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# SEISMICITY AND EARTHQUAKE GROUND MOTION

## (SESSION III)

*The questions not answered in a written form by the author do not appear on the pages of discussion.*

## Seismicity of Japan

Takuzo Hirono*

Japan belongs to the Circum-Pacific Seismic Zone and its seismic activity is more vigorous than any other place of the same zone. Japan experiences earthquakes which are perceptible somewhere on Japan about 1497 times in average year from 1923 to 1959 but they vary considerably from year to year (See Fig.1) and become numerous after any big earthquake or by occasional earthquake swarms. The maximum number for the last 37 years occurred in 1930 amounting to 5770 while the minimum in 1958 was 850. The former was caused by the earthquake swarms which occurred near Hakone..[1].

The geographical distribution of the number of earthquakes which were felt by persons is shown in Fig.2 which is made on the basis of the data of the last 38 years. It indicates that the most frequently felt region is that along the Pacific coast of east and north Japan, while other regions are not so frequent, and the most quiet region is north Hokkaido. Fig.3 is a similar chart made by the late Prof. Omori[2]showing the total number for 6 years from 1885 to 1890 and it shows also that the Pacific coast of east Japan is most frequent. This fact indicates that the trend of the recent seismic activity has not changed very much since that time.

In Fig.2, the largest number of perceptible earthquakes was observed at Tsukuba to the east and Wakayama to the west both of which amount to 137 times per year as the mean value of from 1921 to 1958. [3]This value means that about 18% of the total felt earthquakes in Japan are occurring in these two localities. The former is situated within the most frequently felt region of the Pacific coast, but the latter is isolated outside of that region. The earthquakes of Tsukuba occur mostly at depths of between 30 to 60 Km, while those of Wakayama occur, shallower than 30 Km. Though these two places are habitually occurring regions, sometimes there are temporarily local swarms of earthquakes especially at volcanic regions.

That the most frequently felt region lies along the Pacific coast of north and east Japan suggests that there is a zone of seismic activity off these coasts. Fig.4 which shows the distribution of the epicenters of earthquakes during 1926-1956 assures this suggestion. All these earthquakes have the magnitudes such that the diameters of their perceptible areas are larger than 200 Km, that is, about 4.0 in M scale (the magnitude scale of Gutenberg and Richter) and let us call them A group. Fig. 4 shows that the seismic activity concentrates off the coast of the Kanto District. It extends northwards under the Pacific Ocean along the coast of east and north Japan, while in west Japan it disperses evenly over the land and less active under the sea far off that coast. [4].

The number of earthquakes mentioned above is about 142 in the average year as seen in Fig.5 and it is about 10% of the avarage number of all perceptible earthquakes. Let us call the latter group as F: it involves A in it. Secular variations of these two groups are very different from each other. While F group has been diminishing recently, A group has been increasing. The yearly number of earthquakes with a perceptible area

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of larger than 600 Km in diameter is also shown in Fig.5 as B group. Their magnitudes are larger than 5 ¾ in M scale. They occur about 23 times in the average year, and, hence, it is 16% of A group.

The earthquake which could cause casualties has a magnitude larger than 6. The distribution of such dangerous shocks which occurred during recent 31 years is shown in Fig.6. It also shows that the largest activity is under the Pacific Ocean similar to Fig.4. But as they originated far off the coast, the majority of these shocks ended in harmlessness. Even the earthquakes of the order of 7 in M scale which could kill few thousand persons if it occurs under a crouded city remained in causing a weak tsunami at the worst.

The data of 31 years above mentioned shows that the earthquakes of magnitude larger than 6 occur 16 times in average year, of which 4 are deeper and 12 shallower than 60 Km, and among shallower ones, 10 occur under the sea and 2 on land of which only one causing damage. Those larger than 7.0 in M scale occur twice in average year of which one is deep and once every 3 years on land.

It is true that earthquakes of the order of 7 in M scale occurred occasionally on land, but the earthquakes of the order of 8 did not happen on land during 31 years now under consideration. They occurred under the Pacific Ocean, and they were only 4 times. The last earthquake of the order of 8 which occurred on land is the Mino-Owari Earthquake of 1891 (M: 8.4) which is famous for a fault traced to a distance of about 100 Km. It demolished or badly damaged 142,177 hauses and killed 7273 people.

