NEARSHORE CURRENTS ON A PARTIALLY ROCKY SHORE

BY

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ABSTRACT

Nearshore circulation on a partially rocky shore at Haranomachi Beach, Fukushima Prefecture, Japan has been studied in terms of field observations and numerical experiments for a low energy wave regime and with a physical experiment for a high energy wave regime. No significant distinctions were found in current velocity and rip current spacing between rocky and sandy beaches for the low energy wave regime, however the positions of rip currents were affected by wave refraction from the offshore exposed rocky bottom. On the other hand, since the surf zone bed is largely occupied by an exposed rocky floor for the high energy wave regime, the circulation exhibited fairly irregular patterns, so that a rip current becomes difficult to define, however the positions of inflow across the breaker line were found to be coincident with wave convergence zone.

INTRODUCTION

Japanese coasts have been classified as "island arc collision coasts" according to the global classification of Inman and Nordstrom (1973) based on recent plate tectonics. Since the major morphological feature of these coasts are mountains, rocky coastlines claim a large share of the Japanese Islands.

Because major national parks occupy the most scenic segments associated with rocky shores, recent nuclear and conventional power stations have been and are being placed on the remaining rocky shores.

The term "partially rocky shore" is defined as a rocky shore that has a portion of its beach on an upper part of a rocky bottom profile. Geologically, it consists of less consolidated Tertiary and/or Quaternary sedimentary rocks, such as sandstone and/or mudstone.

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When attempting to assess environmental impacts, such as power stations on rocky shores, coastal engineers face a general lack of information regarding nearshore processes on such shores in comparison with ordinary sandy beaches.

Since 1975, the authors have been making field observations of nearshore currents and the resulting sediment transport on such rocky shores. The study sites are on the Fukushima Coast, which is about an 80 km long rocky coast running north to south, and located about 200 km north of Tokyo, and fronting on the Pacific Ocean (Figure 1).

One nuclear power station is already operating on this 80 km stretch; one nuclear and one conventional power station are under construction; and another two power stations have been proposed. A portion of the results on nearshore circulation for one of the two proposed sites is presented here.

GEOLOGY AND MORPHOLOGY OF THE SITE

Mogi and Iwabuchi(1961) have given a general description and origin of continental shelf topographies off the Fukushima Coast. Figure 1 shows the northern part of Fukushima Coast and also gives the location of the study site, Haranomachi Beach which is about an 8 km long, somewhat embayed, shore.

The general shape of the shoreline of the Fukushima Coast is convex seaward. Roughly parallel contour-lines are found in the areas shallower than 20 m and deeper than 50 m. The remaining area, whose depths lie between 20 m and 50 m, exhibits very complicated configurations, showing relics of valleys eroded during the past glacial age. The ranges of depths here is important, because it just corresponds to the wave refraction zone. The dotted lines indicate relics of valleys traced from submarine topographic charts[Mogi and Iwabuchi(1961)]. These relics can easily be connected with present day streams on land.

The dot appearing at the center bottom indicates the location of a wave gage, whose data will be given later. The cross-sectional profiles along the "A" and "B" lines are shown in Figure 2. The profiles of neighboring drowned valleys are indicated by dotted lines.

The bottom slope of the flat terrace extending up to 40 - 50 m is about 1/500, whereas the shallowest part of the profiles up to 5 - 10 m is filled with recent sediment supplied from small streams and erosion of sea cliffs, producing beach slopes of about 1/70.

An aerial photograph in Figure 3 shows the southern half of Haranomachi Beach taken in 1979. Low lying hills and coastal plains alternately extend east and west from about 10 km inland. Small streams flow into the sea on this coastal plain at internals of 5 to 10 km alongshore. Between them, low sea cliffs run up to 40 m in height, composed on sandstone and mudstone. The cliff at this site, seen in the center of Figure 3, extends about 1.3 km. The jetty appearing on the lower-right is Mano River Inlet, which supplies sediment to the area, about 20,000 to 30,000 m^3 annually.

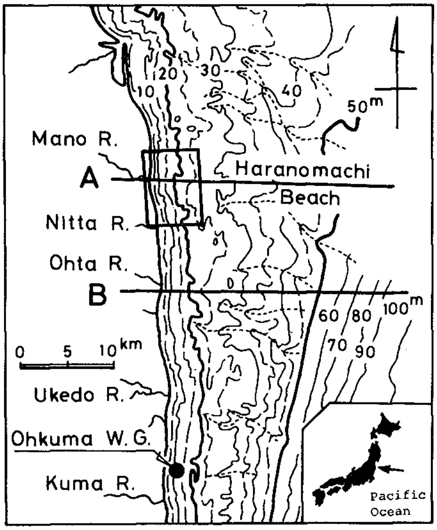

Figure 1 Continental shelf topography off north part of Fukushima Coast. Haranomachi Beach is indicated with a rectangle and dotted lines show inferred drowned valleys traced by Mogi and Iwabuchi(1961).

