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Report on Jetties

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LIST OF ILLUSTRATIONS

A complete set of plates has not been prepared for illustration of this preliminary report. With a few exceptions the charts and drawings to which reference is made are available in the files of the division and district offices which have been requested to comment on specific structures. Copies of the plates referred to in the sections on Rockaway Inlet, East Rockaway Inlet, and Manasquan Inlet are included with this report. The following is a list of all plates to which reference is made.

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SHORE PROTECTION BOARD
Office of the Chief of Engineers
Washington, D. C.

August 15, 1938.

Subject: Report on Jetties.

To: The Senior Member, Shore Protection Board.

1. The following report is submitted in accordance with verbal instructions from the Senior Member of the Shore Protection Board.

I. PURPOSE.

2. The primary purpose of the investigation was to determine the effect of various types of entrance channel stabilization and improvement works on the shore line. In addition, data were available to permit a general comparison of the various types of structures, the factors which have proven beneficial and those which have proven detrimental. These have been included in the report in order that future planning of such structures may profit from the successes and failures of the past.

II. NOMENCLATURE.

3. There exists in reports on this subject a wide divergence in nomenclature. Similar structures serving a common purpose are frequently designated by different names. In this report the following definitions will be adhered to so far as practicable. There are borderline cases in which the structure in question serves two or more purposes. Such cases might appropriately be designated by one of two or more names.

a. Breakwater. A structure whose purpose is to intercept waves and protect a portion of a waterway from wave action.

b. Groin. A structure normal to the shore line whose purpose is the protection or improvement of the shore line.

c. Training Wall. A structure approximately parallel to the direction of the current, whose purpose is to maintain or improve a channel by confining and directing the course of the current in an already restricted waterway.

d. Jetty. A structure approximately parallel to the direction of a current, whose purpose is to maintain or improve a channel by confining and directing the course of the current and by preventing the drifting of beach and bottom materials into the channel from the side.

e. Spur Jetty. A structure normal to the direction of a current, whose purpose is to maintain or improve a channel by confining and directing the course of the current.

III. SCOPE.

4. This report covers the existing jetties from the following points of view:-

a. The effect upon the adjacent shore line and bottom, of the type, alignment and spacing of the structures with reference to currents and drifts.

b. The relative effectiveness and economy of various alignments upon the provision and maintenance of the channel or other physical feature.

c. The effect of the materials used in construction and their disposition in the structure upon the effectiveness of the structure.

d. The relative economy of various materials as to first cost and maintenance cost of the structure.

5. The jetties reported upon have been divided into two general groups for study, single jetties and double jetties. Each group has been subdivided into several types. Representative examples of each type under varying conditions have been selected for detailed study. The report has been prepared in accordance with the following outline:-

a. Single Jetties.

(1) Where littoral drift is from one direction only.

(2) Where natural conditions give the effect of a double jetty.

(3) Where the direction of inlet currents holds the channel against the jetty, including reaction jetties.

b. Double Jetties.

(1) Parallel and oblique to shore.

(2) Parallel and normal to shore.

(3) Converging.

(4) Curved.

c. Miscellaneous.

IV. SINGLE JETTIES.

6. Location. Single jetties or breakwaters have been constructed at many inlets on the coasts of the United States. A list of those of sufficient importance to warrant investigation in this study is given below. From this list, typical structures have been selected for detailed study. In some cases where single jetties were constructed their failure to accomplish the desired results required the subsequent construction of a second jetty. These are considered under double jetties in this report.

a. Location of Single Jetties.

(1) East Entrance, Cape Cod Canal, Mass. (supplemented by short sand trap).

(2) Great Salt Pond, Block Island, R. I.

(3) Housatonic River, Conn.

(4) Southport Harbor, Conn.

(5) Port Chester Harbor, N. Y. (breakwater)

(6) Greenport Harbor, N. Y. (breakwater)

(7) Sag Harbor, N. Y. (breakwater)

(8) East Rockaway Inlet, N. Y.

(9) Jamaica Bay (Rockaway Inlet), N. Y.

(10) Larchmont Harbor, N. Y. (breakwater)

(11) Flushing Harbor, N. Y. (breakwater and curved, or reaction jetty)

(12) Glen Cove Harbor, N. Y. (breakwater)

(13) Manasquan Inlet, N. J.

(14) Broadkill River, Del.

(15) Claiborne Harbor, Md.

(16) Urbanna Creek, Va.

(17) Carters Creek, Va.

(18) Nomini Bay, Va.

(19) Silver Lake Harbor, N. C.

(20) Cape Lookout Harbor of Refuge, N. C. (breakwater)

(21) St. Lucie Inlet, Fla.

(22) Miami Harbor, Fla. (Second jetty subsequently)

(23) St. Petersburg Harbor, Fla.

(24) Port Aransas, (Aransas Pass) Texas (Second jetty subsequently)

(25) San Diego Harbor, Calif.

(26) Newport Bay Harbor, Calif. (Second jetty subsequently)

(27) Santa Barbara Harbor, Calif.

(28) San Luis Obispo Harbor, Calif. (breakwater)

(29) Monterey Harbor, Calif. (breakwater)

(30) Noyo River, Calif.

(31) Humboldt Bay, Calif. (Second jetty subsequently)

(32) Crescent City Harbor, Calif. (breakwater)

(33) Coquille River, Oregon (Second jetty subsequently)

(34) Coos Bay, Oregon (Second jetty subsequently)

(35) Tillamook Bay, Oregon.

(36) Columbia River, Oregon (Second jetty subsequently)

(37) Grays Harbor, Wash. (Second jetty subsequently)

7. Classification of Single Jetties.

a. Successful single jetties. The results of the study indicate that single jetties may be expected to prove successful only when one or more of the following sets of conditions exist.

(1) A littoral drift in one direction only, with practically no reversals of direction.

(a) Examples

1. Jamaica Bay (Rockaway Inlet), N. Y.
2. Santa Barbara, California.
3. East Rockaway Inlet, N. Y.
4. Great Salt Pond, Block Island, N. Y.

(2) Where a fairly stable shore line is so disposed as to parallel the single jetty and give in effect the action of two structures.

(a) Examples

1. San Diego Harbor, Calif.
2. Housatonic River, Conn.
3. Southport Harbor, Conn.

(3) Where a confined and predominant ebb current issues from an inlet or river mouth at such an angle that a single jetty can be so aligned that it lies at an angle to or in a curve across the path of the current. The momentum of the current is used to hold the channel against the jetty without recourse to a second jetty.

(a) Examples

1. Tillamook Bay, Oregon.

2. Flushing Harbor, N. Y.

b. Unsuccessful Single Jetties. In other cases, single jetties have been constructed but have failed of their purpose and have been either abandoned or removed in whole or in part, or supplemented by the construction of a second jetty.

(1) Examples

(a) Manasquan Inlet, N. J.

(b) Miami Harbor, Fla.

(c) St. Petersburg Harbor, Fla.

(d) Port Aransas (Aransas Pass), Texas.

(e) Newport Bay Harbor, Calif.

(f) Humboldt Bay, Calif.

(g) Coquille River, Oregon.

(h) Coos Bay, Oregon.

(i) Columbia River, Oregon.

(j) Grays Harbor, Washington.

8. Detailed Study of Jamaica Bay Jetty. A detailed study of the effect of the Jamaica Bay jetty has been made as an example of the type listed above under paragraph 7a(1). This inlet and jetty have also been described and discussed in detail by the Shore Protection Board in its report on Fire Island Inlet, N. Y. A map taken from that report is appended hereto to show the principal shore line changes.

Owing to the configuration of the shore line the vicinity of Rockaway Inlet is exposed to severe wave attack from the southeast quadrant only. This fact with the existence of strong flood-tide currents moving westward along the shore toward New York Bay results in an active movement of sand from east to west along the shore with no appreciable reversals of direction.

a. Location. Jamaica Bay is a land-locked indentation near the westerly end of the south shore of Long Island, about 8 miles east of The Narrows, New York Harbor. It is connected with the Atlantic Ocean by Rockaway Inlet.

b. History.

(1) Formation of the Inlet. As a result of the sand movement, there has been projected westward from the east land point of the original inlet a narrow compound recurving sand spit nearly 4 miles long, known as Rockaway Point. This point has overlapped the south shore of the west land point, leaving Rockaway Inlet between the spit and the mainland. Between 1835 and 1921, the average annual westward extension of the spit was from 205 to 260 feet. Between 1921 and 1928, an average net loss in lengths of about 57 feet per annum took place. The progressive extension of the spit is shown on Plate 4 of the report of the Shore Protection Board, dated February 13, 1937, on the proposed improvement of Fire Island Inlet, N. Y., a copy of which is appended hereto. Under the natural conditions preceding any improvement of the inlet, there existed through the gorge of the inlet a

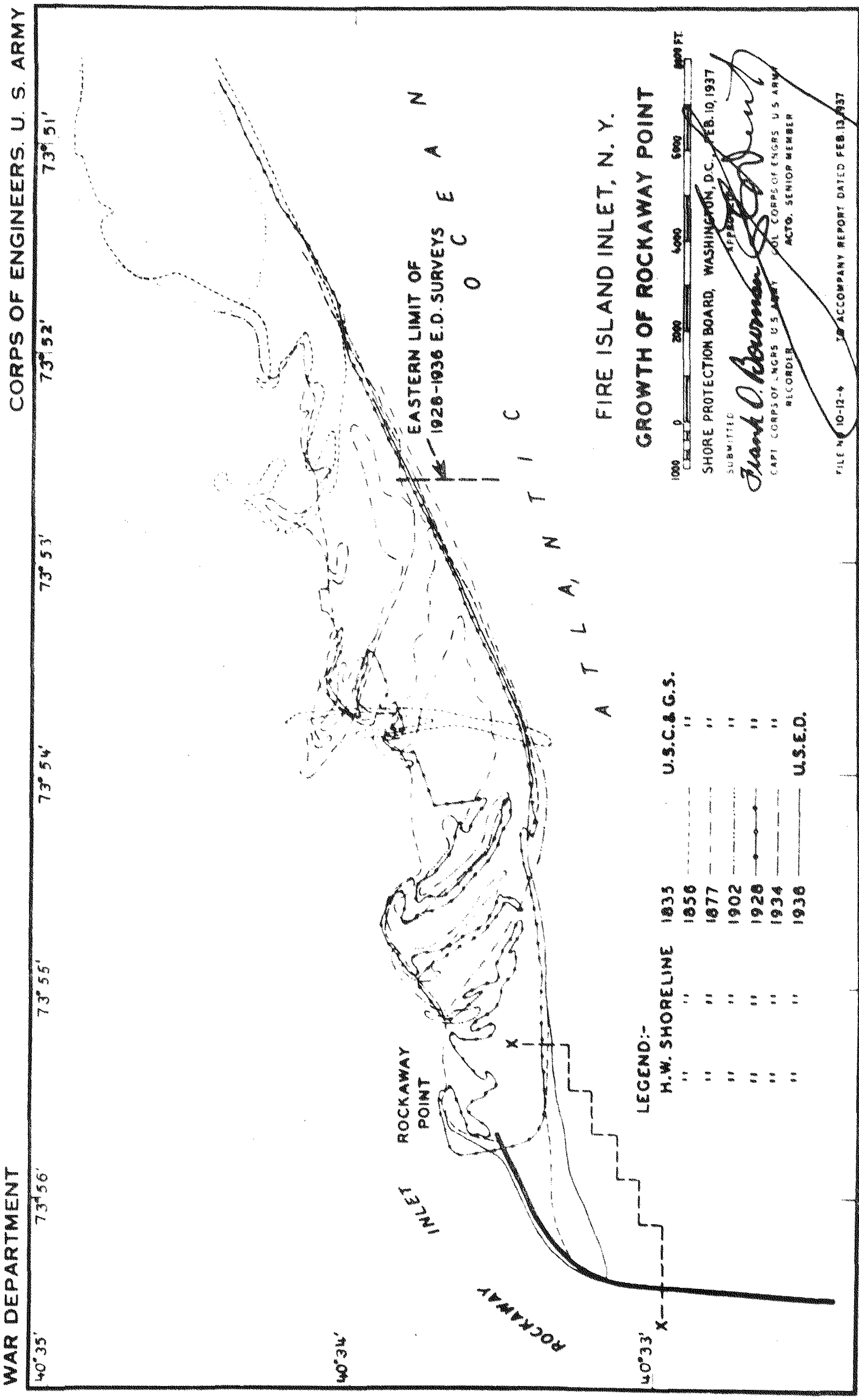

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FIG. 1

natural channel 1000 feet or more wide and up to 45 feet deep. Opposite the tip of Rockaway Point, however, where the channel entered the open ocean, the depths decreased over the bar to a controlling depth of about 20 feet. Eastward of this entrance channel and southward from the tip of Rockaway Point, a shoal area about 6000 feet wide, projected south some 10,000 feet into the ocean, with minimum depths of 6 to 12 feet over considerable areas of its crest.

(2) Plan of Improvement. The River and Harbor Acts of June 25, 1910, and September 22, 1922, adopted a project for Jamaica Bay (H. Doc. No. 1488, 60th Cong., 2nd Session). The plan included among other improvements the provision of an entrance channel through Rockaway Inlet 30 feet deep and 1,500 feet wide, protected by one or two riprap jetties as might be necessary. In view of the unidirectional movement of the littoral drift, it was believed that the proposed entrance channel might be adequately protected by a single jetty. The proposed jetty was to extend from the tip of Rockaway Point, west and south along the easterly side of the channel to the seaward face of the bar. It was expected to intercept the westward movement of the sand and prevent it from encroaching on the channel, without at the same time interfering seriously with the tidal flow through the inlet. Construction of the jetty began on March 11, 1931, and was completed on August 5, 1933. It was constructed of random rock, placed both from a trestle and from barges; 532,973 tons of rock were used costing $1,993,252.99.

c. Shore Line Changes since Jetty Construction.

(1) East of Jetty. The shore line locations east of the jetty for 1928, 1934 and 1936 are shown on Plate . From the original shore end of the jetty outward to the seaward end of the curved section, about 4,500 feet, sand has accumulated against the jetty to a maximum height of 10 feet. The seaward advance of the low-water shore line, about 1,500 feet, has resulted in a straightening of the beach to the jetty.

(2) West of the Jetty. The shore of Coney Island, west of the Jamaica entrance is well protected from storm wave action by the westward and seaward extension of Rockaway Point and the jetty. It is well protected by groins. Prior to the construction of the jetty the beach was from time to time artificially refilled between the groins. Construction of the jetty has caused no noticeable change in those conditions.

d. Offshore Changes.

(1) East of Jetty.

(a) Over the shoal area within 6,000 feet east of the jetty, shoaling has occurred in the landward area and scouring in the seaward area. The 6-foot contour has advanced offshore as much as 1,500 feet. The 12- and 15-foot contours have not shifted materially. Seaward of the 15-foot contour and immediately east of the seaward end of the jetty the crest of the shoal, over which formerly depths of 6 to 12 feet existed, has disappeared. The 24-foot contour, delimiting the shoal area, has experienced comparatively minor shifting tending to shorten and widen the tip of the shoal. The crest of the shoal has present depths of 13 to 25 feet. A study of the contour changes from year to year indicates that the material of the shoal has probably moved south and southwest into deeper water rather than shoreward into the bend of the jetty.

(b) Along the offshore farther east than 6,000 feet from the jetty, the offshore bar has narrowed and moved slightly seaward, the 6-foot contours have shifted seaward, the 12- and 15-foot contours have experienced little change, while the 18-foot and 21-foot contours have shifted shoreward by amounts between a few hundred feet and 1,000 feet. The 24-foot contour has shifted but slightly and the 30-foot contour shows a slight tendency to shift seaward.

