# EFFECTS OF SITE CONDITIONS ON FLOOR RESPONSE SPECTRA

by

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## ABSTRACT

This paper presents a numerical study of the variation of horizontal floor response of a nuclear power plant for different site conditions. Four site configurations are considered in this study - a flexible bedrock foundation, a thin soil layer on flexible bedrock, a soil layer of medium thickness on flexible bedrock and an infinite soil layer. For each of these configurations, the shear wave velocities and damping ratios are varied within a range determined from a statistical evaluation of a large number of data logs for nuclear power plant sites. A finite element linear elastic analysis is used to evaluate the floor response spectra for each model subjected to an artificially generated time history input that matches the USNRC Spectrum at foundation level. Efficient use is made of viscous dampers for modelling non-reflecting boundaries in the finite element models. The results presented in this paper may represent a useful guide in early design decisions or feasibility studies for nuclear power plants.

## INTRODUCTION

The dynamic response of a structure can be modified significantly if the structure causes the soil beneath it to deform. Stiff, heavy structures like nuclear power plants are more likely to cause soil deformation, and consequently the effects of such deformations must be considered when evaluating the dynamic response of these structures. The soil deformation is caused by the structure acting as a dynamic load on its foundation and it gives rise to what is known generally as soil-structure interaction.

The aim of this paper is to present the floor response of a typical reactor building on a variety of soil conditions. Seven site configurations were chosen as being representative of geophysical conditions generally encountered in nuclear plant technology. Finite element models of a nuclear reactor building on the different foundations were then analysed to give the reactor response spectra.

## SOIL MODELS

Neglecting specific information such as layering,material anisotropy, depth dependent properties and water table, (considering that the information would have led to an infinite number of possible configurations) a set of four idealised site configurations was selected to sample local soil profiles encountered in nuclear power plant sites. The idealised configurations consisted of single horizontal soil layers overlaying flexible bedrock.

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The thicknesses of these layers are 0 ft (model A - rock foundation); 50 ft (model B - thin soil layer); 100 ft (model C - intermediate soil layer); and $\infty$ (model D - extra thick soil layer). The thickness of the soil layer in model B is of the same order of magnitude as the radius of the basemat of the reactor building (63 ft) while model D represents an infinite half space.

The four basic parameters used in this study to define the material properties of the soil and bedrock are shear wave velocity ($V_s$) damping ratio ($\beta$), Poisson's ratio ($\nu$) and mass density ($\rho$). The values assigned to the material parameters resulted mainly from a statistical evaluation of data logs for 60 nuclear power plant sites in the U.S.A. This data was supplemented whenever necessary with information derived from published semi-empirical equations and other published data.

The 60 nuclear power plant sites were classified on the basis of the four configurations described above and the distributions of the number of sites with shear wave velocity were plotted for each of the classes. These plots however did not reveal any statistical preference for values of shear wave velocities. Consequently average values were chosen from the range of values established from idealising the data logs. These values are given in Figure 1. For each of the soil layers, two values were selected. The lower values were chosen as being typical of softer sites encountered in nuclear power plant technology, and the higher values represent the stiffer sites.

The data logs for the nuclear power plant sites do not contain information on damping, and consequently, published literature was relied upon to provide values. To establish numerical values, two types of soil that can be associated with the lower set and higher set of shear wave velocities were identified through a consideration of published semi-empirical relations resulting from experimental studies of soil properties (Seed and Idriss, 1970; Hardin and Drnevich, 1970). Based on this study, it was concluded that the lower and higher shear wave velocities are typical of dense saturated sand and gravels respectively. Seed and Idriss (1970) presented a summary of the results of a number of previous investigations of damping ratios for sand. These numerical results are likely to provide sufficiently accurate values for damping ratios of both saturated sands and gravels. The values of 5% and 2% for the damping in the soil and rock respectively was concluded for this study.

The density values and Poisson's ratios assumed in this study are summarised in Figure 1. These resulted directly from the geophysical information of the data logs.

