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

Question No. 03.08.05-7

10 CFR 50.55a and 10 CFR Part 50, Appendix A, General Design Criteria (GDC) 1, 2, 4 and 5 provide the regulatory requirements for the design of the seismic Category I structures. Standard Review Plan (SRP) Section 3.8.5.I.3, “Load and Load Combinations,” states, “These should also include the loads that are induced by the construction sequence and by the differential settlements of the soil under and to the sides of the structures.” Furthermore, SRP Section 3.8.5.I.4, “Design and Analysis Procedures,”, states, “Where a single mat foundation is used for multiple plant structures, attention is given to bending, shear, and similar factors in the basemat that are attributable to uneven settlement, construction sequence, and mat flexibility.”

In DCD Tier 2, Section 3.8.6.4, “Design and Analysis Procedures,” the applicant stated “The maximum differential settlement of foundation is 12.7 mm per 15.24 m (0.5 in per 50 ft) within NI common basemat. The maximum differential settlement between buildings is 12.7 mm (0.5 in) based on enveloping properties of subsurface materials. ” However, it is not clear to the staff how the construction sequence and differential settlement of foundations were considered in the load and load combinations. Therefore, the applicant is requested to describe how the construction sequence and differential settlement of foundations were considered in the load and load combinations. Also, DCD Section 3.8.5 should be updated accordingly.

Response - (Rev.5)

To judge whether the soft soil case is governed for construction sequence analysis, the moment diagram for each section on profiles (S1, S8) is compared under abnormal/extreme environment load combination (LC08). Figure 1 shows the detailed sections in the basemat.

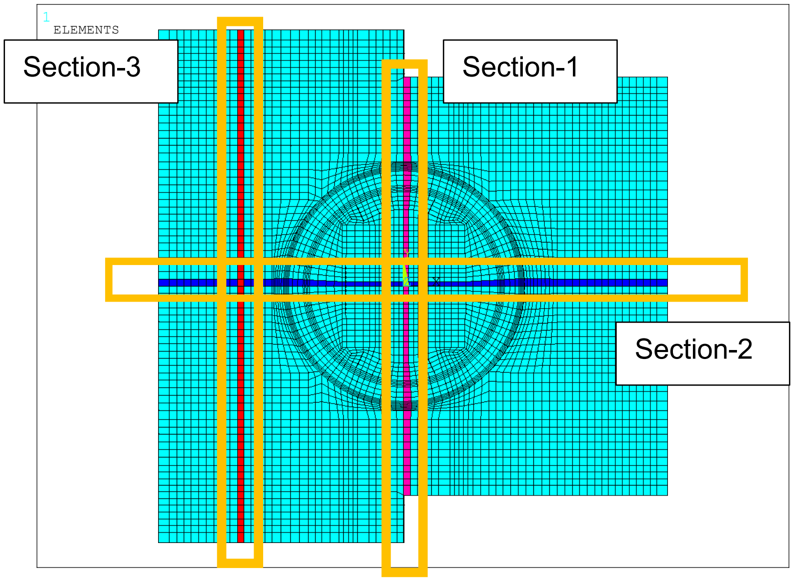
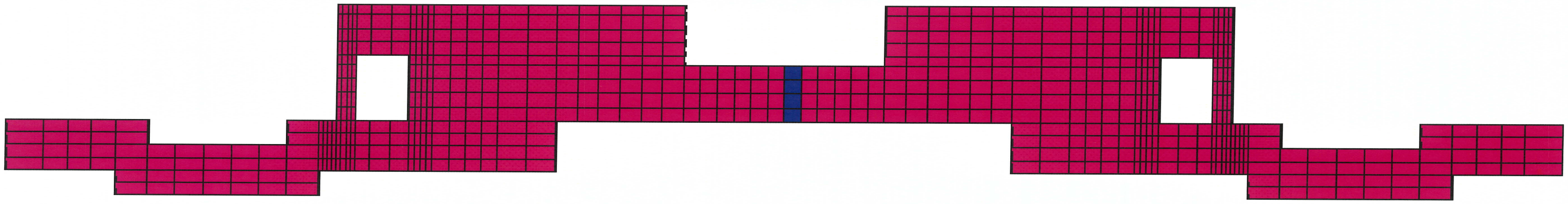