Some of the earthquakes of the order of 8 which occurred under the ocean brought large tsunamis destroying harbours and fishing villages. As a matter of fact, when the submarine origin is under the shallow sea near the land the direct damage of shock is comparatively more severe than the damage due to tsunami as in the case of the Nankaido Earthquake of 1946, while when the origin locates far off the coast under the deep sea bottom, it causes big tsunami devastating the coasts nearest to the origin. This devastation is far greater than the direct damage of shock as in the case of the Sanriku Earthquake of 1933.

As stated above the sea bottom off the coast of the Pacific Ocean of north and east Japan is most vigorous in seismic activity but big earthquakes of the order of 8 in M scale occur also under the Pacific Ocean off the coast of west Japan, and though Fig.6 indicates their epicenters as points, the regions of crustal deformation due to them are thought to occupy considerably large areas. Fig.7 which was made by Mr. Musha[5] shows the epicentral regions of destructive earthquakes during the past two thousand years. It shows the largest areas correspond to the earthquakes of the order of 8 in M scale. When large epicentral areas are also taken as active places, the zone of seismic activity of the Pacific coast is thought to be continuous throughout north, east and west Japan and this is called the Outer Seismic Zone. On the other hand, several earthquakes of the order of 7 in M scale have occurred along the coast of the Japan Sea forming another seismic zone which is called the Inner Seismic Zone. Besides these, several minor ones seem to exist and earthquakes occurring there do not always cause less casualties than those of the two major zones.

Now, it must be noted that in Fig.4 and 6, only the epicenters shallower than 60 Km in depth are shown. As far as seismicity is concerned it would be inadequate to omit deep earthquakes, but there is no record of damage by any eathquake which originated at a depth deeper than 80 Km. Therefore it is not so significant fron the point of view of earthquake engineering that we confine ourselves to show the geographical distribution of deep earthquakes during 1926-1956 (Fig.8). Earthquakes deeper than 200 Km form themselves into seismic zones other than those for shallow earthquakes.

The earthquakes by which damage was caused in Japan since 1900 have amounted to 70 in number[6], among these those bringing the death roll of more than 10 were 24, that is, Japan has about one of these per year. The earthquake which caused greatest number of casualties in Japan was the Kanto Earthquakes of 1923 by which 576,000 houses were destroyed or burnt down and 143,000 persons were killed or missing. The next is the Fukui Earthquake of 1948 in which 39,000 houses were burnt down and 3,579 persons were killed.

One of the most remarkable features of the epicentral region of large earthquakes is its habit of repetition of earthquake's occurrence. For instance, in the Pacific Ocean off west Japan large earthquakes have occurred 7 times or more in almost the same place in the past two thousand years. This is a very important fact as it suggests that the place where people have experienced severe earthquakes will probably be visited some day by another earthquake of a similar intensity. Therefore, the intensity distribution of large earthquakes is very interesting. Fig.9 is an example showing the intensity distribution in the case of the Nankaido Earthquake of 1946.

The scale of earthquake intensity which is now used in Japan consists of 7 grades excluding no feeling (See Table 1). Though determined by the feeling of human body, observed intensity was found to have a considerably close relation with the maximum acceleration of ground motion and it is given by Prof. Kawasumi[7] as

$$a_n = 0.8\,(10^{\frac{n-1}{2}} - 10^{\frac{n}{2}})\ \text{gal} \qquad \text{for } 1 \leq n < 7$$
$$a_0 < 0.8\ \text{gal},$$
$$a_7 > 250\ \text{gal}.$$

where $a_n$ is the acceleration corresponding to the intensity n, and the $7^{th}$ grade of the intensity scale was created after the Fukui Earthquake of 1948.

Damage to houses begins to appear when the intensity attains to 5 grade and houses fall down when it becomes 6 grade. Fig.10 shows the distribution of the number of occurrences of intensities larger than 4 for the last 38 years. It shows that earthquakes with 5,6 and 7 intensity grades occur most frequently in the Kanto District which is Tokyo and its surrounding area, and actually the place where earthquakes of these intensities occur more frequently than any other places is an isolated point, Kofu. The observed number at Kofu is 13 for the same period, but all of them occurred in 1923, the year of the great Kanto Earthquake.

Besides the 108 weather stations of J.M.A. (Japan Meteorological Agency) there are about 1,100 weather sub-stations where seismic intensity is observed without instruments, and all of these stations send in reports on the observations they have made to the J.M.A. This data, especially data regarding the maximum earthquake intensity in a certain place, is made available to construction engineers before they begin to erect constructions of any kind, i.e. buildings, embankments, bridges etc.

