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HISTORICAL STUDY OF CHANGES IN STORM SURGE DISASTERS IN THE OSAKA AREA

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ABSTRACT

Changes in storm surge disasters in the Osaka area were studied on the basis of old documents in which descriptions of disasters have been given for about 1200 years. Storm surge disasters have occurred 53 times in the Osaka area since 700, seven of them are major ones that killed 1000 or more people. The risk to life of these disasters is of the order of 10^{-3}. This value is the potential risk when no countermeasures are taken against storm surge disasters. After the Muroto Typhoon (1934) risk to life in storm surge disasters has been reduced remarkably by the soft and hard countermeasures taken. The mean interval between major storm surge disasters is about 150 years, which corresponds nearly to the return period for the storm surge that accompanied the Muroto Typhoon.

1. INTRODUCTION

Natural disasters which directly affect human beings are caused by an imbalance between such natural forces as earthquakes, volcanic eruptions, typhoons, monsoons and tornados and the resistance to them in inhabited areas. Disasters, which are generally repeatable because of the sequence of natural forces, are related to changes in our social activities, as well as to the strength of the natural forces involved. A storm surge disaster is one of the most typical, catastrophic natural disasters from which inhabited areas suffer. Because Japan recently has shown remarkable material expansion and its coastal areas have fully been developed, the damage potential of disasters has increased. To reduce and mitigate disasters in such areas it is necessary to investigate countermeasures for a catastrophic storm surge disaster of rare frequency. Long term data on disasters make it possible to determine historical changes in the frequency, strength and actual states of catastrophic disasters.

Since 1961, when storm surges that accompanied the Daini Muroto Typhoon struck Osaka, there have been few large storm surge disasters. This is due to the decrease in the number of large typhoons that have directly hit the Japanese islands. Soft and hard countermeasures against storm surge disasters, such as typhoon warning systems and lock gates, also have contributed to the prevention and reduction of major disasters [1]. In the early 1960s, coastal areas in and around Japanese cities were reclaimed for the construction of modern industrial complexes and public facilities. Urbanization advanced greatly in the hinterlands of these reclaimed areas in the 1970s; consequently, the potential of catastrophic storm surge disasters occurring has increased in areas such as Tokyo, Nagoya and Osaka.

The city of Osaka was developed on the site of the old capital of Naniwa (645) on the top

KEY WORDS: Storm surge disaster, Risk to life, Storm surges, Flooding, Osaka bay, Reclamation
Note: Discussion open until 1 March, 1988

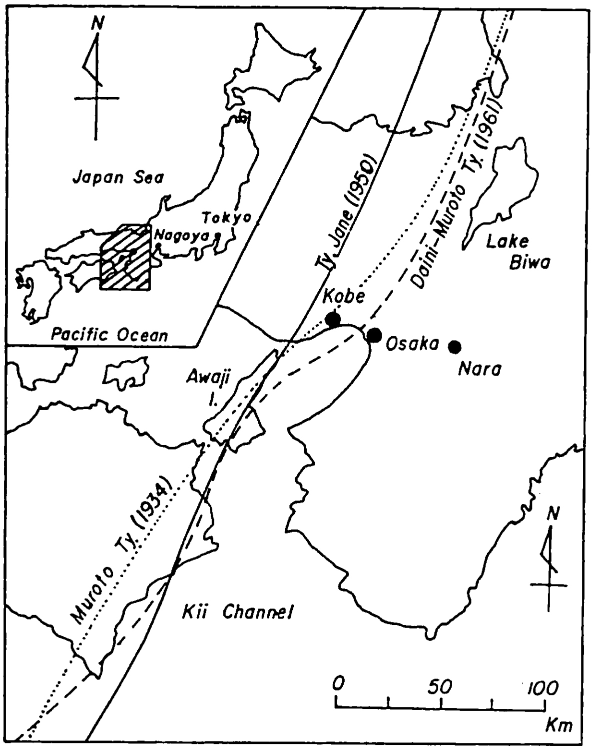

Fig. 1 Map of the area studied and the paths of the three biggest typhoons to strike Osaka since 1900.

of Uemachi Hill. The first storm surge disaster was recorded in 753. Mitsuura Village at the bottom of the west slope of this hill was devastated by storm surges in which some 560 persons were killed. Since 753, many other storm surge disasters have occurred [2]. The city is unfavorably located to withstand storm surges. Typhoons frequently move northeastward just before hitting the Japanese archipelago, and unfortunately the shape of Osaka Bay is elliptical in shape, its major axis running northeast (Fig. 1). When a typhoon passes over western Osaka, a large amount of water piles up at the northeast end of the bay as the storm surges. During spring tides, the tidal range is about 1.85 m. Therefore, a meteorological tide due to a storm surge added to the astronomical tide can produce an extremely high sea level.

Many old documents describe historical storm surge disasters in the Osaka area. We have studied historical changes in the risk to life due to storm surge disasters which were caused by changes in various social and environmental conditions. The frequency of occurrence of major storm surge disasters is verified by statistical data on high tides which we have reported previously [3].

2. TOPOGRAPHICAL BACKGROUND OF THE OSAKA HINTERLAND

The hinterland of Osaka can be divided into three areas; the Kawachi Lowland, Uemachi Hill and a coastal lowland (Fig. 2). In these areas, many people have lived since ancient times; therefore, the topography inevitably has been modified by human activities, as well as by natural phenomena such as river flooding and reclamation of coastal lowland areas. In this section, we describe the topographical characteristics of the flood areas and how they have changed with time.

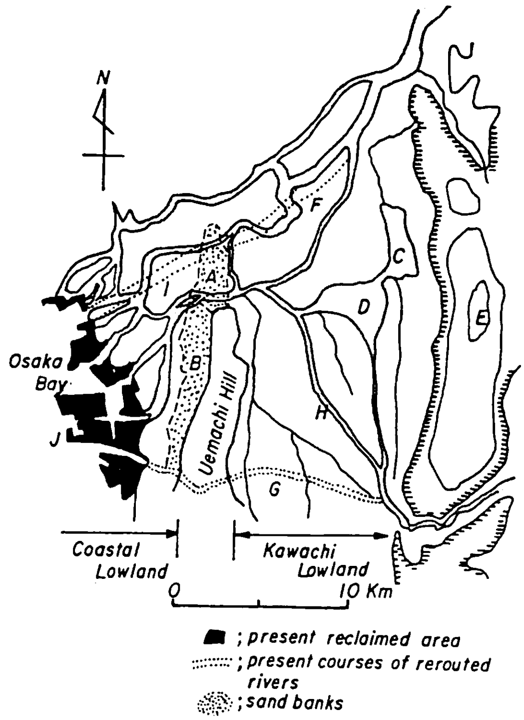

Fig. 2 River systems about the year 1500 and the geographical clasifications in the Osaka Plain (A; Tenma sand bank, B; Nanba sand bank, C; Fukouno Ike, D; Shinkai Ike, E; Mt. Ikoma (642 m), F; Yodo River, G; New Yamato River (rerouted in 1704), H; Yamato River, I; New Yodo River (rerouted in 1900), J; Reclaimed areas after 1600).

2.1 *The Kawachi Lowland*

About 6000 years ago, the sea level rose to a maximum and coastal waters invaded the hinterland; this is called the Jomon Transgression. The area affected consisted of the present Osaka Bay and its eastern enlargement, Ko Kawachi Bay (*ko* means old), as shown in Fig. 3. The solid line in the figure corresponds to the shoreline about 1600 to 1800 years ago, as estimated by Kajiyama et al. [4]. After the sea level had reached a height of about +3 m, it slowly fell to the present sea level, but another slight rise in sea level took place about 2000 years ago that is known as the Yayoi Transregression. In addition, the old Yodo and Yamato Rivers deposited large amounts of sediment every time they flooded.

