

CHAPTER 194

BEACH EROSION IN KUTA BEACH, BALI AND ITS STABILIZATION

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Abstract

Due to the construction of an airport runway, severe beach erosion has taken place on the Kuta beach, a coral-sand beach in Bali. Introducing the most effective wave for beach change in terms of wave transformation on a coral reef, the long-term shoreline change is predicted with changing the positions for the boundary conditions to be used as headlands for stabilizing the beach in the large scale coastal behavior. We could find a possibility of stabilizing the beach against beach erosion by constructing three headlands at the positions found. In this beach, a very small amount of sediment source can only be produced from the activity of sea animals. On the basis of the long-term shoreline change and the theory of the formation of static stable beaches, therefore, a methodology for coral-sand beach stabilization was proposed, and parts of this were constructed. Further improvement for the headlands is needed, but as of 1989, a static stable coral-sand beach has been well-formed between the headlands.

INTRODUCTION

Acceleration of beach erosion throughout the world is now recognized as being due to the way humans have developed and utilized coastal zones and river basins. Many attempts have been made to control beach erosion, but in the long term none have succeeded in stabilizing sandy beaches that are being eroded. Due to current development of coral reef beaches, severe beach erosion has taken place in coral-sand beaches in Bali. One of them is the Kuta beach as shown in Figure 1, facing the Bali straight. Since, in 1968, an airport runway was constructed on the coral flat in this

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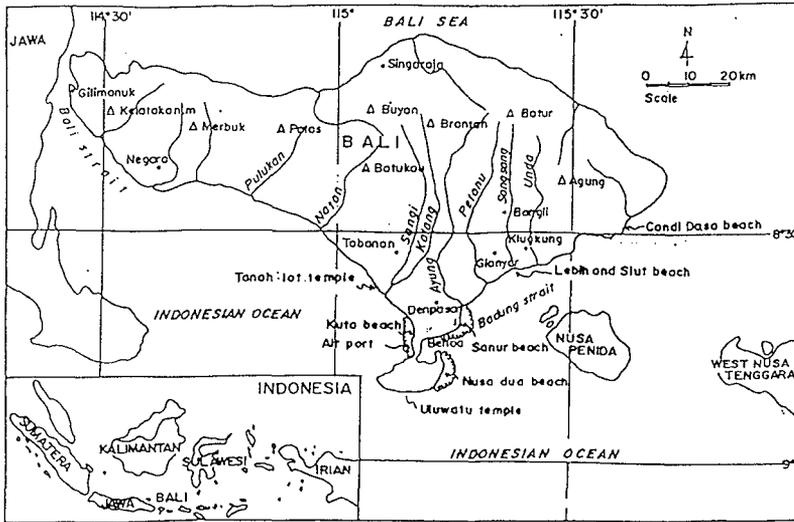
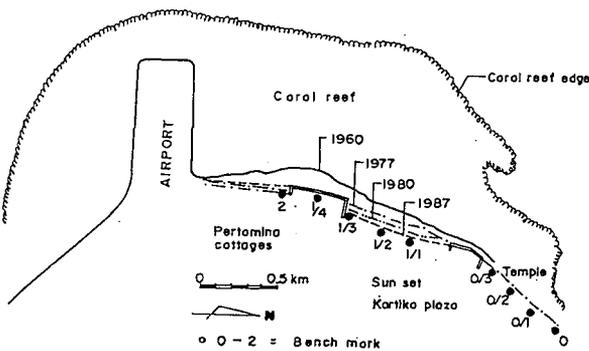
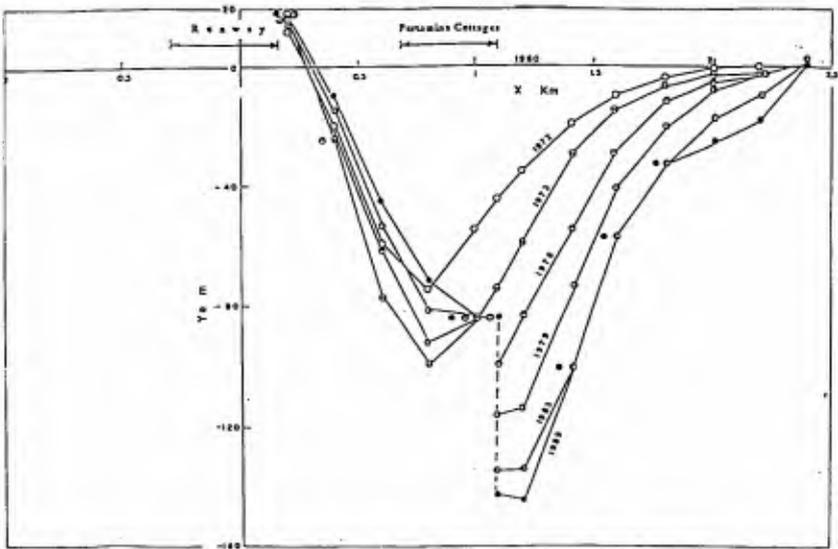