Figure 1. Detailed Section in the NI basemat



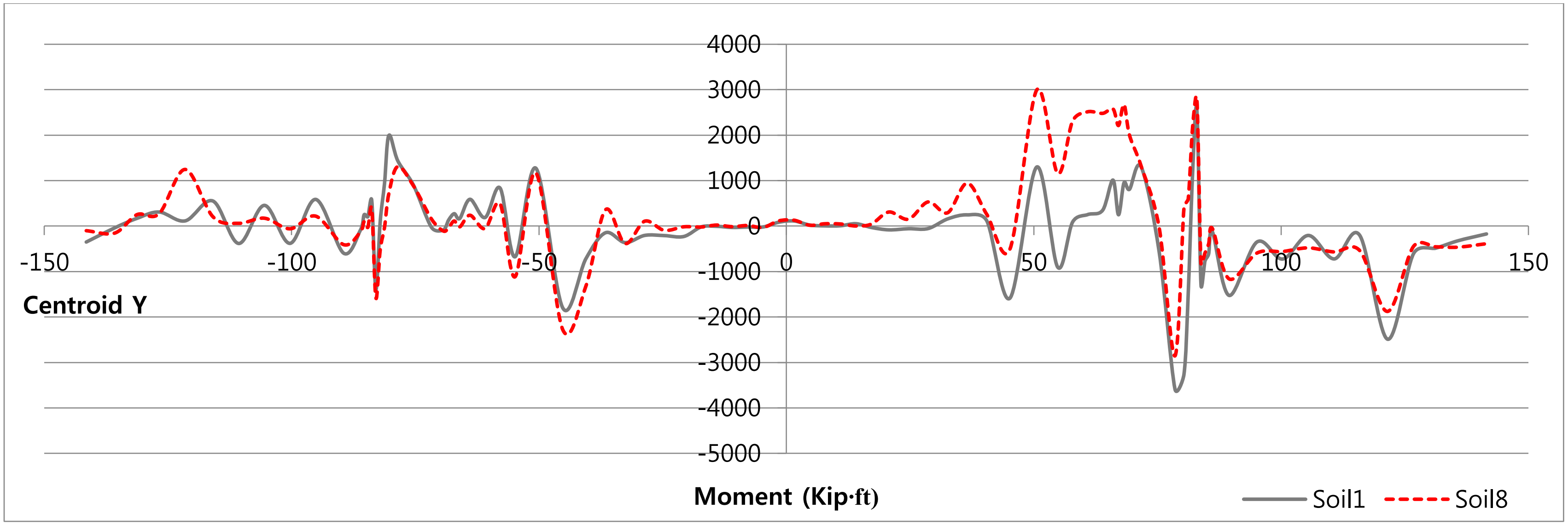
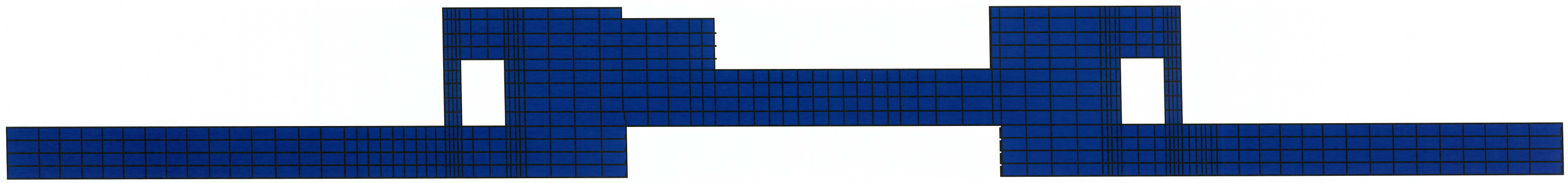