Consequently, about the year 500, Ko Kawachi Bay had mostly silted up. Only two ponds remained, the Shinkai Ike and Fukouno Ike, in the northern part of the hinterland (C and D in Fig. 2). The southern part of this area was a flood plain more than 5 m high with relatively steep slope. In contrast, most of the northern area was typical back marsh less than 1 m high. The old Yamato River transported so much sediment that it became a raised bed and a braided river. The first settlements were located on the natural levees and old river channels because they were relatively high and dry lands. In Fig. 3, contourlines for +5 m above sea level have been drawn to make the topographical characteristics distinct. Deltas had developed at both river mouths and advanced into Osaka Bay through the north end of Uemachi Hill, and the coastal lowland areas formed were marshy and swampy until about 1500.

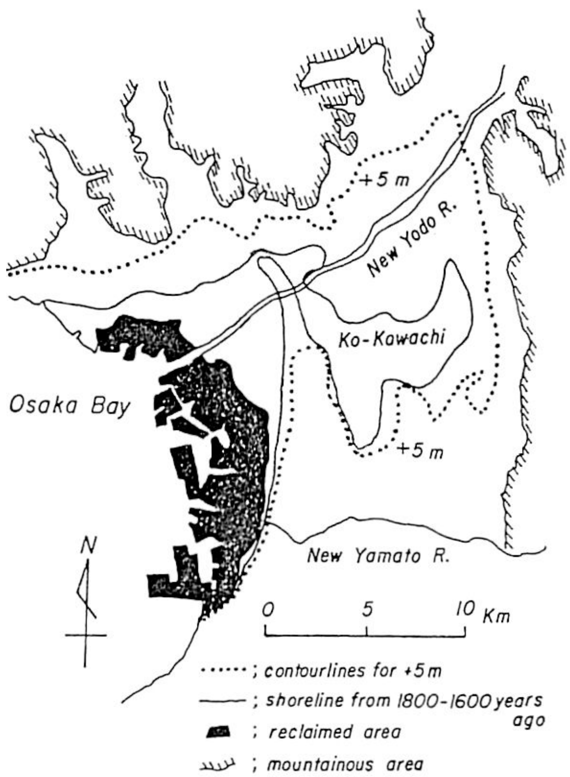

Fig. 3 Topography of the Osaka area about 1600 to 1800 years ago and present reclaimed areas (Contourlines: +5 m above the present sea level).

2.2 *Uemachi Hill*

Uemachi Hill, with a maximum height of 23 m above sea level and a mean width of about 2 km, is in the central area of Osaka. The northern part is higher than the southern part. This hill is a tilted block, the west being the block front with a steep slope. About 700, the shoreline came up to the west foot of the hill, and the northward longshore current transported sediment to this area forming sand banks such as the Tenma and Nanba sand banks (A and B in Fig. 2). Many documents record the difficulties of navigating near the mouth of the Yodo River and in adjacent shallow waters.

2.3 *The Coastal Lowland*

In 1583, Hideyoshi Toyotomi united the nation after almost a century of warfare and constructed Osaka Castle close to the top of Uemachi Hill. Many of his samurai lived on the west slope of the hill and in the adjacent lowlands (Fig. 4). The west part of their residential area first was Higashiyokobori, in which a canal was dug in 1584. This was in the east end of the coastal lowland. Merchants first lived between Higashiyokobori and Nishiyokobori. The canals dug in Osaka first were used for sewerage and later for carrying goods. In the 17th century, the population of Osaka greatly increased and the area grew to be the major center of commerce in Japan. To obtain new housing quarters, a series of large ponds were dug in low-lying floodable land, and large amounts of soil and clay were piled up beside them. We call this reclamation method, *jiage* which first was developed in the Netherlands. In the central area of Osaka, therefore, there came to be many canals.

The Tokugawa Shogunate (1603–1868) encouraged rich merchants to reclaim marshy areas

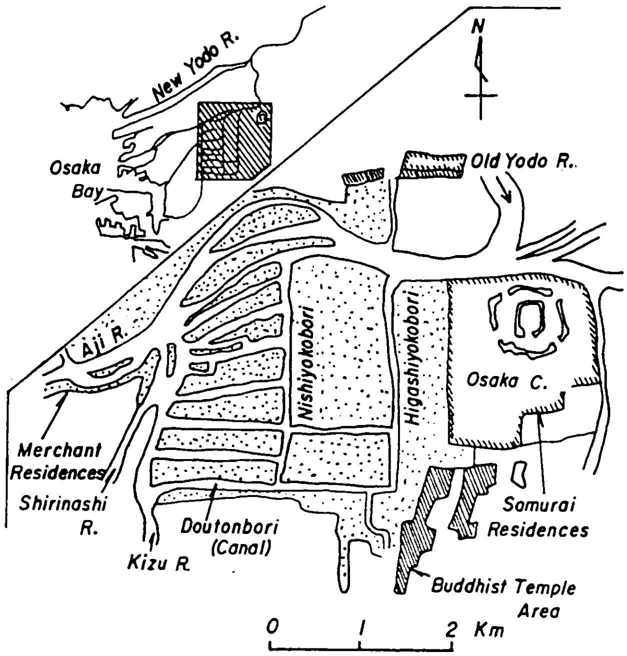

Fig. 4 Residential areas of samurai, priests and merchants in central Osaka and its canal systems in the 1800s.

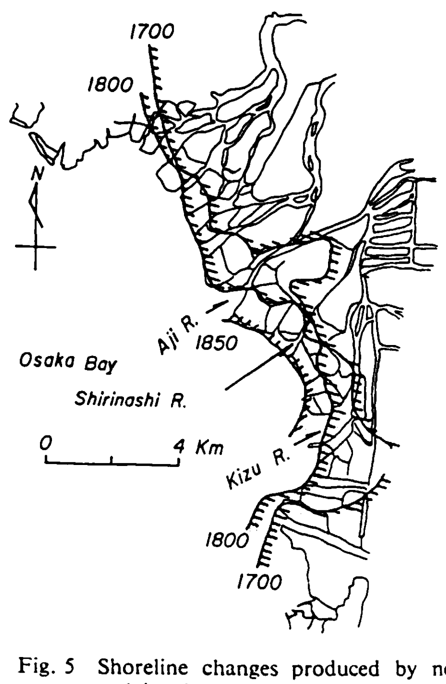

Fig. 5 Shoreline changes produced by newly reclaimed land in western Osaka after 1600.

