88. *Time Rate of Earthquake Energy Release in and near Japan*

By Chuji Tsuboi, M. J. A.
Geophysical Institute, University of Tokyo
(Comm. May 19, 1965)

The magnitude of a number of relatively large earthquakes which have taken place in and near Japan has been determined by H. Kawasumi (1952), C. Tsuboi (1952, 1957) and by the Seismological Section of the Japan Meteorological Agency (1956 with additional material for later years) for various periods of years as follows:

<table>
<thead>
<tr>
<th>Year</th>
<th>Determiner</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1885</td>
<td>H. Kawasumi (1820)</td>
<td>19</td>
</tr>
<tr>
<td>1926</td>
<td>C. Tsuboi (347)</td>
<td>26</td>
</tr>
<tr>
<td>1931</td>
<td>C. Tsuboi (382)</td>
<td>31</td>
</tr>
<tr>
<td>1950</td>
<td>JMA (433)</td>
<td>49</td>
</tr>
<tr>
<td>1955</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1963</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The number given in the parentheses following the name of the respective authors is that of earthquakes which were 6.0 or more in magnitude in each determination.

Since Kawasumi's determination of magnitude is based mainly on macroseismic data, while Tsuboi's and JMA's on seismometrical data, they do not necessarily constitute a uniform material on which the seismic activity in and near Japan can be investigated quantitatively.

The number \(N\) of earthquakes according to magnitude \(M\) is best expressed by

\[
\log N = 0.65 + 1.00(8 - M), \quad (1885-1943),
\]

\[
\log N = 0.11 + 0.87(8 - M), \quad (1926-1963)
\]

for Kawasumi's and JMA's statistics respectively. If the uniform occurrence of earthquakes with respect to time is assumed, the annual earthquake number \(n\) is expressed by

\[
\log n = -1.12 + 1.00(8 - M) \quad \text{(Kawasumi)}, \quad (1)
\]

\[
\log n = -1.47 + 0.87(8 - M) \quad \text{(JMA)}. \quad (2)
\]

The two equations are graphically represented by the line \(K\) and \(J\) in Fig. 1. The separation of the two lines is too large to be attributed to any conceivable difference in the seismic activity in the two periods to which they refer. Seeing that the inclination of the two lines does not differ much, however, a systematic difference is suspected to exist between the Kawasumi and JMA magnitude. If the \(K\) line is shifted by 0.4 towards smaller magnitude, or if the
J line towards larger magnitude by the same amount, the two lines come much closer. If \( (M + 0.4) \) is used instead of \( M \) in eq. (1), it becomes to be

\[
\log n = -1.12 + 1.00(8 - (M + 0.4))
\]

\[
\log n = -1.52 + 1.00(8 - M)
\]

which differs little from eq. (2).

18 years from 1926 through 1943 are commonly involved in the statistics of Kawasumi and of JMA and during this period, 43 earthquakes took place which were 6.0 or more in the JMA magnitude. For these 43 earthquakes, the Kawasumi magnitude is larger than the JMA's by 0.3 on the average.

Both of the above comparisons indicate that the Kawasumi magnitude less 0.4 is equivalent to the JMA magnitude. If \( (M - 0.4) \) is used for the period from 1885 through 1925 which is covered by the Kawasumi statistics and \( M \) as such from 1926 through 1963 which is covered by the JMA statistics, a more or less unified material for the whole 79 years will be available.

During this period, altogether 1231 earthquakes took place which were 6.0 or more in this adjusted magnitude and the number of
earthquakes according to magnitude is best expressed by the equations
\[
\log N = 0.38 + 1.03(8 - M) \\
\log n = -1.52 + 1.03(8 - M)
\]  
(4)
of which the latter is shown in Fig. 1 by the letter T.

The magnitude of each of the 1231 earthquakes having been
determined, the corresponding energy \(E\) can be calculated according
to the Gutenberg-Richter formula:
\[
\log E = 11.8 + 1.5 M.
\]

The total amount of energy which has been released by these
earthquakes sums up to \(161 \times 10^{23}\) erg in 79 years, so that the
average annual rate of release is
\[
(161 \times 10^{23}) / 79 = 2.2 \times 10^{23}\text{ erg}.
\]

The points which are plotted for each year in Fig. 2 represents
the cumulative sum of energy which has been released by earthquakes
since the beginning of 1885 down to the end of the year to which
each of the points refer. In this calculation, no earthquakes which
were 5.9 or less in magnitude are taken. Inclusion of smaller
earthquakes, if this had been done, produces no significant change
of the result.

