CHAPTER 87

Construction of Offshore Fishing Port for Prevention of Coastal Erosion

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Abstract

When constructing a small fishing port along sandy beach, the most important considerations are how to prevent sand deposition at the port entrance and beach erosion along the down–drift side of the port. To solve these problems, an offshore fishing port connected to the shore by a bridge was planned at Kunnui, Hokkaido Prefecture. The port was designed to allow littoral drift to pass between the port and the shore. The appropriate shape and offshore distance of the port to restrict the development of tombolo was determined by hydraulic model tests and numerical simulations of wave–induced current near the port. Bottom sounding was carried out in parallel with the construction work. As a result, development of tombolo was restricted to some extent and no serious beach erosion occurred. This port seems to have generated unexpected strong cell–like circular currents on both sides, and sand deposits deposited by these currents. There are, however, no problems at present concerning the shape, offshore distance and location of the port entrance.

Introduction

In planning a small fishing port along sandy beach, the most important points to be taken into consideration are how to prevent shoaling of the port entrance by drift sand and how to eliminate adverse effects of the structures on coastal topography such as down stream erosion and excessive accretion at the updrift beach. Movement of sea bottom materials is very active in the littoral zone, and even a small sized fishing port must be designed to avoid littoral sand deposits at the port entrance. Extended breakwaters, however, act as a dam and intercept the flow of sediments, and accretion occurs at the updrift side. This creates in some cases deficiency in material supply to the down coast, where erosion occurs. Out of about 3,000 fishing ports in Japan, seventy five percent are in the category of type I according to Japanese classification, which is small scale, used only by fishermen from several adjoining fishing communities and serving an average of 100 boats less than 3 Gross Tonnages.

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The offshore fishing port discussed here was constructed with its entrance out of the surfzone, and thus free of sediment deposition, and connected by a bridge so as to allow littoral drift to pass behind. In case of such a small port, it is not necessary to locate the port very far from the coast, and construction costs are reasonable. The problem is to determine the offshore distance needed to restrict development of tombolo to the extent to allow the passage of drift sand. From this standpoint, this offshore fishing port was planned at Kunnui, in Uchiura Bay, southern part of Hokkaido in 1985 and completed in 1994. This report represents the characteristics of drift sand in the Bay of Uchiura, several investigations to determine the layout of the port, and changes in the bathymetry of the site during the construction.

Outline of The Project Site Conditions

Topography

Kunnui fishing port is located at the head of Uchiura Bay along the eastern side of the Oshima Peninsula. As shown in Fig. 1, the bay is almost a circle, 50 km in diameter and 150 km in length along the coastline. The entrance is open to Pacific Ocean at the southeast side and the width of this entrance is 28 km. The bay is roughly divided into three sections from the viewpoint of the geographical, meteorological and oceanographical conditions such as wind, wave and littoral current.

① Northeast Coast

This section is between Muroran and Shizukari, consisting of coastal cliff made of igneous rock which has strong resistance against erosion and narrow coastline between the cliff and sea. The coastline is generally monotonous and slightly concave or bow-shaped.

② Northwest Coast

This section, between Shizukari and Yakumo, is located in front of the bay entrance. The coast is monotonous, bow-shaped and of sand. The particle diameter of sand at the foreshore is almost uniform. This coast is topographically of emergent, caused by land upheaval. Especially between Shizukari and Kunnui, there is a flat coastal plain. Kunnui fishing port is located at around the middle of this coast.

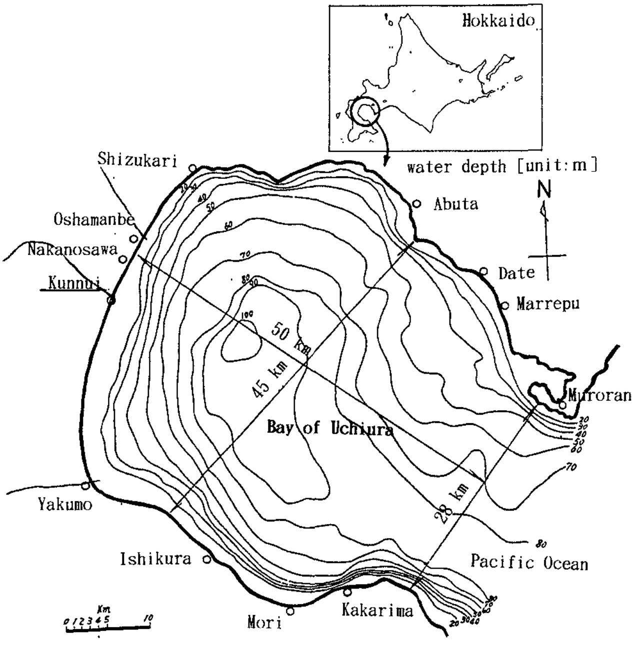

Fig.1 Uchiura Bay

③ Southwest Coast

This region, between Yakumo and Mori, has eroding beaches approached by hills. Sandy coast is limited with, one to two kilometers sandy beaches between capes that exist at intervals. Capes are made of sedimentary rock and considerably eroded. Recently, the construction of a coastal seawall is serving to protect and preserve this coast.

Sea Waves

In this bay, there is hardly any seasonable change in waves, but there are occasional higher waves caused by typhoons in autumn, and low atmospheric pressures passing through the Sea of Japan in winter.

