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.

b. 1. In the basemat analysis, the static elastic modulus (E_{static}) of soil is normally determined by the results of the site-specific pressure meter test. However, table 1613.5.2 in IBC (2009) defines the relationship between soil shear wave velocity and the standard penetration test (STP) blow count for soils. The use of this relationship shall be limited due to the uncertainty between the STP blow count

and the shear wave velocity. This relationship is utilized to compute the reduction factor.

Generally, the elastic modulus of the soil is calculated based on the following equation.

$$\mathrm{E} = \rho V_S^2 \times [2 \times (1 + \mu)]$$

The estimated E and G values correspond to very low strain values. So, these values are reduced to account for the material's strain softening due to higher strains. The reduction factor of the elastic modulus is based on the RQD of the corresponding rock layer. The conservative reduction factor is considered for the rock layer as shown below.

Reduction factor: 0.15 (1800ft/s $\leq$ Shear velocity $\leq$ 2500ft/s)

0.3 (Shear velocity $>$ 2500ft/s)

When shear wave velocity is less than 1800ft/s(sand soil), the range of N values at Vs =1,000 ft/sec is between 37 and 38 based on the results from IBC and Zen et al. (1987). And the static elastic modulus (E_{static}) could be calculated based on the relationship between the static elastic modulus and the N value provided in Bowles (1982). From the relationship between the elastic modulus and the static elastic modulus, the reduction factor 0.1153, is considered for conservatism based on the STP blow count.

For regarding to the reduction factor 0.1153, based on ASCE 4 and related references, the relationship between dynamic elastic modulus $E_{dynamic}$ and static elastic modulus E_{static} is estimated as follows. The results from ASCE 4 are compared with those from SPT blow count.

According to in ASCE 4-98 C.3.3.2.2 and Seed & Idriss (1970), the shear modulus with shear strain level for sand varies as shown in Figure 1. Here $G_{dynamic}$ is the dynamic shear modulus at very low strain (less than 0.0001%) and $G_{dynamic} = \rho V_S^2$. Figure 1 demonstrates the reduction of shear modulus with strain level for sand and the typical variability in the relation. Generic data from the many field and laboratory test results supported the nonlinear behavior of soil with strain level.

Many researchers studied the nonlinear behavior of soil with strain level, that is, the change of elastic modulus of soil with strain level. Jardine et al (1986) , Mair (1993) have shown that the typical static strain levels around geotechnical structures such as retaining walls, foundations, piles and tunnels fall in the range of 0.01~0.1% (Clayton, 2011). Burland (1989) and Finno et al.(2006) suggested that the working static strain level of soil for the well designed foundation is on the order of 0.1%.

Considering both the Seed-Idriss curve (Figure 1) and the static working strain level 0.1 % of soil for foundations, $G/G_{dynamic}$ value corresponding to static strain level 0.1% is in the range of 0.23 ~ 0.37 as shown in Figure 2 and the lower bound value is 0.23. The relationship between G_{static} and $G_{dynamic}$ at the soil site can be considered as $G_{static}/G_{dynamic} = 0.23$. Considering the relation between Elastic modulus E and Shear Modulus G, $\mathrm{E} = \mathrm{G} \times [2 \times (1 + \mu)]$, the relationship between E_{static} and $E_{dynamic}$ at the soil site also can be considered as $E_{static}/E_{dynamic} = 0.23$.

Since the value of $E_{static}/E_{dynamic}$ from Seed-Idriss curve is 0.23 and this value is larger than 0.1153 from SPT blow count related equation, use of $E_{static}/E_{dynamic} = 0.1153$ from SPT blow count is a conservative approach.

