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. 03.08.05-17

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 4.1.2, “Differential Displacement,” describes the approach used to develop the differential displacements within the NI and between the NI and the adjacent TGB. For seismic loading, the relative displacements were determined at only two specific time steps where the maximum average and minimum average of displacements over the entire time history were determined. Also, APR1400-E-S-NR-14006-P, Rev.1, Section 4.1.2 indicates that the differential settlement for seismic loading is calculated based on the maximum and minimum displacements of the basemat (not the differential settlements per 50 ft). This information is not clear. 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 explain how the differential displacements were determined. Also explain why this does not consider the differential displacements at all time steps, which might lead to a higher differential displacement.

Additionally, in TR APR1400-E-S-NR-14006-P, Rev 1, “Stability Check for NI Common Basemat,” Section 4.1.2, “Differential Settlement,” the applicant provided Table 4-3, “Differential Settlements Between NI Basemat and TGB Basemat (Static Loading Case),”which shows the differential settlement between between the NI basemat and the TGB basemat. The staff reviewed the table and noted that the differential settlement for S4 (for moderate site properties), which is 0.250”, is much larger than the differential settlements for S1, which is 0.091”, and S8, which is 0.018”, (for weak and strong site properties, respectively). The applicant is requested to address this discrepancy.

Response – (Rev. 1)

In accordance with SRP 3.8.5 Section II 4, static and dynamic differential settlement was evaluated. According to Table 2.0-1 in the DCD, 0.5 inch per 50 ft in any direction for the seismic category I structures are the acceptance criteria for maximum allowable differential settlement. The acceptance criteria are considered under static plus seismic loads. These are incorporated in DCD Tier 1 Table 2.1-1 and Tier 2 Table 2.0-1 as shown in Attachment 1.

For static loading, the dead and live loads (D+L) are applied in the NI common basemat model considering the boussinesq effect. To check differential settlement, the nodes are chosen within a distance of approximately 50ft. DCD Figure 3.8A-18 shows the node locations of the NI common basemat. The maximum differential settlement per 50 ft for S1, S4, and S8 are 0.21, 0.09 and 0.04 inch, respectively.

For the detailed evaluation of dynamic differential settlement due to seismic loading, all of the displacement data from the SASSI analysis corresponding to all time steps and soil profiles are considered by the following procedure on check points as shown in Figure 4-5 of the Technical Report, APR1400-E-S-NR-14006-P/NP (Rev.1):

a) Organize the vertical displacement corresponding to each seismic excitation (X, Y, Z) by each time step and node. Then, combine the three vertical displacements by SRSS method per each node and time step.

b) At the same time step, choose the maximum combined response (A) and minimum combined response (B) within the check points (basemat SASSI nodes). Then, calculate the differential settlement (A-B). Repeat step b) for all time steps

c) Envelope the calculated differential settlement within all time steps. (Column 2of Table 1)

d) The differential settlement summarized in Table 1 was calculated by following equation to evaluate differential settlement per 50ft. (Column 4in Table 1)

$$\frac{(A - B) \times 50}{\text{Distance}}$$

where, A and B are the maximum and minimum displacements

e) Repeat step a) ~ c) corresponding to soil profiles S1 ~ S9.

According to the procedure above, the results of the maximum and minimum displacement are summarized in Table 1 of the response.

Table 1 summarizes the differential settlement at the time when the differential settlements are maxima for each soil profile. The combined differential settlement for D+L+Es is summarized in Table 2.

