Level B Service Pressure, Deadweight, Steady State Flow Load, Dynamic Fluid Load[2]	Eq 9U NB-3654.2(a)
		Primary plus Secondary S.I.R.	Range of Level B: Service Pressure, Steady State Flow Load, Dynamic Fluid Load[2], Thermal Expansion Load[3], Thermal Expansion Anchor Motion Load[3], Cyclic Thermal Load[4], Material Discontinuity Stress,~~Same as for Level A Primary plus Secondary S.I.R. (except Level B Load and Stress Ranges are used) plus~~ Earthquake Inertial Load[7]	Eq 10U NB-3654.2(b)
		Peak S.I.R.[8]	Range of Level B: Service Pressure, Steady State Flow Load, Dynamic Fluid Load[2], Thermal Expansion Load[3], Thermal Expansion Anchor Motion Load[3], Cyclic Thermal Load[4], Material Discontinuity Stress, Earthquake Inertial Load[7]~~Same as for Level B Primary plus Secondary S.I.R. plus~~, ~~Range of~~ Level B Thermal Radial Gradient Stress (linear and non-linear)	Eq 11U NB-3654.2(b)
		Thermal S.I.R.[5]	Range of Level B: Thermal Expansion Load[3], Thermal Expansion Anchor Motion Load[3], and Cyclic Thermal Load[4]	Eq 12U NB-3654.2(b)
		Primary plus Second-ary Membrane plus Bending S.I.R.[5]	Range of Level B: Service Pressure, Steady State Flow Load, Dynamic Fluid Load[2], Material Discontinuity Stress, Earthquake Inertial Load[7]~~Same as for Level B Primary plus Secondary S.I.R. except Range of Level B Thermal Expansion Load[3], Thermal Expansion Anchor Motion Load[3] and Cyclic Thermal Load[4] is not Considered~~	Eq 13U NB-3654.2(b)
		Alternating S.I. (Fatigue Usage)[6]	Range of Level B: Service Pressure, Steady State Flow Load, Dynamic Fluid Load[2], Thermal Expansion Load[3], Thermal Expansion Anchor Motion Load[3], Cyclic Thermal Load[4], Material Discontinuity Stress, Earthquake Inertial Load[7], Level B Thermal Radial Gradient Stress (linear and non-linear)~~Same as for Level B Peak S.I.R.~~	Eq 14U NB-3654.2(b)
		Thermal Stress Ratchet	Range of Level B Linear Thermal Radial Gradient	NB-3654.2(b)

Table 3-1: Load Combinations and Acceptance Criteria for ASME Class 1 Piping

Service Condition	Service Level	Category	Loading or Stress Component	Acceptance Criteria[1]
		Deformation Limits	As Set Forth in the Design Specification	NB-3654.2(b)
Emergency[9]	C	Permissible Pressure	Maximum Level C Service Pressure	NB-3655.1
		Primary Stress	Coincident Level C Service Pressure, Deadweight, Steady State Flow Load, Dynamic Fluid Load[2]	Eq 9E NB-3655.2(a)
		Deformation Limits	As Set Forth in the Design Specification	NB-3655.3
Faulted	D	Permissible Pressure	Maximum Level D Service Pressure	NB-3656(a)(1)
		Primary Stress[10]	Coincident Level D Service Pressure, Deadweight, Steady State Flow Load, Dynamic Fluid Load[2,11], Earthquake Inertial Load[11], High Energy Line Break Load[11] (Loss-of-Coolant Accident or Secondary Side Pipe Rupture)	Eq 9F NB-3656(a)(2)
		Secondary Stress[12]	MAX[Range of (Bending Moment due to Thermal Expansion Load[3] plus Thermal Expansion Anchor Motion Load[3] plus ½ Earthquake Anchor Motion Load) OR Range of Earthquake Anchor Motion Load]	6Sm[13]
Pressure Testing[15]	-	Primary Membrane S.I.	Test Pressure, Deadweight	NB-3657 NB-3226(b)
		Primary Membrane plus Bending S.I.	Test Pressure, Deadweight	NB-3657 NB-3226(c)

Table 3-1: Load Combinations and Acceptance Criteria for ASME Class 1 Piping

Notes:

