CHAPTER 261

Sandy Beach Stabilization: Preservation of Shirarahama Beach, Wakayama

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Abstract

It is recognized that beach erosion has become a major problem in many countries of the world, but especially in Japan in relation to human activities such as development of coastal areas and river basins. Shirarahama beach in Wakayama facing the Pacific Ocean is a typical packet beach, but duc toeservation of the beach by headlands was proposed. The mcthodology has shown a very good result in making thc beach recovered as cservation of the beach by headlands was proposed. The methodology has shown a very good result in making the beach recovered as a stable sandy beach.

Introduction

Recently, beach erosion problems have been remarkable in many countrics of the world, but especially in Japan due to development of river basins and coastal areas. Many countermeasures have been attempted for preventing thc beaches from severe erosion. It has been learnt from the experiences that no possibility of stabilizing the beaches can be expected, but they have only changed to man-made beaches covered with a great number of concrete units. It is therefore suggested in establishing a methodology for beach erosion control that the long-term characteristics of beach processes in the whole area of the beach must be investigated. Recently, nature-learnt ideas have been employcd gradually in the preservation and stabilization of such sandy beaches.

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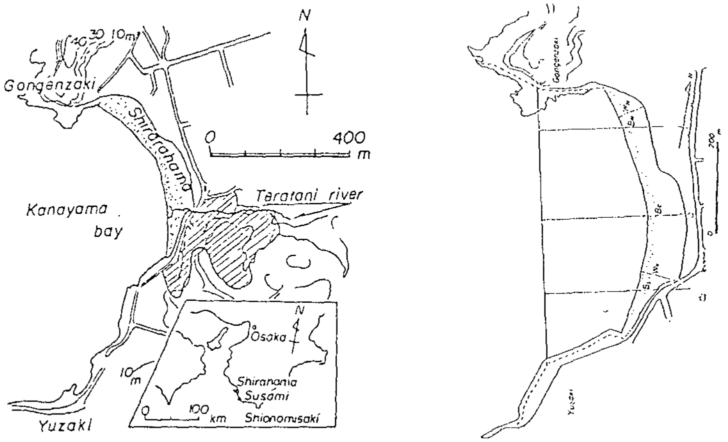
In this paper, a methodology for beach erosion control by headlands is proposed for stabilizing a pocket sandy beach which has gradually be eroded due to current urbanization of its hinterland. As seen in Figure 1, Shirarahama beach which is located in Kanayama bay facing the Pacific Ocean is a typical pocket beach consisted of white



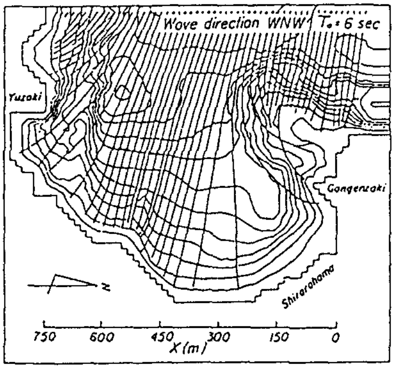
(a) Location and sediment source area (b) Survey lines of beach width
Figure 1. Shirarahama beach in Shirahama-cho, Wakayama and its sediment source area

sand, but as sediment input from the hinterland has decreased due to its current urbanization the shoreline has very gradually retreated. Additionally, the area of Shirahama-cho is one of the most famous hot spring resort areas in Japan, so the local government of Wakayama Prefecture has planned to recover the beach by stabilizing and expanding it as possible. Observations of wave, current and shoreline change and field survey of beach and offshore sediment had been carried out since 1976. Numerical predictions of wave transformation, nearshore currents and shoreline change in the beach were also made. It is concluded that the beach has been so well maintained naturally by the sediment source of white sand through the Teratani river, and that it is formed well as a typical sandy pocket beach which had been stable for a long time. Recently, due to lack of the sediment source from the river the shoreline has very gradually retreated, but it is not so severe beach erosion. Based on the characteristics of the pocket beach naturally formed, a methodology for stabilizing the sandy beach by making a stable sandy beach formed by headlands is proposed, and its applicability was examined by physical experiments. After finding the most cooperative condition of two headlands in producing a stable sandy beach by the experiments, the arrangement of the headlands was made. After the construction of headlands, beach nourishment was partly made between the headlands along the original sandy beach, and now being done. It can be concluded at the present stage that a sandy beach is now being formed well and approaching a stable sandy beach between the headlands which was predicted by physical experiments.

