A Three-Dimensional Soil-Structure Lumped Parameter Analysis for Earthquake Events

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Abstract

In seismic interaction analyses it is convenient to use a lumped parameter model as analog for the elastic half-space. However, in practice the value of lumped parameters applied in the calculation is bounded due to the deficiency in knowledge of proper material values of the generally layered media and due to the restriction of a generally applied modal analysis. The intention of this paper is to investigate the value and the influence of lumped parameters by using a specific finite element discretization instead of the lumped parameter model as analog for the half-space. The specific element discretization may be chosen according to impedance functions and are evaluated by comparison with entirely discretized soil-structure models.

1. Introduction

Soil conditions of sites for nuclear power plants are represented by layered media which may be substituted by an equivalent elastic half-space or by an equivalent layer on an elastic half-space. The reason for that is that due to increasing shear modulus with depth including discontinuities in stiffness values the upper soil region may be treated as bounded layer while approximately the boundary to the lower stiffer soil may be treated as rigid boundary.

For an ideal half-space the frequency-dependent parameters may be substituted by the analog of a frequency independent lumped parameter model showing a close correspondence with the transfer function for the first eigenfrequency /1/.

It may become rather difficult to obtain the proper values for the lumped parameters for a realistic site. In general the stiffness values are chosen according to the static stiffness values of an ideal half-space, and the damping is calculated using a mass parameter which is referred to the actual mass of the building /2/. The definition of the material values for the ideal half-space is the very problem for seismic engineering. Additionally in practice the damping values are artificially limited, which results in some cases in reduction factors about 2. This procedure of changing the damping parame-

ters only, however, violates the analog, since damping, mass and stiffness are one unique analog. For example, according to German regulation KTA 2201.3 the horizontal and rotational modes are restricted to 15 % and the vertical mode is restricted to 30 % of critical damping.

2. Formulation of the problem

Even for the fictitious site condition "elastic layer of limited thickness" the discretization of the soil-structure system is self-prohibited, due to computational reasons the analog lumped parameter model has to be applied. Dependent on the degree of exploration for the local soil material the parameter values may be estimated best or may be calculated by regression analysis using the impedance functions. Impedance function for layered media may be calculated analytically /3/ or by finite element method /4/.

3. Model

In order to investigate the influence of lumped parameter values on a containment building for a nuclear power plant a three-dimensional discreti-

