SOME EFFECTS OF NEARBY STRUCTURES ON THE SEISMIC RESPONSE OF BUILDINGS

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SYNOPSIS

The vibrational characteristics, the pulse wave response and the seismic response of the various combination systems of 3 storey buildings and 10 storey buildings on each of the uniform soft and hard soils, differing separation distance between buildings from 5 m to 50 m are investigated. The result of analysis shows some considerable influences of the adjacent buildings on those characteristics of the systems.

1. INTRODUCTION

It is usual practice in the earthquake resistant design of buildings to consider each building as an isolated structure unaffected by nearby structures. However, in actuality such a building may be surrounded by others and the latter may have interaction effects on the seismic response of the building under consideration in addition to the effects of the site soil conditions. This paper considers the seismic response of buildings by taking into consideration the different surface soil conditions, varying building proportions and differing separation distances between adjacent buildings through several case studies.

2. MODELS OF CASES STUDIED

Soft and hard soil types representative of downtown and uptown Tokyo have been selected. The thickness of the surface soil formation of 15 m (approximately 50 ft) above the firm soil stratum has been adopted in the present study and this layer extends continuously in the horizontal direction. The buildings supported on the surface soil layer are two span 1) 3 storey buildings (N3) with no basement (B0) spaced 5, 10, 25 and 50 m apart; 2) 10 storey buildings (N10) without basement, with one (B1) and two (B2) basement storeys similarly separated; and 3) combination of 3 and 10 storey buildings alternately arranged and separated similarly as in the first two cases. Fig. 1 gives the dimensions of the models and the cases studied. The soil and the building have been transformed to truss elements and the masses concentrated at the appropriate joints to form a vibrational system. The weight of the superstructure has been computed on the bases of 0.98 t/m^2 of the floor area and that of basements on the basis of 1.96 t/m^2. The weight of the soil has been assumed to be 1.8 t/m^3

With regard to the soil, the predominant periods of vibration in the first mode of 0.50 sec and 0.25 sec for the soft and hard soil types have been assumed. In evaluating the shear rigidities of the soil, an inverted triangular shape has been assumed in the first mode of vibration. The vertical rigidities (k_v) were obtained by equating it to the horizontal rigidities (k_h), that is $2(1+v)k_s$ wherein v is the Poisson's ratio, assumed to be 0.45, and k are the horizontal rigidities. The areas of the

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[I] Associate Professor, College of Technology, Waseda University, Tokyo

[II] Professor, Department of Architecture, Waseda University truss elements were computed from the rigidities.

The stiffness of the building frame has been evaluated by taking into consideration the fundamental periods of vibration corresponding to the number of storeys above the ground level and the first mode shape. For buildings with basements, a displacement of unity 1 at the top of the building, 0.05 at the ground level and zero displacement at the bottom of the substructure have been assumed. The rigidities of the vertical (columns) and horizontal (girders) elements have been chosen realistically to take account of the axial deformations.

3. METHODS OF ANALYSIS

Givens-Householder method has been used to investigate the vibrational characteristics for the first 15 mode periods, mode vectors, and modal participation factors. The responses to a pulse wave and actual earthquake waves have been investigated. A pulse wave of 100 gal acceleration of 0.025 sec duration applied 1) horizontally (x-direction) and 2) vertically (y-direction) and 3) 100 gal in the horizontal and 100/3 gal in the vertical direction of the same duration acting simultaneously has been used. The El Centro (1940) NS component and the Taft (1952) EW component reduced to 100 gal maximum acceleration have been applied in the horizontal direction at the level of the firm base formation 15 m below the ground level.

Modal analysis has been employed for response computations and damping coefficient of 5% in the first mode and values proportional to the circular frequencies for the higher modes have been assumed. Modified linear acceleration method has been used for the solution of equations of motion for each of the modes. In addition to displacement, velocity and acceleration responses, strain and kinetic energies have also been computed.

Vibrational characteristics and responses for the surface soil layers and for buildings fixed to the firm stratum at the ground level have been computed for the purpose of comparing the effects of nearby structures on the seismic response of buildings.

4. VIBRATIONAL CHARACTERISTICS OF SOILS AND BUILDING GROUPS

Table 1 shows the periods of vibration for three storey and ten storey buildings and Table 2 indicates the periods for the soft and hard soil formations. The variation in the modal participation factors due to different separation distances between buildings is shown in Fig. 2 for N3, N10, and combination N3-N10 building groups.

