7. *An Estimate of Future Tsunami Damage Along the Pacific Coast of Japan.*

By Ryutaro TAKAHASI,

Earthquake Research Institute.

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Abstract.

Assuming that tsunami activity recorded during historic times is still continuing at present and will continue also in the future, the writer has estimated the degree of danger of tsunami for each village on the Pacific coast of Japan which may be expected in the future. Results are given in Fig. 2 and in Table III.

1. To minimize damage from tsunamis, various types of structures have been devised such as breakwaters, embankments, artificial bars, coastal forests, cushion zones, etc. The most economical and effective type of structure depends, however, on the topography, mainly submarine, of the place under consideration and also on the intensity of the tsunami at that place. In this respect, it is desirable to determine the maximum height of tsunami which may be expected in the future for each village on the Pacific coast.

2. Tsunamis or seismic sea waves occur more frequently in Japan than in any other country in the world. There is no coast line in Japan which has not experienced past tsunamis. According to "Earthquake Records for Japan" (Nippon Jishin Shiryo), about 75 tsunamis have occurred in the sea adjacent to Japan, the oldest one occurring in 684 A.D. and the latest in 1946 at the time of the Nankai Earthquake. Smaller tsunamis which caused no damage and accordingly were not included in the record must be innumerable. Among the tsunamis recorded, there is one that caused the loss of 27,000 lives. In Table I, the dates of historical tsunamis are listed together with the name of the region which suffered damage, the position of the tsunami center and the magnitude M. The origins of these tsunamis are plotted in Fig. 1. Numerals beside the circles are the serial numbers in Table I. Radius of the circle indicates the magnitude of the tsunamis.

Table I. List of Tsunamis.

No.	Date	Damaged Region	Magnitude M	Origin
1	684 Nov. 29	Tosa, Tokaido & Seikaido	3	32.5 N, 134.0 E
2	799 Sept. 18	Hitachi		Distant origin
3	850 Nov. 17	Dewa	1	39.0 N, 139.5 E
4	869 July 13	Sanriku	4	38.5 N, 143.8 E
5	887 Aug. 2	Echigo	1	37.5 N, 138.1 E
6	887 Aug. 26	Nankaido	3	33 N, 135.3 E
7	922	Kii & Kumano	1	33.8 N, 136.7 E
8	1096 Dec. 17	Tokaido	2	34.2 N, 137.3 E
9	1241 May 22	Kamakura	1	35.3 N, 137.3 E
10	1257 Oct. 9	S. Kwanto	1	35.2 N, 140.9 E
11	1360 Nov. 22	Kii, Settsu	2	33.4 N, 135.2 E
12	1361 Aug. 3	Kii, Tosa & Settsu	3	33 N, 135 E
13	1403	Kii	1	33.7 N, 136.5 E
14	1408 Jan. 21	Kii	2~1	33.8 N, 136.9 E
15	1420 Sept. 6	Hitachi	1	Distant origin
16	1433 Nov. 7	Sagami	1	34.9 N, 139.5 E
17	1495 Sept. 12	Sagami	2	35.5 N, 139.2 E
18	1498 Sept. 20	Tokaido	3	34.1 N, 138.2 E
19	1510 Sept. 21	Settsu	0	34.6 N, 135.7 E
20	1520 April 4	Kii	1	33.6 N, 136.3 E
21	1562 June 15	Higo	1	Distant origin
22	1585 June 21	Rikuzen	0	Distant origin
23	1596 Sept. 4	Bungo	2	33.3 N, 131.7 E
24	1605 Feb. 3	Tokaido & Nankaido	3	A 34.3 N, 140.4 E B 33 N, 134.9 E
25	1611 Dec. 2	Sanriku & Hokkaido	4	37.7 N, 144.3 E
26	1614 Nov. 26	Echigo	1	37.5 N, 138 E
27	1616 Sept. 9	Sendai	1	38.1 N, 142 E
28	1633 Mar. 1	Sagami & Suruga	1	35.6 N, 139.2 E
29	1640	Hokkaido	1	Eruption of Komagatake

(to be continued.)

Table I. List of Tsunamis. (continued.)

No.	Date	Damaged Region	Magnitude M	Origin
30	1650 Oct. 31	Echizen	1	
31	1662	Hiuga & Osumi	2	31.7 N, 132 E
32	1676	Hitachi	0	Distant origin?
33	1677 April 13	Rikuchu	2	38.7 N, 144 E
34	1677 Nov. 4	Iwaki, Hitachi & Owari	2	36.6 N, 141.5 E
35	1687 Oct. 22	Rikuzen	0	Distant origin?
36	1696 Feb. 25	Rikuzen	1	Distant origin?
37	1703 Dec. 31	Kwanto	3	34.7 N, 139.8 E
38	1707 Oct. 28	Tokaido, Nankaido & Seikaido	4	33.2 N, 135.9 E
39	1711 Dec. 20	Sanuki	1	34.3 N, 134 E
40	1731 Oct. 7	Rikuzen	1	37.9 N, 140.6 E
41	1741 Aug. 28	Hokkaido & Sado	3	41.5 N, 139.4 E
42	1751	Rikuchu	1	
43	1762 Oct. 31	Sado	1	38.1 N, 138.7 E
44	1763 Jan. 29	Mutsu, Hachinohe	2	40.8 N, 142 E
45	1763 Mar. 15	Mutsu, Hachinohe	1	
46	1768 July 22	Ryukyu Kerama Is.	1	
47	1771 April 24	Ryukyu Ishigaki Is.	3	
48	1780	Etorohu, Chishima	1	
49	1782 Aug. 23	Sagami	0	35.1 N, 139.7 E
50	1791 May 13	Ryukyu	1	Distant origin?
51	1792 May 21	Shimabara	2	32.8 N, 130.3 E Land-slide of Unzendake
52	1792 June 13	Shiriheshi	1	43.6 N, 140.3 E
53	1793 Feb. 8	W. Tsugaru	1	40.7 N, 140 E
54	1793 Feb. 17	Rikuzen, Rikuchu	2	38.3 N, 142.4 E
55	1804 July 10	Uzen, Ugo	1	39 N, 140 E
56	1810 Sept. 25	Oga Penn.	0	39.9 N, 139.9 E
57	1833 Dec. 7	Sado, Uzen	2	38.7 N, 139.2 E
58	1834 Feb. 9	Ezo (Ishikari)	1	43.3 N, 141.4 E

(to be continued.)

Table I. List of Tsunamis. (continued.)