Figure 1. Location of the Kuta beach in Bali island.

beach severe beach erosion began to take place near the runway and has propagated widely on the northern beach (Figure 2 and Photo. 1). Some countermeasures were taken locally, but beach erosion continues to extend northward. In 1975, an UNDP team (Tsuchiya, Yahya and Syamsudin, 1976, and Tsuchiya, 1987) surveyed first the beach erosion problem, and many international advisors also conducted. Recently, an international joint investigation has been carried out with close cooperation between both the Research Institute for Water Resources Development, Agency for Research & Development, Ministry of Public Works of Indonesia and the Disaster Prevention Research Institute, Kyoto University, Japan (Tsuchiya, Syamsudin & Yamashita, 1993). In Figure 1(a), the sorelines measured in 1960, 1977, 1980 and 1987 are shown, and in the figure (b) the distance is taken from the end of the runway in the north direction. Note that severe shoreline retreat has taken place in front of Pertamina Cottages, and that a foreland was formed near the end of runway. Photo. 1



(a) Alongshore shoreline change.



(b) Alongshore and temporary change in shoreline.
Figure 2. Shoreline changes in the Kuta beach since 1960.



Photo. 1. Severe beach erosion near Pertamina Cottage on the Kuta beach taken in 1975.

also clearly shows severe beach erosion by which trees were fallen near Pertamina Cottages.

In Bali island, two prevailing winds, westerly and easterly exist by which waves are generated. Figure 3 shows refraction diagrams of the wave with a period of 15sec, in which the small bounded area shows the Kuta beach. Due to westerly winds, swells are incident from SW to WSW directions, but no effective waves due to easterly winds. A twin mode appears in frequency distributions of coral-sand on the beach. The sediment sizes decrease northward. Figure 4 shows sedimentation cells in the

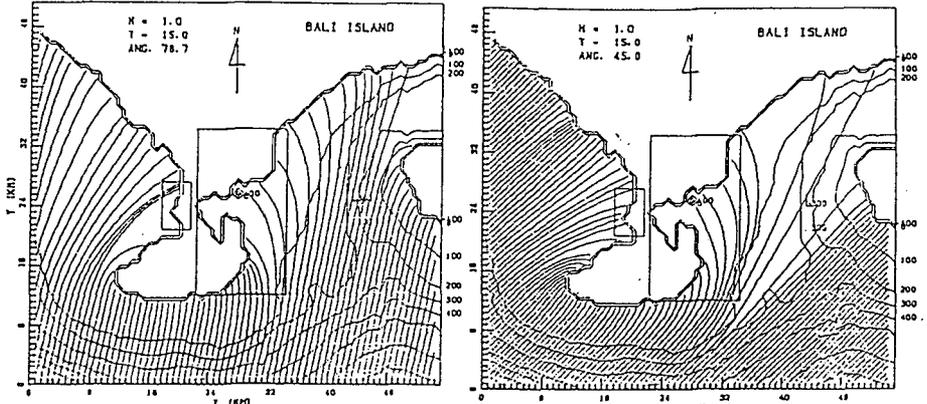


Figure 3. Wave refraction diagrams off the southern part of Bali island.

beach, that was schematically shown using coral-sand characteristics, in which the arrows indicate the possible directions of onshore and longshore sediment transport. Before the construction of the runway there existed a sedimentation cell in equilibrium, but after the construction it was changed by the runway. Note that the main sediment source is only due to coral-sand production from the activity of sea

