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.:	**253-8300**
SRP Section:	**03.07.01 – Seismic Design Parameters**
Application Section:	**3.7.1**
Date of RAI Issue:	**10/19/2015**

Question No. 03.07.01-6

DCD Table 3.7-8 includes the foundation embedment for the Nuclear Island structures (53'-8"), Emergency Diesel Generator Building (EDGB) (8'-6"), and Diesel Fuel Oil Tank (DFOT) (4'-0"). However, staff review of the associated technical reports found different values for the embedments of the same buildings. For the NI structures, other embedment values are 54', 53'-6", and 55' (APR1400-E-S-NR-14002-P, APR1400-E-S-NR-14003-P, and APR1400-E-S-NR-14005-P, respectively). For EDGB, the other value is 9' (approximate, APR1400-E-S-NR-14005-P). For DFOT, the other value is 39' (APR1400-E-S-NR-14005-P). Since the embedment value is an important parameter in seismic soil-structure interaction (SSI) analysis and structure-soil-structure interaction (SSSI) analysis to meet 10 CFR 50 Appendix S requirements, the applicant is requested to make these values consistent among the computer models, the DCD, and the referenced technical reports.

Response

The plant grade elevation of APR1400 standard plant is 98'-8". Since the bottom elevation of the NI basemat is 45'-0", the embedment depth of NI structures is 53'-8". In technical reports APR1400-E-S-NR-14002-P, APR1400-E-S-NR-14003-P, and APR1400-E-S-NR-14005-P, several sentences describe that the embedment depth of NI structures as being 54 ft and 55 ft as approximate values. The value of 53'-6" is the embedment depth used in ACS SASSI model of NI structures. In the ACS SASSI model for SSI analysis of NI structures, the ground surface elevation is considered to be 98'-6" for simplification of the layers in the soil model. Since the embedment depth of the NI is greater than 53 feet, the 2 inch difference in embedment depth is considered to be negligibly small.

Since the bottom elevations of the EDGB and DFOT basemats are 92'-0" and 59'-0", respectively, the embedment depth of EDGB and DFOT are 6'-8" and 39'-8". The 8'-6" and 4'-0" presented in DCD Tier 2, Table 3.7-8 are the thickness of the EDGB and the DFOT basemats.

DCD Tier 2, Table 3.7-8 and technical reports APR1400-E-S-NR-14002-P, APR1400-E-S-NR-14003-P, and APR1400-E-S-NR-14005-P will be revised appropriately, as indicated in the attachment associated with this response.

Impact on DCD

DCD Tier 2, Table 3.7-8 will be revised as indicated in the attachment associated with 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 reports APR1400-E-S-NR-14002-P, APR1400-E-S-NR-14003-P, and APR1400-E-S-NR-14005-P will be revised as indicated in the attachment associated with this response.

Table 3.7-8

Foundation Embedment Depth, Foundation Size, and Total Height of Seismic Category I Structures

Structures	Foundation Embedment Depth, m (ft)	Foundation Size, m (ft)	Maximum Height, m (ft)
Nuclear Island – Reactor Containment Building – Auxiliary Building	See note 1. 16.4 (53′-8″)	Radius 25.6 (84′-0″) 107.3 × 88.1 (352′-0″ × 289′-0″)	87.9 (288′-6″) 56.4 (185′-0″)
Emergency Diesel Generator (EDG) Building Diesel Fuel Oil Tank (DFOT) Room	~~2.6~~ 2.0 (~~8′-6″~~ 6′-8″) ~~1.2~~ 12.1 (~~4′-0″~~ 39′-8″)	39.9 × 18.3 (131′-0” × 60′-0″) 20.3 × 18.3 (66′-6″ × 60′-0″)	17.8 (58′-6″) 18.7 (61′-6″)

(1) The auxiliary building wraps around the reactor containment building with a minimum of 2 inches seismic gap.

2 METHODOLOGY OF FEM DEVELOPMENT FOR NI STRUCTURES

The following considerations are made in the FEM development for the APR1400 NI structures:

- The APR1400 NI structures have a maximum embedded ratio (embedment depth/AB building height=~~55~~ 53.7/171.8) of ~~0.320~~ 0.313 and are considered embedded structures for the seismic SSI analysis.

- Estimates of the maximum frequencies of seismic wave propagation for the nine (9) soil profiles defined in the APR1400 are shown in Table 2-1 for soil layers that are 11 ft thick in the embedment. Among the nine (9) soil cases, five (5) have a maximum frequency above 50 Hz. A soil layer thickness of 11 ft is considered adequate and is accordingly adopted as the mesh size for soil elements and for the NI structural FEM.

- The 10 ft basemat is modeled by shell elements at the bottom surface of the basemat, rather than at the middle surface. This consideration can be justified as the SSI effects are accounted for more closely.

- The effects of vertical shear deformation in a 10-ft-thick common basemat on the seismic SSI analysis are considered insignificant.

- The effects of stiffnesses of local walls (not designed for the shear wall system) on the SSI response are considered small and are not included in the model.

The purpose of the model development is to create a 3-D FEM for SSI analysis of the APR1400 NI structures, which includes the RCB and AB founded on a common basemat. The 3-D SSI analysis is carried out using the SASSI program. The development of a complex 3-D finite element SASSI model of the NI structures consists of the following steps:

- A 3-D primitive model consisting of geometric properties of lines, areas, and volumes is created using the ANSYS program and based on data from the APR1400 drawings. The ANSYS primitive model consists of lines for columns and beams, areas for walls and slabs, and volumes for solid structural components, using key points to define key locations of physical wall-slab connection joints. In the primitive model, all material and geometrical properties are prepared.

- Based on the ANSYS primitive model, fine and coarse models are generated with specified element types, properties, and required mesh sizes.

- The ANSYS coarse model is validated by constructing an ANSYS fine model, obtaining analysis results, and comparing the results to the analysis results of the ANSYS coarse model.

- When the ANSYS AB and RCB coarse models have been verified, the primitive models are combined to create an ANSYS coarse 3-D FEM of the NI structures.

- The ANSYS coarse 3-D FEM of NI structures is converted to SASSI for a 3-D SSI analysis of NI structures.

- The SASSI 3-D FEM of NI structures is numerically optimized for efficient SSI computation.

- The SASSI 3-D FEM of NI structures is verified with its seismic response time histories obtained from the fixed-base condition against those obtained from the ANSYS coarse fixed-base 3-D FEMs of the AB and RCB. The SASSI 3-D FEM of NI structures can be verified by comparing the in-structure response spectra (ISRS) at selected locations.

4 AUXILIARY BUILDING MODEL

This section describes the AB structure and methodology of developing the APR1400 AB FEM.

4.1 Description of AB Structure

53′-8″

The APR1400 AB is a safety-related seismic category I structure with an embedment of ~~approximately 54 ft~~ (Reference 11). It encloses the RCB in the center without structural connection except at the common basemat. The combined RCB and AB with a common basemat are generally referred to as the NI structures. Three adjacent structures, the emergency diesel generator building, turbine generator building, and compound building, are separated from the AB with a typical 3 ft building gap. This building layout with adjacent buildings is shown in Figure 4-1. The primary dimensions of the AB are listed in Table 4-1.