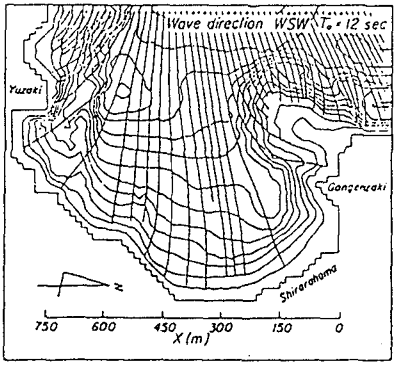
Characteristics of Winds and Waves

In the area of Shirarahama beach, there exist two frequent winds which are due to monsoons in winter season and typhoons in summer season, respectively. Monsoon winds are mainly from NW directions from November to February in the next year, and W direction from March to April. Typhoon winds are subjected to typhoon tracks. Therefore there exist two predominant waves; they are monsoon waves from the NNW and NW directions and typhoon waves from the S and WSW directions, respectively. The monsoon waves are 6 to 8 sec in significant wave periods and up to 5 m in significant wave height in deep water, but more frequent than the typhoon waves of which the wave periods are 10 to 14 sec and the significant wave heights are 5 to 6 m frequently and up to about 8 m in deep water.

The wave refraction diagrams for the monsoon and typhoon waves are shown in Figure 2 where the wave periods and directions are assumed as 6 sec and 14 sec, and NW and WSW for the monsoon and typhoon waves respectively. In the figure, the upper and lower figures deal with wider and narrower areas in the wave refraction areas. It was concluded from the wave refraction that both the monsoon and typhoon waves are coming onto the rocky shore which surrounds the beach obliquely, but the shoreline of the sandy beach normally which is located at the end of Kanayama bay. This fact may explain why the sandy beach is formed naturally well as a pocket beach.



(a) In the case of monsoon waves



(b) In the case of typhoon waves

Figure 2. Wave refraction diagrams of monsoon and typhoon waves in Kanayama bay

Additionally, the tidal range is about 2.0 m due to semi-diurnal tide. The storm surge was recorded over 1 m in 1961 due to Daini-Muroto typhoon, and theAs the area of s ediment sources in the hinterland of the beach has been shown in Fi

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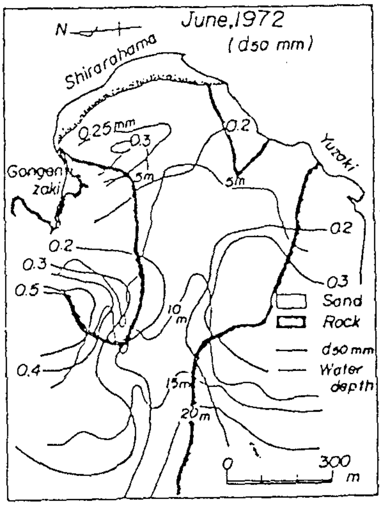
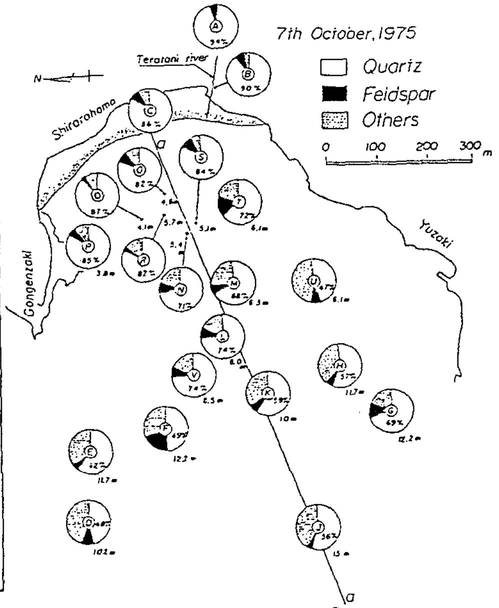
ure 1, the main sediment sources

As the area of sediment sources in the hinterland of the beach has been shown in Figure 1, the main sediment sources were due to sediment input from the Teratani river and the area shaded in the figure about twenty years ago. The distribution of mineral composition of sediment on and off Shirarahama beach and Kanayama bay is shown in Figure 3 (a) where the mineral composition is classified by quartz, feldspars and





(a) Median diameter of sediment (b) Mineral composition of sediment

Figure 3. Distribution of median diameter and mineral composition of sediment on and off Shirarahama beach and in Kanayama bay

others which are mainly shell, respectively. The result of mineral composition can explain the sediment sources. The sediment input was a very little from the river, but since then no sediment input can be observed due to development of the hinterland. This fact is only the cause for gradual beach erosion. The distribution of median size of bottom sediment in Kanayama bay is shown in Figure 3 (b) where the depth contours are also shown. It is noted that the sediment of white sand is only on the narrow areas of sea bottom and the beach.