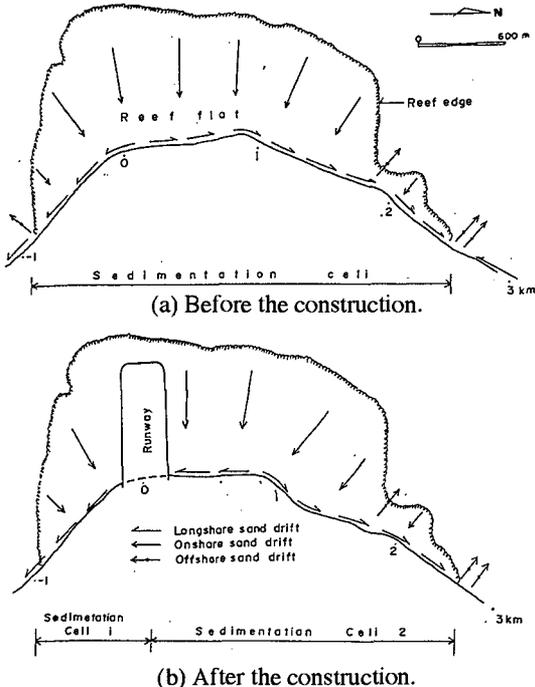


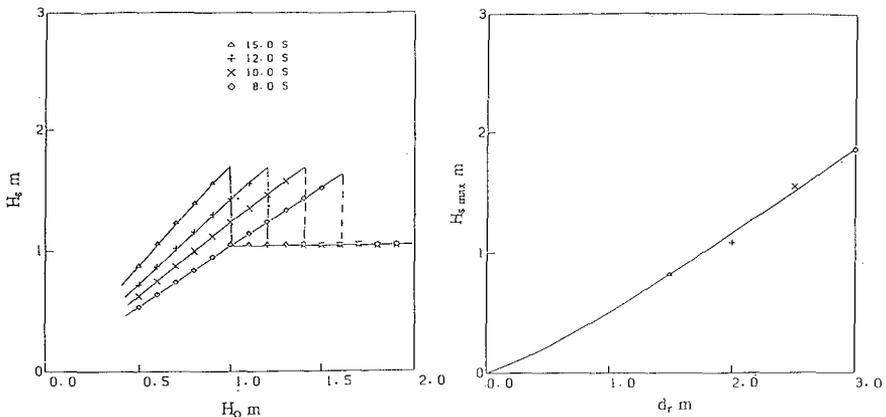
Figure 4. Sedimentation cells formed before and after the construction of the airport runway.

animals and that the northward predominant direction of longshore sediment transport exists. These facts result in severe beach erosion since the airport runway was constructed, especially in the northern area of the beach.

In this paper, we first introduce the most effective wave for beach change in relation to the wave transformation on a coral reef, and second predict long-term shoreline changes with changing the positions for the boundary conditions to be used as headlands for stabilizing the beach against erosion. Third, taking into account an existing small amount of sediment source in the coral-sand beach, a methodology for coral-sand beach stabilization using headlands must be proposed on the basis of long-term shoreline change and the theory of the formation of static stable sandy beaches (Tsuchiya, Chin & Wada, 1993, and Tsuchiya, 1994). Since parts of the proposed headlands were constructed, a coral-sand beach has been well-formed between the headlands. Its plane configuration is compared satisfactorily with the stable one.

THE MOST EFFECTIVE WAVE FOR BEACH CHANGE

No continuous wave observations in Bali have been carried out and no available wave data can be used. In the prediction of shoreline change, we must specify what wave does effectively influence on the beach change. Incident waves onto coral flats are subjected to the water depth on a coral flat (Takayama, Koyama & Kikuchi, 1977, Tsukayama, Nakaza & Gakiya, 1989, and recently Nelson, 1994) and wave set-up on the flat (Seeling, 1982). Wave transformation in the offshore region on a coral reef can be calculated by the usual method, but on the coral flat we must introduce wave damping due to breaking of the propagating wave and bottom friction. Introducing Battjes' bore model (1974) into the conservation of wave energy flux a wave damping



(a) Dependency to deep water wave height (b) Dependency to water depth
 Figure 5. Changes of the wave height at shore with an increase in the deep water wave height and the maximum wave height in relation to the water depth on a coral flat.

model due to breaking is derived and compared satisfactorily with experimental data by Tsuchiya, Syamsudin and Yamashita (1993). Thus, wave transformation on a coral reef was calculated in terms of wave refraction, shoaling, and damping due to breaking and bottom friction to estimate the wave height near the coral-sand beach in

relation to the deep water wave height. Figure 5 (a) shows the relation between the wave height (H_s) near the coral-sand beach and the deep water wave height (H_0), in which the numerals show the wave period, resulting in clearly a maximum wave height (H_{smax}) independent of the wave period. Figure 5(b) shows the relation between the maximum wave height (H_{smax}) and the water depth (d_r) on the coral flat, that clearly indicates a linear relation independent of the wave period. In the evaluation of the water depth on the coral flat for estimating the maximum wave height, wave set-up must be superimposed on the high tide.

