CONSIDERATION ON SEISMIC INTENSITY DISTRIBUTION OF THE GREAT KANTO EARTHQUAKE OF 1923

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Abstract The seismic intensity distribution of the Great Kanto Earthquake was analyzed in order to obtain basic data for seismic risk zoning. In order to explain the seismic intensity distribution, the minimum distance from the fault plane which generated the earthquake was inferred and seven types of landform areas representing particular ground conditions were used. As a result, functional relationships between seismic intensity and the minimum distance from the fault plane could be deduced for each landform area. These relationships are useful for meso-zonation of an area on the basis of earthquake risk potential.

1. Introduction

Restricting earthquake damage to that caused by seismic waves, namely, direct damage, the earthquake damage potential of an area can be shown to be a function of seismicity, ground conditions and characteristics of man-made structures (wooden houses, buildings, roads, bridges, etc.). Seismic risk zoning concerning direct damage of an area, division of an area into a number of zones on the basis of earthquake damage potential, requires research on such topics as follows:

(1) Analysis of seismicity;
(2) Classification of ground conditions into several types depending upon those characteristics which contribute to cause damage, and evaluation of the type of ground conditions from the seismic engineering point of view;
(3) Regional division of an area on the basis of the type of ground condition;
(4) Research on the distribution of structures;
(5) Prediction of the extent, kind and amount of damage.

Among the above topics, those from (1) to (3) are carried out in order to obtain the probable distribution of seismic intensity or of intensity of input to man-made structures.

Taking account of seismic activity and distribution of faults in and around an area, it is possible to obtain deterministically probable characteristics of an earthquake which might produce serious damage in the area. In addition, fault models of past great earthquakes have been seismologically and geodetically analyzed in recent years together with the great progress made in seismology. Let us assume that the seismic intensity distribution during an

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earthquake has been related to the ground conditions and distance from the eathquake fault. Then if a fault model is available, it can be proposed to draw a seismic risk zoning map to evaluate the damage of an earthquake on the basis of the ground conditions. This paper discusses the relationships among the minimum distance to the fault plane which generated the Great Kanto Earthquake of 1923, the seismic intensity distribution which was deduced from damage distribution of wooden houses and the topographic conditions which represent the ground conditions.

2. The Great Kanto Earthquake of 1923

The Great Kanto Earthquake resulted from a slippage of the transform fault along the eastern edge of the Sagami Trough. The earthquake occurred on September 1, 1923, and its hypocenter was placed at 139.3°E and 35.2°N and its magnitude was estimated to be 7.9. An overview of the damage caused by the earthquake, especially damage by fire in Tokyo, was given by Nakano and Matsuda (1980).

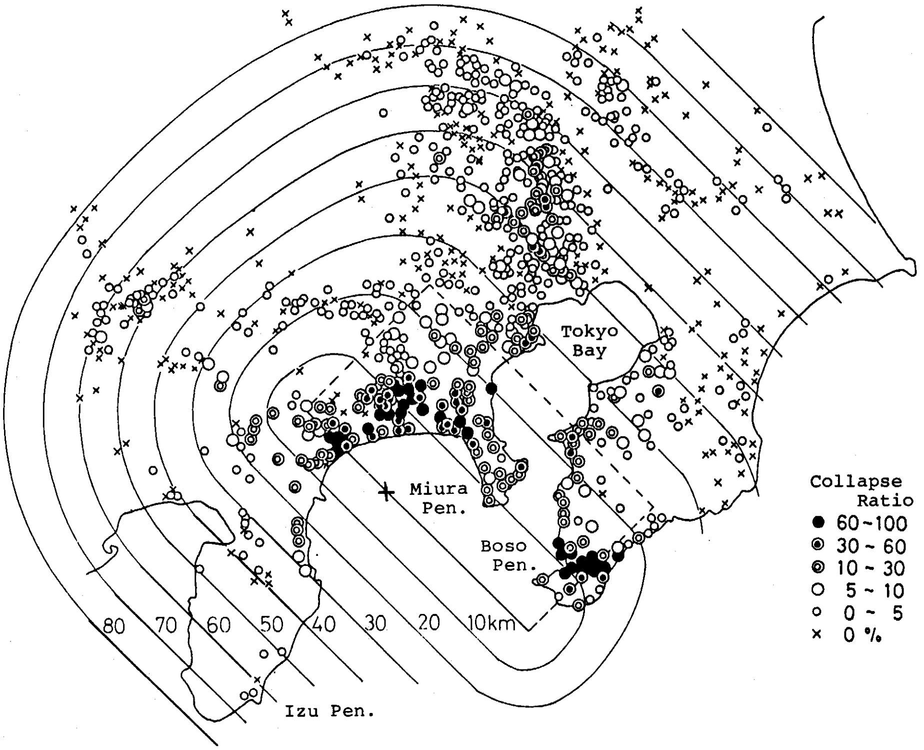


Fig. 1 Distribution of collapse ratios of wooden houses
Plus mark (+): epicenter; Rectangle: Horizontal projection of fault plane (geodetic model); Iso-lines: the minimum distance to fault plane