Shoreline Change: Seasonal and Abnormal Changes

Shoreline change in the beach was observed both by direct measurement and aerial photographs to find its seasonal and abnormal changes. Due to monsoon and typhoon waves of which the wave directions are mainly NW and SSW, respectively, the seasonal shoreline change exists as shown in Figure 4 where the beach widths w_N and w_S, and B_N and B_S are the beach widths defined as shown in Figure 1 (b), the suffixes indicate those near the northern and southern ends, respectively and their ratios are used for seasonal change. The shoreline change for a period of ten years from 1972 is shown in Figure 5. It is recognized that the shoreline has retreated very gradually, and that the abnormal change has taken place sometimes, but the maximum retreat was within 20m and soon recovered. In the case of typhoon the shoreline intends to result in a little accretion near the north end, but retreat near the south end of the beach. Contrarily, in the case of monsoon the shoreline intends to retreat a little near the south end and to do accretion near the north end. It is however noticed that the sandy beach is nearly in equilibrium even fluctuating a little during the periods of typhoon and monsoon because the incident waves are normally approaching the sandy beach to produce no effective longshore sediment transport in changing the curved beach.

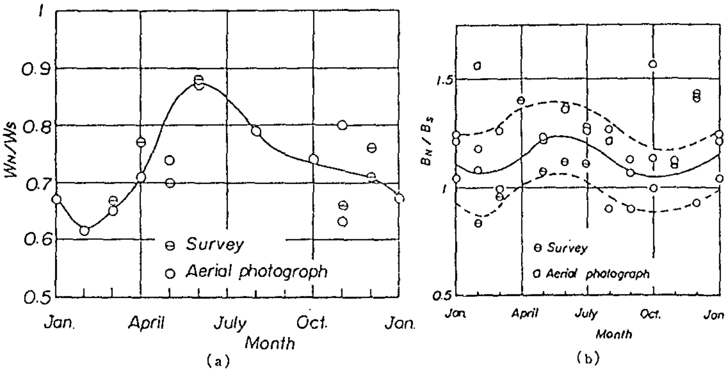


Figure 4. Seasonal change in beach width in terms of beach width ratios on survey lines shown in Figure 1(b)

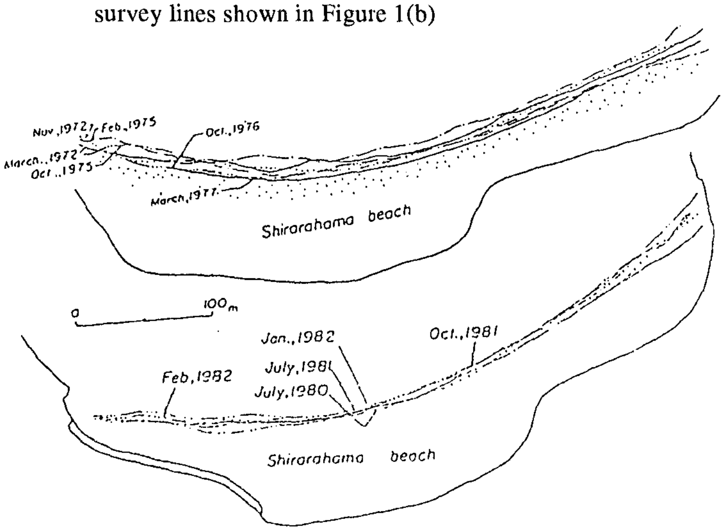


Figure 5. Shoreline changes between 1972 and 1982 in Shirarahama beach

As previously described, beach change in Shirarahama is also due to strong winds resulting in blown sand in spring season. Strong, but dry winds blow from the NW direction and blown sand takes place on the sandy beach to result in beach change as shown in Figure 6 where the erosive and depositional areas are shown in the periods specified. It is recognized from the results that the northern area is eroded, but eroded sediment is deposited in the southern area. The sandy beach intends to be tilted from the northern to southern ends.