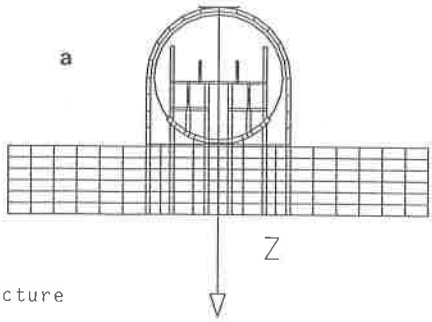


Fig. 1a: Axi-symmetric soil-structure system, model 1

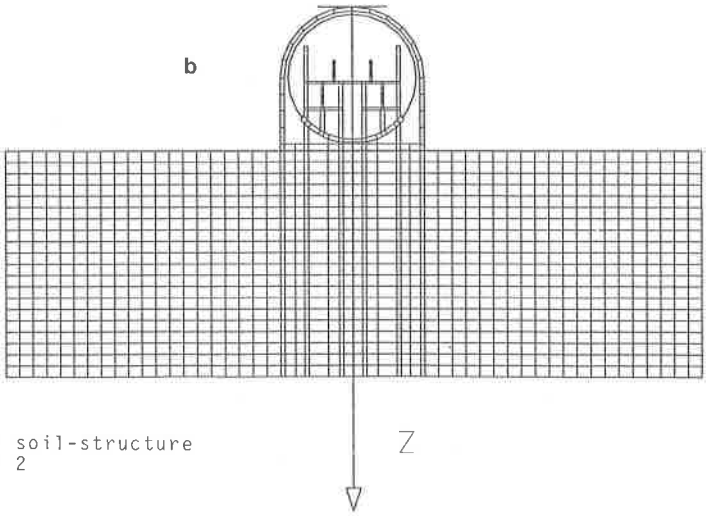


Fig. 1b: Axi-symmetric soil-structure system, model 2

zation using VOLUME elements /5/ is chosen. As for the axi-symmetrical structure the 0th harmonic is decisive for the vertical excitation and the 1st harmonic is decisive for the horizontal excitation, a second discretization is chosen having axi-symmetrical VOLUME elements /6/. Herewith, not only a verification of two computer codes with different mechanical philosophies is stated, but the axi-symmetrical case also permits to discretize soil layers of the overall soil-structure system, see fig. 1. This kind of modeling may be used exceptionally; in any case it gives a proof for the values of the analog lumped parameters.

Lumped parameters are referred to rigid plates on elastic half-space. The structural discretization of three-dimensional systems, however, shows a finite stiffness for the foundation plate. This discrepancy in modeling the plate may influence the analysis, since the lumped parameter for a flexible foundation /7/ deviates from the rigid lumped parameter. The investigations are started with the rigid lumped parameter, the influence of lumped parameters from the flexible plate has to be considered in further analyses. The flexibility of the foundation is most significant for the reduction of damping coefficients of the impedance function /7/, a regression analysis with these reduced parameters shows that the values of stiffness and radiation damping significantly decrease in comparison to the rigid plate parameter. A discretization of the complete soil-structure as shown in fig. 1 gives the influence of the flexible plate for a layered medium.

A further problem for a three-dimensional model is the discretization of lumped parameter values by means of a finite element analog. ASHSD /6/ decouples the horizontal from the vertical excitation, but for the coupled horizontal/rocking mode a specific finite element discretization has to fulfil these stiffness values. The solution when discretizing the soil is to substitute the soil stiffness by one or two layers of solid elements having fictitious values for shear modulus and Poisson's ration, fig. 2. As the elementation of the ASHSD code is sensitive to the ratio as well as to the absolute values of moduli for the discretization with one element layer, a TRUSS element has been included into the code to decouple this stiffness relationship. The two element layer discretization simulates a higher displacement function to adjust the proper stiffness values, since the VOLUME element has a linear displacement function only. The implicit integration scheme has to be modified for radiation damping.

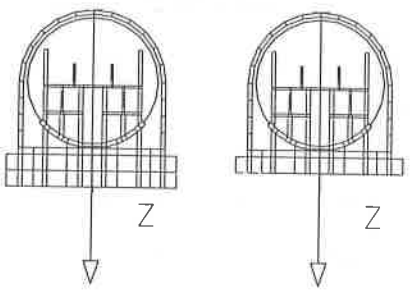
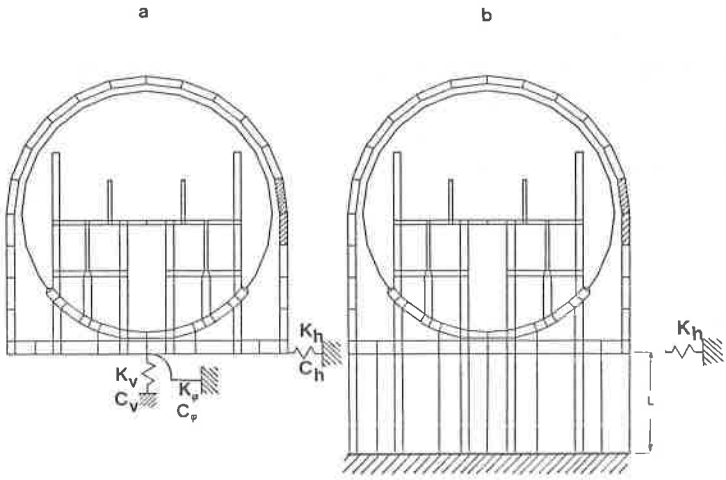


Fig. 2: Finite element analogs for axi-symmetric soil-structure system

For the three-dimensional code ADINA /5/ one layer of three dimensional elements having fictitious values for a Young's modulus and

