

CHAPTER 57
THE DAMAGES OF COASTAL DIKES AND RIVER LEVEES
AND THEIR RESTORATION

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The coasts of Ise Bay and Atsumi Bay were damaged by two big storm surges during the recent seven years, one was the Ise Bay Typhoon in 1959 and the other the Typhoon No.13 in 1953. In this report the aspect of storm surge due to the Typhoon No.13 and the restoration design of the coastal-dikes are described. Then the feature of damages of the coastal-dikes by the Ise Bay Typhoon are compared with the former and the restoration plans are explained.

STORM SURGES DUE TO THE TYPHOON NO.13, 1953 AND RESTORATION OF THE
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General aspect of storm surges

The Typhoon No.13 landed on the Japan island on the 25th of Sept. 1953 at the southern point of Kii peninsula at 15 o'clock, passed through Toba which located near the inlet of Ise Bay at 18 o'clock and advanced northeast with the velocity of 56 km/hour. Crossing the Atsumi Bay, it passed through Okazaki City at 19 o'clock. This Typhoon was different from the Ise Bay Typhoon in its course. The former moved from the inlet of Ise Bay to the Atsumi Bay, and the coast of Atsumi Bay was heavily damaged. As Nagoya district is located on left side of the course of the typhoon No.13, the damages were comparatively small.

In Fig.4.2 the records of the wind directions, wind velocities and atmospheric pressures at several places are shown. In Fig.4.2-a those on right side of its course, and in Fig.4.2-b, those on left side on its course are indicated. On the right side of its course the wind directions at the maximum wind speed were SE - ESE, while on the left side of its course were E - WNW.

In Fig.4.3, deviations from the astronomical tide at each place within the bay are shown, and we see that its maximum value of 1.6 m was recorded at Toba at 18 o'clock, and 1.4 m - 1.5 m at other places.

As shown in Fig.4.2 the lowest atmospheric pressure was about 970 mb. which occurred about 0.4 m statical rise of sea surfaces. Judging from Fig.4.3, we can estimate that in the first place the

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sea-water flew into the Ise Bay through inlet due to the strong wind of SE, and 1 or 2 hours later it flew into Atsumi Bay from the Ise Bay. Furthermore we find out that during about 8 hours from 13 (approached time of typhoon) to 21 o'clock, the total volume of water in Ise Bay and the Atsumi Bay both considerably increased as comparing with the volume before the typhoon reached. It is clear that much sea-water flew in through Irako. So the volume of inflow from open sea must be an important factor for the storm tide in the bay differing from the one in the closed basin.

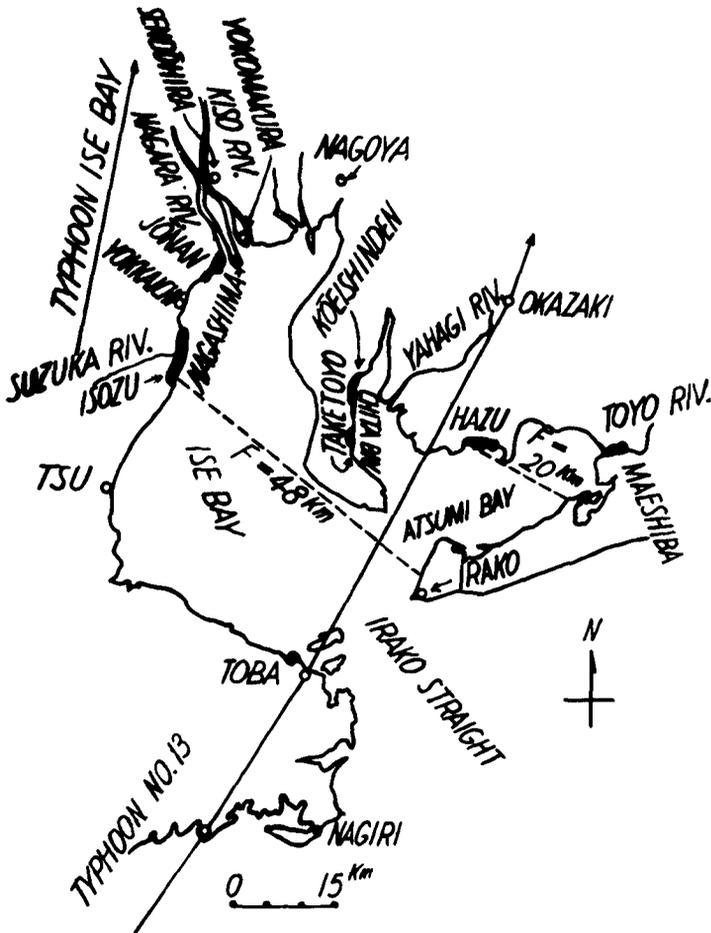


Fig.4.1 Outline map of Ise, Atsumi and Chita Bay.