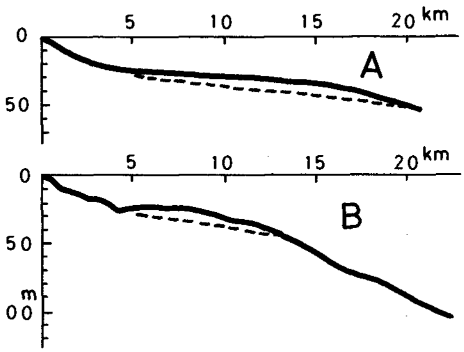

Figure 2 Typical profiles off Fukushima Coasts, after Mogi and Iwabuchi(1961). Range lines are shown in Fig. 1, and dotted lines indicate bottoms of drowned valleys.

Figure 3 Overview of Haranomachi Beach. Mano River Inlet jetty is seen on the lower-right.

A front view of the active sea cliff at this site shown in Figure 3 is given in Figure 4. An indicator of its activity is the existence of fallen materials at the foot of the cliff. In the middle of the cliff, a dark mudstone layer is seen, the upper part of which is composed of sand and sandstone. In front of the cliff, there is a beach about 50 m wide.

A sounding chart for the region off Haranomachi Beach, which covers the nearshore topography up to about 25 m in depth and 6 km alongshore, is given in Figure 5. The cliff seen at the center bottom corresponds to the one in Figure 4. In front of this cliff, there is a beach down to a depth of 4 to 5 m. Beyond it, an exposed mudstone floor appears which is clearly seen by its irregular contour-lines. Parrallel contour-lines seen at the left, indicate that the bottom there is composed of loose sediment. The coastal structure seen at the lower-left is the Mano River entrance jetty. Accretion and erosion occur on both sides of the jetty, indicating the dominant direction of longshore drift.

The geological cross-section of the range line at the left side of the mudstone bedrock is given in Figure 6. At the top, there are sandstone, mudstone, and fine and medium sand layers. At the bottom, mudstone is the base rock comprising the sea floor.

Figure 4 Front view of active sea cliff. Fallen materials are seen at the foot of the cliff.

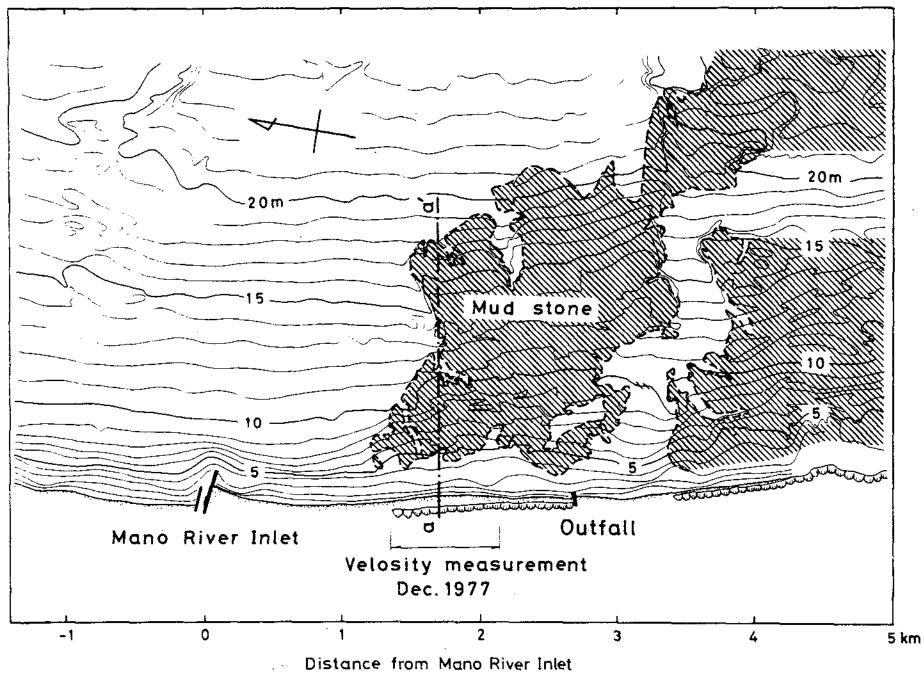

Figure 5 Nearshore topography of Haranomachi Beach. Beach sand covers the upper portion of the rocky profile (a-a' range: Geological cross-section is given in Figure 6). Location of velocity measurement is shown in the center bottom.

