CHAPTER 255

LABORATORY MOBILE BED MODEL STUDIES ON EBB TIDAL SHOAL EVOLUTION

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Abstract

Laboratory mobile bed experiments were conducted to study the ebb tidal shoal evolution process under storm wave conditions. An idealized inlet configuration was chosen for the experiment representing a typical median-sized inlet on the east coast of Florida, USA. Six different cases were tested including a natural inlet and a jettied inlet with different jetty length and jetty type. Formation of ebb tidal shoal was observed in all cases; the rate of growth and location of ebb tidal shoal were different for the cases. Inlet channel shoaling and beach erosion next to the inlet are far more severe in the case of natural inlet than that in the case of jettied inlet. In general, the established tidal shoal tends to grow during the ebb cycles and deteriorate during flood cycles. And partial removal of ebb tidal shoal has shown to increase downdrift beach erosion and reduce the rate of ebb shoal growth, though the rate of change of the mined case rapidly approached that of the case without mining.

1. Introduction

Ebb tidal shoal is a common feature associated with tidal inlets in coastal area. It is created by the combined deposition of littoral material diverted from adjacent beaches together with the alluvial material carried out from inlet by the tidal current. When inlets are stabilized with training structures, ebb tidal shoal can become more prominent as littoral material is diverted further offshore into deeper water. As a consequence, the ebb shoal volume also increases. This causes additional disruption of the normal longshore sediment transport and often results in severe downdrift shoreline recession. In Florida, over 85% of the shoreline erosion is considered to be related to inlets, particularly to those with training structures.

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Since ebb tidal shoal is formed mainly by material diverted from the updrift beach it is a tempting source, and reasonably so, to tap for downdrift beach nourishment. However, such practice is not common because the formation of ebb tidal shoal is part of the natural process and disturbing an ebb tidal shoal environment so close to shoreline without knowing clearly its effects is unsettling.

This paper is aimed at investigating the evolution process of ebb tidal shoal on one hand and finding the possibility of utilizing the sand from ebb tidal shoal on beach nourishment on the other by means of movable-bed physical modeling in the laboratory. To achieve this goal, an inlet model testing is designed and carried out to investigate ebb tidal shoal evolution process and corresponding shoreline responses for a natural and unimproved inlet, an inlet with jetty structures and with the ebb tidal shoal partial removal.

2. Design Of Inlet Model Experiments

The inlet-beach physical model was designed with considerations on experimental constraints and modeling laws. The model was tested under simulated storm wave conditions to insure turbulent flow and suspended sediment transport mode. The modeling law adopted in the present study is shown in Table 1, which is for an inlet-beach system based on the analyses of the experimental results of a series of 2-D and 3-D laboratory model study (Wang, *et al.*, 1994: Wang, *et al.*, 1995).

Table 1: Modeling Law

Geometric Distortion*	Wave Height Distortion	Hydrodynamic Time Scale	Morphological Time Scale
$N_\delta = N_w^{0.4} N_\lambda^{0.8}$	$N_H = \sqrt{N_\lambda}$	$N_T = \sqrt{N_\lambda}$	$N_t = \sqrt{N_\lambda}$

* N_w, N_δ, N_λ are fall velocity, vertical and horizontal length ratios, respectively.

The model experiments were carried out in a wave basin located in Coastal and Oceanographic Engineering Laboratory at the University of Florida. The wave basin has a physical size of 25m wide, 30m long, and 1m deep as shown on Figure 1. The inlet-beach model and a wave maker were located at two long ends of the basin. An ideal inlet, of straight, rectangular channel, with uniform width and depth of 1.75m and 0.2m, respectively, was constructed cutting through a plane beach made of a natural quartz sand (D_{50}=0.19mm). The overall length of the beach from updrift to downdrift ends is 19m. The model is laterally bounded on two wave guides formed by concrete blocks. The wave guides are perforated to allow flows in and out of the test section. The downdrift wave guide is open at the beach end to allow downdrift littoral transport to leave the test section and to be collected in the catch channel. The plane beach consists of a flat back shore segment, a steep-slope foreshore segment, and a mild-slope offshore profile which extends seaward to about 7m form the shoreline beach face before merging with the concrete floor. The beach profile approximates an equilibrium shape of $h = Ax^{0.8}$, which h is water depth, x is seaward distance from shoreline, A is a scale factor.