1. Acceptance Criteria are taken from the referenced section in Section III of the ASME Boiler and Pressure Vessel Code, or are as noted.
2. Dynamic Fluid Loads are occasional loads associated with hydraulic transients caused by events such as valve actuation (safety or relief valve discharge, rapid valve opening/closing), water hammer or steam hammer.
3. Thermal Expansion and Thermal Expansion Anchor Motion Loads are not calculated for those operating conditions where the piping system does not exceed 150F.
4. Cyclic Thermal Load includes loads due to thermal stratification, and stresses due to high cycle thermal striping and thermal penetration (i.e. thermal mixing).
5. The Thermal Bending and Primary plus Secondary Membrane plus Bending Stress Intensity Ranges (Equations 12 and 13) are only calculated for those load sets that do not meet the Primary plus Secondary Stress Intensity Range (Equation 10) allowable.
6. The cumulative fatigue usage factor is calculated by summing the Level A and Level B fatigue usage. If applicable, fatigue usage from Level C and Pressure Testing conditions is also included in the calculation of the cumulative usage factor (see Notes 9 and 14).
7. The Earthquake Inertial Load considered in the Level B Primay plus Secondary Stress Intensity Range, Peak Stress Intensity Range and Alternating Stress Intensity calculations (Equations 10, 11 and 14) is taken as 1/3 of the peak SSE inertial load or as the peak SSE inertial load. If the earthquake inertial load is taken as the peak SSE inertial load then 20 cycles of earthquake loading is considered. If the earthquake inertial load is taken as 1/3 of the peak SSE inertial load then the number of cycles to be considered for earthquake loading is 300 (the equivalent number of 20 full SSE cycles as derived in accordance with Appendix D of IEEE Standard 344-1987).
8. The resultant moment calculated is the maximum of the resultant moment due to the full range of Earthquake Inertial Load or the resultant moment due to the consideration of half of the range of Earthquake Inertial Load with all other applicable loads.
9. If a piping system is subjected to more than 25 Emergency Condition transient cycles which result in an alternating stress intensity (S_a) value greater than that for 10^6 cycles, as determined from the applicable fatigue design curves of Figures I-9.0 in Section III of the ASME Boiler and Pressure Vessel Code, then those cycles in excess of 25 are included in the fatigue calculation that determines the cumulative usage factor. See Section NB-3113(b) in Section III of the ASME Boiler and Pressure Vessel Code.
10. The rules given in Appendix F of the ASME Boiler and Pressure Vessel Code may be used in lieu of those given in NB-3656(a) and NB-3656(b) when evaluating Level D primary stress.
11. Loads due to dynamic events other than High Energy Line Break (i.e. Loss-of-Coolant Accident and Secondary Side Pipe Rupture) and SSE are combined considering the time phasing of the events (i.e. whether the loads are coincident in time). When the time phasing relationship can be established, dynamic loads may be combined by the Square-Root-Sum-of-the-Squares (SRSS) method, provided it is demonstrated that the non-excedance criteria given in NUREG-0484 is met. When the time phasing relationship cannot be established, or when the non-excedance criteria in NUREG-0484 is not met, dynamic loads are combined by absolute sum. SSE and High Energy Line Break loads are always combined using the SRSS method.

Table 3-1: Load Combinations and Acceptance Criteria for ASME Class 1 Piping

12. This secondary stress check is only necessary if the stresses (including those due to Earthquake Inertial Load) exceed the Equation 10U (primary plus secondary stress intensity range for the Upset service condition) allowable stress. See Section NB-3656(b)(4) in Section III of the ASME Boiler and Pressure Vessel Code.
13. Sm = Allowable Design Stress Intensity value from Part D of Section II of the ASME Boiler and Pressure Vessel Code.
14. If a piping system is subjected to more than 10 Pressure Test cycles which result in an alternating stress intensity (S_a) value greater than that for 10^6 cycles, as determined from the applicable fatigue design curves of Figures I-9.0 in Section III of the ASME Boiler and Pressure Vessel Code, then those cycles in excess of 10 are included in the fatigue calculation that determines the cumulative usage factor. See Sections NB-3657 and NB-3226(e) in Section III of the ASME Boiler and Pressure Vessel Code.

