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The movement of tall building on surface ground in Osaka by principal shock and 'Atoyuré' vibration

H. Mukai & T. Hisatoku
Takenaka Corporation, Osaka, Japan

I. Toriumi
Osaka Institute of Technology, Japan

ABSTRACT: It is recognized that the earthquakes in Osaka city include the time-lag quakes called "Atoyuré" after principal shock due to surface waves of the sedimentary plain transmitted from the peripheral rock mountainous region. This paper reports the characteristic behavior of the high-rise building in Osaka city to two earthquakes registered in this building. Maximum value of the horizontal displacement amplitude at the top of the building was observed about 30 to 40 seconds after the principal shock and did not decrease even after elapse of 120 seconds. According to the above observation, it is desirable to install any damping devices on the high-rise building which primary natural period is about 3 seconds for living comfort against low level earthquakes and typhoons occurred often.

1 INTRODUCTION

The mechanism of the surface ground motion in the Osaka sedimentary plain have been made clear by one of the author, Toriumi, from many earthquake records during 30 years. The Osaka plain enclosed the rock mountainous region is like to a basin filled with gelatin. When the earthquake occurs, in the center part of Osaka city, the principal shock that is reached from the rock bottom of the plain with S wave multi-reflected appears and then the secondary wave which period is relatively long appear by transmitting through the surface ground from the peripheral mountainous region. Toriumi gave the name 'Atoyuré' for the time-lag quakes.

It is the purpose of this paper to introduce the interesting behavior of the high-rise building effected by these two waves for two earthquake recorded in the Umeda Center Building designed by the authors.

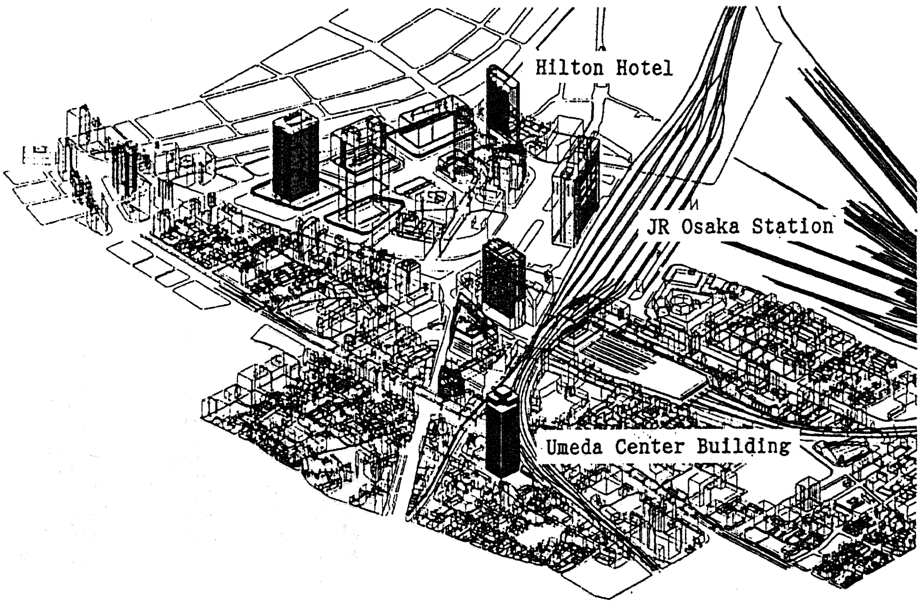


Fig.1 Location of the Umeda Center Building

2 OUTLINE OF THE BUILDING

This building is located approximately 650 meters northwest of Japan Railways Osaka Station. Fig.1 shows the location of the Umeda Center Building among the down town in the Osaka Umeda area. Fig.2 shows the site plan and first floor plan. The building which maximum height is 134.7 meters, consists of 2 basements, 32 floors above ground and a penthouse of one floor. The typical floor plan, as shown in Fig.3, is square shaped with one side 48 meters wide while two opposite corners are recessed in a L shape, 12.8 meters long and 6.4 meters wide. The core plan 19.2 meters square is arranged in the center part. The exterior, as shown in Photo 1, is completely finished in glass by aluminum curtain walls.

With the exception of the foundation, between the high-rise building which rises from center of the site and the lower building, expansion joints are provided at the first basement and ground level, and these components are structurally, clearly separated. The high-rise one is a steel structure with the exception of the reinforced concrete girder at the foundation level.

