Nuclear Buildings on Soft Soil: A Special Soil-Structure Interaction Problem

Vlastar I. APOSTOLESCU
ISPE Nuclear Department, Bucharest, Romania
Ovidiu COMAN
National Commission for Nuclear Activities Control, Bucharest, Romania

ABSTRACT

The soil-basemat-structure interaction problem for the foundation of nuclear buildings of a CANDU 600 MWe NPP on a large reinforced concrete basemat is presented and solved. The existence of the basemat introduces a supplementary step in the classical three-step interaction analysis procedure; this step is necessary in order to determine the seismic excitation at basemat-structure interface.

1 INTRODUCTION

A conceptual solution for the foundation of the nuclear buildings of a CANDU 600 NPP at a site with relatively soft soil and moderate seismicity (SSE/DBE peak horizontal ground acceleration 0.2 g) is presented. The conditions to be met were geotechnical (relatively low soil bearing pressures) and seismic (avoidance of seismic redesign of standard nuclear equipment and systems, previously checked for a reference rock site with an 0.2 g SSE/DBE). Both conditions are met by introducing a large basemat covering the nuclear island.

2 INPUT DATA

These consist of (a) the geotechnical soil strata data (fig.1); (b) the viscoelastic nonlinear dynamic properties, i.e. the G-γ and D-γ curves for each soil stratum (fig.2); (c) the free field seismic ground response spectrum for horizontal motion (fig.3), supplied by the specialised agency; the vertical response spectrum was assumed to be 0.67 times the horizontal one; and (d) the general plan arrangement of the proposed basemat, including building loads (fig.4).

3 ANALYSIS METHOD AND RESULTS

Prior to the main analysis, numerical investigations were ca-

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rried out on a number of simplified equivalent 2D models, in order to determine the minimum mat thickness satisfying both the geotechnical and seismic conditions; this thickness was found to be 6.o m.

The main analysis procedure consists of the following steps:

Step 1 is devoted to the determination of the dynamic soil+mat stiffness matrices for each building. A 3D soil model of 2oo x 24o x 12o m was used; the analysis was performed with the SAPLI 5 code, modified to permit matrix condensation; the resultant stiffnesses were found to be comparable to those determined for a reference rock site without mat (table 1).

A static analysis of the mat-soil system was also performed in this step.

Table 1. Reactor building foundation stiffnesses

	Translations 10^7 t/m			Rotations 10^{10} tm/r		
	k_x	k_y	k_z	$k_{x\varphi}$	$k_{y\varphi}$	$k_{z\varphi}$
Static stiffnesses						
Reference rock site						
-medium soil	o.435	o.435	o.631	o.183	o.183	o.268
Actual site						
-medium soil	o.158	o.158	o.236	o.o67	o.o67	o.o9o
-medium soil+ 6 m mat	o.412	o.419	o.4o7	o.244	o.248	o.94o
Dynamic stiffnesses						
Reference soil site						
-soft soil	1.2o3	1.2o3	1.885	o.5o5	o.5o5	o.7o6
-rigid soil	2.774	2.774	3.875	1.176	1.176	1.752
Actual site						
-medium soil	o.425	o.427	o.682	o.195	o.195	o.231
-medium soil+ 6 m mat	1.o5o	1.o25	o.985	o.488	o.492	1.876
-medium soil+ 8 m mat	1.o8o	1.o6o	1.13o	o.825	o.825	1.56o

Step 2 can be divided into two substeps:

Step 2.1. is concerned with the soil-mat kinematic interaction analysis, carried out with the FLUSH program, on a pseudo-3D model, in which the soil is introduced with its mass, its nonlinear stiffness and nonlinear viscoelastic damping properties, while the mat is introduced only with its stiffness properties. The result is the response spectrum applied to the soil-mat interface (fig.5).

In step 2.2., the stiffness K and mass M matrices are determined for each structure lying on the mat; the matrices are reduced by means of a rigid transformation, relative to the rigidity center of each mat-structure contact area and are of dimension 6 x 6.

