SOIL-STRUCTURE INTERACTION IN NUCLEAR POWER PLANTS: A COMPARISON OF METHODS

by

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SYNOPSIS

We performed an extensive parametric survey to analyze the differences between two methods of calculating soil-structure interaction. One method involves discretizing the soil-structure system and solving for the complete response with the LUSH computer code. The other method solves for the lumped mass structural response with Whitman soil springs. Twelve soil-structure interaction problems are solved by each of these methods. Representative results are presented and discussed.

INTRODUCTION

The debate within the nuclear industry in the United States over the relative merits of various methods of calculating soil-structure interaction has intensified over the last three years. The debate is largely the result of the U.S. Nuclear Regulatory Commission's position generally favoring the finite element approach.[1] Certain sectors of the industry claim that this ruling is without technical basis, that it requires unnecessary expense, and that it inhibits the judgment of the analyst. We have addressed each of these points through lumped mass and finite element calculations on a set of twelve soil-structure interaction problems. The results of these calculations indicate some of the consequences of the choice of method.

APPROACH

The twelve problems involve four different sites of two thicknesses (75 ft, 200 ft) and two stiffnesses (average shear wave velocity of 700 fps, 1500 fps). They consider three different depths of embedment (0 ft, 20 ft, and 40 ft). These cases cover a sufficiently wide range of situations to permit us to draw some general conclusions.

Because of its widespread usage, we adopted the Whitman spring theory[2] for the lumped mass solutions. We recognize that more sophisticated frequency-dependent theories are becoming available and we plan to assess them in a future project. Because of its ability to deal with nonproportional damping, we used the SHOCK computer code[3] to calculate the lumped mass response.

For the finite element approach, we used the LUSH[4] code. LUSH can calculate high-frequency response uncontaminated by undesired damping effects. It does, however, require an equivalent linear solution.

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We developed both lumped mass and plane strain finite element models of a reactor building for use in these calculations. Dynamic equivalence between these models was guaranteed.

Free-field soil properties and a bedrock time-history as determined by a SHAKE calculation served as input to the finite element model.

Input to SHOCK included the soil spring and dashpot constants and a time-history. These were also determined by the SHAKE calculation and by some static soil analyses.

The input to the SHAKE calculations was a surface time-history whose response spectrum closely matched the U.S. Nuclear Regulatory Commission Regulatory Guide 1.60 (Figure 1). The peak acceleration was 0.1 g for the soft sites and 0.3 g for the stiff sites. The acoustic properties of the sites are summarized in Figure 2.

RESULTS AND CONCLUSIONS

All our results are presented in the form of response spectra for 5% damping at two locations in the structure, the basemat and the superstructure (Figure 3). Each plot presents both the lumped mass and the finite element results for the same location. The F plots denote finite element results and the C plots denote lumped mass results. We present the results of a representative five cases; other results are similar. The five cases are keyed in Figure 4.

We first note that the lumped mass results should be conservative because of the damping values chosen.[2] We also note that the frequency window of practical interest is for periods less than 1.0 seconds. Finally, we note that because the structure is very stiff relative to the soil, the basemat response is principally determined by the translational soil spring and dashpot, while the superstructure response is determined more by the rocking spring and dashpot.

First, consider the basemat results. The lumped mass spectral accelerations nearly always exceed those of the finite element method. This is interesting because, in light of our anticipation that the lumped mass results would be conservative, it suggests that the finite element results might be closer to reality. We wish to emphasize however, that this conclusion is premature without a comparison to data. We also notice that for increasing depths of embedment, the finite element results often exceed the lumped mass results. This, we feel, is due to dissimilar models for embedment in the two approaches. A third observation is that the spectral peaks frequently do not align; this must be the result of a difference between the translational soil spring constants in the two approaches. Finally, we see that there is usually a uniform difference between the results at the low period end. This could result from differences in translational damping, the translational spring constant, or perhaps the finite element equivalent linear method. It would appear that none of these differences could be removed by a simple adjustment of either method.

The superstructure results show similar trends. Generally, there is a low period offset between the results, and the spectral peaks do not align exactly, and the lumped mass results generally exceed the finite element results. In addition, however, at 1 to 2 seconds period, the finite element results usually exceed the lumped mass results dramatically. We feel that this results from a difference in the modeling of the rocking spring and may suggest the need for a frequency-dependent spring. As a practical matter, however, the spectral accelerations at these periods are of marginal significance in design.