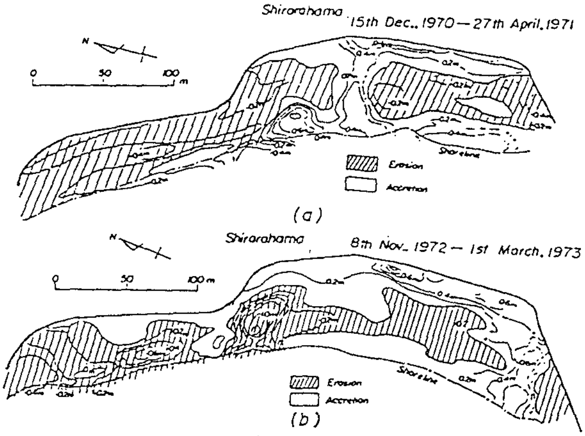


Figure 6. Beach change by blown sand in spring season

Longshore Distribution of Wave Power and Prediction of Shoreline Change

In order to investigate the longshore distribution of longshore sediment transport along Shirarahama beach, the wave power which is actually proportional to the rate of longshore sediment transport is employed. By use of wave data for seven years between April in 1970 and March in 1976 at Susami Fishery Harbor which is located about 20 km south from the beach, the longshore distribution of wave power along the beach was calculated. Figure 7 shows the longshore distributions of annual and seasonal wave power along the beach. This figure clearly describes that in the central part of the beach the wave power is nearly vanished, but near the northern end it takes a null point where it increases in the direction of positive wave power north and in the direction of negative wave power south, and near the southern end of the beach it is also vanished, but it takes a null point too where it decreases in the direction of positive wave power south and in the direction of negative wave power north. It is therefore mentioned that at the northern end the beach intends to be eroded, but fortunately no longshore sediment in the northern direction behind Gongenzaki headland which is curved concave may result in no severe retreat of shoreline, and at the southern end the beach intends to accumulate sediment due to both positive and negative wave power in their directions. Due to the positive wave power in the southern area from the null point where the Teratani river is flowing into a little north, white sand as only sediment sources from the river is transported within the beach.

In the longshore distributions of seasonal wave power, in summer season (typhoon season) the wave power becomes nearly vanished in almost the beach, but only near the northern end beach change may take place to result in shoreline accretion. This may explain the shoreline change due to typhoon waves. Contrarily, in the winter season (monsoon season) the longshore distribution of wave power is quite similar to the annual one so that the tendency in shoreline change may be similar to the annual change as previously discussed. Near the northern end the wave power may result in to accumulate sediment, but it may tend to retreat shoreline. This tendency may

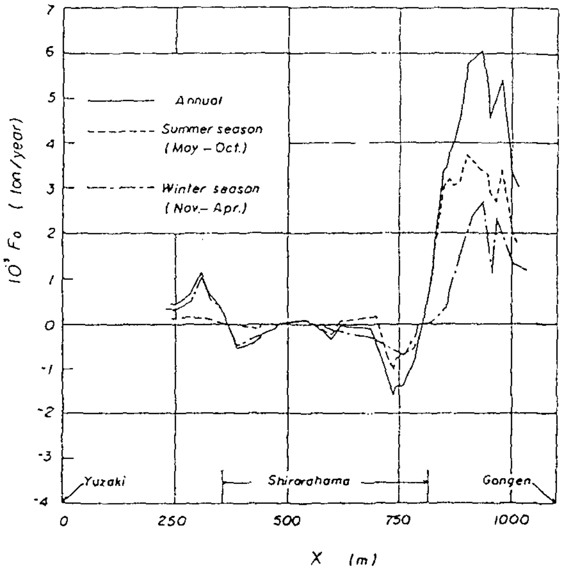
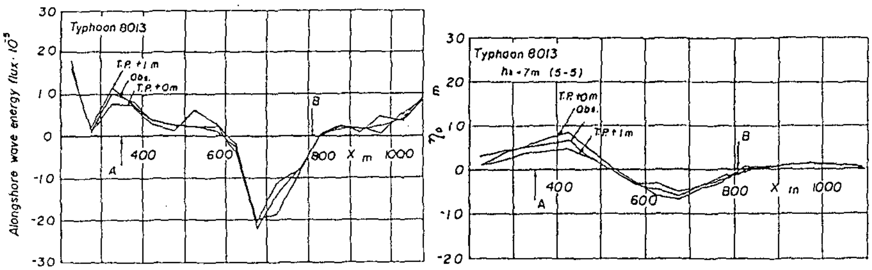


Figure 7. Longshore distribution of annual and seasonal wave power



(a) Wave power distribution (b) Shoreline change predicted

Figure 8. Longshore distributions of wave power generated by Typhoon 8013 along the beach and predicted results of shoreline change

support the shoreline change clearly due to monsoon waves. It can therefore be recognized from these circumstances that the sandy beach is a typical pocket beach naturally well-formed between Yuzaki and Gongenzaki rocky headlands.