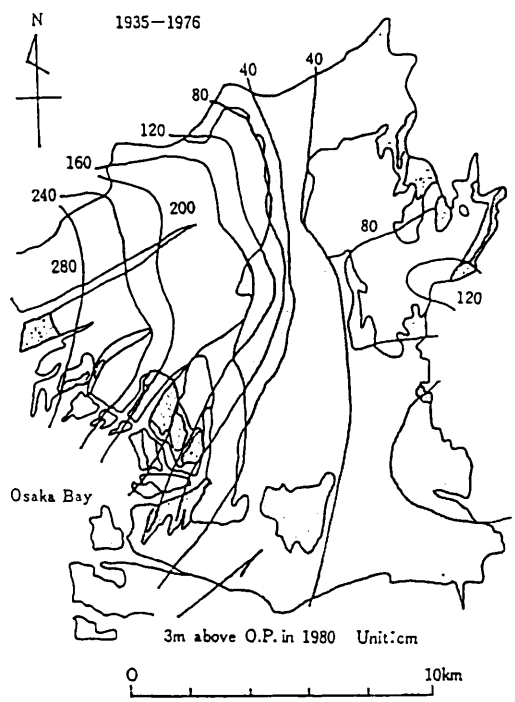

Fig. 6 Subsidence in the Osaka City area between 1935 and 1976 [1].

near the mouths of the old Yodo and Yamato Rivers (in 1704, rerouting of the old Yamato River was completed to prevent flooding in downstream areas (G in Fig. 2)). Historical changes in the shoreline due to reclamation over the past 200 years are shown in Fig. 5. During the Tokugawa Shogunate, the ground level was not changed by reclamation (Fig. 5), but the shoreline had advanced seaward about 4 km. Because the newly reclaimed area was basically low-lying floodable land surrounded by earthen breakwaters called *oki zutsumi*, flooding due to tsunamis and storm surges could easily occur. We call this area Nishi (west) Osaka. Fortunately, most people lived in the central area which was bounded on the west by the Kizu River and on the south by Doutonbori (Fig. 4). Settlements in the Shinden (newly reclaimed area) were not widespread, the land being used for cultivation.

After the Meiji Restoration in 1868, the urbanization and industrialization of Osaka accelerated. Its cotton spinning industry was known as the "Manchester of the East". Also at that time, a master plan for the reconstruction of Osaka Port was enacted to promote overseas and domestic shipping. It included dredging work and the construction of breakwaters and quays. In 1900, the new Yodo River was constructed as a flood protection measure. In the early 1930s, land subsidence began due to the pumping out of ground water for use in industries, and it continued until 1975, at which time regulatory laws were passed that have been very effective in cutting down on the usage of ground water. The subsidence rates between 1935 and 1976 are given in Fig. 6. The maximum rate of subsidence was 2.8 m near the mouth of the Aji River.

3. HISTORICAL CHANGES IN THE RISK TO LIFE DURING STORM SURGE DISASTERS

3.1 *Changes in Population*

In this section we show that a storm surge disaster is one of the most dangerous natural disasters. Risk to life, which is defined as the ratio of the number of dead to the population at that time, is used as a dimensionless parameter to specify the scale of a disaster. Therefore, it is necessary to estimate the population of a particular area at the time of a storm surge disaster.

The population of Japan has increased in four waves during its ten-thousand-year history [5]. The first wave is known as the Jomon Circulation (about 4000 to 5000 years ago) and has been estimated from the number of remains and the size of the colonies found. The second wave began 2000 years ago, and continued for about one thousand years. The third increment in the population took place in the 17th century and the fourth in the 19th century (Fig. 7). For Osaka, the first descriptions of storm surge disasters are recorded in the Shoku Nihongi compiled in 753. Therefore, change in the population after the 8th century has to be studied in detail.

In 670, the Emperor Tenchi took a census, called the Kougo Nenjyaku. A second census was taken in 690 and every six years thereafter for about 20 years. After 824, the censuses became inaccurate because people did not report their actual ages and sexes in order to avoid taxation and corvee labor. Until about 1600, Japan had few official reports; therefore the population before that time must be estimated indirectly.

In 1721 and 1725, the Tokugawa Shogunate took a detailed national census, the population being about 31,277,900. In Edo (Tokyo), more than half million persons lived in the world's largest castle town. Osaka was the second largest town in the country with a population of 382,471. In 1872, a Family Registration Act was promulgated which showed that the population of Japan, at that time, was 34,810,000 and that of Osaka 259,986. Modern census taking was established in 1920, and continues today.

Before 1868, Osaka belonged to Settsu Prefecture, and most storm surge disasters occurred in Settsu and Harima a neighboring prefecture on the west (Fig. 8). The population of Osaka (Osaka here corresponding to the name Osaka Sangou used from 1603 to 1867; thereafter, Osaka City) was reported first in 1625. Before that year, therefore, we must use the prefectural

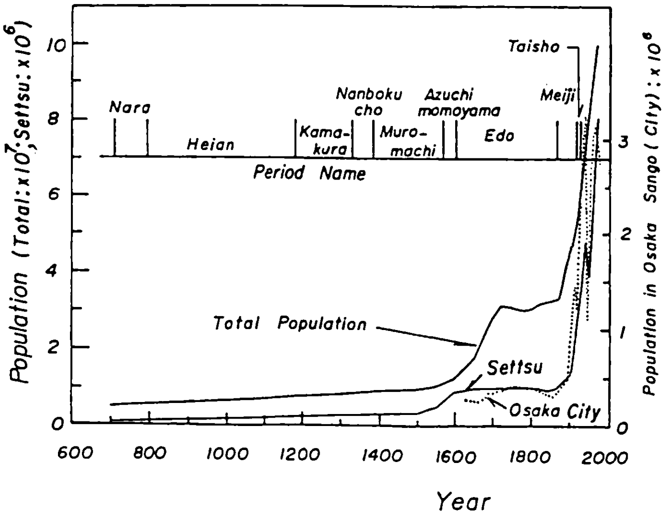

Fig. 7 Historical changes in the total population of Japan, and of Settsu and Osaka Prefectures after 700.

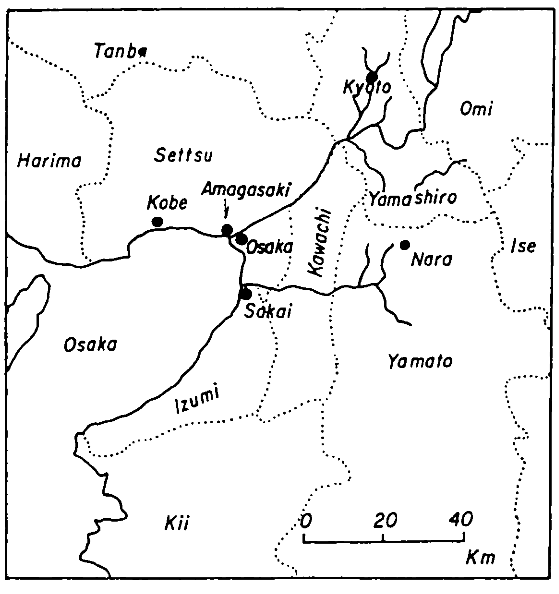

Fig. 8 Names and areas of old administrative units that existed between 1600 and 1867.

population to evaluate the risk to life.

3.2 *Review of the Risk to Life after the Eighth Century*

Changes in the risk to life as well as in the number of dead due to storm surge disasters since 700 are shown in Fig. 9. The scale for the abscissa is enlarged after 1850 for convenience. Note that before 1900 the order of the risk to life was about 10^{-3}. Recent reports show that now in Japan the order of the risks to life due to traffic accidents and natural disasters are 10^{-4} and 10^{-6}. In the U.S.A., the risk to life due to hurricanes is in the order of 10^{-7}. Clearly, historically storm surges in the Osaka area have been very dangerous. The value 10^{-3} shows the high danger potential of storm surges in this area because there were no countermeasures taken before the 20th century.

Storm surge disasters in which nearly 1000 people or more have died have occurred seven times in the past 1200 years, extremely strong storm surges striking Osaka at intervals of about 200 years on the average. In the literature, 53 storm surge disasters have been recorded for the Osaka area, some being grouped very close together (Fig. 9).

