UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

GPU NUCLEAR CORPORATION

EVALUATION OF SOIL-STRUCTURE INTERACTION ANALYSIS

AND THE PROPOSED APPROACH FOR GENERATION OF IN-STRUCTURE RESPONSE SPECTRA

OYSTER CREEK NUCLEAR GENERATING STATION

DOCKET NO. 50-219

1.0 INTRODUCTION

In the evaluation (Ref. 1) of GPU Nuclear Corporation's (the licensee's) 120-day response to Supplement No. 1 to Generic Letter 87-02 (Ref. 2), the staff gave two options to the licensee for the development of in-structure response spectra (IRS) for the resolution of Unresolved Safety Issue (USI) A-46: (1) the licensee may use the ground response spectrum developed during the systematic evaluation program applied at the foundation level, or (2) it may use the site specific ground response spectra (SSRS) developed by the licensee and previously approved by the staff (Ref. 3).

In a letter dated December 23, 1993 (Ref. 4), the licensee indicates that it intends to use the SSRS as input for the development of IRS for use in the resolution of USI A-46. Additionally, the licensee states that it intends to use the spectra (IRS) in conjunction with the damping values specified in Regulatory Guide 1.61 (Ref. 5) and ASME Code Case N-411 (Ref. 6) for all future designs, analyses and evaluations to be performed at Oyster Creek Nuclear Generating Station (OCNGS). This evaluation addresses the approach proposed by the licensee to develop IRS for resolution of USI A-46. It also addresses the suitability of using these IRS in conjunction with the proposed damping values to be used for all future designs, analyses and evaluations.

2.0 EVALUATION

2.1 Seismic Input

In Ref. 3, the staff approved the use of the SSRS (horizontal and vertical components) developed by the licensee's consultant, Weston Geophysical Corporation. To perform soil-structure interaction (SSI) analysis, the licensee's consultant, EQE Engineering Consultants (EQE), developed three statistically independent (correlation coefficients < 0.035) artificial time histories (two horizontal components and the vertical component). EQE verified the adequacy of the artificial time histories by comparing the response spectra generated from the time histories against the corresponding SSRS utilizing the criteria described in Section 3.7.1 of the Standard Review Plan (Ref. 7). The total durations of the time histories were 15 seconds with strong-motion durations varying between 10 and 12 seconds.

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EQE also confirmed the adequacy of the energy content of the artificial time histories by ensuring that, as a minimum, the power spectral density functions (PSDFs) generated from the artificial time histories enveloped 80 percent of the PSDFs generated from the corresponding SSRS. Though Appendix A of Standard Review Plan (SRP) 3.7.1 provides guidance and acceptance criteria when the design response spectrum is the one discussed in Regulatory Guide 1.60 (Ref. 8), the staff considers the acceptance criteria established in the Appendix to be applicable to the site specific response spectrum, developed as 84 percentile non-exceedance probability spectrum e.g., the SSRS at OCNGS. The staff finds the procedure and parameters used to define the ground motion for performing SSI analysis to be acceptable.

2.2 Soil Profiles and Properties

Based on the soil borings drilled during the construction stage (1964), and the results of standard penetration tests, the licensee's consultant, Geometrix Consultants, developed the soil profiles and dynamic soil properties to be used for the SSI analysis. A typical subsurface profile at the site consists of (in sequence of increasing depth) upper fine sand, upper clay, medium sand, lower clay, and a deep Kirkwood formation consisting of fine to medium sand. To define variations of shear modulus and material damping ratios with respect to shear strain, the licensee's consultants (Goemetrix and EQE) made use of the published relationships, general characteristics of the soil units and their experience with regards to the use of the strain-dependent properties. Figure 1 shows the relationships established for critical soil layers. The staff recognizes that the degradation curves utilized by EQE for upper 50 ft of sand layers are not as conservative as the recent findings (Refs. 9,10) at specific sites.

In response to the request for information on this issue, the licensee justified (Ref. 11) the use of the proposed degradation curves by pointing out the differences in the characteristics of the sand-soil layers at the OCNGS site with those at the sites investigated in References 9 and 10. The licensee also emphasized that for the deeper sand layers (> 50 ft), to account for the effects of confining pressures, more conservative degradation curves were used. Considering other conservatisms (as per SRP Section 3.7.2) used in the analysis, the staff finds the use of the proposed soil properties acceptable.

