DEVELOPMENT OF GENERIC SOIL PROFILES AND SOIL DATA DEVELOPMENT FOR SSI ANALYSES

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ABSTRACT

This paper presents the approach to developing generic soil profiles for the design of reactor building for small modular reactor (SMR) nuclear power plant developed by NuScale Power. The reactor building is a deeply embedded structure. In order to perform soil structure interaction (SSI) analyses, generic soil profiles are required to be defined for the standardized Nuclear Power Plant (NPP) designs for the United States Nuclear Regulatory Commission (NRC) in a design control document (DCD). The development of generic soil profiles is based on utilization of information on generic soil profiles from the new standardized nuclear power plant designs already submitted to the NRC for license certification. Eleven generic soil profiles have been recommended, and those profiles cover a wide range of parameters such as soil depth, shear wave velocity, unit weight, Poisson's ratio, water table, and depth to rock strata. The soil profiles are developed for a range of shear wave velocities between bounds of 1000 fps to 8000 fps as inferred from NRC Standard Review Plan (NUREG 0800) Section 3.7.1 and 3.7.2. To account for the soil degradation due to seismic events, the strain compatible soil properties are based on the EPRI generic soil degradation curves. In addition, one dimensional soil dynamic response analyses were performed to study the soil layer input motions for performing the SSI analyses.

INTRODUCTION

In order to design the NuScale Power Plant for design certification, there is a need to establish the soil profiles that are to be for the reactor building design. The information from several standard designs such as ABWR, AP1000, ESBWR, US-APWR and US-EPR submitted to NRC for certification were used towards this need. After the soil data from the existing license submissions was collected a total of 11 soil profiles were grouped into four sets to represent a wide range of site parameters in terms of soil depth, soil profiles and properties (shear wave velocity, unit weight, Poisson's ratio), water table depth, and depth to base rock location. For identification purposes, soil types are designated as Types 1 through 11 based on the shear wave velocity. The data was divided as follows:

- A set of three soil profiles for soils having low shear wave velocity (Types 1, 2, and 3)
- A set of three soil profiles for soils having medium shear wave velocity (Types 4, 5, and 6)
- A set of three soil profiles for soils having high shear wave velocity (Types 7, 8, and 9)
- A set of two soil profiles for special soil cases (Types 10 and 11)

Once the soil profiles had been established, the soil response analysis was performed using the SHAKE2000 computer program [12] to study the soil layer input motions for performing the SSI analysis. All 11 soil profiles were analyzed. The soil response analysis was performed based on generic EPRI strain-compatible soil properties [11] and in-layer acceleration response time histories [10] at the bottom of the foundation of the NuScale reactor building.

DEVELOPMENT OF SOIL PROFILES

Collection of Soil Profile Data

So that we could adequately envelope a variety of sites we collected information on soil profiles used for various standardized reactors that have been submitted to NRC for design certification. The soil profile information includes types of soils defined in terms of depth of soil layers, shear wave velocity, unit weight, ground water elevation, depth of base rock, Poisson's ratio and damping values. The soil data encompasses information from five standardized designs; namely, ABWR, AP1000, ESBWR, USAPWR, and US-EPR from the NRC website. Table 1 provides a brief summary of the information of all the soil profiles collected from the five standardized designs.

Table 1-Soil Profile Information Summary from Various Standard Designs.

No.	Identification	Applicant	Summary of Soil Profiles	DCD/Reference
1	ABWR	General Electric (GE) Nuclear Energy	Six soil profiles, UB, VP3, VP4, VP5, VP7 and R. Strain compatible properties based on papers by Seed & Idriss 1970 [8] and Idriss 1990 [9].	ABWR DCD [1]
2	AP1000	Westinghouse Electric Co., LLC	Seven soil profiles, Soft soil, soft-to-medium soil, Upper bound soft-to-medium soil, Soft rock, Firm rock, Hard rock and Deep soil. Strain-compatible properties based on papers by Seed & Idriss 1970 [8] and EPRI 1993 [10].	AP1000 DCD [2]
3	ESBWR	GE – Hitachi Nuclear Energy (GEH)	Three uniform sites, soft, medium and hard. Four layered sites, soft, medium, and hard layers of varying depth North Anna ESP site. Uniform values are considered to be compatible with SSE strain level.	ESBWR DCD [3]
4	US-APWR	Mitsubishi Heavy Industries, Ltd.	Four uniform elastic halfspace cases for soft soil site, Rock site (Medium 1), Rock site (Medium 2) and Hard rock site.	APWR DCD [4]
5	U.S. EPR	AREVA Nuclear Power	Ten generic soil profiles 1u to 5u, 5a, 1n2u, 2sn4u, 2n3u, and 3r3u. Generic soil properties are taken to be strain-compatible values during seismic events	EPR FSAR [5]

