# *9. An Investigation of the Sanriku Tunami Based on Mareogram Data.*

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**1. Introduction.** In association with the earthquake of March 3, 1933, whose epicentre was at $\lambda = 144°E$ $\varphi = 39°N$, a violent tunami swept over the cities and villages along the coast of Sanriku, (the Pacific coast of Northeast Japan), and those of Hokkaidô. Disturbances of the waters due to the tunami were recorded quite clearly at various stations in Japan, at Honolulu, San Francisco and Santa Monica, U. S. A., and at Iquique, Chili, that is, at the mareograph stations situated around the Pacific Ocean.

In order to study this tunami, the writer collected copies of mareograms from the various stations. They are reproduced in Figs. 8–32 of the Report.[1] The present paper therefore describes the results of study of the Sanriku tunami based on data from these mareograms.

**2. Determination of the Initial Mode and Time of Commencement.** The first step necessary in the present investigation is to determine from the mareograms the initial mode of the disturbances in the sea level due to the tunami. Owing to the following reasons, however, this is a matter of great difficulty.

i) Since the disturbances due to the tunami began at each station generally in the ascending phase of the tide curve, even when the initial mode was actually a downward movement, it is difficult to say from the configuration of the curve in the mareogram whether the initial downward movement had not been preceded by a small upward movement.

ii) The curves in the mareograms are usually superposed by small disturbances, which may be regarded as being due to secondary undulations excited in the bays along the coast where the mareographs are situated. These small disturbances are generally so irregular that

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[1] This volume of the Bulletin, Part II, p. 7.

they obscure the distinct initial mode of the tunami.

An example of a doubtful beginning of the trace of the tunami on the mareogram,[2] obscured by the above mentioned disturbances, is shown in Fig. 1, which is from the mareogram of Kusiro.

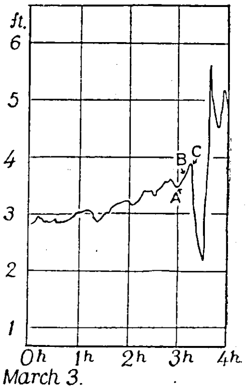

Fig. 1. Mareogram of Kusiro.

In this figure, we notice three points, A, B, and C, from any one of which the tunami might have actually begun. Firstly, we may regard point A as the initial trace of the tunami. The time of commencement then should be $3^h00^m$ a.m.; the initial mode of the movement of the sea level being upward. This assumption would not be correct however if the upward movement next to point A were regarded as the continuation of the undulations that preceded the same point, and which may be due to the seiches that were activated in the bay of Kusiro prior to the arrival of the tunami. Secondly, since point B appears to be a point of inflexion, it may be regarded as the initial trace, the configuration of which might have been produced by the superposition of the upward movement of the tunami on the undulations of the seiches. If this point be taken as the actual initial trace, the time of beginning would be $3^h10^m$, that is, 10 minutes later than the preceding case. But since the configuration of the actual curve is not conspicuous enough to enable us to accept the said point as the true point of inflexion, the assumption is not necessarily accepted as being correct.

Thirdly, since the conspicuous downward movement began at this point B, point C may also be regareded as the initial trace of the tunami. The assumption would probably be correct, if neither A nor B, the above mentioned points in the curve, were the actual initial trace. The time of beginning would then be $3^h14^m$, that is 14 minutes later than that of the first assumption.

The three above-mentioned alternatives with respect to taking the initial trace of the tunami on the mareograms of Kusiro are based on the assumption that the waves were not dispersed during the course of their propagation. If, however, the waves were dispersed, two different

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2) Hereinafter, the beginning of the tunami as traced on the mareogram will be called the "initial trace" for short.

traces of different waves should be noticed according to differences in the velocities of propagation. Accordingly two of the above mentioned traces in the curve may be accepted as being due to these waves having different velocities, that is to say, the one is the trace of the disturbance propagated with wave velocity and the other of that propagated with group velocity. It is, however, very difficult to ascertain from the mareograms of those stations that are situated near the centre of the tunami, which one of the three traces corresponds to the disturbance propagated with wave velocity and which with group velocity. The disturbances that were propagated with different velocities can be singled out in the mareograms of American stations through differences in the configurations of the curves, that is, the undulations in the curves are generally superposed with disturbances of shorter periods that occurred several hours after the tunami was first felt at the stations. As for these different velocities of the tunami waves, owing to scantiness of data, it will not be discussed in the present paper.