(2) In the Entrance Channel. Over a strip roughly 2,000 feet wide west of the jetty, the entrance channel has deepened and widened. Along the northwest shore of Rockaway Point, where the gorge of the inlet enters the wider reach west of the tip of the point, the 24-foot contours on both sides of the channel remain substantially unchanged. The 6-foot contour has moved shoreward toward the jetty about 200 feet. Around the tip of the point, the steep easterly edge of the channel curve has maintained its position. The westerly edge more remote from the jetty has moved westward so that the width of channel between 24-foot contours has increased from the original 500 feet to a present 1,500 feet or more. A shoal which formerly bounded the west edge of the channel at this point, and over which a minimum

depth of about 12 feet existed, has been eroded so that depths of 24 to 28 feet are found. A channel 24 feet or more deep with the exception of one small shoal spot, and from 600 to 1200 feet wide between 24-foot contours has been scoured through the bar where formerly depths of 11 to 18 feet existed. This channel swings over toward the jetty and opens into deep water immediately west of its seaward end. After passing the end of the jetty, it trends away to the southwest. All along the westerly edge of this deepening channel, shoaling has occurred and a bordering shoal appears to be forming. Around the seaward end of the jetty, a deep hole has been scoured with maximum depths of 30 to 32 feet. This has caused the undermining of a section of the jetty about 400 feet from its outer end.

e. Effects of the Jetty.

(1) The observed effects of the jetty are apparently due to its double action of cutting off the sand encroachment into the entrance channel and of eliminating the competition of east-to-west alongshore currents with the predominant ebb current issuing from the inlet. Along that section of the beach lying more than some 6,000 feet east of the jetty, in water less than about 24 feet deep but more than 12 feet deep, the principal current action on the bottom is due to the flood-tide currents. Under the combined action of these currents and deep-seated agitation of storm waves, with a shoreward undertow during offshore gales, the bottom material apparently moved diagonally and gradually shoreward. This action has apparently continued since con-

struction of the jetty as evidenced by the fact that the 24-foot and 12-foot contours have changed but little, whereas the 21-foot and 18-foot contours have moved generally shoreward. The offshore bar along that section of the beach was presumably formed of and is largely maintained by material moving in from deeper water outside.

(2) In the comparatively narrow belt of water between the 12-foot contour and shore, the westward movement due to flood-tide currents is intensified by diagonal wave attack due to the configuration of the shore. The westward movement of the sand takes place principally in that belt and chiefly within the 6-foot contour. Originally a large part of this material was carried past the tip of Rockaway Point and deposited temporarily in the deeper water of the entrance channel. Thence it was moved by the predominant ebb currents issuing from the inlet, and carried seaward to be again deposited on the bar, over which depths of 11 to 20 feet were found. Owing to the constant westward push of the outside currents, there was a tendency to hold the deeper water of the entrance channel to the west against the shoals which formed along the convex side of the curve.

(3) Construction of the jetty intercepted this westward movement of currents and material. The latter, moving chiefly inside the 6-foot contour along the beach, was accumulated in the bend of the jetty. The westward moving current near shore was deflected seaward by the jetty and added to the currents further offshore to reinforce their action near the jetty upon the shoreward face of the east end of the

original bar shoal. The crest of this shoal was thus removed and carried south and southwest around and past the tip of the jetty into water over 24 feet deep, and there redeposited. The crest of that section of the shoal has not changed as much between October, 1936 and September, 1937, as it did at first. It appears that a condition of approximate equilibrium has been established there.

(4) Meantime, the ebb currents from the inlet, relieved of the task of removing shore-drift material deposited in the channel, have been enabled to devote all their energies to scouring out a deeper and wider channel west of the jetty, bounded by a growing shoal along the outside edge thereof. This boundary shoal, no longer exposed to the westward urge of the ocean currents, has grown with sufficient rapidity to force the ebb currents from the inlet into a sharper curve toward the jetty. The material scoured from the channel and not directly redeposited to the westward thereof has been carried seaward and added to that brought around and past the end of the jetty from the east. This has moved the outer face of the bar seaward and transferred it laterally along the shore by current and wave action. As the ebb current passes the seaward end of the jetty, it is compounded with the westward-moving along-shore current rounding the end of the jetty. The resultant scouring action trends sharply away to the southwest.

(5) This jetty has been substantially effective in causing changes for only some 6 years. The resulting changes are still

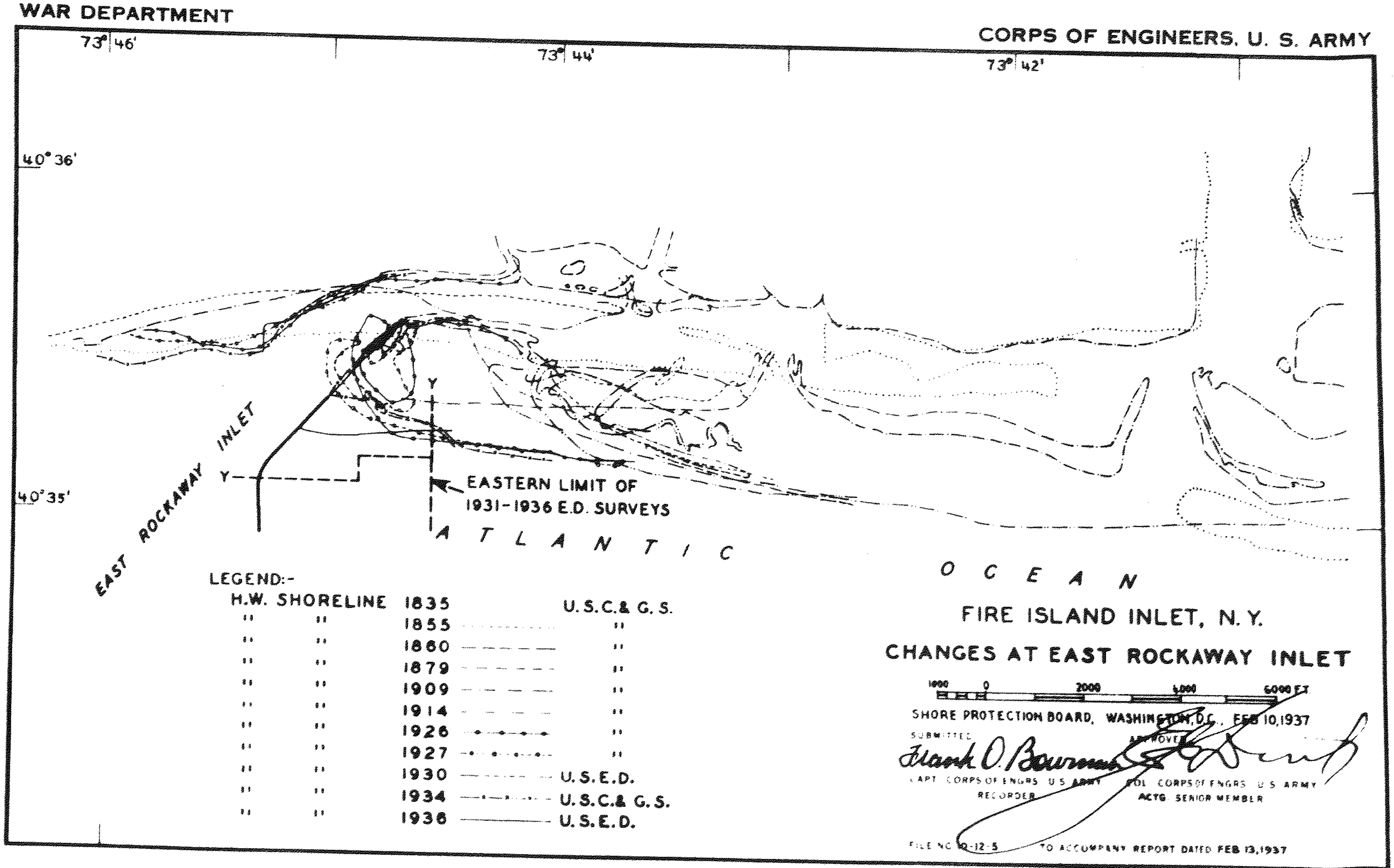

PLATE 5

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FIG. 2

in progress, though apparently at a decelerating rate. It seems probable that further changes will be in the same direction as those already noted but to a limited extent.

9. Economy. During the process of channel scouring some 3,000,000 cubic yards of material have been removed from the area through which the project channel should pass. If the entire cost of the jetty be taken as the cost of the channel improvement to date, the unit cost of such sand removal has been about 66 cents per cubic yard. Or, from another point of view, if the jetty be credited with the removal of material at 15 cents per cubic yard, about $450,000 could be charged off to that activity, leaving approximately $1,500,000 of the total cost to be balanced against channel maintenance and other purposes. Inasmuch as the project channel 30 feet deep and 1,500 feet wide has not as yet been dredged and maintained, no actual data based on experience are available as to the economy of the jetty as a means of channel maintenance. However, in view of the fact that the jetty has caused to form, and is more than maintaining, a channel nearly 1,500 feet wide throughout most of its length, with usual depths of between 25 and 30 feet, it seems likely that it will care for substantially the entire maintenance of the project channel except at its entrance seaward of the jetty end, where material brought out from the channel by ebb currents may be expected to mingle with material carried around the end of the jetty by ocean currents to cause some shoaling. What the rate of such shoaling will be, and the annual cost of its removal,

cannot be determined in advance of the fact. Nor can it be definitely accepted that the single jetty would have been successful during the earlier years of the more rapid growth of the spit.

10. <u>Discussion</u>. If, about $450,000 of the cost of the jetty be charged off to channel improvement, and about $1,500,000 of its cost be considered as having been expended against future channel maintenance, interest at $3\frac{1}{2}$ per cent on that capital investment would yield an annual sum of $52,500. From that point of view, therefore, and neglecting the cost of maintenance of the jetty, if the annual cost of maintenance by dredging alone, would exceed $52,500, the jetty would be economically justified as a measure of channel creation and maintenance. As a unit cost of 15 cents per cubic yard for dredging, that sum would remove annually 350,000 cubic yards of material from the channel. It seems hardly probable that this would have been required, but not impossible. The presumption would appear to be that, if dredging with a seagoing hopper dredge were practicable at a unit cost of 15 cents a cubic yard, or less, the creation and maintenance of the channel could have been accomplished more economically by dredging alone, particularly in view of the fact that some maintenance dredging will be required even with the jetty and that some expenditures for maintenance of the jetty will also be required.

11. <u>Jetty at East Rockaway Inlet, N. Y.</u> The single jetty at East Rockaway Inlet, N. Y., is so similar in the conditions under which it was built, its general shape, and the shore line changes that have

followed its provision, that the foregoing discussion for Rockaway Inlet applies almost equally to the East Rockaway Inlet situation. A map, taken from the report of the Shore Protection Board on Fire Island Inlet, N. Y., and showing the shoreline changes at East Rockaway Inlet, is appended hereto.

12. Breakwater at Santa Barbara, California.

a. Introduction. Although the structure at Santa Barbara, California, is a breakwater rather than a jetty, it exemplifies certain aspects of shore line changes which are of interest, and is therefore included in this study. The nature and causes of the changes are the subject of a comprehensive report by the Beach Erosion Board (H. Doc. No. 552, 75th Cong., 3rd sess.).

b. Location. Santa Barbara is located on the southern coast of California, 90 miles northwest of Los Angeles and 320 miles southeast of San Francisco. (U. S. Coast and Geodetic Survey Chart No. 5261 and the map appended hereto).

c. Description.

(1) General. The rugged and generally rocky coast in the vicinity of Santa Barbara breaks sharply in its alignment at Point Arguello and Point Conception, two headlands about 13 miles apart west of Santa Barbara. North of Point Arguello, the coast extends almost due north for about 40 miles, thence northwesterly. East of Point Conception, the coast extends easterly for over 50 miles, turning then to a southeasterly alignment. About 25 to 30 miles south of the east-

ward-trending section of the coast, 3 islands are set end to end in a chain parallel to the coast line. San Miguel Island is practically due south of Point Conception, and the distance through Santa Rosa Island to the easterly end of Santa Cruz Island is about 55 miles. The waterway between the chain of islands and the mainland is known as Santa Barbara Channel. Santa Barbara is situated on the north shore of Santa Barbara Channel, about 45 miles east of Point Conception.

(2) Local. Just west of Santa Barbara, a rounded headland known as Santa Barbara Point projects southward from the general alighment of the coast, partially protecting a recurving open roadstead east of the point and in front of Santa Barbara. The curving shore of this roadstead was originally composed largely of sand beaches underlain at no great depth by gravel and rock boulders. The tides have a diurnal inequality, the range of tide between mean higher high water and mean lower low water being about 5.4 feet. The maximum storm range is 10.5 feet. Owing to the prevalence of winds and waves from the westerly quadrant, to the sheltering effect of the island chain to the south and the configuration of the shore line, the littoral drift is from west to east, with practically no important reversals of direction.

d. Conditions Prior to Improvement.

(1) The report of the Beach Erosion Board brings out clearly the fact that the beach material along the coast east of Point Conception is furnished by the numerous small streams which drain the narrow watershed along the coast and on the sides of the nearby

mountains. Little if any of this material rounds Point Conception from further north. This sand moved eastward along the shore to and past the Santa Barbara waterfront, and replenished and maintained the beaches at and east of Santa Barbara, which formed a very important part of the recreational attraction of the vicinity. Even under those circumstances, severe storms not infrequently denuded some of the beaches to the underlying gravel for long periods, but these were in time replenished by the sand traveling along the shore.

e. Plan of Improvement.

(1) In order to provide a more sheltered harbor for commercial and recreational navigation, local interests constructed, in 1927-28, a rubble mound breakwater with concrete cap at a cost of about $750,000. The breakwater was originally built roughly L-shaped, with a long arm nearly parallel to the shore for a length of 1,425 feet, and, at its westerly end, a short arm about 400 feet long extending toward the shore but leaving an opening 600 feet wide between it and the shore. The purpose of the gap was to permit the unobstructed flow of the sand along the shore so as to avoid damage to the beaches. For reasons brought out in subsequent paragraphs, the gap was closed in 1930 by extending the shore arm to the shore.

f. Effects of the Breakwater.

(1) Before the gap in the shore arm was closed, sand moving toward the breakwater from the west passed through the gap as was expected. However, instead of continuing to move along the harbor

waterfront to the beaches east of the town, the sand settled in the harbor itself just within the gap, forming a shoal which threatened to fill up the harbor area in the lee of the breakwater. This result proved conclusively that the movement of the sand along the shore was caused primarily by wave action, so that the sand settled as soon as the waves were intercepted by the breakwater. This resulted in the closing of the gap in the breakwater in order to prevent deterioration of the harbor.

(2) With the closing of the gap, the moving sand began to be deposited in the outside angle between breakwater and shore. By the fall of 1933, the shore line had been advanced about 1,000 feet to the angle of the breakwater and by diminishing amounts over the 3,400 feet more or less between the breakwater and Santa Barbara Point. Sand had also banked along the seaward face of the longer arm, and began to round the end of the breakwater and accumulate as a shoal just inside the harbor entrance. In the fall of 1935, about 202,000 cubic yards of material, place measurement, were dredged by a Government hopper dredge from both sides and around the seaward end of the breakwater. This material was spoiled in about 20 feet of water about a mile east of the breakwater in a ridge about 2,000 feet long lying 1,000 feet offshore, in the hope that it might be carried ashore by natural forces to replenish the beaches. Soundings made in 1937 indicate that most of the material still remained in the disposal area, little if any having reached the beaches.

c. With the construction of the breakwater, the sand flow was cut off, and the beaches along the Santa Barbara waterfront and east thereof began to deteriorate. At some places along the shore the sand blanket has been completely removed from the beach, leaving only the cobble and boulder covered foundations. Even where some sand covering remains, it is so thin as to be unsuitable for a bathing beach. The effects of this dearth of sand supply have been felt as far as 13 miles east of the breakwater.