The K and M matrices of the mat are also determined, relative to the rigidity center of each mat-structure contact area; these matrices are of dimension 36 x 36.

The soil K matrix and the mat and structures K and M matrices are then selectively assembled; the dynamic interaction problem is successively solved for each structure separately; the structure involved is assigned only the stiffness properties (fig.6). The analysis is carried out by means of the ASEM code, written to this purpose. The results consist of the response spectra applied to the mat-structure interface, specific for each structure supported on the mat, including the influence of soil, mat and of interactions of adjacent structures (fig.7).

In step 3, a separate full dynamic analysis is carried out for each structure supported on the mat, using the spectral method with modal analysis. The bottom connection of the model is a condensed stiffness matrix of the soil-mat system. The results are seismic stresses, strains, displacements, accelerations, as well as floor response spectra (fig.8, fig.9).

The seismic forces in the basemat were also computed, applying the global reactions, distributed according to elementary rules on the basemat top. An equivalent static analysis was then performed on a 3D model of the mat, considered as a plate supported by an elastic medium, loaded separately with the distributed dynamic reaction of each structure, the earthquake excitation acting along each of the three space directions.

4 CONCLUSIONS

Results support the following conclusions:(a) Effective static and dynamic soil pressures values are below allowable values. (b) The 6 m thick basemat is capable to sustain the maximum bending moment of 2392 tm/m. (c) Maximum seismic structural responses, including floor response spectra, are below values obtained for the reference site, with some unimportant exceptions. (d) The basemat constitutes an effective means to equalise large local pressures and to moderate seismic structural responses. (e) A significant influence of a heavy structure (reactor building) upon the seismic motion of a lighter structure (i.e. service building part II) is evident typically in floor response spectra at frequencies of 8...12 Hz.

REFERENCES

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Kausel E., (1982). Dynamics of structures with foundation interaction. Massachusetts Institute of Technology.

Seed H.B., Idriss I.M., (197o). Soil moduli and damping factors for dynamic response analysis.

NAME AND DESCRIPTION OF LAYER	DEPTHS m	DYNAMIC PROPERTIES			
		V_s m/s	G_0 daN/cm^2	D_0 %	SPECIFIC WEIGHT t/m^3
1. Sandy clay	0.00 -3.00	230	970	5.4	1.80
A. Piedmont deposits: small, medium and large gravel, wits boulders and claysh sand	-8.00 -18.00 -35.00	280 400 480 550 580 700	1630 3347 4820 6328 6933 10250	4.5	2.05
B. Marls with sandy intercalations and volcanic ash	-80.00	420 500	3780 5350	5.1	2.1

