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.:	**255-8285**
SRP Section:	**03.08.05 – Foundations**
Application Section:	**3.8.5**
Date of RAI Issue:	**10/19/2015**

Question No. 03.08.05-12

10 CFR 50.55a and Appendix A to 10 CFR Part 50, General Design Criteria 1, 2, 4, 16 and 50, provide the regulatory requirements for the design of the containment internal structures. Standard Review Plan (SRP) 3.8.5, Section II specifies analysis and design procedures applicable to the foundation of seismic Category I structures.

Technical Report (TR) APR1400-E-S-NR-14006-P, Rev 1, “Stability Check for NI Common Basemat,” Section 3.2.5, “Applied Loads,” states, “The reactions from seismic analyses of the RCB shell and dome, RCB internal structure, and AB are applied as the seismic loads in the basemat model. The response spectrum analysis is used for the RCB shell and dome and RCB internal structure and the equivalent static analysis is used for the AB for seismic analyses of superstructures.” The applicant did not provide a justification for using the two different methods. Per 10 CFR 50.55a; Appendix A to 10 CFR Part 50, General Design Criteria 1, 2, 4, 16 and 50; and SRP 3.8.5, the applicant is requested to address the following:

a. Provide a justification for using the two different methods, the spectrum analysis and the equivalent static methods, for the seismic design of RCB shell and dome; and the RCB internal structures

b. Explain whether this was done only for stability check or for all aspects of design: developing member forces for design, stability evaluation (sliding and overturning), uplift evaluation analysis, basemat soil bearing pressure calculation, settlement analysis, and lateral soil pressure on foundation walls. Wherever, this approach was used should be justified

c. Section 3.2.5 also states that “In the response spectrum analysis, the maximum values of individual modes occur simultaneously; hence, the combined effect is obtained by using algebraic (considering signs) summation of the individual modal responses.” This is not consistent with combining modes as described in NRC RG. 1.92. Therefore, the basis for this approach needs to be justified.

Response

a. The response spectrum analysis and equivalent static method are used in superstructure analyses to consider the effects of seismic load. The response spectrum analysis was performed in the RCB shell & dome and the RCB internal structure analyses. For the auxiliary building, the equivalent static method was performed in the analysis due to the local mode shape.

The difference in the analysis methods does not have an effect on the NI common basemat analysis because the superstructures and NI common basemat are not analyzed concurrently. The reactions of the superstructure are applied as loads in the NI common basemat analysis. The applied forces are reaction forces across the entire base of the superstructure.

Although Table 3-3 of the Technical Report presents three combinations for combining the three seismic input directions, the spatial combination of new NI common basemat analysis was performed in accordance with Regulatory Guide (RG) 1.92.

New NI Common Basemat Analysis

In order to determine the maximum seismic responses from spatial earthquake components in the case of reactions from response spectra method, the 100-40-40 rule described in RG 1.92 is considered. In case of reaction forces and moments from equivalent static method, the 100-40-40 rule was also considered.

The 100-40-40 rule described in RG 1.92 is as follows:

(1) Let R1, R2, R3 be the maximum responses caused by each of the three earthquake components calculated separately, such that

$$|R1| \geq |R2| \geq |R3|$$

(2) The maximum seismic response attributable to earthquake loading in three orthogonal directions is given by the following equation:

$$R = (1.0|R1| + 0.4|R2| + 0.4|R3|)$$

The responses in the RG 1.92 format are treated in the absolute sense, avoiding multiple permutations. Due to that, the maximum seismic response (R) from the three earthquake components has positive values. Then, it is used as $\pm$R in the abnormal/extreme load combination for NI common basemat analysis as indicated in Table 2 of RAI 255-8285 Question 03.08.05-8.

The seismic loading on the NI common basemat model is performed utilizing the 100-40-40 rule to account for the direction combinations. The section forces of the NI common basemat are determined by structural analysis based on the load combination including seismic load from the superstructure under three global direction seismic input. As mentioned above, the reactions of the superstructures from seismic forces are applied as loads in the NI common basemat analysis. In each superstructure (RCB shell & dome, RCB internal structure, AB), the reactions determined separately from the different direction seismic input motions are applied as the seismic load for the NI common basemat analysis considering the different direction of seismic excitation using 100-40-40 rule and the different phase of seismic excitation among the superstructures. In the case of the NI common basemat analysis, the application of the 100-40-40 method was based on the results (reactions) of each superstructure analysis. Additionally, structural analysis of the NI common basemat requires consideration of up-lift characteristics; therefore nonlinear analysis was made by nonlinear spring or nonlinear contact. Lastly, the current method, applying to the 100-40-40 rule in the combining loads for basemat analysis, is worth considering since it is commonly accepted in the general industry including NPP - refer to the following related documents:

[1] NHI's response to US-APWR DCD RAI 1045-7144 Q.03.08.05-Foundation, Docket No. 52-021, ML14024A119, 12/27/2013.

