13. *The Earthquake-Motions on Various Formations of the Earth's Surface. (I). Observation at Kōti City.*

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(Read May 20, 1947.—Received March 31, 1949.)

I. INTRODUCTION.

In the discussions of the serious damages caused by strong earthquakes, Japanese seismologists[1] and architects touched very frequently upon the close relations between damages and formations near the earth's surface.

In order to study the problem more precisely, the writers carried out the seismometric investigations on the earthquake-motions shown near the earth's surface soon after the great earthquakes at Tottori, Nankai and Hukui. The writers reported already the results of researches at Tottori[2] and Hukui,[3] and in the present paper will give an outline of the study conducted by the observations of the after-shocks at Kōti.

2. SEISMOMETRIC OBSERVATIONS OF AFTER-SHOCKS AT KŌTI.

The seismograms of an earthquake, recorded at several stations on the various grounds, even though obtained by the seismographs of the same type, are very much different from one another in their forms, amplitudes and periods. As the causes of these phenomena, it may be remarked as follows:

1) factors due to the different epicentral distances,

2) factors due to the mechanism of the production of seismic waves at the hypocentre,

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1) T. MATUZAWA, *Rep. Imp. Earthq. Invest. Comm.*, **100**, A (1925), 163 (in Japanese). N. NASU, *Rep. Imp. Earthq. Invest. Comm.*, **100**, A (1925), 313 (in Japanese). M. ISHIMOTO, *Bull. Earthq. Res. Inst.*, **10** (1932), 171; **12** (1934), 234; **13** (1935), 592; **14** (1936), 240; **15** (1937), 536. T. MINAKAMI & S. UTIBORI, *Bull. Earthq. Res. Inst.*, **24** (1946), 19 (in Japanese). R. TAKAHASHI & K. HIRANO, *Bull. Earthq. Res. Inst.*, **19** (1941), 534 (in Japanese). S. OMOTE, *Bull. Earthq. Res. Inst.*, **24** (1946), 87 (in Japanese). S. MIYAMURA, *Bull. Earthq. Res. Inst.*, **24** (1946), 99 (in Japanese).

2) T. MINAKAMI, *Bull. Earthq. Res. Inst.*, **22** (1944), 42 (in Japanese).

3) T. MINAKAMI & S. SAKUMA, *Bull. Inv. Comm. Hukui Earthq.*, (1949), (in Japanese).

3) factors due to the disparity in paths of the seismic waves through the earth's crust from the hypocentre to the respective stations.

4) characteristics caused by the ground-formations near the stations.

In addition to these factors, the earthquake-motions depend on the depth of hypocentre, magnitude and epicentral area. For the study of the earthquake-motions due to the ground formations, it is necessary to distinguish the earthquake-motions due to the surface formations from those of other origins. On this account, seismographs were set at 14 stations on the various formations in the city of Kōti and they recorded numbers of after-shocks which took place at the distance of 50–200 km from these stations. Accordingly, for an after-shock which occurred at farther distance than 100km, the seismograms at the stations in Kōti would show differences caused only by the properties of the ground formations near the respective stations. Therefore, the writers made the comparison of these seismograms recorded on the alluvial stratum of various materials and of diverse thickness, with those on the mesozoic formation.

The writers used four seismographs of the horizontal component which have following constants;

Geometrical magnification	Period	Damping ratio	Number of instrument used
350	1.0 Sec.	1 : 10	2
200	1.0 Sec.	1 : 10	2

In order to make everything precise, these four seismographs were tested at the station (No.2) whether they were in good condition or not. After actual constants were obtained, these seismographs were distributed on the alluvial formations one after the other. Needless to say, one seismograph which was set at the standard station (No. 1) on the mesozoic formations, was operated without removal through the period of the present investigation. Thus, sixty-one after-shocks were recorded while the observation was made for 26 days through March 13 to April 7, 1947.

It may be necessary to give here a brief description of the geographical sketch on and around Kōti city. The town of Kōti is bounded by hills of mesozoic formations towards its north, south and west, and connected by the alluvial plain towards its east. Although Kōti is situated at the corner of this alluvial plain, several low hills of mesozoic formations are scattered in the town just like isolated islands on the alluvium. Accordingly, the thickness of the alluvial layer in the town is various, but as a general trend, it decreases towards the western part of the town. As the result

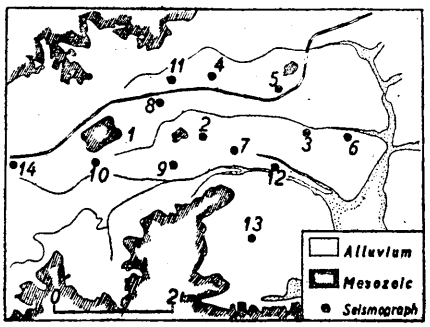

Fig. 1. Stations.

