RAI 255-8285

DRAFT 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

The static and dynamic cases are considered in the differential settlement evaluation. Differential settlement is evaluated in the static loading case (D+L) in technical report APR 1400-E-S-NR-14006-P, Rev1. With regard to differential settlements by seismic loading, the displacement results from the seismic analysis calculation were used (refer to Figures 4-6 through 4-14 regarding displacements of the basemat due to seismic loading in the technical report). Note that the differential settlement by seismic loading was obtained from the time- history analysis which does not consider any other loads.

In DCD Tier 2, Section 3.8.5.4 and technical report APR 1400-E-S-NR-14006-P, Rev.1, the construction sequence analysis considers the pouring and hardening stages and is evaluated for 19 basemat segments. The purpose of the analysis is to check the stress changes of the concrete and settlement distribution corresponding to the construction sequence. The applied loads are the self–weight of the NI common basemat without any other loads.

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 short term and long term settlement of the soil under the foundation.

To accomplish the construction sequence analysis, the generic geotechnical parameters are used. Among soil profiles S1, S4, and S8, soil profile S1 is the most critical soil profile for the settlement, and is to be considered. The given data of generic geotechnical parameters for soil profile #1 are;

1) Type of soil and layer which is sand, soft rock, and rock.

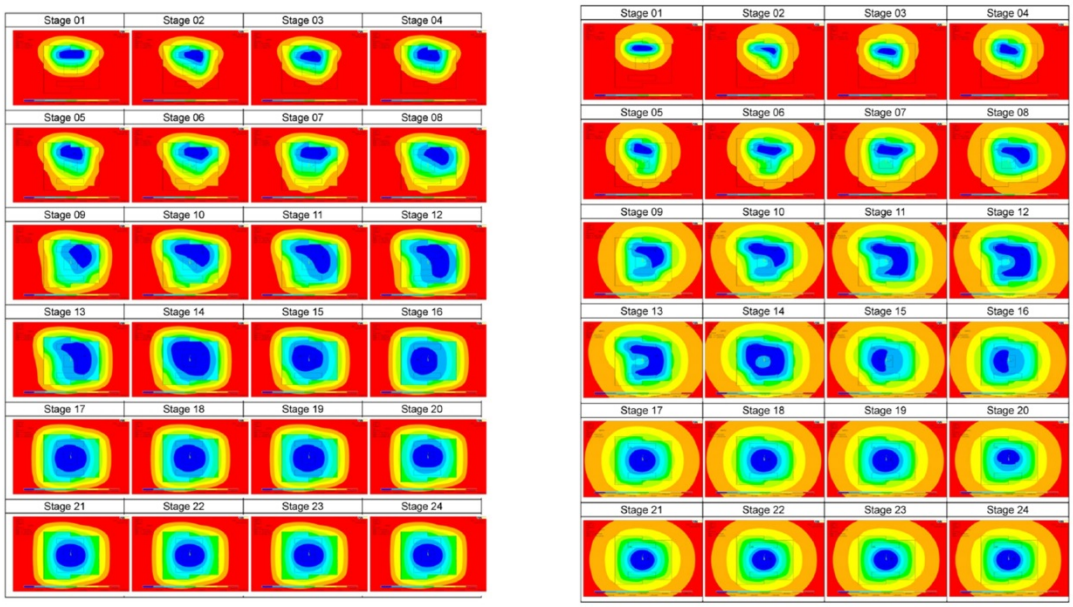
2) Shear wave velocity of sand, soft rock, and rock: 1173~3789ft/s for sand, 5778~6325ft/s for soft rock, and 9200ft/s for rock.

3) Unit weight of sand, soft rock, and rock: 0.125~0.130k/ft^3 for sand, 0.135k/ft^3 for soft rock, and 0.155k/ft^3 for rock.

NRC Feedback: Generally, it is expected that the softer soil profile (profile #1) would govern the design; however, sometimes other soil stiffness cases govern the design, and thus, should be considered or further justification provided. Also, explain how soil stiffness values were determined for the static load cases and dynamic seismic load case, which are expected to be different. In addition, see staff comment below regarding how values of soil springs were determined which relates to this staff request.

[KHNP INPUT #1]

1) The construction sequence analysis for the NI common basemat is described in section 5.0 of technical report (APR1400-E-S-NR-14006-P, Rev. 1). From the technical report, the settlements distribution contour for soil profiles S1 and S8 show that soft soil profile (S1) governs the stiff soil profile (S8) due to the concentration of settlement around the NI common basemat.



Soil Profile S1 **Soil Profile S8**

Figure 1. Settlement Distribution Contour for Construction Sequence Analysis

Based on the characteristic of soil profiles S1 through S8, of which soil layers consist of sand, soft rock or rock, the settlements during construction shall not govern for sand and/or rock site because the total amount of applied loads on the soil profiles S1 through S8 during construction is less than after construction. In addition, reinforcements or supports for building structures during concrete pouring and hardening are not performed in the DC application phase. Therefore, the design of building structures is not affected by the results of the construction sequence analysis if the settlement does not exceed DCD Table 2.0-1 specified criteria. If the settlement exceeds the acceptance criteria in the DCD Table 2.0-1, the construction sequence will be modified to meet the acceptance criteria in DCD Table 2.0-1 by the COL applicant.

The settlement trend or shape will not be affected until the characteristics of soil such as stiff/soft spots, soil type (granular/cohesive), loss of cement in the mudmat, and uniformity of soil layers are not changed. This variation of soil characteristics affects not only the basemat analysis, but the whole design procedure and results. Therefore, the variations of soil characteristics not enveloped by the generic soil profiles will be addressed in the COL application phase to account for specific site parameters.

2) The static soil stiffness value (E_{static}) and FE model for soil, (where each soil layer is modeled with SOLID185 elements in the ANSYS program), is used in the construction sequence analysis. The details of the stiffness values of soils are discussed in response to RAI 255-8285, Question 03.08.05-16.