The AB houses important facilities including the fuel handling area, spent fuel pool, cask loading pit, refueling canal, cask decontamination pit, auxiliary feed water (AFW) tanks, main control room, equipment hatch access, and others. The AB structural system consists of shear walls in the east-west (E-W) and north-south (N-S) directions and a total of seven (7) major floor and roof slabs. The walls and slabs are made of normal reinforced concrete. Columns and girders are also used to support floor and roof slabs. The shear walls have various sizes of door openings and corridors partial openings on floor slabs.

4.2 Development of Finite Element Models for AB Structure

This section describes the development of 3-D AB FEM for SSI analysis.

For simplification of the soil layers used in the SSI analysis, the embedment depth of 53′-6″ is considered in the SASSI model of the AB structure.

4.2.1 Coordinate System

A rectangular Cartesian coordinate system is used for the ANSYS and SASSI models. The origin in a horizontal plan of this coordinate system is located at the center of the RCB. In this coordinate system, the positive X points to the plant east direction, the positive Y to the plant north direction, and the positive Z to the vertical upward direction, as shown in Figure 4-2.

4.2.2 Material Properties

The major AB structural components are reinforced concrete structures. Material properties of uncracked-concrete for the basemat, slabs, walls, and columns are listed in Table 4-2. Material properties for the horizontal cracked concrete model and vertical cracked concrete model based on the ASCE 43-05 are listed in Tables 4-3 and 4-4, respectively. Material properties of structural steel for columns and for girders are listed in Table 4-5. Critical damping ratios are taken from NRC RG 1.61.

4.2.3 Common Basemat for AB and RCB

The 10 ft thick basemat, as shown in Figure 4-3 serves as a common foundation for the AB and RCB. In the basemat, the central circular area with a radius of 83’-6” serves as the RCB foundation, while the rest of the basemat supports the AB with an embedment of 53’-6”. The two buildings are separated with a minimum 2 in. seismic gap above the top surface of the common basemat at El. 55’-0”.

The AB and RCB common basemat is modeled separately in the ANSYS by four (4)-node elastic SHELL63 elements for the AB at the bottom surface of the concrete foundation (El. 45’-0”) to account more closely for SSI effects and by eight (8)-node SOLID45 elements for the RCB concrete foundation, as shown in Figure 4-4 for the coarse mesh. To provide continuation of rotational deformation at the interface of AB shell elements and RCB solid elements, a dummy massless ring of shell elements is extended from the edge to inside the RCB, beneath the solid elements as depicted in Figures 4-5 and 4-6.

3. DESCRIPTION OF NI STRUCTURES

This section contains a description of the NI structures. The NI structures are classified as safety-related Seismic Category I structures. The RCB and AB are separate from each other above the basemat and have a minimum 2 in seismic gap between them. In the plant layout, the AB wraps around the RCB. The finished grade of the plant is at El. 98’-8”. The top of the NI common basemat is at El. 55’-0”. Thus, the exterior walls of the AB are embedded to a depth of ~~about 44 ft~~ 43′-8″ below the finished grade of the plant. The thickness of the NI reinforced concrete basemat is nominally 10 ft. The methodology and results used to develop the finite element models (FEMs) for the APR1400 NI structures are presented in Technical Report APR1400-E-S-NR-13002-P, “Finite Element Seismic Models for SSI Analyses of the NI Buildings” (Reference 11).

3.1 Description of RCB Structures

The RCB of the APR1400 is a safety-related Seismic Category I structure and comprises the following three concrete sub-structures:

- Containment structure (CS)
- Primary shield wall (PSW)
- Secondary shield wall (SSW)

The CS is also referred to as a pre-stressed concrete containment vessel. The PSW and SSW are combined to form the reinforced concrete internal structure (IS) and are the supporting structures for the reactor coolant system (RCS).

The CS and IS are separated by a 2 in gap and are connected only at their basemat at El. 78’-0”. There is no interaction between the two structures except through the common basemat.

3.1.1 Containment Structure

The CS is a cylindrical post-tensioned shell with 4.5 ft thick walls. The dome is hemispherical with 4 ft thick walls. The intersection of the cylindrical and hemispherical shapes is called the spring-line and is at El. 254’-6”.

The CS has four openings, as follows:

- Each opening has a diameter of 11.16 ft.

Two of the openings are the north side, and two are on the east side.

- The personnel emergency exit airlock opening (one on the north side and one on the east side) is at center El. 103’-9” and azimuth 280°.
- The personnel access airlock opening (one on the north side and one on the east side) is at center El. 159’-9” and azimuth 234°.

The CS also has one equipment hatch opening.

- The opening is on the east side, has a 26 ft circular opening, and is at center El. 167’-6” and at azimuth 280°.

The CS has three 14 ft wide buttresses with thicknesses varying from 7.0 ft to 7.5 ft. The buttresses are

- Reactor vessel (RV) , which is supported by four columns and the PSW
- Two (2) steam generators (SG), which are supported horizontally by the PSW and SSW and vertically at the base by concrete pedestals at El. 112'-10"
- Four (4) reactor coolant pumps (RCP), which are supported laterally on beams spanning from the PSW to SSW (at two elevations) and vertically (gravity) on a concrete pedestal at El. 103'-0"
- The PZR, which is supported laterally by its own encasement walls (shaft) and vertically by a concrete slab at its base

3.2 Description of AB Structure

The auxiliary building (AB) is a safety-related Seismic Category I structure with an embedment depth of ~~approximately 54 ft~~ 53′-8″. It encloses the RCB in the center without a structural connection except at the common basemat.

The AB is a rectangular, reinforced concrete structure. The building includes the electrical and control areas, main steam valve house, chemical and volume control system areas, emergency diesel generator area, fuel handling area, spent fuel pool, cask loading pit, refueling canal, and auxiliary feed water (AFW) tanks.

The AB is bordered on the west by the turbine generator building (TGB), on part of the south side by the compound building (CPB), and on part of the east side by the emergency diesel generator building (EDGB). The gaps between the AB and TGB, between the AB and CPB, and between the AB and EDGB are 3 ft. Gaps below the finished grade of the plant are backfilled with compacted structural fill granular (SFG).

The AB structure comprises reinforced concrete shear walls in the E-W and N-S directions for lateral load resistance and a composite of reinforced concrete walls and slabs with main columns and girders for vertical load resistance.

Figure 3-4 is an isometric view of the AB structure. For simplification of the soil layers used in the SSI analysis, the embedment depth of 53′-6″ is considered in the SASSI model of the AB structure.

compatible shear wave velocity profiles obtained from the analyses using H1 and H2 seismic inputs are then averaged to produce the averaged shear-strain-compatible shear-wave-velocity profile for each generic site profile. The averaged shear-strain-compatible shear-wave-velocity profiles obtained for S1 through S9 are the free-field site profiles used to develop the seismic SSI analysis models.

For the free-field site response analysis for each generic site profile, a low-strain soil column model is developed for use in the SHAKE analysis. The SHAKE soil column models are developed to pass vertically propagating plane seismic shear waves up to a cut-off frequency of at least 50 Hz. The SHAKE soil column models developed for all nine (9) generic site profiles are tabulated in Appendix A, Tables A-1 through A-9. The averaged shear-strain-compatible shear-wave-velocity profiles obtained from the SHAKE soil column analyses and the associated compression-wave-velocity profiles for all nine generic site profiles are tabulated in Appendix A, Tables A-10 through A-18.

Using the averaged shear-strain-compatible shear wave velocity profiles as tabulated in Appendix A, Tables A-10 through A-18, the free-field site response amplification (transfer) function computed for the horizontal ground surface motion relative to the horizontal outcrop motion of top of the half space for profiles S1 through S9 is plotted, as shown in Figure 4-6.