Soil Profiles for NuScale Design

The NuScale Reactor Building is a deeply embedded structure, with an embedment depth of 80 feet and as such the foundation on any specific site is expected to be on a competent material. NRC Standard Review Plan (SRP) Section 3.7.1 [6] defines competent material as in-situ material having a minimum shear wave velocity of 1000 fps. In addition, the NRC SRP Section 3.7.2 [7] indicates that for structures founded on materials having a shear wave velocity of 8000 fps or higher, under the entire surface of the foundation, a fixed base assumption is acceptable. Hence, it is reasonable for the NuScale standard design to consider soil profiles in the range of shear wave velocities between 1000 fps to 8000 fps. From the review of the soil profiles information of other standard plant designs described above, it was determined that the following ranges of soil profile are appropriate for the NuScale standard design:

- **Lower Shear Wave Velocity Profiles:** Similar to ABWR VP3, AP1000 soft soil, and AP1000 soft-to-medium soil.
- **Medium Shear Wave Velocity Profiles:** Similar to ABWR VP4, AP1000 upper bound soft-to-medium soil, and AP1000 soft rock.
- **Higher Shear Wave Velocity Profiles:** Similar to ABWR VP7, AP1000 firm rock, and AP1000 hard rock.

In addition to the above, the following special cases of soil profile should also be considered:

- **Special Soil Profiles:** Similar to ABWR UB profile and AP1000 deep soil profile.

Based on the above criteria, a total of eleven soil profiles were selected for the standard design of the NuScale reactor building. Figure 1 shows a graphical view of all 11 profiles.

