A Comparison of Responses from Different Seismic Soil-Structure Interaction Analyses

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ABSTRACT

Several different horizontal seismic analyses are made of a PWR reactor containment and the resultant responses are compared. The base case is one of the containment sitting on a soil site with a depth of 55 feet to bedrock and 36 feet of backfill surrounding the plant structures. The containment is embedded for about one third of its perimeter. The containment is cylindrical with a height from the top of the basemat to top of the dome of 197.5 feet a diameter of 147.5 feet, and a basemat thickness of 26 feet. The analysis methods are fixed base, frequency-independent impedance function, frequency-dependent impedance function, finite element with backfill and finite element without backfill. The results show that response frequencies are in approximate agreement and that there are notable differences in response amplitudes predicted by the different methods.

1. INTRODUCTION

The purpose of the study is to compare results from several different horizontal seismic analyses of a reactor containment using different methods of analysis and the same seismic criteria. Both the impedance method and the finite element method (FLUSH) of analysis are used.

2. SEISMIC MODELS

The mathematical model of the PWR reactor containment is a lumped mass and beam element model with 31 dynamic degrees of freedom, fig. 1. This model is used in all analyses. The fixed base mode shapes and frequencies are shown in fig. 2A. Two other building models are used in the finite element analyses. These are a plane strain finite element model for the auxiliary building and a lumped mass and beam element model for the turbine building. The finite element soil structure models include all three buildings. The other models do not include the auxiliary building and turbine building.

The impedance function methods used to model the soil are constant impedance functions (springs & dampers)[1], frequency-dependent impedance functions assuming the soil is a uniform elastic half space and frequency-dependent impedance functions considering the effects of layering [2]. No material damping is used in the constant impedance function method, 0.6% in the frequency dependent uniform half space model, and about 6% in the layered model. Low strain soil properties are used for all impedance funtions analyses.

The FLUSH program [3] is used for the finite element soil model. The FLUSH model is shown in fig. 1 with the containment model used in all analysis. The soil damping used in FLUSH is about 6%.

3. SEISMIC CRITERIA

The input motion is specified at the level of the base of the structure. It is a synthetic time history which has response spectra which envelope the response spectra of Regulatory Guide 1.60 [4]. Damping values used for the strcutre are those of Regulatory Guide 1.61 [5].

4. ANALYSIS

The analyses performed are given in table I. Acceleration time histories and response spectra are calculated for all analyses except the fixed base analysis where accelerations are obtained using the modal analysis response spectrum method. The fixed base accelerations are the square root of the sum of the squares results (SRSS) and the other accelerations are maximum time history results. The impedance function analyses are performed with fast fourier transform (FFT) analysis program [6] with the exception of the method of equivalent modal damping [7] where the modal analysis time history method is used. The mode shapes and frequencies in the modal analysis equivalent modal damping method are calculated by an approximate method using the fixed base mode shapes and frequencies and the soil spring and base mass properties.

5. RESULTS

The mode shapes and frequencies presented in fig. 2 demonstrate the differences between the modes and frequencies of response of the fixed base and flexible base structures. The flexible base structure having lower natural frequencies and exhibiting translation and rocking at the base. The acceleration profiles in fig. 2C show only small differences in acceleration with the analysis using FLUSH being the lowest. The results of the frequency

dependent half space analysis with 6% material damping are nearly the same as the equivalent modal damping results with no material damping, both in acceleration profile and response spectra and are not plotted on any figures.

The response spectra in fig. 3 show that the layered impedance function results have higher values than either the uniform half space or the FLUSH results. In the FLUSH results with the artificially stiff backfill there are peaks in the response spectra which are not present in the other analyses. These peaks occur at 11.3 hz which is approximately the natural frequency of the stiff backfill, table II.

The iterated shear wave velocities presented in table III show that there is relatively little reduction in shear wave velocity from the low strain values for these analyses. In the impedance function analyses the peak of the response spectra at the top of the containment occur at a slightly higher frequency than the peak of the response spectra at the base of the structure (3.78 hz vs 3.60 hz). The natural frequency of the structure is 3.78. Thus, the natural frequency of the structure occurs on the slope of the base response spectra.

6. CONCLUSIONS

All analyses yield fundamental frequencies of response and building accelerations which are in close agreement. The peak amplitudes of the response spectra differ by a noticeable amount. The lower amplitude of the uniform half space analysis is apparently caused by the higher radiation damping than in the layered solution. The response amplitudes are lower in the uniform half space model even though the material damping used is lower. However, the comparable FLUSH results, without backfill, show even lower results in spite of the inclusion of the effects of layering. The FLUSH analysis with artificially stiff backfill demonstrates that the backfill causes a response at the backfill frequency. This is not apparent in the analysis with standard backfill because the standard backfill has the same fundamental frequency as the soil structure system, see table II. The fact that the natural frequency of the structure occurs on the sloping portion of the base response spectra indicates that if a two step analysis were done with a building model being excited with the base motion calculated from one of the analyses performed here, the resulting responses could vary in amplitude depending on the frequency of the model being excited. Any analyses with a frequency much different than 3.78 hz. would yield responses which would be in error in amplitude.

