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Influence of size of plains on earthquake motion characteristics

S.Ohba & I.Toriumi
Osaka Institute of Technology, Japan

ABSTRACT: This paper discusses the influence of plain dimensions (plain area and sedimentary layer thickness) on the predominant period and duration of earthquake motion, based on records of earthquake observations in the Osaka Plain and the Fukui Plain. The results of earthquake observations show that earthquake motion in a sedimentary plain surrounded by mountains is markedly influenced by surface waves propagated horizontally through the sedimentary layer, with surrounding mountains as secondary hypocenter. An analysis based on the findings revealed that the predominant period and duration of earthquake motion in the Osaka Plain are longer than those in the Fukui Plain, which is smaller than the Osaka Plain.

1. Introduction

Earthquake motions in a sedimentary plain are the synthesis of:
(a) main motions resulting from the multiple reflection of S waves in the sedimentary layer on the base rock; and
(b) delayed motions resulting from surface waves propagated horizontally through the sedimentary layer from the border between the mountains and the plain (Fig. 1)[1].
A comparison between earthquake motions observed in the Osaka Plain and those observed simultaneously in the Fukui Plain, whose size is smaller than that of the Osaka Plain, reveals a marked difference between the earthquake motion characteristics in the two plains. Supposedly, the difference in earthquake motion characteristics observed during the same earthquake was caused by the areas and sedimentary layer depths of the plains. This paper first discusses the difference between the plains in size, then that in earthquake motion, and finally the cause of the latter difference.

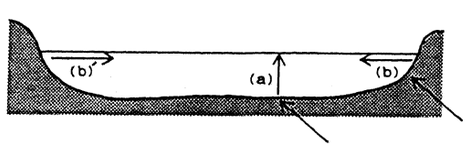


Fig. 1 Propagation of earthquake waves

2. Underground Structures of the Osaka and Fukui Plains

The locations of the Osaka and Fukui Plains are shown in Fig. 2. The horizontal distance between the plains is approx. 150 km. Both are examples of a sedimentary plain located in a basin surrounded by mountains.
The Osaka Plain is located in the north east of an oval-shaped basin, comprising part of the Osaka Bay, with a 40 km minor axis and an 80 km major axis. Fig. 3 (a) is a contour map of depth to base rock in the Osaka Plain, which also shows the geology of the plain[2].
The thickness of the sedimentary layer increases with the distance from the surrounding mountains; at the mouth of the Yamato River, the layer is 2 km thick. Fig. 3 (b) is a section diagram of the ground in the east-west direction, corresponding to the portion of the plain shown by a dotted line in Fig. 3 (a) . The sedimentary layer to the east of the Uemachi Fault is approx. 1 km thick, while that to the west of the fault is approx. 1.5 km thick. It has also been confirmed that two layers with different rigidities exist to the west of the Uemachi Fault.
As show in Fig. 4 (a) , the Fukui Plain represents a 20 km by 10 km rectangle. The area of plain is smaller than that of the Osaka Plain. Fig. 4 (b) shows the thickness of the sedimentary layer in the portion of the plain shown by a dotted line in Fig. 4 (a) . The sedimentary layer of the Fukui Plain, 100 to 300 m thick, is conspicuously thinner than