Another example of doubtful initial traces of tunami is shown in Fig. 2, reproduced from the Hakodate mareogram.

In this curve, we notice two points, A and B, eithr one of which may be the actual initial trace of the tunami. Moreover, at point A, we notice two traces of the waves begining with an upward movement. If these oscillations are disregarded, the general movement of the sea level is downward from A to B, where the upward movement began abruptly with considerable amplitude. If we regard the general downward movement from A to B as the initial mode of the tunami disturbance, the time of beginning would be $3^h 49^m$, whereas by regarding point B as the initial trace, it would be $4^h 00^m$, the initial mode being upward. It is, however, difficult to say which trace is the most likely one showing the actual initial mode of the tunami.

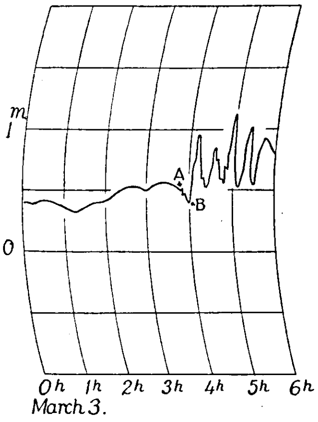

Fig. 2. Mareogram of Hakodate.

Besides those already mentioned, there are several other sources of error in determining the time of commencement of the tunami, which may be due to

i) Lack of uniformity in the velocity of the drum carrying the recording paper.

ii) Lags and leads in the time marks on the mareograms.

iii) Errors in reading the times of the initial traces of the tunami on the mareograms.

Of these, the errors due to wrong time marks could be reduced considerably if the disturbances due to the elastic waves of the earthquakes were recorded as in the mareograms of Yokosuka and Yokohama, the time of commencement of earthquake waves does not differ by more than a minute for different stations. The errors from other sources, however, amount to five or more minutes. It may, therefore, be expected that the time of commencement determined by direct readings from mareograms may involve average errors of about five minutes.

The modes of initial motions of the sea level, the time of commencement and travel time, together with the approximate period of initial oscillations due to the tunami, have been estimated for the various stations, the results being given in Table I. It should be noted that in the Table, the time for Honolulu is referrd to the local time of meridian 157° $30'W$, the time for San Francisco and Santa Monica to that of meridian $120°W$, the time for Iquique to that of the meridian $60°W$, while those for the Japanese stations are referred to the local time of meridian $135°E$.

**3. Determination of the Origin of the Tunami.** In order to determine the position of the origin of the tunami from the data of travel times from the mareograph stations of Kusiro, Muroran, Hakodate, Tukihama, Tyôsi, and Hutami (in Ogasawara)[3], the following procedure was employed.

Assuming the velocity of wave propagation to be

$$v=\sqrt{gh}, \tag{1}$$

as usual, where $h$ is the depth and $g$ the acceleration due to gravity, we have

$$t=\int_0^s ds/v=\int_0^s ds/\sqrt{gh}, \tag{2}$$

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[3] The data for the travel time for Tyôsi and Hutami are from the report published by Sekiguti and Nakano, Central Meteorological Observatory.

R. SEKIGUTI and M. NAKANO, *Kensinzihô*, **7** (1933), 71, (in Japanese).

Table I.

