Reports on Chile Tsunami, May 24, 1960

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Preface

High waves caused by sumbarine earthquakes often cross wide oceans, and attack the coasts very far from the epicenters. There, the heights and the strength of the waves are modified in accordance with the size and the shapes of the coasts, often causing disastrous destructions. Such waves are called *Tsunami* in this country, and we have many records of disasters of *Tsunami*. The Pacific coast of Tohoku district with its numerous embayments is one of those coasts which are susceptible to the repeated attacks of *Tsunami*. There, houses and often whole villages were washed away accompanied with the loss of many lives. Records are numerous in which such destructions caused entire removals of settlements towards inland and higher localities. When the time passes and the memories get faded in people's mind, however, the people are again attracted by the wealth of coasts, and come back to the life on the coast, to be persecuted by the next disaster. Thus, the *Tsunami* is not only a geophysical phenomenon, but also an agent of geographical importance in various parts of the world.

On May 24, 1960, a *Tsunami* of rather minor scale caused by a submarine earthquake off the coast of Chile, attacked Sanriku, the Pacific coast of Northern Tohoku. Within the same day, we organized and dispatched three teams of the field survey to investigate the damages caused by the Tsunami which was named "Chile Tsunami", while the destructions were still fresh. The teams covered the entire coast suffered from the disaster, and collected information keeping good cooperation with other parties organized by the Institutes of Geology and Geophysics of The Tohoku University. The following are the reports of th teams dispatched by the Institute of Geography.

Toshio Noh

I. Arrival Time of Chile Tsunami

The Tsunami,[1] caused by the severe earthquake which occurred off the coast of central Chile (38° S, 73.5° W) at $4^h\,11^m$, May 23, 1960, traveled about 16900 km on the Pacific Ocean and reached the northeast coast of Japan after 22^h40^m–23^h00^m. In the past, the northeast coast of the Tohoku district, so called the Sanriku coast, suffered often from the damages by the Tsunami, and in such cases the people of this district could usually feel the earthquakes before the appearence of the Tsunami, because most of the earthquakes occurred in the adjacent seas. But this time, they could not feel the earthquake before the appearence of the Chile Tsunami. Furthermore, the physical character of the Chile Tsunami and the distribution of damage differed from those by the adjacent earthquakes.

Fig. 2 shows the distribution of the arrival time of the first wave of the

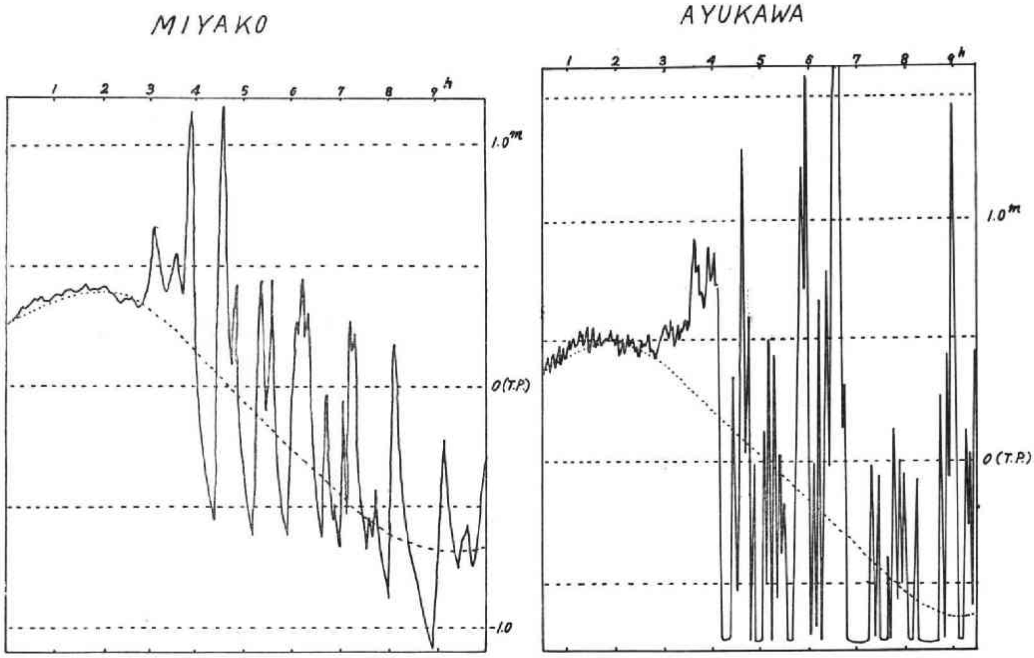

Fig. 1 Marigrams at May 24th, 1960.

Tsunami, based on the marigrams. (Fig. 1). The arrival time is the time when the wave height begins to change greatly from the normal curve of the changes of the tidal level. The first wave on the Sanriku coast appeared as the form of the up-wave. The earliest was 2^h37^m at Eno-shima and the latest was 3^h22^m at Shiogama. The time was earlier on the coast facing the ocean and at the island, and was later at the bay head. The amplitudes of the first waves were within the range of about 46–99 cm.

The appearence time of the maximam amplitudes of the Tsunami was 3^h55^m at Kuji which was the earliest and 7^h00^m at Eno-shima, the latest. The maximum amplitudes were within the range of about 3–6 m and the largest was 5.95 m at Kuji. The periods were 58–100 min. and were fairly longer than those of the major

1) The word Tsunami, a combination of the Japanese word tsu meaning a port and nami a long wave (hence 'long-wave-in-harbour'), is defined as a seismic sea-wave.

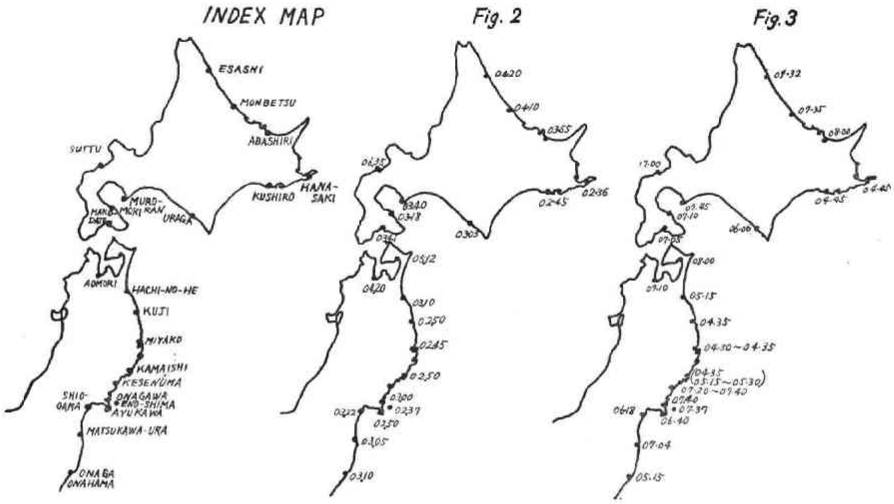

Fig. 2 Arrival Time of First Wave of Chile Tsunami
Fig. 3 Appearance Time of Highest Wave of Chile Tsunami

Tsunami attached the Sanriku coast in the past.

