13. *Analytical Results of the Acceleration Seismograms obtained at Tokyo and Yokohama.*

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(Read Dec. 18, 1951 and March 23, 1954.—Received March 31, 1954.)

1. Introduction.

It is very clear from the records of earthquakes in the past that the degree of damage to houses by earthquake changes considerably with place. Particularly the damage to the houses of old Japanese style differ remarkably according to place, concerning which there are numerous records. This phenomenon may be in close relation to the problem of damage prevention, and many studies have been made to bring the cause of it to light in such fields of science as seismology, architecture and civil engineering, since seismology was established systematically as a science. But a satisfactory solution to this has not yet been given.

The conception that the property of earthquake motion depends on the nature of ground was deduced from many observational studies together with a number of mathematical ones. But the relation existing between earthquake motion which is variable according to ground property and the earthquake damage to houses cannot be represented quantitatively. It is a subject involving many unsolved problems.

As to the relation of earthquake damage to ground property, the first key for its solution was the fact that houses are damaged by acceleration of earthquake motion and that the acceleration depends on the ground property.

Then an acceleration seismograph having been invented, the acceleration of earthquake motion was directly measured, and it was found that the maximum acceleration of earthquake motion is hardly varies even if extremely different cases are compared, e.g. the case when old Japanese-style houses suffered seriously and the case when the earthquake damage was almost negligible. It was also found from the observation that every place has the predominant period of earthquake motion.[1]

1) M. ISHIMOTO, *Bull. Earthq. Res. Inst.*, **10** (1932), 171; **12** (1934), 234; **13** (1935) 592; **14** (1936), 240; **15** (1937), 536.

When this predominant period of the ground is approximate to the natural period of building, a resonance-like phenomenon is apt to occur to the building. Consequently it was concluded that earthquake damage to buildings has a close relation to the predominant period of the ground.[2]

In this paper, referring to the acceleration seismograms and the results mentioned above, the accelerations of earthquake motion observed at several places in Tokyo and Yokohama are compared and it is aimed to clear up the relation of acceleration amplitude to predominant period as well as the relation of the number in succession of a definite period to the period of earthquake motion.

2. The maximum acceleration of earthquake motion observed at several places in Tokyo and Yokohama.

From the observations made at several places in Tokyo and Yokohama by means of acceleration seismographs, Ishimoto found that, in the earthquake of which the distance from the earthquake origin is short, the acceleration on firm ground, as in the up-town of Tokyo, is greater than on soft ground, while earthquake of long distance from the origin becomes slightly greater on softer ground as in the down-town of Tokyo.[3]

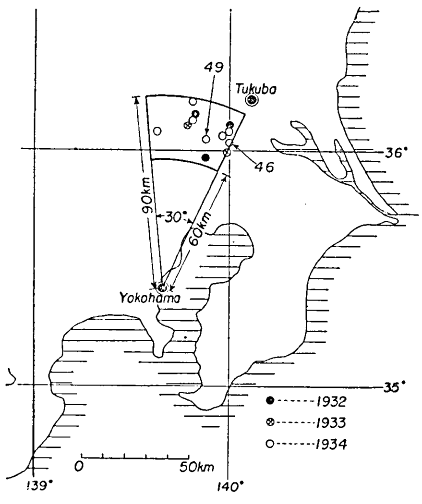

Fig. 1. The positions of the earthquake origins accepted as data in Yokohama.

The characteristics of earthquake motion is determined from the mechanism of seismic-wave generation and the materials of the pass of wave propagation besides the distance from the origin. In the case of analytical investigation of the seismograms obtained at Yokohama, the influence from these factors was eliminated with all caution possible. It was decided that earthquakes in a limited region should be accepted as data for study in order to investigate the relation between the property of earthquake motion at a certain place and the crust structure and the material

2) T. SAITA, *Shinsai* (Iwanami-Shoten, Tokyo, 1935), pp 283–324, (in Japanese).
3) M. ISHIMOTO, *loc. cit.*, 1), **10, 13.**

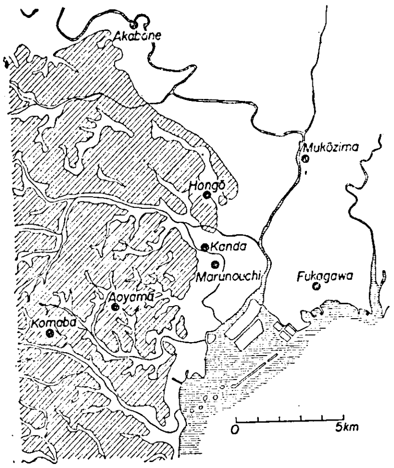

Fig. 2a. The positions of the temporary observing stations in Tokyo. Blank region and hatched one represent alluvium and other geological formations respectively.