No.	Date	Damaged Region	Magnitude M	Origin
59	1835 July 20	Rikuzen	2	37.9 N, 141.9 E
60	1836 Sept. 5	Rikuzen	1	
61	1843 April 25	Kushiro & Nemuro	2	41.8 N, 144.8 E
62	1854 Dec. 23	Tokaido, Nankaido	3	34.1 N, 137.8 E
63	1854 Dec. 24	Ise, Tosa, Kii & Kyushu	3	33.2 N, 135.6 E
64	1856 Aug. 23	Toshima	2	43 N, 141.1 E
65	1865	Ryukyu	1	
66	1867	Formosa (Kiirun)	2	
67	1868 (Aug. 16?)	Ryukyu, Rikuzen	0	Distant origin (Equador)
68	1872 Mar. 14	Iwami	1	34.8 N, 132 E
69	1883 Aug. 27	Sagami, Satsuma	0	Distant origin (Eruption of Krakatoa)
70	1894 Mar. 22	Nemuro, Kushiro	2	(42 N, 145.1 E)
71	1896 June 15	Sanriku	4	39.4 N, 144.4 E
72	1897 Aug. 5	Sanriku	1	38.2 N, 143.7 E
73	1912 June 8	Sanriku	0	
74	1915 Nov. 1	Sanriku	1	
75	1917 May 6	Formosa	1	
76	1918 Sept. 8	Etorohu	2～3	
77	1922 Nov. 12		0	Chili Tsunami
78	1923 Sept. 1	Kwanto	2	35 N, 139.8 E
79	1933 Mar. 3	Sanriku	3	39.1 N, 144.2 E
80	1939 May 1	Oga Penn.	0	40 N, 139.8 E
81	1940 Aug. 2	Shakotan Penn.	1	44.1 N, 139.2 E
82	1944 Dec. 7	Tokaido	3	34 N, 137.1 E
83	1945 Jan. 13	Mikawa	1	34.8 N, 137.2 E
84	1946 Dec. 21	Nankaido	3	33 N, 134.8 E

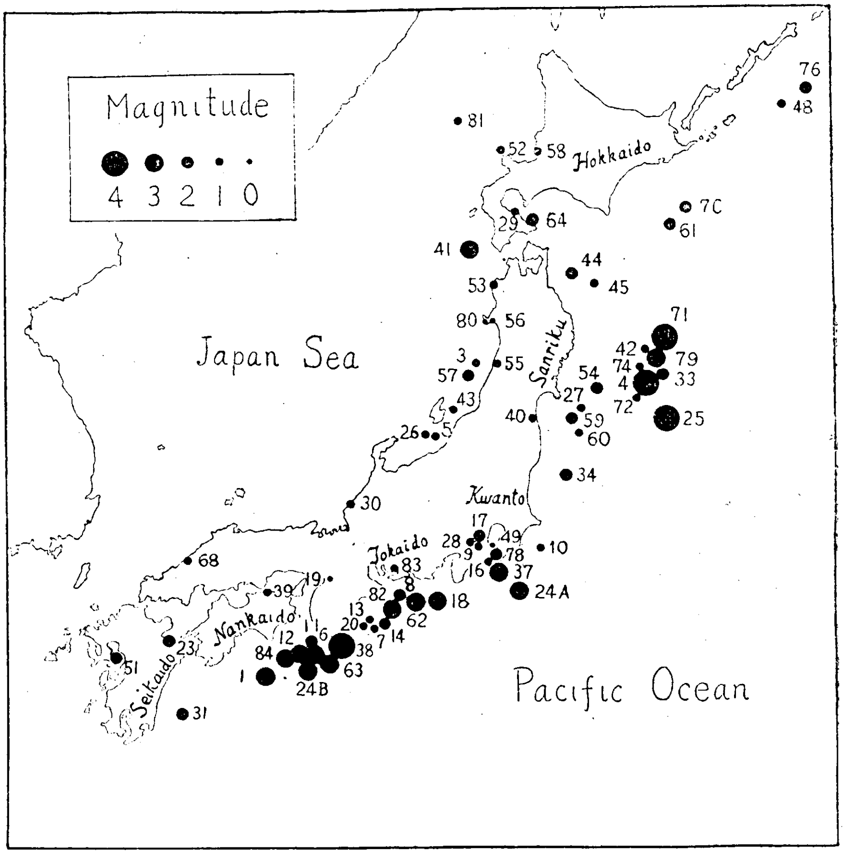

Fig. 1. Distribution of tsunami centers.

The position of the origin of each tsunami was determined from the distribution of damage caused not only by the tsunami but also by earthquake motions. In this connection, the list of earthquakes in historic times prepared by H. Kawasumi[1] has been of great help. As to the magnitude of tsunamis, they have been classified into five classes, according to the maximum wave height observed at the coast, as A. Imamura[2] formerly did. The severest or the fifth class tsunamis are those with a maximum wave height of 30 m or more, and the fourth class ones with a wave height of 15 m. In this classification, the maximum wave height is reduced by one-half with decreasing magnitude of unity. This classification amounts in the end

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[1] H. KAWASUMI, On Some Measure of Earthquake Danger. The IXth I.U.G.G. Congress Rep.

[2] A. IMAMURA, *The Science of the Sea*, Vol. II, p. 2.

to classifying tsunamis according to their total energy, as mentioned below, since the distances to the origin of all tsunamis from the coast do not differ much one from the other.

As may be seen from Fig. 1, earthquakes accompanied by tsunamis have occurred most frequently off the coast of Sanriku (NE Japan, Pacific side), Nankaido (W Japan, Pacific side) and Loochoo Islands, though the last region is not shown in the figure. They occur less frequently off the coasts of Kwanto, Hokkaido and Kurile Islands. Along the coasts of Japan Sea, they occur rarely, except along the western coast of Hokkaido.

The distribution of tsunami origins depends, of course, on the position of seismic zones as well as on the nature of seismic activity characteristic to each seismic zone. In the so-called inner seismic zone, which runs along the coast of Japan Sea, earthquakes are generally local and occur either on the boundary between land and sea, or entirely on land, so that only a small percentage of earthquakes in this zone produce such submarine land deformation which cause tsunamis. On the Pacific side, however, the zone of destructive earthquakes runs entirely off the coast, so that every great earthquake causes a tsunami.