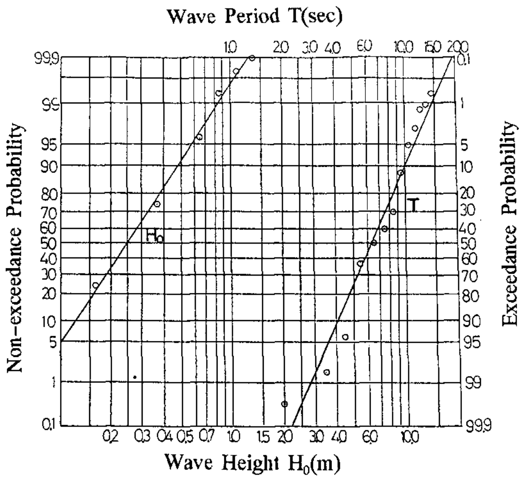

Fig.2 Non-exceedance Probability of Waves (Nakanosawa Observation Point)

Along the northwest coast, where Kunnui fishing port is located, principal wave direction is ENE~SE, and mostly at a right angle to the coastline. Wave observation is conducted at Nakanosawa, located 5 kilometers north-north-east of Kunnui. Probability of non-exceedance on wave height and period from 1968 to 1981 are shown in Fig. 2. Waves less than 0.5 m account for 90 percent. Frequency distribution of waves is shown in Fig. 3. This figure indicates predominant wave periods are around 5 sec. and over 9 sec. This shows two types of waves, one generated in the bay and the other from the Pacific Ocean. As shown in Table 1, incident waves range from ENE to SSE, but predominant wave direction is from ESE to SE, and is almost at a right angle to the coastline.

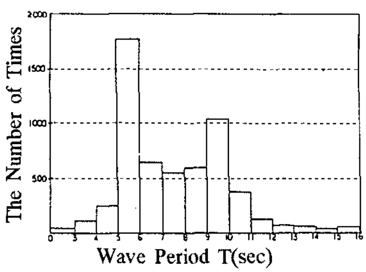

Fig.3 Frequency Distribution of Observed Waves (1968~1981, at Nakanosawa)

Table 1 Wave Height[H] Distribution by Directions (1968~1981, at Nakanosawa)

Wave Height H(m)	Direction ENE	E	ESE	S E	SSE	Total
0.0~0.5	−	39	2157	1889	30	4115
0.5~1.0	−	1	682	736	−	1419
1.0~1.5	70	−	33	11	2	116
1.5~2.0	−	−	3	−	−	3
2.0~2.5	−	−	3	−	−	3
2.5<	−	−	−	−	−	0
Total	70	40	2878	2636	32	5656
%	1.24	0.71	50.88	46.60	0.57	100.00

Average wave height is 0.4 meters, and average wave period is 7.5 sec.

According to the significant design wave investigations for the port conducted by Hokkaido prefecture, maximum yearly wave height is for storm wave coming from the Pacific Ocean, and wave heights with some return periods were obtained by

Table 2 Wave Height with a Return Period of N years

Direction	Return Period of N years	1 year	3 years	5 years	10 years	20 years
E S E	Wave Height H(m)	2.1	3.7	4.5	5.6	6.8
	Period T(sec)	6.4	7.8	8.5	9.4	10.4
S E	Wave Height H(m)	2.9	5.0	5.9	7.0	8.0
	Period T(sec)	7.1	8.9	9.6	10.6	11.4

Table 3 Equivarent Deepwater Wave

Condition	Direction	Deep Sea Wave		Equivarent Deepwater	Direction	Breaker Depth
		H_0(m)	T_0(sec)	Wave Height H_0'(m)		h_b (m)
Ordinal Storm	E S E	2.1	6.0	1.3	E S E	2.15
(in 1 year)	S E	2.9	8.0	1.7	E S E	2.89
Storm	E S E	6.8	10.0	3.5	E S E	5.67
(in 20 years)	S E	8.0	11.0	4.1	E S E	6.64

statistical analysis on 20 waves each for ESE and SE, applying the Weibull Distribution Method. The result is as per Table 2.

Deep sea significant design wave was decided as wave height of 8.0 m and wave period of 11.4 sec with return period of 20 years. The bay entrance is not very wide, so equivalent deepwater wave height is calculated based on angular spreading of wave energy and refraction coefficient. For these effects, equivalent deep sea wave height of design wave 4.1 m and breaker depth is 6.6 m from ESE, as per Table 3.

Tidal and Littoral Current

Highest water level on record is +2.00 meters, mean monthly-highest water level is 1.4 meters, mean water level is 0.5 meters and mean monthly-lowest water level is 0.0 meters above datum level. As for littoral and tidal currents, field investigations conducted by Civil Laboratory of Hokkaido Development Bureau, for 2 years 1963 to 1965, were available, as per Fig. 4. Characteristics are as follows:

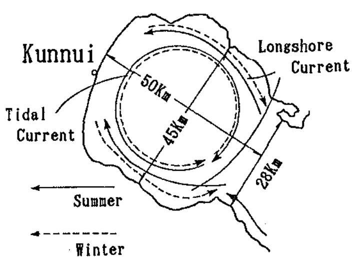

Fig.4 Currents in Uchiura Bay

① Tidal current in the bay becomes a loop current, clockwise in summer and counter clockwise in winter, influenced by ocean currents outside the bay.

② Correlation between direction of littoral current and incident wave direction is high, and the dominant direction of littoral current corresponds to prevailing direction of incident wave.

③ In normal weather, littoral current in the bay depends on season. Along northeast and southwest coasts, direction is towards the head of bay in summer, and from head forward the entrance in winter. But along the northwest coast, direction is opposite on the Shizukari side and Yakumo side, with the neighborhood of Oshamanbe as a border.

④ Velocity of tidal current is about 16 cm/sec.