Table 3-4: Design Conditions, Load Combination and Stress Criteria for ASME Class 2&3 Buried Piping

Loading Condition	Service Levels	Loads	Stress Criteria
Design	-	Primary Stress Loads: Pressure$^{(1)}$, Weight Loads, Other Sustained Mechanical Loads	Equation 8$^{(5)}$ NC/ND-3652
Normal/ Upset	A/B	Occasional: Pressure$^{(1)}$, Weight Loads, Other Sustained Mechanical Loads, DFL	Equation 9U$^{(5)}$ NC/ND-3653.1 (Level B Only)
		Secondary Stress: Thermal Expansion, TAM, Thermal Friction Forces	Equation 10M$^{(2)\,(4)}$ NC/ND-3653.2(a)
		Non-Repeated Anchor Movement	Equation 10a NC/ND-3653.2(b)
		Sustained Plus Secondary Stress: Pressure$^{(1)}$, Weight Loads, Other Sustained Mechanical Loads, Thermal Expansion, TAM, Thermal Friction Forces	Equation 11M$^{(3)\,(4)(5)}$ NC/ND-3653.2(c)
Emergency	C	Occasional Stress: Pressure$^{(1)}$, Weight Loads, DFL	Equation 9E$^{(5)}$ NC/ND-3654.2(a)
Faulted	D	Secondary Stress: SSE effects~~Inertia~~ & SAM(M_{SSE}), Thermal Expansion and TAM (M_C), Friction Axial Forces from Thermal Expansion	See note 6

Notes:

1. Pressure for buried pipe includes internal pressure and the soil overburden loads and loads due to motor vehicles and train cars.
2. Equation 10 modified to include stress due to axial friction forces caused by thermal expansion and soil interaction.
3. Equation 11 modified to include stress due to axial friction forces caused by thermal expansion and soil interaction.
4. Stresses must meet Equation 10M or 11M, not both.
5. Buried piping systems must be designed to meet the external pressure load criteria of NC/ND-3133 of the ASME Code.
6. $$\frac{i(M_{SSE}+M_C)}{Z}+\varepsilon_a E_{sct}+\varepsilon_b E_{sct}+E_{sct}\alpha(T_2-T_1)\leq \text{ lesser of } 3S_h \text{ or } 2S_y \qquad \text{Equation A.}$$

   OR

   $$\frac{2i(M_{SSE})}{Z}+2\varepsilon_a E_{sct}+2\varepsilon_b E_{sct}\leq \text{ lesser of } 3S_h \text{ or } 2S_y \qquad \text{Equation B}$$

   For definition of terms, see Section 3.10.3.1.

Table 3-5: Impact Factor for Surface Load Effect on Buried Pipes (Reference 13)

Cover thickness (ft)	Surface Load Condition	
	Highways	Railways
0 - 1	1.50	1.75
1 - 2	1.35	1.50
2 - 3	1.15	1.50
> 3.0	1.00	1.35

Table 3-6: Recommended Surface Load for Buried Pipe

(Reference 13)

Cover thickness, ft	Surface load transmitted to pipe (lb/in^2)		Cover thickness, ft	Surface load transmitted to pipe (lb/in^2)	
	Highway H20	Railway E80		Highway H20	Railway E80
1	12.50	-	16	Negl.	3.47
2	5.56	26.39	18	Negl.	2.78
3	4.17	23.61	20	Negl.	2.08
4	2.78	18.40	22	Negl.	1.91
5	1.74	16.67	24	Negl.	1.74
6	1.39	15.63	26	Negl.	1.39
7	1.22	12.15	28	Negl.	1.04
8	0.69	11.11	30	Negl.	0.69
10	Negl.	7.64	35	Negl.	Negl.
12	Negl.	5.56	40	Negl.	Negl.
14	Negl.	4.17			

4.2.2.3 Modal Combination

The inertial response of a piping system in a seismic response spectrum analysis is considered in two parts. The modal analysis calculates the peak response of the piping system for all natural frequencies of the system below a defined cutoff frequency. ~~These low frequency (or non-rigid) modes consist~~This analysis consists of all modes with seismic excitation frequencies up to the frequency at which spectral accelerations return to the zero period acceleration (ZPA). This frequency is referred to as the ZPA cutoff frequency. For the U.S. EPR, the ZPA cutoff frequency is 40Hz for seismic analysis or as defined by figure 2 and 3 in RG 1.92[20], Rev. 2. Higher ZPA cutoff frequencies may be required for other dynamic load cases.

