REVISED RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

APR1400 Design Certification

Korea Electric Power Corporation / Korea Hydro & Nuclear Power Co., LTD

Docket No. 52-046

RAI No.:	**183-8197**
SRP Section:	**03.07.02 – Seismic System Analysis**
Application Section:	**3.7.2**
Date of RAI Issue:	**08/31/2015**

Question No. 03.07.02-4

10 CFR 50 Appendix S requires that the safety functions of structures, systems, and components (SSCs) must be assured during and after the vibratory ground motion associated with the safe shutdown earthquake (SSE) ground motion through design, testing, or qualification methods. In accordance with 10 CFR 50 Appendix S, the staff reviews the adequacy of the seismic analysis methods used to demonstrate that SSCs can withstand seismic loads and remain functional. Per the guidance in SRP Section 3.7.2.II.4, the staff reviews the calculation of the ground contact ratio to ensure that linear SSI analysis remains valid. The ground contact ratio is defined as the minimum ratio of the area of the foundation in contact with the soil to the total area of the foundation, computed in each time step throughout the SSI analysis. The acceptance criterion is that linear SSI analysis methods are appropriate provided the ground contact ratio is equal to or greater than 80 percent. The ground contact ratio can be calculated from the linear SSI analysis using the minimum basemat area that remains in compression with the soil. If the ratio is less than 80 percent, then the effect of the nonlinearity due to the foundation uplift should be evaluated.

In Sections 4.1.1 and A.4.1.1 in APR1400-E-S-NR-14006-P, Rev. 1 the applicant described its ground contact ratio calculation for the nuclear island (NI) common basemat and EDGB/DFOT basemat respectively. Further, Tables 4-1 and A-2 of the report provide the calculated ground contact ratios for the NI common basemat and EDGB/DFOT basemat, respectively. Per the guidance in SRP Section 3.7.2.II.4, in order to assist the staff in its review of the adequacy of the calculated ground contact ratios, the applicant is requested to clarify whether the specified ground contact ratios represent the minimum ratio of the area of the foundation in contact with the soil to the total area of the foundation, computed in each time step throughout the SSI analysis time history. If not, provide the technical basis for the adequacy of the alternate method used to calculate the ground contact ratio as applicable.

Response – Rev. 1

The specified ground contact ratios in Tables 4-1 and A-2 of technical report APR1400-E-S-NR-14006-P, Rev. 1, “Stability Check for NI Common Basemat” for the NI common basemat and the emergency diesel generator building/ diesel fuel oil tank (EDGB/DFOT) room basemat, respectively, are not calculated directly from the SSI analysis results of each time step.

The ground contact ratios are calculated from the structural analysis models and their results, instead of the seismic analysis models and the SSI analysis results in order to include all the applicable load cases that are considered in the uplift check.

When combining the load cases, the reactions from the response spectrum analyses of the reactor containment building (RCB) shell and dome and the RCB internal structure using in-structure response spectra, and the equivalent static analyses of the auxiliary building (AB) and the EDGB/DFOT are applied as the seismic loads (maximum SSI analysis results) in their basemat models.

Because the maximum values of individual modes occur simultaneously in the response spectrum analysis, the individual modal responses are summed algebraically. Three directional reaction forces from the seismic analysis of superstructures in each seismic excitation are combined using the 100-40-40 rule. All possible seismic load sign (±) combinations of the three directional reactions are considered. These calculations and combination sequences give the most critical condition in the uplift check.

To obtain a more accurate ground contact ratio, the calculation is performed using SSI time history results as the seismic loads in accordance with the guidance in SRP Section 3.7.2.II.4. The same site profiles (S01, S04, and S08) are considered. The contact area is calculated by checking the stress of the rigid spring elements which connect the NI basemat and the underlying soil in the ACS SASSI model. In order to obtain the stresses, the z-directional force components of the spring elements computed at 4,096 time steps (0.005 sec. interval) throughout the ACS SASSI analysis of NI structures are divided by their tributary areas.

Load combinations consider all possible permutations of the z-directional forces resulting from the three directional seismic inputs (total of eight combinations) as follows:

