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SENSITIVITY OF SEISMIC FOUNDATION BEARING DEMAND USING RANDOM VIBRATION THEORY AND TIME HISTORY METHODS

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ABSTRACT

SASSI2010 solves the Soil-Structure Interaction (SSI) problem in the frequency domain. The user may enter either an Input Response Spectra (IRS) for a solution using the method of Random Vibration Theory (RVT) or a time history that is compatible to the IRS. When using RVT, the user may request maximum forces; whereas, with the time history method, time histories of forces may be requested.

The purpose of this paper is to assess the differences in foundation bearing pressure demand obtained using the Random Vibration Theory (RVT) method and the time history method.

An SSI model representative of a deeply embedded nuclear structure is generated for the studies. A soft soil profile is considered in conjunction with a motion typical of the Western United States (WUS). The total seismic bearing demand is computed using two methods. The first method is by direct output from SASSI2010. In the second method, the total force is computed by summing the reaction forces for every time step.

BACKGROUND

Recent reviews of Nuclear Safety-Related Structures indicate some reviewers prefer the use of multiple time histories as opposed to a single time history to ensure that input load is not underestimated. The compatibility of response resulting from the RVT method in SASSI2010 and the response resulting from the use of a single time histories matched to the same IRS is demonstrated in this study.

STRUCTURAL MODEL

A 3-D SASSI2010 model, with two lines of symmetry, is created based on a structure configured with a footprint of 200’ by 300’ and an embedment of 140’. Views of the 3-D model are shown in Figures 1 and 2.

The 3-D model generated is intended to represent the maximum footprint and embedment of the structure and the approximate global SSI response, with only major shear walls included. This decreases the computational effort as well the complexity of the structural responses, so that the global SSI effect can be easily determined.

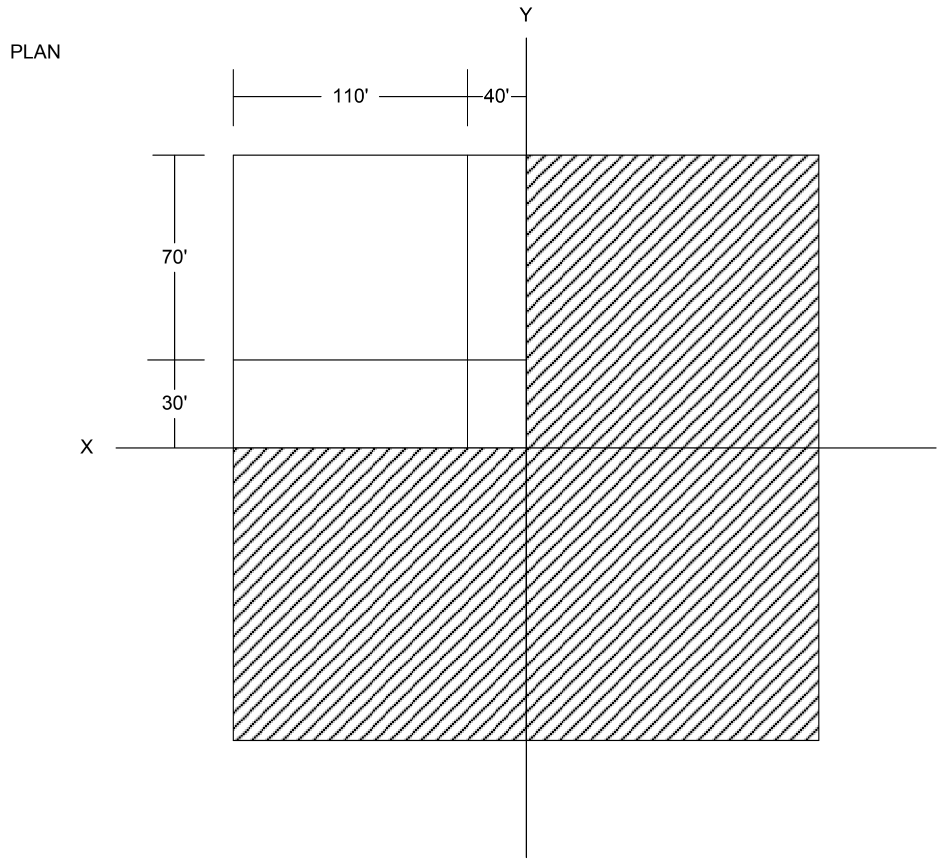


Figure 1. Plan View of the 3-D Structural Model.