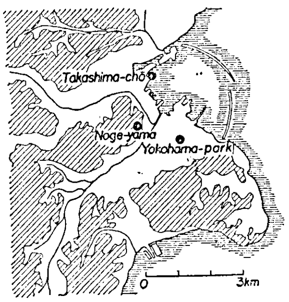

Fig. 2b. The positions of the temporary observing stations in Yokohama. Blank region and hatched one represent alluvium and other geological formations respectively.

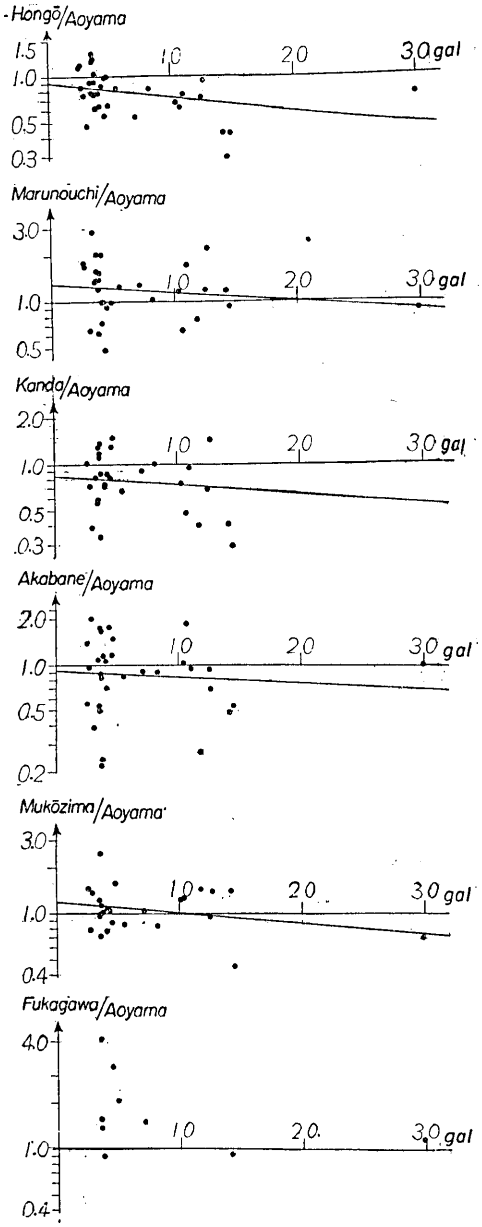

Fig. 3. Relation between the maximum acceleration and the ground property in Tokyo. Ordinate: maximum acceleration ratio; abscissa: maximum acceleration amplitude at Aoyama.

property of the ground there. The region enclosed within four lines, that is a straight line passing through Yokohama and Mt. Tsukuba, a straight line running to the direction of 30° west from Yokohama and two circles of 60 km and 90 km radii of which the centers are Yokohama, is adopted. Fig. 1 indicates the limited region and the earthquake origins treated in this paper. Fig. 2 shows the geographical positions of the temporary observing stations in Tokyo and Yokohama.

Earthquakes concerned are the ones which are recorded as seismic scale II and III by the Central Meteorological Observatory, Tokyo, during 1932–1934.

In Fig. 3, taking Aoyama where the ground is firm as the standard for observations at Tokyo, the relation between the maximum acceleration at Aoyama and the ratio of the maximum in several places to that observed at Aoyama is shown. As is seen from Fig. 3, there are only small differences between the maximum accelerations at Akabane, Mukōzima and Fukagawa where the ground is soft and the maximum at Aoyama of firm ground, and as a whole the former ones, that is the maximum acceleration at soft ground, show a tendency of being rather small.

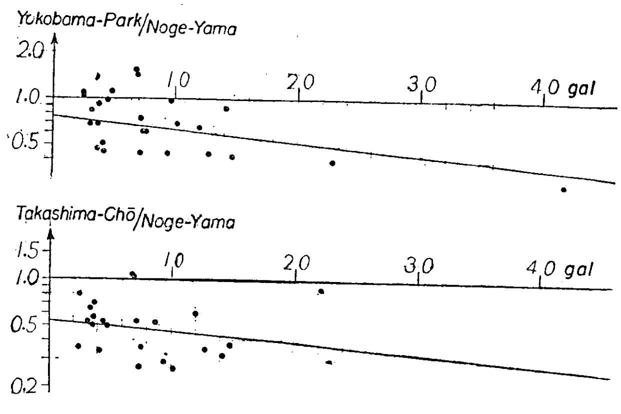

Fig. 4. Relation between the maximum acceleration and the ground property in Yokohama. Ordinate: maximum acceleration ratio; abscissa: maximum acceleration amplitude at Nogeyama.