Table 1. SRSS-Combined Vertical Displacement (UZ) from SASSI in NI Basemat

Site Profile	Difference (ft)	Distance (ft)	Differential Settlement per 50ft (ft)	Time (sec)
S1	0.018	288.630	0.003	8.62
S2	0.014	187.159	0.004	12.56
S3	0.011	187.159	0.003	12.52
S4	0.010	165.162	0.003	13.55
S5	0.004	253.804	0.001	15.30
S6	0.006	337.350	0.001	13.25
S7	0.005	402.351	0.001	13.22
S8	0.002	182.023	0.001	15.29
S9	0.003	90.256	0.001	15.29

Table 2. Combined Maximum Differential Settlement for D+L+Es in NI basemat

	Differential Settlement (inch)		
Loading Case	S1	S4	S8
Static (D+L)	0.21	0.09	0.04
Seismic (Es)	0.038	0.035	0.007
Combined (+)	0.248	0.125	0.047
Combined (-)	0.172	0.055	0.033

For static loading, the dead and live loads (D+L) are applied in the Emergency Diesel Generator Block (EDG) and Diesel Fuel Oil Storage Tank (DFOT) structure model with soil springs. This model did not considered the boussinesq effect, since it does not effect the basemat analysis due to their small size. To check differential settlement due to static loading cases, the nodes are chosen within a distance of approximately 50ft as in shown figures from RAI 255-8285 Question 03.08.05-10. The maximum differential settlement per 50ft for S1, S4, and S8 are 0.178, 0.101 and 0.042 inches for the EDGB, and 0.284, 0.110 and 0.021 inches for the DFOT respectively.

For differential settlement in the EDG and DFOT due to seismic loading, all of the displacement data from the SASSI analysis corresponding to all time steps and soil profiles are considered by the same procedure used in the NI basemat analysis. The check points for the EDG and DFOT is SASSI nodes as shown in Figures 1 and 2.Tables 3 and 4 summarizes the differential settlement at the time when the differential settlements are maxima for each soil profile in the EDG and DFOT.

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Figure 1. Location of EDG Basemat SASSI Nodes for Relative Displacement Calculation

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Figure 2. Location of DFOT Basemat SASSI Nodes for Relative Displacement Calculation

Table 3. SRSS-Combined Vertical Displacement (UZ) from SASSI in EDG

Site Profile	Difference (ft)	Distance (ft)	Differential Settlement per 50ft (ft)	Time (sec)
S1	0.005	72.043	0.0037	7.605
S2	0.006	97.645	0.0031	8.5
S3	0.005	55.856	0.0043	7.62
S4	0.003	72.043	0.0024	7.61
S5	0.003	41.463	0.0038	10.49
S6	0.004	113.536	0.0017	7.61
S7	0.005	113.536	0.0024	6.745
S8	0.001	88.827	0.0003	10.51
S9	0.001	113.536	0.0004	10.575

Table 4. SRSS-Combined Vertical Displacement (UZ) from SASSI in DFOT

Site Profile	Difference (ft)	Distance (ft)	Differential Settlement per 50ft (ft)	Time (sec)
S1	0.0024	47.347	0.0025	8.605
S2	0.0031	47.347	0.0032	8.61
S3	0.0008	89.567	0.0004	7.575
S4	0.0008	66.500	0.0006	7.915
S5	0.0007	72.954	0.0005	10.5
S6	0.0003	34.740	0.0005	15.15
S7	0.0004	72.954	0.0003	13.15
S8	0.0003	67.887	0.0002	7.3
S9	0.0004	47.347	0.0004	9.77

For justification of the procedure used for dynamic differential settlement due to seismic loading, the new procedure is applied to consider the other variations that might lead to higher differential settlements.

New procedure

The new procedure for maximum differential settlement within a building is the difference of combined displacement between adjacent points around all selected points considered for differential settlement. The procedure is summarized as follows:

A) Organize the vertical displacement corresponding to each seismic excitation (X, Y, Z) by each time step and node. Then, combine the three vertical displacements by SRSS method per each node and time step.

B) At same time step, the differential settlement under dynamic loading cases was determined by following equation between the points (A and B in Figures 4 and 5 of Technical Report, APR1400-E-S-NR-14006-P, Rev.1) obtained for site profiles S1 through S9. The equation is,

$$[\text{Differential settlement}]_{(A\text{-}B)} = \frac{(A-B)\times 50}{\text{Distance}}$$

Where,
A and B are combined vertical displacements at each arbitrary points
In addition, distance means the difference between A and B

C) Based on results of B), choose the maximum differential settlement at same time

D) Repeat procedure B) ~ C) for each time step

E) Choose the maximum differential settlement against whole time steps

F) Repeat the B) ~ E) corresponding to soil profiles S1 ~ S9 (Total 45,158,400 case)

Based on the new procedure, the maximum dynamic differential settlement due to seismic loading of NI common basemat is summarized in Table 5. The combined differential settlement for D+L+Es is summarized in Table 6.

