Reprinted from
Coastal Sediments '77
ASCE/Charleston, South Carolina/November 2-4, 1977

Corpus Christi Water Exchange Pass 1972-1976

by

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INTRODUCTION

The Corpus Christi Water Exchange Pass extending from Corpus Christi Bay to the Gulf of Mexico through Mustang Island, Texas was opened in August 1972. Its channel was approximately 3 km long by 30 m wide by 2.4 m deep. The ocean end was jettied for a length of about 400 m and was dredged 50 m wide and 3.5 m deep. The jetties extended across approximately 2/3 the width of the bar-trough system which is quite dynamic but usually has three well developed offshore bars. A 23° bend was located about one km from the ocean end of the channel, and a highway bridge constricts the channel just seaward of the bend. A more complete description is given by Behrens et al. (1977).

Tides are mixed, diurnal, and semidiurnal and vary from 0.2 to 0.9 m in range. Breakers average 0.8 m in height and 6 to 7 seconds in period. Alongshore transport rates average 555 x 10^3 m^3 gross and 48 x 10^3 m^3 net (southwestward) yearly. The strongly bimodal character derives from a bimodal wave generating wind system with onshore south-southeasterly trade winds predominating from March to September and strong northeasterly to northwesterly winds (northers) associated with cold fronts occurring from September through March.

This inlet was monitored to some degree for four years from pre-opening to August 1976. Monitoring observations included LEO wave observations (Bruno and Hiipakka, 1973), tide level recording, current velocity measurements, and surveys of beach profiles, offshore bathymetry and 18 to 22 channel cross sections. Most of the data from these observations are presented in Watson and Behrens (1976) and Behrens et al. (1977).

OBSERVED SEDIMENTARY RESPONSES

Ocean Beach

The jetties began acting as groins almost as soon as construction began. By one year after opening, 85,000 m^3 had accumulated on the upright side and 29,000 m^3 on the downdrift side with some unknown amount of erosion indicated beyond one km downdrift. After the first year a considerably different pattern developed. First, it became apparent that effects extended beyond the 1.2 km distance from each jetty that was originally surveyed, but they probably did not extend beyond 2.5 km

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in each direction. Second, the updrift side (beyond about 300 m) lost about 150,000 m^3 while the downdrift side gained 76,000 m^3. Actually there was almost no net drift (4% of a gross of 510,000 m^3) during this period. During the last period of beach monitoring (summer 1974 - spring 1975) there was a further small gain downdrift (20,000 m^3) and a return of about 1/3 of the previous year's loss (57,000 m^3) on the updrift side. Calculated net alongshore transport for this period was equal to the updrift gain.

The resultant effect for the entire period was an accumulation of about 50,000 m^3 updrift of the jetties and 125,000 m^3 downdrift. Much of this took place before the channel was opened while the jetties were acting as simple groins. Since effective tidal currents operated through the channel, there has been net loss updrift and accumulation of well over 100,000 m^3 downdrift.

Ocean Mouth

The outermost (third) bar of the bar-trough system migrated outward but was usually continuous around the mouth of the jetties. The second bar moved out to about the position of the end of the jetties but was usually separated from them by a trough which carried the alongshore current from the inner surf zone out around the jetties. At times when the alongshore currents were strongest, this trough developed into a scour hole at the seaward end of the updrift jetty. Depths at this point were generally about 2 m, but scour holes up to almost 6 m were observed. Volumetric changes alternated between erosion and deposition in this zone. Changes of up to 25,000 m^3 were observed, but they were generally less than 10,000 m^3.

Bay Mouth

The 2.4 m deep channel originally extended across about 300 m of 0.3 to 0.6 m deep sand flats before entering the deeper water of Corpus Christi Bay. A simple, single lobed, flood tidal delta of about 50,000 m^3 developed within 9 months of the pass opening. The delta decreased controlling depths to less than one meter by that time. The second year the delta's morphology matured somewhat with the development of lateral channels, a wider mouth, and wave recurving of the distal lip of the central chute or ramp. Increased erosion at the immediate mouth of the channel reduced the volume of the delta by over 20% during its third year in spite of continued shoaling which decreased the controlling depth to about 0.5 m during the pass' third year.

