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Division V

ASSESSMENT OF THE LOCAL DISTRIBUTION OF SOIL SPRING STIFFNESS CONSIDERING FREQUENCY DEPENDENCE OF THE FOUNDATION, SITE, AND GROUND MOTION

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ABSTRACT

In this paper, the local distribution of soil spring stiffness considering the frequency dependence of the foundation, site, and ground motion is assessed. Soil springs are used as simplified method to account for the Soil-Structure Interaction (SSI) response of a soil media on a structure. Typically, this method is used for preliminary analysis or approximate structural member sizing, as it is not as rigorous as conducting an SSI analysis considering explicitly the combined response of the structure and the site.

There is a wealth of information available on the global stiffness for static and dynamic soil springs assuming a rigid foundation and uniform soil. However, industry standard publications, such as ASCE/SEI 4, "Seismic Analysis of Safety-Related Nuclear Structures and Commentary" and the US Nuclear Regulatory Commission Standard Review Plans do not provide firm provisions with regard to local variations in soil spring stiffness.

Using SASSI2010, a simple representation of a rectangular structure in analyzed. Soil-Structure Interaction analysis is conducted with a variety of soil properties and ground motions. The structure mass and stiffness is representative of a typical nuclear safety-related structure.

Springs are added to every perimeter node on the structure with interacts with the soil. Rigid properties are assigned to these springs so that the resultant spring force is representative of the actual soil pressure imparted on the structure during the seismic event. The rigid spring resultant force is considered the base case in the study. Local distribution of soil spring stiffness is related to the "rigid spring" resultant forces.

STRUCTURAL MODEL

A three-dimensional SASSI2010 model is created for a structure with a footprint of 100' by 100'. The model consists of grade slab elements with a 5' uniform mesh. Integral with the slab elements are beam members at locations where a shear wall would be present. This includes all the perimeter of the slab, two internal y-direction running shear walls at quarter points, and one internal x-direction running shear wall at the center of the slab. The thickness and density of the slab are adjusted to vary the foundation stiffness. The elastic modulus and density of the frame elements are adjusted to simulate different shear walls rigidity and load transfer. A damping ratio of 4% is implemented.

The three-dimensional model includes springs connecting the grade slab and soil at the base of the structure. The spring connectivity is shown in Figure 1.

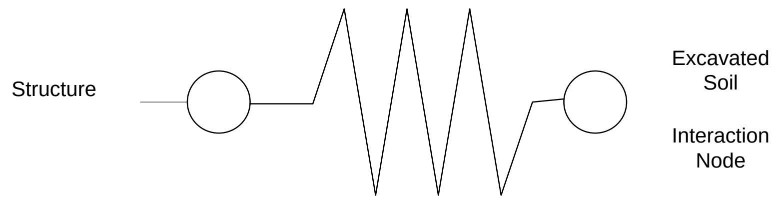

Figure 1. Spring Connectivity.

The springs are assigned a stiffness of 100 times the modulus of elasticity of concrete and a damping value consistent with the structure.

Soil Cases

In order to capture a range of soil frequency content, three soil cases are considered. The shear wave velocity profiles for the three cases are shown in Figure 2.

Case 1 (C1) represents a soft soil with a depth to hard rock of about 1000'. The average over the column of unit weight is 0.130 kcf, shear wave velocity is 1435 fps, compression wave velocity is 5042, and damping is 4%. Case 5 (C5) represents a medium rock site with a depth to hard rock of 1000'. The average over the column of unit weight is 0.158 kcf, shear wave velocity is 5379 fps, compression wave velocity is 11086, and damping is 1%. Case 7 (C7) represents a "hard" rock site with a depth to 9200 fps hard rock of 300'. The average over the column of unit weight is 0.167 kcf, shear wave velocity is 7676 fps, compression wave velocity is 13900, and damping is 1%.