Fig. 1 SOIL LAYER PROPERTIES

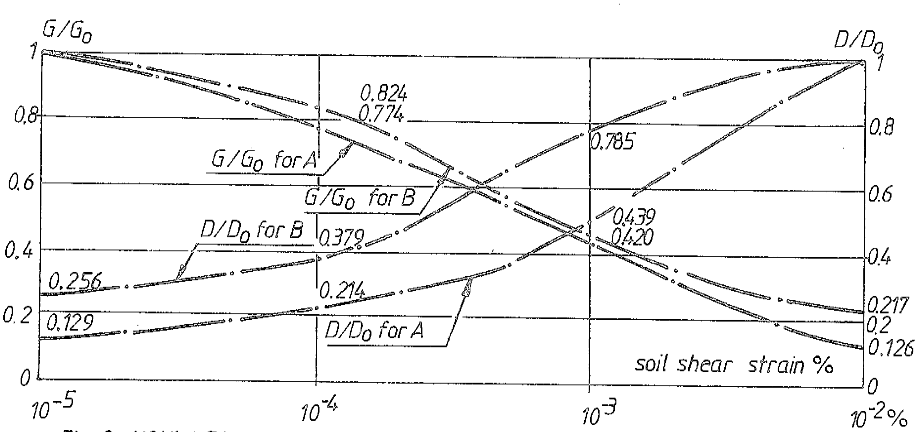

Fig. 2 NONLINEAR DYNAMIC SOIL PROPERTIES

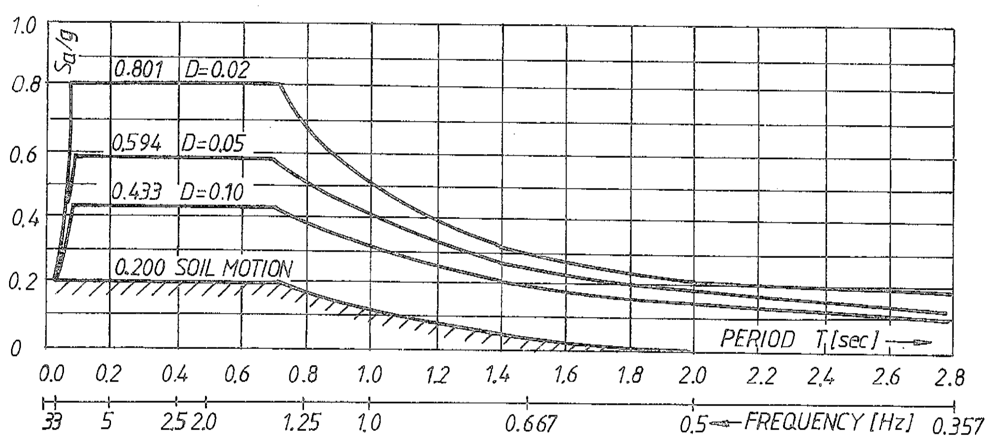

Fig. 3 FREE FIELD SOIL SEISMIC ACCELERATION RESPONSE SPECTRUM

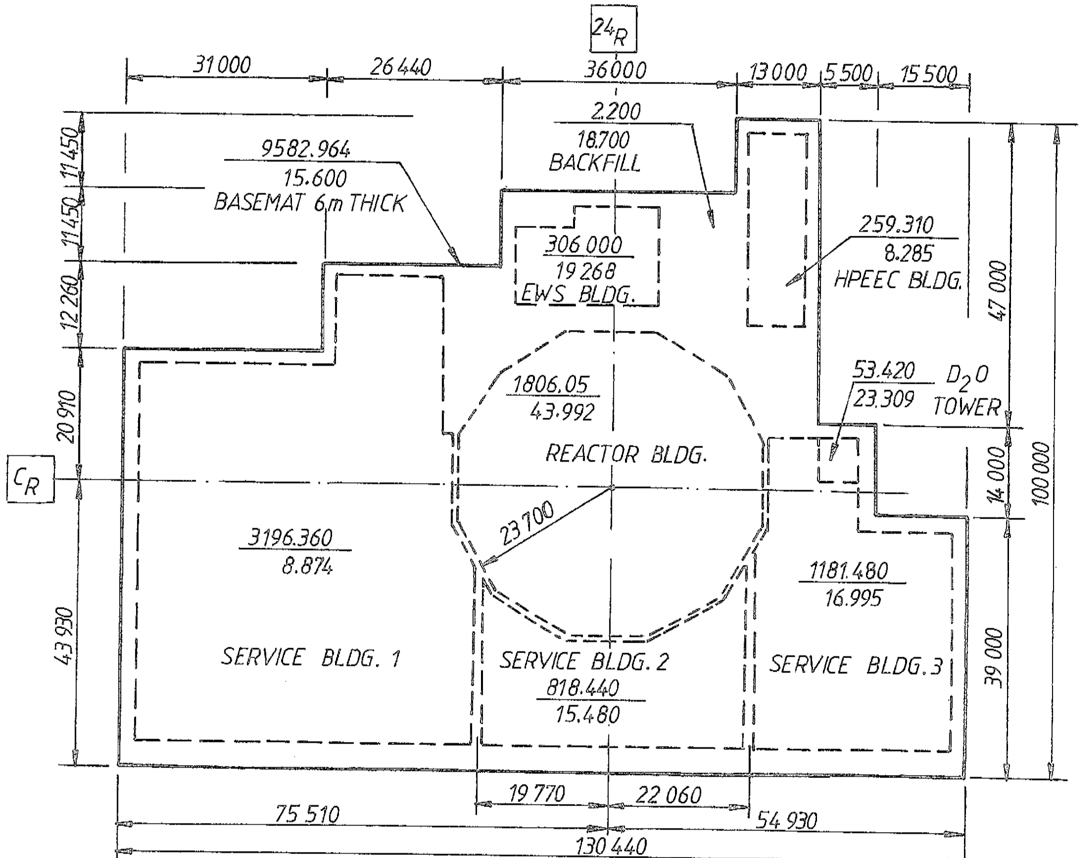

Fig. 4 GENERAL ARRANGEMENT OF BASEMAT. FOR EACH STRUCTURE SUPORTED ON MAT THE UPPER NUMBER DENOTES CONTACT AREA IN m^2; LOWER NUMBER DENOTES AVERAGE PRESSURE IN TONS/m^2 AT TOP OF BASEMAT

