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COMPARISON OF SEISMIC RESPONSES WITH A RANGE OF SOIL-STRUCTURE INTERACTION PARAMETERS AND COMPUTATIONAL METHODS

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SUMMARY

This paper presents the results of a comparative study that was made by SGN in order to determine the influence of specific soil-structure interaction parameters on the main physical quantities of the seismic response for typical buildings of a nuclear fuel reprocessing plant. The considered parameters were the soil dynamic shear modulus, the soil-structure interaction impedances calculation method, the presence of adjacent buildings and the building embedment.

INTRODUCTION

In order to determine the influence of several soil-structure interaction parameters on the seismic response of typical buidings of a nuclear fuel reprocessing plant, SGN has performed a study on the models of four buildings. The study consists in evaluating the seismic response of these buildings with a range of numerical parameters such as the dynamic shear shear modulus and several cases of logical parameters such as the calculation hypothesis and method and in showing the tendancy for each parameter variation.

GENERAL DATA

Main characteristics of studied buildings are shown below :

TYPE	WEIGHT (t)	WIDTH (m)	LENGTH (m)	HEIGHT (m)
A	53 159	42,40	44,30	35,80
B	106 318	42,40	88,60	35,80
C	70 030	36,40	50,30	40,90
D	105 606	37,20	73,20	53,76

The dynamic models used were equivalent vertical beam and concentrated mass models. The input seismic motion was specified as a single ground acceleration response spectrum for all buildings (see fig. 1).

Except for the study of embedment effects, the foundation soil was assumed to be an homogeneous infinite half space with a 1.8 t/m^3 density and a 5% internal damping ratio.

Seismic response of the buildings were computed by a modal spectral calculation and a simple quadratic combination of the individual modal responses.

Soil-structure interaction was represented by mass, springs and dampers computed by one of the methods described herebelow.

RICHART and HALL method

This method takes into account the rectangular shape of the foundation, but does not allow for variation of impedances with frequency. the version used was the one with soil mass associated with foundation raft mass.

ROSENBLUETH method

This method has the same features as the previous one. It thus takes into account a rectangular foundation shape, constant impedances and soil mass associated with foundation raft mass.

DELEUZE method

This method was developed for circular foundations. Rectangular foundation shape were taken into account by a computational artifice using a circular foundation with the same surface area or inertia. Variation of soil impedances with frequency was taken into account. This method was established for a linear distribution of soil stress, whereas the considered case entails a stiff displacement.

TAJIMI method

This method is similar to the DELEUZE method, but has been developed for a rectangular foundation and the formulae are simpler. Only the damping values depend on the frequency. Vertical displacement is not considered.

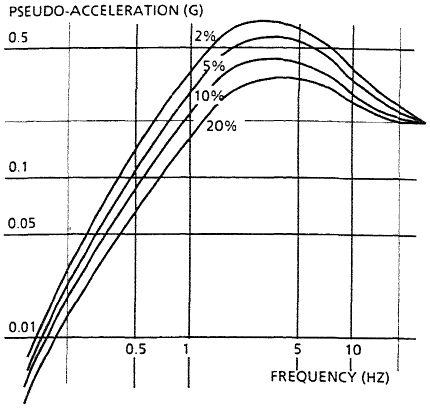

Fig.1 - Ground response spectrum used for the study

SOPHONIE method

The SOPHONIE program computes the impedances for a rectangular shaped building foundation by representing it by several discrete circles. Each elementary circle impedance is computed using the DELEUZE functions. Discrete element computations should yield a surface area and inertia equal to those of the actual raft.

The assumptions used with this method are the closest to reality:

*allowance for actual foundation shape

*allowance for variation of impedances with frequency

*allowance for stiff displacement of the foundation.

Complementary rules about damping Soil damping is taken equal to half of the radiative damping given by the hereabove described method plus the internal damping (5%), limited to a 30% upper bound.

Modal damping ratio are computed as balanced material damping ratios.

Modal damping is limited to a 20% upper bound.

INFLUENCE OF SOIL DYNAMIC SHEAR MODULUS

Dynamic analyses of A building were performed for various soil dynamic modulus between 50 and 30000 MPa and infinitely stiff soil (sixed base). The impedances were computed by the DELEUZE formulae for the fundamental mode frequency in each direction. Main results are shown in figures 2 through 5.

