ArevaEPRDCPEm Resource

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Subject:	DRAFT Response to U.S. EPR Design Certification Application RAI No. 376, FSAR Ch. 3, Supplement 5, Questions 03.08.01-48 and 03.08.03-24
Attachments:	RAI 376 Supplement 5 Response US EPR DC - DRAFT.pdf

Getachew,

AREVA NP Inc provided on June 24, 2010 a schedule in RAI 376 Supplement 3 for the final responses to, among others, questions 03.08.01-48 and 03.08.03- 24 (July 29, 2010). Attached is a draft response to those questions to support an interaction with the NRC, if needed. Let me know if the staff has questions or if the response to these questions can be sent as final.

Thanks,

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Response to

Request for Additional Information No. 376, Supplement 5

3/25/2010

U. S. EPR Standard Design Certification
AREVA NP Inc.
Docket No. 52-020
SRP Section: 03.08.01 - Concrete Containment
SRP Section: 03.08.03 - Concrete and Steel Internal Structures of Steel or Concrete Containments
SRP Section: 03.08.05 - Foundations
Application Section: 3.8

QUESTIONS for Structural Engineering Branch 2 (ESBWR/ABWR Projects) (SEB2)

Question 03.08.01-48:

Follow-up to RAI 190, Question 3.8.1-28

The response to this RAI has provided a discussion on the methodology used to determine seismic modification factors, which are then used in the equivalent static seismic analysis of the Nuclear Island (NI) Common Basemat Structure. Also included in the discussion is a limited comparison of results between SSI and equivalent-static analyses. The response to RAI 03.08.01-28 does not provide the requested information in sufficient detail for the staff to conclude that the methodology meets the seismic analysis procedures presented in SRP 3.7.2.II.1 and 3.8.1.II.4. Therefore, the staff requests AREVA to submit the following information:

1. The RAI response indicated that forces and moments were obtained from "application of maximum accelerations (determined from the SSI analysis) on a detailed finite element static model," presumably as factors multiplying the mass associated with each degree of freedom in the static FE model, and that "accelerations are then adjusted by a modification factor until the SSI-derived results are in effective agreement with the statically calculated results." The RAI response did not demonstrate that the equivalent static approach using the modification factors is conservative with respect to the results obtained using the SASSI analyses. To demonstrate that the seismic demands in the static FE model are adequately represented, (1) provide the specific steps used in developing the seismic modification factors and (2) justify that the use of the seismic modification factors leads to conservative estimates of the seismic demands for the equivalent static FE model in accordance with the request in Items 2 and 3 below.

2. The results provided in the RAI response, for the comparisons between the SSI analysis and static analysis, make no reference to the direction of the seismic ground motion. Clarify if the "base" forces and moments provided correspond to a specific direction of ground motion or if they already represent the combined results from the three directions of ground motion. The staff notes that a technically acceptable comparison of results should be made using an independent comparison in each of the three orthogonal directions of ground motion.

3. The results provided in the RAI response refer only to "base" forces and moments in the NI Common Basemat Structure, and to a single soil case. To verify the adequacy of the proposed methodology, provide numerical results to confirm that the force resultants (integrated moments and shears) from the equivalent static FE model analyses are equal to or more conservative than the force resultants from the SSI analyses. This should be done for an adequate number of elevations representative of the vertical distribution of the structure, for soil cases that represent the range of soil properties, and for all Seismic Category I structures.

4. Since the SASSI stick model used for SSI analysis is a simple representation of the NI Common Basemat Structure, explain how the proposed equivalent static methodology including the use of the modification factors account for localized flexibilities of structural elements such as floor slabs and walls that may experience accelerations higher than ZPA values, as well as other higher mode effects that cannot be captured by the SASSI stick model.

5. As a result of discussions on this topic held during the meeting on December 14-15, 2009 at AREVA offices, AREVA indicated that they understood the concerns raised by the staff and they may revise their analysis approach to eliminate the use of modification factors. AREVA is requested to explain whether the use of modification factors will be eliminated, in which case Items 1 through 4 above would no longer apply.