Using the soil profiles and strain-dependent soil properties, EQE calculated high-strain soil properties (Shear moduli, damping ratios) corresponding to each layer of the soil profile utilizing the computer program SHAKE. The lower bound low-strain soil properties were considered as one-half the best estimate, and the upper bound low-strain soil properties were considered as two times the best estimate, with two limitations of SRP Section 3.7.2: (1) The upper bound high-strain shear modulus to be greater than the best estimate low-strain shear modulus, and (2) the high-strain material damping not to exceed 15 percent.

The seismic input (time histories) were applied 3 ft below the grade level to neglect the influence of soft (shear wave velocity ≈ 300 ft per sec) upper layer of the soil in the SSI analysis. The water table at OCNGS site varies between 18 ft to 25 ft below the grade level. For SSI analysis, EQE established the water table at 20 ft below the grade and used the properties of saturated soil for soil layers below the established water table.

Based on the seismic input at 3 ft below the grade level, and the three high-strain soil profiles, EQE generated free-field time histories and associated response spectra at 5 percent damping at the foundation level using the computer program SHAKE. The spectra for the three soil profiles were enveloped (in each direction) and compared with the 60 percent of the spectra at the surface. If, in any frequency range, the enveloped spectrum is less than the 60 percent of the corresponding surface spectrum, the surface time history was modified to increase the power in the frequency range of deficiency. The modified time histories are proposed to be used for the SSI analysis and for generating IRS. The staff finds the proposed method consistent with the intent of SRP Section 3.7.2, and is acceptable for generating in-structure response spectra.

2.3 Structural Model

EQE developed a three-dimensional lumped mass dynamic model of the reactor building for use in the SSI analysis. The model included separate sticks for the reactor building, drywell vessel, biological shield wall, and reactor pressure vessel. Massless rigid links were added to the reactor building model connecting the center of mass to the extreme locations of the floors to generate in-structure response spectra including the contribution from rocking and torsion. The intermediate restraints (supports) attached to the drywell vessel, biological shield wall, and to the reactor vessel were modeled as one-dimensional springs where they were judged to contribute to the response of the model.

2.4 SSI Model and Sensitivity Studies

EQE had performed selected sensitivity studies using an equivalent two-dimensional model which adequately characterized all aspects of SSI model. Sensitivity studies were performed to evaluate soil layer discretization, foundation rigidity, bonding/unbonding of structure and foundation, and to evaluate the effects of soil property variations on IRS.

To determine the discretization adequacy for the SSI analysis, EQE performed analyses utilizing five mesh sizes that would transmit seismic waves with frequencies higher than 33, 25, 12.5, 7 and 2 Hertz (Hz). High strain best estimate soil properties and equivalent two-dimensional model were used in the sensitivity analyses. The IRS generated at three nodes of the structural model were compared. The comparison indicated that the IRS calculated for meshes transmitting 33 to 7 Hz were essentially the same. Based on this study, EQE decided to discretize the soil, for the SSI analyses, such that frequencies up to 12 Hz are accurately modeled. The staff considers this criterion reasonable for generating IRS.

Two sensitivity analyses, one considering the foundation slab to be rigid, and the other allowing the foundation slab to have its own flexibility, were performed. The comparison of the IRS at the three nodes indicated essentially the same response pattern throughout the frequency range of interest. EQE decided to use the rigid foundation system assumption for the SSI analyses. The staff agrees with the rigid foundation system assumption.

Similar sensitivity analyses were performed for bonded, partially bonded and unbonded soil-foundation system, and for the effects of variation in soil properties. The comparisons indicated that a reasonable assumption would be to use bonded soil-foundation system, and that the upper bound soil properties gave maximum responses.

