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INFLUENCES OF GROUND CONDITIONS AND INPUT MOTIONS ON DYNAMIC BEHAVIOR OF BUILDINGS

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SUMMARY

The dynamic behavior of buildings during an earthquake depends on ground conditions and input seismic motions. Three pile-supported buildings were observed under many seismic conditions to compare individual response characteristics. The results were that the response acceleration of the buildings on hard ground was approximately 2 times larger than that for soft ground. This,. however, was reversed when the input seismic motions had a long predominant period as in a long-distance earthquake. This paper proposes an evaluation method for various soil-foundation dynamic constants, and investigates the aforementioned phenomena by analyzing a spring-mass interaction model.

INTRODUCTION

As is well known, response characteristics of buildings during an earthquake are determined by the interaction of the soils, buildings and input motions. For several years the authors have conducted seismic observations of three buildings which are identical in plan and cross-section but with different ground conditions, and have investigated individual response characteristics to earthquakes (Ref. 1). This paper discusses the influences of ground conditions and input motions on the response to earthquake of the buildings on the basis of observation records and analysis using a interaction model by spring-mass system.

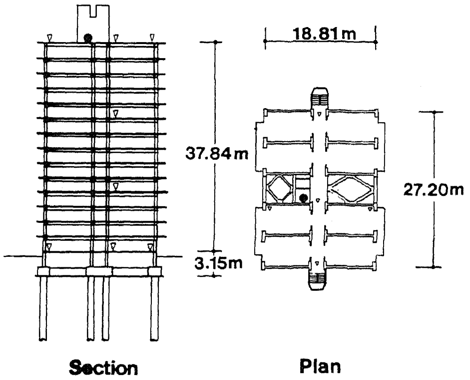


Fig. 1 Outline of buildings

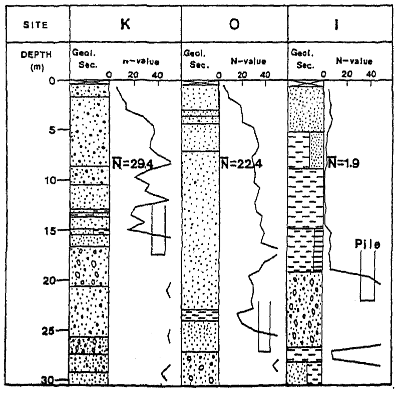


Fig. 2 Soil boring logs

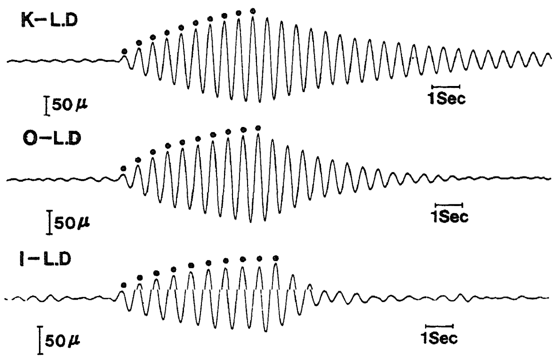


Fig. 3 Man-excited vibration records for three buildings

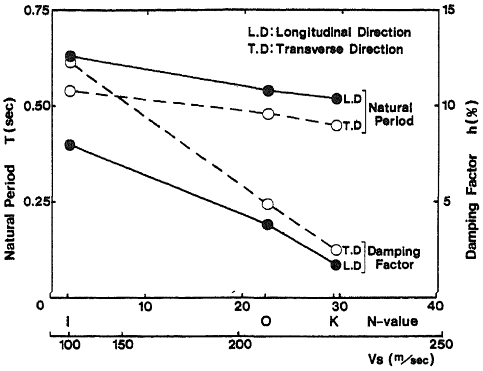


Fig. 4 Basic dynamic characteristics of the three buildings

BASIC CHARACTERISTICS OF BUILDINGS AND GROUND CONDITIONS

The buildings observed, K, O and I, are fourteen-story steel frame reinforced concrete structures as shown in Fig. 1, and are apartment houses. The three buildings are supported by cast-in-place concrete piles of 120 cm and 100 cm in diameter and approximately 20 m in length. As shown in Fig. 2, buildings K and O are on diluvium with average N values (up to GL-10 m) of 29.4 and 22.4, respectively. Building I is built on 20 m thick soft alluvium with an N value of 1.9. Buildings O and I are located close to the center of Osaka Plain, while K is about 1 km from the foot of the surrounding mountains.

A man-excited vibration test was applied to the three buildings. Displacement waveforms obtained at the top floors of each building are as shown in Fig. 3 (Ref. 2). The marks ● in the figure indicate man-excited vibrations repeated ten times by fourteen persons. In spite of the identical structures of the buildings, a clear difference was observed in the natural period and damping factor, depending on ground conditions. Basic dynamic characteristics of the buildings are as shown in Fig. 4. A building on soft ground with a lower N value has a longer natural period and larger damping factor compared with one on hard ground.