Figure 2. Detailed Section-01 and Moment Diagram under Abnormal/Extreme Case



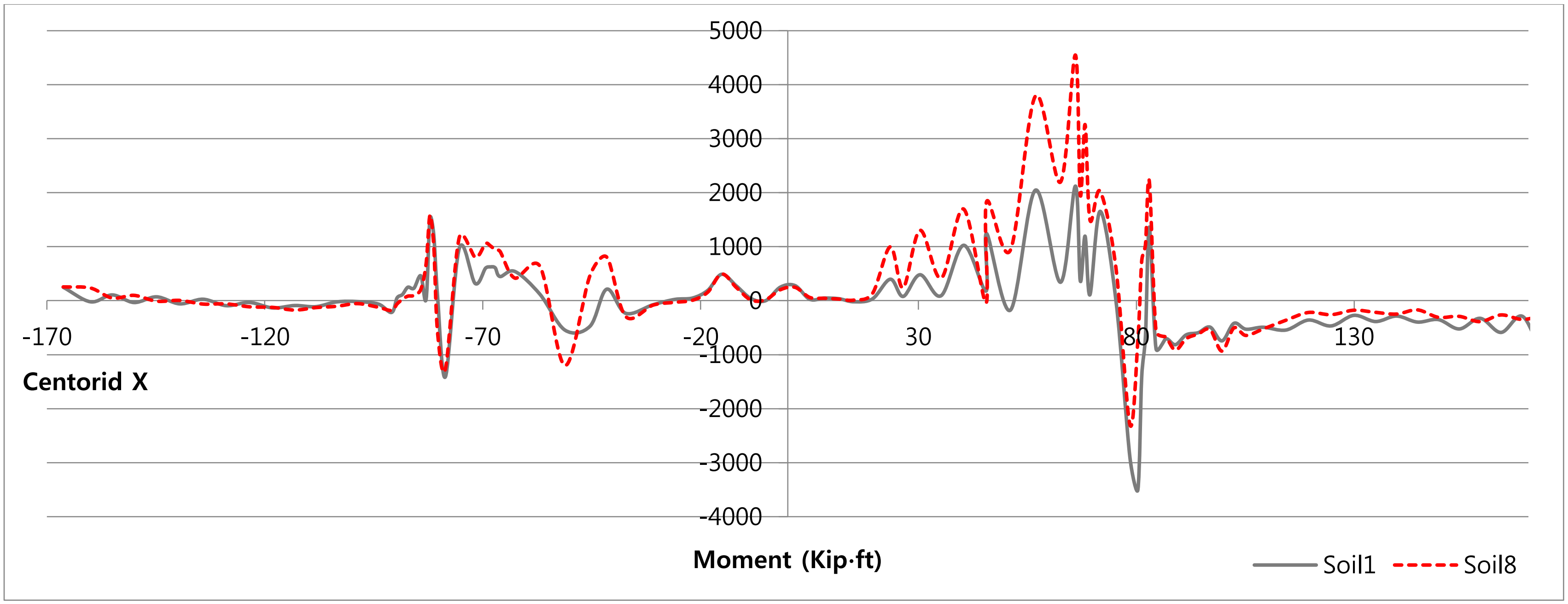


Figure 3. Detailed Section-02 and Moment Diagram under Abnormal/Extreme Case

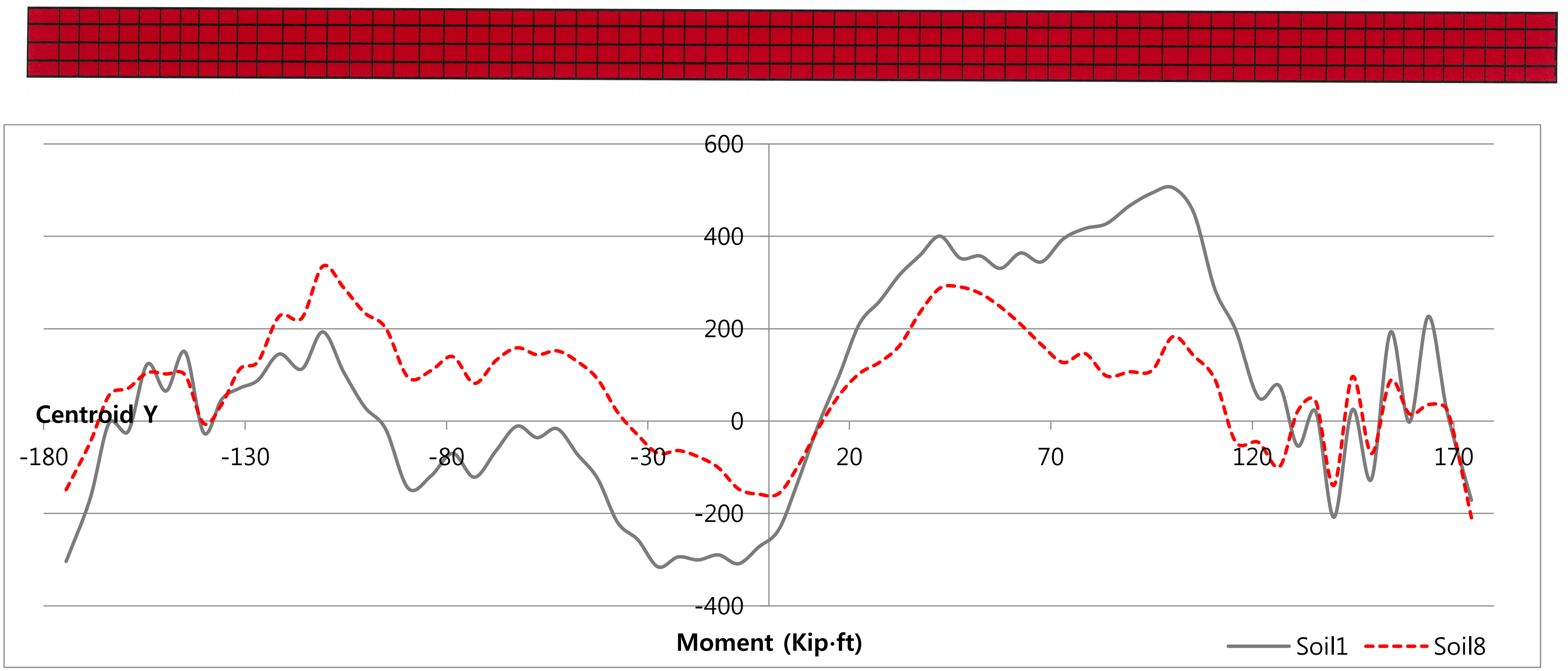


Figure 4. Detailed Section-03 and Moment Diagram under Abnormal/Extreme Case

Based on three figures above (Figures 2 thru 4), it is not clear which soil case condition is governed for the basemat design. Therefore, both soil profiles S1 and S8 are considered for construction sequence analysis.

The construction sequence analysis model consists of foundation media model considered 11 layer (soil layer model), NI common basemat, and superstructures (Auxiliary building, internal structures, and Shell & Dome). For construction sequence within Ni common basemat, 19 basemat concrete segments were determined based on concrete placement and hardening stages. For construction sequence within superstructures, five segments were determined to consider direction of construction sequence. For construction sequence analysis, the concrete used in analysis is normal weight concrete with the compressive strength of 5,000 psi at 91 days and 6,000 psi at 91 days for NI common basemat and superstructures, respectively. The concrete strength is assumed at the four hardening conditions to consider change of strength due to concrete pouring sequence.

For construction, the properties of foundation media model is applied in table 2-3 of Technical report (TeR) APR1400-E-S-NR-14006-P/NP, Rev, 3. For post-construction, the following equation based on several experimental results, suggested Schmertmann (1970), is considered in soil profile S01 because of sand profile. For post construction in soil profile S08 corresponding to rock profile, it is not necessary to consider the creep effect of soil.