5. VIBRATIONAL CHARACTERISTICS OF SOIL-BUILDING GROUPS

(A) Periods of Vibration. Table 3 gives the periods of vibration for the soil-building group interaction. Following comments are made regarding the results obtained.

(1) Case of N3-N3 Group. The periods of vibration for the combina-

tion arrangement of N3 buildings are longer than for the N3 building considered by itself in all the modes and this trend is more noticeable for the soft soil than for the hard soil type.

Periods of vibration in the 1st to 4th modes contribute considerably to the response. The effect of the separation distance of the N3-N3 group on the period in the 1st mode is to lengthen it as the buildings come closer together and it becomes shorter as the separation distance increases. In the 2nd mode, the period becomes shorter as the buildings come closer together and longer as the separation distance increases. The variation in the 1st and 2nd mode periods is more pronounced when the buildings are closely spaced and less pronounced when the separation distance is increased. The 3rd mode period becomes shorter as the separation distance is increased up to 25 m but at 50 m separation, the period again increases to a value corresponding to 5 m separation. The variation in the 4th mode period is not as simple as in the 1st and 2nd mode periods.

(2) Case of N10-N10 Group. The periods of vibration for the combination arrangement of N10 buildings are longer than for N10 building considered as isolated in all the modes although such increases are not as prominent as for the N3-N3 combination arrangement.

The effect of the separation distance between buildings in this case on the periods in the modes is to shorten the 1st mode period and to lengthen the 2nd mode period as the buildings come nearer together. The 3rd and 4th mode periods become shorter as the building separation decreases. These are tendencies opposite to those for the N3-N3 building group.

(3) Case of N3-N10 Group. General tendencies are similar to the N10-N10 group but the 1st mode period is longer when the building separation distance is decreased as was noted for the N3-N3 case.

(4) Effects of Basement Depth. For the 10 storey buildings with 1, 2, and 3 basement storeys, the effect of the basements is generally to shorten the periods of vibration as the basement depth is increased. This influence is more evident as the buildings are placed closer together.

(B) Modal Participation Factors and Functions. The variation in the values of the modal participation functions for the first 3 modes in the horizontal direction (x) is shown in Fig. 3. Modal participation function is obtained as the product of the modal participation factor in the direction considered and the corresponding modal shape value.

For the N3-N3 group, the values of the m.p. (modal participation) factors are large for the first 5 modes and these have significant influence on the seismic response. The values for the higher modes are less and are of less importance than the lower mode values. However, when the separation distance between buildings becomes great (50 m), values of significance are found to exist in the higher modes.

For the N10-N10 group, tendencies similar to the three storey building group are noted. When the substructure depth is shallow (B1) and the separation distance is large (25~50 m), m.p. factors of importance are noted to exist in the higher modes.

For the N3-N10 group, even when buildings stand close together, m.p. factors of significance are found in the higher modes, indicating the interaction effects of the low building acting on the high building and vice versa.

Participation modal functions for the soil-building group models exhibit shapes that indicate the influence of the soil conditions in the lower modes in producing building deformations due to rocking. This tendency is pronounced for the three storey buildings without basements but rocking deformation is small for ten storey buildings with basements.

For the N3-N10 combination group, the N10 building shows large m.p. functions in the 1st and 2nd modes and a large value appears for the N3 building in the 3rd mode. The low and high buildings do not deform independently of each other but affect each other which is observable in the plot of the m.p. functions.

Modal participation functions due to vertically directed inputs for the N3 building show large values for the 3rd to 5th modes and for N10 building in the 5th to 7th modes. The effect of separation distance on the deformation of the top of the N3 building in the N3-N10 combination as reflected in the m.p. function appears in the 6th to 7th modes when the separation distance is small and in the 8th and 9th modes when the distance is large. Furthermore, the m.p. functions in the horizontal direction (x) are very small so that horizontal deformations due to up and down motions is believed to be small.

