CHAPTER 106

TOPOGRAPHIC CHANGE RESULTING FROM CONSTRUCTION OF A HARBOR ON A SANDY BEACH: KASHIMA PORT

by

Norio TANAKA* and Shoji SATO**

* Hydraulics Division
** Head of Marine Hydrodynamics Division

Port and Harbour Research Institute, Ministry of Transport

Nagase, Yokosuka, Japan

ABSTRACT

This paper presents some general properties on topographic change on the shore and sea bed in the vicinity of ports and harbours constructed on the sandy beach, mainly with the case study of Kashima Port. Following three characteristics of the topographic change due to prolongation of breakwaters are discussed; that is,

i) The shoaling and the change of topography in the area surrounded by breakwaters and shoreline.
ii) Topographic change of artificial beach in the updrift beach of breakwater having the long oblique part.
iii) Erosion and accretion of downdrift beach due to the prolongation of the oblique part of breakwater.

INTRODUCTION

Port Kashima, the biggest new industrial port in Japan, has been constructed on the central part of a bow-shape sandy coast of 70 killometers long facing the Pacific Ocean as shown in Fig. 1 and Fig. 2. Since 1961, before the start of the construction works, many kinds of field investigations and model experiments have been conducted by the Port Construction Office of Ministry of Transport and the Port Construction Office of Ibaragi Prefecture under the continuous co-operation of Port and Harbour Research Institute.

Authers had reported the some results of these investigations on the characteristics of this coast before the begining of the construction works in the 10th Conference on Coastal Engineering (S. Sato and N. Tanaka, 1966). Furthermore, one of authers had already presented a paper on the topographic change during the early period of the construction works in the 12th Conference

Fig. 1 The location of Kashima Port and other harbours mentioned in this paper.

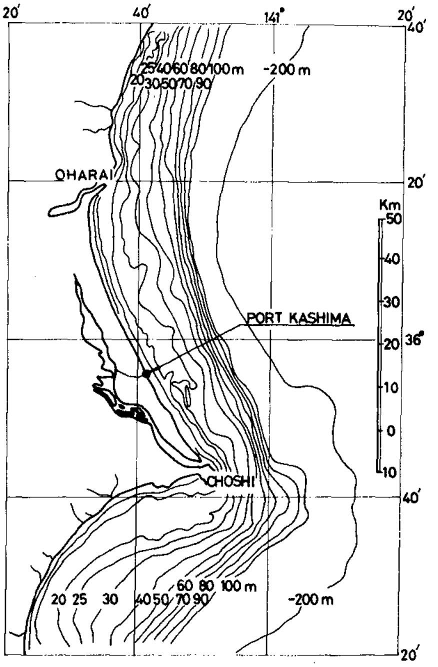


Fig. 2 Kashima Coast and the location of Kashima Port.

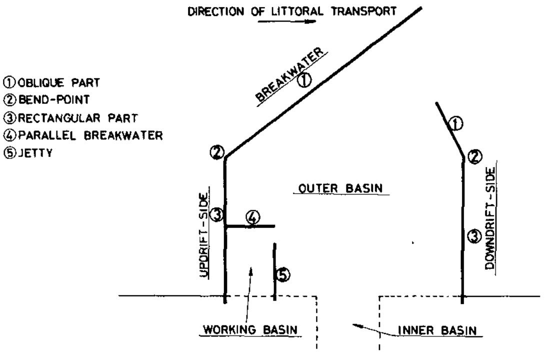


Fig. 3 The terminology in this paper.

on Coastal Engineering (S. Sato and I. Irie, 1970). Therefore, this paper composes a series with these other papers. The terminology emplyed in this paper is given in Fig. 3.

THE CHARACTERISTICS OF THE COAST AND THE LITTORAL DRIFT OF KASHIMA COAST

The northern portion of Kashima Coast has a narrow beach with the cliff of Kashima Plateau and the Naka River flows out to the sea at the northern end. The southern portion is a part of the alluvion formed by the Tone River and has wide beach with sand dunes. The influence of the discharged materials from these two rivers is restricted in the area near to their river mouth, and it is considered that the source of sand drifted in the central portion should be the coast itself.

The natural topography before the port construction was comparatively simple and stable. At the central portion where Kashima Port is located a sand dune of about 8 meters high above L. W. L. ran along the coast and the backshore was 50 to 80 meters wide and 3 to 4 meters high. There were alongshore bars at 100 to 300 meters seaward from the shoreline which were of 0.5 to 2 meters deep at the crest and of 1.5 to 3 meters deep at the trough. In the offshore area of those alongshore bars, the sea bed topography was very smooth and depth contour lines ran parallel each other until the water depth reaches to 20 meters. But, the area less than 40 meters beyond 20 meters in water depth is very gentle in the bottom slope and reaches to the seaward edge of the submerged terrace and depth contour lines make complex curves. The sea bed slope was about 1/10 to 1/30 in the forshore, about 1/50 to 1/60 in the inshore and about 1/100 to 1/120 in the area shallower than 20 meters depth in the offshore.

Waves approach almost perpendicularly to the coast from the direction of northeast to east-southeast, though the southerly waves exceed the northerly ones a little in summer and the oppsite takes place in winter. The annual predominant direction of waves depends on the frequency of typoons approached to this coast; in the year when typoons frequently attack this coast, the southerly waves prevail. The maximum significant wave observed in this coast has been about 6.5 meters in height and almost 10 to 13 seconds in period.

The mean diameter of bottom materials is about 0.15 millimeters in the offshore zone and 0.2 to 0.6 millimeters in the inshore zone. The alongshore littoral transport per year has been estimated to be the order of 600,000 cubic meters both in the southerly and northerly directions, though the southerly transport slightly exceeds the northerly one (S. Sato and N. Tanaka, 1966).

CONSTRUCTION WORKS OF PORT KASHIMA

The general plan of Port Kashima was set in 1962, but it was modified in 1968 according to an increase of ship sizes as shown in Fig. 4.

The construction works began at April 1963 with dumping of rubble stones for the south jetty of the working basin for small crafts. By April 1975, the north breakwater of 1050 meters long, the parallel breakwater of working