2.5 Generation of In-Structure Response Spectra

EQE utilized the seismic input, soil profiles, structural model, and the parameters affecting the SSI analysis, as discussed above, for generation of IRS at various floors and locations in the OCNGS reactor building. The overall methodology used in calculating the structural response was the CLASSI methodology. SASSI computer code was used to calculate the frequency dependent impedance and scattering function of the embedded foundation. Three soil profiles were analyzed: best estimate, lower bound, and upper bound (as discussed above). For design and verification, the individual IRS for each case will be smoothed and broadened. The IRS for the upper and lower bound soil cases will be broadened ± 10%, and those for the best estimate case will be broadened ± 15%. The smoothed and broadened spectra will be enveloped and used as design in-structure spectra. A typical enveloped and broadened spectrum together with the upper bound, best estimate, and lower bound spectra are shown in Figure 2. The IRS will be generated for various damping values, and for Safe Shutdown Earthquake and Operating Basis Earthquake.

Three components of the input motion will be applied simultaneously in the SSI analyses using a three dimensional model. The structural model includes nodes at the extreme locations of the floors. Thus, the design in-structure response spectra will automatically incorporate the three-dimensional effects of the seismic input, and those resulting from torsion and rocking.

2.6 Future Use of IRS

In addition to the use of the IRS, thus generated, in the resolution of USI A-46, the licensee intends to use IRS in conjunction with damping values specified in Regulatory Guide 1.61 and ASME Code Case N-411 for all future designs, analyses and evaluations to be performed at OCNGS. The provisions of the ASME Code Case are related to the damping values of Class 1, 2, and 3 piping and have been endorsed by the staff in Regulatory Guide 1.84 (Ref. 9) provided the specified conditions are satisfied. Condition (2) limits the use of the damping values of the Code Case to the analyses in which current seismic spectra and procedures are employed. For the purpose of the use of the Code Case, the SSRS developed for OCNGS is considered as a spectrum developed using current procedures. Thus, the staff sees no objection to the use of the IRS, thus generated, for any future designs, analyses and evaluations provided the OCNGS Safety Analysis Report is amended to reflect the proposed changes for future work. Also, the IRS may be used in conjunction with damping values specified in Regulatory Guide 1.61 and ASME Code Case N-411 subject to the conditions specified in Regulatory Guide 1.84.

3.0 CONCLUSION

Based on the review of licensee's submittals, the staff considers the approach proposed for generation of IRS to be consistent with the provisions of SRP sections 3.7.1, 3.7.2 and 3.7.3, and finds it acceptable for use in the resolution of USI A-46. However, when available, the licensee should provide the IRS generated for El 95 ft (±) in the Reactor Building, 50 ft (±) in the drywell, and for the control room elevation in the control building for confirmatory review by the staff.

Moreover, the staff accepts the use of the IRS, thus generated, for any future designs, analyses and evaluations provided the OCNGS Safety Analysis Report is amended to reflect the proposed changes for future work. Also, the IRS may be used in conjunction with damping values specified in Regulatory Guide 1.61 and ASME Code Case N-411 subject to the conditions specified in Regulatory Guide 1.84.

4.0 REFERENCES

1. Letter from A. Dromerick (NRC) to J. Barton (GPUN), "Evaluation of OCNGS 120-day response to Supplement 1 to GL 87-02," November 1992.

2. Supplement 1 to Generic Letter (GL) 87-02, "Verification of Seismic Adequacy of Mechanical and Electrical Equipment in Operating Reactors, Unresolved Safety Issue (USI) A-46," May 1992.

3. Letter from A. Dromerick (NRC) to J. Barton (GPUN), "Review and Evaluation of Site Specific Response Spectra" - OCNGS, March 1992.

4. Letter from R. Keaton (GPUN) to NRC, "In-structure Response Spectra," December 1993.

5. Regulatory Guide 1.61, "Damping Values for Seismic Design of Nuclear Power Plants," October 1973.

6. Code Case N-411, ASME III, Division 1, "Damping Values for Response Spectra Analysis of Class 1, 2, and 3 piping," Reaffirmed 1992.

7. Standard Review Plan (SRP) for the Review of Safety Analysis Reports for Nuclear Power Plants, August 1989.

8. Regulatory Guide 1.60, Revision 1, "Design Response Spectra for Seismic Design of Nuclear Power Plants," December 1973.

9. Idriss, I. M., "Response of Soft Soil Sites During Earthquakes," Proceedings of the H. B. Seed Memorial Symposium, Berkeley, California, May 1990.

10. GEI Consultants, "Dynamic Soil Properties for the K-Reactor Area," Technical Memorandum Prepared for Westinghouse Savannah River Company, August 1991.