As it is impossible for one station to determine the exact origin of earthquake the above mentioned 108 stations, each being equipped with seismographs of one and 100 in magnification, form a network and work together in order to ascertain an earthquake's origin, and the location and the intensity distribution of the earthquake felt by persons are generally announced officially about 50 minutes after the occurrence of the earthquake and when there is a fear of tsunami by a submarine earthquake, a tsunami warning is to be issued from some of 8 tsunami warning centers within 20 minutes after the earthquake's occurrence. Then, of course, the network of communication needs to work at its highest speed so that the warning is in time for the arrival of tsunami.

Casualties by earthquakes are tending to increase because city populations are growing larger and larger and large industrial constructions such as factories etc. are becoming more and more. In order to prevent such casualties not only earthquake proof engineering but also earthquake prediction is important. Consequently, seismologists in Japan who have the facilities to do so are concentrating their efforts on this problem of earthquake prediction. This has been one of the major problem facing seismologists in Japan since the days of Prof. Omori and Imamura.

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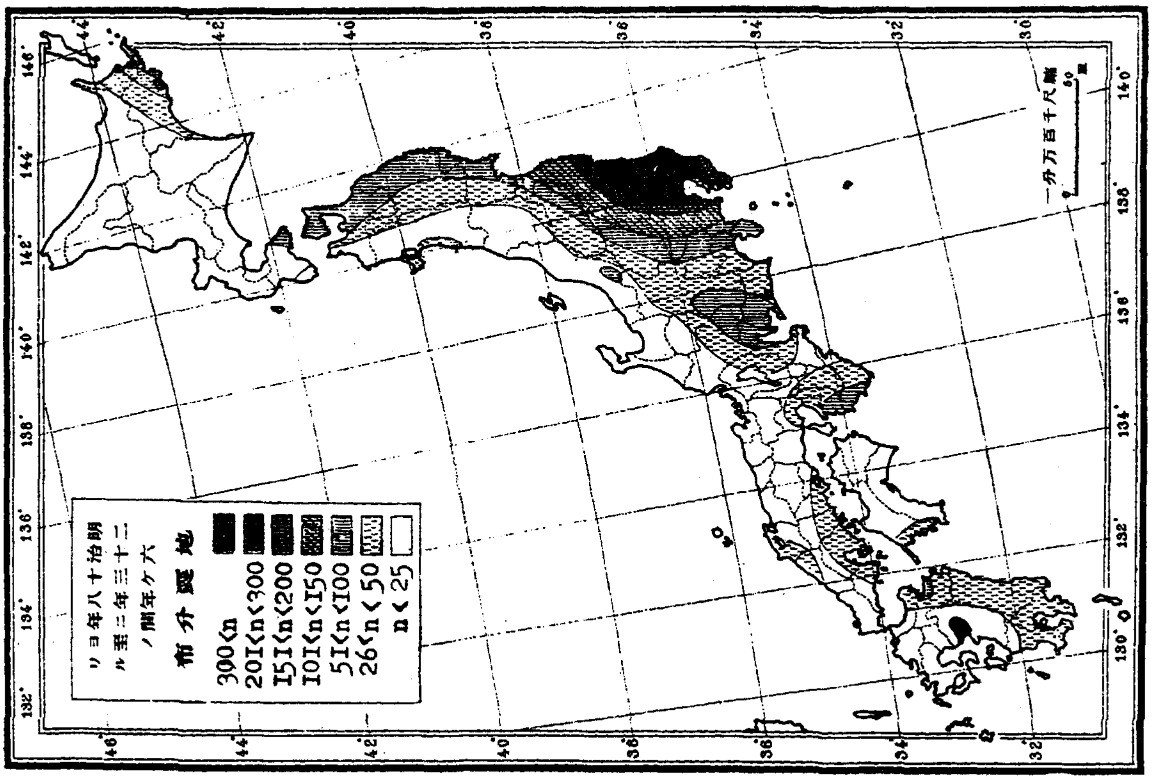


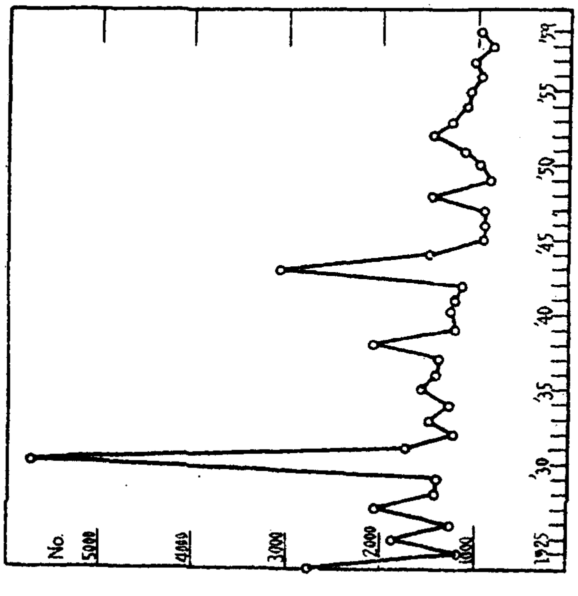




Fig. 1 The secular change of the number of earthquakes felt in Japan in each year.