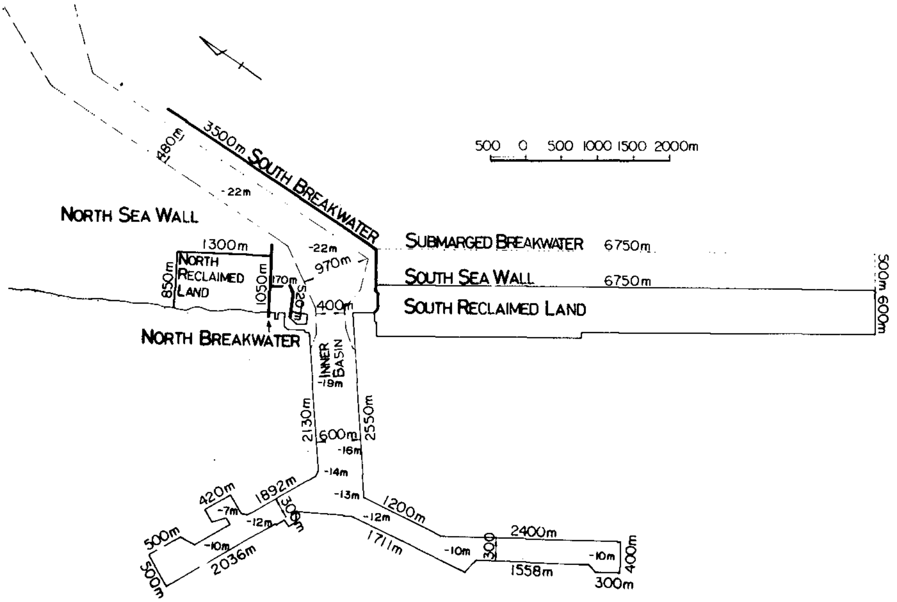


Fig. 4 The general plan of Kashima Port

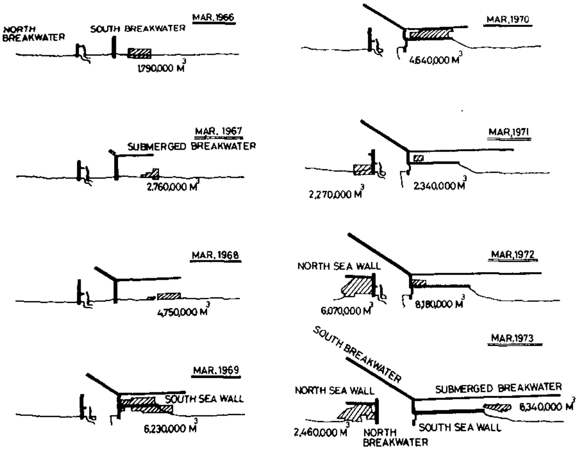


Fig. 5 The process of the construction works of structures and the discharge of dredged sand.

basin and the south breakwater of 4300 meters long have been completed.

In April 1965, the dredging works of the inner basin was begun without disturbing the shoreline in the outer basin by cutter-suction dredgers which entered into the inner basin through the beach of the working basin by cutting it. The shoreline in the outer basin was cut in September 1968 to connect the inner basin to the outer basin. The dredged sand has been dumped on the beaches of both sides of the harbour. In the period from April 1965 to April 1975, the amount of the sand dumped on the beach has reached to about 50 millions cubic meters.

In this period, the bulkheads were constructed for reclaimed land in the both side of the harbour and the submerged breakwater was also built in front of the south man-made beach. The processes of these works are shown in Fig. 5 and Fig. 6.

SHOALING OF THE OUTER BASIN OF HARBOUR FOLLOWING THE PROLONGATION OF BREAKWATERS.

Figure 7 shows sounding maps for each summer in the period from 1963 to 1968, during which the breakwaters were constructed but no dredging works were initiated in the outer basin. In this figure, solid lines indicate the constructed portions of breakwaters and dotted lines denote the portions where only the rubble mound base of caisson was constructed.

The comparison of the sounding maps of 1965 and 1966 indicates that the depth contour lines shallower than 5 meters moved landward at the middle of coast between the south and north breakwater and offshoreward near the both breakwaters, as the rectangular parts of those breakwaters were prolonged. This tendency became much clear with the prolongation of the oblique part of the south breakwater and the depth contour lines took more convex shape. Moreover, the mean direction of the beach in the outer basin became to take more oblique angle to the shoreline of former days, and the most receded point of shoreline was shifting northward with the prolongation of the oblique part of the south breakwater; this can be seen from the comparison of the sounding maps of 1967 to 1968.

On the other hand, the central portion of the outer basin was shoaled, the depth contour lines deeper than 7 meters becoming concave in shape as shown in the maps of 1966 to 1968.

Severe scouring were seen in the vicinity of the tip of the breakwaters when they were in the surf zone, as well as at the inside of the rubble mound. These characteristics of the sea bottom topography around breakwaters are commonly found in other harbours as reported by Sato and Irie (S. Sato and I. Irie, 1970).

Figure 8 indicates the volume change of sand in the outer basin in the same period as that of Fig. 7. Solid lines indicate the change of sand volume in each area shown in the note of this figure as well as that of the total area of the outer basin, while the dashed line is the volume change of the sand dumped on the south coast. In this four years, sand of about 2 millions cubic meters increased in the outer basin in total and the accretion of sand

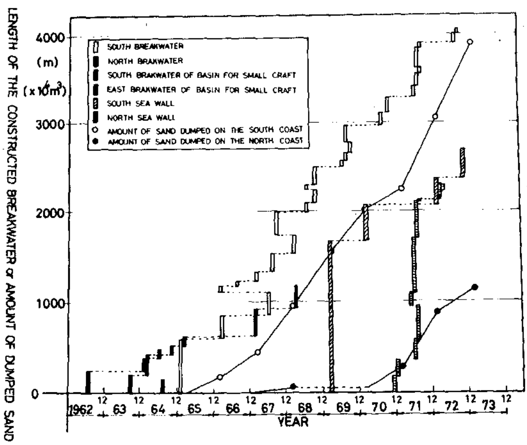
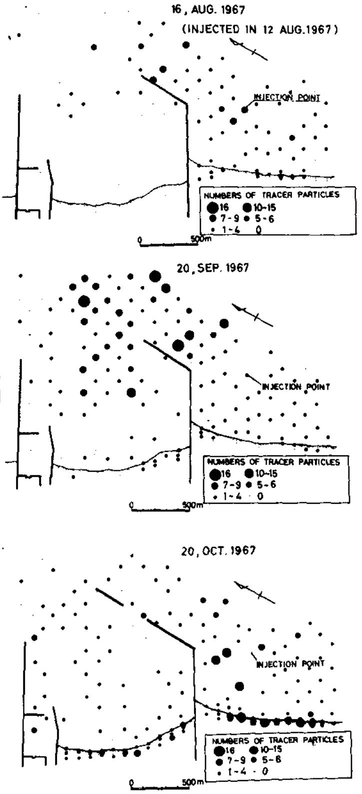


Fig. 6 The length of constructed structures and the amount of dumped sand onto beach.



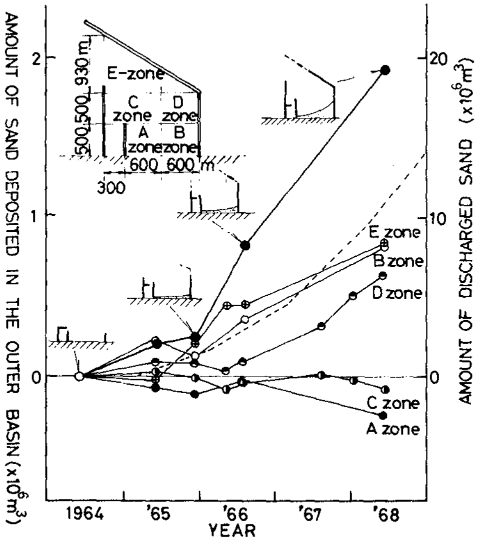


Fig. 8 The volume change of sand in the outer basin (in the period of 1964 to 1968).

Fig. 9 The distributions of fluorescent tracers.