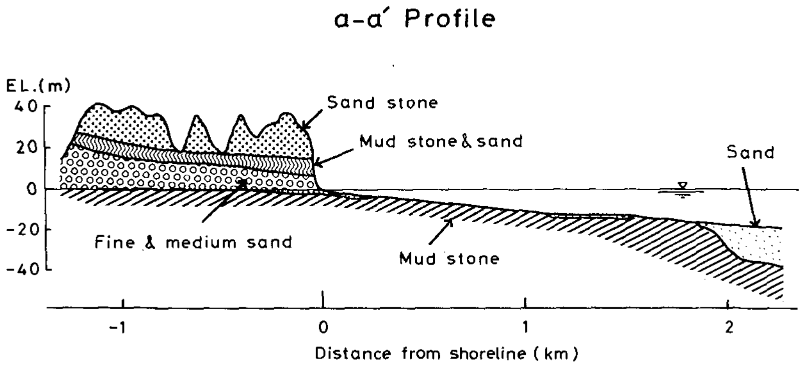

Figure 6 Typical geological cross-section of the site. Location of the a-a' range line is given in Figure 5.

WAVE CLIMATE OF THE AREA

Wave climate data are available from the Ohkuma wave gage as shown in Figure 1. The gage depth is 12 m. Using refraction diagrams, Ohkuma wave gage data over a 5 year period from 1966 to 1971 were converted to wave heights off Haranomachi Beach and allowed us to fill in the lack of records, by wave hindcasting. The resulting combined plot of frequency of wave heights and periods is shown in Figure 7. The typical wave height range is less than 4 m, and the wave periods range from 8 s to 14 s. The maximum significant wave height during this period was 8.3 m in November, 1970.

Wave direcitons were obtained by visual observation twice daily with a transit at Ohkuma observatory at the Fukushima 1st Nuclear Power Station, Tokyo Electric Power Co., Inc. As shown in Figure 8 the most dominant direction is obviously normal to the shore, that is, from the east.

The preponderance of normally incident waves is evidently caused by the fairly gentle continental shelf profile as shown in Figure 2, and is important in view of wave refraction, which in turn may produce a certain wave height disbribution alongshore.

Figure 9 is a typical refraction diagram[Wilson(1966)] for 10 sec waves incident normally onto the northern Fukushima Coast from the east. Wave convergence and divergence caused by the diversified offshore submarine topography as shown in Figure 2 are clearly seen.

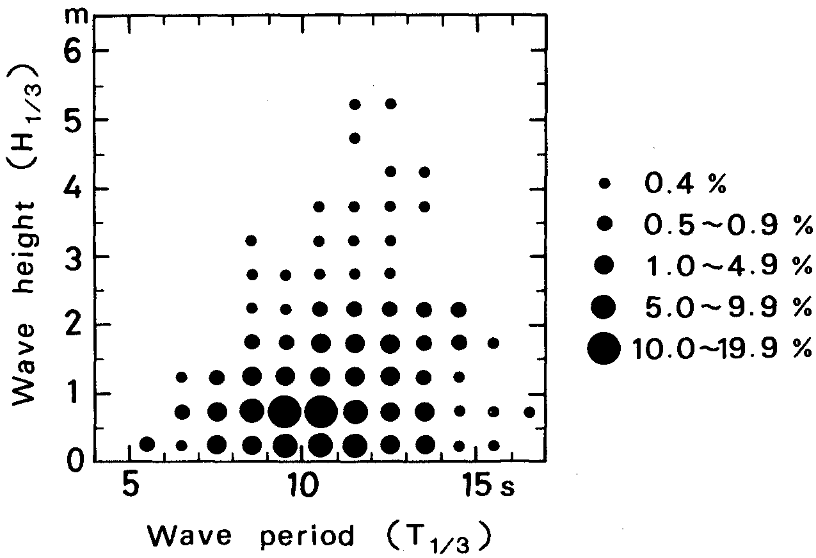

Figure 7 Combined plot of frequency of wave heights and periods over a 5 year from 1966 to 1971 off Haranomachi Beach.

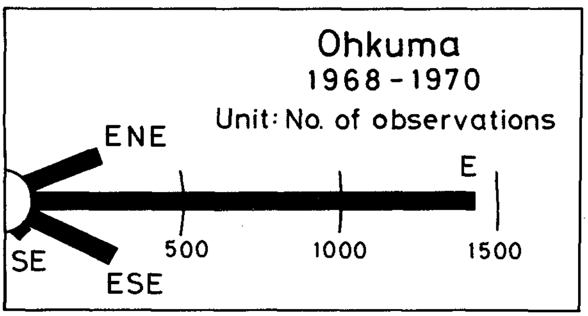

Figure 8 Wave rose at Ohkuma wave Observatory at the center of Fukushima Coast, modified after Toyoshima et al.(1973).