A schematic of experiment setup

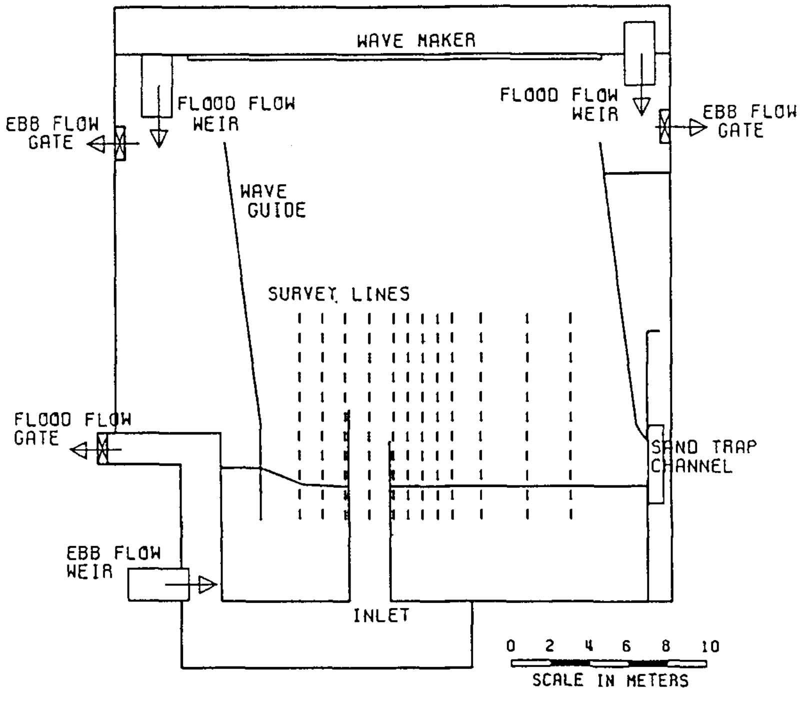

Figure 1: The Schematic Setup for Movable-Bed Inlet Physical Model.

The inlet is offset from the center towards the updrift with the updrift beach length of 5m and downdrift beach length of 12m. The wave generator is located about 27m form the shoreline based on an average water depth about 0.35m. Tidal currents are generated by recirculating water through the circulation channels connected with the wave basin. The flow discharge is controlled by the flood and ebb flow weir boxes. Water is supplied form the upper basin weir boxes (flood flow weirs) for flood current and from the lower basin weir box (ebb flow weir) for ebb current. A curved feeder beach section at the updrift end allows for continuous and more uniform sediment supply to the downdrift which is purely due to wave-induced transport.

3. Experimental Conditions

Six different experimental cases and associated conditions are summarized in Table 2. Tidal currents are simulated in the experiment by alternating ebb and flood cycles at equal interval of 40 minutes, which is equivalent to a semi-diurnal tidal period at 1:80 geometrical scale ratio according to Froud number criterion. A constant discharge of 0.04 m^3/sec is used for both ebb and flood cycles. The cross-sectional averaged currents in the inlet are maintained to be 0.12 m/s and 0.14 m/s for the flood and ebb cycles, respectively. The tidal range is 3 cm in the experiment.

Table 2: Test Conditions of Inlet-Beach System Experiment.

Case	Wave height	Incident wave condition (Wave period: 1sec) Wave angle	Beach slope		Jetties (type) e: even length u:uneven length	Model time (min)
			Foreshore	Offshore		
C1	8 cm	15 deg	1:2.4	1:14.5	none	480
C2	8 cm	15 deg	1:2.9	1:14.5	Riprap(u)	1600
C3	8 cm	7.5 deg	1:2.9	1:14.5	Caisson (u)	3200
C4	7 cm	7.5 deg	1:2.9	1:14.5	Caisson (e)	3200
EC1	7 cm	7.5 deg	1.2.9	1:14.5	Caisson (e)	3200
EC2	7 cm	7.5 deg	1:2.9	1:14.5	ebb shoal mining	3200

Experiment C1 is to simulate a natural inlet; C2 is to simulate a jettied inlet with riprap type jetties; C3 and C4 are to simulate a jettied inlet with caisson type jetties. In Case C2 and C3, the inlet consists of an updrift jetty of 1.5m and a downdrift jetty of 0.7m, both straight and perpendicular to initial shoreline. The uneven updrift and downdrift jetty geometry of an inlet is common in Florida. In C4, the updrift and downdrift jetty jetties have the same length of 1m. Experiment EC1 and EC2 were conducted to investigate the effects of ebb tidal shoal removal. Experiment EC1 is the case without removal of ebb tidal shoal and EC2 is the case with removal of ebb tidal shoal. Both experiments have the same test conditions as that of C4, except C4 has a slight larger width of the inlet. The jetty elevation is about 5cm above the flood tide water surface and jetty width is 20cm. Figure 2 shows the initial bathymetry for natural inlet case. Also, the major difference between riprap and caisson type jetties is that the riprap is porous and not sand tight whereas the caisson is impervious.