Table 5. SRSS-Combined Vertical Displacement (UZ) from SASSI in NI Basemat Based on New Procedure

NI Basemat				
Soil Case	Max. Differetial Settlement per 50ft(inch)	Node ID#1	Node ID#2	Time(sec)
S1	0.1515	9587	9343	7.535
S2	0.1452	9587	9343	7.53
S3	0.1121	9587	9343	9.4
S4	0.1093	9587	9343	13.54
S5	0.0408	9587	9343	9.34
S6	0.0523	9957	9819	13.22
S7	0.0488	9786	9804	13.18
S8	0.0248	9587	9343	9.335
S9	0.0319	9587	9343	9.335

Table 6. Combined Maximum Differential Settlement for D+L+Es in NI basemat Based on New Procedure

	Differential Settlement (inch)		
Loading Case	S1	S4	S8
Static (D+L)	0.21	0.09	0.04
Seismic (Es)	0.152	0.109	0.025
Combined (+)	0.362	0.199	0.065
Combined (-)	0.058	-0.019	0.015

Tables 7 and 8 summarize the maximum dynamic differential settlement due to seismic loading for each soil profile in the EDG and DFOT based on chosen nodes (Refer to Figures 1 and 2).

Table 7. Summary of Maximum Differential Settlement for EDG Based on New Procedure

EDG				
Soil Case	Max. Differential Settlement per 50ft(inch)	Node ID#1	Node ID#2	Time (sec)
S1	0.0992	425	422	7.595
S2	0.1100	502	499	7.6
S3	0.0677	422	419	8.51
S4	0.0447	425	444	7.61
S5	0.0521	444	441	10.49
S6	0.0578	422	419	10.515
S7	0.0858	422	419	6.745
S8	0.0104	462	459	10.565
S9	0.0158	422	419	10.57

Table 8. Summary of Maximum Differential Settlement for DFOT Based on New Procedure

DFOT				
Soil Case	Max. Differential Settlement per 50ft(inch)	Node ID#1	Node ID#2	Time (sec)
S1	0.0344	126	73	7.59
S2	0.0451	73	9	14.58
S3	0.0103	126	73	15.155
S4	0.0129	126	73	7.73
S5	0.0103	116	121	10.475
S6	0.0055	126	73	15.15
S7	0.0064	116	121	13.15
S8	0.0055	72	1	6.99
S9	0.0080	116	121	8.46

Differential settlement between the NI common basemat and the Turbine Generator Building (TGB) basemat is evaluated within the seismic category I structure. TGB analysis is not performed due to not including the seismic category I structure. In addition, safety system and piping in the TGB are not connected between the NI and TGB basemat. Table 4-3 described in Technical Report, APR1400-E-S-NR-14006-P, Rev. 1, “Stability Check for NI Common Basemat". The description of differential settlement between NI and TGB basemat in subsection 4.1.2 will be deleted as shown Attachment 2.

Impact on DCD

DCD Tier 1 Table 2.1-1 and Tier 2 Table 2.0-1 will be revised, as indicated in Attachment 1 to this response.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

Technical Report APR1400-E-S-NR-14006-NP, Rev.1 Section 4.1.2 and Table 4-3 will be revised, as indicated in Attachment 2 to this response.

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based on the maximum and minimum displacements of the basemat (not the differential settlements per 50 ft). Added #1

The maximum probable differential settlements of the APR1400 NI common basemat are 0.18 and 0.1 in. for the static (D+L) and seismic (Es) loading conditions, respectively. Therefore, it is concluded that the critical criterion for differential settlement, is 0.5 in. differential settlement per 50 ft.