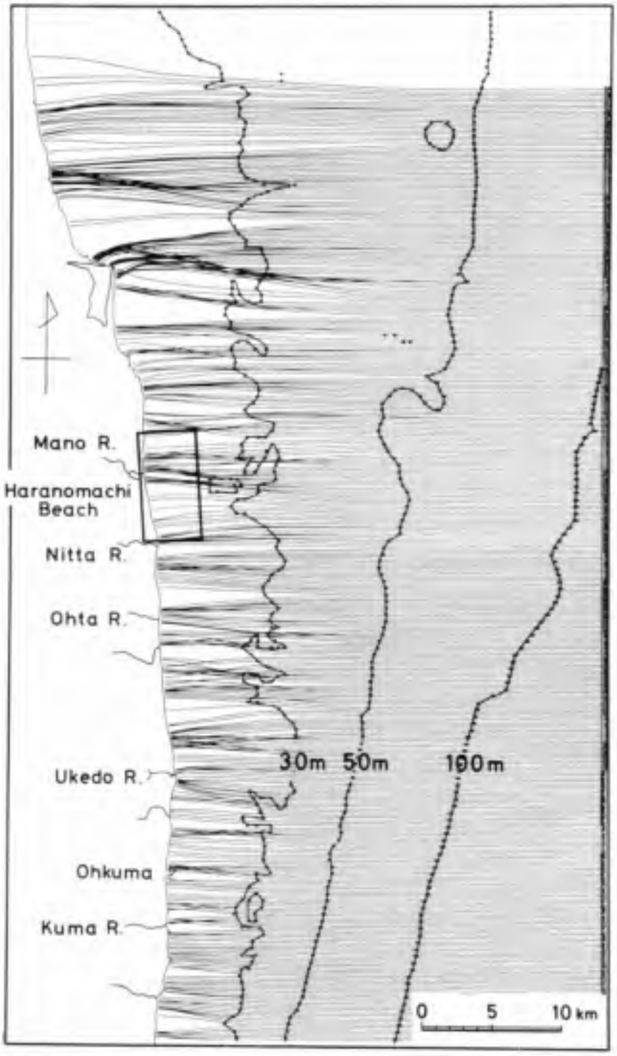

Figure 9 Refraction diagram of 10 s waves incident normally to the northern Fukushima Coast.

NEARSHORE CURRENT OBSERVATION ON HARANOMACHI BEACH
UNDER LOW ENERGY WAVE CONDITIONS

Measurements of rip current spacings were made by the tethered float technique[Sasaki et al. (1978)], seven times between December 1977 and August 1978 on a beach section about 8 km long, south of the Mano River Inlet. The southern end of this beach seciton is bounded by a small groin shaped irrigation drain. Also, velocity field measurements using a balloon[Sasaki and Horikawa (1975)] were carried out in December 1977 in front of the cliff, as shown at the center bottom in Figure 5.

Results from three of the seven measurements are shown in Figure 10. The CASE numbers appearing at the top also give a rough indication of wave height, and they correspond to about 1 m (1.0 m), 2 m (2.4 m), and 3 m (3.1 m), respectively. The wave periods were 11 s - 12 s, and the widths of the surf zone, X_b, *were 60 m, 120 m, and 150 m, respectively. Wave direcitons outside of the breaker line were measured by transit.*

In CASE-1, a pure southward longshore current system extending about 2 km long due to northerly incident waves is apparent, except near the Mano River Inlet. Such a typical longshore current has rarely be seen on such a gentle beach like this. On the other hand, several rip currents developed in CASE-2 and 3, resulting in the formation of an asymmetrical cellular circulation[Harris (1969)].

The circulation patterns do not exhibit large differences from those on ordinary sandy beaches under a similar wave climate, because beach sediments cover the surf zone or nearshore zone sea floor down to a depth of 4 to 5 meters as was seen on the sounding chart.

However, comparing the positions of rip currents with refraction diagrams, it is found that the positions of rip currents coincide with regions of wave divergence, particularly in CASE-3. The ratio of rip current spacing to the surf zone width also shows no significant differences from those on a sandy beach.

Additional evidence for the similarity of this rocky beach to a sandy beach was obtained from computing the bottom roughness length from velocity measurements. On the day following CASE-3 in Figure 10, velocity measurements in front of the northern end of the cliff (Figure 11) were made by aerial photography from a tethered balloon. The breaker height and period were 1.7 m and 12.5 sec, respectively. The wave incidence was somewhat shifted to the north. And it was almost windless.