## FINITE-ELEMENT MODELS

The structural model of a typical reactor building is shown in Figure 2, together with the finite-element model. The discrete masses in the finite-element model are connected by springs representing shear and rotational stiffnesses. Masses 2 to 6 represent the external structure while masses 7 and 8 represent the internal structure. Both of these structures are connected to a rigid basemat (mass 1). The finite elements used in this study are 2-D plane-strain elements, and so the axisymmetric reactor structure was represented as an equivalent 2-D structure. The method used for this conversion is similar to that adopted by Isenberg (1970). The damping in the structure was assumed to be 5% of critical in all deformable modes.

Figure 3 schematically depicts the type of soil-structure model used in this study. This model makes use of viscous elements at the bottom soil boundary to represent the infinite boundary conditions. The paper by Kunar, Beresford and Cundall (1977) describes this model in detail with regard to its efficiency and accuracy, while the method of analysis is described in another paper by Hitchings, Kunar and Beresford (1976).

In all cases, the sizes of the soil finite elements in the vertical direction were chosen to ensure an effective frequency transmission of 33 Hz. The damping ratio of the soil and structure was assumed to be constant for all modes.

## STRUCTURAL RESPONSE

Figures 4 and 5 show the floor response spectra for all site conditions at the basemat level and the spray pipes connection level (centre of gravity of mass 6 - Figure 2). The response spectra of the basemat of the structure give a clear indication of the degree of soil-structure interaction by comparing their shape with the response spectrum curve for the specified surface motion (Figure 4). Larger differences in the shape indicate greater degrees of soil-structure interaction. From Figure 4, it is clear that there was little or no interaction for model A - the rock foundation. However, as the soil stiffness decreased, the structure modified the motion at the basemat level more and more. This was evident from the response spectra in Figure 4, where the spectrum for the softest soil model (model B1) deviates the most from the input control spectrum and the hardest soil model (model D1) deviates the least. The following conclusions can be derived from Figures 4 and 5 regarding the structural response:

a) A foundation of shear wave velocity greater than 6000 ft/sec will not significantly influence the behaviour of the structure, i.e., there is little or no soil-structure interaction.

b) For a peak input acceleration of 0.1g, the highest peak acceleration at the basemat is 0.2g. This corresponds to the softest soil condition (model B1). For the rock foundation, the peak acceleration is 0.1g as expected.

c) The basemat response spectra are significantly different from the spectrum of the input motion for soft and medium soils. The differences become larger as the soil stiffness decreases.

d) The site condition has a considerable influence on the resonant peaks of the structural response (Figure 5). The first natural frequency of the combined soil-structure system for example, reduces quite considerably as the soil gets softer, i.e., as interaction increases. This frequency has changed from 8.2 Hz for model A to 2.5 Hz for the softest site condition of model B1. This first natural frequency is associated with the flexural vibration of the external structure. The frequency for the rock foundation case agrees very closely with the corresponding resonant peak for a fixed-based model.

e) The maximum acceleration experienced by the structure for all the site conditions is 0.28g. This occurs at the top of the external structure when the plant is sited on rock. The corresponding acceleration at the top of the internal structure is 0.23g.

## ACKNOWLEDGEMENTS

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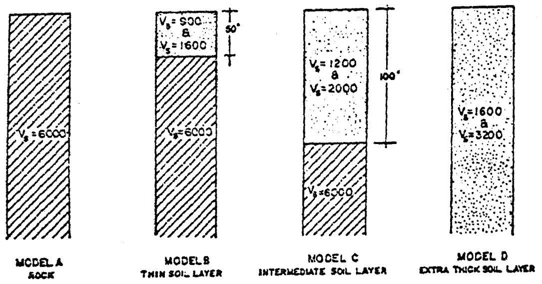


| | DAMPING RATIO | DENSITY (lbs/ft³) | POISSON'S RATIO |
|---|---|---|---|
| ROCK | 2% | 150.0 | 0.25 |
| SOIL | 5% | 130.0 | 0.35 |

$V_s$ = SHEAR WAVE VELOCITY IN FT/SEC.

