EFFECTS OF SOIL PROFILES ON THE SEISMIC RESPONSE OF BUILDINGS

by

JOJI SAKURAI[I] and J.K. MINAMI[II]

SYNOPSIS

Damage to buildings and structures observed in past earthquakes seems to indicate that non-uniform soil profiles may be responsible in part at least for the effects noted. Seismic response of buildings located on concealed valley profile, exposed mound profile and continuous valley and mound profiles have been investigated. The mound profile is assumed to be of hard diluvium and the valley profile of soft aluvium confined by hard soil at both ends. Low rigid buildings are affected adversely more than taller flexible buildings. Seismic response is high for low buildings located at the edge on the mound profile and when located near the center on the valley profile. Higher responses occur with increasing width of valley profiles. The seismic response of buildings differs markedly from the case of buildings supported on horizontally uniform soil layers.

INTRODUCTION

At the time of the 1968 Tokachi-oki earthquake in north-eastern region of Japan, low rigid reinforced concrete buildings located near the edge of a stretch of hills in the city of Hachinohe suffered serious structural damage. Also, in the 1975 Oita earthquake in the southern region of Japan, the ground floor columns of a 4 storey reinforced concrete hotel building of modern design built on a slope, were badly damaged. In California, unusually high accelerations were reported to have been recorded on rugged terrain near the Pacoima dam site near the epicenter in the 1971 San Fernando earthquake.

On the other hand, residences of wooden construction on sedimentary soil near exposed hillsides at the time of the 1948 Fukui earthquake suffered large heaving due to violent ground movements induced in part if not entirely due to the soil profile.

The effects of soil profiles on the seismic response of buildings is an interesting problem and the authors have made some case studies on the seismic response of buildings on exposed mound profile, confined valley profile, and cyclically recuring mound and valley profiles which are described in this paper.

SIMULATION MODELS AND METHOD OF ANALYSIS

The mound (M) profile consisting of hard diluvium and the valley (V) profile consisting of soft aluvium confined between hard soil formation at

I Professor, College of Technology, Waseda University, Tokyo
II Professor, Dept. of Architecture, Waseda University, Tokyo

both sides as shown in Fig. 1 were studied initially. The vibrational characteristics of hard and soft soil types are represented by the predominant period of 0.25 sec for the hard soil and of 0.5 sec for the soft soil. The models are truss type and the diagonal elements are proportioned to have the required stiffnesses to produce the assumed vibrational values. The soil profile consists of 3 layers, each of 5m thickness. The buildings of two 5m spans range from 3, 5, 10 and 15 storeys above the ground level (GL), the storey height being 3.5m. A damping ratio of 5% has been assigned to the soil and the building in the fundamental mode and damping ratios are assumed to be proportional to the circular frequencies in the higher modes.

In the later studies, cyclic truss type models such as the one shown in Fig. 2 has been used. In order to reduce the number of degrees of freedom of the soil-building interacting model, the unit module in both the horizontal and vertical directions has been doubled so that the surface soil formation consists of three layers, each of 10m thickness. The building width is 20m consisting of two 10m spans and storey height of 7m, representing two normal storeys. The buildings are of 2, 4, 8, and 16 storeys with and without a basement (B2) corresponding to two ordinary storeys. The V-profile is adjoined on each side by M-profiles. The cyclic model width is measured center to center of the M-profiles. The vibrational periods of the 30 meter surface soil layers have been assumed to be the same predominent periods, namely, 0.25 sec for the hard soil and 0.5 sec for the soft soil and element stiffnesses determined to satisfy the vibrational values assumed.

The building is initially located at the center of the M-profile to determine the vibrational characteristics and the seismic response for this location. The building is next moved 10m horizonally and the analysis is repeated until the building is located at the center line of the V-profile.

The masses of the soil and building components of the interacting soil-foundation-building (SFB) system are concentrated at the intersection of the vertical and horizontal members of the model. The diagonal members are proportioned for the required stiffnesses to simulate the soil, the foundation, and the building components.

