EFFECTS OF INPUT STRUCTURAL DATES FOR DISPLACEMENTS AND INTERNAL FORCES OF STRUCTURES IN CASE OF EARTHQUAKE

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Abstract

This paper analyses the effects of uncertainties in the modulus of elasticity of the constructional material, soil stiffness and the mass of structure on models corresponding to two typical structures in the Paks Nuclear Power Plant. The structure has been modelled as a beam model, and in computation of soil springs, a stiff foundation has been taken into account. Analyses show that masses must be taken into account as correctly as possible, but the effects of soil stiffness are sharply different with flexible and rigid structures. This effect in the case of flexible buildings is less important than in the case of rigid-box-like structures.

1. INTRODUCTION

In earthquake computation of structures, structural models of increasing preciseness are created, and engineers try to take the interactions between structure and soil into account approaching the reality as close as possible. For performing computations with models of high degree of freedom, not linear due to frequency-dependent soil stiffness, efficient computations methods have been elaborated. The decision on exciting spectra necessary for earthquake calculation is based on extensive analyses. Afterwards, some basic data must be given as input parameters at the beginning of computations. The task seems to be simple as modulus of elasticity of the reinforced concrete structure or the soil (soil strata) are well-known parameters. However, real values actually occurring are not known, values chosen by engineers based on various considerations will be surely others than the real ones. The same applies to the mass of the structure. No model can be precise enough to accurately demonstrate the masses computable from the dead weight of the structure, weight of the auxiliary structures (coverings, etc.) and technological equipment. In static tests, uncertainties due to these inaccurate parameters can be handled easily (e.g. applying appropriate safety factors with loads). However, in earthquake examinations, discrepancies of the above mentioned characteristics affect the dynamic properties of the system. If another frequency belongs to a given oscillation pattern, another value of the exciting spectrum must be used in computations. This value may be either larger or smaller than the original one depending on the location of the given frequency in the spectrum curve.

From the above follows that results of the dynamic computations must be handled and interpreted with proper caution because of the uncertainties in the input parameters.

2. TEST PARAMETERS AND MODELS

Effect of alteration of the modulus of elasticity of the reinforced concrete structures was examined so that calculations were carried out not only for the design data, i. e. values determined on the basis of related codes but also for three quarters and four thirds of the corresponding value:

$$0.75 \times E_{giv} < E < 1.33 \times E_{giv}$$

For mass characteristics, a large difference like with the modulus of elasticity cannot occur in a careful examination, therefore, the test interval was as follows:

$$0.9 \times M_{giv} < M < 1.1 \times M_{giv}$$

At the same time, in the case of soil stiffness much greater differences were foreseen because there is really a much greater uncertainty in these data. Furthermore, analysable effects can be only awaited for these marked differences.
Therefore:

$$0.1 \times R_{giv} < R < 10 \times R_{giv}$$

In the above relations E_{giv} , M_{giv} and R_{giv} are the given parameters, while E, M and R are the parameters the analyses were carried out with.

Presumably, effect of deviations in the individual parameters will be different for a flexible structure and a structure that can be regarded as a rigid box. In accordance with this, the ventilation chimney (Fig. 1) in Paks NPP as a flexible structure and an auxiliary building as a rigid box (Fig. 2) were chosen for tests.

Out of the horizontal and vertical response spectra applied in the tests, the horizontal response spectrum can be seen in Fig. 3.

The structure has been modelled as a beam model, and in computation of soil springs, a stiff foundation has been taken into account.

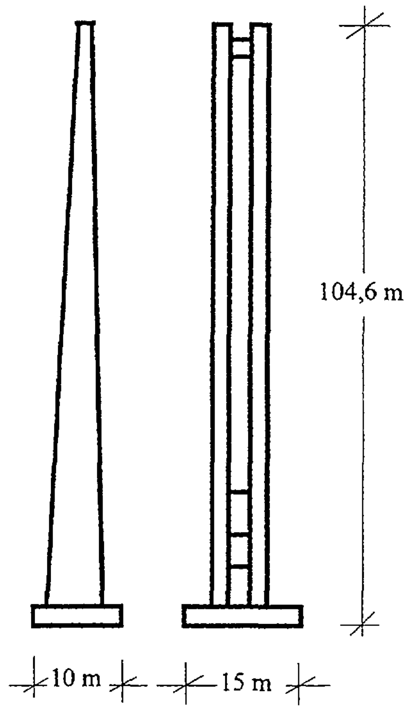

Figure 1. Flexible reinforced concrete structure: Ventilation chimney

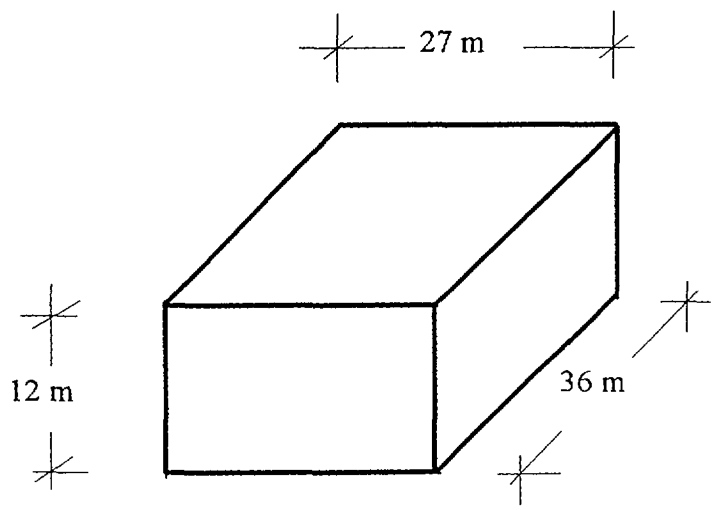

Figure 2. Reinforced concrete building with thick walls and slabs: Auxiliary building concrete block