The mode shapes and frequencies for the modal analysis equivalent modal damping appear from their shapes not to be accurate, but based on the response spectra for the top and base and the acceleration curves, they are accurate enough to yield results comparable to the other methods for the points on the structure where results are presented. The results for this method of analysis might not be accurate enough for other points.

7. ACKNOWLEDGEMENT

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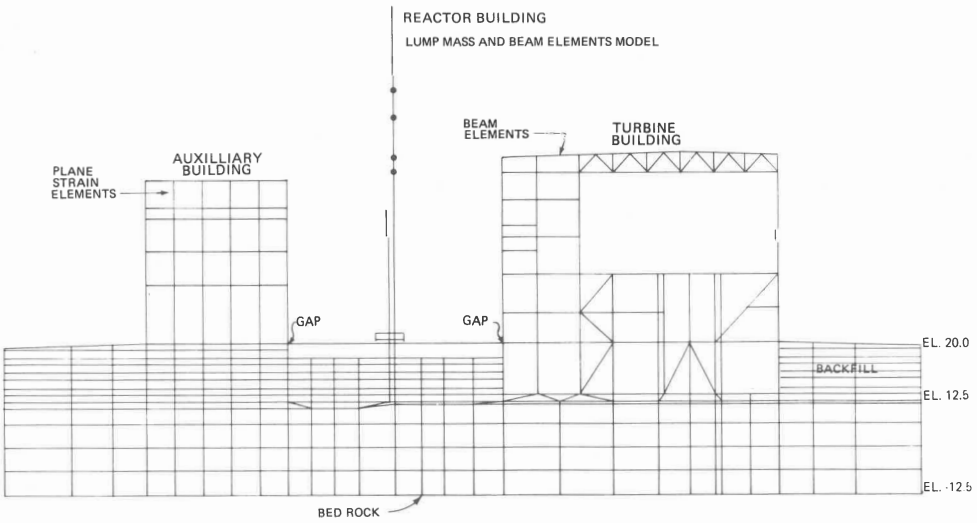


FIGURE 1-FLUSH MODEL

Table I Analyses Performed

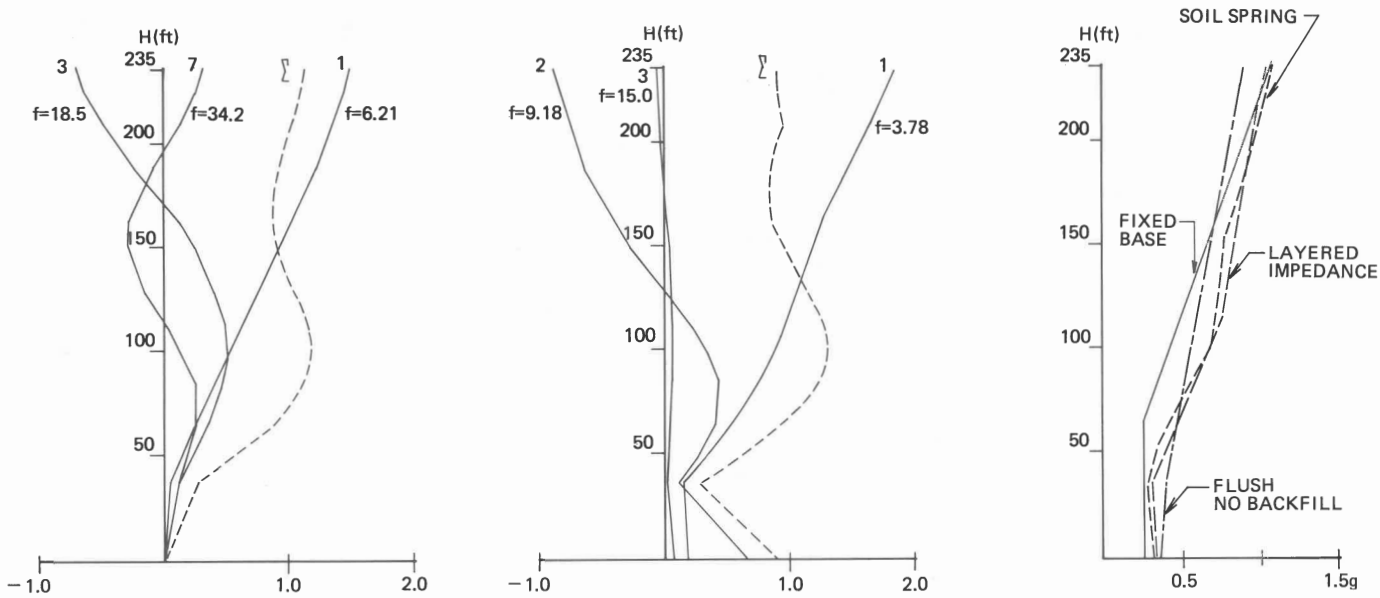
Fixed Base	Modal Analysis Response Spectrum
Impedance	1. Constant with Equivalent Modal Damping 2. Constant with FFT solution 3. Frequency Dependent with FFT solution a. Uniform half space b. Layered half space
Finite Element (FLUSH)	1. No backfill 2. Regular Backfill 3. Very stiff backfill

Table II Approximate Horizontal Soil Column Frequencies (Hz.)