At modal frequencies above that corresponding to the ZPA, pipe members are considered rigid. The acceleration associated with these rigid modes is usually small. However, in certain situations the response to high frequency modes can significantly affect support loads, particularly axial restraints on long piping runs. To account for the~~se~~ effects of the residual rigid response, a missing mass correction is applied.

When performing response spectrum analyses using USM, the inertial response from the modal analysis is also divided into two types of response, periodic or rigid. At low frequencies, in the amplified regions of the response spectrum, the total inertial response is considered as a periodic response. Beyond this region but below the ZPA cutoff frequency (intermediate frequencies), the modal response consists of both periodic and rigid components. The total inertial solution is then determined by combining the individual modal responses, both periodic and rigid, and the residual rigid response per the guidance of RG 1.92 as discussed in Sections 4.2.2.3.1 through 4.2.2.3.4.

For analyses performed using ISM, all modal response at frequencies below the ZPA cutoff frequency is treated as periodic while the response above this frequency is rigid. The treatment and combination methods of these responses to obtain the total inertial solution will be performed per NUREG-1061 as discussed in Section 4.2.2.3.5 below.

4.2.2.3.1 USM Periodic Modal Responses~~Low Frequency (Non-Rigid) Modes~~

RG 1.92 provides guidance on combining the individual periodic modal results due to each response spectrum in a dynamic analysis performed using USM.

~~The combination method used shall consider the effects of closely spaced modes. Modes are defined as being closely spaced if their frequencies differ from each other by 10 percent or less of the lower frequency.~~

For piping systems with no closely spaced modes, the square root of the sum of the squares (SRSS) method is applied to obtain the representative maximum response of each element, as shown in the following equation:

$$R = \left[\sum_{k=1}^{N} R_k^2 \right]^{\frac{1}{2}}$$

Where R = the representative maximum response due to the input component of the earthquake,

R_k = the peak response due to the kth mode,

N = the number of significant modes.

This method may produce unconservative results for piping systems with closely spaced modes. Therefore, the double sum ~~approved~~ method~~s~~ for combining ~~closely spaced modes~~the periodic modal responses considering either the Rosenblueth or Der Kiureghian correlation coefficients provided in RG 1.92 will be used to obtain a more accurate modal response for frequencies below the rigid range. ~~These include the Grouping, Ten Percent and Double Sum methods, as well as the less conservative methods in Revision 2 of RG 1.92[16]~~.

~~For piping systems analyzed using ISM methods, modal result s are combined without the consideration of closely spaced modes, per NUREG-1061[18]. Therefore, for these systems, modal results are combined by the SRSS method presented above.~~

4.2.2.3.2 USM Rigid Components of Modal Response

In the intermediate frequency region where modal responses consist of both periodic and rigid components, these components are separated using either the Gupta Method or Lindley-Yow method as presented in RG 1.92.

The rigid individual modal responses will then be combined by algebraic summation.

~~4.2.2.3.2~~4.2.2.3.3 ~~High Frequency (~~Residual Rigid~~) Modes~~ Response

Piping system modes with frequencies greater than the ZPA cutoff frequency are considered as high frequency or rigid range modes. For flexible piping systems, the high frequency response may not be significant since a significant portion of the system mass is excited at frequencies below the ZPA. However, for piping systems, or portions of piping systems, which are more rigidly restrained or have lumped masses near rigid restraints, a significant portion of the system mass may not be accounted for in the low frequency modal analysis. This mass which is not excited at the lower frequencies is termed the "missing mass" of the system. While high frequency modes usually involve small displacement amplitudes and small pipe stresses, they can have a significant impact on support loads.

The response from high frequency modes must be included in the response of the piping system. Guidance for including the missing mass effects is provided in RG 1.92 for USM.

The peak modal responses of the system at frequencies above the ZPA are considered to be in phase. Thus, the responses of all high frequency modes are combined by algebraic summation.

The U.S. EPR will use the method presented in RG 1.92 or the left-out-force method described below for calculating and applying the response of the high frequency modes based on applying a missing mass correction. Although this method uses a different computational procedure than described in RG 1.92, Appendix A, the two methods produce the same result. The left-out-force method is used by SUPERPIPE and BWSPAN uses the method in Appendix A of RG 1.92.