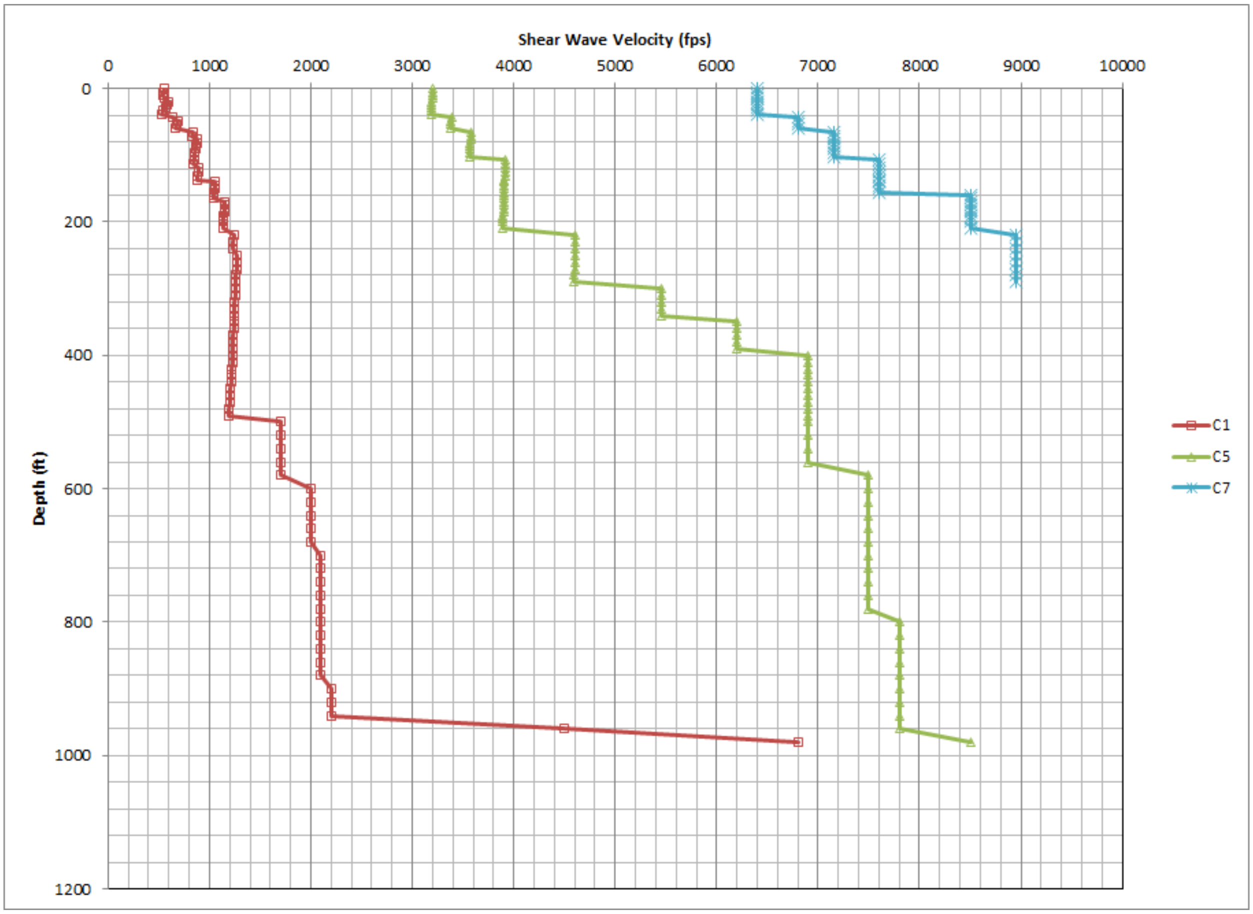

Figure 2. Soil Profile Summary.

Input Motions

Two different 5% damped input motion acceleration response spectrum are used in the study as shown in Figure 3.

The Central and Eastern United States (CEUS) motion has a peak response in a high frequency range as is characteristic of earthquake response in that region of the United States. This motion is paired with the medium rock (C5) and "hard rock" (C7) site cases due to the compatibility with the rich high frequency content of these site cases.

