Interaction of a Reactor and an Auxiliary Building During an Earthquake

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Abstract

The structure-soil-structure interaction of two adjacent buildings is analysed including nonlinear effects from opening of compression-only contacts between the base mats of the buildings. The actual geometries of the base mats are accounted for by use of a 3-dimensional soil-structure model. For comparison, maximum response values are also presented for the cases in which the interaction with the adjacent structure through the soil and through the bearings are neglected. The interaction effects are not of major importance.

1. Introduction

A circular PWR-reactor building and its adjacent auxiliary building have a common joint along one third of the periphery of the reactor building. The earthpressure of the backfill with a hight of approximately 10 m results in net static horizontal forces acting in opposite directions on each of the buildings. As the bituminous ground water seal under the base mats cannot transmit permanent shear forces, large shear keys under the base mats would be required. In order to avoid shear keys and to save construction cost and time, reinforced elastomeric bearings are placed vertically between the two base mats. They can transmit the lateral earthpressure forces directly from one mat to the other, and during an earthquake, their elasticity prevents large impact forces, which were to be expected at a concrete-against-concrete contact of the two base mats. Thus overstressing in the joint is avoided, and high frequency input motion from mutual pounding of the mats is reduced.

It is investigated how much these bearings as well as the coupling through the soil affect the seismic response of the structures. The investigation is performed in the context of an actual project, and both a minimum and a maximum soil stiffness for the given site are considered. The static compressive force in the bearings is varied because of the uncertainty in the earthpressure.

For comparison, response values will also be presented for the cases in which the interaction with the adjacent structure through the soil and through the bearings are neglected.

2. Models

In the analysis, the actual geometries of the base mats are included by use of a 3-dimensional soil-structure model (Fig. 1). The soil is treated as a linear visco-elastic layered medium which extends laterally to infinity and vertically to a depth of 260 m. At this depth boundary conditions are applied which absorb P- and S-waves impinging from above at small and moderate angles from the vertical direction /1/. The soil medium is joint to the base mats of the structures by collocation at the elements shown in Fig. 1.

By the aid of semi-analytic explicit solutions for dynamic point and disk loads applied on or within a layered medium /2,3,4/, a flexibility matrix is computed which relates displacements and forces of the soil medium at the center nodes of the elements (with three degrees of freedom at each node). As the base mats are actually rather stiff compared to the soft alluvial soil, they are assumed rigid for simplicity. With this assumption, the big flexibility matrix can be transformed into a foundation stiffness matrix with six degrees of freedom for each base mat. The flexibility and the stiffness matrices are frequency dependent.

In order to further simplify the subsequent analyses, only planar motion along the plane indicated in Fig. 1 is considered, neglecting torsional effects. Thus the 12 by 12 foundation stiffness matrix is reduced to a 6 by 6 matrix.

The structures are modelled by shear and bending beam elements and lumped masses including rotational inertia. Fig. 2 shows the model. The label KB in Fig. 2 indicates the coupling of the structures through the soil by a 6 by 6 matrix. KS denotes the spring which simulates the reinforced elastomeric bearings between the two base mats.

3. Methods of analysis

The structural response is analysed in the frequency and in the time domain. In the case of the frequency domain analysis transient time history response is computed by fast discrete Fourier transforms (FFT).

Radiation damping from soil-structure interaction can be handled more accurately in the frequency domain than in the time domain; however, nonlinear effects can be investigated only in the time domain. Therefore, modal damping values for a modal analysis in the time domain are chosen so that a good match of the resulting maximum response values with those of the frequency domain analysis is obtained for the linear case, in which the bearings between the base mats are allowed to sustain tension. With these modal damping values the nonlinear case, in which the bearings can resist compression only, is analysed by performing a step-by-step integration and treating the nonlinearity through corrective forces on the right-hand-side of the equations of motion.