Storm surge disasters since 1900 are shown in Fig. 10. There were three big ones caused by the Muroto (1934), Jane (1950) and Daini Muroto (1961) Typhoons. The paths of these typhoons are shown in Fig. 1. Before the Muroto Typhoon, there was no modern weather forecasting system nationally or locally. After 1934, meteorological observations by aircraft and

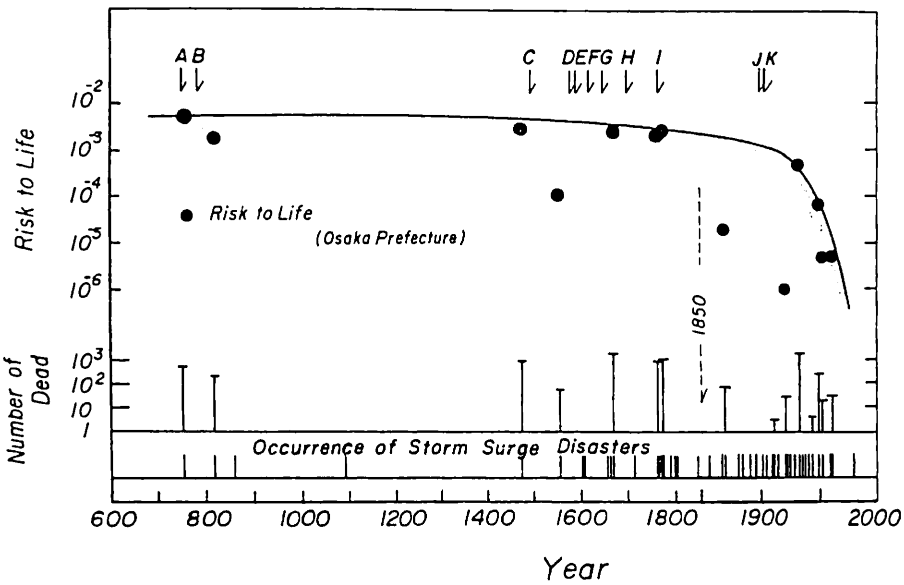

Fig. 9 Changes in the risk to life and the number of dead due to storm surge disasters in Osaka over 1200-year period.

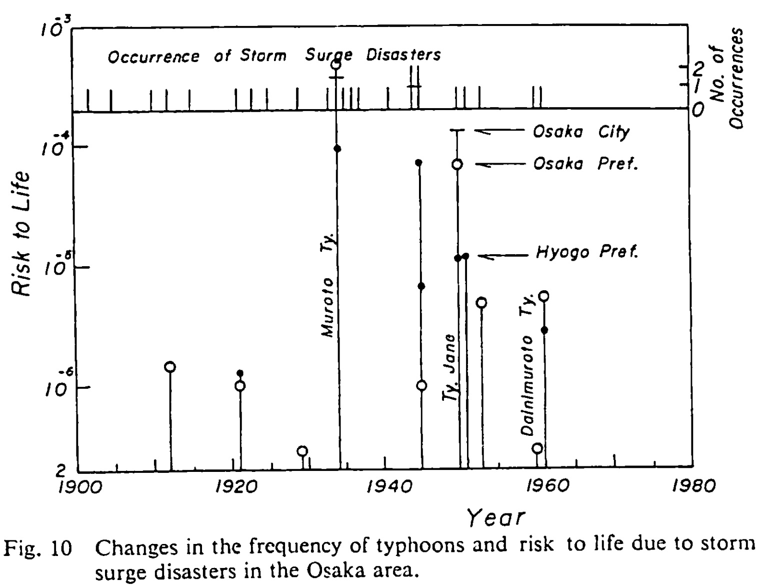

Fig. 10 Changes in the frequency of typhoons and risk to life due to storm surge disasters in the Osaka area.

hard, preventive countermeasures, such as building anti-flood breakwaters and embankments in coastal lowland areas were started. Because of the establishment of countermeasures against storm surge disasters, the order of the risk to life was reduced to 10^{-7} for the storm surge that accompanied the Daini Muroto Typhoon in 1961.

3.3 *Characteristics of Storm Surge Disasters from 700 to 1600*

At the beginning of the eighth century, Naniwa prospered on Uemachi Hill and at the west foot of the hill, were located the foreign trading ports of Naniwazu and Tamatsukurie which traded with China. In 744 (A in Fig. 9), the capital was moved from Yamato (Nara) to present-day Osaka. In 788 (B in Fig. 9), the construction of the Horie canal being dug at the southern foot of Uemachi Hill was stopped. It is estimated about 90,000 people lived in this area.

In the documents studied, the first storm surge disasters reported in Japan were in 701 on Awaji Island and in Harima (present Hyogo Prefecture). In 753, a storm surge disaster took place at Mitsuura, Settsu (present Osaka Prefecture) in which according to the Shoku Nihongi about 560 people were killed. Therefore, the risk to life is estimated to have been greater than 10^{-3}. Along the west foot of Uemachi Hill, a sea cliff developed which later changed into a wave-formed beach. It is believed that most people lived in this narrow area along the coast. In those days, sand banks had already developed, and the water had become shallow in adjacent areas. Therefore, small villages located in this area probably were the worst defensive position when storm surges were generated.

No report of storm surge disasters in Osaka has been found for the period of 1000 to 1500. In all of Japan, only seven storm surge disasters have been reported for this period [2]. Therefore, the situation at Osaka probably was the same as that for the whole country. The reason why so few meteorological records remain from this period is that national politics was very unsettled, the center of political power shifting from Kyoto to Kamakura, located about 40 km southwest of Tokyo, between 1185 and 1222 and back again in the 1300s. And from that time until 1600 the country was swept with intermittent wars. During these years of political confusion, it was difficult to preserve any official documents and reports about natural disasters.

The number of typhoons per 12 years that hit Japan remained nearly constant during this unsettled period [6]. Changes in the total number of typhoons that have passed through the Kyoto area in 12-year spans from 710 to today are shown in Fig. 11. The 12-year period is a convenient interval with which typhoons have struck Japan over the past one thousand years. We concluded that the decrease in the number of storm surge disasters reported is mainly owing to the loss, or lack, of documents and reports due to political instability.

During the medieval period (1200–1600) there was no active urbanization around Uemachi Hill except in the temple towns of Yuuhigaoka and Tamatsukuri and the port town of Watanabeno-tsu. The important ports were located near relatively deep water areas such as Amagasaki and Hyogo, and in the 16th century at Sakai. These deep water ports were not affected by the delta of the Yodo River. Only small fishing villages were scattered along the west side of Uemachi

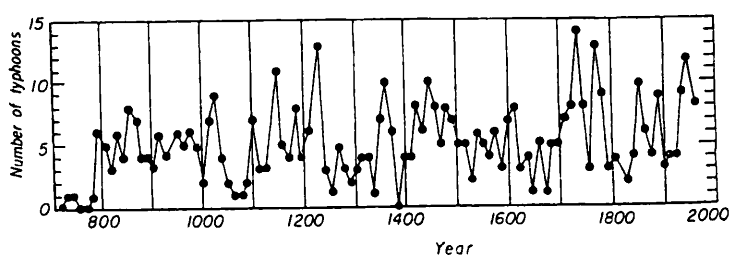

Fig. 11 Changes in the number of typhoons passing through Kyoto since 700 (12-year periods) [6].

Hill. In 1470, the Shin Sect priest Rennyo constructed Ishiyama Honganji Castle on Uemachi Hill and many Shin believers gathered in this area. Historical documents show that in this period storm surge disasters occurred twice, at Sakai (1475) and at Amagasaki (1557).

