SEISMIC RESPONSE OF BUILDINGS WITH AND WITHOUT BASEMENTS AND PILES

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1. INTRODUCTION

Many buildings have basements and are often supported by piles when the soil is weak. In this case, the basement substructure and the pile foundation should be considered in estimating the seismic response resulting from the soil-pile-substructure interaction effects on the buildings. This paper deals with some effects that basements and piles have on the behaviour of buildings under seismic conditions.

Soft and hard types of soil found in the Tokyo area have been selected and buildings of different number of storeys, namely 3, 5, 10 and 15, with differing number of basement storeys, namely zero, 1, 2, or 3 have been selected in this study. For the case of buildings that are supported on piles, the number of piles of a given cross-sectional area has been computed from the assumed design loads. For the purpose of comparison, buildings fixed at the ground surface (ignoring the substructure and piles) have also been analyzed.

The effects of alternate soft and hard layer formation effects on the seismic response of buildings, the case of soft soil formation in a concave configuration and that of hard soil formation in a convex configuration, and dynamic and potential energies in the building during seismic disturbances have also been investigated but not reported in this paper.

2. MODELIZATION AND METHODS OF ANALYSIS

The soil-building prototype is represented by a truss type model as shown in Fig. 1 and the piles by flexural elements fixed at the bottom (pile tip) and at the top (bottom of the basement). The soil and the building masses are concentrated at the corresponding joints in the truss model.

To determine the vibrational characteristics and seismic response of the adopted model, earthquake input of 100 gal acceleration is fed at the boundary of the surface soil layer and the firm bed formation 15 m below the ground level. Earthquake wave forms used are the El Centro (1940) NS component and the Taft (1952) EW component.

Uniform soft soil (S) and uniform hard soil (H) are the basic soil types. In addition, soft-hard-soft soil formation (S-H-S) and hard-soft-hard soil formation (H-S-H) have also been investigated. The soil formation is considered to be continuous in the horizontal direction. The

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vibrational periods of the surface soil formation are shown in Table 1 and those for the building superstructures in Table 2.

Givens-Householder method has been used to obtain the vibrational characteristics for the first fifteen modes. Modified linear acceleration method has been used to obtain the seismic response. Damping coefficient for the first mode of 5% and values for the higher modes proportional to the circular frequencies have been assumed.

3. VIBRATIONAL CHARACTERISTICS

(a) Periods of Vibration. A five storey (N5) building supported on soft soil (S) is shown in Fig. 2 and a fifteen storey (N15) building resting on the same soil type (S) in Fig. 3. The relation of periods of vibration for corresponding modes is also indicated. It is evident that as the depth of the substructure (basement) increases, the periods of vibration in all modes tend to decrease and this tendency is more pronounced for the taller buildings than for the lower buildings. Further, when piles are driven, the periods of vibration in all modes tend to become shorter when compared with the case of no piles being used. Furthermore, this tendency is more evident for soft soil type than for the hard soil type.

For non-uniform soil formations, the cases of H-S-H and S-H-S have indicated that the range of the periods of vibration is within the bounds of periods of vibration for the uniform soft and uniform hard soil formations. As the hard soil component increases, the period of vibration became shorter. See Table 3.

(b) Modes of Vibration. For low buildings, basements and piles have important effects on the modes of vibration. As evidence of this fact, Fig. 4 shows the modal participation functions for a three storey building (N3) without a basement (BO) and without piles and Fig. 5 the same for the case with piles. (Note that modal participation function is the product of the modal participation factor in the direction considered and the corresponding mode shape). As evident from Figs. 4 and 5, the presence of piles reduces sway and rocking motions. Also, they tend to move the mode of vertical motions towards the higher modes. In the case of low buildings, the vertical motion component is prominent in the low modes whereas for taller buildings, this phenomenon is not observed in the same modes.

The effects of the substructure depth as reflected in the amount of sway and rocking motion components at the top of the building for the first mode vibration are shown in Table 4. From these results, the rocking component is greater than the sway component for tall buildings than for low ones. As the number of basement storeys increases, both the sway and rocking motions are reduced, the former to a less extent than the latter. The presence of piles has effects similar to those due to substructures.

For the cases of soft and hard soils, the total amount of sway and rocking components is considerably greater in the former case but the amount of reduction in the movement components due to basements and piles seems to be more pronounced for hard soils than for soft soils. From the above results, basements and piles are more effective in restricting rocking motion than sway and this effect seems to be more prominent in harder soils.