Bottom Slope

Contour lines are almost parallel to coastline. Bottom slope is approx. 1/90 as far as −7.0 meters. Depending on season, a step is formed, in some cases at water depth of 2 to 3 meters.

Bottom Materials

Table 4 Median Grain Diameter[d_{50}] and Sorting Coefficient[S_0] by Water Depth

Date	Offshore Distance (m)	- 60	+ 60	+300	+500	+700
	Water Depth (m)	+1.0	-1.0	-4.5	-7.0	-8.5
Nov., 1984	d_{50} (mm)	0.25	0.21	0.17	0.15	0.08
	$S_0=(d_{75}/d_{25})^{1/2}$	1.48	1.43	1.21	1.38	1.42
Jul., 1985	d_{50} (mm)	0.29	0.22	0.16	0.15	0.14
	$S_0=(d_{75}/d_{25})^{1/2}$	1.19	1.23	1.21	1.20	1.33

This coast is emergent, and the existing coastline is assumed to have been deposited at about −20 m sea bottom. Particle diameter of sand is less than 0.22 mm, and well sorted. Median grain size (d_0) has a smaller value depending on water depth toward offshore. Median grain size and coefficient of screening by water depth is shown in Table 4.

Drift Sand

· Changes of Coastline

According to field interviews, the shoreline around Kunnui fishing port retreated about 25 m during the 40 years from 1925 to 1965, and yearly average retreat was 0.6 m/year. Further, according to the coastal deformation map based on topographical maps (1/50,000) made by the Geographical Survey Institute from 1896 to 1975 at Oshamanbe,10 km from the port, shoreline retreat continued up to around 1969

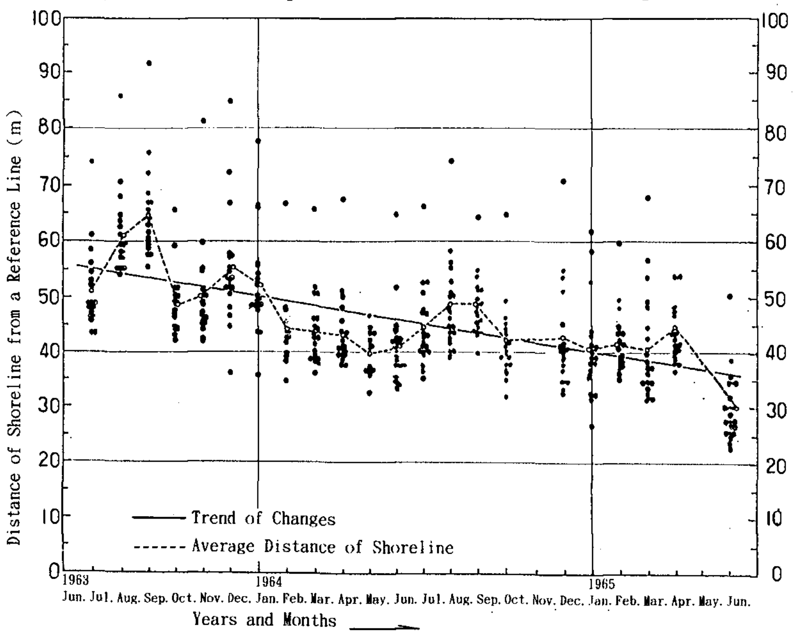

Fig.5 Changes of Shoreline from a Reference Line (at Nakanosawa)

but there was little retreat afterwards. Today, a balanced situation is maintained, but considerable seasonal changes seem to be occurring. Fig. 5 shows the investigation results on change of coastline at Nakanosawa from June 1963, to June 1965. Distances to coastline measured from 21 key piles installed at 50 meters intervals are plotted monthly. Average distance is shown by a dotted line and the total trend by a solid line. The trend is forwards coastline advance in summer and retreat in winter. For those 2 years, the coastline retreated by about 20 meters on an average but seasonal change was also substantial, from 10 to 15 meters. From this figure the following features are recognized;

① Throughout the year, accretion and erosion repeat alternately and a seasonal cycle is observed.

② Erosion trend is observed from October to February and deposition from March to September, though there exist some variations depending on the annual wave conditions.

③ Retreat of shoreline is, in most cases, sudden rather than gradual. It is assumed that coastal erosion is caused by waves generated by typhoon around autumn and cyclones passing through the Sea of Japan in winter, and that in such cases erosion is not completely recovered even after a long period of calm sea.

· Relation among Wave Energy, Average Length to Coastline and Foreshore Sand Volume

Assuming that E_h is wave energy transmitted across a plane of unit width perpendicular to the direction of wave advance at water depth h; and E_b is wave energy at breaker position; $E_b = (b_n/b_b)E_h$: and E_a is energy passing through unit width parallel to coastline per unit time, therefore $E_a = E_b \cdot \mathrm{Sin}\,\alpha \cdot \mathrm{Cos}\,\alpha$. In these equations b_n/b_b is sq. of refraction coefficient and α is wave crest angle with shoreline at breaker position. Assuming that at water depth h, H is wave height, L is wave length and T is wave period, from Small Amplitude Waves Theory, $E_h = n\,H\,L\gamma/8T$, and γ is unit weight of sea water and n is ratio between wave velocity and group velocity. Therefore, incident angle is divided to $+\alpha$ and $-\alpha$, if right angle direction against coastal line is set as 0. Assuming that E_L is the energy of waves come in from left hand side and E_R from right hand side. Fig. 6 shows change of length and foreshore sand volume up to coastline from key pile and the relation with ΣE_L as well as ΣE_R and also ($\Sigma E_L - \Sigma E_R$). For calculation of ΣE, it was assumed that the measured waves at noon continued until the following noon, and the energies from the both sides are added up separately for each month. Shoreline advance occurred when ($\Sigma E_L - \Sigma E_R$) is within the range of E_R, and shoreline retreated when this is within the E_L range. As a result of this survey, it was concluded that in this area, onshore–offshore sand transport is dominant under usual wave occurrence, and under unusual weather conditions, longshore littoral transport