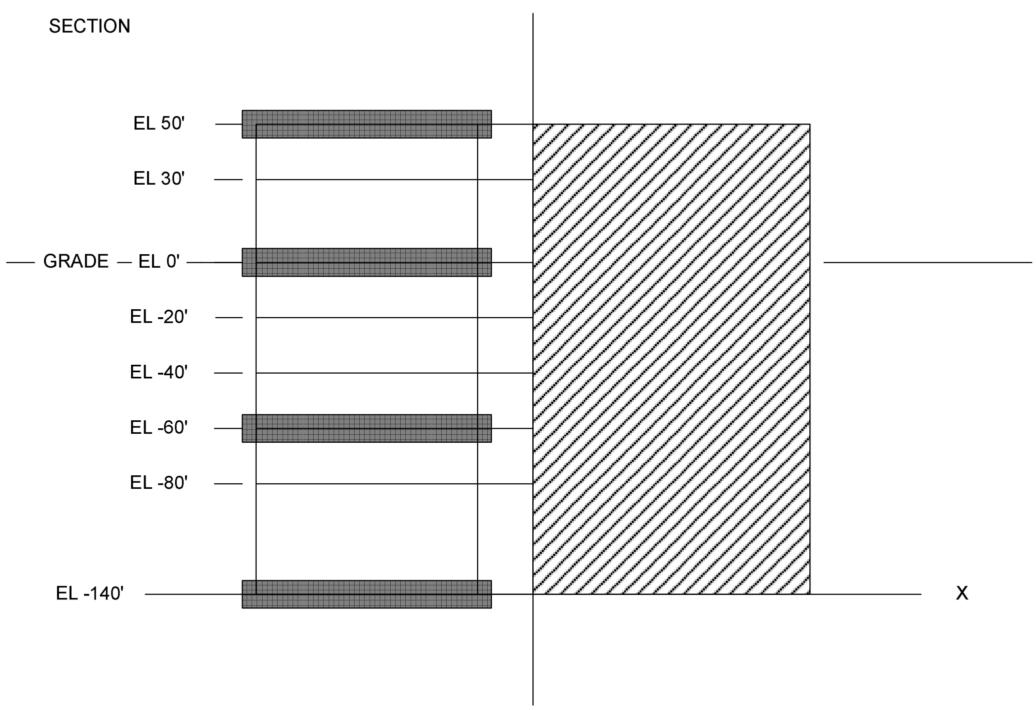


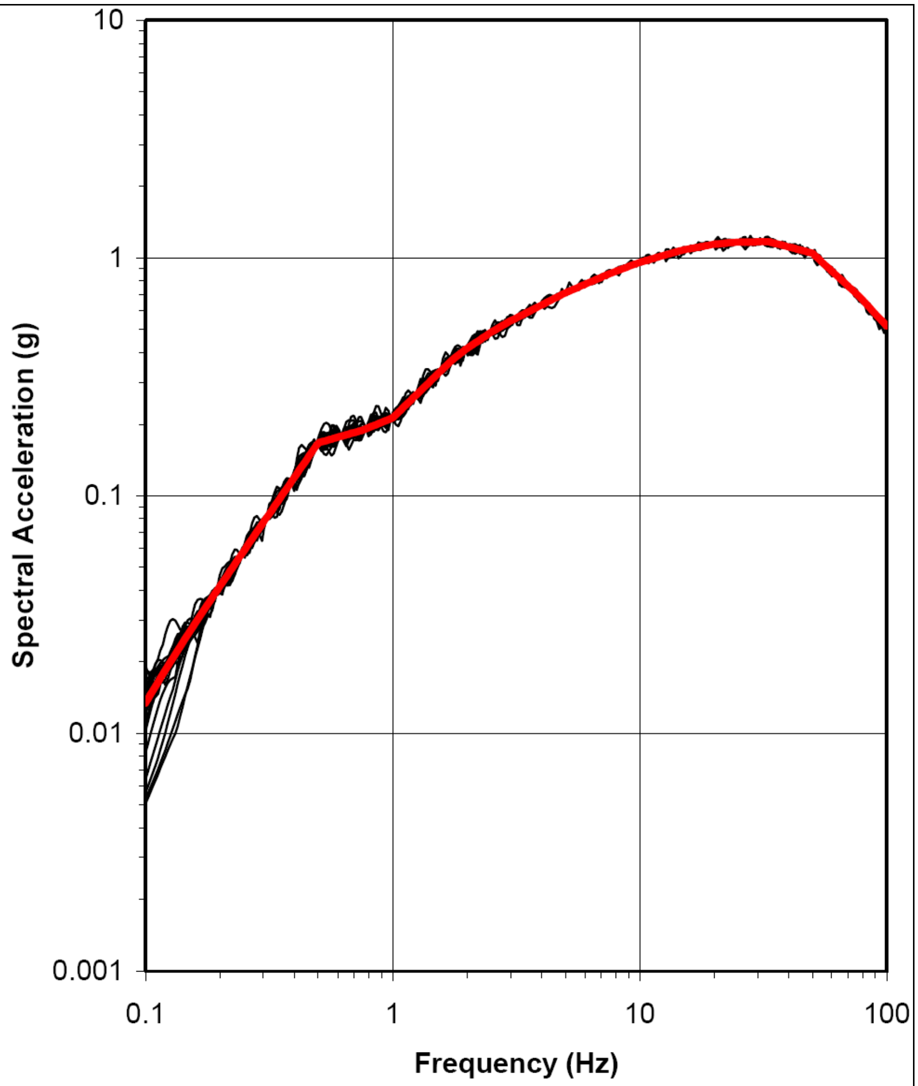
Figure 2. Elevation View of the 3-D Structural Model.

RVT AND TH ANALYSIS COMPARISON

SASSI2010 solves the Soil-Structure Interaction (SSI) problem in the frequency domain. The user may enter either an Input Response Spectra (IRS) for a solution using the method of Random Vibration Theory (RVT) or a time history that is compatible to the IRS.

Description of Analysis Cases

Thirty-one analysis cases are considered, one case with IRS input and thirty cases with different seed time histories matched to the IRS. The IRS and matched time histories are plotted in Figure 3.



Note: Thin black lines show ARS calculated from each time history, red line is the target spectrum

Figure 3. Input Motions Considered.

The structure and soil models are identical for each case. The soil model properties consist of a uniform soil profile with a shear wave velocity of 2,500 fps, compression wave velocity of 4,677 fps, and damping of 5%.

Comparison of Results

Acceleration Response Spectra (ARS) are compared for a node at the furthest corner of the mat (Node 1), see Figure 1. The X-Direction responses for all analysis cases are shown in Figure 4. The RVT response is shown as the red curve with circle symbols. The responses for the time history cases are shown in light grey. The average of the time history cases is shown as the black curve. The Y-Direction responses for all analysis cases are shown in Figure 5. The Z-Direction responses for all analysis cases are shown in Figure 6.