The fundamental horizontal site frequencies for profiles S1 through S9, as shown in Figure 4-6, are tabulated in Table 4-3 and plotted in Figure 4-7. As indicated in Table 4-3 and Figure 4-7, the fundamental horizontal site frequencies for profiles S1 through S9 range from 1.27 to 12 Hz. The site frequencies form an approximate log linear site-frequency-versus-site-profile-case straight line. Hence, profiles S1 through S9 represent a wide range of site frequencies from soft soil sites to hard rock sites.

The dynamic properties for the free-field generic site profiles S1 through S9, given in Appendix A, Tables A-10 through -18, are the properties that are used to develop the free-field soil/rock models for the SSI analyses of the NI structures.

4.5 Strain-Compatible Dynamic Properties of Backfill

For the SFG backfill material that is used next to the exterior walls of Seismic Category I structures from the ground surface to an embedment depth of ~~55~~ 53.5 ft, the low-strain shear-wave-velocity profiles are obtained from the low-strain shear modulus, G_{max}, values computed from Eq. (4-2). The compression-wave-velocity profile of SFG associated with the low-strain shear-wave-velocity profile is derived from the low-strain shear-wave-velocity profile and Poisson's ratio of SFG, which is equal to 0.33. Because the SFG backfill is below the maximum design groundwater table elevation at the ground surface, the derived compression wave velocity values that are less than the compression wave velocity of water (4,800 ft/sec) are replaced by a value of 4,800 ft/sec.

The shear-strain-compatible shear-wave-velocity profiles for the SFG backfill are obtained from the computed low-strain shear-wave-velocity profiles and the shear-modulus-degradation and damping-variation curves shown in Figure 4-5, using the averaged horizontal shear strains computed from the free-field site response analyses for the generic site profiles S1 through S9. The profiles computed for the generic site profiles S1 through S9 are tabulated in Appendix A, Tables A-19 through A-27.

The dynamic properties of SFG computed for the generic site profiles S1 through S9, which are given in Appendix A, Tables A-19 through A-27, are the properties that are used to develop the SFG backfill models for the SSI analyses of the NI structures.

5. SOIL-STRUCTURE INTERACTION ANALYSIS

For the design of the APR1400 RCB and AB, seismic SSI analyses are performed for the NI structures that are supported on a common basemat. The SSI analyses are performed for all nine (9) generic site profiles S1 through S9 and one analysis case with a rigid uniform halfspace supporting medium that simulates the fixed-base analysis case (S10).

Both uncracked and cracked concrete stiffness cases are considered in the SSI analyses (References 17, 18, 19). For the uncracked concrete stiffness cases, the SSI cases that are analyzed are designated as S1U through S10U. For the cracked concrete stiffness cases, the SSI analysis cases are designated as S1C through S10C.

5.1 SSI Analysis Methodology and Computer Program

For the APR1400 standard plant design, seismic SSI analyses are performed using the 3-D finite-element SASSI analysis methodology (Reference 5) and the associated SASSI computer program (Reference 20). Because the NI structures of the APR1400 standard plant are embedded in site soil/rock media to a depth of ~~55~~ 53.7 ft below the finished grade of the plant, the seismic SSI analyses performed using SASSI explicitly consider the ~~55~~ 53.5 ft embedment effect on the seismic response. Following the SASSI analysis methodology, the foundation embedment is considered in the SASSI analysis using the Direct (or Flexible Volume) Method of substructuring.

Since the Direct Method is adopted for the SASSI analyses of ~~55~~ 53.5 ft embedded NI structures, which are modeled using FEMs, the resulting SASSI analysis models developed for the SASSI analyses contain a large number of dynamic degrees of freedom (DOF) along with a large number of SSI nodal DOF below grade. As a result, in order to generate seismic SSI responses for all 20 analysis cases described above within a reasonable computer solution time, the current available Fast Solver Version of the ACS-SASSI computer program (Reference 20) which has large capacity is adopted to perform the SASSI computations.

5.2 Soil-Structure Interaction Models

The SSI analysis models developed for the APR1400 NI structures consist of three substructure models: a free-field site model, an excavated soil volume model, and a structure model including the backfill model.

Free-Field Site Models

The SASSI free-field site models are the same as the shear-strain-compatible free-field site models obtained from the free-field site response analyses described in Section 4.0. The dynamic soil/rock properties used for the SASSI site models are the average shear-strain-compatible soil/rock dynamic properties shown in Appendix A, Tables A-10 through A-18, for the generic site profiles S1 through S9. The layering configuration of the SASSI free-field site models is maintained for all nine (9) site profiles. The maximum wave passage frequencies resulting from the layering configuration of the free-field site model for site profiles S1 through S9 are listed in Table 5-1. As indicated in Table 5-1, the maximum wave passage frequencies of the model vary approximately from 18 to 119 Hz.

Excavated Soil Volume Models

The NI structure site is excavated to El. 42'-0", which is 3 ft below the bottom of the NI structure basemat. Three-dimensional (3-D) solid elements are used to model the excavated soil volume. The FEM developed for the excavated soil volume of the NI structure foundation, including the over excavation for the backfill, is shown in Figure 5-1. This model configuration is maintained for the nine (9) generic site profile S1 through S9. The model contains a total of 9,254 nodes. Each node has three (3) dynamic DOF. The model consists of five (5) horizontal soil/rock layers from the ground surface at El. 98'-8". The actual ground surface elevation in the model is taken at El. 98'-6" down to the bottom of the basemat at El. 45'-0"

2 DESCRIPTION OF STRUCTURES IN POWER BLOCK

This section presents description of the APR1400 seismic category I structures (RCB, AB, and EDGB) and seismic category II structures such as the compound building (CPB) and turbine generator building (TGB) which are located in the power block. The schematic layout of the APR1400 power block is shown in Figure 2-1.

The AB is bordered on its west side by the TGB, on part of its south side by the CPB and on part of its east side by the EDGB. The gaps provided between the AB and TGB, between the AB and CPB, and between the AB and EDGB are all 3 ft. These gaps below the plant's finished grade are backfilled with compacted structure fill granular (SFG).

2.1 Description of NI

The NI structures are classified as safety-related seismic category I structures. The RCB and AB are separate from each other above the basemat with a minimum 2 in. seismic gap. In plant layout, the AB wraps around the RCB completely. The plant's finished grade is at El. 98'-8". The top of the NI common basemat is at El. 55'-0". Thus, the exterior walls of AB are embedded to a depth of ~~about 44 ft~~ 43′-8″ below the plant's finished grade. The thickness of the NI reinforced concrete basemat is nominally 10 ft.

2.1.1 RCB

The RCB is a safety-related seismic category I structure and is comprised of three concrete substructures:

- Containment structure (CS)
- Primary shield wall (PSW)
- Secondary shield wall (SSW)

The CS is also called the pre-stressed concrete containment vessel. The PSW and SSW are combined to form the reinforced concrete internal structure (IS), and are the supporting structures for the reactor coolant system (RCS).

The CS and IS are separated by 2 in. gap and only connected at their basemat at El. 78'-0". Therefore, there is no interaction between the two structures except through this common basemat.

Figure 2-2 shows the typical section view of the RCB.

2.1.2 AB

The AB is a safety-related seismic category I structure with an embedment depth of ~~54 ft approximately~~ 53′-8″ including basemat thickness. It encloses the RCB in the center without structural connection except at the common basemat.