OBSERVATION OF EARTHQUAKE RESPONSE OF THE BUILDINGS

An example of acceleration records obtained at the top floors of the buildings is given in Fig. 5. The observation was made during a short-distance earthquake about 60 km from the epicenter, with magnitude 5.9 and seismic intensity IV (JMA scale) at Osaka. The acceleration waves at the ground surface were recorded at observation point A on diluvium located in the center of the Osaka Plain (Ref. 3). As the figure indicates, response acceleration of buildings *K and O on hard ground was 2 or 3 times larger than building I on soft ground.*

Acceleration waves obtained during a long-distance earthquake with a long predominant period with the epicenter 220 km away are shown in Fig. 6. This figure indicates that unlike a short-distance earthquake, response acceleration for building I on soft ground is larger than that for O on hard ground. Period characteristics of input seismic motion thus exert a larger influence on the earthquake response of the buildings.

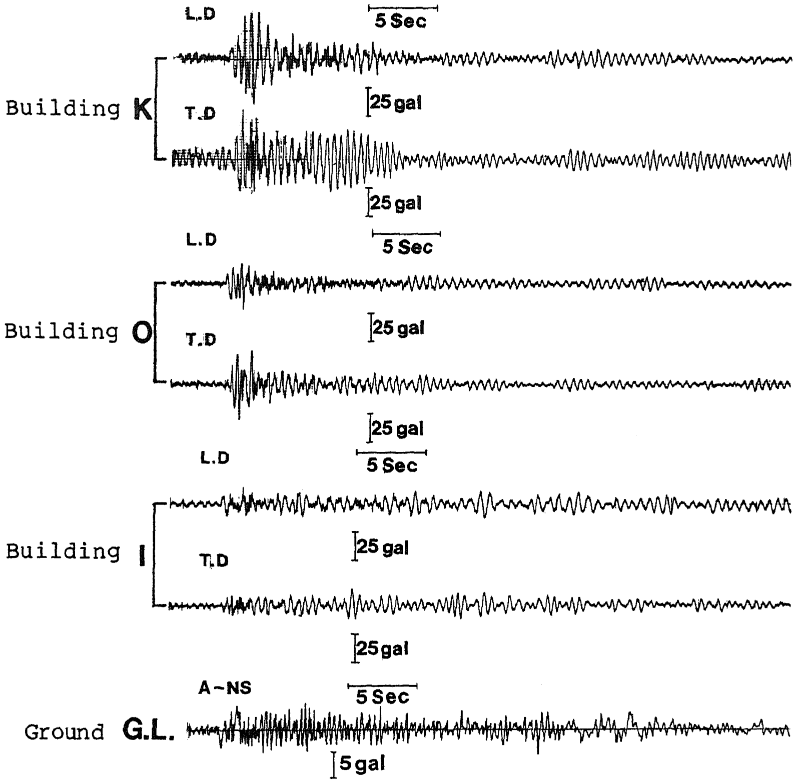


Fig. 5 Acceleration records obtained on the top floor at three buildings and ground surface during a short-distance earthquake (within 100 km epicentral distance)

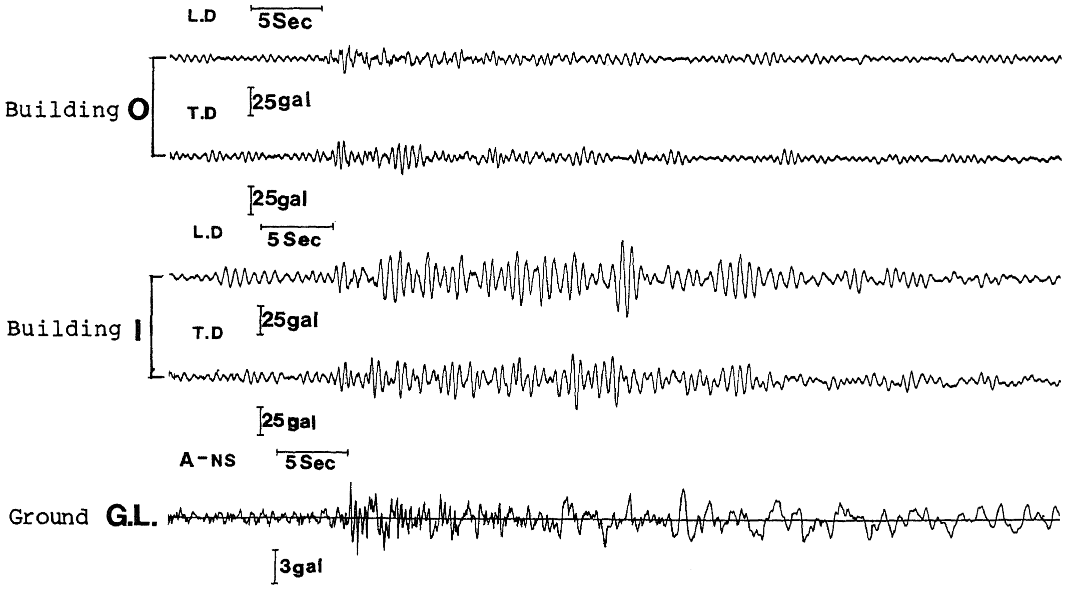


FIg. 6 Acceleration records obtained on the top floor at two buildings and ground surface during a long-distance earthquake (without 200 km epicentral distance)