Figure 8 (a), as an example, shows the longshore distribution of wave power which is generated by Typhoon 8013 where the tidal levels are shown in T.P. and observed one, and the area of the sandy beach is specified by arrows A and B respectively in the southern and northern ends. Near the northern end it tends to accumulate sediment a little, but near the southern end it shows to result in some rates of longshore sediment transport in the southern direction. The changes in wave power by the typhoons by which the maximum significant wave height of about 7 m in deep water were calculated. By use of the wave power the shoreline changes by the typhoon were calculated by one line theory of shoreline change prediction as shown in Figure 8 (b) where the threshold water depth in the sand drift zone was assumed as 7 m. The figure shows that only a little shoreline change takes place by typhoons, but the longshore tendency of shoreline change near the southern end is a little different from those in Figure 2, probably due to sediment input from the neighboring rocky shores where no longshore sediment transport exists actually. The duration of the longshore sediment transport in the northern direction was short say about 10 hrs., but no remarkable shoreline change was observed. It is concluded again from the shoreline change that this sandy beach has been in the table condition as a typical pocket beach.

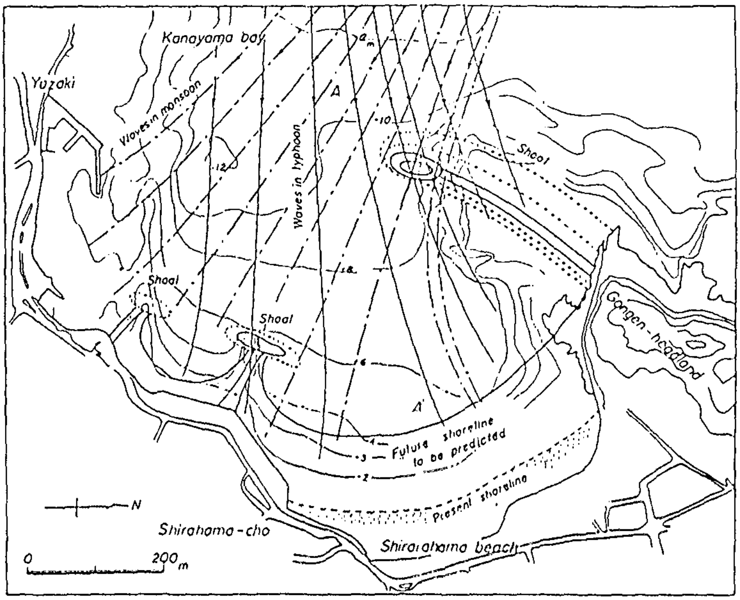
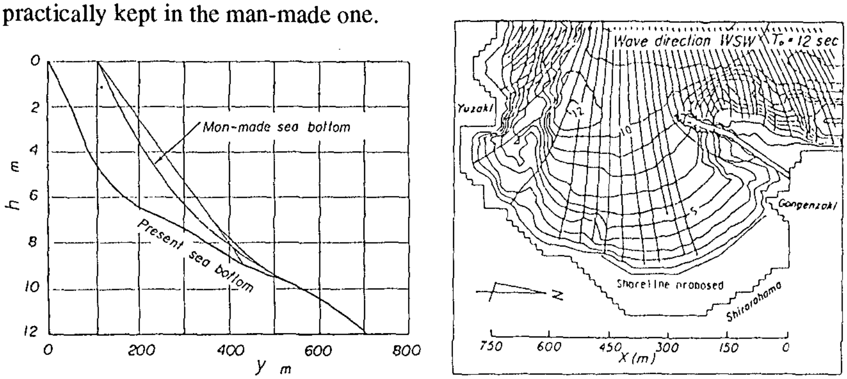


Figure 9. Methodology for preservation of Shirarahama beach by headlands

Additionally, numerical calculations were made to predict nearshore currents by monsoon and typhoon respectively, and drift currents by strong winds during monsoon and typhoon. It was found that a little nearshore circulation exists both in the cases of monsoon and typhoon, but northern drift currents exist by NW wind in monsoon and opposite currents exist by SW wind in typhoon.

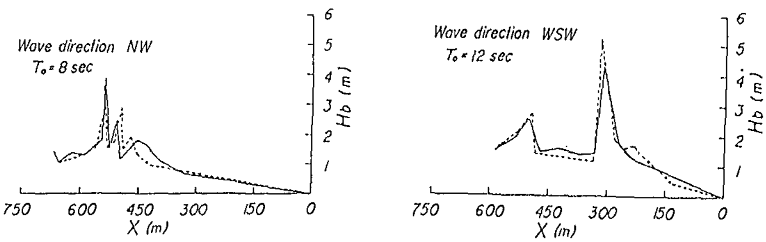
Methodology for Beach Preservation by Headlands