The AB is a rectangular-shaped reinforced concrete structure. The building includes the electrical and control area, main steam valve house, chemical and volume control system areas, emergency diesel generator area, spent fuel pool, cask loading pit, refueling canal, and auxiliary feed water tanks.

The AB structure system is composed of reinforced concrete shear walls in both east-west (E-W) and north-south (N-S) directions for the lateral load resistance and the composite of reinforce concrete walls and slabs with the columns and girders for vertical load resistance.

Figure 2-3 shows the typical section view of the AB.

2.2 Description of EDGB

The EDGB is a safety-related seismic category I structure and is comprised of two separate concrete structures:

- EDGB
- Diesel fuel oil tank (DFOT) room

The EDGB is one of the APR1400 standard plant structures with an embedment depth of ~~9 ft approximately~~ 6′-8″. Also the DFOT room is an APR1400 standard plant structure with an embedment depth of ~~39 ft approximately~~ 39′-8″. The EDGB separates from the AB with a typical 3 ft building gap, and separates from the DFOT room with a typical 3 ft gap.

The structural system of the EDGB consists of shear walls in both E-W and N-S directions, and a total of 2 major floor slabs. These walls and slabs are made of reinforced concrete structures. The DFOT room consists of reinforced concrete shear walls and roof slabs. Steel girders are used to support the DFOT room roof.

Figure 2-4 shows the typical section view of the EDGB.

2.3 Description of CPB

The CPB is a non-safety-related seismic category II structure with an embedment depth of 42 ft approximately. The CPB separates from the AB with a typical 3 ft gap. The top of basemat is at El. 63'-0". The exterior walls of the CPB are embedded about 36 ft.

The shape of the CPB is a rectangular type. The major dimension of the CPB is 216 ft long and 178 ft wide. The CPB is composed of rectangular reinforced concrete walls, steel columns, steel girders, and reinforced concrete slabs. The CPB structure is designed to preclude a structural failure that results from the safe shutdown earthquake (SSE) and that degrades the structural integrity of the adjacent AB.

The CPB is a five-story structure. The major floors are located at El. 63'-0", 85'-0", 100'-0", 120'-0" and 139'-6". The labyrinth walls that create numerous compartments utilized for the radwaste management system components are arranged in the basement and first two floors.

Figure 2-5 shows the typical section view of CPB.

2.4 Description of TI

The three structures, namely, (1) TGB, (2) switchgear area (SGA), and (3) turbine generator pedestal (TGP), of the turbine island (TI) are separate above their common basemat. The TGB and TGP are structurally completely separated above the common basemat with a seismic gap between them. The TGB and SGA are structurally connected below the plant’s finished grade but are structurally separated above grade with also a seismic gap between them.

The top surface of the TI common basemat is mostly at El. 73’-0”, but some areas of the basemat sink further down to El. 55’-0”. The configuration of the entire TI structures are approximately rectangular in plan having maximum plan dimensions of about 340 ft in the plant EW direction and about 195 ft in the plant NS direction. The TGB has an overall height of about 127 ft above the plant grade and the outside walls of the TI are embedded to a depth of about 50 ft below grade.

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.:	**253-8300**
SRP Section:	**03.07.01 – Seismic Design Parameters**
Application Section:	**3.7.1**
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Question No. 03.07.01-7

DCD Section 3.7.1.1.2 states that “V/A and AD/V2 should be consistent with characteristic values for the magnitude and distance of appropriate controlling events defining the uniform hazard response spectra.” The staff consider a check of V/A and AD/V2 to be not appropriate for DC because the standard design is based on postulated site parameters and there are no characteristic events and other site-specific information associated with the synthetic acceleration time histories. The discussion of V/A and AD/V2 in the SRP is intended to be used for site-specific applications. Therefore, the applicant is requested to remove the information related to the check of V/A and AD/V2 from the APR1400 DCD and referenced technical reports (APR1400-E-S-NR-14001-P, Rev. 0 and APR1400-E-S-NR-14004-P, Rev. 1), or provide justification on why this information is included in these documents.

[NOTE: In the conference call on 08/20/2015, the applicant indicated that the CSDRS and HRHF time histories are based on seed motions (Northridge earthquake and Nahanni earthquake, respectively) and the comparison of V/A and AD/V2 to target values is to double check the consistency between seed motions and CSDRS or HRHF time histories. However, since the seed records are modified to match the CSDRS and HRHF spectra, the earthquakes for the seed motions are not necessarily meaningful for the CSDRS and HRHF spectra.]

Provided that an adequate justification will be provided by the applicant to the question above and the description of the V/A and AD/V2 will be maintained in the DCD and the referenced technical reports, the staff also requests that the applicant provide the following additional information to assist the staff’s evaluation of the information related to V/A and AD/V2 check:

Section 3.2.3 of APR1400-E-S-NR-14001-P, Rev. 0, Seismic Design Bases, describes the development of target and target ranges for V/A and AD/V2, which references RG 1.60, NUREG-0003, and NUREG/CR-6728. The report indicates that the target median values are determined from NUREG-0003, which is the basis for the RG 1.60 design response spectra, while the standard deviations used to define the target ranges are based on NUREG/CR-6728 (considering both WUS sites and CEUS sites). Since the design response spectra resulted from

NUREG-0003 and NUREG/CR-6728 are different, the applicant is requested to justify why the standard deviations from NUREG/CR-6728 are applicable to the response spectrum targets taken from NUREG-0003.

Since the CSDRS are not the same as RG 1.60 design response spectra, the peak values A, V, D and their ratios V/A and AD/V2 are not necessarily the same as those for the RG 1.60 spectra. As such, the applicant is requested to justify why the target median values from NUREG-0003, which are applicable to the RG 1.60 spectra, are also applicable to the APR1400 CSDRS.

In DCD Section 3.7.1.1.2, Section 3.2.3 of APR1400-E-S-NR-14001-P, and Section 3.3.4 of APR1400-E-S-NR-14004-P, Rev. 1, Evaluation of Effects of HRHF Response Spectra on SSCs, the notations of "m+σ", "m-σ", or "m±σ" are used to represent the range of the variation in the target values. However, as described in Section 3.3.4 of APR1400-E-S-NR-14004-P, Rev. 1, the actual meaning of "m+σ" is m×exp(σ), which indicates that σ is not standard deviation but log-standard deviation. As such, the applicant is requested to revise the notations in the DCD and the technical reports to properly reflect the mathematical meaning.

Response

The descriptions related to V/A and AD/V2 will be deleted from the DCD and the technical reports, as indicated in the attachment associated with this response.

Impact on DCD

DCD Section 3.7.1.1.2, 3.7.1.1.3, Table 3.7-2 and Table 3.7-4 will be revised, as indicated in the attachment associated with 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-14001-P/NP, Rev. 0, Section 3.1, 3.2.3, 3.3, Table 3-1, Table 3-2, Table 3-5, and Table 3-6 and technical report APR1400-E-S-NR-14004-P/NP, Rev. 1, Section 3.3.1, 3.3.4, 3.6, Table 3-5, Table 3-6, and Table 3-9 will be revised, as indicated in the attachment associated with this response.