In 1583, the Civil Dictator, Hideyoshi Toyotomi, constructed Osaka Castle on Uemachi Hill (D in Fig. 9) as well as surrounding residential areas. At that time, the Kawachi Lowland was almost silted up with sediment that had accumulated from the flooding of the Yodo and Yamato Rivers. The discharge of sediment from the north end of Uemachi Hill rapidly increased, and flooding was frequent in the midstream areas of the Yodo and Yamato Rivers; therefore, about 1590 Hideyoshi constructed new banks to improve river channels which were called *bunroku-tei* and *taikou-zutsumi, tei* and *zutsumi* meaning bank or levee (D in Fig. 9). The Yodo delta also had advanced.

3.4 *Increases in Storm Surge Disasters from* 1600 *to* 1900

In the year shown by F in Fig. 9, the Tokugawa Shogunate reclaimed the coastal lowland around Osaka in order to have new cultivated land to tax. The merchants residential area had enlarged rapidly in the central part of Osaka (G). The newly reclaimed land acted as the buffer against flooding by storm surges and tsunamis, but because of the increase in population and proliferation of business and industry, many people soon were living on reclaimed coastal sites. Severe storm surge disasters that killed more than one thousand people occurred three times between 1600 and 1900 and, during these years, two disastrous tsunamis hit Osaka. The risk to life in this period was estimated to be greater than 10^{-3}. The maximum population in Osaka was about 410,000 in 1700. The rerouting of the Yamato River in 1704 produced an accumulation of sediment near Sakai which thereafter became prone to strikes by large storm surges.

Prior to the 20th century, people did not understand the nature and causes of typhoons; violent winds were called *kamikaze*, or god winds. When flooding occurred along with *kamikaze*, people considered the disasters *tensai*, "produced by the gods". Local feudal lords were responsible for the control and prevention of flood disasters, and were ordered by the shogunate to preserve residential and cultivated areas from flooding. The official reports of disasters submitted to the Tokugawa Shogunate often were fabrications, damages being underestimated in order to show the local lord in a good light. Because of this, data on the number of dead are very scarce in the many official reports and documents. In addition, after flooding large numbers of harmful insects appeared which are the crops and caused famine. Historically, this has been the typical cycle of natural disasters throughout Japan.

According to the Kanbunroku report and the private diary Yamaga Sokou Sensei Nikki, more than 2000 people died in 1670; also, and nine wooden bridges were destroyed by big ships that were set adrift by storm surges. The estimated area flooded and the location of the destroyed bridges are shown in Fig. 12, together with the number of people who died along the coast due to broken river banks and breakwaters. The area flooded is nearly the same as that flooded by the Ansei Nankaidou tsunami in 1854 [7], for which the estimated astronomical tide is shown in Fig. 13. That storm surge struck about noon, which means that it occurred at about the time of the mean sea level.

In 1897 (J, Fig. 9), a construction office was opened at Osaka Port. It was established to construct relatively deep berths as steamships could not enter the very shallow waters of the port because of sediment transported by the old Yodo River. In 1900 (K, Fig. 9), the old Yodo River was rerouted as shown in Fig. 3. Fortunately, no severe storm surge disasters were generated between 1850 and 1900.

3.5 *Effects of Hard and Soft Countermeasures after* 1900

Since 1900, regular tidal observations have been made at Osaka Port (the first in 1873, but with an interruption of 17 years from 1883 to 1900). The annual highest tides at Osaka Port

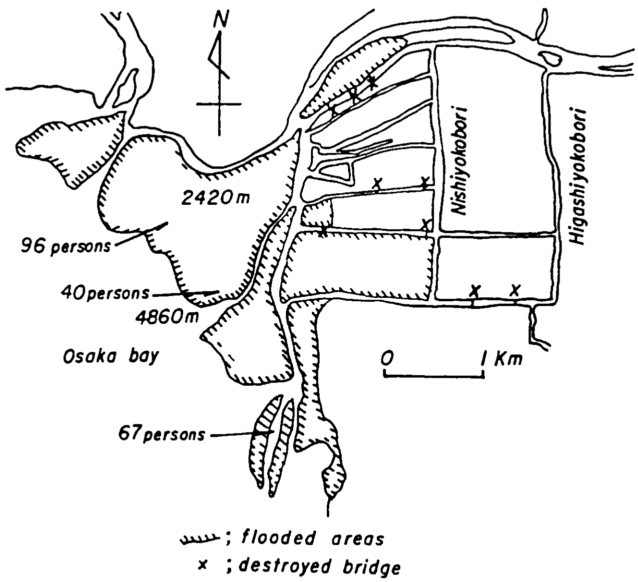

Fig. 12 Estimated area flooded due to storm surges in 1670 and locations of destroyed bridges (Numbers indicate the number of persons who died because soil-made break-waters along the shoreline of Osaka broke and the length of broken river banks and breakwaters).

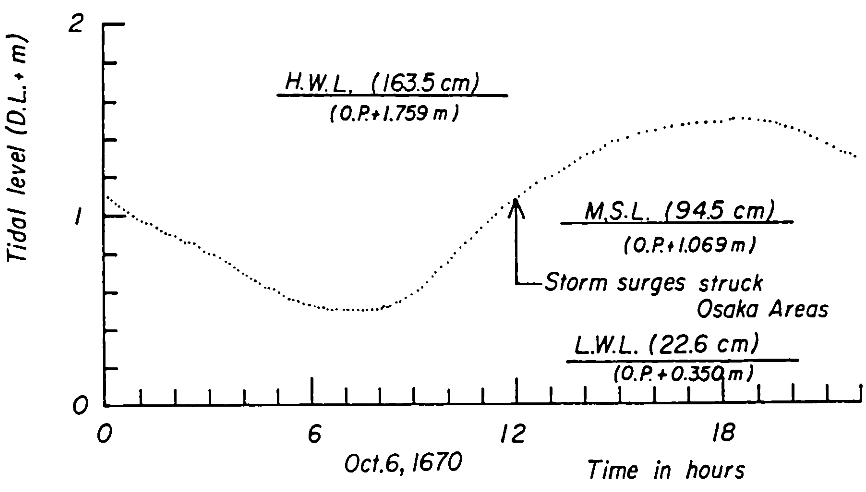

Fig. 13 Astronomical tidal levels estimated with 40 tidal components for Oct. 6, 1670 when the Kanbun storm surges struck Osaka.

after 1900, together with those at Kobe, Kushimoto and Tannowa are shown in Fig. 14. There have been three big storm surges during this period. The characteristics of recent typhoons and their accompanying storm surges are summarized in Table 1. In the first quarter of the 20th century rapid business and industrial expansions took place due to the large demand for industrial products after the First World War. In the port area, coastal sea dikes were cut in some places to facilitate loading and transportation. Moreover, because of the long absence of storm surge disasters, people tended to forget about them. In 1934, the biggest recorded storm surge, generated by the Muroto Typhoon, struck Osaka in the early morning of September 21st. Hourly

Table 1 Characteristics of the Muroto, Jane and Daini Muroto Typhoons and their accompanying storm surges.