| Station | Time of commencement | Sense of first motion | Approx. period of first motion | Travel time |
|---|---|---|---|---|
| | March III | | | |
| Nemuro | $3^h$ $33^m$ | down | $20^m$ | $63^m$ |
| Kusiro | „ 14 | „ | 28 | 44 |
| Muroran | „ 55 | „ | 20 | 85 |
| Hakodate | „ 48 | „ | 22 | 78 |
| Hatinohe | „ 08 | up | 17 | 38 |
| Kesennuma | „ 39 | „ | 9 | 69 |
| Tukihama (Oppa Wan) | „ 24 | „ | 10 | 54 |
| Isinomaki | „ 41 | „ | 16 | 71 |
| Hanabuti-zaki (Siogama) | „ 32 | „ | ? | 62 |
| Siogama | „ 46 | „ | 32 | 76 |
| Nakagawa | „ 04 | ? | 14 | 34 |
| Aburatubo | „ 39 | ? | 15 | 69 |
| Yokosuka | „ 57 | down? | 51 | 87 |
| Yokohama | $4^h$ 29 | „ | 54 | 119 |
| Tôkyô | | | 70 | |
| Simidu | 3 55 | | 72 | 85 |
| Hosozima | 4 55 | ? | 10—31 | 145 |
| Honto (Karahuto) | 6 30 | ? | 20 | 240 |
| | March II | | | |
| Honolulu | $14^h$ $32^m$ | Down | 26 | $7^h$ $32^m$ |
| San Francisco | 19 52 | ? | 17 | 10 22 |
| Santa Monica | 20 26 | ? | 17 | 10 56 |
| | March III | | | |
| Iquique | $11^h$ $30^m$ | ? | ? | 22 00 |

for time $t$ required to travel distance $s$, and

$$s=\int_0^t v dt=\int_0^t \sqrt{gh}\, dt, \qquad (3)$$

for distances over which the waves are to be propagated during time interval $t$.

Then, taking each station as an imaginary source of the waves whence the waves are propagated with velocity $\sqrt{gh}$, we obtain a curve representing the imaginary wave front for each station at any time.

The curve for the wave front after a certain time interval and equal to the observed travel time for each station is thus obtained, as shown by the dotted lines in Fig. 3. If the wave front of the actual tunami were coincident with the envelope of these curves of imaginary wave fronts at the time when the earthquake began at its origin, the disturbance from the origin of the tunami should have reached the mareograph stations at the observed time of commencement within the range of possible errors. On the other hand, these curves of imaginary wave fronts should meet approximately at a point, provided the tunami had propagated from a point source, whereas the curves, as shown in the figure do not actually meet at a point. The area enclosed by the envelope of the curves of imaginary wave fronts is some 600 km. in linear dimensions, as shown by the shaded area in Fig. 3.

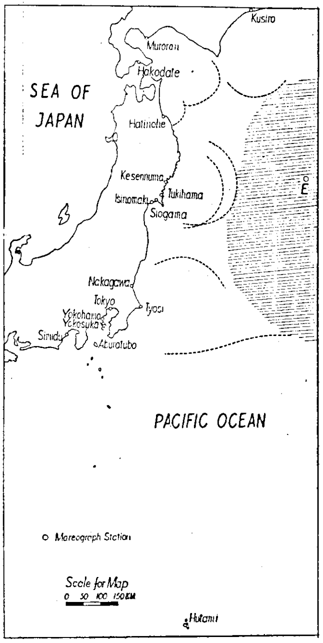

Fig. 3. Origin of the tunami.

On the other hand, we have $T=30$ minutes for the approximate period of the initial oscillations of the tunami at several stations. Assuming the period to be 30 minutes and the velocity of propagation to be 245 metres per second, that is, the velocity at the surface of the ocean with a depth of 6000 metres, we have for the wave length

$$L=vT \fallingdotseq 441 \text{ km.},$$

which is nearly the same as the linear dimensions of the area of the source of the tunami.

Before entering upon a discussions of the result obtained above, we have to determine a point that corresponds to the hypothetical source of the tunami from the intersection of the curves representing the imaginary wave fronts corresponding to several tens of minutes of time before the occurrence of the earthquake. The curves for this time meet approximately at a point. The point corresponding to the hypothetical source of the tunami was thus determined to be $\lambda=146°E$ $\varphi=39°N$, denoted by $E$ in Fig. 3.

If the tunami had actually propagated from the point source determined above with velocity $\sqrt{gh}$, then the times of commencement at the mareograph stations may differ considerably from those observed. The time required for the wave to travel distance $s$ from $E$ to each mareograph station along paths orthogonal to the curves of the imaginary wave fronts, can be calculated by using formula (2). The differences between the travel times and the observed times, $(t'-t)$ thus calculated, are shown in Table II.