3. A tsunami is a train of long waves. Its wave front is emitted from the periphery of the submarine dislocated area and the wave is propagated with a velocity

$$V = \sqrt{gH} \ ,$$

where g is the acceleration of gravity and H the depth of the sea. The total energy emitted from the origin is given by

$$E = \pi \rho g VR \sum A^2 T \ ,$$

where ρ is the density of sea water, R the distance from the origin, A the amplitude and T the half-period of tsunami waves. The summation must be made with respect to all half-periods. In the case of 1933 tsunami, the wave height A at the 200 m depth line off the bay of Ohunato has been estimated to be 3 m by Stokes' law since the wave height at a cape, where the sea depth is 20 m, was observed to be 5 m. Average half-period was 7.5 min. and the number of main half waves 5. The total energy thus calculated, is 16×10^{22} erg, and is about 1/1000 of the total energy of seismic waves as given by H. Kawasumi[3] and others.

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[3] H. KAWASUMI, *1948 New Zealand Pan Pacific Congress Rep.*; B. GUTENBERG, *Seismicity of the Earth.*

According to A. Imamura, the wave height of 1611 tsunami, whose magnitude was 4, was about twice those of 1933 tsunami, whose magnitude is assumed to be 3. The total energy of 1611 tsunami may therefore be considered to have been four times larger than that of 1933 tsunami. We may then generally calculate the total energy of a tsunami of magnitude M from the relation

$$E = E_0 10^{0.6M} \text{erg} ,$$

where $E_0 = 25 \times 10^{20}$. In calculating the energy of tsunami, the values of A, T, V must preferably be taken from observation at the place nearest to the origin. When using data obtained at long distances, the convergence and divergence of wave energy caused by refraction and reflection of waves must be taken into consideration.

4. Examination of Table I shows that tsunami activity has not been the same throughout historic time; there has been three active periods, the first period covering the interval from 680~950, the second period from 1200~1500, and the third period from 1600 to date. These active periods coincide naturally with those of earthquakes. Since the duration of these periods is about three to four hundred years, we may consider that the last active period is not yet over.

The number of tsunamis which have occurred during the last 350 years, classified according to their magnitude and region of occurrence, is shown in Table II.

Table II.

Region / Magnitude	From Loochoo Is. to Kwanto	From Sanriku to Kurile Is.	W. Kyushu and Japan Sea	Total
4	1	2	0	3
3	7	2	1	10
2	3	7	2	12
1	5	9	9	23
0	1	1	2	4
Total	17	21	14	52

The energy of these tsunamis becomes as follows (unit: 10^{20} erg):

Table III.

Region	From Loochoo Is. to Kwanto	From Sanriku to Kurile Is.	W. Kyushu and Japan Sea	Total
During 350 years	19330	19730	3350	42400
Per 100 years	5520	5640	960	12110
Per 1 tsunami	1139	940	240	810

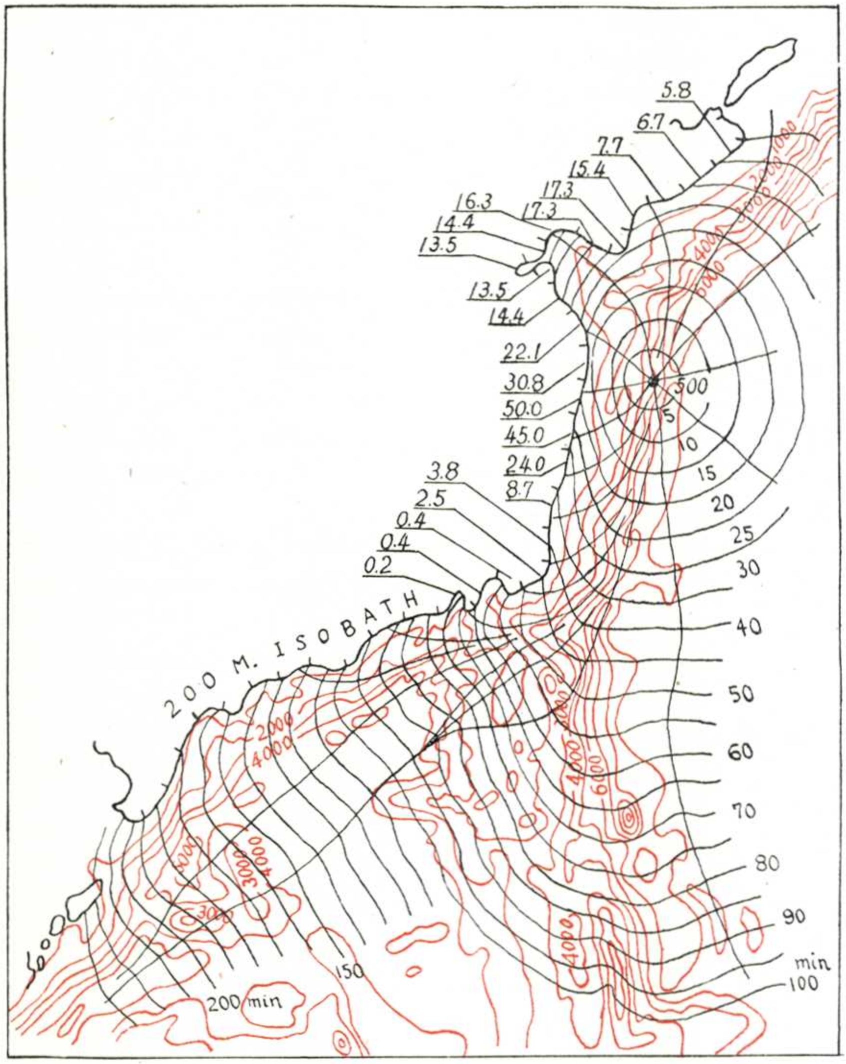

Fig. 2. An example of the refraction diagram.

It may not be absurd, then, to expect, that energy of tsunami to be liberated from each region will be at the same rate as those calculated above during the coming several decades. We may assume further that the energy will be emitted from each part of the seismic zone in proportion to the tsunami activity of that part in the past.

5. When a quantity of energy $\phi(Q)\,dS$ is emitted uniformly in all directions from an area dS around a place Q, the quantity of energy that reaches the unit length (83 km) of 200 m depth line off P will be given by $\phi(Q)D(P,Q)dS$. $D(P,Q)$ represents the distribution function and its numerical value can be obtained graphically from refraction diagrams drawn according to Huygens' principle and the velocity formula. The 200 m depth line is adopted here instead of the beach line for reasons given below.

Fig. 2 is an example of the refraction diagram. In the figure, $\phi(Q)\,dS$ is taken as 500. Numerals on the 200 m depth line represent values of $\phi(Q)\,D(P,Q)\,dS$ for this case.