11. Docketed fax from Y. Nagai (GPUN) to A. Dromerick (NRC), "Response to Request for Additional Information on Shear Modulus Reduction and Damping Curves," Dated January 11, 1995.

12. Regulatory Guide 1.84, Revision 28, "Design and Fabrication Code Case Acceptability, Section III, Division 1," April 1992.

Attachments: Figures 1 and 2

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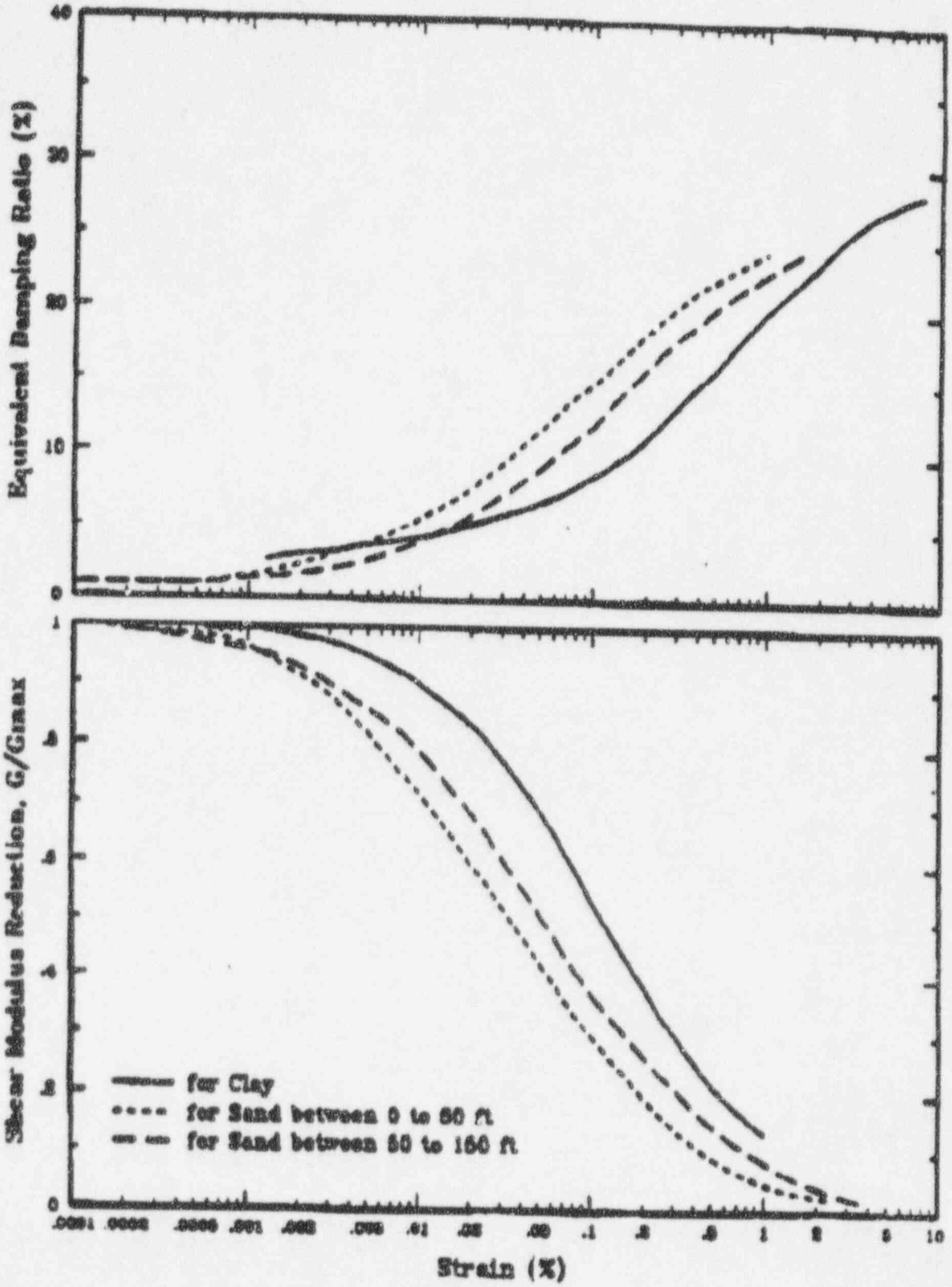