With regard to the costs of the calculations, we found that the finite element approach was computer-intensive while the lumped mass approach was manpower intensive. The total dollar cost was about the same.

The judgment required for each approach varied appreciably. The finite element approach is relatively straightforward in implementation, and very little is required of the analyst. On the other hand, the lumped mass approach requires that the analyst quantify the effect of layers on the springs and dashpots, determine an appropriate input excitation, and establish a radiation damping coefficient.

We conclude that the lumped mass results are generally conservative relative to the finite element results because of differences in modeling. While providing valuable information concerning the relative difference in results, our study cannot at this time single out a clearly superior method. Such a determination must be based on good soil-structure interaction data. The data could be from artificial sources (nuclear explosions, high explosives, shaker tables) or from real earthquakes. We hope that it will soon be available.

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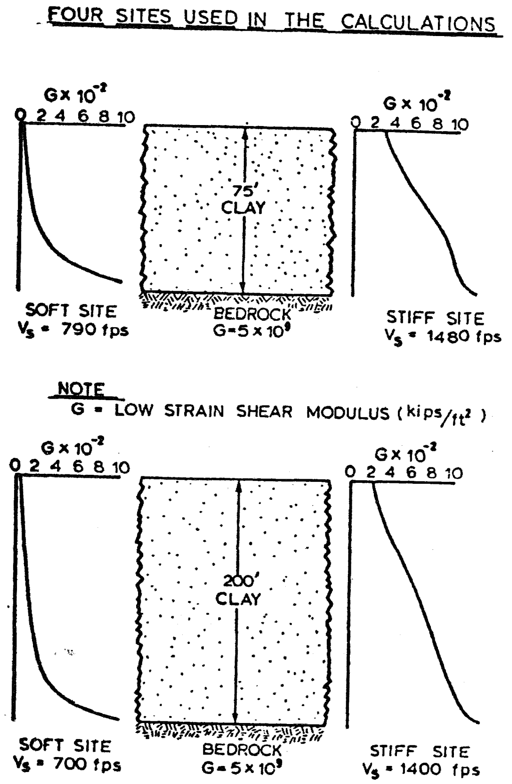