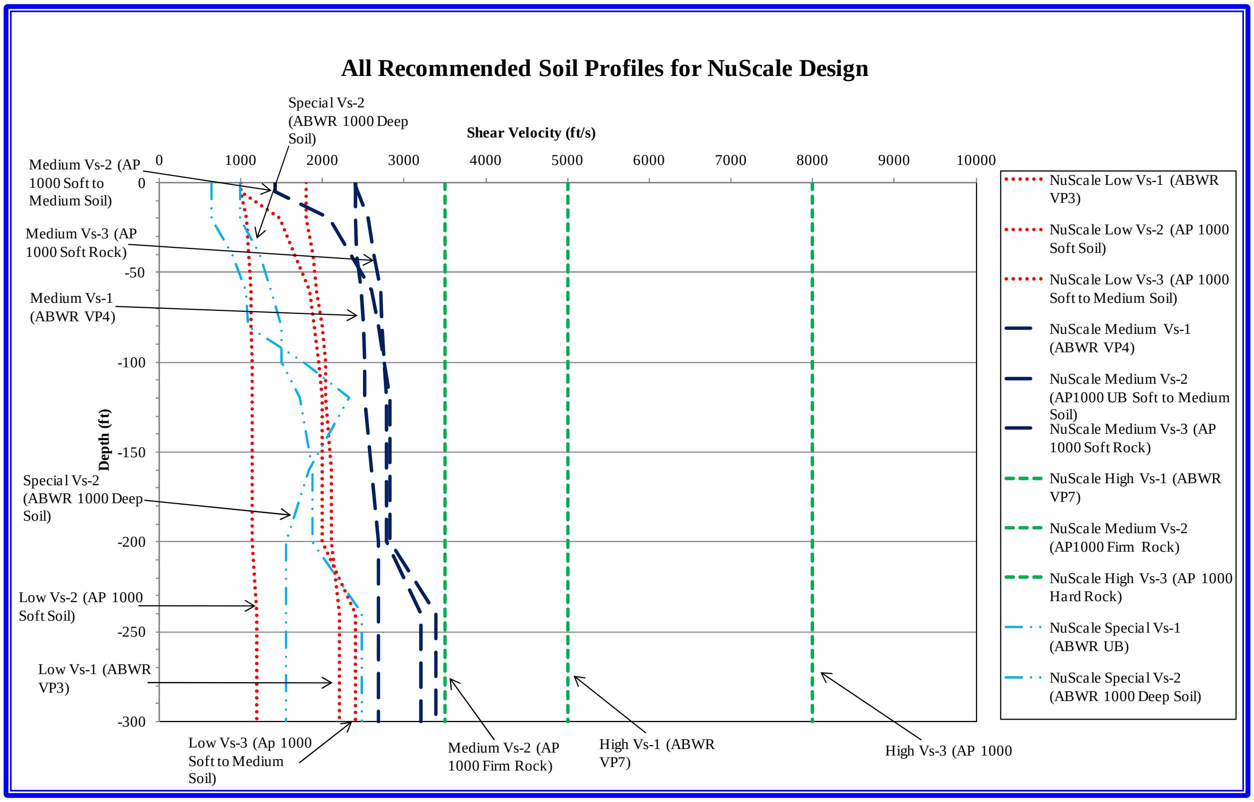

Figure 1. NuScale Standard Design – All Recommended Soil Profiles.

For performing SSI analysis, in addition to the establishment of representative soil profiles, definition of strain compatible soil properties was required. For the NuScale design, the strain compatible soil profiles were based on generic EPRI [11] soil degradation curves which define the variance of parameters such as shear modulus and damping values with respect to shear strain. Figures 2 and 3 show the EPRI generic strain compatible soil properties.

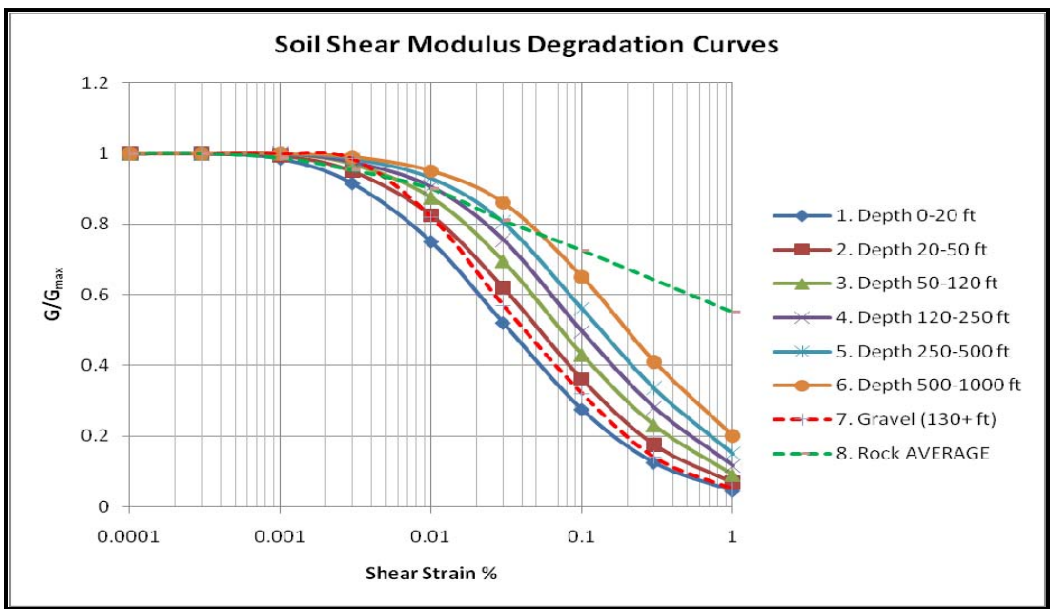

Figure 2. Soil Shear Modulus Degradation Curves (EPRI Generic ENA Site).