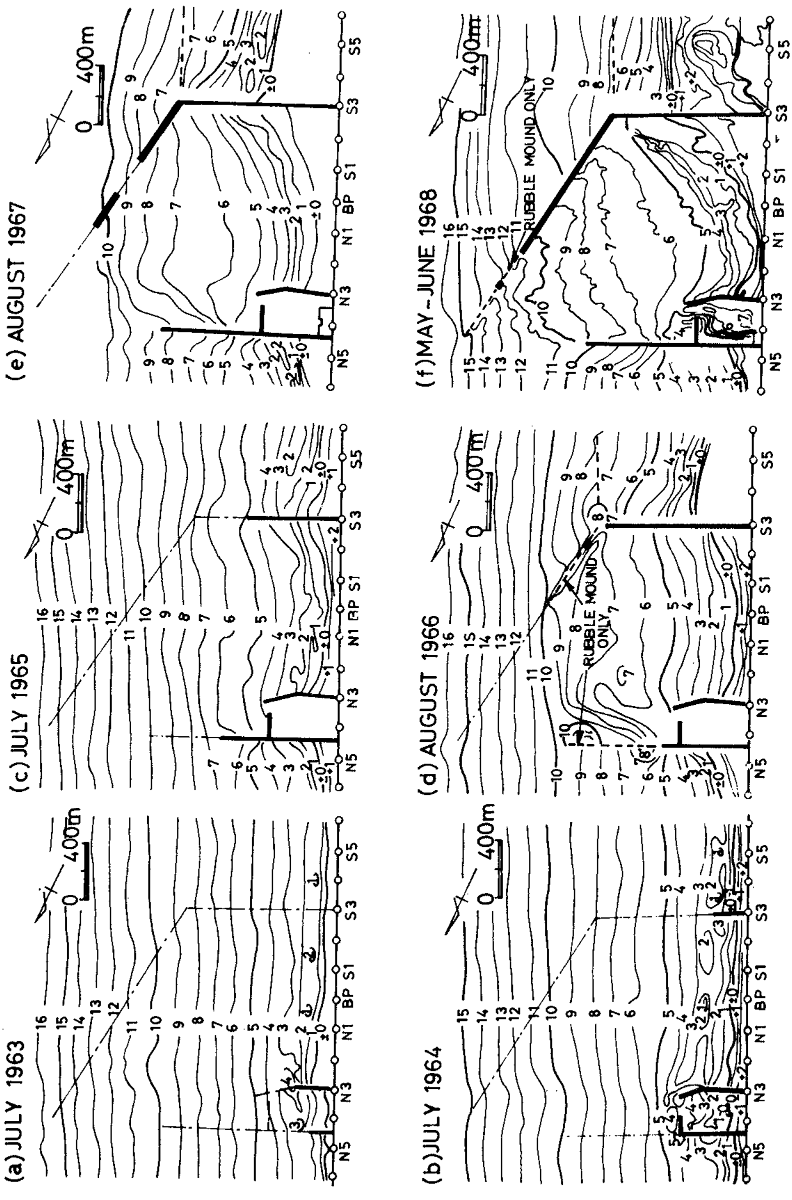


Fig. 7 Sounding maps for each summer from 1963 to 1968

took place in the area B, D and E which are located near the south breakwater. On the other hand, the area A and C were scoured gradually. These pattern of the volume change of sand is considered to be closely related to the diffraction of waves and formation of the counter-clockwise circulating currents in the outer basin as reported by authers (S. Sato and I. Irie, 1970 and N. Tanaka, 1974).

In Fig. 8, the change of the total volume of sand of the outer basin seems to have close correlation with the amount of sand dumped on the south coast. Figure 9 shows the distribution of fluoresent tracers injected in the offshore zone of the south coast on 12th of August, 1967. The result clearly indicates the movement of sands which move offshoreward along the south breakwater and enter into the outer basin going around the tip of the south breakwater.

TOPOGRAPHIC CHANGE OF ARTIFICIAL BEACH CONSTRUCTED USING THE DREDGED SAND

As mentioned above, since April 1965, dredged sands have been discharged onto the south coast and the amount of the these sand reached to about 22 millions cubic meters until March 1971. The change of the shore line in this period is shown in Fig. 10. In this figure, the x, y and z axes indicate the alongshore distance from the south breakwater, the distance between the shoreline and the datum line, and the years of survey, respectively. Therefore, the thick solid lines represent the shape of the shoreline at a certain time and the thick dashed-dot lines indicate the change of the distance between the shoreline and the datum line.

The shoreline of the south coast began to advance seaward near the south breakwater due to the discharge of dredged sand, and the beach continued to extend seaward or southward until 1970. But, after the winter of 1970, although discharge of dredged sands was continued, the artificial beach began to be eroded from the neighbourhood of the south breakwater and this erosion was extended southward.

In pace with the change of the shoreline, the beach profiles also changes as shown in Fig. 11. The slope of sea bed in the part shallower than 10 meters deep became steeper gradually with the advancement of the shoreline, but after the beginning of the erosion, the slope returned toward the original one the reverse process of that mentioned above.

Figure 12 indicates the relationship between the advancement of the shoreline and the slope of the sea bed at each water depth. The slope of sea bed became steeper with the advancement of the shoreline and reached to a certain critical slope for the water depth of 10 meters and less. The average values of these critical slopes were as follows:

range of water depth	average value of the critical slope
0 to 2 meters	1/25
2 to 4 meters	1/50
4 to 6 meters	1/60
8 to 8 meters	1/65
8 to 10 meters	1/100

The difference between these critical slope and the natural one before fill is the largest in the area of 2 to 4 meters depth, and it becomes small in both the shallower or deeper area.