4. SEISMIC RESPONSE

The variation in the seismic shear coefficients (base shear coefficients) in the first storey of buildings of different heights due to El Centro earthquake input is shown in Fig. 6. Largest values are for N5 or N3 buildings and piles tend to increase these values for buildings of all heights. Also, an increase in the substructure depth tends to increase the base shear coefficients. Similar tendency was also found for the Taft earthquake with certain exceptions.

The maximum displacements at the top of buildings for the El Centro earthquake are indicated in Fig. 7. In this case, the displacement response for the hard soil is less than for the soft soil and basements likewise reduce the response (with the exception of N15 building). However, the results from the Taft earthquake indicate that basements do not necessarily lessen the displacement response.

5. CONCLUSIONS

An increase in the depth of the substructure tends to shorten the periods of vibration of the superstructure indicating increased rigidity imparted to the entire vibrating system and it significantly reduces the displacements due to rocking motion. Piles likewise produce effects similar to basements.

In the case of low buildings without a basement, unusual up and down motions develop in addition to sway motion. However, when a basement is provided, this phenomenon is reduced. For higher buildings with basements, the rocking motion is reduced but sway is not much restricted.

Basements and piles do not per se produce favorable seismic response in the elastic range and investigations extending into the plastic range may indicate advantageous aspects, such as from hysteretic damping.

The concept of "Shell Type Foundation for Earthquake Resistance" by J. K. Minami presented at the World Conference on Earthquake Engineering, Berkeley, California in 1956, gave evidence that increasing the depth of the foundation increased significantly the bearing capacity under static loads. The series of investigations dealing with "Some Effects of Substructure and Adjacent Soil Interaction on the Seismic Response of Buildings" by the co-authors (Proc. 4WCEE Vol. 3 A6-71, Santiago, Chile 1969) is an extension of the shell foundation concept to dynamic loading conditions. Appreciation is expressed to Kazuo Koizumi, Junji Ohi and Tomio Ohno, who while enrolled as students in the Dept. of Architecture of Waseda University, gave their cooperation on this project.

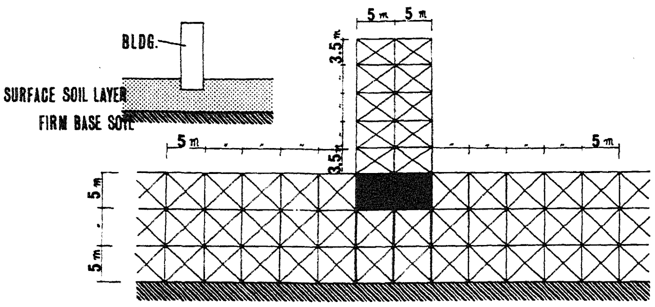

Fig. 1 TRUSS TYPE MODEL

Table 1. SOIL PERIODS

n	HARD	SOFT
1	0.2475	0.5178
2	0.1329	0.2801
3	0.1328	0.2801
4	0.1239	0.2615
5	0.1192	0.2515

Table 2. BLDG PERIODS

N	1-MODE	2-MODE
3	0.247	0.098
5	0.420	0.165
10	0.857	0.303
15	1.470	0.522

Table 3. PERIODS FOR 1-5 MODES

	HARD	H-S-H	S-H-S	SOFT
1	0.2993	0.4025	0.4780	0.5502
2	0.2351	0.2858	0.3599	0.3891
3	0.1367	0.2036	0.2455	0.2853
4	0.1336	0.1873	0.2446	0.2718
5	0.1237	0.1802	0.2421	0.2611