Table II. Actual and Calculated Travel Times.

| Station | $t$, acutual travel time | $t'=\int ds/\sqrt{gh}$, calculated travel time | $t'-t$ |
|---|---|---|---|
| Kusiro | $44^{m}$ | $60^{m}$ | $16^{m}$ |
| Muroran | 85 | 102 | 17 |
| Hakodate | 78 | 102 | 24 |
| Hatinohe | 38 | 89 | 51 |
| Kesennuma | 69 | 78 | 9 |
| Tukihama | 54 | 70 | 16 |
| Isinomaki | 71 | 105 | 34 |
| Tyôsi | 51 | 104 | 53 |

In Table II, it will be noticed, as may be expected, that the diffenences $(t'-t)$ are generally greater than 10 minutes; those for several stations exceeding 30 minutes, even when the marks are taken for the initial marks of the tunami for the porpose of making the travel time as large as possible. Such differences are greater than those which may be expected to be due to errors in determining the initial trace in the mareograms. We have consequently to fall back on one of two possible explanations regarding the origin of the tunami. One is that the area of the source of the tunami is about 600 km. in linear dimensions, as illustrated in Fig. 3, while the other is that the waves of the tunami might have started from point source $E$ some 20–30 minutes before the earthquake occurred. Even were both of the above explanations correct, we have no information, in the state of our present knowledge as to what happened within the area of the source of the tunami, corresponding to that covered by a wave length.

Mr. Noguti[4] has pointed out that the calculated travel times for stations in Miyagi prefecture agree fairly well with those observed, the

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[4] K. NOGUTI, *Kensinzihô*, 7 (1933), 81, (in Japanese).

assumption being of course that the centre of the tunami coincides with the epicentre of the earthquake, that is, 144° *E* 39°*N*. This result, however, does not contradict the present conclusion, that the center of the tunami is of the order of some 600 km. seeing that the nearest point to the stations in Miyagi prefecture on the boundary of the central area of the tunami approximately coincides with the epicentre of the earthquake.

**4. Velocity of Propagation.** The velocity of propagation of the tunami, usually assumed to be $v=\sqrt{gh}$, approximately, should be corrected when certain physical conditions of the waters and the boundary surfaces have to be taken into consideration. These corrections may lead to modifications in the explanations of the discordances in the calculated travel times with those observed, and consequently also that regarding the origin of the tunami, referred to in the preceding paragraph.

The correction for the propagational velocity of the tunami, taking into account the curvature of the earth's surface, as first pointed out by Prof. H. Nagaoka takes the form[5)]

$$v=\left\{1-\frac{3}{(2n+1)\rho}\right\}^{\frac{1}{2}}\sqrt{gh}.$$

In practice, however, the correction term, $\frac{3}{(2n+1)\rho}$, may be very small, even when the wave length is of the order of 1000 km., so that the effect of the curvature may be disregarded.

Prof. T. Terada[6)] has discussed the effect of deformation of the ocean bed caused by difference in hydrostatic pressure due to difference in the load of the water that occur between the elevated and the depressed parts of the water waves. He deduced, as an extreme case, that $kh$ is small and $hk'$ is large, so that $\coth kh=1/kh$ and $\coth kh'=1$, the expressions for wave velocity $c$ and group velocity $U$, as

$$c=\left(1-\frac{1}{p'+r}\right)^{\frac{1}{2}}\sqrt{gh},$$

and
$$U=c-L\frac{dc}{dL}=\sqrt{1-\frac{1}{\rho'+r}}\left(1+\frac{2r}{(\rho'+r-1)(p'+r)}\right)\sqrt{gh},$$

respectively, and, as another extreme case that the thickness of the

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5) H. Nagaoka, *Proc. Tokyo Phys. Math. Soc.*, [ii], 4 (1907), 113.