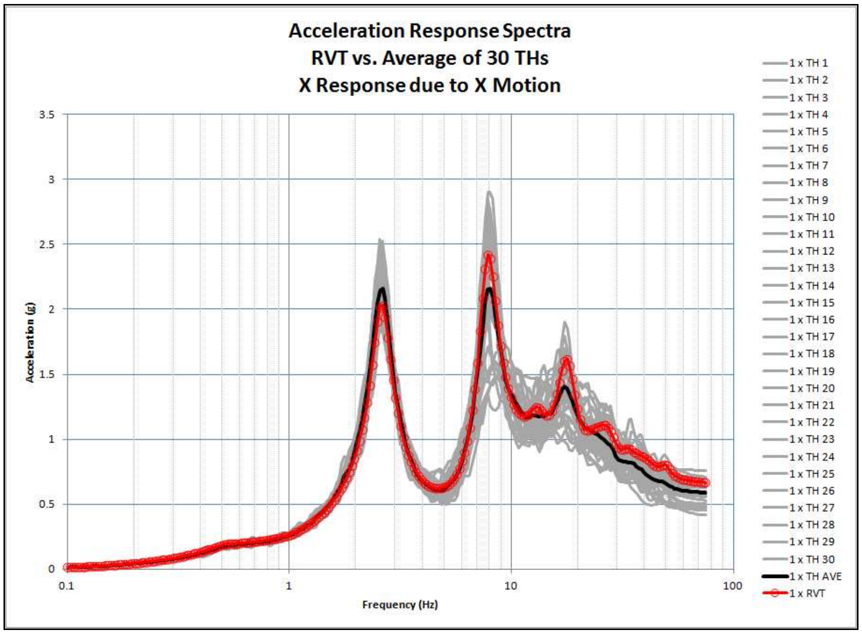


Figure 4. X-Direction Responses –Node 1.

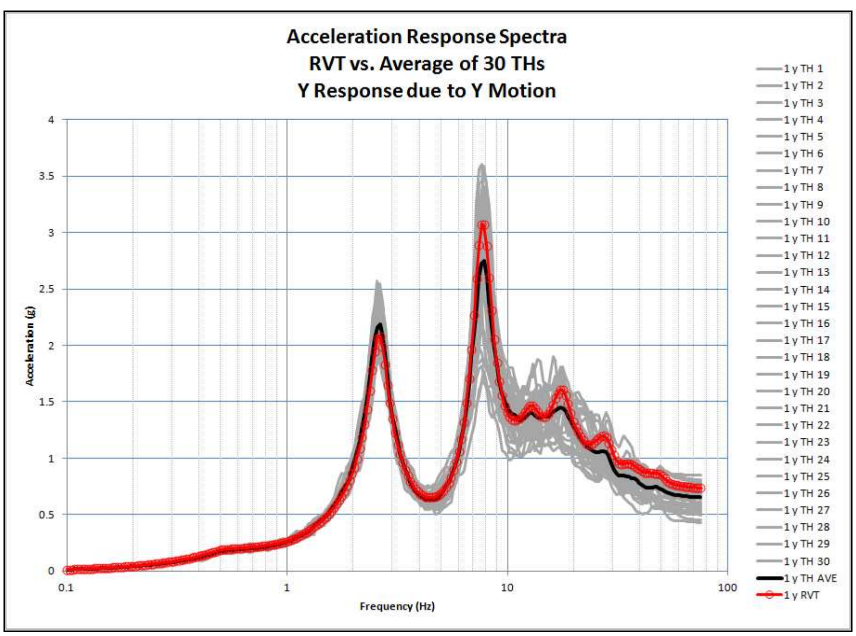


Figure 5. Y-Direction Responses –Node 1.