Channel

The first response of the channel took place while dredging was still proceeding. At the time of first break-through, a very small mouth fed a large channel, and for the first month while the dredge finished clearing out the jettied section the channel accumulated about 23,000 m^3 of fill. Immediately after this the opposite situation of an oversized mouth feeding a smaller channel existed; and erosion increased the overall channel volume to its original size by the end of the first year of the inlet's history. This was accomplished chiefly in the bayward 2/3 of the channel while the seaward 1/3 equilibrated by accumulating an approximately equal volume.

Erosion of all but the jettied section of the channel continued halfway through the second year to mid-winter 1974 when the channel was about 16,000 m^3 larger than its original volume. After March 1974 deposition predominated throughout most of the channel and continued to do so through 1976. Over 90,000 m^3 accumulated during this period which reduced the channel to about 75% of its original volume. Deposition predominated in the seaward 30% of the channel which was reduced to about 1/2 its original volume.

Significant asymmetry in channel morphology occurred in the seaward 1/3 of the inlet. The original bend quickly became a meander which eroded its outer bank and migrated at a rate of about 9 cm/day. This caused several difficulties such as flanking the highway bridge and exposing a gas pipeline; so the section was filled to its original position and bulkheaded with aluminum sheet for about 370 m toward the end of the second year (June - July 1974). The section remained relatively stable for about 2 years and then joined the general shoaling tendency of the rest of the channel during the summer of 1976.

Seaward of the bend a narrow thalweg 1.2 to 1.8 m deep formed adjacent to the updrift (northeastern) jetty within a few months of opening and eventually extended bayward to the highway bridge over the next several years. This was accompanied by shoaling to intertidal depths adjacent to the downdrift (southwestern) jetty. This shoal seemingly extended bayward especially after bulkheading of the bend. However only small net volume changes took place until spring of the fourth year.

OBSERVED TIDAL HYDRAULICS

Tides were recorded almost continuously during the third year of pass operation and diurnal discharge measurements were made during the first and third years. Discharges varied greatly with tide type from about 1×10^6 m^3 during semidiurnal tides which occurred at lunar equatorial positions to 5×10^6 m^3 during diurnal tides which occurred at maximum lunar declinations. Diurnal tides always had greater ranges but could occur anywhere from syzygy to quadrature, so use of spring and neap to designate maximum and minimum tidal ranges or discharges is inappropriate in this case. Discharge measurements were made randomly with respect to lunar declination so no exact comparison can be made between study periods. However, the mean total diurnal discharge decreased from 3.7 to 2.2×10^6 m^3 from the first to the third year of operation (with 8 and 12 observations respectively).

Another indication of the decrease in tidal currents from the first to the third years is the decrease in maximum current velocity from 2.5 to 1.25 ft/sec. Mean velocities calculated from friction coefficients determined during the discharge studies, surveyed channel geometry, and long term tide gage data using the Manning equation were about 30 cm/sec (1 ft/sec) throughout the third year except during winter northers when mean ebb tide velocities approached 60 cm/sec.

The friction coefficient (Manning's n) increased the first year from 0.019 to 0.030 as larger bedforms developed in the channel. During the third year it remained within this range increasing somewhat from summer to late fall (0.024 to 0.029) and decreasing then to spring (0.029 to 0.021). Seaward of the bend the value was always higher (0.029 to 0.044) than bayward of it.

The most striking characteristic of tidal flow during both study periods and apparent in discharges calculated from tidal records as well as measured directly was the general predominance of flood over ebb currents in velocity, duration, and volume. The ratio of directly measured flood to ebb discharges was 1.63 the first year and 1.62 the third year; and the ratio calculated from tide recordings of the third year was about 2:1. This situation seemingly prevailed except during northers when ebb discharge has been observed to exceed flood by almost 8:1.