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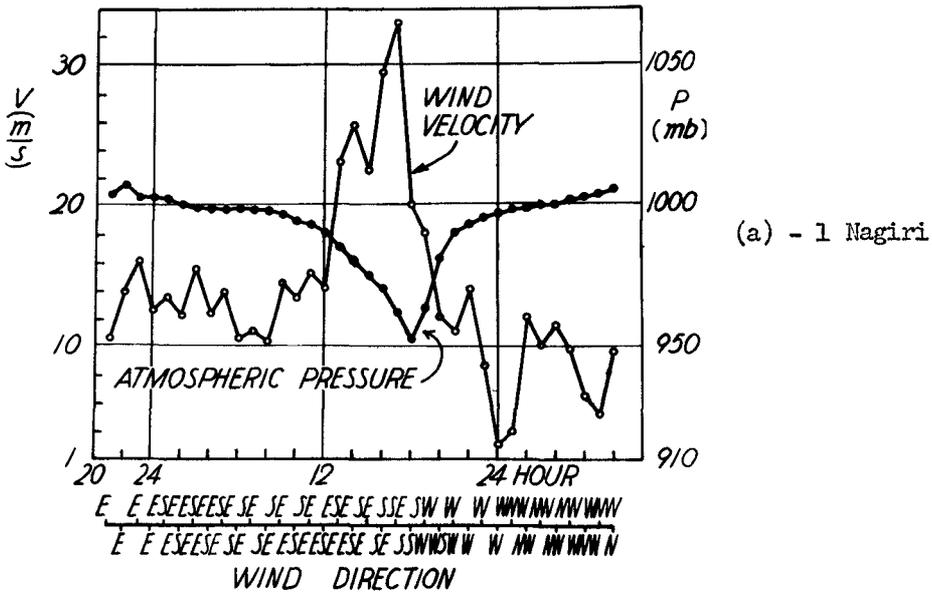
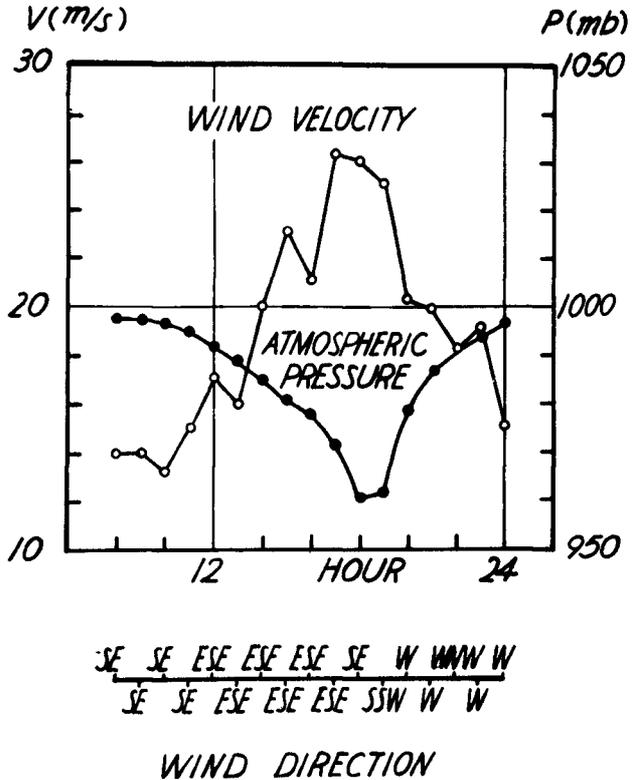
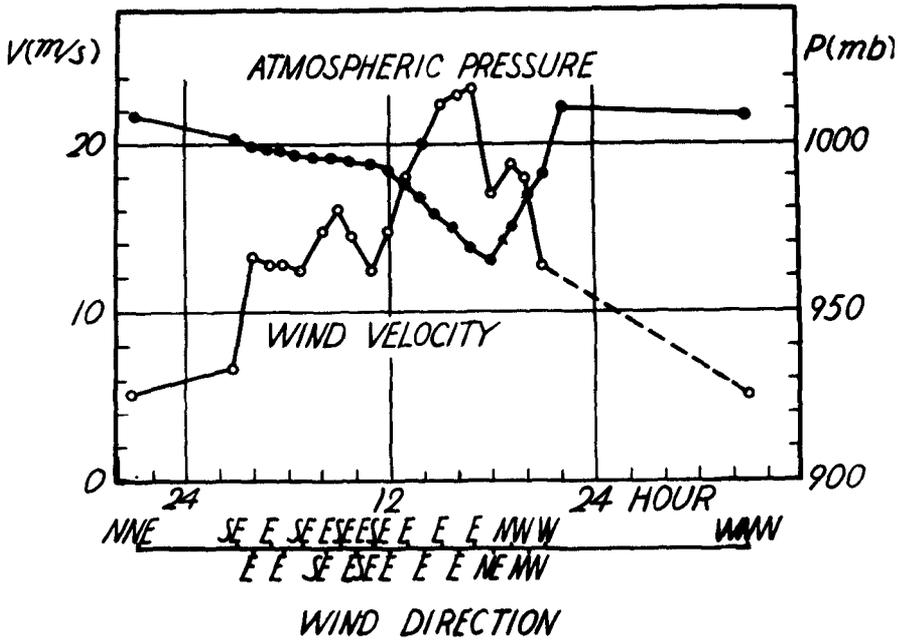


Fig.4.2 Weather Condition at each place on the occasion of the Typhoon No.13.

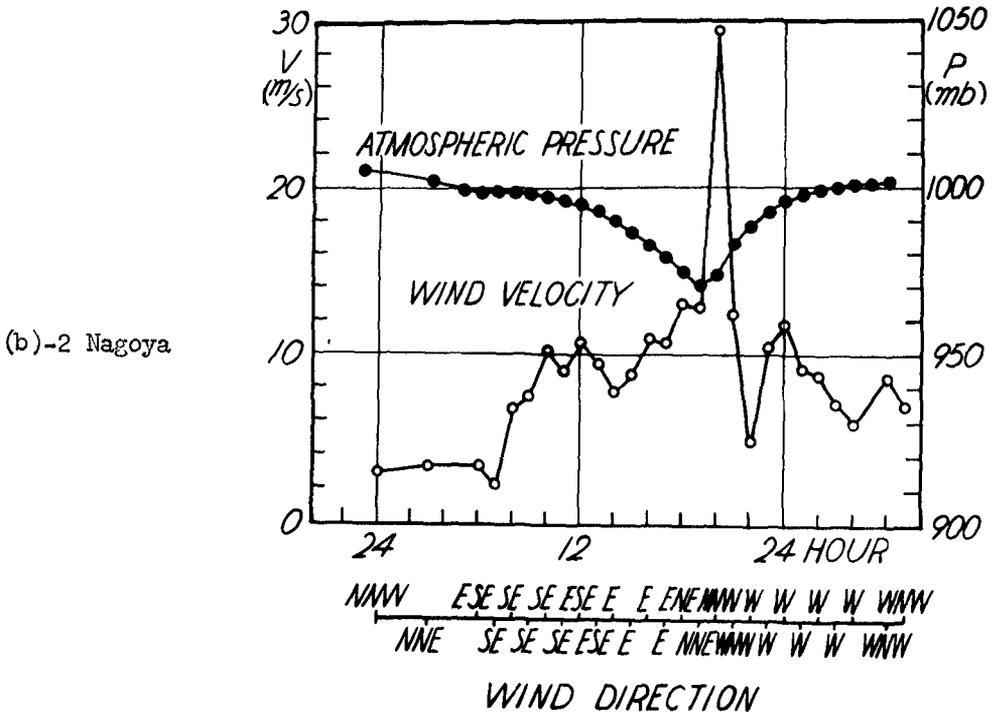
(a) - 2 Irako



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(b) - 1 Tsu



(b) - 2 Nagoya

Fig.4.2 Weather condition at each place on the occasion of the Typhoon No.13.