A double tube structure system consisting of a peripheral frame and inner frame with columns and beams connected by rigid joints was adopted. To increase story rigidity of the inner frame, braces with ends rigidly jointed were provided between columns with the exception of exits and entrances where piping outlets etc. are installed.

As shown in Fig.3 and 4, these frames are symmetrical in two directions to the principal axis for all floors for utmost effort to suppress torsional deformation caused by eccentricity. To further enhance 3-dimensional effect, a feature of the tube structure, columns are arranged closely together at 3.2 meters apart, matching the intervals of grids for the planing.

Table 1 shows a comparison between the natural period obtained by three dimensional frame analysis of the structure shown Fig.4 and the natural period picked up from a vibration experiment.

The primary damping constant gained from free vibration waveform after input excitation at the 31st floor level was 1.1% in the I direction and 1.3% in the II direction.

Table 1 Natural period (sec.) from analysis and test

	I dir.		II dir.	
order	analysis	test	analysis	test
1	3.73	3.03	3.41	2.86
2	1.29	0.92	1.21	0.87
3	0.70	0.51	0.67	0.48

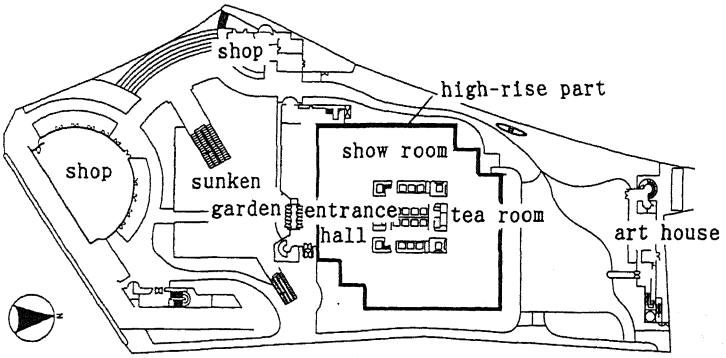


Fig.2 Site and first floor plan

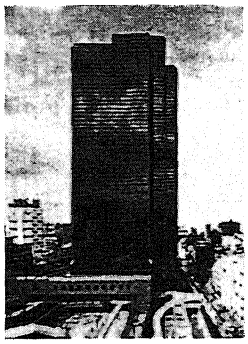


Photo 1 Outside view from south

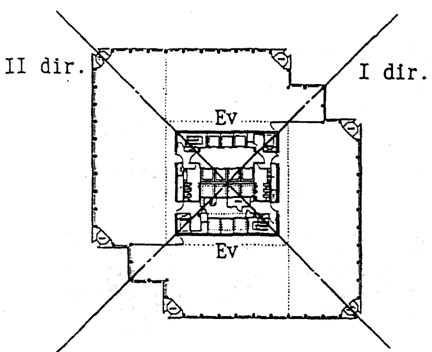


Fig.3 Typical floor plan

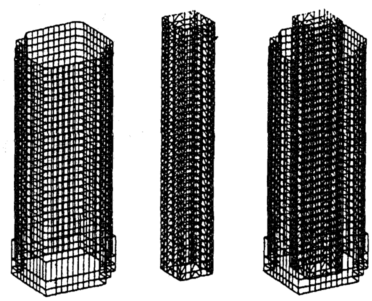
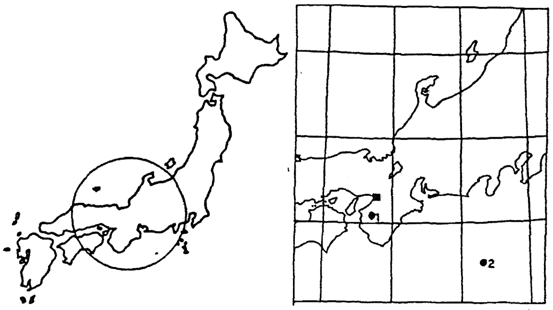


Fig.4 Double tube structure

3 EARTHQUAKE OBSERVATION RESULTS

On May 9, 1987 and September 24, 1990, earthquakes continuing for more than 2 minutes were registered in the Umeda Center Building. Both earthquakes were relatively small with a maximum surface ground acceleration of several cm/sec^2. The outline of the two observed earthquakes and the installed positions of the seismographs are shown in Fig.5. An accelerometer is installed at approximately the center of the high-rise building on floor levels 31, 15, and basement 2, and a velocity seismograph and an accelerometer are installed 1 meter under the ground surface between the site boundary and the basement outer wall. The components in the principal axis I and II directions and the vertical directions of the high-rise building are the objects of observation.

