Review:

A Century of Countermeasures Against Storm Surges and Tsunamis in Japan

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The countermeasures against storm surges and tsunamis in Japan are briefly reviewed covering roughly the last century. In spite of 22,000 deaths resulting from the Meiji Great Sanriku Tsunami just before the 20th century, neither central government nor local governments took effective countermeasures.

The first positive countermeasures were taken by the central and local governments after the Showa Great Sanriku Tsunami and the Muroto Typhoon in early 1930s. The Seashore Act was enacted in 1956. After the 1959 Ise Bay Typhoon and the 1960 Chilean Tsunami, it has been the general practice to construct coastal dikes 5-6 m high as defense countermeasures. Tsunamis exceeding this height are met by combining structures, tsunami-resistant town development and defense systems. Quantitative tsunami forecasting announced by the Japan Meteorological Agency is currently state-of-the-art globally in terms of swiftness, preciseness and details.

Keywords: storm surge, tsunami, comprehensive countermeasures, land use, forecasting

1. Introduction

Japan has an area of 380,000 km^2, only one quarter of which constitutes arable and otherwise usable lowlands. Japanese big cities such as Tokyo, Osaka, and Nagoya are located on such lowlands, and fisheries and other commercial activities flourish in coastal areas.

National conditions, however, make Japan's coastal areas vulnerable to storm surges and tsunamis. Because Japan is on the ordinary route of typhoon, an average of 3 typhoons strikes Japan directly among some 27 occurring each year. It is impossible to evade the influences from flood and storm surge caused by these typhoons. On the side of the Pacific Ocean, the Japan Trench and similar structures built by subduction of the Pacific and Philippine Plates are the sources of submarine earthquakes accompanied by tsunamis. On the Japan Sea side, there is another plate boundary, where tsunamis also occur.

Under these conditions, the Japanese people have somehow managed their lives and continued their activities. The last 100 years, however, have brought significant changes, involving modern technological developments and increased use of coastal areas. After chronologically reviewing disasters caused by storm surges and tsunamis, we discuss how defensive measures have changed due to these disasters.

Forecasting is often effective in warning against immediate disaster for evacuation. Storm surge forecasting is omitted in this paper, because it is less urgent than tsunami forecasting and is integrated into weather forecasting. The history and development of tsunami forecasting by the Japan Meteorological Agency which can be said is state-of-the-art globally is briefly described.

2. Major Storm Surges and Tsunamis in the Last 100 Years

The last 100 years is reviewed below, focusing on storm surges and tsunamis influencing defense countermeasures in some degree.

In 1896, lacking any advance earthquake signs, the Meiji Great Sanriku Tsunami hit the Sanriku coast in northeastern Japan. This tsunami ran up to nearly 40 m high in some places and took 22,000 lives. Main defense countermeasures after this disaster were movement of residence to higher ground, planned and promoted by local celebrities, with no active commitments by central and local governments.

As time passed, those relocating to higher ground gradually returned to the lowlands. Thirty seven years later, in 1933, another big tsunami hit the Sanriku coast, ran up to 30 m in some places and claimed nearly 3,000 victims. This time, the central government reacted swiftly, conducting damage investigations, restoration planning, and restoration projects. At the time various prototypes of methods for tsunami defense such as structures, tsunami-resistant town development, and software-type measures including tsunami forecasting can be already recognized. Many stricken areas were fishing villages and small coastal towns.

In 1934, the Muroto Typhoon hit the Kinki Region, bringing disastrous storm surges around Osaka City, perhaps Japan's first example of disaster in a modern industrial and commercial city. In the process of restoration, some ideas of restoration project of the Showa Great Sanriku Tsunami in the previous year were adopted. However, because depth of inundation this time reached only some meters and storm surges disaster had urban characteristics, construction of seawall was mainly proposed. And storm surge forecasting was also expected.

In 1941, tsunami forecasting went into practical use in the Sanriku Region. In 1946, triggered by the Aleutian Tsunami, JMA (Japan Meteorological Agency) expanded tsunami forecasting nationwide.

In 1950 the western part of the Osaka City was hit by Typhoon Jane. Concrete seawalls that are prototype of hard defense countermeasures to protect big cities were adopted then. The seawalls constructed in Osaka protected the city later when the Second Muroto Typhoon struck in September, 1961.

From this year, the national coastal defense project was undertaken.

In 1952, tsunami forecasting, although still in the trial stage, proved its practical usefulness when the Tokachi-Oki Earthquake occurred.

In 1953, the Typhoon No.5313 damaged mainly rural areas from the Chita Peninsula to Mikawa Bay. Faulty coastal dike design was uncovered when the typhoon destroyed the dike, but financial restrictions kept countermeasures from being implemented at the time.

In 1956, the Seashore Act was enacted, legally authorizing coastal defense projects.

In 1958, “construction standards for coastal defense structures” stated in the Seashore Act were completed, clarifying technical grounds and methods.

In 1959, the Ise Bay Typhoon significantly damaged dwellings and other structures and left 5,000 dead. The typhoon course was almost correctly forecasted but the height of storm surge was underestimated below the actual 5-meter inundation.

With this disaster as a momentum, the Disaster Countermeasures Basic Act was enacted in 1961. This act stressed the importance of disaster prevention information, and every kind of radio networks for disaster prevention was improved.