6. PULSE WAVE RESPONSE

The maximum relative displacements at the top of N3 and N10 buildings due to a horizontal pulse wave are shown in Fig. 4. The pulse wave response indicates tendencies more clearly than do responses to earthquake wave inputs. For example, for the case of N10-N10 combination, the response is small when the separation distance is small and at 25 m and 50 m separation distances, the differences in the response are not clearly discernible. The displacements at the top of the N10 building in the N3-N10 combination are not greatly influenced by changes in the separation distance which is an aspect different from the responses obtained from using actual earthquake wave inputs.

7. RESPONSE TO EARTHQUAKE MOTIONS

Displacement response is influenced generally by the first few modes whereas acceleration response is influenced by the modes extending to higher modes. Soft soils are affected more by higher modes compared with hard soils. Within the scope of the present investigation, the displacement response is somewhat larger with increasing separation distances.

Figs. 5 and 6 show some of the results of response studies in the form of seismic story shear coefficients and kinetic energy and strain energy for the cases studied due to earthquake motions mentioned. The maximum responses occur relatively early, about 2 to 5 secs for the El Centro earthquake and during 6 to 8 secs for the Taft earthquake after the initial shaking.

(A) Maximum Response Values. The responses in the horizontal x-direction are first considered. For the soil types and buildings considered, the responses to the El Centro earthquake are larger than to the Taft earthquake and this tendency is more prominent for the soft soil than for hard soil conditions.

For the N3-N3 building group, the deformations are larger for soft soil type and accelerations are greater for hard soil type. There is noted a tendency for both the deformations and accelerations to rapidly decrease as the separation distance between buildings becomes less.

The N10-N10 building group also displays the tendency for the responses to decrease as the separation distance becomes less but this tendency is less distinct at intermediate separation distances. The effect of basement depth on the deformation responses does not show a general trend but this is believed to be due to the peculiar characteristics of the earthquake wave forms.

For the N3-N10 combination group, the responses at the top of the N3 building are small for separation distances of 5, 10, and 25 m and for the N10 building, the responses are less with increasing number of basement storeys. However, when the separation distance is 50 m, the response becomes smaller as the basement depth is reduced. It is noted again that both the displacement and acceleration responses are less at small separation distances although this tendency is not as pronounced as in the other cases.

The responses in the vertical y-direction are next considered. The responses in this direction due to differing separation distances are similar in pattern to those in the horizontal direction but their values are smaller. For N3 building, however, notably large response is observed which fact should not be ignored nor neglected in the design of low buildings.

The responses at the ground level tend to become smaller as the building separation distance is reduced. For the N3-N10 combination case, the effect of the basement depth of the N10 building is apparent in the response at the ground surface of the N3 building.

(B) Seismic Shear Coefficients. These values for the El Centro earthquake are shown in Fig. 5.

For the N3-N3 group, seismic shear coefficients become smaller with decreasing distances of building separation. This same tendency has been observed also for the Taft earthquake with some exceptions that are believed to be due to the peculiar characteristics of this earthquake motion.

For the N10-N10 group, the effect of varying the separation distances is not great.

For the N3-N10 combination group, the values are smaller for the N3 building compared to the N3-N3 case and for the N10 building, the values are of the same order as for the N10-N10 case.

(C) Energy Responses. Kinetic and strain energies in the buildings due to the El Centro earthquake have been computed and are shown in Fig. 6. The maximum values of these energies were found to become less as the building separation distance became smaller. Specially for the N3 building supported on soft soil, the strain energy is noted to be notably small compared to the kinetic energy and this is thought to be due to dissipation or dispersion of energy to the surrounding soil. It is also noted that for the N3 building near the N10 building, the energy situation is more favorable than for the N3 building standing alone.

8. CONCLUSIONS

Within the scope of the present investigation, it may be said that from the practical engineering point of view, the effects of nearby structures on the seismic response of buildings are generally favorable and not necessarily unfavorable. This is a tentative conclusion for which to be grateful to the Earth. From the viewpoint of mutual interaction of nearby buildings on each other, it is conceivable that they affect each other even when the separation distances are considerable. Other facets of this problem are under investigation.