4. Cases analysed

a) Case KB = 0, KS = 0

Reactor and auxiliary building are investigated separately. Coupling of the buildings through the soil and through the spring between the base mats is neglected. Therefore, the soil-structure interaction model (Fig. 1) includes in this case only the base mat of one building at a time. The analysis is performed via the frequency domain.

b) Case KB, KS = O

Same as a), but coupling of the buildings through the soil is included.

c) Case KB, KS

Coupling of the buildings through the soil and a spring between the base mats is included. The spring has a stiffness of 50 MN/mm and can sustain tension. A linear analysis via the frequency domain is performed.

d) Case TD-L

Same as c), but the analysis is performed in the time domain by modal analysis. The structural modes are computed using the values of the frequency dependent 6 by 6 foundation stiffness matrix at the first resonant frequency computed for c). Modal damping values are selected so that a good match with the maximum response of the frequency domain analysis, case c), is obtained.

e) Case TD-NL

Same as d), but non-linear analysis which accounts for the fact that the spring between the base mats cannot sustain tension. The static compression force in the spring is set to zero as a lower limit.

f) Case TD-NL

Same as e), but the static compression force in the spring is set to 50 MN, which is the earth pressure force on the buildings at rest condition.

The same acceleration time-history is used as ground motion input to both buildings in each of the six cases. It corresponds to the USNRC standard spectrum /5/ except for frequencies below 2,5 Hz, where the spectral values are somewhat reduced. Its maximum acceleration is 0,2 g.

5. Results of analysis

Maximum accelerations computed for the six cases are listed in Table 1 for nodes 3 and 14 at the auxiliary building and nodes 4, 33, and 38 at the reactor building. The differences between values at any one node are small, and the differences are not consistent for all nodes. This indicates that neither structure-soil-structure interaction nor the relatively stiff elastomeric bearings between the base mats have a significant effect on maximum structural response. The effects are of similar size as those which would result from different input time-histories that correspond to the same ground response spectrum.

Fig. 3 presents horizontal acceleration response spectra (at 2% damping) for the structural motion computed by way of the frequency domain analyses with and without coupling effects. The structure-soil-structure interaction (KB) as well as the spring between the mats (KS) do not affect the spectra significantly, except for some decrease of the response peak at the base mats (see node 4 in Fig. 3).

Fig. 4 indicates that the linear modal analysis yields somewhat higher response at frequencies below 3 Hz and somewhat lower response at frequencies above 3 Hz than the frequency domain analysis (KB, KS). The differences between the frequency domain analysis and the matched modal analysis are of similar size as those in Fig. 3 between the frequency domain analyses with and without coupling effects.

Fig. 5 shows the nonlinear effects caused by the no-tension spring between the base mats. The nonlinear effects are more visible in case of no static compression of the spring (TD NL) than in the case with 50 MN static compression (TD NL-5,not shown in Fig. 5). In both cases, the nonlinear effects on the response spectra are insignificant.

The maximum gap between the elastomeric bearings (fixed to one base mat) and the opposite base mat, which opens and closes during the earthquake, is computed to less than 4 mm. The maximum earthquake induced compression force in the spring, representing the bearings, is less than 100 MN, which is approximately 30% and 40% of the maximum base shear force of the reactor and auxiliary building, respectively. However, this spring force hardly increases the total shear forces in the structures. The base shear forces due to ground motion are large when both base mats move horizontally more or less in phase and small when both mats move in opposite directions. Therefore the forces transmitted through the bearings are small when the base shear forces are large and vice versa.

All results presented are for soft alluvial soil conditions (the shear modulus increases from 100 MN/m^2 at the foundation level to 350 MN/m^2 at 200m depth). The response accelerations computed for stiff alluvial soil conditions (shear modulus isdoubled) are higher, because the fundamental eigenfrequencies of the structures are increased and moved towards the peak of the ground acceleration spectrum. However, the effects of structure-soil-structure interaction and of the bearings between the base mats is as small or even smaller than in the soft soil case.

6. Conclusions

The seismic interaction of the reactor and the auxiliary buildings due to coupling through the soil and due to the elastomeric bearings between the base mats is not very important.

Elastomeric bearings can be used to transmit lateral earthpressure forces from one building to the other (in order to avoid large shear keys under the base mats) without increasing the seismic response of the structures and the equipment.