The total rate of longshore sediment transport plays the most important role in the shoreline change. By introducing the longshore sediment transport rate, therefore, the wave height changes were calculated with changing wave period as shown in Figure 6, in which the upper two curves indicate the effective wave heights that representatively were calculated by linear and nonlinear wave theories, and the lower shows the dependency of the relative total rate of longshore sediment transport on the wave period. There exists a maximum total rate of longshore sediment transport at the wave period of about 14sec, but the wave height is nearly constant. The wave having the period and the maximum wave height can be used as the most effective wave in the coral-sand beach process in the Kuta beach. But, the incident angle of the wave should be assumed to be SW in the calculation.

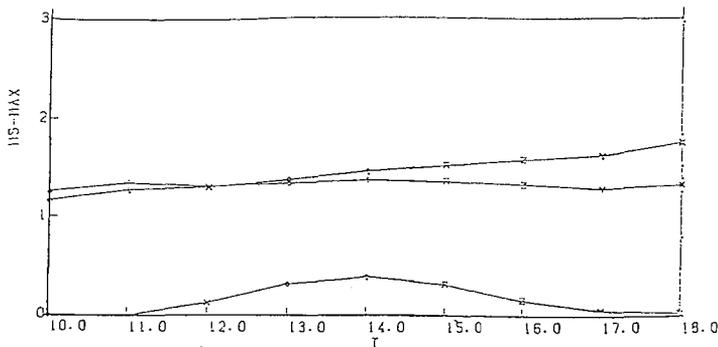


Figure 6. Changes in the maximum wave height and the relative longshore sediment transport rate with the wave period at a central position of the Kuta beach.

WAVE TRANSFORMATION, NEARSHORE CURRENTS AND LONG-TERM SHORELINE CHANGE

Wave refraction and nearshore currents on the coral reef

Transformation of the most effective wave respectively was calculated by the usual methods of wave ray and mild-slope equation (Yamashita, Tsuchiya, Matsuyama & Suzuki, 1990). Figure 7 shows the wave ray diagram that was calculated under the high tide condition including an effect of wave set-up. In the figure, the thick line indicates the reef edge. Note that wave concentration clearly exist at two locations in the northern beach where severe beach erosion has taken place. This fact was understood more exactly in wave height distributions obtained by the method of mild-slope equation (Syamsudin, 1993). Introducing the result of wave fields into the equations of nearshore currents, nearshore currents on the coral flat also were calculated as shown in Figure 8. The result demonstrates that there appear remarkable

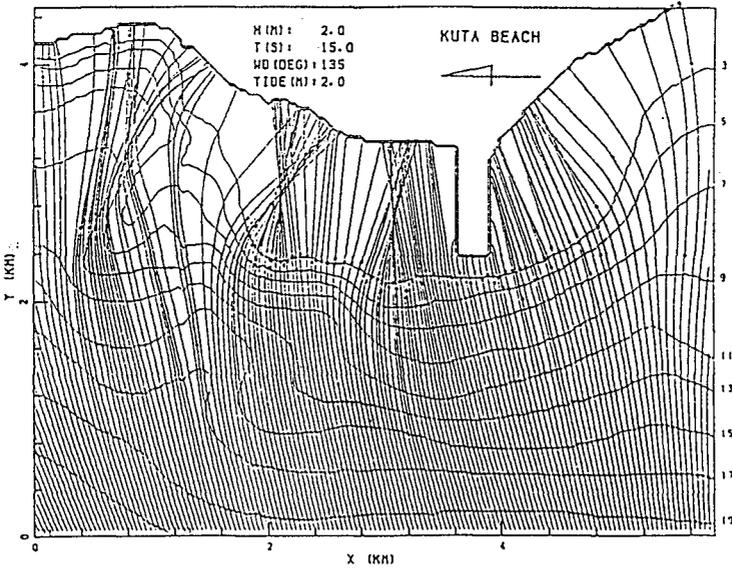


Figure 7. Wave ray diagram of the most effective wave in the Kuta beach.