4. Experimental Procedures

The model experiments is conducted according to the following procedures: (1) Prepare initial inlet model bathymetry, (2) Conduct initial profile survey at selected cross-sections as shown in Figure 1, (3) Adjust water level and discharge to the specified ebb conditions, (4) Start wave maker to generate storm waves, (5) Run the ebb cycle experiment for 40 minutes, (6) Readjust water level and tidal flow for the flood condition, (7) Start wave generator and run the flood cycle for 40 minutes, (8) Repeat steps from (3) to (7) until an prominent ebb tidal shoal is established, and (9) Reshape the model to its initial bathymetry for the next experiment. Eleven bottom profile surveys were conducted at irregular time intervals, shorter in the early stage and longer later in the experiment. Sediment accumulated inside the inlet and outside of the downdrift boundary was collected at the same time when bottom surveys were conducted. Both dye and sand tracer studies were conducted from time to time. The dye study was for current pattern observation and was documented by video recordings. Sand tracers were used for visual examination on sediment transport pattern. No quantitative measure of sand tracer movement was attempted.

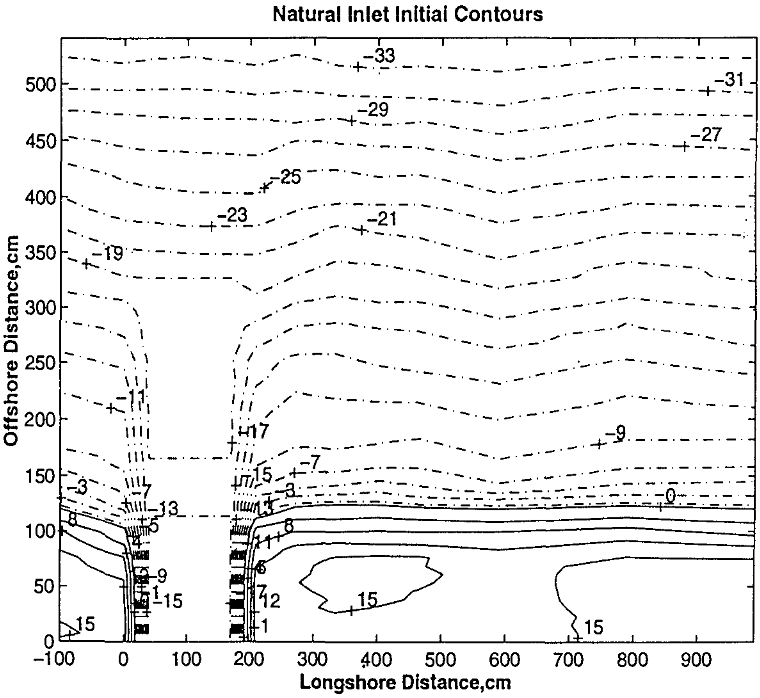

Figure 2: Initial Topographic Contours for Natural Inlet Experiment

The initial topography of Case EC2 was prepared by modifying the final topography (3200 min) of EC1, which included mining of ebb tidal shoal and downdrift beach nourishment. Sand was removed from the ebb shoal and inlet channel areas which is indicated by the dashed rectanger in Figure ?. This sand was used in all for the downdrift beach nourishment in the preparation of initial topography of EC2.

5. Experimental Results

Formation of ebb tidal shoal was observed in all cases; the location of ebb tidal shoal and the rate of growth were different. In the laboratory, + 2cm above the initial bottom profile was chosen as the reference plane to present the results of ebb tidal shoal growth.