When considering the characteristics of settlement for sand, and the relationship between settlement and applied load, the settlement of sand is controlled by immediate settlement, and the settlement is dependent upon the amount of load applied. So, the settlement during construction will be smaller than the settlement described in the technical report, which is for after construction.

Based on the soil properties of DCD Table 3.7A-1, the generic geotechnical parameters which are assumed for the construction sequence analysis are below;

1) The soil layers of DCD Table 3.7A-1 ~~will be~~ are considered.

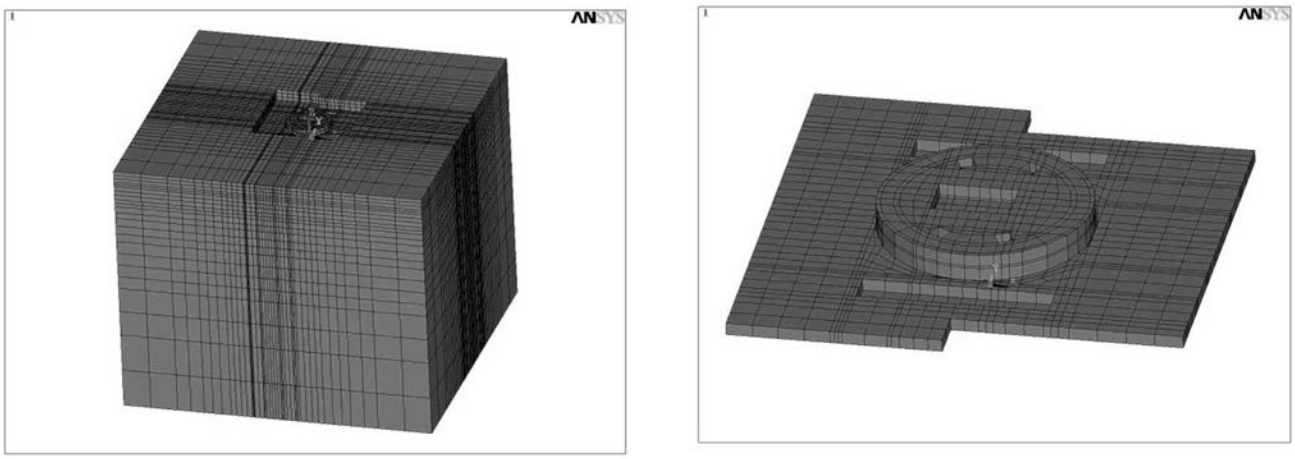
2) Based on the sand soil characteristics, the settlement will occur immediately, so the analysis of long-term settlement is not required.

3) The analysis ~~will~~ refer to the construction sequence ~~of the building structures~~ of Shin-Kori units 3&4, instead of using the actual construction sequence.

NRC Feedback: The description of the construction sequence for the basemat and structures on the NI, in what stages (e.g. up to what elevations) should be described in the technical report and summarized in the DCD.

[KHNP INPUT #2]

The construction sequence analysis for the NI common basemat is described in technical report section 5.0 (APR1400-E-S-NR-14006-P, Rev. 1). The construction sequence analysis model consists of foundation media (soil layer model) and the NI common basemat (up to EL. 78 ft for the RCB and 55 ft for the Auxiliary Building, Figure 5-2 in the technical report).



(a) Soil Model **(b) NI Common Basemat**

Figure 2, Construction Sequence FE Model

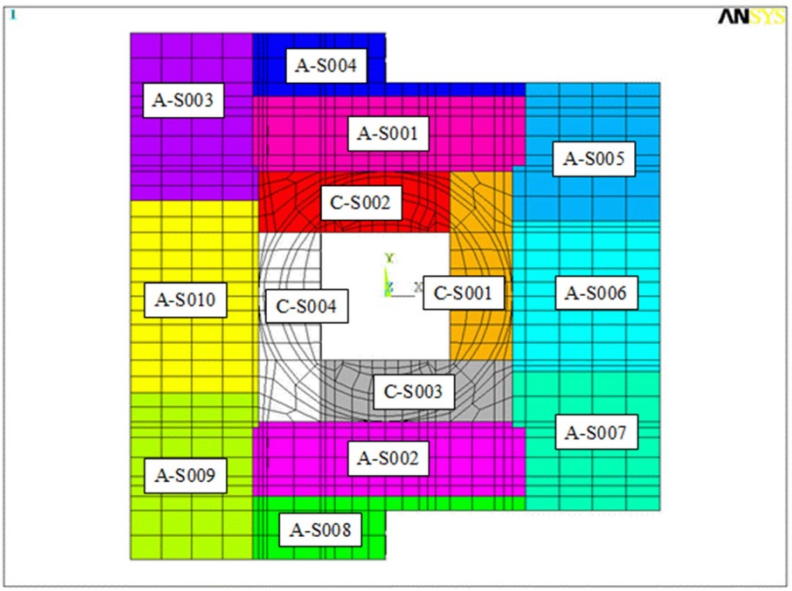
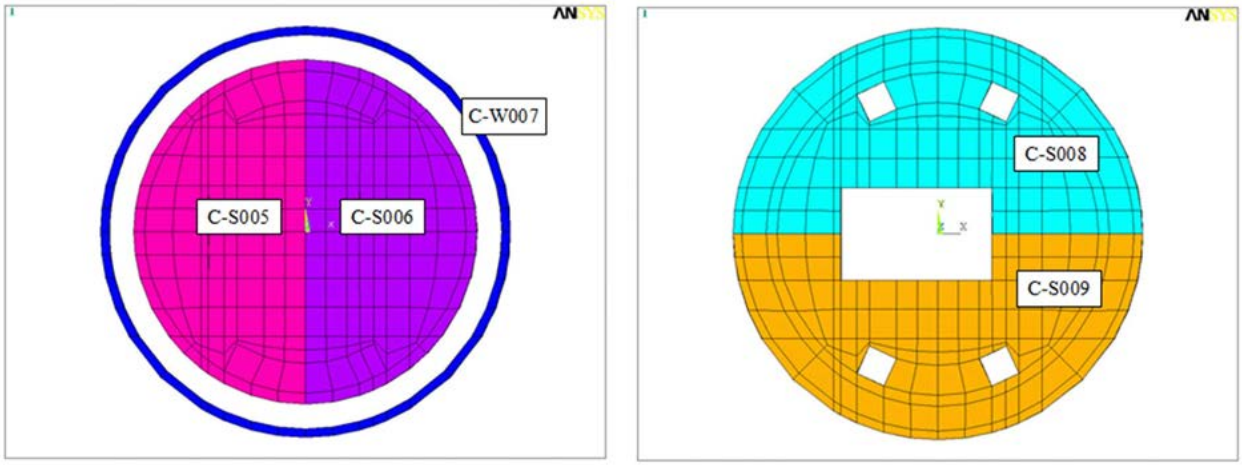