Response to Question 03.08.01-48:

Use of seismic modification factors has been eliminated. U.S. EPR FSAR Tier 2, Section 3.8 will be revised to reflect this change.

FSAR Impact:

U.S. EPR FSAR Tier 2, Section 3.8 will be revised as described in the response and indicated on the enclosed markup.

Question 03.08.03-24:

Follow-up to RAI 155, Question 03.08.03-10

The response to this RAI indicates that the 100-40-40 method described in ASCE 4-98 is mathematically equivalent to the 100-40-40 method described in RG 1.92, Rev. 2, and that FSAR Sections 3.8.3.4.4 and 3.8.4.4.1 will be revised to clarify any ambiguity regarding the 100-40-40 method.

However, it is not clear to the staff that the 100-40-40 rule is being correctly implemented in the design of the U.S. EPR. For example, the response to RAI No. 248 Question 3.7.2-26 and FSAR Tables 3E.2-1 through 3E.2-5 appears to indicate that each 100-40-40 rule permutation is being considered as a different load combination in the design. This is not technically acceptable because it could lead to an unconservative structural design. There appears to be some confusion between the combination of responses due to multiple ground motion directions and the combination of multiple interacting force/moment resultants. AREVA should compare their implementation of the 100-40-40 rule with the interpretation of this rule illustrated by the example given below, and any discrepancies should be addressed. AREVA should also confirm that the 100-40-40 rule is only being used in the context of linear analysis since the principle of superposition is no longer valid when nonlinear behavior is assumed.

<u>Clarification of the 100-40-40 Rule for Use in Structural Design</u>

To clarify the correct implementation of the 100-40-40 rule, consider the case of a concrete shell element as an illustrative example. The multiple interacting force/moment resultants are then Tx, Ty, Txy, Nx, Ny, Mx, My, and Mxy.

Assume that the seismic analysis yields the following results due to ground motions in directions 1, 2, and 3. The numerical values represent the maxima of each force/moment resultant (in absolute values) caused by each of the three ground motions calculated separately. Note that these maxima do not typically occur at the same time instant.

Direction	Tx	Ty	Txy	...	Mxy
E1	20	10	2	...	200
E2	37	6	5	...	300
E3	59	2	7	...	250

There are 24 different permutations of the 100-40-40 rule, of which only the first three and the last are listed below.

Permutation	Tx	Ty	Txy	...	Mxy
+1.0*E1+0.4*E2+0.4*E3	58.4	13.2	6.8	...	420
-1.0*E1+0.4*E2+0.4*E3	18.4	-6.8	2.8	...	20
+1.0*E1-0.4*E2+0.4*E3	28.8	8.4	2.8	...	180
....	...	...	...	...	...

-0.4*E1-0.4*E2-1.0*E3	-81.8	-8.4	-9.8	...	-450
Maximum	81.8	13.2	9.8	...	480

The technically correct interpretation of the 100-40-40 rule considers each force/moment resultant to be the maximum of the 24 permutations. Therefore, Txmax=81.8, Tymax=13.2, Txymax=9.8, ..., Mxymax=480. (It is interesting to note that, as expected, the SRSS rule results in lower values, Txmax=72.5, Tymax=11.8, Txymax=8.8, ..., Mxymax=439.)

For structural design, simultaneous interaction of the force/moment resultants is necessary (e.g. for use with interaction diagrams). However, as previously noted, the 100-40-40 rule (or SRSS) yields only maxima that do not typically occur at the same time instant. An acceptable conservative approach for structural design, also endorsed by ASCE 4-98, is to use permutations of the values Tx=±81.8, Ty=±13.2, Txy=±9.8, ..., Mxy=±480 (a total of 28=256 permutations). For example, if only Tx and Ty are assumed to interact, then only the pairs (+81.8, +13.2), (-81.8, +13.2), (+81.8, -13.2), and (-81.8, -13.2) need to be used.