3. RESULTS OF THE VENTILATION CHIMNEY

Fig. 4 shows the beam model of the chimney. The comparative test has been carried out for the horizontal displacement in point 1 at the chimney top, for vertical displacement in point 2 in the middle of the base plate. Internal forces were analysed in beam section 3 (in clamp cross-section of the chimney), girder 4 connecting both chimneys, and girder 5 in the base plate.

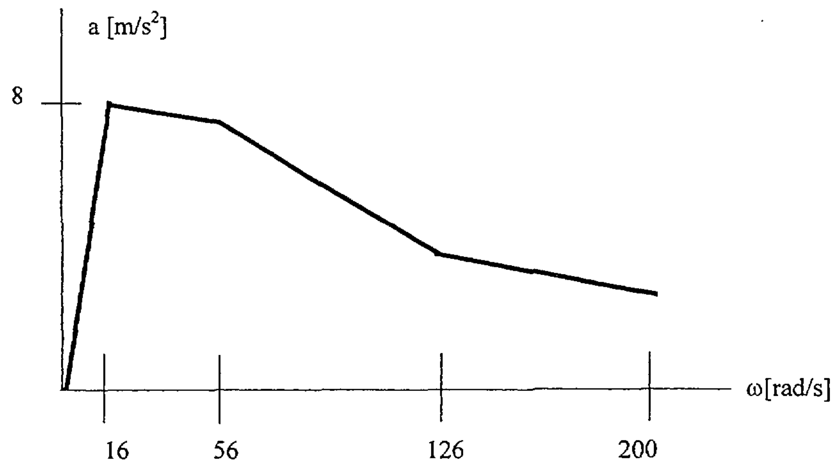

Figure 3. Horizontal Response Spectrum

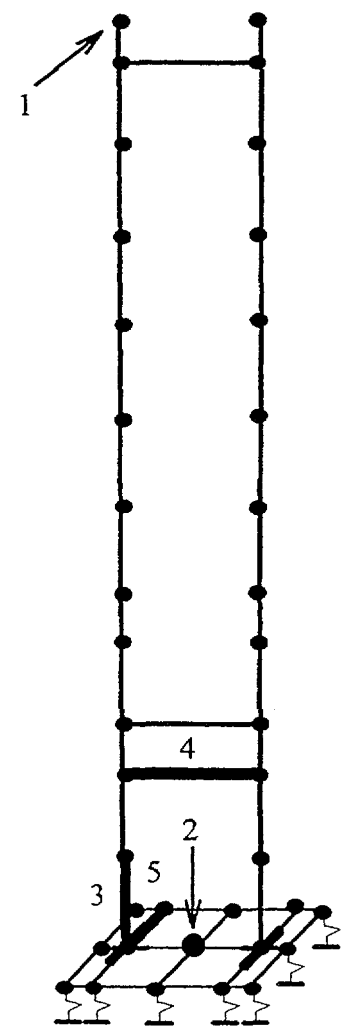

Figure 4. Beam model of ventilation chimney

At first, the eigenvector value necessary for the appropriate accuracy was analysed. If all eigenvectors belonging to the complete spectrum shown in Fig. 3 will be included in the tests, 42 eigenvectors must be used for the given structure because

$$\omega_1 = 1.37 \text{ rad/s}, \quad \omega_{42} = 208.7 \text{ rad/s}.$$

Table 1 demonstrates that horizontal displacement of the chimney top can be already obtained rather accurately with 3 eigenvectors, while calculation of appropriate accuracy of the vertical displacement of the middle point in the base plate requires at least 10 eigenvectors.

Bending moment and shear forces can be computed rather precisely with 10 eigenvectors, but accurate normal forces result only from more than 20 eigenvectors. Finally, in comparative tests 30 eigenvectors were included. Fig. 5 displays the location of the natural circular frequencies in the response spectrum. It reveals that for the flexible structure the first natural circular frequencies belong to the fast increasing section of the spectrum, and the eigenvectors included in the computations correspond to natural circular frequencies belonging to high values of the spectrum curve.