The remarkable facts to be noted in Fig. 2 are:
1) The points are limited in distribution between two parallel

\[\text{Cumulative Sum of Released Energy (10^{23} erg)}\]
\[\text{Year}\]
\[1900 \quad 1920 \quad 1940 \quad 1960\]

Fig. 2. Cumulative sum of energy released by earthquakes \((M \geq 6.0)\).
straight lines, $S$ and $S'$.

2) The distance between the two lines corresponds to $25 \times 10^{23}$ erg which is very close to the energy of the largest conceivable earthquake. In other words, the points in Fig. 2 do not deviate from the line $S$ by any more than the energy of the largest conceivable earthquake.

The following will be one of the simple interpretations for the above two facts.

1) The upper straight line $S$ represents the cumulative sum of energy supplied to the crust and/or mantle of the earth in and near Japan from which earthquakes originate.

2) The supply of energy is remarkably uniform with respect to time, its cumulative sum being expressed by a linear equation

$$S = (2.24 t + 1.91) \times 10^{23} \text{erg},$$

where $t$ is the number of years counted from 1885.

3) The deviation of the point for a certain year in Fig. 2 from the line $S$ corresponds to the amount of supplied energy minus released energy up to that particular year, so that it may be interpreted as representing the amount of energy which is potentially being stored in the crust and/or mantle of the earth.

4) The amount of this stored energy cannot be larger than a certain limit that corresponds to the energy of the largest conceivable earthquake.

Fig. 3 shows the year-to-year variation of deviation of the point.

Fig. 3. Year-to-year variation of deviation of the points from the straight line $S$. Vertical line: annual release of energy.
from the straight line \( S \), which is interpreted here as indicating the amount of energy stored. The series of horizontal lines drawn in the same figure express the energy in terms of magnitude. The vertical lines in Fig. 3 show the amount of energy released in each year. It is clearly seen that it is when the stored energy is large that earthquakes of large magnitude take place. But the converse is not always true. For instance, during 20 years from about 1895, although the stored energy was pretty high, much of it was released by many earthquakes which were not very large in magnitude.

If a point in Fig. 3 is on the level of a certain \( M \), it may be said that an earthquake having that magnitude \( m \) may occur and also that an earthquake having magnitude larger than \( M \) is very unlikely to occur. The former statement does not mean that an earthquake having that magnitude \( M \) will occur. From the energetic points of view, it does not make any difference whether the stored energy \( E \) is released by one single earthquake or it is by \( n \) earthquakes each with the energy \( E/n \).

The above statistics has been made for the whole area of Japan and its neighbourhood. If the area is divided into several units and each of the units is investigated separately, the uniformity of energy release does not show up. A certain size of area appears to be necessary for the uniformity of energy release to be established. Whether or not this size differs in various seismic regions of the world is an important problem to be studied.

As was stated, the average energy release by earthquakes is \( 2 \times 10^{23} \) erg/year for the whole area of Japan and its neighbourhood. In this connection, it is interesting to recall that A. Sugimura and others (1963), from the distribution of volcanic material recently ejected in this same area, estimated the average annual amount of heat energy carried out by volcanism is \( 7 \times 10^{23} \) erg. No large weight can be put on the numerical factors, but it is noteworthy that the annual rate of energy release by the seismic and volcanic activity is both several units in the order of \( 10^{23} \) erg/year. In Japan, as in other geophysically similar regions of the world, the site of high seismicity and of volcanism do not coincide, the former being situated towards the ocean side. It may be suspected if the energy which manifests its display in these two kinds of activity is supplied from the interior of the earth primarily in a similar way and in a similar rate. In one area, the supplied energy is released mainly in the form of seismicity with little volcanism, while in the other, it is released mainly in the form of volcanism with little seismicity. It is also interesting to note that recent measurements (K. Horai, 1964) have shown that heat flow is comparatively low in the Pacific offshore of
Northeastern Honshu (the main island of Japan) where the seismic activity is high.

References

Japan Meteorological Agency: Catalogue of Major Earthquakes which Occurred in and near Japan (1926-1956).