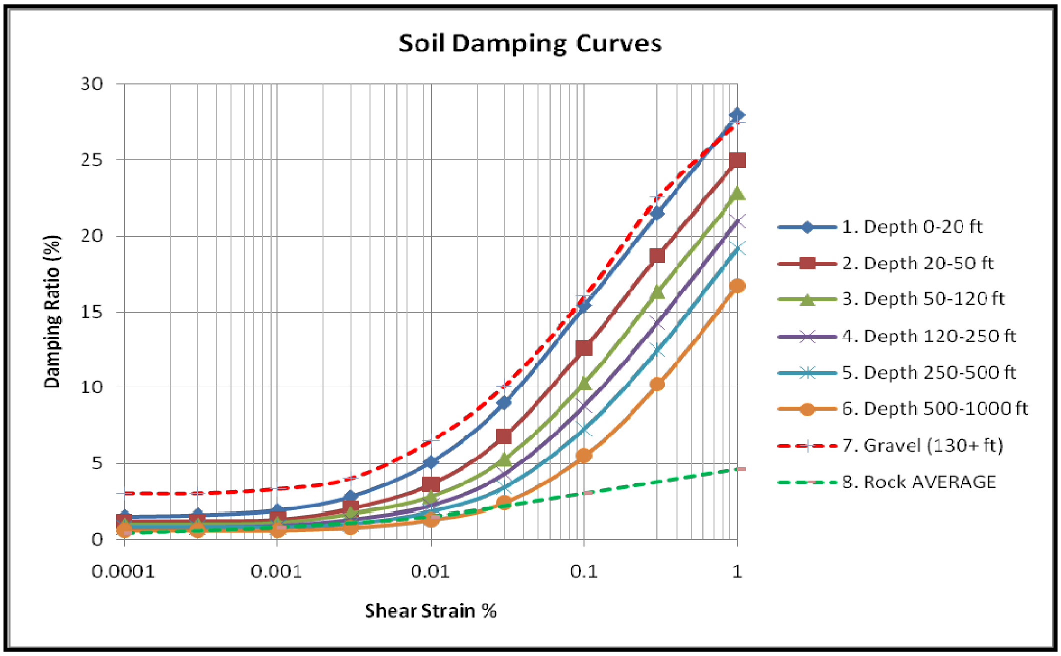

Figure 3. Soil Damping Curves (EPRI Generic ENA Site).

SOIL RESPONSE ANALYSIS

For the determination of input ground motions to be used for the SSI analysis a soil response analysis was performed using the SHAKE2000 program [12]. SHAKE2000 approximates a non-linear hysteresis soil behavior using an equivalent linear stiffness and replacing hysteretic energy dissipation mechanism by an equivalent damping.

Methodology: SHAKE2000 Analysis Procedure

The SHAKE2000 investigation is a one dimensional (1D) analysis of a layered soil column subjected to a seismic wave propagating in the vertical direction and only one acceleration time history component can be applied as the excitation input. The objective was to calculate final strain-compatible soil properties applicable to all components of excitation. To obtain the strain-compatible soil properties in terms of shear modulus and damping applicable to all excitation components, two SHAKE2000 analyses were performed for the S-wave excitations using the North-South and East-West acceleration time histories. An average of the two strain-compatible shear moduli and damping ratios were obtained for all layers and will be used in performing the SSI analyses. A P-wave excitation was performed to obtain the in-layer vertical excitation component to be used in SSI analysis.

Soil Profile

The typical soil profile is shown in Figure 4, where the location of a NuScale Reactor Building is indicated by the dashed lines. As shown, the embedment depth of the structure is approximately 80 feet.

