CHAPTER 42

CHARACTER AND STABILITY OF A NATURAL TIDAL INLET

By

Curtis Mason[1] and Robert M. Sorensen[2]

ABSTRACT - An environmental study was conducted at Brown Cedar Cut, a natural unstable barrier beach inlet connecting East Matagorda Bay, Texas, with the Gulf of Mexico. The objectives of this study were to determine the physical and hydraulic properties of the inlet, and to investigate the inlet's historical stability, as well as its short-term response to a number of physical processes. Results of the study indicate that hurricanes and continuing erosion of adjacent beaches enhance the long-term stability of the inlet. During winter months, the rapid passage of strong frontal systems and associated winds, as well as substantial amounts of rainfall, are primarily responsible for the day-to-day viability of the channel boundaries. In the absence of such forces, the predominance of littoral drift over the limited flushing ability of astronomical tidal currents leads to degradation of the inlet channel and westward migration of the entire inlet system.

INTRODUCTION - The coastline of Texas is characterized by a barrier island and lagoon regime which extends over 80% of the coastline. Separating these islands are over a dozen tidal inlets of various sizes, ranging in width from a few hundred feet to over one mile. Although these inlets have been studied to some extent in the past by Price (6,7,8,9,10) and Carothers and Innis (1), little attempt has been made to correlate the various environmental factors with observed changes in the inlet's geometric properties. Therefore, a field investigation of a small tidal inlet was undertaken to identify and establish the relative importance of those natural processes influencing the behavior of the inlet, and to determine its long and short-term stability.

The inlet selected for study was Brown Cedar Cut, located about twenty-five miles south of Freeport, Texas, as shown in Figure 1. This inlet is the sole direct connection between the Gulf of Mexico and East Matagorda Bay, a shallow estuary some fifty-four square miles in area. This site was selected for its small size and because maintenance of the channel is due entirely to natural processes.

HISTORICAL BACKGROUND - Brown Cedar Cut was formed during a hurricane in 1929 (4), and since that time has exhibited considerable variation in size and location, actually closing for three years between 1964 and 1967. An analysis of historical charts and photographs revealed that the inlet's behavior is characterized by a periodic sequence of events. The initial break through the barrier island results from the action of large waves, high tides, and torrential rainfall associated with hurricanes, which establish a wide, relatively deep channel. Subsequently, the northeast side of the inlet elongates toward the southwest in response to dominant wave conditions and related depositional processes. As the inlet migrates westward, the channel lengthens, tidal velocities decrease, and deposition occurs throughout the channel. If undisturbed by severe weather conditions, migration continues until the inlet closes. Usually, however, the channel is re-enlarged at the original position before closure occurs.

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1. Oceanographer, USACE Coastal Engineering Research Center, Washington, D.C.
2. Assoc. Prof. Dept. of Civil Engineering, Texas A&M University, College Station, Texas.

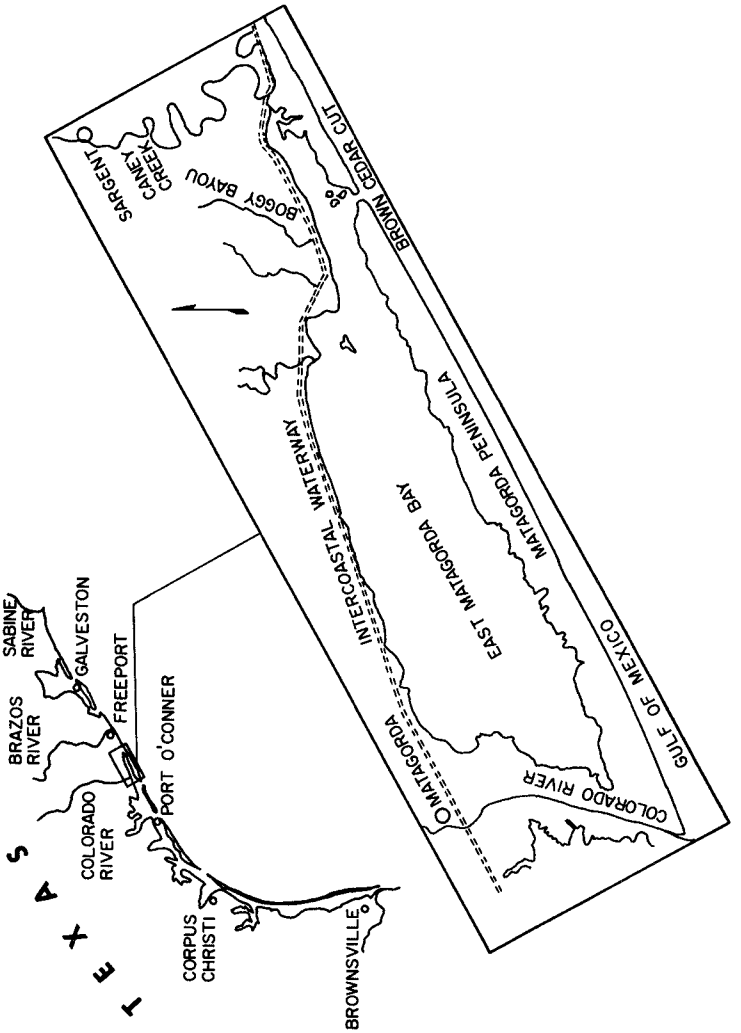

FIGURE I. EAST MATAGORDA BAY AND ENVIRONS

In addition to the generally erosive forces of hurricanes and other storms another factor appears to have played a major role in the stability of Brown Cedar Cut. Analysis of coastal charts indicates that since 1929, the adjacent shoreline has receded over 1500 feet. Thus, the effective length of the channel has been reduced, and the resulting decrease in frictional resistance has allowed velocities to remain relatively high, precluding closure.

INLET PROCESSES - Comprehensive surveys of the inlet were initiated in October, 1970, to determine those factors influencing changes in shape, size, and stability. Beach and shallow water elevations were determined using standard surveying equipment and a fathometer. Data obtained were employed in the analysis of the inlet's response to natural processes as follows.