Table 1. Accuracy of displacements and internal forces at ventilation chimney

place of analysis	kind of value	number of eigen vectors						
		3	5	10	15	20	30	42
1	H. disp.	99,2	100,0	100,0	100,0	100,0	100,0	100,0
2	V. disp.	90,7	90,7	97,1	100,0	100,0	100,0	100,0
3	N	83,9	83,9	85,8	99,8	99,8	100,0	100,0
	T	49,1	49,1	96,2	97,7	97,7	100,0	100,0
	M	85,8	85,8	99,5	99,9	99,9	100,0	100,0
4	N	7,1	7,1	67,8	90,6	90,6	99,4	100,0
	T	84,6	84,6	99,6	99,7	99,7	100,0	100,0
	M	84,8	84,8	99,7	99,7	99,7	100,0	100,0
5	N	27,2	67,0	94,3	94,3	99,6	100,0	100,0
	T	82,7	91,7	95,6	99,9	100,0	100,0	100,0
	M	82,7	91,9	95,9	99,9	100,0	100,0	100,0

$\omega_1 = 1,4$ $\quad \omega_{10} = 22,5$ $\quad \omega_{15} = 38,1$ $\quad \omega_{30} = 119,9$ rad/sec

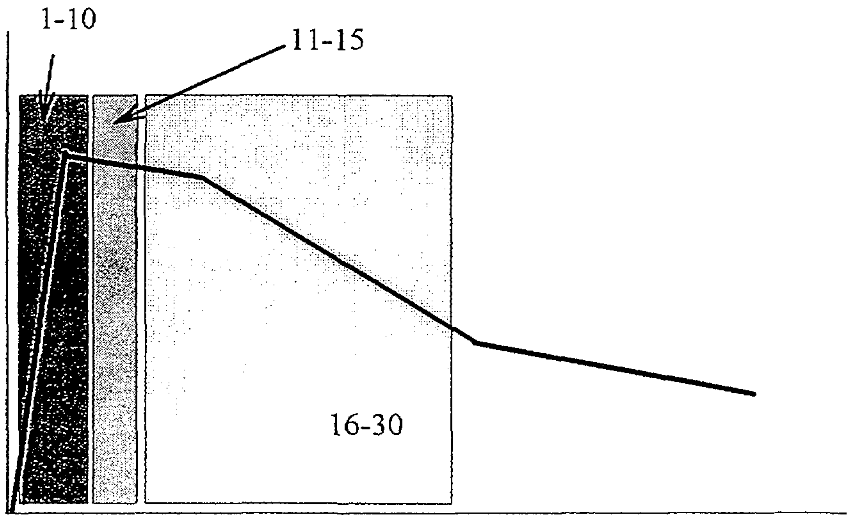

Figure 5. Natural circular frequencies in the spectrum at ventilation chimney

Fig. 6 shows the role of differences in modulus of elasticity of reinforced concrete in the solution. It can be seen that with decreasing modulus horizontal displacement increases, while vertical displacement and internal forces decrease. While modulus was diminished by 25% (or increased by 33%) in comparison to the value taken originally, changes in internal forces made no more than 15%.

Fig. 7 underlines the importance of precise choice of masses. It can be seen that a mass growth of 10% may even result in a 10% increase of internal forces.

Fig. 8 demonstrates the effect of soil stiffness. Difference was deliberately chosen not really. In spite of the fact that soil stiffness was reduced to 10% and enlarged to tenfold value, a maximum change of 25% in internal forces and horizontal displacement was observable. Simultaneously, vertical displacement increased, then decreased five times the original value. This means that in the case of flexible structures, mistakes in soil characteristics little influence the displacements and internal forces occurring due to flexibility. This small effect of soil stiffness change can be explained by the location of the natural circular frequencies in the spectrum. The location of the first ten most important natural circular frequencies in the spectrum hardly depends on the soil parameters (Fig. 9).

4. RESULTS OF THE ANALYSES OF THE AUXILIARY

Beam model of the building is depicted in Fig. 10. Comparative tests were here carried out for the horizontal displacement in point 1 in the upper plane of the structure, for the vertical displacement in point 2 in the bottom plane. Internal forces were examined in beam section 3 in the