Standard Backfill	3.4
Soil Below Containment	9.0
Total Soil Column with Standard Backfill	2.5
Stiff Backfill	12
Total Soil Column with Stiff Backfill	5.1

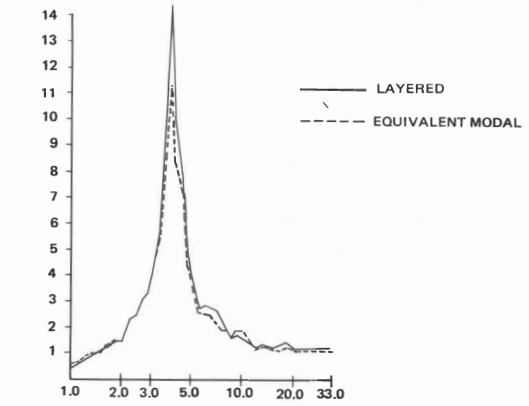
Table II Soil Shear Wave Velocities

Layer	Elevation at Top of Layer (ft)	Standard Low Strain V_s (ft/sec)	Standard Iterated V_s (ft/sec)	Stiff Iterated V_s (ft/sec)
1	20.0	506	473	1677
2	18.5	602	481	1664
3	13.5	689	498	1644
4	10.0	729	477	1612
5	5.0	741	446	1517
6	1.0	772	425	1491
7	- 4.5	794	418	1471
8	- 8.0	794	395	1456
9	-12.5	1950	1697	1694
10	-16.0	1950	1685	1680
11	-22.5	2230	1954	1942
12	-39.5	2430	2134	2116
13	-54.0	2650	2339	2308

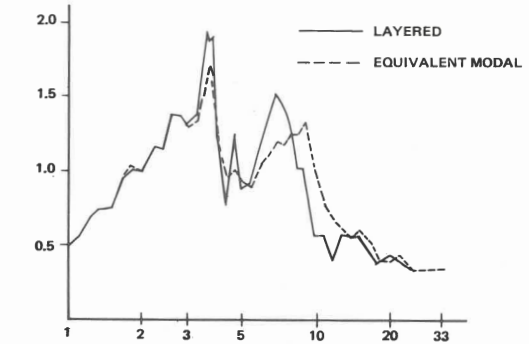


NOTE: MODES NOT INDICATED ARE MODES OF THE INTERNAL STRUCTURE AND EQUIPMENT

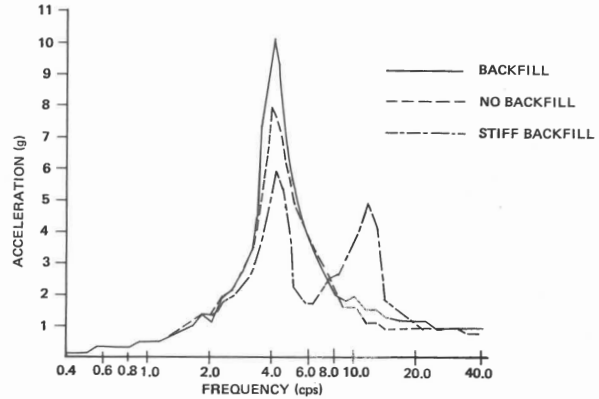
FIGURE 2 - MODE SHAPES, FREQUENCIES AND ACCELERATION PROFILES



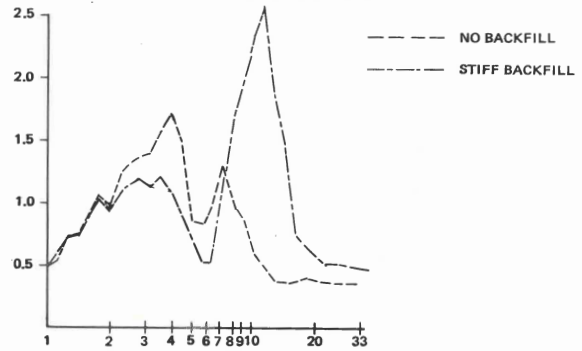
A) TOP OF CONTAINMENT IMPEDENCE



B) BASE OF CONTAINMENT IMPEDENCE



C) TOP OF CONTAINMENT FLUSH



D) BASE OF CONTAINMENT FLUSH

FIGURE 3 - 2% DAMPING RESPONSE SPECTRA