Local contours of the mean water level were drawn for each pair of consecutive surveys, thus delineating the nature of gross changes. Determination of environmental conditions prevailing during the interim was important, but considerably more difficult. Current velocities between surveys were computed from measured tidal differential time histories obtained from tide gages. However, observations of wave conditions were available only for brief periods, so an indirect method for determining the nature of the wave activity was employed.

Although wave characteristics are not always proportional to wind direction and magnitude at the site, it was felt that a reasonable correlation could be made. Wind observations taken at a nearby location at six hour intervals and occurring between survey dates were first sorted according to direction - those having a strong north component, i.e. north, north-northwest, and north-northeast, were grouped together as north. Similar groups were established for east, south, and west. Winds from the northeast, southeast, southwest, and northwest formed four other groups of wind velocity observations. The velocities in each group were then summed, and these sums were divided by the number of days in the observation period. The resulting values are daily averages of the relative forces of prevailing winds. Computations were performed for each survey interval and plotted in the form of a wind force rose on the corresponding shoreline comparison figure.

A detailed discussion of the nature and probable causes of changes in inlet geometry is presented below in chronological order.

October 24: The general configuration of the inlet and prominent reference points are indicated in Figure 2. The distance between shorelines at the mouth was about 1450 feet, but wide shoal areas extended outward from the banks, and the portion of the channel greater than six feet deep was only about four hundred feet wide. The inlet exhibited the typical north-south orientation of other Texas inlets (10), and the main channel followed a winding path through interior islands to the bay. The east side of the inlet was a sand spit that exhibited a well defined "hook" configuration. The origin of hooked or recurved spits was reported by Evans (2), who concluded that they form as a result of wave refraction around the spit end. However, Evans' findings require that for growth of such structures, waves must approach the spit obliquely from the mainland or upcoast side, in this case from the east or southeast. Waves approaching normal to the beach or from a southerly direction will not transport sand to the spit end, and may in fact actively erode the spit area. The converse is true for the west spit; growth due to wave refraction will occur only when waves strike the beach with a predominately south or west component. In both cases, however, refraction of offshore waves by the adjacent gulf shoals may cause local directional variability.

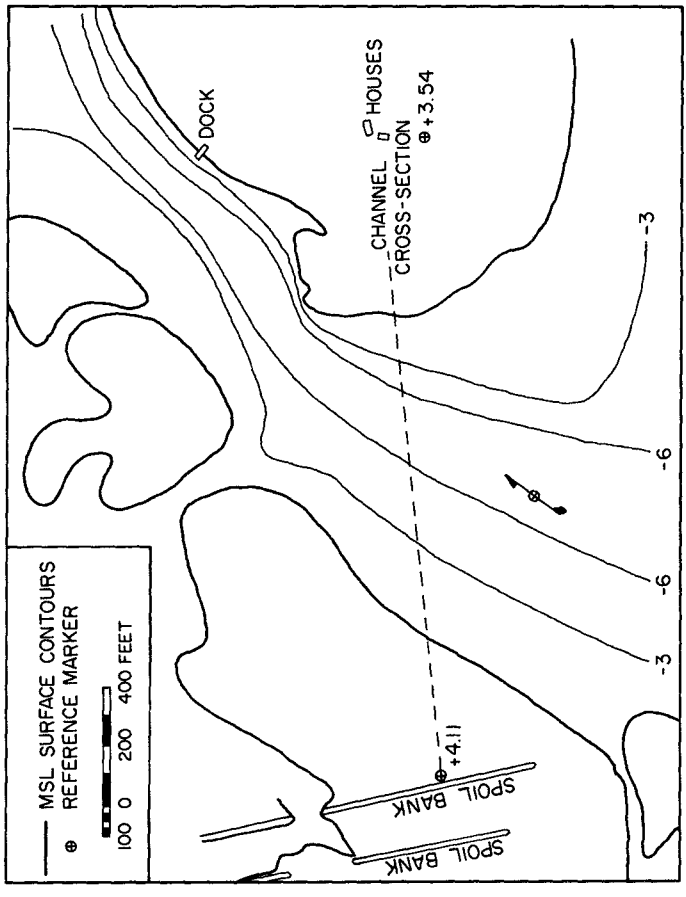

FIGURE 2. BROWN CEDAR CUT LOCATION CHART, 24 OCTOBER, 1970

October 24 to February 20, Figure 3: The first presentation of shoreline comparisons indicates significant spit growth on both sides of the inlet during the four month interval. Wind activity during this period was moderate, and exhibited a north and east predominance. Rainfall throughout the period was below normal. Casual observations of spit contours in December indicated that growth was minor until January. By February, the eastern recurved spit had extended about three hundred thirty feet towards the southwest, and a total of 21,600 cubic yards of sand had accumulated shoreward of the February 20 mean water contour. The growth of the west spit a distance of 535 feet northward is attributed primarily to refraction of waves from both the south and east. However, the action of tidal currents may have contributed to the total deposition of 14,400 cubic yards landward of the February 20 mean water contour.

February 20 to 27, Figure 4: During this period the second hook on the east spit was modified considerably. Predominant wind direction was from the east, and deposition occurred along the entire southwest edge. Wave activity on the 27th was of great magnitude and almost directly from the east, and a southwestward flowing longshore current of over three feet per second was measured near the inlet. Current velocities during this period showed a strong predominance for ebb flow resulting from the passage of a frontal system on the 21st, which depressed the bay waters for over three days. Therefore, wave refraction patterns were modified by the outward flowing water during that time. Although not exhibiting a hook configuration, a considerable area at the end of the spit did experience growth, as indicated by the cross-hatching in Figure 4. Much of this growth occurred in the form of a beach ridge, as shown in the profiles of Figure 4. Numerous investigators (3,11,12) have commented upon conditions required for growth of such a feature, and the primary factors appear to be significant wave activity and relatively constant water level. Tidal records from an inlet tide gage indicated that semi-diurnal neap tides prevailed between February 25 and 27, and averaged less than one-half foot in range. In addition, the mean water level during this time was considerably above the long term mean water level, which would enhance growth of the ridge. Wind data indicated that winds from the east and southeast blew continuously from the 24th to the 27th, meaning that the observed wave activity had probably been in effect for some time. Thus, all evidence points to rapid building of the ridge by wave run-up. A series of similar ridges was formed between March 4 and 20, and these also corresponded to periods of small tidal fluctuations and high wave activity. As will be shown later, an entire series of these recurved beach ridges subsequently formed across the northeast spit.