6) T. Terada, *idid.*, [ii], 6 (1912), 260.

magma layer under the crust is finite and small compared with the wave length,

$$c=\sqrt{(1-\varepsilon)gh}\,,$$

$$U=c\left(1+\frac{2\varepsilon}{1-\varepsilon}\cdot\frac{r}{\sqrt{r^2+4\rho'}}\right),$$

where

$$\varepsilon=\frac{1}{2\rho'}\left\{(r^2+4\rho')^{\frac{1}{2}}-r\right\},$$

$$r=\frac{\kappa^4 E D^3}{12(1-\sigma^2)g},$$

$$\kappa=\frac{2\pi}{L},$$

$$\left.\begin{array}{l} E=\text{Young's modulus} \\ \sigma=\text{Poisson's ratio} \\ D=\text{Thickness} \end{array}\right\}\text{of the bed plate,}$$

$$\left.\begin{array}{l} \rho'=\text{Density} \\ h'=\text{Depth} \end{array}\right\}\text{of lower layer.}$$

The velocity of wave propagation may be retarded or advanced by 30% at most, in the last extreme case. Even upon using the velocity of this extreme case, the calculated travel time for Japanese stations do not agree with those observed, whereas the same velocity when used in connection with date from Honolulu, San Francisco, and Santa Monica, gave fairly successful results. Assuming the uniform depth of the Pacific Ocean to be 5000 metres, the travel time along the paths shown in Fig. 4 is calculated by formula (3) in which case distance $s$, measured in km.,

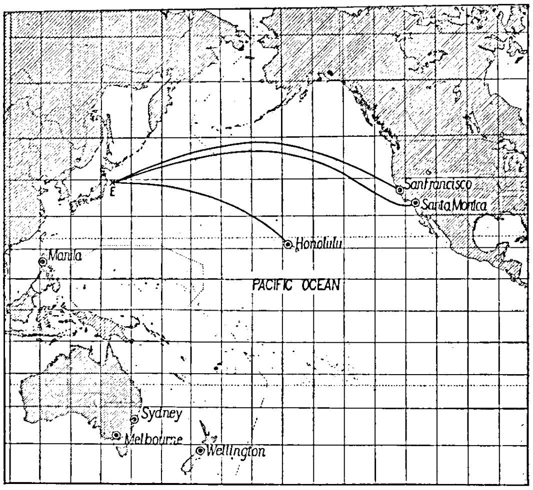

Fig. 4. Path of the tunami waves in the Pacific Ocean.

is 111 times the angular distance $\varDelta$ in degrees, calculated from the lonigtudes $\lambda$, $\lambda_E$ and the latitudes $\varphi$, $\varphi_E$ of the stations and the centre of the tunami by using formula

$$\cos\varDelta = \cos\varphi\cos\varphi_E\cos(\lambda_E-\lambda)+\sin\varphi\sin\varphi_E.$$

The ratios of the calculated travel times for the foreign stations to those observed are shown in Table III, in which we notice that the observed travel times are nearly 5–9% greater than those calculated.

Table III.

| Station | $t_{cal}$ | $t_{obs.}$ | $t_{cal}/t_{obs.}=\frac{\sqrt{gh}.}{v}$ | $\varDelta$ |
|---|---|---|---|---|
| Honolulu | $7^h\ 8{\cdot}2^m$ | $7^h\ 32^m$ | 0·947 | 50·8° |
| San Francisco | 9 30 | 10 22 | 0·913 | 67·3° |
| Santa Monica | 10 10·9 | 10 56 | 0·936 | 73·0° |
| mean | | | 0·932 | |

This discrepancy may be corrected, if we assume $v$ (the velocity of propagation) $=1{\cdot}1\sqrt{gh}$, which agrees with the latter extreme case treated by Prof. Terada, then $r$ approximately equals 1·0.

On the other hand, the calculated travel times to San Francisco and Santa Monica, assuming velocity to be $\sqrt{gh}$, agree well with the observed ones, if we assume the uniform depth of the Pacific Ocean to be 4000 metres, ignoring deformation of the ocean bed. But it cannot be decided at present whether the determination of travel time with the assumption of velocity for a uniform depth of 4000 metres is nearer reality than determinations with corrections for deformations of the ocean bed.