SOIL MODELLING



LUMPED PARAMETER

(HALF SPACE)

G = 300 MN/m²
(SOIL SHEAR MODULUS)

ν = 0.45

FEM-DISCRETIZATION

E = F (SOIL)
(MODULUS OF ELASTICITY)

ν = F (SOIL)

L = F (SOIL)

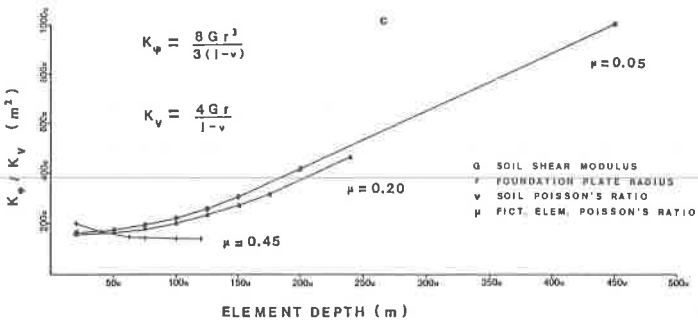


Fig. 3a: Three-dimensional lumped parameter analog for soil-structure interaction

Fig. 3b: Three-dimensional finite element analog for soil-structure interaction

Fig. 3c Correlation between half-space and FE analog

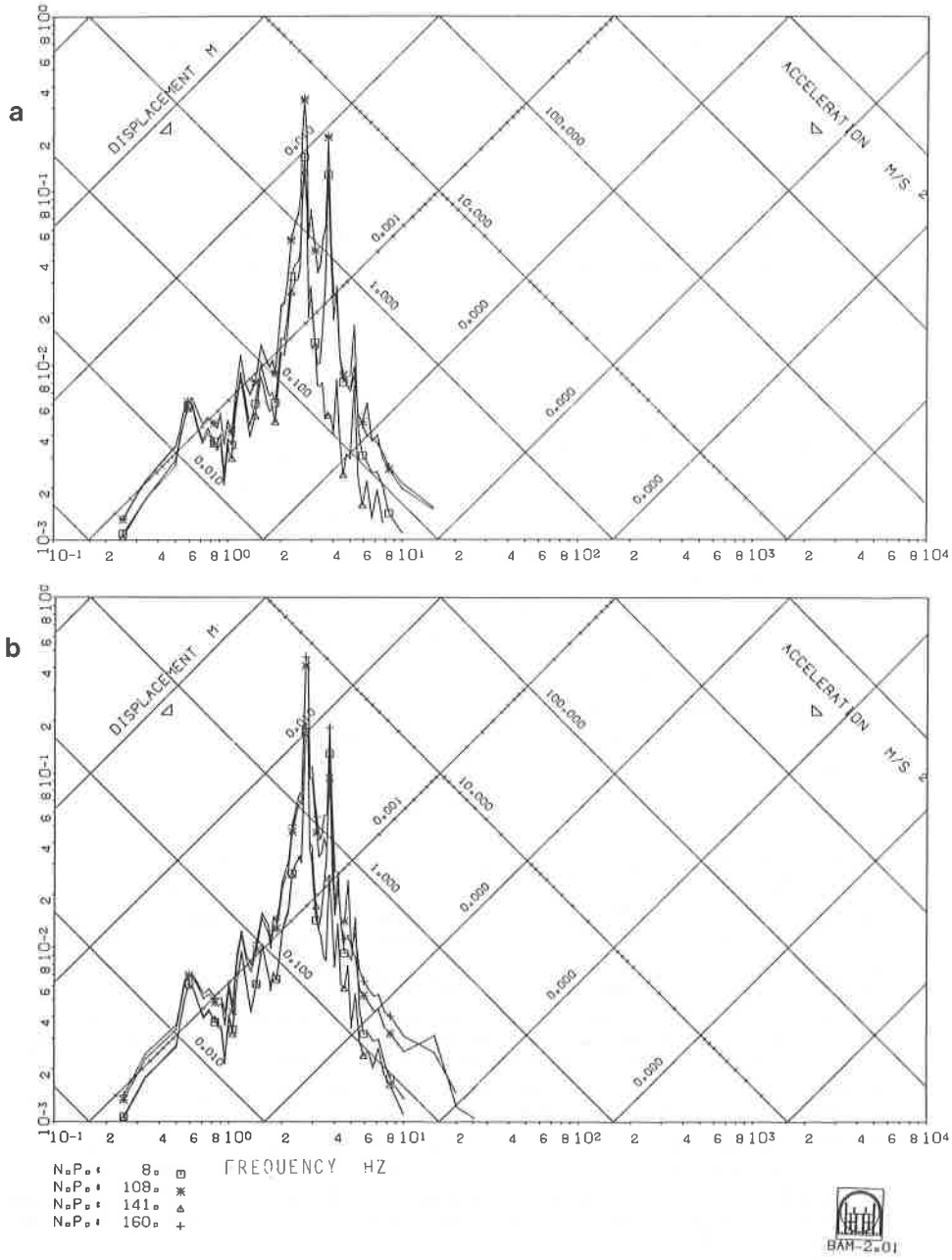


Fig. 4a: Response spectrum for model 1 with rigid foundation plate

Fig. 4b: Response spectrum for model 1 with flexible foundation plate

Poisson's ratio simulates the rocking and the vertical mode, for the horizontal mode TRUSS elements have to be applied in addition /8/. The terms of the stiffness matrix for a three-dimensional VOLUME element are rather difficult to verify, but it can be demonstrated that they are coupled through Poisson's ratio, element depth and ratio of element depth to element width. Young's modulus is only a multiplier. This behaviour allows for a typical discretization to generate a diagram where the ratio of rocking stiffness to vertical stiffness is depending on element depth, Poisson's ratio being parameter, fig. 3. For the absolute value of stiffnesses Young's modulus has to be multiplied; radiation damping has to be added to the model appropriately.

The calculations are based on TAFT excitation (TAFT N 69W), which is related to the free field surface by deconvolution for all discretizations.

4. Numerical results and conclusion

The parametric investigations for the considered models are rather costly and have not been finished. As a first result fig. 4 shows the influence of the foundation plate stiffness for model 1.