As to Yokohama, Nogeyama of firm ground was taken as the standard, Fig. 4 illustrates the comparison of the acceleration at Nogeyama with those obtained at the Yokohama Park and Takashima-chō where the ground is soft. Fig. 4 indicates that the maximum accelerations at the Yokohama Park and Takashima-chō are almost one half of the maximum at Nogeyama of firm ground.

3. The relations of frequency to period and acceleration to period.

Concerning several earthquakes observed at such places in Yokohama as Nogeyama, the Yokohama Park and Takashima-chō, the following facts were studied. As to all waves coming out from the time when the acceleration becomes half of the maximum amplitude to the time when it reduces itself to the same amount after it rises to the maximum, the relation of the frequency to the period and the relation of the acceleration to the period were studied. The results are shown in Figs. 5 and 6.

Figs. 5 and 6 indicate that at Nogeyama the number of waves of 0.3–0.4 sec period are predominant and the maximum acceleration

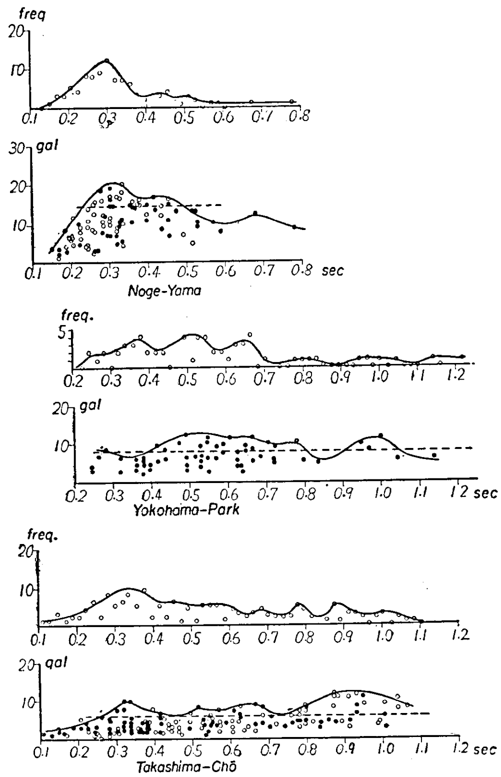

Fig. 5. Relations of frequency-period and of acceleration-period concerning the earthquake of 1934 VIII 3 at three places in Yokohama.

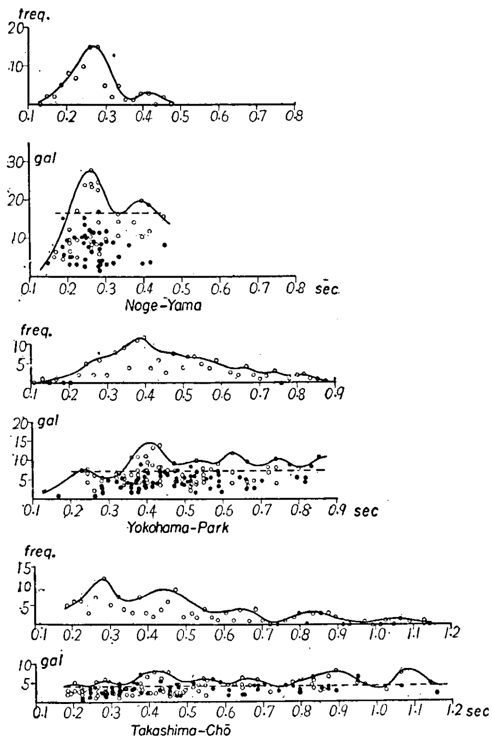

Fig. 6. Relations of frequency-period and of acceleration-period concerning the earthquake of 1934 IX 1 at three places in Yokohama.

are also at such periods. Although the frequency of the period at the Yokohama Park is different in respective earthquakes, it may be true that in many cases the maximum frequency appears around the period of 0.3–1.0 sec. Also it may be certain that the acceleration becomes larger around the period when the frequency is large. In the relationship of the wave number and the acceleration amplitude to the period of earthquake motion at Takashima-chō, there are no clear peaks, while in the relation of frequency-period and that of acceleration-period there is a considerable likeness.

