Part 4
DESIGN OF COASTAL WORKS

Chapter 23

DESIGN AND PERFORMANCE OF SEA WALLS IN MISSISSIPPI SOUND

Francis F. Escoffier, Engineer,
Mobile District, Corps of Engineers,
Department of the Army, Mobile, Alabama

The purpose of this paper is to describe briefly the various types of sea walls that have been constructed on Mississippi Sound, the performance of each type, and the conclusions with regard to sea wall design that can be drawn from this information.

DESCRIPTION

Mississippi Sound is a long narrow body of water that extends east and west a distance of about 75 miles along the coasts of Mississippi and Alabama. It is separated from the Gulf of Mexico by a series of barrier islands that lie about 10 miles offshore. See Figure 1. The water depths increase progressively from the mainland to the islands where they reach extreme values of 15 to 20 feet.

Tides in the sound are chiefly diurnal, having one high and one low in a 24-hour period. The mean tidal range is about 1.4 feet.

The mainland north of the sound is low and much of it is subject to inundation by storm tides. The natural shores are made of loose and highly erodible sand except in low marshy places where a black peat or muck is usually found. The offshore slope is very flat, the 6-foot depth contour generally lying more than a half-mile from the shore.

The coast is highly developed as a summer resort area and many hotels, summer homes, tourist cottages, and bath houses have been built. U. S. Highway 90, the principal coastal artery, runs along most of the shore.

HURRICANES

Unfortunately the sound lies in the path of tropical hurricanes and is subject to high storm tides and severe wave attack. These hurricanes have not only been destructive to beaches, bath houses, and sea walls, but have at times raised storm tides which inundated much of the land and carried the destructive action of the waves far inland.

The formation of high storm tides is favored by the shallowness of the water and by the progressively diminishing depths of water met by the wind-driven currents as they move inshore through both the Gulf of Mexico and the sound. When the generating wind blows from the southeast quadrant, the converging shoreline formed by the mainland and the delta of the Mississippi River acts to confine the wind-driven water and thus to further augment the height of the storm tide.

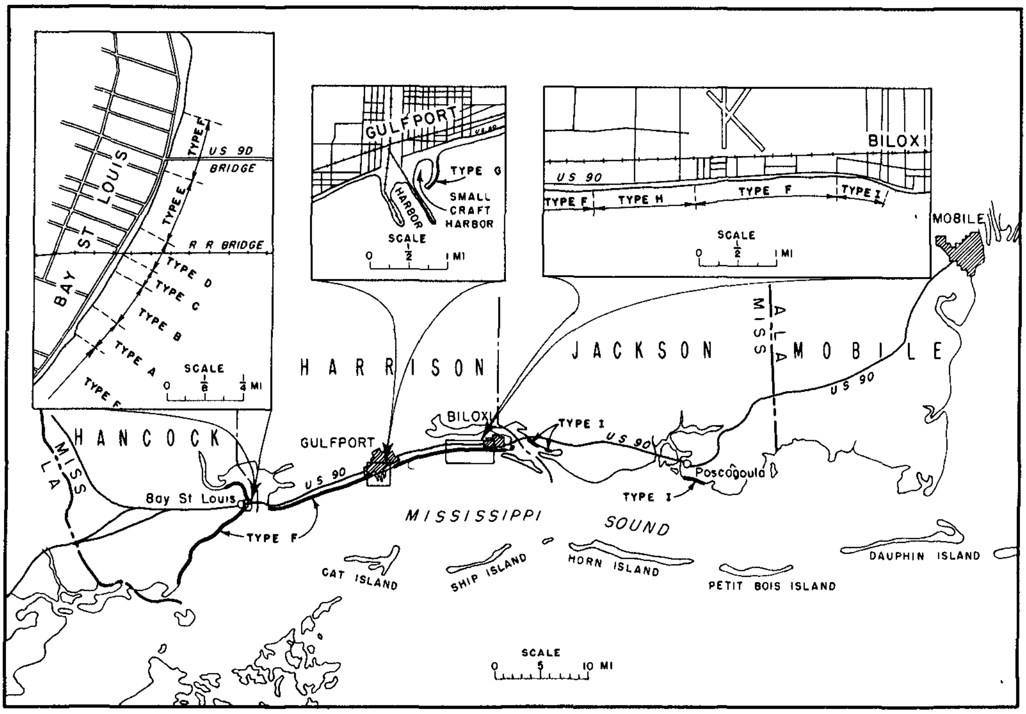

Fig. 1. The sea walls of Mississippi Sound.