In addition, the differential settlement between the NI basemat and the other buildings is checked. Additional FE analyses for the turbine generator building (TGB), which is the building adjacent to the NI common basemat are performed for the differential settlement between the NI basemat and other buildings. The superstructure of the TGB consists of braced steel frames, and the basemat of the TGB is located at El. 73 ft 0 in.. The subgrade moduli for the TGB analysis corresponding to S1, S4, and S8 are 28.52 kcf, 121.37 kcf, and 877.20 kcf, respectively (see Table 2-4). The settlement analyses for the TGB basemat are carried out using the GTSTRUDL program. Figure 4-15 shows the FE model for the TGB basemat analysis. The maximum settlements of the NI and TGB basemats are used for calculating the differential settlement. Table 4-3 shows the differential settlement between the NI basemat and the TGB basemat. From the analysis results, it is concluded that the criterion for the differential settlement between the NI basemat and the other buildings, which is 0.5 in., is acceptable.

Added #2

4.1.3 Site Interface for the Nuclear Island Common Basemat

The bearing pressures of the NI common basemat by static and seismic loadings are evaluated in this subsection.

For the bearing pressure, the D+L load (static) case and LC08 through LC15 (dynamic) cases are applied in the basemat and the maximum bearing pressures of the basemat are obtained from the ANSYS static analysis. Table 4-4 shows the bearing pressures by static and dynamic loadings. These bearing pressures are satisfied because the allowable bearing capacity is less than or equal to 15 ksf (static) and 60 ksf (dynamic).

4.2 Stability Check of the Nuclear Island Common Basemat

The NI common basemat structure is evaluated for stability against overturning, sliding, and flotation. The calculated factors of safety against overturning, sliding, and flotation for the applicable load combinations satisfy the criteria shown in Table 4-5.

The normal design groundwater elevation for the APR1400 is 96.67 ft. The extreme groundwater elevation (design basis flood level) is the same as the plant grade level (98.67 ft) for seismic Category I, II, and III structures considering the probable maximum flood level.

In the earthquake load, axial force, shear force, and moment due to horizontal and vertical excitation of the structure are obtained from seismic analysis. Table 4-6 shows the enveloped results of the seismic analysis corresponding to each site profile (S1 through S9). Since the seismic load governs the wind load, a stability check is not considered for the wind load condition. In addition, the earth pressure effect is neglected for a conservative stability check.

4.2.1 Overturning Check

For the overturning check, the possible minimum resisting moment and maximum driving moment are conservatively calculated. In addition, when overturning is checked in combination with seismic forces (E_s), the hydrostatic force at the design water level (H_e) is used. Minimum resisting moment is obtained by multiplying the effective dead load ($D-H_e$) by the minimum distance (d_{min}). Maximum driving moment consists of the overturning moments due to horizontal moments (M_x and M_y), seismic shear forces (F_x and F_y), and upward seismic force (V). The 100-40-40 method is used for upward seismic force.

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#1
For the detailed evaluation of dynamic differential settlement, all of the displacement data corresponding to all time steps are checked. Table 4-7 summarizes the maximum displacement, the minimum displacement, and the differential settlement at the time when the differential settlements are maxima for each soil profile. As a result, the maximum differential settlement in Table 1 is approximately 0.0075 ft. (0.09 in.), which is also less than 0.1 inch.

#2
The differential settlement between two buildings is not consistent with the site profiles because it depends on a variety of parameters such as the excavation depth, magnitude of applied load, area of applied load (basemat net area) as well as the site profiles.

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Table 4-7

Z(VT) displacement due to Z- input from SASSI

Z(VT) displacement due to Z-input from SASSI						
Site Profies	Max (ft)	Min (ft)	Differen ce (ft)	Distnace (ft)	Differential Settlement per 50ft (ft)	Time (sec)
S1	7.979E-03	5.165E-04	0.0075	251.922	0.0015	7.05
S2	3.490E-04	-6.353E-03	0.0067	218.365	0.0015	6.87
S3	3.614E-04	-3.962E-03	0.0043	250.89	0.0009	6.83
S4	3.240E-03	6.510E-05	0.0032	220.614	0.0007	7.20
S5	1.221E-03	-1.559E-04	0.0014	258.423	0.0003	7.18
S6	1.517E-03	-6.629E-05	0.0016	220.614	0.0004	7.19
S7	1.284E-03	-1.184E-04	0.0014	147.976	0.0005	7.18
S8	7.136E-06	-8.199E-04	0.0008	194.567	0.0002	6.59
S9	3.841E-05	-8.581E-04	0.0009	308.443	0.0001	6.59