Generally speaking, in firm ground the curve of frequency-period has a sharp peak, while in the ground of thick alluvium it is flat. Then it may be concluded that in firm ground the acceleration becomes specially large at a certain period, but it becomes smaller at other periods. In softer ground large acceleration covers a considerably wide range of period.

4. Relation between the number in succession of a definite period and that period of earthquake motion.

Since the earthquake motion involves waves of various periods, there may be a number of waves of which the periods coincide with the natural periods of buildings. However, even in those cases, unless the waves of such periods continue for some while, the vibration amplitude of buildings increases in rather a small degree.

By giving the forced vibration of constant amplitude and period to an ordinary building, the vibration amplitude of the building increases at every vibration and it reaches to the asymptote value after several vibrations. Therefore, the frequency of the waves succeeding and their periods may be an important problem for the study of earthquake-proof construction.

On this occasion, with the seismograms obtained at three places in Yokohama, the number in succession of the waves of equal period was studied. As in the preceding chapter, the interval from the time when the acceleration is the half of the maximum to the time when it becomes the half of the maximum again after reaching the maximum is adopted.

As to the period, it is considered to be equal in three ways; that is in the first case $\pm 5\%$ is accepted to be the allowable limit, the second $\pm 10\%$ and the last $\pm 20\%$. Concerning the two earthquakes of 1934

VIII 3 and 1934 IX 1, the seismograms obtained at Nogeyama, the Yokohama Park and Takashima-chō in Yokohama were analysed, with the results given is in Figs. 7 and 8.

These figures show that in the case where the error of period is within $\pm 5\%$, the maximum number in succession is four at all places.

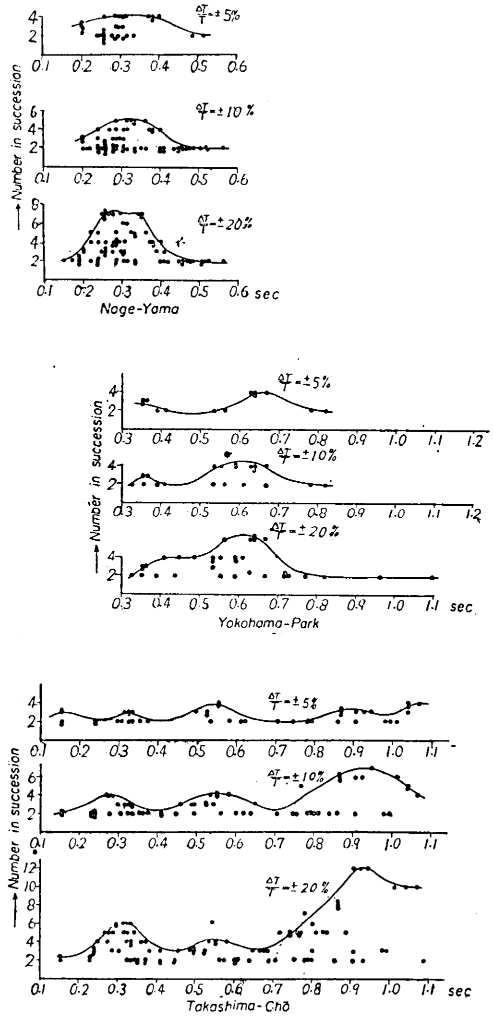

Fig. 7. Distribution of the number in succession of the waves of a definite period concerning the earthquake of 1934 VIII 3 at three places in Yokohama.

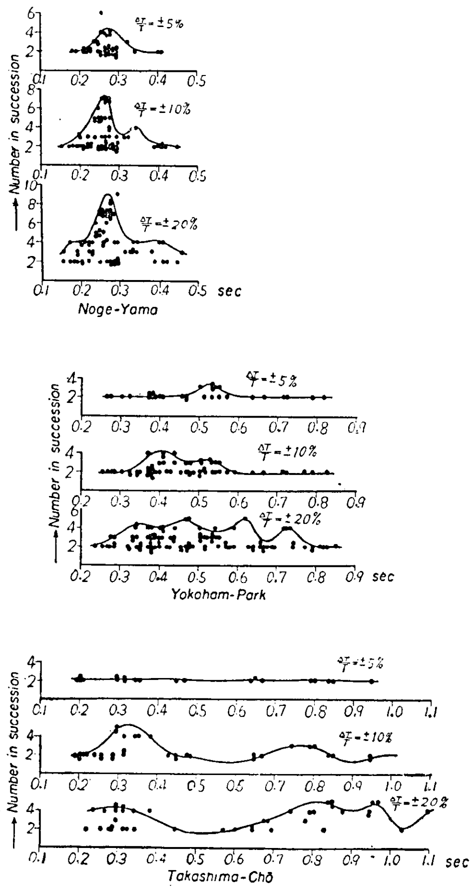

Fig. 8. Distribution of the number in succession of the waves of a definite period concerning the earthquake of 1934 IX 1 at three places in Yokohama.