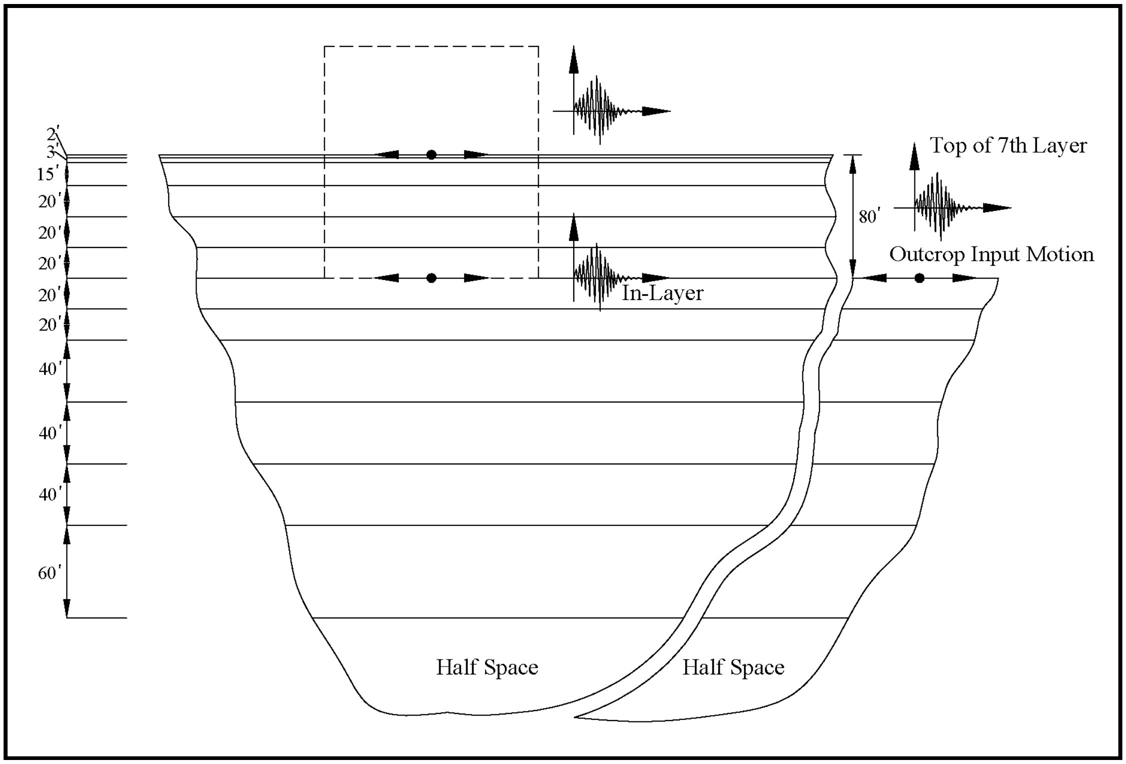

Figure 4. NuScale Soil Layer Profile.

Seismic Input Excitation

The response spectrum compatible synthetic acceleration time histories generated for the NuScale project were used as the seismic input in the SHAKE2000 soil response analysis. Two sets of synthetic spectrum compatible time history motions were developed for the NuScale design as described in Reference 10. The first set of synthetic time histories was generated to be compatible with the Certified Seismic Design Response Spectra (CSDRS) and the second set of synthetic time histories was generated to be compatible with the Generic High Frequency Hard Rock Response Spectra (GHFHRRS). For each time history set, there were two horizontal (SV and SH) and one vertical (PV) components. SV designates the first horizontal shear-wave (S-Wave) excitation component; SH designates the other horizontal S-Wave component; and PV designates the vertical pressure-wave (P-Wave) excitation component. Figures 5 and 6 excerpted from Reference 10 show horizontal acceleration response spectra for 5% damping for CSDRD and GHFHRRS respectively.

The synthetic time histories compatible with CSDRS and GHFHRRS, eleven generic soil profiles, and EPRI generic soil degradation curves have been used for the SHAKE2000 soil response analysis. The damping value was limited to no more than 15%. The CSDRS are considered for all eleven soil profiles, and GHFHRRS is considered for only rock Soil Profile Types 7, 8 and 9.

Discussions on SHAKE 2000 Analysis Results

Figure 7 shows horizontal (N-S) response spectrum accelerations for eleven soil profiles in terms of acceleration response spectra for CSDRS for 5% damping. Figure 8 shows the corresponding response spectra for GHFHRRS. These were compared with respect to the input acceleration response spectra at the bottom of the foundation shown in Figures 5 and 6. Based on the reviews of Figures 7 and 8 and the review of transfer functions (not reported in this paper), harder soil and rock profiles do not show much amplification, but the soft Soil Profile Type 11 shows significantly high amplification around 2 Hz. Soil Profile Type 2 shows a reduction in the ground surface response. Because of unrealistic damping considerations, Type 2 profile can provide unrealistic benefits in the responses whereas Type 11 soil profile can cause unrealistic penalties. Further reviews will be performed for Soil Type 2 and 11 SHAKE2000 results. However, the SHAKE2000 analysis results from other profiles indicate, in general, that the selected soil profiles are reasonable for the NuScale design.