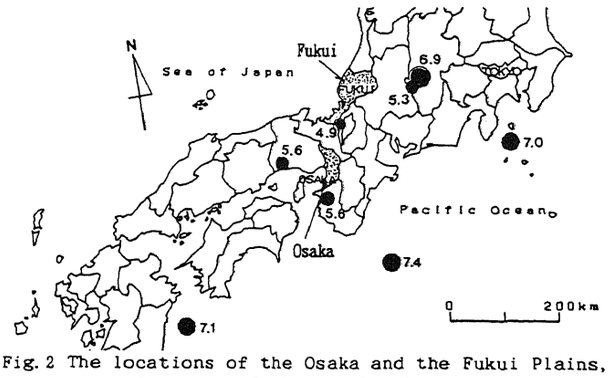
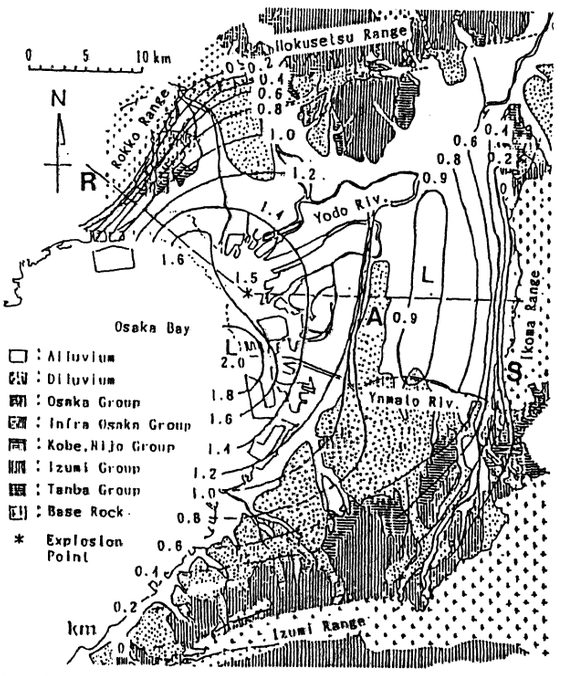
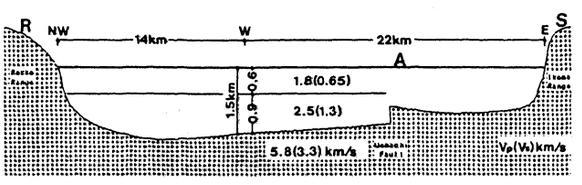


Fig. 2 The locations of the Osaka and the Fukui Plains, and epicenters of the earthquake observed simultaneously in the two Plains

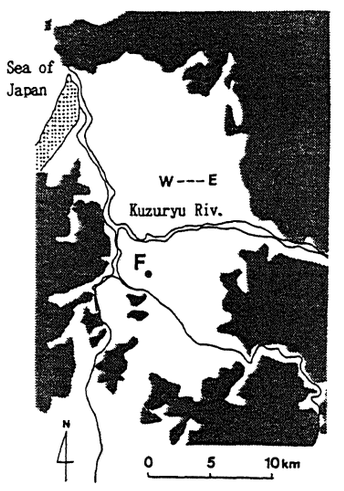


(a) Contour map of depth to base rock in the Osaka Plain and earthquake obsarvetion Points (A, R, S)

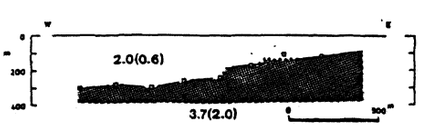


(b) section of the underground in the east-west direction

Fig. 3 The Osaka Plain[2)]



(a) The Fukui Plain and surrounding mountainous regions



(b) section of the underground in the east-west direction

Fig. 4 The Fukui Plain[3)]

that of the Osaka Plain[3]. Earthquake observation points (A, R, S and F) mentioned in this paper are shown in Fig. 3 (a) and Fig. 4 (a).

3. Propagation of earthquake waves and duration of earthquake motions in the sedimentary plain

Delayed motions correspond to surface waves propagated horizontally in the sedimentary layer from surrounding mountains, at a velocity of 600 m/sec.. Fig. 5 presents an example of delayed motions, taking the case of an earthquake of Magnitude 5.6 (Osaka Intensity Ⅱ) whose epicenter is located in the north of Wakayama Prefecture to the south of the Osaka Plain ; the distance from the epicenter is approx. 55 km. Shown in the figure are the records of the earthquake observed at five locations (shown in Fig. 5) on the base rock mountains and the sedimentary layer of the plain, after time adjustment according to the horizontal distance from the Ikoma mountains. The straight line in Fig. 5 shows the velocity of surface wave propagating from the Ikoma mountains to the center of the plain (600 m/sec.). Earthquake waveforms observed at locations in the central part of the plain are clearly divided by straight line into the first halves corresponding to main motions and the second halves corresponding to delayed motions.