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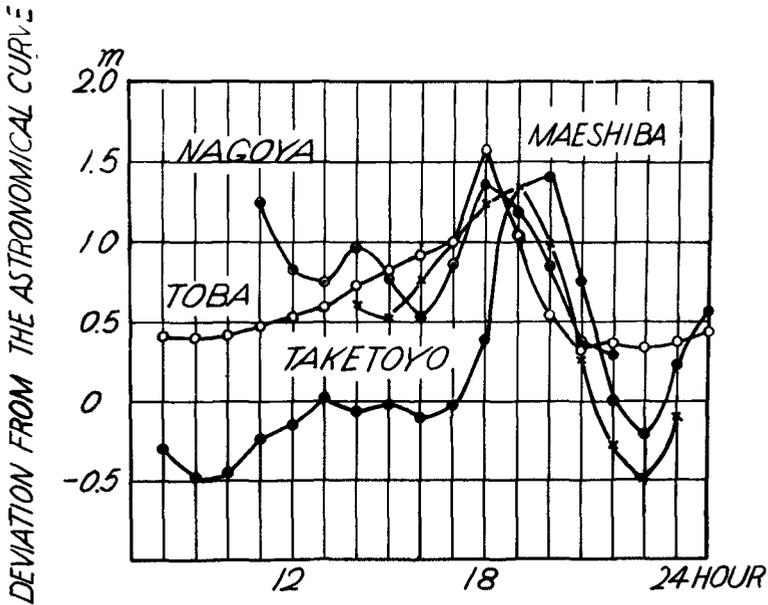


Fig.4.3 Deviation from the astronomical tide at each place on the occasion of the typhoon No.13.

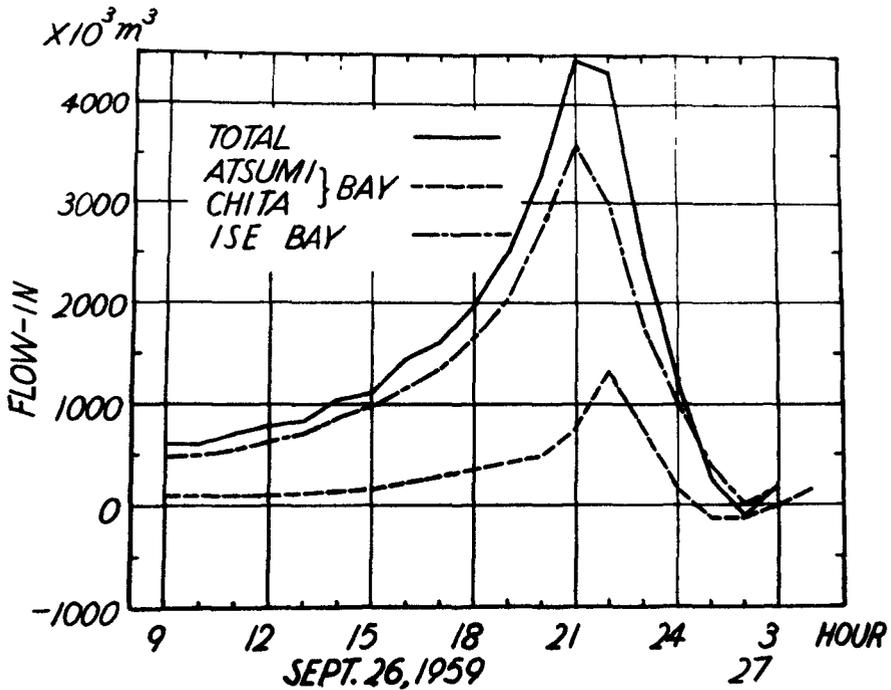


Fig.4.4 Sea water volume flowing into each bay on the occasion of the typhoon No.13.

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Such a phenomenon also occurred in the attack of the Ise Bay Typhoon. Fig.4.4 shows the total volume of inflow into the bay which was calculated by using the simultaneous deviations of water level from the astronomical tide at several points in the attack of Ise Bay Typhoon. From this figure, we find out that there already was extraordinary flow into the bay at 9 o'clock. So it is considered that at this time there was extraordinary inflow due to the wind set up near the entrance of the bay and that the inflow was transported in the shape of long wave due to the disturbance near the typhoon center. After this initial time, the inflow increased exponentially up to its maximum value of 450 million tons (cumulative volume) which occurred at 21 o'clock. Fig.4.5 indicated the change of SE, SSE and SW components of wind force observed at Irako Weather Station near the bay entrance. Then it is considered that the water flew into the bay from open sea by the SSE - SE component of wind force because the bay opens towards SSE - SE.

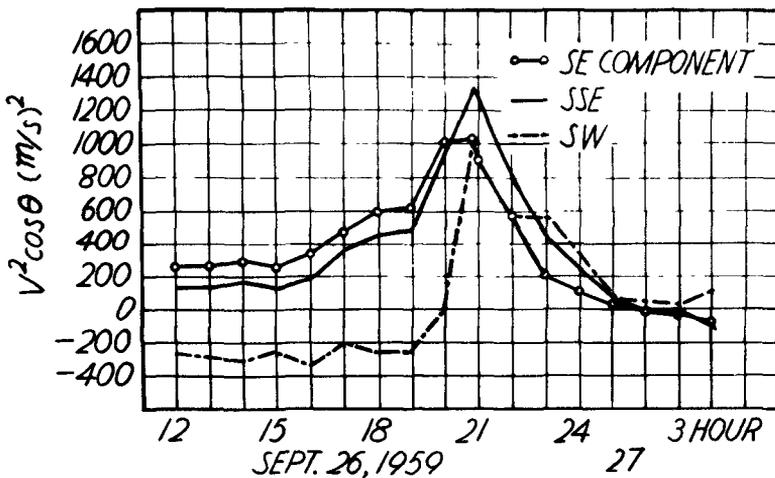


Fig.4.5 Wind force at Irako on the occasion of the Typhoon No.13.