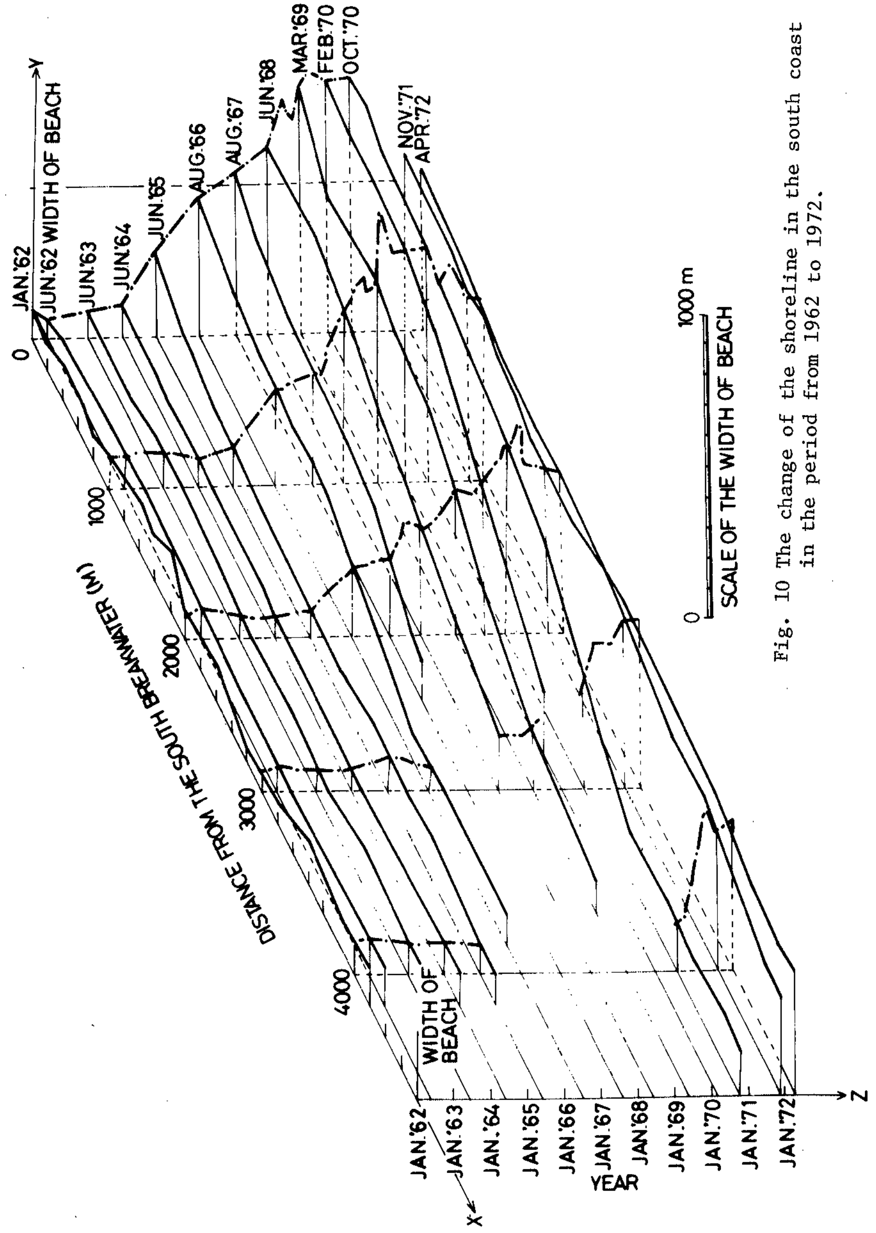


Fig. 10 The change of the shoreline in the south coast in the period from 1962 to 1972.

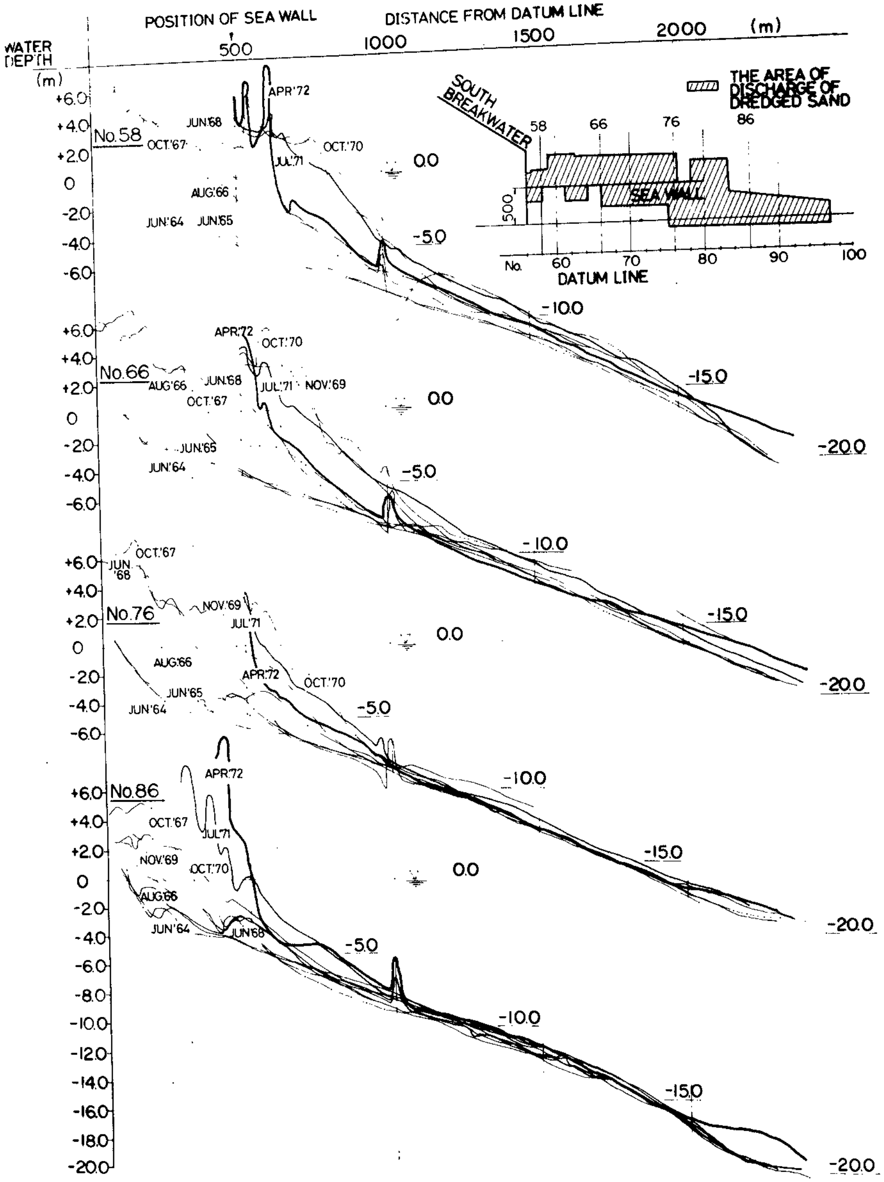


Fig. 11 The change of profiles of the south coast

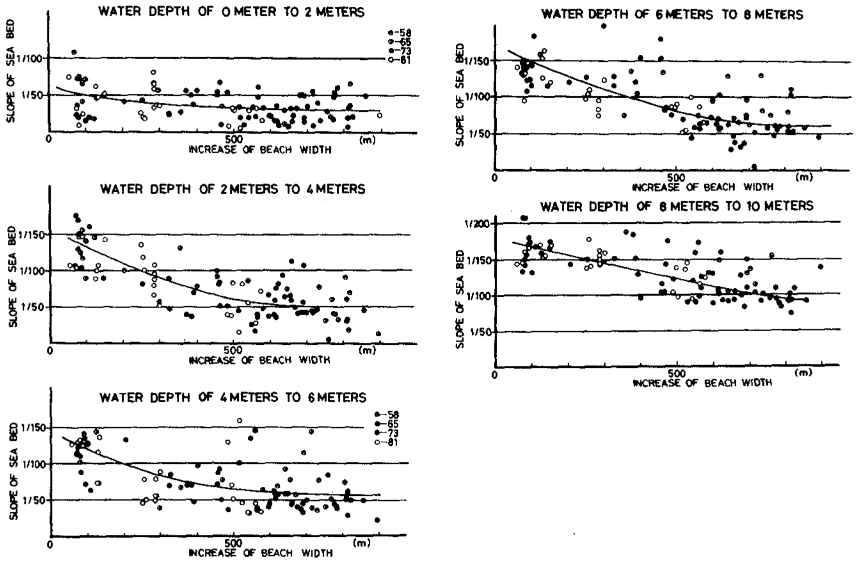


Fig. 12 The relationship between the advancement of the shoreline and the slope of sea-bed.