However, the waves more directly related with the damage are usually not the maximum-amplitude-waves, but the highest waves, the waves which brought about the highest water level. On the appearence time of the highest waves in the case of Chile Tsunami[2], the earliest time was 4^h30–35^m at Miyako, Kamaishi and Kuji, and the latest time was 7^h00–40^m at Kesen-numa and Eno-shima. (Fig. 3) The time difference was about 3 hours. As the time difference of tide in the Sanriku coast was only about 25 minutes, such factors as the Seiches in a bay etc. seem to have produced the striking difference of the appearence time of the maximum-amplitude-wave and the highest wave.

The relation between the time of tide and the appearence time of highest waves will be considered. At May 24th, the time of high tide was 2^h00^m at Miyako and the time of low tide 9^h13^m. Therefore, the appearence time of the highest waves was about at the mid-time between the high and low tides. If the highest wave appears at the time of the high tide, the height of the highest wave will increased by 20cm at Miyako and 75 cm at Ayukawa. If the wave comes at the time of the low tide, the height will be reduced by 80 cm and 40 cm respectively. Next, as the high atmospheric pressure spread over the district on that day, the tide level was about 15 cm lower than the normal level.

According to the people of the Sanriku coast who suffered from the Tsunami-

2) The data were collected from the marigrams and the hearing in the field.

damage, in the cases of the Tsunami casused by the adjacent earthquakes such as those in 1896 and 1933, high waves which looked like a wall dashed against the coast, but the Chile Tsunami beat upon the shore as if the tide rose quickly. Especially, as described in the next chapter, the maximum-wave heights of the Chile Tsunami at the bay heads of the long embayment rose 2 or 3 times higher than those at the bay mouths and also at the bay heads of more open bays, almost contrary to the conditions in 1933. These are the outstanding features of the Chile Tsunami and the difference seems to be caused by the longer wave-length and the longer principal period (40–100 min.). The principal periods of the Tsunami in 1896 and 1933 were abuot 15 min. Hideo Fukui

II Maps of Maximum Inundation Heights during the Chile Tsunami

The earthquake, which occurred in the vicinity of Chile on May 23th, 1960, gave rise to the Chile Tsunami which struck the Pacific Coast of Japan on May 24th. The writer in this paper does not intend to discuss any specialized problem of the Chile Tsunami but only to present maps which represent the areal distribution of maximum inundation heights (MIH) caused by the Tsunami. These maps contribute to the information collected by the five members of Inst. Geogr., Tohoku Univ., T. Noh, H. Fukui, Y. Watanabe, N. Hasegawa, and K. Fujiwara, who surveyed various aspects of the Chile Tsunami along the Sanriku Rias coast about one week after its appearance.

Fig. 4 shows the distribution of MIH along the entire Pacific coast of Japan. Fig. 4 is derived from the "provisional report on Chile Tsunami, May 24th, 1960".

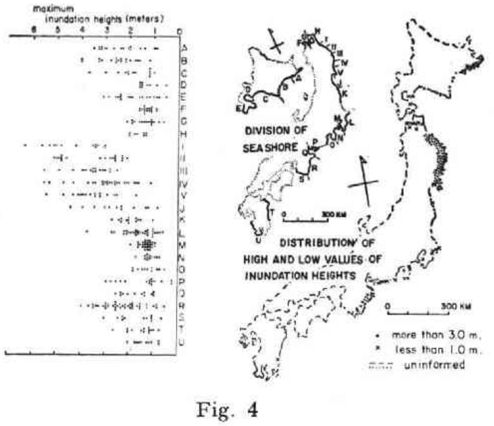

Fig. 4

published by Investigation Parties of the Chile Tsunami in Japan. This research organization authorized both local detailed surveys and extensive surveys which covered major portions of the Pacific coast of Japan with the result that a wealth of data exists. Therefore, the writer sampled the values recorded in the extensive surveys by means of the "every 3rd or fifth surveyed point sustem" according to their distribution along the shore line. That is, Division A–E; Fac. Sci. and Techn., Tohoku Univ., and Division F–U; Fac, Sci. and Res. Inst. Earthq., Tokyo Univ., Met. Res. Inst., Tokyo, Fac. Sci. Nagoya Univ., and Fac. Sci. Kyushu Univ. The values are adjusted to T.P. (averaged tidal level of Tokyo Bay) through the comparison of tidal level tabulates and the chronical data of the survey. In the figure, values of 1.0–3.0 meter are common in whole Pacific Coast, but generally high values in the following three districts are notable, (1) Rias type coast of Sanriku (I–IV), (2) Southeastern shore line of Hokkaido (A–C) and (3) Southeastern coast of Kii Peninsula (R). In the Sanriku coast, any division scarcely represents the values less than 2.0 m, though the range of deviation within a division is uaually greater than 4.0 m. On the other hand, values more than 4.0 m are seldom seen in the latter two districts and values over 2.0 m are rather rare on other parts of the Pacific Coast except the above three districts.

Sanriku district is famous for frequent local Tsunami which originate from frequent earthquakes in its vicinity, and the rias type topography usually increases the effects of Tsunami phenomena. However, despite the fact that the Chile Tsunami was recoredd in a far wider area than local Tsunami as is shown in Fig. 1., the Chile Tsunami also shows peculiarly high values in Sanriku. It is unclear whether it is accidental or a matter of consequence. It might be a result of a local beam of Tsunami energy affected by the shape of the continental shelf or there may be other explanations. On the other hand, local topography of rias coast surely enlarges the maximum value of inundation heights as is the case in the southeastern half of the Kii Peninsula.

The values of the Chile Tsunami in Sanriku district are more precisely shown in Fig. 5. These values were established mainly from material evidence of the Tsunami (mud, seaplants, debris etc.) by the members of Inst. Geogr,. Tohoku Univ. The values are adjusted to T.P. values in the same manner as Fig. 1, except those of surveyed points 46–91 where the standard level was assumed from remnants signifying the normal high tide level. The broken line represents inundation heights of the Tsunami of March 3, 1933, the last and one of the largest local Tsunami in recent times.