The collapse ratios of wooden houses for each district in the Kanto Region were listed in reports made by the Imperial Earthquake Investigation Committee (Matsuzawa, 1925). Collapse ratios are defined by dividing the number of totally collapsed wooden houses by the number of households for each district, because the number of wooden houses existing before the Great Kanto Earthquake was unknown. The distribution of the collapse ratios of wooden houses shown in Fig. 1 is derived from these data.

Two fault models of the Great Kanto Earthquake have been presented by Kanamori and Ando (1973) on the basis of seismological and geodetic data. The fault model deduced from geodetic data, namely, the geodetic model, was adopted in this paper because the model better explains the distribution of damaged wooden houses than the seismological model (Mochizuki et al., 1978). The geodetic model shows the earthquake fault to be 85 km long, 55 km wide and dipping toward the northeast with a dipangle of 30 degrees. The horizontal projection of the fault plane is shown in Fig. 1. This fault plane recorded a right lateral-horizontal displacement of 6 m and reversal-vertical displacement of 3 m in 1923.

3. Seismic Intensity Deduced from Tombstones

The authors have briefly discussed why Japanese seismologists often examine the sizes of tombstones distributed in a shaken area and the method of using tombstones as a substitute for seismographs (Matsuda et al., 1981). We would again like to present the procedure for estimating the maximum horizontal acceleration from the size of tombstones, because the method is peculiar to Japanese seismology and it is important for the problem being discussed here.

A Japanese tombstone usually has the form of a parallelepiped. Therefore the maximum horizontal acceleration (A) necessary to topple it can be obtained by the following equation,

$$A = \frac{W}{H} \times g \qquad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (1)$$

where H and W are the height and width of the shorter side of the base, respectively, and g is the acceleration of gravity. The maximum horizontal acceleration obtained from the width-height ratio of a fallen tombstone is somewhat lower value than the actual motion of the cemetery ground. On the other hand, a higher value is obtained from the width-height ratio of a non-fallen tombstone. That is, the true maximum horizontal acceleration is expected to lie between the accelerations derived from fallen and non-fallen tombstones.

The maximum horizontal acceleration derived from tombstone toppling analysis has a very high reliability. Mochizuki and Kobayashi (1976) analyzed motions of a body induced by earthquake excitation. They classified the motions into four types: slip, rocking, rocking-slip and jump. They also examined the relationship between the falling of a body and these four types of motion. As a result, they ascertained that tombstones are indeed useful for estimating the maximum horizontal acceleration caused by an earthquake.

Cemeteries are broadly and fairly densely distributed, because every old community usually has a common cemetery. Accordingly, tombstones are a good tool to estimate the distribution of the maximum horizontal acceleration.

Mononobe (1926) and Nakamura (1925) derived some 30 records of seismic intensity during the Great Kanto Earthquake from the width-height ratios of tombstones distributed in the affected area. As mentioned before, collapse ratios of wooden houses for districts throughout the Kanto Region were listed in the reports made by the Imperial Earthquake Investigation Committee. First of all, the relationship between seismic intensity and collapse ratios of wooden houses was analyzed in order to convert the collapse ratios into seismic intensity and to grasp the distribution of seismic intensity for the whole of the Kanto Region.

This idea is based upon the studies done by Mononobe (1933). He defined a seismic intensity (K) as the value obtained from dividing A by g, namely,

$$K = \frac{A}{g} = \frac{W}{H} \qquad \text{(2)}$$

Also, he related the collapse ratios of wooden houses (P) with the seismic intensity (K) in the form of Eq. (3):

$$P = \frac{100}{\sqrt{\pi}} \int_{-\infty}^{hy} e^{-h^2y^2} d(hy) \qquad \text{(3)}$$

Here, $y = K - K_0$, where K_0 is the mean earthquake-resistant strength of wooden houses (If $K = K_0$, 50% of wooden houses would totally collapse.); $h = 1/\sqrt{2}d$, where d is the standard deviation of earthquake-resistant strength of wooden houses as a function of K (Accordingly, h can be regarded as an index indicating the uniformity of earthquake-resistant strength of wooden houses). Mononobe (1933) estimated that K_0 and h were in the range of 0.45 to 0.50 and 7 to 10, respectively, in the Great Kanto Earthquake.