MODELS TO BE USED IN SOIL-STRUCTURE INTERACTION

FIG. 1

DAMES & MOORE

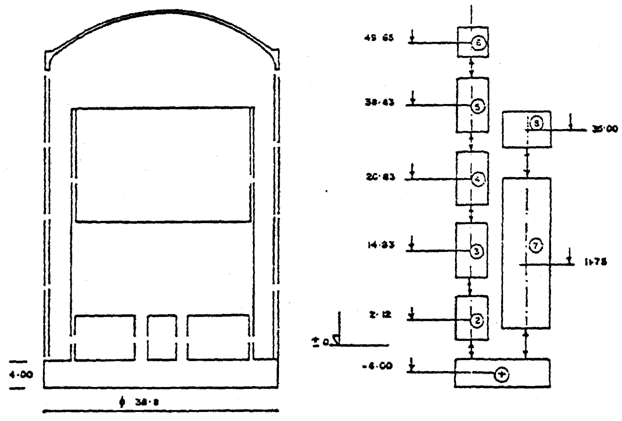


FIGURE 2 STRUCTURAL MODEL

DAMES & MOORE

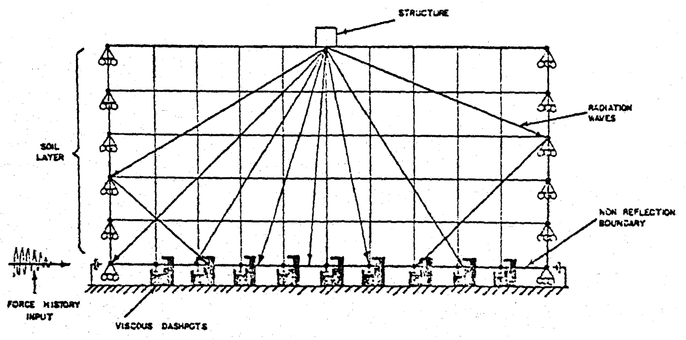
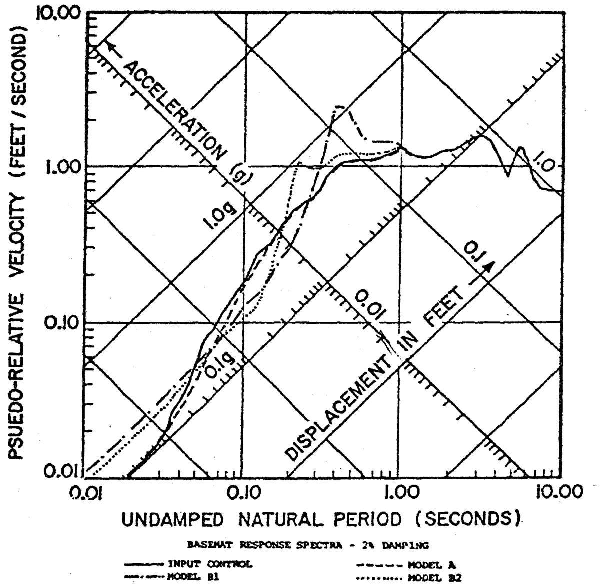
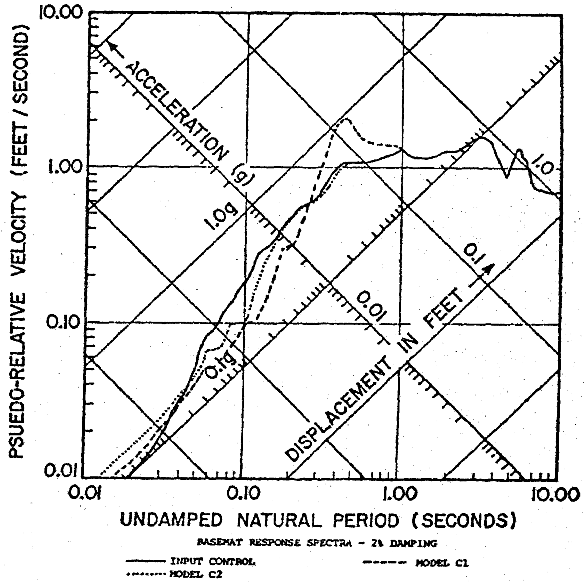


FIG 3

MODEL PROPOSED TO BE USED IN SOIL-STRUCTURE INTERACTION PROBLEM.