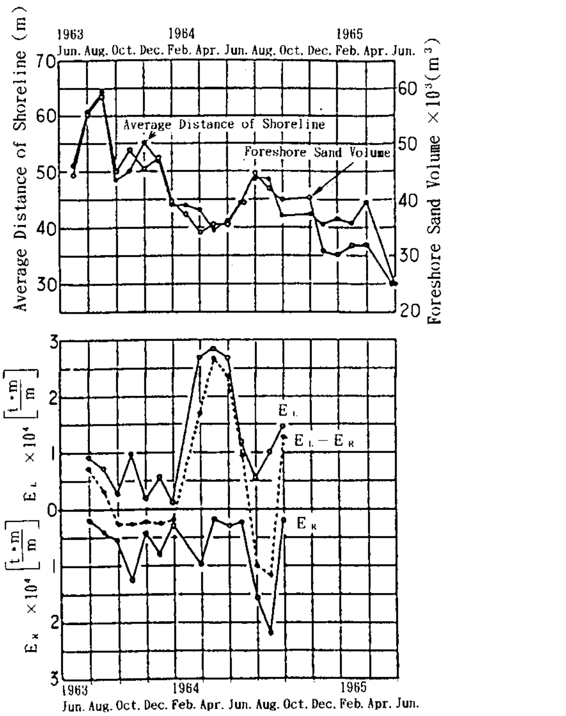

Fig.6 Relationship between Average Shoreline, Sand Volume and Wave Energy(at Nakanosawa)

parallel to the coast is predominant. The coastline thus advances when E_R surpasses E_L , and vice-versa. Direction of predominant littoral transport is from right to left.

Coastal Changes of the Adjoining Fishing Port and Coastal structures

Yakumo Fishing Port

Yakumo fishing port is located at 23 km from Kunnui. Construction work began in 1951. Fig. 7 shows the coastal changes of this port. Due to drift sand moving from right to left, sand was deposited along the upstream shore, and it became difficult to maintain water depth at the port entrance. Considering the smallness of particle diameter at this coast, and the changing direction of dominant longshorc current depending on season, an offshore breakwater as shown in this figure was installed. Sand accumulates at the back of the offshore breakwater in summer and when wave and flow change direction in winter, flushing of sand by natural forces acts as a counter–measure. Consequently, this counter–measure succeeded in preventing excessive sedimentation at the port entrance.

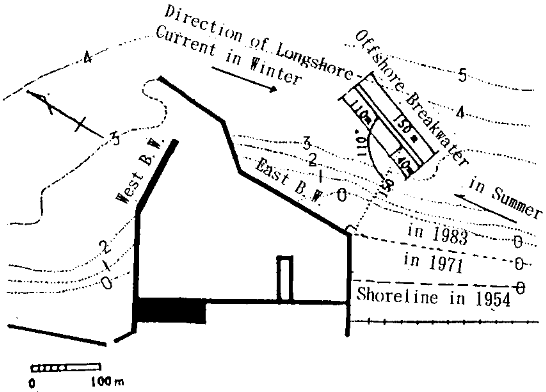

Fig.7 Shoreline Changes at Yakumo Fishing Port

However, as water depth at the port entrance had already been reduced to 3 meters, and onshore drift sand is flowing in from the port entrance, maintenance dredging is still carried out every year.

Offshore Breakwaters for Shellfish Propagation Ground at Yakumo

From 1976 to 1981, three offshore breakwaters had been constructed with the purpose of "sakhalin surf–cram" propagation grounds about 13 km from Kunnui. The specifications of these offshore breakwaters are; 200 m in length, 50 m between successive breakwaters, 200 m of offshore distance and –3.0 m as site depth. As this area is very near and topographically similar to Kunnui, bottom materials and slope are similar to that at Kunnui. Fig. 8 shows coastal changes caused by the construction of these offshore breakwaters. The type of the breakwater is of permeable riprapping tetrapod with crown height of D.L.+3.0 m.

As shown in Fig. 8, as the construction work progressed, extensive tombolo developed behind the breakwaters and the coastline advanced by about 100 m at low water level. The adjoining coast was eroded, and at the left–hand coast even the foundation of the existing seawall was eroded. Accretion was remarkable and three tombolo were connected to each other. Fig. 9 shows bathymetry in August of 1984. As the development of the right–side tombolo is greater and coastal erosion is greater than on the left side, the dominant direction of drift sand is supposed to be from right to left.