The approach described above is consistent with ASCE 4-98. If this approach or RG 1.92 Rev. 2 is not utilized, then AREVA should provide the technical basis for any proposed alternative.

Response to Question 03.08.03-24:

Use of the 100-40-40 method has been eliminated. Instead of the 100-40-40 method, 100 percent of ZPA_x, ZPA_y and ZPA_z are used to perform a fixed base static analysis, and the results are combined using the square root of the sum of the squares (SRSS) method, as illustrated in the following equations:

$$P_R = \pm\sqrt{P_X{}^2 + P_Y{}^2 + P_Z{}^2}$$

$$M_R = \pm\sqrt{M_X{}^2 + M_Y{}^2 + M_Z{}^2}$$

Where the number of permutations for design = $2^n = 2^2$ = (++, --, +-, -+).

U.S. EPR FSAR Tier 2, Section 3.7 and Section 3.8 will be revised to remove references to the 100-40-40 method and replace them with the SRSS method.

FSAR Impact:

U.S. EPR FSAR Tier 2, Sections 3.7 and 3.8 will be revised as described in the response and indicated on the enclosed markup.

U.S. EPR Final Safety Analysis Report Markups

3.7.3.6 Three Components of Earthquake Motion

Following the modal combination of results, the responses of the subsystem 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 of RG 1.92.

Response Spectrum Method

The seismic loads from all three components of the earthquake are combined using the SRSS method as follows:

$$R = \pm\sqrt{\sum_i R_I^{\;2}}$$

Where:

R = any response of interest

R_I = 1, 2 and 3 is the response component for each of the two horizontal components and one vertical component of earthquake motion, respectively.

Time History Method

In a linear time history analysis, the analysis may be performed separately for each of the three components of earthquake motion, or one analysis may be performed by applying all three components simultaneously if the three components of earthquake motion are statistically independent in accordance with Section 3.7.1.2. When linear time history analyses are performed separately for each component, the combined response for all three components may be obtained using the SRSS rule to combine the maximum responses from each earthquake component, as illustrated above.

When the seismic analysis is performed using simultaneous application of the time history input, the responses may be obtained individually for each of the three independent components and combined algebraically at each time step to obtain the combined response time history:

$$R(t) = \sum R_i(t)$$

Equivalent Static Load Method

The seismic loads from the three components of the earthquake motion are combined using the SRSS method ~~or 100-40-40 percent spatial combination rule, as in response spectrum analysis~~.

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Extreme Environmental Loads

Extreme environmental loads are those loads that are credible but are highly improbable (GDC 2). The RB internal structures are protected by the RSB and the RCB; therefore, tornado and external missile loads do not apply. This load category includes:

- Safe Shutdown Earthquake (E')—SSE loads are those loads generated by an earthquake with a peak horizontal ground acceleration of 0.30g. Seismic loads in the vertical direction and two orthogonal horizontal directions are considered to act simultaneously. Section 3.7 provides a description of how SSE loads are determined and combined. SSE loads are considered due to applied inertia loads, including dead loads, live loads, and hydrodynamic loads (i.e., water in storage pools and tanks), including combination of these loads using the square root of the sum of the squares (SRSS) method ~~or the 100-40-40 percent rule described in Section 3.8.3.4.4~~.

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Abnormal Loads

Abnormal loads are those loads generated by a postulated high-energy pipe break causing a LOCA within a building or compartment (GDC 4 and GDC 50). This event is classified as a DBA. Included in this category are: Internal flooding loads (F_a), Pressure loads (P_a), Thermal loads (T_a), Accident pipe reaction loads (R_a), and Pipe break loads (R_r).

The Pipe break load is subcategorized as Pipe break reaction loads (R_{rr}), Pipe break jet impingement loads (R_{rj}), and Pipe break missile impact loads (R_{rm}). These loadings include a dynamic load factor to account for the dynamic nature of the load, unless a time-history analysis is performed to justify otherwise.