If we denote the energy which will be emitted from Q during the coming 100 years by $\phi(Q)$, the total energy which will reach the 200 m depth line off P becomes

$$\int_Q \phi(Q)\,D(P,Q)\,dS\,.$$

Integration must cover all sources.

In the actual calculation of the values of the above integral, assuming for $\phi(Q)$ the values given in Table III, the energy sources were concentrated, for the sake of simplicity, into several points in the manner indicated in Table IV to obtain the final values shown in Fig. 3. In this figure, the thick lines indicate the 200 m isobathymetric lines, and numerals show the values of the integral in units of 10^{20} ergs. Values are not given for the coast of Japan Sea, as it was not possible to estimate the values of $\phi(Q)$ with any degree of certainty due to scarcity of distribution of tsunami origins. Danger of tsunami occurring is great at the coast which is near to the section with large values.

This is correct, however, only with respect to average or general tendency for a locality and its neighbourhood; it is, of course, a different problem to estimate in what proportion the energy which reaches a section of 200 m depth line will be distributed among the villages on the coast adjacent to that section. It depends mainly on the submarine topography

Table IV. $\int \phi(Q)\,\dot{D}(P,Q)\,dS$ (in units of 10^{20} ergs.)

Concentrated tsunami origins					No. of sections of 200 m isobathymetric line																	
No.	Locality	N. Lat.	E. Long.	$\phi(Q)$	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	Off Iterup Is.	44.2	148.5	500	24.2	11.4	4.0	3.2	0.6	0.6	0.6	0.2	0.2	0.2	0.2	1.2	1.4	1.4	0.8	0.4	0.4	0.4
2	Off Shikotan Is.	43.3	147.1	500	51.6	41.6	21.0	22.5	3.8	0.5	1.0	1.0	0.2	0.2	0.2	2.0	4.0	4.0	4.0	4.0	4.0	3.2
3	Off Kushiro	42.3	145.5	700	56.0	67.6	63.0	56.0	31.5	9.1	4.4	2.3	2.3	2.3	2.3	11.2	11.2	9.1	9.1	6.8	4.0	1.9
4	Off Erimo C.	41.5	144.5	800	17.8	31.0	53.5	71.6	89.0	20.2	13.2	8.9	4.4	4.3	13.2	28.8	26.8	24.5	24.5	4.3	3.2	0.9
5	Off Aomori	40.6	144.2	590	4.3	9.8	20.6	26.1	26.1	13.0	9.8	5.5	5.5	8.7	15.2	37.0	37.0	28.2	21.8	9.8	4.3	2.0
6	Off Kamaishi	39.6	143.8	1000	11.6	13.4	15.4	30.8	34.6	34.6	32.6	28.8	27.0	27.0	28.8	44.2	61.6	100.0	90.0	48.0	17.4	7.6
7	Off Kinkasan	38.3	143.0	1000	15.5	15.5	4.0	3.0	5.0	3.8	6.0	6.0	2.0	8.5	15.5	48.8	83.0	83.0	90.3	83.0	39.0	24.5
8	Off Fukushima	37.1	142.4	500	2.0	1.2	1.4	1.4	2.0	0.8	0.8	1.6	2.2	3.2	3.2	12.0	19.2	32.8	52.0	46.2	30.8	21.2
9	Off Hitachi	36.0	141.8	200	0.4	0.2	0.2	0.2	0.2						4.0	1.0	2.6	8.0	13.0	16.0	20.0	22.0
10	Off Boso Penn.	35.2	141.1	590	1.0	0.5	0.0	0.0	0.0							1.5	2.5	16.0	16.0	31.5	31.5	47.0
11	Off Boso Penn.	34.3	140.2	1000	0.5	0.5	0.2	0.2	0.0						0.2	0.5	1.5	6.5	17.3	21.7	28.4	50.0
12	Off Ise Bay	34.0	137.3	1000													0.2	0.2	0.3	0.3	0.3	0.4
13	Off Kii	32.8	134.7	1500													0.2	0.4	0.9	1.9	3.4	4.1
14	Loochoo Is.	29.8	130.2	1500															0.2	0.3	0.3	0.3
Sum					185	193	183	215	193	83	68	54	44	54	79	188	251	314	340	274	187	186

(to be continued.)

Table IV. $\int \phi(Q) D(P, Q) dS$ (in units of 10^{20} ergs.) (continued.)

Concentrated tsunami origins					No. of sections of 200 m isobathymetric line																
No.	Locality	N. Lat.	E. Long.	$\phi(Q)$	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
1	Off Iterup Is.	44.2	148.5	500	0.4	0.4	0.2	0.2	0.2	0.2											
2	Off Shikotan Is.	43.3	147.1	500	3.2	3.2	0.8	0.2	0.2	0.2	0.2										
3	Off Kushiro	42.3	145.5	700	0.9	0.7	0.5														
4	Off Erimo C.	41.5	144.5	800	0.9	0.9	0.5														
5	Off Aomori	40.6	144.2	500	0.6	0.2	0.2														
6	Off Kamaishi	39.6	143.8	1000	5.0	0.8	0.8	0.4													
7	Off Kinkasan	38.3	143.0	1000	9.8	3.8	1.5	0.8	0.8	1.0	1.0	0.5	0.5	0.5	0.2						
8	Off Fukushima	37.1	142.4	500	16.0	10.0	2.0	1.6	1.4	0.8	0.8	0.4	0.2	0.2	0.2						
9	Off Hitachi	36.0	141.8	200	12.0	4.0	4.0	1.0	0.6	0.2	0.2	0.2	0.2	0.2	0.2						
10	Off Boso Penn.	35.2	141.1	500	62.5	15.0	10.0	5.0	2.5	2.5	1.5	0.5	0.5	0.5							
11	Off Boso Penn.	34.3	140.2	1000	113.2	47.8	41.3	10.8	4.3	15.2	21.6	17.2	6.5	8.7	6.5	2.7	0.7	0.8	1.3	0.5	0.2
12	Off Ise Bay	34.0	137.3	1000	0.6	0.8	1.0	6.0	0.0	69.0	367.0	118.0	9.0	1.0							
13	Off Kii	32.8	134.7	1500	2.6	2.6	2.6	2.6	4.5	25.0	75.0	94.3	229.0	244.0	151.0	75.0	75.0	19.9	19.3	7.5	2.1
14	Loochoo Is.	29.8	130.2	1500	0.3	0.3	0.2	0.3	0.5	1.4	2.7	4.2	5.8	6.7	7.5	29.2	19.2	63.4	91.6	183.0	127.0
Sum					228	91	66	29	15	116	470	215	252	262	166	107	95	84	112	191	129

between the 200 m depth line and the shore, on the shape and direction of a bay, and on the position of any village in the bay.