Plan of the Fishing Port

In the past, before Kunnui fishing port was developed, fishing boats were hauled

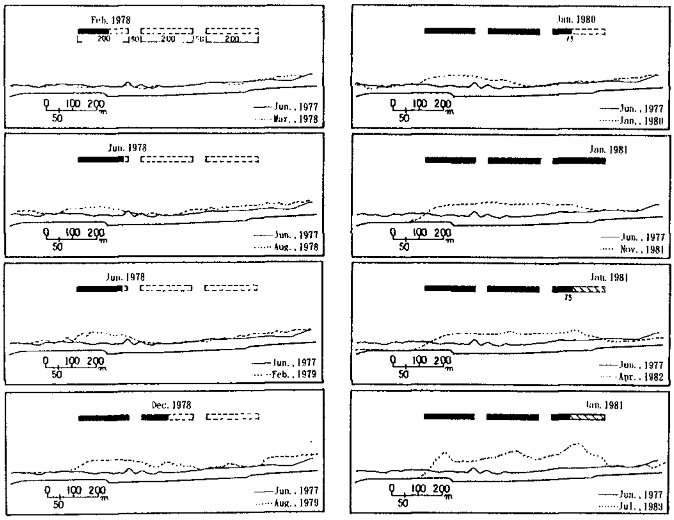

Fig.8 Changes of Shoreline behind Offshore Breakwater at Yakumo

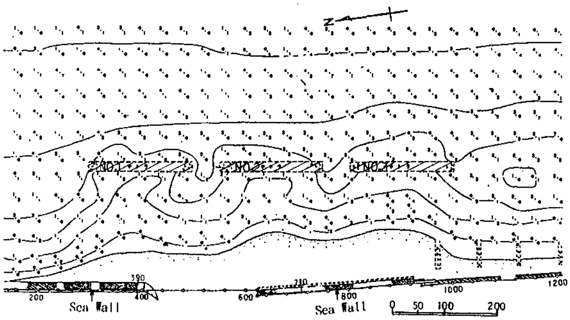

Fig.9 Bathymetry of Yakumo Shell-Fish Propagation Ground (Aug., 1984; Two and Half Years after the Completion of Offshore Breakwater)

up on the foreshore, much man power and time was needed for lifting and launching fishing boats. Major catches are scallop, flatfish, salmon and tuna. The fisheries are managed under stable conditions with gillnet, small setnet and salmon large setnet fisheries, and shallow water aquaculture of scallop. Kunnui fishing port was designed to serve as a vessel mooring area and a base for prepparing and managing fishery operation.

Shape of the Port

Merits and demerits of detached fishing ports are discussed by Sakai. In case of small-scale ports, a large area for port facilities is not required, but if a plan be conducted only directing our attention to the scale of a plane layout, or the port design is concentrated only on facility layout, ignoring the presence of littoral drift, and the port entrance is set inside the breaker zone where drift sand movement is heavy, then the function of the port may be impaired. On the other hand, if the port layout is determined from a viewpoint of preventing sedimentation at the port entrance, a rather large-scale port design is indispensable in order to set the port entrance far offshore side beyond the breaker zone. In this respect, however, a port constructed at a properly selected offshore site as a kind of man-made island may not require higher total costs than a conventional port.

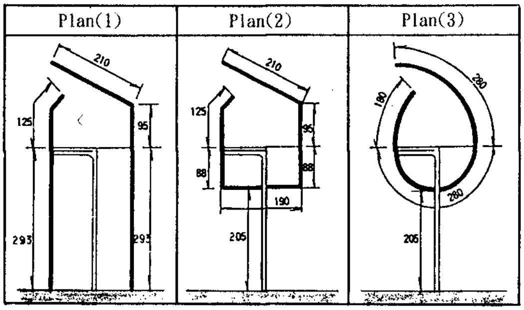

Fig.10 Layout Plan of Kunnui Fishing Port

Several draft plans were examined, considering the influence on adjoining coast, sedimentation at port entrance, ease of construction and construction cost. Two basic cofigurations were considered; one was a conventional type extending offshore; and the other was a detached island type. Further, two detached types were considered; one with a curved shape to decrease wave dumping effect by the port, and the other with an angular form. Fig. 10 shows these types; ① Plan 1 : Conventional type of port ② Plan 2 : Island type of port with angular lines ③ Plan 3 : Island type with curved breakwater to produce rough waves behind the sheltered area. Although Kunnui is a small port, if the port was constructed based on the conventional method of installing shore-connected breakwaters, it was assumed that longshore transport would be interrupted and beach accretion up-coast as well as erosion down-coast would occur. Further, if the port entrance was set in the surf zone, there was a risk of sedimentation at the port entrance. In fact, these troubles occurred at Yakumo port, as already mentioned. In order to prevent the influence of drift sand as much as possible, an offshore island type fishing port was adopted.

From a standpoint of coastal structure, an island fishing port is considered to be very similar to an offshore breakwater. In this case, the point was how to balance the need to prevent development of tombolo with construction costs. The longer the offshore distance, the smaller the development of tombolo, but the higher the construction cost. Therefore, the following conditions are key for determination;

① Water depth at the port entrance is deep enough to prevent being blocked by drift sand under adverse wave conditions. ② Port is designed such as to decrease formation of tombolo. ③ Offshore distance has to be great enough to prevent the port from being connected to shore by development of tombolo. ④ Reasonable construction cost based on comparison with costs estimated for conventional port, including relation between offshore distance, maintenance and management cost if longshore drift transport were totally interrupted and beach erosion occurred.

Offshore distance was initially set at around 200 m, and investigations were carried out for several different distances.

Scale of the Fishing Port

Port scale was planned according to the forecasted number of fishing boats which would utilize the port, as per Table 5. Pursuant to Fishing Port Planning Criteria, the facilities and scale are as per Table 6.