$$C_2 = 1 + 0.2\log_{10}(\frac{t}{0.1}) \quad \text{where, t is time, in years}$$

In the equation, c2 means that correction factor to account from creep in soil. Considering 60 years, at the end life of plant, C2 is almost 1.55. For foundation media model in post-construction condition, the existing modulus of foundation media model is divided by correction factor based on assuming elastic deformation of soil.

Based on explanation, two construction sequences for check possibility of different cases are performed corresponding to case 1 (Counterclockwise) and case 2 (Clockwise) against each soil profiles S01 and S08. As a result, for various settlements (maximum vertical settlement, maximum tilting settlement, maximum differential settlement, and angular distortion) under construction and post-construction condition, it was calculated based on analysis results.

Maximum vertical settlement

Maximum vertical settlement is the maximum calculated vertical deformation for the construction and post-construction phases under sequence No.58 and 59, respectively. Table 1 shows the maximum settlement for construction and post-construction phases. EDGB and DFOT, the maximum vertical settlement is determined.

Table 1. Maximum Vertical Settlement for Construction and Post-Construction for NI, EDGB, and DFOT building

[Unit: ft]

Structures	Category	Max. settlement			
		Soil profile S1		Soil profile S8	
		#1	#2	#1	#2
NI building	Construction (Sequence No. 58)	0.286	0.282	0.012	0.0120
	Post-construction (Sequence No. 59)	0.386	0.380	Not considered [1]	
EDGB building	Construction	0.142		0.005	
	Post-construction	0.218		Not considered [1]	
DFOT building	Construction	0.172		0.005	
	Post-construction	0.266		Not considered [1]	

[1] Since soil profile S08 consists of rock profile, the creep effect of soil is not considered.