The duration of earthquake motions in the Osaka Plain varies with the horizontal distance between the surrounding mountains and the observation location in the plain ; the duration is short in areas on the border between the mountains and the plain, while it is markedly longer in the central part of the plain. This variation in the duration of earthquake motions is not caused by the difference in the conditions of the surface layer, such as that between a diluvial layer and an alluvial layer ; rather, it results from the fact that the synthesis of an S wave, corresponding to main motions, and a surface wave in the sedimentary layer, corresponding to delayed motions, takes place at different points of time, depending on the observation location. Fig. 6 is a schematic representation of this situation. In regions Ⅰ, located near mountains from which delayed motions are propagated, main and delayed motions commence at about the same time, resulting in their overlap. At region Ⅱ, delayed motions begin immediately before the end of main motions, resulting in continuous motions, with the main motions as the first portion and the delayed motions as the second portion. At region Ⅲ in the central part of the plain, the main and delayed motions are clearly recognizable as two separate waveforms. As shown in the figure, the difference in the time of synthesis of main and delayed motions results in variation of duration of earthquake motions, depending on the observation location.

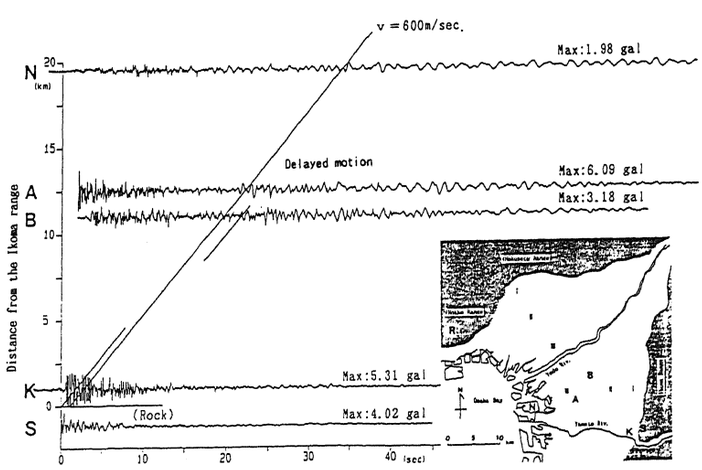


Fig. 5 Earthquake waveforms observed simultaneously in and arround the Osaka Plain