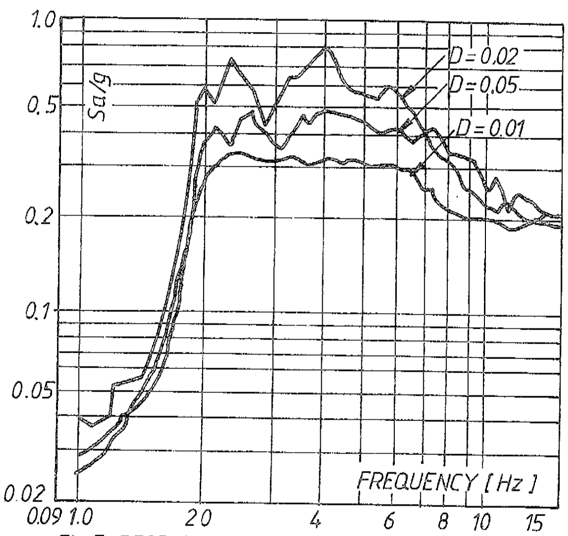

Fig 5 RESPONSE SPECTRUM AT SOIL-MAT INTERFACE

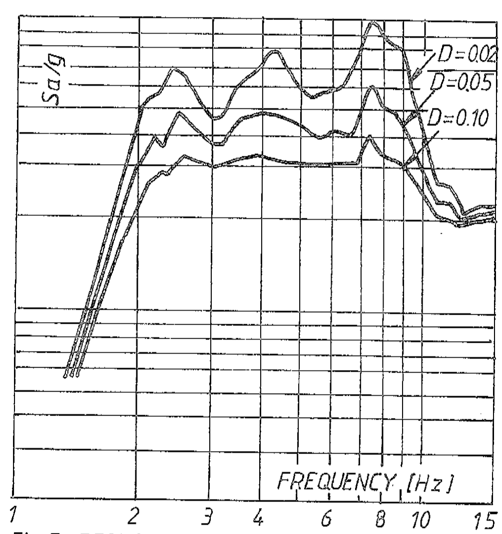

Fig.7 RESPONSE SPECTRUM AT MAT-REACTOR BUILDING INTERFACE

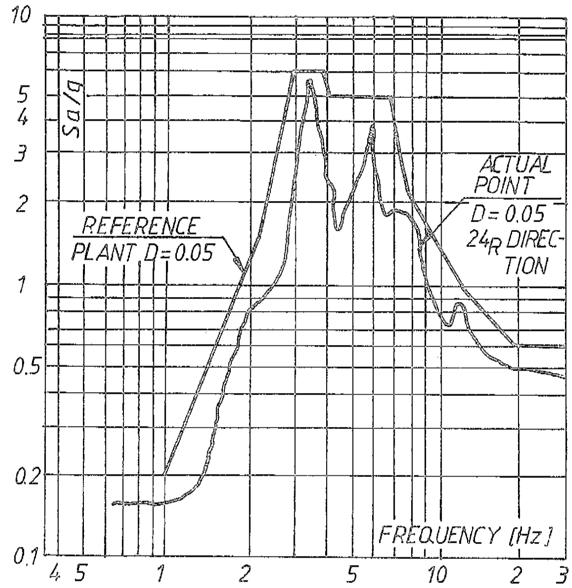

Fig. 8 FLOOR RESPONSE SPECTRUM REACTOR BUILDING ELEV. 117.45. COMPARISON WITH REFERENCE PLANT SPECTRUM