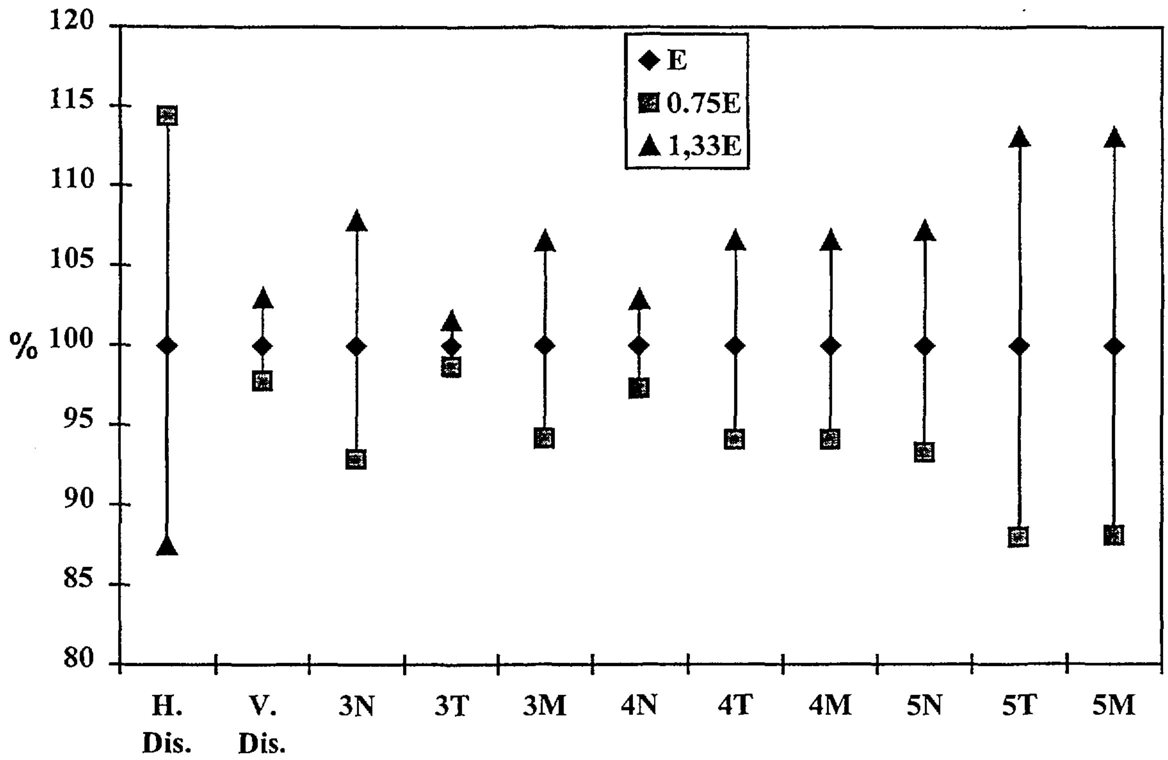

Figure 6. Influence of modulus of elasticity at ventilation chimney

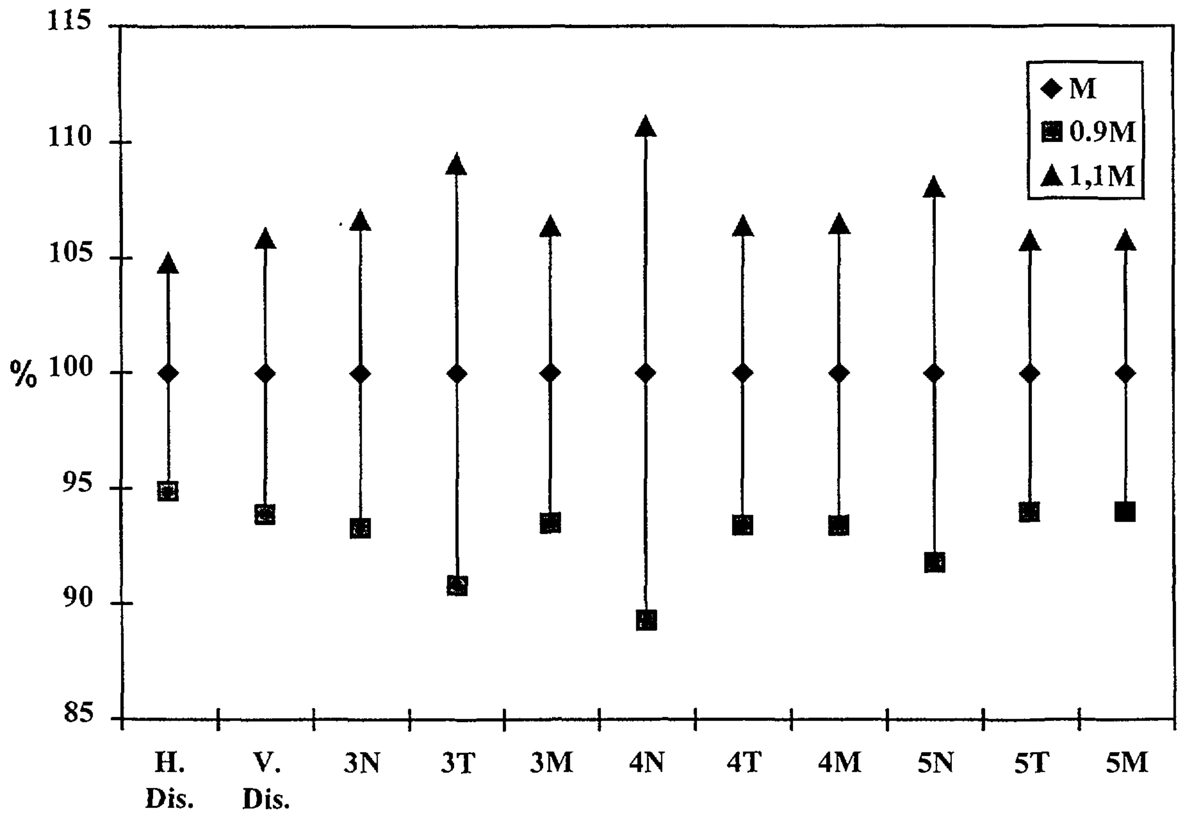

Figure 7. Influence of mass at ventilation chimney

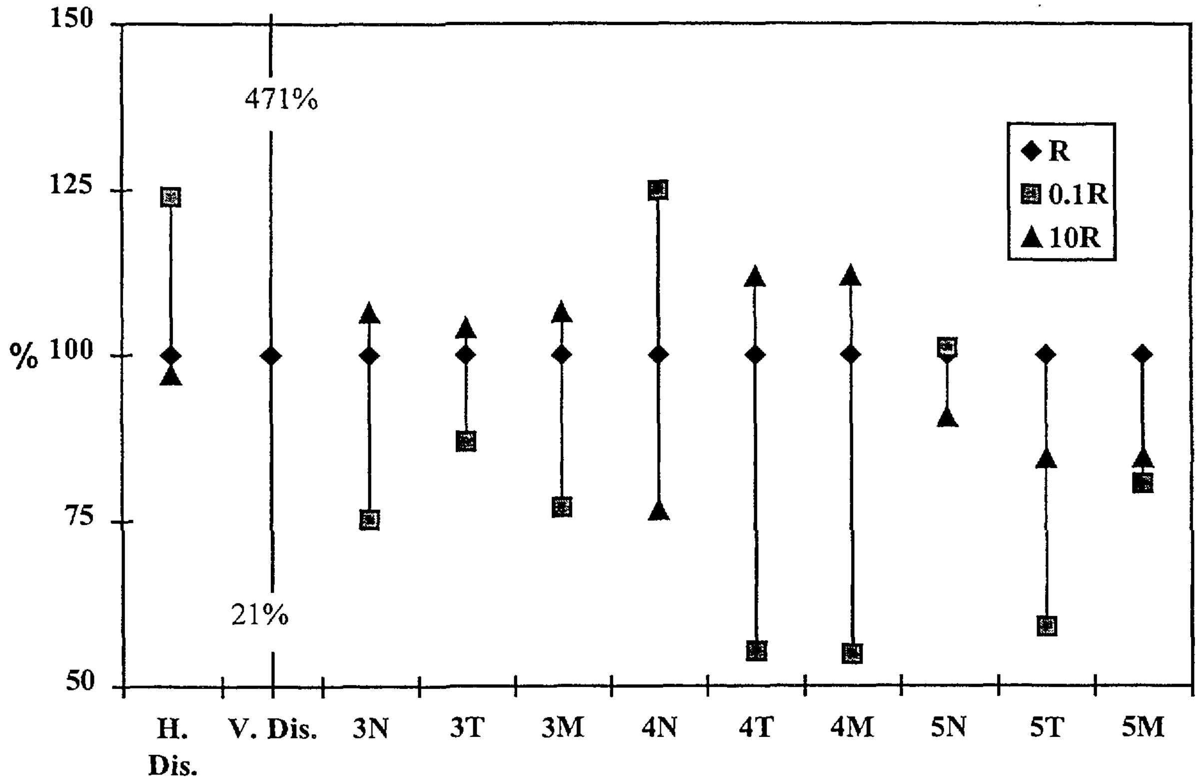

Figure 8. Influence of soil stiffness at ventilation chimney

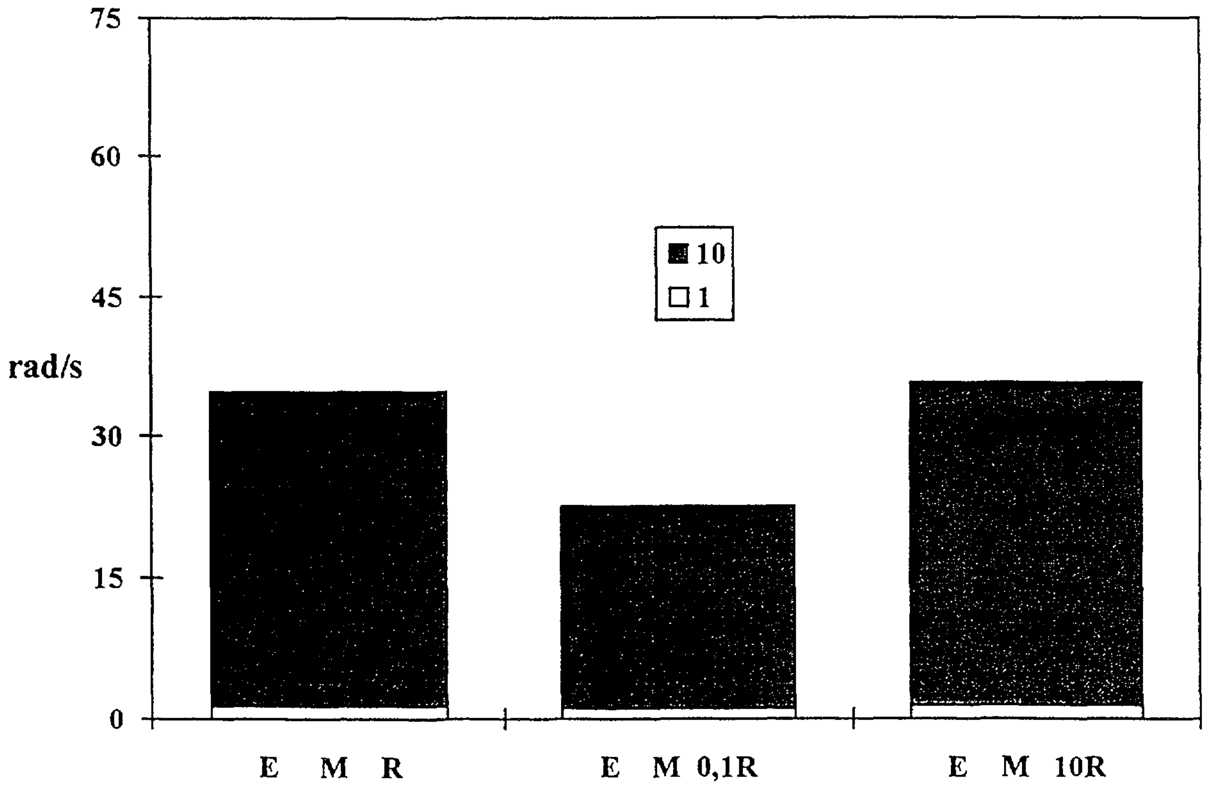

Figure 9. Location of the first ten natural circular frequencies at ventilation chimney