13. Detailed Study of San Diego Bay Jetty.

a. Location. An instance of the second class of single jetties, (par. 7a(2)) is that at the entrance of San Diego Bay, California, a few miles north of the Mexican border.

b. Description. The gorge of the entrance channel extends about due north and south between Point Loma on the west and North Island on the east, and is generally about 3,000 feet wide. Point Loma is a narrow rocky headland projecting south from the mainland, about 14,000 feet wide at its base and 27,000 feet long. Its width 19,000 feet north of the tip is about 6,000 feet, and tapers progressively to about 2,000 feet near the rounded south tip. About 6,500 feet north of the south tip of Point Loma, a narrow rocky spur known as Ballast Point projects from the east shore of Point Loma across the entrance toward the southwest tip of North Island, known as Zuniga Point, sharply reducing the width of the entrance at that point to about 1,700 feet. Northward of the gorge, the shores of Point Loma and North Island diverge to open up into San Diego Bay. The natural deep water channel, about 1,500 to 2,000 feet wide between 24-foot contours, with natural depths generally between 30 and 70 feet, curves northeast, east and southeast around the north shore of North Island through about a 120° arc with a centerline radius of some 10,000 feet. The south shore of North Island trends east from the entrance, and Point Loma projects south into the ocean more than a mile beyond Zuniga Point. These conditions are shown on U. S. Coast and Geodetic Chart No. 5107, and on the map herewith.

c. History. Under the natural conditions preceding the construction of the jetty, the shore line adjacent to the harbor entrance was protected by Point Loma and North Island from active wave attack except from the south and southeast. The predominant littoral drift was thus from southeast to northwest, toward the entrance. This movement was reinforced by flood-tide currents moving northward under the draw of the entrance. The large area of San Diego Bay, coupled with tidal ranges of 5.6 to 9.0 feet, caused powerful tidal currents through the entrance channel. The flood currents, entering the wide opening between the tip of Point Loma and the shore of North Island, and concentrated progressively as they approached the narrow entrance, acted over the entire area and against both shores to move material toward the entrance, whereas the ebb currents issuing from the narrow entrance tended to be confined to a narrow area extending almost due south from the entrance. Under the influence of these currents, beach and bottom materials were carried north and northwest toward the entrance and deposited in the angle of the shore or carried through the entrance and deposited on the middleground shoal north of Ballast Point. Such material deposited in the path of the powerful ebb currents issuing from the entrance was moved back seaward and redeposited on the offshore bar seaward of the south tip of Point Loma. There had thus been built up a shoal known as Zuniga Shoal, projecting southward from Zuniga Point, roughly symmetrical with Point Loma and separated from it by the deeper channel maintained by the ebb currents. The base of Zuniga Shoal between 18-foot contours was about 7,000 feet wide along the shore, and the 18-foot contour at its pointed southern tip was about 9,000 feet south of the shore. The west face of the shoal next to the natural channel was steep, the 6-foot and 18-foot contours being only 100 to 300 feet apart. The east face was flat, with 6-foot and 18-foot contours about 3,000 feet apart. The crest of the shoal was thus near its westerly edge. Although the shoal shifted back and forth somewhat under varying conditions, it had maintained its general shape and size fairly constant between 1851 and 1893, when the jetty was started.

d. Plan of Improvement. The River and Harbor Act of September 19, 1890, provided for a single jetty extending from Zuniga Point south along the crest of Zuniga Shoal to about the 12-foot contour at the southern tip of the shoal. It was believed that this structure would so concentrate the ebb currents on the bar as to increase the controlling depth from 21 feet to 26 feet. The jetty was begun in September, 1893 and completed in 1904. It was built in part of granite and in part of sandstone, on brush mattresses. The stones ranged from 50 pounds to 6 or 7 tons in weight, averaging 2 to 3 tons.

e. Shore Line Changes since Jetty Construction.

(1) East of Jetty. As soon as the jetty was extended seaward from the shore line, sand began to accumulate against it on the east side, and during its construction the shore line east of the jetty advanced over a shore length of 2,100 feet for a maximum advance of 700 feet next to the jetty. Some sand also percolated through or passed over the jetty to bank up against its west face. Since completion of the jetty, the low water line has advanced generally by between 250 and 400 feet for a distance of about 7,000 feet along the shore. Farther east and south, there has been a tendency to recession with which, however, the jetty presumably had no connection.

(2) West of the Jetty. Considerable erosion of the shore of North Island opposite Ballast Point occurred. The rocky easterly shore of Point Loma shows little change.

f. Offshore Changes.

(1) East of Jetty. As the jetty was extended seaward, the crest of the shoal was scoured ahead of it by between 3 and 13 feet, chiefly by flood currents crossing the shoal toward the entrance. This added considerably to the estimated cost of the structure. The 6-foot contour has advanced seaward an average of about 500 feet, curving across the angle between jetty and shore to meet the jetty about 2,000 feet from shore. The 12-foot contour also advanced an average of 200

feet, the amount increasing to about 500 feet as the tip of the shoal was approached. At the tip, however, the 12-foot contour moved shoreward by 1,500 feet or more, so that the tip became shorter, wider and more rounded. The 18-foot contour also advanced along the east side by from 400 to 750 feet, but receded nearly 2,000 feet at the tip.

(2) <u>West of Jetty</u>.

(<u>a</u>) <u>Between the Jetty and the East Edge of the Channel</u>. The general effect has been a progressive change from a slight fill at the shore angle to an increasing erosion toward the seaward end. The 6-foot contour, which met the jetty in 1898 about 1,700 feet from its landward end, now meets it only a few hundred feet from the landward end. The 12-foot contour, which in 1898 paralleled the jetty roughly at usual distances of between 400 and 800 feet therefrom, and which rounded the seaward end of the jetty, has changed its position but little off the landward 2,000 feet of the jetty but has receded sharply seaward of that point and now meets the jetty about 3,500 feet shoreward of its seaward end. The 18-foot contour has remained about unchanged off the shoreward 2,000 feet of the jetty, receding then sharply to meet the jetty about 2,500 feet from its seaward end, whereas in 1898 it rounded the jetty tip about 1,700 feet seaward thereof - a total recession along the line of the jetty of about 4,200 feet. Around the seaward end of the jetty a deeper hole has scoured, with depths of over 30 feet where only about 12 feet existed formerly.

(b) In the Channel. Little effect of the growing jetty upon the channel and bar was observed until the jetty approached completion, when a deepening of about $1\frac{1}{2}$ feet took place on the crest of the bar. The greatest depth secured by scour was about $22\frac{1}{2}$ feet instead of the 26 feet hoped for, and channels dredged to 27 and 28 feet soon shoaled to 24 or 25 feet, and have required considerable redredging for the maintenance of project depths.

(c) Between the Channel and Point Loma. There has been a general tendency toward deposit, expecially active toward the inner end of the entrance near Ballast Point. The 6-foot contour has moved offshore fairly uniformly between 150 and 200 feet. From the tip of Ballast Point south along the channel a distance of a mile, the 12-foot contour has moved offshore by 500 to 1300 feet, and the 18-foot contour by 200 to 700 feet. Farther south around the southeast tip of Point Loma, both 12-foot and 18-foot contours have only advanced channelward by between 100 and 300 feet, and the top of a tailing shoal which extended south along the edge of the former channel line has been removed to depths greater than 18 feet.

(d) Inside Ballast Point. A final change which has been brought about by construction of the jetty has been a decrease in the rate of deposit of material on the middleground shoal in the entrance channel north of Ballast Point. This shoal was originally formed and maintained largely by sand carried from the south across Zuniga Shoal and through the narrow entrance by flood-tide currents.

Before construction of the jetty, attempts were made to dredge a channel between the middleground and North Island, but such channel had always filled in rapidly. Since the jetty has cut off the movement of sand across Zuniga Shoal, the dredging necessary to maintain the inner channel through the gorge has greatly diminished.

14. Detailed Study of Tillamook Bay Jetty.

a. Location. An instance of the third case of fairly successful use of a single jetty (par. 7a(3)), in which the momentum of a diverted current is used to hold it against the jetty is afforded by the structure at Tillamook Bay, Oregon, about 50 miles south of the mouth of the Columbia River.

b. Description. The bay is about 6 miles long and 3 miles wide and generally shoal; five small rivers empty into it. The tidal range varies between 7.9 and 11 feet. The predominant littoral drift is from north to south, although winter storms, particularly, may reverse the direction at times.

c. History. Prior to the construction of the jetty, the bay emptied into the ocean through a gorge about 750 feet wide, with a maximum depth of about 60 feet and usual depths of 25 to 40 feet. The channel through the gorge extended northwesterly to a point about 2,000 feet north of the south land point. It then turned sharply almost due west toward the ocean, with depths of over 18 feet for over a mile west of the bend before the shoreward face of the offshore bar was reached. Over the crest of the bar the inner and outer 18-foot contours were only about 600 feet apart and the controlling depth was 17 feet.

d. Plan of Improvement. The River and Harbor Acts of July 25, 1912, and March 4, 1913, provided for the jetty and a channel over the bar 18 feet deep and as wide as could practically and economically be maintained. Construction of the jetty was begun in March 1914, and was completed in October 1917. There were placed in the jetty 428,671 tons of rock at a cost of over $700,000. The jetty extended in a westerly direction from the shore north of the entrance, roughly parallel to the natural outside channel and from 1,300 to 1,700 feet north thereof. It was slightly curved toward the channel at its outer end. It was about 5,400 feet long and built up to about high water. In 1931-33, the jetty was repaired and extended to 5,700 feet long; 320,350 tons of rock were used for this work at a cost of over $525,000.

e. Shore Line Changes since Jetty Construction.

(1) North of the Jetty. Both high and low water lines have advanced. The high water line has advanced along the jetty about 3,000 feet, the advance diminishing rapidly to 500 feet about 3,000 feet north of the jetty, and to 100 feet or less some 10,000 feet north of the jetty. The low water line has advanced about 1,300 feet next to the jetty, The advance diminishing rapidly in the first 3,000 feet north of the jetty. Farther north a general advance of 100 to 200 feet has occurred.

(2) South of the Jetty. The ocean shore line of the south land point has receded. Over a shore length of some 15,000

feet, the high water line has receded from 600 feet at the north end to 100 feet farther south. The low water line has receded 1,500 feet at the north end, diminishing to the south.

f. Offshore Changes.

(1) North of the Jetty. The 18-foot contour has changed but little except in the 1,000 feet immediately north of the seaward end of the jetty. There the contour has bulged seaward along and beyond the jetty for about 2,000 feet. The general result has been a filling in of the angle between the jetty and the shore. There has been a steepening of the beach and offshore bottom, and a building out of a shoal in prolongation of the jetty alignment.

(2) South of the Jetty. The original channel which lay some 1,500 feet south of the jetty swung rapidly northward. By 1916, while the construction of the jetty was still in progress, scouring along its south face was noticeable. By 1918 the ebb current, issuing in a northwest direction from the gorge, had scoured a channel from 22 to 35 feet deep and 400 feet wide along the south edge of the jetty. By 1930 depths in this channel had increased to 25 to 40 feet. The depth therein has since been maintained at not less than 20 feet, with maxima of 47 or 48 feet. The currents following this channel along the jetty attacked the offshore bar seaward of the jetty end. In 1917 the controlling depth over the bar was but 10 feet; in 1918, 22 feet over a width of 200 feet; in 1919, 24 feet for a width of 1,000 feet. The crest of the bar had been moved seaward 1,000 feet. At that

time, however, shoaling began to take place, probably because, with advance of the shore line along the jetty, material from the north had begun to sweep around the end of the jetty. In 1920, the controlling depth was reduced to 21 feet for a width of 1,000 feet; in 1921 to 13 feet. Between 1921 and 1927, controlling depths of 16 to 19 feet were maintained in that channel, but the width was decreased from 1,000 feet to a usual width of about 300 feet, and the crest of the bar moved shoreward from an original 2,000 feet to a final 1,400 feet beyond the end of the jetty. Some shiftings back and forth, with minor variations in depth, occurred, presumably as a result of varying storm conditions, but the general average remained constant. A second channel also opened up extending southwesterly from the end of the jetty, with depths of 18 to 19 feet over widths of as much as 800 feet. In 1928, however, the general shoaling of the bar had progressed to the point where the currents could no longer maintain the bar channel. It shoaled rapidly to a depth of only 12 feet. In 1929, 66,898 cubic yards of sand were dredged from the bar channel, despite which it shoaled to 11 feet; in 1930, 96,622 cubic yards were dredged and the depth increased to 14 feet; in 1931, 72,251 cubic yards were dredged, increasing the controlling depth to 17 feet; in 1933, 139,107 cubic yards were dredged, increasing the depth to 20 feet over a width of 400 feet. By 1936, with no maintenance dredging, the channel had shoaled to $14\frac{1}{2}$ feet on the center line range, although a depth of 20 feet was still available 200 feet south of the range. Meanwhile the

18-foot contour off the south land point moved landward by from over 2,000 feet at the north end to some 200 feet at the south limit. The interception by the jetty of the southward moving sand supply has doubtless contributed to the recession along the south land point.

15. Although those and other instances indicate that under certain favorable conditions a single jetty may be successful, there are other instances in which a single jetty has failed to accomplish the results expected, necessitating the construction of a second jetty. Examples of this are found at the mouth of the Columbia River, Oregon, at Coquille River and at Coos Bay, both in Oregon, at Humboldt Bay and Newport Bay, both in California, and at Grays Harbor, Washington, at Aransas Pass, Texas, and at Miami Harbor, Florida. There are also numerous instances in which althouth two jetties were planned, one was constructed substantially in advance of the other, thus affording, for a time, opportunity to observe its effect as a single jetty. A study of those cases indicates that only under special and rather unusual circumstances can it be expected that a single jetty will be successful.

16. At Miami Harbor, for example, it was anticipated that the north jetty would be sufficient, in view of the north-to-south direction of the predominant littoral drift. The jetty was extended 1,500 feet from shore, but when channel dredging to 18 feet was attempted thru the land strip south of the jetty, it was found that the south land point of the inlet opening was cut back. The dredged channel filled in very rapidly. The construction of the south jetty therefore became necessary.

17. Similarly, at Humboldt Bay, California, it was originally believed that a single jetty extending from the south land point and cutting off the predominant south-to-north littoral drift, would be effective in stabilizing the channel. After construction of the single jetty was begun it was found that the north land point began to erode rapidly. The width of the entrance increased during the first year from 2,100 feet to 3,500 feet, and during the second year from 3,500 feet to over 5,000 feet (Annual Report for 1900, pp. 4237-4245). It was found necessary to construct a north jetty. Immediately following its provision the north land point began to be repaired by accretion, which has continued since.

18. At the entrance to Newport Bay, California, which is discussed in more detail hereinafter, a single jetty was provided on the west side of the entrance in 1918. The beach west of the jetty then receded over a considerable distance, and was subsequently restored by the deposit of dredged material. The beach east of the entrance also receded steadily until 1928, when the east jetty was provided. Sand then began to accumulate along the adjacent shore east of the jetties, and a stable beach has formed there. West of the jetties the tendency continued to be one of recession.