The Western United States (WUS) motion has a peak response in a low frequency range as is characteristic of earthquake response in that region of the United States. This motion is paired with the medium rock (C5) and soft soil (C1) site cases due to the compatibility with the rich low frequency content of these site cases.

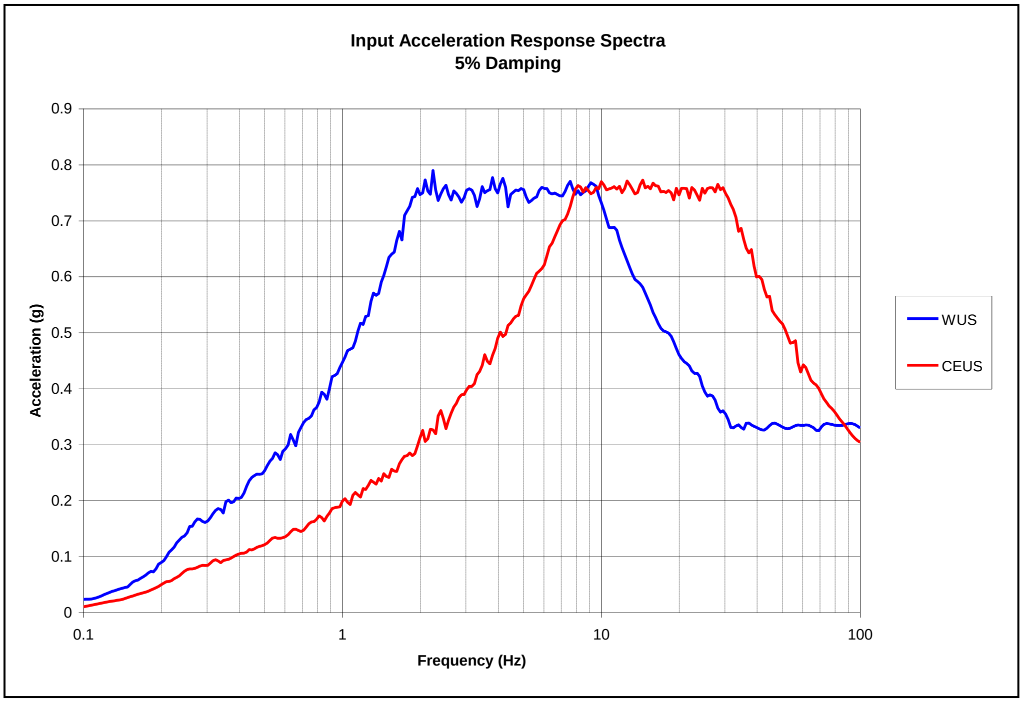

Figure 3. Input Motions.

ANALYSIS

Soil-Structure Interaction (SSI) analysis is completed using SASSI2010 (Ostadan and Deng, 2011). Random Vibration Theory (RVT) is employed; hence, reported spring values represent maximum values. The effects of soil pressure timing in analysed for a case study using the same site and motion charactersitics, comparing RVT and time history methods in a prior SMiRT 22 paper. For the case considered, the maximum soil pressure values occurred overwhelmingly at one time step, suggesting the sensitivity of timing on bearing pressure was inconsequential for the structure considered (Anderson et al., 2013).

For the four analysis cases considered in this paper, the spring force values are printed at each foundation node and depicted in a bubble plot. The size of the bubble is proportional to the magnitude of the spring force. Several iterations of model properties are analysed to assess the distribution of spring values.

The first iteration included a basemat with the elastic modulus and density of concrete and 4% damping. The frame elements are initially assigned typical concrete properties similar to the basemat. For this iteration there is no distinguishable variation to the spring responses.

The next iteration of the model included a 250 pcf density for the basemat and a 1’ thickness to incite more flexible behaviour. For this iteration, again there is no distinguishable variation to the spring responses.