For the considered building, the study showed that:

* The first mode is a soil mode for a dynamic shear modulus G less than 1000 MPa and a structural mode for G greater than 10000 MPa in the horizontal direction or 30000 MPa in the vertical direction,

* Soil structure interaction is effective up to extremely high soil dynamic shear modulus values (40000 MPa),

* Its influence generally tends to increase the exerted forces, except for the extremely low values of G (less than 150 MPa in the horizontal direction and 30 MPa in the vertical direction),

* The increase of exerted forces is greater in the vertical direction than in the horizontal direction,

* The influence of soil structure interaction reaches a peak when the frequency of the first natural mode equals the frequency at which the ground response spectrum is at a maximum, i.e. in our case for a 4 to 5 hz frequency, which corresponds to a 500 to 1000 MPa value of G in the case of the A building,

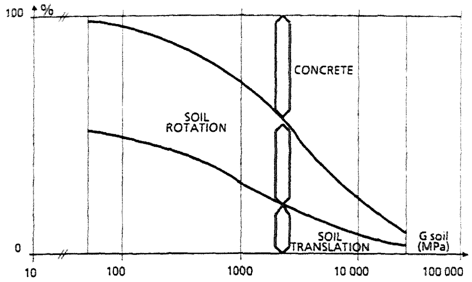

Fig.2. Horizontal seismic component in the building transverse direction: potential energy distribution

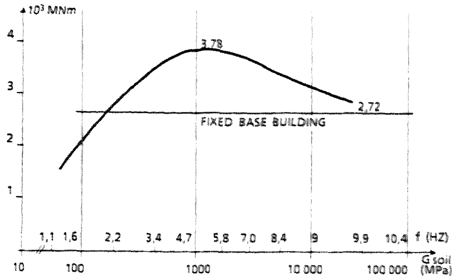

Fig.3. Horizontal seismic component in the building transverse direction: moment at building base

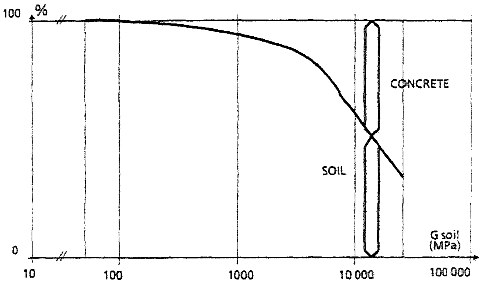

Fig.4. Vertical seismic component : potential energy distribution

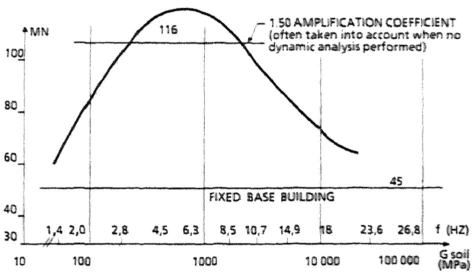

Fig.5. Vertical seismic component : vertical forces at building base

* The basic 1.50 amplification coefficient often used to compute the vertical response without any dynamic analysis is conservative for stiff soils(G greater than 2000 MPa) and slightly below actual values for non-rigid soils(G less than 2000 MPa) taking into account the unfavourable 20% mode damping limitation. The validity range of this conclusion would of course be wider without this limitation.

INFLUENCE OF SOIL IMPEDANCE COMPUTATIONAL METHOD

The study aimed at evaluating the influence of the soil structure interaction computational method used on the dynamic seismic design results obtained for a building. The building taken as an example is rectangular with a length-to-width ratio of 2(B building). A parameter variation study was performed on the value of G in the 50-30000 MPa range. Main results are shown in figures 6 to 9.

Natural frequencies The results obtained with the various methods used are very similar. The SOPHONIE program yield the highest frequencies. It is therefore advisable to assess the natural frequencies using a simple method(RICHART and HALL or ROSENBLUETH) before using one of the other methods, nearer to the reality but requiring iterative computations for determining the natural frequencies.