The following are evident. (1) Values show a range of from 1.0 to 6.5m, but most of them range from 2.0 to 4.0 m. Particularly high values of over 4.0m appear

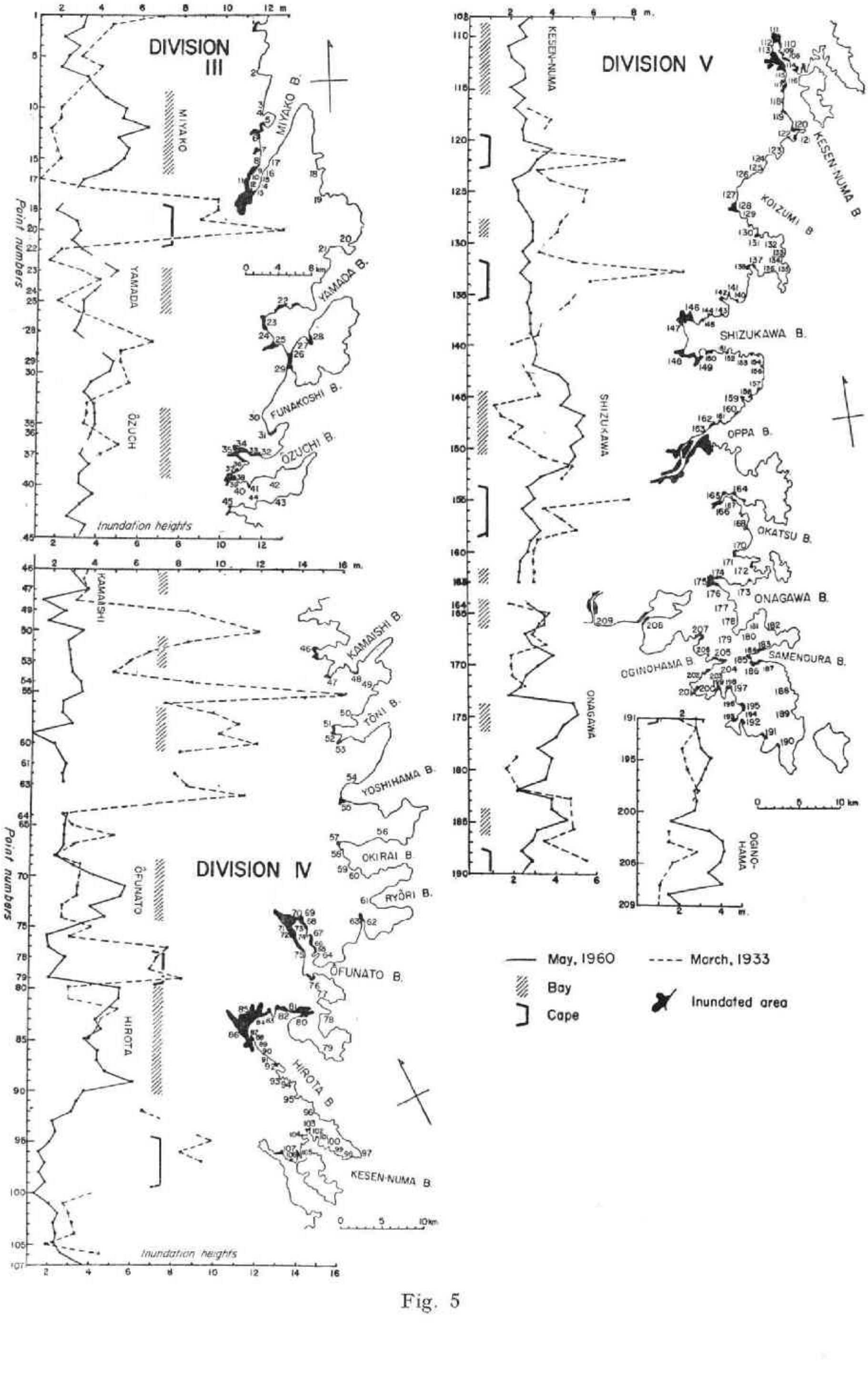
DIVISION III
DIVISION IV
DIVISION V
Point numbers
Inundation heights
MIYAKO
YAMADA
ŌZUCH
KAMAISHI
ŌFUNATO
HIROTA
KESEN-NUMA
SHIZUKAWA
ONAGAWA
OGINO-HAMA
MIYAKO B.
YAMADA B.
FUNAKOSHI B.
OZUCHI B.
KAMAISHI B.
TŌNI B.
YOSHIHAMA B.
OKIRAI B.
RYŌRI B.
ŌFUNATO B.
HIROTA B.
KESEN-NUMA B.
KOIZUMI B.
SHIZUKAWA B.
OPPA B.
OKATSU B.
ONAGAWA B.
OGINOHAMA B.
SAMENOURA B.
May, 1960
March, 1933
Bay
Cape
Inundated area

Fig. 5

concentrated in the following areas (i) The bays of Miyako, Yamada and Ozuchi in the northern area, (ii) Ofunato and Hirota Bay in the middle area and (iii) the two independent bays of Shizukawa and Onagawa in south. The tendency for high and low values to alternate in thier areal distribution is somewhat similar to that found along the whole Pacific Coast. (2) The range of variation is far smaller than the range in the local Tsunami in 1933. (2) In most of the bays, the inundation heights of the Chile Tsunami are high at the bay heads and low at the capse. This is in marked contrast to the characteristics of the 1933 Tsunami. Values resulting from the local Tsunami of 1933 usually exceed the values of the Chile Tsunami and often especially high values over 10 m were recorded at cape locations. The values in Chile Tsunami rarely reach such peculiarly high levels, but in many case they exceed the values of 1933 at the bay heads. (4) On the west (inside) coast of Ojika peninsula, the Tsunami in 1933 showed relatively low MIH as compared to the cocean side, but values for the Chile Tsunami are not lower proportionaly to those of the other areas. Characteristics (1) and (3) are closely related to Tsunami damage. Coastal villages in Sanriku usually have constructed artificial banks along the shore. Such walls are planned for the purpose of protection from stormy high tides. Many of these are constructed to reach about 2.0 m above the normal sea level. Therefore the critical MIH level in terms of property destruction and loss of human life is the amount of excess over 2.0 m. On the other hand, a high MIH elevation at a bay head means the concentration of Tsunami energy at a place where human settlements are large and densely distributed. Further, such settlements occupy the low land of beaches, deltas, and others as compared to the usual occupation of high marine terraces at a cape area.

Fig. 6 illustrates examples of the effects of local topography. Hirota and Shizukawa typically show high MIH elecations at bay heads. This type occures most typically in large, deep bays especially when these bays have a rectangular shape as is shown in these two example. On the other hand, the relation of the