- Seismic directional combination #1: $+1.0 \cdot SSE_{EW} + 1.0 \cdot SSE_{NS} + 1.0 \cdot SSE_{VT}$
- Seismic directional combination #2: $+1.0 \cdot SSE_{EW} + 1.0 \cdot SSE_{NS} - 1.0 \cdot SSE_{VT}$
- Seismic directional combination #3: $+1.0 \cdot SSE_{EW} - 1.0 \cdot SSE_{NS} + 1.0 \cdot SSE_{VT}$
- Seismic directional combination #4: $+1.0 \cdot SSE_{EW} - 1.0 \cdot SSE_{NS} - 1.0 \cdot SSE_{VT}$
- Seismic directional combination #5: $-1.0 \cdot SSE_{EW} + 1.0 \cdot SSE_{NS} + 1.0 \cdot SSE_{VT}$
- Seismic directional combination #6: $-1.0 \cdot SSE_{EW} + 1.0 \cdot SSE_{NS} - 1.0 \cdot SSE_{VT}$
- Seismic directional combination #7: $-1.0 \cdot SSE_{EW} - 1.0 \cdot SSE_{NS} + 1.0 \cdot SSE_{VT}$
- Seismic directional combination #8: $-1.0 \cdot SSE_{EW} - 1.0 \cdot SSE_{NS} - 1.0 \cdot SSE_{VT}$

Algebraic summation is applied at each time step to consider the combined effect of input motions in the x-, y-, and z-directions. The final resultant stress time histories are combined with the stresses obtained from the z-directional springs of the static load analysis. The stiffness of the LINK180 element used to model the z-directional spring is defined to represent the entire soil column below the basemat. Here, the static loads include the dead load (D), the seismic live

load (SSL, 25% of live loads), and the buoyancy load (Lh) due to groundwater. Using these load combinations (D + SSL + Lh + seismic time history loads), the minimum contact ratios of the area of the basemat in contact with the soil to the total area of the basemat are determined as follows:

Site Profile	Ground Contact Ratio (%)	Seismic Directional Combination Number
S1 Uncrack	94.2	1
S1 Crack	94.1	1
S4 Uncrack	89.7	5
S4 Crack	91.1	7
S8 Uncrack	84.6	1
S8 Crack	88.0	6

The ground contact ratios re-calculated using SSI time history results with static analysis results are less than current ground contact ratios described in Tables 4-1 of technical report APR1400-E-S-NR-14006. Since the former is more accurate than the latter, DCD Tier 2 and the associated technical report will be revised using the re-calculated ground contact ratios.

Impact on DCD

DCD Tier 2, Table 3.8A-16 will be revised, as indicated in the attachment associated with this response.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

Technical report APR1400-E-S-NR-14006-P/NP, “Stability Check for NI Common Basemat,” Rev.1 will be revised, as indicated in the attachment associated with this response.

Table 3.8A-16

Uplift Area Ratios of NI Common Basemat

Soil Profiles	Load Combinations	Area at Bottom of Basemat (ft^2)	Uplift Area (ft^2)	Uplift Area Ratios (%)
Soil #1	LC08	113,590	20,530.86	18.07 %
	LC10		3,976.67	3.50 %
	LC12		10,393.17	9.15 %
Soil #4	LC08		22,540.91	19.81 %
	LC10		2,455.38	2.16 %
	LC12		9,933.7	8.75 %
Soil #8	LC08		23,353.56	20.56%
	LC10		8,470.57	7.46 %
	LC12		17,032.33	14.99 %

Site profile	Concrete Stiffness	Critical Load Combination	Ground Contact Ratio (%)
S1	Uncrack	1.0 D+1.0 SLL+1.0 Lh+1.0 SSE_{EW}+1.0 SSE_{NS}+1.0 SSE_{VT}	94.2
	Crack	1.0 D+1.0 SLL+1.0 Lh+1.0 SSE_{EW}+1.0 SSE_{NS}+1.0 SSE_{VT}	94.1
S4	Uncrack	1.0 D+1.0 SLL+1.0 Lh+1.0 SSE_{EW}+1.0 SSE_{NS}+1.0 SSE_{VT}	89.7
	Crack	1.0 D+1.0 SLL+1.0 Lh+1.0 SSE_{EW}+1.0 SSE_{NS}+1.0 SSE_{VT}	91.1
S8	Uncrack	1.0 D+1.0 SLL+1.0 Lh+1.0 SSE_{EW}+1.0 SSE_{NS}+1.0 SSE_{VT}	84.6
	Crack	1.0 D+1.0 SLL+1.0 Lh+1.0 SSE_{EW}+1.0 SSE_{NS}+1.0 SSE_{VT}	88.0

D=Dead Load

SLL=Seismic live load (25% of live loads)

Lh=Buoyancy load due to groundwater

3.2.2 Material Properties

Linear-elastic material properties of concrete including modulus of elasticity, Poisson's Ratio and mass density are used in accordance with design criteria for the APR1400. The material properties of the NI structures are summarized in Table 3-1.