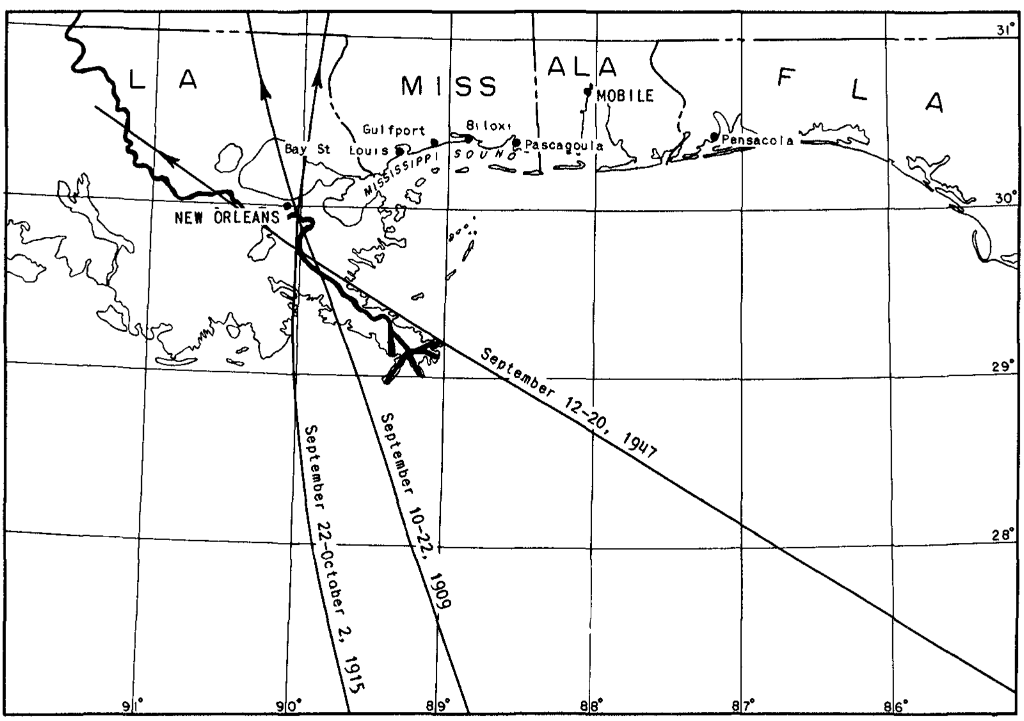

Fig. 2. Tracks for the hurricanes of 1909, 1915, and 1947.

Figure 2 shows the paths followed by the three most destructive hurricanes that have occurred since 1900 on the coast under consideration. These are the hurricanes of 1909, 1915, and 1947.

It should be noted that the centers of these hurricanes all moved inland a short distance west of Mississippi Sound. Their extreme destructiveness on the north shore of the sound is due to this fact. Cline (1926) has shown that the strongest winds occur in the right rear quadrant of a hurricane and that the paths followed by the wind in that quadrant are not curved as one might expect in view of the counterclockwise circulation of a cyclone but have a fairly uniform direction which is roughly the same as the direction of advance of the center. Because of this uniformity in direction of the wind in the right rear quadrant the effective fetch is large. The length of the fetch and the unusual strength of the wind in that quadrant favor the generation of high storm tides and heavy wave action which affect primarily the coast to the right of the line of advance of the hurricane.