・Entrance Water Depth

If a port is constructed offshore, the risk for sedimentation at the entrance becomes lower as the entrance water depth gets deeper, but cost increases. For deciding the depth of the port entrance, critical depth for sediment movement is adopted as a yardstick. This critical depth is classified into two types; critical water depth for surface sediment movement and critical water depth for complete sediment movement. The former concerns mass movement of surface sand at the bottom along wave direction; and the latter indicates movement which can cause change of waterdepth. According to the formula developed by Sato and Tanaka, these depths are expressed as follows;

Table 5 Usage of Kunnui Fishing Port[G.T.: gross tonnage]

The Grade of Fishing Boats	1983 (Results) The Number of Fishing Boats	Total G.T.	after Completion(Forecast) The Number of Fishing Boats	Total G.T.
< 3 G.T.	32	67	6	67
3~ 5 G.T.	7	24	46	161
5~10 G.T.	0	0	4	28
Total	39	91	56	256

Table 6 Necessary Facilities

	Facilities	Length or Area
Mooring Facilities	Quay Wall -3.0m	100 m
	Boat Yard[Shipway]	80 m
Land for Facilities	Land for Facilities +3.0m	12,100 m^2

(Surface Sediment Movement)

$$\frac{H_0}{L_0}=1.35\left(\frac{d}{L_0}\right)^{\frac{1}{3}}\left(\sinh\frac{2\pi h_i}{L}\right)\left(\frac{H_0}{H}\right)$$

(Complete Sediment Movement)

$$\frac{H_0}{L_0}=2.4\left(\frac{d}{L_0}\right)^{\frac{1}{3}}\left(\sinh\frac{2\pi h_c}{L}\right)\left(\frac{H_0}{H}\right)$$

Where,
Affix o : offshore wave
h_i : Critical water depth for surface sediment movement
h_c : Critical water depth for complete sediment movement

As a result of bottom survey, median diameter of bottom sand is d_{50} = 0.08–0.26. During investigation period, H_0' = 2.2 m and T = 12.3 sec were observed. After storm wave subsided, recognized isobath was up to −6.5 m, with d_{50} of 0.26 mm. The calculated values were h_i = 6.6 m and h_c = 3.1 m. For wave with return period of one year, equivalent deep water wave height H_0' is 1.7 m, with h_i= 7.7 m–12.5 m and h_c=3.7 m–5.7 m. According to these results, the entrance depth was determined to be deeper than D.L–5.7 m.

These factors were established based on the analysis of existing materials, site investigations and simulations, and thus may not represent in full the actual site conditions. Consequently, an hydraulic model test was conducted, and the results were compared.

Layout of the port

· Model Test

To compare the angular and curved offshore fishing ports, a hydraulic model test was carried out. As bottom slope is gentle, the distorted model was applied through trial and error. Mode Scale was 1/100 in horizontal and 1/70 in vertical. Tests were carried out for the angular type (Plan 2) and the curved type (Plan 3) with waterdepth −5.5 m, −6.5 m, −7.0 m. Offshore distance was initially set at 200 m and tests were conducted for several distances around this figure. Sand used in the tests has a median grain size of 0.22 mm. The purpose of the tests was qualitative comparison of tombolo development.

Test Waves were for waves with return period of 1 year and 20 years, and wave direction was ESE and SE. As a verification method, sand movement by tracer in the Model was arranged to correspond to the move of fluorescent sand at the site. As it is difficult to reproduce actual site conditions in the model, only qualitative comparisons ware conducted.

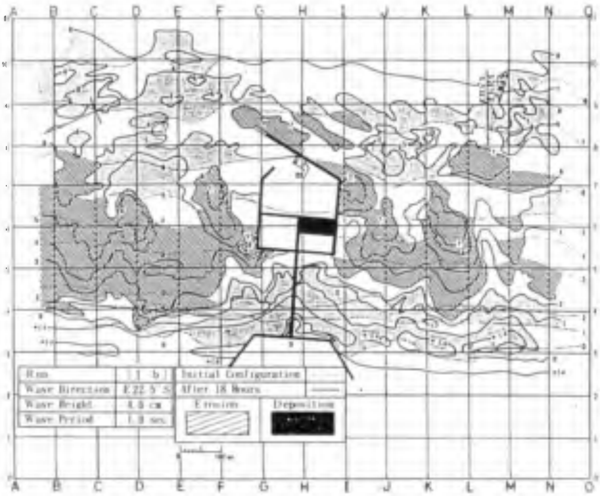

Fig.11 Example of Sea Bottom Change by Hydraulic Model Test[Plan(2)]

A total of 24 hydraulic model tests were performed for various wave conditions and offshore distances. As a qualitative comparison between angular type and circle type, tests showed no tombolo protruding from water surface for the circle type, because of higher wave height and rougher water behind the port compared to the angular type. Two examples of the results of the tests are shown in Fig. 11 and Fig. 12.

In this case of the angular type, conspicuous tombolo was observed, while no tombolo appeared in the circle type even though incident wave was a little higher. A long and slender shoal, however, elevation of which was the same as the water surface, was formed along the center line behind the port, where waves from both sides collided with each other. Another characteristic was local scouring along and at the corners of breakwaters in the angular type, in contrast to that deposition area appeared along breakwaters up to water depth of –5.0 m to – 6.0 m in the circle type. This phenomena seemed to be caused by strong return flow along the structures.

• Numerical Simulation of Wave Induced Current

For Plan 3, numerical calculation of wave induced offshore current was conducted to confirm the speed of return flow. The result of the computation is shown in Fig. 13.

The wave conditions in this case are; wave direction ESE, equivalent deep water wave height is 2.2 m (at depth of –6.0 m it is about 2.0 m), and wave period 8.0 sec. The range of computation is 1,000 m, along the coast and offshore. Mesh interval is 20 m. In this case, a circular current with velocity 10 to 30 cm/sec developed behind the port. Part of this current flows offshore along outlying facilities as return flow. This flow might result in sediment transport and deposition along port outlying facilities as seen in the model test. If the –2 m isobath reaches the port entrance, the entrance may not be maintained. In the hydraulic model test, this phenomenon occurred until initial water depth of –3.5 m.