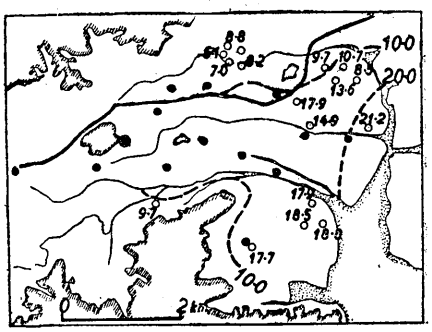

Fig. 2. Depth of a layer of fine sand (in m).

of the several borings performed in the town, it was found that there is a thin layer of fine sand within alluvium. As shown on the map of Fig. (2), the depth distribution of this sand layer represents, to some extent, the feature of the alluvium.

3. Characteristics of the Earthquake-Motions on the Alluvium.

In order to indicate the characteristics of the earthquake-motions on the alluvium, the writers paid attention to the maximum amplitude, the total duration and the mean period or predominant one of after-shocks. In other words, as to the amplitude, they made the ratio of the maximum amplitudes on the various formations to that of the standard station (1) which is situated on the mesozoic formations. It must be added that the

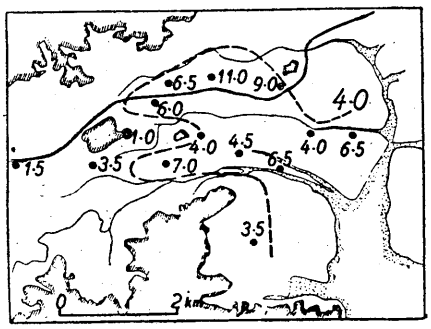

Fig. 3. Ratio of amplitude for remote earthquakes.

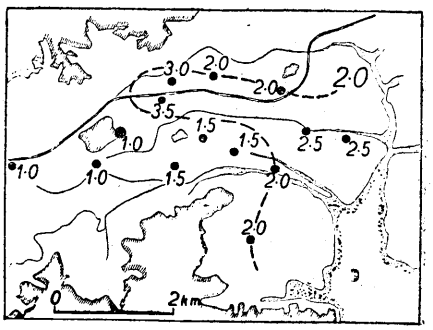

Fig. 4. Ratio of amplitude for near earthquakes.

ratio above mentioned coincides with the ratio of the mean amplitude in the principal earthquake-motions. As seen in the geographical distributions of these amplitude-ratio (Fig. 3), the amplitude of the earthquake-

motions on the alluvial formations are remarkably large, of which at several stations, their amplitudes show nearly ten times as large as those on the mesozoic formations. However, the amplitude-ratio is remarkably reduced and almost two or three times for the earthquake of small epicentral distance, as shown in Fig. (4). For an example, the seismograms of two after-shocks, at various grounds are shown in Plate 1 and 2, whose epicentral distance is about 17km for the former and 150km for the latter.

Secondarily, the writers remark the disparities of the total duration of the earthquake-motions on the various formations. For the purpose, the comparisons of the earthquake-motions are made by the ratios of the total duration as done in the amplitude. As the result, it is made clear that the total duration of the earthquake-motions lasts always longer than that on the standard station which is located on the rocky and hard formations. The geographical distribution of ratio defined above is illustrated on the map of Fig. 5.

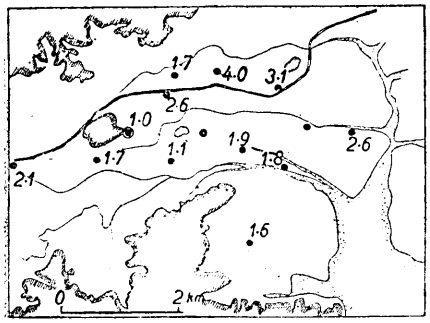

Fig. 5. Ratio of total duration.