Fig. 3 The distribution of the numbrt of felt earthquakes during 6 years from 1885 to 1890 (Taken from Prof. Omori's Jishingaku-kowa)

Fig. 2
The distribution of the number of felt earthquakes in the avarage year from 1921 to 1958.

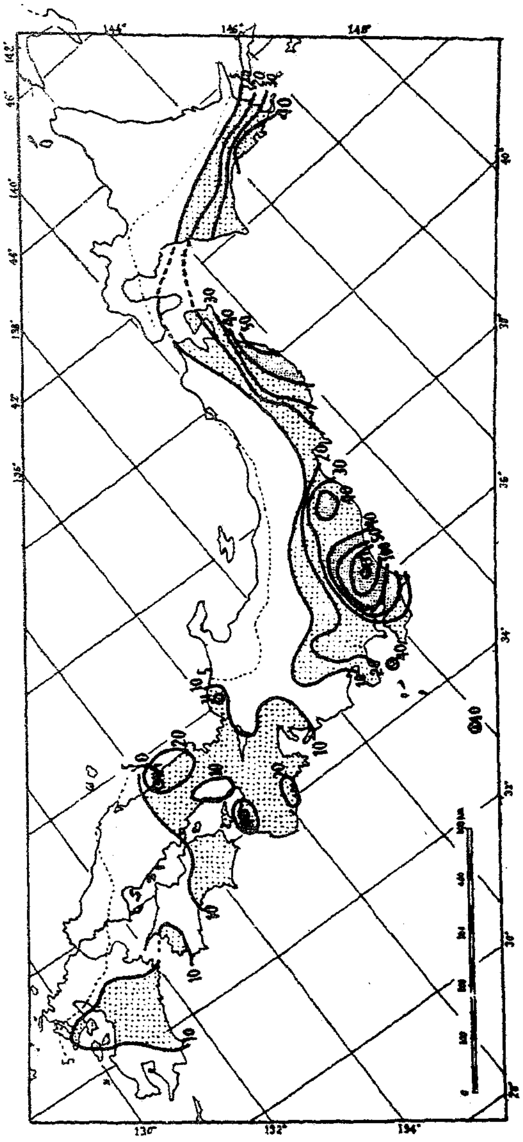
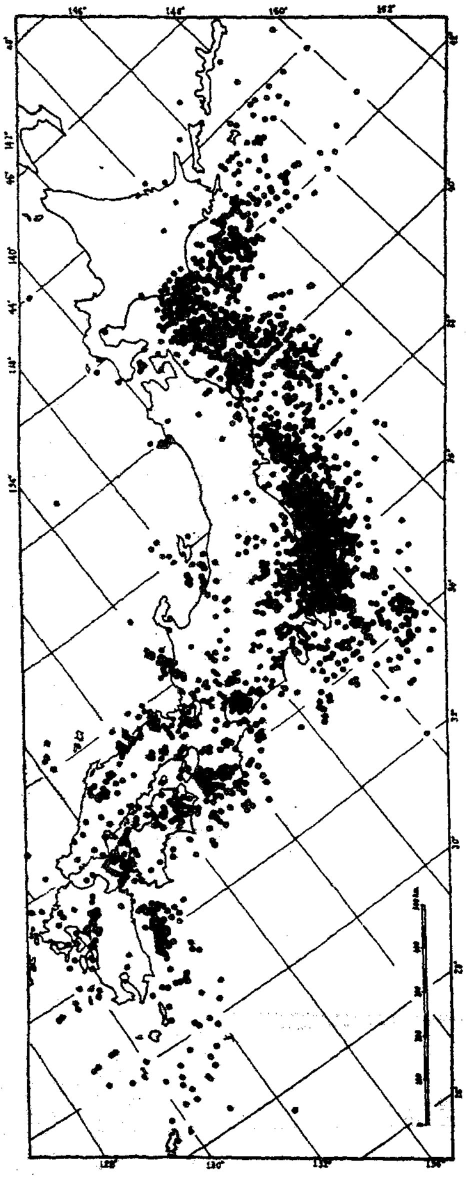


Fig. 4
The distribution of the centers of earthquakes larger than that with the felt area of the diameter of 200 km (1926-1956).