Based on the natural circumstances of Shirarahama beach as a well-formed pocket beach and their stability, a methodology for preservation must be proposed. Expanding the beach width about fifty meters offshore for utilization of the beach as marine resort, the sandy beach must be stabilized. The main items in the methodology are 1) a eouple of stable sandy beaches are formed as shown in Figure 9. By extending Gongennzaki headland about forty meters in under water, the monsoon and typhoon waves are controlled to reduce their heights effectively and to make a stable sandy beach formed, and constructing a couple of headlands of T-shaped groins, the waves are also controlled to make sandy beaches formed as tombolos. 2) In order to make stable sandy beaches formed between them, sandy beaches to be formed must be cooperated naturally and dynamically to result in a couple of well-formed stable sandy beaches as pocket beaches. The necessary conditions are verified experimentally. And 3) for marine resort the water mixing in the bay as well as the beach are promoted by tides and incident waves. As previously discussed, the incident waves are approaching the present beach nearly normally. This circumstances of wave incidence must be introduced in the formation of stable sandy beaches. The present beach profiles near Gongenzaki headland are reformed as shown in Figure 10 (a). The incident waves are refracted by the man-made sea bottom to approach the beach nearly normally, as shown in Figure 10 (b). Figure 11 shows changes in breaker height at the present and man-made bottom topography by which the present circumstances of wave refraction is practically kept in the man-made one.



(a) Man-made sea bottom (b) Wave refraction

Figure 10. Man-made bottom topography and wave refraction of typhoon waves

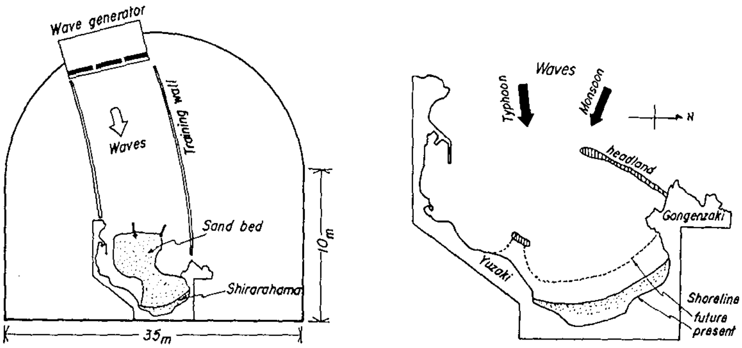


(a) In the case of monsoon wave (b) In the case of typhoon wave

Figure 11. Comparison between breaker heights on present and man-made bottom topography

Experimental Verification on Formation of Stable Sandy Beaches by Headlands

Physical model experiments of which the experimental setup is shown in Figure 12 were carried out by use of the similitude for beach change by Tsuchiya and Itoh (1981) in nondistorted model with a horizontal and vertical scale of 1/64 and experimental fine sand with a median size of 0.021 cm and specific gravity of 2.65, respectively. Experimental waves are typhoon and monsoon waves from NW and WSW directions of which the periods are 0.75 and 1.30 sec, respectively. By operating a wave generator of monochromatic waves over 800 hrs in total, fifteen runs were performed in various conditions to find the applicability of the proposed methodology and the most effective lengths of headlands in cooperating sandy beaches to be formed between them as stable sandy beaches. In the experiments, waves and nearshore currents in the beach were also examined experimentally to find characteristics of wave transformation and mixing in nearshore currents. Measured data of waves and currents



(a) Experimental basin and model (b) Model in detail

Figure 12. Experimental setup for verification of formation of stable sandy beaches

were compared with their numerical predictions with fairly good agreement. By use of the man-made topography near Gongenzaki headland, wave transformation in the beach were measured to find the efficiency in wave refraction. Additionally, submerged breakwaters for interrupting offshore sediment transport in the beach were examined. The main results of the experiments can be summarized as:

1) Reproduction of the formation of present sandy beach was successfully made in the physical model. It was experimentally verified that the beach is really a stable sandy beach as a pocket beach formed well naturally both by Yuzaki and Gongenzaki headlands in relation to the action of monsoon and typhoon waves.

2) Shoreline changes in the cases of headlands used were made experimentally. Some of the experimental results in finding the most suitable arrangement of headlands are shown in Figure 13 where the experimental runs are shown, but the detail are omitted. It was concluded that the necessary extending length of Gongenzaki headland by which a stable sandy beach is formed well was determined as about 30 m, and that the other headland should be made as a T-shaped groin being a small island or shoal by which a stable sandy beach is well formed.