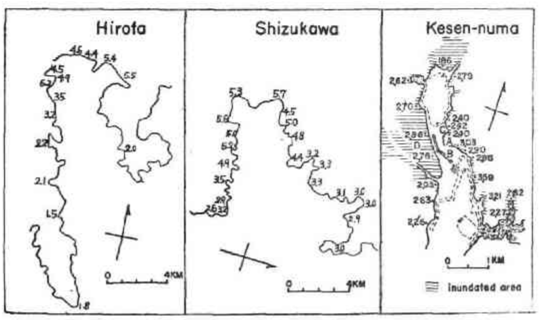

Fig. 6

direction of a bay's long axis to high MIH levels is unclear. Many small bays, especially narrow ones, do not represent such a tendency clearly. They often exhibited their highest values at points midway between the bay mouth and head. An example of this case is illustrated by Kesen-numa bay, and the distribution of MIH in this bay exhibits also some effects of more local topography. It shows followings. (1) MIH reaches its highest values where the marine channel streching northward along the east coast of the bay disappeares and the depth of the water abruptly becomes shallow. (2) the Tsunami turned its attack front from north to west at small cape A. This is proved by the fact that the inlet bank B fell to the westward. Further the shift in the Tsunami current might be a cause of the new deposition of sand in C which was ascertained by the survey of Hydrog. Div., Marit. Safety Bood. As a result of this turning, MIH in the east coast are highest at the southern part of C cape and decrease at the northern protected portion of the cape. Further, MIH on the west shore were greatly elevated at a point just west of C cape and resulted in the largest inundation on the delta area of D. (3) To the north of C cape, MIH decrease toward the bay head until they were only 1.0 m when they passed the shallow bay of less than 10 m in depth. These aspects, which were observed at Kesen-numa Bay, are found partly in the other bays, and suggest that MIH in long narrow bays is affected by the influence of local topography on the flowing water mass. Yoshio Watanabe

III Damage on Sanriku Coast, caused By The Chile Tsunami

1. Characteristics of the Tsunami in the coast of Sanriku district

A Tsunami caused by an earthquake that broke out off the coast of Chile on May 23th, 1960, far beyond the Pacific Ocean, attacked the east coasts of Japanese Islands in the early morning of May 24th. No earthquake shocks preceded the Tsunami. The east coast of northeastern Japan (Sanriku district) has suffered the biggest damage from it. The coast of Sanriku district has been known as an area frequently attacked by Tsunami, and has undergone several severe destructions, such as those in 1896 and 1933.

According to the sites of epicentra of earthquakes that caused the Tsunami, the past Tsunami along the Sanriku coast may be classified into four groups.

1) Tsunami due to Sanriku earthquakes, which is sub-classified to A) the earthquakes with epicentra 100 km or more off the coast, and B) the earthquakes with epicentra 20–60 km off the coast.

Table 1 Type of Tsunami

Type	Date			Scale of Tsunami
I A	July	13	869	large
	July	2	1611	〃
	April	13	1677	medium
	Feb.	7	1793	〃
	June	15	1896	large
	Aug.	5	1897	small
	May	3	1933	large
I B	Sep.	9	1616	small
	Oct.	21	1869	〃
	Nov.	5	1938	〃
II	July	31	1640	〃
	Aug.	23	1782	〃
	April	25	1843	medium
	Aug.	23	1856	〃
	June	4	1893	small
	May	22	1894	〃
	Sep.	8	1918	〃
	Nov.	4	1918	〃
	May	4	1952	medium
	Nov.	7	1058	〃
III	Nov.	5	1952	〃
IV	Aug.	13	1868	〃
	May	9	1877	〃
	Aug.	17	1906	small
	May	24	1960	large

Table 2. Tsunami Caused by the earthquake in Southern America influenced to Sanriku Coast

Date of Tsunami	Date of earthquake	Origin of earthquake	Scale of Tsunami at Sanriku
Oct. 22 1687	Oct. 20 1687	Lima, Callao (Peru)	small
July 9 1730	July 8～9 1730	Concepcion, Santiago (Chile)	small
May 26 1751	May 24 1751	Concepcion, Santiago (Chile)	small
Nov. 8 1837	Nov. 7 1837	Valdivia (Chile)	small
Aug. 15 1868	Aug. 13 1868	Bolivia, Arica (Chile)	medium
May 11 1877	May 9 1877	Arequipa (Peru) Cobija, Tacapilla, Jquique (Chile)	medium
Feb. 2 1906	Jan. 31 1906	Ecuador	small
Aug. 18 1906	Aug. 17 1906	Valparaiso (Chile)	small
Nov. 12 1922	Nov. 11 1922	Atacama (Chile)	small
April 7 1943	April 6 1943	Salamanca, Ovalle, La Serena (Chile)	small
May 24 1960	May 23 1960	Concepcion	large

2) Tsunami caused by the earthquakes off the coasts of Tokachi in southern Hokkaido, and Kuril (Chishima) Islands.

3) Tsunami caused by the earthquakes off the Kamchatka Peninsula.

4) Tsunami caused by the earthquakes off the west coast of South-America.

Above all, in the Sanriku district, Tsunami of I A) group are very destructive, because the coast is situated near the epicentra, and also because it is a submerged coast with numerous embayments which often cause abnormally high waves of Tsunami. Most of the destructive Tsunami in the past were caused by the earthquakes of this group as seen in 1896 and 1933. However, it is noteworthy that Tsunami of category 4) have also attacked the coast of Sanriku district in the past. The last Chile-earthquake Tsunami which belongs to "far-off-earthquake Tsunami" type, shows quite a contrast in its nature with the Sanriku Tsunami of March 3rd. 1933 which was a "near-by-earthquake Tsunami", and this resulted in different distribution and magnitude of damages.

2. Maximum heights of Tsunami and the shapes of bays

As to the distribution of maximum heights of Tsunami waves, Professor Hideo Fukui and Professor Yoshio Watanabe will report in the other chapters. However, as the maximum heights of Tsunami have much to do with the extent of destruction, it may be worth while to refer to the maximum heights of Tsunami also here.

Generally speaking, the maximum heights of the last Chile Tsunami were lower than that of Tsunami in 1933. In that case, the heights of waves were larger at bay-heads (5–6.3 m) of deep embayments than the bay-mouths and capes (2 m). However, the heights of waves caused by the last Tsunami were only 2–3 meters at the V-shaped or U-shaped embayments facing to the open sea, where 6–20 meters of heights at the bay-heads and bay-mouths were recorded in 1933.

The oscillation which dicides the heights of waves at bay-heads, is a compound of the forced oscillation by the waves from the open sea and the oscillation proper to the bay. Therefore, there is a close relation between the wave heights and the periodicity of the proper oscillation of a bay and that of Tsunami waves. Accordingly, the relation between the maximum heights of Tsunami waves and proper preiodicity of a bay may also be close. On the assumption that the bay shape is a simple rectangular and the depth of water in the bay is uniform, the proper periodicity of the bay may be formulated as follows :

$$T = 4L/\sqrt{gh}$$

T : proper periodicity of the bay
L : depth of the water
h : length of the bay
g : gravity

According to the report by Mr. Hideo Watanabe, in the analysis of 30 bays in the Sanriku coast from Hachinohe bay, Aomori Prefecture, to Oginohama bay, Miyagi Prefecture, the relation between the proper periodicity of a bay and the maximum height of Tsunami waves is shown in Fig. 8. By the last Chile Tsunami, the relation was nearly inverse to the case in 1933, namely the larger the proper periodicity of a bay, the higher the maximum height of wave at the bay-head,

Fig. 7. Index Map.