7. References

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Table 1: Peak accelerations [cm/s²] obtained from different analyses for points of reactor and auxiliary building

Identifications		KB=0 KS=0	KB KS=0	KB KS	TD L	TD NL	TD NL-5
coupling through soil		no	x	x	x	x	x
contact spring		no	no	x	x	x	x
freq. domain analysis		x	x	x			
linear TD analysis					x		
non-linear TD analysis						x	x
static contact force [MN]						0	50
Nodes	3	160	170	157	161	163	161
	14	167	183	172	171	176	171
	4	152	131	151	162	153	162
	33	129	130	126	125	130	124
	38	152	145	152	153	160	153

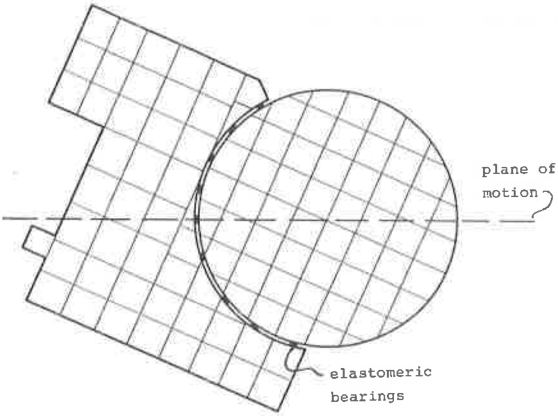

Fig. 1: 3-D model of base mats on layered soil

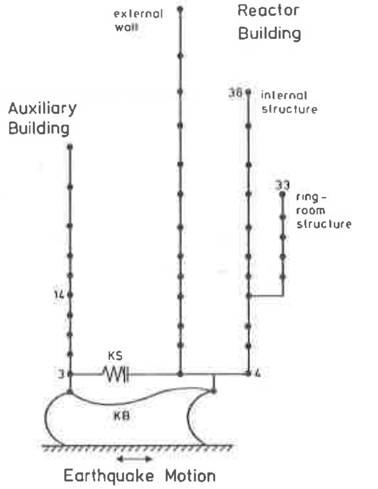

Fig. 2: Structural models coupled through soil (KB) and spring between base mats (KS)

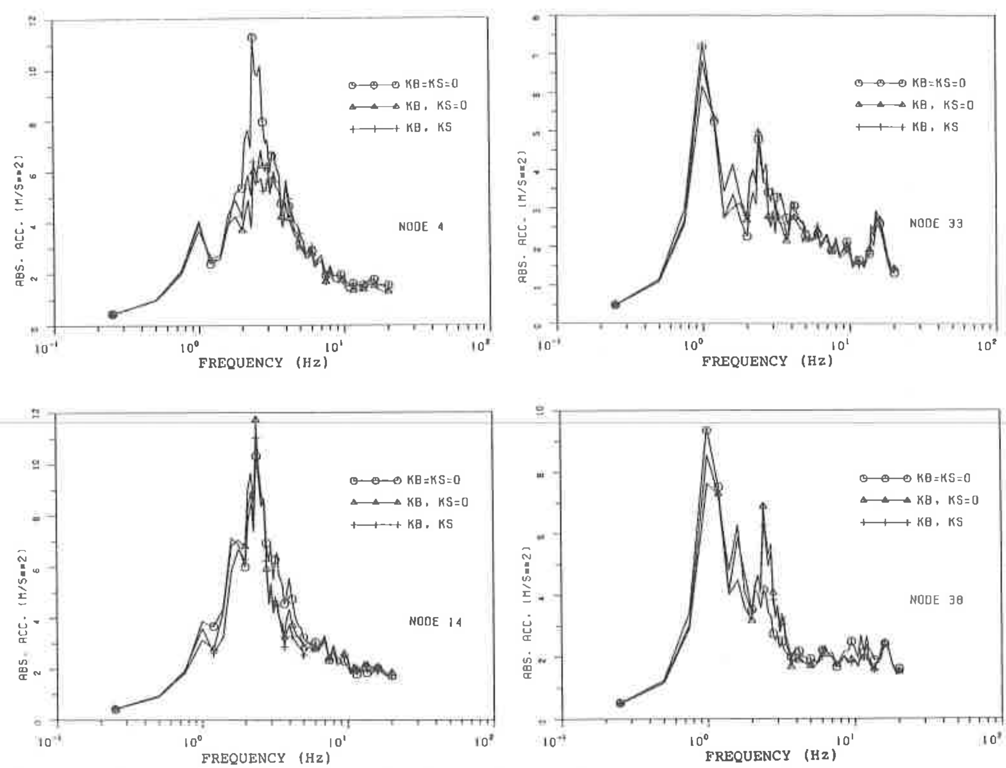

Fig. 3: Response spectra for horizontal acceleration with and without interaction of adjacent building through soil and bearings