The total inertia forces in a system considering a piping system under simple excitation, in a steady-state condition with a unit acceleration applied in a specified direction is mathematically represented by:

$$\{F_t\} = [M]\{r\}$$

Where $\{F_t\}$ = Total inertia forces in the specified direction

$[M]$ = Mass matrix

$\{r\}$ = Mass point displacement vector produced by a statically applied unit ground displacement

The sum of the inertia forces for all modes included in the modal analysis is calculated as:

$$\{F_s\} = \sum_{n=1}^{N} \{F_n\} = \sum_{n=1}^{N} [M]\{\phi_n\}\{\phi_n\}^T [M]\{r\}$$

Where $\{F_s\}$ = total inertia force seen by the system in the low frequency modal analysis

$\{F_n\}$ = inertia force of mode n

$\{\phi_n\}$ = mode shape

N = number of modes calculated in the modal analysis

Therefore, the missing, or left out, forces considering a unit ground acceleration in a specified direction are calculated as:

$$\{F_m\} = \{F_t\} - \{F_s\} = [M]\{r\} - \sum_{n=1}^{N}[M]\{\phi_n\}\{\phi_n\}^T[M]\{r\}$$

Or:

$$\{F_m\} = [M]\{r\}\left[1 - \sum_{n=1}^{N}[M]\{\phi_n\}\{\phi_n\}^T\right]$$

The missing inertia forces are calculated independently for all input components of earthquake motion (i.e., in each direction for each support group). The mode displacements, member end action, and support force corresponding to each missing force vector is determined with a modal acceleration equal to the ZPA.

As an alternative, when using the Lindley-Yow method, the Static ZPA method for calculating a total mass rigid response presented in RG 1.92 Section C.1.4.2 may be used.

~~These results are treated as an additional modal result in the response spectra analysis. This missing mass mode is considered to have a modal frequency and acceleration equal to the cut-off frequency used in the modal analysis. These modal results are combined by the SRSS method with the low frequency modal results using the methods described in Section 4.2.2.3.1.~~

~~For systems analyzed using USM, the rigid range (missing mass) results will be combined with the low frequency modal results in accordance with Regulatory Position C.1.5.1 of RG 1.92. For systems analyzed using ISM, the missing mass results will be combined with the low frequency modal results by SRSS, per NUREG-1061."~~

4.2.2.3.4 USM Complete Inertial Response

For USM response spectra analyses, the complete inertial response is calculated using the methodology provided in RG 1.92 Section C.1.5. In using these methods, the total rigid response will be calculated by algebraic summation of the applicable rigid response components and then combined with the total periodic response using the SRSS method.

4.2.2.3.5 ISM Combination of Modal Responses

For piping systems analyzed using ISM methods, modal results are combined without the consideration of closely spaced modes, per NUREG-1061. Additionally, the entire modal response for modes below the ZPA cutoff frequency is treated as a periodic response. Therefore, for these systems, modal results are combined by the SRSS method presented in Section 4.2.2.3.1 above.

The residual rigid response will be calculated using the missing mass method as that presented in Section 4.2.2.3.3. This missing mass response will then be combined with the low frequency modal results by SRSS, per NUREG-1061.

~~These results are treated as an additional modal result in the response spectra analysis. This missing mass mode is considered to have a modal frequency and acceleration equal to the cut-off frequency used in the modal analysis. These modal results are combined with the low frequency modal results using the methods described in Section 4.2.2.3.1.~~

4.2.2.4 Directional Combination

Following the modal combination of results, the responses of the piping system due to each of the three orthogonal earthquake motion inputs are combined. The collinear responses due to each of the input components of motion are combined using the SRSS method [20].

4.2.2.5 Seismic Anchor Motions

In addition to the dynamic inertia loads, the effects of differential displacements of equipment or structures to which the piping system attaches during a safe shutdown earthquake shall also be considered. The maximum relative displacement for each support location may be obtained from the results of the structural dynamic analysis for the supporting structure or calculated from the applicable floor response.

4.2.5 *Damping Values*

RG 1.61, Rev. 1 damping values will be used for Independent Support Motion response spectra and Time-History analysis. RG 1.61, Rev. 1 will also be used for piping systems analyzed using uniform support motion response spectra. Frequency dependent damping, as defined in Figure 1 of Regulatory position C.2 of RG 1.61, Rev. 1, may be used for a piping analysis provided the five (5) conditions defined in Regulatory Position C.2 are met.

For piping systems analyzed using a uniform enveloped response spectra analysis, RG 1.61, Rev 1 damping will be used in conjunction with RG 1.92, Rev. 2.