The studies on lumped parameters for three-dimensional discretizations are performed in order

- to determine the proper lumped parameter values for the given model,
- to investigate the influence of soil stiffness values and radiation damping values on the global structural response. Values are varied within a suitable bandwidth.

Other load cases like aircraft problems can also be investigated with the three-dimensional discretization for a soil with fictitious values.

References

/1/ F. E. Richart, J. R. Hall, R. W. Woods, "Vibrations of soil and foundations", Englewood Cliffs, New Jersey: Prentice-Hale Inc., 1970

/2/ König und Heunisch "Methodenuntersuchungen zur erdbebensicheren Auslegung von Kernkraftwerken", Forschungsprogramm Reaktorsicherheit, 1979

/3/ J. E. Luco "Impedance functions for a rigid foundation on a layered medium" Nuclear Engineering and Design 31 (1974) 204-217

/4/ T. S. Atalik, J. E. Luco, A. H. Hadjian "Dynamic modeling of the visco-elastic half-space by finite elements", 2nd ASCE Specialty Conference on Structural Design of Nuclear Plant Facilities, 1975

/5/ ADINA - A finite element program for automatic dynamic incremental nonlinear analysis, Report 82448-1, MIT (1976)

/6/ ASHSD - Dynamic stress analysis of axisymmetric structures under arbitrary loading, Report 69-10, University of California (1969)

/7/ M. Iguchi, J. E. Luco "Dynamic response of flexible rectangular foundations on an elastic half-space", Earthquake Engineering and Structural Dynamics 9 (1981) 239-249

/8/ F. Buchhardt, G. Magiera, W. Matthees, M. Weber, "Untersuchungen zum Tragverhalten eines Kernkraftwerkes für den Lastfall Flugzeugabsturz", Amts- und Mitteilungsblatt der BAM 14 (1984), Nr. 3