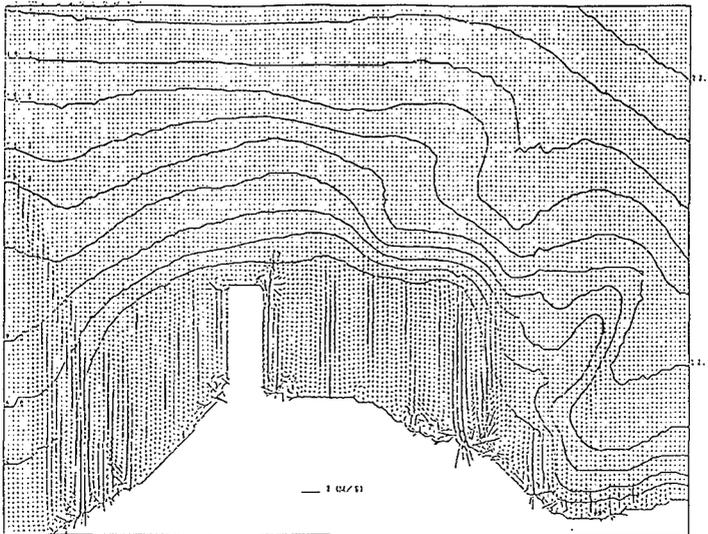


Figure 8. Nearshore currents on the coral flat in the Kuta beach.

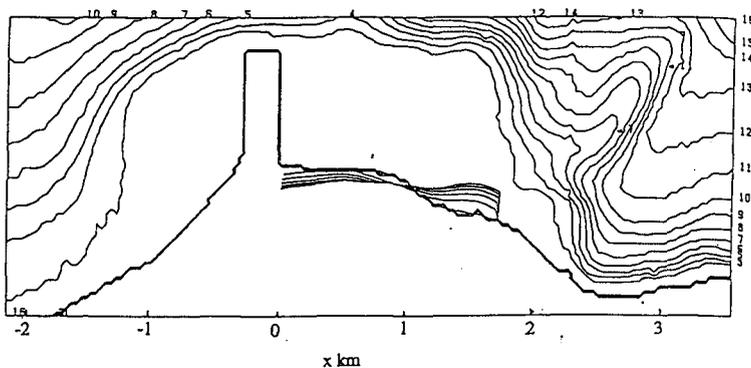
nearshore circulation cells that are formed near the end of the runway and locations

where waves concentrate. Unfortunately, we could not find direct influence of the runway on the nearshore circulation. It may be necessary for obtaining more realistic results to change the incident angle of the wave a little southward.

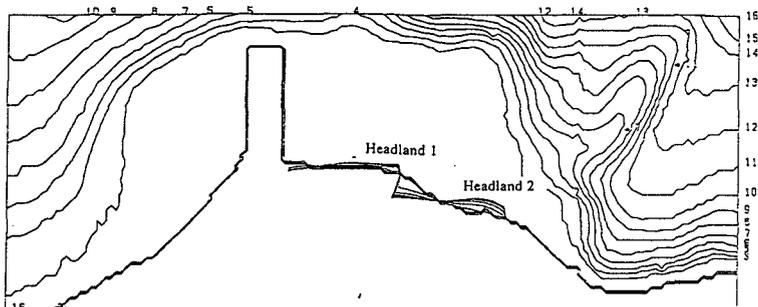
Prediction of long-term shoreline change under boundary conditions

As previously stated, we can not estimate the annual duration of the most effective wave. We must investigate whether the beach can be stabilized by some boundary conditions for shoreline change in the long-term shoreline change. In the prediction of long-term shoreline change, therefore, no use of the wave duration is necessary for the prediction.

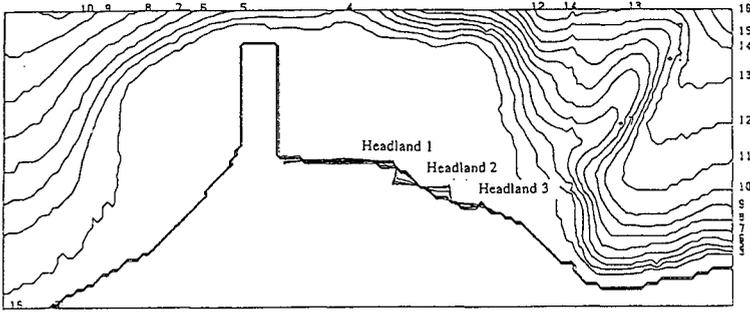
Applying the long-term shoreline change prediction model (Yamashita, Tsuchiya, Matsuyam & Suzuki, 1990, and Tsuchiya, Yamashita, Izumi & Tottori, 1993), we predict the long-term shoreline changes in the Kuta beach in order to find the most suitable locations of man-made boundary conditions, as headlands for stabilizing the entire beach. The single, two and three boundary conditions respectively are given as headland 1, headland 2, and headland 3, and no wave diffraction by the boundary conditions are included in the prediction. Figures 9 and 10 show the predicted results, in which the solid curves between the headlands indicate shoreline change at intervals of the total run indicated in hours. Figure 10 shows the more detailed expression for the shoreline changes shown in Figure 9. When the single boundary condition was given at the central location of the beach, as shown in Figures 9 (a) and 10 (a), due to



(a) In the case of single boundary condition.