In 1960, a tsunami that propagated from Chile caused large-scale damage in wide areas from Hokkaido to Okinawa, although the height of inundation reached only 5-6 m.

These two large-scale seashore disasters, Ise Bay Typhoon and Chile Tsunami which occurred in two consecutive years, gave opportunity to make fundamental form of coastal defense structures afterwards. Because both disasters can be coped with by coastal dike 5-6 m high or so, hard defense countermeasures were given first priority, being supported by the fact that the plan to double the nation’s income built up national strength at that time.

Since then, no really large-scale disasters have been caused by storm surges, partly because the highest level, 5-6 m, of inundation due to storm surges can be relatively easily prevented by structures. Another reason is that the locations necessary to be protected are limited on the geographical condition that storm surges would occur in the innermost parts of the bays open to the south along the course of typhoon in many cases.

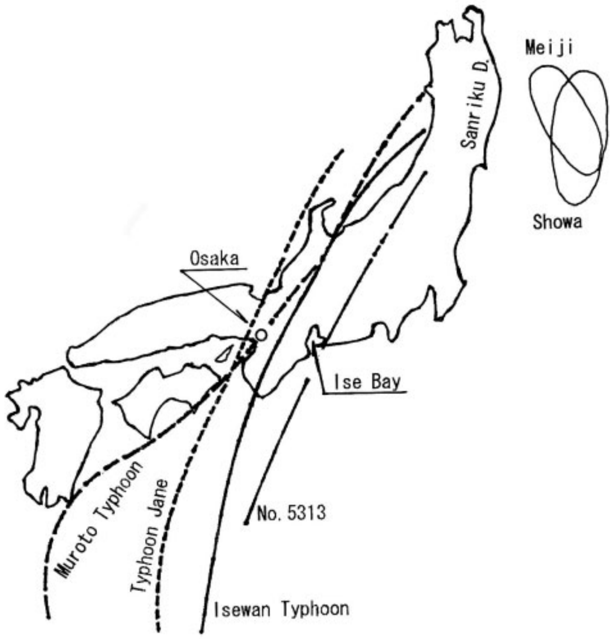


Fig. 1. Storm surges and tsunamis referenced in text.

In contrast, the defense countermeasures against tsunamis have been more difficult. Tsunamis along Japan’s extensive coastline may reach height exceeding 10 m, which cannot be adequately defended against only structurally. Accordingly, in March 1983, it was recognized and proposed that the combination with soft defense countermeasures were needed. Soon after this proposal, in May 1983, a tsunami was generated by the Nihonkai-Chubu Earthquake. Its maximum run-up height was 15 m.

In case of the 1993 Hokkaido Nansei-Oki Earthquake, the maximum run-up height of tsunami was 30 m and tsunami forecasting could not be in time. As a result, it was 1997 when an agreement was reached that a combination of three factors – defense structures, tsunami-resistant town development, and defense systems – is fundamental for tsunami prevention countermeasures.

In 1999, quantitative tsunami forecasting was realized, improving precision and swiftness in prediction.

Following this progress and taking up storm surges and tsunamis, the changes in each time are described below.

3. The 1896 Meiji Great Sanriku Tsunami
– Preceding Modern Technology –

In the evening of the Boy’s Festival, on May 5, Meiji 29, of the old lunar calendar (June 15, 1896) a tsunami struck the Sanriku Region (**Fig. 1**). Because of the “tsunami earthquake”, the preceding quake by which was small and seismic intensity was 2 at most on the seismic scale of Japan Meteorological Agency, none thought to evacuate, leaving some 22,000 victims of the tsunami.

Many telegraph stations, which themselves functioned as the basis for communications, were damaged, making it difficult to grasp the actual situation. Roads and bridges were destroyed, food transport became impossible, and the dispatch of relief to survivors was delayed. Access to the stricken area by sea was further hindered by the tremendous amount of floating debris. Damage is estimated to have totaled up to 10% of the national budget at that time (Shuto, 2005 [18]).

This significant wide-area disaster uncovered many problems, ranging from immediate post-disaster relief to restoration projects, and provided many potential lessons.

Most defense countermeasures against tsunamis were relocations to higher ground, many of them at the private expense of individual citizens. In some cases, volunteers proposed relocation, developed residential land using contributions, etc., and relocated in groups. In Miyagi Prefecture, the prefectural government bore expenses for constructing the road to the planed site of relocation. Relocation sites number 43, but the number of group relocations only 7.

As years passed and memory faded, many residents returned to their original lowland locations. Return after 10 years had passed was remarkable. They suffered again 37 years later when the next disaster, the 1933 Showa Great Sanriku Tsunami struck. Ten reasons that Tanakadate and Yamaguchi (1938) [19] suggested as the factors in such a return included the following 4:

1. Those who worked in fisheries found it too far from their homes to the beach.
2. Drinking waters was insufficient in high places.
3. People were strongly attached to their ancestral lands.
4. Tsunamis are comparatively infrequent.

More concretely, Yamaguchi (1952) [23] pointed out that, in locational relationship between the workplace – in this case, usually the beach – and the home, at locations 15 m or more in height and 400 m or more in distance, many returned to their original homes.

4. The 1933 Showa Great Sanriku Tsunami – Comprehensive Tsunami Defense Countermeasures Began –

Early in the morning on March 3, 1933, on the day of the Girl's festival, after an intense earthquake (**Fig. 1**), a large tsunami struck the Sanriku Region. Although pre-tsunami tremors were intense enough to cause many residents to evacuate, the dead and missing numbered over 3,000.