The 200 m depth line generally corresponds to the brink of continental shelves, the slope of the sea bottom suddenly becoming steep from here towards the sea. Consequently the wave front of tsunamis becomes almost parallel to isobathymetric lines at or near the depth of 200 m, regardless of the position of tsunami centers, since the velocity of propagation of long waves is proportional to the square root of the sea depth. It is only natural that the ratios of energy distributed among different but nearby villages are always similar and almost independent of the position of tsunami sources.

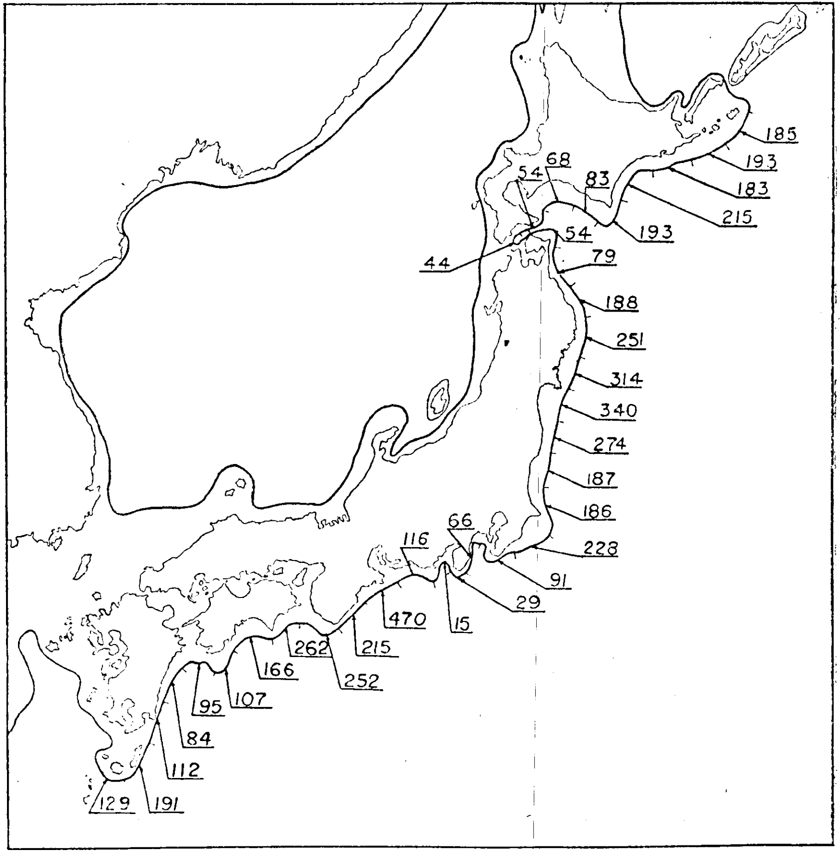

Fig. 3. Estimated amount of energy (in units of 10^{20} ergs) that will reach each section (83 km long) of 200 meter isobath within the next 100 years.

If we denote this ratio of distribution by $T(P)$, an estimate of the energy at any particular village P becomes

$$T(P)\int\phi(Q)\,D(P,\,Q,)dS\,.$$

6. As observed at the sea shore, a tunami may appear sometimes merely as a gradual rise and fall of the sea surface (calm case), sometimes as a progressive, rolling or breaking water wall (moderate to severe case) or sometimes as a water jet with a great velocity rushing toward the shore (extremely severe case). These features depend on the wave height of tsunamis and these different features may sometimes be observed at different portions of one and the same bay.

Even when the sea surface rises gradually, the water gains remarkable velocity when it reaches land, especially when the land is broad and flat. In many cases, this velocity exceeds 1 m/sec. Damage to houses is caused directly or indirectly by the hydrodynamical pressure due to this water flow. This pressure is proportional to the square of the velocity so that, in final, damage may be regarded to be proportional to the square of the water height or to the energy, since the periods of tsunami waves are almost the same everywhere and at any time. This conception may be allowed when we consider that the area invaded by the tsunami at any village is in most cases proportional to the square of the wave height at the village.

We may, therefore, consider the sum of the energy of all tsunamis that may attack P within the next century as the index $K(P)$ of the danger of tsunami at the place P. We then obtain

$$K(P)=T(P)\int\phi(P)\,D(P,\,Q)dS\,.$$

As mentioned above, $T(P)$ is a coefficient which depends on the topography, on land and under water, of the point P. It is very difficult or troublesome, if not impossible, to determine $T(P)$ theoretically. The value of $T(P)$ is most simply obtained from the relation

$$T(P)=A^2/E\cdot D(P,\,Q)\ ,$$

if the total energy E of a tsunami, the position Q of the tsunami center, and the wave height A of the tsunami observed at P are known.

The values of $T(P)$ have been calculated in this way for all villages on the Pacific coast of Japan from the data on 1933 tsunami ($E=1600\times10^{20}$ erg),

Table V. Wave heights of tsunamis and $T(P)$.

Locality	1896 Tsunami	1933 Tsunami	1944 Tsunami	1946 Tsunami	$2\,T(P)$
	m	m	m	m	
Same	3.3	2.9			0.230
Yagi	10.6	3.5			0.340
Ogonai	12.1	3.0			0.250
Kuki	12.1	3.3			0.300
Tamagawa	18.2	4.2			0.490
Horiuchi	12.1	8.0			1.750
Ootanabe	15.2	7.4			1.500
Raga	22.7	8.4			1.950
Omoto	12.1	4.4			0.540
Taro	14.6	10.0			2.000
Chikei	17.0	12.1			2.900
Aneyoshi	18.8	21.0			8.850
Omoe	10.9	8.8			1.550
Otobe	9.1	10.9			2.400
Aramaki	12.1	7.2			1.025
Miyako Bay:					
Shirahama	8.5	1.0			0.020
Kuwagasaki	9.1	4.0			0.320
Sokei	6.0	4.0			0.320
Takahama	3.0	2.0			0.080
Kanahama	3.9	2.0			0.080
Yamada Bay:					
Oosawa	3.9	2.0–2.5			0.950
Yamada	5.5	3.0–4.0			0.320
Origasa	3.3	1.9			0.070
Funakoshi Bay:					
Koyadori	15.2	6.6 (12.0)			1.250
Tanohama	9.1	5.1			0.500
Funakoshi	15.2	5.0			0.500
Kirikiri	10.6	5.5			0.600
Namiita	10.6	5.2			0.550
Oozuchi Bay:					
Ando	4.2	3.4			0.230
Oozuchi	2.7	3.3			0.215
Hakozaki	5.8	4.3			0.370
Nehama	5.5	4.0			0.320
Ryooishi	11.2	10.0			2.000

(to be continued.)