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APPENDIX A

AREA OF VERTICAL, HORIZONTAL AND DIAGONAL ELEMENTS OF 2-SPAN BUILDING AND SOIL LAYERS (cm^2)

N	3			5			10			15		
	Vert.	Horiz.	Diag.	Vert.	Horiz.	Diag.	Vert.	Horiz.	Diag.	Vert.	Horiz.	Diag.
15										52.70	143.0	0.340
14										52.70	143.0	0.657
13										52.70	143.0	0.951
12										52.70	143.0	1.223
11										52.70	143.0	1.473
10							50.00	143.0	0.891	65.00	143.0	1.699
9							50.00	143.0	1.692	65.00	143.0	1.903
8							50.00	143.0	2.404	65.00	143.0	2.084
7							60.50	143.0	3.028	65.00	143.0	2.243
6							60.50	143.0	3.526	65.00	143.0	2.379
5				50.00	143.0	1.361	60.50	143.0	4.007	78.70	143.0	2.492
4				50.00	143.0	2.450	60.50	143.0	4.363	78.70	143.0	2.583
3	40.50	143.0	2.274	60.50	143.0	3.266	72.00	143.0	4.631	78.70	143.0	2.651
2	40.50	143.0	3.790	60.50	143.0	3.811	72.00	143.0	4.808	78.70	143.0	2.696
1	40.50	143.0	4.548	60.50	143.0	4.083	72.00	143.0	4.898	78.70	143.0	2.718
B1	304.0	1070	34.10	453.0	1070	30.70	539.0	1070	36.75	591.0	1070	20.40
B2	608.0	2140	68.20	908.0	2140	61.40	1078	2140	73.50	1182	2140	40.80
B3	912.0	3220	102.2	1360	3220	92.00	1620	3220	110.2	1773	3220	61.20

AREA OF SOIL ELEMENTS (cm^2)

	HARD SOIL			SOFT SOIL		
Dep	Vert.	Horiz.	Diag.	Vert.	Horiz.	Diag.
D 5	31.60	15.80	14.95	7.06	3.53	3.42
D10	74.00	52.80	34.90	16.50	11.78	7.95
D15	95.20	84.60	44.90	21.20	18.85	10.30

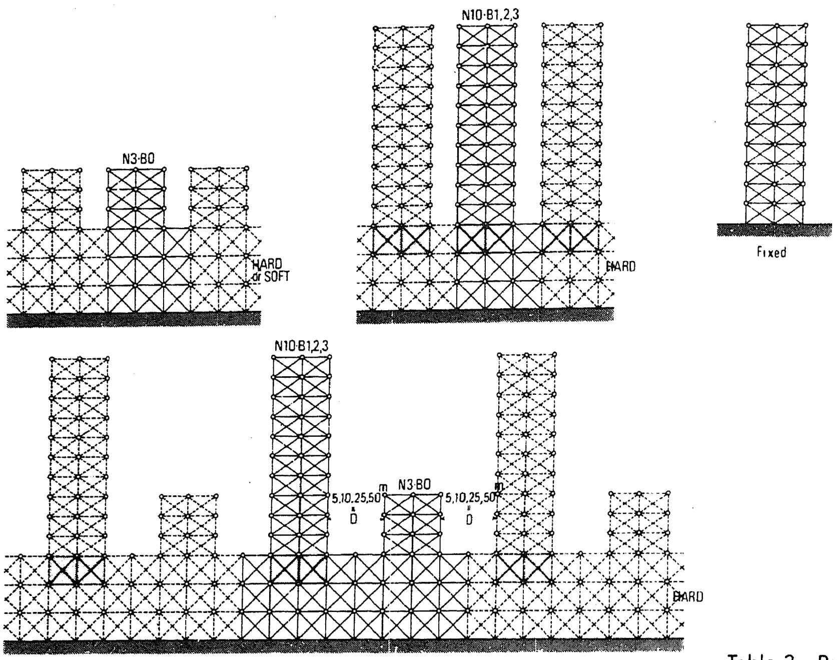


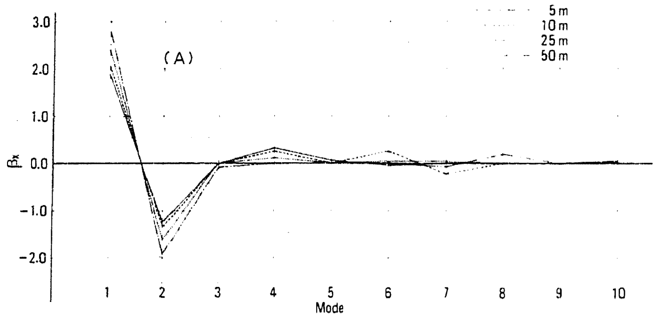
Fig. 1 Models of Cases Studied

Table 1 Soil Periods (sec)