3) The efficiency of man-made bottom topography for wave refraction and a submerged breakwater as a barrier for interrupting offshore sediment transport were examined experimentally as shown in Figure 14 where the man-made bottom is shown by shaded area in (a) and the barrier is located in the central area of Kanayama bay as shown in (b). It was concluded that the man-made bottom topography is practically

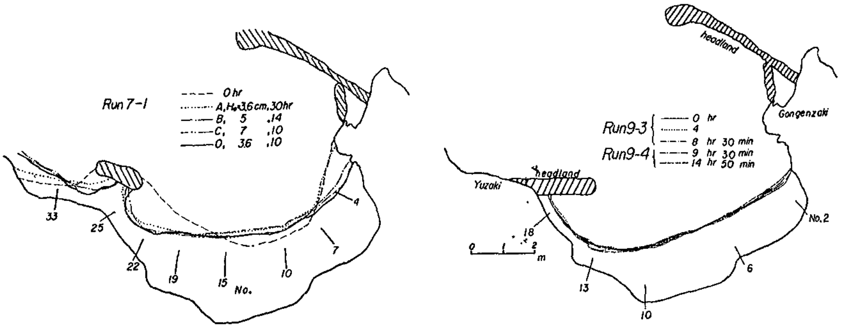
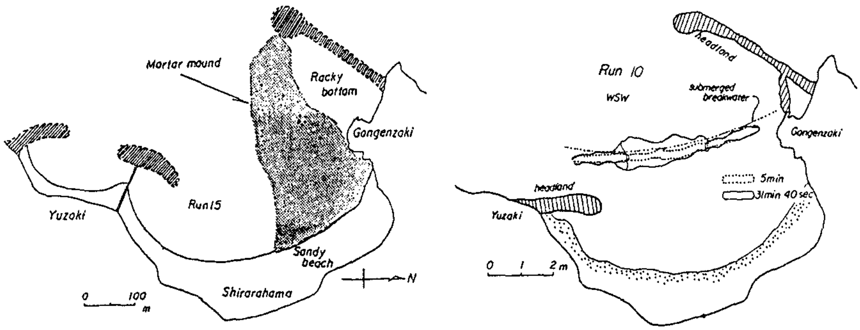
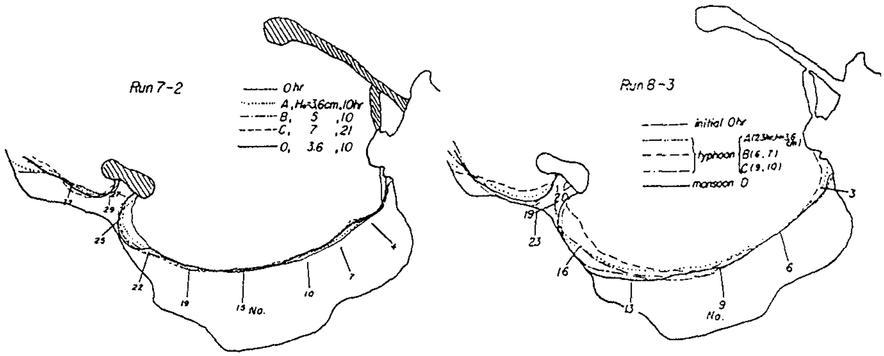


Figure 13. Shoreline changes in the cases of T-shaped groin and inclined groin, and Gongenzaki headland extended about 40 m under water



(a) Bottom topography (b) Distribution of fluoresent sand

Figure 14. Man-made bottom topography for wave refraction and distribution of fluorescent sand around submerged breakwater as barrier



(a) Impractical beach nourishment (b) Adequate beach norishment

Figure 15. Shoreline changes in the cases of impractical and adequate beach nourishment in formation of stable sandy beach

effective to make the incident wave refracted to approach normally the beach resulting in a stable sandy beach. It was however noted that the barrier is effective to interrupt offshore sediment transport, but once sediment has been transported offshore the barrier the sediment can not be transported again onshore through the barrier. It was therefore suggested that such a barrier is not so effective in the formation of stable sandy beaches.

4) The total volume of beach nourishment was experimentally examined in the formation of stable sandy beach by the headlands. As shown in Figure 15 (a), after impractical beach nourishment a stable sandy beach can not be formed well especially near the southern headland of T-shaped groin, and after adequate beach nourishment a stable sandy beach can be well formed as shown in (b). As schematically shown in Figure 16, the formation condition of a stable sandy beach between the headlands can be explained as: By Gongenzaki headland extended, a curved sandy beach is formed