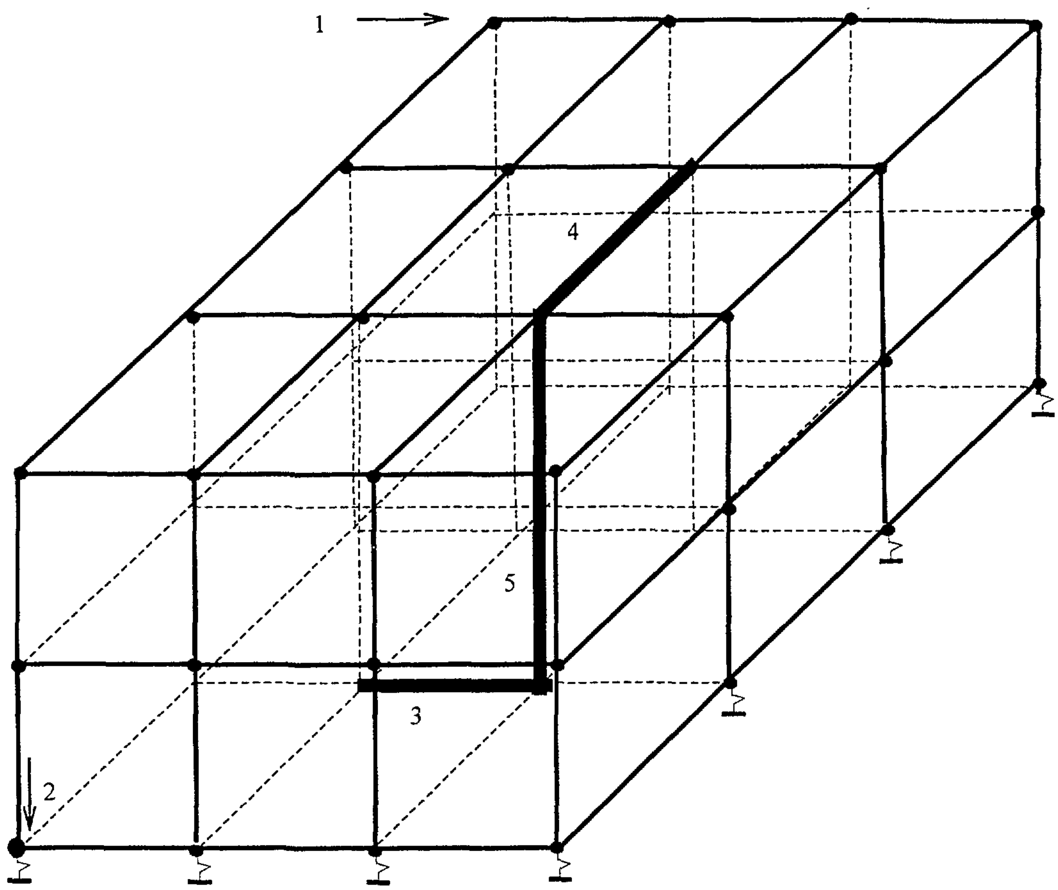

Figure 10. Beam model of auxiliary building concrete block

base plate, beam 5 in the wall and beam 4 in the upper plate. The whole spectrum covered now 44 eigenvectors.

$$\omega_1 = 9.63 \text{ rad/s}, \quad \omega_{44} = 203.7 \text{ rad/s}.$$

On the basis of Table 2 it can be stated that use of 10 eigenvectors results in computation of both displacements and internal forces with the appropriate accuracy. Fig. 11 shows that the first seven natural circular frequencies belong to the upper part of the fast growing section of the spectrum curve, and eigenvectors to be included in computations correspond in this case again to the natural circular frequencies belonging to the high values of the spectrum curve.

