Coupling of Impedance Functions to Nuclear Reactor Building for Soil-structure Interaction Analysis

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SUMMARY

Finite element model of a nuclear reactor building is coupled to complex soil impedance functions and soil-structure-interaction analysis is carried out in frequency domain. In the second type of analysis applied in this paper, soil impedance functions are used to evaluate equivalent soil springs and dashpots of soil. These are coupled to the structure model in order to carry out the time marching analysis. Three types of soil profiles are considered: hard, medium and soft.Results of two analyzes are compared on the same structural model. Equivalent soil springs and dashpots are determined using new method based on the least square approximation.

1 INTRODUCTION

Consider nuclear reactor building resting on soil and excited by an earthquake acceleration time history. The soil is generally assumed to be horizontally layered. The upper subsystem representing a structure is modelled by Finite Elements as a 3D beam model, Fig.1.

Impedance functions of soil are calulated using the method based on Green's Function approach in frequency domain (Luco and Apsel, 1983).

In order to perform time marching analysis, impedance functions of soil are replaced by equivalent SDOF systems which are determined for each DOF of the coupling point of structure and soil. Its parameters are called Equivalent Soil Spring, Vibrating Mass and Equivalent Soil Damping.

2 FREQUENCY DOMAIN ANALYSIS USING COUPLED IMPEDANCES

Finite element model of the structure gives rise to the family of algebraic equations

$$(M\circ\Omega^2 + i\circ C\circ\Omega + K)\circ X(\Omega) = P\circ A(\Omega)$$

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one for each driving frequency Ω, where $X(\Omega)$ and $A(\Omega)$ denote the Fourier transforms of displacement $x(t)$ and input ground acceleration $a(t)$, respectively and $i=\sqrt{-1}$. The term

$$S(\Omega) = (-M\circ\Omega^2 + K) + i\circ C\circ\Omega$$

is known as Complex Stiffness Matrix of the upper subsystem. Evidently, the function $S(\Omega)$ and the impedance function of soil, denoted by $I(\Omega)$, can algebraically be coupled as blocks of the matrix of the total system. The resulting system of equations to solve has now the form

$$\begin{bmatrix} S_{11}(\Omega) & S_{12}(\Omega) \\ S_{21}(\Omega) & S_{22}(\Omega)+I(\Omega) \end{bmatrix} \circ X(\Omega) = P\circ A(\Omega)$$

where index 2 denotes the DOF's of the coupling point which is adjacent to soil and structure. Such algebraic equation is given for each driving frequencies Ω of interest. Now, the standard frequency domain analysis is applied.

3 TIME MARCHING ANALYSIS USING SOIL EQUIVALENT

In order to couple soil with the upper structure in time domain the mechanical equivalents for already calculated impedances are to be determined. We present here a new method for this task, which uses an approximation of impedances as functions of frequencies in relevant frequency intervals. In comparison with the classical procedure which uses impedance functions pointwise only, this is a more natural approach from the mathematical point of view. This is due to mathematical property of the Fourier transformation that a single spring in time domain corresponds to function in frequency domain rather then to a single impedance value, (Schwartz, 1961).

In our approach the best SDOF system in the sense of mathematical Least Square Method is determined, which fit given complex soil impedances.Due to the nature of the problem, however, it is dependent on the frequency interval starting at zero frequency and ending at some frequency which we call Edge Frequency and denote by f_{edge}.

Let us discuss the notion of the edge frequency more closely. From practical point of view, edge frequency will not be higher then the maximum frequency used in the calculation of the impedance functions.From engineering point of view, the higher the edge frequency, the more usefull equivalent SDOF system, that is the more frequency range can be covered by an equivalent SDOF system. Therefore,the task is to choose highest possible f_{edge}. This will obviously be limited from above by the quality of the impedance functions due to physical fact, that the soil profile does not behaves like a SDOF system exactly, and therefore the numerical least square error will increase for high values of f_{edge}. In opposite, the worse the impedance functions are, the smaller f_{edge} can be taken, that is the more severe the SSI problem is.