Unlike previously, those from academic circles and central and prefectural governments worked together conducting investigations, proposing countermeasures, and planning and implementing restoration projects.

4.1. Proposals on Comprehensive Countermeasures

In terms of countermeasures, the Council on Earthquake Disaster Prevention of the Ministry of Education proposed "notes on prevention against tsunamis" (1933). Printed in June 1933 – about 3 months after the tsunami –, it was an extremely swift reaction for its time. The 10 major points specified in these notes on countermeasures against tsunamis are as follows:

"**Relocation to high ground**. This was the most favored action. Housing, schools, and municipal office should be built on high ground.

Coastal dikes. Ordinary coastal dikes, although effective against wind waves, are ineffective against large tsunamis. Targeting coastal dikes against tsunamis, however, would make them too large, and financially impractical.

Tsunami control forests. Because tsunami control forest damps the power of tsunamis, this measure is recommended if enough flat land along the seashore enables sufficient planting.

Seawalls. These could be effective for smaller tsunamis.

Tsunami-resistant areas. If the place is busy quarter and the height of tsunami is not so high, the place is to be designated as tsunami-resistant area. Solid concrete buildings whose foundations reach deep in the ground are to be built in the front line of the area.

Buffer zones. When trying to prevent tsunami from penetrating by structures, the water level rises inevitably resulting in flooding in neighboring areas. In order to receive this flooding, river routes, valleys, and other lowland areas are to be designated as buffer zones to be sacrificed.

Evacuation routes. Roads to safe higher ground are necessary everywhere.

Tsunami precaution. Tsunami forecasting is difficult to implement, however if phenomena caused by tsunamis were carefully observed and evaluated, this could be helpful to evacuation.

Tsunami evacuation. The aged, children and weak should be evacuated to safe higher ground where they could wait for about one hour. Ships more than a few hundred meters offshore, had best move farther offshore.

Memorial events. In tsunami disaster prevention, the worst enemy is time, because people increasingly disregard earlier caution as time passes and memory fades. Holding memorial services, erecting monuments, etc, help keep events alive in people's minds."

These points emphasize the combination of the three factors recommended in the present comprehensive tsunami defense countermeasures (see section 7): 1. defense structures, 2. tsunami-resistant town development, and 3. defense systems.

4.2. Planning and Implementation of Restoration Plan

4.2.1. Tsunami-Resistant Town Development

It was the Ministry of the Interior which drafted and implemented restoration plans (City Planning Department, 1934 [2]).

In order to draft the countermeasures, mapping had to be undertaken first. To speed up work quickly, aerial photographs were taken, – a rare thing at that time –, and plans of land development for housing were drafted onto the photographs.

It was said that “different policies are adopted between the large community with urban-like configuration and the small community living on fishery and agriculture.” In coastal communities mainly occupied fishing concerns and secondarily by agriculture, it was recommended first to relocate entire villages to higher ground, if any, or to cut slopes to develop residential areas. Only in Osabe, Iwate Prefecture, the original ground was raised instead of relocating communities to higher ground.

To prevent residents from returning to their original land, the Miyagi prefectural government regulated the land use. Prefectural Order No.33 on “the regulation of architecture in tsunami stricken area” designated specific areas where building was forbidden and penalties were prescribed in case of violation. This prefectural order was applied to 26 sites in Miyagi Prefecture (Miyagi Prefecture, 1934 [8]).

4.2.2. Defense Facilities

While implementing relocations to higher ground, it was recognized that some urban districts already forming centers of social life, such as transport, economic and educational, could not be moved to safer zones. In these cases, seawalls were constructed, e.g., at Taro village, Yoshihama-Hongo, Kamaishi, Yamada and so on.

Tsunami control forests were planted in many places. Immediately after the 1933 tsunami disaster, under the guidance of Dr. of Forestry Honda Seiroku and Dr. of Science Imamura Akitsune, an investigation of tsunami disasters was conducted and afforestation planning for 150 sites was drafted (Forestry Bureau, 1934 [5]).

4.2.3. Defense System

Efforts toward realization of tsunami forecasting were undertaken and tsunami forecasting was implemented in 1941 (Section 6).

To pass on the experience and knowledge gained on tsunamis to subsequent generations, some 150 monuments were erected in Aomori, Iwate, and Miyagi prefectures, inscribed with such wording as “If an earthquake hits, exercise caution about tsunamis”, “Earthquake, roaring of the sea, then comes tsunami”, “If tsunamis come, go to higher ground than here” and “It is forbidden to dwell within endangered zone” etc. (Shuto, 2001 [17]).

5. 1950 Typhoon Jane – Storm Surge Disaster and its Countermeasures in Industrial and Commercial City –

5.1. 1934 Muroto Typhoon as Herald (Japan Society of Civil Engineers, 1936 [7])

Muroto Typhoon was violent typhoon which landed at Muroto Promontory in the south shore of Shikoku and took its course in the northeastern direction on the west side of Osaka Bay as shown in **Fig. 1**. When the typhoon struck Muroto Promontory, the lowest atmospheric pressure of 911.9 hPa (Miyazaki, 2003 [9]) and the maximum instantaneous wind velocity of 60 m/s and over were recorded. This wind velocity had remained the standard to be met in building architecture until the Building Standards Act was revised in 2001. Trees, power lines and utility poles were toppled and trains derailed and overturned. Heavy rain and flooding left a death toll exceeding 700, and 6,500 sites where dikes were breached and 1,753 bridges were washed away.