Revised design on coastal-dikes

In Japan, the design specification on coastal-dikes was not determined at that time, and the design methods had been discussed among the engineers and related agencies. In 1953, as the studies on wind waves generated in shallow waters had not yet been developed into practice, the Ministry of Construction, Japan, made temporarily a plan to calculate the wave height by Holitor's experimental formula and to estimate the wave period by SMB method, making a comparative study of past experimental formula and observational results by T.H.Saville, while the Ministry was making studies on the wind waves.

The wave run-up on coastal-dikes of which slope are vertical to 1 on 1 was determined by Fig.4.6. These curves were proposed by the Public Works Research Institute, Ministry of Construction, combining experimental results of wave run-up with the highest wave theory in shallow waters.

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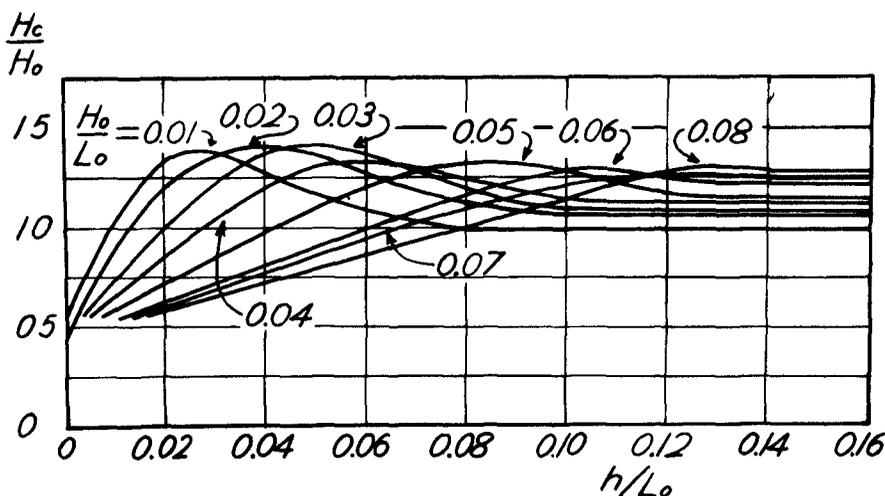


Fig.4.6 Wave run-up as a function of structure depth and wave steepness.

As the heights of dikes determined by Fig.4.6 are not always sufficient to prevent wave overtopping in the strong wind, it is also necessary to cover the back slope of dikes with solid material. Making comparative study of the design method mentioned above and the aspect of damages of coastal-dikes, we conducted the revised design.

From the records of tidal levels, we found out that the highest tidal level along the coast of Ise Bay was about 2.5 m above T.P. (T.P. is the mean tidal level of Tokyo Bay), and at the inner part of Atsumi Bay it was slightly higher, for example, the tidal level at Maeshiba was T.P. 2.80 m. The highest tidal level appeared at 18 - 20 o'clock.

To estimate the waves in bay at the time of Typhoon, we investigated the relationships between the wind velocity of E - ESE and the wind duration from wind records shown in Fig.4.2, and those were tabulated in Table 1. The longest fetch in the Ise Bay and Atsumi Bay is about 60 km, and the wind speed is 20 - 25 m/s, so the minimum duration is calculated at 3.5 - 4.0 hrs by S.M.B. method. From Table 1, it is considered that the waves at the time of Typhoon No.13 reached at stational condition at the wind velocity of 25 m/s.

Next, we made some investigations on the causes of the damages on coastal-dikes of the Hazu coast.

There were two types of coastal-dikes in this district. The first type with height of T.P. 4.92 m was covered with the concrete having thickness of about 10 cm up to the back slope. The second type was made of soil and had the height of T.P. 4.00 m, and it was covered with turf.

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Table - 4.1 The relation between wind velocity of E - ESE direction and duration on the occasion of the Typhoon No.13 at Irako and Tsu.

Duration (hr)	Mean velocity of wind (m/s)	
	Irako	Tsu
1.0	26.1	23.3
2.0	25.8	23.1
3.0	25.3	22.8
4.0	24.5	22.2
5.0	23.6	21.5
6.0	22.5	18.6

For the first type, although its back berm was scoured, its whole body was left. The second type was destroyed by scouring. It is clear that in the case of second type the waves got over it due to insufficient dike height and it is considered that the covering of first type of dikes was also insufficient. At Hazu coast, the fetch in ESE was 20 km, and it is estimated that the wave height was $H = 1.6$ m, and the period was $T = 5.0$ sec. Because the water depth at the time of maximum tides was $h = 4.4$ m, we can see from Fig.4.6 that the height of wave run-up to coastal dike become $H_c = 2.0$ m. As the tidal level is T.P. 2.70 m, the height of run-up is T.P. 4.70 m. This height is lower than that of first type of coastal-dike and higher than that of second type.

So we can explain the causes of failure as follows:

- a) The back slope of first type of coastal-dike was scoured but its body did not break down.
- b) The soil of second type of coastal-dike was scoured by wave overtopping.

From the similar calculation over about 200 km of coast line along the Ise Bay and Atsumi Bay, and the investigation on causes of damages, we obtained the following conclusions.

- 1) When the dike height is lower than the height of wave run-up as shown in Fig.4.6 and the back slope has no solid covering, the damages of dikes are inevitable.
- 2) When the dike height is as much as the height of run-up as shown in Fig.4.6, the thickness of concrete covering of back slope should be more than 10 cm.

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3) The coastal-dike of which the foundation of front slope was scoured was rare, We suppose that this is due to the large rise of tidal level and the deep water depth. So it is sufficient to use the same depth of foundation as original in making restoration design.

Based upon the results of investigation on causes of damages mentioned above, the restoration design of coastal-dikes for the Typhoon No.13 was conducted as follows:

The design tidal level was taken to be the sum of "the mean high tidal level of new and full moon" and "the maximum deviation from astronomical tide due to Typhoon No.13".

The design waves were calculated by maximum fetch at each place and wind velocity $V = 25$ m/s of Typhoon No.13, because of the change in wind direction due to the course of typhoon.

The heights of restoration coastal-dikes designed in such a steps are compared with that of original coastal-dike and are shown in Fig.4.7.