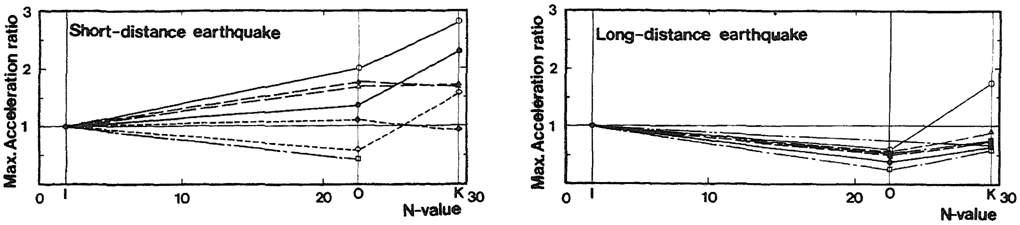


FIg. 7 Effects of differences in ground conditions and input seismic motions on response acceleration of buildings

Earthquakes of seismic intensity II (JMA scale) or greater at Osaka were observed at the three buildings. The ratios of maximum response acceleration for buildings K and O to the value for I as a reference level were obtained for short- and long-distance earthquakes, with period characteristics of input motion taken into consideration. The results are shown in Fig. 7. For a short-distance earthquake with a short predominant period of one second or less, buildings K and O on hard ground show higher amplification ratio than I on soft ground. However, for a long-distance earthquake with a long predominant period exceeding one second, this tendency is reversed. This is presumably because, for a long-distance earthquake, acceleration for hard ground is smaller than that for soft ground and also because a building on hard ground responds to a narrow range of input motion period. It was also noticed that the maximum acceleration for building K tended to be larger than that for O. This is supposedly because building K is located on a mountain-plain boundary area and such a locational difference causes a difference in input seismic motion.

SETTING OF DYNAMIC MODEL AND ANALYSIS OF EARTHQUAKE RESPONSE

Calculation of spring constants and damping factors The observation findings were analyzed in terms of earthquake response, with the building replaced by a interaction model of spring-mass system as shown in Fig. 8. Spring constants for soil-foundation interaction were evaluated by static calculation at the foundation bottom . In calculating the horizontal spring constants using equation (1), consideration was given to the embedment depth of the foundation(Refs. 4,5). Pile head displacement was evaluated by using Chang's formula for a fixed pile head, with proper correction made for coefficient of horizontal subgrade reaction depending on the amount of pile deformation. Horizontal spring constant (K_H) is shown as follows:

$$K_H=K_{Hp}+K_{Hw}+K_{Hf} \quad \text{-----(1)}$$

where K_{Hp}: Horizontal resistance of piles
K_{Hw}: Front passive earth pressure for embedded portion
K_{Hf}: Side frictional resistance for embedded portion

$$K_{Hp}=nk_hB/\beta \quad \text{-----(2)}$$

where $\beta=(k_hB/4E_pI_p)^{1/4}$

n : number of piles
B : Pile diameter (cm)
E_p: Young's modules of pile (kg/cm^2)
I_p: Geometrical moment of inertia for pile (cm^4)
k_h: Coefficient of horizontal subgrade reaction corrected with pile head displacement taken into account (kg/cm^3)

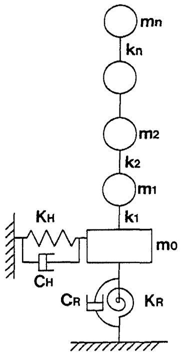


Fig. 8 Analytical model

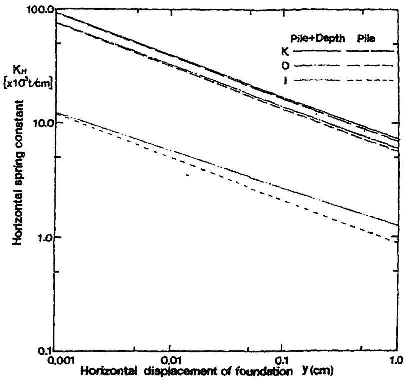


Fig. 9 Relation between horizontal displacement of foundation and horizontal spring constants