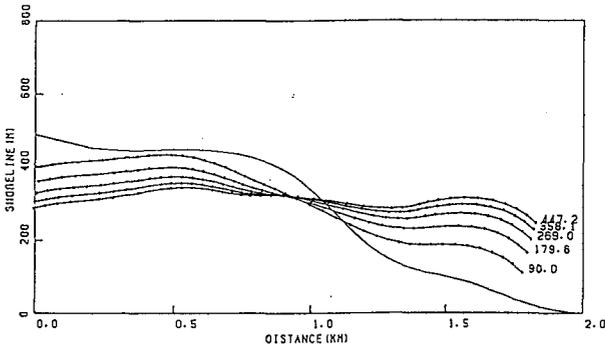
(b) In the case of two boundary condition.



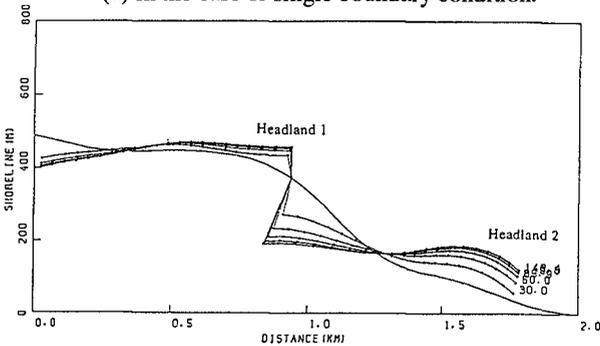
(c) In the case of three boundary condition.

Figure 9. Long-term shoreline changes predicted under the single, two and three boundary conditions, respectively.

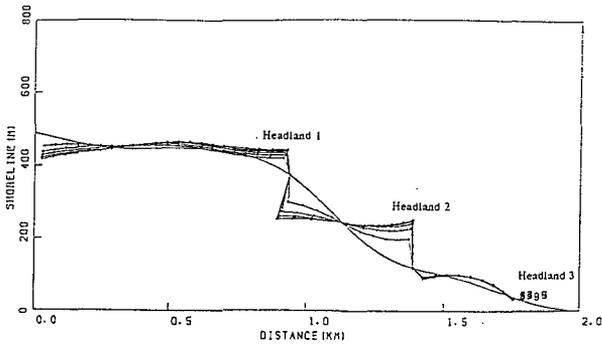
northward longshore sediment transport, severe shoreline retreat takes place widely near the end of the runway. In contrast, shoreline accretion occurs severely further down coast. In the case of two boundary conditions, as shown in Figures 9 (b) and 10 (b), little shoreline retreat takes place widely between the end of the runway and the headland 1, but shoreline retreat occurs down coast from the headland 2, resulting in



(a) In the case of single boundary condition.



(b) In the case of two boundary condition.



(c) In the case of three boundary condition.

Figure 10 Detailed expression of long-term shoreline changes predicted under the single, two and three boundary conditions, respectively.

remarkable shoreline accretion further down the coast to the headland 2. If shoreline change is predicted for the coast down the headland 2, shoreline retreat may take place there. If wave diffraction by the headland 2 is included in the prediction, shoreline change rate may reduce down coast.

Finally, when three headlands are given, as shown in Figures 9 (c) and 10 (c), there appears a nearly same tendency of shoreline change as the second case, but magnitude of shoreline change becomes lesser than the second. We recognize that little shoreline change takes place between the headlands 2 and 3, making the shoreline near the headland 3 continued the original one naturally.

METHODOLOGY FOR CORAL-SAND BEACH STABILIZATION AND ITS APPLICATION

The principal methodology for coral-sand beach stabilization

Beach erosion takes place locally due to change in the sedimentation cell on a coral reef beach, and extends more widely down coast in the direction of longshore sediment transport. In coral-sand beaches, there exists a natural system of the formation process of coral-sand beaches surrounded by the coral flats. The system is governed biologically and also in the nearshore dynamics on coral flats. The sediment sources are generally due to mainly 1) the activity of coral and other sea animals, producing a very little sediment source into the coral-sand beach, and partially 2) sediment sources from rivers if flowing into the coral flat. As previously stated in the sedimentation cell, the Kuta beach has only the sediment source that are produced from the activity of sea animals. To stabilize the beach against erosion, therefore, we must first consider its formation process of the coral-sand beach and the long-term shoreline change along the entire beach in the large scale coastal behavior. Second, we must investigate whether the beach can be stabilized by some boundary conditions for beach change. When we found the most suitable positions for the boundary conditions necessary for stabilizing the beach in the large coastal behavior, based on the theory of the formation of static stable sandy beaches (Tsuchiya, Chin and Wada, 1993, and Tsuchiya, 1994), we can establish a principal methodology for coral-sand beach stabilization.