[2] Aging Facility (AP) Foundation Design, Document ID. 170-DBC-AP00-00100-000-00A, Oct. 2007.

Additionally, Refer to RAI 255-8285 Question 03.08.05-11 for a comparison between SSI analysis and static analysis used in the equivalent static method. The response to Question 03.08.05-11 shows that the equivalent static method is sufficient to reflect the results of SSI analysis.

b. The results of the response spectrum analyses and the equivalent static analysis were used for all aspects of design, with the exception of the stability evaluation (sliding and overturning) and analysis for settlement for seismic loading. For the stability evaluation and settlement analysis for seismic loading, the seismic analysis results of SASSI were used to obtain the axial force, shear force, and moment for seismic excitation.

In case of maximum seismic soil bearing pressure (29.6 ksf in soil profile 08), it was determined using the maximum values under design load combination 08 ~ 15 indicated in Table 3-5 of Technical Report, APR1400-E-S-NR-14006-P, Rev.1. Therefore, it cannot be compared with bearing pressure from SASSI results under seismic loading.

c. In the response spectrum analysis, the algebraic mode combination was used to compute the reactions for NI common basemat analysis and SRSS mode combination to generate design member forces for RCB shell & dome and internal structure.

In the new NI common basemat described in RAI 255-8285 Question 03.08.05-8, the mode combination was applied to Complete Quadratic Combination (CQC) combination method to consider modes with closely spaced frequencies in design of basemat and evaluation of settlement, design member forces of RCB shell & dome and internal structure.

To compare between the algebraic summation and the CQC method, the summation of reactions in internal structures are checked in Table 1 as shown below. The table shows that the reactions from algebraic summation are also reasonable compared with CQC summation. Unlike the above justification about algebraic summation, the reactions calculated based on CQC summation are used in the new analysis of NI common basemat with foundation media model in accordance with RG 1.92. Therefore, Technical Report, APR1400-E-S-NR-14006-P/NP will be revised as shown in the attached markups in the response for RAI 255-8285, Question 03.08.05-8.

Table1. The Summary of Comparison between Algebraic Summation and CQC method

	RCB Internal Structure								
	X excitation			Y excitation			Z excitation		
Method	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ
Algebraic Summation	90,164	13,481	109,240	8,770	88,231	129,456	2,814	4,205	63,975
CQC	51,268	18,762	87,502	10,097	44,611	81,693	4,478	5,677	50,481

	RCB Shell & Dome								
	X excitation			Y excitation			Z excitation		
Method	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ
Algebraic Summation	83,664	43,228	178,505	43,249	84,464	182,308	5,740	5,996	104,800
CQC	73,626	38,339	201,401	38,980	79,422	219,644	6,529	6,187	93,846

In the case of bearing pressure, new analysis was performed under static loading cases (Dead+Live). The stability evaluations (sliding and overturning) is not related with the NI common basemat anlaysis. In case of uplift, it was evaluated to combine the results from the NI common basemat analysis under static loading case and results from the SASSI analysis under dynamic load.

Lastly, in the case of later soil pressure loads including static earth pressure and dynamic earth pressure on embedded walls, it was applied as reaction forces and moments from auxiliary building structural analysis in the new NI common basemat as indicated in the Table B1-6 of RAI 255-8285 Question 03.08.05-8 (attachment). Refer to RAI 227-8274 Question 03.08.04-7 regarding a discussion of the dynamic earth pressure.

Impact on DCD

There is no impact on the DCD.

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, Rev.1 will be revised as attached markups in the response for RAI 255-8285, Question 03.08.05-8.

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.:	**255-8285**
SRP Section:	**03.08.05 – Foundations**
Application Section:	**03.08.05**
Date of RAI Issue:	**10/19/2015**

Question No. 03.08.05-16

10 CFR 50.55a and Appendix A to 10 CFR Part 50, General Design Criteria 1, 2, 4, 16 and 50, provide the regulatory requirements for the design of the containment internal structures. Standard Review Plan (SRP) 3.8.5, Section II specifies analysis and design procedures applicable to the foundation of seismic Category I structures.