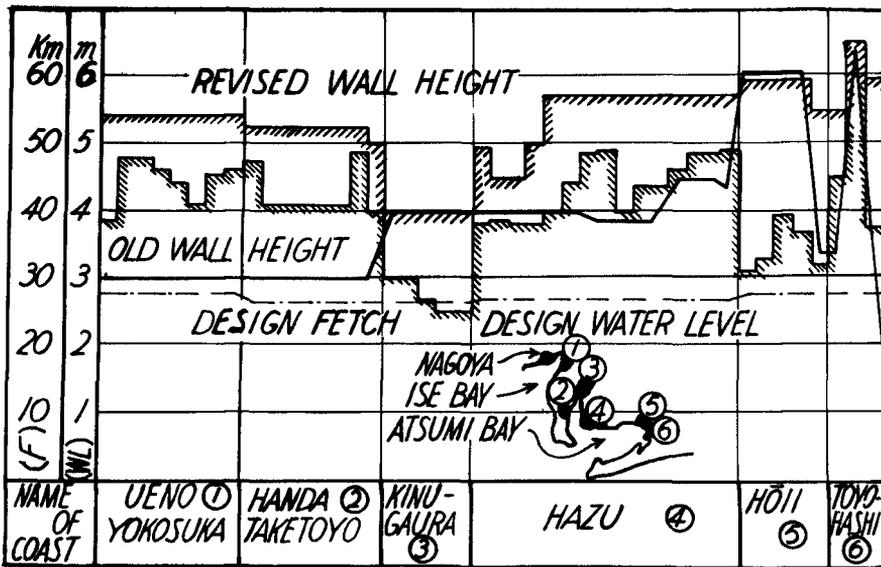


Fig.4.7 The height of restoration coastal-dike and established one.

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The height and structure of restoration coastal-dikes for Typhoon No.13 were designed under the lines mentioned above, and the field works had been conducted according to it. But just because the Ise Bay Typhoon had come before completion of field work, the heavy damage was

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Based upon the disaster investigations on several storm surges in the past, it was indicated that in the case of coastal-dikes of which the crest and the back slope are not covered with solid materials such as concrete, the dike bodies were easily scoured by wave overtopping and spray, and the whole body of coastal-dikes was to break down easily as the result. The prime cause of this disaster also consisted in the scouring of dike body by wave overtopping and spray.

Table 4.2 The general condition of established coastal dike, and the highest tidal level and wave height at each place on the occasion of Ise Bay Typhoon.

Name of coast	Crest height	Front slope	Condition of covering	Highest tidal level estimated	Wave height estimated
Koeishinden	T.P. 4.9 m	1:3	front slope stone crest no cover back slope concrete	T.P. 3.0 m	2.0 m
Nanyo	5.5 ~ 5.75	1:2.5 1:3	front slope stone crest turf back slope turf	3.9	1.8
Ama	5.5 ~ 6.0	1:3	front slope stone & concrete crest turf back slope turf	3.9	1.8
Nagashima	6.0 ~ 6.5	1:3	front slope stone crest turf & concrete back slope block	3.5	2.0
Jonan	5.5	1:4	front slope stone crest no cover back slope no cover	3.5	2.0
Tomidahama	5.5	1:2	front slope step type crest no cover back slope no cover	concrete 3.3	2.6
Ishihara	4.5 ~ 5.0	1:1	front slope stone crest concrete back slope stone	3.0	3.4
Isozu	5.5	1:1.5	front slope concrete crest concrete back slope concrete	3.0	3.4

In Table 4.2, the dimensions of coastal-dikes along each coast (see Fig.4.1), the highest tidal level at the time of Ise Bay Typhoon, the

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estimated waves, etc. are indicated. From this table, we see that the difference between the crest height and the highest tidal level is about 1.5 - 2.5 m except Nagashima coast. On the other hand, since the wave height is 1.8 - 3.4 m, it is supposed that there was considerable wave overtopping at each place during the strongest time of storm surge when we considered the wave run-up.

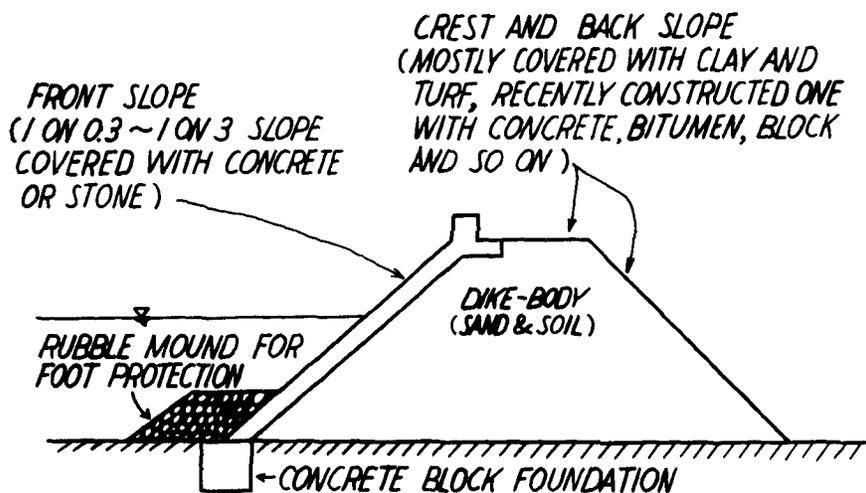


Fig.4.9 Typical cross section of coastal dike with embankment type.

There are Nagashima and Jonan coastal-dikes at the left and right sides of Nagara River respectively. Their cross sections are almost the same, and only their heights are different in about 1 m. Since the shape of sea bottom in front of coastal-dikes are almost coincided with each other, it can be supposed that the tidal levels and waves are almost the same. Nevertheless Jonan coastal-dike were broken down almost over the whole area as shown in photo.4.1-a, while Nagashima coastal-dike were broken down only 200 m of the 1.5 km length as shown in photo.4.1-b, although the dike body was scoured considerably by wave overtopping and situated in a dangerous condition. This is an example to show the difference of damages due to the difference of dike heights. As shown in Table 4.2, the tidal level near this coast is T.P. 3.5 m and wave height is 2 m. Under the condition that slope is 1 : 3, water depth at the toe of coastal-dikes is 4 - 5 m, and steepness is about 0.05, wave run-up become about 1.5 times of wave height. Calculating the maximum height of wave crest from these values mentioned above, we obtain T.P. 6.5 m. Therefore, we suppose that although the Jonan coastal-dike was always attacked by wave overtopping, the rate of wave overtopping at Nagashima coastal dike was very small, and the coastal-dike was only attacked by some extent of spray. This is an example to show that if the height of coastal dikes is taken the maximum crest height of significant wave, there will be a considerable strength of the coastal-dike to resist the waves without any covering on the dike crest and the back slope.