19. In the case of the jetties at the entrance to the Columbia River, discussed in detail hereinafter, a south jetty $4\frac{1}{4}$ miles long was constructed first. The initial effects were most gratifying; the migration of the channel over the offshore bar was checked and a straight-

out channel scoured through the bar about 1 mile wide and 30 feet or more deep. Then the bar channel began to widen both north and south, and shoaled to about 20 feet. The south jetty was then extended another 3 miles, and maintenance dredging tried on the bar without satisfactory results. It was finally decided to build a north jetty. After its construction the channel over the bar narrowed and deepened to over 40 feet. This has been maintained since that time. The shoreline both north and south of the jetties has advanced.

20. At Grays Harbor, Washington, discussed in more detail hereinafter, it was decided, after considerable difference of opinion (Annual Report for 1895, p. 3517 et. seq.) that a single south jetty should be built. This was begun in 1898, and completed to a length of 13,784 feet, in 1902. The jetty caused large accumulation of sand along both sides and recession of the north land point. In the channel, the first effect was gratifying. Between 1898 and 1902, the channel was diverted to a westerly course across the bar, and deepened from an original 11 feet to about 19 feet. During the following years, however, scouring around the end of the jetty created a second channel, and the main channel shoaled and shifted considerably. By 1907, the minimum channel depth over the bar was reduced to 12 feet. It was then decided that a north jetty would be necessary.

21. At Aransas Pass, Texas, more fully discussed hereinafter, it was similarly decided that a single jetty would be sufficient. This was built from the south land point between 1881 and 1884, to a length of

4,050 feet from the shore. The seaward 1,698 feet recurved northward toward the channel, presumably with the idea of utilizing the principle of the reaction jetty. The jetty accumulated sand along both sides. There was an initial deepening effect upon the channel. The original depths over the bar had varied from 7 to $9\frac{1}{2}$ feet. This was increased between 1881 and 1885 to nearly 12 feet. In 1886 a severe storm shifted the channel southward toward the jetty and shoaled it to about 10 feet. By 1888 the minimum channel depth had diminished to 8.8 feet. The project was then turned over to a private company, and two jetties were built.

22. From a study of these and other cases it is indicated that only in the exceptional case can a single jetty be expected to prove successful. Even in cases which promise the possibility of success for a single jetty, it is advisable to plan the jetty with the probability in mind that a second jetty will sooner or later have to be provided.

V. JETTIES (DOUBLE)

23. Location. Double jetties have been provided at a number of sites on the coasts of the United States. A list of the more important is given below. From this list, typical cases have been selected for more detailed study and description.

a. Location of Double Jetties.

(1) Saco River, Me.

(2) Newburyport Harbor, Mass.

(3) Nantucket Harbor, Mass.

(4) Block Island Harbor of Refuge, R. I.

(5) Point Judith Harbor of Refuge, R. I.

(6) Connecticut River (Saybrook jetties), Conn.

(7) Milford Harbor, Conn.

(8) Bridgeport Harbor, Conn.

(9) Mattituck Harbor, N. Y.

(10) Patchogue Harbor, N. Y.

(11) Browns Creek, N. Y.

(12) Shark River, N. J.

(13) Manasquan Inlet, N. J.

(14) Cheesequake Creek, N. J.

(15) Wilmington Harbor (Christiana River), Del.

(16) Cold Spring Inlet, N. J.

(17) Ocean City Inlet, Md.

(18) Winyah Bay, S. C.

(19) Charleston Harbor, S. C.

(20) Savannah Harbor, Ga.

(21) Fernandina Harbor, Fla.

(22) St. Johns River, Fla.

(23) Fort Pierce Inlet, Fla.

(24) Lake Worth Inlet, (Port of Palm Beach) Fla.

(25) Hollywood Harbor, (Port Everglades) Fla.

(26) Miami Harbor, Fla.

(27) Caseys Pass, (Venice Inlet) Fla.

(28) Sabine Pass, La. and Tex.

(29) Galveston Harbor, Tex.

(30) Freeport Harbor, Tex.

(31) Port Aransas, (Aransas Pass) Tex.

(32) Brazos Island Harbor, Tex.

(33) Newport Bay Harbor, Calif.

(34) Humboldt Bay, Calif.

(35) Coquille River, Oregon.

(36) Coos Bay, Oregon.

(37) Umpqua River, Oregon.

(38) Siuslaw River, Oregon.

(39) Yaquina Bay, Oregon.

(40) Nehalem River, Oregon.

(41) Columbia River, Oregon.

(42) Grays Harbor, Wash.

(43) Guillayute River, Wash.

24. Classification of Double Jetties. Double jetties will be discussed under the following headings:-

a. Parallel jetties oblique to the shoreline.

b. Parallel jetties normal to the shoreline.

c. Converging jetties.

d. Curved and reaction jetties.

It should be noted, however, that many cases partake of the characteristics of two or more of these classifications; these will be considered under the heading to which their chief characteristics assign them.

25. Location of Double Jetties Oblique to Shoreline. Among the more important cases of double jetties which have been constructed oblique to the shore line are the following:-

a. Shark River Inlet, N. J.

b. Manasquan Inlet, N. J.

c. Miami Harbor, Fla.

d. Sabine Pass, La., and Texas.

e. Newport Bay, Calif.

f. Humboldt Harbor, Calif.

g. Yaquina Bay, Ore.

26. Detailed Study of Manasquan Inlet, N. J.

a. Location. Manasquan Inlet, N. J., connects the Manasquan River and a number of coastal lagoons with the Atlantic Ocean, about 26 miles south of Sandy Hook.

b. History.

(1) Migration. The predominant littoral drift at Manasquan Inlet is from south to north. Prior to the construction of the jetties, the inlet had a tendency to move northward, owing to the elongation and overlapping of the south land point and erosion of the beach to the north. When the northward migration had proceeded far enough to considerably reduce the hydraulic capacity of the inlet, it would break through at some other point nearer the southerly end of the overlapping south spit. The old inlet would close, and the migration cycle would be renewed.

(2) Early Improvements. In 1881 the inlet was in about its present location. Between 1881 and 1886, north and south dikes were built by the Federal Government across the ends of the land points on each side of the inlet to stabilize the opening. At first these dikes had a beneficial effect, resulting in deepening the channel over the bar from about 1½ feet to about 4 feet. By 1884 a shoal was forming inside the inlet on the north side, and encroaching southward into the inlet channel. Progressive southward growth of the shoal forced the channel over against the south dike, and finally flanked the structure. By 1889 the inlet had broken through south of the south dike and the channel between the dikes was almost blocked by the inside shoal encroaching from the north and by a tailing sand spit growing northward from the south land point around the seaward end of the south dike and across that entrance to the inlet. The shoaling continued and by 1920 the inlet was completely closed by a high sand bar which filled the original channel between the dikes as well as the flanking channel south of the south dike. The inlet was reopened by local interests, and in 1922 a Haupt-designed "reaction" jetty of timber piles and cribbing was built by local interests along the south side of the entrance channel. This jetty completely failed of its purpose, and the inlet closed again in 1925. The reaction jetty was buried in the accumulated sand.

(3) Plan of Improvement. The River and Harbor Act of July 3, 1930 adopted the existing project for Manasquan Inlet (H.Doc.

No. 482, 70th Cong., 2nd sess.). This provided for two random stone jetties with steel sheet-pile core walls, extended at their shoreward ends by steel sheet-pile bulkheads. The north jetty is 1,230 feet long, and projects into the ocean along the alignment of the old north dike produced. The south jetty is parallel thereto, about 400 feet therefrom, and 1,030 feet long, and projects somewhat farther seaward than the north jetty. The jetties form an angle of about 120° with the shore line to the north and 60° with the original shore line to the south. They thus project at a sharp angle into the approach of the predominant littoral drift. The jetties were completed in 1931, and a channel 150 feet wide and 8 feet deep was then dredged between them to reopen the inlet. The remains of the old south dike and reaction jetty were removed. In 1933 the channel was enlarged to 250 feet wide and 10 feet deep between the outer ends of the jetties, flaring to 300 feet wide and 8 feet deep between the inner ends. The dredged material was deposited on the beach north of the north jetty.

c. Shore Line Changes since Jetty Construction.

(1) General. The changes in the shore line and the offshore area caused by the construction of the jetties are set forth in detail in the report of the Beach Erosion Board on "Beach Erosion at Manasquan Inlet, N. J., and Adjacent Beaches" (H. Doc. No. 71, 75th Cong., 1st sess.). As soon as the jetties began to project seaward of the shore line, the beach in the angle between the south jetty and shore began to advance and that in the angle north of the north jetty to recede. With

some occasional reversals due to storms, to the deposit of dredged material on the north beach, and to the construction of a protective bulkhead and 2 groins adjoining the north jetty, the general tendency for the beach to advance on the south and recede on the north of the jetties has continued.

(2) <u>South of South Jetty</u>. By 1931, when the jetties were completed, the beach south of the south jetty had advanced along the jetty about 400 feet. The advance tapered to zero about 1,000 feet south of the jetty. Since 1931, the junction point of the beach with the jetty has remained fairly constant, with minor advances and recessions of less than 50 feet. Within a short distance south of the jetty more extensive variations have taken place, affecting the shore line over a front of about 4,000 feet. Within 300 to 1,000 feet of the jetty, the shore line advanced from 50 to 100 feet between October, 1934, and March, 1935. It then receded from 25 to 80 feet by May 13, 1935, nearly to its former location. By July 20, 1937, it had advanced about 50 feet, and by January 6, 1938, had again receded by 20 to 25 feet in the 500-foot front next to the jetty while advancing some 40 feet along the shore further south. The net result of these changes during the past 3 years has been to change the average position of the shore line south of the jetties but little. The possibility is indicated that further considerable and permanent advance of the shore may not take place, at least at the rapid rate experienced during the first two or three years.

(3) North of the North Jetty. North of the north jetty, over a distance of some 4,000 feet along the shore, the net effect on the shore line itself has been one of recession. The amount of change increases as the jetty is approached. It is most noticeable within 1,000 feet thereof. Despite the fact that over 600,000 cubic yards of dredged material were deposited on the beach north of the jetty during the original opening of the inlet channel in 1931 to 1933, and material dredged during maintenance in 1937 was again deposited in this area, the shore line immediately north of the jetty receded so extensively and rapidly as to threaten to flank the shoreward end. This required the construction of a steel bulkhead and groin to hold the beach at that point. Even this protection was found insufficient, except in the first 230 feet or so north of the jetty, and in 1936 the Beach Erosion Board recommended that the existing bulkhead north of the jetty be extended northward along the shore over a distance of 2,400 feet from the jetty, and that four additional groins each 300 feet long and spaced 300 feet apart be built. To date the bulkhead has been extended northward to a length of about 700 feet from the jetty and the southernmost of the four additional groins has been constructed. These structures have resulted in holding the beach immediately north of the jetty.

d. Offshore Changes.

(1) General. Over large areas seaward of the 20-foot contour, the changes in progress along the beach appear to be practically

reversed. The tendency of the shore line itself to advance south of the jetties and recede north thereof has been accompanied by an erosion of the sea bottom off the advancing beach and a filling of the bottom off the receding beach.

e. Effects of the Jetties.

(1) The observed effects of the jetties are apparently due to a number of interacting causes. The prevailing winds blow for about 6 months of each year on the average from the northwest, west and southwest, or offshore. Many of the severe storms also blow from that quarter. Onshore winds blow somewhat more frequently from the south and southeast than from the north and northeast, but severe gales are experienced from both quarters. As a result, the predominant littoral drift is from south to north, but this direction is not infrequently and in important degree reversed.

(2) It is probable that the prevailing offshore winds and storms set up offshore surface currents with a corresponding onshore undertow, tending to move bottom material from deeper water toward the beach. This would explain in part the scouring in deep water and accretion of the beach observed south of the jetties. This material was also moved generally northward with the predominant littoral drift, particularly along the beach itself, until it reached the south jetty, where it tended to accumulate in the angle between jetty and shore. The beach slope was thus rapidly steepened until the waves were enabled to carry offshore down the slope about as much material as was brought

in by beach drift and other causes, whereupon the shore line became fairly fixed in an average curve about which it oscillated as varying directions and intensities of wind and wave caused erosion or accretion during alternating periods. These jetties have only been in position for some seven years, and it is not unlikely that over a longer period of time the advance of the south beach will proceed farther than it has so far - perhaps to and beyond the end of the south jetty.

(3) The principal changes north of the north jetty appear to have been due to winds and storms from the northeasterly quarter. The erosive effect of these was somewhat intensified by the cutting off by the jetty of replenishing sand moving north along the beach. Waves approaching the shore from the northeast struck both shore and jetty at an angle, and tended to run together along them, with increasing height and concentration of volume and energy into a smaller and smaller crest length, until the final concentration attacked the shore at its junction with the jetty. Thus the recession of the shore became more rapid and pronounced as the jetty was approached. This concentration of wave attack from the northeast is readily apparent in an aerial photo of the vicinity printed as Plate B in the report of the Beach Erosion Board, and attached hereto.

(4) The water piled up on the beach escapes as an undertow, carrying with it much of the beach material churned into suspension. This undertow is held, by the north-to-south drift induced by the northeast wind and waves, against the side of the jetty, following it

out to and around the end, whence the drift currents carry it away southward for deposit in deeper water offshore. This offshore undertow is probably responsible, in conjunction with waves breaking at an angle against the jetty, for the scouring of the deeper trench along the toe of the jetty slope. At the time the photo was taken, dredged material from the channel was being deposited on the beach north of the north jetty, and the course of that material is plainly shown in the picture.

(5) Ultimately the material so removed from the beach north of the jetty was returned northward by the predominant northward drift, and deposited largely in deeper water offshore beyond the ends of the jetties. This process would explain the shoaling offshore in the northern area instead of the scouring which might have occurred as it did to the south had not the scour been more than counteracted by the supply of dredged and other material carried into the area from the beach north of the jetty.

f. Discussion.

(1) The question of chief interest in connection with this study is what, if any, beneficial or injurious effects upon shore line changes were produced by the obliquity of the jetties to the shore line. Although any discussion of this aspect of the case must be to some extent conjectural, some pertinent evidence is afforded by a study of the aerial photo hereinbefore referred to and of another printed as Plate C in the report of the Board. Plate B records the conditions during a wave advance from the northeast; Plate C those

WAR DEPARTMENT CORPS OF ENGINEERS, U.S. ARMY

BEACH EROSION BOARD

MANASQUAN INLET, N.J.