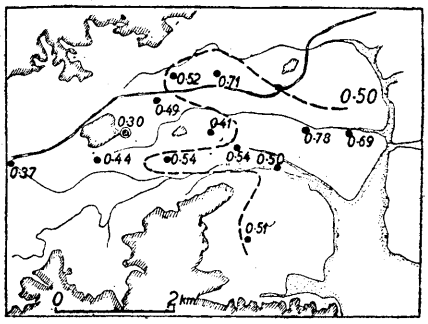

Fig. 6. Mean period (in second).

Last but not least, the writers indicate the characteristics of the earthquake-motions by means of their mean periods and predominant periods. According to the result of period analysis, the mean periods are without exception longer on the alluvium than on the old formations. In addition, there is no predominant period in the earthquake-motions on the mesozoic formations. Although at several stations on the alluvium which is not so extremely thick, the predominant period has always a fixed value, on the eastern stations where the alluvial layer is thick, their predominant periods depend on the epicentral distance and do not show a definite value. As will be seen on the map in Fig. 6, the mean periods at the stations (1) and (4) which are located on the rocky and hard formations, are 0.3 sec. and 0.4 sec. respectively, namely, they are shorter than those on the alluvium. On the other hand, on the alluvial formations, the deeper is alluvial layer the longer is mean period. Namely, the mean period shows 0.5–0.6

sec. on the central part of the town and 0.5–0.8 sec. on the eastern part of it. Contrasting the geographical distribution of the mean period with that of the maximum amplitude or the total duration, we can recognized clearly that the longer the mean period is the larger the amplitude and the larger the total duration.

To sum up, the characteristics of the earthquake-motions are very remarkably dependent on the surface formations of the ground.

4. Cocluding Remarks.

The phenomenon of the anomalous distribution of amplitude, that the amplitudes at several stations on the alluvium are several times as large as that on the mesozoic formations, is mainly caused by extreme smallness in the elastic constant of the soil materials as against that of the mesozoic formations.

It will be reasonable that at these stations within the town of Kōti, their earthquake-motions of an earthquake whose epicentre is distant more than 100km, must be almost similar one another, provided that the ground formations near these stations are similar. In other words, the earthquake-motions of such a distant earthquake must be similar in their amplitudes, periods and durations under the alluvial stratum of the town. Therefore, if dissipation and reflections within the alluvial stratum are put out of question, the total energy of the earthquake-motions at station on the alluvium, must be not different from that on the mesozoic formations.

According to experiments,[4] the elastic constants of rocks and soils, such as found at Kōti, are estimated at 10^{10}–10^{11} C.G.S. for the former and nearly 10^{8}–10^{9} C.G.S. for the latter. Consequently, the ratio of the elastic constants in these two kinds of material is nearly 100 or 10. If the energy of the earthquake-motions in the elastic medium is proportional to the products of elastic constants and the square of amplitude, it is reasonably explained that the amplitudes of the earthquake-motions on the alluvial formations are ten or three times as large as those on the mesozoic formations.

As mentioned already, the amplitude ratio at the stations on the alluvium is reduced in the near earthquakes, in which the earthquake-motions of short periods are markedly predominant. This phenomenon will be explained by the well-known fact that the earthquake-motions of short period are more remarkably dissipated within soil material than those of longer period.

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4) M. Ishimoto & K. Iida, *Bull. Earthq. Res. Inst.*, **14** (1936), 632; **15** (1937), 67. K. Iida, *Bull. Earthq. Res. Inst.*, **16** (1938), 131; 396.

The existence of deep or shallow alluvial layer upon the mesozoic formations and the marked disparities of the elastic properties in these two kinds of material will put the reasonable interpretation upon various phenomena in connection with periods and the total durations of the earthquake-motions.

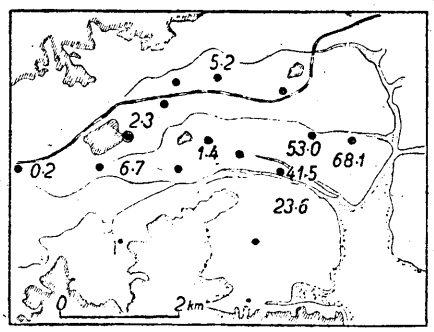


Fig. 7. Damage percentage.