In the natural inlet experiment, a small shoal formed immediately near the entrance in the first ebb and flood cycles as the beach material was rapidly carried seaward to form nearshore breaking bars. Inside the breaking line, sediment from the updrift beach was seen to move towards the inlet by strong wave action. Outside the breaking line, sediment was carried across the channel and deposited at downdrfit side of the channel outside the surf zone. Beach erosion was severe at both sides of the inlet from the beginning of the experiment. In the following ebb and flood cycles, the initial shoal built near the inlet entrance continued to grow and expand to form channel shoal and ebb tidal shoal. The experiment was stopped at 480 minutes or six complete tidal cycles as both channel shoaling and beach erosion became excessively severe. The shoreline erosion pattern was nearly symmetrical with respect to the inlet center. The generation and growth of the ebb tidal shoal and also the shoreline patterns in Experiment C1 using the net +2cm as the base contour are exhibited in Figure 3. It is seen that shoaling began at the channel entrance and grew in both directions towards offshore and into the channel. At 120 minutes, channel shoal and ebb tidal shoal can be separately identified. The ebb shoal began to shift towards downdrift after 120 minutes. At the end of 480 minutes, a drastic ebb tidal shoal was establish while the channel shoaling was seen to extend and reconnect with the ebb shoal.

In the jettied inlet experiments, general sediment transport patterns were similar in the beginning ebb and flood cycles. Accretion of sediment occurred at the tips of both updrift and downdrift jetties. Generation of ebb shoal was not evident in this early stage. In subsequent time, the sediment transport patterns became different,
which then influenced the development of the ebb tidal shoal. In C2, the updrift jetty tended to attract sediment owing to the structural porosity. Accordingly, sediment was heavily deposited on both sides of the updrift jetty around its tip. In C3 and C4, on the other hand, more updrift sediment was seen to bypass the jetty. In these jettied inlet experiments, beach erosion was significant only at the downdrift side, particularly in C2 owing to the larger incident wave angle. In C4, the ebb tidal shoal was generated more closer to the inlet than in C2 and C3 due to the small incident wave height. Compared with C4, EC1 had more centered ebb tidal shoal and much less channel shoaling because of the smaller width of the inlet which tended to transport more sediment bypassing the jetties.

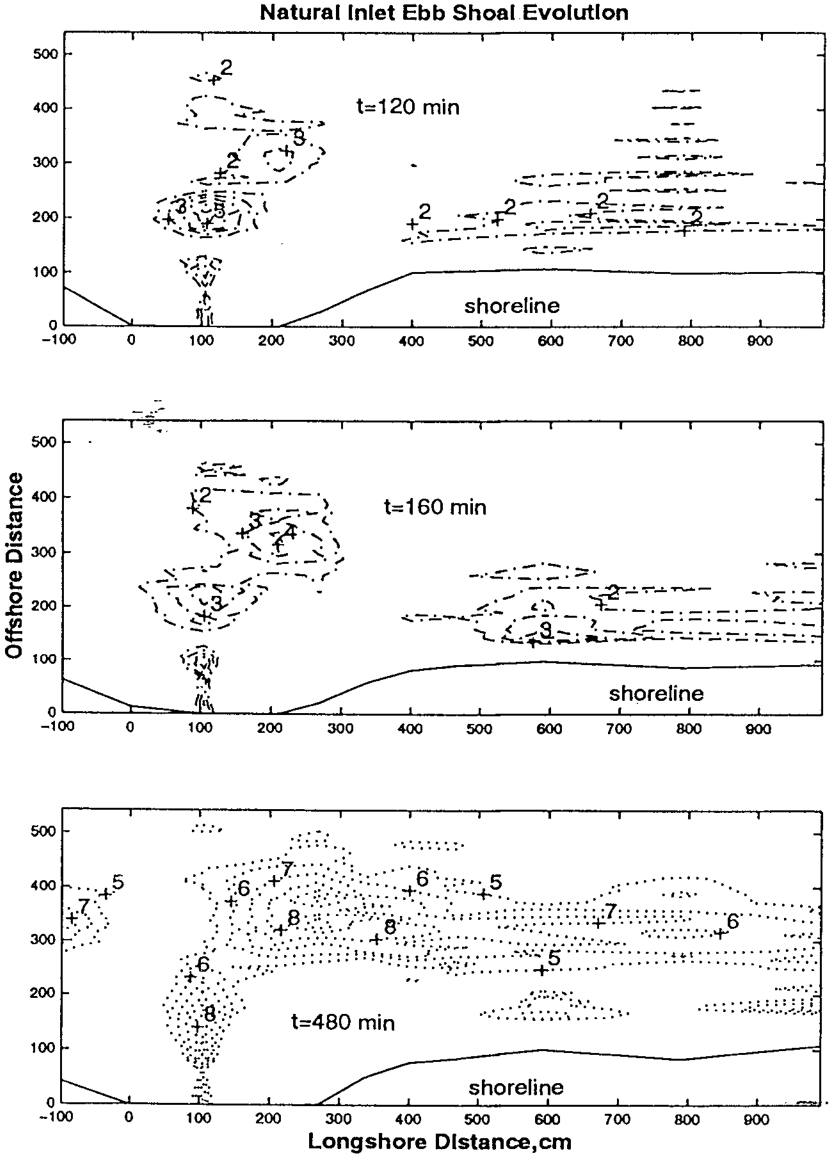

Figure 3: Ebb Tidal Shoal Evolution in Experiment C1.