Figure 12 shows comparisons of the observed velocity field with computed ones using Sasaki's(1975) numerical model, which applies Jonsson's(1966) wave friction factor on Noda's(1974) circulation model. The southward longshore current is dominant in the observed velocity field and its velocity ranges around 50 cm/s. Computations of the velocity field were made with roughness lengths of 2 cm, 5 cm, and 10 cm. Comparison of the computed velocity fields with the observed one shows that the 5 cm roughness length gave the most reasonable estimate of the current velocity.

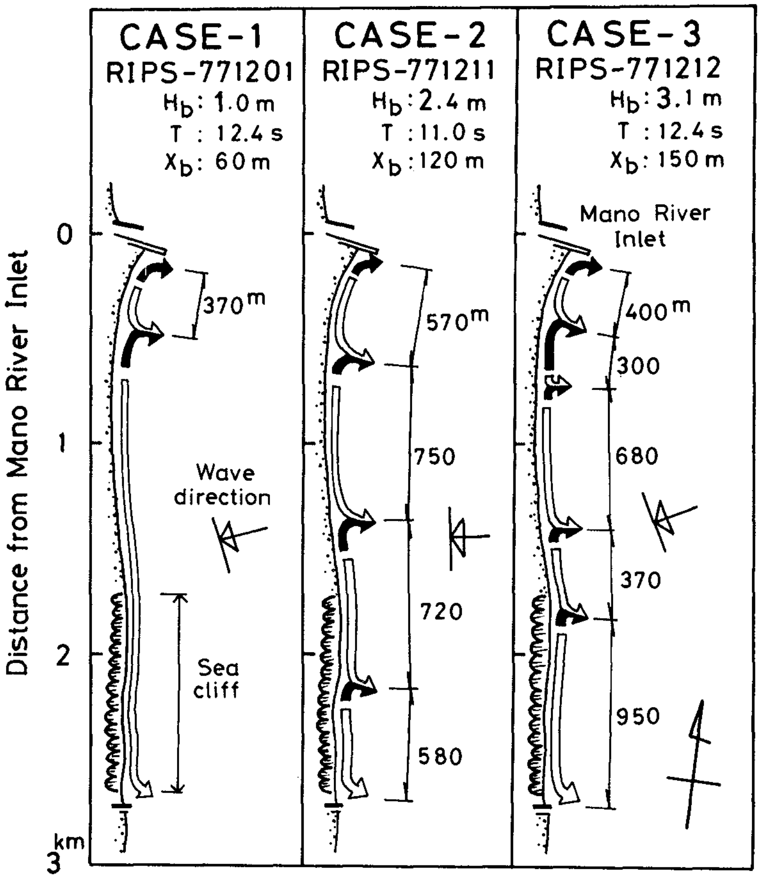

Figure 10 Selected observed nearshore current patterns under low energy wave conditions on Haranomachi Beach.

Figure 11 Aerial photograph of a part of Haranomachi Beach where the velocity measurements was made.

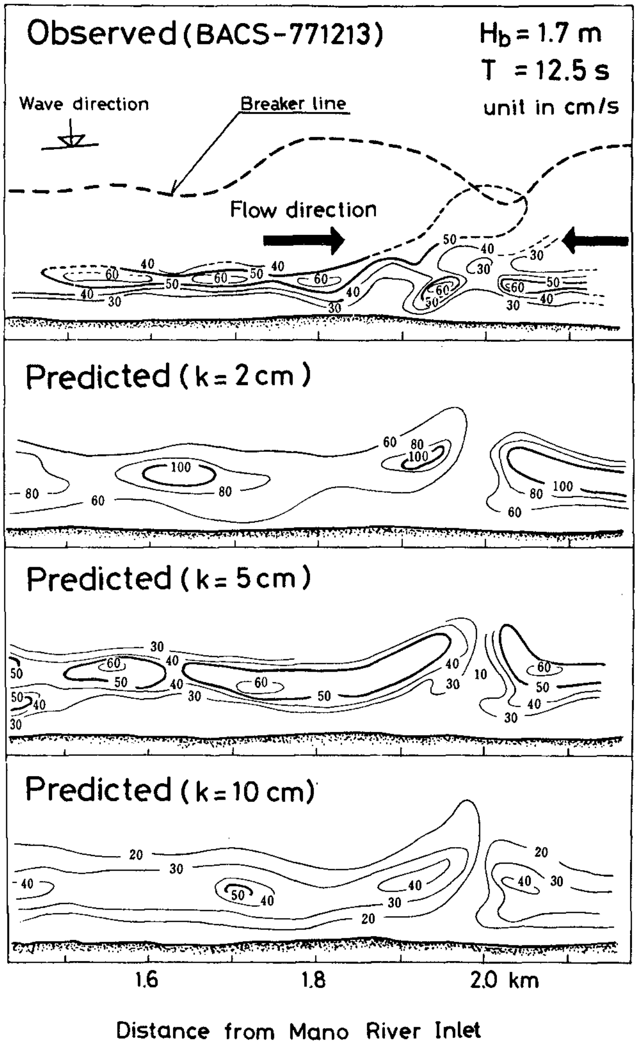

Figure 12 Comparison of observed and predicted current speeds. Reasonable estimate of the current speed is given when roughness length for the bottom, k is 5 cm.