n	SOFT	HARD
1	0.5178	0.2476
2	0.2801	0.1329
3	0.2801	0.1329
4	0.2615	0.1238
5	0.2515	0.1192
6	0.2515	0.1192

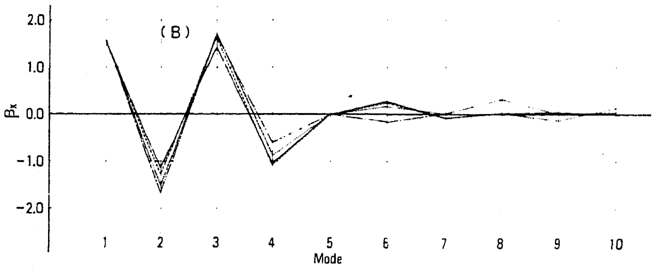
Table 2 Bldg. Periods (sec)

n	N3	N10
1	0.2470	0.8544
2	0.0982	0.3028
3	0.0615	0.1826

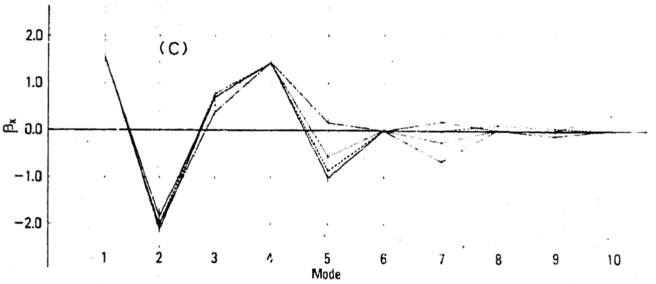


N3(B0)-N3(B0), Soft Soil (D=5.10.25.50m)

β_x ---- Modal Participation Factor Horizontal (β_y ---- Ditto, Vertical)



N10(B1)-N10(B1), Hard Soil



N10(B1)-N3(B0), Hard Soil

Fig. 2 Variation in Modal Participation Factors due to Bldg. Separation

Table 3 Periods for Soil-Bldg. Interaction

Type	D (m)	Vibration Periods (sec)		
		1st mode	2nd mode	3rd mode
N3 Fixed		0.2470	0.0982	0.0615
N3(B0)-N3(B0) SOFT	5	0.6023	0.3385	0.2951
	10	0.5851	0.3541	0.2888
	25	0.5611	0.3770	0.2839
	50	0.5463	0.3978	0.2984
N3(B0)-N3(B0) HARD	5	0.3230	0.2183	0.1412
	10	0.3152	0.2236	0.1382
	25	0.3042	0.2313	0.1360
	50	0.2979	0.2369	0.1467
N10 Fixed		0.8544	0.3028	0.1826
N10(B1)-N10(B1) HARD	5	0.9432	0.3179	0.2022
	10	0.9548	0.3165	0.2091
	25	0.9571	0.3136	0.2235
	50	0.9571	0.3122	0.2338
N10(B2)-N10(B2) HARD	5	0.9212	0.3155	0.1929
	10	0.9217	0.3145	0.1971
	25	0.9244	0.3131	0.2129
	50	0.9256	0.3123	0.2279
N10(B3)-N10(B3) HARD	5	0.8996	0.3126	0.1888
	10	0.9002	0.3121	0.1902
	25	0.8993	0.3113	0.2004
	50	0.9014	0.3110	0.2200
N10(B1)-N3(B0) HARD	5	0.9601	0.3192	0.2921
	10	0.9575	0.3163	0.2938
	25	0.9563	0.3126	0.2938
	50	0.9571	0.3117	0.2957
N10(B2)-N3(B0) HARD	5	0.9262	0.3169	0.2897
	10	0.9268	0.3153	0.2925
	25	0.9268	0.3129	0.2942
	50	0.9268	0.3120	0.2939
N10(B3)-N3(B0) HARD	5	0.9014	0.3142	0.2872
	10	0.8993	0.3128	0.2912
	25	0.9014	0.3113	0.2935
	50	0.9014	0.3107	0.2942