In addition to heavy rains and flooding, in Osaka City at the inner part of the bay and to the right of the typhoon route, storm surges raised tide levels to O.P. $+5.10$ m. In Osaka Prefecture, 188,700 houses were severely affected, including 800 washed away and 29,300 totally or partially destroyed. At Osaka Port, dikes and piers were totally wrecked, vessels weighting 3,000 tons and more drifted after anchor chains were severed, and small rivers in the city were blocked by sunken ships. Coastal railways were so covered with ships and drift wood debris that it took several days to remove them.

In the industrial lowland, many factory buildings were damaged or collapsed and dozens of factories were totally washed away without trace. Because inundation continued more than a week and factories were filled with muddy sea water, machinery, equipment, and important documents were damaged. In the industrial area alone, the dead numbered 57 and the injured 1,600 (Osaka Industry Association, 1936 [13]).

Although coastal dikes and other defense structures withstood external forces on their seaside front surfaces, their backsides were scoured and destroyed by overflowing water. This gave important suggestion to structural design.

As option of disaster defense countermeasures, construction of coastal dike, control of ground height of architecture, and regulation of land use etc. were considered, but only reinforcement of drainage facility was remarkable after all. New construction and reinforcement of outer breakwaters were expected, however the influences of the World War II hindered its progress. Subsidence caused by groundwater pumping proceeded at 10-20 cm per year and in around 1945 partial inundations were repeated due to abnormal high tide unrelated to typhoons (Osaka Prefecture and Osaka City, 1960 [14]).

5.2. Typhoon Jane and Restoration Measures – Appearance of Hydrologic Statistics and Hydraulic Experiment – (Osaka Prefecture and Osaka City, 1960 [14])

The Typhoon Jane, which caused serious damage around Osaka in 1950, was originally expected to take another course, but instead changed its course as it approached Japan, struck Shikoku, moved forward in the northeastern direction on the western side of Osaka Bay, and consequently took a course very similar to that of

Muroto Typhoon (**Fig. 1**). With the lowest atmospheric pressure of 970 hPa, the maximum instantaneous wind velocity of 44 m/s, and the storm surge tide level of O.P. +3.85 m, the Typhoon Jane was smaller than the Muroto Typhoon, but it moved so slowly that it lasted roughly twice as long, 6.5 hours. It destroyed or otherwise damaged 178,400 houses, left 240 dead and missing, and 21,120 injured.

Taking this opportunity, the permanent comprehensive storm surge defense countermeasures were to be taken drastically. As far as the planned tide level concerned, statistical analysis was performed based on the records for the last 50 years, the Muroto Typhoon, the largest typhoon in this period, was selected as the baseline of outer force, and the planned storm surge tide level was set at O.P. +5.0 m expecting the free board of 20 cm. This value was judged to be the occurrence probability of once in 813 years. The planned height was decided based on this standard height and geographical conditions, taking into account the influence of wind waves, decremented storm surge, and the presence or absence of water gates.

Outer breakwaters which were expected to mitigate storm surge after the Muroto Typhoon were given up because, judging from findings in a large-scale hydraulic experiment, outer breakwaters could not prevent storm surges from going into the port and rivers in the city.

Embankments with a height exceeding this storm surge tidal level were considered safest but were implemented only partially. The reason for that was too much amount of earth and sand required, difficulty in the case of many facilities to be relocated, long lasting construction periods, difficulty of the subsidence countermeasures to be taken after the completion of the work and so on.

The construction of dikes along the seacoast was also proposed but judged to be difficult to complete, because water or lock gates on rivers which were used as a part of the port would be too many and difficult to manage.

Eventually seawalls were constructed around each area separately. Completed seawalls took the form of a concrete parapet and backside grounds were also covered with concrete, implementing important lessons learned from the Muroto Typhoon.

Seawalls constructed at the time protected the areas completely against the Second Muroto Typhoon in 1960.

6. 1959 Ise Bay Typhoon and 1960 Chile Tsunami – Completion of Prototype Coastal Defense Structures and Appearance of Electronic Computer –

6.1. Seashore Act and Standards on Coastal Structures Construction

The coastal defense project for protecting coastal areas from disaster started in 1950 and was legally authorized under the Seashore Act enacted in May 1956. Article 14 of the Act stipulated to embody "the standards on construction of coastal defense structures". The standards were worked out in December 1958.

During this period in September 1953, Typhoon No. 5313 (**Fig. 1**) significantly damaged again the area around the Chita Peninsula, the eastern coast of the entrance to Ise Bay (Aichi Prefecture, 1957 [1]). In this case also it was reconfirmed that overflowing water washed away the backside of dikes and then destroyed them as in the case of the Muroto Typhoon. But in restoration process enough repairs could not be done. With disasters occurring in many places in 1953, the amount of damage peaked after the World War II, and economic conditions at the time made it impossible to cope.

Construction standards were revised after the Ise Bay Typhoon the next year and the prototype of coastal defense structures was established.