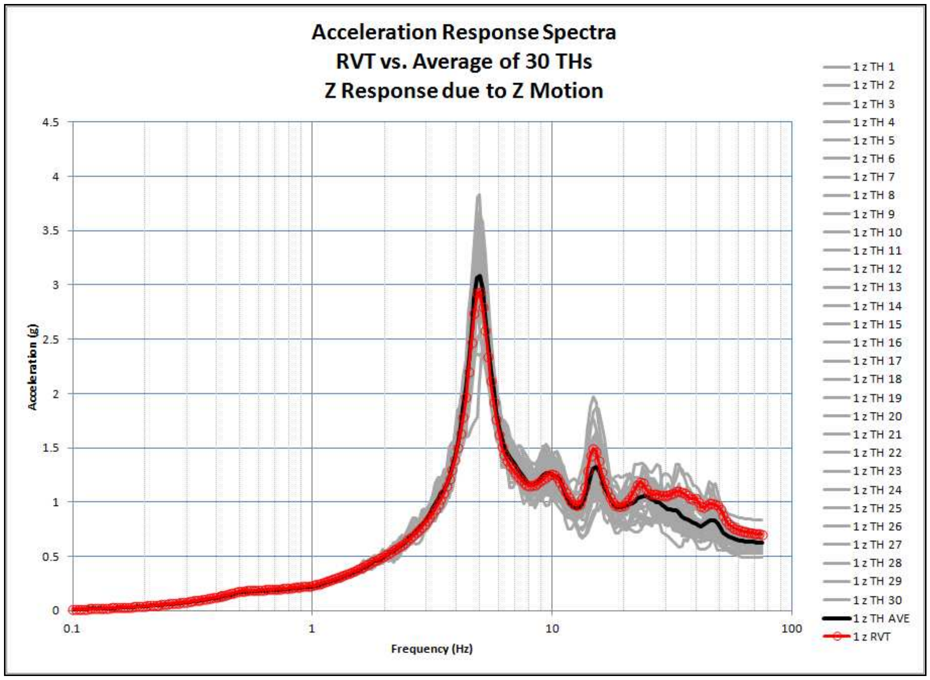


Figure 6. Z-Direction Responses –Node 1.

Acceleration Response Spectra (ARS) are compared for a node at the further corner at grade (Node 4201), see Figure 1. The X-Direction responses for all analysis cases are shown in Figure 7. The Y-Direction responses for all analysis cases are shown in Figure 8. The Z-Direction responses for all analysis cases are shown in Figure 9.

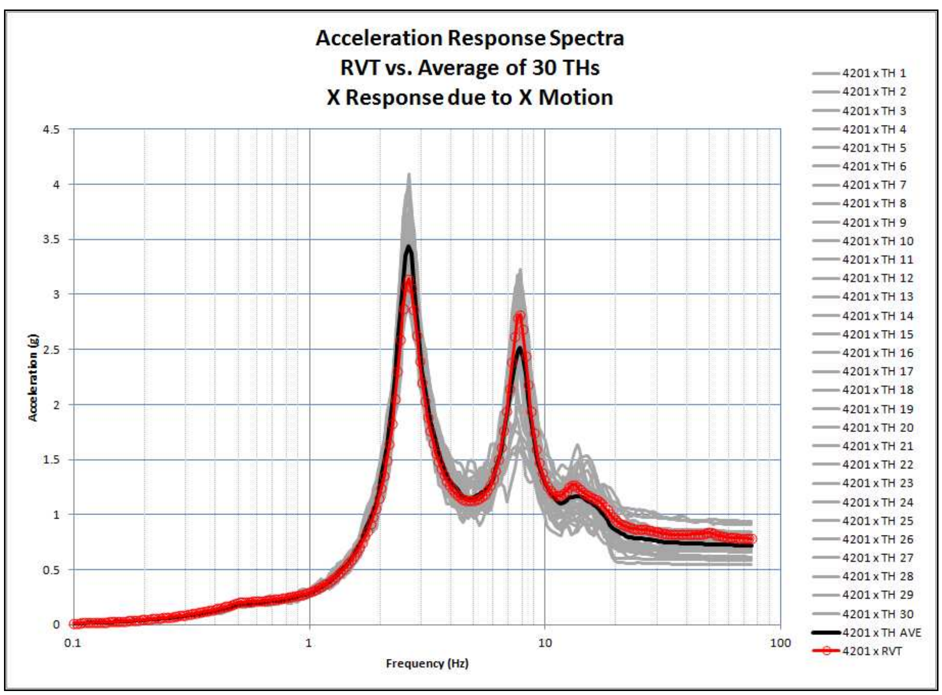


Figure 7. X-Direction Responses –Node 4201.