DISCUSSION

Tidal Asymmetry

The most unexpected and perhaps most significant characteristic of the Corpus Christi Water Exchange Pass was its large tidal asymmetry, i.e., the large excess of flood over ebb tides. This can be explained quite readily in terms of wind set-up and bay hydrography. The predominant onshore winds enhance flood tides by causing set-up on the ocean side of the pass and set-down on the bay side. Set-up on the opposite side of the bay can be drained off by two artificial channels (the Corpus Christi Ship Channel and the Intracoastal Waterway) and one natural channel (Corpus Christi Bayou connecting Corpus Christi Bay with Aransas Bay to the northeast). Thus the water level differential across the barrier island at the site of the inlet could be maintained indefinitely.

This effect could be postulated to extend through the Texas intracoastal estuarine system to the 'end of the line' which is Matagorda Bay (no northeastern outlet). It is interesting to note that Matagorda Bay has the largest natural inlet (Pass Cavallo) of the interconnected bay system.

Ocean Beaches

The winds producing the flood tide dominance also cause northeastward longshore transport which is the net updrift direction. On the other hand, the absence of this effect usually correlates with winds that have a northerly component and produce the slightly predominant southwesterly longshore transport. These correlations probably account for the effect of the jetties on the ocean beaches other than the simple groin effects, i.e., the large accumulation in the downdrift rather than the updrift direction. This would occur because winds causing northeastward longshore transport would cause much of the material so transported to be lost into the pass in the excess flood currents caused by the same wind system. On the other hand, southwestward moving drift would encounter equal or ebb dominated currents at the pass mouth and be bypassed around it. Thus the updrift side would be starved relative to the downdrift side. It is suggested that this is at least contributory if not a major cause of downdrift offset at tidal inlets.

Short Term Effects

Although each survey period had a unique combination of winds, tides, and wave conditions, close examination of erosion and deposition within the tidal channel showed that sedimentation is greatly enhanced by surf conditions with waves one meter or higher and by decreasing tidal ranges. High ocean surf increases the supply of suspended material (wash load) at the channel mouth; and tidal currents capable of moving a bed load will erode when waves are so low as to provide no sediment supply. During waning tidal ranges (from maximum lunar declinations to equatorial positions) less sediment is moved with each succeeding cycle, thus more remains behind (i.e., is deposited). Conversely, during waxing ranges each succeeding discharge is greater, can carry more sediment, and thus erodes.

The magnitude of fornightly waxing and wanning of tidal ranges is usually much greater than longer term variations (60 cm vs. 30 cm or less respectively). Thus short term sedimentary effects may obscure longterm effects by the "noise" they cause in bathymetric observations. This was demonstrated by one set of 4 weekly channel cross section surveys made in November 1974. Between one pair of weekly surveys total channel volume varied by 28,000 m^3. This much change occurred only one other time between monthly or longer interval surveys in four years of monitoring. The large volume was deposited when high ocean surf conditions occurred as tides were diminishing to a neap, semidiurnal phase (near coincidence of quadrature and equatorial lunar positions). Scheduling channel surveys at the same stage in the lunar cycle, thereafter, reduced considerably the scatter in plots of parameters such as mean channel cross sectional area.

Stability

Channel volumes and cross sectional areas trend downward so consistently from 1974 through 1976 that there can be little doubt that the inlet is unstable and will eventually close. A prediction for this time is July 1980. The basis of this prediction involves an Escoffier diagram analysis (O'Brien and Dean, 1972). Although this type of analysis was developed for a single inlet system, application of it to the Corpus Christi Water Exchange Pass shows that the channel responds to short term stresses (sediment loads) much as the analysis predicts.