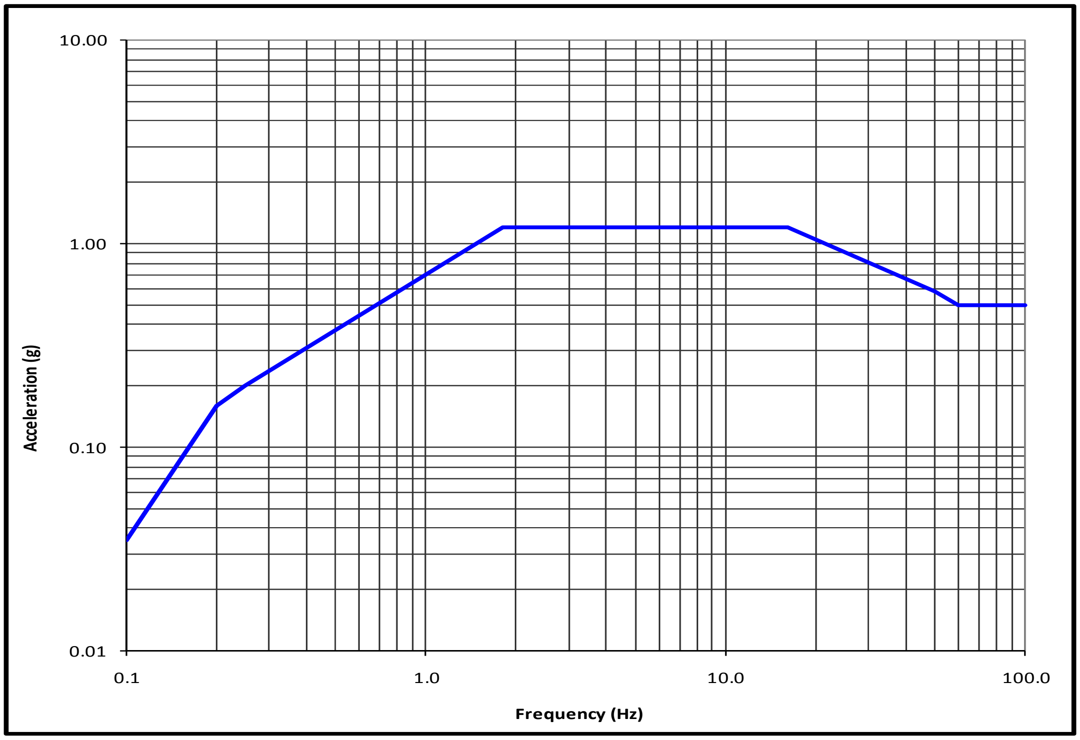

Figure 5. Horizontal CSDRS (5% Damping).