<u>Maximum Tilting settlement</u>

Tilting settlement is calculated as the ratio of the differential vertical settlement for at the opposite edges of the buildings to the length between two edges. To check tilting settlement, the check points are determined as shown figure 5. Of the construction sequence, the maximum tilting settlement for the construction and post-construction phase is checked by following equations under sequence No.58, end of construction, and No. 59, post-construction. Table 2 shows the maximum tilting settlement for NI common basemat. For EDGB and DFOT buildings, construction sequence and tilting settlement are not needed because these buildings are relatively small and simple structures, and there are sufficient gaps between the EDGB/DFOT buildings and NI buildings.

$$\text{Maximum tilting settlement} = \arctan(\Delta Uz/L)$$

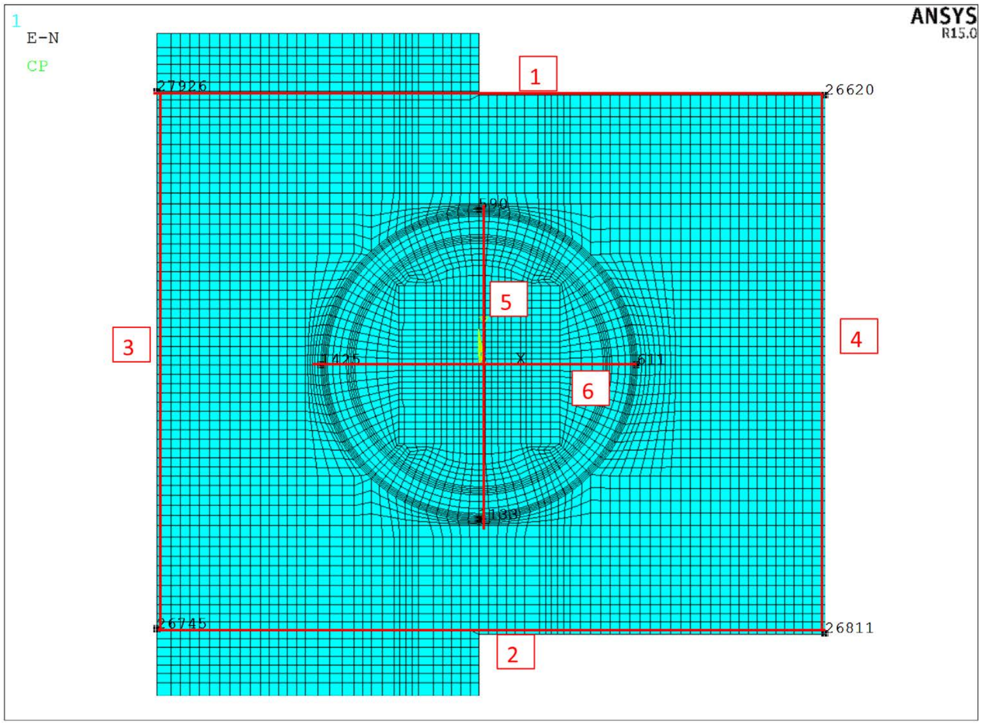


Figure 5 Check Group for Tilting Settlement

Table 2. Tilting Settlement for Construction and Post-Construction for NI building

[Unit: degree]

Category	Max. Tilt settlement		Soil profile S1		Soil profile S8	
	Sequence	Direction	#1	#2	#1	#2
Construction	Sequence No.58	E-W	0.00725	0.00507	0.00015	0.00006
		N-S	0.01253	0.00993	0.00032	0.00030
Post-Construction	Sequence No.59	E-W	0.00989	0.00606	Not considered [1)]	
		N-S	0.0136	0.00961		

[1)] Since soil profile S08 consists of rock profile, the creep effect of soil is not considered.

<u>Maximum differential settlement between structures</u>

For maximum differential settlement between structures under construction and post-construction, vertical settlement of NI basemat is obtained from sequence No.58 and No.59. However, vertical settlement of EDGB/DFOT is obtained from analysis which does not consider construction sequence analysis since the other structures (i.e., EDGB/ DFOT) are not required. The construction sequence analysis is not needed because these buildings are small and simple structures, and there are sufficient gaps between the EDGB/DFOT buildings and NI buildings. For differential settlement between adjacent structures, it is determined based on following six cases. Table 3 shows the summary of differential settlement between NI common basemat and EDGB/ DFOT basemat. Figure 6 shows the locations for differential settlement between structures.

1) Difference between maximum vertical settlement regarding adjacent nodes of EDGB and minimum vertical settlement regarding adjacent nodes of NI common basemat.

2) Difference between minimum vertical settlement regarding adjacent nodes of EDGB and maximum vertical settlement regarding adjacent nodes of NI common basemat.

3) Difference between maximum vertical settlement regarding adjacent nodes of DFOT and minimum vertical settlement regarding nodes of NI common basemat.

4) Difference between minimum vertical settlement regarding adjacent nodes of DFOT and maximum vertical settlement regarding nodes of NI common basemat.

5) Difference between maximum vertical settlement regarding adjacent nodes of DFOT and minimum vertical settlement regarding nodes of EDGB basemat.