6.2. 1959 Ise Bay Typhoon (National Association of Disaster Prevention, 1965 [11])

In September 1959, a super large typhoon with a central atmospheric pressure of 943 hPa seriously damaged all the area around the Ise Bay, as it moved along the western side of the bay, wrecking havoc the inner part of the bay left undamaged by Typhoon No.5313 in 1953. In the Nagoya Port located in the inner part of the bay the anomaly caused by storm surge was 3.55 m, the highest exceeding 3.1 m recorded when the Muroto Typhoon struck the Osaka City.

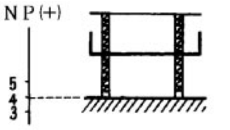
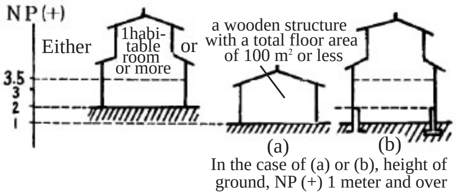
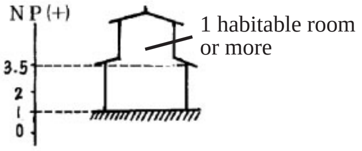
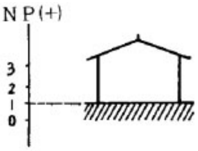
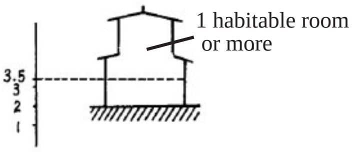
In Aichi and Mie prefectures, 31,000 ha was inundated, the dead and missing numbered 4,651, and the injured accounted for 33,025, and the total sufferers were 1,204,608 people. The fact that the northern Ise Bay included the Chukyo industrial area, whose population density was relatively high, contributed to the disaster.

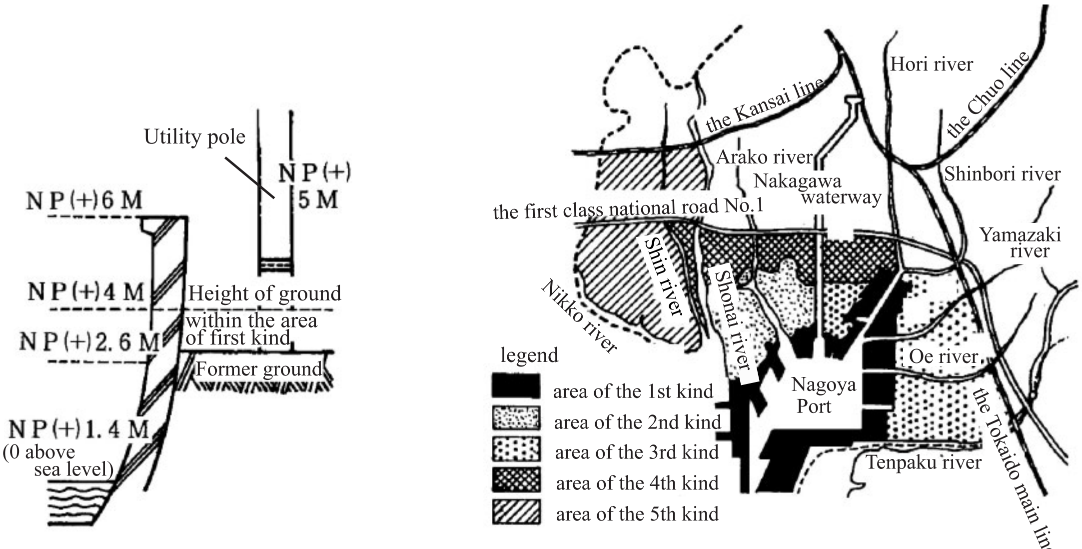
The inundated area was considerable, and Nabeta reclamation remained submerged under sea water nearly four months. Much of seaside lowlands reclaimed there during the Edo period (1605-1868) was zero meters above sea level, and in some places −0.5 m to −1.6 m below sea level. Groundwater had also been depleted due to rapid industrialization, causing considerable subsidence around Nagoya.

In addition to water damage, an estimated 200,000 tons of lumbers was washed from lumberyards and the 5-6 ton logs became deadly weapons, adding to the human death and injury and housing damage.

After this disaster, computerization came advanced enough to be applied in storm surge calculation. The Japan Meteorological Agency conducted storm surge calculations on main bays. When drafting storm surge defense countermeasures for Tokyo Bay, it was estimated that the Ise Bay Typhoon would take 11 different courses, and the results were adopted (Unoki and Isozaki, 1962 [22]).

Economic growth represented by plans to double the nation's income had just begun, with a high degree of coastal area use in industrial development anticipated. "The Storm Surge Conference for Ise Bay etc." which consisted of ministries and government offices as well

	Structure	Height of Ground	Example
Area of the first kind	Waterproof structure excluding wooden structures Exceptions: Total floor area of waterproof structure is 100 m^2 or less without habitable room	NP (+) 4 meters and over	
Area of the second kind	Waterproof structure Height of one habitable room or more, NP (+) 3.5 meters and over	NP (+) 2 meters and over	
Area of the third kind	Same as above	NP (+) 1 meter and over Exceptions: Foundation with NP(+) 1 meter and over	
Area of the fourth kind	Waterproof structure	Same as above	
Area of the fifth kind	Waterproof structure Height of floor of one habitable room or more, NP (+) 3.5 meters and over	NP (+) 2 meters and more Exeptions: Foundation with NP(+) 2 meters and over	



NP (+)

Nagoya City seaside disaster prevention zones

Fig. 2. Regulations on land use based on Nagoya municipal ordinance.

as academicians examined the defense countermeasures against storm surge disasters. Nagoya City regulated land use through municipal ordinance. Important points to note include the following.