It is clear now, that the notion of edge frequency gives rise to an efficient numerical criterium for SSI, (Danisch and Delinic, 1989).

In the critical case when the numerically accepted f_{edge} is too small to include relevant frequencies for dynamic analysis, there will be no satisfactory approximation of soil impedances by any SDOF system, at all. In this case the more sophisticated methods should be applied, (Lysmer et al., 1981).

4 RESULTS OF ANALYSIS

Table 1 and 2 show the soil profile properties and equivalent SDOF choice respectively. In what follows comparison of response spectra is made between impedance solution in the frequency domain and time marching solution using equivalent SDOF system for different soil profils:

Fig 2 response spectra in the case of soft soil and rock.

Fig 3 floor response spectra at reactor vessel support for soft and hard soil.

The results show the previously discussed effect, i.e. the softer the soil, the less satisfactory the SDOF approximation of soil is, cf.Fig. 3.

5 COMPARISON OF METHODS

Generic preference for any of these two methods - frequency domain approach and equivalent SDOF system - can not be advocated because the relevance or irelevance of a specific advantage or disadvantage in a method depends on the problem to be solved.

The substructuring method is inevitable if the Eigenvalue Problem is to be solved in order to determine the Natural Frequencies of the structure. The same is true if time domain analysis should be performed, e.g. non-linear problem of uplift etc. However, the mechanical interface between soil and structure which appears in this case leads to a well known problem in handling of soil radiation damping including following two problems:

- estimatation of soil radiation damping
- correct treatement of it in the analysis of total system[1].

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[1] This aspect is the main reason for the well known "KTA limitation of the radiation damping" in the german KTA code.

In the frequency domain approach this problem does not occur because there is no explicit soil-structure interface, at all. Therefore the equivalent soil parameters are not needed and will usually not be estimated in the analysis.

On the other hand, frequency domain method can cause much calculation effort. Its another deficiency is that high frequency problems, e.g. aircraft impact can not be properly handled.

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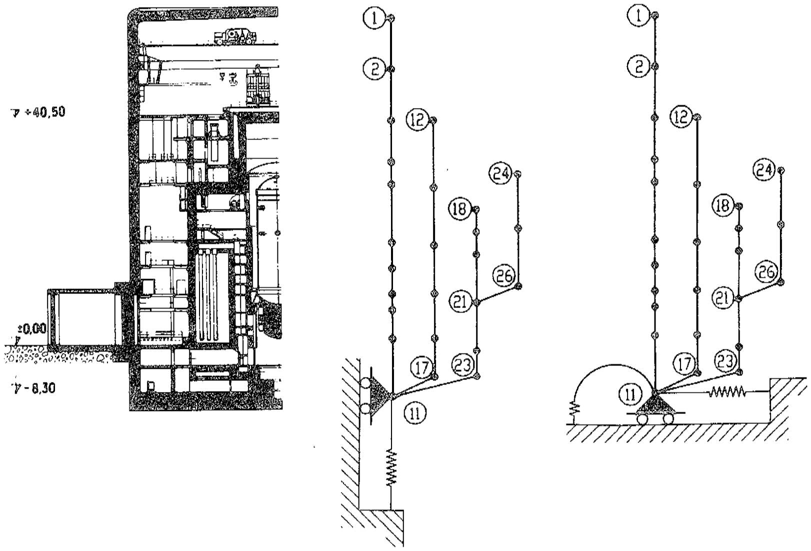

Fig.1 Finite element model

Soil	Thickness (m)	Shear modul (MN/m^2)	Poisson ratio -	Damping %	Spec.mass (t/m^3)
SOFT	1/2 space	50.0	0.47	5.0	2.10
	10.0	93.0	0.47	6.8	2.06
	10.0	103.0	0.47	7.7	2.10
MEDIUM	20.0	103.0	0.47	9.0	2.10
	20.0	134.0	0.47	9.5	2.06
	14.0	287.0	0.47	9.0	2.06
	Bedrock	600.0	0.32	7.0	2.14
ROCK	1/2 space	2000.0	0.32	2.0	2.10