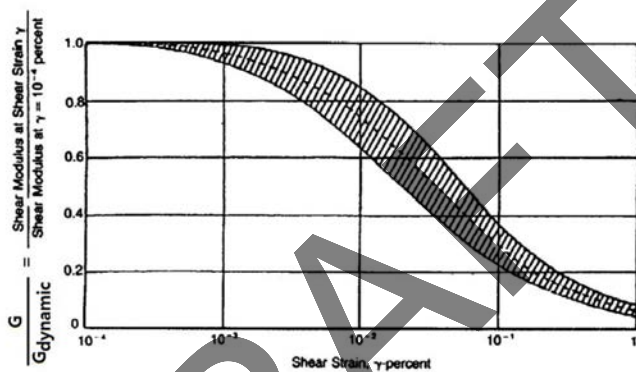

Figure 1. Variation of Shear Modulus with Shear Strain for Sands

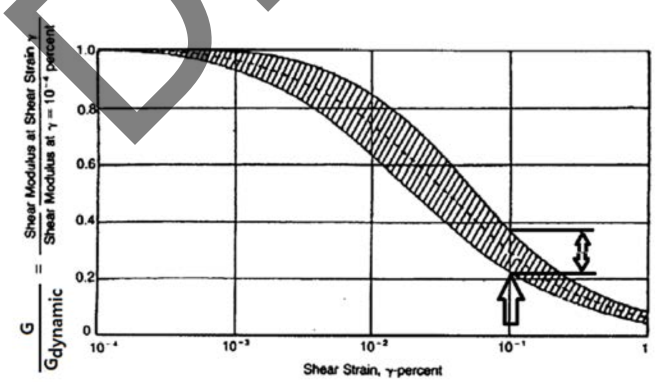

Figure 2. $G/G_{dynamic}$ of Soil at strain level 0.1%

There are various parameters of soil which could be defined through the site survey and should be incorporated in the basemat design. So, the COL applicant

shall perform a site-specific evaluation of NI stability using the site-specific measured E_{static}, the APR1400 basemat model, and the methodology described in DCD Tier 2, Subsection 3.8.5. DCD Tier 2, Section 3.8.6 will be revised to include a COL item, COL 3.8(13), requiring the COL applicant to perform a site-specific evaluation of NI stability, as shown in Attachment 2 to this response.

References of RAI 03.08.05-16.b.1

1) ASCE 4-98 Seismic Analysis of Safety related Nuclear Structures and Commentary

2) Burland, J. B. (1989), “Small is beautiful: the stiffness of soils at small strains”, Ninth Laurits Bjerrum Lecture. Can. Geotech. J. 26, No. 4, 499–516.

3) Clayton, C. R .I. (2011), “Stiffness at small strain: research and practice”, Geotechnique 61, No. 1, 5–37

4) Finno, Richard J. and Tu, Xuin (2006), “Selected topics in numerical simulation of supported excavations”, Proceedings of the International Conference on Numerical Modeling of Construction Processes in Geotechnical Engineering for Urban Environment, 3–19

5) Jardine, R. J., Potts, D. M., Fourie, A. B. & Burland, J. B. (1986). “Studies of the influence of nonlinear stress–strain characteristics in soil–structure interaction”, Geotechnique 36, No. 3, 377–397

6) Mair, R. J. (1993), “Developments in geotechnical engineering research: applications to tunnels and deep excavations”, Unwin Memorial Lecture 1992, Proc. Instn Civ. Engrs, Civ. Engng 3, No. 1, 27–41.

7) Seed, H. B. and Idriss, I. M. (1970), “Soil Moduli and damping factors for Dynamic Response Analysis”, Report No. 70-10, Earthquake Engineering Research Center, University of California Berkeley.

2. Regarding the uncertainty of the relationship between shear wave velocity and STP blow counts, the COL applicant shall perform a site-specific evaluation if the site is found to have a shear wave velocity of less than 1800ft/s.

3. For conservatism with regards to settlement, the effects of soil confinement are not considered in the basemat model. Generally, if the effect of soil confinement is considered, settlements are decreased. So, the compression only spring elements are used to represent the soil without the effect of soil confinement. Also, $E_{dynamic}$ values are not used for the basemat analysis.

4. Even though the ratio of E_{static}/ $E_{dynamic}$ is extremely low, E_{static} is used for the basemat analysis in order to generate large settlement, conservatively. And 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 1ksf load was applied to obtain the vertical subgrade moduli.

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

3. The horizontal displacements corresponding to the depth are varied in a parabolic shape. Because using the maximum displacement is not conservative, for the design of basemat, the equivalent horizontal displacement was used to determine the horizontal subgrade moduli in order to obtain conservatively large member forces; the obtained member forces are used in the basemat design. The stiffer horizontal spring value could produce the larger member forces (in-pane force in basemat) for horizontal loads because the 3D FE basemat model has horizontal spring at the edge of the basemat. The equivalent horizontal displacement is calculated from the length of rectangular shape which has same area of parabolic area and is two thirds of the maximum horizontal displacement.

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 which are modeled as a boundary condition for analyses of the NI common basemat.

Impact on DCD

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-P/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 a site-specific evaluation of NI stability using the site-specific measured Estatic, the APR1400 basemat model, and the methodology described in DCD Tier 2, Subsection 3.8.5.

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 a site-specific evaluation of NI stability using the site-specific measured Estatic, the APR1400 basemat model, and the methodology described in DCD Tier 2, Subsection 3.8.5.