Items	Muroto Typhoon	Typhoon Jane	Daini Muroto Typhoon
Date	Sep. 9, 1934	Sep. 3, 1950	Sep. 16, 1961
Lowest atmospheric pressure (mb)	954.3	970.3	937.3
Moving velocity of typhcon (km/hr)	60	58	50
Maximum mean wind velocity for ten minutes (m/s)	42.0	28.1	33.3
Instantaneous maximum wind velocity (m/s)	more than 60	44.7	50.6
Highest tidal levela bove O.P. (m)	4.2	3.85	4.12
Total precipitation (mm)	22.3	62.2	44.2
Maximum anomaly (m)	2.92	2.37	2.45

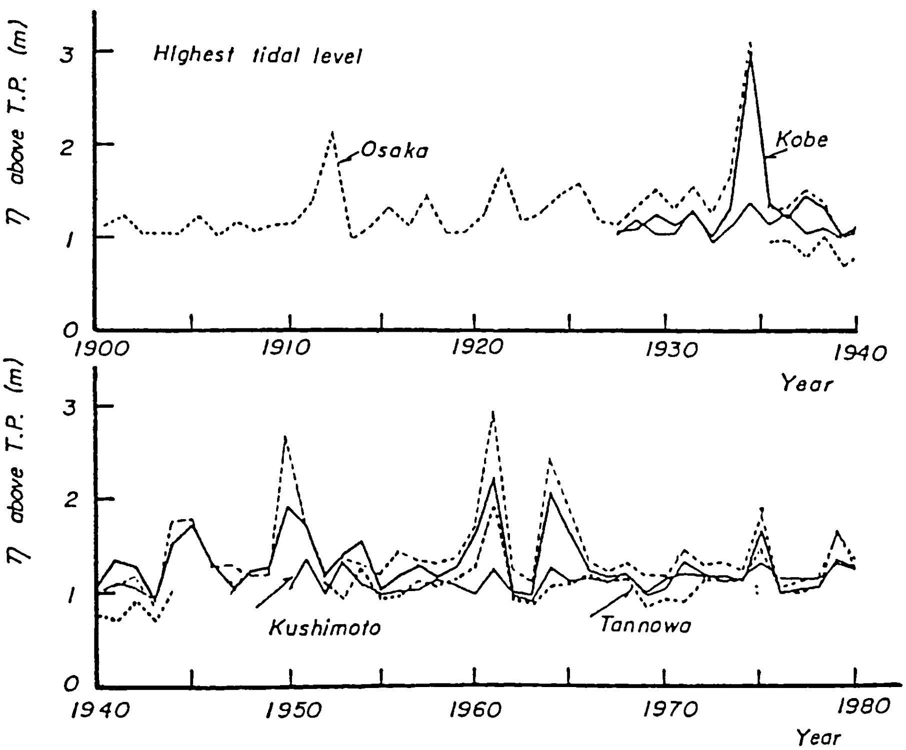

Fig. 14 Annual variations in the highest tides at Osaka, Kobe, Kushimoto and Tannowa.

changes in the level of the tide above O.P., which corresponds approximately to the low water in Osaka Port, are shown in Fig. 15. The area flooded is shown in Fig. 16. In these figures, the storm surges generated by Typhoon Jane in 1950 and the Daini Muroto Typhoon in 1961 are shown for comparison.

After the Muroto Typhoon, both soft and hard countermeasures against storm surges were greatly improved. In particular, a typhoon warning system was developed based on data collected by aircraft and meteorological radars. The construction of embankments in low-lying coastal areas was begun in 1934 and has been very effective in reducing the damage caused by storm surges. Embankments totalling about 1,323 ha (Fig. 17) were constructed. To make them, sediment was dredged from the bottoms of the Aji, Kizu and Shirinashi Rivers and piled

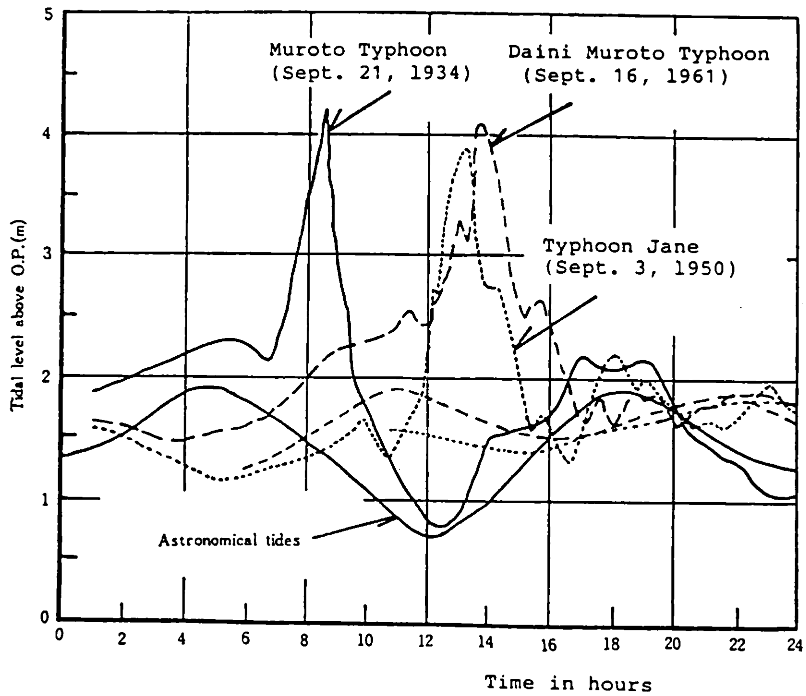

Fig. 15 Tidal curves in Osaka during Typhoon Jane, and the Muroto and Daini Muroto Typhoons.

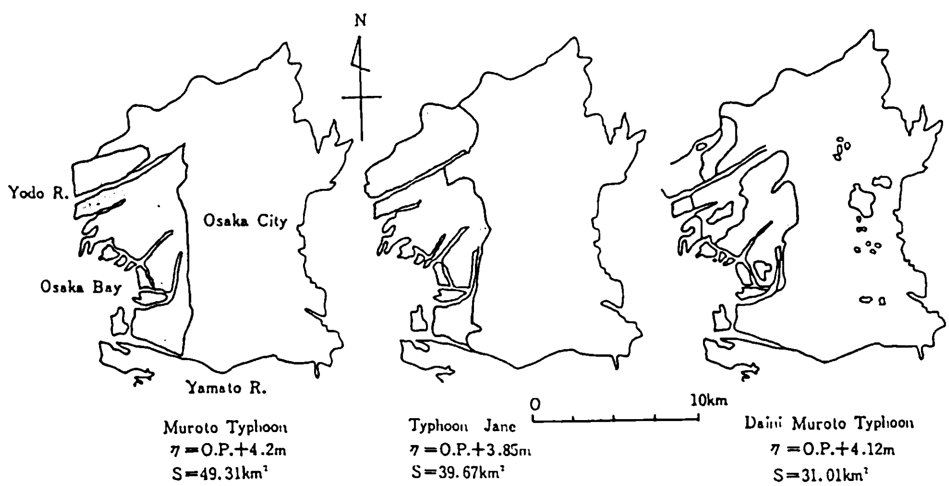

Fig. 16 Areas in Osaka City inundated with flooding due to storm surges accompanying Typhoon Jane, and Muroto and Daini Muroto Typhoons.

up to an average of 2 m (O.P.+3.5 m). During late embankment construction, Typhoon Jane struck, but flooding was remarkably reduced by the embankments already in place.