Correlation coefficient for H1 and VT = 0.079

Correlation coefficient for H2 and VT = 0.029

The design time histories are statistically independent because the correlation coefficients between the design time histories are less than 0.16 as specified in Standard Review Plan (SRP) 3.7.1 (Reference 5). Therefore, the representative maximum response of interest of the APR1400 SSCs can be obtained either by performing separate analyses for each of the three components of design time histories or by performing a single analysis with all three components of design time histories applied simultaneously.

The design time histories have a total time duration equal to 20.48 seconds and a corresponding stationary phase, which is the strong-motion duration defined as the time required for the Arias Intensity rise from 5 percent to 75 percent in more than 6 seconds.

The design time histories are developed following the spectrum matching acceptance criteria of Option 1, Approach 1, in Section II of SRP 3.7.1. The comparison plots of the response spectra of the design time histories versus the design response spectra for 2, 3, 4, 5, 7, and 10 percent critical damping are shown in Figures 3.7-6, 3.7-7, and 3.7-8. The figures demonstrate that the design time histories envelop the design response spectra for those damping values, satisfying the requirement of SRP 3.7.1 that no more than 5 points fall below and by no more than 10 percent below the design response spectra. The response spectra are computed at the frequency intervals given in Table 3.7.1-1 of SRP 3.7.1.

~~According to SRP 3.7.1, the ratios V/A and AD/V^2, where A, V, D are peak ground acceleration, ground velocity, and ground displacement, respectively, should be consistent with characteristic values for the magnitude and distance of the appropriate controlling events defining the uniform hazard response spectra. The target and target ranges of values for the other design ground-motion time-history parameters are the median (m) values and the median (m) ± one standard deviation (σ) (i.e., m ± σ), ranges. The determination of these target and target ranges of values is based on the methodologies and ground motion databases as described in NRC RG 1.60 and relevant NUREG reports, namely, NUREG-0003 (Reference 6) and NUREG/CR-6728 (Reference 7). Table 3.7-2 shows a comparison of the ratios V/A and AD/V^2 for the time histories and the guidance in NUREG/CR-6728 and that the ratios are between the target values, target median ± σ.~~

The time histories are developed following the spectrum matching acceptance criteria of Option 1, Approach 1, in Section II of SRP 3.7.1. The comparison plots of the response spectra of the time histories versus the HRHF response spectra for 2, 3, 4, 5, 7, and 10 percent critical dampings are shown in Figures 3.7-17, 3.7-18, and 3.7-19. The figures demonstrate that the time histories envelop the HRHF response spectra for those damping values, satisfying the requirement of SRP 3.7.1 that no more than 5 points fall below and by no more than 10 percent below the HRHF response spectra.

~~According to SRP 3.7.1, the ratio V/A and AD/V^2 should be consistent with characteristic values for the magnitude and distance of the appropriate controlling events defining the uniform hazard response spectra. The target and target ranges of values for the other design ground-motion time-history parameters are the median (m) values and the median (m) ± one standard deviation (σ) (i.e., m ± σ) ranges. The determination of these target and target ranges of values is based on the methodologies and ground motion databases as described in NUREG/CR-6728. Table 3.7-4 shows a comparison of the ratios V/A and AD/V^2 for the time histories and the guidance in NUREG/CR-6728 and that the ratios are between the target values, target median ± σ.~~

For the development of the HRHF-response spectra-compatible target PSDs in the frequency range from 0.3 to 80 Hz, the time-history simulation method described in NUREG/CR-5347 is used. The resulting piecewise log-log linear horizontal and vertical target PSD developed is given in Tables 3.7-5 and 3.7-6. The minimum required horizontal and vertical PSD is then 0.8 times the horizontal and vertical target PSD.

The PSDs of the acceleration time histories compatible with the HRHF response spectra are presented in Figures 3.7-20 through 3.7-22. The PSDs of the acceleration time histories exceed the minimum required PSD throughout the entire frequency range.

The evaluation methodology and results of the APR1400 for the HRHF seismic input motions are provided in Appendix 3.7B.

3.7.1.2 Percentage of Critical Damping Values

Damping values used for various nuclear safety-related SSCs are based on NRC RG 1.61 (Reference 10). These values are expressed in percentages of critical damping and are given in Table 3.7-7. Damping values of soil to be used in soil-structure interaction

Table 3.7-2

Comparison of Ratios V/A and AD/V^2 for CSDRS

Component	V/A, cm/sec/g (in/sec/g)	Target V/A, cm/sec/g (in/sec/g)			AD/V^2	Target AD/V^2		
		med-σ	median	med+σ		med-σ	median	med+σ
H1	148.08 (58.3)	87.63 (34.5)	121.92 (48.0)	169.67 (66.8)	6.2	4.2	6.0	8.6
H2	151.64 (59.7)	87.63 (34.5)	121.92 (48.0)	169.67 (66.8)	5.8	4.2	6.0	8.6
VT	160.02 (63.0)	87.63 (34.5)	121.92 (48.0)	169.67 (66.8)	4.2	4.2	6.0	8.6

Table 3.7-2

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Table 3.7-4

Comparison of Ratios V/A and AD/V^2 for HRHF Seismic Input Motions

Component	V/A, cm/sec/g (in/sec/g)	Target V/A, cm/sec/g (in/sec/g)			AD/V^2	Target AD/V^2		
		med-σ	median	med+σ		med-σ	median	med+σ
H1	48.62 (19.14)	30.43 (11.98)	42.34 (16.67)	58.88 (23.18)	8.26	3.92	6.14	9.63
H2	57.61 (22.68)	30.43 (11.98)	42.34 (16.67)	58.88 (23.18)	5.69	3.92	6.14	9.63
VT	54.53 (21.47)	30.43 (11.98)	42.34 (16.67)	58.88 (23.18)	7.53	3.92	6.14	9.63

Table 3.7-4

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3. DESIGN TIME HISTORIES

This section presents the analytical methods and procedures for use in generation of design time histories compatible with the CSDRS and generated time histories satisfying the SRP section 3.7.1, option 1 approach 1 response spectrum and PSD enveloping guidelines and criteria for design time histories.

3.1 Guidelines and Criteria for Time History Generation

In accordance with the guidelines provided in the SRP section 3.7.1 for option 1 approach 1, the following are desirable procedures of the design ground motion time histories:

(1) Design time histories are based on recorded seed motion time histories.

(2) The set of time histories shall consist of time histories in three mutually orthogonal directions (two horizontal and one vertical).

(3) The time interval of time-history digitization, t, shall be less than $1/(2f_n)$ where f_n is the highest frequency of interest.

(4) The minimum acceptable strong motion duration, which is defined as the time required for the Arias Intensity to rise from 5% to 75%, shall be 6 seconds.

(5) The three (two horizontal and one vertical) time histories shall be mutually statistically independent from one another. The criterion for statistical independence is based on the cross-correlation coefficients computed for any pairs of time histories; these calculated coefficients shall be less than 0.16.

~~(6) The ratios V/A and AD/V^2, where A, V, and D, are peak ground acceleration, ground velocity, and ground displacement, respectively, shall be consistent with characteristic values determined for the low and high-frequency events described in Appendix D of NRC RG 1.208 (Reference 7).~~

In accordance with the guidelines provided in the SRP section 3.7.1 for option 1 approach 1, the following are the response spectra and PSD enveloping requirements:

(1) The response spectra from the time history must envelop the target CSDRS for all damping values used in the seismic response analysis.

(2) For each applicable damping value, the response spectrum of the time history shall envelop the target design response spectrum with no more than five points falling below the target spectrum by no more than 10% of the target spectral values.