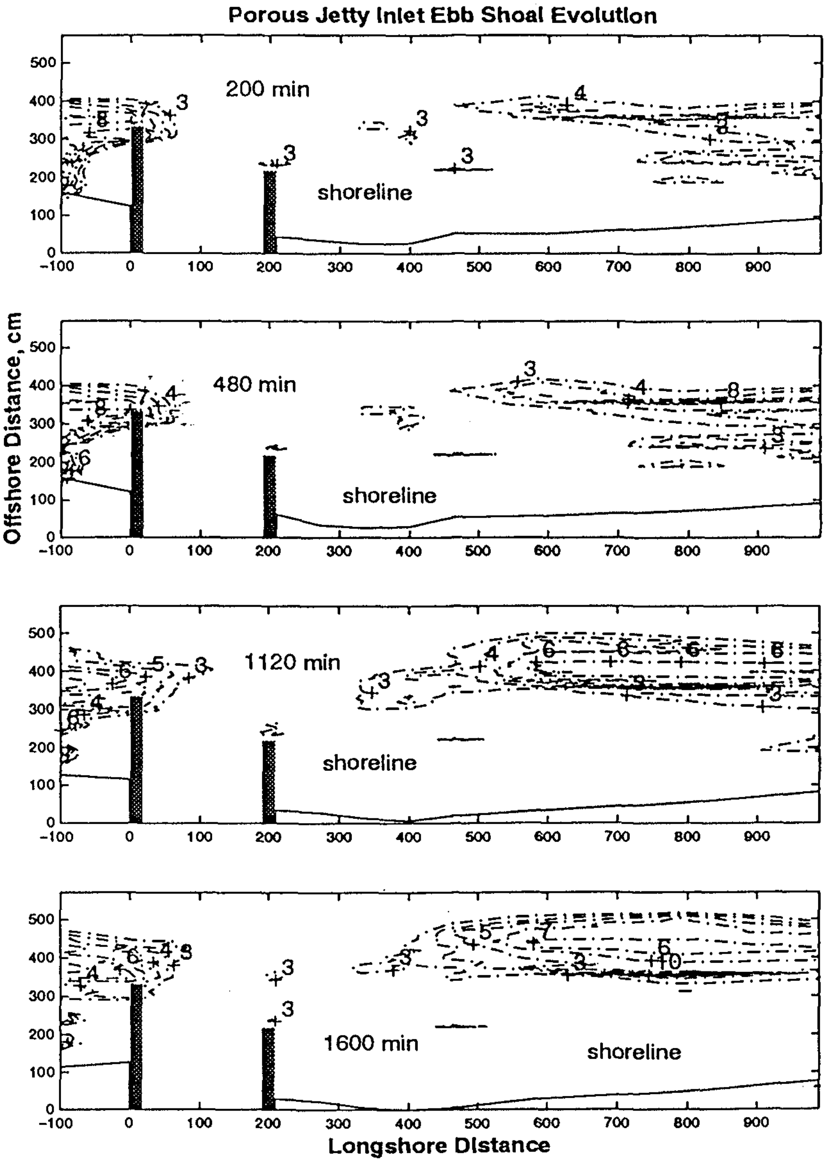

Figure 4: Ebb Tidal Shoal Evolution in Experiment C2.