The next iteration examined in this paper includes stiffer frame elements. The frame elements representing the shear wall behaviour are assigned an elastic modulus approximately 2 magnitudes larger than reinforced concrete. For this iteration, a force pattern becomes apparent in the spring resultants.

Changes to the model after this iteration produce the same pattern in different magnitudes. For simplicity only this iteration of the model is presented in the next section.

RESULTS

Bubble plots are shown for the C1_WUS, C5_WUS, C5_CEUS, and C7_CEUS cases in Figure 4, 5, 6, and 7, respectively.

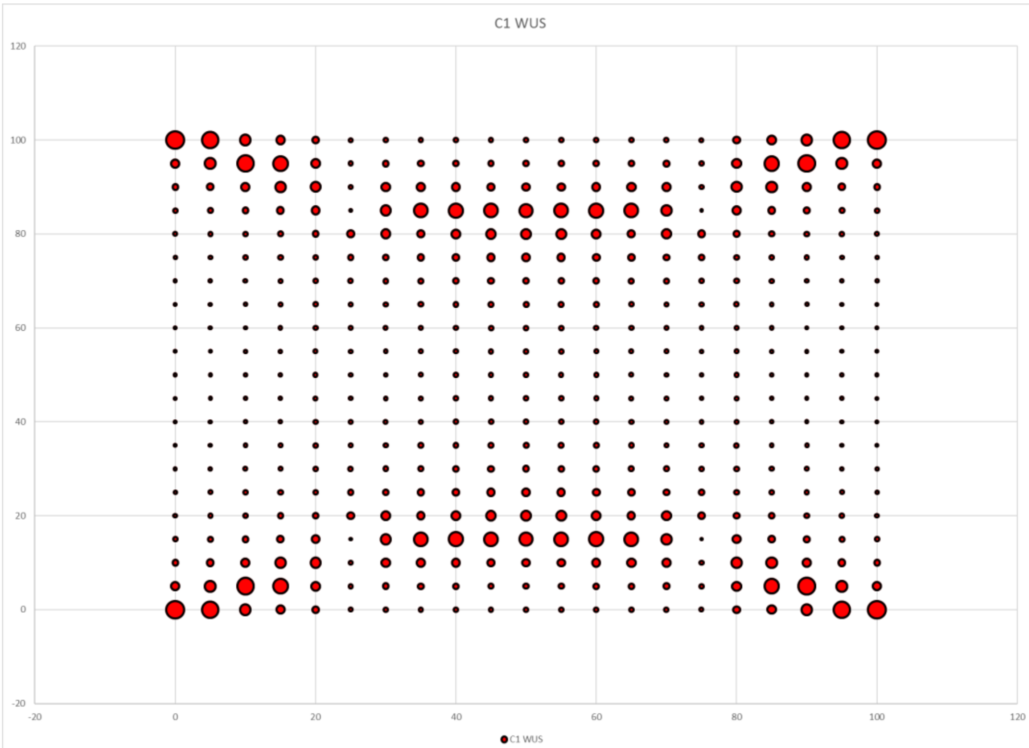

Figure 4. Case 1 Soft Soil Western United States Motion Foundation Spring Response.