(3) In checking the spectrum-enveloping, the set of frequencies at which the response spectra are to be calculated shall be the standard set of 81 frequencies from 0.2 Hz to 50 Hz as specified in the SRP section 3.7.1 table 3.7.1-1.

(4) The PSD of the time history shall adequately match a target PSD that is compatible with the target DRS. For DRS other than the NRC RG 1.60 response spectra, response-spectrum-compatible target PSDs shall be generated. In generating the target PSDs, the guidelines and procedures provided in the SRP section 3.7.1, appendix A can be used.

(5) The time-history PSD shall generally envelop the minimum-required target PSD, which is set at 80% of the target PSD, in the frequency range between 0.3 Hz and 50 Hz.

recorded time histories have their response spectra matching generally well with the target response spectra over a relatively wide frequency band.

3.2.3 General Procedures

In generating the set of three-component design time histories for the CSDRS, the seed motion recorded from the 1994 Northridge earthquake at the West Covina recording station as described in subsection 3.2.2 to produce the initial time histories for modifications. In order to improve convergence in the spectrum-matching iterations and produce modified time histories having a more realistic appearance like real earthquake accelerograms, while satisfying the stationary-phase strong-motion duration requirement, these initial time histories are (a) scaled to have a maximum acceleration of 0.3g; (b) re-digitized to have a time interval of 0.005 second; (c) truncated to retain the strong-phase duration of the time histories to 4,096 points (total duration of 20.475 seconds); and (d) intensity-modulated by an intensity envelope function, $g(t)$ as shown in Figure 3-7, before they are used as the initial time histories for time-history modifications using the computer program SYNQKE-R (Reference 10).

SYNQKE-R performs adjustments to the initial time history by automated iterations. For each cycle of iteration, the time-history response spectra are compared with the target response spectra of corresponding damping values and the necessary time-history adjustments to achieve spectrum-matching for the cycle are automatically solved. By repeating this iteration process and constantly monitoring the convergence to within the SRP spectrum-enveloping guidelines, a final modified time history that has response spectra closely matching with the target multiple-damping response spectra and satisfying the SRP spectrum-enveloping guidelines is obtained.

The final modified acceleration time histories so obtained are then integrated to obtain their integrated velocity and displacement time histories. From these results, baseline corrections are performed, as necessary, to minimize the residual velocity and displacement values and, at the same time, produce the desirable integrated maximum velocity and displacement values, giving the baseline-corrected acceleration time histories. Time-history response spectra of the baseline-corrected time histories are then computed and compared with the target spectra to provide reasonable assurance that the SRP spectrum-enveloping guidelines are still satisfied; otherwise, further time-history adjustments and baseline corrections are performed until the guidelines are satisfied.

~~The CSDRS-compatible time histories generated shall also be checked for reasonable compliance within the target ranges of values of another set of ground-motion time-history parameters. In addition to the maximum acceleration (A), of the generated time history, these other time-history parameters to be checked include the maximum velocity (V), maximum displacement (D), V/A, and AD/V^2 ratio values.~~

(1) The target and target ranges of values for these other design ground-motion time-history parameters shall be the median (*m*) values and the median (*m*) ± one standard deviation (σ), i.e., $m \pm \sigma$, ranges. The determination of these target and target ranges of values is based on the methodologies and ground motion databases as described in NRC RG 1.60 and relevant NUREG reports, namely, NUREG-0003 (Reference 11) and NUREG/CR-6728. The determination of the target and target ranges of values for these other design ground-motion time-history parameters is described below.

(2) The PGA of the CSDRS is 0.3g for both the horizontal and vertical components of ground motion. Thus, the target maximum acceleration (A) of the CSDRS-compatible time histories is generated as 0.3g. Also, the CSDRS adopt the horizontal and vertical NRC RG 1.60 DRS for the frequency range below 9 Hz. The CSDRS are enhanced from the spectra values of the NRC RG 1.60 DRS in the high frequency range from 9 to 50 Hz.

~~(3) The higher high-frequency motion contents in the frequency range from 9 to 50 Hz associated with the CSDRS will not have a significant effect on the integrated velocity and displacement~~

time histories. Thus, the development of the target values and associated target ranges of values for the maximum velocity (V) and maximum displacement (D) of the CSDRS-compatible time histories to be generated is based on the ground motion study results published in NUREG-0003, which is the basis of the NRC RG 1.60 DRS, and the results in NUREG/CR-6728, which is the basis of NRC RG 1.208.

(4) From the study results published in NUREG-0003, the target median (m) values of maximum velocity (V), maximum displacement (D), V/A ratio, and AD/V^2 ratio of the time histories to be generated, scaled to the PGA value of 0.3g, are given in Table 3-1.

The target ranges of V, D, V/A, and AD/V^2 values are developed to be the median ± one standard deviation (σ) (i.e., "$m \pm \sigma$" ranges). The standard deviation for each parameter is derived from the database of values published in NUREG/CR-6728. For conservatism, the smallest of eight σ values each parameter is used, because the smallest σ value will lead to the smallest range of variation for the parameter. The eight σ values are obtained from the ground-motion databases for the Western United States (WUS) and CEUS rock and soil sites, for distance bins 50-100 km, and for earthquake magnitudes 6.3 to 7.5, as given in Table 3-5 (on page 3-12) and Table 3-6 (on pages 3-14 and 3-15) of NUREG/CR-6728.

Based on the σ value derived for each parameter as described above, the target $m \pm \sigma$ ranges of the parameter values so derived for the CSDRS-compatible time histories to be generated are shown in Table 3-2.

3.2.4 Method for Developing Spectrum-Compatible Target PSD Function

In order to check the adequacy of the PSD of each of the spectrum-compatible time histories generated, horizontal and vertical target PSDs compatible with the horizontal and vertical DRS, respectively, are required.

(1) Horizontal Target PSD for $f \le 9$ Hz

The horizontal CSDRS are the same as the horizontal NRC RG 1.60 DRS for the frequency range below 9 Hz. The method for developing the horizontal CSDRS-compatible target PSDs below 9 Hz follows the procedure and uses the standard horizontal PSD functions presented in the SRP section 3.7.1, appendix A, which is applicable for the NRC RG 1.60 horizontal DRS anchored to the PGA of 1.0g.

To obtain the horizontal target PSD compatible with the horizontal CSDRS, the one-sided horizontal target PSD, SH(f), where f is cycles per second (cps), expressed in the units of (m^2/sec^4)/cps, is obtained from the one-sided PSD, SH(ω), where ω is in the units of radians per second (rps), presented in appendix A of SRP, section 3.7.1, which are in the units of m^2/sec^3, or (m^2/sec^4)/rps, scaled by the square of the ratio of the horizontal PGA of 0.3g for the APR1400 to the PGA of 1.0g for the NRC RG 1.60 DRS as follows:

$$S_H(f) = 2\,\pi\, S_H(\omega) \times (0.30)^2, \qquad f \le 9 \text{ Hz}$$

where the values of $S_H(\omega)$ are obtained from Eq. (2) of SRP section 3.7.1, appendix A.

(2) Horizontal Target PSD for $f > 9$ Hz

For the frequency range between 9 and 50 Hz, for which the CSDRS differ from the NRC RG 1.60 DRS, the method presented in the SRP section 3.7.1, appendix A can no longer be used. Thus, for developing the CSDRS-compatible target PSD in the higher frequency range above 9 Hz, the time-history simulation method described in NUREG/CR-5347 (Reference 12) is used.