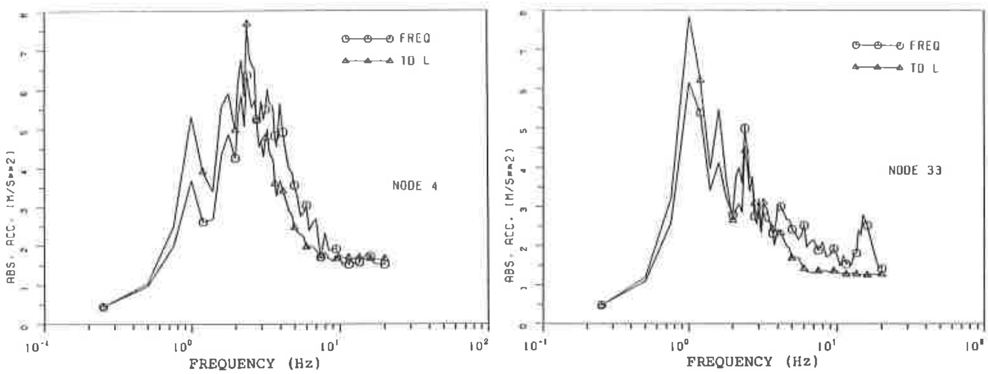

Fig. 4: Response spectra for horizontal acceleration with interaction of adjacent building, frequency domain vs. modal analysis

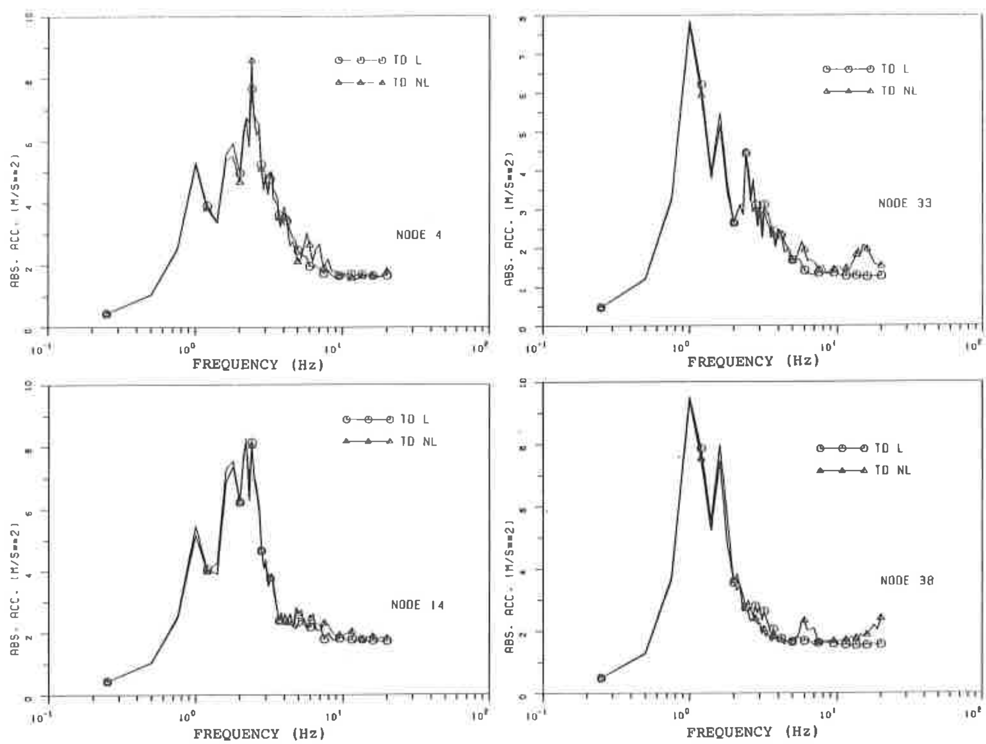

Fig. 5: Response spectra for horizontal acceleration with interaction of adjacent buildings, linear vs. nonlinear analysis