Figure 1

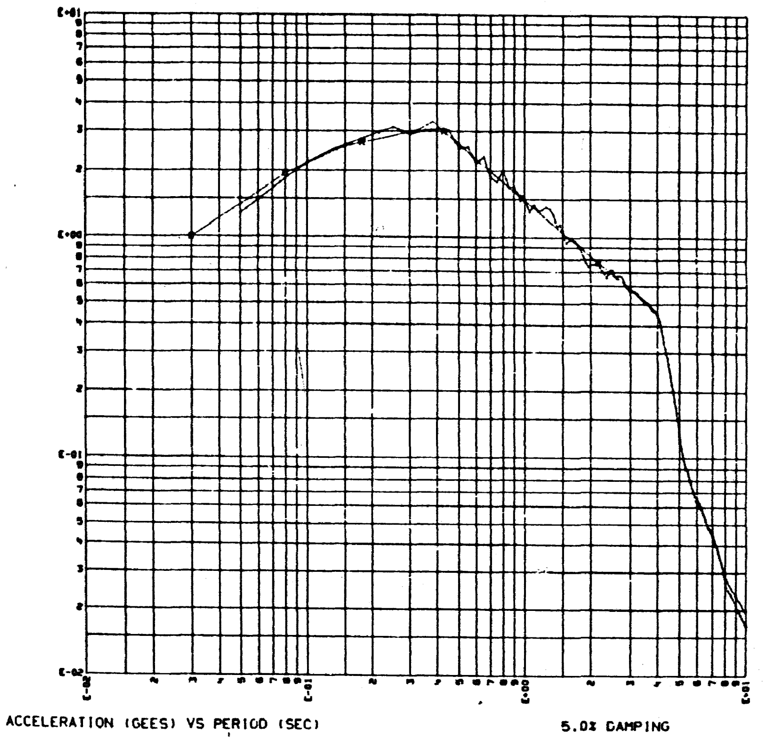

Figure 2

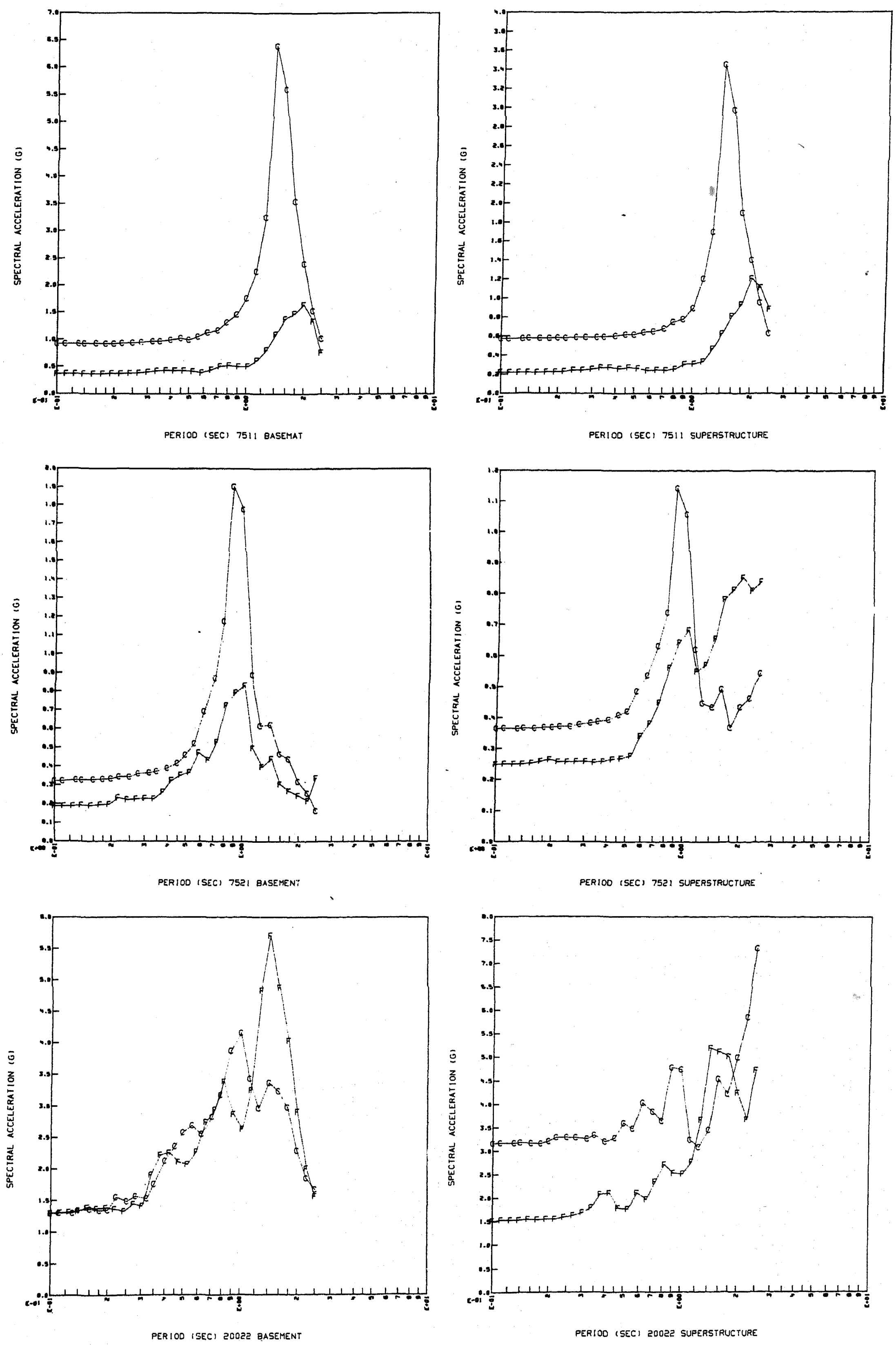
SPECTRAL ACCELERATION (G)
PERIOD (SEC) 7511 BASEMAT
PERIOD (SEC) 7511 SUPERSTRUCTURE
PERIOD (SEC) 7521 BASEMENT
PERIOD (SEC) 7521 SUPERSTRUCTURE
PERIOD (SEC) 20022 BASEMENT
PERIOD (SEC) 20022 SUPERSTRUCTURE
C
F

