The HRHF vertical target response spectra for the 2, 3, 4, 7, and 10 percent damping ratios were generated by multiplying the V/H ratios for the CEUS rock site conditions by the corresponding HRHF horizontal target response spectra.

The generated HRHF horizontal and vertical target response spectra for the 2, 3, 4, 5, 7, and 10 percent damping ratios are shown in Chapter 3, Figures 3.7-12 and 3.7-13, respectively. The guidelines and criteria described in NRC SRP Section 3.7.1, Rev. 4, for Option 1 Approach 1 (Reference 6), were used for generating a set of three-component acceleration time histories compatible with HRHF target response spectra. The generated HRHF horizontal and vertical acceleration time histories, named H1H and H2H for both horizontal directions and VTH for vertical direction, are plotted along with the integrated velocity and displacement time histories that are presented in Chapter 3, Figures 3.7-14, 3.7-15, and 3.7-16, respectively. The comparisons of the time history response spectra with the corresponding HRHF horizontal and vertical target response spectra for each damping value are shown in in Chapter 3, Figures 3.7-17, 3.7-18, and 3.7-19.

3.7B.3 High Frequency Site Profiles

Among the nine generic site-shear-wave-velocity profiles (site profiles S1 through S9) developed for the APR1400 standard plant design, the site profiles that could be classified as hard-rock sites are S8 and S9. For site profile S8, the depth of bedrock where the rock shear-wave velocity (Vs) is equal to 2,804 m/sec (9,200 ft/sec) is 61 m (200 ft). For site profile S9, the depth of bedrock where the Vs is equal to 2,804 m/sec (9,200 ft/sec) is 30.5 m (100 ft).

Site profile S9 was determined to be more critical when subjected to the HRHF horizontal seismic input motion than site profile S8, based on a comparison of the horizontal site response amplification transfer functions from the bedrock where Vs is equal to 2,084 m/sec (9,200 ft/sec) for site profiles S8 and S9. Therefore, the soil-structure interaction (SSI) analysis using the HRHF seismic input motion was performed for site profile S9.

3.7B.4 Soil-Structure Interaction Model

For the evaluation of the impact of HRHF seismic input motion on the APR1400 standard plant design, the nuclear island SSI model described in Subsection 3.7.2 ~~was~~ were analyzed using the ACS SASSI computer program. Acceleration time histories compatible with the HRHF target response spectra are applied at the finished grade.

and emergency diesel generator building

of the nuclear island

The methodology developed by Tseng and Lilhanand, as described in the 1997 EPRI report TR-102631 (Reference 7), was used for the SSI analysis using ACS SASSI to incorporate spatial incoherence in the seismic input motions. The methodology uses the hard-rock coherency functions for horizontal and vertical seismic ground motions developed by Abrahamson (Reference 8). The analysis considering spatial incoherence of the HRHF seismic input motions was performed for a total of 15 principal coherency modes. The analysis results obtained from SRSS of the responses of modes 1 through 7 are compared with the corresponding results obtained from SRSS of the responses of modes 1 through 12 (Reference 3). These comparisons indicate that 7 modes are adequate for capturing the incoherent-motion SSI responses of the APR1400 nuclear island structures because the addition of the responses for modes greater than mode 7 leads to insignificant changes in the generated ISRS. Comparisons of in-structure response spectra (ISRS) generated from coherent and incoherent seismic input motions compatible with the HRHF response spectra based on SRSS of 7-mode responses showed little difference in the response spectra below 4 Hz. In the high frequency range above 30 Hz, the incoherent ISRS were lower than the coherent ISRS.

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The seismic responses ISRS at selected major locations in nuclear island structures resulting from the CSDRS and HRHF seismic inputs were compared to assess the significance of the HRHF response spectra. The comparison showed that most HRHF response spectra exceed the CSDRS response spectra above 10 Hz. The results are typical of the comparative responses found throughout the APR1400 standard plant.

The exceedances of HRHF-based ISRS in the high frequency range were evaluated to confirm that the high frequency response has marginal effect on the equivalent SSCs qualified by analysis for the ISRS developed from the APR1400 CSDRS.

3.7B.5 Evaluation Methodology

An evaluation of the representative APR1400 SSCs was performed to demonstrate that the APR1400 nuclear power plant is qualified for high frequency seismic response. The evaluation was made on the SSCs that are potentially sensitive to high frequency input selected by screening.

The safety functions of the SSCs selected by screening were assessed using high frequency seismic input to verify that their seismic responses are non-damaging.

SSI analysis considering spatial incoherence of HRHF input motions was also performed on a combined finite element model of the emergency diesel generator building and diesel fuel oil tank room of APR1400. Case studies were performed to confirm adequacy of the number of frequencies and modes used for incoherent analyses (Reference 3).

3.7B.6 General Selection Screening Criteria

The following general screening criteria were used to identify representative APR1400 SSCs to be evaluated to demonstrate the acceptability of the APR1400 nuclear power plant for high frequency motion:

a. Importance to safety, including the safety function for the safe shutdown earthquake (SSE) event and the potential failure modes due to an SSE. SSCs whose failure modes do not affect the ability to achieve safe shutdown are excluded.

b. Location in areas of the plant that is susceptible to large, high frequency seismic inputs. The analyst verifies that the equipment or structure in the location has high frequency response to seismic input by evaluating the HRHF seismic response spectra at the equipment/structural attachment points.

c. Significant modal response within the region of high frequency amplification, as defined by items such as modal mass, participation factor, stress, and deflection. The analyst determines that the equipment or structure has dynamic response in the region of the seismic input associated with the high frequency amplified response that would result in significant stress or loads that are included in the load combinations.

d. Significant total stress compared to allowable stress in load combinations that include seismic loads. This criterion complements the criterion in item c where it is determined that the seismic stress due to equipment/structure response in the high frequency region is meaningful compared to the allowables and is therefore included in the load combinations.

The portions of the SSCs that were selected for evaluation of their high frequency seismic response were as follows:

a. Building structures

   1) Reactor containment building internal structure

   2) Reactor containment building containment structure

   3) Auxiliary building

   4) Emergency diesel generator building and diesel fuel oil tank room

b. Reactor coolant system (RCS)

  1) Reactor vessel internals (RVI) and core

  2) Component supports and nozzles of the RCS

c. Piping system

d. Safety-related electrical equipment

3.7B.7 Evaluation

3.7B.7.1 Building Structures

Maintaining the structural integrity of the nuclear island structures is important to the safety of the plant. Representative portions of the building structures that were evaluated for the effect of high frequency input were selected based on the areas with the potential to experience high seismic shear and moment loads in a seismic event.

The evaluation consisted of a comparison of the seismic loads and equivalent acceleration from high frequency input to those obtained from the APR1400 design-basis CSDRS for the representative building structures. The nuclear island structures were considered to be qualified for high frequency input if the seismic loads and equivalent acceleration from the CSDRS enveloped those from the high frequency input.

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3.7B.7.2 Reactor Coolant System

The RVI support the core and are therefore important to safety. RVI consist of complicated components whose natural frequencies are in the relatively high frequency range.

RCS component supports were selected as one of the evaluation items because they help maintain the capability of RCS components to perform their intended safety-related functions.

Nozzles were evaluated because piping failures generally occur at high stress locations, such as at the nozzles of a component, and they represent the sensitivity of the reactor coolant loop piping to high frequency excitation.