Changes in the establishment of other hard countermeasures; preventive construction such as dikes and locks, took place as follows: During the first stage of the storm surge countermeasure project, dikes were built along rivers and canals, and harbor areas were constructed. Because maps showing the earliest constructions were lost because of war, they can only be listed; (1)

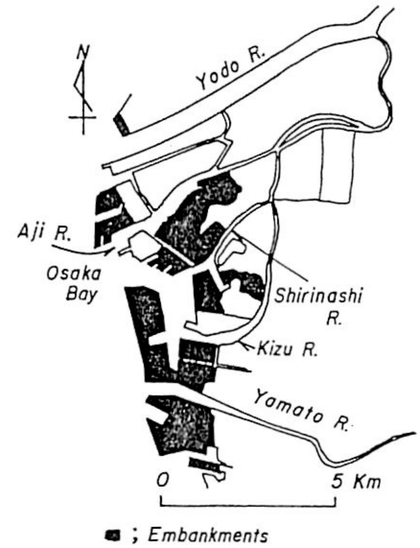

Fig. 17 Locations of embankment areas (+2 m above ground level) built after 1934.

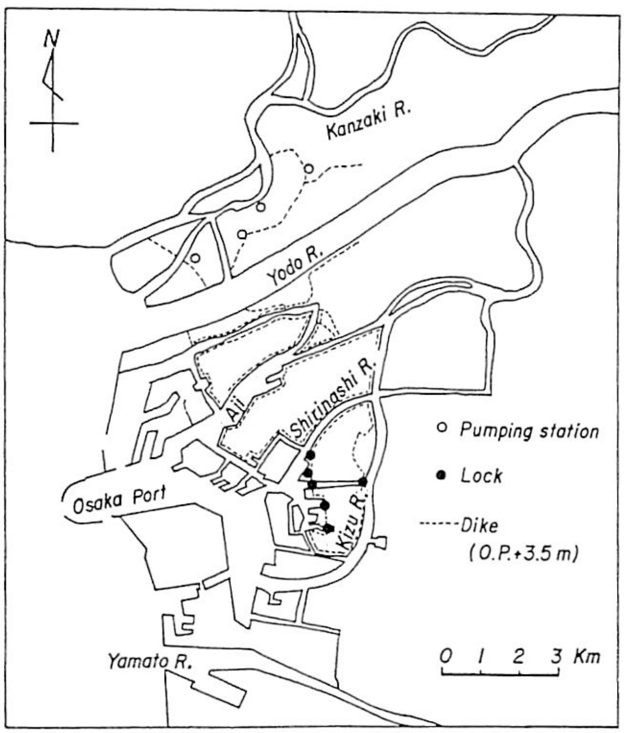

Fig. 18 Map showing hard countermeasures taken in the Osaka area between 1946 and 1950.

Anti-flood walls along rivers and canals; 16,520 m (O.P.+3.5 m). (2) Dikes in harbor areas (O.P.+3 to 3.5 m) made of wooden piles 2,880 m, of concrete 7,140 m and of soil 1,060 m. (3) Breakwaters totalling 11,080 m, of which newly constructed ones total 6,780 m and those of reinforced concrete 4,300 m.

After the Second World War, a second (urgent) anti-storm surge disaster project was begun, the main purpose of which was to repair old dikes destroyed by bombing or by land subsidence. Temporary dikes totalling about 50 km were constructed (Fig. 18). Because of insufficient money and building materials, most dikes were constructed of rubble, cinder and used brick. The height for these dikes was O.P.+3.5 m. A third (permanent) construction project lasted three years from 1949 to 1952, in which reinforced concrete was used and dikes were extended more than 36 km. The height for these dikes was O.P.+4 m in the harbor area, 3.8 m along the main rivers and 3.5 m elsewhere. Included in this 3-year project was the construction of pumping stations and small locks (Fig. 18). This project was briefly interrupted by Typhoon Jane in 1950.

The fourth project was begun in 1950. Dikes along rivers and canals in the Osaka area were constructed as the first step (Fig. 19). The second step, the construction of locks, was started in 1965. Three locks of nearly the same size, having arch gates with spans of 57 m and clearances of O.P. +12.5 to 28.7 m, were built at the mouths of the Aji, Shirinashi and Kizu Rivers. They were the biggest in the world at that time and symbolized the entire flood prevention project. The total length of the dikes that were reconstructed was more than 250 km. Another 26 locks and 38 pumping stations also have been constructed. Fortunately, there has been no big storm surge since this project began.

The latest hard countermeasures undertaken consist of the construction of three big locks at the same river mouths and anti-flood dikes with heights of O.P.+5.7 m outside of the locks and O.P.+4.5 m within them. When the Daini Muroto Typhoon struck Osaka, about 100,000 people

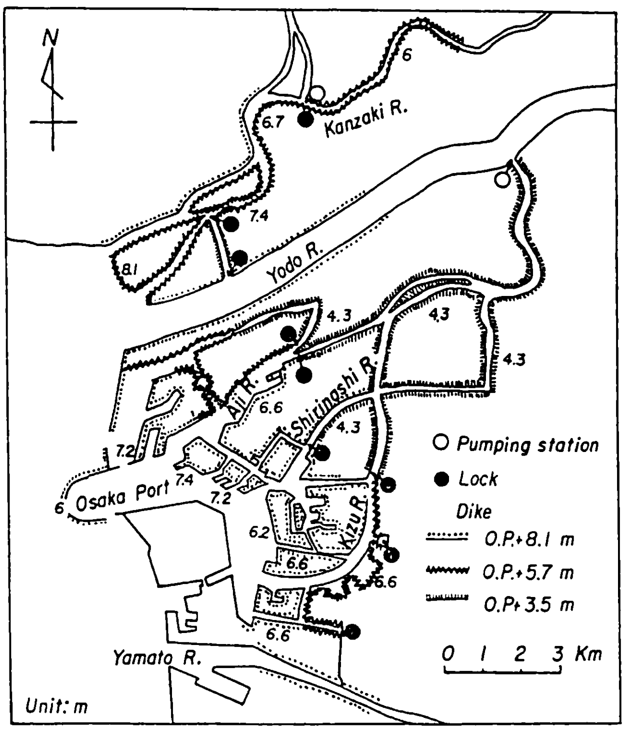

Fig. 19 Map showing hard countermeasures taken in the Osaka area after Typhoon Jane (1950).

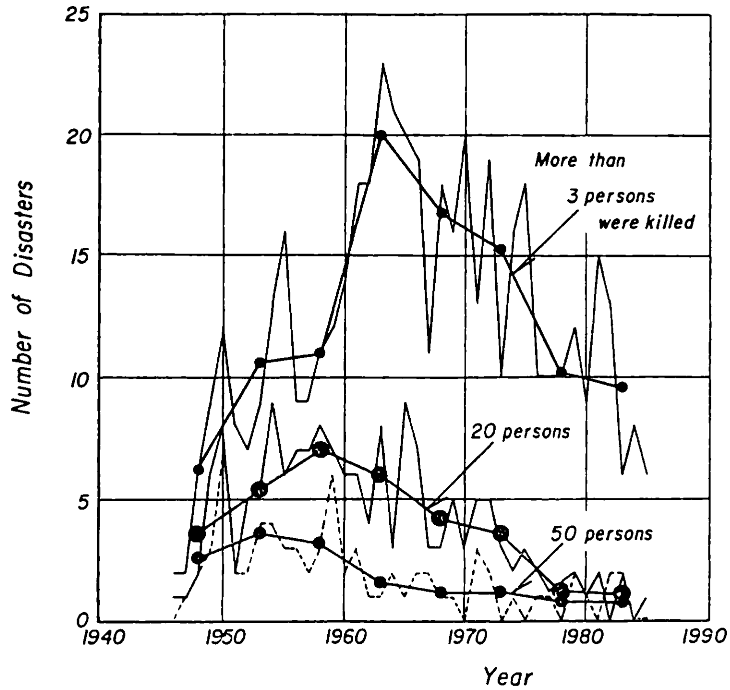

Fig. 20 Changes in the number of disasters caused by typhoons and heavy rainfall (Black circles: 5-year averaged values, Numerals: Number of people killed).

in the coastal area had already taken refuge in public buildings such as schools and local government offices. Therefore, there were no human victims of its accompanying storm surge. Also, in spite of substantial land subsidence, damage was caused only by water overflowing the concrete dikes, not by breakage.