6) Difference between minimum vertical settlement regarding adjacent nodes of DFOT and maximum vertical settlement regarding nodes of EDGB basemat.

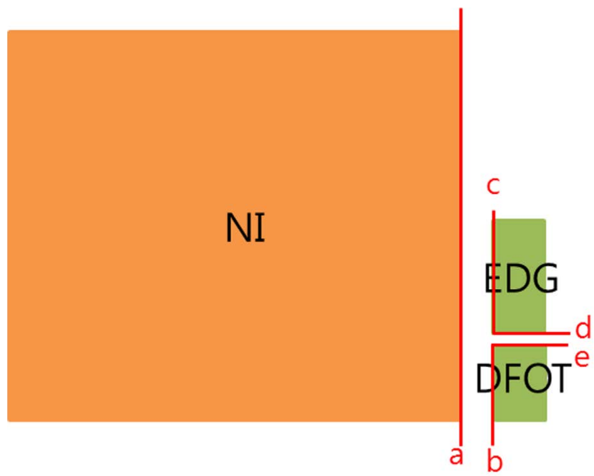


Figure 6 The Locations for Differential Settlement between Structures

Table 3. Differential Settlement between Structures for All buildings under Construction and Post-Construction

Line (Figure 6)			Max. differential settlement between structures [Unit: inch]							
			Construction				Post-construction			
			S01		S08		S01		S08	
			Max	Min	Max	Min	Max	Min	Max	Min
a	NI common basemat	Case1	2.171	1.566	0.078	0.051	3.358	2.671	Not considered [1]	
		Case2	2.020	1.527	0.074	0.052	3.132	2.620		
c	EDGB Basemat		1.701	1.670	0.061	0.046	2.615	2.582		
b	DFOT Basemat		2.066	0.986	0.054	0.027	3.193	1.521		
	Differential Settlement (NI and EDGB basemat)		0.501		0.009		0.776			
	Differential Settlement (NI and DFOT basemat)		1.185		0.002		1.837			
d	EDGB Basemat		1.701	1.474	0.061	0.047	2.615	0.189		
e	DFOT Basemat		2.066	1.787	0.053	0.034	3.193	2.773		
	Differential Settlement (DFOT and EDGB basemat)		0.592		0.027		0.925			

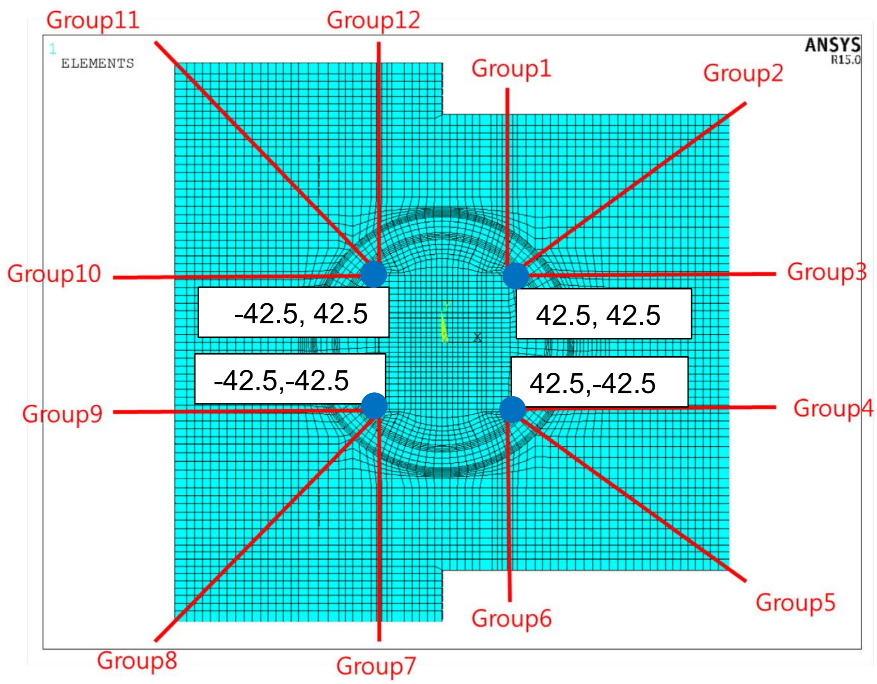
[1] Since soil profile S08 consists of rock profile, the creep effect of soil is not considered.