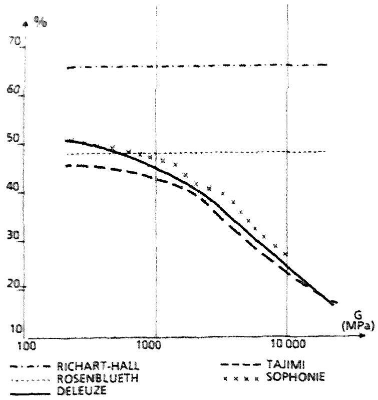

Fig. 6. Horizontal seismic component in the building transverse direction :radiative damping of the horizontal spring

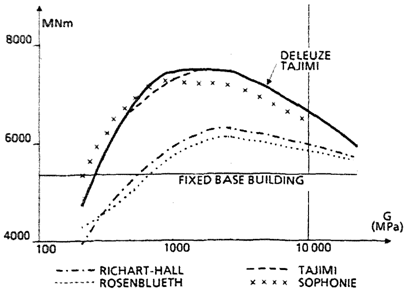

Fig. 7. Horizontal seismic component in the building transverse direction : moment at building base

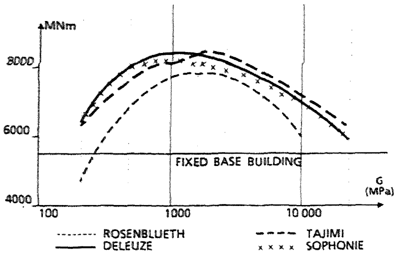

Fig. 8. Horizontal seismic component in the building longitudinal direction: moment at building base

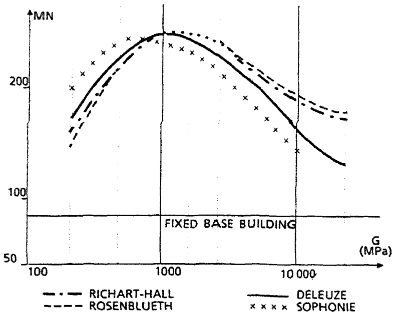

Fig. 9. Vertical seismic component vertical forces at building base

Soil radiative damping The DELEUZE and TAJIMI methods and the SOPHONIE program yield similar results. The RICHART and HALL and ROSENBLUETH methods yields significantly different results compared to those three methods. The results of the ROSENBLUETH method are closer to those of the three methods above than the results of RICHART and HALL for the horizontal direction, the inverse being true in the vertical direction.

Overall seismic forces at building base The seismic computation results for each group of methods (RICHART and HALL and ROSENBLUETH on one hand; DELEUZE,TAJIMI and SOPHONIE on the other hand) were very similar. The forces determined by the first group were much smaller than the others in the horizontal direction and were a little smaller for low soil moduli(<1000 MPa). They were greater for the high soil shear moduli(>1000 MPa) in the vertical direction.
A simple method (RICHART and HALL or ROSENBLUETH) is often used to design the building in a preliminary stage. It was showed that, in such instances seismic forces at the building base may be underestimated in the horizontal direction compared with the values that could be obtained using the DELEUZE,TAJIMI or SOPHONIE methods . Consequently it is careful to increase by about 15% the horizontal shear forces computed and by about 30% the overturning and bending moments.

Pseudo-accelerations at building top These pseudo-accelerations provide a proportional indication of the forces exerted at the top of the building.In the horizontal direction, the effect of soil-structure interaction on the forces exerted at the top of the structure is not the same as at the base. The increase compared to blocked base building case is smaller and a decrease is even observed for a soil shear modulus below 1000 MPa in the transverse direction and 5000 MPa in the longitudinal direction.The effect of soil-structure interaction in the vertical direction is the same for forces exerted at the top and at the base of the building.

INFLUENCE OF DAMPING LIMITATION

Computation rules currently applied at SGN require three types of damping limitation. The first is a limitation of radiative damping to half the value computed in an infinite, homogeneous half space hypothesis, it allows to take into account foundation soil discontinuities. The two others are a limitation of damping for each soil spring to 30% and a limitation of mode damping to 20% of the critical value. The study attempted to determine the order of magnitude of their influence on seismic responses. The most important differences are found for vertical forces. Figure 10 and 11 show the results for B building: the elimination of the 30%(soil) and 20%(mode) damping limitation would result in a particularly significant decrease of seismic forces in the vertical direction and a more significant decrease for the low soil shear moduli. In the horizontal direction, only very low shear moduli (<2000 MPa) show a decrease of forces. In the considered cases, the maximum decrease was 30% for the vertical forces.