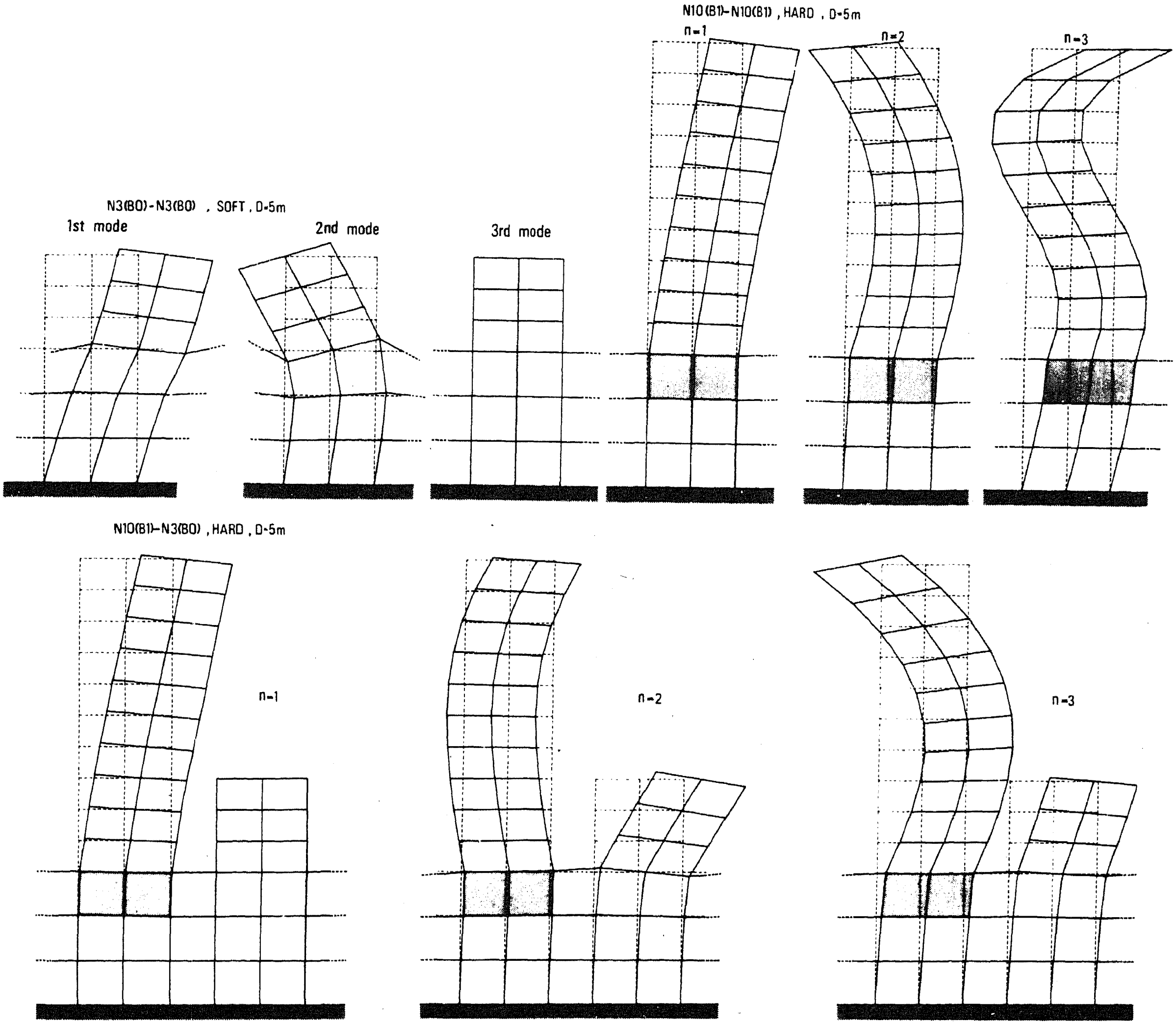


Fig. 3 Modal Participation Functions

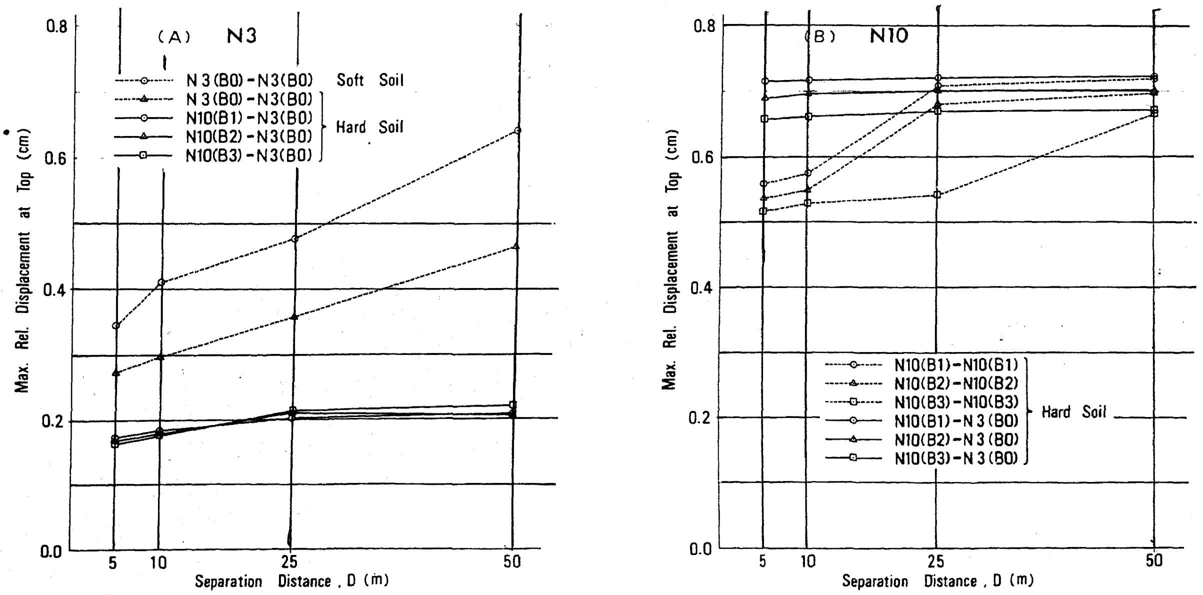