Several other assumptions may be made in connection with the proper corrections for the values of the velocity of propagation in order that they shall harmonize with the observed travel time; for instance, the superposition of an ordinary current of considerable velocity, taking into account the deformation of wave fronts due to coriolis forces, etc.,[7]

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[7] Regarding the propagational velocity of the tunami associated with the Krakatoa eruption of 1883, Verbeek gave as the velocity of the waves, $v=\sqrt{\frac{g}{2h}(h+\varepsilon)(2h+\varepsilon)}$, where $\varepsilon$ is the amplitude. Although this is applicable to waves propagated in shallow seas, it is not satisfactory with data from the Japanese stations for the Sanriku tunami, in which the waves are assumed to have been propagated from a point source. c.f. Captain Wharton's Report of the Krakatoa Eruption of 1883.

but neither of them give satisfactory results for the velocity of the waves that are propagated to the Japanese stations, whereas they are satisfactory for waves recorded at the American stations, which are at greater distances from the centre of the tunami.[8] It may, therefore, be better at present to presume, as stated in the preceding paragraph, either that the area of the origin of the tunami was of considerable extent or that the tunami had started from the origin several tens of minutes in advance of the earthquake that occurred.

**5. Period and Amplitude.** In discussing the question of the period and the amplitude of the tunami, it may be said that, if the secondary undulation was excited in the bays by disturbance due to the tunami, the curves in the mareograms showing the undulations of the tunami should have been more or less deformed, especially when the period of the waves approximated the normal oscillation of the waters of the bay. Examples in which the usual oscillations of the bays were fairly well excited are shown in the mareograms of Kusimoto,[9] Aburatubo, etc.

The ratios of $T$ to $T_0$, the period of normal oscillations of the bay, for several bays[10] are shown in Table IV.

It may be suggested from a study of this Table that the large amplitude of the tunami at Hutami,[11] Ogasawara, may partly be due to amplification by resonance. The amplification factor for the amplitude of the tunami may be such a function of $T/T_0$ as will become very large when the ratio $T/T_0$ is very near unity.

Table IV.

| Station | $T_0$ | $T/T_0$ |
|---|---|---|
| Nemuro | $11^m$ | 1·9 |
| Kusiro | 22 | 1·2 |
| Muroran | 53 | 0·4 |
| Hakodate | 52 | 0·5 |
| Kesennuma | 60 | 0·2 |
| Tukihama | 24 | 1·2 |
| Ayukawa | 8 | 1·6 |
| Nakagawa | 6 | 2.8 |
| Simidu | 21 | 3·4 |
| Kusimoto | 18 | 1·2 |
| Hosozima | 19 | 0·5, 1·6 |
| Hutami | 18 | 0·9—1·0 |

Notwithstanding the foregoing considerations, it

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[8] For travel times for distant stations, the velocity of the waves alone may be a matter for consideration; the areal dimensions of the source of the tunami are negligible.

9), 11) c. f. R. Sekiguti and M. Nakano, *Kensinnzihô*, *loc. cit.*

[10] The data of $T_0$ are due to K. Honda, T. Terada, Y. Yosida and D. Isitani, *Publ. Imp. Earthq. Invest. Comm.*, 6 (1908); and S. Yamaguti, *this Bulletin*.

seems a remarkable fact that in the mareograms of stations west of the Bôsô peninsula, waves with shorter periods than 30 minutes are scarcely recorded, while the amplitudes are conspicuously small compared with those in the mareograms of northern stations. The relation between amplitude and distance are plotted in Fig. 5, in which we notice as expected from the fact referred to above, though not very apparently, different logarithmic relations for groups of waves of different periods.

The waves with shorter periods in the above diagram are those recorded in the northern stations. This fact may perhaps show the effect of the presence of the islands of the Idu and the Ogasawara group, extended in chains southward from Osima, near the southern end of the Idu peninsula, to Iwozima, which might have interfered with the progression of waves of shorter periods.

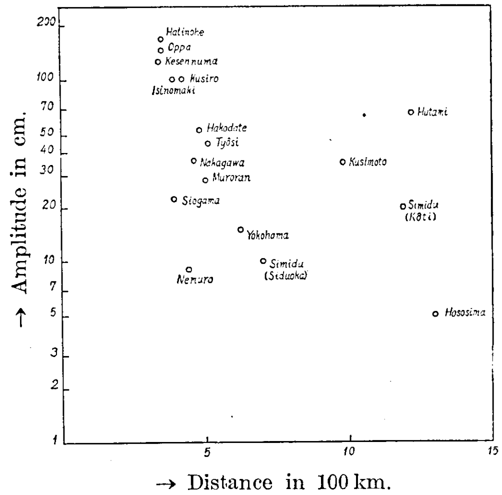

Fig. 5. Amplitude—Distance relation of the tunami waves.