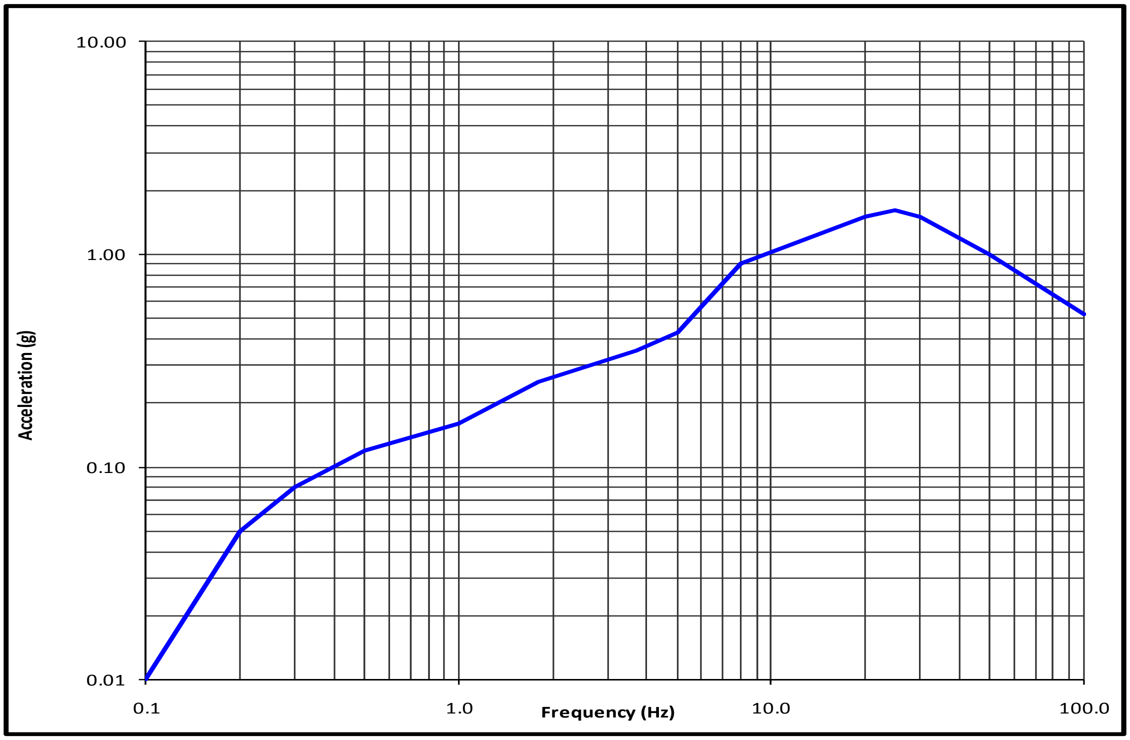

Figure 6. Horizontal GHFHRRS (5% Damping).

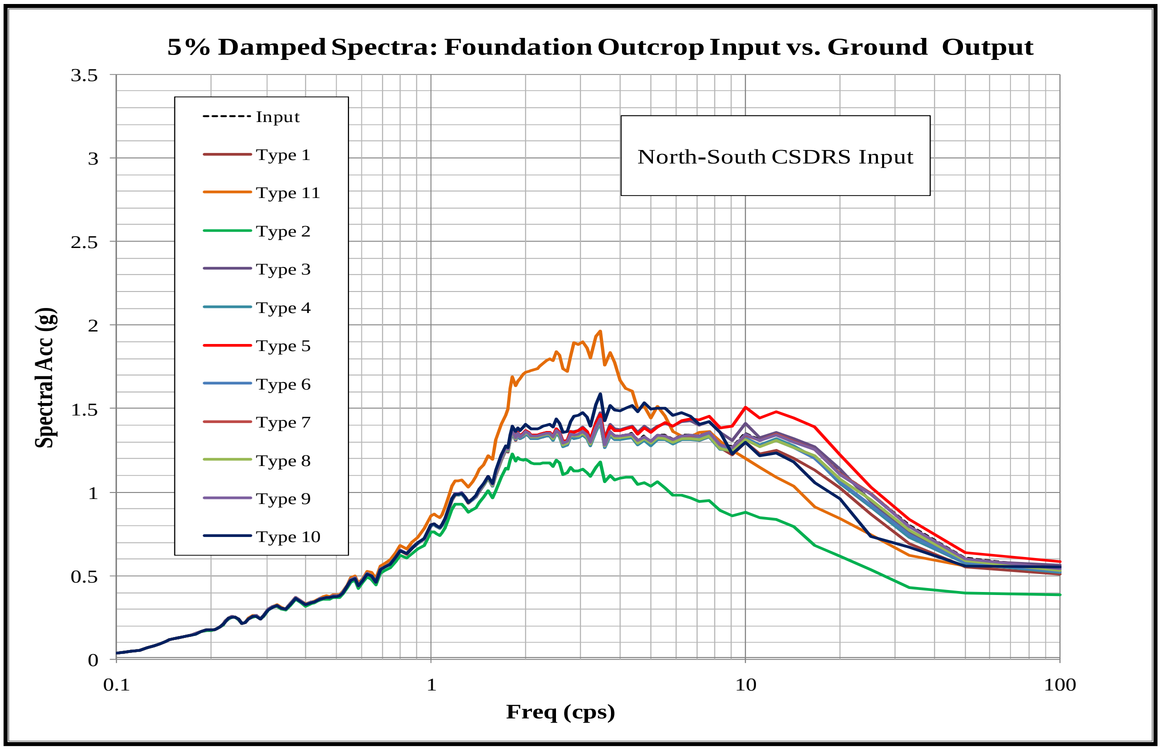

Figure 7. Responses Due to CSDRS Horizontal (N-S) Input.