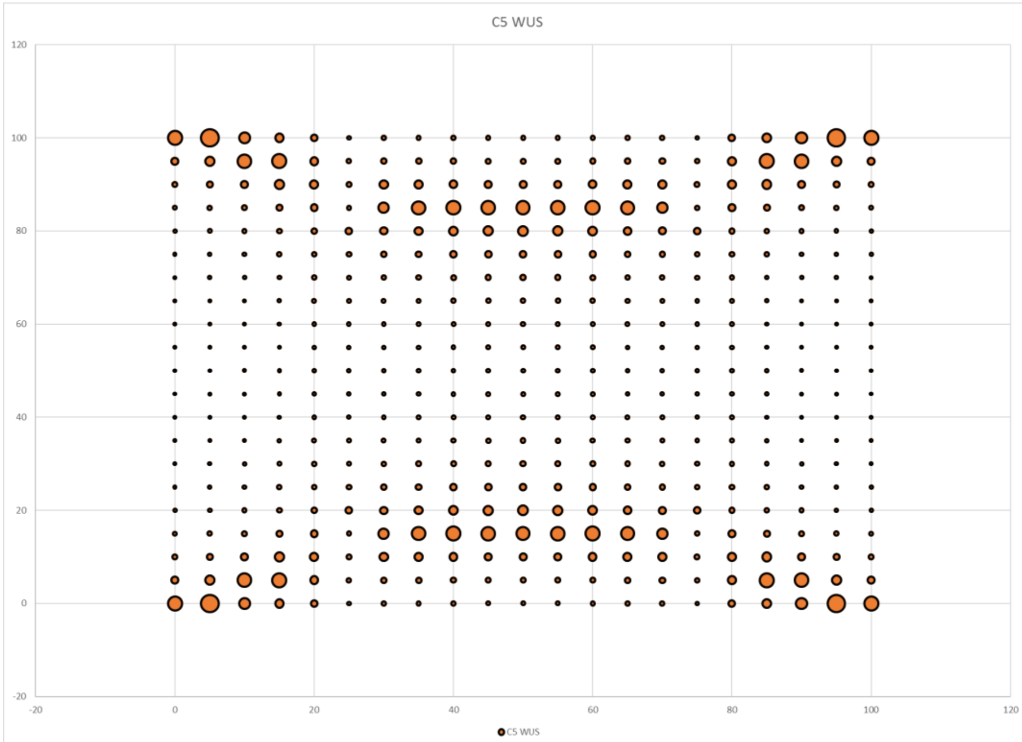

Figure 5. Case 5 Medium Rock Western United States Motion Foundation Spring Response.

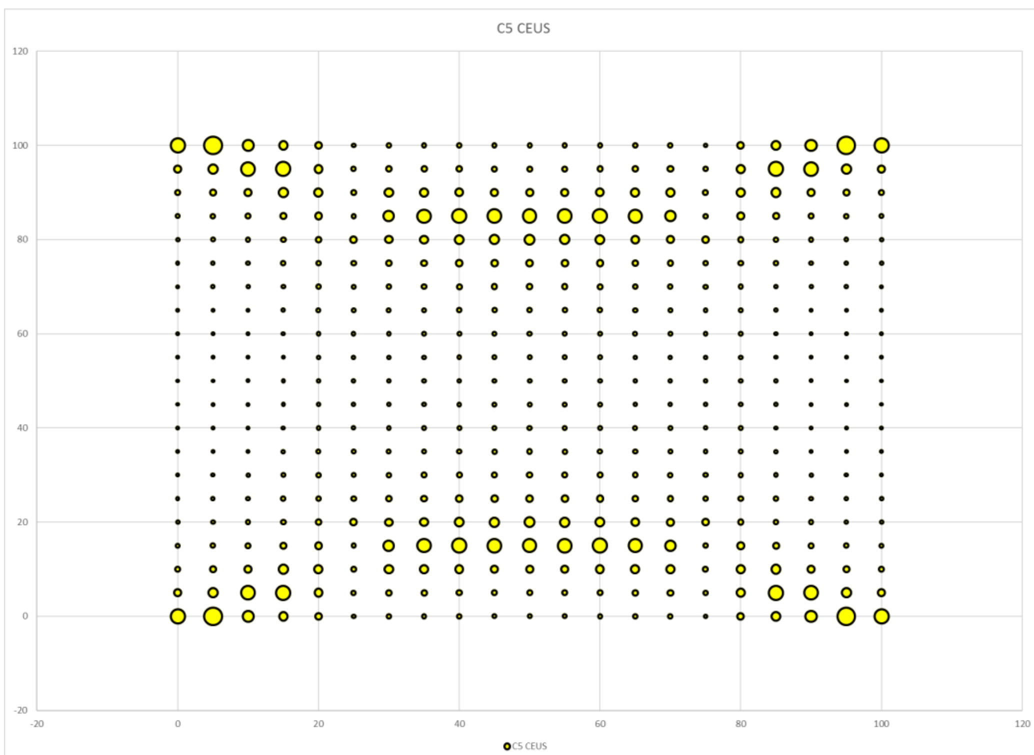

Figure 6. Case 5 Medium Rock Central and Eastern United States Motion Foundation Spring Response.