February 27 to March 4, Figure 5: Wind and current activity during this period were dominated by the effects of a strong frontal system which passed through the area on March 2. The maximum recorded value of tidal differential occurred on March 3, when the Bay level was 1.8 feet higher than that of the Gulf, producing ebb velocities in excess of 3.5 feet per second. The west spit was effectively unchanged over the period, and the mean water contours at the southeast corner of the east spit also maintained position. However, the first hook was eroded about twenty feet and the tip of the spit migrated seaward about two hundred feet. Observations of the banks at both locations revealed the existence of small vertical bluffs extending about one foot above the water's edge. Although the exact cause of this erosion is unknown, degradation of the spit end during the morning of March 4 was observed to result from refracted waves from the Gulf. However, it is highly doubtful that the extensive erosion experienced at interior locations was due to similar processes. More likely is the possibility that strong ebb currents flowed along the shore and eroded large sections of the banks into the vertical configurations exhibited.

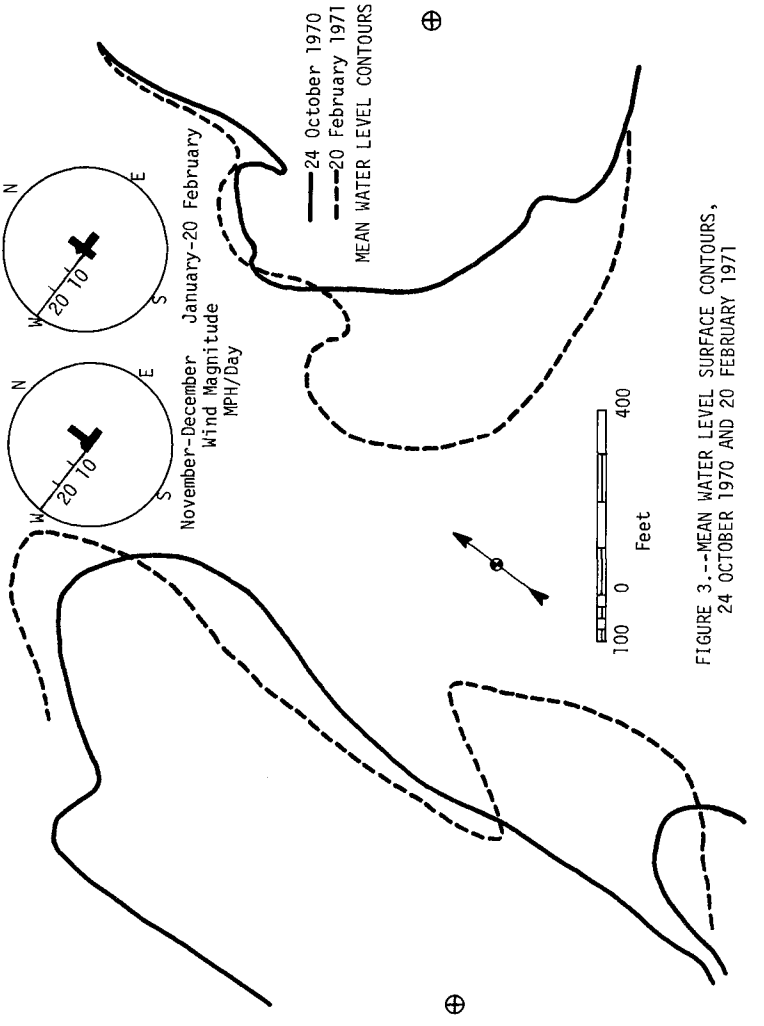

FIGURE 3.--MEAN WATER LEVEL SURFACE CONTOURS, 24 OCTOBER 1970 AND 20 FEBRUARY 1971

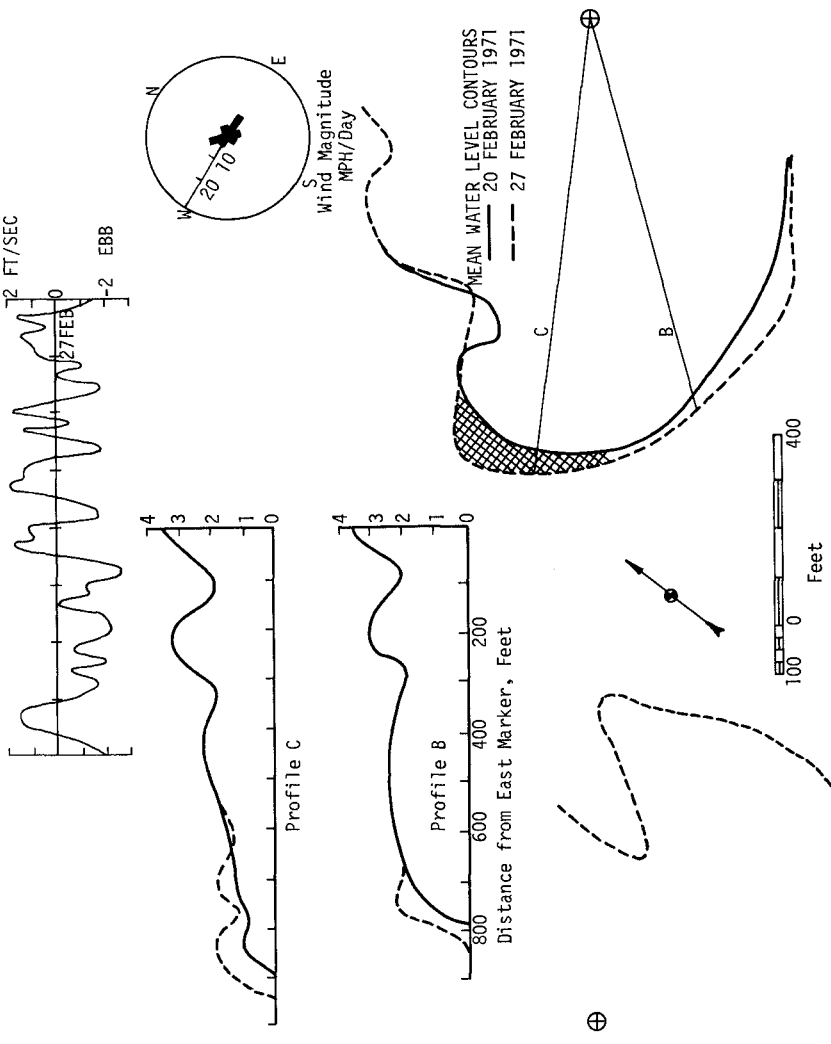

FIGURE 4.--MEAN WATER LEVEL SURFACE CONTOURS, 20 AND 27 FEBRUARY, 1971

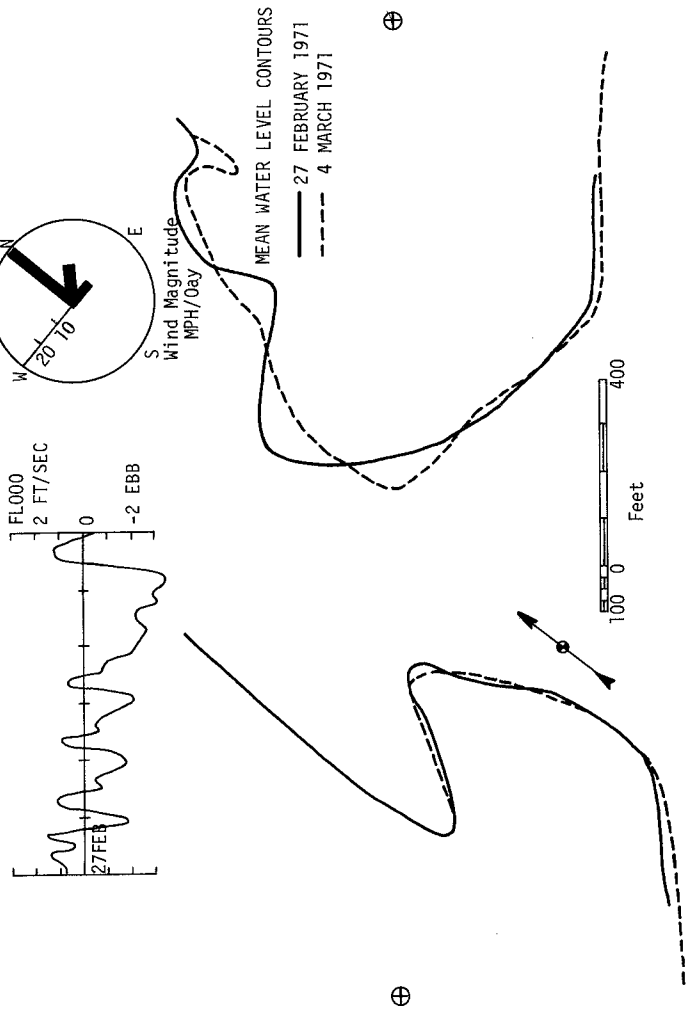

FIGURE 5.--MEAN WATER LEVEL SURFACE CONTOURS, 27 FEBRUARY AND 4 MARCH, 1971

March 4 to 20, Figure 6: Strong winds from the south and moderate flood currents predominated during this period, although the passage of two frontal systems did produce short-term ebb currents of significant magnitude. The inlet apparently responded primarily to wave activity from the south. The west spit acquired a slight bulge at the southeast corner, and built northward, exhibiting a pronounced recurved configuration. Waves and currents moving inward through the channel caused significant degradation of the east bank, but some deposition of this material occurred on the north side.

March 20 to April 3, Figure 7: Diurnal tidal ranges during this period were far above normal, averaging about 1.4 feet. Therefore, current velocities in the order of 1.6 feet per second prevailed, and were about evenly balanced between flood and ebb. Wave conditions were observed at three different occasions during this period and above-average breaker heights of about four feet were evidenced each time. Steep waves from the south and east, in combination with some of the highest recorded water levels, are assumed to be responsible