Fig.6 show the acceleration records of three directions of the respective observation points and Fig.7 shows the velocity records at the ground level to the earthquake No.1. The maximum values and their time of occurrence are shown right upper parts of each waveform.



	No.1	No.2
earthquake	No.1	No.2
date	'87/5/9 12:54	'90/9/24 6:14
magnitude	5.6	6.6
position of epicenter		
north latitude	34.2	33.0
east longitude	135.4	138.6
distance of epicenter	60 km	340 km
earthquake intensity	II	III

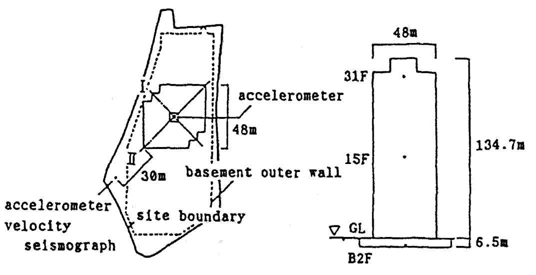


Fig.5 Outline of the two earthquakes and the position of seismographs

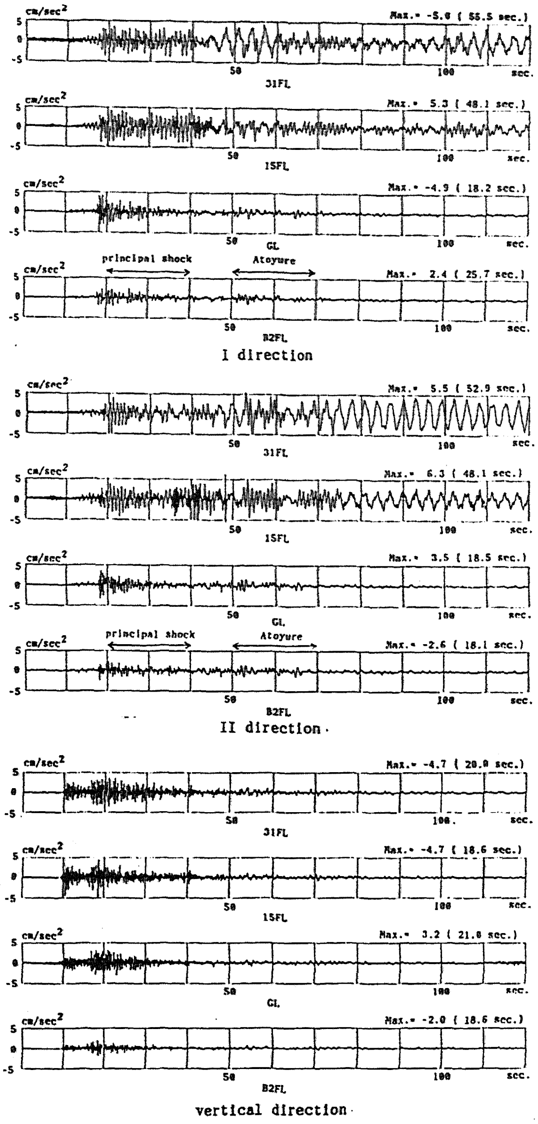


Fig.6 Acceleration records of earthquake No.1

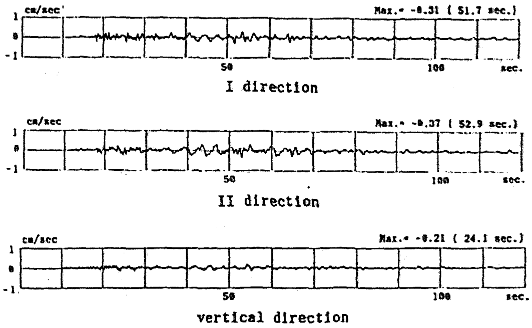


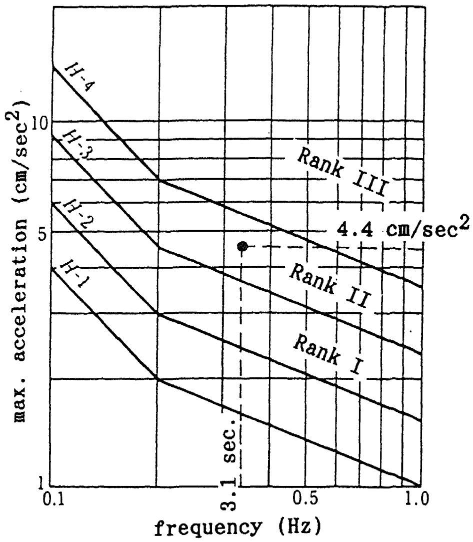
Fig.7 Velocity records of earthquake No.1

On observing the ground surface acceleration wave forms in the I and II directions, the principal shock begins from 18 seconds and ends around 40 seconds but time-lag quakes continue for 50 to 70 seconds subsequently. This phenomenon coincides with earthquake motion characteristics of the central part of the Osaka plain (Reference Fig.1).