This value falls within a representative value for a sandy floor [Jonsson et al.(1974), Skovgaard et al.(1975)], and provides strong evidence of the similarity of this partially rocky shore to a sandy beach in a low energy wave regime. In contrast, for a primarily rocky floor, the authors have found that the values of the bottom roughness should be greater than 20 cm.

PREDICTED NEARSHORE CIRCULATION PATTERN UNDER STORM WAVE CONDITION IN A LABORATORY WAVE BASIN

To simulate currents in a high energy wave regime, labolatory experiments were performed on a fixed bed in a 70 m wide by 40 m long wave basin at the University of Tokyo. Figure 13 shows the laboratory set-up of the fixed beach model scaled to 1/125. No distortion of the vertical scale was made. About 8 km of the somewhat indented shore bounded by promontories was modeled down to a depth of about 25 m. Seven 10-m long regular wave generators were arranged as seen in the top of Figure 13. About half of the sea floor area to be tested was covered by exposed base rock.

Under high seas, the surf zone bed, particularly the breaker zone bed, is largely occupied by an exposed rocky bed similar to a laboratory fixed bed. High energy wave regimes for deep water wave heights of 4 m and 6 m were similated. The corresponding model wave heights were 3.2 cm and 4.8 cm, respectively. The wave incidence was normal to the shore as frequently occurs in the field.

Wave heights were measured by a capacitance type on-offshore direction wave gage array placed successively alongshore and consisting of 11 sensors. Nearshore current fields were measured with an array of 5 motor-driven cameras, tracing dye patches and small floats released in the nearshore zone. Current direcitons were also measured with 15 cm long yarns attached at one end to each 1-m reference grid spacing on the floor.

Figure 14 shows the resulting current patterns for both cases, indicating very irregular circulation patterns. The thick black and white arrows denote northerly and southerly currents, respectively, and the thick broken lines indicate the breaker line. Widths of the surf zone averaged 500 m and 1000 m, respectively.

Due to their complex circulation pattern, it is not as easy to define rip currents as on a sandy beach, but the location of the inflow of water into the surf zone can be identified without much difficulty. Comparing these nearshore circulation patterns with refraction diagrams, keeping in mind the above facts on the characteristics of irregular current patterns, it is found that the positions of the onshore currents entering the surf zone at the breaker line are significantly controlled by the location of wave convergence due to refraction over irregular offshore submarine topographies. However, coincidence between positions of rip currents and wave divergence was less significant than for the onshore current.

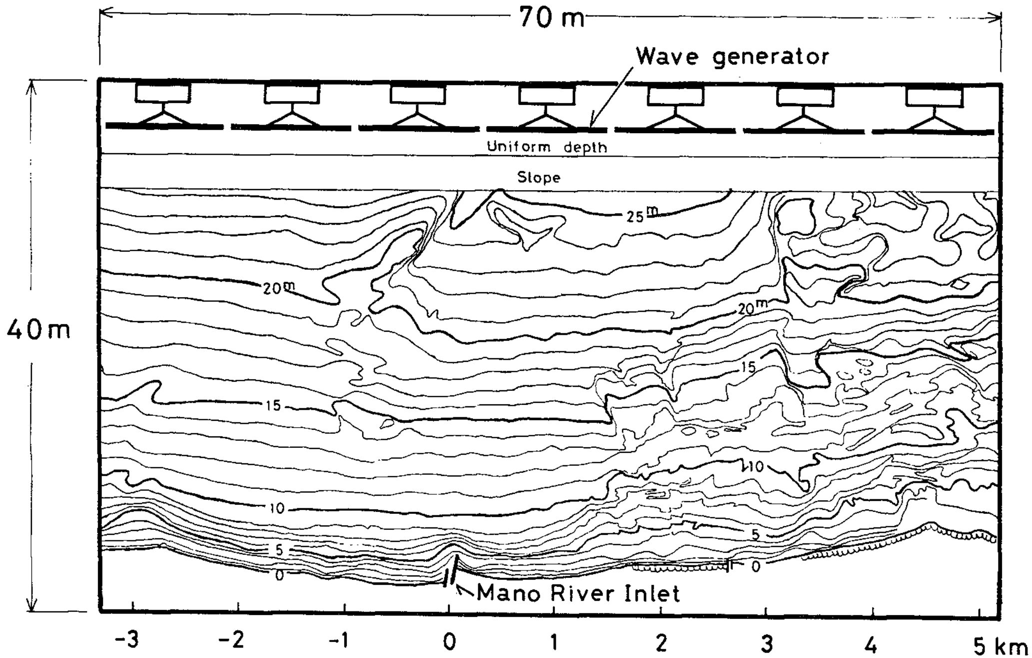

Figure 13 Laboratory set-up of 1/125 scaled fixed bed model in a 70 m x 40 m wave basin at the University of Tokyo.