Givens-Householder method has been used to determine the vibrational characteristics for the first 15 modes. The modified linear acceleration method has been used to determine the seismic response for base shears, base overturning moments and base axial forces.

The 1940 El Centro earthquake accelerations normalized to 100 gal maximum horizontal and 60 gal maximum vertical accelerations are used as input excitations at the base rock level, -15m for M and V profiles and -30m from the ground surface for the cyclic model.

RESULTS OF STUDY

(A) Mound and Valley Profiles

For both the M and V profiles, low buildings are affected more than taller flexible buildings. For the M-profile, largest seismic response occurs when low buildings are located at the edge of the profile where sway is considerable. This dangerous situation can be avoided by locating the building some distance from the edge. In the case of the V-profile, the largest seismic response occurs when low buildings are located near the center of the profile.

(B) Cyclic M-V-M Profile

The natural periods for the four storey building N4, when located at the center of the mound profile and at the center of the valley profile of different widths are shown in Fig. 3. The periods of vibration for the surface soil only for different cyclic widths between the mound centers are shown in Fig. 4. When this distance is short, the fundamental period is close to the natural period for the hard soil (0.25 sec) but as the distance is increased, it approaches the period for the soft soil (0.5 sec). The variation in the natural periods for the second to the fourth modes are also shown in the same figure.

The variations in the natural periods for N4 building for cyclic width of 160m profile at different locations are shown in Fig. 5.

The base shears, base overturning moments and base axial forces have been computed for various locations for different height buildings, N2, N4, N8B2 and N16B2. The variation in the base shear coefficients, C_B are shown in Fig. 6. It is to be noted that the variation in the seismic coefficients for the cyclic profile is quite different than for uniform soil layers in the horizontal direction as reported in another paper by the authors at this Conference (1) and more fully in another paper (2).

The base overturning moment coefficient, C_M, (defined as the total overturning moment at the ground level storey divided by the product of the building weight and the distance to its centroid from the ground level) varies in a manner closely resembling the variation pattern for the base shear coefficient, C_B.

The base axial force coefficient, C_A, (defined as the ratio of the axial force in the column at the ground level divided by the building weight above that level) produces axial force variation of plus-minus 20% of the building weight at the base due to 60 gal vertical component input at the base rock level for low buildings supported on horizontally uniform hard soil formation and such axial forces in the columns diminish with increasing natural periods of the SFB system and with decreasing soil stiffness as reported previously (2)(3). Different soil profiles also produce significant effects. For near focus earthquakes, greater changes in the column stress condition may occur and, in combination with the horizonal earthquake component effects, may not be dismissed as being insignificant as it usually is in current earthquake resistant design practice.

The problem relating to the effects of soil profiles on the seismic response of buildings is under investigation but findings to date indicate that different soil profiles have significant effects on the earthquake response of buildings, particularly on low buildings located at the edge of the mound (M) shaped profile and near the center line of the valley (V) shaped profile.

CLOSING REMARKS

The series of studies relating to the seismic response of buildings in the soil-foundation-building interacting systems has led to the proposal of a new method of estimating the earthquake forces on buildings which takes into consideration four soil types (rock, hard, soft and filled) with different damping ratios for each soil type (1). It has been established that there exists a singular response spectrum for each soil kind and this family of response curves has been integrated into a Multiple Spectra (MS) Response Curves for use in seismic design of buildings. The design seismic coefficient, C_{dB}, takes into account the seismicity zone factor, the importance factor, structural framing coefficient and the basic base shear coefficient but not the soil profile factor. When the effects of the latter are more clearly understood, the soil profile factor may be included in determining the design seismic coefficient to estimate the earthquake force on the building under consideration.