As shown in Figure 3, the predominant waves are incident nearly normal to the coral-

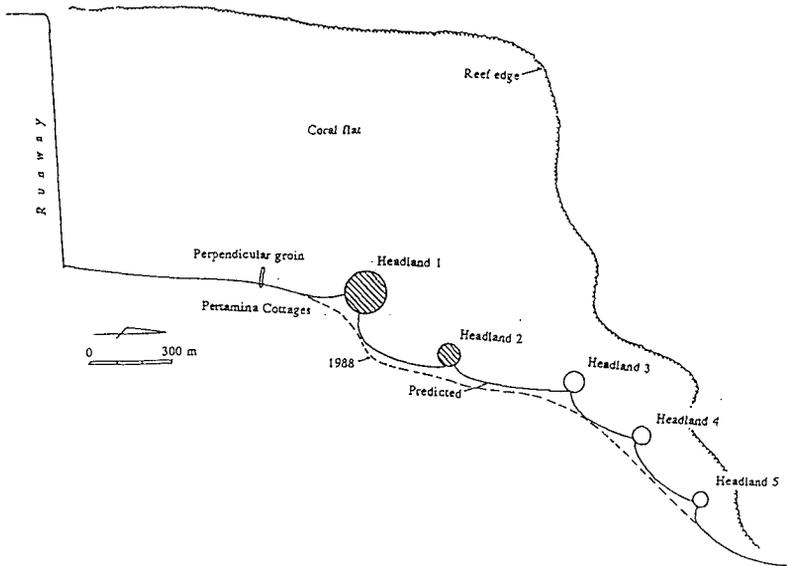


Figure 11. A methodology for coral-sand beach stabilization proposed for the Kuta beach.

sand beach. In relation to the formation of the convex coral reef, the coral-sand beach is formed convex offshore by a very little sediment source from the sea animals production (Tsuchiya, 1987). As only a little sediment source maintains the Kuta beach, into which no river flows, static stable beaches must be formed on the basis of the theory of the formation of stable sandy beaches (Tsuchiya, Chin & Wada, 1993, and Tsuchiya, 1994). The theory recognizes that, when two boundary conditions for shoreline change are given at the ends up and down costs, a stable sandy beach can be formed in relation to longshore sediment transport. When no longshore sediment transport is given from up coast, a static stable sandy beach is formed between the boundaries. In other words, no longshore sediment transport exists along the beach formed. Therefore, a series of head-

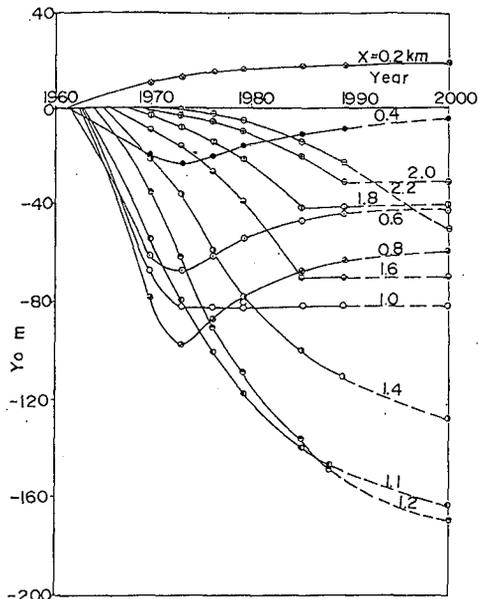


Figure 12. Temporary change in shoreline at several locations on the Kuta beach.

lands that constitute the boundary conditions for shoreline change can then be spaced suitably so as to produce a series of well-stabilized coral-sandy beaches.

As previously shown in Figures 9 (c) and 10 (c), we have found a possibility for stabilizing the beach against beach erosion by constructing three boundary condition for shoreline change at the specified locations shown in the figure. In other words, when three headlands are constructed at the locations, the long-term shoreline change along the entire beach becomes an equilibrium state, in which a static stable coral-sand beach is formed. We can not construct a mathematical headland having no wave diffraction and deflection. Therefore, we must experience to construct it practically. A methodology for coral-sand beach stabilization was proposed as shown in Figure 11, in which the three headlands are to be constructed, and two others, but smaller may be needed to compensate for the direct effect of the headland 3 on shoreline change. A small groin shown in the figure was constructed before the application of the proposed methodology, to remove a cusped foreland formed near the runway.