for the recession of the west spit shoreline. Wave action from the east would usually cause cross-channel growth of the east spit. However, during this period the only growth experienced was in a northerly direction up the channel. It is theorized that the strong tidal currents, acting in concert with southerly waves, precluded any permanent effects of easterly waves, and in fact actively eroded the east bank. However, the material eroded was apparently transported northward, and subsequent deposition occurred in a pattern characteristic of wave refraction processes, i.e. a well-defined recurved spit.

Although waves and currents are responsible for most changes in the inlet, the influence of two additional natural forces must be considered. First, movement of beach sand by strong winds will contribute to changes in the exposed regions of the spit. Examination of the survey data revealed moderate spit modification above the high water mark, which probably resulted from wind action. Large-scale wind erosion is tempered by the existence of vast quantities of shells, which enhance the surface stability. In addition to wind effects, the influence of surface runoff and rainfall is very important. Significant amounts of fresh water contributed to the Bay can produce substantial differences in elevation between Bay and Gulf waters. The resulting ebb currents possess a potential for eroding the inlet banks and enlarging the channels.

HYDRAULIC PROPERTIES - The characteristics and stability of a tidal inlet are governed primarily by the exchange of water through its channels between the ocean and enclosed bay. The quantity of water exchanged and the velocities developed through the inlet are dependent upon the magnitude of the astronomical and meteorological tidal differentials. In order to determine the hydraulic properties at Brown Cedar Cut, it was necessary to obtain a continuous record of either the velocity or the tidal differential. Since instrumentation of the inlet for velocity information was prohibitively expensive and subject to interference by natural human forces, a plan for installation of two recording tide gages was implemented. Velocity time histories were then computed from the tidal differential histories using Manning's equation. Discharge measurements were taken over a complete tidal cycle to calibrate the inlet.

TIDAL DATA - Collection of tide records was performed using Leupold and Stevens Water Level Records Type F, Model 68, which were installed at the positions indicated in Figure 8. They were operated from February 1 to April 9, 1971, and sufficient data were collected to allow meaningful calculations of tidal differentials over most of the recording period.