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(a) Nagashima coastal dike



(b) Jonan coastal dike

Photo.4.1 The damages of coastal dikes near the mouth of Nagara River.

In photo 4.2, the views of house damages behind the coastal-dikes of Ishihara coast situated at the left side of Suzuka River are shown. We can see that although a considerable rate of waves had invaded explicitly over the coastal-dikes, they were damaged only a part and the original shape was almost remained. The sections of coastal-dikes are indicated in Fig.4.10, and their crests and back slopes are solidly covered.

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is as much as 4 m in some places. In this region, the coastal dikes were considered to be destroyed by the wave pressure directly.

In photo 4.3, the aspect of damages of coastal-dikes at Isozu coast which located at the right side of Suzuka River is shown. These coastal-dikes were constructed after the disaster suffered from Typhoon No.13 in 1953.

The cross section of the dike is shown in Fig.4.11.



Photo.4.3 The damage of Isozu coastal dike.

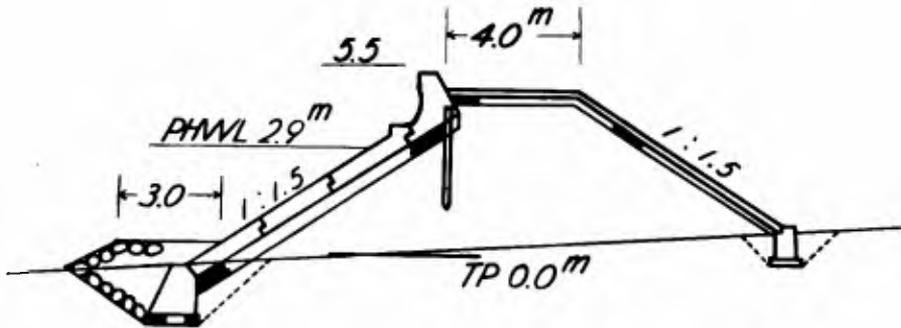


Fig.4.11 Typical cross section of Isozu coastal dike.

The front slope is 1 : 1.5 and the front slope, crest, and back slope are all covered with the concrete. The design water level was T.P. 2.9 m, the design wave height was about 2 m and the crest height was 5.5 m. For the Ise Bay Typhoon, the tidal level was T.P. 3 m, the wave height was 3.4 m, and the latter was considerably higher than designed wave height.

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The reasons why the whole body of coastal-dike destroyed can presumably be interpreted as follows. Some voids were formed in the parts of joints by wave pressure. Consequently a large quantity of soil flew out through the void and at last the dike body was broken down.

The water depth in front of coastal-dike is 3.4 m, and the ratio of water depth to wave height is about 1.2, so it is just in a condition for wave breaking, then we may say that there existed considerably large pressure exerted on the dike body.

The damage aspect of coastal-dike in Koeishinden at Handa, located at the inner part of Chita Bay, is shown in photo.4.4. The covering of these crest was not yet constructed.



Photo.4.4 The damage of Koeishinden coastal dike at Handa.

The aspect of the overturning of parapet is also seen in this photograph, and this phenomenon was seen everywhere in this disaster. The front surface of the usual coastal dikes in this district is constructed from two parts, one of which is a flat concrete slab and the other is a heavy concrete parapet.

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Such a heavy parapet will be easily overturned by wave pressure, if the dike soil near the crest flows out due to wave overtopping. In Koeishinden the parapets were supported by wood piles, but these piles were not so effective to support them against the lateral force.

The overturning of parapet could be also seen everywhere in the inner part of Ise Bay (photo.4.5). The tidal level in the Ise Bay Typhoon was fairly higher than the designed level, so the wave energy was concentrated about the parapet. This might be a reason of many overturning in the region.



Photo.4.5 The overturning of parapet in the coastal dike at the left side of Nikko River.

The other aspects of damages of coastal-dike are as follows.

- (a) The foundation of back slope was scoured by the wave overtopping.
- (b) As the dike soil contained sea water and had the tendency of sliding, the foundation swelled forward and lastly the whole of back slope was slidden down. These examples were also seen numerously in this disaster.

Until now, the studies on wave pressure are mostly conducted about the breakwaters and we had no suitable formulas for the coastal-dikes. Therefore, the coastal-dike has been designed only based upon the experience and no mechanical calculation conducted. Now, at the Public Works Research Institute, Ministry of Construction, the relations between front slopes and wave pressures are being investigated experimentally.

The restoration design of coastal dike which were destroyed by the Ise Bay Typhoon was conducted as follows:

The design tidal level was taken to be the sum of mean high tidal

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level at the typhoon season and "the maximum deviation from astronomical tide due to the Ise Bay Typhoon".

The wave height was calculated by Bretschneider's method in considering the friction of sea bottom, using the direction and velocity of wind at each place in the time of the Ise Bay Typhoon. The height of coastal-dike was determined by adding the design tidal level to the run-up height of design wave.

The cross sections of coastal-dikes were so-called the type of embankment as shown in Fig.4.12, and were determined by taking consideration of the aspect of damages mentioned above. In designing of that we specially stressed subjects as follows:

(i) Parapet was lightened as much as possible, and reinforced bar inserted so that it could resist both the wave pressure and earth pressure.

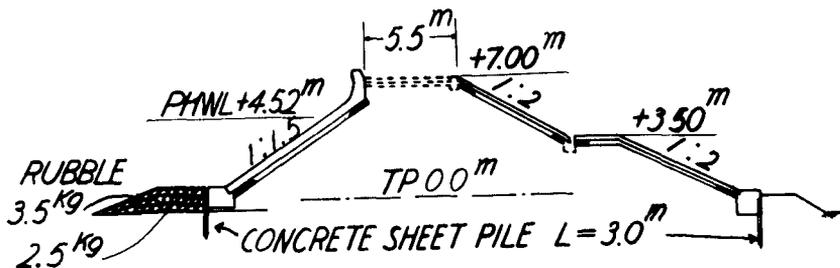


Fig.4.12 Typical cross section of restoration coastal dike.