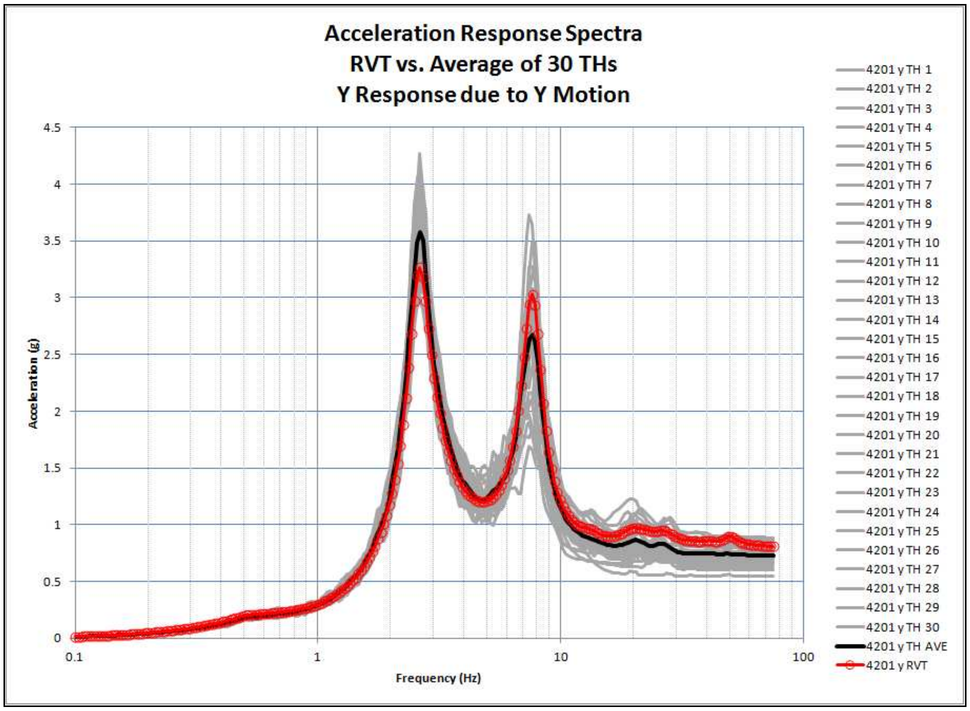


Figure 8. Y-Direction Responses –Node 4201.