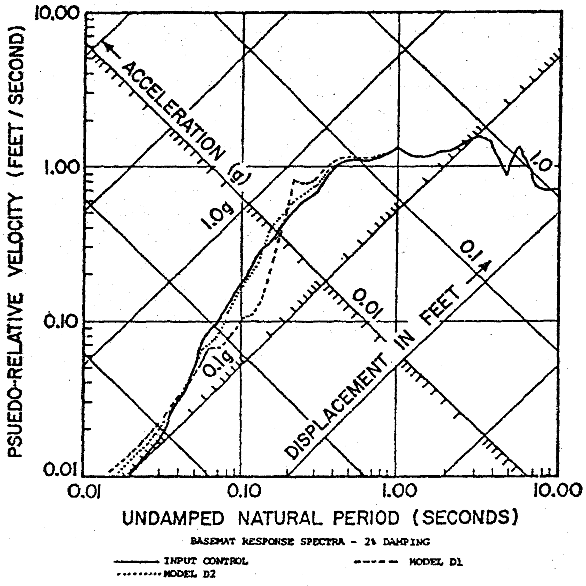
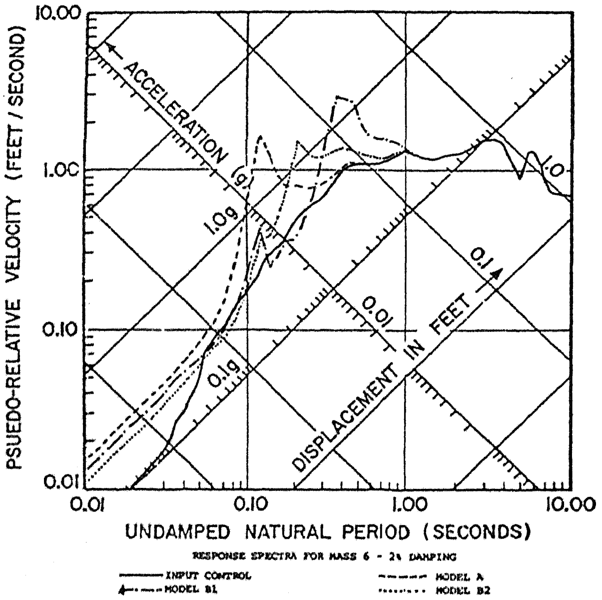
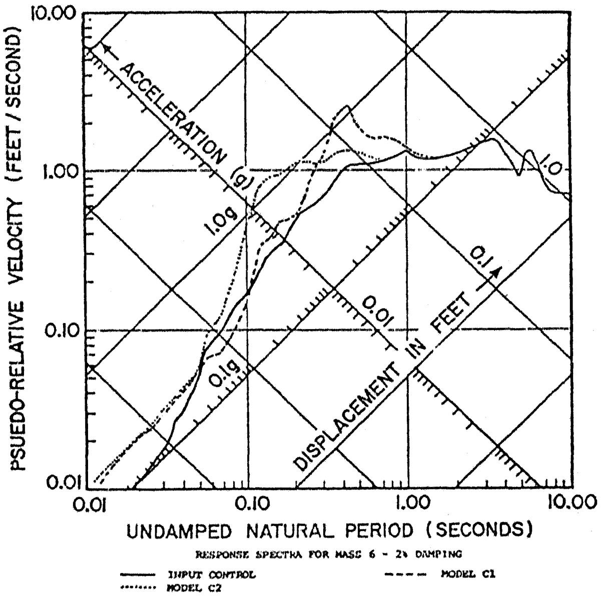