In Fig. 12 the effects of soil stiffness alteration are demonstrated. Unlike the flexible structure, now there is a considerable change both in internal forces and horizontal displacement, i. e. in rigid-box-like structures, the importance of mistakes in soil characteristics is much larger than with flexible structures. The more important role of soil stiffness alteration is explained by the location of the natural circular frequencies in the spectrum. Fig. 13 illustrates that the location of the most important first ten natural circular frequencies immensely depends on the soil parameters.

Table 2. Accuracy of displacements and internal forces at auxiliary building concrete block

place of analysis	kind of value	number of eigen vectors				
		5	7	10	20	30
1	H. disp.	100,0	100,0	100,0	100,0	100,0
2	V. disp.	82,4	100,0	100,0	100,0	100,0
3	N	68,2	98,7	98,9	100,0	100,0
	T	98,4	99,9	99,9	100,0	100,0
	M	99,7	99,9	99,9	100,0	100,0
4	N	92,9	97,7	99,4	100,0	100,0
	T	98,5	99,1	99,2	100,0	100,0
	M	98,7	99,4	100,0	100,0	100,0
5	N	30,9	99,8	100,0	100,0	100,0
	T	99,8	99,9	100,0	100,0	100,0
	M	99,8	99,9	99,9	100,0	100,0

$\omega_1 = 9,6$ $\omega_7 = 27,7$ $\omega_{10} = 37,3$ $\omega_{20} = 58,9$ $\omega_{30} = 129,6$ rad/s

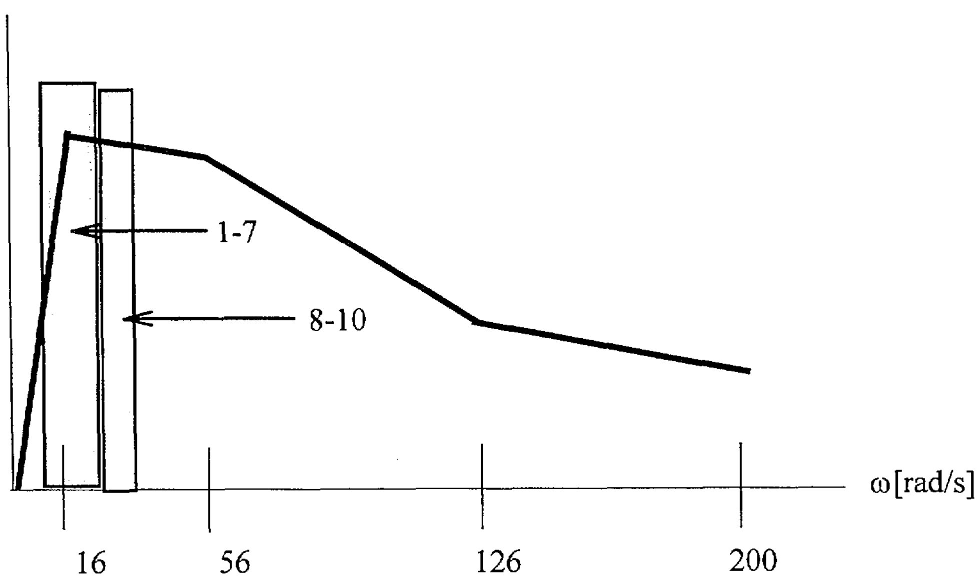

Figure 11. Natural circular frequencies in the spectrum at auxiliary building concrete block