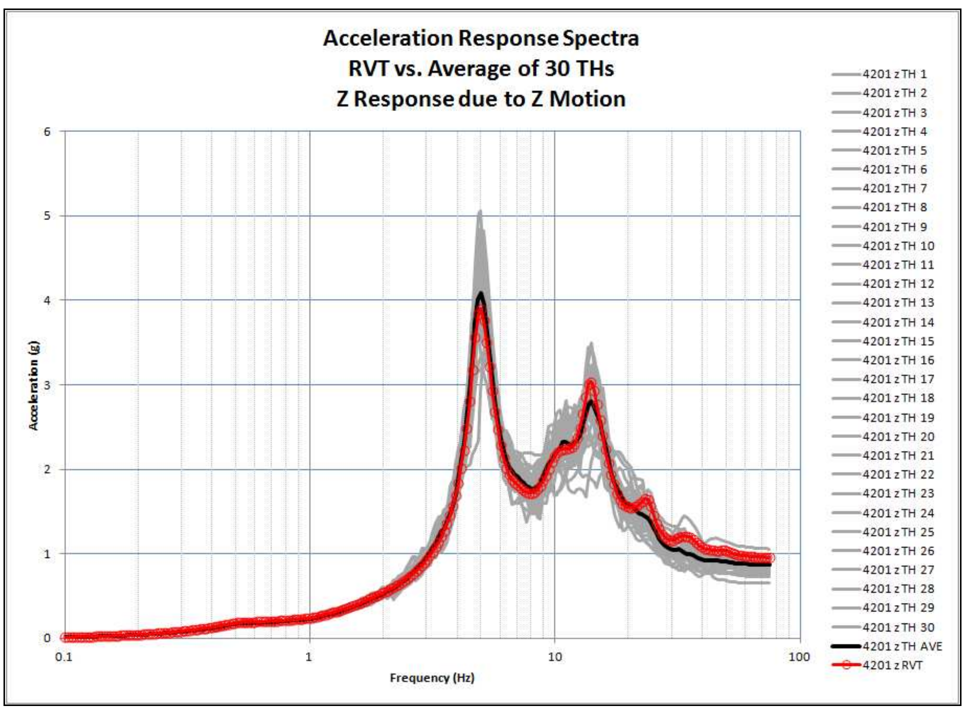


Figure 9. Z-Direction Responses –Node 4201.

Observations

The RVT responses consistently exhibit zero-period accelerations that are larger than those produced by the averaged time history generated responses. It is evident that the frequency content of the RVT ARS match that of the averaged time history generated responses.

DETERMINATION OF MAXIMUM SOIL PRESSURE TIMING AND MAGNITUDE

The difference in soil pressure calculations when using the RVT method of input versus inputting a time history as determined by matching a seed time history to the IRS is assessed in this Section.

The time steps at which maximum vertical forces occur at the base of the structure are evaluated. If a majority of the maximums occur at the same time, there may be no appreciable benefit to using the time histories of the stress forces in lieu of maximum forces for estimation of soil pressure.

Description of Analysis Cases

Three analysis cases are considered. The 3-D model as shown in Figures 1 and 2 is modified to include springs connecting the structure and soil at the base of the structure. The spring connectivity is shown in Figure 10.

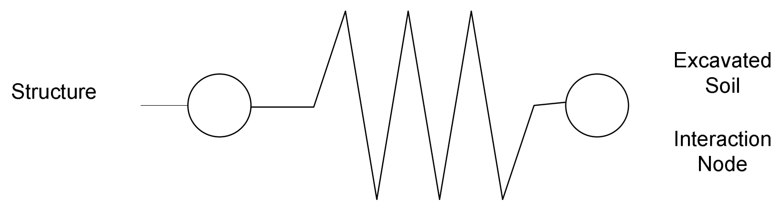


Figure 10. Spring Connectivity.

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

For all cases a soft soil profile is used in conjunction with a motion typical of the Western United States (WUS). The shear wave velocity profile of the soft soil is shown in Figure 11.