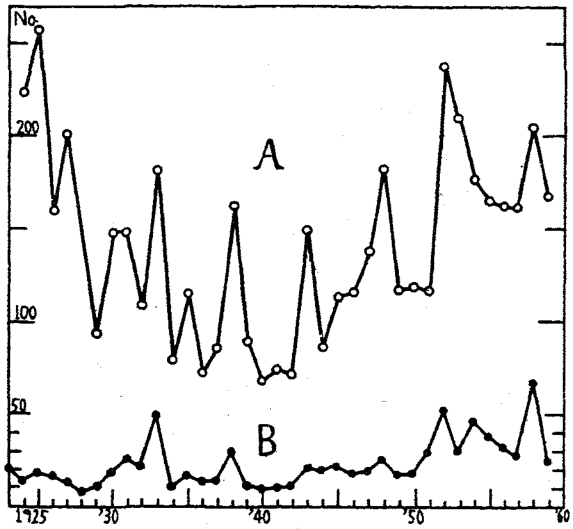



Fig. 5

The secular changes of the number of earthquakes which occurred in Japan in each year: A group—the diameter of the felt area is larger than 200 km. B group—the diameter larger than 600 km.

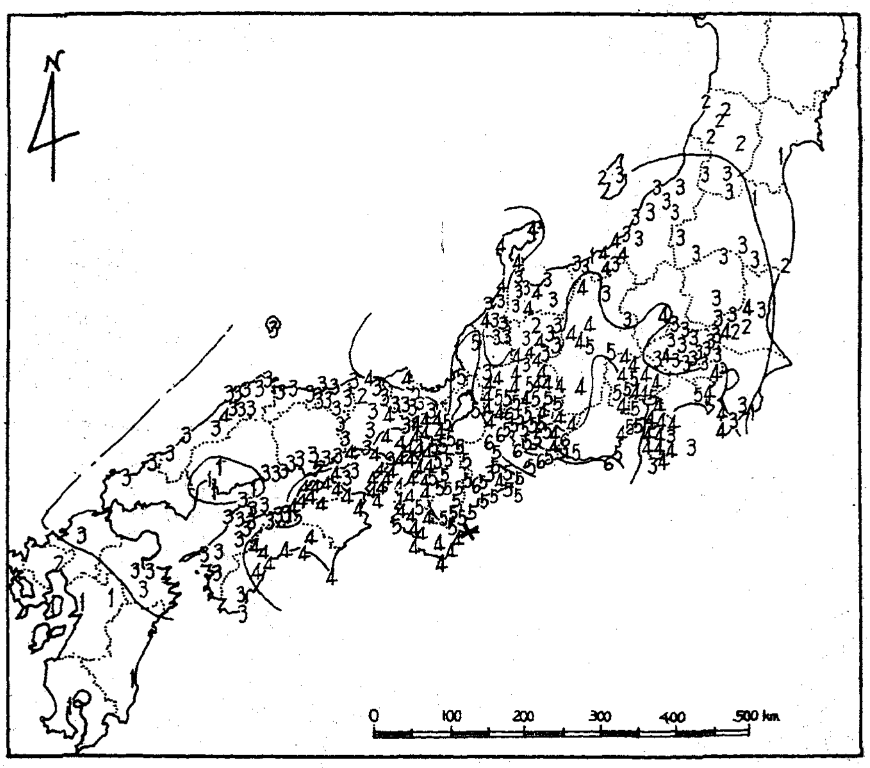



Fig. 9 The intencity distribution due to the Tonankai Earthquake of 1944.

