RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

APR1400 Design Certification

Korea Electric Power Corporation / Korea Hydro & Nuclear Power Co., LTD

Docket No. 52-046

RAI No.:	**255-8285**
SRP Section:	**03.08.05 – Foundations**
Application Section:	**3.8.5**
Date of RAI Issue:	**10/19/2015**

Question No. 03.08.05-11

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.A states, “Appropriateness of the method for determination of the bending moments and shear forces in the mat foundation for seismic loads.” SRP Section 3.8.5.II.3, Load and Load Combinations, states, “The specified loads and load combinations used in the design of seismic Category I foundations are acceptable if found to be in accordance with those combinations described in Subsection II.3 of SRP Section 3.8.1 for the containment foundation and with those combinations listed in Subsection II.3 of SRP Section 3.8.4 for all other seismic Category I foundations.” SRP Section 3.8.5.II.4.B states, “For seismic Category I concrete foundations other than the containment foundations, the procedures are in accordance with the ACI 349, with additional guidance provided by RG 1.142.”

In DCD Section 3.8A.2.4.1, “Basemat,” the applicant describes the analysis and design methods for the AB basemat. Based on the staff’s review, the staff identified the following items that need to be addressed to ensure that the analysis and design methods are acceptable.

(a) For the AB and EDG buildings, equivalent static analyses were performed. SRP 3.7.2 II.1.B indicates that when using an equivalent static analysis method, justification should be provided to show that the system can be realistically represented by a simple model and the method produces conservative results in terms of responses. Therefore, applicant is requested to provide justification that the use of the equivalent static method of analysis is appropriate for the AB and the EDG buildings.

(b) In DCD Tier 2, in subsection 3.8.5.4.1, “Analysis for Loads during Operations,” and Appendix 3.8A subsection 3.8A.2.4.1, “Basemat,” the applicant stated that the reinforced concrete foundations for the seismic Category I structures are analyzed and designed for the reactions due to static, seismic and all “other significant loads” at the base of the superstructures supported by the foundation. It is not clear to the staff why the applicant only identifies “other significant loads” and not all other loads. Therefore, applicant is requested to describe why it only identifies “other significant loads” and not all other loads.

(c) In DCD Tier 2, Appendix 3.8A,”Structural Design Summary,” subsection 3.8A.2.4.1, “Basemat,” the applicant stated that, “Since the rigid connection between walls and basemat is not simulated in the analysis model of the NI common basemat structure, the basemat of the AB is not subject to any moment that might occur. Therefore, the additional structural analysis was executed to obtain the magnitude of the moment transferred from walls and columns, which were subjected to lateral loads.” The applicant’s approach is not clear to the staff. Therefore, applicant is requested to explain, in sufficient detail, the analysis model, boundary conditions, soil springs, how loads were applied, what accelerations are applied, and why it appears that only additional moments from the walls and columns are applied, and not all forces from the superstructure above the basemat. If only forces from the superstructure were included, then the applicant is requested to explain how the forces from the basemat inertial response were considered in the seismic analysis. The applicant is also requested to explain whether the seismic analysis of the AB basemat was performed separately, or was considered in the same NI concrete basemat model and analysis described in DCD Section 3.8A.1.4.2 used to obtain the member forces.

(d) In DCD Tier 2, Appendix 3.8A,”Structural Design Summary,” subsection 3.8A.2.4.1, “Basemat,” the applicant stated that, “The required reinforcements for axial force and out-of-plane flexural force are determined for combined bending and axial load according to the ACI design handbook (ACI 340R).” The ACI handbook follows the strength designing method of ACI 318, rather than ACI 349. Therefore, applicant is requested to explain why the ACI design handbook (ACI 340R) was considered acceptable.

Response

(a) Total shear forces at each elevation of the AB and EDG that were calculated using the equivalent static method have been compared with the results from the SSI analysis to provide justification for using the equivalent static method. The SSI analysis and structural analysis are modeled with a full 3D model.