Maximum Angular distortion

Maximum angular distortion is $\beta = \delta/L$ is a measure of differential vertical displacement between two adjacent points separated by the distance, L. To determine the angular distortion, three sequences (sequence No. 22 , No.58, and No.59) of all sequences are selected for soil profile S01 and two sequences (sequence No.22 and No.58) for soil profile S08. Based on deformation result from each sequence (No.22, 58, and No.59), the 12 groups are determined to check points for angular distortion as shown Figure 7. These groups are selected along vertical, horizontal and diagonal direction based on starting points. The coordinates in the four boxes indicate the starting points of the red lines for each group.

For checking angular distortion per each group corresponding to soil profiles (S1, S8), it is plotted by vertical displacement along the distance between adjacent nodes within each group as indicated attachment 1. These vertical displacement graphs are used as the acceptance criteria for the COL applicant, not maximum angular distortion value since these figures show the curvature of the entire basemat.

As shown in graphs on pages 46 thru 57 of attachment 1 regarding to angular distortion plotted from adjacent nodes within nodes, the red line indicated the boundary of each segment of basemat. The change of sharp slope indicated in red line is caused by the difference of construction time. In order words, the reason why the shift is occurred is to consider different construction steps at the same nodes in the analysis. Therefore, slope due to step change is not considered for angular distortion. For EDGB and DFOT buildings, construction sequence and maximum angular distortion are not needed because these buildings are relatively small and simple structures, and there are sufficient gaps between the EDGB/DFOT buildings and NI buildings.



● Starting points of each group for displacement graph for angular distortion

Figure 7 Check Group for Angular Distortion (Unit: feet)

Based on explanation above, the description and results of construction sequence will be included in DCD Tier 2 section 3.8.5.4.2.1 and Tables 3.8-12 thru 3.8-14 as shown pages 7 thru 11 of attachment 1. In addition, section 5 of Technical report, APR1400-E-S-NR-14006-P/NP, Rev.3 will be revised as shown pages 5 thru 56 of attachment 1. Based on the analysis results of construction sequence for NI building and structural analysis under static loads for EDG and DFOT, four settlement criterion will be included in DCD Tier2 Table 3.8-12 through 3.8-14, and Section 3.8.5.4.2.2.d as shown attachment 1.

For structures, systems and components (SSCs) design for relative displacement of adjacent structures under static and seismic loadings, the description will be included in DCD Tier 2 section 3.8.5.8, 3.9.2.2.8, 3.9A.1.1, and 3.9A2.1, as shown attachment 2.

According to SRP 3.8.1, 3.8.3, 3.8.4 and 3.8.5, the Seismic Category I Structures including foundation and superstructures should be designed to take into account the additional member forces and moments induced by the effects of the construction sequence and the instantaneous and long term settlement of the soil under the foundation. Any difference in forces and moments between sequential analysis and reference analysis is added to dead load in all load combinations.

Although the construction sequence analysis is fulfilled in the DC stage, the construction sequence analysis will be re-evaluated in the COL stage based on the actual site condition and construction sequence established by COL applicant. COL information items (COL 3.8(18), COL 3.8(19)) will be added to the DCD, as indicated in the attachment 1 associated with this response.

Revision 5 of this response is revised to incorporate editorial error of referenced tables referred to in COL 3.8(15).

Impact on DCD

The changes that were proposed in Revision 4 of this RAI response have been incorporated into Revision 2 of the DCD; therefore, only the pages containing proposed changes as a result of Revision 5 of this response are included in the Attachment.

- Referenced tables referred to in COL 3.8(15) will be revised as indicated in the attachment.

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

The changes that were proposed in Revision 4 of this RAI response have been incorporated into Revision 4 of Technical Report, APR1400-E-S-NR-14006-P/NP; therefore, there is no impact on the technical report.

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Table 1.8-2 (8 of 39)