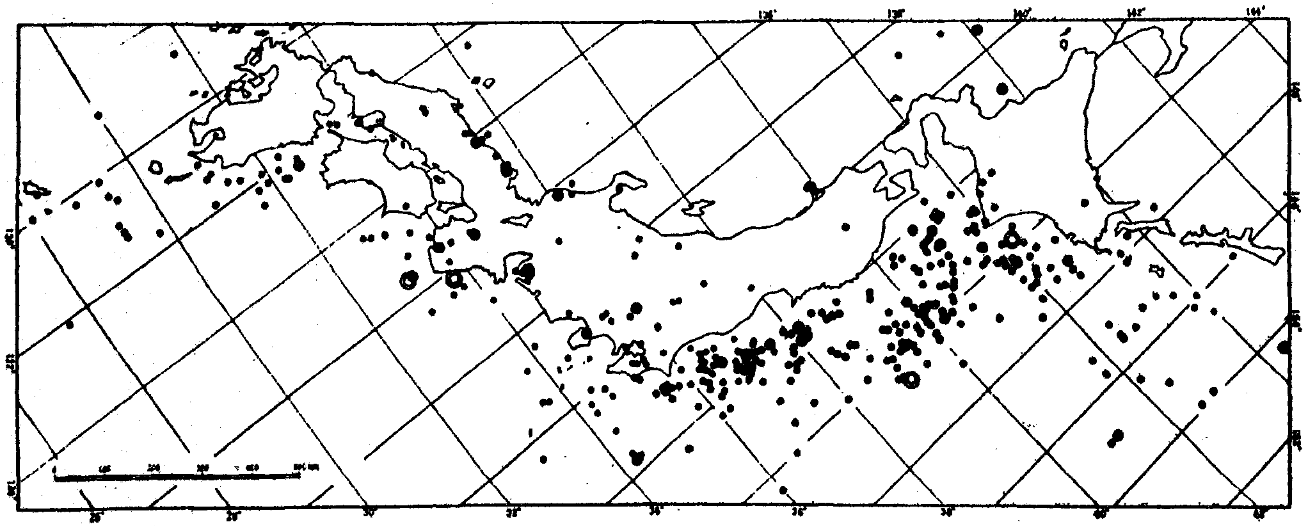


Fig. 6

The distribution of the centers of earthquakes larger than that of magnitude 6 which occurred during 1926–1956.

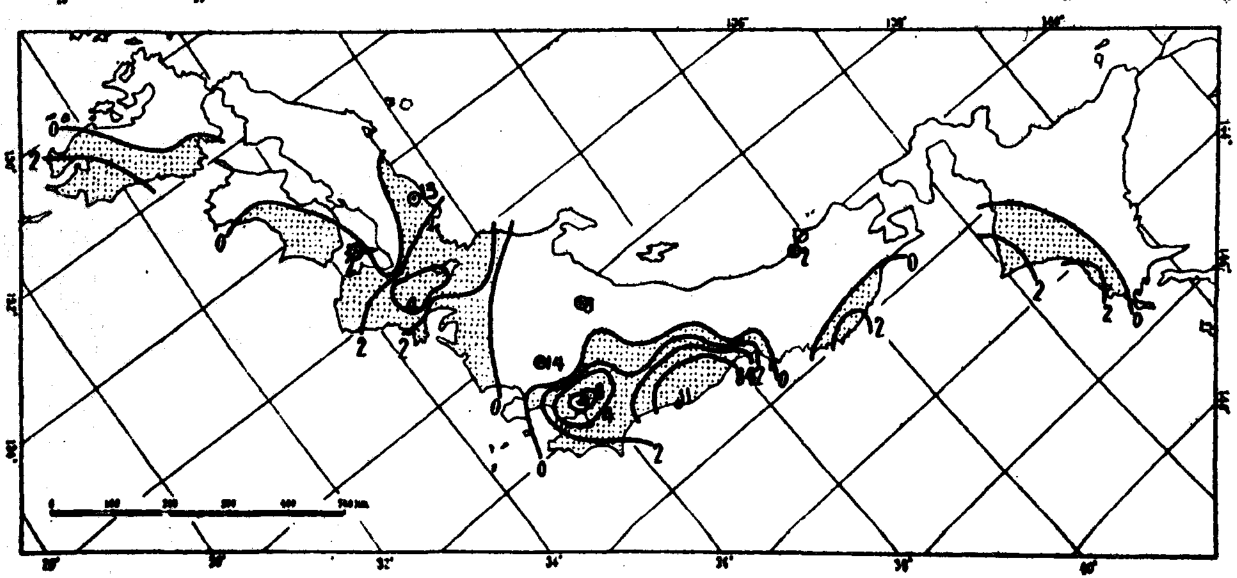


Fig. 10

The distribution of the observed number of intensities larger than the 4th grade during the years from 1921 to 1958.