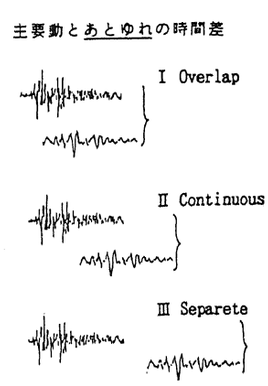


Fig. 6 The synthesis of an S wave and a surface wave group

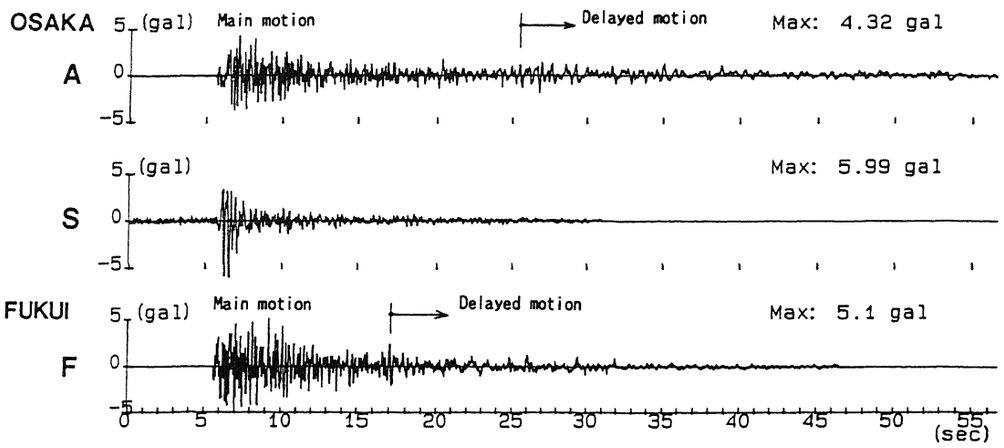


Fig. 7 The acceleration waveforms observed simultaneously in the Osaka and Fukui Plains (Mag. : 4. 9)

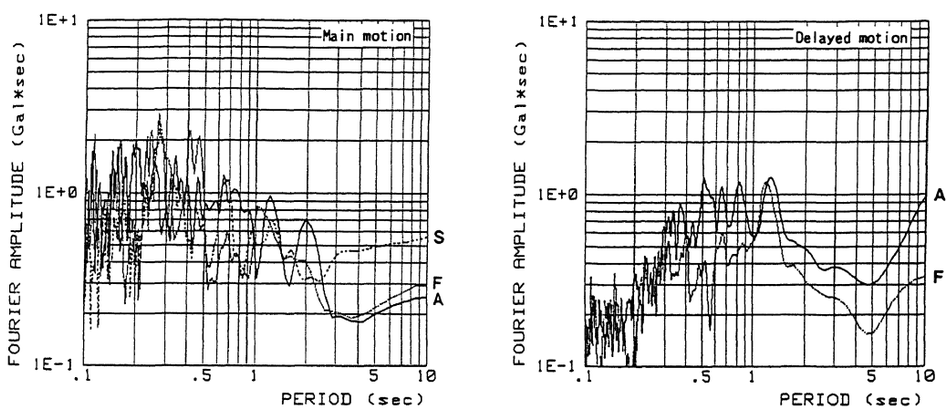


Fig. 8 Fourier spectra for the portions corresponding to main and delayed motions

4. Difference between the Earthquake Motion Characteristics of the Osaka and Fukui Plains

4.1 Earthquake Waveforms Observed Simultaneously in the two plains

In light of the fact that earthquake motion is influenced conspicuously by the characteristics of the hypocenter, data on earthquake of different magnitudes (4. 9 and 6. 9) were compared and examined. The epicenters of the earthquake are marked ◉ in Fig. 2. The distance from the epicenter is 100 and 200 km. The epicenter of the earthquake of magnitude 4. 9 is equidistant from the Osaka and Fukui Plains.

Fig. 7 shows the horizontal component of the acceleration waveform observed during the earthquake of Magnitude 4. 9. The waveform observed at Point A on the sedimentary layer of the Osaka Plain is shown at the top; the waveform observed at Point S on the base rock of mountains surrounding the plain is shown in the middle; and the waveform observed at Point F on the sedimentary layer of the Fukui Plain is shown at the bottom. Conspicuously, the duration of earthquake motion at Point A or F on the sedimentary layer is longer than at Point S. Each waveform is composed of a portion corresponding to main motions, at which short periods prevail, and another portion corresponding to delayed motions, at which relatively long periods prevail. Fig. 8 shows Fourier spectra for the portions corresponding to main and delayed motions, which indicate the characteristic of the periods of earthquake motion in the plains. As can be seen from the figure, periods of 1. 3 seconds prevail during delayed motions in both plains.