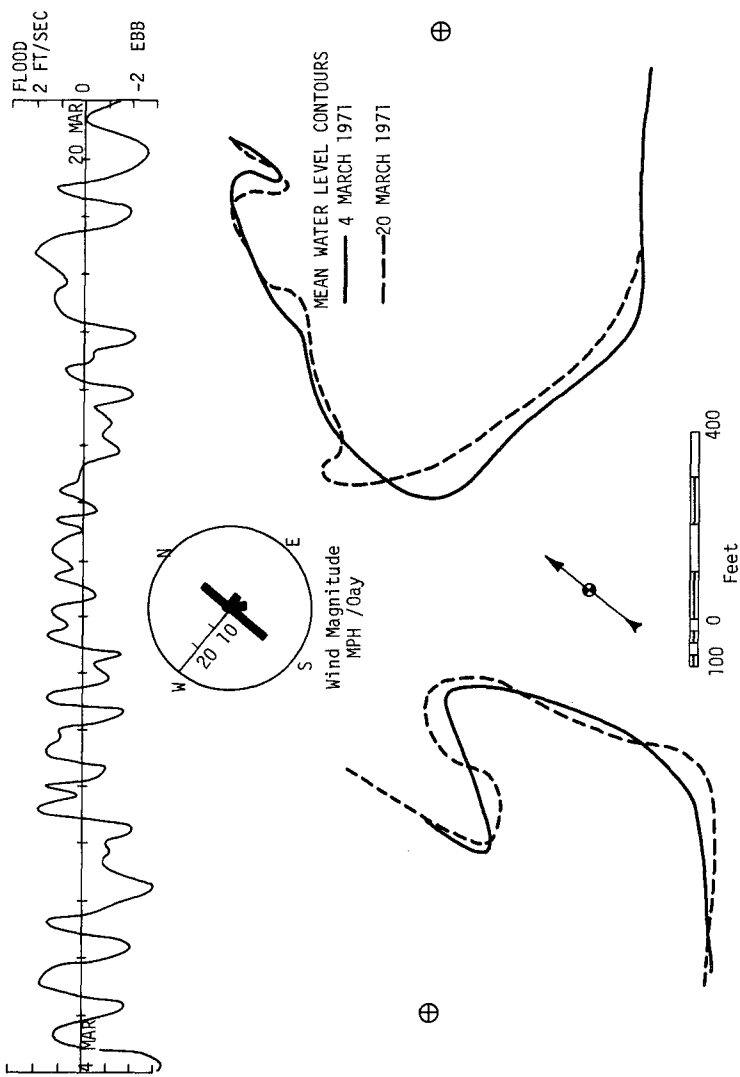

FIGURE 6.--MEAN WATER LEVEL SURFACE CONTOURS, 4 AND 20 MARCH, 1971

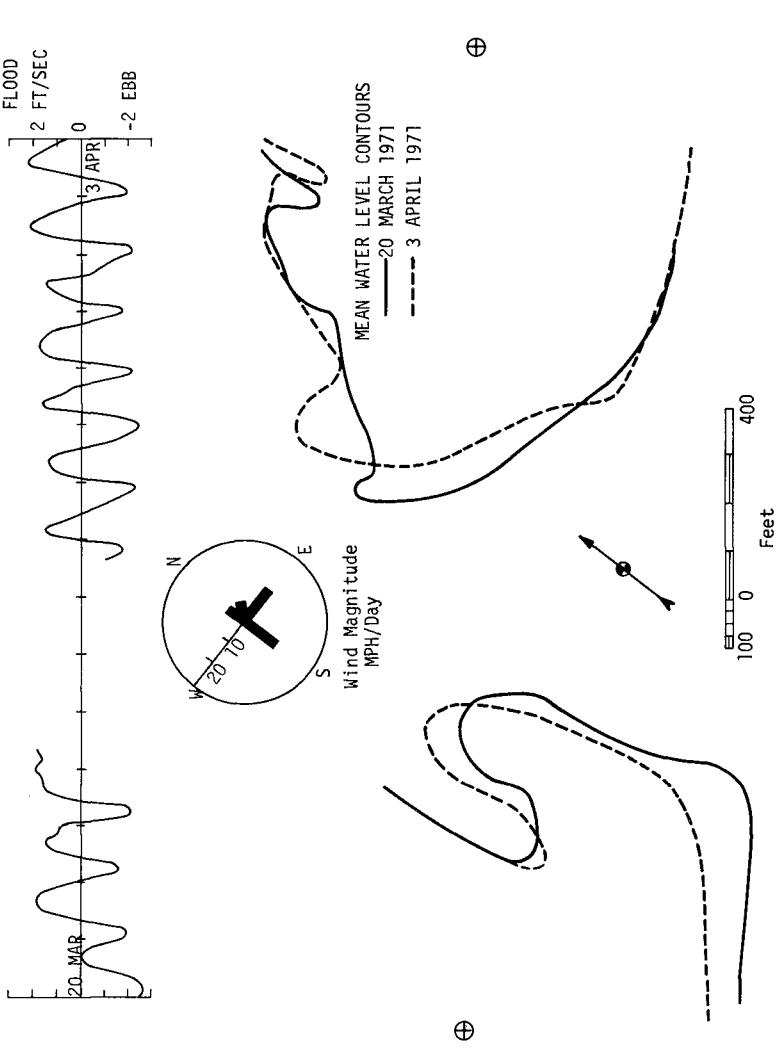

FIGURE 7.--MEAN WATER LEVEL SURFACE CONTOURS, 20 MARCH AND 3 APRIL, 1971

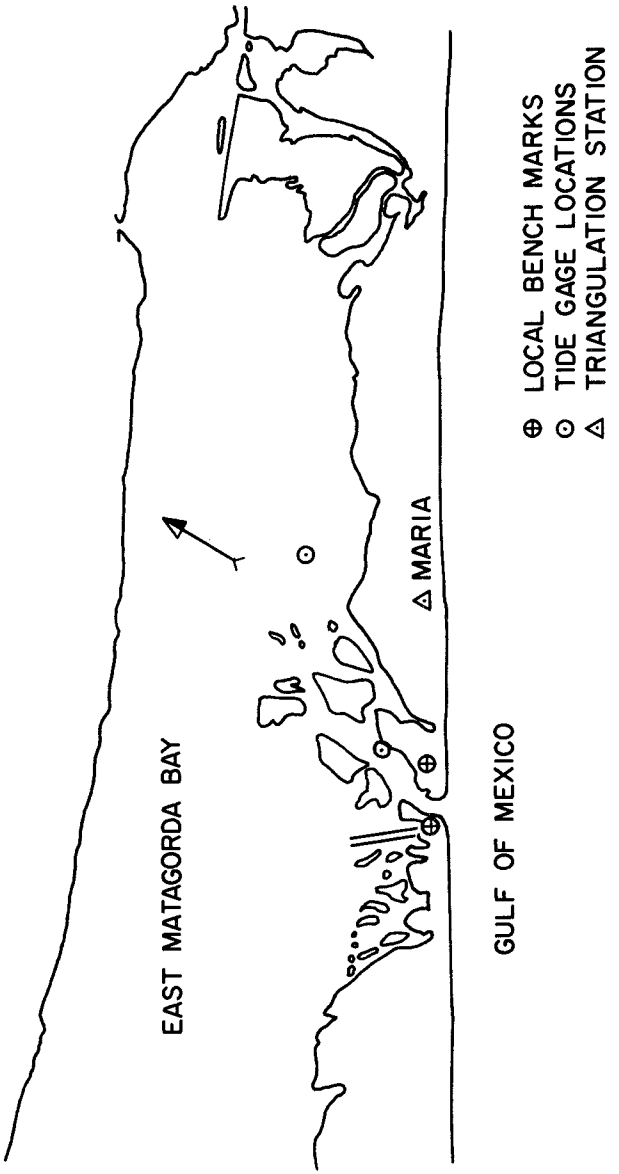

FIGURE 8. POSITIONS OF SEMI-PERMANENT MARKERS, BROWN CEDAR CUT

Analysis of the records was performed to determine the mean water level (MWL) over the reporting period. This value was ob ained by determining the average elevation of the water surface, using data points on the inlet tide record spaced at two hour intervals. The averaged values were then assumed to represent mean water level in both the Bay and Gulf. In addition to determining the MWL value, other tidal data required for related calculations were obtained and are presented in Table 1.

Tide Gage	Mean Low Water	Mean High Water	Mean Range	Maximum Low Water	Maximum High Water	Maximum Range
#1 (Inlet)	-.44	+.37	.81	-2.40	+1.40	3.80
#2 (Bay)	-.10	+.14	.24	-0.92	+1.20	2.12

TABLE 1 TIDAL CHARACTERISTICS AT BROWN CEDAR CUT, FEET FROM MWL DATUM, FEBRUARY 1 TO APRIL 9, 1971.

VELOCITY DATA - Knowledge of the current velocities through Brown Cedar Cut was important for the determination of the Bay tidal prism, as well as for correlations with the observed patterns of erosion and deposition discussed previously. For the purposes of this study, Manning's equation was considered sufficiently accurate for calculations of the velocity time history:

$$V = \frac{1.486\ R^{2/3} S^{1/2}}{n} \qquad (1)$$

where n = Manning coefficient (0.02), R = hydraulic radius (4.43 ft), S = slope of water surface ($\Delta H/L$), L = inlet length (6000 ft), and ΔH = ocean-bay tidal differential. Thus,

$$V = 2.60\ |\Delta H|^{1/2} \text{ (sign } \Delta H).$$

Applying this relationship to the previously determined tidal differential data, the current velocity time histories were computed. Additional statistics obtained during the analysis are presented in Table 2.

Tidal Current	Velocity, fps			Per Cent of Time		
	V_{max}	V_{avg}	Current Direction	V>1.8fps	V>2.2fps	V>2.6fps
Flood	2.2	1.1	44	1.6	0	0
Ebb	3.5	1.5	56	14.0	7.3	3.0

TABLE II VELOCITY CHARACTERISTICS AT BROWN CEDAR CUT, FEBRUARY 1 TO APRIL 9, 1971.

Considering the large number of assumptions required for the use of Manning's equation, it was considered desirable to compare the theoretical velocities with experimentally determined values. Therefore, a twenty-five hour velocity measurement study was performed on March 4 and 5, 1971.

A Gurley-Price current meter suspended on a rod from a small boat was used to determine velocity vs. depth profiles. These measurements were taken at approximately two hour intervals at the stations indicated in Figure 9. The channel cross-section was obtained using both a graduated rod and an ultrasonic fathometer. The following geometric parameters were established: cross-