Application of the proposed methodology

Among the headlands, the headlands 1 and 2 had been constructed independently with concrete-filled concrete piles in 1985 and 1988, respectively. The respective headlands are of groin and offshore breakwater type. Due to the local circumstance of Indonesia, therefore, these headlands have too steep slopes to reduce wave reflection. No beach nourishment was carried out between the headlands. Figure 12 shows the shoreline change after the construction of the runway. Referring to Figures 2 and 12,

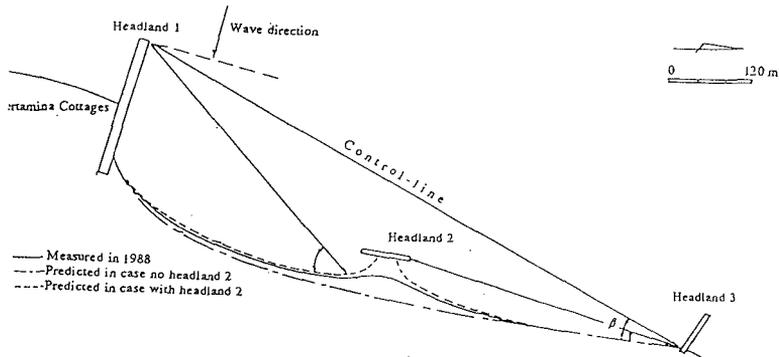


Figure 13. Shoreline changes after the construction of headlands 1 and 2 in comparison with the shoreline configuration for the static stable sandy beach.

severe shoreline retreat has taken place after the construction of the runway, but after the construction of the headlands the shoreline positions tend to approach equilibrium ones. Figure 13 shows the shoreline change between the headlands, comparing it with the static stable shoreline configuration that was obtained by an empirical relation of equilibrium bay configuration (Hsu, Silvester & Xia, 1987). The shoreline is approaching to the final shape of shoreline. Photo. 2 (a) and (b) show actual views of the formation of coral-sand beach between the headlands 1 and 2, in which (a) and (b) respectively were taken in the north and south directions in 1989. In Photo. 2 (a), there are a number of tetrapods that were placed on for protecting the beach locally about 1978. Waves are breaking at the same time along the beach, not showing a peeling phenomenon. This fact demonstrates that no longshore sediment transport

exists along the beach that has been well-formed as static stable coral-sand beach. In Photo. 2 (b), a tombolo is formed behind the headland 2 of offshore breakwater type, and is connected with the beach shown in Photo. 2 (a) by forming a stable coral-sand



(a) Taken in the north direction.



(b) Taken in the south direction.

Photo. 2 A static stable coral-sand beach is being formed between headlands 1 and 2 in the Kuta beach taken in 1989.

beach. We conclude, therefore, that further improvement are necessary in constructing headlands, but such a static stable beach has been well-formed between the headlands 1 and 2, and that, as shown in Figure 11, the adjacent beach is also well-formed by the headland 3, tending to connect with the natural northern one. We further conclude that, when well-designed headlands are constructed at the most suitable locations for the boundary conditions for shoreline change, a series of static stable coral-sand beaches can be formed in the large coastal behavior.

CONCLUSION

In coral-sand beaches, sediment sources are mainly due to the sea animals production so that a very little amount can maintain the beach. Since no available wave data exist

in the Kuta beach, Bali, the most effective wave for beach change has been discussed in terms of wave transformation on a coral reef. By the use of the most effective wave, we predicted long-term shoreline changes in the large scale coastal behavior, with changing positions for the boundary conditions for shoreline change. We found the most suitable arrangement of headlands as the boundary conditions for stabilizing the entire beach against beach erosion.

On the basis of this findings and theory of the formation of static stable beach, a methodology for coral-sand beach stabilization was proposed. Since parts of the headlands proposed in the methodology were constructed, a stable beach had been well-formed between the headlands. We concluded that the coral-sand beach had almost approached the final shape of static stable one. Therefore, since the application of the proposed methodology has been examined satisfactorily, this methodology can be applied to other coral-sand beaches.

When Professor Y. Tsuchiya, the second author revisited Bali in 1990, however, the coral-sand beach that had been forming so wonderfully was no longer there. Dr. A. R. Syamsudin, the first author and Professor Tsuchiya who were standing on the groin were angered by the reconstruction of this beach with two big groins to make a marine resort, rather than beach preservation.

Acknowledgments

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