The hurricanes of 1909, 1915, and 1947 are said to have caused almost complete destruction of buildings in the unundated areas subject to wave action. It was largely the severe destruction caused by the hurricane of 1915 that awoke the people living along the coast to the need for protecting their shores. This was one of the most intense hurricanes in the history of the Gulf Coast. A storm tide of 9.6 feet was experienced at Gulfport and of 11.8 feet at Bay Saint Louis.

Following the 1915 hurricane the coast enjoyed a remarkable period of 32 years during which only minor hurricanes were experienced. This period was brought to a close by the extremely destructive hurricane of September 1947. Velocities in the right rear quadrant of this hurricane reached 100 mph and more. The direction of the wind as this quadrant lay over Mississippi Sound was roughly from east to west. The result was the creation of a storm tide that increased in height progressively from east to west. The following maximum storm tides occurred:

Location	Elevation, m.s.l.
Pascagoula, Miss.	7.68
Biloxi, Miss.	11.12
Gulfport, Miss.	14.03
Bay Saint Louis, Miss.	15.22

The sea walls were completely overtopped and numerous boats, including some of considerable size, were driven over the sea walls and some distance across the land. The waves passed over the sea walls to create havoc with buildings of all kinds landward of the walls. During the early part of the hurricane before the tide had reached the top of the sea walls and while it was still possible for an observer to remain near the walls it was observed in Harrison County that the angle of incidence of the approaching waves was roughly 45°. The same observers were unable to estimate the height of the waves at that time. One observer between Bay Saint Louis and Gulfport who was able to see the waves from a second-story window of his home estimated that the height of the waves at the maximum tide was roughly 6 feet. From the storm tides, the wind velocities, and other known factors, A. H. Glenn (1951) has estimated the maximum breaker height at Bay Saint Louis to be about 8 feet.

THE SEA WALLS

The City of Bay Saint Louis, in Hancock County, between the years 1915 and 1920 constructed 5500 feet of sea wall along the shore adjacent to the city's main business district. The County of Hancock added 10 miles of sea wall during the period 1926 to 1928. Harrison County constructed 26 miles of sea walls during the period of 1925 to 1928. Jackson County completed about 3.5 miles of sea walls in 1929. In all there are now about 41 miles of sea walls along the north shore of Mississippi Sound.

The upright sea walls, types A, B, C, D, and E, shown in Figures 3 through 7, are of early construction. The overall length of these walls is 3050 feet.

The type A wall shown in Figure 3 was originally of brick masonry construction. The concrete face and the buttresses were added several years after the original construction. It is understood that the wall is equipped with tie backs but the position and type of construction of the tie backs are not known. During a minor hurricane in 1940 this wall tilted seaward and some backfill was lost. The wall was repaired and survived the 1947 hurricane with little or no damage.

The type B sea wall is shown in Figure 4. The depth to which this structure extends is not known. Neither is it known whether it is provided with tie backs. This wall survived the 1947 hurricane with little or no damage.

It is probable that the type D wall, shown in Figure 6, was originally a continuation of the type C wall which is shown in Figure 5. If this is correct, then the buttresses are later additions made to strengthen the wall. Along part of this wall some backfill has been lost and the wall has tilted landward. Where this has occurred severe cracking has taken place at the junction of the buttresses and the horizontal beam near the top of the wall. Along much of the type C wall the tie backs have failed and the wall has tilted seaward. Some backfill has been lost. It is apparent that corrosion of the tie backs has been a factor in causing this damage.

Much of the type E sea wall, shown in Figure 7, has failed by falling seaward. The concrete anchor piles were broken apparently because the backfill had been washed away from around them and the piles were not capable of functioning as cantilevers. The wall itself failed by breaking at the juncture of the wall and the footing.