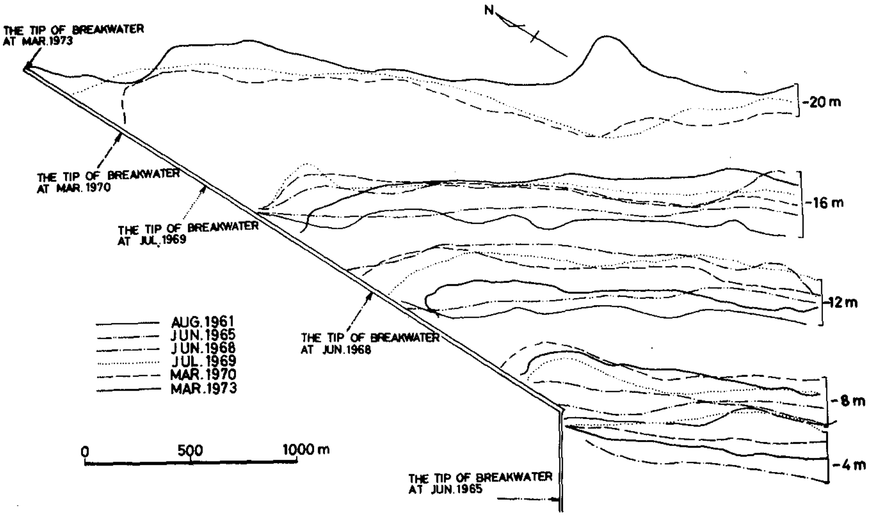


Fig. 13 The change of depth contour lines in the offshore side of the south breakwater.

Some amount of sand discharged onto the south coast was transported by waves and currents to the offshore side of the oblique part of the south breakwater forming a submarine bank along the breakwater. But, after the winter of 1970, this submarine bank was also rapidly scoured. The change of depth contour lines of 4, 8, 12, and 20 meters deep is shown in Fig. 13. In this figure, the attention is called for the fact that the contour lines of 16 and 20 meters deep moved offshoreward even after the beginning of scour of the submarine bank.

Figure 14 is the distribution of the difference of the water depth surveyed in the different years; i. e., the upper figure is the difference of depth in the period of the growth of the submarine bank from April 1965 to August 1970 while the lower one is the difference in the period of scouring of bank from August 1970 to March 1973. In the period of the growth of the submarine bank, the decrease of the water depth was the largest near the bending point of the south breakwater. The area of considerable shoaling extended from that point toward the tip of the breakwater forming a belt within the distance of about 200 meters from the breakwater. On the other hand, in the period of scouring, the scouring was found only around the bending point of the south breakwater, and the extent of scouring was the severest along the foot of the breakwater. The offshore area of this zone was continuously shoaled even after the beginning of the scouring of south coast.

Such the examples of the erosion at the updrift side of a long oblique breakwater are found in many other ports as in the cases of Sendai Harbour and Hachinohe Harbour shown in Fig. 15. These two harbours are located at the end of long sandy beaches facing the Pacific Ocean, where waves from the down drift side are sheltered by a headland. Although updrift side of these harbours are shoaled over the wide area, the erosion of the same pattern as Kashima Port is found near the breakwater of the updrift side.

Such erosion at the updrift side of a long oblique breakwater may be considered to be caused by the currents formed along the breakwater due to waves. Fig. 16 indicates examples of experimental results on the currents due to waves around the breakwater prolonged obliquely. The experiments were conducted using a fixed bed model having the bottom slope of 1/15 in the landward of the shoreline and 1/30 in the seaward of it. Model waves of 4 centimeters in height and 0.8 seconds in period were acted from the direction perpendicular to the shoreline. In this figure, thick solid lines indicate the breakwater, and the origin of the co-ordinate is taken at the point of intersection of the shoreline to the breakwater.

In every case, currents which flow updriftward along the breakwater and the shoreline are formed. These currents turn their direction offshoreward at a certain point, the position of which goes away from the breakwater with the increase of the length and obliquity of the breakwater. The velocities of these currents also increase with the length of breakwater, but the increase of the length in the offshore area of the surf zone is not so effective.

EROSION AND ACCRETION OF DOWNDRIFT BEACH BY THE PROLONGATION OF BREAKWATER.

Figure 17 shows the sounding maps for each winter in the period from 1970 to 1973 in which the oblique part of the south breakwater was prolonged beyond the tip of north breakwater. The dotted lines in each maps represent the

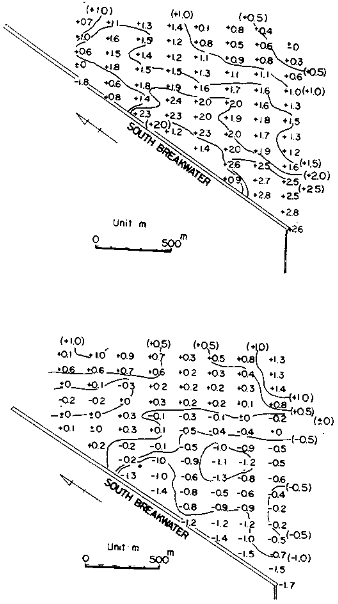


Fig. 14
The distribution of the differences of the water depth surveyed in the different year.

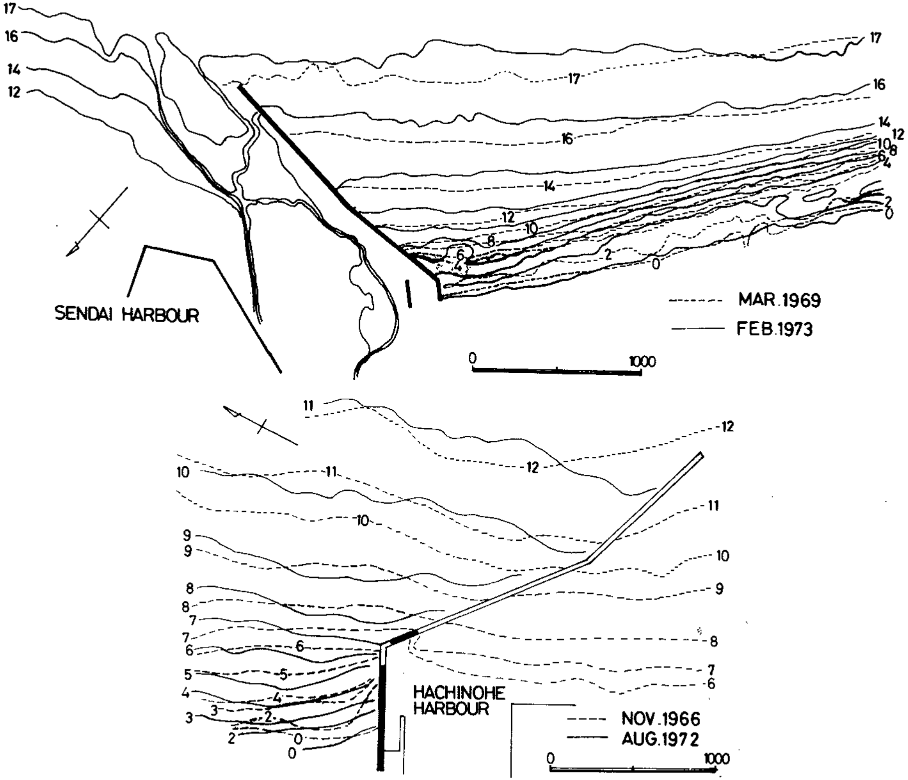


Fig. 15 Examples of the erosion at the updrift side of a long oblique breakwater (Sendai Harbour and Hachinohe Harbour).