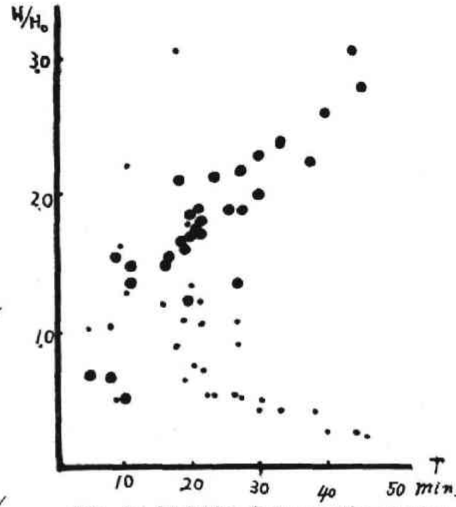

Fig. 8. Relation between the proper periodicity of bay and the maximum height (m) of Tsunami waves (by Hideo Watanabe)

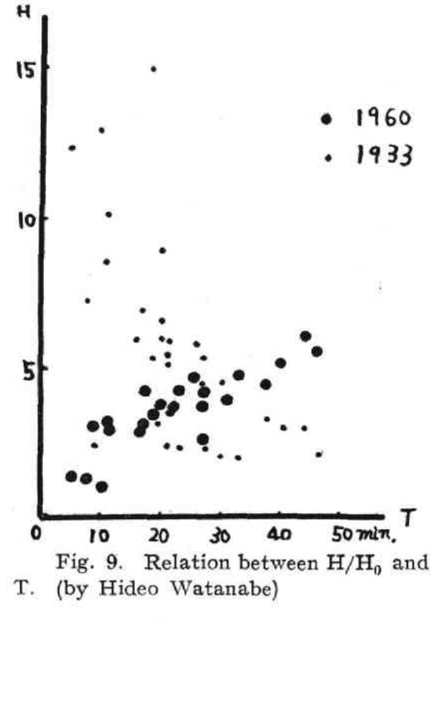

Fig. 9. Relation between H/H_0 and T. (by Hideo Watanabe)

up to the same value as the periodicity of Tsunami wave (about 60 min.). However, in 1933, in spite of the short periodicity (10–20 min.) of Tsunami waves, the maximum height of the wave was higher only in the range under 20 min. of the proper periodicity. If one compares the both elements of H/H_0 and T, (H/H_0 and T are used in the place of H and T. H : maximum height of wave at bay-head, H_0 : maximum height of wave in the open sea, T : periodicity of waves in the open sea. T may show nearly uniform value and T was used insteads of T/T_0 in this case), in the case of 1960 the H/H_0 increases with the growth of proper periodictiy. And in 1933, only in the range of proper periodicity correspondent with periodicity of Tsunami waves, the value of H/H_0 was large. The large value of H/H_0 means that the maximum heights of Tsunami waves at bay-heads are higher than the height of waves in the open sea. Thus, in 1933 at the V-shaped bays with short proper periodicity facing to the open sea such as Ryori bay, Taro bay, and Yoshihama bay, the maximum heights of waves were large, and in the case of far-off-earthquake Tsunami of 1960, in the deep embayments with long proper periodicity such as Miyako bay, Oofunado bay, Hirota bay, Kesen-numa bay, Shizugawa bay and Onagawa bay, the heights were larger. In other words, in the coast of Sanriku district, there are bays of two types : The one is the type of the bays in which the maximum height of waves is large in the case of near-by-earthquake Tsunami, and the other is that the bays with large maximum heights caused by far-off-earthquake Tsunami. Thus the distribution of wave-heights is mainly influenced by the shape of bays.

3. Distribution of the damages

In Iwate and Miyagi Prefectures, the damages due to the Chile Tsunami were concentrated in the area from Miyako city to Shiogama city, and loss of human lives numbered 105, 2408 houses were destroyed or washed away, the number of partly destroyed houses were 2771, the number of the houses with floors submerged reached to 10567, and 1951 ha of arable land was flooded under the water. Moreover, the damages of railroads, roads, bridges, fishing boats and equipments for fishery reached to a colossal amount of 18400 million yen in the two prefectures.

Analyzing the damages of the late Chile Tsunami, one may notice that the distribution of the damages was tolerably restricted. For instances, the deads reached to 97 persons in three cities, Oofunado, Rikuzen-takada and Shizugawa, and the destruction of houses was concentrated to Miyako, Yamada, Oozuchi, Oofunado, Rikuzen-takada, Shizugawa, Okatsu and Onagawa. The character of the damages become clearer by comparison in small unit section. The settlements in the Sanriku coast are classified into three categories according to the grades of

Table 3 Damages in Iwate Pref. and Miyagi Pref. (June. 26th., 1960)

		the dead	destroyed houses	half-destroyed houses	houses of which floor was submerged	houses flooded up under the floor	damaged non-resided houses (public building, and works)	damaged paddy fields	damaged dry fields
		(persons)	(houses)	(houses)	(houses)	(houses)	(houses)	ha	ha
Iwate Pref.	Taro	0	0	0	0	0	0	10	17
	Miyako	0	99	66	219	345	60	92	82
	Yamada	0	133	166	1007	188	100	110	80
	Oozuchi	0	80	187	639	345	225	27	14
	Kamaishi	0	28	25	768	530	63	78.4	50.5
	Sanriku	0	0	0	0	0	10	2	33
	Oofunado	53	384	532	250	101	810	120	171
	Rikuzen Takada	8	148	119	208	47	416	157	117
	Total	61	872	1095	3091	1556	1681	596.4	564
Miyagi Pref.	Karakuwa	0	0	1	55	53	34	14	15.3
	Kesennuma	2	32	40	2071	2099	0	196.5	12.2
	Motoyoshi	0	0	0	2	0	6	13	0
	Utazu	0	12	1	30	27	46	14	5.3
	Shizugawa	37	965	364	0	0	0	180	31
	Kitakami	0	0	0	10	39	0	1.2	5
	Kahoku	0	0	0	0	10	0	1.0	3
	Okatsu	0	87	93	300	145	1250	1.5	40
	Onagawa	0	289	900	2000	150	0	30	50
	Ojika	1	1	1	339	203	229	25.5	10.5
	Ishinomaki	2	84	167	1724	1384	5	34.0	3.8
	Yamoto	0	0	0	1	1	0	0	0
	Naruse	0	12	10	36	180	0	106	35
	Rifu	0	0	0	0	1	0	0	0
	Shiogama	2	16	10	752	422	30	37.5	12.8
	Shichigahama	0	38	0	165	185	0	2.4	0
	Total	44	1536	1676	7485	4899	1600	566.6	223.9
	Accumulative	105	2408	2771	10576	6455	3281	1163.0	787.9

Table 4 Damage by Tsunami in the past

	the dead	destroyed house
869	about 1000 persons	? houses
1611	1786	
1896	21953	10370
1933	2955	6542
1960	123	5352

the damages, and are plotted in Figure 10, using the maximum heights of Tsunami waves in 1933 and 1960. According to the figure, it is reasonably understood that the settlements suffered severer where the maximum heights of Tsunami waves in 1960 were higher than in 1933, though the absolute maximum heights were not so high. The damaged areas in 1960 were different from those in 1933, and they were