In computing the time-history PSDs, the equivalent stationary duration for each of the time histories H1, H2, and VT are determined from the cumulative energy (Arias Intensity) time-history plots shown in Figures 3-35, 3-36, and 3-37, respectively. From these plots, the equivalent stationary duration for each time history is determined and the results are shown in Table 3-4. These comparisons within the frequency range of 0.3 to 50 Hz are shown in the plots of Figures 3-38, 3-39, and 3-40, respectively, for time histories H1, H2, and VT. As can be seen from these comparison plots, the PSDs of the time histories generated generally conform to and envelop the corresponding minimum required target PSDs.

~~The maximum acceleration (A), maximum velocity (V), maximum displacement (D), V/A and AD/V^2 ratios of the generated H1, H2, and VT time histories are listed in Tables 3-5 and 3-6.~~

In order to check the statistical independence among the three-component spectrum-compatible time histories, which are to be applied simultaneously to the seismic response analysis with zero time-lag, the cross-correlation coefficients of any pair of time histories with zero time-lag are calculated and checked against the SRP section 3.7.1 threshold value of 0.16 to determine the statistical independence between any pair of time histories. The results are listed in Table 3-7. The computed values of cross-correlation coefficients as shown in Table 3-7 are all less than the threshold value of 0.16. Thus, the three final modified time histories generated can be considered mutually statistically independent from one another.

Table 3-1

Target Median Values of APR1400 CSDRS-Compatible Time Histories

A (g)	V (in/sec)	D (in)	V/A (in/sec/g)	AD/V²
0.30	14.4	10.8	48.0	6.0

Table 3-1

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Table 3-2

Target Ranges of Values of APR1400 CSDRS-Compatible Time Histories

Parameter	V (in/sec)	D (in)	V/A (in/sec/g)	AD/V²
σ	0.47	0.65	0.33	0.36
m-σ	9.0	5.6	34.5	4.2
m	14.4	10.8	48.0	6.0
m+σ	23.0	20.7	66.8	8.6

Table 3-2

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Table 3-5

Maximum Acceleration (A), Velocity (V), and Displacement (D) of Generated Time Histories

Component	A (g)	V (in/sec)	Target V (in/sec)			D (in)	Target D (in)		
			m - σ	Median (m)	m + σ		m - σ	Median (m)	m + σ
H1	0.300	17.5	9.0	14.4	23.0	16.5	5.6	10.8	20.7
H2	0.300	17.9	9.0	14.4	23.0	16.1	5.6	10.8	20.7
VT	0.300	18.9	9.0	14.4	23.0	13.0	5.6	10.8	20.7

Table 3-5

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Table 3-6

V/A and AD/V² Ratios of Generated Time Histories

Component	V/A (in/sec/g)	Target V/A (in/sec/g)			AD/V²	Target AD/V²		
		m - σ	Median (m)	m + σ		m - σ	Median (m)	m + σ
H1	58.3	34.5	48.0	66.8	6.2	4.2	6.0	8.6
H2	59.7	34.5	48.0	66.8	5.8	4.2	6.0	8.6
VT	63.0	34.5	48.0	66.8	4.2	4.2	6.0	8.6

Table 3-6

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(2) The set of time histories should consist of time histories in three mutually orthogonal directions - two horizontal and one vertical.

(3) The time interval of time history digitization, t, shall be less than 1/(2 fn) where fn is the highest frequency of interest. For the APR1400, the interval of time history digitization shall be 0.005 second, which corresponds to a fn of 100 Hz.

(4) The minimum acceptable strong-motion duration, which is defined as the time required for the Arias Intensity to rise from 5 to 75 percent, should be 6 seconds.

(5) The three time histories (two horizontal and one vertical) shall be statistically independent from one another. The criterion for statistical independence shall be based on the cross-correlation coefficients computed for any pairs of time histories and these calculated coefficients shall be less than 0.16.

~~(6) In addition to the duration, the ratios V/A and AD/V^2, where A, V, and D are peak ground acceleration, ground velocity, and ground displacement, respectively, should be consistent with characteristic values determined for the low and high frequency events described in Appendix D of NRC RG 1.208 (Reference 16).~~

3.3.2 Response Spectrum and Power Spectral Density Enveloping Requirements

In accordance with the guidelines and criteria for Option 1 Approach 1, the response spectrum and power spectral density (PSD) enveloping requirements for design time histories are as follows:

(1) The response spectra from the time history must envelop the target HRHF response spectra for all damping values used in the seismic response analysis.

(2) For each applicable damping value, the response spectrum of the time history shall envelop the target response spectrum with no more than five points falling below the target spectrum by no more than 10 percent of the target spectral values.

(3) In checking spectrum-enveloping, the set of frequencies at which the response spectra are to be calculated shall be the standard set of 92 frequencies from 0.2 Hz to 80 Hz as specified in SRP 3.7.1 Table 3.7.1-1.

(4) The PSD of the time history shall adequately match a target PSD, which is compatible with the target design response spectra. For design response spectra other than the NRC RG 1.60 response spectra, the response spectrum-compatible target PSDs should be generated. In generating the target PSDs, the guidelines and procedures provided in Appendix B to SRP 3.7.1 can be used.

(5) The time history PSDF shall generally envelop the minimum required target PSD, which is set at 80 percent of the target PSD, in the frequency range between 0.3 Hz and 80 Hz.

3.3.3 Selection of Initial Seed Motion Time Histories

To comply with the SRP 3.7.1 guidelines, design time histories should be generated from the recorded, actual earthquake ground motion called “seed motion”. The selection guidelines of a set of recorded time histories to be used as the seed motion for the generation of the HRHF response spectrum-compatible design time histories are follows:

(1) The three component seed motion time histories, two horizontal and one vertical, should come from the same earthquake event and recording station.

~~3.3.4 Other Relevant Ground Motion Parameters~~

~~To comply with the guidelines and criteria in SRP 3.7.1, the response-spectrum-compatible time histories to be generated should also be checked for reasonable compliance within the target value of ranges of other associated design ground motion parameters. In addition to the maximum acceleration, A, of the generated time history, the other ground motion parameters to be checked include the maximum velocity, V, maximum displacement, D, and V/A and AD/V2 ratios.~~

~~The target and target ranges of values for these other design ground motion parameters defined to be the median (m) values and median (m) ± one standard deviation (σ), i.e., m±σ, ranges. The target and target ranges of values are determined based on the methodologies and ground motion databases described in SRP 3.7.1 and NUREG/CR-6728.~~

~~The peak ground acceleration (PGA) of the selected APR1400 HRHF response spectra is 0.46g for both the horizontal and vertical components of ground motion. Thus, the target maximum acceleration (A) of the HRHF response spectrum-compatible time histories is A = 0.46g.~~

~~From the study results presented in NUREG/CR-6728, the target median (m) values of maximum velocity V, maximum displacement, D, V/A and AD/V² ratios of the HRHF response spectrum-compatible time histories to be generated, scaled to the target PGA value of A = 0.46g, are given in Table 3-5. The target ranges of V, D, V/A, and AD/V² values defined to be the median ± one standard deviation (m±σ) ranges are shown in Table 3-6. The standard deviation (σ) for each parameter is derived from the ground motion databases for CEUS rock sites for earthquake magnitudes of 6.3 to 7.5 and epicentral distance bins 0-100 km, as given in Table 3-6 (on pages 3-14 and 3-15) of NUREG/CR-6728. For conservatism, the smallest of the σ values of each parameter for the CEUS rock motions for magnitudes of 6.3 to 7.5 and for epicentral distance 0 to 100 km is used. The smallest σ value leads to the smallest target range of variation for the parameter considered and is therefore, the most conservative.~~