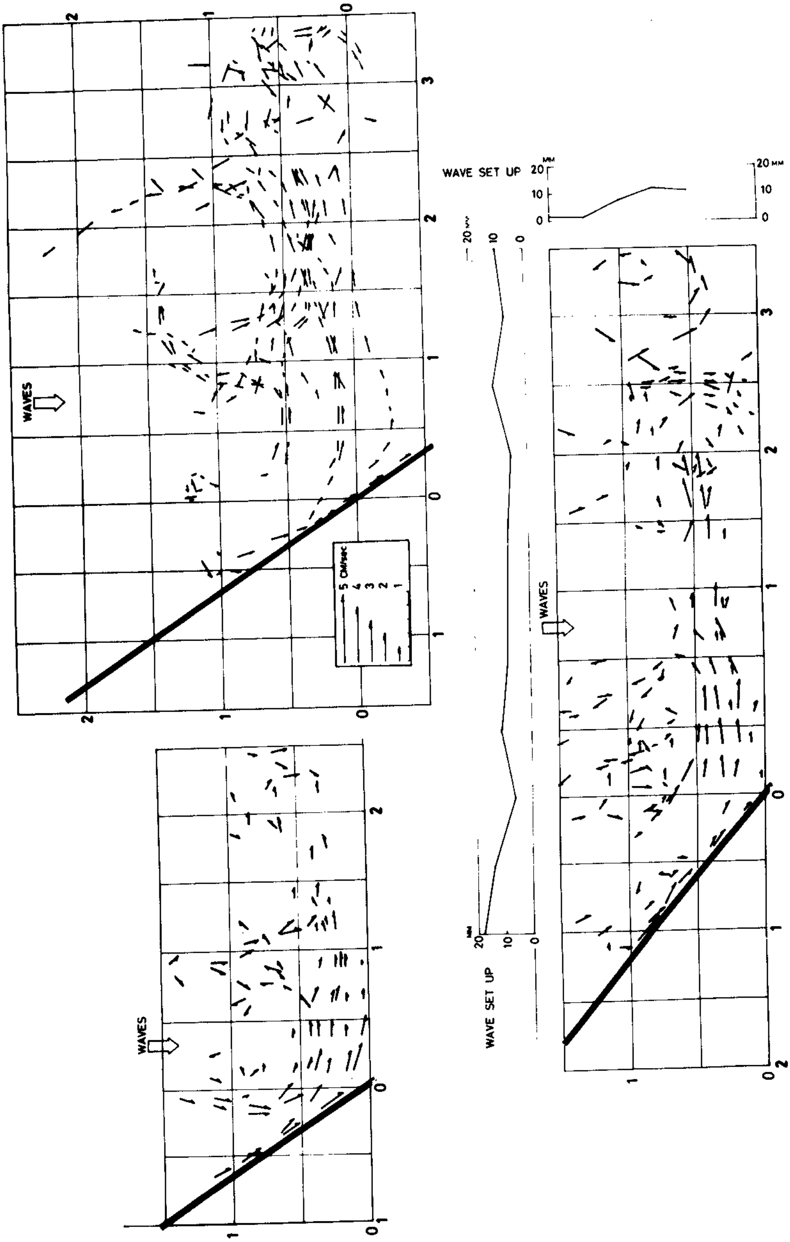


Fig. 16 Examples of results of the model experiment on the currents due to waves along the breakwaters prolonged obliquly (wave height= 4 cm, period= 0.8 sec.).

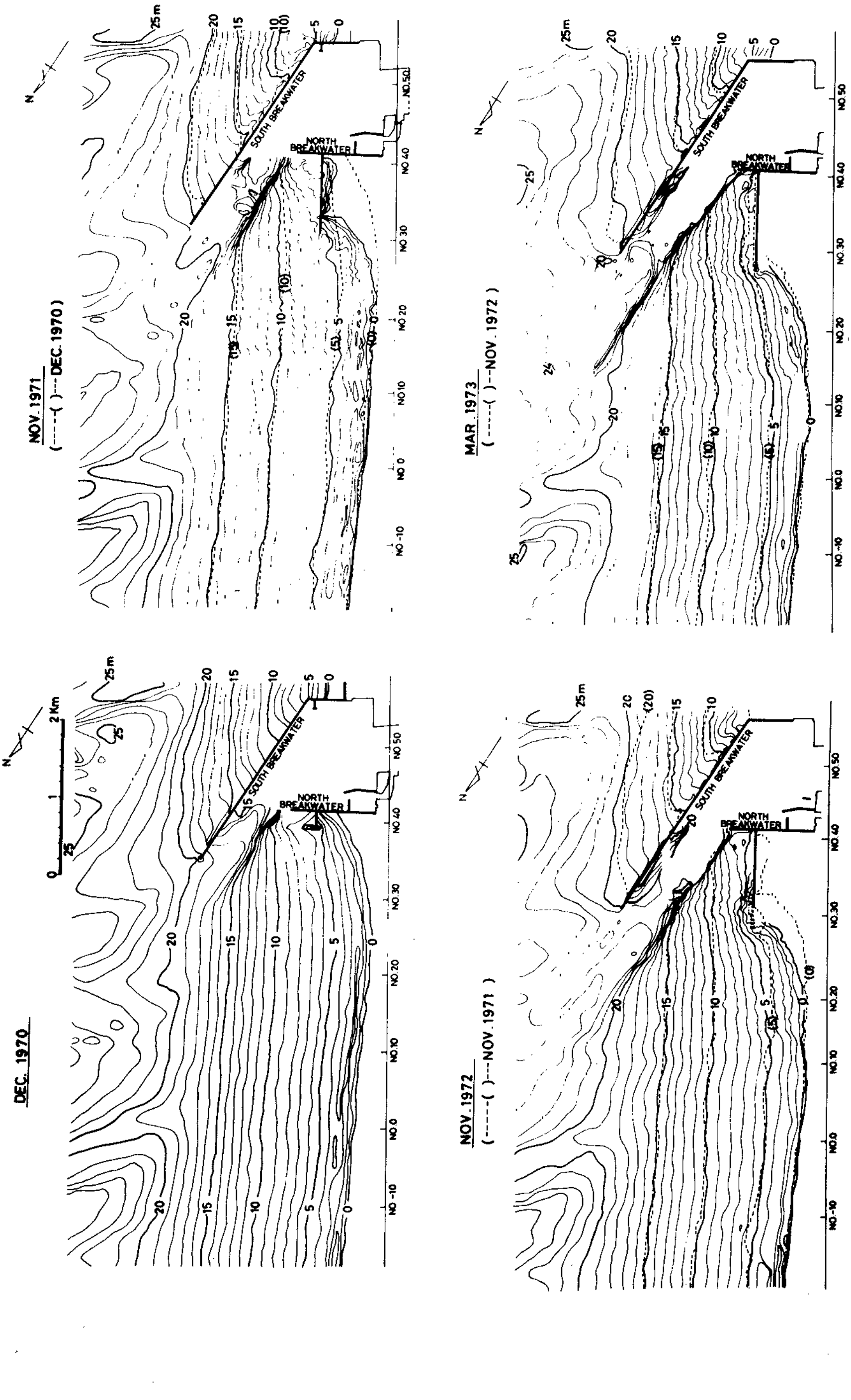


Fig. 17 Sounding maps for each winter in the period from 1970 to 1973.