Table V. Wave heights of tsunamis and $T(P)$. (continued.)

Locality	1896 Tsunami	1933 Tsunami	1944 Tsunami	1946 Tsunami	$2\,T(P)$
	m	m	m	m	
Kamaishi Bay:					
Kamaishi	4.5–8.2	3.7			0.275
Ureishi	4.2	3.9			0.300
Hirata	5.2	3.7			0.275
Hongo	14.0	12.0			2.850
Koshirohama	16.4	8.6			1.500
Arakawa	10.6	5.8			0.675
Yoshihama	24.2 (?)	13.6–16.3			4.550
Okirai Bay:					
Imaurahama	9.7	9.9			1.225
Okirai	10.3	11.1			1.550
Koishihama	10.3	8.3			0.850
Shirahama	21.8	22.1–28.7			8.150
Ryori	10.6	8.6–9.7			1.050
Oofunato Bay:					
Nagahama-takonoura	—	4.1			0.210
Akazaki	3.6	2.4			0.070
Oofunato	3.3	3.4			0.145
Shimo-funato	5.5	4.1			0.210
Suezaki-hosoura	6.7	4.1–6.2			0.325
Hirota Bay:					
Tadaide	10.6	9.0			1.000
Atsumari	2.7	19.5			4.750
Oonohara	7.9	9.8			1.075
Takata Bay:					
Tomarihama	7.6	6.4–8.5			0.700
Mikkaichi	2.4	3.0			0.115
Osabe	3.3	6.0			0.450
Tadakoshi	8.5	8.6			0.925
Ishihama	8.5	6.0–9.5			0.750
Kesennuma Bay:					
Tsurugaura	4.2	4.5			0.250
Shukuhama	4.2	3.0			0.115
Ooshima-nagasaki	6.7	6.3			0.500
Ooshima-urahama	2.1	2.0			0.050
Koizumi Bay:					
Ooya	5.2	4.5–5.5			0.305

(to be continued.)

Table V. Wave heights of tsunamis and $T(P)$. (continued.)

Lacality	1896 Tsunami	1933 Tsunami	1944 Tsunami	1946 Tsunami	$2T(P)$
	m	m	m	m	
Koizumi Bay:					
Hikadohama	5.2	4.0			0.200
Oosawa	8.2	5.7			0.400
Nijuichihama	6.0	5.9			0.435
Kurauchihama	6.0	4.4			0.240
Minatohama	6.7	3.5			0.150
Tanoura	4.9	5.1			0.325
Shizukawa Bay:					
Irimae	3.3	3.6			0.160
Hosoura	3.6	2.5			0.075
Shimizuhama	3.3	2.2			0.060
Hiraiso	4.0	3.0			0.115
Shizukawa	2.1	1.5			0.030
Hayashihama	1.8	3.2			0.130
Oritate	2.7	2.7			0.090
Mitobe	2.4	2.1			0.055
Tsunomiya	4.0	3.6			0.160
Takihama	4.0	2.4			0.070
Fujihama	5.2	5.3			0.350
Nagashimizu	4.9	4.6			0.265
Kotaki	6.0	9.7			1.175
Oppa Bay:					
Oozashi	5.2	3.8			0.180
Kozashi	4.6	4.6			0.265
Aikawa	4.6	5.5			0.375
Oomuro	4.0	3.7			0.170
Naburihama	3.3	3.3			0.135
Okachi Bay:					
Myojinhama	2.4	2.0			0.050
Okachi	3.0	3.9			0.190
Funato	2.7	3.5			0.150
Karakuwa	1.8	2.1			0.055
Wakehama	2.1	1.8			0.040
Namiita	2.4	2.1			0.055
Sashihama	2.7	2.1			0.055
Omaehama	3.0	2.2			0.060
Oura	2.4	2.7			0.090

(to be continued.)

Table V. Wave heights of tsunamis and $T(P)$. (continued.)

Locality	1896 Tsunami	1933 Tsunami	1944 Tsunami	1946 Tsunami	$2\,T(P)$
	m	m	m	m	
Onagawa Bay:					
Takenoura	6.1	2.0			0.050
Ishihama	2.4	2.6			0.085
Onagawa	2.7	2.2—2.8			0.080
Nonohama	3.0	2.4			0.070
Iikonohama	2.7	2.0			0.050
Sameura Bay:					
Yoriiso	2.7	2.4			0.080
Maetsuna	2.4	2.0			0.055
Samenoura	3.0	5.0			0.350
Yakawa	3.3	5.2			0.375
Ojika Penn.:					
Tomarihama	6.0	3.7			0.190
Yamadori	4.2	3.0—3.6			0.150
Ayukawa	2.1	2.3—3.2			0.110
Kobuchi	2.4	2.9			0.115
Ooharahama	1.8	2.3			0.075
Koamikura	2.1	3.0			0.125
Oginohama	2.1	2.9			0.115
Momoura	1.2	1.2			0.020
Ishinomaki	0.6	1.0			0.015
Tsu			1		0.009
Kawana			0.5		0.003
Matsuzaka			1.0		0.009
Oominato			2		0.049
Kagamiura			2.5		0.049
Nagaoka			2.0		0.031
Matoya			3		0.070
Nakiri			3.5	1.0	0.044
Funakoshi-sotoura			3.5	1.2	0.044
Funakoshi-uchiura				1.8	0.590
Katada			3	2.2	0.034
Fuseda			2.2	1.0	0.010
Wagu			5	1.0	0.009
Koshiga				1.5	0.418
Ago Bay:					
Ugata			2		0.032

(to be continued.)

Table V. Wave heights of tsunamis and $T(P)$. (continued.)