3.2.3 Finite Element Model

The NI structure is modeled using the following ANSYS program shell, solid, beam, and link elements:

- NI common basemat: SOLID185 elements
- RCB shell and dome: SOLID185 elements
- In-containment refueling water storage tank (IRWST) and fill concrete: SOLID185 elements
- Primary shield wall (PSW): SOLID185 elements
- Secondary shield wall (SSW): SHELL181 elements
- AB concrete wall and slab: SHELL181 elements
- AB steel column and girder: BEAM4
- Nonlinear ground (compression only): LINK180

The nominal element size in the NI common basemat is approximately 5 feet. Figure 3-1 shows the full FE model for the basemat structural analysis. In addition, the AB structure, RCB internal structure, RCB shell and dome, and basemat structure analysis models are shown in Figures 3-2 through 3-5, respectively.

3.2.4 Boundary Condition

Link (LINK180) elements are used for boundary conditions between the basemat structure and ground to consider the compressive behavior of the underlying subgrade. The LINK180 element is a uniaxial tension-compression element with three degrees of freedom for translation in the nodal x, y, and z directions at each node. It is useful to describe the tension-only (cable) and/or compression-only (gap) condition.

Figure 3-6 shows the LINK180 element application as the boundary condition. The compression-only option is applied to the LINK180 elements connected directionally with the basemat structure, and the fixed-boundary condition is applied to the opposite side node of the LINK180 element. The stiffness of the LINK180 element is defined to represent the entire soil column below the basemat. Axial (tributary) areas of LINK180 elements are calculated by applying unit pressure to additional modeled shell element models that have the same geometry as the basemat model. Figure 3-7 shows the analysis model for the tributary area calculation.

3.2.5 Applied Loads

The applied loads analysis considers dead loads, live loads, post-tension loads for tendons embedded in the RCB shell and dome, containment pressure loads, pipe break load, seismic load, and buoyancy load due to groundwater.

4 STABILITY EVALUATION OF THE NUCLEAR ISLAND COMMON BASEMAT

This section presents the stability evaluation of the APR1400 NI common basemat against overturning, sliding, and flotation, and an evaluation of the settlement of NI common basemat.

4.1 Settlement of the Nuclear Island Common Basemat

4.1.1 Basemat Uplift

This section presents the uplift check of the NI common basemat during seismic excitation. According to NUREG-0800, Standard Review Plan (SRP) 3.7.2, calculation of the ground contact ratio to provide reasonable assurance that the linear soil-structure interaction (SSI) analysis remains valid is required. The ground contact ratio is defined as the minimum ratio of the foundation area in contact with the ground to the total area of the foundation. The linear SSI analysis methods are acceptable if the ground contact ratio is equal to or greater than 80 percent.

~~Among the results from the NI common basemat analysis, the three load combination cases of LC08, LC10, and LC12, which are shown to have the uplift phenomenon, are considered for uplift check. Figures 4-1 through 4-3 show the deformation contour of the AB basemat in accordance with S1, S4, and S8. Table 4-1 shows the uplift area ratios of the NI common basemat. The APR1400 NI common basemat contact area during basemat uplift is 80 percent or greater.~~

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4.1.2 Differential Settlement

Checks of the differential settlements of the NI common basemat are presented in this subsection. The differential settlements are divided by the differential settlement within the NI common basemat and the differential settlement between the NI basemat and other buildings.

For the differential settlements by static loading, the dead and live loads (D+L) are applied in the basemat. The node locations used to check the settlement are determined based on the deformation results of the NI common basemat (see Figures 4-1 through 4-3). In addition, the nodes within a distance of approximately 50 ft are selected to check the differential settlement. Figure 4-4 shows the description and node location at the bottom of the NI common basemat for checking the settlement. Table 4-2 shows the differential settlements at S1, S4, and S8. The maximum differential settlements per 50 ft for S1, S4, and S8 are 0.176, 0.072, and 0.037 in., respectively.

For the differential settlements by seismic loading, the displacement results from the seismic analysis calculation are used. In the seismic analysis, the displacements of the basemat relative to the free-field are calculated at the 50 nodes shown in Figure 4-5. Figures 4-6 through 4-14 show the Z-displacement of the basemat relative to the free-field according to site profiles. These results are obtained from the analysis of seismic loading only; dead load is not included. These results are obtained as follows:

- Relative displacement time histories at the 50 selected basemat nodes are obtained using the SASSI RELDISP module.
- The average of the 50 relative displacement time histories is calculated.
- A snapshot of the relative displacements is obtained at the time of the minimum average time history and at the time of the maximum average time history.

From Figures 4-6 through 4-14, the maximum differential settlement by seismic loading is approximately 0.006 ft (0.072 in.), which is less than 0.1 in.. The differential settlement by seismic loading is calculated

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The ground contact ratio calculation is performed according to the guidance in SRP Section 3.7.2.II.4. The site profiles, S01, S04, and S08, are considered to calculate the area of the basemat in contact with the soil. The contact area is calculated by checking the stress of the rigid spring elements which connect the NI basemat and the underlying soil in the SSI analysis model. In order to obtain the stresses, the z-directional force components of the spring elements computed at each time step throughout the SSI analysis of NI structures are divided by their tributary areas.

