STANDARD PROBLEMS TO EVALUATE SOIL STRUCTURE
INTERACTION COMPUTER CODES

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ABSTRACT

The seismic response of nuclear power plant structures is often calculated using lumped parameter methods. A finite element model of the structure is coupled to the soil with a spring-dashpot system used to represent the interaction process. The parameters of the interaction model are based on analytic solutions to simple problems which are idealizations of the actual problems of interest. The objective of the work reported in this paper is to compare predicted responses using the standard lumped parameter models with experimental data. These comparisons are shown to be good for a fairly uniform soil system and for loadings which do not result in nonlinear interaction effects such as liftoff.

INTRODUCTION

Lumped parameter methods are often used to compute the seismic response of nuclear power plant structures. The lumped parameter method is based upon a finite element model of the structure coupled to the free field with a system of springs and dampers intended to represent the interaction process. The free field motion is then input to the base of the spring/damper interaction model. There are two major areas of uncertainty associated with the use of this method. The first is concerned with the numerical values to be assigned to the spring/damper model. The second area of uncertainty is concerned with the neglect of feedback effects from the structural motion to the free field.

The objective of the work reported in this paper is to compare predictions made with standard lumped parameter models with experimental data. Two sources of experimental data are considered. The first is measurements taken on the Fukushima Nuclear Power Plant Station (1) during a magnitude 7.4 earthquake. The second is the SIMQUAKE II experiment conducted by EPRI (2). A test region was loaded with a high explosive charge designed to simulate an earthquake. Several models of containment structures were placed in the test area.

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Two computer codes are used to perform the computations. SIM Code (3) is used to perform the lumped parameter calculations. This code uses beams (including shear deformations) to model the structure. The standard equations are used to obtain the interaction parameters but the user has the option of specifying different values. The solution is carried out in time domain and results are given in the form of time histories and/or response spectra at selected nodes. SLAVE Code (4) is used to calculate free field motions at any desired location given the response at one location and the soil properties. The computations in SLAVE Code are based on the assumption of a vertically propagating shear wave in the free field.

The basis for the selection of the interaction parameters is first discussed with emphasis placed on those aspects which lead to the uncertainties in the method. Comparisons with the Fukushima data is then made followed by the correlations with the SIMQUAKE data.

SELECTION OF INTERACTION PARAMETERS

The purpose of the interaction lumped parameter model is to convert relative motion of the soil and structure to forces acting on the structure so that a dynamic analysis giving the structural response may be performed. A fundamental assumption is that the free field motion, used as input to the model, is not effected by the structural motion. The values used for the interaction parameters are based on analytic, steady state solutions to the problem of a rigid foundation vibrating on an elastic half space. The interaction process is divided into two parts. One is at the interface of the structure base and the soil while the second is between the sidewall of the structure and the free field.

Bycroft (5) developed one of the earlier solutions for a rigid circular foundation vibrating in an elastic half space. Solutions were found for vertical translation, horizontal translation, rocking and twisting response of the foundation for a specified harmonic forcing function. These results may then be used to determine frequency dependent equivalent springs and dampers. Many studies have been conducted to extend these results and to evaluate frequency independent springs that would be valid in frequency ranges of interest. The resultant form of the equations now in use are,

$$K_H = 28.8 G R (1-u)/(7-8u)$$

$$K_R = 2.13 G R^3/(1-u)$$

$$K_V = 4 G R/(1-u)$$

$$C_H = 18.24 R_C R^2(1-u)/7-8u)$$

$$C_R = 0.4 R_C R^4/(1-u)$$

$$C_V = 3.4 R_C R^2/(1-u)$$

flexibility is included, the first 12 modes of the system range from 2.5 cps through 20.0 cps.

A comparison of the spectra from the predicted responses, using the measured pulse at -4 M as input, and the measured in-structure pulses are shown on Fig. 4. As may be seen, the correlation between the two spectra is rather good.