These qualitative tests, however, were unable to confirm what would occur at the actual site. Furthermore, although conspicuous tombolo was not formed in the model test, a considerable size of tombolo was assumed to develop from this calculation. Putting all these various results together, along with last but not least, consideration of total cost, layout shown in Fig. 14 was adopted.

Topographic Changes During Construction

The construction work commenced in 1988, and proceeded in the following order: ①Road bridge ②West side seawall ③Bridge approach

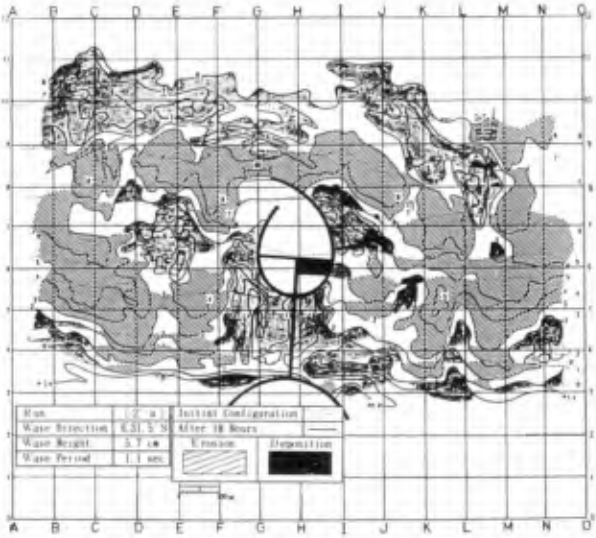

Fig.12 Example of Sea Bottom Change by Hydraulic Model Test[Plan(3)]

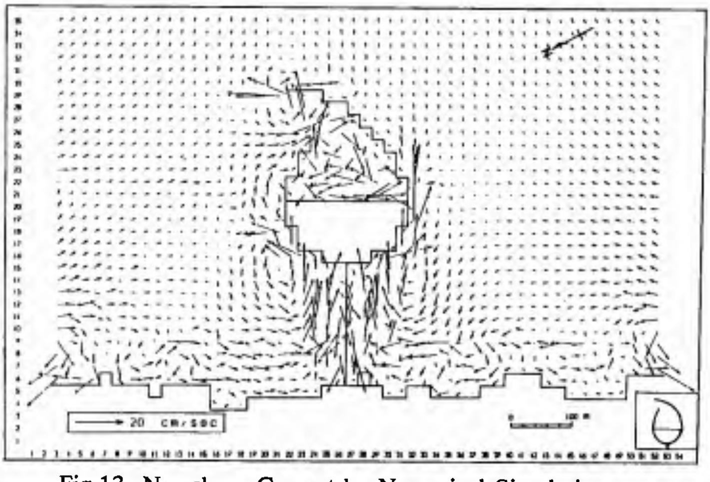

Fig.13 Nearshore Current by Numerical Simulation [H_0=3.6m, T=8.0sec.: H=2.0m at h=−6.0m]

④Southern seawall ⑤Southern breakwater ⑥Eastern breakwater ⑦Northern seawall ⑧Northern breakwater
⑨ Mooring facilities ⑩Reclamation of land for facilities. During the construction, sounding survey was conducted every year around August and September. The coastal configuration at each stage of work was compared against with the base survey conducted in August, 1985. As was predicted, a tombolo was formed at the rear of the port. Fig. 15 shows changes of coastline (development of tombolo) at

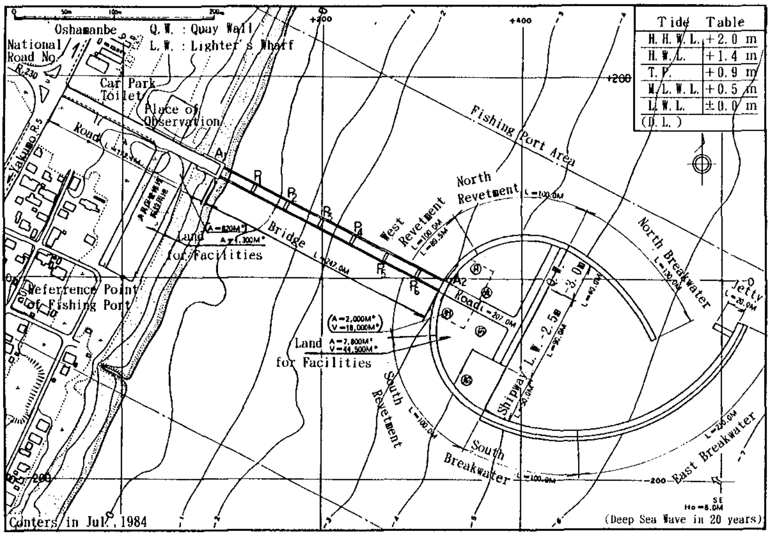

Fig.14 Final Plan of Kunnui Fishing Port

M.W.L. (D.L.+0.5 m). The tip of the tombolo advances seaward with the progress of the construction work. But maximum length of advancement is only about 60 m and the size is not so great. Fig. 16 illustrates the changes of shoreline at L.W.L. (D.L.+0.0 m). The seaward tip of the coastline is long and sharp but changes its shape adapting to imposed wave conditions much like a kind of cuspate spit, and almost touches the port in recent years. Fig. 17 shows bathymetric changes. Since this port consists of impermeable breakwater and a coastal structure 300 m long and 200 m wide, bathymetric change is, in general, different from that of a conventional offshore breakwater shown in Fig. 9, which is of permeable type with low crown height. In the case of common offshore breakwaters, local scouring is generally observed at both ends, but in the case of an offshore fishing port, there exists no scouring because of the smooth linear change in the line of the structure. Due to influence of return flow, sand deposition occurs as far as −6 m on the right−side and −5 m on the left−side along the port and shape of the isobath becomes convex near the port.