The maximum acceleration occurrence time at the 15th and 31st floors of the building was around 50 seconds and this approximates the starting time of time-lag quakes. It is considered that the cause for this arises from the long period maximum velocity component of around 50 seconds as observed in the velocity records at ground level in Fig.7.

The problem seen here is that, especially at the 31st floor level, the acceleration amplitude in the I direction gradually becomes smaller after the end of the earthquake but again amplifies around 100 seconds and that in direction II, hardly any damping is seen even after the end of the earthquake. At the 31st floor in the II direction, shocks continued at a natural period of 3.1 seconds, 4.4 cm/sec^2 amplitude. As shown in Fig.8, AIJ Guidelines are satisfied but it is easy to assume that the vibration continuing for more than one minute is certainly not a comfortable feeling for the normal person. Later, it was reported that one person, working on the 29th floor, developed symptoms similar to seasickness and had to return home. Although a damping constant of not less than 1% was obtained in the excitation experiment results, as observed from the velocity record in the II direction Fig.7, a phenomenon such as this developed after 90 seconds even though input energy had become lower. The reason for this is not clear at present.

Fig.9 shows a comparison of the velocity record at the ground with the velocity waveform obtained by integrating the acceleration record. The shape of the waveforms and amplitudes correspond well and as shown later, therefore it is considered that the displacement waveform of the building well reflects the actual situation.



31st floor response of II direction in earthquake No.1

Fig.8 AIJ Guidelines for habitability of office

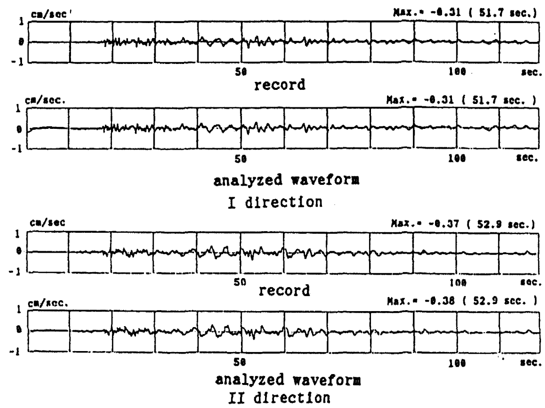
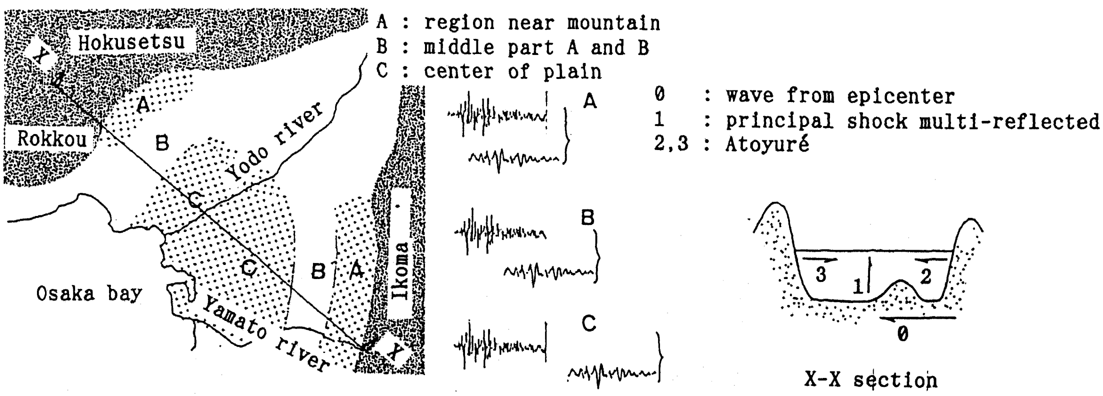


Fig.9 Comparison of records with analyzed waveforms for velocity at ground level



Reference Fig.1 Time difference between principal shock and Atoyuré in Osaka plain

Fig.10 shows the transfer function of acceleration the 31st and 15th floor to ground surface. The predominant period at the time of the earthquake roughly coincides with the primary and secondary natural period by the vibration experiment and it is considered that the building vibrated in a condition where the primary and secondary modes overlapped.