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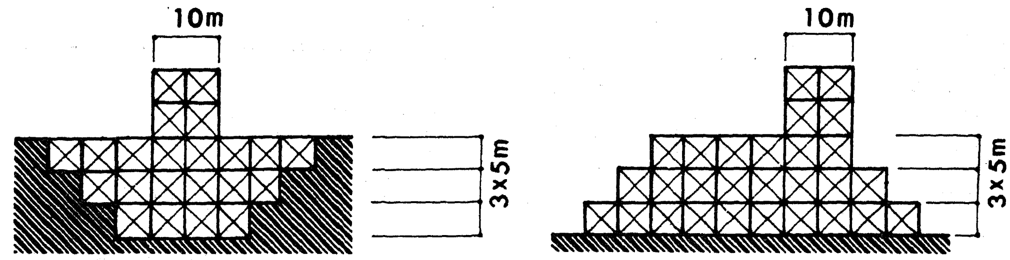

Fig. 1 Valley (V) and Mound (M) Profiles

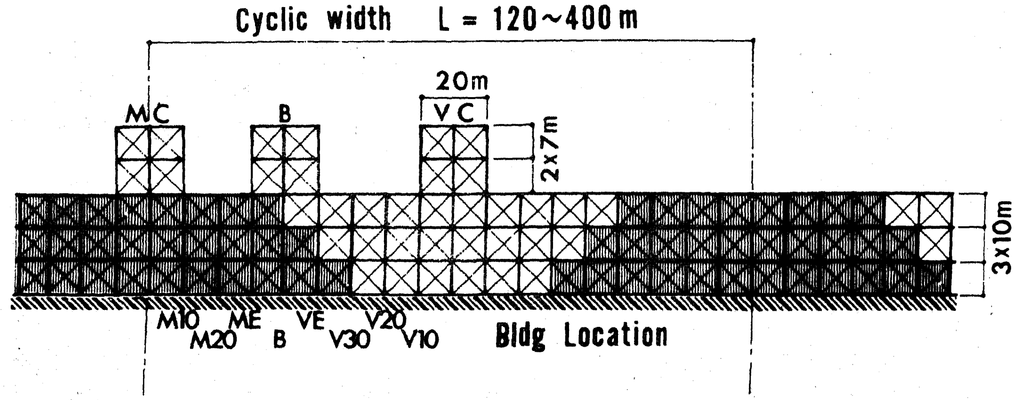

Fig. 2 Cyclic Truss Type M-V-M Profile Model

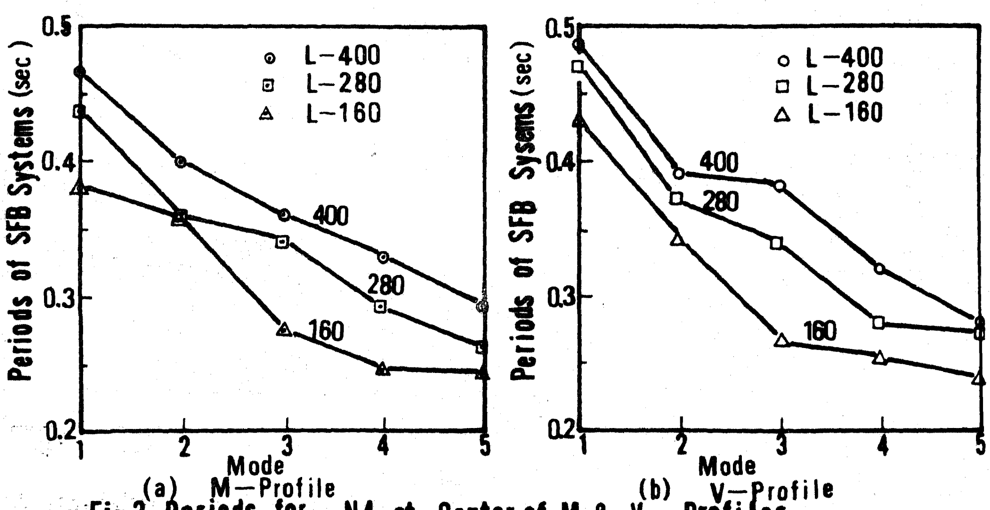

Fig.3 Periods for N4 at Center of M & V Profiles