Technical Report (TR) APR1400-E-S-NR-14006-P, Rev 1, “Stability Check for NI Common Basemat,” Section 2, “Site Profiles for the APR1400 Nuclear Island Common Basemat,” describes the generic site profiles for the APR 1400 NI common basemat. The staff reviewed this section and noted that additional information is needed in order to perform its safety review of the DCD application. Per 10 CFR 50.55a; Appendix A to 10 CFR Part 50, General Design Criteria 1, 2, 4, 16 and 50; and SRP 3.8.5, the applicant is requested to address the following:

a. Section 2.2, “Review of the Elastic Modulus of Generic Sites,” states that “The HFE program is in effect from the start of the design through the completion of the initial plant startup testing program. At startup the HFE program results will be provided to the combined operating license (COL) holder.” The applicant is requested to describe what the HFE program is and how it relates to the design and analysis during the design certification phase and COL phase.

b. Section 2.2.1, “Elastic Modulus of Soil Sites,” describes the approach used to develop the static elastic modulus E_{static} and the dynamic elastic modulus $E_{dynamic}$ used in the finite element models. The following items need to be addressed:

   1. The approach for E_{static} is based on the relationship between E_{static} and the standard penetration test (STP) blow count. For the type of large structures in the APR1400 design, E_{static} is not normally generated using relationships based on STP blow counts. Therefore, the applicant is requested to utilize accepted industry methods for development of E_{static}.

2. The uncertainty in the relationships presented in APR1400-E-S-NR-14006-P, Rev.1, Section 2.2.1 between SPT blow count (N) and shear wave velocity (Vs) is very high. Any COL applicant will have to use site-specific measurements to define velocity profiles, including layer velocities and uncertainties, thicknesses, etc. that will then be used to compare with the range of profiles used in the DCD design. Therefore these SPT relationships are not considered acceptable for use in defining properties utilized in the design within the DCD and the technical report. Similarly, site velocity properties defined for rock layers will have to be generated by measurements and not by the relationships described in APR1400-E-S-NR-14006-P, Rev.1, Section 2.2 and Figure 2-2. The applicant is requested to adequately address the uncertainty between the STB blow count and the shear wave velocity.

3. The approach used for $E_{dynamic}$ is the elastic modulus. From the information provided, it is not clear how this formulation was used to capture the effects of soil confinement when representing the soil by compression only truss elements in the model. The applicant is requested to provide a detail description regarding its dynamic elastic approach.

4. APR1400-E-S-NR-14006-P, Rev.1, Section 2.2.1 indicated that the relationship between Elastic and $E_{dynamic}$ at the soil site is 0.1153. This ratio appears to be extremely low and is probably due to the questions raised in Item (a) and (b) above. The applicant is requested to update the approach to calculating $E_{static}/E_{dynamic}$ and confirm the adequacy of the resulting ratio based on other sources of information and industry practice.

c. In Section 2.3, “Material Properties and subgrade Modulus of Site Profiles for the APR1400,” it is stated, “The subgrade moduli of three site profiles are obtained from an ANSYS analysis.” The description of the development of the moduli should be expanded in order to understand the approach used. The applicant is requested to provide an explanation of the following: (1) whether only a vertical static 1 ksf load was applied to obtain the vertical soil moduli, (2) whether the vertical load was applied only to the basemat foundation region, (3) what is the technical basis for indicating that the horizontal subgrade moduli were determined using two-thirds of the horizontal displacement caused by what appears to be a vertically applied pressure load, and (4) if the LINK180 ANSYS element is only utilized to represent the soil in the settlement analysis and construction sequence, why is the horizontal moduli needed.

Response

a. The description in Section 2.2 of the Technical Report is an editorial error. Therefore, the description will be revised, as shown in Attachment 1 to this response.

TS

TS

TS

TS

2. Based on the uncertainty of the relationship between shear wave velocity and STP blow counts, the COL applicant shall perform a site-specific evaluation if the applicant site is found to have a shear wave velocity of less than 1000ft/s. Therefore, the COL applicant shall perform additional analyses regarding the site-measure (shear wave velocity) if it is less than 1000ft/s. A site-specific evaluation (differential settlement, soil bearing pressure and sliding evaluation [if needed]) and 3D FEM global analysis for basemat design of seismic category I structures using the site-specific measured E_{static}, and methodology, as described in DCD Tier 2, Subsection 3.8.5 and Technical Report APR1400-E-S-NR-14006-P/NP will be performed. DCD Tier 2, Section 3.8.6 will be revised to include a COL item, COL 3.8(13), as shown in Attachment 2 to this response.