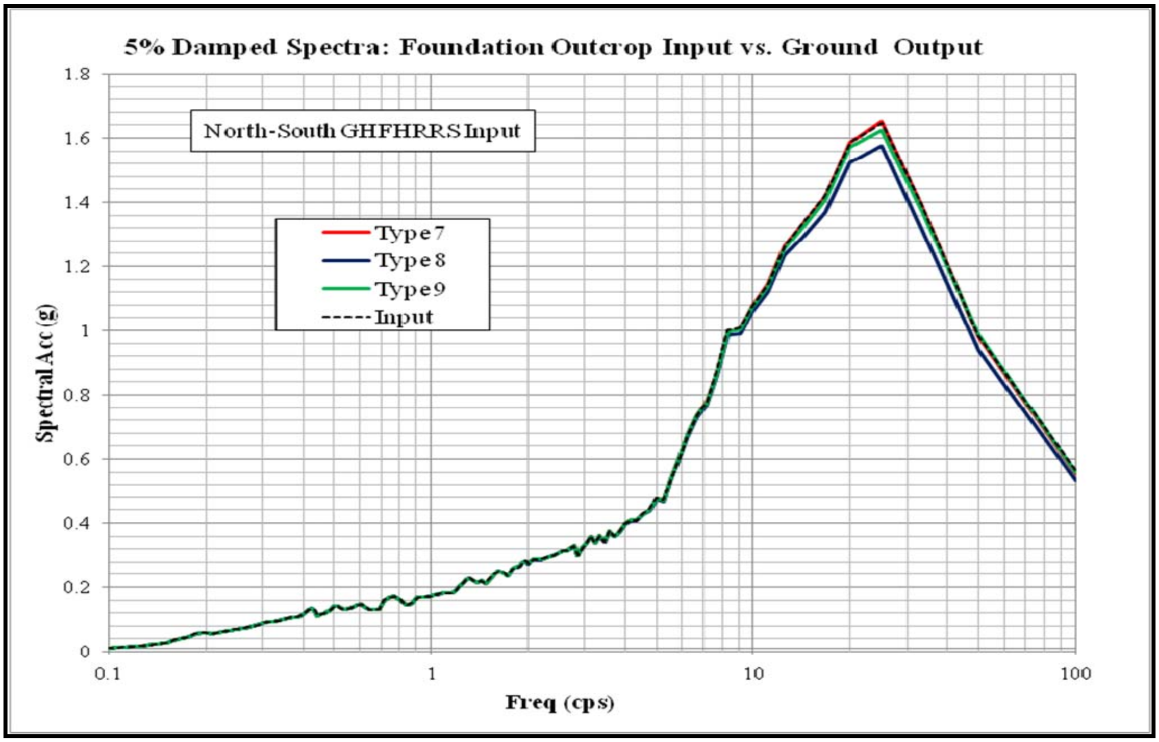

Figure 8. Responses Due to CSDRS Horizontal (N-S) Input

CONCLUSION

The flexibility to be able to site a NuScale Plant in a variety of locations has been a longstanding objective. To that end four sets of eleven generic representative soil profiles have been defined for the NuScale reactor design. These soil profiles have been arrived at based on the reviews of soil profiles used in the standardized design of various reactors (ABWR, AP 1000, ESBWR, US-APWR and U.S.EPR) that have been submitted to the NRC for certification. These soil profiles represent a range of shear wave velocities between the bounds of 1000 fps and 8000 fps. These soil profiles together with the strain compatible soil properties based on generic EPRI soil degradation curves will form the basis for performing SSI analysis for the NuScale reactor design.

Additionally one dimensional soil dynamic response analysis have been performed using SHAKE2000 computer program to study the soil layer input motion for performing the SSI analysis. The preliminary analysis results from SHAKE2000 analysis study indicate that the selected eleven soil profiles are reasonable for the NuScale reactor design.

ACKNOWLEDGEMENT

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