For comparison of the results of the present study with the damages of dwelling houses caused by the Nankai earthquake, the damage percentages of it in fourteen sections of Kōti city are shown on the map of Fig. 7. The damage percentages (P) are defined as following[5]:

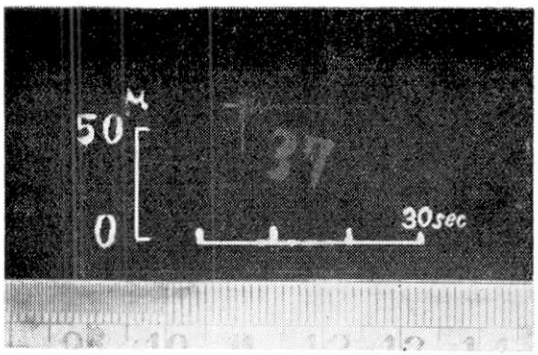
$$P = \frac{N + \frac{1}{2}M}{S} \times 100\%\ ,$$

where N: numbers of houses totally destructed,
M: numbers of houses seriously damaged,
S: total number of houses in a section.

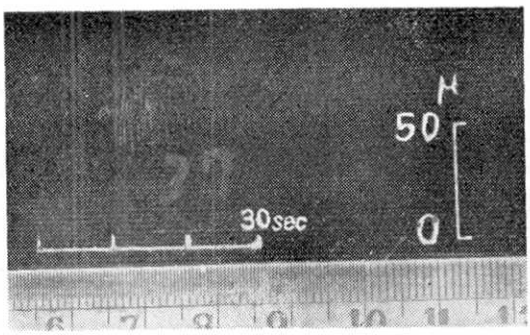
After all, the comparison shows the fact that only the earthquake damages have the close connection with the characteristics of the earthquake-motions due to the formations near the earth's surface.

In conclusion, we wish to express our thanks to the official of Kōti Prefecture and the Department of Education, with whose financial aid the present study was made possible.

5) S. MIYAMURA, loc. cit.

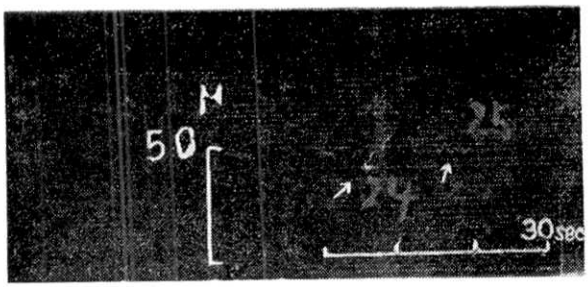


(a)



(b)

(a) Seismogram obtained on the mesozoic formation.
(b) Seismogram obtained on the alluvial formation.



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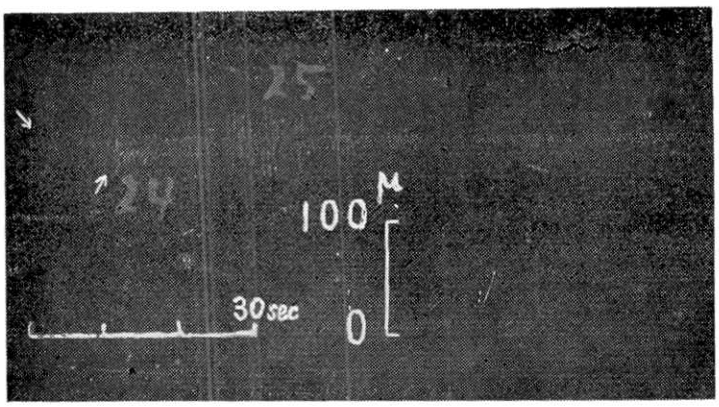

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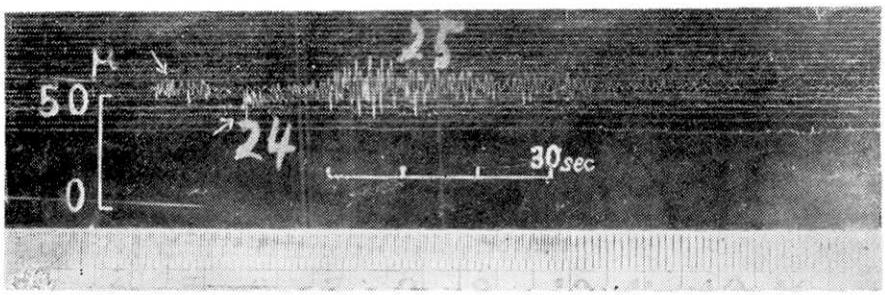

(c)

(a) Seismogram of the station (1) on the mesozoic formation.
(b) (c) Seismograms of the stations (4), (6), on the alluvium.