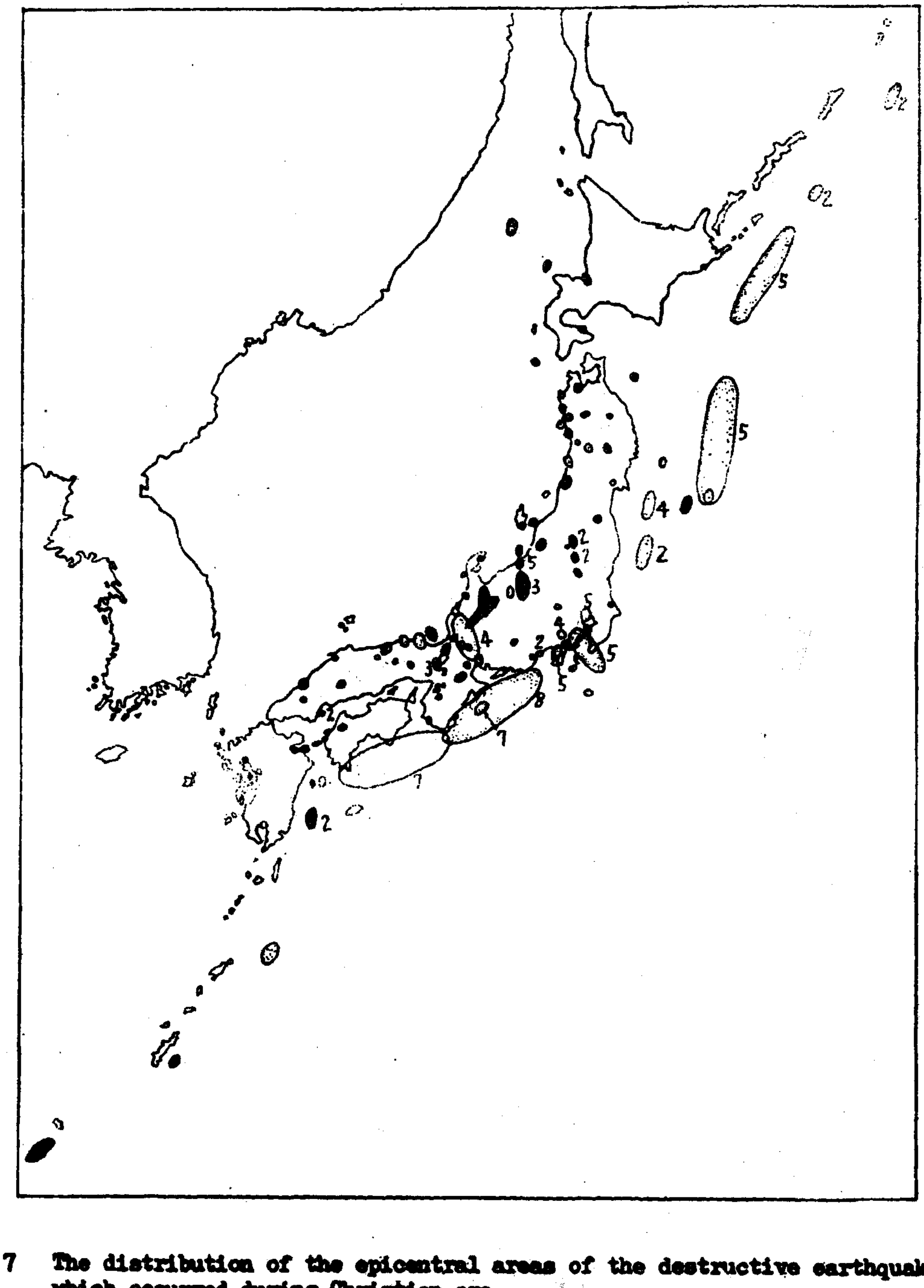


Fig. 7 The distribution of the epicentral areas of the destructive earthquakes which occurred during Christian era.
The black area occurred before 1890. Numerals mean the number of occurrences at the same place.