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12.7 mm (0.5 in) per 15.24 m (50ft) in any direction for Seismic Category I structures under static and seismic load

Table 2.1-1 (2 of 3)

Tornado	
Maximum Tornado Wind Speed	102.8 m/s (230 mph)
Translational Speed	20.6 m/s (46 mph)
Maximum Rotational Speed	82.2 m/s (184 mph)
Radius of Maximum Rotational Speed	45.7 m (150 feet)
Pressure Drop	8.274 kPa (1.2 psi)
Rate of Pressure Drop	3.447 kPa/s (0.5 psi/s)
Missile Spectra	Table 2 (Region I) of NRC RG 1.76 (2007)
Hurricane	
Maximum 3-Second Wind Gust Speed	116 m/s (260 mph)
Missile Spectra	Table 1 of NRC RG 1.221 (2011)
Soil Properties	
Minimum Allowable Static Bearing Demand	718.2 kPa (15 ksf) (3)
Minimum Allowable Dynamic Bearing Demand	2,872.8 kPa (60 ksf) (3)
Minimum Shear Wave Velocity	304.8 m/s (1,000 ft/sec)
Liquefaction Potential (yes/no)	No
~~Maximum Differential Settlement inside Building~~	~~12.7 mm (0.5 in) per 15.24 m (50 ft) in any direction~~
~~Maximum Differential Settlement between Buildings~~	~~12.7 mm (0.5 in)~~
Minimum Soil Angle of Internal Friction	35 degrees
Slope Failure Potential (yes/no)	No
Fault Displacement Potential (yes/no)	No
Backfill Material Density	137 pcf
Backfill Material Dynamic Poisson's Ratio	0.33
Backfill Material Dynamic Properties (Minimum Dynamic Shear Modulus, kg/cm^2) - Shear Strain	
• 1% • 0.1% • 0.01% • 0.001% • 0.0001%	0.05 0.22 0.54 0.85 1.00

Maximum Allowable Differential Settlement inside Building

76.2 mm (3.0 in) between NI Common Basemat and EDG Building & DFOT Building 12.7mm (0.5 in.) under static and seismic load

Maximum Allowable Differential Settlement between Buildings

Table 2.0-1 (3 of 4)

Parameter Description	Parameter Value
Certified Seismic Design Response Spectra (CSDRS) Referencing SSE	See Figures 2.0-1 and 2.0-2
Hard Rock High Frequency (HRHF) Response Spectra(4)	0.46g peak ground acceleration See Figures 2.0-3 and 2.0-4
Fault Displacement Potential (yes/no)	No
Minimum Allowable Static Bearing Demand	718.2 kPa (15 ksf)(3)
Minimum Allowable Dynamic Bearing Demand	2,872.8 kPa (60 ksf)(3)
Minimum Shear Wave Velocity	304.8 m/s (1,000 ft/s)
Liquefaction Potential (yes/no)	No
~~Maximum Differential Settlement inside Building~~ Maximum Allowable Differentail Settlement inside Building	~~12.7 mm (0.5 in) per 15.24 m (50 ft) in any direction~~ 12.7 mm (0.5 in) per 15.24 m (50ft) in any direction for Seismic Category I structures under static and seismic load
~~Maximum Differential Settlement between Buildings~~ Maximum Allowable Differential Settlement between Buildings	~~12.7 mm (0.5 in)~~ 76.2 mm (3.0 in) between NI Common Basemat and EDG Building & DFOT Building 12.7mm (0.5 in.) under static and seismic load
Minimum Soil Angle of Internal Friction	35 degrees
Slope Failure Potential (yes/no)	No
Backfill Material Density	137 pcf
Backfill Material Dynamic Poisson's Ratio	0.33
Backfill Material Dynamic Properties (Minimum Dynamic Shear Modulus, kg/cm^2) - Shear strain	
1 %	0.05
0.1 %	0.22
0.01 %	0.54
0.001 %	0.85
0.0001 %	1.00

based on the maximum and minimum displacements of the basemat (not the differential settlements per 50 ft).