The analysis involves calculating maximum velocities for cross sectional areas of various channel lengths. Where maximum velocities peak, the corresponding cross sectional area is as small as the channel can get (for the specified length) without causing increased friction to decelerate the flow and allow sedimentation to quickly close the inlet.

While the whole channel's mean cross section has steadily decreased from about 110 m^2 to 80 m^2, the Escoffier diagram analysis indicates that reduction would have to be well below 30 m^2 to force closure. This has occurred (minimum area of 26 m^2) for small portions of the channel; but analysis shows that for such lengths, critical cross sectional areas are more like 15 m^2. The fact that the inlet remains open and such small cross sections do not remain for long periods of time (one month or longer) shows that the inlet remains stable to these short term stresses as the Escoffier diagram analysis predicts.

The closing time prediction was made by calculating the regression line between time and mean cross sectional area, translating this line to the minimum cross sectional area by subtracting the mean difference between minimum and mean areas from the Y intercept term of the regression equation, and projecting that line to a critical cross sectional area for a length of channel that is typically narrowed to a minimum throat section. Additionally, short term fluctuations were taken into account by further translating the line by two standard deviations of the minimum cross sectional area below its regression line.

The closing tendency of the inlet agrees with several stability indices that have been used. For example:

Parameter	Stable Value	Observed Value	Dimensions
cross sectional area calculated from tidal prism (Jarrett, 1976)	1300- 2300	850- 1200	ft^2
maximum discharge/ gross littoral drift (Bruun & Gerritsen, 1960)	>0.01	$1.3x10^{-4}$	
spring tidal prism/ 2(annual littoral drift) (Bruun & Gerritsen, 1960)	>100	1 - 2	
bottom shear stress (Bruun & Gerritsen, 1960)	>0.09	0.075	lbs/ft^2

A remaining question is what caused the depositional trend to become established only after 1½ years of the pass' existence (at the beginning of 1974)? Of the many environmental parameters examined only annual rainfall made a similar large change at the same time that the channel seemed to change from an erosional to a depositional mode. The period 1967 - 1973 was the wettest in the recorded history of south Texas. Rainfall averaged close to 100 cm annually whereas the average is only 64 cm. Furthermore, 1973 was the wettest of the 7 years in this unique period. On the other hand, 1974 had only the average amount of rainfall and was actually near the dry side of the normal mode. Although no measure is available to indicate the quantitative role of runoff in the tidal dynamics of this inlet, the higher volume of runoff would obviously enhance ebb rather than flood tides and may have done so enough to weaken the flood tidal dominance and its role in supplying littoral drift for channel filling.

CONCLUSIONS

The case history of the Corpus Christi Water Exchange Pass demonstrates that several empirical indicators of inlet stability would validly predict the closing tendency observed. However, the rate of closure is slow, and the Pass has remained in operation for four years and is projected to stay open for eight years with almost no maintenance expenditure. The resilience of the Pass to short term sediment loads is predicted by Escoffier diagram analysis in spite of the fact that the Pass is not the only inlet to the bay it serves as assumed in the derivation of the analysis technique.

Wind set-up and bay hydrography lead to an unusually large tidal asymmetry wherein flood tides exceeded ebb tides by as much as 2:1 over long periods. This, in turn, lead to greater accumulation downdrift than updrift of the jettied pass entrance and may be similar to the process which produces downdrift offsets of natural inlet entrances.

ACKNOWLEDGEMENTS

The studies which provided data for this paper were done under research contracts DACW72-72-C-0027 and DACW72-74-C-0017 from the U. S. Army Corps of Engineers Coastal Engineering Research Center and IAC (74-75)-0536, IAC(74-75)-1442, and IAC(76-77)-0702 from the Texas Parks and Wildlife Department. Many very helpful contributions to the study were made by Curtis Mason, the CERC contracts technical monitor. Essential assistance throughout many phases of the work was provided by P. D. Carangelo, H. S. Finkelstein, and W. H. Sohl.

University of Texas Marine Science Institute Contribution 213, Galveston Geophysics Laboratory.

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