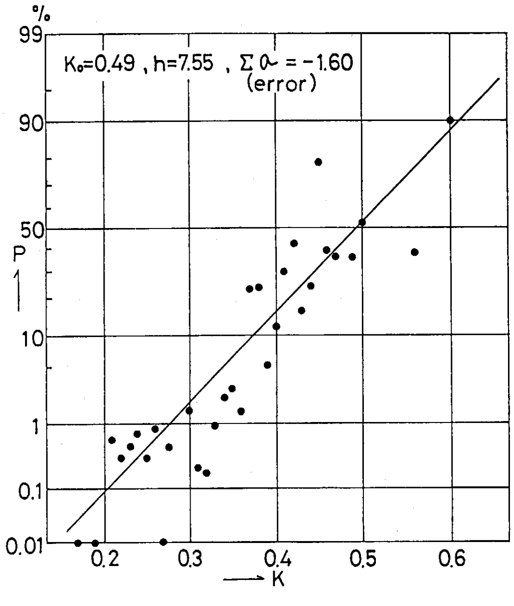


Fig. 2 Relationship between collapse ratio of wooden houses (P) and seismic intensity (K)

The authors, however, have reexamined the values of K_0 and h using the 30 records of seismic intensity obtained by Mononobe (1926) and Nakamura (1925), and have determined those parameters under the condition that the sum of the errors is a minimum in Eq. (3). As a result, K_0 and h were found to be 0.49 and 7.55, respectively (Fig. 2).

It should be pointed out that the seismic intensity deduced from collapse ratios of wooden houses is suitable for evaluating the intensity of earthquake motion for engineering purposes. Even though a large value of maximum horizontal acceleration of earthquake motion might be recorded by a seismograph, if the earthquake motion was composed of only short-period waves, it may not posses sufficient energy to fell tombstones or wooden houses (Kobayashi and Nagahashi, 1969; Mochizuki et al., 1981; Tanaka, 1981).

4. Relationships between Seismic Intensity, Minimum Distance from Fault Plane and Landforms

Seismic intensity at a site during an earthquake with a certain magnitude is determined by the hypocentral distance and ground condition. Epicentral distance is usually used instead of hypocentral distance. The epicenter of the Great Kanto Earthquake of 1923 is indicated in Fig. 1 by a plus mark. The collapse ratios of wooden houses are also shown. It is seen that in