Abnormal loads include the following loads:

- Internal flood loads (F_a)—Loads resulting from internal flooding of containment during or following a postulated DBA.
- Pressure load (P_a)—Pressure equivalent static load within or across a compartment generated by the postulated pipe break and including a dynamic load factor to account for the dynamic nature of the load.
- Thermal load (T_a)—Thermal loads generated by the postulated pipe break and including T_o.
- Accident pipe reactions (R_a)—Pipe reactions generated by the postulated pipe break and including R_o.
- Pipe break loads (R_r)—Local equipment and piping loads generated following a postulated pipe break. Unless a time-history analysis is performed to justify

3.8.3.4.4 Seismic and Other Dynamic Analyses and Design

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Seismic analyses and designs of the RB internal structures conform to the procedures described in Section 3.7.2. ~~The procedures in ASCE Standard 4-98 are used in the analysis and design of structural elements and members subjected to load combinations that include seismic loadings.~~ Seismic accelerations are determined from the structural stick model described in Section 3.7.2. These accelerations are applied to the ANSYS model of the RB internal structures as static-equivalent loads at the elevations used in the stick model.

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Seismic SSE (E') loads are obtained by multiplying the dead load and 25 percent of the design live load by the structural acceleration obtained from the seismic analysis of the structure. Seismic loads are also considered due to the mass of fluids in tanks and canals as described herein (Section 3.8.3.4.4). ~~The design live load is used for the local analysis of structural elements and members.~~ Consideration is given to the amplification of these accelerations due to local flexibility of structural elements and members. Construction loads are not included when determining seismic loads. Other temporary loads are evaluated for contributing to the seismic loads on a case-by-case basis.

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Seismic loads from the three components of the earthquake are combined using the SRSS method, where resultants are obtained using the following formulas:

$P_R = \pm\ \mathrm{sqrt}(P_x^2 + P_y^2 + P_z^2)$

$M_R = \pm\ \mathrm{sqrt}(M_x^2 + M_y^2 + M_z^2)$

The number of permutations for design are $2^n = 2^2$ = (++, --, +-, -+). ~~or the 100-40-40 percent rule described in ASCE 4-98. The 100-40-40 combination is expressed mathematically as follows:~~

~~Where:~~

~~R = the reaction force or moment that is applied in the three orthogonal directions x, y, and z.~~

~~$R = (\pm 1.0R_X \pm 0.4R_Y \pm 0.4R_Z)$~~

~~$R = (\pm 0.4R_X \pm 1.0R_Y \pm 0.4R_Z)$~~

~~$R = (\pm 0.4R_X \pm 0.4R_Y \pm 1.0R_Z)$.~~

The effects of local flexibilities in floor slabs and wall panels are considered to determine if additional seismic accelerations should be applied to their design beyond those determined from the seismic stick model. Local flexibility evaluations are performed by determining the natural frequency of the floor or wall panel and

Severe Environmental Loads

Severe environmental loads are those loads that could be encountered infrequently during the plant life (GDC 2). This load category includes:

- Wind loads (W)—Wind loads are those loads resulting from wind pressure acting on external surfaces of structures due to normal design wind speeds. See Section 3.3.1 for wind parameters and methods used to determine wind loads. Wind loads in this category do not include tornado wind forces.

- Operating basis earthquake (OBE)—There are no OBE loads applicable to the design of other Seismic Category I structures, since an OBE level of one-third the SSE has been selected. See Section 3.7 for a description of the OBE.

Extreme Environmental Loads

Extreme environmental loads are those loads that are credible but are highly improbable (GDC 2). This load category includes:

- Safe shutdown earthquake (E')—SSE loads are those loads generated by an earthquake with a peak horizontal ground acceleration of 0.30 g. Seismic loads in the vertical direction and two orthogonal horizontal directions are considered to act simultaneously. Section 3.7 provides a description of how SSE loads are determined and combined. SSE loads are considered due to applied inertia loads, including dead loads, live loads, hydrodynamic loads (i.e., water in storage pools and tanks), and soil loads, including combination of these loads using the square root of the sum of the squares (SRSS) method ~~or the 100-40-40 percent rule described in Section 3.8.4.4.1~~.