Figure 3

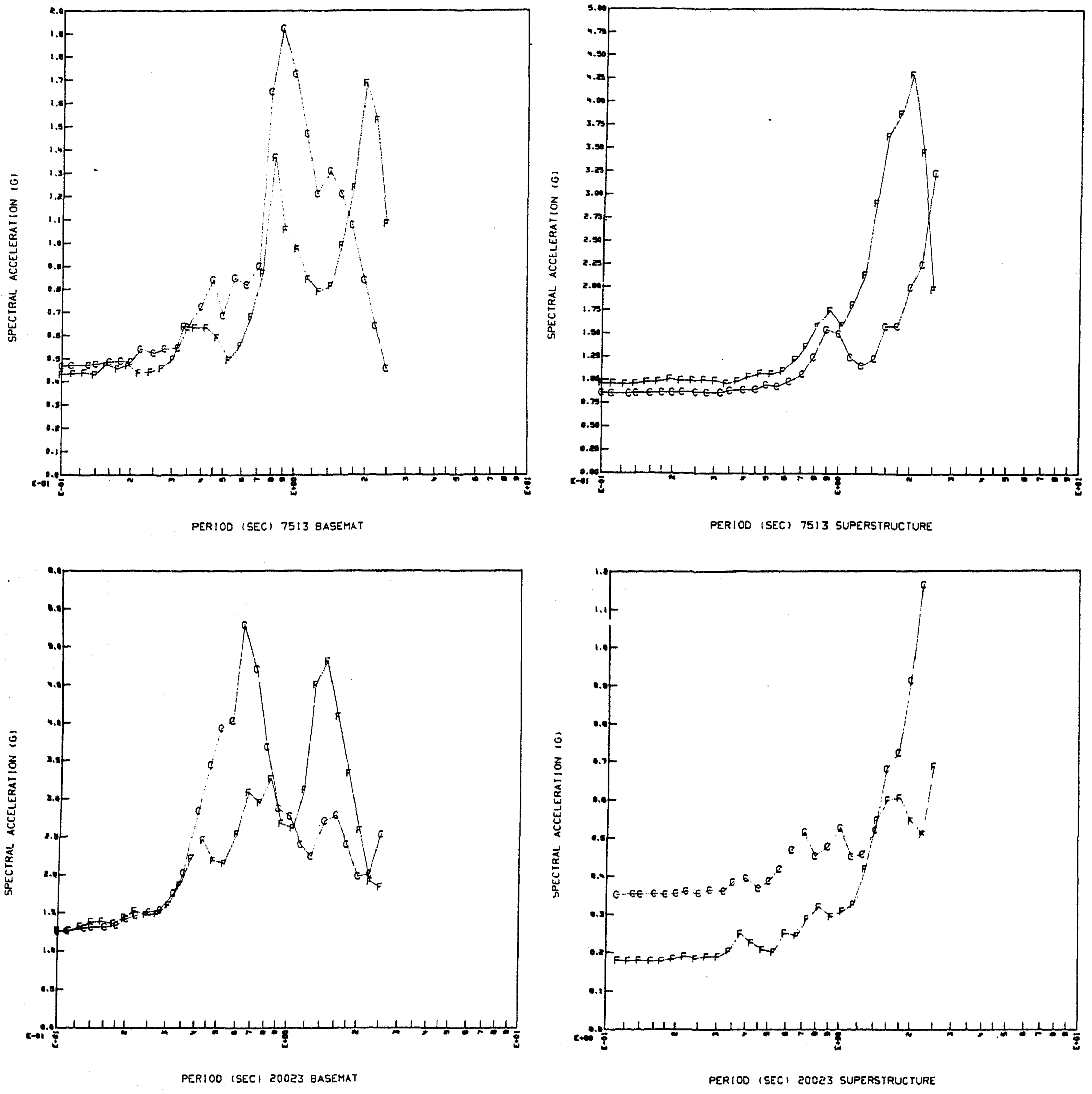

Figure 3
[CON.]

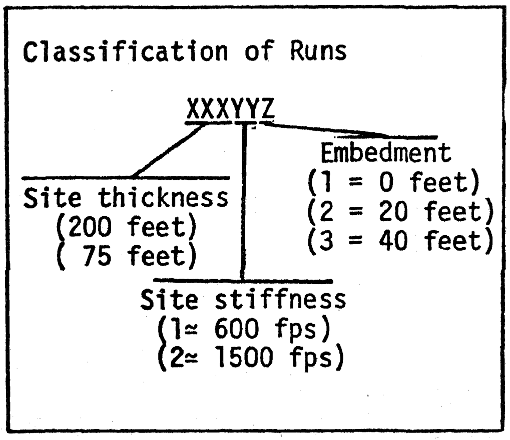

Figure 4