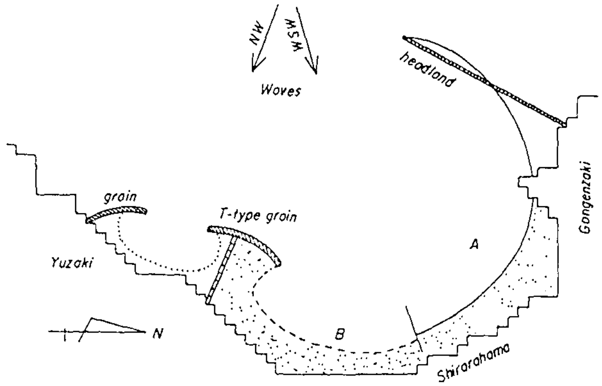
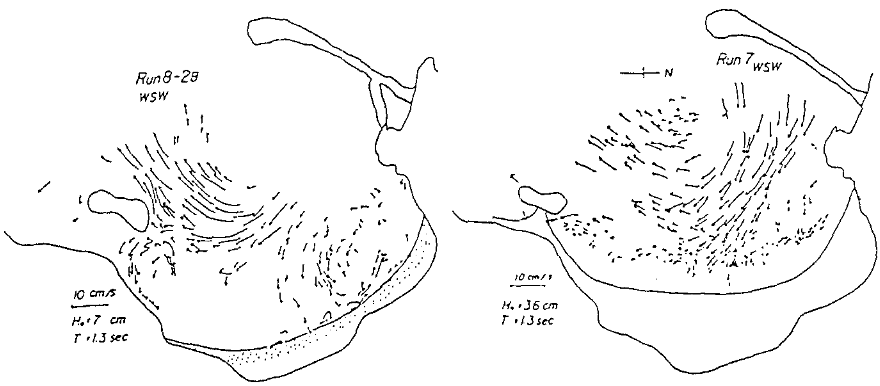


Figure 16. Formation condition of stable sandy beach by headlands



(a) Before beach nourishment (b) After beach nourishment

Figure 17. Examples of nearshore current patterns in stable sandy beach formed by headlands

as A in the figure, but the southern end of the beach extends south. Another sandy beach is formed by the headland of T-shaped groin as shown by B, but the northern end may extends north. When the two sandy beaches are cooperated by which the southern and northern ends of the beaches must be well-continued smoothly, a stable sandy beach can be well-formed between the headlands.

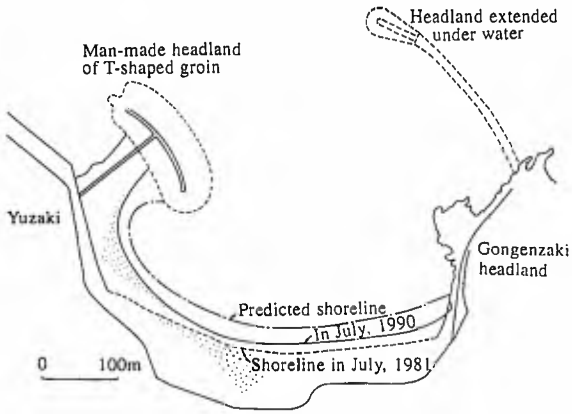


Figure 18. Predicted shoreline of stable sandy beach to be formed by Gongenzaki headland extended and headland of T-shaped groin in Shirarahama beach after adequate beach nourishment and present shorelines after beach nourishment as of 1990

5) Spatial distributions of wave height and current were compared with their numerical results. The comparison was satisfactorily made, and showed that, as shown in Figure 17 for example, mixing phenomena in nearshore current take place due to waves. Based on the experimental verification of the formation of a stable sandy beach, the

Photo. 1. Present aerial view of stable sandy beach being newly formed in Shirarahama beach after beach nourishment as of 1991

shoreline in the formation of stable sandy beach by extending the present shoreline about 50 m offshore is predicted as shown in Figure 18.

Construction of Headlands and Beach Nourishment

In 1983 Gongenzaki headland was extended about 40 m, and the headland of T-shaped groin was constructed in 1987. After the construction of the headlands beach nourishment have been made by using nearly same material imported as the original white sand. The total volume of nourished sand is 35,000 m^3 as of 1990. Shorelines along the beach have been measured. In Figure 18, the recent shorelines are shown in comparison with the predicted one. Photo.1 shows the present situation of the newly formed sandy beach between the headlands. The further beach nourishment is needed for the final formation of a stable sandy beach between the headlands, but the shoreline configulation is quite similar to the predicted one.

Conclusion

Based on the natural circumstance of Shirarahama beach a methodology of beach preservation by headlands was proposed. The two headlands were constructed and extended, and beach nourishment has being made, but the shoreline configulation has being approaching the predicted final shoreline of a stable sandy beach between the headlands well. It is therefore concluded that the proposed methodology for preservation of Shirarahama beach by headlands could be applied satisfactorily in the formation of a stable sandy beach.

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