(ii) The covering of front slope was connected to the foundation block by reinforced bar in order to resist the uplift pressure of sea water.

(iii) Sheet piles were driven in at the toe of foundation blocks in order to protect from creating the hole at the down part of the covering of front slope due to penetrating water.

(iv) In order to commence the covering of crest and back slope soon after banking, the condensation of dike soil was accelerated by vibrofloatation method.

(v) Sheet piles were driven in at the foundation of back slope in order to stop the outflow of penetrating water and to protect the outflow of dike soil.

(vi) The foundation of back slope was constructed not to contact with directly channels behind coastal-dike in order to increase the transverse resistance of the foundation.

(vii) Porous concrete was used at the lower part of covering of back slope in order to decrease the uplift pressure due to penetrating water.

Damages of river levees and their counter plan

The phenomenon that storm surge went upstream in a river was seen

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at each river which flow into the Bay. For example, we'll take up the case of Kiso River which flows into the inner part of Ise Bay as shown in Fig.4.13.

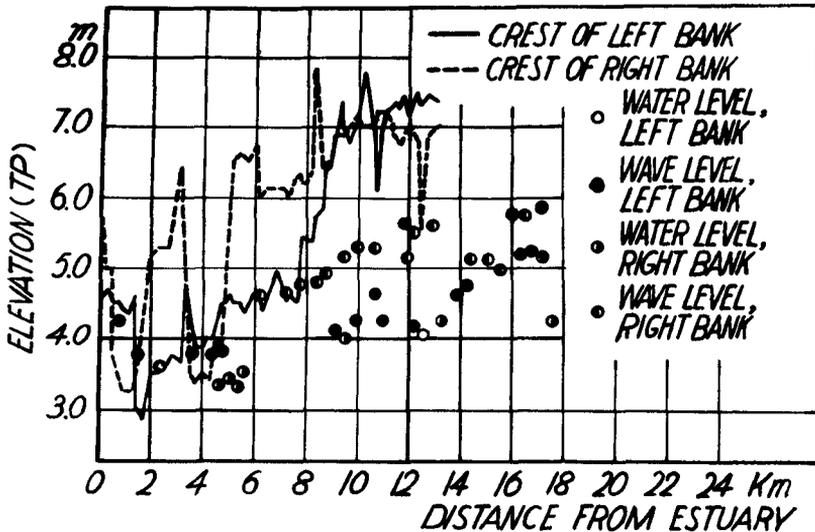


Fig.4.13 The water level rising of Kiso River on the occasion of Ise Bay Typhoon.

As storm surges invade into the river, it is seen that water level tends to rise up. Judging from observational results, this fact is also recognized at Nagara, Ibi, and Shin River. It seems that the rate of water level rising in river mainly concerns with the wind shearing force. To investigate this point in the Kiso River, plotting the relationships as shown in Fig.4-14 between the difference of water levels recorded at Yokomakura and Sendohira, and the square of wind velocity at Kuwana, a very good correlation is recognized. Therefore, it will be effective means for estimating storm surges in rivers, if this relationships are studied furthermore. The flow direction of the upper reach of Kiso River is about SSE and it just coincided with the wind direction, so that such effect due to the wind shearing force is seemed to appear distinctly. So it is supposed that in such a case that the directions of river and wind are very different, the phenomenon mentioned above does not always appear. In addition, it is considered that the effect of run off from upper stream was very slight, as the rain fall before the time of the highest tidal level was a very small quantity in Kiso River.

In designing the height and structure of river levees at an estuary and in the downstream reach, the effect of waves has been scarcely taken in consideration by this time. In Ise Bay Typhoon, we saw many examples of the river levees at an estuary and in the downstream reaches which were destroyed by wave force or wave overtopping.

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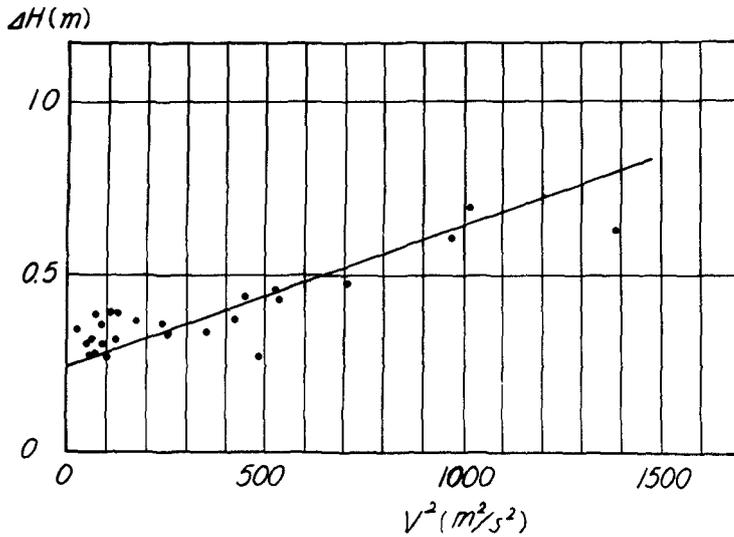


Fig.4.14 The relation between the difference of water levels observed at Yokomakura and Sendohira, and the square of wind velocity.

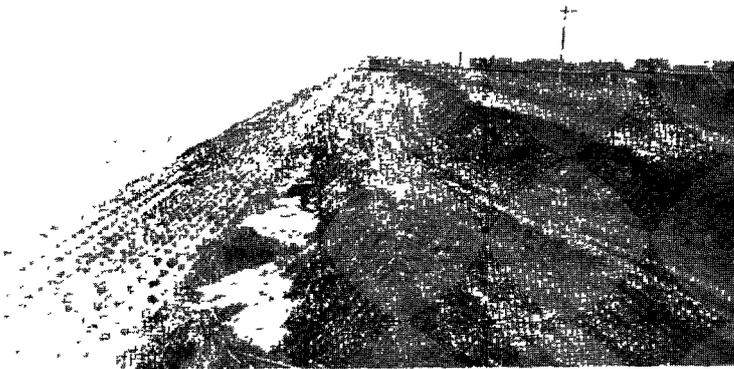


Photo.4.6 The damage of the levee at the right side of Yahagi River.