AERIAL VIEW JULY 2, 1931

OFFICE OF THE CHIEF OF ENGINEERS, U.S.A. WASHINGTON, D.C. DEC 6, 1936

SUBMITTED APPROVED

Frank O. Bowman

CAPT. CORPS OF ENGRS., U.S. ARMY RECORDER

COL., CORPS OF ENGRS., U.S. ARMY SENIOR MEMBER

FILE NO 1-7-37.B TO ACCOMPANY REPORT DATED MAY 18, 1934

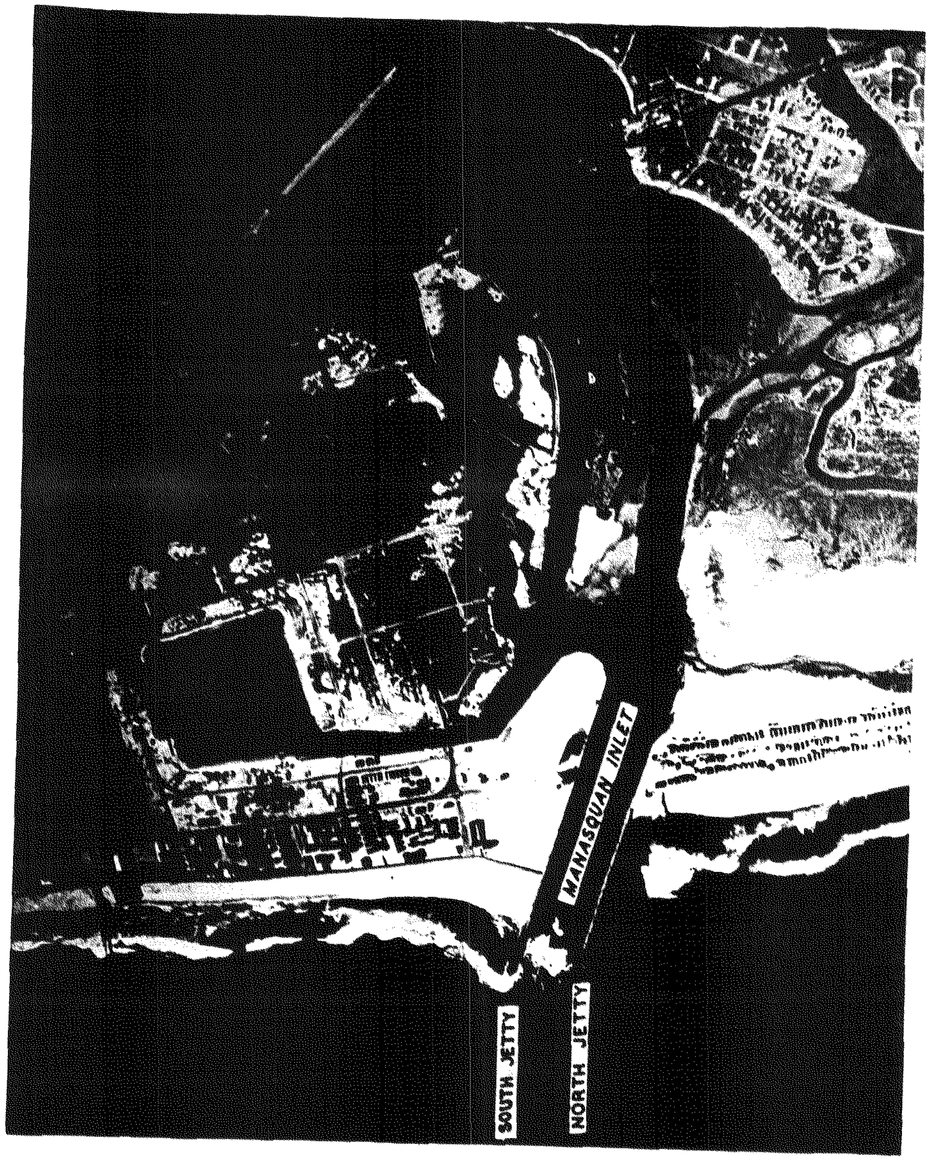
PLATE B

S.P.B. JETTY REPORT 8/15/38

FIG. 5

WAR DEPARTMENT

CORPS OF ENGINEERS, U. S. ARMY



BEACH EROSION BOARD

MANASQUAN INLET, N.J.

AERIAL VIEW JAN. 23, 1933

OFFICE OF THE CHIEF OF ENGINEERS, U.S.A. WASHINGTON D.C. DEC. 9, 1935

SUBMITTED	APPROVED
Frank O. Bowman	[signature]
CAPT. CORPS OF ENGRS., U.S. ARMY RECORDER	COL. CORPS OF ENGRS., U.S. ARMY SENIOR MEMBER

FILE NO. 1-7-37 C   TO ACCOMPANY REPORT DATED MAY 15, 1936

PLATE C

S.P.B. JETTY REPORT 8/15/38

FIG. 6

during a wave advance from the southeast.

(2) A study of Plate B shows quite clearly that when the waves are advancing from the northeast, both the volume of water in each wave and the associated energy are concentrated toward the junction of jetty and shore. It shows equally clearly that such waves rounding the seaward end of the south jetty are refracted into a curved form so that they meet the curve of the beach near the jetty nearly normally at all points. This refraction increases the length of each wave crest and diminishes the volume and energy at any given point, and therefore decreases the vigor of the wave attack on the shore.

(3) Plate C shows almost as clearly that waves from the southeast are travelling practically along the direction of the south jetty, when they reach it; there is thus less tendency toward concentration of the wave attack on the junction of jetty and shore. The ends of the waves are retarded against jetty and shore and their middle section forges ahead of the ends so that the wave strikes the curved shore about normally at every point, as do the northeast waves. It seems probable that the position and curvature to which the beach rapidly advanced at first, and which it seems to have approximately maintained in recent years, were determined by the fact that with that position and curvature the waves from all directions impinge upon the beach as nearly as possible normally at all points.

(4) In contrast to the considerable refraction of waves from the northeast by the south jetty, Plate C shows that waves from the

southeast are refracted but little in rounding the tip of the north jetty, and attack the beach at an angle almost from the junction of jetty and shore, instead of striking the beach about normally.

(5) Had the jetties been constructed substantially normal to the shore line, the following changes in their observed effects upon the shore line might have been thereby effected:-

(a) North of the north jetty, the length of wave crest from the northeast intercepted between the jetty tip and the shore would have been reduced and the concentration of their attack upon the junction of jetty and shore correspondingly decreased. The volume and force of the undertow would have been proportionally less. The greater change in direction of the southbound drift necessary to round the jetty would have dissipated more of its energy. Waves from the southeast, on the other hand, would have been more actively refracted, striking the shore near the jetty more nearly normally, with decreased tendency to move material northward along the beach. The rapid removal of beach and dredged material should therefore have been greatly retarded.

(b) South of the south jetty, the length of wave crests from the southeast intercepted between the jetty tip and the shore would have been increased, and those waves would have met the jetty at a greater angle. Concentration of wave attack on the junction of jetty and shore would have increased. The deflection of the predominant northward drift to round the jetty would have been facilitated, and the refraction of waves from the northeast and the bowing of waves from the southeast, diminished. All this should have led to a more effective and extensive removal of sand from the shore angle, and a diminished accumulation of material in that angle. The shore line changes on the two sides of the jetties should thus have been more nearly equalized.

27. Jetties at Shark River Inlet, N. J. The jetties constructed by local interests at Shark River Inlet, N. J., present a very similar case to those at Manasquan. These jetties project into the ocean at an angle of about 125° with the general shore line, and as at Manasquan Inlet, the acute angle faces into the northward advance of the predominant littoral drift. The changes in shore line caused by these jetties are strikingly similar to those heretofore described for Manasquan Inlet. There is the same accumulation of sand in the angle between the south jetty and the shore, with the difference that the shore has built out to the end of the jetty and the shoaling extended beyond it, instead of building out part way as at Manasquan, and then apparently halting its seaward advance at least temporarily. This difference may be due to the fact that the Shark River Inlet south jetty has been in place longer than that at Manasquan Inlet, or to the fact that the former is only 650 feet long whereas the latter is 1,030 feet long. There has been the same erosion of the shore line north of the north jetty, more active and extensive in the immediate vicinity of the junction of the jetty and shore, and which would presumably have progressed even farther had it not been checked by groins. There has been at Shark River Inlet a

similar general advance seaward of the 6-foot contour and a movement landward of the 12-foot and 18-foot contours. All these changes are susceptible of explanation on the same basis as those at Manasquan, without the complication arising from the deposit of a large volume of dredged material on the north beach.

28. Jetties Oblique away from Drift.

a. Location. Examples of jetties oblique to the shore line, but at an angle away from instead of into the direction of the predominant littoral drift are:-

(1) Miami Harbor, Fla.

(2) Sabine Pass, La. and Tex.

(3) Newport Bay, Calif.

(4) Humboldt Bay, Calif.

(5) Yaquina Bay, Oregon.

29. Jetties at Sabine Pass, La. and Tex.

a. Location. The jetties at Sabine Pass, on the boundary between Louisiana and Texas, have resulted in notable changes in the adjacent shore lines, and under water conditions which differed in some respects from those obtaining at other inlets. Sabine Pass is a tidal waterway some 7 miles long and 2,000 to 5,000 feet wide which connects Sabine Lake with the Gulf of Mexico. Sabine River empties into Sabine Lake and thence through the pass into the Gulf. The conditions are shown on U. S. Coast and Geodetic Survey Chart No. 517, and on the map herewith.

b. Conditions Prior to Improvement. Prior to improvement of the pass, there existed in the pass itself a narrow and winding channel with an available navigable depth of about 20 feet. Outside the Gulf entrance, the bottom sloped off gradually, and there was a bar across the entrance; in 1884, the 24-foot contour was about 18,000 or 20,000 feet offshore. The bottom material in the pass and offshore was chiefly soft mud, instead of the sand usually found at inlets. The flood current entered the pass around the east point, and the ebb current flowed out around the west point. The ebb currents had created and maintained a fairly fixed channel through the bar averaging about 4,500 feet wide with a controlling depth of 6 to 6½ feet. The prevailing winds were from the south to east quadrant, and the most severe storms were from the north and northwest in winter and from the southeast in summer. As a result, there was a marked predominant littoral drift from east to west past the mouth of the pass.

c. History. Under the original project for improvement of the pass, dredging was carried on every year between 1876 and 1881 in an attempt to provide and maintain an entrance channel through the bar 12 feet deep, 150 feet wide, and 2½ miles long. Although the desired depth was several times secured, shoaling followed rapidly and the channel deteriorated.

d. Plan of Improvement. The River and Harbor Act of August 2, 1882, provided for the two jetties (H. Doc. No. 47, 47th Cong., 1st sess.). The west jetty was begun in January, 1883, and the east in

March, 1885; construction proceeded alternately, and by 1896 the east jetty had been extended to a length of 19,500 feet and the west jetty to 14,875 feet. By August, 1900, the east jetty was 25,100 feet long and the west 22,000 feet long. The jetties were raised, repaired and somewhat extended from time to time. By 1912 the east jetty was about 25,270 feet long and the west about 21,860 feet long. The jetties are slightly converging to an opening 1800 feet wide at their seaward ends. They were built of random rock on rush mattresses.

e. Effect of Jetties on Channel.

(1) As the jetties advanced seaward, scouring took place between them, but to a much less extent than had been anticipated. By 1893, when dredging was begun in the entrance channel, the controlling depth had been increased by scour from 7 feet to a little over 10 feet. In 1893-94, a channel was dredged through the bar 16 feet deep by 100 feet wide. By 1895, the channel had been dredged to 25 feet deep by 100 feet wide. Between 1896 and 1899, 600,000 cubic yards were dredged from the channel to maintain the 25-foot depth. In 1900 and 1901, the channel shoaled from 25 feet to 20 feet, and 260,000 cubic yards were then dredged to increase that depth to 22.5 feet.

(2) Between 1901 and 1922, rapid shoaling took place continuously in the entrance channel, and maintenance dredging was required practically every year. During the 21 years, 7,850,942 cubic yards of mud, were dredged from the entrance channel in maintaining controlling depths ranging from 19 to 29 feet, on a 25-foot project depth.

(3) In 1922, the project dimensions were increased to 30 feet deep by 200 feet wide between the jetties and 33 feet deep by 450 feet wide seaward of the jetties. In 1935 the present project dimensions were adopted, namely, 600 feet wide and 36 feet deep from Gulf to the outer ends of jetties, decreasing progressively between the jetties to 400 feet wide and 34 feet deep at the inner ends of the jetties. Between 1922 and 1937, 25,376,357 cubic yards were dredged from the entrance channel in securing the enlarged project and even so full project widths have not yet been attained. Doubtless a considerable though indeterminable amount of this was material which accumulated in the channel during the period. In 1937 alone, 1,811,029 cubic yards were removed as maintenance.

(4) The history of this improvement shows that the jetties have had little effect in so concentrating the ebb currents as to assist materially in keeping the channel open by scour. The jetties were designed with the idea of maintaining a channel 20 feet deep by 100 feet wide. In the first place they proved inadequate even for that planned purpose, and in the second place, the cross-section of the existing channel is 6 to 8 times as great as that for which they were designed. Therefore, even had the original design been perfectly adequate for its purpose, it would be inadequate for the existing channel. This examplifies a fact common to practically every system of jetties included in this study, namely, that whatever engineering basis there may have been for the adopted spacing of the jetties was predicated upon

channel dimensions which were later increased so that even a design originally adequate for its purpose was no longer entirely effective. Jetties have been spaced too far apart in many more instances than too close together.

f. Shore Line Changes.

(1) East of the Jetties. In the 55 years since the jetties were begun, the shore line has advanced notably both east and west of the jetties. To the east, on the side from which the predominant littoral drift comes, the low water line has advanced next to the jetty about 7,400 feet into the Gulf.

(2) West of the Jetties. On the west or downdrift side, the shore line has advanced along the jetty about 4,000 feet.

g. Offshore Changes.

(1) East of the Jetties. On the east or updrift side, the 6-foot contour has advanced about 9,000 feet. The 12-foot contour receded at first about 1,500 feet between 1884 and 1922, then advanced again by about 2,000 feet by 1937, a net advance of about 500 feet. The 18-foot contour advanced about 2,000 feet between 1884 and 1894, then receded about 2,000 feet by 1922. It then advanced from 1,000 to 2,000 feet by 1937. The 24-foot contour has advanced fairly continuously a total distance of about 7,000 feet, chiefly in the form of a shoal just outside of and along the alignment of the east jetty. The 30-foot contour has advanced along the line of the jetties and channel by 10,000 feet or more.

(2) West of the Jetties. On the west or the downdrift

side, the 6-foot contour has advanced about 10,700 feet next to the jetty. It is now somewhat seaward of the 18-foot contour on the east side. The 12-foot contour has advanced some 8,000 feet and the 18-foot contour about 10,000 feet, the latter being now about opposite the 24-foot contour on the east side of the channel. The 24-foot contour has also advanced about 10,000 feet, and is now about 2,000 or 3,000 feet farther offshore to the west of the jetties than to the east.

(3) Summary. There has thus been greater accretion on the west or downdrift side of the jetties than on the east or updrift side. Approaching the jetties from the east, the 18-foot contour, for example, sensibly parallels the shore at a distance of 13,000 to 14,000 feet therefrom until the jetties are almost reached. It then bends sharply offshore around the jetty ends. West of the jetties, however, it swings farther offshore, with a maximum offshore distance of about 22,000 feet some 4,000 feet west of the jetties, returning gradually to its usual offshore distance of some 13,000 feet only at a point about 38,000 feet west of the jetties. The jetties have thus created a rounded shoal projecting from shore, but instead of the shoal being disposed more or less symmetrically about the jetties as an axis or about an axis on the updrift side, the axis in this case is about 10,000 feet on the downdrift side of the jetties.

(4) Discussion. The formation of this extensive shoal on the downdrift rather than the updrift side of the jetties is probably due to two principal causes. First, the nature of the bottom material, which

is soft mud. Currents carrying this material from the east along the shore toward the jetties can much more readily retain it in suspension and carry it around and past the jetty ends for deposit in the quieter water west of the jetties than if it were heavier sand. Ebb currents issuing from between the jetties trend off to the west, and carry their suspended mud in that direction. Second, a large amount of material dredged from the channel has been deposited west of the jetties, and has contributed in no small measure to the formation of the shoal on that side. The long flat slope offshore tends to cause the higher waves to break far out and to be converted largely into waves of translation, and the frequency of offshore winds and gales from the north and northwest, by inducing a shoreward undertow, may also contribute to the general onshore movement of bottom material. The shore-building forces predominate over the shore eroding forces, and the general resultant is a tendency for the shore to advance on both sides of the jetties.