According to Technical Report (TR) APR1400-E-S-NR-14005-P/NP, individual SSI analyses for stand-alone structures and coupled SSSI analyses for the power block were performed for the hard, medium, and soft soil cases to evaluate the SSSI effects on the APR1400 standard plant structures. Based on this assessment, it was concluded that the NI structures have negligible effects on their seismic responses due to adjacent structures such as the EDGB, compound building, and turbine island structures. The EDGB seismic responses are affected by the adjacent structures including the NI structures for the soft soil case only. However, the enveloped design-basis seismic force of the EDGB is governed by the results obtained from the fixed-based analysis among the nine SSI analysis and one fixed-base analysis applicable. The ratio of the design-basis fixed-based case to design-basis SSI analysis case is greater than or equal to the amplification factors of the ISRS determined from the SSSI analyses for the soft soil case. Therefore, the design-basis seismic response forces need not be increased to consider the SSSI effects on the EDGB. Tables 1 through 3 summarize the comparison between the SSI results and the equivalent static method for the AB, EDGB and DFOT, respectively. Based on the comparison, the equivalent static method is more conservative that that the SSI analysis.

Table 1 - Comparison Between SSI Analysis and Equivalent Static Method for the AB

	Structural Analysis_AB (a) (equivalent static method)					Seismic Analysis_AB (b)					Comparison (a/b)				
Elevation	FX	FY	FZ	MX	MY	FX	FY	FZ	MX	MY	FX	FY	FZ	MX	MY
213.5~250	7,288	9,646	3,930	387,082	306,331	5,425	7,174	2,920	314,174	197,979	1.34	1.34	1.35	1.23	1.55
213~213.5	17,605	16,861	7,986	675,317	887,446	14,787	13,126	5,504	478,184	711,285	1.19	1.28	1.45	1.41	1.25
195(Area24)~	26,466	25,321	10,251	967,459	1,237,964	19,263	17,401	6,656	765,341	945,752	1.37	1.46	1.54	1.26	1.31
195(Area13)~	20,088	15,395	10,604	211,473	1,113,487	10,174	7,661	5,262	184,377	550,634	1.97	2.01	2.02	1.15	2.02
174~	95,614	92,658	48,565	4,051,864	2,598,653	68,233	66,361	30,736	2,430,827	2,518,524	1.40	1.40	1.58	1.67	1.03
156~	135,587	146,113	76,780	4,741,437	4,933,444	101,579	111,413	54,516	4,762,013	4,780,395	1.33	1.31	1.41	1.00	1.03
137.5~	185,412	210,140	118,592	8,177,509	7,780,191	143,267	165,299	88,733	7,929,215	7,729,526	1.29	1.27	1.34	1.03	1.01
120~	246,180	279,707	164,806	12,670,304	11,725,504	193,300	222,571	124,868	12,005,966	11,199,955	1.27	1.26	1.32	1.06	1.05
98.5~	297,325	343,981	208,104	19,093,970	17,331,751	240,185	282,559	162,898	18,111,608	16,597,000	1.24	1.22	1.28	1.05	1.04
77~	340,725	405,851	257,260	27,595,648	24,540,401	277,236	335,937	203,768	25,105,085	22,507,797	1.23	1.21	1.26	1.10	1.09
67~	362,176	430,430	283,173	31,840,655	28,119,978	293,250	358,622	225,936	28,399,238	25,433,525	1.24	1.20	1.25	1.12	1.11
55~	378,747	447,140	303,042	37,573,016	32,976,139	300,911	369,591	238,280	32,392,109	28,921,247	1.26	1.21	1.27	1.16	1.14

Table 2 - Comparison Between SSI Analysis and Equivalent Static Method for the EDGB

	Structural Analysis_AB (a) (equivalent static method)					Seismic Analysis_AB (b)					Comparison (a/b)				
Elevation	FX	FY	FZ	MX	MY	FX	FY	FZ	MX*	MY	FX	FY	FZ	MX	MY
135~150	3,803	3,803	2,090	72,735	141,818	2,860	2,847	1,576	39,109	37,590	1.33	1.34	1.33	1.86	3.77
100~135	12,431	10,974	6,920	419,950	606,108	9,995	8,745	5,578	298,138	342,807	1.24	1.25	1.24	1.41	1.77