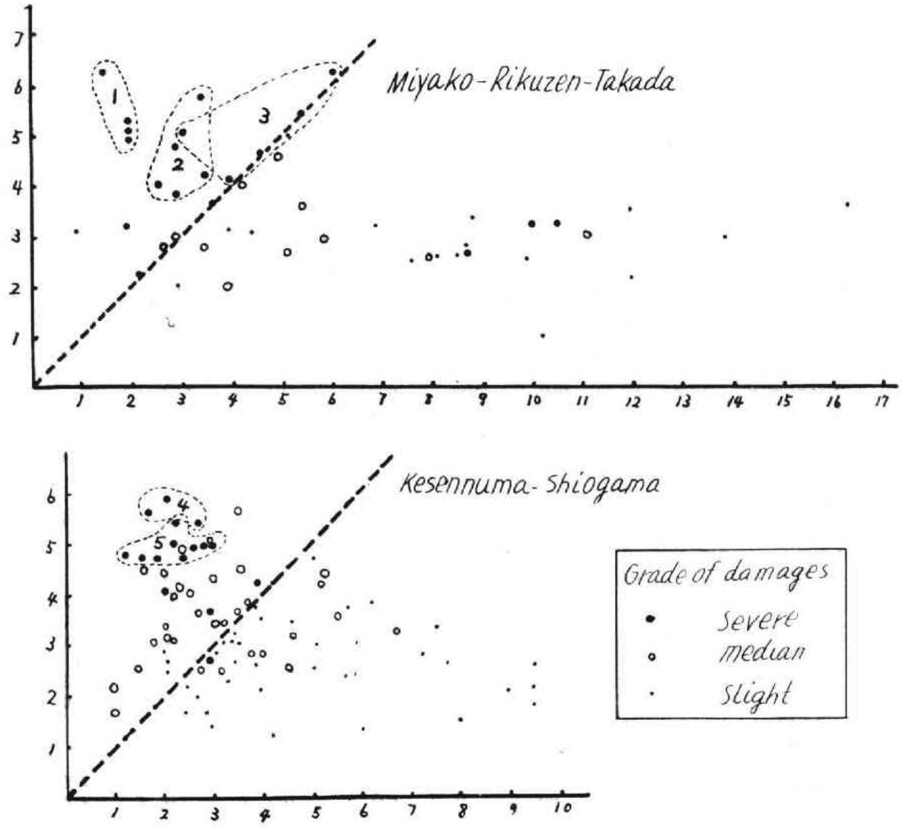

Fig. 10. Classification of settlements according to the grades of damges and wave heights of Tsunami.

1. Miyako Bay, 2. Ofunado Bay, 3. Hirota Bay, 4. Shizugawa Bay, 5. Onagawa Bay

located at the heads of deep embayments.

However, in comparison of the damages of the last Tsunami with those of the Tsunami in 1896 and 1933, it was a relief that the deads were less in 1960 than in 1896 and 1933, when the figures were 21953 and 2955 respectively.

4. Damages and land-forms

It was already stated that the maximum heights of Tsunami waves and accordingly the grade of the damages were related to the shapes of bays. The distribution of wave-heights and damages was also influenced by the submarine landforms of the bays. Along the main valley and its deeper branches, the Tsunami maintained its speed, and the damages were severe as seen at Oofunado bay, Kesen-numa bay and Shiogama bay. Especially at the settlements located on deep submarine valleys or their branches, most of houses was destroyed or washed away, leaving their foundation stones only, as observed at Akazaki (Ofunado bay) and Ryogae (Hirota bay).

In the deep bays where the maximum heights were larger, usually the beach ridges are undeveloped at the bay-heads, and the coastal plains were formed by comparatively large rivers. By the last Tsunami, the waves ran over the beach ridges which did not play the role of a natural tide-break, and flooded the inner part of coastal plains. Thus a great deal of damage was done to settlements and arable lands.

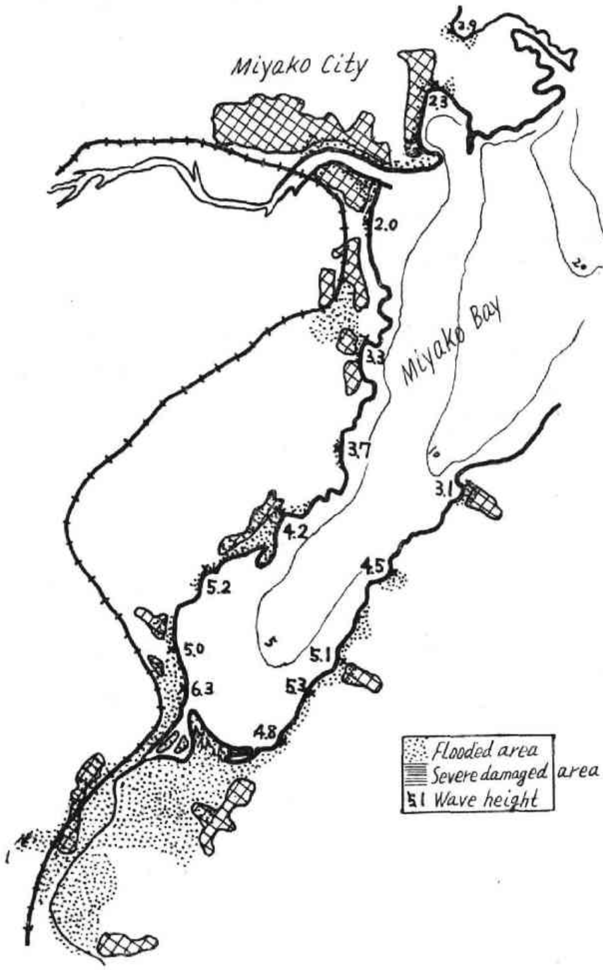

Fig. 11. Miyako Bay.

At many places, the sea water flowed in and out along the river, overflowed and destroyed the banks, and flooded the cultivated fields. And at the upper part of the river much effluence was accumlated. In such a case the damaged area was distributed along the river course. In general, the bay heads of coastal plains with an extensive damaged areas by this Tsunami, had been used as arable land. As the Tsunami attacked the area, just at the time of transplanting of rice, the newly transplanting plants were soaked in the sea water as well as suffered from the salt in the soil. Thus the rice culture suffered from the salt damage, and the amount of the damage on rice plants was by far larger than that of the destruction of arable land. The areas severely damaged by salt were Miyako bay, Oozuchi bay, Oofunado bay Hirota bay and Kesen-numa bay.