30. Comparison of Cases. In the foregoing cases of jetties oblique to the shore line into the advance of the littoral drift (Manasquan Inlet and Shark River Inlet) the general effect on the shore line has been erosion in the downdrift obtuse angle and accretion in the updrift acute angle. At Sabine Pass, where the jetties were oblique away from the direction of the littoral drift, the result was accretion in both angles, but a much greater accretion in the downdrift acute angle. At Miami Harbor, Florida, Humboldt Bay, California, and Yaquina Bay, Oregon,

the effect of the jetties has also been accretion in both angles, but with the greater accretion in the updrift angle. All these cases, however, tend to confirm the analysis of the effect on the shore line changes at Manasquan and Shark River Inlets which would have been produced by diminishing the obliquity of the jetties (Pars. 26f(5)(a)-26f(5)(b)) It may even be concluded that some slight obliquity away from the advance of the predominant littoral drift might be advantageous insofar as equalizing the shore line changes on both sides of the jetties, and particularly in avoiding erosion in the downdrift angle. Before this conclusion can be accepted, however, the case of the jetties at Newport Bay, California, should be considered.

31. Jetties at Newport Bay, California.

a. Conditions Prior to Improvement. The entrance to this harbor was very unstable prior to the improvement. It moved eastward 2,000 feet between 1875 and 1888. The deeper channel through the entrance also shifted back and forth, tending to be close to the easterly side during the fall and winter months, then shifting gradually across to the westerly side and being close to that side during the summer months. The shore line lies generally southeast and northwest. The jetties project slightly east of south, forming an angle of about 135° with the shore to the west and 45° with that to the east. Wave approach is usually from the west or southwest. Flood tide currents set northward along the coast. There seems thus to be a conflict of tendencies to littoral drift both northwest and southeast with first one and then the other ascendant, and no well-defined predominance in either direction.

b. Plan of Improvement.

(1) The west jetty was constructed in 1918, 2,200 feet long into 18 feet of water at its outer end. The east jetty was built in 1928, to a length of 700 feet into water 5 feet deep at its outer end. In 1935 and 1936, the west jetty was extended to a length of 2,860 feet and the east to 1,620 feet.

c. Effects of the Jetties.

(1) The immediate effect of the construction of the west jetty was erosion of the beach to the west, particularly active in the vertex of the oblique angle between jetty and shore, and active recession of the east land point and beach. After construction of the east jetty, the shore in that acute angle began to advance, and has filled out along the jetty. Recession of the beach west of the jetties has continued, and local interests counteracted it to some extent by pumping about 5,000,000 cubic yards of sand from Newport Bay across the barrier strip and depositing it on the beach.

(Note) If predominant drift is east to west, this places Newport in the class with Manasquan and Shark River, with similar effects on shore line. If from west to east, it places Newport in an intermediate class, with the orientation of Sabine Pass, Miami, et. al. but shore line effects of Manasquan. The final write up and placing in report will have to await the receipt of additional information.

32. Parallel Jetties Normal to Shore Line.

a. Location. Another type of jetties is that of parallel jetties substantially normal to the shore line. Instances of this type on various sections of the coast are:-

(1) Cold Spring Inlet, N. J.

(2) Savannah Harbor, Ga.

(3) Fort Pierce Inlet, Fla.

(4) Lake Worth Inlet, Fla.

(5) Freeport Harbor, Tex.

(6) Coos Bay, Oregon.

33. Jetties at Cold Spring Inlet, N. J.

a. Location.

(1) Cold Spring Inlet, N. J. is located near the southerly extremity of the New Jersey Coast, where the general southwesterly trend of the coast bends sharply to the west to Cape May Point, on the east side of the entrance to the Delaware River. It is about 5½ miles slightly north of east of Cape May Point. The inlet connects Cold Spring Harbor (also known as Cape May Harbor) with the Atlantic Ocean. The general vicinity is shown on U. S. Coast and Geodetic Charts No. 1219 and 234, and on the map herewith.

b. Description.

(1) Owing to the configuration of the shore line, Cold Spring Inlet is exposed to wave attack from the southwest through southeast to northeast directions only. The violent gales are more frequently from the northeast, and tend to move beach material to the west toward Cape May Point. This tendency is reinforced by strong

flood tide currents moving westward toward the entrance to Delaware Bay, and by eddy or reaction currents which also set to the west along the shore when the ebb currents are issuing from the bay. Except for the comparatively rare times when storms from the southwest are blowing, the littoral drift is practically constantly from east to west. The shore line is straight and free from any but minor irregularities. The mean tidal range at the inlet is $4\frac{1}{2}$ feet, with very much greater storm ranges.

c. History.

(1) Prior to construction of the jetties, the gorge of the inlet passed through the barrier land strip between Cold Spring Harbor and the ocean in a south-southeasterly direction. It was fairly stable in position and dimensions. The inlet was about 500 feet wide, with depths of as much as 29 feet in the gorge. The ocean entrance to the inlet was obstructed by an offshore bar about $\frac{1}{2}$ mile out, over which depths of 3 to $3\frac{1}{2}$ feet were found. Under the urge of waves and currents, beach and bottom material was carried practically continuously along the coast from east to west to be deposited ultimately on the extensive shoals off Cape May Point in the entrance to Delaware Bay. A gradual recession of the shore line had been taking place for many years.

d. Plan of Improvement.

(1) The River and Harbor Act of March 2, 1907 (H. Doc. No. 388, 59th Cong., 2nd sess.) provided for a channel 25 feet deep and 400 feet wide through the inlet, protected by two parallel jetties 700

feet or more apart. The east jetty is a rubble mound 4,548 feet long; the west jetty is 4,410 feet long, of which the shoreward 2,000 feet is of stone filled pile and timber construction and the balance rubble mound. The jetties were built 850 feet apart. Construction of the jetties began in 1908 and was completed in 1911. About 326,049 tons of rock were used, in addition to piling, brush, and other materials. The cost was $721,203.12 not including incidental government costs. Dredging of the channel was completed in 1913. The structures have thus been operative for 25 years or more. During the dredging of the channel, about 1913 and 1914, some 1,000,000 cubic yards of spoil were placed upon the beach west of the west jetty. A small quantity of spoil was also deposited east of the east jetty.

e. Shore Line Changes.

(1) Since construction of the jetties the principal changes in the shore line which can be ascribed in part at least to their presence have been an advance east of the jetties and a recession west thereof. The beach east of the east jetty has advanced 1600 feet along the jetty itself, and the advance has been backed up along the beach in progressively diminishing amount as far as Wildwood, N. J. about 5 miles east of the jetties. West of the jetties the beach advanced about 1,000 feet by 1924, due in part at least to the deposit of dredged material in that area, but has since receded by some 200 feet along the jetty, the same recession extending to a point about 6,700 feet west of the jetties, where the system of groins protecting the developed area of

Cape May begins. Owing to the action of these groins, assisted by the influx of material eroded from the unprotected area between the jetties and groins, the changes which might otherwise have resulted along that section of the shore have been largely prevented, and the shore line has remained substantially unchanged.

34. Other instances of parallel jetties normal to the shore line on a straight coast line which have produced similar effects on the shore line are those at Fort Pierce Inlet and Lake Worth Inlet, Florida; in both cases accretion has occurred on the north or updrift side and erosion on the south or downdrift side, except for a comparatively small area in the angle between jetty and shore, where accretion has occurred. At Freeport Harbor, Texas, a somewhat different result followed construction of the jetties. Between about 1890 and 1930, the shore line on the east or updrift side advanced about 900 feet while that on the south or downdrift side advanced over 4,000 feet. During that period, however, the entire discharge of the Brazos River passed into the Gulf between the jetties, carrying with it large quantities of silt, especially during floods. This silt was carried westward by the predominant littoral drift and deposited to the west of the jetties, causing that shore to advance more rapidly than that to the east, the effect being similar to that at Sabine Pass, Louisiana and Texas (Par. 29g(3)). In 1930, however, the discharge of the Brazos River was diverted to a new channel, about 8 miles south of the jettied entrance, and since then the shore line changes have taken place under more usual conditions.

Under these conditions the east or updrift shore has advanced from 100 to 600 feet over more than a mile of shore whereas the west or downdrift shore has receded by as much as 1,000 feet or more in places. Since the elimination of the river deposits, therefore, the effect of the jetties at Freeport have been the same as at the other similar locations heretofore mentioned.

35. At Coos Bay, Oregon, jetties normal to the shore line have caused advance on both the updrift and downdrift sides. In that case, the situation is complicated by the fact that, about a mile south of the jetties, on the downdrift side, a rocky promontory projects sharply from the shore into the ocean about 1,500 feet, acting itself as a long groin to trap material rounding the ends of the jetties or tending to escape southward along the intervening shore. This material is then carried back toward the downdrift side of the south jetty during the frequent severe storms blowing from the west, and is thus held in the pocket between the jetty and the point.

36. Jetties at Savannah, Ga.

a. Description of Conditions.

(1) The jetties at the mouth of the Savannah River, Ga., present complications not found in those heretofore considered. Instead of extending directly into the ocean from a fairly uniform and featureless shore line, the Savannah River jetties are located at the apex of a triangular indentation in the general run of the coast. From the north land point at the mouth of the river, the shore extends northeasterly.

From the south side of the mouth it extends generally somewhat south of east to the northeast tip of Tybee Island, breaking there sharply to the south. From Hilton Head, about 8 miles northeast along the coast from the Savannah River, a long shoal projects east of south about 8 miles. A straight line drawn from the southeasterly tip of this shoal to the mouth of the Savannah River is also about 8 miles long, and passes through the northeast point and roughly along the north shore of Tybee Island.

(2) The sphere of influence around the mouth of the Savannah River is thus in the form of an equilateral triangle, of which the east side is formed by the shoal projecting from Hilton Head, the west side by the shore line between Hilton Head and the mouth of the Savannah River, and the south side or base by the shore between the river mouth and the northeast point of Tybee Island and by shoals projecting eastward from the point of the island. The Savannah River empties into this triangular area at its southwest vertex and in an easterly direction parallel with its base. Calibogue Sound empties into it at its northern apex, west of Hilton Head, and in a north and south direction roughly perpendicular to the base. The main channel from the triangle to the ocean passes out in a southeasterly direction at the southeast vertex of the triangle. The general features of the locality are shown on U. S. Coast and Geodetic Survey Chart No. 440 and on the map herewith.

(3) From a point on the crest of the east shoal about

6 miles south of Hilton Head, a straight line drawn along the crest of Gainor Bank to the mouth of New River, about the midpoint of the west side of the triangle, divides the area roughly into the spheres of influence of Calibogue Sound and the Savannah River. Flood tide currents moving along or toward the shore from the open ocean pass in a westerly direction over the crest of the east shoal and are immediately drawn northward along the deeper channel west of the shoal to enter Calibogue Sound. Ebb currents issuing southward from the sound spread gradually eastward seeking to escape over the crest of the east shoal. There is a general concentration of the flood currents toward the shore and the north end of the shoal. The ebb currents issuing from the sound tend to carry southward along the shoal before being diverted seaward to pass over it. These back and forth currents across the shoal create and maintain 3 or 4 shifting curved channels through the shoal.

(4) Flood tide currents entering the triangle through the channel and over the shoals at its southeast apex are drawn sharply around the projecting northeast tip of Tybee Island and thence westerly toward and into the entrance of the Savannah River. Prior to the construction of the jetties, the ebb currents also followed that course in reverse, issuing eastward from the three channels of the lower river, and being crowded against the tip of Tybee Island by the considerable remnant of the southward moving ebb current from Calibogue Sound which had not escaped over the east shoal, as well as by less

potent ebb currents from New River and other small streams entering the ocean along the northwest side of the triangle.

b. Conditions Prior to Improvement.

(1) Effects of Tidal Currents. Prior to the improvement, the interaction of these various currents had produced the following principal effects upon the shore line and offshore bottom:

(a) Flood currents rounding Tybee Island Point had eroded material from the east face of the point and carried it westward toward the mouth of the Savannah River. The ebb current, reinforced by the river flow, had brought material downstream for deposit at the mouth. Material from both directions had thus formed shoals in and outside of the river mouth. The river discharge on the ebb had created and maintained 3 more or less equal channels, separated by long narrow sand bar islands through these shoals. Through these three channels the river entered the ocean and the constant conflict between ebb and flood currents resulted in shiftings and shoalings which rendered none of the channels consistently suitable for navigation.

(b) The preponderant ebb current issuing eastward from the river, compounded with the ebb currents from New River and Calibogue Sound moving southeast and south respectively, cut close to the tip of Tybee Island and in turn eroded the north face of the point and carried material eastward around it for deposit offshore along the easterly shore of the point, building out a shoal in that area, to which was added material brought south along the seaward face of the east shoal by the predominant north-to-south littoral drift. Along the east shore of Tybee Point there was thus a constant conflict between a northward movement of material by flood currents and winds from the southeast, and a southward movement by ebb currents and northeasterly winds and gales. The net resultant of this conflict was a preponderant movement toward the south with a recession of the tip and east shore of the island. Meantime the southerly tip of the east shoal tended to elongate southward and encroach on the channel under the urge of the predominant littoral drift. This trend was counteracted by the tendency of the ebb current to cut across the south tip of the shoal and maintain its course to sea.

c. Plan of Improvement.

(1) The improvement of the river mouth for navigation consisted of the construction of several wing dams and training walls by which the northernmost of the three outlets was blocked off, the south channel partially blocked, and the river discharge concentrated and directed largely into and along the middle channel, and in the further confining and directing of the current between two parallel jetties extending seaward from the entrance to that channel, as shown on the maps. These structures were provided in successive stages chiefly between 1885 and 1895.

d. Effect of Jetties.

(1) On Channel. The improvement has resulted in considerable modification of the regimen of the waterway, and in correspond-

ingly considerable shore line changes. At the mouth of the river, increasing the capacity of the middle channel by scour and dredging has diminished the proportion of the tidal and river flow carried by the south channel. This resulted in shoaling in that channel and in other side channels. The jetties now confine the river discharge to a point north of and slightly beyond the northeast tip of Tybee Island, thereby eliminating the former erosion of that tip by ebb currents. The ebb currents are no longer deflected so far south by the New River and Calibogue Sound currents. They impinge upon the west side of the east shoal a mile or more farther north than was formerly the case. The current is then deflected more sharply southeastward along the west edge of the shoal and travels farther in that direction before swinging toward the east into the open ocean.

(2) On Tybee Island. On Tybee Island, the tendency of the flood currents has always been to erode the east shore and deposit around the tip to the north. The ebb currents tended to erode the north shore and deposit on the east. Prior to construction of the jetties, the ebb currents were more effective than the flood. There was deep water and a straight shore on the north face of the point, and shoal water and a projecting shore on the east face. The diversion of the ebb currents north and east away from the point has given full play to the flood currents which still round the point. This is probably supplemented by an eddy current when the ebb is running. As a result, there has been erosion in the entire offshore area east of Tybee Island.

The east face of the point has receded by as much as 1,600 feet, whereas the north tip has advanced by about 2,400 feet toward the seaward ends of the jetties. The entire area north and northwest of the point between it and the south jetty has shoaled. Material carried into that area by the flood currents has been picked up in part by ebb currents flowing out of the south channel and between the south jetty and the north shore of Tybee Island. It moves eastward past the tip of the island to form a pointed shoal extending somewhat south of east from the tip of the island roughly along the south edge of the present ship channel. The south tip of the east shoal has advanced southward by some 4,000 feet, and the course of the deep-water channel has become more zig-zag.

37. Converging Jetties. Examples of converging jetties in which the shoreward ends are considerably farther apart than their seaward ends are:-

a. Newburyport Harbor, Mass.

b. Ocean City, Md.

c. Winyah Bay, S. C.

d. Charleston Harbor, S. C.

e. Fernandina Harbor, Fla.

f. St. Johns River, Fla.

g. Galveston Harbor, Tex.

h. Brazos Island Harbor, Tex.

i. Coquille River, Ore.

j. Umpqua River, Ore.

k. Columbia River, Oregon.

l. Grays Harbor, Wash.