- Mx is result from SASSI analysis in fixed base condition (S10)

Table 3 - Comparison Between SSI Analysis and Equivalent Static Method for the DFOST

	Structural Analysis_AB (a) (equivalent static method)					Seismic Analysis_AB (b)					Comparison (a/b)				
Elevation	FX	FY	FZ	MX	MY	FX	FY	FZ	MX	MY	FX	FY	FZ	MX	MY
100~120	1,607	1,771	906	37,411	23,795	1,051	1,170	591	19,570	15,292	1.53	1.51	1.53	1.91	1.56
63~100	6,364	5,439	4,671	226,496	236,908	4,569	3,865	3,361	138,428	155,258	1.39	1.41	1.39	1.64	1.53

(b) The intent of the statement “other significant loads” is to communicate that all other loads that affect the basemat analysis are included in the analysis. For example, some loads (operating pressure, jet impingement load, etc.) do not affect the stability of the basemat or basemat design forces. DCD Tier 2 Section 3.8.5.4.1 and 3.8A.2.4.1 will be revised to state that all other loads affecting the basemat analysis are included, as indicated in the attachment associated with this response.

(c) The detailed information for the individual superstructure analyses is summarized in Table 1. In the case of the NI basemat model, Table 2 describes the connection between NI common basemat and to the superstructure and subgrade.

Table 1 - Summary of Individual Superstructure Analyses

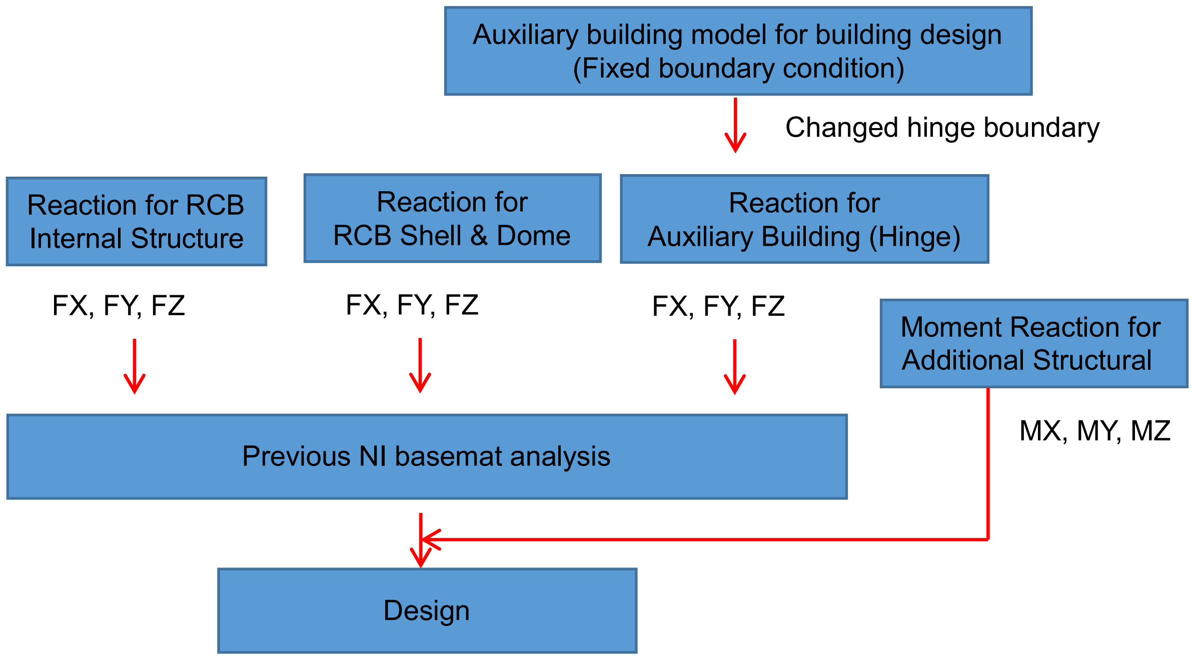
Item	**Individual Superstructure**		
	RCB Shell & Dome	**RCB Internal Structure**	**Auxiliary Building**
Element Type	Solid (Brick type)	Solid (Brick type)	Shell type
NI Basemat	None	None	None
Subgrade	None	None	None
Boundary Condition	Fixed Base Condition (EL.78 ft.)	Fixed Base Condition (EL.78 ft.)	Fixed Base Condition (EL.78 ft.)
Seismic analysis	Response Spectrum Analysis	Response Spectrum Analysis	Equivalent Acceleration (from SASSI output based on each floor)
Reference Figure	DCD Figure 3.8-12	DCD Figure 3.8A-13	DCD Figure 3.8-23