Load combinations consider all possible permutations of the z-directional forces resulting from the three directional seismic inputs (total of eight combinations). Algebraic summation is applied at each time step to consider the combined effect of input motions in the x-, y-, and z-directions. The final resultant stress time histories are combined with the stresses obtained from the z-directional springs of the static load analysis. The static loads include the dead load, the seismic live load (25% of live loads), and the buoyancy load due to groundwater. Due to the different mesh configuration between the SSI analysis model and the structural analysis model, the nodal stress of the SSI analysis model is combined with the average stress of the nearest nodes of the structural analysis model. Table 4-1 shows the minimum contact ratios of the area of the basemat in contact with the soil to the total area of the basemat. The minimum ground contact ratio considering the APR1400 NI common basemat uplift is greater than 80 percent.

Table 3-5

Load Combinations for NI Common Basemat Analysis

Position	Condition	Load Case	Load Combination
RCB Basemat	Test	LC01	1.0D+1.0L+1.0Lh+1.0F+1.0Pt
	Normal	LC02	1.0D+1.0L+1.0Lh+1.0F
	Severe	LC03	1.0D+1.3L+1.3Lh+1.0F
	Abnormal	LC04	1.0D+1.0L+1.0Lh+1.0F+1.5Pa
AB Basemat	Test	LC05	1.1D+1.3L+1.1Lh+1.0F+1.0Pt
	Normal	LC06	1.4D+1.7L+1.4Lh+1.0F
	Abnormal	LC07	1.0D+1.0L+1.0Lh+1.0F+1.4Pa
RCB and AB Basemat	Abnormal /Extreme	LC08	1.0D+1.0L+1.0Lh+1.0F+1.0Pa+1.0Yr +1.0Es01
		LC09	1.0D+1.0L+1.0Lh+1.0F+1.0Pa+1.0Yr +1.0Es02
		LC10	1.0D+1.0L+1.0Lh+1.0F+1.0Pa+1.0Yr +1.0Es03
		LC11	1.0D+1.0L+1.0Lh+1.0F+1.0Pa+1.0Yr +1.0Es04
		LC12	1.0D+1.0L+1.0Lh+1.0F+1.0Pa+1.0Yr +1.0Es05
		LC13	1.0D+1.0L+1.0Lh+1.0F+1.0Pa+1.0Yr +1.0Es06
		LC14	1.0D+1.0L+1.0Lh+1.0F+1.0Pa+1.0Yr +1.0Es07
		LC15	1.0D+1.0L+1.0Lh+1.0F+1.0Pa+1.0Yr +1.0Es08

Where:

D = Dead load

L = Live load

F = Post-tension load of tendon embedded RCB shell and dome

Pa = Design internal pressure of RCB shell and dome

Pt = Internal pressure of RCB shell and dome at testing phase

Yr = Pipe break load

E_s = Seismic load

Lh = Buoyancy load due to groundwater

Table 4-1

Uplift Area Ratios for NI Common Basemat

Site Profile	Load Combinations	Area at Bottom of Basemat (ft^2)	Uplift Area (ft^2)	Uplift Area Ratios (%)
S1	LC08	113,590	20,530.86	18.07 %
	LC10		3,976.67	3.50 %
	LC12		10,393.17	9.15 %
S4	LC08		22,540.91	19.81 %
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	LC12		9,933.7	8.75 %
S8	LC08		23,353.56	20.56%
	LC10		8,470.57	7.46 %
	LC12		17,032.33	14.99 %

Ground Contact Ratios of NI Common Basemat

Site profile	Concrete Stiffness	Critical Load Combination	Ground Contact Ratio (%)
S1	Uncrack	1.0 D+1.0 SLL+1.0 Lh+1.0 SSE_{EW}+1.0 SSE_{NS}+1.0 SSE_{VT}	94.2
	Crack	1.0 D+1.0 SLL+1.0 Lh+1.0 SSE_{EW}+1.0 SSE_{NS}+1.0 SSE_{VT}	94.1
S4	Uncrack	1.0 D+1.0 SLL+1.0 Lh+1.0 SSE_{EW}+1.0 SSE_{NS}+1.0 SSE_{VT}	89.7
	Crack	1.0 D+1.0 SLL+1.0 Lh+1.0 SSE_{EW}+1.0 SSE_{NS}+1.0 SSE_{VT}	91.1
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D=Dead Load

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Lh=Buoyancy load due to groundwater