Table 1 Soil profile

		Stiffness (kN/m)	Efective Mass (t)	Damping (kNs/m)
horizontal	SOFT	.682E+07	.631E+03	.711E+06
vertical		.755E+07	.296E+05	.241E+07
rocking		.426E+10	.471E+07	.359E+09
horizontal	MEDIUM	.127E+08	.106E+04	.105E+07
vertical		.208E+08	.378E+05	.363E+07
rocking		.901E+10	.598E+07	.459E+09
horizontal	ROCK	.260E+09	.425E+04	.473E+07
vertical		.318E+09	.216E+05	.858E+07
rocking		.158E+12	.109E+08	.120E+10

Table 2 Calculated equivalent SDOF

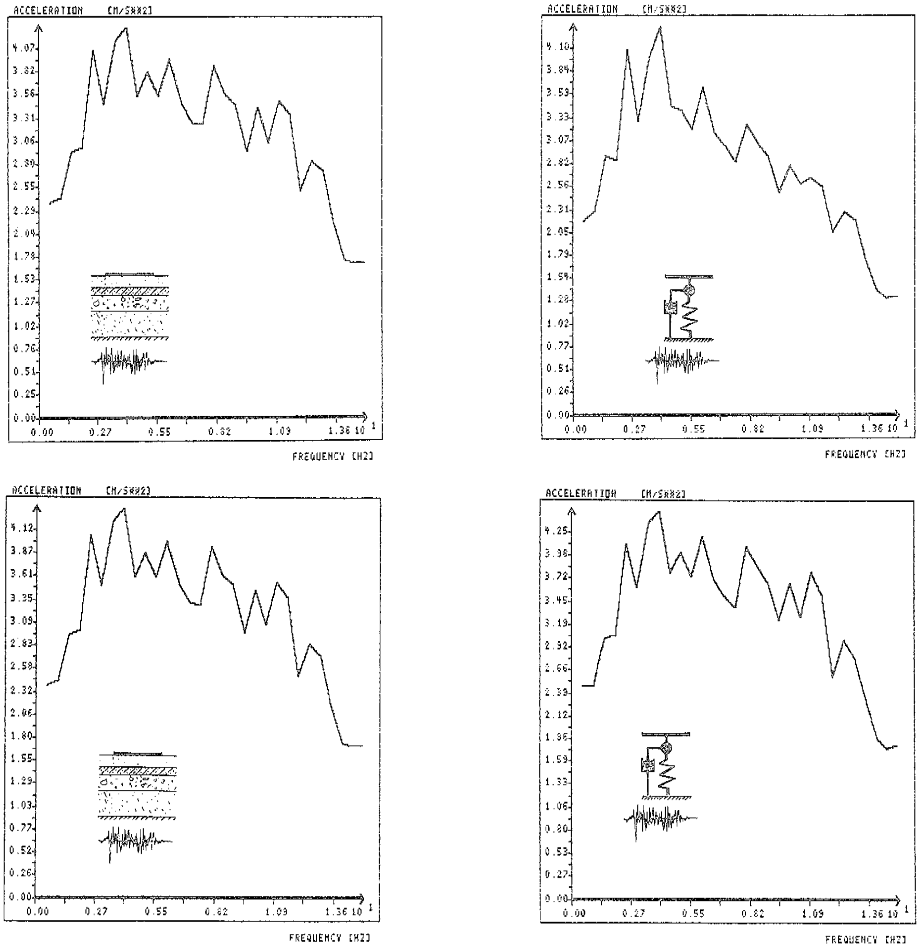

Fig.2 Response spectra without building structure for the case of soft soil (above) and rock (down)