Table 2 - Description of NI Basemat Connections

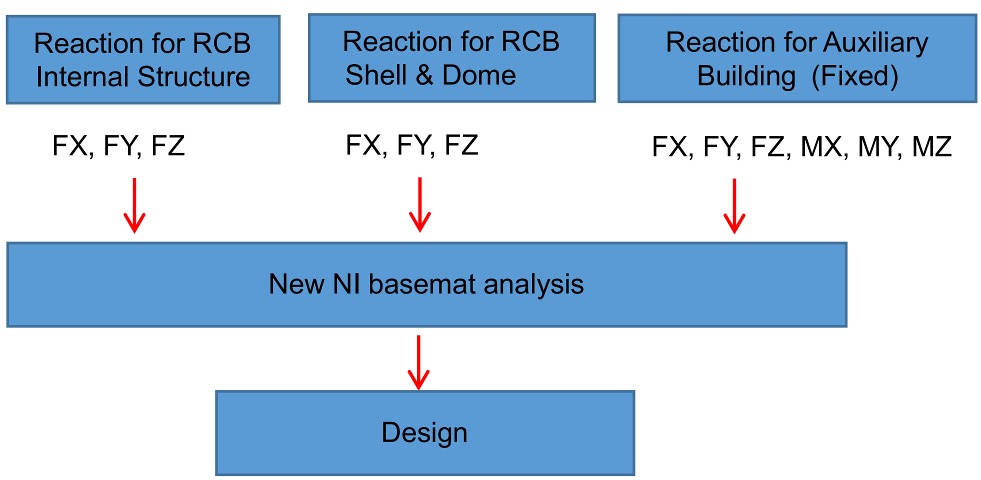
<table>
<tr><th rowspan="2">Item</th><th>NI Common Basemat*</th></tr>
<tr><th>New Analysis</th></tr>
<tr><td rowspan="2">Subgrade</td><td>Soil Spring varied across the foundation (Static loading cases)</td></tr>
<tr><td>- Foundation Media Model
- (Dynamic loading cases)</td></tr>
<tr><td>Boundary Condition
(connection of each superstructure)</td><td>Upper Part of NI basemat: Target170</td></tr>
<tr><td rowspan="2">Boundary Condition
(connection of subgrade)</td><td>Soil spring – Node sharing</td></tr>
<tr><td>Foundation Media Model – Contact Method
(Surf to Surf contact)</td></tr>
</table>

* The analysis for NI common basemat was revised to consider boussinesq effect of soil and out of phase between buildings.

As shown Table 1, the reaction forces (FX, FY, FZ) from individual RCB Shell &Dome and internal structure analysis were directly applied as input loads at the top of NI common basemat for the NI common basemat analysis. However, for the auxiliary building, the previous NI common basemat analysis used transitional forces and rotational moments, which were calculated separately. In order to minimize confusion in the structural analysis, the new NI basemat analysis used 3- transitional and rotational moments from the auxiliary building analysis, as shown in Figure 1.



a) Previous NI common basemat



b) New NI common basemat

Figure 1 – Analysis Procedure for NI Basemat.

- Explanation of Figure 1 - a)

  In order to compute the reaction for auxiliary building analysis, the boundary condition was changed to a hinge support, as shown Figure 1-a). Therefore, only forces from auxiliary building were applied for NI common basemat analysis. The additional structural analysis was performed to consider out-of-plane moments transferred from superstructure wall to basemat.