The waves in rivers are different from those generated at coast. In rivers the water depths are small, and the river course crooks, so the waves are in general smaller than those generated at coast. Most waves always invade into the estuary without the reduction of wave

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heights, and the waves especially in narrow estuaries propagate along the levees. Therefore it is considered that large waves scarcely strike the coastal-dikes perpendicularly.

The difference between the constructions of river levees and coastal-dikes is the covering works. In general, the front slopes of river levees are covered with stone or concrete up to the design high water level, and the front slopes above design high water level are covered with turf. The causes of disaster of river levees at the time of Ise Bay Typhoon can be divided into two groups, one of which is the wave actions and another is the overflow (including wave overtopping). Photo.4.6 shows the aspect of damage of the right side walls at the places of 0 - 2 km upstream from the mouth of Yahagi River. The upper part of front face and back slope were covered with turf. As a wave direction and the line of dikes were not strictly in parallel but at a slight angle in the middle of typhoon, the front slope covered with turf was broken down by wave force.

Fig.4.7 shows the aspect of damages of levee at the left side of Nabeta river. At this place, the height of dike was increased by the concrete parapet wall.

The parapet wall has the openings (1.2 m in width) for passage at regular intervals, and at the time of storm surges, the opening was designed to close with a flush board. But as the openings were not closed actually at the time of storm surge, the sea water overflowed through the openings and the back slopes of dikes were scoured, and at last the whole of levees were broken down.

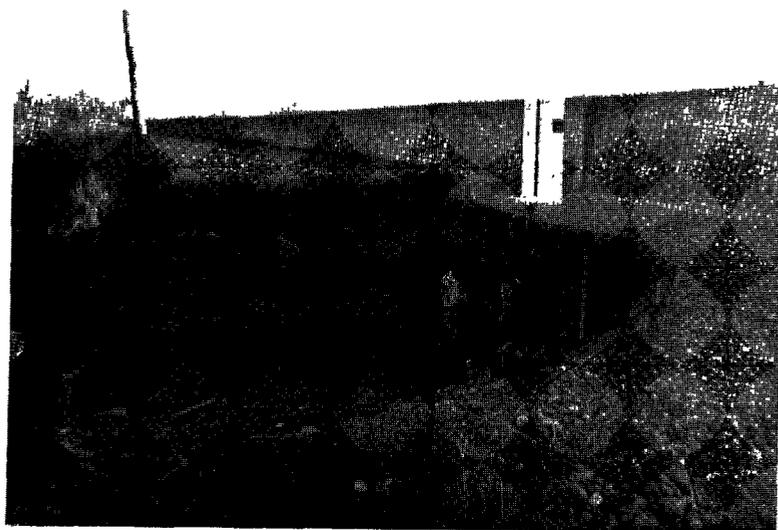


Photo.4.7 The damage of the levee at the left side Nabeta River.

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In addition, there were other examples of destruction. The slope surface of dikes were destroyed by water seepage as seen often in the flood. At the mouth of a river, we also saw many places where the connecting points between coastal-dikes and river levees were damaged. The fact that the height of river levee is smaller than coastal-dikes discontinuously at the connection point, or the different structures of dikes and surface covering, might be a reason for the damages.

Referring the aspect of damages of river levees mentioned above, it is necessary to determine the heights and structures of the dikes in rivers, from the stand points of wave heights and wave forces which will be occurred in storms. When the waves invade into the rivers, wave run-up may not be considered because there is no impact of waves upon walls if the waves direction and the river levee are in parallel each other, but when the wave direction and the line of river levees are not in parallel, a fairly wave run-up can be expected due to the impact of waves upon the walls.

The height of waves propagating from various directions of offshore to the river mouth, can be determined by the fetch and refractions in the same condition of wind.

When the waves propagated from the entrance of Bay to the direction of A as shown in Fig.4.15, the heights of waves invading into the river are large, because the fetch is large and there is no effect of refraction due to the topography of the sea bottom. However, because the wave direction and the river levees are in parallel each other and there exists no impact of waves, it will be good enough to consider only the height of wave crest. When the waves travel to the direction of B, the fetch is smaller than that in the case of A, and there is the effect of refraction. So the height of waves entering the river is smaller than that of A. However, because the waves impact on river levees skewly, the run-up of waves will occur.

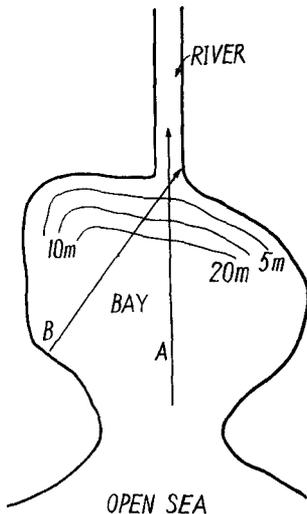


Fig.4.15 The relation between incident direction of wave and river course.

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Therefore in such a case, as a criterion for determining the levee height, we must take the higher one after comparing the height of wave run-up and the height of wave crest in the case of A. That is, more the wave direction are inclined with the river levee, less the wave height itself is, but more vivid the phenomenon of wave run-up is. Therefore it is necessary to make comparison and investigation for various cases in determining the reasonable height of walls.

As the waves invading into rivers are affected by the friction of river bed, in proportion to the distance from the river mouth, the wave height will be decreased in general, but when the propagating direction of waves coincides with the wind direction, the wave height is not always decreased. Therefore, considering the wave height, the wave direction, the direction of river course, the water depth, the river width, and the wind condition, etc., we must determine to what extent the waves should be considered. Moreover, when the river course is tortuous, the river width changes abruptly, or large bars existed, the convergence, divergence and refractions of waves and the considerable change of wave height will be expected. We can get the same conclusions about the indentation of sea dikes, and there were many examples showing the damages at this part at the time of Ise Bay Typhoon.

The designs of height and structure of the levees in the rivers Kiso, Nagara, Suzuka, Yahagi and Toyo, were established based upon the procedures mentioned above, and to make more clear the key points in the design, the large scale hydraulic model tests are carried on at the Public Works Research Institute, Ministry of Construction.