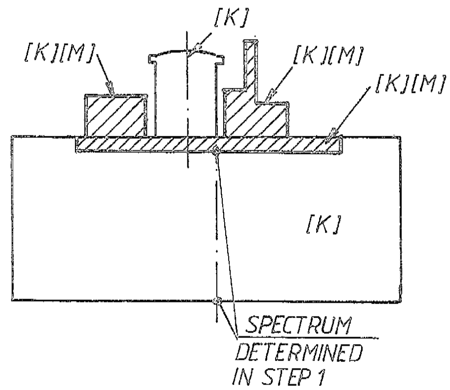

Fig. 6 MODEL USED FOR THE SOIL-MAT REACTOR BUILDING STRUCTURE INTERACTION

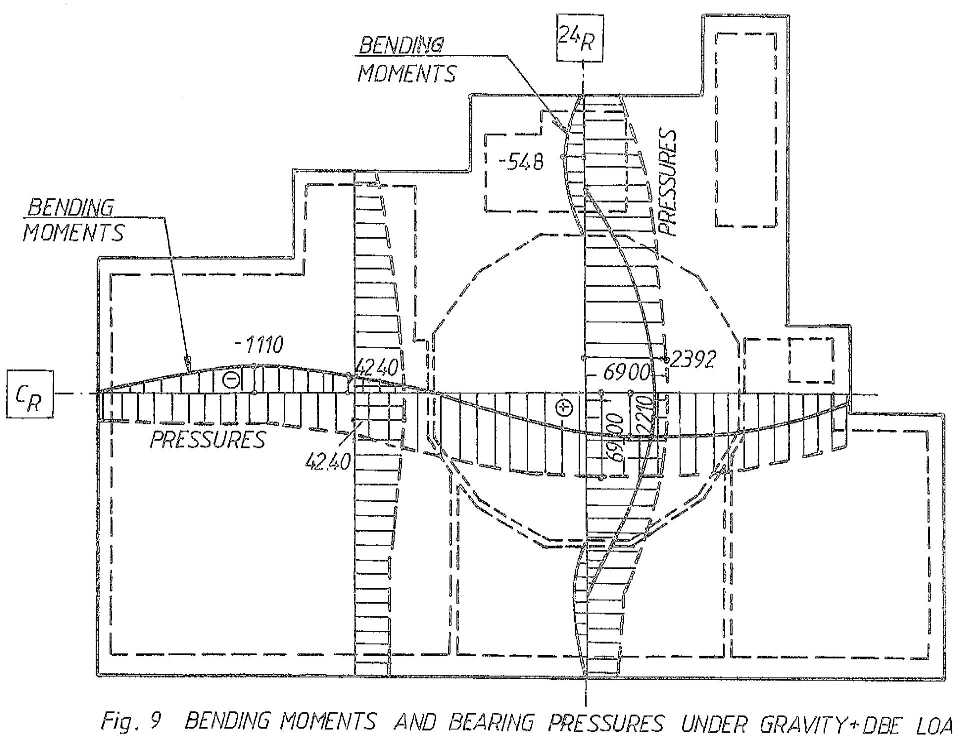

Fig. 9 BENDING MOMENTS AND BEARING PRESSURES UNDER GRAVITY+DBE LOADS

—— BENDING MOMENTS [tm/m]

--- BEARING PRESSURES [tons/m^2]