At the planning stage of this port, we considered only the similarities with an offshore breakwater, but in reality, coastal changes adjoining the port also show similarities with the changes usually caused by a long jetty.

Bathymetric changes since 1992 hint at the existence of large scale and strong cell−like circular currents on both sides of the port. Along this current, scouring of sea bottom occurs in the onshore direction and deposition in the offshore direction. The width of this circular current is approximately 400 m, and this results in the start of tombolo 300 m − 350 m on both sides from the center line of the port. Retreat of the coastline is 30 m at right and 10 m at left and stable. In comparison with yearly shoreline changes by attacking waves before the construction of the port, this retreat is small and stable and thus there are no problems concerning coastal erosion, even though there is no seawall at this beach. Over a distance of 400 m from the center line, no particular change can be seen in the coast except for seasonal changes.

The point is whether we have obtained the desired results or not. At this coast,

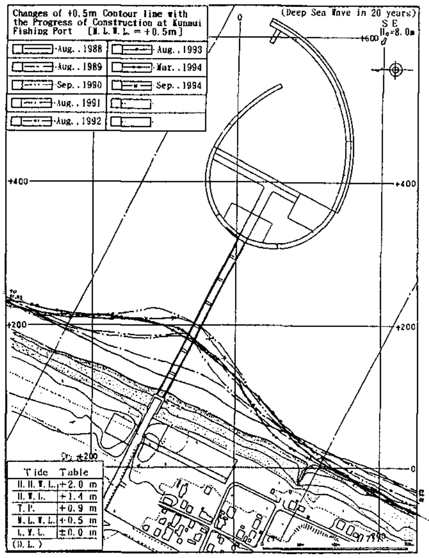

Fig.15 Change of +0.5m Contour line with the Progress of Construction at Kunnui Fishing Port[M.L.W.L.=+0.5m]

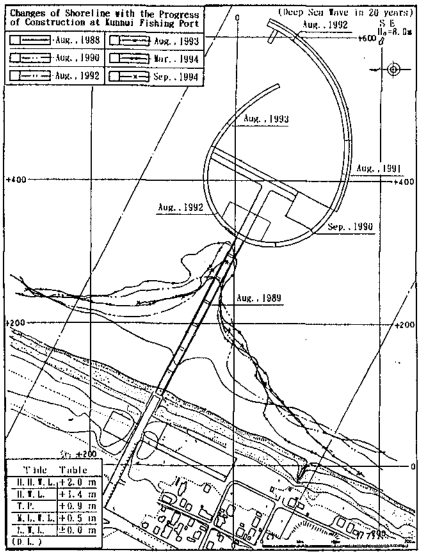

Fig.16 Changes of Shoreline with the Progress of Construction at Kunnui Fishing Port[at L.W.L.=±0.0m]

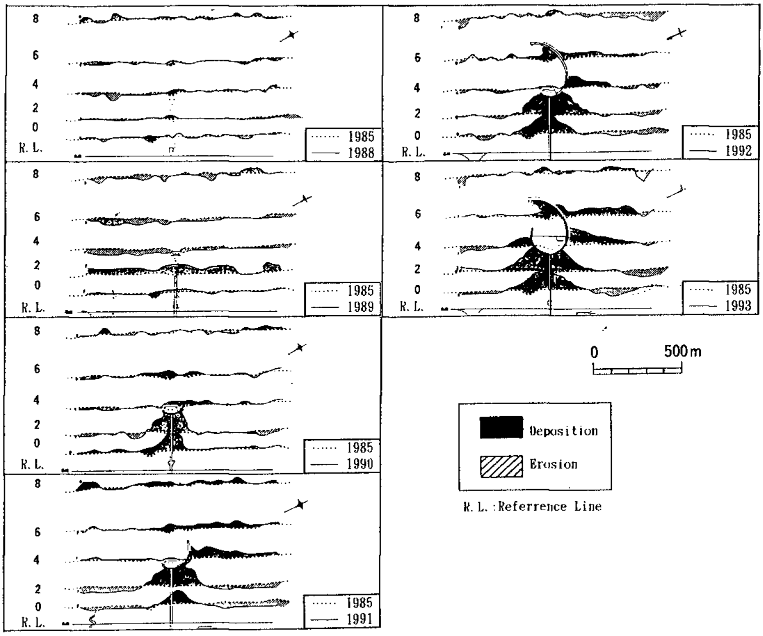

Fig.17 Changes of Contours with the Progress of Construction at Kunnui Fishing Port

onshore–offshore sand drift dominates under normal conditions and longshore sand drift during high waves, but except for low water, there remains a channel at the rear, and we thus think it stands to reason that littoral current flows behind the port. It is only 3 years, however, since the port took shape, and we are thus going to continue field observations and make a final decision in the future.

Conclusion

Our research focused on how to prevent beach erosion and sand deposition at the port entrance. For the time being, this purpose seems to be satisfied at Kunnui fishing port, but careful examination of bathymetric charts conducted in parallel with the construction work indicated that there occurred large scale cell–like circular currents at both side of the port. This current transports sand onshore and scours the sea–bottom en–route and deposits sand behind and along the port when it is flowing in the offshore direction. In this sense, the location of port entrance at the depth of −6.5 m, and over 400 m offshore from the coastline is supposed to be adequate in this case. We learned that it is important not only to restrict tombolo generation but also to predict the scale and strength of cell–like circular currents in planning this type of fishing port.

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