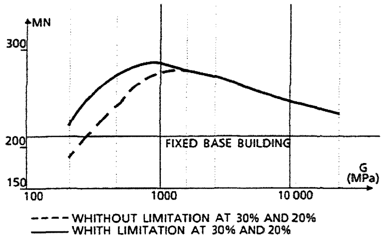

Fig. 10. Horizontal forces at building base in the longitudinal direction

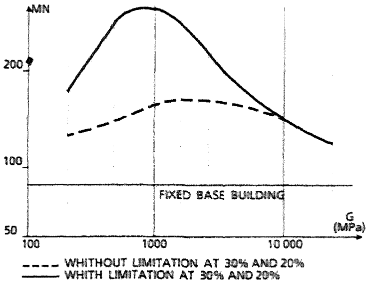

Fig. 11. Vertical forces at building base

INFLUENCE OF INTERACTION BETWEEN ADJACENT BUILDINGS

The study compared soil impedances and seismic responses for two contiguous buildings:

a) without taking into account interaction between the buildings(each building designed as a separate structure),

b) taking into account interaction between buildings.

The computations were performed using the SOPHONIE program(the only method among those listed hereabove that can take this phenomenon into account) for A and C buildings. Terms were input to allow for coupling between the two foundation rafts. Mode damping was limited to 50% (instead of 20%). Main results are shown in figures 12 & 13.

Allowance for the presence of an adjacent building yields in the considered case:

* an increase of diagonal terms of the impedance matrix
* a slight decrease of the first eigenfrequencies essentially due to the presence of non diagonal terms in the impedance matrix.
* a decrease of the soil radiative damping .

Finally the global seismic forces were increased by

* 10% in the direction towards the adjacent building
* 25% in the perpendicular direction

* 30% in the vertical direction for the most unfavourable case of soil shear modulus. It must be therefore noticed that this tendancy is not true in the *direction of adjacent building for very low soil shear moduli.*

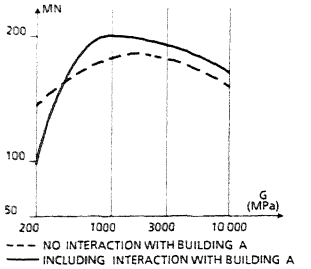

Fig. 12.Horizontal forces at C Building base in the direction of A Building

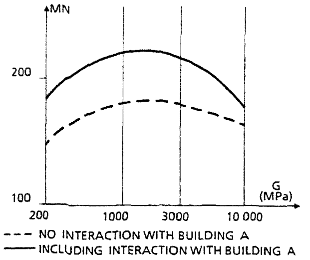

Fig. 13.Horizontal forces at C Building base in the direction perpendicular to the direction of A Building

INFLUENCE OF BUILDING EMBEDMENT

D building, which is embedded 28.50 m into the soil, was considered in the transverse horizontal direction. Surface seismic motion was the accelerogram of the SAN FERNANDO earthquake. Seismic motion at the foundation level was deconvoluted through the original soil layer using the SHAKE program. The influence of embedment on the soil impedances was computed using NOVAK's formulae, assuming that the building is surrounded by an infinite embankment the dynamic shear modulus of which was taken equal to 5% the foundation soil modulus.

Comparison of ground response spectra at the natural land surface and at the foundation level indicated a decrease in spectral accelerations for frequencies above 4 hz. Near the building fundamental frequency(5 to 6 hz), the decrease is about 35% for a damping value of 5%.
Low frequency components were not modified. Decrease in the overturning moment and the shear force at the base due to the deconvolution was 28%.

Presence of the embankment had little influence, less than 10% on the element stiffness. However, its influence was much greater on the damping values, particularly for the rocking motion(multiplied by 4). In the considered case the decrease in the overall moment or forces exerted at the building base was found to be about 20%.

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