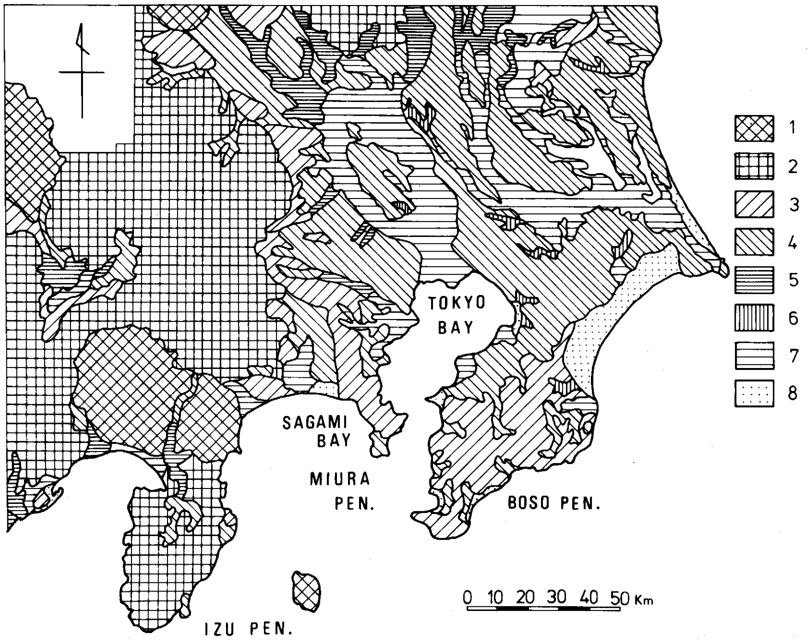
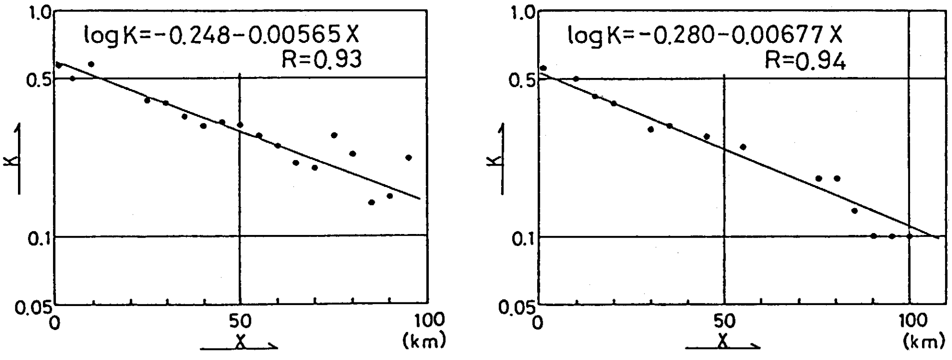
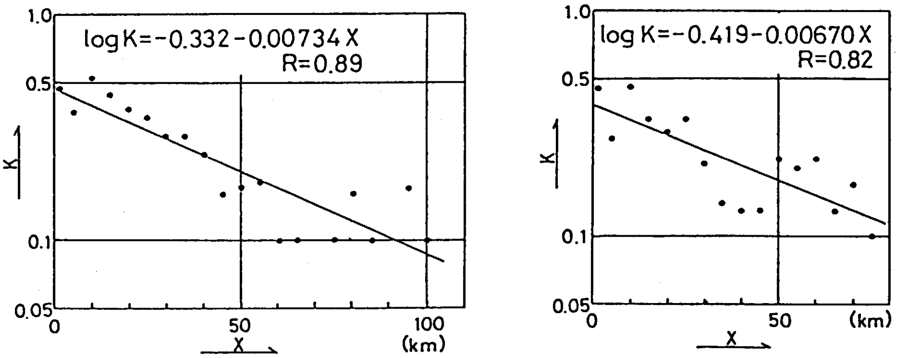


Fig. 3 Landform classification of Kanto Region
1: Volcano, 2: Mountan, 3: Hill, 4: Terrace, 5: Alluvial fan, 6: Valley flat, 7: Deltaic lowland, 8: Coastal plain



(a) Deltaic lowland (b) Valley flat



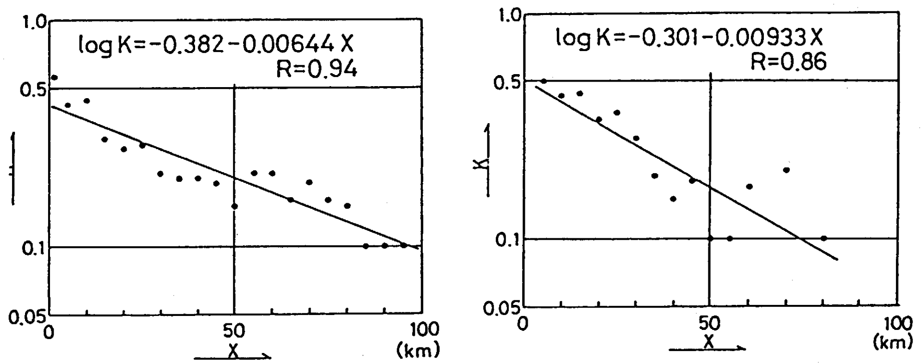
(c) Coastal plain (d) Alluvial fan

Fig. 4 Relationships between the minimum distance to fault plane (X) and seismic intensity (K)

this figure, the distribution of collapse ratios of wooden houses can not be well explained by the epicentral distance. For example, although the southern part of the Boso Peninsula is located 50 km from the epicenter, very high collapse ratios were recorded.