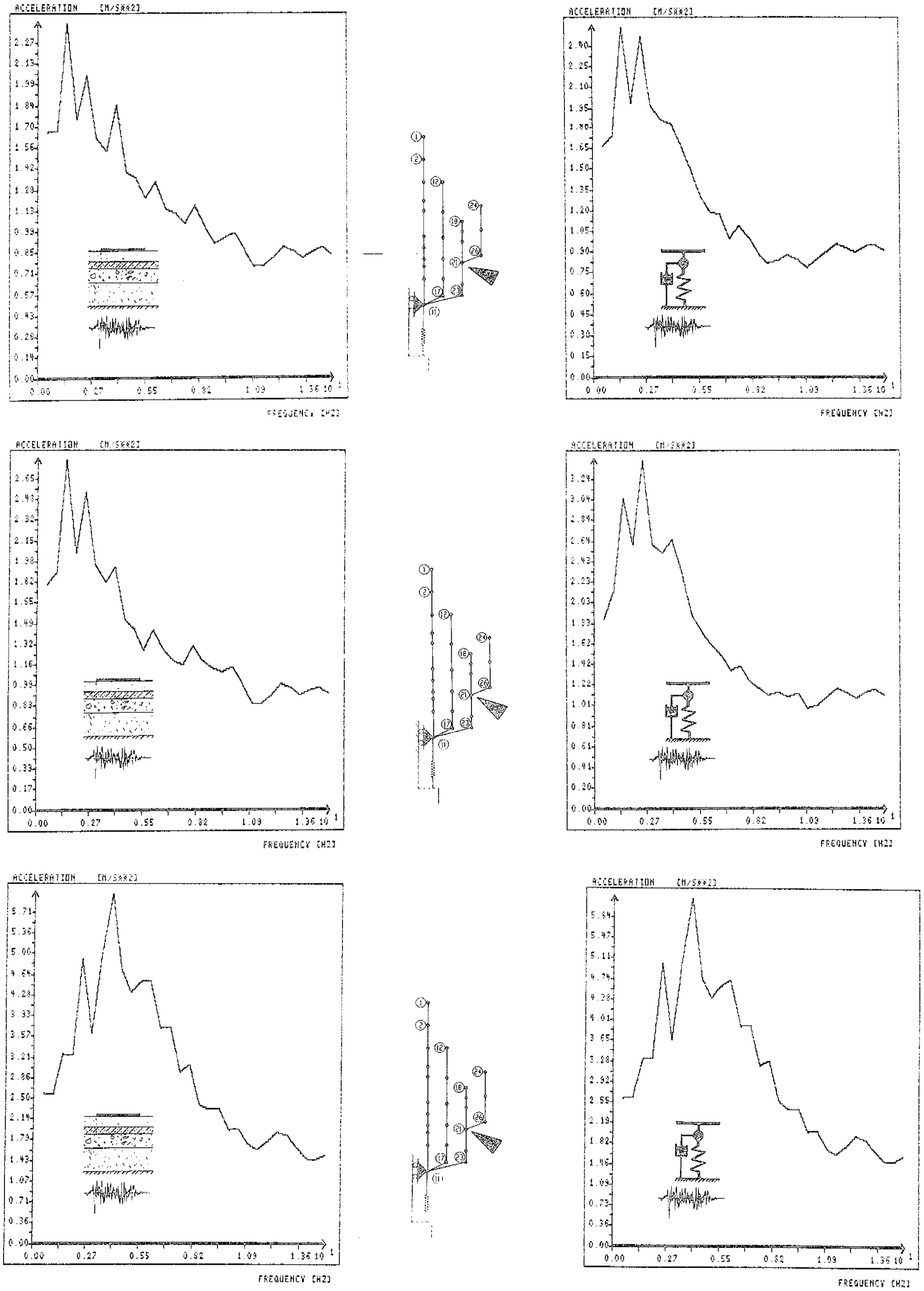

Fig 3 Response spectra including building structure at reactor pressure vessel support for soft soil (above), medium soil (middle) and rock (down)