TS

TS

4. Although the ratio of E_{static}/ $E_{dynamic}$ is extremely low, E_{static} is used for the basemat analysis in order to generate large settlement, which is a conservative approach. This ratio is applied to the soil foundation of site profile1 where the shear wave velocity is less than 1800 ft/sec.

c. 1. A vertical static load of 1ksf was applied to obtain the vertical subgrade modulus. In order to consider the boussinesq effect in soil vertical springs across the basemat, the subgrade modulus of the vertical soil springs was calculated based on the vertical displacement of each basemat node.

2. The vertical load is only applied to the basemat foundation region.

TS

TS

TS

4. The LINK 180 ANSYS element is utilized to represent soil in the structural and settlement and construction sequence analyses. The horizontal modulus is used in soil springs is modeled as a boundary condition for analyses of the NI common basemat. For a detailed construction sequence, refer to the RAI 255-8285 3.8.5 Question 7.

Impact on DCD

DCD Tier 2 Table 1.8-2 and Subsection 3.8.6 will be revised, as indicated in Attachment 2 to 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-NP, Rev.1 Section 2.2 will be revised, as indicated in Attachment 1 to this response.

2 SITE PROFILES FOR THE APR1400 NUCLEAR ISLAND COMMON BASEMAT

This section describes the generic site profiles for the APR1400 NI common basemat.

2.1 Shear Wave Velocities of APR1400 Sites

The APR 1400 is designed with a standard design concept to enable construction on various foundation conditions enveloping rock and soil foundations. The generic sites for the APR1400 include nine site categories (S1 through S9) that represent a variety of characteristics and configurations of rock and soil foundations as well as one fixed case. Figure 2-1 shows the profile of the shear wave velocities of the nine generic site categories. As shown in Table 2-1, unit weight and Poisson's Ratio corresponding to shear wave velocity are used to evaluate each site property. Table 2-2 shows the soil and rock definition by shear wave velocity based on the international building code (IBC).

2.2 Review of the Elastic Modulus of Generic Sites

Deleted

~~The HFE program is in effect from the start of the design through the completion of the initial plant startup testing program. At startup the HFE program results will be provided to the combined operating license (COL) holder.~~

2.2.1 Elastic Modulus of Soil Sites

In accordance with IBC, the N value from the standard penetration test (SPT) in the ground with a shear wave velocity V_s = 600~1,200 ft/sec is 15 < N < 50. Therefore, where V_s =1,000 ft/sec, the N value can be interpolated as follows:

$$N = 15 + (1{,}000-600) / (1{,}200-600) \times (50-15) = 38$$

In addition, the relationship between the N value and V_s is described in Zen et al. (1987) as follows:

$$V_s = 89.1 \times (N)^{0.34} \text{ m/sec}$$

Where V_s =1,000 ft/sec (= 304.8 m/sec), the N value can be calculated as N = 37. Based on the results from IBC and Zen et al. (1987), the range of N values at V_s =1,000 ft/sec is between 37 and 38.

The relationship between the static elastic modulus (E_{static}) and the N value is provided in Bowles (1982) as follows:

$$E_{static} = 18{,}000 + 750 \times N \text{ (kPa)}$$

$$E_{static} = (15{,}200 \text{ to } 22{,}000) \times \ln N \text{ (kPa)}$$

Where, N = 37 (V_s =1,000 ft/sec, minimum value), the static elastic modulus is obtained as E_{static} = 45,750 kPa, 54,885 kPa, and 79,440 kPa from the relationship between E_{static} and N, respectively. Therefore, the mean static elastic modulus can be determined as E_{static} = 60,025 kPa = 60 MPa = 1,253 ksf.

In addition, the relationship between the maximum dynamic elastic modulus ($E_{dynamic}$) and V_s is as follows:

$$E_{dynamic} = (\gamma / g) \times (V_s)^2 \times [2 \times (1+ \nu)]$$

Where, γ is unit weight, ν is Poisson's ratio, and g is gravity acceleration. Where V_s =1,000 ft/sec, γ = 125 pcf, and ν = 0.4, the dynamic elastic modulus is $E_{dynamic}$ = 10,860 ksf = 520 MPa. The relationship between E_{static} and $E_{dynamic}$ at the soil site is $E_{static}/ E_{dynamic}$ = 0.1153.

COL 3.8(7) The COL applicant is to confirm that uneven settlement due to construction sequence of the NI basemat falls within the values specified in Table 2.0-1.

COL 3.8(8) The COL applicant is to provide the necessary measures for foundation settlement monitoring considering site-specific conditions.

COL 3.8(9) The COL applicant is to provide testing and inservice inspection program to examine inaccessible areas of the concrete structure for degradation and to monitor groundwater chemistry.