According to information received from Wellington (New Zealand) and Manila (P. I.) the disturbances due to the Sanriku tunami were not recorded there, which fact may be due to the disturbing effects of the islands of the South Pacific, that is, Micronesia and Polynesia, in the same way as that mentioned in the preceding paragraph.

On the other hand, the tunami was recorded at Iquique, Chili, evidently with considerable amplitude, though that station is much farther from the origin of the tunami than either Wellington or Manila. The path of the waves to this station, however, is open and free from such obstacles as islands and shallow seas which may interfere with the passage of the waves.

In the mareogram of Fort Denison, Sydney, the disturbances from the tunami, if any, is either obscured or failed to be recorded at the time when the tunami should have appeared, theoretically, whereas at

2 a. m., March 5, 47 hours after the earthquake occurred at the origin, a train of waves is noticed. If these waves were in reality those of the Sanriku tunami, the following may be one of several possible explanations of the phenomenon; that is, ths waves of the tunami, which were reflcted from the curved coast line of America were focussed at Sydney, since Sydney and neighbourhood correspond to the focus of a reflector on the American coast. This explanation is due to G. E. P. Hart,[12] who has studied the tunamis associated with the Chilian earthquake of 1922 and the Wellington earthquakes of 1929 and 1931, etc.

In the mareograms of Japanese stations along the coast of the Sea of Japan, the disturbances due to the tunami have had no effect at all, excepting those recorded at Honto, on the western coast Karahuto, the mareogram of which is shown in Fig. As will be seen from the figure, the tunami may be noticed at Honto by its regular disturbances, though moderate in amplitude, with a period of about 20 minutes, having begun at 6.30 a. m., March 3.

**6. Summary and Conclusion.** In the present paper, I have pointed out the following facts regarding the Sanriku tunami, based on a study of mareograms.

i). It is very difficult to determine the initial trace and mode of the disturbances in the mareograms. The beginning of the tunami may be in error to the extent of some 5 minutes.

ii). The amounts of departure of the observed travel times from those calculated, on the assumption that the tunami was propagated from a point source, are considerable for Japanese stations situated near the origin of the tunami. For this, two possible explanations are postulated; one is that the centre of the tunami was of rather wide area, while the other is that the tunami had started from the source several tens of minutes before the occurrence of the earthquake. The former explanation finds support in the fact that the area of the source is of the same order of magnitude in linear dimensions as the wave length of the tunami.

iii). The propagational velocity of the tunami was corrected in several ways. The correction due to Prof. Terada is in good accord with data from the American stations, which deviate slightly from those expected by assuming the ordinary velocity of propagation, $v=\sqrt{gh}$, and the mean depth of the Pacific Ocean to be 5000 metres.

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12) G. E. P. HART, *Australian Surveyors*, 4 (1931), 192.

iv). Island and shollow seas seem to have disturbed the waves in their passage; the disturbing effects being greater for waves of shorter periods.

The results of the present investigations go to show that the phenomenon of tunami require considerable further study for their elucidation.

In conclusion, the writer wishes to express his sincere thanks to Professors Torahiko Terada and Misio Isimoto for their kind advices and suggestions. His cordial thanks are also due to Mr. H. Matuo, of the Doboku-Sikenzyo, to the Hydrographic Department of the Imperial Navy, the Military Land Survey, the Prefetural authorities of Hokkaidô, Aomori, Miyagi, and Ibaraki, the U. S. Coast and Geodetic Survey, the Sydney Harbour Trust, and all the other foregin stations, etc., who have kindly placed copies of mareograms and other information relative to the tunami at the writer's disposal.

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## 9. 験潮儀の記録による三陸津浪研究

地震研究所 宮部直巳

昭和8年(1933)3月3日，三陸沖に起つた地震は津浪を伴つたが，各地の験潮儀がその津浪を記録したので其等の記象を蒐集するとともに二三の津浪に關する問題を考究してみた.