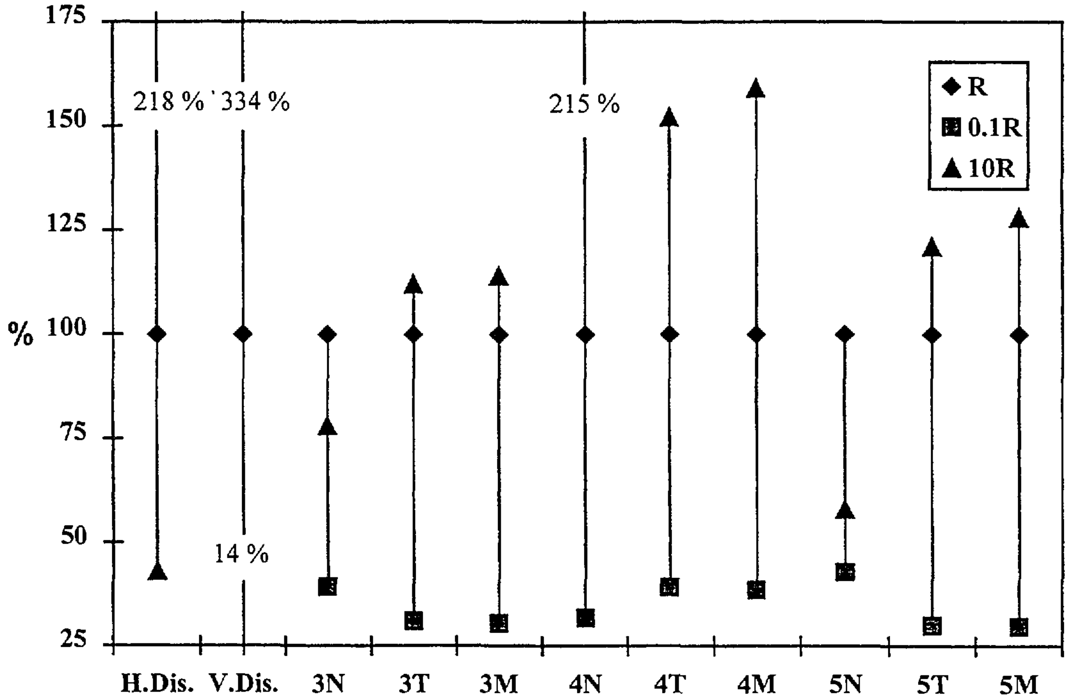

Figure 12. Influence of soil stiffness at auxiliary building concrete block

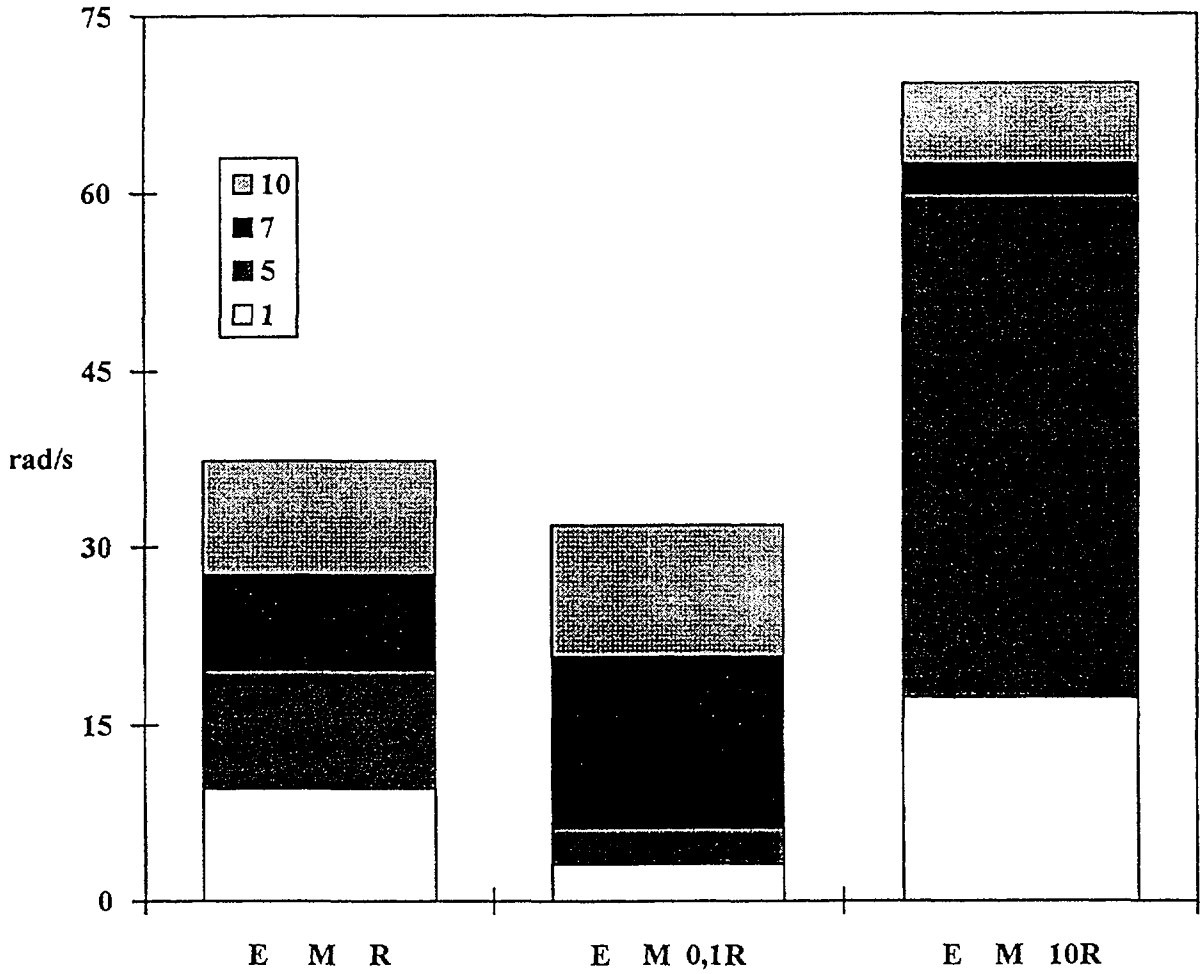

Figure 13. Location of the first ten natural circular frequencies at at auxiliary building concrete block

CONCLUSIONS

Analyses show that masses must be taken into account as correctly as possible because mistakes appearing in displacements and internal forces are proportional to mistakes made in computation of masses. At the same time, it is a comforting result that mistakes in modulus of elasticity of the structural material appear in a much less degree in internal forces, i. e. the results obtainable by values given in code specifications are close to the ones obtained by the actual modulus of elasticity.

Effects of soil stiffness are sharply different with flexible and rigid structures. In the latter case, mistakes made in soil stiffness computation lead to a significant discrepancy with the real results. This effect is, however, in the case of flexible buildings not important.

ACKNOWLEDGEMENTS

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