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  The SSE component of soil loads is determined using densities for saturated soil to account for the weight of the soil plus the weight of either normal or flood water levels. This includes using load cases for normal groundwater level at 3.3 feet below plant grade, and for flood water level at 1.0 foot below plant grade. Earthquake-induced soil pressures are developed in accordance with Section 3.5.3 of ASCE 4-98.

- Tornado loads (W_t)—Tornado loads are those loads on external surfaces of structures resulting from a design basis tornado. See Section 3.3.2 for tornado design parameters and methods used to determine tornado loads. See Section 3.5 for design methods and parameters used to determine tornado-generated missile loads. Tornado loads include:

  – Tornado wind pressure (W_w).

  – Tornado differential pressure (W_p).

  – Tornado-generated missiles (W_m).

Openings in walls and slabs of other Seismic Category I structures are shown in construction drawings. Openings are acceptable without analysis if they meet the criteria identified in ACI 349, Section 13.4.2. Round pipe sleeves are used in lieu of rectangular penetrations where possible. Corners of rectangular openings in walls and slabs are provided with diagonal reinforcing to reduce cracking due to stress concentration at these locations in accordance with ACI 349, Section 14.3.7.

Appendix 3E describes analysis and design results for critical sections of other Seismic Category I structures.

Section 3.7.2 addresses design procedures applicable to non-safety-related structures to preclude adverse interaction effects on Seismic Category I structures.

Static Analysis and Design

Dead loads (D), live loads (L), hydrostatic loads (F), soil loads and lateral earth pressure loads (H), wind loads (W), pipe reactions (R_o), and normal thermal loads (T_o) are considered in the analysis and design of other Seismic Category I structures for the static normal load concrete and service load steel loading combinations. Concrete and steel members are designed to accommodate these static loads within the elastic range of their section strength. For concrete structures, uncracked section properties are used to proportion loadings to members. However ultimate strength design is used to reinforce concrete elements and members subjected to the normal factored loading combinations defined in Section 3.8.4.3.2.

Static fluid pressure loads are considered for design of the walls and floors of tanks and storage pools. Moving loads are considered for mobile plant equipment (e.g., cranes, hoists, truck bays in buildings, maintenance aisles).

Seismic and Other Dynamic Analyses and Design

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Seismic analyses and designs of other Seismic Category I structures conform to the procedures described in Section 3.7.2. ~~The requirements of ASCE 4-98 are used in the analysis and design of structural elements and members subjected to load combinations that include seismic loadings.~~ Seismic accelerations are determined from structural stick models as described in Section 3.7.2. These accelerations are applied to the finite element computer models of other Seismic Category I structures as static-equivalent loads at the elevations used in the stick model.

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Seismic SSE (E') loads are obtained by multiplying the dead load and 25 percent of the design live load by the structural accelerations obtained from the seismic analyses of each structure. A minimum of 75 percent of the roof snow load is included in the structural mass for seismic analysis of Seismic Category I structures. Seismic loads are also considered due to the mass of fluids in tanks and canals as described below for hydrodynamic loads. ~~The full potential live load, including precipitation, is used for~~

~~the local analysis of structural elements and members.~~ Consideration is given to the amplification of seismic accelerations obtained from the structural stick model of each structure, due to local flexibility of structural elements and members. Construction loads are not included when determining seismic loads. Other temporary loads are evaluated for contributing to the seismic loads on a case-by-case basis.

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Seismic loads from the three components of the earthquake are combined using the SRSS method, where resultants are obtained using the following formulas:

$P_R = +- \text{ sqrt}(P_x^2 + P_y^2 + P_z^2)$

$M_R = +- \text{ sqrt}(M_x^2 + M_y^2 + M_z^2)$

The number of permutations for design are $2^n = 2^2 = (++, --, +-, -+)$.