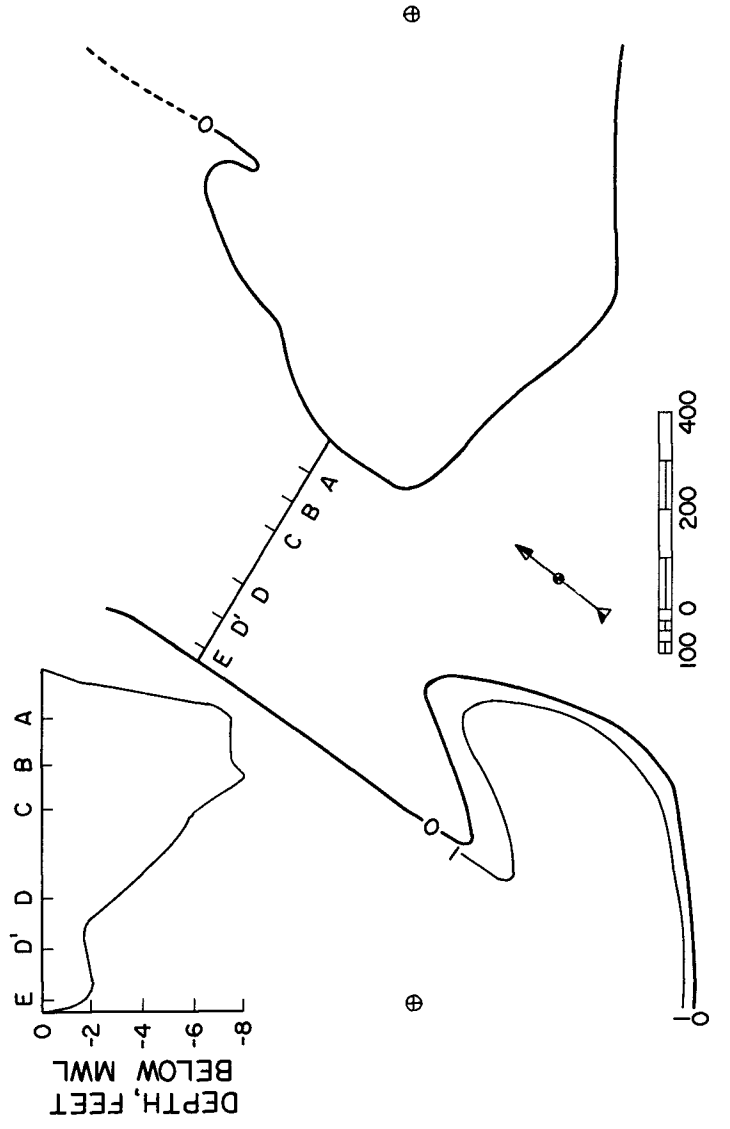

FIGURE 9. LOCATION OF VELOCITY MEASUREMENT STATIONS

sectional area, 2480 square feet; wetted perimeter, 560 feet; hydraulic radius, 4.43 feet.

The measured velocities are plotted against $\sqrt{\Delta H}$ in Figure 10 with a straight line best-fitted to the points. The slope of the line shows almost perfect agreement with Manning's equation. However, for a ΔH of zero, the experimentally determined velocities indicate a value of 0.5 feet per second. The origin of this excessive flood component is unknown. It may result from the transport of water into the inlet by littoral currents or wave action. Breakers on the offshore bar were about four feet in height, and the longshore current velocities were approximately 2 feet per second.

TIDAL PRISM COMPUTATIONS - To evaluate the flushing capability of the inlet, and for comparison with theoretical stability criteria, a determination of the tidal prism of Matagorda Bay was made using two methods. From an analysis of tide gage data, a prism, P_I is obtained from:

$$P_I = A_B h$$

where P = tidal prism, A_B = area of bay (1.5×10^9 ft^2), and h = range of bay tide (0.24 ft). Thus,

$$P_I = 3.6 \times 10^8 \text{ ft}^3.$$

A second method equates the prism to the velocity of water flowing through the inlet:

$$P_{II} = VA_C T$$

where V = average velocity through inlet (1.26 ft/sec), A_C = cross-sectional area of inlet (2480 ft^2), and T = tidal period (89280 seconds). This gives

$$P_{II} = 2.8 \times 10^8 \text{ ft}^3.$$

The first method yields a value 25% higher than that from the velocity method. This is understandable, since the tidal fluctuation is not uniform throughout the bay, decreasing with distance from the inlet. Also, error is introduced by the influx of an unknown amount of water from the Intracoastal Waterway through numerous connecting channels. However, errors in the velocity values may also influence the comparison. Therefore, for purposes of future computation, a representative tidal prism of 3.0×10^8 cubic feet will be assumed.

A comparison with O'Brien's theoretical stability criteria can now be made. In an analysis of the tidal prism, cross-sectional area ratio for a large number of inlets, O'Brien (5) reported the following linear relationsbip was approximated for most non-jettied stable inlets:

$$A_c = 2 \times 10^{-5} P.$$

Based on the representative tidal prism of 3×10^8 cubic feet, and a March 4 cross-sectional area of 2480 square feet:

$$A_c = .83 \times 10^{-5} P.$$

Thus, relatively good agreement is indicated, as Brown Cedar Cut exhibits a tendency for closure.

RECENT STABILITY - Since the final complete topographic survey of April, 1971, the inlet has been monitored on an infrequent basis. However, through the use of aerial photographs and occasional cross-channel profiles, several interesting features have been observed.

Figure 11 indicates that in July, 1971, the west spit continued to elongate toward the north. The gorge closely skirted this spit, but the channel appears to turn sharply southwestward a short distance seaward of the beach face, paralleling the shore for a few hundred feet before turning sea-