38. Jetties at St. Johns River, Florida.

a. Location.

(1) As a comparatively simple instance of converging jetties those at the mouth of the St. Johns River, Florida, may be cited. Their vicinity is shown on U. S. Coast and Geodetic Survey Charts Nos. 577 and 1243, and on the map herewith.

b. Conditions Prior to Improvement.

(1) Prior to improvement, the river entrance was very unstable. Just within the mouth the width gradually increased from 1.735 feet at Mayport to about 2,500 feet at the southwest point of Fort George Island, the north land point of the entrance. The shore lines then diverged gradually, the north shore soon curving northward away from the entrance, whereas the south shore continued south of east for about two miles before recurving toward the south. The south land point thus projected seaward over a mile farther than Fort George Island. There was a fairly stable channel within the river, 400 to 600 feet wide with an available navigable depth of 20 to 21 feet. But as the entrance flared into the ocean, the depths decreased over a bar completely across the entrance. Parts of this bar were bare at low water and the maximum depths on the crest of the bar were only 6 to 8 feet.

(2) The prevailing winds for about 80 per cent of the

year are from the southeast. These are usually moderate. The violent gales from the northeast usually occur in winter. There is a long slow movement of beach material from south to north during most of the time, and the beaches tend to build out slowly. This tendency is more than counteracted by the rapid movement of beach material from north to south during the northeasters. Although the prevailing drift is from south to north, the predominant drift is from north to south.

(3) Under the influence of the predominant drift, the channel over the bar was originally crowded southward toward the long, straight northeast face of the south land point. When it reached its southernmost position it would break through at some point nearer the northern end of the bar, and repeat its migration. There were also abrupt non-periodic shiftings due to storms. The crests of the shoals which were bare at low water moved about all over the bar area. These changes are clearly shown on a map published in the Annual Report of the Chief of Engineers for 1879, opposite page 784. The mean tidal range at the entrance is 5.3 feet.

c. Plan of Improvement.

(1) The original plan for the jetties provided that they were to start from opposite land points of the entrance and converge to near the bar, extending then parallel and 1,600 feet apart. The north jetty was to be 9,400 feet long and the south jetty 6,800 feet long, extending to the 16-foot contour on the seaward face of the bar. The outer 2,000 foot section of each jetty was to be built to half-tide

level and the remaining shoreward sections to 3 feet below mean low water. They were to be 20 feet wide on top, and to be built of alternate courses of brush mattress and stone, but the use of brush was found unsatisfactory due to the inroads of the teredo, and was soon abandoned. It was also found advisable to raise the jetties beyond the elevations originally planned.

(2) The south jetty was begun in 1880 and the north jetty in 1882. They were raised and extended at various times and completed to their present lengths in 1895 and 1900 respectively. The north jetty is 14,300 feet long and the south jetty 11,183 feet long. The shore ends are about 6,000 feet apart, and the jetties converge to 1,600 feet apart at a distance of 4,022 feet from their seaward ends. From this point they are parallel to the ends. They were built of granite, partly on brush mattresses but chiefly without, and stone has been added from time to time to raise them to their present height of 8 feet above mean low water. In recent years several thousand feet of the shoreward end of the north jetty have been capped with concrete to prevent passage of sand through the interstices of the jetty.

(3) The cost of the north jetty has been $990,410, and of the south, $1,119,014, for new work. About $1,500,000 have been spent for maintenance of the structures.

d. Shore Line Changes Since Construction of the Jetties.

(1) The principal changes in the adjacent shore lines and bottom since construction of the jetties have been:

(a) The current velocities between the jetties have been so concentrated and intensified that a channel 800 feet wide and 30 feet deep is now maintained between them with comparatively little dredging.

(b) The offshore bar, formerly about midway of the jetty length, has been moved seaward to its present position about 4,000 feet seaward of the jetty ends, and somewhat south of the jetty alignment. At first some dredging was required to provide project depth through the bar in its new position. Since then it has remained substantially stable.

(c) North of the jetties, accretion has extended the south point of Little Talbot Island southward by about 3,000 feet. This has forced the mouth of Fort George River, which empties into the ocean around the south tip of Little Talbot Island, southward almost against the north jetty. The mouth of this river formerly went through a cyclic migration from north to south similar to that of the channel through the bar. It now seems fairly stabilized in its position close to the north jetty. A long narrow sand point has built out along the north side of the north jetty to about 4,500 feet from the original shore line. This point is formed partly of beach material brought down the coast and partly of material dredged from the channel between the jetties and spoiled north of the north jetty.

(d) For about 1 mile south of the south jetty, accretion has filled in the angle between the jetty and shore, the maximum advance along the jetty being some 4,000 feet. This prograding seems to be continuing. This accretion has apparently been caused by the deposit of sand carried northward along the beach by southeast winds during the summer months.

(e) Beginning about 1 mile south of the jetties, the shore line for several miles farther south has receded considerably, the effect having been particularly noticeable during northeasterly gales. This recession has presumably been somewhat hastened by the interception of the predominant southward drift by the jetties.

39. Jetties at Brazos Island Harbor, Texas.

a. Shore Line Changes.

(1) The shore line changes at Brazos Island Harbor, Texas, have been similar to those at the St. Johns River entrance. The converging jetties become parallel and 1,200 feet apart for the seaward 2,000 feet of their lengths. North of the north jetty, on the updrift side, the mean low water shore line has generally advanced over a distance along the shore of about $\frac{3}{4}$ mile, the greatest advance being along the jetty and amounting to over 800 feet. South of the south jetty, on the downdrift side, the shore line advanced along the jetty about 1,600 feet, but the advance extended only over about 2,000 feet of the beach. South of the north jetty there has followed a general recession of the seaward side of the north land point over a distance of 1,000 feet from the jetty, the maximum recession having been about 400 feet. North of the south jetty the shore receded

rapidly by as much as 1,100 feet over a distance of 1,700 feet from the jetty between 1927 and 1936, but has advanced slightly since.

40. Jetties at Coquille River, Oregon.

a. Shore Line Changes.

(1) The results at Coquille River, Oregon, have also been similar to those at the St. Johns River. North of the north jetty, on the updrift side, the high water shore line has remained fixed except within about 1,000 feet of the jetty, in which angle the shore line advanced by as much as 500 feet along the jetty. The low water line, on the other hand, advanced between 400 and 600 feet over more than a mile of shore. South of the south jetty, both high water and low water shore lines advanced about 600 feet along the jetty. The advance extended over a distance of some 4,000 feet south to where Coquille Point and a group of rocky islands act as a huge groin projecting into the ocean and aiding in retaining the deposited sand between them and the jetty. The 18-foot contour advanced 200 to 300 feet over a space of 2,000 feet seaward of the ends of the jetties. Inside the base of the south jetty, a recession of the south land point of about 750 feet took place.

41. Jetties at Umpqua River, Oregon.

a. Shore Line Changes.

(1) At the mouth of the Umpqua River, Oregon, there has been the same advance of the shore line on the north or updrift side, amounting to 5,000 feet along the north jetty, and extending over

was carried forward ahead of the north jetty. Both jetties were below low water and sand was carried southward across the north jetty line to form a shoal encroaching upon the channel and driving it over against the south jetty. This shoal finally crossed the channel necessitating removal of 600 feet of the jetty to enable ships to traverse the channel. The channel continued to swing to the south till 1897, when, with increasing height of the south jetty, a new deep channel started to scour between the jetties about 1,000 feet south of the north jetty. During 1897-98, the south channel shoaled so rapidly as to require frequent maintenance dredging and removal of parts of the south jetty, to open a gap for the channel to pass through. During 1900-1901, the north jetty was raised and extended rapidly, with a simultaneous acceleration of the scouring of the new north channel. This channel finally broke through the bar to deep water and was put in service in 1902.

d. Changes since Completion of Jetties.

(1) In Channel. After completion of the jetties the north channel began to shoal again, and the channel along the south jetty to deepen. The crest of the bar moved eastward to and beyond the ends of the jetties. As a result of this action and dredging, there are at present two channels between the jetties, one near each jetty, with depths of from 30 to over 40 feet, separated by a middleground shoal about 1,000 feet wide between 30-foot contours. Depths over the shoal vary from 14 to 28 feet. This situation could doubtless have been avoided had the parallel section of the jetties been spaced considerably

less than 4,000 feet apart. The channel along the north jetty alone breaks through the bar to the northeast around the seaward end of the north jetty, and is the one used by shipping. The south channel fans out over the bar, with a controlling depth of about 22 feet.

(2) Shore Line Changes.

(a) North of North Jetty. The shore line has built out along the jetty about 1,300 feet between 1900 and 1934, the advance tapering off for about 2 miles north of the jetty.

(b) Between Jetties. The shore line has built out along the south side of the north jetty about 1,300 feet between 1900 and 1934, a considerable part of the accretion being ascribed to the passage of sand through the jetty. On the north side of the south jetty, the shore line advanced about 1,200 feet along the jetty between 1879 and 1900, the advance diminishing to zero within 2,000 feet along the shore. Since 1900, a slight recession of 100 to 250 feet has taken place, the least change being against the jetty.

(c) South of the South Jetty. The low water line has advanced along the jetty about 800 feet, the advance diminishing progressively for a mile south along the shore.

(3) Offshore Changes.

(a) North of the North Jetty. Between 1900 and 1934, the 6-foot contour near the junction of jetty and shore has advanced seaward and the old north channel filled up. Farther offshore off the seaward two-thirds of the jetty length, the crest of the original bar has scoured, the amount of the deepening increasing progressively as the end of the jetty is approached.

(b) Between the Jetties. Except for shoaling in the immediate angle between jetty and shore, scouring has generally taken place. The crest of the bar has been carried seaward and southward. The outer 30-foot contour, which was formerly 500 or 600 feet beyond the jetty ends, is now about 4,000 feet seaward thereof.

(c) South of the South Jetty. The angle between jetty and shore has filled in. The 6-foot contour has moved seaward as much as 3,000 feet in places, and the old south channel has filled in. On the other hand, off the seaward half of the jetty length, where the original bar crest was located, scouring has taken place. Farther south along the shore, the 12-foot contour has receded 700 to 900 feet and the 6-foot contour nearly 2,000 feet in places.

(4) Summary of Changes. Apart from the deepening between the jetties due to their confining of the currents, the effect both north and south of the jetties has been to flatten off the crest of the old offshore bar, carrying some of the material shoreward into the angle between jetty and shore, and some probably seaward to the new bar. It is probable that the results would have been more generally beneficial had the jetties been spaced closer together.

43. Jetties at Winyah Bay, S. C.

a. Description.

(1) The jetties at Winyah Bay, S. C., are in many respects

comparable with those at Fernandina Harbor. As in that case, the jetties converge from the north and south land points to a distance of 4,000 feet apart for 4,179 feet at the outer ends. The south jetty, however, is straight and extends 4,200 feet beyond the north jetty. The ebb current issuing from the inlet approaches the south jetty almost at right angles and has to be turned to an easterly course to reach the sea.

b. Effects of the Jetties.

(1) General. In general, the effects of these jetties have been similar to those at Fernandina. The original offshore bar has been deepened both between, north of and south of the jetties.

(2) North of North Jetty. The north point shore line has extended along the jetty about 2,500 feet and advanced seaward away from the jetty by between 100 and 1,500 feet. Seaward of the new low water shore line, however, there has been a general deepening where the former offshore bar was located, until the former 18-foot contour was reached; beyond that, shoaling took place so that the old 18-foot contour advanced seaward by about 6,000 feet on line with and for 10,000 feet north of, the alignment of the north jetty.

(3) South of South Jetty. An even more pronounced accretion and shoaling has taken place south of the south jetty with the exception of a comparatively small area along the crest of the original bar, where deepening has occurred, the area between the seaward end of the south jetty and the shore has shoaled. The former main channel, which extended across and south of the south jetty near shore, has filled

up, and the shoaling has been so great as to create a crescent-shaped sand bar, bare at high tide, following roughly an arc of a circle drawn about the shoreward end of the jetty as a center with a radius equal to half the length of the jetty. This bar extends from the south side of the jetty around to within about 2,500 feet of the shore.

(4) Between the Jetties. There is a considerable similarity between the Winyah Bay jetties and those at Fernandina. There are two deeper channels at the entrance, one near each jetty, separated by a middleground shoal. In this case, however, owing to the considerable change in the direction of the current, the deepest channel hugs the south jetty. Depths in this channel are 20 to 26 feet. The north channel is wider but more shallow. Depths are from 12 to 23 feet. There are general depths of 3 to 6 feet on the crest of the middleground shoal.

c. Discussion.

(1) Here again it seems that the width of 4,000 feet left between the jetties was unnecessarily and perhaps inadvisedly great. Except in the vicinity of the middleground shoal and the former main channel near the shore end of the south jetty, where shoaling has occurred, the interjetty area has generally scoured, particularly where the crest of the former offshore bar was located. The principal differences between the Winyah Bay and Fernandina jetty effects has been that there has been less deposit to the north and more to the south of the former than of the latter.

44. Jetties at Columbia River, Oregon.

a. Location.

(1) One of the largest and most successful cases of converging jetties is that at the mouth of the Columbia River, Oregon. They are shown on U. S. Coast and Geodetic Survey Chart No. 6151 and on the accompanying map.

b. Conditions Prior to Improvement.

(1) Prior to any improvement, the river at its mouth flowed northwest between Point Adams (the south land point at the entrance) and Chinook Point. It then swung to a westerly course around the north tip of Point Adams and entered the ocean between Point Adams and Cape Discovery, a rocky headland which formed the north land point of the entrance. Landward of Cape Discovery, Bakers Bay opened northward off the main course of the river. The river channel at times followed a sharp loop into Bakers Bay and passed out to sea on a southwesterly course past Cape Discovery. The width between Point Adams and Chinook Point was about 18,000 feet and between Point Adams and Cape Discovery about 30,000 feet.

(2) The large amount of sand brought down by the river, and the wide variations in current velocities between flood and low stages, led to a constant and considerable shifting of the sand bars both within and without the entrance. At times there was only one main channel. Usually there were two or three branching channels separated by shifting shoals. At times the main channel would swing

close around the north tip of Point Adams and enter the ocean in a southwesterly direction. At these times there would be an extensive middleground shoal in the area between Point Adams and Cape Discovery. At other times a sand spit known as Clatsop Spit would build out northwest from Point Adams toward Cape Discovery, forcing the channel offshore and diminishing the area of the middleground shoal, or even eliminating it entirely. Projecting south and southwest from Cape Discovery there was a second shoal, known as Peacock Spit. Between the main channel and the loop channel in Bakers Bay there is a third shoal known as Sand Island. Connecting the west shore of Cape Discovery with the west shore of Point Adams there was a wide crescent-shaped offshore bar, of which Peacock Spit and Clatsop Spit were the north and south shoreward ends, respectively.

(3) Through all the shiftings of shoals and channels within the river entrance, there was usually maintained a practicable depth of at least 40 feet in the main channel until the offshore bar was reached. There the channel shoaled and widened, and the available depth over the bar was generally less than 30 feet, and sometimes as little as 20 feet. This fact, added to the fact that the channel crossed the bar, from one time to another, over the entire arc between close to Point Adams to close to Cape Discovery, hampered the use of the river entrance as a harbor by shipping. A good account of the changes in the conditions up to 1903 is found in the Annual Report for 1903, beginning on page 2305.

c. Plan of Improvement - (Single Jetty)

(1) Description. It was at first believed that a single south jetty, extending northwesterly from Point Adams along the crest of Clatsop Spit to the offshore bar, and preventing the escape of a considerable portion of the ebb current southwest across the spit, would sufficiently concentrate the ebb flow upon a restricted section of the offshore bar to create and maintain a channel through the bar with a navigable depth of 40 feet. The construction of the jetty was begun in 1885, and it had advanced to its planned length of $4\frac{1}{2}$ miles by 1892, although not to its full final height throughout. The jetty was constructed of a mattress foundation course with rock piled thereon, the materials being placed from a trestle.