Figure 3. Individual Segments of Basemat below RCB and AB(El. 35′-0″ ~ El. 55′-0″)



a) RCB Area (El. 55′-0″ ~ El. 68′-0″) **(b) RCB Area (El. 68′-0″ ~ El. 78′-0″)**

Figure 4. Individual Segments of Basemat below RCB (El. 55′-0″ ~ El. 78′-0″)

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4) The effects of the design for Seismic Category I structures due to the actual construction sequence ~~will~~ are not accounted for due to the uncertainty of the generic geotechnical parameters and construction sequence, if the settlements do not exceed the allowable settlements in DCD Table 2.0-1.

NRC Feedback: Since the “actual construction sequence due to the uncertainty of the generic geotechnical parameters and construction sequence” is not known at this time, it is not clear why the last phrase in Item 4 above indicates a condition when these effects will or will not be accounted for. It appears that in either case, the effect for the “actual construction sequence” cannot be accounted for now. However, at this time, a selected construction sequence or several alternative construction sequences can be evaluated now. These construction sequences can be described in the technical report and the DCD. Then a COL Item should be defined to confirm that the actual construction sequence will follow the sequence reported in the DCD and ensure that the site-specific settlements are smaller than those evaluated and reported in the DCD.

[KHNP INPUT #3]
Based on the characteristic of soil profiles S1 through S8, of which soil layers consist of sand soft rock or rock, the settlements during construction shall not govern for sand and/or rock site because the total amount of applied loads on the soil profiles S1 thru S8 during construction is less than after construction and there is sufficient margin for the total and differential settlements. The reinforcements or supports for building structures during concrete pouring and hardening are not performed in the DC application phase. The reinforcements or supports for construction shall be performed in accordance with the results of the construction sequence analysis by the COL applicant that accounts for the specific site parameters.

Differential settlement between the nuclear island foundation and the foundations of adjacent buildings does not have an adverse effect on the safety related functions of structures, systems, and components. Differential settlement under the nuclear island foundation could cause the basemat and buildings to tilt. Much of this settlement occurs during the civil construction prior to final installation of the equipment. Differential settlement of a few inches across the width of the nuclear island would not have an adverse effect on the safety related functions of structures, systems, and components. DCD Table 2.0-1 provides guidance to the COL applicant on predictions of differential settlement that are acceptable without further evaluation. The predicted settlements covers the periods before construction begins through the construction phase and for the subsequent plant operating period or otherwise justified. The predicted settlements shall be based on conservative assumptions of soil properties. If the predicted settlements exceed the limits specified in DCD Table 2.0-1, a detailed evaluation and revised construction plan will be performed by the COL applicant. During construction and plant operation at a soil site, settlements would be measured and compared to the predicted settlement values and any exceedances would require additional investigation.

The procedures for the construction sequence analysis are below,

1) The concrete used in this analysis is normal weight concrete with the compressive strength of 5,000 psi at 91 days. The concrete strength is assumed at the three hardening conditions to consider the change of the strength due to the concrete pouring sequence.

2) The relation between the age and the strength of the concrete complies with the relationship for moist-cured concrete made with normal portland cement proposed by ACI Committee 209. The modulus of elasticity for concrete is calculated by the equation, ~~$57{,}000\sqrt{f_{ck}}$~~ $57{,}000\sqrt{f'_c}$, as given in ACI 349. The tensile strengths of concrete ~~will be~~ was considered.

   Explain how tensile strength is considered e.g., what tensile strength limit value is used; if it is reached, is the tensile stiffness removed; sensitivity effect if tensile strength is not considered because it is difficult to predict the tensile strength of concrete, especially partially cured concrete, and why is the term "f_{ck}" used rather than f'_c .

[KHNP INPUT #4]
The term "f_{ck}" is a former expression for "f'c". To eliminate confusion, "f_{ck}" will be changed to "f'_c" as shown below.

The relation between the age and the strength of the concrete complies with the relationship for moist-cured concrete made with normal portland cement proposed by ACI Committee 209. The modulus of elasticity for concrete is calculated by the equation, $57{,}000\ \sqrt{f'_c}$, as given in ACI 349. The tensile strengths of concrete will be considered.

The tensile strength of concrete will be calculated in accordance with the text book 'unified Theory of Reinforced Concrete' by Thomas T. C. Hsu. The tensile strength is used to check the

concrete tensile stress during construction to determine whether the tensile strength has been exceeded or not.

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3) Based on the construction techniques, the mat foundation is divided by concrete pour zones. The segments of concrete block are added to the construction-site according to the order of the prescribed concrete pouring. The concrete pour sequences and hardening condition of each segment are considered. Construction sequence analysis ~~will be~~ is performed by a finite element method using a computer program. The number of analyses is the number of concrete pouring stages and an additional 3 analyses to consider the completion of hardening of ~~all~~ the concrete segments of basemat.