1. Construction of storm surge breakwaters

The construction of storm surge breakwaters which had been given up in Osaka was realized. Unlike in Osaka, breakwaters were placed far offshore, creating sufficient area behind breakwaters to prevent wind waves from entering through the narrow entrance of the bay. The storm surge breakwaters were constructed at a depth of 8.5 m and were 8.2 km long, with two openings in them, one 350 m wide and the other 50 m wide.

2. Coastal dikes with three surfaces covered

To cope with overflowing storm surges and overtopping wind waves, the front, top, and rear side of coastal dikes were to be covered with concrete perfectly.

3. Nagoya municipal ordinance No.3 (March 24, 1961)

Based on land use, planning, location in relation to the sea etc., seaside disaster prevention zones were classified into 5 and regulated (**Fig. 2**).

Zoning regulations held that (i) no wooden structures were to be permitted at dangerous places, and (ii) emergency room for evacuation was provided at a height above the expected water inundation (Public Works Research Institute, 1981 [15]).

6.3. 1960 Chile Tsunami (Iwate Prefecture, 1969 [6])

On May 23rd in 1960 at four eleven in the morning Japan Standard Time, an immerse earthquake with Ms8.5, Mw9.5 was occurred off the coast of Chile and generated a huge tsunami. The tsunami struck all sides of the Pacific, and arrived Japan after 22.5 hours. Because earthquake could not be sensed in Japan, it was completely unexpected. Taking this opportunity, the Pan-Pacific Tsunami Warning System was introduced.

Pacific coastal areas from Hokkaido to Okinawa were damaged. The tsunami hitting Sanriku was 5-6 m high and that in other regions 3-4 m high. Areas hit especially hard were Hokkaido, Sanriku, Joban, and southern Shikoku. It left 119 dead, 20 missing, 1,571 houses completely destroyed and 1,259 houses washed away. Arable lands, ships etc., were extensively damaged.

"The Special Act on the Tsunami Defense Countermeasures Project in Regions Suffering from the Chile Earthquake Tsunami in May 1960" was enacted. "The Council on Countermeasures against the Chile Earthquake Tsunami" studied and decided an urgent Chile tsunami countermeasures project plan in November 1961. Its main contents are planning standards, amount of tsunami defense countermeasures projects and the plan for tsunami breakwaters.

Because the height of this tsunami in the coast was 5-6 m at most, defense countermeasures consisted mainly of the construction of defense structures, seawalls and coastal dikes providing direct protection. The crest height of structures was decided based on actual records for the Chile Tsunami, taking into account the importance of protecting places behind structures and the size of past tsunamis, adding a further free board of 0-2.2 m. Seawalls were made of concrete and coastal dikes had front, top and back covered with concrete.

On this occasion, as the structure which was in little conflict with the daily use, the world's first tsunami breakwaters was proposed and constructed at a depth of 38 m. This construction is a large scale work even at present. The effect of the tsunami breakwaters was confirmed through the numerical calculation by electronic computer.

All urgent Chile tsunami defense countermeasures were completed in 1966. Only in Iwate Prefecture, in order to take the countermeasures against other tsunamis in the past, the construction work of new coastal dikes as well as the works to raise the coastal dikes which had been already completed in the Chile tsunami defense countermeasures have continued and the works are still on now in 2006.

Fig. 3. Automatic tsunami forecasting tower in Kamaishi constructed in 1934.

Soon after the completion of urgent Chile tsunami defense countermeasures, the 1968 Tokachi-Oki Earthquake Tsunami hit Sanriku but caused no significant damage.

7. History of Tsunami Forecasting

7.1. Forecasting Tower in Kamaishi

An automatic tsunami forecasting tower (**Fig. 3**) was erected after the 1933 Showa Great Sanriku Tsunami. It could electrically detect abnormal fluctuations in tidal level immediately before a tsunami and announce it to local residents by sounding a siren. It was expected to forecast a tsunami a dozen minutes before its arrival in Kamaishi City. The great expenses needed to construct such towers, however, prevented the construction of any more (Civil Engineering Section, Iwate Prefecture, 1936 [3]). The tsunami forecasting tower in Kamaishi in fact no longer exists, but remains only in the memories of the local elderly.

7.2. Period When Manual Method Was Used (Morita, 1942 [10]: Uchiike and Hosono, 1993 [21])

In 1941, a tsunami warning organization was founded for the Sanriku coast. Judging from tsunami forecasting chart drafted empirically (the former form of **Fig. 4**), tsunamis were forecasted at meteorological stations in its jurisdiction. Forecast was transmitted to local residents within 10-20 minutes after earthquake occurrence by radio and by telephone to the police station.

In the legal system of the Meteorological Business Act enacted in June 1952, the comprehensive plan for tsunami forecasting transmission was integrated. Just before its formal decision, the 1952 Tokachi-Oki Earthquake Tsunami occurred on March 4 and this forecasting system succeeded.