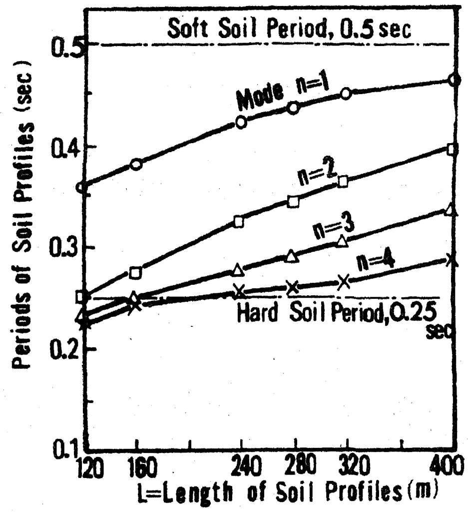

Fig.4 Soil Periods

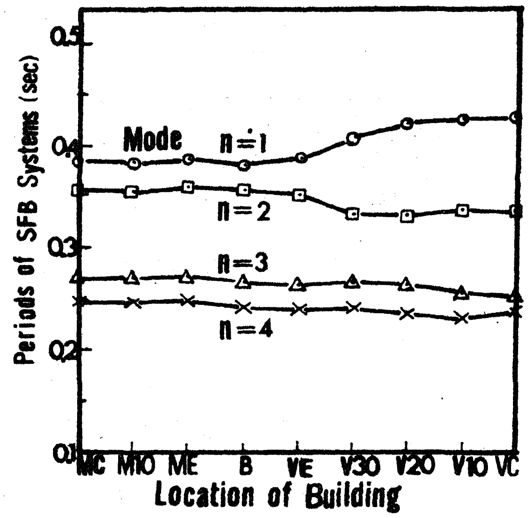

Fig.5 Periods for N4(Piles) on L-160

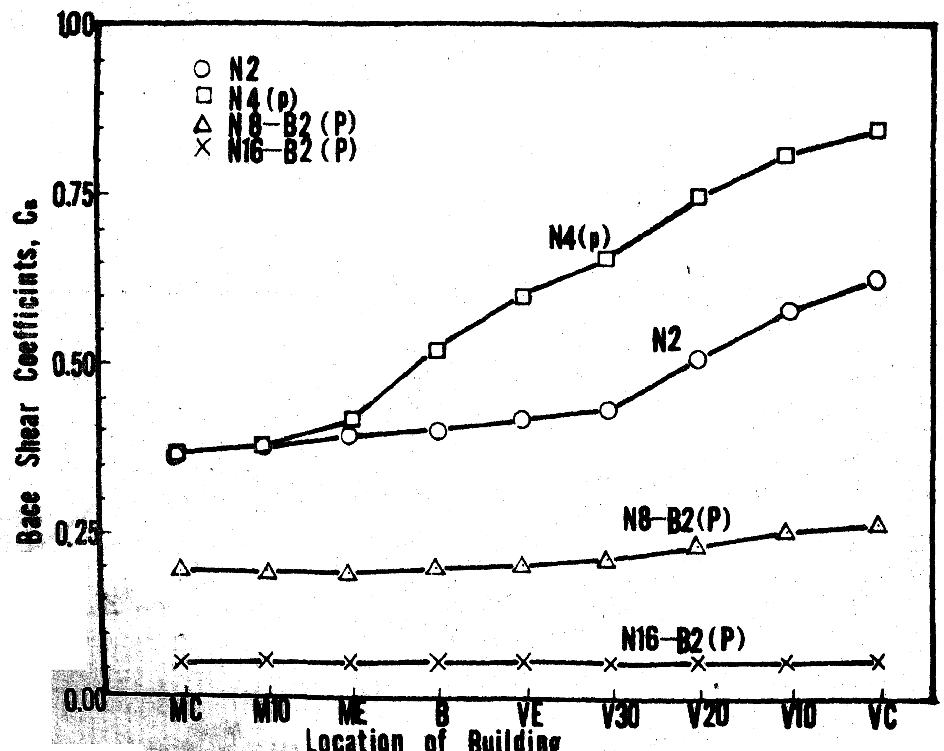

Fig.6 Location of Building and Base Shear Coefficients, C_B Considering Piles(p) and Piers(P)