Locality	1896 Tsunami	1933 Tsunami	1944 Tsunami	1946 Tsunami	$2\,T(P)$
	m	m	m	m	
Ago Bay:					
Goza			2.5	1.6	0.051
Hamashima				1.0	0.203
Hiyamaji				0.9	0.184
Shioya				1.0	0.203
Nanbari			3.5	2.0	0.099
Gokasho Bay:					
Syukudaso				1.0	0.203
Gokashoura			3	1.6	0.073
Shimotsuura				1.6	0.518
Hazamaura				1.6	0.518
Konza			3.4		0.094
Nakajima			3.5		0.099
Yoshizu			6		0.410
Shimazu			6		0.410
Nagashima			4		0.233
Nishiki			6		0.437
Kaino			4.6		0.309
Katsuragi			4		0.233
Owashi Bay:					
Sugari			5	1.1	0.364
Yaguchi			7.5	2.3	0.816
Ikuma				1.9	0.341
Hikimoto			3	0.8	0.131
Owashi			5.0	2.0	0.364
Kuki			7	1.1	0.715
Hayata				1.1	0.715
Gata Bay:					
Mikiura			3.9	2.1	0.249
Nagara				2.3	0.500
Mikisato			3.9	2.6	0.249
Furue				2.4	0.544
Kada			7.1	3.6	0.823
Minamiwanai			5.5	2.8	0.735
Kajiga			4.9	2.1	0.394
Arasaka			7.1	3.5	0.824
Arashika			8.4	3.0	1.150

(to be continued.)

Table V. Wave heights of tsunamis and $T(P)$. (continued.)

Locality	1896 Tsunami	1933 Tsunami	1944 Tsunami	1946 Tsunami	$2\,T(P)$
	m	m	m	m	
Ootomari			5.2	2.0	0.377
Kodomari			5.5	2.1	0.415
Kinomoto			3.0	4.0	1.510
Atawa				2.0	0.285
Udono				1.5	0.161
Shingu			3	3.5	0.580
Ukui			3		0.316
Ookarachi			3		0.316
Nachi			4.5	3	0.710
Katsuura			2.4	2	0.202
Taiji			4.5		0.710
Shimosato			2.5		0.377
Uragami			6.2	3	1.351
Koza			3.5	3.6	0.736
Nishimukai			1.9		0.217
Tahara			2.5		0.731
Ooshima			2		0.241
Hashigui				4.6	0.567
Kushimoto			2	4.2	0.282
Fukuro				6.2	0.702
Arita				5.4	0.534
Tanami				4.1	0.306
Eda				4.8	0.419
Esumi			2.5		0.876
Susami				4.2	0.501
Hiki			1	3.0	0.256
Asaragi			4	4.0	0.686
Fukurotani				5.8	1.445
Shirahama				3.7	0.585
Tanabe Bay:					
Tanabe			1	2.7	0.315
Mikonohama				3.2	0.438
Mōri				4.7	0.950
Atonoura				4.4	0.828
Uchinoura				4.4	0.828
Ikeda				3.0	0.386
Hosono				3.1	0.411

(to be continued.)

Table V. Wave heights of tsunamis and $T(P)$. (continued.)

Locality	1896 Tsunami	1933 Tsunami	1944 Tsunami	1946 Tsunami	$2T(P)$
	m	m	m	m	
Tanabe Bay:					
Kogaura				3.2	0.439
Amishirazu				2.9	0.360
Nabemachi-yamauchi				2.1	0.189
Nabemachi				1.2	0.062
Matsubara				2.5	0.268
Shioya				2.8	0.336
Kiripe				1.7	0.073
Inami				4.9	0.694
Hachimanhashi Joryu				2.7	0.183
Gobo			0.5	3.0	0.465
Hii Bay:					
Mio				3.8	0.761
Ao				2.9	0.433
Ubuu				3.0	0.464
Koura				3.3	0.559
Yura Bay:					
Yura				4.0	0.824
Fukei				3.8	0.740
Itotani				3.5	0.630
Jin				1.3	0.090
Ato				3.9	0.778
Ooi				3.3	0.561
Kashiwa				3.0	0.464
Ogui				2.5	0.321
Katakui				2.5	0.321
Yuasa Bay:					
Yuasa				3.2	0.665
Hiro				4.9	1.134
Minojima-tatsugahama				1.5	0.158
,, takata				1.9	0.185
,, sunohara				1.8	0.167
,, yaki				1.1	0.062
Shimotsu Bay:					
Shimotsu			0.5	3.0	0.458

(to be continued.)

Table V. Wave heights of tsunamis and $T(P)$. (continued.)

Locality	1896 Tsunami	1933 Tsunami	1944 Tsunami	1946 Tsunami	$2\,T(P)$
	m	m	m	m	
Shimotsu Bay:					
Kata				2.5	0.322
Oosakiura				2.3	0.272
Tosaka				2.5	0.322
Shioura				2.5	0.322
Kuroe Bay:					
Kotoura				2.4	0.296
Nadaka				4.1	0.865
Torii				4.1	0.865
Shimizu				3.6	0.667
Suwasaki				4.2	0.905
Wakanoura Bay:					
Dejima				2.7	0.375
Wakanoura				1.9	0.186
Kata				1.6	0.132
Oosaka-chikuko				0.6	0.019
Hamadera				1.0	0.053
Kishiwada				1.0	0.053
Sano				0.3	0.005
Tannowa				0.3	0.005
Sumoto				0.9	0.042
Fukura				1.8	0.322
Yura				0.9	0.042
Nada				1.5	0.116
Nujima				1.5	0.116
Ama				1.5	0.116
Minato				0.3	0.005
Shitsuki				1.0	0.053
Naya				0.3	0.005
Sano				0.3	0.005
Tokushima				2.0	0.128
Muya				0.6	0.012
Komatsujima				2.0	0.128
Tachibanaura:					
Ookata				2.0	0.128
Tomosaki				1.9	0.119
Tachibana				3.3	0.348

(to be continued.)

Table V. Wave heights of tsunamis and $T(P)$. (continued.)

Locality	1896 Tsunami	1933 Tsunami	1944 Tsunami	1946 Tsunami	$2T(P)$
	m	m	m	m	
Tachibanaura:					
Kugui				3.6	0.415
Akaishi				2.5	0.200
Yuki Bay:					
Yuki				4.0	0.286
Tai				2.0	0.071
Kiki				4.2	0.314
Hiwasa Bay:					
Ebisu				3.6	0.232
Tai				1.5	0.032
Inoue				4.4	0.345
Mugi				4.5	0.334
Asakawa Bay:					
Awaura				4.0	0.264
Asakawa				4.7	0.364
Sawase				2.9	0.139
Dewashima				3.2	0.168
Tomooku				1.6	0.048
Nasa				3.7	0.294
Hamazaki				2.0	0.086
Shishikui				4.5	0.434
Tsubakidomari Bay:					
Tsubakidomari				1.9	0.115
Kobukikawara				2.2	0.155
Tsubaki				3.0	0.288
Hiramatsu				2.8	0.247
Shirigui				1.4	0.063
Kannoura				3.9	0.325
Nene				5.0	0.535
Shiina				3.0	0.105
Muroto				2	0.086
Ioki				3	0.386
Aki				3	0.376
Tei				2.9	0.361
Urato Bay:					
Kōchi				0.5	0.017
Tanezaki				1.4	0.135

(to be continued.)