FIGURE 4

BASEMAT RESPONSE SPECTRA



RESPONSE SPECTRA FOR MASS 6 - 2% DAMPING



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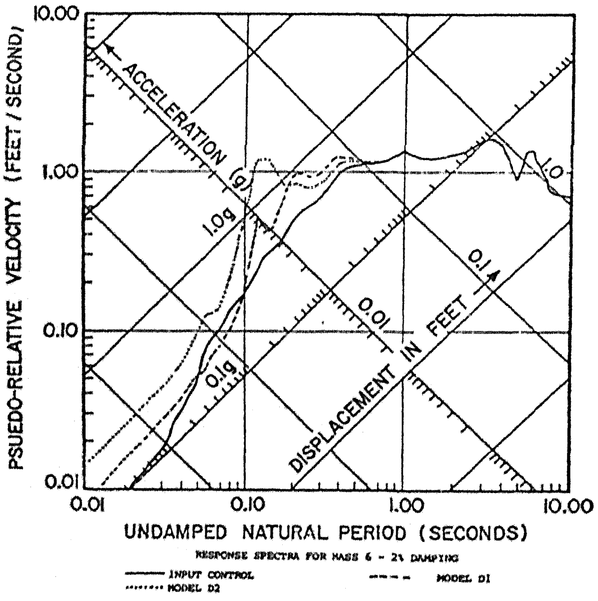

RESPONSE SPECTRA FOR MASS 6 - 2% DAMPING

FIGURE 5

RESPONSE SPECTRA AT MASS 6.

## DISCUSSION

### D.K. Paul (India)

1. In the present method if the base rock is sufficiently deep then the radiation waves may undergo multiple reflection from the vertical boundaries and finally absorbed at the base. These multiple reflection might introduce certain error. Further, the depth of embedment is one of the important parameter in the determination of seismic response of reactor building of an atomic power plant. The method suggested will introduce more error with the increase of depth of embedment. The concept of consistent boundary employed by Kausal, Roesset and Waas (1975) seems to be useful since the method is efficient and can also be used for embedded foundation. Please comment.

2. Based on the study, would the authors suggest the minimum distance of the vertical boundary from the center of edge of a symmetric structure and also what should be the minimum depth of viscous boundary in case of model D of the study.

Reference: Kausal, E., Roesset, J.M., Wass, G., "Dynamic Analysis of Footings on Layered Media" Journal of the Engg. Mechanics Division, ASCE, NOEMT, Proc. paper 11652, Oct.1975, pp: 679-693.

### Author's Closure

With regard to the question of Mr. Paul, we wish to state that the authors accept the criticism that the accuracy of the model described in their paper would deteriorate if embedment is considered. The model was developed specifically for surface structures as pointed out in the paper by Kunar, Beresford and Cundall, (1977).

The consistent boundary employed by Kausel, Roesset and Wass (1975) is very useful, but applies to the vertical boundaries only. There is no reason why the model proposed in our paper could not be combined with the consistent boundary of Kausel et. al., to provide a good model with quiet boundaries at the base and vertical boundaries. This model would allow embedment of structures without any significant loss of accuracy. This combined model is being considered by the authors and it is expected that the results would be made available to the public in the near future.

While a detailed parametric study was not performed, our results suggest that the vertical boundary should be at a distance of about 3 to 5 times the radius of the basemat of the structure. For shallow foundations (eg. model B) 3 times the radius is sufficient which for very deep foundations (model D), a value of 5 times the radius should be adequate.

The minimum depth of the viscous boundary is determined by the assumption that the radiation waves are plane as they cross the boundary. The results indicate that a depth of twice the radius of the basemat for model D give sufficiently accurate answers.

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1. R. Kunar, P. Beresford, P. Cundall, "A tested soil-structure model for surface structures", Proceedings of the International Symposium on Soil-Structure Interaction, January 1977, Roorkee, India.

2. Kausel, Roesset, Wass, "Dynamic Analysis of Footings on Layered Media", Journal of Eng. Mechanics Division, ASCE, October 1975.