是等の研究に先だつて，験潮記象の上から津浪の到達した時刻，最初の水面の動き方を讀みとらねばならないが. 茲に，困難な問題がある. 第1に，この津浪の起つた時刻は大體何處の記象を見ても上げ潮の中途に相當するので，津浪による最初の水面の動きが下方であつたとしても，その前に緩徐な上昇波が來たかのやうにみえるのである. 加ふるに，第2に，多くの場合には各港灣の副振動が重つて表はれてゐるので，その爲めに，津浪による最初の水面の動きが，隱蔽されてしまふこともあるので到達時刻や，最初の波の形を比較的詳細に知らうとすることは，かなり困難な事になるのである. 更に，記象紙を卷く回轉ドラムの回轉速度の不均一や，時計の不正確や，記象から時刻を讀みとる時の誤差等があり，結局，津浪到達の時刻については 5 分程度の誤差を許容しなければならないと思はれる.

以上の如き困難を冒して得られた各地の験潮儀の資料から津浪の中心を定める爲に先づ津浪の傳播速度を $\sqrt{gh}$ とする. $t$ なる時間の間に津浪の傳播する距離は，從つて

$$s=\int_0^t vdt=\int_0^t \sqrt{gh}\cdot dt.$$

となる. そこで，各験潮儀の所在地を假に浪の中心としてこゝから上記の速度で四方に浪が播つてゆくとすれば，$t$ の種々なる値に對してそれに相當する wave front が畫ける. 第3圖に點線で示したものは，釧路，室蘭，函館，月濱，氣仙沼，銚子，二見（小笠原）の諸島のデータを用ひて畫い

た地震の發生した時刻に於けるwave frontである．故に，地震の發生した時の津浪のwave frontは點線で示した假のwave frontのenvelopeに一致してゐなければならない．卽ち，若し，地震と同時に津浪が起つたものとすれば津浪の中心は，縞蔭を施した部分で示されるやうな廣い面積を占めることになる．この部分の徑は約600 kmになる．そして，各驗潮儀の記錄の始めに現はれてゐるやうに津浪の週期が20分乃至30分であるとすれば，例へば30分の浪については，波長$L$は速度を深さ6000米の場所のものをとれば$L=vT=441$ kmとなり，大體に於いて，津浪の中心の面積に匹敵する．又津浪が地震の起る數十分前に旣に起つて地震の起つた時刻には丁度，上述第3圖の縞蔭の部分全體に擴つてゐたと考へても差支はない．何れにしてもこの1波長以內の出來事は，理論的に想像することは難しいのであるが，津浪の中心がこの程度の大いさを持つと考へても大した差支はないやうに思はれる．

津浪の傳播速度についても色々な補正方法が考へられるが，何れも，本邦の記錄にあらはれた著しい事實卽ち，その結果から想像される津浪の中心が大きな擴がりを有するであらうといふことを根本的に變改せねばならぬ程度の補正を求めることは困難である．布哇，加州等の北米諸港への傳播速度に關する補正も太平洋の深さの分布が明かでない以上は，補正が充分意味あるものであるか否かは斷定出來ない．

伊豆小笠原等の諸群島，南太平洋の諸群島や，淺海が，津浪の傳播を妨げるであらうとは，記錄の上から想像される．卽ち，東京灣內の諸港，淸水其他の本州の南岸の諸港に於ける驗潮儀の記錄には，20分乃至30分程度の波でも記錄されて居ないで，大體50分—60分程度の週期の波が主であり，その振幅も著しく小さい樣に思はれる．又．Manila, Wellington (New Zealand)からは津浪が現はれてゐないといふ報告があり．Sydneyの記錄には津浪の到達するであらうと期待される時刻には現はれて居らず．Melbourneでも同樣である．之に反して，Honolulu (Hawai), San Francisco, Santa Monicaはもとより，南米ChiliのIquique港に於いても尙相當の振幅を持つて記錄されてゐる．Iquiqueの記錄では全振幅20-30 cmに及んでゐる．是等の事實は前述の如く，群島や淺海の作用と思はれるのである．