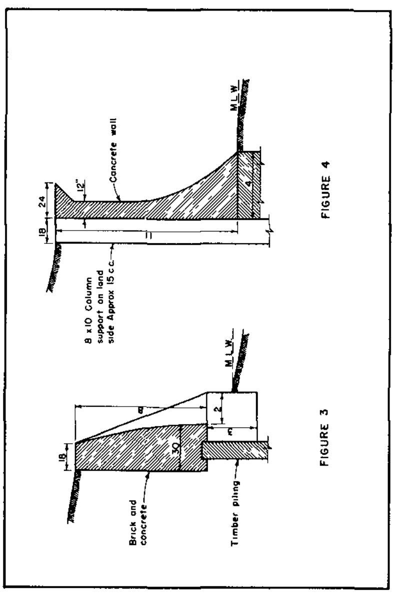

Fig. 3. Type A sea wall.
Fig. 4. Type B sea wall.

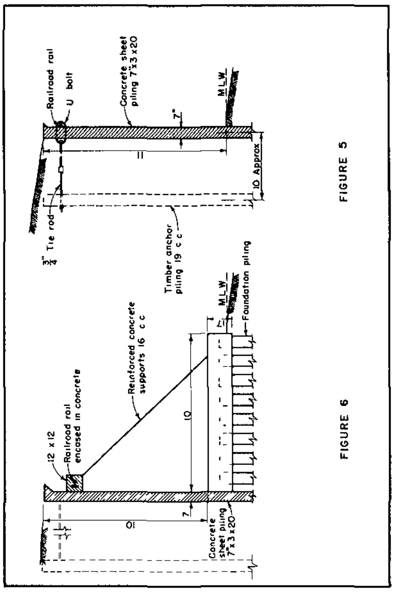

Fig. 5. Type C sea wall.
Fig. 6. Type D sea wall.

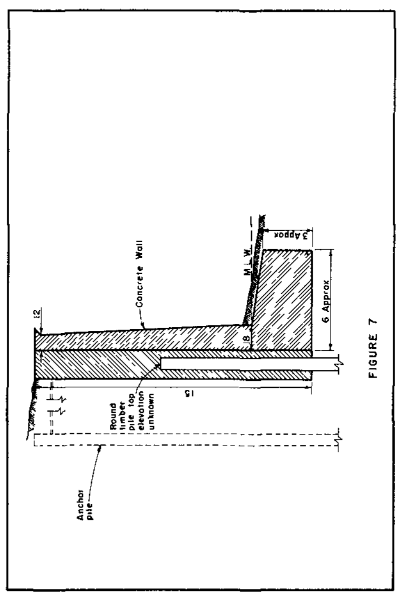

Fig. 7. Type E sea wall.

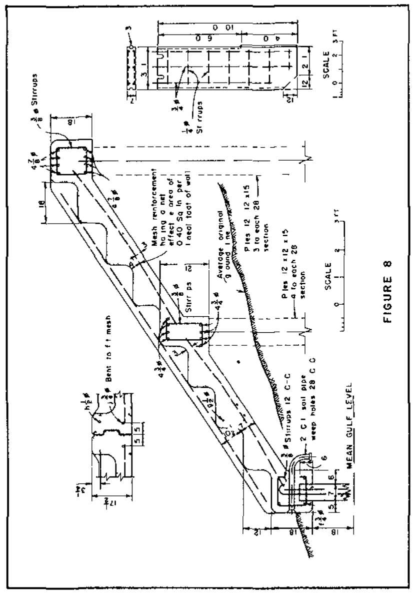

Fig. 8. Type F sea wall.

The type F or stepped sea wall shown in Figure 8 represents the predominant type of construction on the coast. There are about 10.7 miles of this type of wall in Hancock County and 24.0 miles in Harrison County. The number of steps varies from 3 to 10. When the number of steps is less than nine the middle row of pilings is omitted. The reinforcement shown in these sections is that used in the Harrison County walls which were designed by H. D. Shaw of Gulfport, Mississippi. The stepped walls in Hancock County are similar in design although timber piling has been substituted in some cases for the concrete piling.

Cracks appeared in many of the stepped slabs soon after they were completed. In the Harrison County walls a crack appeared at the intersection of the bottom step and the riser of the second step. A transverse crack from top to bottom also appeared at the center of many of the slabs. In some of the stepped slabs in Hancock County a crack appeared along the line of support of the middle row of piles.