Fig. 4 Max. Relative Displacements at Top due to Horizontal Pulse Input

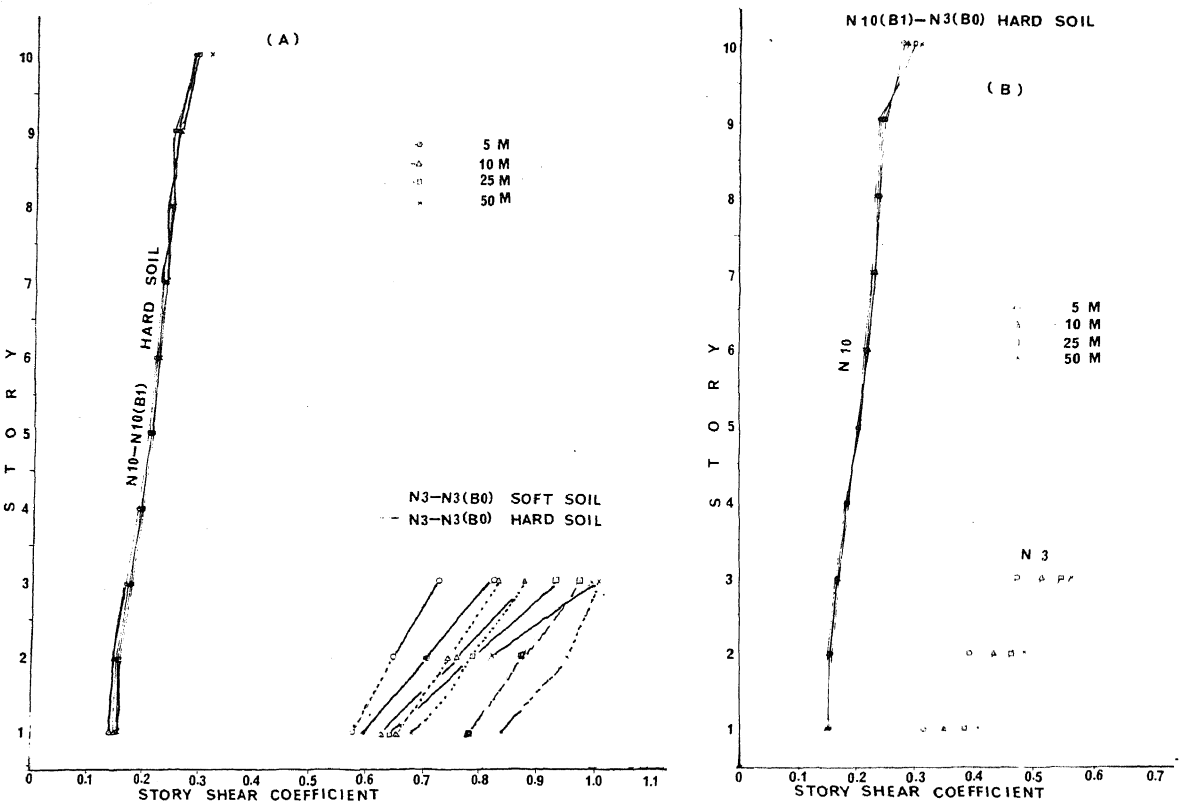


FIG 5 SEISMIC SHEAR COEFFICIENT DUE TO EL