~~For the maximum velocity V, the minimum σ value selected from Table 3-6 of NUREG/CR-6728 is 0.40. Thus, the value for "m+σ" is computed as m+σ = m×exp (σ) = 8.53×exp (0.40) = 12.73 in/sec and the value for "m-σ" is computed as m-σ = m×exp (-σ) = 8.53×exp (-0.40) = 5.72 in/sec.~~

~~For the maximum velocity D, the minimum σ value selected from Table 3-6 of NUREG/CR-6728 is 0.57. Thus, the value for "m+σ" is computed as m+σ = m×exp (σ) = 3.63×exp (0.57) = 6.42 in. and the value for "m-σ" is computed as m-σ = m×exp (-σ) = 3.63×exp (-0.57) = 2.05 in.~~

~~The σ-values of 0.33 and 0.45 for V/A and AD/V², respectively, as given in Table 3-6 are smaller and, hence, more conservative than the corresponding σ-values of 0.48 and 0.54, respectively, given in NUREG-0003 (Reference 18), which are applicable for the NRC RG 1.60 horizontal design response spectra (Reference 19).~~

3.4 Method for Generation Spectrum-compatible Time Histories

Two methods have generally been adopted for the generation of response-spectrum-compatible time histories: (a) the time domain time history adjustment method and (b) the frequency domain time history adjustment method. To generate a time history that is compatible with a set of multiple damping target response spectra based on a recorded actual earthquake seed motion time history, the time domain time history adjustment method is usually adopted because it preserves the motion characteristics of the recorded seed motion.

3.4.1 Analytical Background

The method for generating a design time history with response spectra closely matching a family of target buildup) having a constant slope $S = [E_i(t_{p2}^i) - E_i(t_{p1}^i)]/(t_{p2}^i - t_{p1}^i)$. The equivalent stationary duration T_s^i for the entire time history as determined from Eq. (3-3) is the duration over which the total energy of the time history is built up from 0 to 100 percent with the constant slope S. This procedure of calculating T_s^i is illustrated in Figure 3-27.

(2) Compute the one-sided PSD, $S_i(f)$ of the time history $a_i(t)$ using the following equations:

$$S_i(f) = \frac{|A_i(f)|^2}{T_s^i} \quad (3\text{-}4)$$

Where $|A_i(f)|$ is the amplitude of the Fourier spectrum obtained from the following equation:

$$A_i(f) = \int_0^{T_i} a_i(t)e^{-2\pi ft}dt \quad (3\text{-}5)$$

Where T_i is the total duration of the time history $a_i(t)$.

(3) Smooth the time history PSD $S_i(f)$ using the moving average technique over a ±20 percent frequency bandwidth centered at the frequency *f*, in accordance with the guidelines in NUREG/CR-5347 (Reference 24), to give the smoothed time history PSD $\tilde{S}_i(f)$.

The smoothed time history PSD, $\tilde{S}_i(f)$, obtained from step (c) above is then compared with the minimum required target PSD, $\tilde{S}_i(f)$, to check the adequacy of the power content of the generated time history.

3.6 Generation Results

The acceleration time histories generated using the procedure described in Section 3.4 consist of two horizontal (H1H and H2H) and one vertical (VTH) components. Time histories H1H, H2H, and VTH are applied in the horizontal E-W, horizontal N-S, and vertical directions, respectively. The time interval of time history digitization, Δt, is 0.005 second, which corresponds to the highest frequency of interest of 100 Hz.

The horizontal H1H acceleration time history is plotted along with the integrated velocity and displacement time histories in Figure 3-28. The comparison of the time history response spectra with the corresponding horizontal target HRHF response spectra for the corresponding damping values are shown in Figure 3-29. Similar results for the horizontal H2H time history are shown in Figures 3-30 and 3-31. Similar results for the vertical time history VTH are shown in Figures 3-32 and 3-33.

~~The maximum acceleration (A), maximum velocity (V), maximum displacement (D) and V/A and AD/V2 ratios of the generated H1H, H2H, and VTH time histories are listed in Table 3-9~~

To show the statistical independence of the set of time histories, the cross-correlation coefficients of pairs of the HRHF response spectrum-compatible time histories are given in Table 3-10. The values all are below 0.16, thus satisfying the SRP Section 3.7.1 (Reference 15) threshold for statistical independence.

Table 3-5

Target Median Values for APR1400 HRHF Response-Spectrum-compatible Time Histories

Distance (km)	M	A (g)	A (cm/sec^2)	V (cm/sec)	D (cm)	V/A (cm/sec/g)	AD/V^2
0-10 rock	6.53	1.16	1138.5	39.74	7.84	34.37	5.63
	7.25	0.89	873.5	58.4	22.33	65.84	5.7
10-50 rock	6.32	0.25	245.4	7.95	1.7	31.75	6.58
	7.38	0.34	333.7	19.85	9.17	58.24	7.78
50-100 rock	6.38	0.09	88.3	2.99	0.46	32.59	4.66
	7.46	0.15	147.2	7.33	3.98	50.29	10.6
	median values =	0.295	289.5	13.90	5.91	42.33	6.14
	target median values =	0.46	451.5	21.67	9.22	42.33	6.1

Distance (km)	M	A (g)	A (in/sec^2)	V (in/sec)	D (in)	V/A (in/sec/g)	AD/V^2
0-100 km	6.3- 7.5	0.46	177.7	8.53	3.63	16.67	6.14

Table 3-5

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Table 3-6

Target Ranges of V, D, V/A, and AD/V²

Parameter	V (in/sec)	D (in)	V/A (in/sec/g)	AD/V^2
σ [1)]	0.40	0.57	0.33	0.45
m-σ [3)]	5.72	2.05	11.98	3.92
m [2)]	8.53	3.63	16.67	6.14
m+σ [4)]	12.73	6.42	23.18	9.63

Notes:

1) σ values for V, D, V/A and AD/V² are the minimum log-normal standard deviations for the CEUS rock motions for M = 6.3 to 7.5, and R = 0-100 km obtained from Ref. (6).
2) m = median values of V, D, V/A, and AD/V² for given distance and M are obtained from Ref. (6).
3) m -σ = m×exp(-σ)
4) m+σ = m×exp(σ).
5) Median values of V, D, V/A, and AD/V² are obtained from statistics of the values in the columns.

Table 3-6

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Table 3-9

Statistics of HRHF Response Spectrum-compatible Time Histories

Com-ponent	A (g)	Target	V (in/sec)	Target Range (in/sec)	D (in)	Target Range (in)	V/A (in/sec/g)	Target Range	AD/V²	Target Range
H1H	0.463	0.463	8.86	5.72 – 12.73	3.63	2.05 – 6.42	19.1	11.98 – 23.18	8.27	3.92 – 9.63
H2H	0.463	0.463	10.50	5.72 – 12.73	3.51	2.05 – 6.42	22.7	11.98 – 23.18	5.70	3.92 – 9.63
VTH	0.463	0.463	9.94	5.72 – 12.73	4.16	2.05 – 6.42	21.5	11.98 – 23.18	7.53	3.92 – 9.63

Table 3-9

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