Figure 1. Recommended Shear Modulus Reduction and Damping Curves

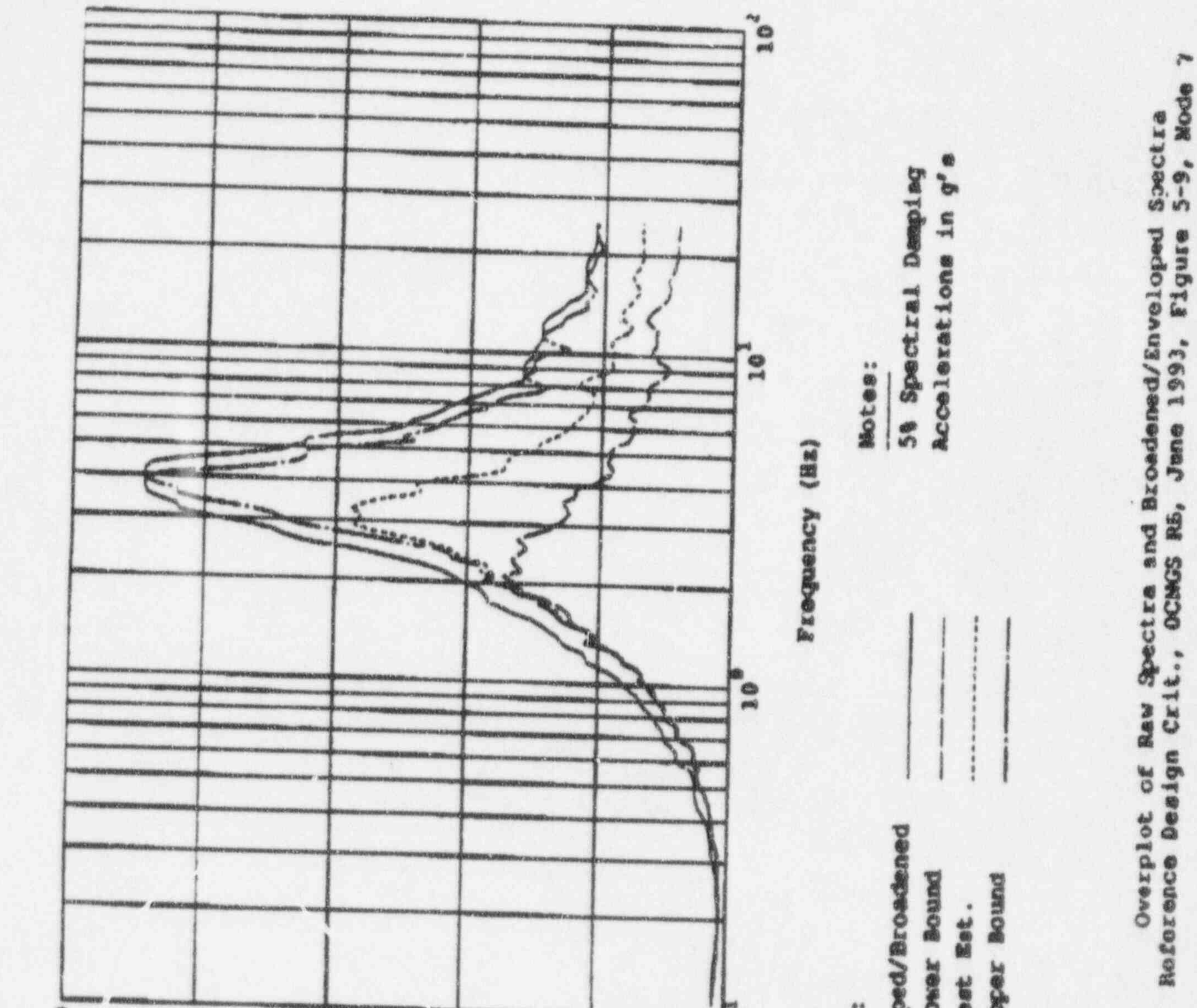

Figure 2. Typical Enveloping Broadened Spectrum