depth contour lines of one year before.

In the area sheltered by the south breakwater at the outside of the north breakwater, the depth contour lines shallower than 15 meters moved seaward year by year. At the north side of these shoaled area, the zone shallower than 5 meters in depth was eroded. Moreover, these shoaling and erosion zone seem to extend to the north and the deeper area with the prolongation of the south breakwater.

Figure 18 indicates the change of the distance between the shoreline and the datum line measured along the fixed surveying lines in the north coast. At the line of No.27 to 39 located near the north breakwater, the shoreline advanced seaward gradually during the early years and after a certain years the advancement of shoreline was accelerated rapidly. At the lines of No.15 and 21, the shorelines moved seaward or landward slowly during the early years, but after a certain years the shorelines receded suddenly and then advanced again few years after. Furthermore, at the lines of No.3 to 9 located the most far away from the north breakwater, the shorelines were stable or erosive in the early years, but they were eroded rapidly after a certain years. The sudden change of shoreline movement occurred earlier at the line near to the north breakwater than the farther one. This fact means that the boundary between the shoaled area near the north breakwater and the eroded area of north side of it was shifted northward year by year.

Figure 19 indicates the relationship between the position of the tip of the south breakwater and the most eroded place or the north boundary of the accreted area near the north breakwater. In this Figure, dates written along the south breakwater and the shoreline indicate the times when the tip of the south breakwater, the most eroded place, and the boundary of the accreted area were located at respective positions. The thin solid lines and dashed-dott lines are the lines connecting the tip of the south breakwater to the most eroded place and the boundary of the accreted area at the same date, respectively.

In this figure, three solid lines run almost parallel each other, keeping the constant angle of 45 degrees with the predominant wave direction. Likewise, the three dashed-dot lines run parallel, keeping the angle of 30 degrees.

Figure 20 shows the distribution of differences of the water depth between the sounding maps of December 1970 and March 1973 as well as two lines which make the angle of 45 degrees and 30 degrees with the predominant direction of waves at the tip of the south breakwater. It is known from this figure that the area remarkablly shoaled in the offshore area is also in the south side of the line of 30 degrees.

The above mentioned pattern of the change of the sea bed topography can be found frequently in other harbours as shown in Fig. 21, which indicates the changes of shorelines measured on aerial photographs. Harbours shown in this figure are located on the sandy beach facing the open sea. In these examples, the angles of the line connecting the tip of the main breakwater and the most eroded place measured from the wave direction are among 40 to 50 degrees. On the downdrift side boundary of accreted area, this angles are among 20 to 30 degrees.

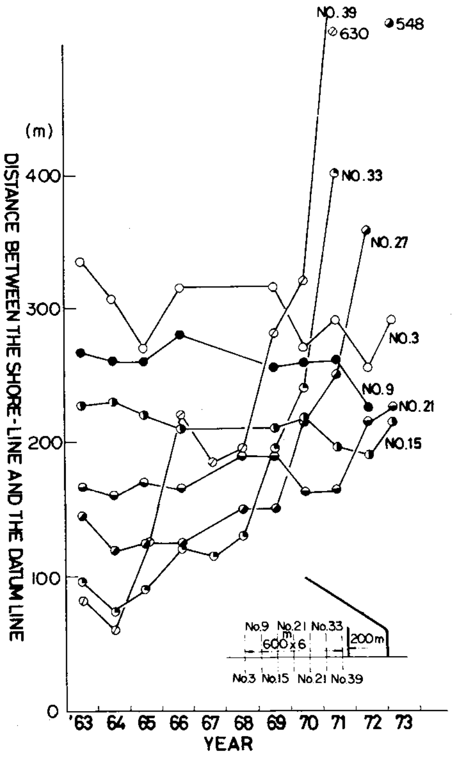


Fig. 18 The change of the distance between the shoreline and the datum line in the north coast.

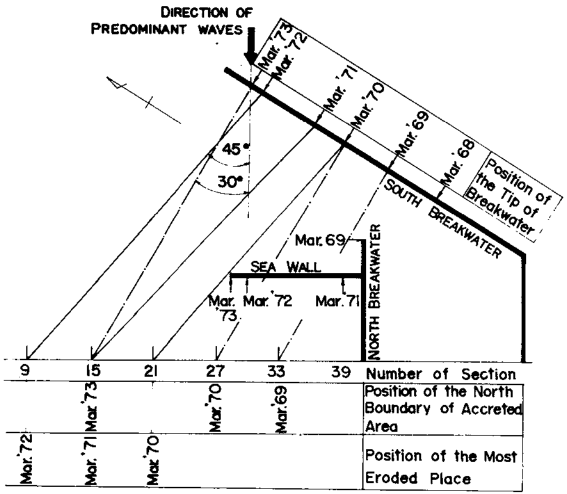


Fig. 19 The relationship between the position of the tip of the south breakwater and the most eroded place of the north boundary of the accreted area.

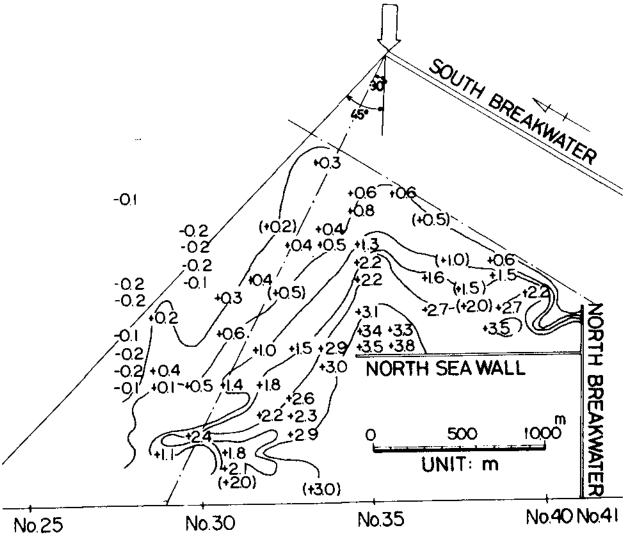


Fig. 20
The distribution of deffrences of the water depth between the sounding maps of Dec. 1970 and Mar. 1973.