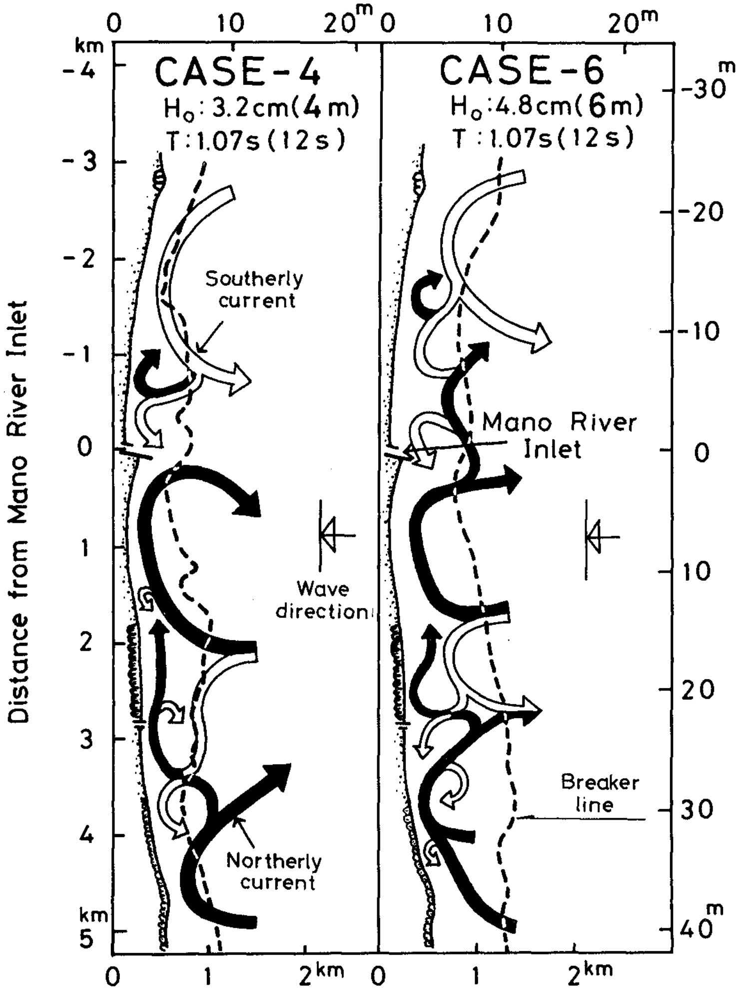

Figure 14 Predicted nearshore circulation pattern under high energy wave conditions for 4 m and 6 m waves in the laboratory wave basin.

DISCUSSION

A plot of the positions of water inflow, measured in the laboratory, and of rip currents, measured in the field, on a 12 s period wave refraction diagram for normally incident waves is shown in Figure 15. Good correlations can be seen between the positions of wave convergence and water inflow (larger open arrows), and between the positions of wave divergence and rip currents (smaller arrows) as stated above. Because a detailed sounding chart necessary to provide a finer wave ray separation, as seen in Figure 15, was not available in the offshore region beyond a depth of about 25 m, the effects of refraction due to the drowned valley (Figure 1, 2) have not been included in Figure 15. However, the increase of refraction due to inclusion of drowned valleys would not change the major conclusions, since its extent is not so large compared with refraction on nearshore zone (Figure 9).

A very similar and comprehensive study has been made by Shepard and Inman(1950) in the early stage of coastal engineering. However, the La Jolla and Scripps Canyons, where they did their study has a much more pronounced topography and is located nearer (approx. 300 m) to the shore than those here. Thus we expect that the effects on wave refraction should be much larger in their study.

CONCLUSIONS

1) *In the low energy wave regime, no significant differences were found in the current velocity, rip current spacing and bottom roughness for a sandy beach. However, the positions of rip currents were coincident with wave divergence points due to refraction over an offshore exposed rocky bed.*

2) *In the high energy wave regime, currents exhibited a fairly irregular circulation pattern. However, the positions of inflow across the breaker line were found to be coincident with the wave convergence points.*

To quantify nearshore currents on a rocky shore, nearshore current velocity measurements in the high energy wave regime would be necessary to evaluate bottom frictional forces.