In natural disasters caused by typhoons and local heavy rainfall, the taking of soft and hard countermeasures leads to a remarkable reduction in damage [1]. This tendency became very clear after the Ise Bay Typhoon (1959), as shown in Fig. 20 which summarizes historical changes in the number of disasters caused by storm surges, floods and landslides in the Japanese archipelago. In this figure, the thick lines were obtained for an average period of five years. In the storm surge disasters that accompanied the Ise Bay Typhoon, about 5000 people were killed, this large loss of lives was seen to mainly be due to the lack of accuracy and thoroughness for the disaster information disseminated and to the lack of taking of refuge [8].

Disasters in which more than 50 people have died have decreased since the Ise Bay Typhoon, but loss of life in disasters such as debris flow and landslides was high up to 1950. Recently, loss of life in such disasters has tended to decrease, probably because of the decrease in typhoons that have struck Japan and the improvements made in soft and hard countermeasures taken against disasters.

4. RETURN PERIOD OF HUGE STORM SURGE DISASTERS

In Japan, the longest, official tidal records kept are for Kobe, covering about 80 years as of 1986. In Osaka, old data include the effects of subsidence, but only about 60 years of tidal records can be used for analysis. When hard countermeasures against storm surge disasters, such as sea dikes and locks, are planned, it is necessary to determine the highest tidal level in relation to specific return periods. Usually, the return period used in the planning of these countermeasures is taken from the limited tidal records, so that extrapolation of the data by statistical analysis is necessary. Consequently, the predicted tidal levels generally include some error. Therefore, by also making an historical analysis, the applicability of the statistical results can be generally verified.

We previously have proposed a new approach, based on the direction of a typhoon's track, which can be used to determine the probability of extremely high tides due to storm surges, as well as their return periods [3]. The frequency distributions for the highest tides and maximum

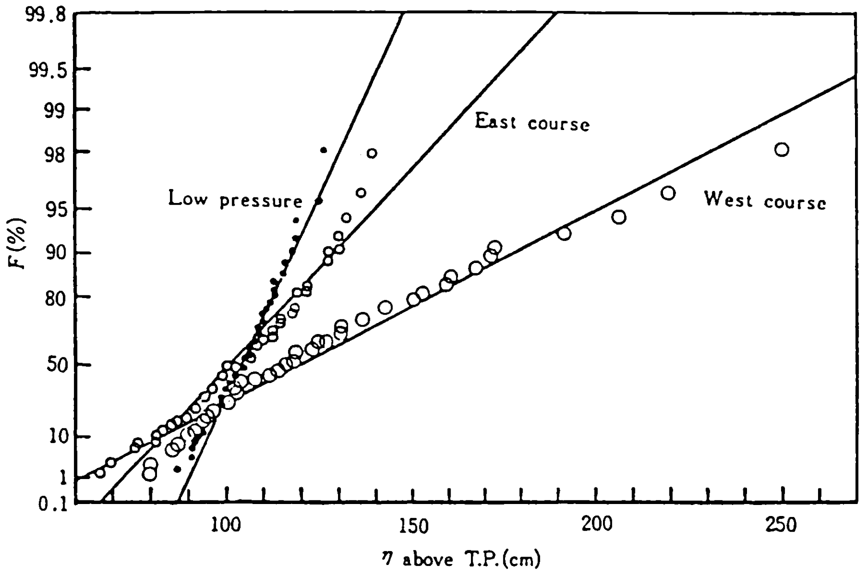

Fig. 21 Gumbel distribution showing the highest tides in Kobe for east- and westbound typhoons and cyclones [3].

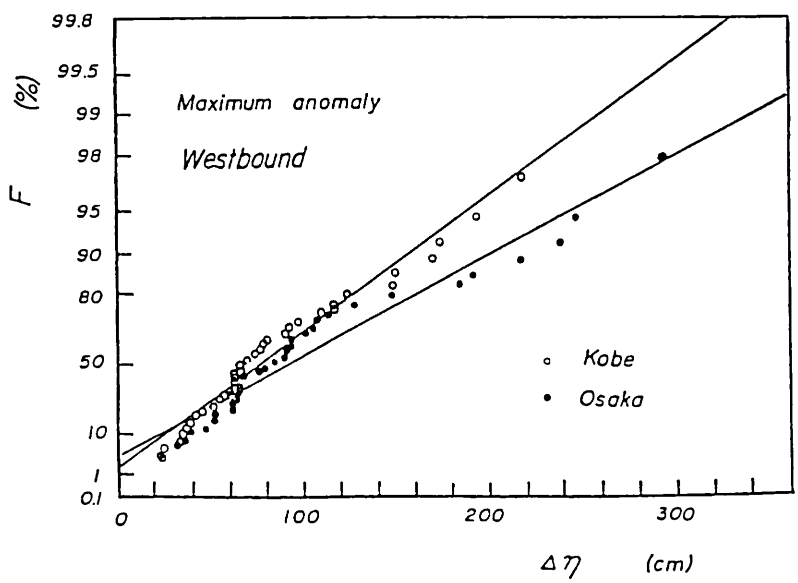

Fig. 22 Probability of the occurrence of maximum anomalies generated by typhoons passing west through the Osaka and Kobe areas [3].

anomalies in Osaka and Kobe, obtained by our analytical method, are shown in Figs. 21 and 22. In Fig. 21, T.P. is equal to O.P.+1.2 m. The fit of the data to a Gumbel distribution is fairly good in comparison with traditional methods. In particular, the scattering of the data is much improved for a portion of the relatively high tidal levels and the maximum anomalies generated by typhoons passing along the western side of Osaka Bay.

A comparison of Figs. 12 and 16 shows that the areas flooded are similar; therefore, the scale of the storm surges may be nearly same. The return period of the maximum anomaly in Osaka at the height of 3.5 m (which is somewhat larger than that of the Muroto Typhoon) is about 120 years. The historical changes in storm surge disasters show that severe storm surges have occurred seven times in about 1200 years. The mean interval of occurrence is about 200 years (if the Daini Muroto Typhoon is included, 170 years). But, it is necessary to be careful with the historical data as the lack of documents that describe storm surge disasters between 900 and 1400 has been pointed out. When this omission is taken into consideration, the mean interval is estimated to be about 150 years, so that the historical estimated mean interval still agrees fairly well with the statistically obtained values we have reported.

5. CONCLUSIONS

Changes in storm surge disasters in the Osaka area for approximately 1200 years were obtained from historical documents, public and private. In order to study the effects of hcanges in the natural and social environments on storm surge disasters, we first investigated changes in the topography and social situation in this area. Seven huge storm surges, in which a thousand or more people were killed have struck Osaka during the past 1200 years. Before 1900, the order of the magnitude of risk to life was 10^{-3}, which seems to be the upper potential of storm surge disasters because before that date there were few, or no countermeasures taken. The mean interval of the occurrence of severe storm surge disasters is about 150 years, which has been verified by our statistical analysis of recent high tides.

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