The maximum probable differential settlements of the APR1400 NI common basemat are 0.18 and 0.1 in. for the static (D+L) and seismic (Es) loading conditions, respectively. Therefore, it is concluded that the critical criterion for differential settlement, is 0.5 in. differential settlement per 50 ft.

~~In addition, the differential settlement between the NI basemat and the other buildings is checked. Additional FE analyses for the turbine generator building (TGB), which is the building adjacent to the NI common basemat are performed for the differential settlement between the NI basemat and other buildings. The superstructure of the TGB consists of braced steel frames, and the basemat of the TGB is located at El. 73 ft 0 in.. The subgrade moduli for the TGB analysis corresponding to S1, S4, and S8 are 28.52 kcf, 121.37 kcf, and 877.20 kcf, respectively (see Table 2-4). The settlement analyses for the TGB basemat are carried out using the GTSTRUDL program. Figure 4-15 shows the FE model for the TGB basemat analysis. The maximum settlements of the NI and TGB basemats are used for calculating the differential settlement. Table 4-3 shows the differential settlement between the NI basemat and the TGB basemat. From the analysis results, it is concluded that the criterion for the differential settlement between the NI basemat and the other buildings, which is 0.5 in., is acceptable.~~ Deleted

4.1.3 Site Interface for the Nuclear Island Common Basemat

The bearing pressures of the NI common basemat by static and seismic loadings are evaluated in this subsection.

For the bearing pressure, the D+L load (static) case and LC08 through LC15 (dynamic) cases are applied in the basemat and the maximum bearing pressures of the basemat are obtained from the ANSYS static analysis. Table 4-4 shows the bearing pressures by static and dynamic loadings. These bearing pressures are satisfied because the allowable bearing capacity is less than or equal to 15 ksf (static) and 60 ksf (dynamic).

4.2 Stability Check of the Nuclear Island Common Basemat

The NI common basemat structure is evaluated for stability against overturning, sliding, and flotation. The calculated factors of safety against overturning, sliding, and flotation for the applicable load combinations satisfy the criteria shown in Table 4-5.

The normal design groundwater elevation for the APR1400 is 96.67 ft. The extreme groundwater elevation (design basis flood level) is the same as the plant grade level (98.67 ft) for seismic Category I, II, and III structures considering the probable maximum flood level.

In the earthquake load, axial force, shear force, and moment due to horizontal and vertical excitation of the structure are obtained from seismic analysis. Table 4-6 shows the enveloped results of the seismic analysis corresponding to each site profile (S1 through S9). Since the seismic load governs the wind load, a stability check is not considered for the wind load condition. In addition, the earth pressure effect is neglected for a conservative stability check.

4.2.1 Overturning Check

For the overturning check, the possible minimum resisting moment and maximum driving moment are conservatively calculated. In addition, when overturning is checked in combination with seismic forces (E_s), the hydrostatic force at the design water level (H_e) is used. Minimum resisting moment is obtained by multiplying the effective dead load ($D\text{-}H_e$) by the minimum distance (d_{min}). Maximum driving moment consists of the overturning moments due to horizontal moments (M_x and M_y), seismic shear forces (F_x and F_y), and upward seismic force (V). The 100-40-40 method is used for upward seismic force.

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Table 4-3

Differential Settlements between NI Basemat and TGB Basemat (Static Loading Case)

Basemat / Differential Settlement	Max. Settlement (in.)		
	S1	S4	S8
NI Basemat	4.063	0.853	0.187
TGB Basemat	3.972	1.103	0.205
Differential Settlement	0.091	0.250	0.018

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