~~Seismic loads from the three components of the earthquake motion are combined using the SRSS method or the 100-40-40 percent rule described in ASCE 4-98. The 100-40-40 combination is expressed mathematically as follows:~~

~~Where:~~

~~R = the reaction force or moment that is applied in the three orthogonal directions x, y, and z:~~

~~$R = (\pm 1.0R_X \pm 0.4R_Y \pm 0.4R_Z)$~~

~~$R = (\pm 0.4R_X \pm 1.0R_Y \pm 0.4R_Z)$~~

~~$R = (\pm 0.4R_X \pm 0.4R_Y \pm 1.0R_Z)$.~~

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The effects of local flexibilities in floor slabs and wall panels are considered to determine if additional seismic accelerations should be applied to their design beyond those determined from the seismic stick model. Local flexibility evaluations are performed by determining the natural frequency of the floor or wall panel and comparing this to the frequency of the zero period acceleration on the applicable response spectra. Additional acceleration is applied when the natural frequency of the panel results in higher accelerations than the zero period acceleration. In cases where local flexibilities are determined to be a factor, additional out-of-plane accelerations are applied to the inertia loads on these panels for determining out-of-plane bending and shear loads.

Additional seismic loads due to accidental torsion are considered as described in Section 3.7.2. This is to account for variations in material densities, member sizes, architectural variations, equipment loads, and other variations from the values used in the analysis and design of other Seismic Category I structures. Due to these potential

For the loading combinations identified in Section 3.8.5.3, the minimum factors of safety required to prevent sliding and overturning are specified in Table 3.8-11—Minimum Required Factors of Safety Against Overturning, Sliding, and Flotation for Foundations.

Normal lateral earth pressure loads consider saturated soil up to a groundwater elevation of -3.3 feet relative to site finished grade. Lateral soil loads due to external floods consider saturated soil up to elevation -1.0 feet relative to site finished grade. Seismic loads from all three components of the earthquake motion are combined using

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the SRSS method or the 100-40-40 percent rule described in ASCE 4-98, the same as described in Section 3.8.4.4. The SSE components of soil loads are determined using densities for saturated soil to account for the weight of the soil plus the weight of either normal or flood water levels. Earthquake-induced lateral soil pressures are obtained from SSI analyses for NI common basemat structures and are developed in accordance with Section 3.5.3 of ASCE 4-98 for the other Category I structures. The design of embedded elements, such as embedded walls on basemats, assumes that the lateral pressure due to the SSE is in phase with the inertial loads. In cases where passive pressure is assumed to act on embedded structures in the stability check against sliding, the walls of the structure are evaluated to withstand such earth pressure. Section 3.8.4.4.2 provides further information on how seismic-induced lateral earth pressures are determined for the NI Common Basemat Structure. These lateral load effects are considered in structure sliding and overturning analyses. Refer to Section 2.5.4.2 for the soil parameters used to determine soil loads and lateral earth pressure.

When the effects of vertical seismic acceleration are included in the stability check against sliding, the unfactored dead weight of the structure is used to calculate the resistance to sliding due to friction.

Buoyancy effects of saturated soil due to a groundwater level of elevation -3.3 feet below finished grade or to a flood water level of elevation -1.0 feet below finished grade are considered when performing sliding and overturning analyses. For uplift evaluations (i.e., flotation and seismic overturning), dead load includes the weight of water permanently stored in pools and tanks. Justification is provided for live loads that are included in loading combinations when evaluating structures for the effects of sliding and overturning.

The effects of differential foundation settlements are applied concurrently with the dead load using the same load factors. Also, the effects of varying settlements between adjacent foundations are considered for the design of mechanical and electrical systems (e.g., piping, cables) that are routed between structures founded on separate basemats. See Section 3.8.4.4.5 for analysis and design procedures for Seismic Category I buried items that interface with structures on separate foundations.