In the additional structural analysis, the individual auxiliary building model is used. Applied loads, including seismic acceleration to the superstructure model, are identical to the loads used in the individual auxiliary building structural analysis. For the boundary condition of the additional building analysis, the degree of freedom at the support nodes is only released for rotation to transfer out-of-plane moment to the basemat, soil springs are not considered. This causes out-of-plane moments and forces in the shell elements at basemat. Therefore, both were used in the basemat design. However, the purpose of the additional analysis is to account for the basemat global analysis and capture the local effect on the basemat.

- Explanation of Figure 1 - b)

According to the response to RAI 255-8285 Question 03.08.05-12, the new NI common basemat analysis is evaluated as discussed below.

The forces and moments from the individual auxiliary building analysis were used for the NI common basemat analysis. The equivalent accelerations (X: 0.27g, Y: 0.31g Z: 0.31g) in the individual auxiliary building analysis from 68′-0″ to 78′-0″ were determined to consider the inertial effects of the basemat during seismic state. These equivalent accelerations were applied to the entire NI common basemat to consider the inertial effects during seismic state.

Figure 2 is the sample image for explanation how to impose the force and moment for the new NI common basemat analysis.

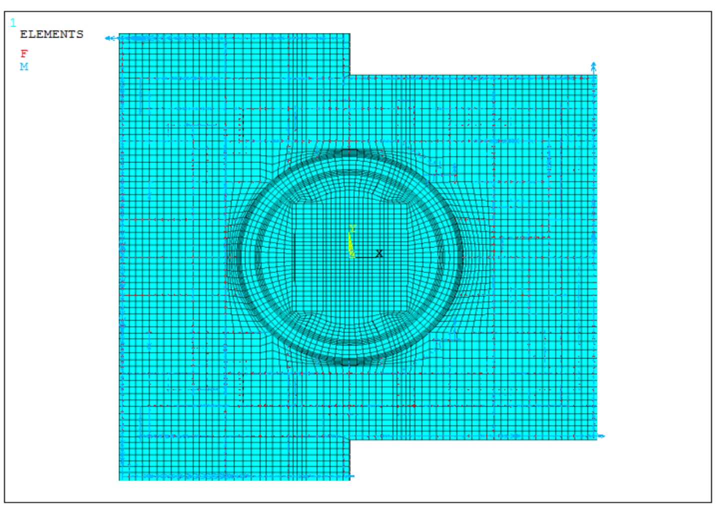
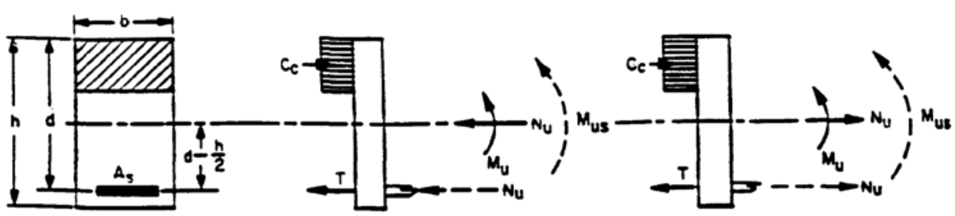


Figure 2 - Applied the force and moment (New NI Common Basemat Analysis)

In the NI common basemat analysis (previous and new), the NI basemat is modeled by solid-elements (SOLID 180) for the entire mat. In order to consider the stiffness effect of the superstructure, the superstructure finite element models, such as the RCB internal structure, RCB shell &dome, and the auxiliary building, are connected to the NI common basemat by using the contact method in ANSYS. The contact element type (TARGE170 & CONTA175) was applied between superstructure and the entire NI basemat. The contact option is multipoint constraint (MPC) and the behavior of the contact surface is always bonded to each other. The reactions computed by the superstructure analysis are used as nodal loads in the basemat analysis to consider all loads, including seismic loading, from the superstructure.