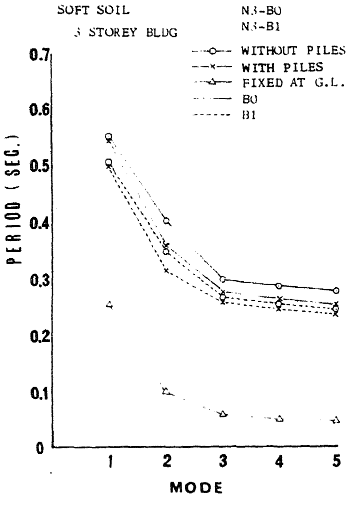

Fig.2. PERIODS FOR FIRST 5 MODES

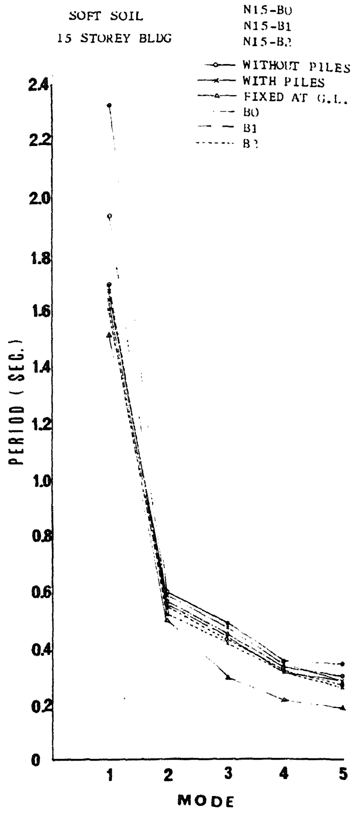

Fig. 3 PERIODS FOR FIRST 5 MODES

Fig. 4 MODAL PARTICIPATION FUNCTIONS FOR N3-BO, SOFT SOIL WITHOUT PILES

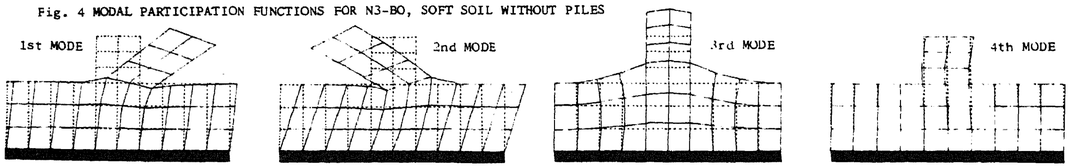

Fig. 5 MODAL PARTICIPATION FUNCTIONS FOR N3-BO, SOFT SOIL WITH PILES

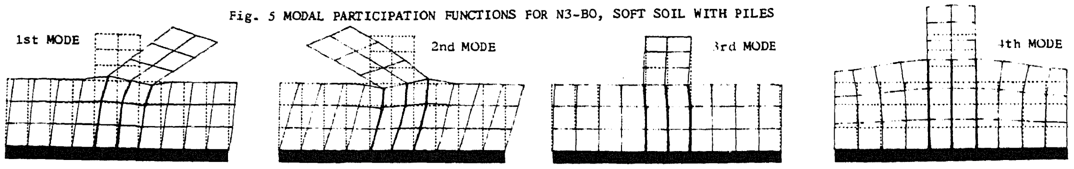

Table 4 SWAY & ROCKING COMPONENTS

N	B	HARD SOIL		SOFT SOIL	
		Sway %	Rock'g %	Sway %	Rock'g %
3	0	14.7	14.3	55.0	22.0
	1	12.6	8.0	55.0	17.3
	2	11.6	5.7	50.9	16.8
5	0	6.9	18.5	22.3	45.6
	1	6.7	9.1	18.7	27.6
	2	6.2	5.8	18.4	19.0
10	0	3.2	21.0	9.0	54.0
	1	2.1	13.3	6.8	37.2
	2	2.0	8.4	6.9	23.1
15	0	0.6	23.0	1.6	56.5
	1	0.5	11.1	3.2	31.8
	2	0.5	6.8	3.1	18.5

(note) without piles

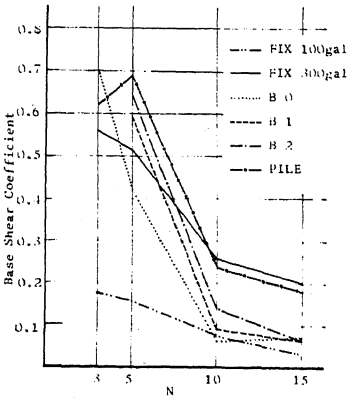

Fig. 6 BASE SHEAR COEFFICIENTS

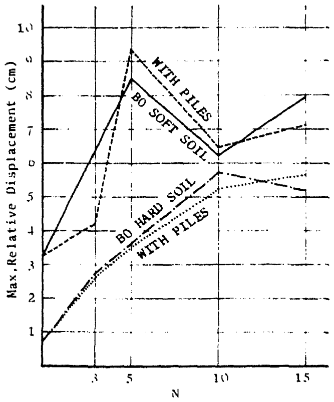

Fig. 7 MAX. RELATIVE DISPLACEMENTS