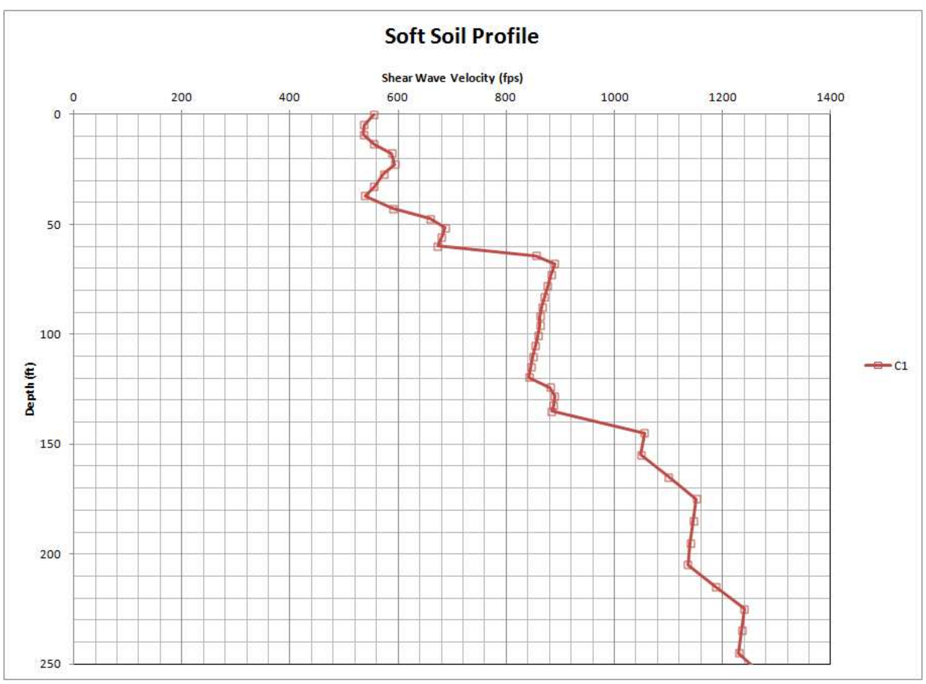


Figure 11. Soft Soil Profile.

The first analysis case (RVT – Max) uses RVT with direct input of the IRS. Maximum vertical forces are extracted for every spring element at the base of the structure.

The second analysis case (TH – Max) considers input of a time history determined by matching a seed time history to the IRS. Maximum vertical forces are extracted for every spring element at the base of the structure.

The third analysis case (TH – TH) considers input of a time history determined by matching a seed time history to the IRS, the same time history as the TH – Max case. Time histories of the vertical forces are extracted for every spring element at the base of the structure.

Comparison of Maximum Vertical Spring Force Values

For analysis cases RVT – Max and TH – Max, the maximum vertical spring force for every spring element at the bottom of the model are summed. For analysis case TH – TH, the vertical spring forces for each spring element are summed based on time step and then maximum values for each spring are summed. The resulting total vertical spring force totals are summarized in Table 1.

Table 1. Vertical Spring Forces.

	Vertical Force (kip)	Percent Difference
RVT - Max	62648	-1%
TH - Max	65990	4%
TH - TH	63462	-

Note, percent difference is taken with respect to case TH – TH.

Comparison of Maximum Vertical Spring Force Timing

For analysis case TH – TH, spring forces are reported for 16384 time steps for a total duration of 81.92 seconds. For each spring element, the time step corresponding time to the maximum force is determined.

The maximum forces for all the spring elements occur between 19.42 seconds and 19.54 seconds. The number of maximum occurrences for each time step is shown in Table 2.

Table 2. Time Occurrences.

	Time (Seconds)	Number of Occurrences
	19.44	49
	19.45	40
	19.46	33
	19.47	25
	19.42	13
	19.53	5
	19.54	3
	19.43	3
	19.48	3
Standard Deviation	0.04	

OBSERVATIONS

The RVT responses consistently exhibit zero-period accelerations that are larger than those produced by the averaged time history generated responses. It is evident that the frequency content of the RVT ARS match that of the averaged time history generated responses.

The comparison of vertical forces resulting from different analysis techniques indicates that there is little sensitivity to the method of soil pressure computation for the structural configuration considered. This is evidenced by the extremely close spacing of the times at which the maximum spring forces occur.

CONCLUSIONS

The negligible change in ARS computed using the RVT method with one IRS compared with the ARS computed using the average results from thirty time histories matched to the IRS indicates that the RVT method is adequate for use in lieu of using multiple compatible time histories.

For the embedment, footprint, and soil conditions considered, there is no significant benefit to computing the vertical spring forces by summing the force time histories based on time step. Extracting the maximum vertical spring forces directly, in conjunction with the RVT, results in a comparable demand to that resulting from the time step method.

REFERENCES

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