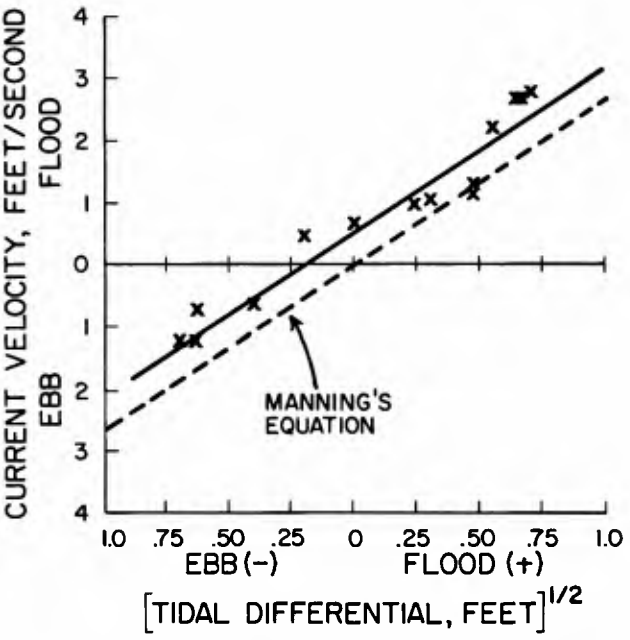

FIGURE 10. OBSERVED CURRENT VELOCITY VS. TIDAL DIFFERENTIAL

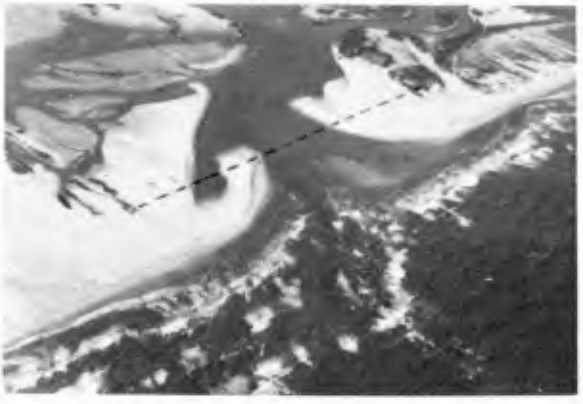

FIGURE 11 --BROWN CEDAR CUT, JULY, 1971

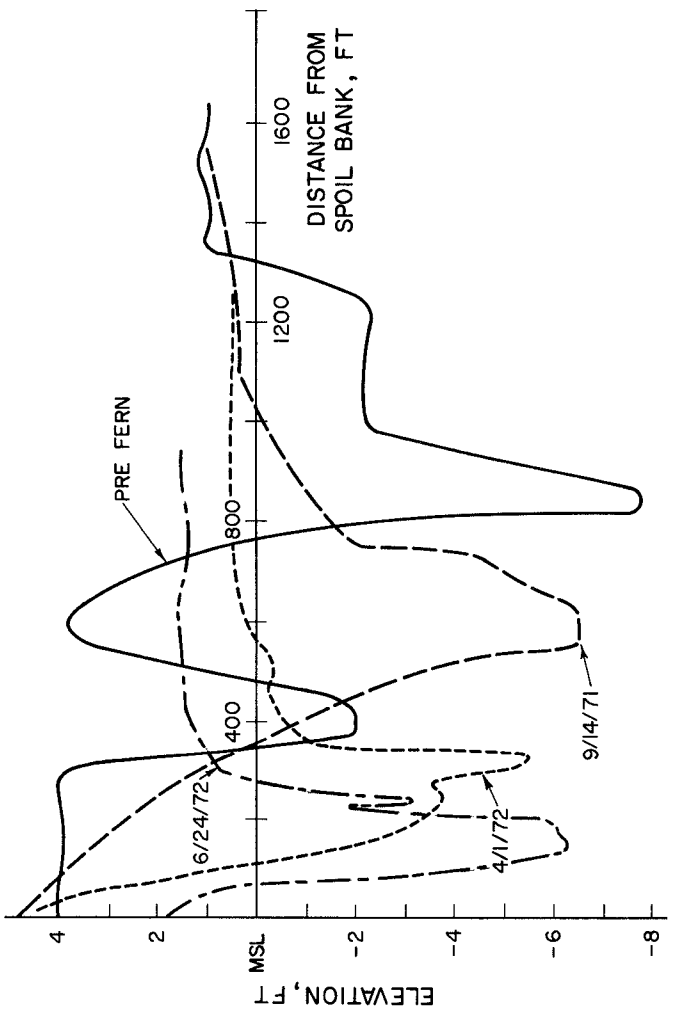

FIGURE 12. PROFILES ACROSS BROWN CEDAR CUT

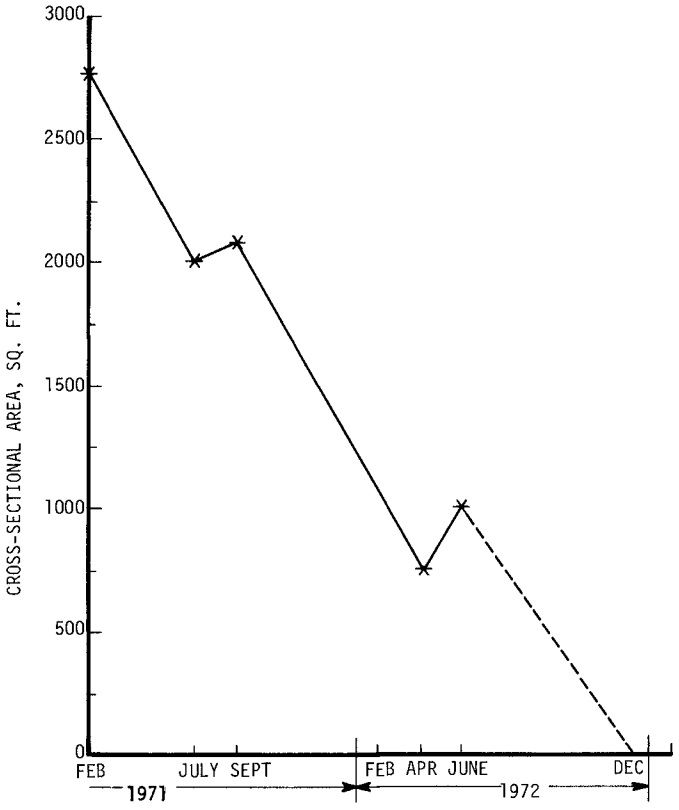

FIGURE 13.--VARIATION OF CROSS-SECTIONAL AREA, 1971-1972

ward. Growth of a major shoal area above the mean low water line is indicated adjacent to the east spit.

In September, 1971, Hurricane Fern crossed the coast within a few miles of the inlet, and provided an unusual opportunity to evaluate the effects of a storm on the inlet. Pre and post hurricane cross-sectional profiles along the line indicated in Figure 11 were compared in Figure 12. Complete eradication of the west spit occurred, and the gorge migrated 250 feet westward, occupying virtually the same position as the former spit. However, the east spit experienced some growth, although the storm increased water levels at the site to about five feet above MWL. Therefore, only a minor increase of 200 square feet in the cross-sectional area of this profile was experienced.

A profile taken in April, 1972, also shown in Figure 12, indicates that the gorge migrated approximately 300 feet westward since September, and the area was reduced from 2100 square feet to 760 square feet.

On June 24, 1972, a final cross-channel profile was obtained. The continuing migration of the gorge, a distance of about 200 feet since April 1, is illustrated in Figure 12. However, since April the cross-sectional area had increased to about 1000 square feet, apparently the result of locally heavy spring rains in the Matagorda Bay watershed.

Using the cross-sectional variation with time as documented from the profiles, it is felt that a rough prediction concerning the possibility of closure of Brown Cedar Cut can be made. Figure 13 illustrates the rather rapid decrease in area since February 1971. With the exception of slight increases resulting from Hurricane Fern and spring rains, the inlet appears to be closing at an average rate of 200 square feet per month. Barring the occurrence of hurricanes or above-average rainfall, and assuming the above rate of closure, the dashed line in Figure 13 indicates that Brown Cedar Cut will close naturally in December, 1972. Periodic surveys of the inlet are to be taken to evaluate the accuracy of this prediction.

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