CENTRO(1940)NS INPUT

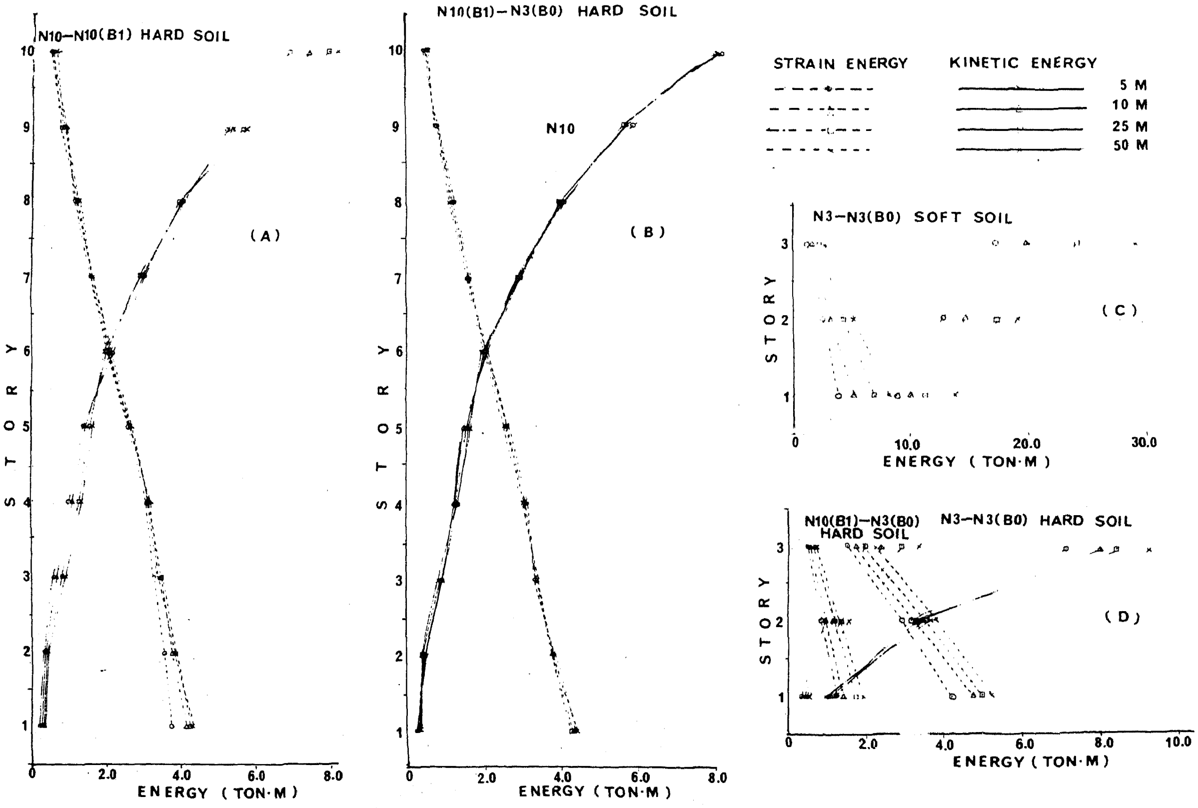


FIG 6 MAX. STORY STRAIN AND KINETIC ENERGIES DUE TO EL CENTRO(1940)NS INPUT