COMPARISONS WITH SIMQUAKE II DATA

The SIMQUAKE II experiment was conducted on June 2, 1977 at the University of New Mexico's McCormick Ranch test site. Figure 5 shows a plan of the test bed. The loading was generated from the two planar arrays located about 150 feet from the area containing the structural models. Six structural scale models of containment structures were used with the scale factors varying from 1/8 to 1/24. About 150 channels of instrumentation was included in the free field and in the structures. The soil has shear wave velocities varying from 800 fps to 1100 fps in the top 90 feet.

Comparison between lumped parameter predicted responses and measured responses are made for the 1/8 scale model. The structure is a cylindrical structure having a diameter of 15 feet and a height of 22.5 feet. The walls of the cylinder are 1.51 feet thick and the base is 2.26 feet. The structure is embedded 25% into the ground. The structural frequencies are sufficiently high so that it is modeled as a rigid body. The interaction frequencies are 10.6 cps, 20.9 cps and 25.5 cps respectively for rotational, vertical and horizontal responses.

The response of the structure is generated using the standard interaction parameters described above with measured pulse taken as input. Horizontal spectra at the base and top of the structure are generated from the predicted and measured responses. Comparisons of the two are shown on Fig. 6. A reasonable comparison between the two is found at the base, but there is poor correlation at the top of the structure. This occurred because the input had a sufficient amplitude to cause the base of the structure to separate (liftoff) from the soil. The effect of this was to significantly reduce the rocking frequency thereby transferring the energy in the spectra from the high to low frequency range.

The vertical response of the structure is also calculated and comparisons between the calculated and measured vertical in-structure vertical spectra are shown on Fig. 7. Once again liftoff effects result in a poor correlation between the lumped parameter and measured spectra.

CONCLUSIONS

Comparisons are made between response predictions based on lumped parameter models and measured data. Two sources of measured data are used. The first is data collected at the Fukushima Reactor Containment Building

during a moderately large earthquake. The second is the SIMQUAKE II experiment where model containment structures were subjected to motions designed to simulate large earthquake motions. The following conclusions are based on these comparisons:

1) The concept of a vertically propagating shear wave, upon which the convolution methods are based, appears to be reasonable for sites such as Fukushima. Comparisons of spectra, for pulses generated from the -40 M elevation pulse, with measured pulses show good agreement in overall shape with some discrepancies in amplitude spectral accelerations than the measured pulses. This would indicate that the hysteretic soil damping model used in the convolution analysis may underestimate soil damping effects.

2) The standard methods of calculating the interaction springs and dampers give results which are compatible with the measured in-structure motions provided the level of excitation is low enough so that liftoff does not occur. The differences which are found between the measured and calculated spectra are attributable to the values used for the interaction dampers. It may be that the use of frequency independent dampers should be reevaluated.

3) When the earthquake magnitude is high enough to cause liftoff, the standard interaction parameters result in poor predictions for the rotational and vertical components of the structural motion. The result of liftoff is to cause the rocking frequency of the structure to be significantly reduced from that predicted with the standard interaction models. It appears that the linear interaction model will not be adequate to represent the nonlinear effects associated with liftoff.

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Fig. 1 Site Configuration.

- LEGEND
- MEASURED AT CL
 - △ 10 PCT ROCK DAMPING
 - + 15 PCT ROCK DAMPING
 - × 20 PCT ROCK DAMPING

Fig. 2 Spectra Calculated at - 4 M Using Pulse at - 40 M.

(a) Building Cross Section

(b) Model

Fig. 3 Fukushima Reactor Containment Model.

Fig. 4 Comparison of Measured and Calculated Spectra For Fukushima Using Measured Input Motion and Standard Interaction Parameters.

Fig. 5 Siquake II Test Bed.

(a) Base of Structure

(b) Top of Structure

Fig. 6 Comparison of Measured and Calculated Horizontal Spectra For SIMQUAKE II Structure Using Standard Interaction Parameters.

Fig. 7 Comparison of Measured and Calculated Vertical Spectra for SIMQUAKE II Structure Using Standard Interaction Parameters.