Fig.11 shows the displacement waveform of the various observation points. It is seen that for both directions I and II, deformation at 31st floor is not so great when the principal shock is continuing 20 to 40 seconds. The displacement amplitude increases from when time-lag quakes occurs and dampens after the end of the time-lag quakes but again amplifies at around 100 seconds in the I direction. In the II direction, the displacement amplitude does not dampen even if the end of the time-lag quake. These phenomenon are the same as with the fact observed from the acceleration record.

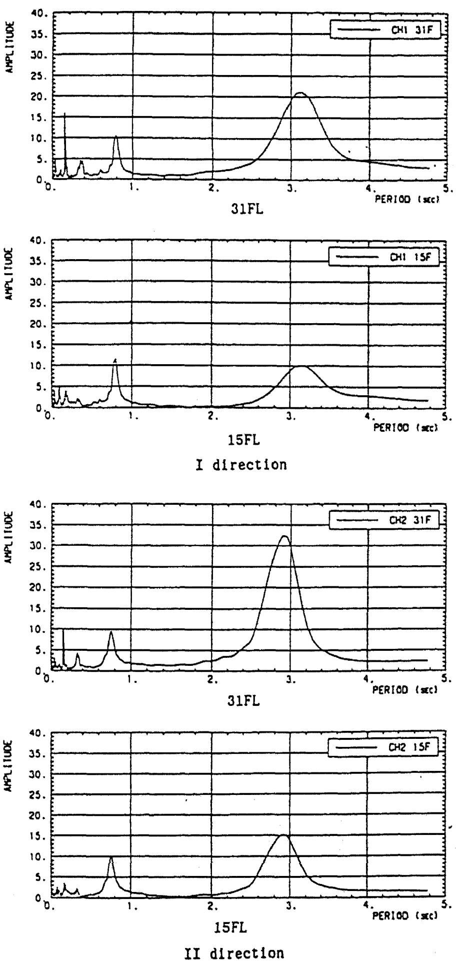


Fig.10 Transfer function

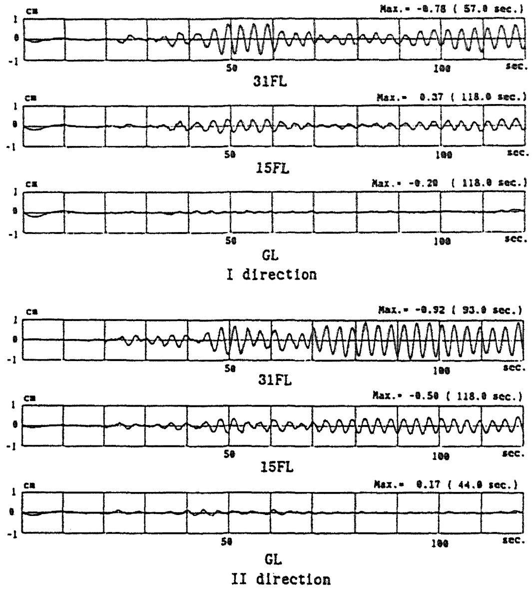


Fig.11 Displacement waveforms

Fig.12 shows a comparison of observed waveforms on displacement at 31st floor level with waveforms which are obtained from dynamic analysis using the building property. The equivalent story shear rigidity of each floor was revised to match the primary natural period from the experiment. Also the damping constants are used for test one. The observed waveforms at ground level were used for the inputted acceleration. From the figure, it can be seen that the behavior of the structure can be well traced by simulation.

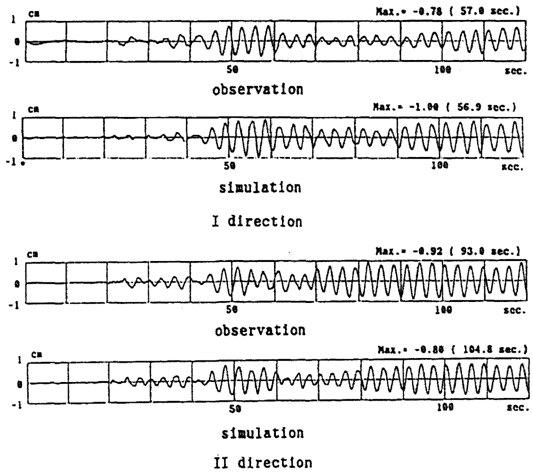


Fig.12 Comparison of observation with simulation for displacement waveform at 31st floor

The acceleration records of earthquake No.2 are shown in Fig.13. The prominent time-lag quakes seen earthquake No.1 was not observed but these waves continue for extremely long time that is the characteristic of long distance earthquakes.