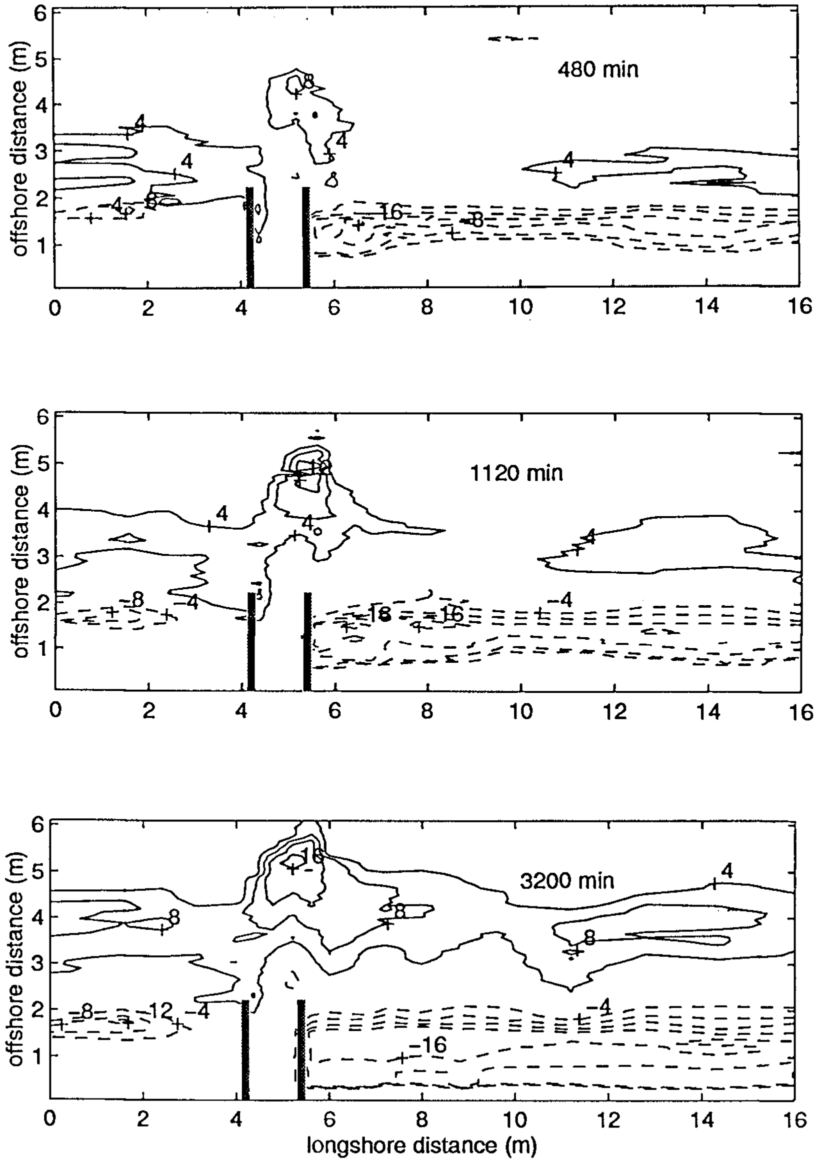

Figure 5: Ebb Tidal Shoal Evolution in Experiment EC1.

Figure 4 to 5 present the evolution pattern of ebb tidal shoal in C2 and C3 , respectively. Figure 6 compares the ebb tidal shoal volume for C1,C2, C3 and EC1. It is seen that the growth of ebb tidal shoal was unsteady in the early stage in these cases. The ebb shoal simply grew during ebb cycles but shrunk during flood cycles. After the first few cycles, the ebb tidal shoal began to grow steadily, almost in a linear fashion. The process was much rapid in the case of the natural inlet than the jettied inlet. The rate of growth apparently slowed down at a later stage of the experiment.

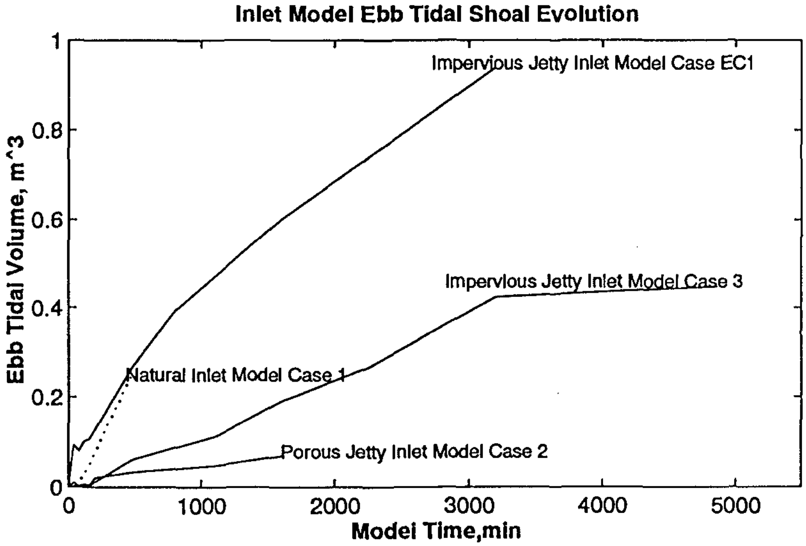

Figure 6: Comparison of Ebb Tidal Shoal Volume Changes for C1, C2, C3 and EC1

Experiments EC1 and EC2 were conducted to study the effect of the partial ebb tidal shoal removal. Figure 7 shows the ebb tidal shoal evolution process after part of the ebb tidal shoal sand was removed and used as the downdrift beach nourishment in EC2.