When composite modal damping is applied in a dynamic analysis (either time history or response spectrum), each model subgroup (piping, supports, equipment, etc) is assigned an appropriate damping value per RG 1.61 R1. The equivalent modal damping matrix, or composite modal damping matrix, is calculated for each mode by one of the two methods shown below:

Note: the highlighted text was provided to NRC in response to RAI EPR-32 and deemed acceptable by NRC

$$\bar{\beta}_j = \{\phi\}^T[\bar{M}]\{\phi\} \qquad (1)$$

$$\beta_j = \frac{\{\phi\}^T[\bar{K}]\{\phi\}}{K^*} \qquad (2)$$

Where:

K^* = $\{\varphi\}^T[K]\{\varphi\}$

[K] = assembled stiffness matrix

$\bar{\beta}_j$ = equivalent modal damping ratio of the jth mode

$[\bar{K}],[\bar{M}]$ = the modified stiffness or mass matrix constructed from element matrices formed by the product of the damping ratio for the element and its stiffness or mass matrix

$\{\varphi\}$ = jth normalized modal vector

Note: Damping beyond 20% will not be used.

~~5.4.1.2 *Restrained Elbows*~~

~~In some instances where a single full anchor support is not feasible, a set of supports placed around an elbow may be used to separate analysis models. In this method, an elbow must be restrained as shown in Figure 5-1. This creates a structurally rigid zone around the elbow in which the piping effects from one end of the restrained section are not transmitted beyond the other end.~~

~~The piping within the restraints shown in Figure 5-1 is impacted by the piping on both sides of the restrained elbow. Therefore, the results from both analyses are combined to obtain pipe stresses and hanger loads for the restrained elbow section of the pipe.~~

~~5.4.1.3 *Restrained Tees*~~

~~A restrained tee is similar to a restrained elbow. The restrained tee is used to divide the branch and run pipe into separate models when the decoupling criteria in Section 5.4.2 are not met. The restraint configuration is shown in Figure 5-2.~~

~~The piping within the restraints shown in Figure 5-2 is impacted by both the branch and run pipe. Therefore, the results from both analyses are combined to obtain pipe stresses and hanger loads for the restrained tee section of the pipe.~~

Figure 5-1 Restrained Elbow

(DELETED)

~~Where L is equal to the recommended support span per Table 4-1 and L1 and L2 are defined as follows:~~

~~Dimension~~	~~Nominal~~	~~Minimum~~	~~Maximum~~
~~L1~~	~~6"~~	~~Fitting Weld Clearance~~	~~6"~~
~~L2~~	~~L/4~~	~~L/8~~	~~L/4~~

Figure 5-2 Restrained Tee

(DELETED)

~~Where L is equal to the recommended support span per Table 4-1 and L1 and L2 are defined as follows:~~

~~Dimension~~	~~Nominal~~	~~Minimum~~	~~Maximum~~
~~L1~~	~~6"~~	~~Fitting Weld Clearance~~	~~6"~~
~~L2~~	~~L/4~~	~~L/8~~	~~L/4~~

6.8 *Support Self-Weight Excitation*

6.8.1 *Seismic Loads*

The response of the support structure itself to SSE loadings is to be included in the pipe support analysis. In general, the inertial response of the support mass will be evaluated using a response spectrum analysis similar to that performed for the piping. Damping values for welded and bolted structures are given in Revision 1 to RG 1.61. This support self-weight SSE response, the piping inertial load SSE response and the SSE loads from SAM are to be combined by absolute sum.

6.8.2 *Other Dynamic Loads*

For the U.S. EPR Reactor Coolant Loop analysis, the support structures have been explicitly modeled with the piping. Due to this inclusion of the supports in the piping model, the dynamic effects of the support structures are inherently included in the overall results for all dynamic loadings (including seismic). For other Class 1, 2 or 3 piping system analyses, the support structures are not expected to be explicitly modeled in the piping analysis. The analyses will assume rigid support points in the piping model using the default stiffnesses in the analysis code, with support rigidity confirmed as discussed in Section 6.7. As also discussed in Section 6.7, if supports do not meet the requirements in Section 6.7, the actual support stiffnesses will be determined for all supports within that model and will be used in a reanalysis of the piping along with the mass of the support. Therefore, the dynamic characteristics of supports that are not rigid will be included in the piping analysis.

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