4) ~~After hardening of all basemat concrete segments, the construction sequences analysis of superstructures, such as the containment building, internal structures, and auxiliary building, will be conducted. The superstructures are also divided by each concrete segment.~~ For the construction sequences analysis of superstructures, such as the containment building, internal structures, and auxiliary building, will be conducted by COL applicant. The COL applicant performs the construction sequence analysis of basemat again in accordance with actual site profiles with same methodology of the technical report section 5.0 (APR 1400-E-S-NR-14006-P, Rev.1). After hardening of all basemat concrete segments, the construction sequences analysis of superstructures, such as the containment building, internal structures, and auxiliary building, will be conducted. The superstructures are also divided by each concrete segment.

NRC Feedback: The term “will be” appears in several locations above. Confirm that this analysis was or is being performed during the design certification phase.

[KHNP INPUT #5]
The construction sequence analysis, up to the top of the basemat, was performed as described in KHNP INPUT #2. The construction sequence analysis including the NI building structure will be performed in the COL application phase.

In the COL stage, the construction sequence analysis will be conducted corresponding to the actual construction schedule and soil profile parameters, as described in DCD COL 3.8 (10). The differential settlement of the basemat will be checked and the construction sequence analysis results will be provided.

A COL information item (COL 3.8 (11)) will be added to the DCD, as indicated in the attachment associated with this response.

NRC Feedback: In addition to all of the above feedback, some items that were supposed to be addressed in the related RAI 255-8285 Questions 03.08.05-9 and 03.08.05-18, that referred to this RAI for the information, were not provided or adequately described. The additional information relates to criteria in SRP 3.8.5.II.4 E, J and K. One example of missing information in the case of criteria in SRP 3.8.5.II.4 K is: modeling of the soil stiffness (e.g., how values of soil springs were determined, including methodology/equations) for static loads and dynamic

(seismic) loads which would be expected to be different, and would be expected to be a function of soil type (granular vs. cohesive), foundation size, and time (short term vs long term), as well as how the soil springs were distributed across the foundation. In addition to the criteria in SRP 3.8.5.II.4 E, J and K, further guidance is provided in the NRC document entitled, "Technical Rationale for Enhancements to Seismic and Structural Review Guidance" on NRC ADAMS (ML14238A161), under the section Technical Issue No. 7, which also references a section in the U.S. Army Corps of Engineers (USACE) Manual No. 1110-1-1904. In addition, there is also guidance in a paper entitled, "Structural Design Challenges in Design Certification Applications for New Reactors," Proceedings of the ASME 2011 Pressure Vessels & Piping Division Conference, PVP2011-57600. Therefore, the applicant is requested to describe how settlements and construction sequence were evaluated to address the analysis and design parameters discussed in SRP 3.8.5.II.4 E, J and K, which appears to be lacking in this response and in RAI 255-8285 Questions 03.08.05-9 and 03.08.05-18.

[KHNP INPUT #6]

In the construction analysis, the foundation media model represented the soil profile instead of soil subgrade modulus.

1) Modeling of the soil stiffness (static): Static soil stiffness value (Estatic) and the FE model for soil, with each soil layer modeled with SOLID185 elements in the ANSYS program, is used In the construction sequence analysis. The details of the static/dynamic stiffness values of soils are discussed in the response to RAI 255-8285, Question 03.08.05-16.

2) Soil type: The generic soil profiles in the APR1400 project consist of sand, soft rock and rock. Considering the characteristics of sand and rock for settlement as indicated in DCD Table 3.7A-1 ~ 9, the settlement of the APR1400 basemat is calculated by the instantaneous settlement of sand, though time-consolidation effects are not considered. The COL applicant shall consider time-consolidation effects if cohesive soil is found in the site. Differential settlement of the basemat and bearing stress shall be checked to demonstrate acceptability.

3) Foundation size: The construction sequence analysis model consists of foundation media (soil layer, SOLID185 elements in the ANSYS program) and the NI common basemat. To capture the Boussinesq effect in soils, the foundation media model is used instead of the soil spring model. For the basemat analysis and construction sequence analysis with actual site profiles, the foundation media model developed with same methodology in technical report (APR1400-E-S-NR-14006-P, Rev. 1) will be used.

   The ratio of the width of the basemat is (1148 ft) / (353 ft) = 3.25 and the ratio of width of the foundation media is (1151 ft) / (356 ft) = 3.23 which exceeds 3.0. For the depth of foundation, the full depth of the generic soil profile was used; the ratio is (1000 ft) / (356 ft) = 2.81.