Fig. 9 shows the waveform of the earthquake of a greater magnitude (6. 9). The figure

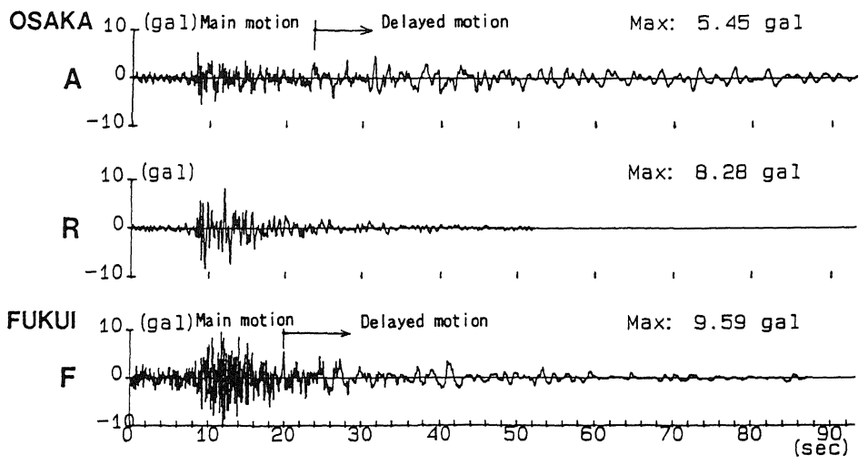


Fig. 9 The acceleration waveforms observed simultaneously in the Osaka and Fukui Plains (Mag. :6. 9)

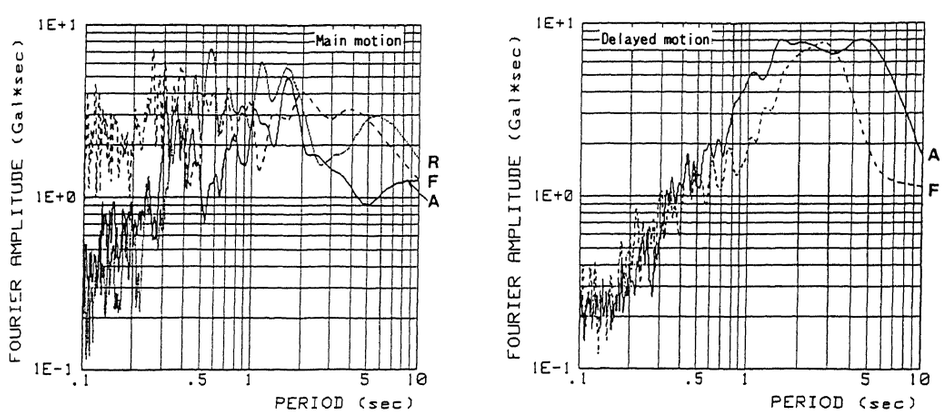


Fig. 10 Fourier spectra for the portions corresponding to main and delayed motions

indicates that the prevailing periods and duration of the earthquake are longer than those of the earthquake of Magnitude 4. 9. The duration at Point A or F on the sedimentary layer is longer than that at Point R on the base rock. In particular, the duration at Point A in the Osaka Plain (more than 1 minute) is conspicuously longer than that at Point F in the smaller Fukui Plain.

The amplitude at Point A in the Osaka Plain dose not significantly decrease after the end of main motions. Fig. 10 shows the results of the analysis of periods during main and delayed motions. While short periods prevailed during main motions, the amplitudes of short-period motions decrease and periods of 1 second or longer prevail during delayed motions. However, the range of periods prevailing in the Osaka Plain (1. 5 to 5 seconds) is wider than that in the Fukui Plain (2 to 3 seconds).

4. 2 Period Characteristics

In order to analyze the difference between the Osaka and Fukui Plains in general earthquake motion characteristics, period characteristics were examined for seven earthquakes of Magnitudes 4. 9 to 7. 4, observed simultaneously in the plains; the epicenters of the earthquakes are shown in Fig. 2. Fig. 11 shows Fourier spectra for these earthquakes, with the maximum acceleration set uniformly at 10 gal. According to the figure, periods prevailing in the plains are clearly different. The maximum prevailing period is longer in the Osaka Plain (approx. 5 seconds) than in the smaller Fukui Plain (approx. 3 seconds). The figure indicates that prevailing periods in the plains are related to hypocenter characteristics, since longer periods become more prevalent with the increase in earthquake magnitude.