The auxiliary building basemat was not separately modeled - the same NI common basemat was used to obtain the member forces.

(d) The ACI design handbook (ACI 340R) was used only for adopting the methodology to combine bending and axial loads. The basemat is designed based on the strength design method, in accordance with ACI 349. The picture below, from the ACI design handbook, is used to provide a theoretical understanding. ACI 340R will be added to the Reference section as shown in Attachment 2. Since ACI 340R is neither a Code nor a Standard, it will not be added in Table 3.8-1 of DCD Tier 2.



Axial Compression

$$M_{us} = M_u + N_u \left(d - \frac{h}{2}\right)$$

$$A_s = \frac{M_{us}}{d a_n} - \frac{N_u}{\phi f_y}$$

Axial Tension

$$M_{us} = M_u - N_u \left(d - \frac{h}{2}\right)$$

$$A_s = \frac{M_{us}}{d a_n} + \frac{N_u}{\phi f_y}$$

Impact on DCD

Subsection 3.8.5.4.1, 3.8A.2.4.1 and 3.8.7 will be revised, as indicated in the attached markups.

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

There is no impact on any Technical, Topical, or Environmental Report.

Analysis and Design Methods

all other loads that affect basemat analysis

The reinforced concrete common basemat is analyzed and designed for the reactions due to static, seismic, and ~~all other significant loads~~ at the base of the superstructures. The forces and moments of the basemat area are obtained by application of design loads to the integrated static three-dimensional FEM. The analysis methods and procedures of the NI common basemat are described in Subsection 3.8A.1.4.2.3. Figure 3.8A-29 shows the solid element model of the basemat for the AB and RCB.

Since the rigid connection between walls and basemat is not simulated in the analysis model of the NI common basemat structure, the basemat of the AB is not subject to any moment that might occur. Therefore, the additional structural analysis is executed to obtain the magnitude of the moment transferred from walls and columns, which are subjected to lateral loads. The design forces and moments for the AB basemat are summarized in Table 3.8A-26.

The AB basemat model is divided into 15 element sets as shown in Table 3.8A-26. The design loads are sorted by these element sets and the basemat design is performed in each element set. The AB basemat is designed in accordance with the requirements of ACI 349. Required reinforcements are calculated based on the governing required capacities obtained from finite element analysis for each design area.

Top and bottom reinforcements are calculated considering axial force, out-of-plane flexural force, and in-plane shear force. The required reinforcements for axial force and out-of-plane flexural force are determined ~~for combined bending and axial load according to the ACI design handbook (ACI 340R)~~. The required reinforcement for in-plane shear force is determined per ACI 349.

The resultant shear forces are checked with the design nominal concrete strength and appropriate shear reinforcement steel is provided in the areas where the resultant shear force exceeds the design nominal shear strength.

per ACI 349, but a methodology taken from ACI handbook (ACI 340R) is adopted to combine axial force and out-of-plane flexural force.

Design Summary

The basemat is symmetrically reinforced to resist the potential moments as a result of differential settlement of the foundation. The maximum top and bottom reinforcements are 3-#18 bar at 300 mm (12 in.) spacing for each direction. The maximum shear

The reinforced concrete basemat of the reactor containment building is designed in accordance with ASME Section III, Division 2, Subsection CC. Other seismic Category I basemats of reinforced concrete are designed in accordance with ACI 349 and the provisions of NRC RG 1.142 where applicable.

The design and analysis details for the foundations of safety-related structures are discussed in Subsections 3.8A.1.4.2, 3.8A.2.4.1 and 3.8A.3.4.1.

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. In addition, the common basemat is analyzed for construction sequences to minimize any potential differential settlement during construction.

3.8.5.4.1 Analyses for Loads during Operation

all other loads that affect basemat analysis

The reinforced concrete foundations of seismic Category I structures are analyzed and designed for the reactions due to static, seismic and ~~all other significant loads~~ at the base of the superstructures supported by the foundation. The effect of the temperature load in the basemat is negligible and is not considered in the basemat analysis based on ACI 349. According to ACI 349, thermal gradients less than approximately 38 °C (100 °F) need not be analyzed because such gradients do not cause significant stress in the reinforcement or strength deterioration. In the NI common basemat, the temperature gradient is approximately 50 °F and a uniform temperature change is less than 10 °C (50 °F). The analysis of the foundation mat is performed by a three-dimensional finite element structure model, and the forces and moments determined in the analysis are input to the structural design.