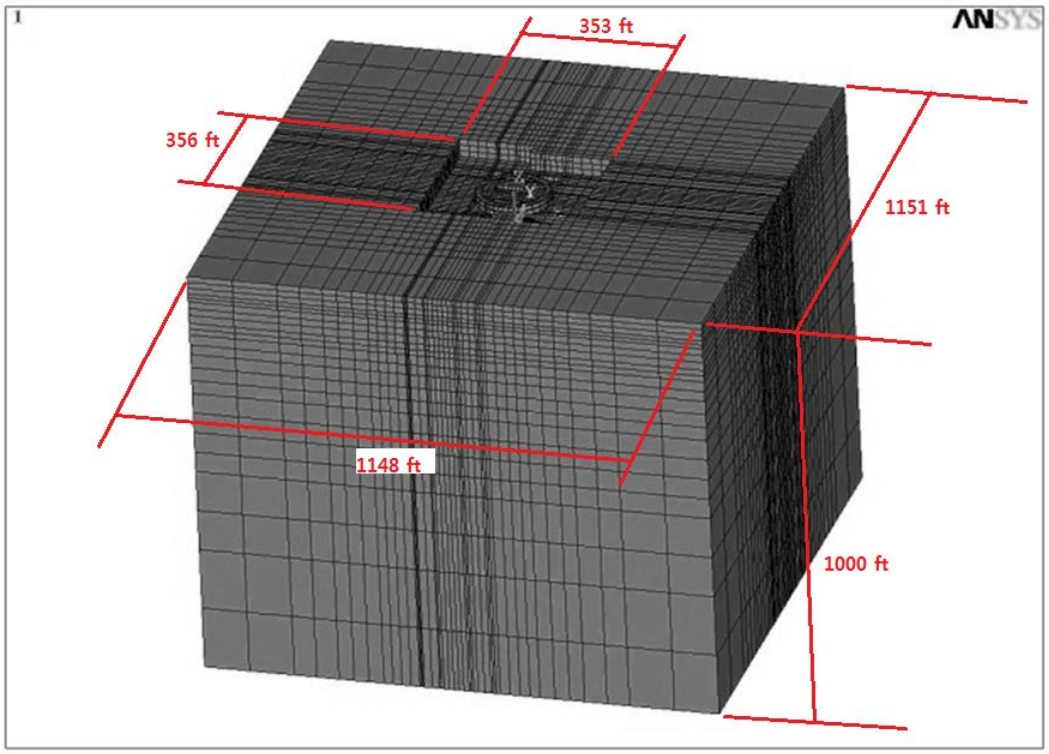

Figure 3. Dimension of Construction Sequence Foundation Media Model

4) Time (short term vs long term): The generic soil profiles in the APR1400 project consist of sand, soft rock and rock. Considering the characteristics of sand and rock for settlement, the settlement of the APR1400 basemat is calculated by the instantaneous settlement of sand, though the time-consolidation effects are not considered. The COL applicant shall consider time-consolidation effects if cohesive soil is found in the site. Differential settlement of the basemat and bearing stress shall be checked to demonstrate acceptability.

As a result of resolution of the above questions and the other related RAI questions on these topics, it is anticipated that the technical report on these topics, DCD, and COL Item(s) would be accordingly updated.

[KHNP INPUT #7]
As discussed above, the COL item will be revised as shown below.

New COL item

COL 3.8 ~~(11)~~(13) The detailed construction sequence analysis for the basemat and superstructure shall be performed according to the construction ~~schedule~~ plan. ~~The differential settlement of the basemat shall be checked to demonstrate~~

~~acceptability.~~ The construction shall use foundation media model developed with same methodology in the technical report, actual material properties, and superstructure model that was used for DC application. And the differential settlement of the basemat, bearing stress, and concrete stress shall be checked to demonstrate acceptability. If the results exceed limits of Table 2.0-1, a detailed evaluation and revised construction plan will be described by the COL applicant.

Existing COL item

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.

Unresolved Question No. 03.08.05-9

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.II.4.~~H~~.E, states, "Detailed explanation of how settlement is evaluated, including potential effects of static or dynamic differential settlement, dependence on time (i.e., short term vs. long term), effect of the soil type (i.e., granular vs. cohesive), and effect of the foundation type and size (e.g. basemats, spread footings). Evaluation of the effects of settlement on construction procedures. Evaluation of the allowable settlement (total and differential) that can be accommodated in the foundation/structures." Also, SRP Section 3.8.5.II.4.~~H~~.J, states, "Explanation of how loads attributable to construction are evaluated in the design. Some examples of items to be discussed include the excavation sequence and loads from the construction sequence of the mat foundation and walls, as well as the potential for loss of subgrade contact (e.g., because of loss of cement from a mud mat) that may lead to a differential pressure distribution on the mat." SRP Section 3.8.5.II.4.~~H~~.K, states "An essential aspect of the design and analysis procedures for seismic Category I foundations is the stiffness modeling of the soil material under and to the sides of the structures. Soil stiffness can be represented by means of analytical or numerical (e.g., solid finite elements, distributed springs) formulations that are appropriate for the loading conditions as well as for the soil type, foundation type and size, and time scale being considered."

In DCD Tier 2, Section 3.8.5.4.2, "Analysis of Settlement during Construction," the applicant provided limited description as to how settlement is evaluated. In the applicant's technical report (TR) APR1400-ES-NR-14006-P, Rev 1, "Stability Check for NI Common Basemat," the applicant describes the evaluation of the settlement of the NI basemat; however, Section 3.8.5.4 of the DCD does not reference the report. Furthermore, it is not clear to the staff how the criteria in SRP 3.8.5.II.4 E, J, and K are implemented.

Therefore, the applicant is requested to describe the design and analysis procedures to explain how the elements described in SRP 3.8.5.II.4 E, J and K are incorporated in APR14000 design, and include this information in DCD Section 3.8.5.

Response

According to SRP Section 3.8.5.II.4.E, the settlement was evaluated as follows:

(1) Effects of static and dynamic differential settlement

To evaluate the static differential settlement, the static load (D+L) was applied to the NI common basemat model. The differential settlements were computed based on a distance of approximately 50ft between two nodes. DCD Tier 2, Table 3.8A-17 shows the summary of the differential settlement in the NI basemat, and Figure 3.8A-18 shows the node locations at the bottom of the NI common basemat.

For differential settlement by seismic load, the displacement results from the seismic analysis (SASSI) are used. The relative displacements were considered in all time steps at 50 selected nodes. DCD Tier 2, Figures 4-6 through 4-14 show the relative displacement in selected nodes at the time computed for the maximum and minimum displacement of all time steps.

To address the evaluation for settlements, see NRC feedback provided in related RAI 255-8285 Questions 03.08.05-7, -17, and -18.

[KHNP INPUT #1]
For static differential settlement, the static loading case (dead + live load) was applied to the basemat analysis model with soil springs which were calculated from the subgrade modulus.
For differential settlement by seismic load, the soil stiffness was calculated by strain-compatible soil profiles. Additionally, all of the displacement data corresponding to all time steps from SASSI analysis for differential settlement during seismic excitation was checked as detailed in the response to RAI 255-8285 Question 03.08.05-17. Table 1 in the response to RAI 255-8285 Question 03.08.05-17 summarized the findings and indicated that the maximum differential settlement was approximately 0.0075 ft (0.09 in).