The effects of ebb tidal shoal removal on downdrift beach were evaluated by comparing the total volume of sand eroded from the beach between the downdrift jetty and downdrift boundary in experiments EC1 and EC2. This comparison of downdrift beach erosion and erosion rate versus the elapsed time is shown in Figure 8. It is seen that the downdrift beach erosion is overall significant in EC1 and EC2, with a greater erosive rate in EC2 than in EC1, though at the later stage, this difference became much smaller.

The degree of restoration of the ebb tidal shoal was evaluated by comparing the volumes of the ebb shoal in EC1 and EC2 as shown in Figure 9. At 800 min, the ebb tidal shoal in EC2 has less volume than the shoal in EC1 implying a slower rate of growth in EC2. However, from 800 min to 1600 min, the ebb shoal growth approaches a steady rate in both experiments. The rate of growth fluctuates greatly in the first 160 min reflecting the effects of the short time intervals corresponding to individual ebb and flood tides.

6. Conclusion

Based on the experimental results, inlet channel shoaling and beach erosion in the cases of jettied inlet experiment were not as severe as compared to the case of the natural inlet. Apparently, the presence of jetties slows down the inlet shoaling and beach erosion near the inlet. It is evident that jetty structures are necessary for tidal inlets under strong wave environment.

Formation and growth of ebb tidal shoal were observed in all the inlet experiments. The location and rate of growth of ebb shoal were different, though.The ebb tidal shoal were created and expanded during ebb cycles but deteriorated and diffused during flood cycles. The porous jetty tended to attract sediment deposition near the inlet entrance whereas impervious jetty caused more sediment bypassing the inlet.

Mining an ebb tidal shoal has shown to increase downdrift beach erosion and reduce the rate of ebb shoal growth at certain degree. However, the rate of change of the mined case rapidly approached that of the case without mining, which implies the feasibility of using sediment from ebb tidal shoal in downdrift beach nourishment. The experiment was successful in reproducing ebb tidal shoals observed in nature.
However, more research work is needed to gain the insight of dynamics of the system.

Acknowledgement

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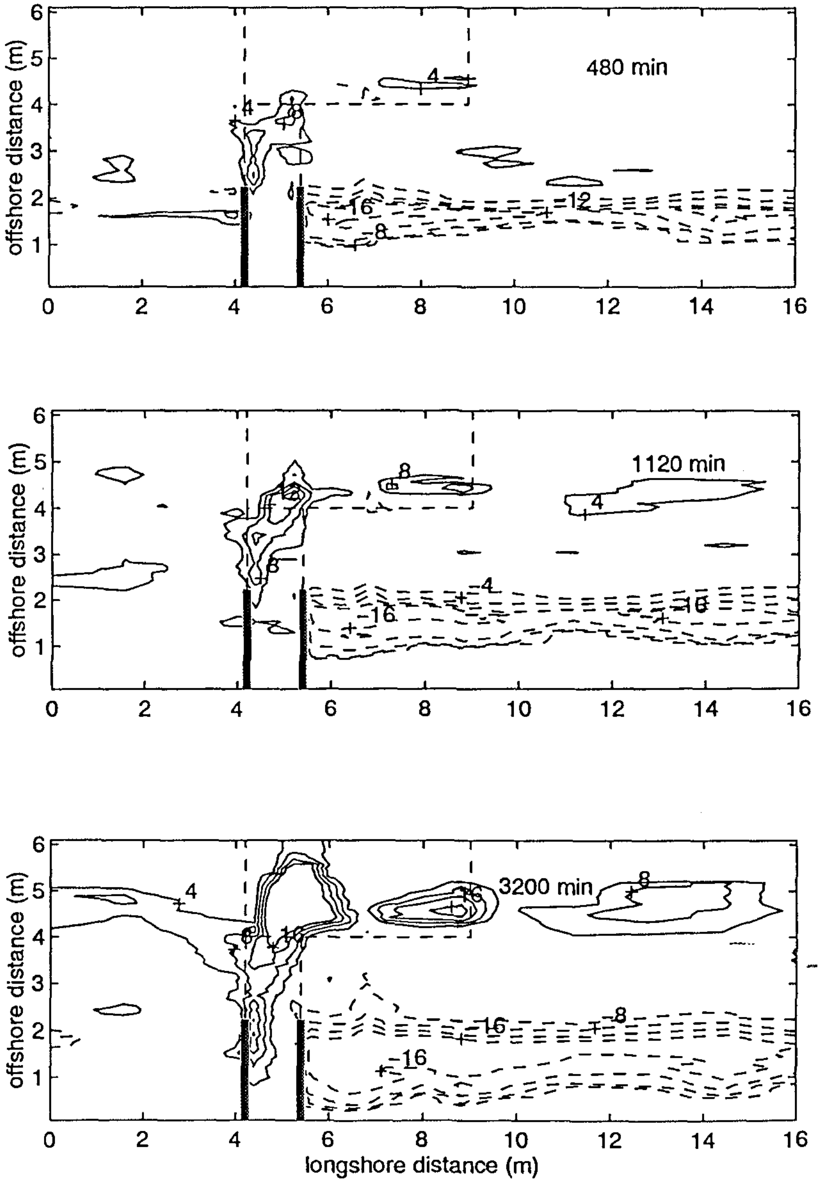