Fig.14 shows the displacement response waveforms on the 31st floor. In this wave too, a large response is seen at the time the principal shock ends, at around elapsed time of 65 seconds. Even at 200 seconds when recording end, the maximum amplitude value is about 1/2 and this means that the people inside the building felt considerable shock for more than 2 minutes. In direction I, at around 155 seconds or after more than one minute after the end of the principal shock, an amplitude of a level of the main shock is seen again and this is similar to the tendency of earthquake No.1.

These phenomenon are all caused by the characteristic of the Osaka plain, and at least from the aspect of living comfort, the time-lag quakes is an important factor in designing high-rise building in Osaka.

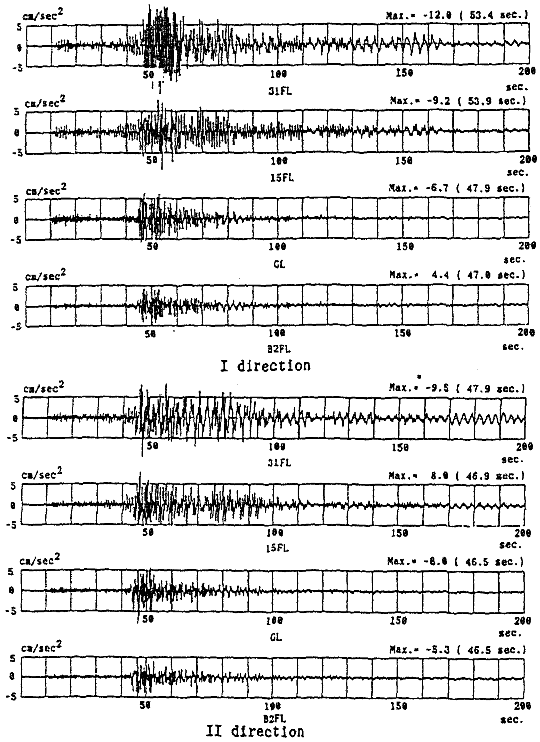


Fig.13 Acceleration records of earthquake No.2

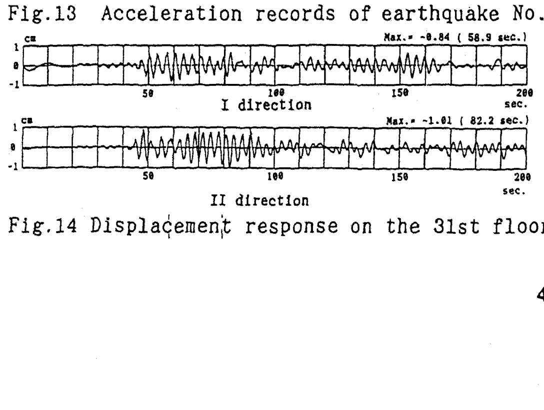


Fig.14 Displacement response on the 31st floor

4 CONCLUSION

The following conclusions are summarized from the above two earthquake records in the sedimentary surface layer of Osaka plain and from the response records of the high-rise building.

1. In the behavior of the horizontal ground motion at the time of an earthquake, long period components appear after the principal shock which is characteristic of the central part of Osaka city due to surface waves of the sedimentary plain transmitted from the peripheral rock mountainous regions.

2. There are cases where the maximum horizontal response value is generated by the time-lag quakes several tens of seconds after the end of the principal shock.

3. Response by the time-lag quakes is long and in some cases, amplitudes of maximum levels may be repeated more than twenty times.

4. The behavior of a building can be sufficiently simulated using the properties obtained from the vibration experiment.

5. At the time of these earthquakes, the building vibrated in a condition where primary and secondary modes overlapped.

6. In regard to vertical direction, it was found that hardly no amplified vibration occurs in the upper floors of the building.

These results were obtained by only two relatively small earthquakes and use of these records by simple extension for designing of buildings may be open to argument, but with high-rise buildings constructed on Osaka plain,possibility is high that time-lag quakes, rather than the principal shock,may be dominant in generating responses. Furthermore, with maximum amplitude levels continuing more than one minute caused by ground motions of this level which generate relatively frequently, living comfort is markedly impaired and in this respect, countermeasures by damping devices and such will be effective.

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