The analysis and design of the foundations consider the effects of potential mat uplift, with particular emphasis on differential settlements of the basemat.

The foundation of the seismic Category I structure analysis is performed considering a soil/rock properties beneath the foundation as a nonlinear spring elements. The model is capable of determining the possibility of uplift of the basemat from the subgrade during postulated SSE events. The vertical spring at each node in the analytical model acts in

30. Regulatory Guide 1.91, “Evaluations of Explosions Postulated to Occur on Transportation Routes Near Nuclear Power Plants,” Rev. 2, U.S. Nuclear Regulatory Commission, April 2013.

31. Regulatory Guide 1.115, “Protection Against Low-Trajectory Turbine Missiles,” Rev. 2, U.S. Nuclear Regulatory Commission, January 2012.

32. Regulatory Guide 1.143, “Design Guidance for Radioactive Waste Management Systems, Structures, and Components Installed in Light-Water-Cooled Nuclear Power Plants,” Rev. 2, U.S. Nuclear Regulatory Commission, November 2001.

33. ASCE 7-05, “Minimum Design Loads for Buildings and Other Structures,” American Society of Civil Engineering/Structural Engineering Institute, 2006.

34. GTSTRUDL User Guide, GTSTRUDL Version 31, Georgia Institute of Technology, August 2010.

35. Research Council on Structural Connections, “Specification for Structural Joints Using ASTM A325 or A490 Bolts,” 2004.

36. AWS D1.1, “Structural Welding Code,” American Welding Society, 2010.

37. ASTM C191, “Standard Test Method for Time of Setting of Hydraulic Cement by Vicat Needle,” American Society for Testing and Materials.

38. ASTM C109, “Standard Test Method for Compressive Strength of Hydraulic Cement Mortars,” American Society for Testing and Materials.

39. ASTM A36, “Standard Specification for Carbon Structural Steel,” American Society for Testing and Materials.

40. APR1400-E-S-NR-14006-P, “Stability Check for NI Common Basemat” Rev. 0, KHNP, November 2014.

41. ACI 340R, “Design of Structural Reinforced Concrete Elements in Accordance with the Strength Design Method of ACI 318-95” American Concrete Institute.

Table 3.8-1 (2 of 2)

Document Reference No.	Document Designation	Document Title
21	ACI 311.1 R	ACI manual of concrete inspection
22	ACI 315	Details and detailing of concrete reinforcement
~~23~~ 24	ACI 347	Guide to formwork for concrete
~~24~~ 25	ANSI/ANS 8.1	Nuclear criticality safety in operations with fissionable materials outside reactors
~~25~~ 26	ANSI/ANS 8.17	Criticality safety criteria for handling, storage, and transportation of LWR fuel outside reactors
~~26~~ 27	ANSI/ANS 57.2	Design requirements for light water reactor spent fuel storage facilities at nuclear power plants
~~27~~ 28	ASTM C570	Standard specification for nuclear grade boron carbide power
~~28~~ 29	ASTM E3	Preparation of metallographic specimens
~~29~~ 30	ASTM E190	Guided bend test for ductility of weld
U.S. Regulations		
30	10 CFR Part 50	Domestic licensing of production and utilization facilities
31	10 CFR Part 52	Licenses, Certifications, and Approvals for Nuclear Power Plants
32	10 CFR Part 100	Reactor site criteria

ACI American Concrete Institute
AISC American Institute of Steel Construction
AISI American Iron and Steel Institute
ANS American Nuclear Society
ASME American Society of Mechanical Engineers
ASTM American Society of Testing and Materials
AWS American Welding Society

23 ACI 340R Design of Structural Reinforced Concrete Elements in Accordance with the Strength Design Method of ACI 318-95