Figure 7: Ebb Tidal Shoal Evolution in Experiment EC2.

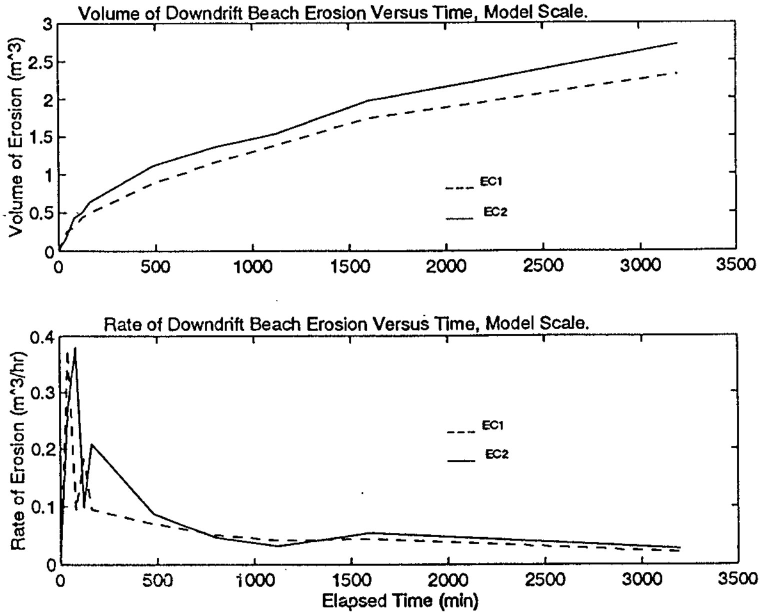

Figure 8: Comparison of Downdrift Beach Erosion in Experiments EC1 and EC2.

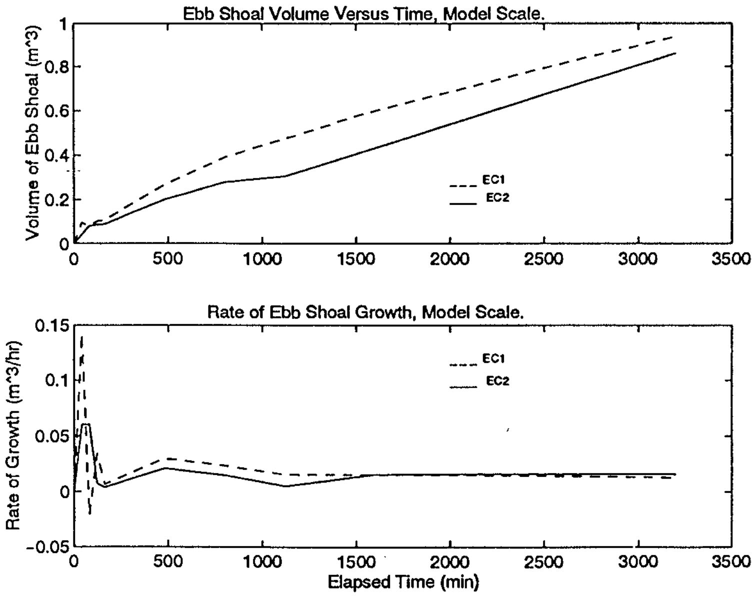

Figure 9: Comparison of Ebb Tidal Shoal Evolution in Experiments EC1 and EC2.

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