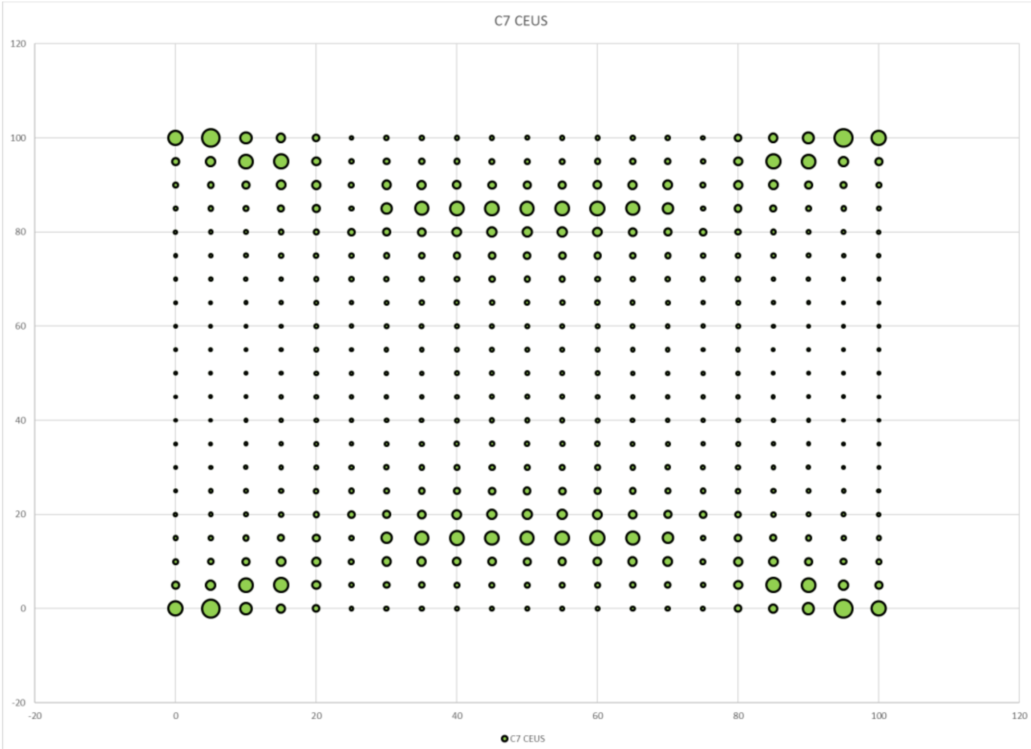

Figure 7. Case 7 "Hard Rock" Central and Eastern United States Motion Foundation Spring Response.

CONCLUSIONS

As can be seen from the figures, the distribution for the foundation spring response is similar for each soil and motion combinations. The magnitudes of spring values are different for each case and mostly dependent on the input motion, despite the similar distribution.

Further iterations of the structural properties are needed to reach the point at which the spring value distribution changes with soil and motion characteristics.

REFERENCES

Anderson, L.M., McHood, M., Deng, N., and Ostadan, F. (2013). "Sensitivity of Seismic Foundation Bearing Demand Using Random Vibration Theory and Time History Methods", 22nd International Conference on Structural Mechanics in Reactor Technology, San Francisco, CA.

Ostadan, F. and Deng, N. [2011], "Bechtel Version of SASSI2010 – A System for Analysis of Soil-Structure Interaction", Version 1.1. Geotechnical and Hydraulic Engineering Services, Bechtel National Inc., San Francisco, CA.