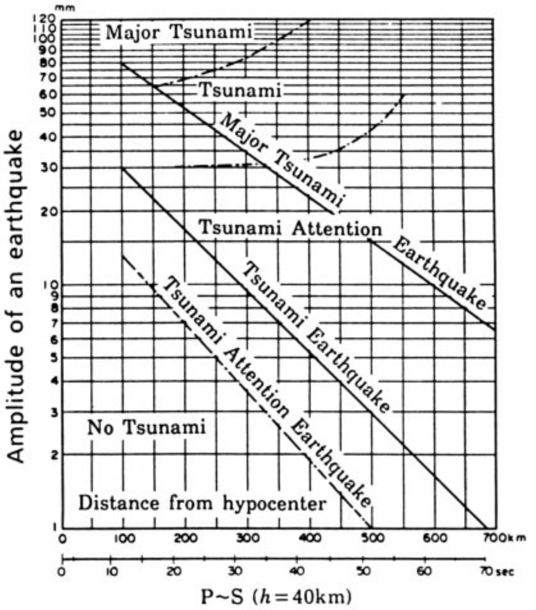


Fig. 4. Tsunami forecasting chart used for 40 years.

The work process of tsunami forecasting at this time was as follows. When an earthquake occurred, officials in charge in each meteorological station read the observation data from seismographs in their offices and transmitted this data to the tsunami forecasting centers by wire or by radio. At the tsunami forecasting centers, based on this data and its own data, the epicenter and magnitude were determined and information on whether tsunamis would occur was judged from a tsunami forecasting chart (**Fig. 4**).

Such manual procedures required 17 minutes until forecasting was completed at the tsunami forecasting center, only after which transmission was made to local coastal residents.

7.3. Speeding Up the Process (Uchiike and Hosono, 1993 [21])

To shorten forecasting time, a Local Automated Data Editing and Switching System (L-ADESS) was introduced in fiscal 1980. Observation data from seismographs were sent through dedicated lines via manual input and reading, and then evaluated by computer, shortening the forecasting process to about 10 minutes.

However, the fastest tsunamis in the 1983 Nihonkai-Chubu Earthquake Tsunami arrived 7 minutes after quake occurrence. This fact necessitated automation of all stages from earthquake detection to epicenter calculation. The Earthquake Phenomena Observation System (EPOS) established in the headquarters of the Meteorological Agency until fiscal 1987 and the Earthquake and Tsunami Observation System (ETOS) introduced to the tsunami forecasting centers until fiscal 1993 shortened tsunami forecasting time to about 7 minutes.

In July 5, 1993, the Hokkaido Nansei-Oki Earthquake Tsunami arrived in 3-5 minutes some places. The Meteorological Agency then switched from S wave use to that of P waves. Because tsunami earthquake early detection network was prepared nationwide and the result from tsunami forecasting chart was switched to that from numerical calculation, the time needed for tsunami forecasting was shortened to 3-5 minutes.

Introduction of the NOWCAST Earthquake Information system in JMA made it possible to determine epicenter and earthquake magnitude within several seconds. Since October 2, 2006, tsunami forecasting is issued within 2 minutes after an earthquake is detected.

7.4. Introduction of Numerical Calculation (Tatehata, 1997 [20])

Tsunami forecasting chart (**Fig. 4**) was used for 40 years, dividing Japan into 18 tsunami forecasting areas with forecasts announced locally. But there were two big problems. One was the length of forecasting sea area. For example the fourth area including the prefectures from Aomori to Fukushima was longer than 500 km and there could be large differences in the same area. The second problem was that more detailed forecasting classification was needed than rough estimates such as “large tsunami (exceeding about 3 m in the high place)”.

For these reasons, calculation was conducted for 100,000 cases to build a database. The number of tsunami forecasting sea areas was increased to 66. And “large tsunami” was divided into five stages of 3 m, 4 m, 6 m, 8 m, and 10 m and above, “tsunami” two stages of 1 m and 2 m and “tsunami caution” one stage of 0.5 m.

Quantitative tsunami forecasting based on numerical calculation began from April 11, 1999.

7.5. Transmission of Tsunami Forecasting (National Land Agency etc., 1997 [12])

Tsunami forecasting is transmitted 3 ways.

1. Simultaneous forecasting and warning transmission system: Disaster prevention information announced by the Meteorological Agency is transmitted simultaneously by fax to disaster prevention organizations and press organizations. Through this system in jurisdictional meteorological observatories and local meteorological observatories, tsunami forecasting is transmitted to most of the organizations concerned.

2. Automated Data Editing and Switching System (ADESS): Under ADESS, jurisdictional meteorological observatories etc. collect data on weather and earthquakes observed in all local meteorological observatories on the one hand and information analyzed or announced by jurisdictional meteorological observatories is distributed to local meteorological observatories on the other hand.

Disaster prevention information systems in administrational disaster prevention organizations such as the Fire Defense Agency and prefectures are connected on-line with this ADESS and receive tsunami forecasting through this system.

3. Emergency information satellite simultaneous transmission system: Emergency information such as tsunami

forecasting and earthquake information is transmitted via the meteorological satellite "Himawari (sunflower)" introduced in 1994. Once a dedicated receiver is set, everyone receives tsunami forecasting information from the Japan Meteorological Agency quickly and directly.

8. Comprehensive Tsunami Disaster Prevention

8.1. Switching from Post-Event Countermeasures to Pre-Event Preparedness

Preparedness against damage from storm surges caused by typhoons is relatively easy to conduct via the defense structure, because sea water levels are usually limited to 5 or 6 m, even when anomaly, wind waves and astronomical tide are considered together. Once weather forecasting was well developed, it was possible to announce forecasting and warning useful in evacuation with enough time.