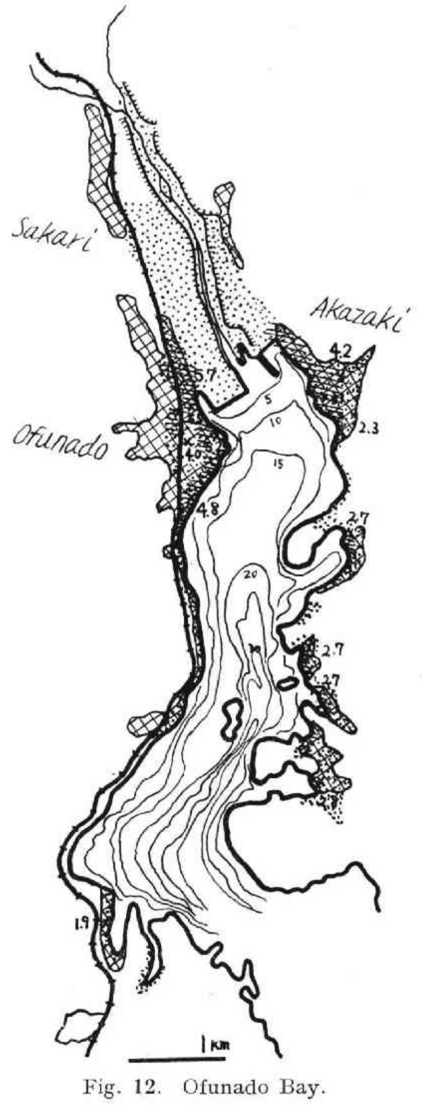

Fig. 12. Ofunado Bay.

5. Damages and settlements

At the bay-heads of the deep embayments where the Tsunami waves were high this time, such as Miyako bay, Kamaishi bay, Oofunado bay, Hirota bay, Kesen-numa bay, Shizugawa bay, Onagawa bay and Shiogama bay, there are settlements of considerable sizes. Those are Miyako, Kamaishi, Oofunado, Rikuzen-takada, Kesen-numa, Shizugawa, Onagawa and Shiogama. These cities are not only local centers of administration or commerce, but also fishing ports, and there are processing plants of fishery products, cement factory (Oofunado) and iron-foundry (Kamaishi). Consequently, these cities suffered the loss or destruction of fishing boats, equipments of factories and commercial goods, besides the damages of houses. At Oofunado city, the port and the factories were constructed on the land reclaimed from the foreshore of a delta. However, the Tsunami waves were so strong that large fishing boats were given a hoist over the wharf, and the freight cars near fish market were wrecked. Generally the water force of Tsunami was stronger at the ebb of the tide than at the rise of the tide, therefore the inner foundation of the tide-break and the quay-walls of ports were excavated by the ebb-tide from backside. In this way, the quay-walls were destroyed at Oofunado, Hachinohe, Kamaishi, etc., together with destruction of the houses by the same operation.

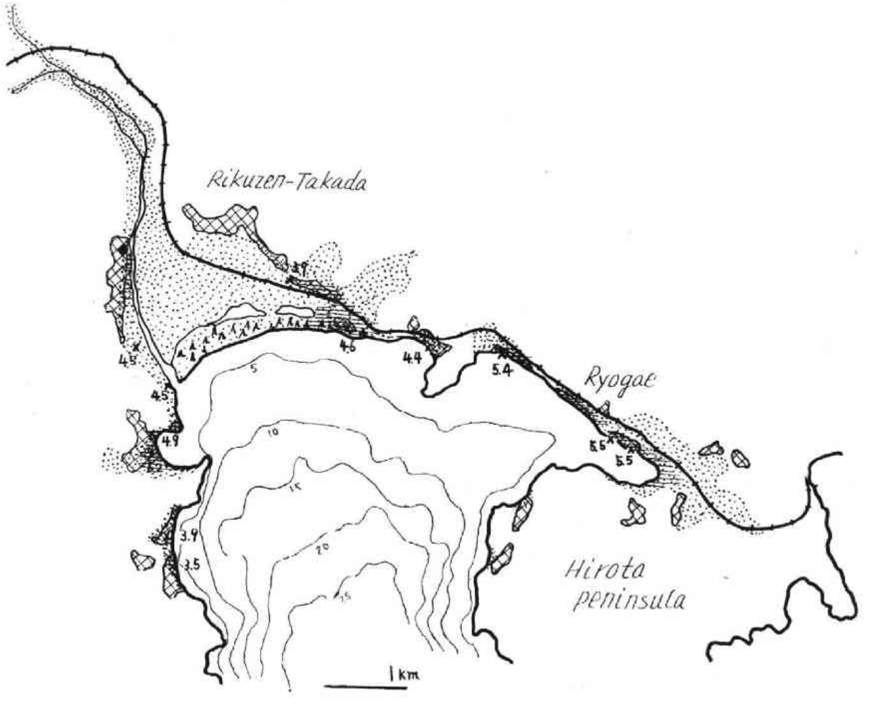

Fig. 13. Hirota Bay.

Owing to the destruction of the quay of ports, some factories near the ports were not only washed by the sea water and the machines got rusted, but also they suffered from the loss by the suspension of landing and shipping.

Almost all wooden frames for oyster culture were carried away, especially in Oofunado bay, Hirota bay, Kesen-numa bay and Shizugawa bay. At the fishing villages engaged in oyster culture, owing to the low tide-break, many workshops were overthrown or destroyed, and houses were flooded above floor by 2 meters.

As to the distribution of damaged houses within a settlement, in the densely bulit areas old houses were destroyed as if they were thinned out from the mass,

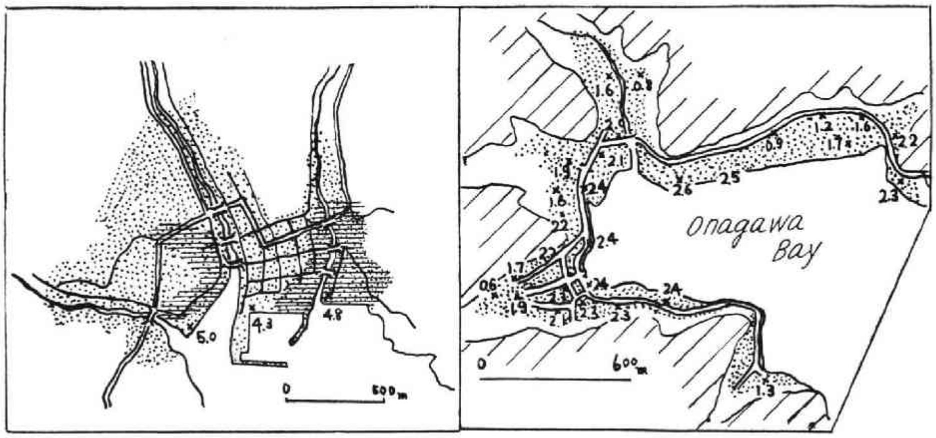

Fig. 14. Shizugawa and Onagawa.

and the public buildings and newly built houses of concrete or mortar with solid foundations were flooded without destruction. Road running at a right angle to the coast received severer damage, because here the Tsunami could find its way with ease, and the innumerable destroyed driftages were flowed along the roads and played havoc with the houses. This fact was common in all the damaged settlements, and the damages of houses by the driftages were larger than those by the immediate impact of Tsunami waves.