To explain these cracks it should be considered that the joints between the stepped slab and its supporting piles are rigid or nearly so. The maximum bending moments produced by differential settlement or other causes therefore occur in the vicinity of these joints. Some cracks were of sufficient size to permit sea water to reach the reinforcement. The result at many points was rust bleeding, expansion of the reinforcing steel by corrosion, and further cracking and breaking of the concrete.

The stepped sea walls also suffer from the defect of not being sand tight. The storm sewers that pass through the sea walls were placed directly on sand. Through differential settlement or otherwise the joints in the sewer pipes failed and permitted the escape of backfill. The concrete sheet-piling cut-off wall also permitted the escape of sand. The sheet piles used in the cut-off wall were provided with tongue and groove joints only for the lower parts. See Figure 8. Above that, two grooves were provided, the theory being that the cavity formed by two adjacent grooves would be filled with grout and thus rendered sand tight. During construction it was found that the cavities filled with sand and could not effectively be grouted; consequently the cut-off wall could not be made sand tight. The loss of backfill caused the further deterioration of the storm sewers and the collapse of the sidewalks adjacent to the sea wall.

During the 1947 hurricane the stepped sea walls failed in a number of places. Available evidence indicates that in most cases the slabs moved seaward when they failed. What probably happened is that the alternating downward and upward forces exerted by the peaks and troughs of the waves as they reached the wall produced continually reversing stresses in the wall which caused the concrete in the vicinity of the supporting piles to crack and crumble until finally the joints failed entirely. The slab was then lifted from its supports and moved seaward. As a general rule the sheet piling cut-off wall tilted seaward but the bearing piles broke away from the slab without tilting.

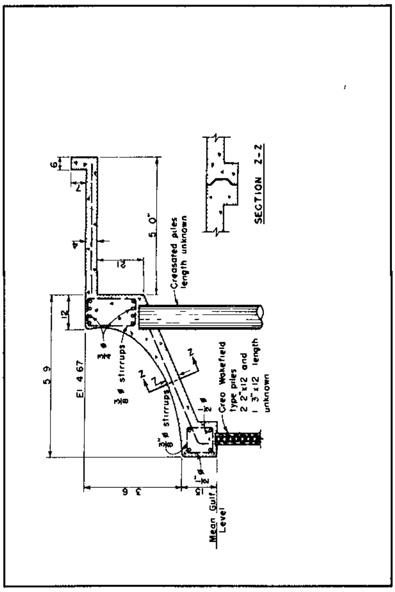

Fig. 10.

Fig. 9. Type G sea wall.
Fig. 10. Type H sea wall.
Fig. 11. Type I sea wall.

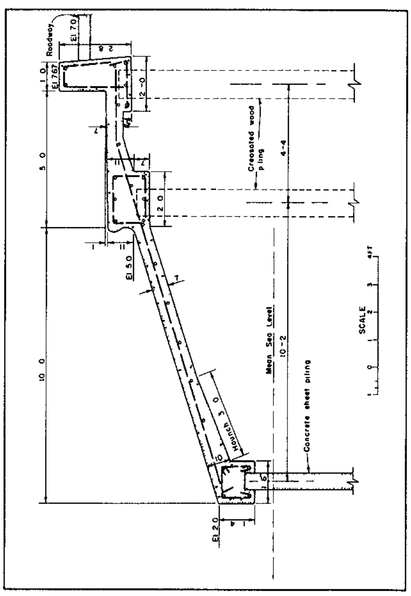

Fig. 9.