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(2) Short term and long term

Short term settlement is evaluated as a construction sequence analysis. Therefore, the detailed analysis will be accomplished corresponding to the actual construction sequence using the same methodology described in DCD Tier 2, Section 3.8.5.4. The response to RAI 255-8285, Question 03.08.05-7 will perform a detailed construction sequence analysis to determine effects on settlement.

Long term settlement is evaluated by assuming long duration loads acting during the entire life of the plant. Change in the soil spring parameter to account for time dependent effects are not considered because the site specific soil conditions are not available. This is related with DCD COL item, COL 3.8 (7).

To address the evaluation for settlements, see NRC feedback provided in related RAI 255-8285 Questions 03.08.05-7, -17, and -18. Also, the adequacy of the response cannot be determined until the detailed construction sequence analysis to determine effects of settlement, to be provided in the response to Question 03.08.05-7, is completed. However, that should be performed after an acceptable approach is identified.

[KHNP INPUT #2]
See response 1) of KHNP INPUT #1 in RAI 255-8285 Question 03.08.05-7.

In the case of long term settlement, some evaluation in the design certification phase should be considered to ensure that the design can accommodate long term settlements as well. The DCD should also clearly identify in one of the existing COL Items (e.g., COL 3.8 (8)) on settlement or settlement monitoring that the COL applicant is to confirm that the settlements during construction and long term

settlement resulting from the site-specific soil conditions fall within the values used in design. Note that monitoring of settlements and differential settlements, including a settlement monitoring program is discussed in SRP Section 3.8.5 and the referenced documents identified in the NRC feedback to RAI 255-8285 Question 03.08.05-7.

[KHNP INPUT #3]
For the case of long term settlement, see 4) of KHNP INPUT #6 in RAI 255-8285 Question 03.08.05-7.

An active settlement monitoring system throughout the entire construction sequence, as well as a long-term (plant operation) plan, shall be implemented. By monitoring the settlement throughout construction, the COL applicant will be able to modify the construction sequences of adjacent buildings to conform to the site's settlement characteristics and minimize differential settlement. For soil sites, the potential heave or rebound of the excavation bottom, the effect of dewatering, and the effect of foundation loading during construction should be monitored by the COL applicant.

In case of the settlement monitoring program, COL item (COL 3.8(8)) will be changed as shown below.

COL 3.8(8) The COL applicant is to provide a site-specific program to monitor the foundation settlement and differential settlements in accordance with Regulatory Guide 1.160.

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(3) Effect of soil type

Three generic site soil profiles (S1: Soft, S4: Medium, S8: Hard) are used to consider the effects of soil conditions on settlement. The selected profiles have been chosen to be a representative sample.

No comment.

(4) Effect of foundation type and size

The 3D FE NI common basemat model with superstructure was developed to consider the effect of actual foundation size and shape. The FE NI common basemat model is shown in DCD Tier 2, Figure 3.8A-12.

This question was intended to address the development of the soil springs, not to the understanding of the extent of foundation included in the 3D FE NI common model. Since this topic is already discussed in the staff feedback to RAI 255-8285 Questions 03.08.05-7, the response to this item can be provided there.

[KHNP INPUT #4]
See response 3) of KHNP INPUT #6 in RAI 255-8285 Question 03.08.05-7.

According to SRP Section 3.8.5.II.4.G, an evaluation of stiff and soft spots should be considered in analysis of the basemat. The stiff and soft spots are not predictable before the site survey or site excavation for the specific site. So, if these are found during excavation, the COL applicant shall perform basemat analysis considering stiff and soft spots (DCD COL item, COL 3.8 (11)) or the soft spots must be excavated and backfilled with a substance which prevents additional effects and uncertainty such as differential settlement.

Normally, consideration of stiff and soft regions under the basemat in the design certification phase is prudent to avoid potential problems during the COL applicant phase. Otherwise, there may be no or little margin in the design to accommodate deviations from a "uniform" assumption of soil stiffness across the entire soil foundation. The applicant is requested to explain why this is not considered in design and then confirmed using a COL Item. Alternatively, confirm that the current approach being followed will require a site-specific evaluation of all seismic Category I structures to ensure the design remains valid for any deviation in the soil stiffness properties assumed in the design, and what design margin is available to address this potential for additional loads, and why this margin is sufficient.

In addition, the proposed markup for COL 3.8 (11) states: "The COL applicant is to perform a foundation evaluation including stiff and soft spots using the methodology described in DCD Tier 2, Section 3.8.5.4." DCD Section 3.8.5.4 should be enhanced to provide sufficient guidance and criteria for performing such evaluations.

[KHNP INPUT #5]
See response 1) of KHNP INPUT #1 in RAI 255-8285 Question 03.08.05-7.

According to SRP Section 3.8.5.II.4.J, the evaluation of settlement during the construction sequence will be performed corresponding to the actual construction sequence using the same methodology described in DCD Tier 2, Section 3.8.5.4 (Please refer to Question 03.08.05-7). If the actual soil status and loss of cement from the mud mat is expected after the site survey or site excavation, loss of subgrade contact due to loss of cement from a mud mat is considered corresponding to the actual site status (DCD COL item, COL 3.8 (12)). The detailed analysis will be performed using the same methodology described in DCD Tier 2, Section 3.8.5.4.

Additional questions related to the criteria in SRP Section 3.8.5.II.4.J for settlement and construction sequence are captured by RAI 255-8285 Questions 03.08.05-7, -17 and -18. Also, adequacy of the response cannot be determined until the detailed construction sequence analysis to determine effects of settlement, to be provided in the response to Question 03.08.05-7, is completed. However, that should be performed after an acceptable approach is identified.

As discussed in the previous item above on stiff and soft spots, it is prudent to consider in the design certification phase potential detrimental effects that might occur during and after construction, such as loss of cement in the mud mat leading to differential pressures on the mat. Otherwise, there may be no or little margin in the design to accommodate these effects. Therefore, the applicant is requested to explain why this is not considered in design in some manner, even though there is a COL Item to evaluate for this condition by the COL applicant if it exists.