In case of ±20%, it is only five at the Yokohama Park, while at Nogeyama it is about eight, two times larger than in case of ±5% error. At Takashima-chō the number in succession is different in each earthquake and when the error allowable is ±20%, there will be two different results. One is that the number in succession is unchanged from the case of ±5% error allowable just as at the Yokohama Park, and the other is that it becomes over two times larger than in the case of ±5% error.

The distribution of number in succession to the period is similar to both the curves of frequency-period and of acceleration-period. For example, concerning Nogeyama the peak of number in succession is seen clearly about at 0.30 sec and concerning the Yokohama Park very small peaks are seen at 0.3–0.7 sec. In Takashima-chō case, somewhat large peaks of number in succession are seen at about 0.3 and 0.9 sec.

6. Conclusion.

The following are found from the close examination of the acceleration seismograms observed at several places in Tokyo and Yokohama: The maximum acceleration is smaller on soft ground than on firm ground. On firm ground, vibrations of large acceleration are found only within a narrow range of period as 0.3–0.4 sec, and on soft ground, on the contrary, great acceleration covers such a wide range of period as 0.2–1.0 sec.

Among the actions of earthquake motion against buildings, an important one is the frequency of the wave of a definite period following successively. When the ground is firm, the waves of a definite period succeed several times only around the period when the acceleration reaches its maximum. On the contrary, on soft ground the waves of a definite period succeed several times within a wide range of period just like both the distribution of acceleration to period and that of frequency to period.

As to the relation between earthquake damage to buildings and property of ground, there are many elements involved, but at least the following may be ascertained from this study: Japanese-style wooden houses and other buildings do not always show an equal tendency as to the relation between earthquake damage and ground property. Japanese-style wooden houses on soft ground are damaged seriously, while the damage to the buildings of other types are not so clearly influenced by the ground property and in some cases it is influenced reversely to the case of Japanese-style wooden houses.[4]

Such a phenomenon can be explained from the peculiarity of Japanese-style wooden houses. The natural period of such houses becomes as much as two times longer before they collapse. On the firm ground where the curve of acceleration-period has a sharp peak, the period of houses will become longer and the amplitude stops increasing even if the houses have the natural period which coincides with that of an earthquake. But on soft ground, as the curve of acceleration-period is flat, earthquake motion involves the period which coincides with the period of the building even after the natural period becomes larger according to the increase of amplitude. Then on soft ground, consequently the increase of amplitude continues till the houses collapse.

In conclusion we wish to express our thanks to Miss S. Yoshizawa who assisted us in preparing this paper.

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13. 東京横浜における加速度地震計記象の解析結果

地震研究所 {金井清 / 鈴木正治}

東京横浜の数ケ所で石本博士が観測した加速度地震計記象を，詳しくしらべた結果，次の事柄がわかつた.

即ち，堅い地盤では，加速度が大きく，一定周期の波が数回続く地震動は，狭い範囲の周期，0.3～0.4 sec，に限られている．それにひきかえて，軟い地盤では，加速度が或程度大きく，一定周期の波が数回続く地震動が，広い範囲の周期，0.2～1.2 sec，にわたつている.

従つて，極く微小な破壊によつて周期が急速に長くなるような構造物は，堅い地盤では，たとえ共振的現象が起つても，すぐにその域を脱け出る可能性が大きい．これに反して，このような構造物は，軟い地盤では，一たび共振的現象に入ると，たとえ破壊によつてその構造物の周期がのびても，どこまでも共振現象が続くことになる.

地盤と震害程度の関係は，日本式木造家屋とその他の構造物とでは，傾向がかなりちがう．その原因は，いろいろ考えられるが，以上の事は，その大きなものの 1 つであろう.

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4) K. KANAI, *Bull. Earthq. Res. Inst.*, **27** (1949), 97.
K. KANAI and S. YOSHIZAWA, *Bull. Earthq. Res. Inst.*, **29** (1951), 209.