In contrast to storm surges, tsunamis may arrive a few minutes after earthquake occurrence, making it difficult to evacuate following tsunami forecasting. Structural measures are not always sufficient, either, because in some places the tsunami height could far exceed 10 m.

In 1976, when the supposedly immanent Tokai Earthquake was a buzz topic, an epoch-making move was made. In the past after a large tsunami, it was discussed how to take tsunami defense countermeasures, including clearance work of disaster. In 1976, however, it was recommended that methods to take tsunamis defense measures in tsunami prone area (Sanriku coast) would be examined as pre-event preparedness.

In Iwate Prefecture, coastal dikes 5-6 m high had been constructed tentatively as urgent Chile tsunami defense countermeasures. After this, work went on to further raise coastal dikes, in some places exceeding 12 m, to match the height of past tsunamis. Iwate and other prefectures began to examine whether the dike height really was enough or which tsunamis to target in plans. "A guidance on comprehensive disaster prevention countermeasures in tsunami prone areas (proposal)" was worked out in March, 1983 (River Bureau, Ministry of Construction, 1983 [16]). It stated that three factors, defense structure, defense regional planning, and defense systems were to be combined. This was what developed from suggestions after the Showa Great Sanriku Tsunami in 1934. The guidance was reorganized 14 years later into the guidance currently in effect.

8.2. "Guidance on Reinforcement of Tsunami Disaster Prevention Countermeasures in Local Disaster Prevention Planning"

In the Hokkaido Nansei-Oki Earthquake Tsunami in July 1993, an unexpected situation arose. First, tsunami forecasting was too late. Second, in Okushiri town, the 5th district of Aonae was protected by seawalls 4.5 m high, which was supposedly tsunami-proof, and while the seawalls themselves remained almost intact, the entire community was washed away without a trace. Housing not damaged by the tsunami burned down due to unexpected fire outbreaks.

After the disaster, 7 government offices concerned with tsunami disaster prevention policies, including the National Land Agency; the Ministry of Agriculture, Forestry and Fisheries, Structure Improvement Bureau; the Ministry of Agriculture, Forestry and Fisheries, Fisheries Agency; the Ministry of Transportation; the Meteorological Agency; the Ministry of Construction; and the Fire Defense Agency agreed to "guidance on reinforcement of tsunami disaster prevention countermeasures in local disaster prevention planning" (National Land Agency etc., 1997 [12]).

Although some revisions were made, this was the successor of guidance proposed in 1983. Over 10 years have passed since then, and advances in technology during this period were incorporated into this new guidance. The most marked change is how planned tsunamis are selected, detailed below.

This involves the largest past tsunami from which credible materials can be obtained and possible tsunamis caused by the largest earthquake that can be supposed to occur based on present knowledge and science. After comparing both tsunamis, one with the higher water level on coast is selected as the standard tsunami to ensure safety insofar as possible.

Tsunami selection thus involves past records and scientific prediction. This is a quite different method to select standard tsunami from previous one. The Central Disaster Management Council announces earthquakes and tsunamis thus estimated as the standard force to be prepared for, especially after the Indian Ocean Tsunami in 2004. This method adopted scientific prediction in tsunami preparedness for the first time.

As mentioned earlier, defense structure, tsunami-resistant town development, and defense systems are to be combined.

Although the "defense structure" is the basic form of tsunami defense countermeasures, the level of defense structures is set considering the local situation and the effect of structures and examined comprehensively combined with tsunami-resistant town development and defense systems. Thus this level of preparedness by structure does not always correspond to standard tsunami.

From the viewpoint of "town development", as a realistic problem, many cases exist in which not all housing and important facilities can be relocated, so it is important to convert potentially dangerous places to tsunami-resistant through land use, reinforcement of buildings etc., being consistent with medium- and long-range regional land use planning.

Seaside zones and hinterland require different use and various facilities to promote local industries and improve living environments. To promote safety against tsunamis in response to area planning, it is important to continue tsunami-resistant land use consistent with such use of seaside zones in each area.

In order to encourage such land use and to improve evacuation & relief countermeasures, it is important to incorporate the viewpoint of tsunami defense countermeasures in improving transport and public facilities that are the backbone of land use.

The "defense system" is generally stipulated in Disaster Countermeasures Basic Act etc. and this "guidance" explains the main points to be examined in tsunami disaster prevention. These points are improvement in tsunami forecasting and warning, evacuation based on this information, disaster prevention training in response to tsunamis and disaster prevention education to make people aware of tsunamis and what to do in the event of tsunamis.

9. Conclusion

Storm surge and tsunami defense countermeasures have shown rapid advancements in the last 100 years. Advances have been induced from the scale and form of disaster dependent on human society and have been realized supported by technology and economic strength.

In the 40-some years since 1960, defense structures have been main countermeasures, because the height of storm surges caused by the Ise Bay Typhoon and the height of the Chile Tsunami were only 5-6 m, the height that could be coped with by the defense structure.

Given the recognition of external forces exceeding such a defense structure, the importance of software-type countermeasures has been increasingly acknowledged.

Natural disasters occur when nature and human society cross. The basis of disaster prevention countermeasures should be an awareness that anomalous disasters are just as likely to happen as predictable disasters.

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