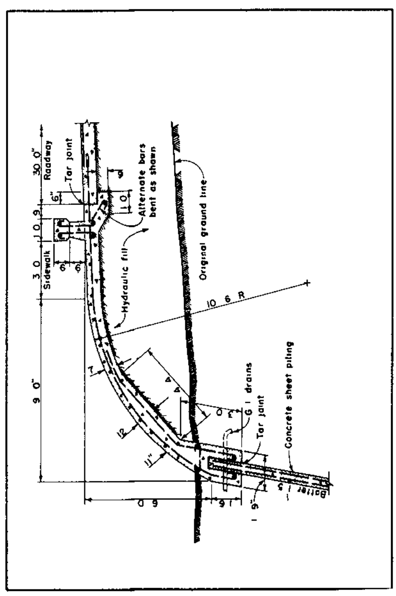

Fig. 11.

In connection with the stepped sea walls it should be stated that the number of sections of the wall that failed constitutes but a small percentage of the total number along the coast. In Hancock County about 1.8 percent of the stepped walls was lost and in Harrison County about 0.4 percent.

There are about 2,500 feet of the type-G sea wall shown in Figure 9 on the east and south sides of the causeway at the Gulfport small-craft harbor. Several sections of this sea wall were lost during the hurricane. These sections were lifted from their supporting piles by hydrostatic uplift and moved seaward. The concrete slab broke at the point where it meets the cap on top of the sheet-piling wall.

There are about 1.3 miles of the type H concave sea wall shown in Figure 10 at Biloxi in Harrison County. Several sections of this wall were lifted from its supporting piles by hydrostatic pressure and moved seaward during the hurricane.

The type I sea wall, shown in Figure 11, has a convex face instead of the usual concave face. There is about 0.65 mile of this wall at Biloxi in Harrison County, 1.6 miles at Ocean Springs, and 2.0 miles at Pascagoula, both of which are in Jackson County. This wall depends on backfill for all of its support except that provided at the toe by the sheet-piling cut-off wall. It suffers from the defect that it facilitates rather than hinders the movement of waves over the wall and onto the adjacent roadway. This wall has lost little or no backfill and there is no evidence of settlement in either the wall or the adjacent roadway. It weathered the 1947 hurricane with practically no damage. It should be mentioned, however, that all three of the locations where this wall is found are in relatively sheltered positions where the wave action during the 1947 hurricane was not as severe as it was elsewhere in the sound.

DISCUSSION AND CONCLUSIONS

It should be realized that much of the natural ground that lies landward of the sea walls on Mississippi Sound is below the level of the more extreme storm tides that have occurred in the sound. For that reason damage due to inundation is inevitable or at least cannot be prevented by means of sea walls. However, sea walls of suitable height can serve the purpose of intercepting the waves and thus protecting the property behind the walls from the destructive action of the waves.

The determination of the height of a sea wall on a coast subject to high storm tides is largely a matter of economics. It may not be possible to justify a sea wall of sufficient height to prevent overtopping of the wall at all times. The probable frequency of occurrence of storm tides and waves severe enough to pass over the wall and cause damage to the property landward of the wall must be considered. As formulas presently available for estimating wind tides and wave heights in shallow bodies of water are somewhat unreliable, use should be made of past records insofar as possible. In this connection it may be stated that comprehensive studies of wind tides and waves on Lake Okechobee in Florida are now being made by the Corps of Engineers and more reliable formulas should become available in the future.

In evaluating the effectiveness of a sea wall against an assumed combination of storm tide and wave height it may be assumed roughly that, if the top of the wall is at a level equal to or greater than the storm tide plus the wave height, little wave damage will occur to property landward of the sea wall. It is assumed of course that adequate protection has been provided for the backfill which may otherwise be seriously damaged by spray thrown over the wall.

Much of the damage that has occurred to sea walls on Mississippi Sound and elsewhere has been due to the loss of backfill. Backfill may be lost through defective joints or drains. It may also be lost if the wall is overtopped or if it is flanked at either end.

To prevent the loss of backfill extreme care should be taken to obtain tight joints between the sheet piles and elsewhere in the sea wall. If there is any doubt as to the sand tightness of the joints, graded filters should be provided behind them. Graded filters should also be provided behind all drains and weep holes. Where reinforced-concrete sheet piling is used for a cut-off wall the tongue-and-groove joint should extend the full length of the pile.