[KHNP INPUT #6]
See response 1) of KHNP INPUT #1 in RAI 255-8285 Question 03.08.05-7.

The evaluation of settlement which satisfies the criteria of SRP Section 3.8.5.II.4.K will be completed until March 31, 2016. The evaluation will consider the consistency between soil stiffness and the magnitude of soil strains used in the SSI analysis, the dishing or Boussinesq effects, and will include a comparison between toe bearing pressure used in the foundation design and the toe bearing pressure obtained from the SSI analysis. Upon completion of the analysis, TeR APR1400-E-S-NR-140006 will be revised.

Additional questions related to the criteria in SRP Section 3.8.5.II.4.K are captured by RAI 255-8285 Questions 03.08.05-7, -17 and -18. Also, adequacy of the response cannot be determined until the detailed analysis, to be provided in Question 03.08.05-7, is completed. It should be noted, that the information needed to address the criteria in SRP Section 3.8.5.II.4.K should cover not only settlement but also overall analysis/design for seismic Category I foundations, i.e., settlements and differential settlements, construction sequence, and development of member forces from these effects for use in design, how they will be included in design along with other loads. Other items in SRP Section 3.8.5.II.4.K.i that are not included in any of the RAI responses should also be addressed.

New COL items:

COL 3.8 (11) The COL applicant is to perform a foundation evaluation ~~including stiff and soft spots~~ using the methodology described in DCD Tier 2, Section 3.8.5.4 if stiff or soft was founded in the site. The differential settlement of the basemat and bearing stress shall be checked to demonstrate acceptability. If the results exceed limits of Table 2.0-1, a detailed evaluation is achieved. Or, soft and stiff spot is replaced appropriately to meet the limits of Table 2.0-1 by the COL applicant.

COL 3.8 (12) The COL applicant is to evaluate the loss of subgrade contact due to loss of cement from the mud mat using site specific data and the methodology described in DCD Tier 2, Section 3.8.5.4.

Related Existing COL items:

~~**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.~~

Replaced with new COL item COL 3.8 (13) in the response of RAI 03.08.05-7

COL 3.8 (8) ~~The COL applicant is to provide the necessary measures for foundation settlement monitoring considering site-specific conditions~~ The COL applicant is to provide a site-specific program to monitor the foundation settlement and differential settlements in accordance with Regulatory Guide 1.160.

DRAFT Question No. 03.08.05-18

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 IA structures.

Technical Report (TR) APR1400-E-S-NR-14006-P, Rev 1, "Stability Check for NI Common Basemat," Section 5.0, "Construction Sequence Analysis," describes the construction sequence analyses performed for the NI basemat, and indicates that Sites S1 and S8 were used for the calculations. Figure 2-1, "Shear Wave Velocity of Generic Site Categories," indicates that site S□2 is softer than Site S1 in the top 100' of the profile and will be expected to lead to larger construction settlements and structural demands. 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 provide the basis for using the Site S1 rather than S-2. Also, if any site considered for construction of the APR1400 design has soil conditions that lead to settlements greater than those computed for S1 and S8 in the DCD and technical report, explain how that will be addressed.

Additionally, the staff believes that most construction sequence studies are based on assuming either (1) a sand profile where settlements occur instantaneously as load is applied, or, (2) a fine-grained soil where settlements are delayed due to potential time-consolidation effects. These two bounding profiles can lead to different demands on the structural elements. Also, an evaluation of short term and long term settlements are normally evaluated for the basemat and the superstructures, and incorporated into the design. The above considerations could not be identified in the analysis and design of the basemat and superstructures. Therefore, the applicant is requested to address how settlement and construction sequences during the short term condition of the basemat and superstructure, as well as long term condition were considered in the analysis studies and in the design of the basemat and superstructures.

Also, it is not clear how a differential displacement of 0.5 in. per 50 ft. can be used by the COL applicant to confirm the design adequacy of the basemat and superstructure. Usually, displacement of basemat results in bending distortion between adjacent points, not simply differential displacements. Therefore, the applicant is requested to explain how the COL applicant is supposed to check for settlements, and revise the technical report, applicable sections of the DCD, and COL item(s) accordingly.

Response

1) The applicant is requested to provide the basis for using the Site S1 rather than S2 soil profile.

   Soil profile S1 is chosen as the representative soil profile even though soil profile S2 is softer than S1 at some depths. To find the weakest of the site profiles, the subgrade moduli of S1 and S2 are compared, as shown below in Table 1. The subgrade moduli are calculated using the methodology described in technical report APR1400-E-S-NR-14006-P, Rev. 1, "Stability Check for NI Common Basemat," Section 2.2.1, "Elastic Modulus of Soil Sites." The values or S1 are presented in Table 2-4, "Equivalent Subgrade Moduli of Site Profiles" of the TeR. Since the subgrade modulus of S1 is less than S2, S1 has been selected for the construction sequence analyses performed for the NI basemat. If the site specific soil information identified by the COL applicant as a result of performing the actions

required by COL 3.8 (10) is not enveloped by soil profiles S1 ~ S9, and the soil condition leads to greater settlement, the COL applicant shall perform the analysis required by COL 3.8 (11) (please see KHNP's response to RAI 255-8285, Question 03.08.05-7) and determine the acceptability of the site specific settlements obtained.

Table 1 Comparison of Soil Profile 1 and Soil Profile 2

Site Profile	Max. Displacement (ft)	Subgrade modulus (fcf)
NI Basemat		
S1	0.028046 (Z,Vertical)	Kv=35.66
S2	0.020109 (Z,Vertical)	Kv=49.73

Basing the soil profile for evaluation of construction sequence, on the lowest value of subgrade modulus alone may not lead to an adequate design. The effect of soil stiffness on this one value alone may not lead to governing loads. While consideration of soft soil generally may lead to governing loads, that is not always the case everywhere in the basemat and structure near the basemat. Typically, soft, medium and hard soil should be considered or an adequate basis provided. Also, see feedback provided in related RAI 255-8285 Questions 03.08.05-7, -9, and -17, in order to ensure a complete and consistent response.