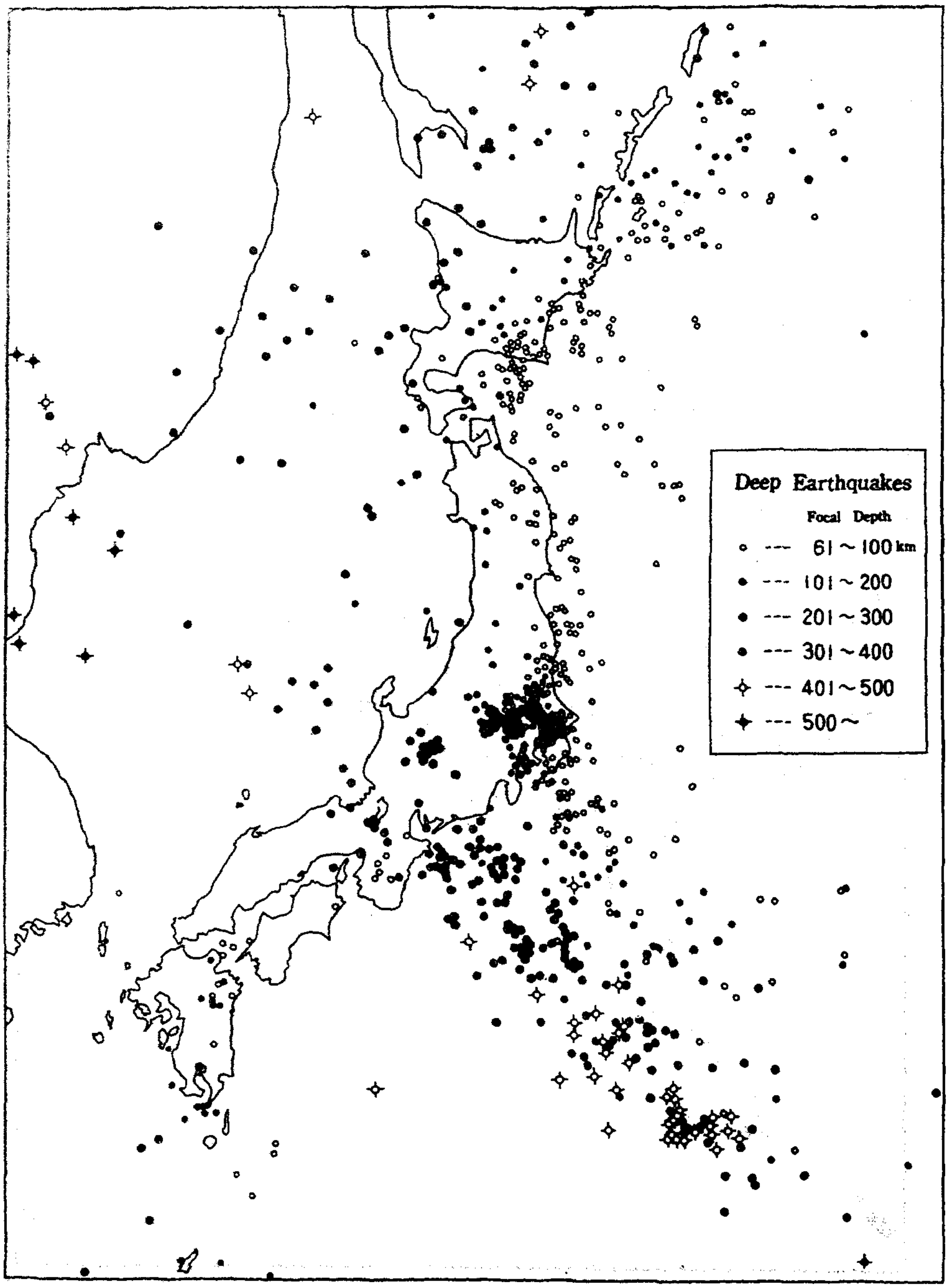



Fig. 8 The distribution of the earthquakes whose focal depths are deeper than 60 km (1926 - 1956).

Table 1 Scales of seismic intensity

The intensity of the shock is estimated according to the scales 0 - VII as follows :-

| | No Feeling | Slight | Weak | Rather Strong | Strong | Very Strong | Disastrous | Very Disastrous |
|---|---|---|---|---|---|---|---|---|
| Scale | 0 | I | II | III | IV | V | VI | VII |

0; No Feeling: Shocks too weak to cause human feelings, registered only by a seismograph.

I; Slight: Extremely feeble shocks only felt by persons at rest or by those who are observant to an earthquake.

II; Weak: Shocks felt by most persons, slight shaking of doors and Japanese latticed sliding doors (Shoji).

III; Rather Strong: Slight shaking of houses and bildings, rattings of doors and Japanese latticed sliding doors (Shoji), swinging of hanging objects like the electric lamps, moving of liquids in vessels.

IV; Strong: Strong shaking of houses and buildings, overturning of unstable objects, spilling of liquids out of vessels.

V; Very Strong: Cracks in the walls, overturning of gravestones, stone lanterns etc., damaging of chimneys and mud-and-plaster warehouses.

VI; Disastrous: Demolition of houses less than 30%, landslips, fissures on the roads, the ground etc.

VII; Very Disastrous: Demolition of houses more than 30%, intense landslips, large fissures in ground, the faults.