If it is impracticable or uneconomical to construct a sea wall completely free from overtopping, the fill should be protected with a pavement. If only overtopping by spray is anticipated a water-tight pavement of concrete or asphalt with a well-anchored watertight joint at the wall will be satisfactory. Recurving the face of the sea wall seaward at the top to direct the spray toward the sea will also be helpful. If, however, the wall is designed to permit overtopping by storm tide and waves then a water-tight pavement will not be satisfactory because it will be subject to the destructive action of hydrostatic uplift as the trough of a wave passes over it. It is unlikely that weep holes with graded filters can be provided with sufficient capacity to relieve this uplift. A more reliable solution would be to provide a riprap pavement placed on a gravel blanket.

If the end of a sea wall does not abut another sea wall or similar structure, a wing wall should be provided to prevent flanking. A vertical bulkhead will ordinarily serve for this purpose. The wing wall should extend inshore a distance greater than the maximum recession likely to occur on the adjacent unprotected shore. The wing wall should be backfilled on both sides and the fill, together with part of the surrounding ground, should be covered with a riprap pavement lying on a gravel blanket.

If the sea wall is long there is some advantage in dividing it into separate compartments by means of transverse diaphragms. In this way the loss of backfill will be localized if a break occurs in the sea wall. In view of the frequency with which backfill from behind sea walls has been lost in the past and in view of the difficulty in designing a sea wall entirely secure against such loss, it is desirable to design sea walls to be as nearly safe structurally as possible without the backfill. This is particularly important in the case of a sloping or stepped sea wall supported by bearing piles, as a slight settlement of the fill is inevitable and no pressure between the slab and the fill can be relied upon to support the wall. Where tie-back anchors are used, the anchors should be piles driven to ample penetration and the tie-backs should be capable of functioning in compression as well as in tension.

It is desirable to maintain a beach of adequate height in front of a sea wall. In addition to having both a recreational and an aesthetic value such a beach adds to the stability of the sea wall by increasing the soil pressure against the toe and the cut-off wall. It retards or prevents the escape of backfill if the wall is not sand tight and provides protection against wave attack by forcing the waves to break before they reach the wall. However, in the case of a storm tide that raises the water level above the beach, this protection is partly lost.

With a view to obtaining such a beach, sand is now being pumped in front of the sea walls in Harrison County by means of hydraulic dredges. This is being done as part of a cooperative project between the County of Harrison and the Corps of Engineers. It is hoped that information obtained from this operation will be helpful in planning similar projects elsewhere.

The action of waves on the sea walls of Mississippi Sound has not been observed during the fury of a severe hurricane. Nor is it likely that the mere visual observation of such wave action would throw a great deal of light on the complex phenomena involved in the reflection or breaking of waves against the many varieties of sea walls on this coast. These phenomena together with the pressures that they create against the sea walls are therefore beyond the scope of the present paper. They are appropriate subjects for investigation in model laboratories.

The importance of hydrostatic forces behind a sea wall should be emphasized. Available evidence indicates that these forces have been the dominant factor in causing sea-wall failures on Mississippi Sound. The need for providing tie-backs and anchor piles behind vertical walls capable of functioning after the backfill has been lost has already been mentioned. In the case of stepped, sloping, or curved walls resting on bearing piles the slabs should be securely fastened to the supporting piles to resist the uplift due to the hydrostatic forces under the slabs. Since these slabs are subject to alternating downward and upward forces as the peaks and troughs of the waves reach the wall, they should be reinforced to withstand the resulting bending moments. To resist the alternating horizontal thrust against the wall the bearing piles should be of sufficient strength and penetration to function as cantilevers after the fill has been lost.

To prevent the corrosive action of the sea water on the reinforcing steel, the concrete should have the lowest porosity attainable and should cover the steel by not less than three inches. At this point the author would like to suggest that there may here be a fertile field for the use of prestressing as a means of keeping the outer face of the sea wall under compression and thus preventing the passage of sea water through haircracks to the reinforcing steel.

ACKNOWLEDGMENT

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