[KHNP INPUT #1]

As discussed in the response to RAI 255-8285 Question 03.08.05-7, based on the characteristic of soil profiles S1 through S8, of which soil layers consist of sand, soft rock or rock, the settlements during construction shall not govern for sand and/or rock site because the total amount of applied loads on the soil profiles S1 through S8 during construction is less than after construction.

From the construction sequence analysis for the NI common basemat described in section 5.0 of technical report (APR1400-E-S-NR-14006-P, Rev.1), the settlements distribution contour for soil profiles S1 and S8 shows that soft soil profile (S1) govern the stiff soil profile (S8) due to the concentration of settlement around the NI common basemat.

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2) The applicant is requested to address how settlement and construction sequences during the short term condition of the basemat and superstructure, as well as long term condition were considered in the analysis studies and in the design of the basemat and superstructures.

Evaluation of short term and long term settlement analysis for the NI common basemat and superstructure analysis is to be performed by the COL applicant; COL 3.8 (11) is to be added to DCD Tier 2, as indicated in the applicant's response to RAI 255-8285, Question 03.08.05-7 to require the COL to perform the analyses. Two categories of settlements are to be evaluated; (1) Short term settlement, at the end of construction, and (2) Long term settlement, at the end of the operational life of the plant. The end of construction is defined as the time when building structures and major equipment are in place. The loading

scenarios for the construction sequence analysis will be set by the COL applicant. Moreover, the effect of both immediate and time dependent deformation, including bending distortion produced up to the end of construction, and end of life, will be calculated based on primary consolidation theory and viscous deformation analysis by the COL applicant. Also, the COL applicant shall check the integrity of the basemat and superstructure design based on the results of the settlements.

Even though, a COL Item is defined to address settlement and construction sequences during short term and long term conditions, the APR1400 plant design during design certification should include this evaluation. Then, the COL applicant can confirm that the site-specific conditions are acceptable against what was assumed in design. Also, see NRC feedback provided in related RAI 255-8285 Questions 03.08.05-7, -9, and -17, in order to ensure a complete and consistent response.

[KHNP INPUT #2]

The construction sequence analysis for the NI common basemat is described in section 5.0 of the technical report (APR1400-E-S-NR-14006-P, Rev. 1). In this construction analysis, the short term condition was considered due to the characteristics of the generic soil profiles of the APR1400 project. Long term conditions and time-consolidation effects are not required due to the sand soil characteristics in the generic soil profiles of the APR1400. The COL applicant shall consider time-consolidation effects if cohesive soil is found in the site. The differential settlement of the basemat and bearing stress shall be checked to demonstrate acceptability.

DCD Table 2.0-1 provides guidance to the COL applicant on predictions of settlements and differential settlement that are acceptable without further evaluation. The predicted settlements will cover the periods before construction begins through the construction phase and for the subsequent plant operating period or otherwise justified.

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3) The staff believes that most construction sequence studies are based on assuming either (1) a sand profile where settlements occur instantaneously as load is applied, or, (2) a fine-grained soil where settlements are delayed due to potential time-consolidation effects.

According to IBC, Section 1613; ASCE 7-05; and NAVFAC DM 7.01, Chapter 5, soils whose shear wave velocities are between 600 and 1200 feet per second are considered to be stiff soils, as shown in Table 2 below.

Table 2 Site Class Definitions

SITE CLASS	SOIL PROFILE NAME	VERAGE PROPERTIES IN TOP 100 feet		
		Soil shear wave velocity, Vs	Standard penetration resistance (N)	Soil undrained shear strength (S_U)
A	Hard rock	Vs > 5,000	N/A	N/A

B	Rock	2,500 < Vs ≤ 5,000	N/A	N/A
C	Very dense Soil and soft rock	1,200 < Vs ≤ 2,500	N > 50	$S_U \geq 2,000$
D	Stiff soil profile	600 < Vs ≤ 1,200	15 < N < 50	$1000 \leq S_U \leq 2,000$
E	Soft soil profile	Vs ≤ 600	N < 15	$S_U \leq 1,000$

The smallest shear wave velocity of any soil layer for the nine (S1 through S9) APR1400 generic soil profiles is the first layer in site profile S1; the shear wave velocity of this layer is 1173 ft/sec. The stiff soil is considered to be sand. The fine-grain soil characteristic for time consolidation effects was not considered in the basemat analysis due to site profile S1 not being classified as soft soil. The COL applicant will use site specific soil characteristics in their evaluation of differential settlement, as required by COL 3.8 (11), as added by KHNP's response to RAI 255-8285, Question 03.08.05-7.

As noted in Item 2 above, the design certification should consider the effects of the range of soil profiles and types (i.e., sand or fine-grained, or both). Then, the COL applicant can confirm that the site-specific conditions are acceptable against what was assumed in design. Also, see feedback provided in related RAI 255-8285 Questions 03.08.05-7, -9, and -17, in order to ensure a complete and consistent response.

[KHNP INPUT #3]

The generic soil profiles in APR1400 project, S1 through S8, define various soil profiles and types which are considered in the DC phase. Other soil profiles not enveloped by the generic soil profiles in the APR1400 project affect not only the basemat analysis, but the whole design procedure and results. Therefore, the variations of soil characteristics not enveloped by generic soil profiles will be addressed in the COL application phase and account for specific site parameters.

Table 2.0-1 provides guidance to the Combined License applicant on predictions of settlements and differential settlement that are acceptable without further evaluation. The predicted settlements covers the periods before construction begins through the construction phase and for the subsequent plant operating period or otherwise justified.