Table 3.8-12 thru Table 3.8-14

Item No.	Description
COL 3.8(15)	The COL applicant is to provide a site-specific monitoring program and to monitor maximum vertical settlement, differential settlement, tilt, and angular distortion to ensure they are less than the criteria in Table 2.0-1, ~~Table 3.8.5-12 thru Table 3.8.5-14,~~ and section 3.8.5.4.2.2.d during construction and plant operation.
COL 3.8(16)	The COL applicant is to provide testing and inservice inspection programs to examine inaccessible areas of concrete structures for degradation and to monitor groundwater chemistry.
COL 3.8(17)	The COL applicant 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 3.8(18)	A detailed construction sequence analysis to determine the resulting construction settlements, including the various standard soils profiles (S01-S04, S06-S09) and sequencing of concrete pours for the NI common basemat (RCB and Auxiliary Building), and superstructure model (Auxiliary Building, internal structures, and Shell & Dome), is presented in Section 3.8.5.4.2. A comparison of the four types of construction settlements (i.e. maximum vertical settlement, tilting settlement, maximum differential settlement between structures, and angular distortion) to the maximum criteria is summarized in Tables 3.8-12 through 3.8-14, and section 3.8.5.4.2.2.d. The COL applicant should use the construction sequence settlement analysis given in Section 3.8.5.4.2, substituting site-specific soil layer conditions, to ensure that the four types of settlement criteria described in Table 3.8-12 thru Table 3.8-14, and section 3.8.5.4.2.2.d. are satisfied. An alternative construction sequence and settlement analysis may be performed by the COL applicant in response to 1) the inability to meet the settlement criteria described in Table 3.8-12 thru Table 3.8-14, and section 3.8.5.4.2.2.d. using the DCD approach discussed in Section 3.8.5.4.2 or 2) Other site specific factors that may require a different construction plan and foundation sequence. However, in either case the COL applicant shall satisfy four types of settlement criteria described in Table 3.8-12 thru Table 3.8-14, and section 3.8.5.4.2.2.d..

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The COL applicant is to confirm that uneven settlement due to construction sequence of the NI basemat falls whthin the values specified in Table 2.0-1 (COL 3.8(14)).

3.8.5.7 Testing and Inservice Inspection Requirements

Testing and inservice surveillance of the basemat are performed in accordance with the requirements described in Subsections 3.8.1.7 and 3.8.4.7.

Table 3.8-12 thru Table 3.8-14

The COL applicant is to provide a site-specific monitoring program and to monitor maximum vertical settlement, differential settlement, tilt, and angular distortion to ensure they are less than the criteria in Table 2.0-1, ~~Table 3.8.5-12 thru Table 3.8.5-14~~, and section 3.8.5.4.2.2.d during construction and plant operation (COL3.8(15)).

The COL applicant is to provide testing and inservice inspection programs to examine inaccessible areas of concrete structures for degradation and to monitor groundwater chemistry (COL 3.8(16)).

The long-term settlement is the site-specific characteristics. The COL applicant is to provide the soil parameters for APR1400 site (COL. 3.8(17)).

3.8.5.8 SSCs between structures

Differential settlements (76.2 mm (3.0 in) shown in DCD Table 2.0-1) between structures (NI and EDG, NI and DFOT, EDG and DFOT) are used for design of SSCs under static loads.

The SSCs between buildings or structures are designed to allow the relative displacement or resist the forces due to relative movements of buildings. For this purpose, the floor response spectra and seismic anchor motions are used in the following procedure.

1) Seismic analyses of building structures are performed to compute floor response spectra and seismic anchor motions for the SSCs design.

2) SSCs shall have the support details to allow relative movements of between buildings or structures.

3) The seismic anchor motions between buildings or structures are considered in the SSCs design.

COL 3.8(9) The COL applicant is to determine construction techniques to minimize the effects of thermal expansion and contraction due to hydration heat, which could result in cracking.

COL 3.8(10) For safety and serviceability of seismic Category I structures during the operation of the plant, the COL applicant is to provide appropriate testing and inservice inspection programs to examine the condition of normally inaccessible, below-grade concrete for signs of degradation and to conduct periodic site monitoring of ground water chemistry. Inservice inspection of the accessible portion of concrete structures is also to be performed.

COL 3.8(11) The COL applicant is to verify that the coefficient of friction between the lean concrete and waterproofing membrane is greater than or equal to 0.55.

COL 3.8(12) The COL applicant is to provide reasonable assurance that the design criteria listed in Table 2.0-1 are met or exceeded.

COL 3.8(13) The COL applicant is to verify that the coefficient of friction between the lean concrete and the supporting medium at the site is equal to or higher than 0.55. In order to meet this requirement, the COL applicant is to determine the specific undulation pattern in Figure 3.8-27 for two perpendicular horizontal directions.

COL 3.8(14) 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.

Table 3.8-12 thru Table 3.8-14

COL 3.8(15) The COL applicant is to provide a site-specific monitoring program and to monitor maximum vertical settlement, differential settlement, tilt, and angular distortion to ensure they are less than the criteria in Table 2.0-1, ~~Table 3.8.5-12 thru Table 3.8.5-14~~, and section 3.8.5.4.2.2.d during construction and plant operation.

COL 3.8(16) The COL applicant is to provide testing and inservice inspection programs to examine inaccessible areas of concrete structures for degradation and to monitor groundwater chemistry.

COL 3.8(17) The COL applicant is to provide the following soil information for the APR1400 site: 1) elastic shear modulus and Poisson's ratio of the