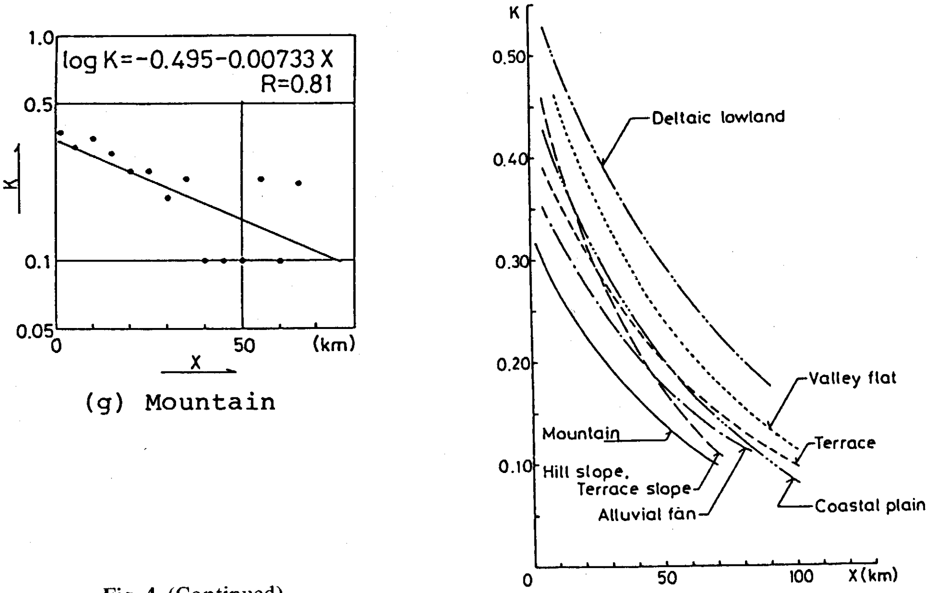
The authors tried to explain the distribution of collapse ratios of wooden houses by using the minimum distance to the fault plane of the geodetic model as mentioned above. Iso-lines of the minimum distance to the fault plane are also shown in Fig. 1.

As the damage caused by the Great Kanto Earthquake was very wide scale, a precise investigation of ground conditions for the whole area is impossible. However, it is well known that a landform area which is composed of a series of landform types has its own ground condition (Kadomura, 1967). Because landform types which represent various micro-reliefs of the terrain surface are defined by four geomorphological criteria of age, shape, genesis and constituent material (Nakano, 1963), a landform area is composed of peculiar materials reflecting its own development history and processes working on it. If the seismic intensity distribution can be related to topographic conditions, seismic risk zoning map can be proposed on the basis of a landform area classification map. The landforms of the Kanto Region can be classified into eight types of landform area of (a) deltaic lowlands, (b) valley flats, (c) coastal plains, (d) alluvial fans, (e) terraces, (f) hill slopes and terrace slopes,



(e) Terrace

(f) Hill slope and terrace slope



(g) Mountain

Fig. 4 (Continued)

(h) K-X relationships

(g) mountain and (h) volcanic landforms (Fig. 3). Volcanic landforms, however, were classified as belonging to other landform areas corresponding to the peculiar ground conditions. For example, depositional landforms composed of pyroclastic flow were put together with terraces.

Figs. 4 (a) – (g) show the relationships between minimum distance from the fault plane (X) and the seismic intensity (K) into which the collapse ratios of wooden houses were converted by using Eq. (3). The values of the seismic intensity shown in Fig. 4 are averaged every 5 km with regard to X. The K-X relationships were taken as the functional form, $\log K = a + bX$, and a and b were determined by the method of least squares. High correlation coefficients (R) ranging between 0.81 and 0.94 were obtained for the landform areas.

Seven K-X relationships are plotted on the same graph of normal scale to facilitate a visual comparison of the differences among the landform areas (Fig. 4h). The deltaic lowland shows the highest values of K followed by the valley flat, coastal plain and alluvial fan in descending order. This order is very reasonable from the geomorphological and the seismic engineering points of view, because deltaic lowlands are composed of thick sandy-muddy deposits, coastal plains consist of sandy deposits and alluvial fans are composed of gravelly deposits. The materials composing valley flats are usually muddy but their thickness are thinner than those of deltaic lowlands. The curve of K-X for hill slopes and terrace slopes intersects other curves, which is unexplainable. However, it is seen that as a whole, reasonable relationships between K and X are obtained.

5. Concluding Remarks

The seismic intensity of the Great Kanto Earthquake was determined for each district in the Kanto Region by relating the collapse ratios of wooden houses to the seismic intensity as deduced from the width-height ratio of tombstones. The seismic intensity distribution was explained through use of the minimum distance from the fault plane which generated the earthquake and landform areas instead of ground conditions. As a result, the seismic intensity was reasonably related to the minimum distance from the fault plane for each landform area.

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