The settlements located at the bay-heads in V-shaped bays have often experienced the severe damage of destructions by Tsunami in the past. In these areas the tide controlling embankments and forests as tide-breaks were constructed

Table 5. Damage of settlements

	1896		1933		1960	
	1	2	1	2	1	2
Taro	326 (326)	1850	491 (551)	958 (3661)	333	0
Miyako	300	12	4	1	41	0
Yamada	454 (786)	1283	≒300	?	732	0
Orikasa	95 (190)	65 (940)	1	3	732	0
Ryoishi	127 (129)	701 (840)	93 (96)	?	36	0
Toni-Hongo	154 (154)	798 (810)	≒100	350 (557)	4	0
Akazaki	290 (383)	497	?	?	215	3
Ofunado	74 (295)	83	?	?	884	50
Otomo	?	?	97	18	79	2
Shizugawa	? (5000)	?			1329	37
Onagawa	50 (60)	?			1189	0

1) Numbers of destroyed houses
2) Numbers of loss of human lives
( ) Total numbers befor the attack of Tsunami

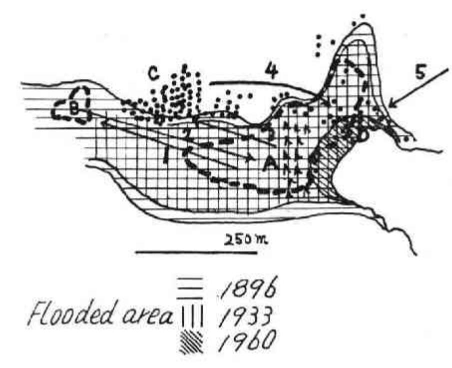

Fig. 15. Movement of Settlement.
(Hongo, Tôni Bay)

A. Ruins of original settlement
B. Ruins of moved settlement after the attack of Tsunami in 1896
C. Present settlement
D. Houses which have moved back since 1933
1. Movement after the attack of Tsunami in 1896
2. Reversional movement to original settlement (1896–1933)
3. Movement after the attack of Tsunami in 1933
4. Removal to lowland in the time from 1933 to 1960
5. Migration from other areas

based on the past bitter experiences with great effect on the protection from Tsunami damage. They are distributed at Taro, Yamada, Oozuchi and Yoshihama, where the greater part of the inhabitants was destroyed in a moment in 1896 and in 1933. In both cases Tsunami waves were 10 m or more high in these areas. However, in the last Tsunami the maximum heights of Tsunami waves were only about 2 m, and the beach ridges of sandy coasts played the role of tide-breaks, therefore there was not much chance for the artificial constructions to show their efficiency.

On the other hand, some of the settlements in this areas had moved inland to the higher places after the attacks of Tsunami in 1896 and 1933. However, some of them moved back to the lowland along the coast such as Ryori, Ryoishi, Koshirahama and Hongo. For the small scale fishermen, to live in higher places was very inconvenient for their activity. They suffered from the damages both in 1933 and 1960, though, fortunately, the damage was rather slight in 1960 thanks to the low wave heights.

6. Conclusion

In the case of the last Chile Tsunami, the damages were severe at the deep embayments from the southern part of Iwate Prefecture to the middle part of Miyagi Prefecture, and this is an area which was rather slightly injured at the time of Sanriku Tsunami in 1933. At the V-shaped bays in the middle part of Iwate Prefecture the damages were nearly inverse to the case of above areas. The reason why the relation between wave heights and their damages were not the same in these two cases, may be attributed to the difference of the shapes of bays and the submarine landforms. The difference of the shapes of bays bears the difference of the proper periodicity of waves in the bays, and at the time of the last Chile Tsunami with a long periodicity being a Tsunami caused by "far-off earthquake", the bay-head areas of deep embayments which have long proper periodicity suffered severely from the Tsunami.

At the bay-head areas the settlements of all sizes are located, and the arable lands are distributed with considerable acreage. In these areas some measures had been taken in order to protect against the Tsunami. Those are such as the construction of tide controlling banks and forests, and also the movement of settlements to higher places behind the coast. These countermeasures were based on the experience of the Tsunami in 1933. However, the construction of lagre scale tide- breaks was not too easy, and the movement of large settlements is very difficult, because the productive activities of people are impeded by the measures. Thus the measures have been taken insufficiently in this areas.

After the attack of the last Tsunami, the local governments of the prefectures with damaged areas have already started to draw permanent plans against Tsunami, and the central government appropriated 2800 million yen in the budget of 1961. Howerver, this amount of money is very insufficient to carry out the measures successfully.

To make successful plans, one must consider the two different possibilities of Tsunami; the "near-by-earthquake Tsunami" and the "far-off-earthquake Tsunami". At the same time, the measures must be a part of the plan of multiple purpose development of the area.

One can say that the last Chile Tsunami was very instructive for the promotion of countermeasures as it was a typical case of the Tsunami caused by a far-off-earthquake.

Norio Hasegawa

Photo. 1. The tip of tangue of the first Tsunami flowing upstream the Kesen River.

Photo. 2. Destroyed sand-dune with pine trees at the head of Hirota bay.

Photo. 3. At Ryogae located at the head of Hirota bay, settlers' houses were destroyed severely and their foundation-stones were only remained.

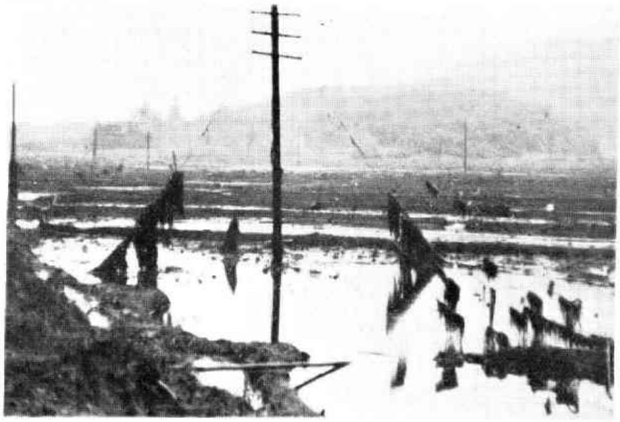

Photo. 4. Paddy fields of Otomo area, Hirota bay, after the flood of sea water.

Photo. 5. Agglomerated materials of oyster culture. Oofunado bay.

Photo. 6. Oofunado city was damaged severely by Tsunami.

Photo. 7. Accumulated materials of houses flowed by Tsunami on the field at Sano, Oofunado bay.

Photo. 8. Fishing boat driven high and dry on the quay of the port of Oofunado.

Photo. 9. Destroyed area of a river side at Shizugawa.

Photo. 10. At port of Ryori, the settlements once moved on high marine terrace were safe from the last Tsunami, whereas the houses located lower part were damaged by the Tsunami.