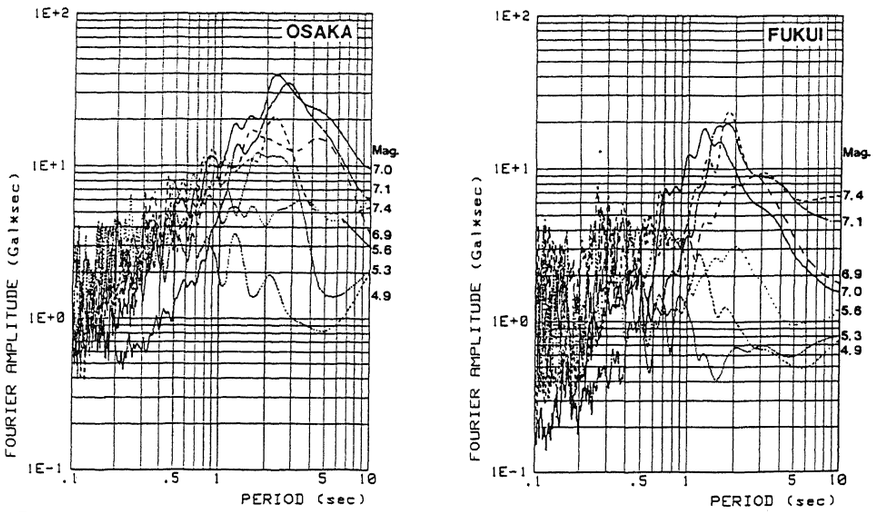


Fig. 11 Fourier spectra for the earthquake motions observed simultaneously in the Osaka and the Fukui Plains

5. Discussion of the Results of Earthquake Observations

The results of simultaneous earthquake observations in the two plains, considerably different in size, revealed that plain size greatly influences the duration and period characteristics of earthquake motion. This fact is due to the correlation between the duration of earthquake motion and the area of a plain, and that between the prevailing period and the sedimentary layer thickness. In the following, the duration of earthquake motion is discussed.

As mentioned above, earthquake motions in a sedimentary plain are the synthesis of S waves propagated upward and surface waves propagated horizontally in the sedimentary layer. The time at which the synthesis occurs varies with plain size and observation point. The propagation velocity of surface waves in a sedimentary layer depends on frequency; the velocity of waves with periods of 1 to 1.5 seconds is 600m/sec., and that of waves with periods of approx. 4 seconds is 800m/sec.. Based on these velocities, the time between the start of main motions and the arrival of surface waves from surrounding mountains at Point A in the Osaka plain is calculated at 15 to 20 seconds, and the corresponding time for Point F in the Fukui Plain at 10 to 13 seconds. These results correspond to observed waveforms shown in Fig. 7 and 9. Delayed motions result from the arrival of ensuing surface waves from the surrounding mountains. The time required for the arrival of the ensuing waves increases with the increase in plain size, prolonging the duration of earthquake motion.

6. Conclusions

The results of earthquake observations in the Osaka and Fukui Plains, with considerably different plain sizes, are summarized as follows:

(1) Earthquake motions at an observation point are influenced greatly by earthquake magnitude. The prevailing period and duration of earthquake motion increase with the increase in earthquake magnitude.

(2) The duration of earthquake motion in a sedimentary plain depends on plain size, particularly on plain area. The duration in the Osaka Plain is more than twice as long as that in the Fukui Plain, which is smaller than the Osaka Plain in area.

(3) The prevailing period depends on plain size, particularly on sedimentary layer thickness. The prevailing period in the Osaka Plain is longer than that in the Fukui Plain, whose sedimentary layer is thinner than that of the Osaka Plain. The maximum prevailing period is approx. 3 seconds in the Fukui Plain, and approx. 5 seconds in the Osaka Plain.

Refferences

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