Table V. Wave heights of tsunamis and $T(P)$. (continued.)

Locality	1896 Tsunami	1933 Tsunami	1944 Tsunami	1946 Tsunami	$2T(P)$
	m	m	m	m	
Urato Bay:					
Urato				1.5	0.155
Mimase				1.3	0.117
Usa Bay:					
Hashida				3.9	1.050
Usa				3.7	0.945
Fukushima				1.2	0.099
Yokonami				1.3	0.116
Susaki Bay:					
Koura				4.6	2.120
Miyanotani				5.2	2.695
Nomi				4.2	1.760
Oonogo				2.7	0.840
Susaki				3.3	1.087
Anwa				4.7	2.210
Kure Bay:					
Kure				3.9	1.518
Kamata				2.8	0.820
Kaminokae				2.7	0.730
Saga				4.7	0.950
Kamikawaguchi				4.5	0.870
Shimota				3.5	0.358
Nuno				2.0	0.117
Shimonokae				3.2	0.298
Iburi				2.7	0.213
Shimizu				0.8	0.119
Komame				3.0	0.676
Urajiri				1.2	0.185
Sukumo				1.2	0.185
Morosaki				0.5	0.003
Nishiura				0.5	0.003
Fukue				0.5	0.003
Maisaka				0.8	0.024
Onmaezaki				2.0	0.421
Uchiura				1.0	0.088

1944 tsunami ($E = 880 \times 10^{20}$ erg) and 1946 tsunami ($E = 720 \times 10^{20}$ erg). They are tabulated in Table V.

According to the results of calculation, $T(P)$ is constant for each of these tsunamis. From $T(P)$ and the values shown in Fig. 2, we can estimate, in a statistical sense, the maximum wave height, the velocity of the overflowing water, and many other quantities regarding future tsunamis at each place on the coast.

The author believes that this estimation on the probable future tsunamis will be useful in planning various means to guard against future tsunamis.

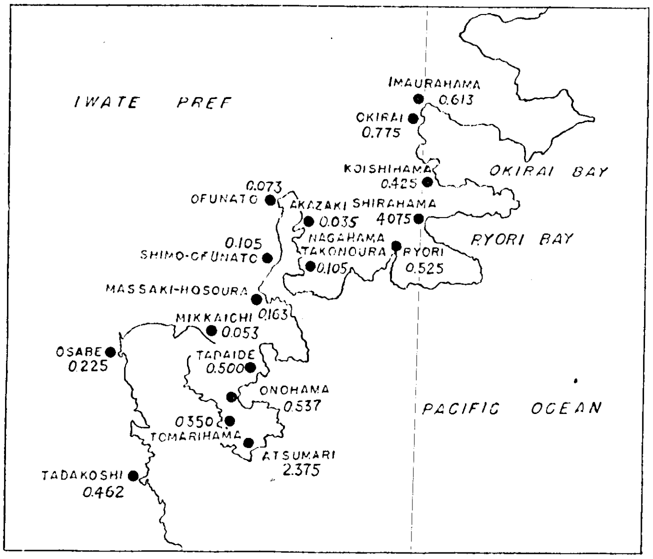

Fig. 4. $T(P)$ and the topography.

As an example, a part of the Pacific coast (Iwate Prefecture) with a typical ria topography where damage from tsunamis is always large is shown in Fig. 4. Numerals in the figure are $T(P)$ values for the place. We can readily see in the figure how the $T(P)$ values are related to the shape of the bay. The tsunami is very violent at places where $T(P)$ values exceed 0.5.

In conclusion, the author expresses his sincere appreciation to Mr. Tokutaro Hatori, who undertook the troublesome task of arranging the observed data on the Tonankai 1944 tsunami and the 1946 tsunami and also calculated the values of $T(P)$.

7. 本邦太平洋沿岸各地に於ける津浪の危險度

地震研究所　高橋龍太郎

過去における地震活動の趨勢が，こゝ暫くは續くものと假定すると，太平洋沿岸の 200 m 等深線の内，P 地點の沖合に當る區分 (長さ 83 km) に，今後100年間に到達する津浪のエネルギーは

$$\int_Q \phi(Q)\,D(P,Q)\,dQ \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (1)$$

で與へられる。此處に $\phi(Q)$ は Q 點から今後 100 年間に放出されるであらう津浪のエネルギー，$D(P,Q)$ は Q 點から出た津浪エネルギーが 200 m 等深線の P 點沖合の區分に分配される割合で，P, Q の相互位置と海深分布とから決る函數である。積分は全浪源地帶に就いて行ふ。

一方に於て，P 部落における津浪の危險度の目安として，其處で豫想される各回の津浪の波高の自乘の，100 年間に亙る總和を採ることゝすれば，此れは其の部落における延浸水面積，延被害額等に比例するものとなるであらうし，又其の部落に襲來する津浪エネルギーの總和にも比例する筈である。從つて前記 (1) 式の値と，此の危險度の目安としての波高の自乘の和との比を $T(P)$ とすれば，$T(P)$ は 200 m 等深線と部落間の海底，海岸の地形にのみよつて定まる函數で，浪源の位置や津浪の大きさには關係しない筈である。其れは 200 m 等深線といふのは大凡陸棚の緣に當つてゐて，津浪の前線は浪源の位置にかかわらず，大體この等深線に平行になるからである。

從つて (1) 式の値は津浪の地域的危險度を，$T(P)$ の値は各地の地形，位置等による，局地的危險度の相對値を示すものと見うる。(1) 式の値に $T(P)$ を乘じたものは P 地點の綜的合危險度を示すものとなる。

本文第 3 圖に於いては浪源の分布を十數ケ所に凝集して圖式計算した (1) 式の値を示した。又第 5 表には 1933 年の三陸津浪 (總エネルギー $E=1600\times10^{20}$ エルグ), 1944 年の東南海地震津浪 ($E=880\times10^{20}$ エルグ) 及び 1946 年の南海地震津浪 ($E=720\times10^{20}$ エルグ) の際の各地の波高 A から

$$T(P) = A^2/E{\cdot}D(P,Q) \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (2)$$

なる關係によつて計算した $T(P)$ の値が示してある。

第 4 圖に一例を示した樣に，$T(P)$ の値の大きい所は地形が津浪に對して不利な所である。