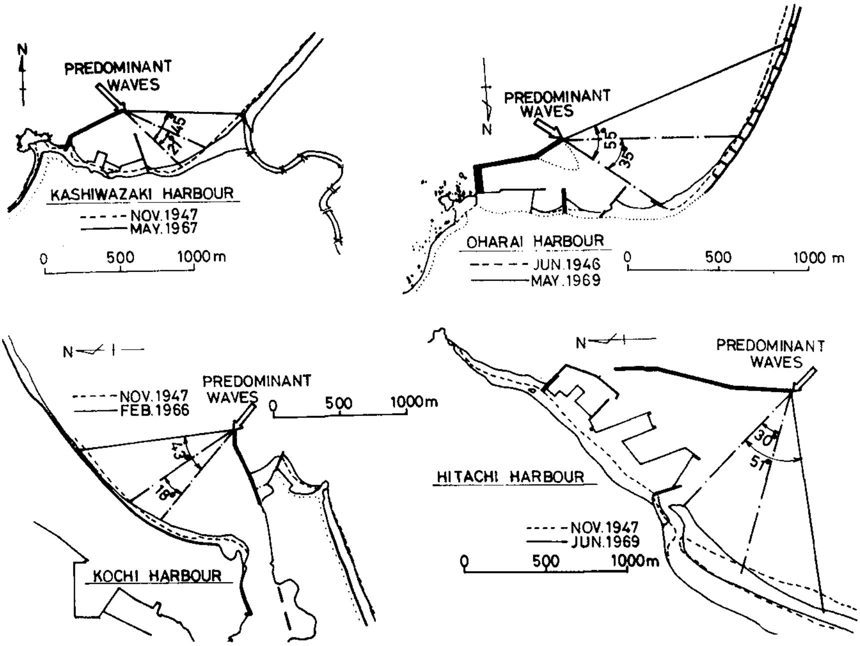


Fig. 21 Examples of the topographic change at the downdrift side of harbours (Kashiwa-zaki Harbour, Oharai Harbour, Khochi Harbour and Hitachi Harbour).

As demonstrated in the example of a model experiment shown in Fig. 22, the cause of this kind of topagraphic change is considered to be the currents formed in the downdrift side of this harbour due to waves diffracted at the tip of the main breakwater. The experiment was performed in the same model in the former chapter under the same wave condition. Due to wave diffraction, the wave height becomes small behind the breakwater. As the result of this decrease of wave height, the wave set-up also decreases from the open portion toward the sheltered area behind the breakwater as shown in the upper graph of Fig. 22. This alongshore gradient of the wave set-up is considered as the main cause of the currents which transport bed materials toward the sheltered area behind the main breakwater.

CONCLUSION

The following points were made clear as the general properties on the change of the topography of sea bed caused by construction of new ports, that is:

1) When the oblique part of updrift side breakwater did not cover the tip of the downdrift side breakwater, the outer basin was shoaled remerkably. Almost all the materials entered into the outer basin were carried by the circulating currents and were deposited behind the updrift side breakwater of at the central portion of the outer basin. The central part of the beach in the outer basin was eroded due to these currents. As the result ot these change, the shoreline in the outer basin took convex shape.

2) When the shoreline advanced due to the discharge of dredged sands, the profile became steeper gradually and reached to a critical one. But, in the erosion period, the slope of man made beach returned toward the original one taking the reverse process with one in the progressive period.

3) After the length of the oblique part of updrift side breakwater reached to about 2,000 meters, the updrift beach of this breakwater was severely eroded due to currents formed along the oblique part of updrift side breakwater.

4) Since the time when the oblique part of updrift side breakwater was prolonged beyond the tip of downdrift side breakwater, a certain place of the downdrift beach began to be eroded, and the harbour side of this eroded place was accreted. The position of this eroded place and the boundary of accreted area were shifted with the prolongation of the updrift side breakwater.

5) The line connecting the tip of updrift side breakwater with the most eroded place or the downdrift side boundary of the accreted area alway kept a constant angle with the predominant wave direction. These angle were about 40 to 50 degrees for the most eroded place and 20 to 30 degrees for the boundary of the accreted area, respectively.

6) The cause of this change of sea bed topography is considered to be the currents formed in the downdrift side of the hatbour due to waves diffracted at the tip of updrift side breakwater.

REFERENCES

1) Shiji SATO and Norio YANAKA; Field investigation on sand drift at Kashima Coast, Proc. of 10th Conf. on Coastal Engineering, Sept. 1966.

2) Shoji SATO and Isao IRIE; Variation of topography of sea bed caused by the construction of breakwaters, Proc. of 12th Conf. on Coastal Engineering, Sept. 1970.

3) Shoji SATO, Norio TANAKA and Katsuhiro SASAKI; The case history on variation of sea bottom topography caused by the construction works of Kashima Port, Report of P.H.R.I., Vol. 13, No. 4(2), Dec. 1974 (in Japanese)

4) Norio TANAKA; Topography change of sea bed around harbours constructed on sandy beach, Proc. of L974 Annual Research Presentations of P.H.R.I, Dec. 1974 (in Japanese)

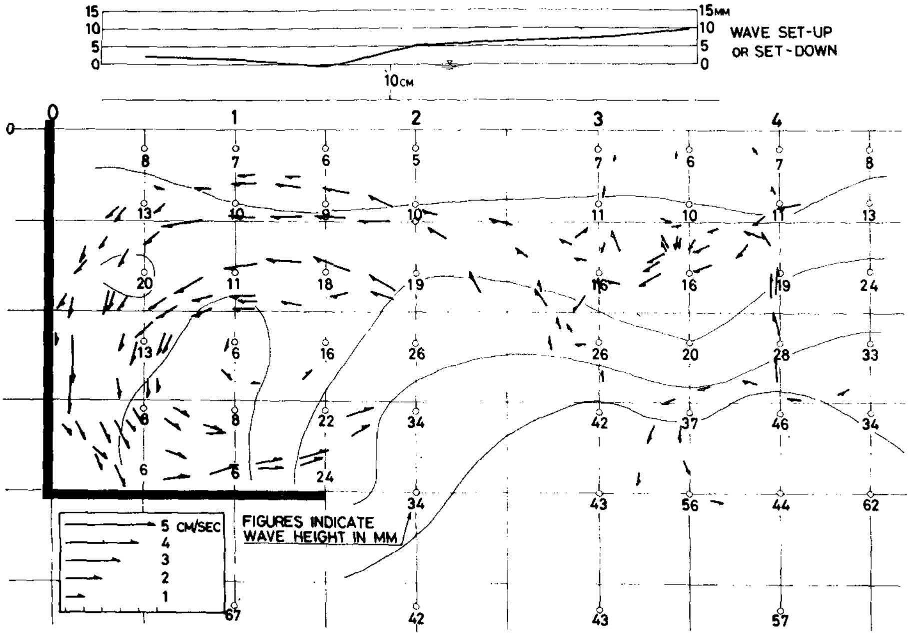


Fig. 22 An example of a model experiment on the currents formed in the downdrift side of the harbour due to waves.