COL 3.8.(10) The COL applicant is to provide the following soil information for the APR1400 site: 1) elastic shear modulus and Poisson's ratio of the subsurface soil layers, 2) consolidation properties including data from one-dimensional consolidation tests (initial void ratio, Cc, Ccr, OCR, and complete e-log p curves) and time-versus-consolidation plots, 3) moisture content, Atterberg limits, grain size analyses, and soil classification, 4) construction sequence and loading history, and 5) excavation and dewatering programs.

COL.3.8(13) The COL applicant shall perform site-specific evaluations if the shear wave velocity is less than 1000ft/s. The site-specific evaluations (differential settlement, soil bearing pressure, and sliding evaluation [if needed]) and 3D FEM global analysis for basemat design of seismic category I structures shall be performed using the site-specific measured Estatic and the methodology described in DCD Tier 2, Subsection 3.8.5 and Technical report APR1400-E-S-NR-14006-P, Subsection 4.

3.8.7 References

1. 10 CFR Part 50, “Domestic Licensing of Production and Utilization Facilities,” U.S. Nuclear Regulatory Commission.

2. ASME Section III, Subsection NE, “Class MC Components,” The American Society of Mechanical Engineers, the 2007 Edition with the 2008 Addenda.

3. ASME Section III, Division 2, “Code for Concrete Containments,” Subsection CC, American Society of Mechanical Engineers, 2001 Edition with 2003 Addenda.

4. Regulatory Guide 1.35, “Inservice Inspection of Ungrouted Tendons in Prestressed Concrete Containment,” Rev. 3, U.S. Nuclear Regulatory Commission, July 1990.

5. Regulatory Guide 1.35.1, “Determining Prestressing Forces for Inspection of Prestressed Concrete Containments,” U.S. Nuclear Regulatory Commission, July 1990.

Table 1.8-2 (5 of 29)

Item No.	Description
COL 3.8(7)	The COL applicant is to confirm that uneven settlement due to construction sequence of the NI basemat falls within the values specified in Table 2.0-1.
COL 3.8(8)	The COL applicant is to provide the necessary measures for foundation settlement monitoring considering site-specific conditions.
COL 3.8(9)	The COL applicant is to provide testing and inservice inspection program to examine inaccessible areas of the concrete structure for degradation and to monitor groundwater chemistry.
COL 3.8(10)	The COL application is to provide the following soil information for APR1400 site: 1) Elastic shear modulus and Poisson's ratio of the subsurface soil layers, 2) Consolidation properties including data from one-dimensional consolidation tests (initial void ratio, Cc, Ccr, OCR, and complete e-log p curves) and time-versus-consolidation plots, 3) Moisture content, Atterberg limits, grain size analyses, and soil classification, 4) Construction sequence and loading history, and 5) Excavation and dewatering programs.
COL 3.9(1)	The COL applicant is to provide the inspection results for the APR1400 reactor internals classified as non-prototype Category I in accordance with RG 1.20.
COL 3.9(2)	The COL applicant is to provide a summary of the maximum total stress, deformation, and cumulative usage factor values for each of the component operating conditions for ASME Code Class 1 components except for ASME Code Class 1 nine major components. For those values that differ from the allowable limits by less than 10 percent, the contribution of each loading category (e.g., seismic, deadweight, pressure, and thermal) to the total stress is provided for each maximum stress value identified in this range. The COL applicant is to also provide a summary of the maximum total stress and deformation values for each of the component operating conditions for Class 2 and 3 components required to shut down the reactor or mitigate consequences of a postulated piping failure without offsite power (with identification of those values that differ from the allowable limits by less than 10 percent).
COL 3.9(3)	The COL applicant is to identify the site-specific active pumps.
COL 3.9(4)	The COL applicant is to confirm the type of testing and frequency of site-specific pumps subject to IST in accordance with the ASME Code.
COL 3.9(5)	The COL applicant is to confirm the type of testing and frequency of site-specific valves subject to IST in accordance with the ASME Code.
COL 3.9(6)	The COL applicant is to provide a table listing all safety-related components that use snubbers in their support systems.

COL.3.8(13) The COL applicant shall perform site-specific evaluations if the shear wave velocity is less than 1000ft/s. The site-specific evaluations (differential settlement, soil bearing pressure, and sliding evaluation [if needed]) and 3D FEM global analysis for basemat design of seismic category I structures shall be performed using the site-specific measured Estatic and the methodology described in DCD Tier 2, Subsection 3.8.5 and Technical report APR1400-E-S-NR-14006-P, Subsection 4.