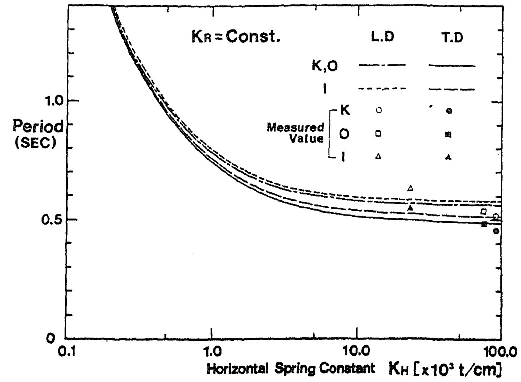


Fig. 10 Effects of soil-foundation spring constants on natural period

$k_h = k_{h0} y^{-1/2}$ -----(3)

where y : Horizontal displacement of pile head (cm)

$k_{h0} = 5.6NB^{-3/4}$ -----(4)

where N : Average N value obtained in standard penetration tests

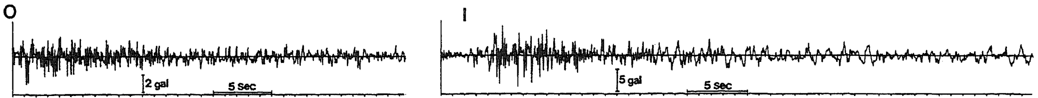
Effects of horizontal displacements of foundation on horizontal spring constants for the three buildings are shown in Fig. 9. Horizontal spring constants tend to decrease as horizontal displacements increases.

Rocking spring constants were evaluated based on vertical displacement comprising pile settlement and axial pile deformation, with the rate of axial force reaching the pile end modified depending on ground conditions, and were obtained in accordance with the plane pile arrangement.

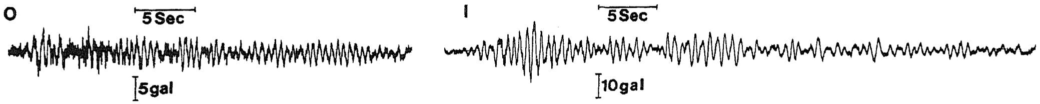
The relation between horizontal spring constants and natural period is depicted in Fig. 10. As this figure indicates, natural period tends to become longer as horizontal spring constants decrease. Measured values plotted in the figure were obtained in the man-excited vibration tests. These measured values closely correspond to the theoretical values.

To evaluate soil-foundation damping characteristics, response observed when a specified vibration was given at the top of the building was analyzed with a soil-foundation damping factor assumed, and calculation was repeated on a trial and error basis until analytical results corresponded to the observed waves obtained man-excited vibration tests. The soil-foundation damping factor obtained when both waveforms almost agree are, in the building's longitudinal direction, 2%, 10% and 20% for buildings K, O and I respectively. Those in the transverse direction are approximately 1.5 times larger. The value for the structure is 2% for each building.

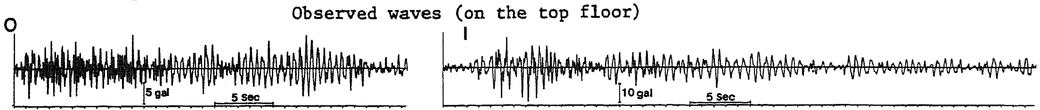
<u>Comparison of observed and calculated waves</u> Fig. 11 shows the waves during an earthquake observed on the ground and on the top floors of building O and I, in comparison with the calculated waves for the two buildings by an analytical model as shown in Fig. 8. Those models, though simplified, satisfactorily represent the differences in response acceleration waves, maximum acceleration and vibration period between the two buildings with different ground conditions.



Input ground motion (Observed waves)



Observed waves (on the top floor)



Calculated waves (on the top floor)

Fig. 11 Comparison of observed and calculated waves for two buildings on different ground conditions

CONCLUSION

Observation and analysis conducted for the three buildings with identical plans and cross-section and different ground conditions are summarized below.

(1) Basic dynamic characteristics of buildings definitely depend on ground condition. As shown by the man-excited vibration test results, the building on soft ground has about 1.2 times longer natural period, and about 5 times larger damping factor than that on hard ground.

(2) Response characteristics of buildings during an earthquake are interrelated with period characteristics of input seismic motions in addition to the ground conditions. For a short-distance earthquake with a predominant one second or shorter period, a building on soft ground shows smaller maximum acceleration than that on hard ground. This tendency, however, is reversed for a long-distance earthquake with long predominant period exceeding one second.

(3) Response characteristics of buildings are greatly influenced by dynamic spring constants and damping factors for soil-foundation interaction. It has been confirmed that by using the evaluation method for the dynamic spring constants and damping factors proposed herein, behavior of a building during an earthquake can be estimated from simplified models.

ACKNOWLEDGMENT

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