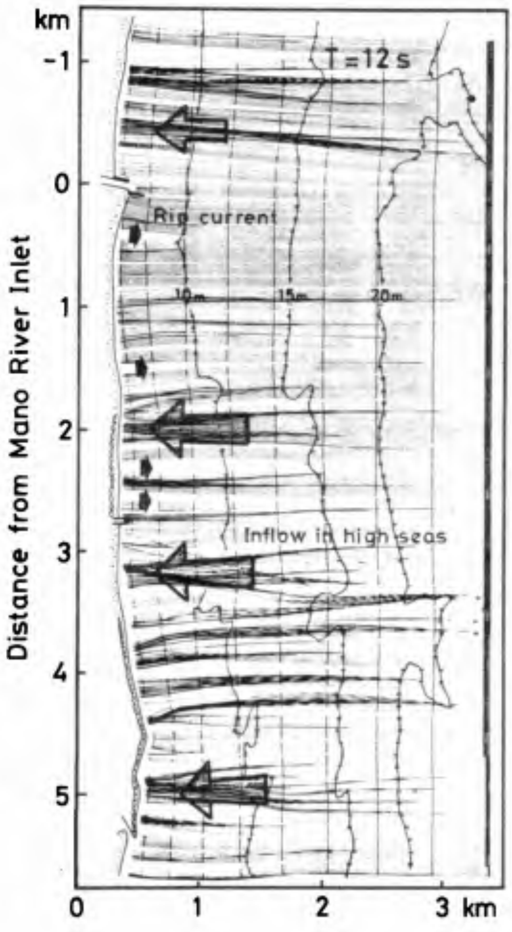

Figure 15 Comparison of positions of rip currents and inflows with positions of wave divergence and convergence on a 12 s refraction diagram incident normally to the shore. Larger open arrows and smaller arrows indicate the points of inflow in high seas and rip currents in low energy waves, respectively.

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The findings in the present paper are not to be construed as an official Soso Coast Beach Erosion Review Committee position.

REFERENCES

Harris, T.F.W.(1969): Nearshore circulation, Field observations and experimental investigations of an underlying cause in wave tanks, Symposium on Coastal Engineering, South Africa.

Horikawa, K., M.C. Lin, and T.O. Sasaki(1978): Mixing of heated water discharged in the surf zone, Proc. 16th Coastal Eng. Conf., ASCE, Hamburg, 2563-2583.

Inman, D.L. and C.E. Nordstrom(1971): On the tectonic and morphologic classification of coasts, Jour. Geol., 79, 1-21.

Jonsson, I.G.(1966): Wave boundary layers and friction factors, Proc. 10th Coastal Eng. Conf., ASCE, Tokyo, 127-148.

Jonsson, E.G., O. Skovgaard and T.S. Jacobsen(1974): Computation of longshore currents, Proc. 14th Coastal Eng. Conf., ASCE, Copenhagen, 699-714.

Mogi, A. and Y. Iwabuchi(1961): Submarine topography and sediments on the continental shelves along the coasts of Johban and Kashimanada, Geographical Review, 34(3), 159-177. (in Japanese).

Noda, E.K.(1974): Wave-induced nearshore circulation, Jour. Geophys. Res., 79(27), 4097-4106.

Sasaki, T.O. and K. Horikawa(1975): Nearshore current system on a gently sloping bottom, Coastal Eng. in Japan, 18, 123-142.

Sasaki, T.O.(1975): Simulation of shoreline and nearshore current, Proc. Civil Engineering in the Oceans/III, ASCE, Newark, Del, 179-196.

Sasaki, T.O., K. Horikawa, and S. Hotta(1976): Nearshore current system on a gently sloping beach, Proc. 15th Coastal Eng. Conf., ASCE, Honolulu, 626-644.

Sasaki, T.O. and K. Horikawa(1978): Observation of nearshore current and edge waves, Proc. 16th Coastal Eng. Conf., ASCE, Hamburg, 791-809.

Shepard, F.P. and D.L. Inman(1950): Nearshore water circulation related to bottom topography and wave refraction, Trans. AGU, 31(2), 196-212.

Skovgaard, O., I.G. Jonsson and J.A. Bertelsen(1975): Computation of wave heights due to refraction and friction, Proc. ASCE, 101(WW1), 15-32.

Sunamura, T.(1973): Coastal cliff erosion due to waves - Field investigations and laboratory experiments - Jour. Fac. Eng., University of Tokyo, 32, 1-86.

Toyoshima, O., H. Okuda, and T. Mutoh(1973): On the beach erosion and beach characteristics on Fukushima Pref. Coast, Proc. 20th Coastal Engineering Conf. in Japan, 507-511. (in Japanese).

Wilson, W.S.(1966): A method for calculation and plotting surface wave rays, TM-17, Coastal Engineering Research Center, Corps. of Engineers.