(2) Effects of Single Jetty.

(a) As soon as the jetty began to project from the shore, sand began to accumulate against both south and north sides. The spit continued to lengthen and widen between low water lines on both sides throughout the construction period. The widening to the south was more extensive. The widening of the dry-land area of the spit was accompanied by a recession of the 18-foot contours along the sides, and an advance along the axis at the tip. By 1895, Clatsop Spit had widened between low water lines, and narrowed and lengthened between 18-foot contours on the south side of the jetty until the 18-foot contour was 10,000 feet offshore at the landward end and 4,000 feet off from the jetty near its seaward end. Over 3,200 acres of beach had been created in that area. North of the jetty, the area along the jetty had filled up over a width of 1,000 to 3,000 feet away from the jetty, beyond which limit scouring of the channel had occurred. There was a recession northward of the north edge of the channel. The spit had extended seaward 14,000 feet in line with the jetty until the 18-foot contour at its tip was about 15,000 feet seaward of the end of the jetty. Beyond the tip of Clatsop Spit, a channel 30 feet deep and 7/8 mile wide had been scoured through the bar. It extended almost due west into the ocean. Up to that time the results had been very favorable.

(b) Between 1895 and 1903, however, the channel deteriorated. The section over the bar shoaled along its south edge and was crowded northward, while the westerly tip of Clatsop Spit was eroded. This widening of the channel both north and south with shoaling in the middle continued until in 1900 the depth was reduced to 23 to 24 feet. By 1902, two channels crossed the bar, separated by a middleground shoal, the north channel 21 feet deep and the south 20 feet deep. The widening of the bar channel was accompanied by a shortening of the tip of Clatsop Spit and by heavy scouring around the seaward end of the jetty.

(c) In 1904, extension of the jetty and maintenance dredging by the Chinook were begun. As the jetty was extended, Clatsop Spit advanced correspondingly. The bar channel narrowed and deepened again. In 1910, the advance of Clatsop Spit filled up the south channel. By 1911, the bar channel had shifted 3,500 feet farther northwest and deepened to $27\frac{1}{2}$ feet. The channel within the river shifted northward by filling along the jetty and erosion of the opposite edge. By 1914, the jetty had been extended about 3 miles. Although conditions over the bar had improved somewhat, it had become evident that the channel could not be stabilized at the location and depth desired without the provision of the north jetty.

d. Double Jetties.

(1) Effect on Channel during Construction. Between 1914 and 1917, the north jetty was built. As the jetty was extended, Peacock Spit shoaled rapidly along the advancing jetty, whereas the projecting tip of Clatsop Spit was washed away. The bar channel moved back southward. By 1915, a new channel had been opened closer to the end of the south jetty, with a depth of 30½ feet. By 1916, three channels crossed the bar, the north channel 31 feet deep, the main channel 36 feet deep and the south channel 31 feet deep. By 1917, the north channel had shoaled to 30 feet, whereas the main channel had deepened to 41 feet and the south to 32 feet.

(2) Effect on Channel after Completion. During the next few years, partly by scour and partly by dredging, a channel 40 feet deep and 6,000 to 8,000 feet wide was created crossing the bar in a southwesterly direction. This channel had a center depth of 45 to 46 feet over a width of 2,000 to 3,000 feet. Since that time it has maintained itself without dredging. In 1937, 12,737 tons of asphaltic mix was placed in the seaward end of the south jetty in an attempt to reinforce it against storm attack. About 2/3 of that material was

demolished within the year.

e. Summary of Changes.

(1) The principal changes in Clatsop Spit may be summarized as follows:- In 1885, when the south jetty was started, the spit was a broad sand shoal extending west of northwest from the land to Point Adams. The 18-foot contour was about 18,000 feet offshore, and the wide flat tip of the spit was about 18,000 feet across normal to its axis. By 1895, when the first $4\frac{1}{4}$ mile section of the jetty had been completed, the material from the sides of the spit had been removed so that the 18-foot contour on the sides had receded by from 3,000 to 5,000 feet. The eroded material was deposited along the axis of the jetty and shoal so as to widen the dry land area and extend the length of the spit by about 16,000 feet. The shoal was then roughly twice as long and half as wide within the 18-foot contour as in 1885. Between 1895 and 1904, when the extension of the jetty began, the spit shortened and widened again. The 18-foot contour at the tip receding about 11,000 feet, and at the sides advancing generally about 3,000 feet each way.

(2) After extension of the south jetty but prior to construction of the north jetty, i.e., between 1904 and 1914, there was little change in Clatsop Spit north of the jetty. There was marked erosion along its seaward face, the 18-foot contour moving inward toward the jetty by 4,000 to 5,000 feet and more. Since constructing the north jetty, the 18-foot contour north of the south jetty has advanced seaward along the jetty about 7,000 feet in general over a width of 4,000 feet

from the jetty. A farther recession of 1,000 to 1,500 feet has taken place along the seaward face of the spit.

(3) During construction of the first section of the south jetty, the deflection northward of the ebb currents caused a recession of the 18-foot contour south and east of Cape Disappointment by 3,000 feet and more as the channel broke through the bar and shifted northwestward. This recession was accompanied by an advance on the northwest side of Peacock Spit. Between 1895 and 1914, the 18-foot contour advanced again south and west by 4,000 to 6,000 feet. There was a recession of 500 to 2,000 feet on the northwest face of the spit. With construction of the north jetty the spit south of the jetty eroded rapidly. The 18-foot contour receded about 11,000 feet along the jetty line and 2,000 feet south of the cape. An advance took place north of the jetty, the high water line advancing seaward about 10,000 feet along the jetty and filling out from 2,000 to 5,000 feet off the jetty. The 18-foot contour advanced about 5,000 feet westward beyond the end of the jetty. This westward advance of the north shoal accompanied the southward swing of the bar channel toward its present position.

(4) As might be expected, these changes show an intimate interconnection. Thus the great elongation of Clatsop Spit between 1885 and 1895 was accompanied by a recession of the south and east edge of Peacock Spit. The recession of Clatsop Spit between 1895 and 1914 was accompanied by an advance of Peacock Spit. Since construction of the north jetty, the recession of Peacock Spit has been accompanied by an

advance of the opposite area of Clatsop Spit, and the growth of Peacock Spit north of the north jetty has been accompanied by a recession of Clatsop Spit south of the south jetty.

45. Jetties at Grays Harbor, Washington.

a. Similarity to Columbia River Jetties. The converging jetties at Grays Harbor, Washington, present many points of similarity to those at the mouth of the Columbia River, although on a smaller scale. As at the mouth of the Columbia, it was first believed that a single jetty would produce the desired results. It was later found that this was ineffective and a second jetty had to be built.

b. Original Conditions.

(1) The conditions existing originally at the entrance of Grays Harbor are described in considerable detail in the Annual Report for 1895, beginning at page 3517. The gorge of the entrance lay between Point Brown on the north and Point Hanson (now known as Point Chehalis) on the south. In the harbor, a number of channels running between tidal flats bare at low water converged into a single channel northeast of Point Hanson. The single channel then flowed southwesterly and westerly close to Point Hanson. It was separated from Point Brown by a shoal area over 2 miles wide. In the gorge, depths of from 50 to 100 feet existed in a channel 2,500 feet wide at its narrowest point and about 6 miles long. This comparatively narrow and deep cut widened and shoaled as it extended westward into the ocean, until over the crescent-shaped offshore bar, the crest of

which was some 8 miles offshore, there was no defined permanent channel. A number of shifting outlets existed in which the controlling depths were usually about 12 to 13 feet. The north shore end of the offshore bar at Point Brown was known as North Spit, and the south end at Point Hanson as South or Trustee Spit.

(2) The land points originally showed a persistent and characteristic tendency to terminate in recurving tailing sand spits, sometimes several in number and a mile long, turning inward from the tip of the land points toward the harbor. In 1862, the shortest distance between high water lines on the two points was about 17,000 feet. The distance from the north point high water line to the low water line was about 9,000 feet, the corresponding south point distance about 4,000 feet, leaving between the low water lines an opening 4,000 feet wide through which the entrance channel passed. Along the ocean face of North Spit, a sandy peninsula and island bare at high water extended from the shore of Point Brown somewhat east of south a distance of over 3 miles. This terminated in a recurving sand spit similar to those at the two points, turned inward toward the harbor.

c. Changes prior to Improvement.

(1) Between 1862 and 1899, when actual construction of the south jetty was begun, the principal shore line changes were the extension of Point Hanson toward the northwest and west by accretion, and the gradual retraction and recurving shoreward of the island projecting from the north point until it practically joined the north

point shore. By 1899, the northwest face of Point Hanson, both high water and low water lines, had built out into the ocean by a mile or more. The sand bar island off North Spit had curled north and east by from 2,000 feet at its north end to 10,000 feet at its south tip. It remained as another of the inwardly recurving spits which terminated both land points.

d. Description of Improvement.

(1) In 1899, the south jetty was begun. By 1903 it had been extended to a length of 13,784 feet, slightly north of west along the crest of South or Trustee Spit. Owing to the failure of the original estimate to allow for the additional material required due to scouring of the bottom ahead of the advancing jetty, the funds were insufficient to extend the jetty to the originally planned length of 18,500 feet. No work was done from 1903 to 1908. In 1908 the north jetty was started. It was completed in 1916. The jetties were built of stone on brush mattress foundations. The material was placed from trestles.

e. Changes since Improvement.

(1) With one jetty only.

(a) South of Jetty. Between 1899 and 1908 one jetty alone was functioning. During this time South Spit extended seaward along the south side of the jetty. The high water line of the beach advanced a maximum of over 2,500 feet near the jetty, the advance tapering south along the shore to 1,000 feet at a distance of

10,000 feet south of the jetty. The low water line made a corresponding advance. Shoaling occurred over a belt 500 feet wide along the south edge of the jetty, and over an area 2,000 feet wide extending seaward along the jetty alignment from 1,500 feet east of the jetty end to 4,000 feet west thereof. In the obtuse angle between the shoaled areas next to the jetty and shore, however, erosion had taken place, so that the 12-foot, 18-foot, 24-foot, and 30-foot contours had moved shoreward by maxima of from 1,200 to 2,000 feet roughly along the bisector of the angle.

(b) North of Jetty. Immediately north of the first jetty, scouring had taken place, so that the 24-foot contour along the south edge of the deep channel had approached the jetty by from 100 feet at its shoreward end to 1,500 to 2,000 feet along its seaward half. This shifting of the south channel edge was accompanied by an almost equal shift southward of the north edge of the channel, due to a wide-spread shoaling north thereof. The average width of the channel in its new position was about the same as that before the jetty was built. Across the crest of the bar the new channel had deepened somewhat. Depths of 12 to 24 feet were found where only 12 to 13 feet had existed before the jetty was built. Farther to the north the crest of the old bar south and west of Point Brown had deepened, so that the 12-foot contour had moved landward by better than a mile in places. The ocean face of the bar had shoaled so that the 18-foot contour had advanced 3,000 to 4,000 feet and the 24-foot and 30-foot contours an almost equal amount.

(2) Shore Line Changes with Both Jetties.

(a) North of North Jetty. Between 1908, when the north jetty was started and the present time, the high water line north of the north jetty has advanced 7,500 feet southwestward along the jetty. The advance tapers off gradually toward the north, but is still 3,000 feet, 12,000 feet north of the jetty. The low water line has advanced only 5,500 feet and less than 3,000 feet at the same locations, so that the beach is steeper in its new location than it formerly was. This advance did not take place at a uniform rate throughout the period. Between 1908 and 1916, a comparatively slow and uniform advance of the high water line took place, totalling about 3,000 feet at most for the period. In 1912 a small shoal bare at low water appeared in the bend of the jetty. By 1914 this had extended to a width of 4,500 feet along the jetty, and a length of 7,000 feet perpendicular to the jetty. In 1916 a small shoal bare at high water appeared in the bend of the jetty and the low water shoal had practically joined the main land. By 1920 the shoal bare at high water had greatly enlarged but was still separated from the main land point. By 1921 the shoal had been united with the land at its northerly end, leaving a lagoon bare at low water between the hooked spit and the jetty. The changes since 1921 have been comparatively minor, consisting of alternate advances and recessions which have left the shore line in a fairly stable average position. About 75 per cent of the shore line advance occurred during the 10 year period between 1912 and 1921. These were the years immediately following the construction to full length and height of the north jetty.

(b) South of South Jetty. The construction of the north jetty had little effect on the shore line south of the south jetty. Between 1906 and 1937 there has been a slow and generally uniform recession of both high water and low water shore lines south of the south jetty. The maximum recession near the jetty has been 2,400 feet for the high water line and 3,500 feet for the low water line. The advance tapers off to zero in about 12,000 feet along the shore. This general recession has been interrupted at times by periods of slight advance, but the general tendency has been uniform.

(3) Offshore Changes with Both Jetties.

(a) Between the Jetties. There has been a tendency to shoal along the south side of the north jetty shoreward of the bend and on the north and northeast faces of the south land point. Where shoaling has occurred there has been evidenced a pronounced tendency for the material of the shoals to move inward toward the harbor. Thus in 1921, when the shoal north of the north jetty bend was joined to the mainland, and its hitherto rapid growth north of the jetty ceased, the south tip crossed the jetty at the bend to form a small projecting spit recurving toward the harbor. By 1923 this spit had elongated to a length of 2,500 feet above high water. By 1924 its length was 5,000 feet, with a width of 300 to 700 feet. Since 1924 it has lengthened but little, but has widened and narrowed alternately by accretion and erosion on its south or channelward face. Its greatest width at the tip was over 2,000 feet in 1936, and its greatest width in 1937 was about 900 feet. Southward of this spit the 12-foot contour has advanced toward the channel by a maximum of nearly 2,000 feet. At the shoreward end of the jetty, scouring has taken place over about 4,000 feet of the jetty length. This has caused the high water line to shift northward 1,400 feet, from 800 feet south to 600 feet north of the jetty. The north tip of the south land point has extended northeastward in a spit 3,500 feet long and 1,200 feet wide within the high water line. It parallels the deep water channel toward the bay. North and east of the spit shoaling has taken place.

(b) In the Channel Area. The south edge of the deeper channel, which had scoured and moved southward before the north jetty was built, continued to scour against the south jetty to and beyond the seaward end. The north edge of the channel, which had moved south under the urge of shoaling along the north side when only one jetty existed, has deepened. The 18-foot contour moved north 3,500 feet in places, the 24-foot contour about 3,000 feet, and the 30-foot contour from 1,500 to 2,000 feet. The 36-foot contour in 1937 coincided roughly with the 30-foot contour in 1909 between the seaward ends of the jetties and the junction of south jetty and shore. Through the gorge the 1937 36-foot contour is found about where the low water line of the middleground shoal was formerly located. The original middleground shoal of 1909 moved harborward and diminished in size. It finally disappeared about 1925. Over its site water now 12 to 40 feet deep is found.

(c) Seaward of the Jetty Ends. This tendency toward scouring between the jetties was projected seaward beyond the ends of the jetties over the crest of the original bar for about a mile along the line of the south jetty produced and nearly 2 miles along the line of the north jetty produced, nearly to the 30-foot offshore contour. Due west of the jetty ends, the 24-foot contour shifted seaward about 700 feet on the line of the south jetty produced, but shifted shoreward about 3,500 feet on the line of the north jetty produced. The scouring also extended north of the north jetty over a belt about 2 miles wide offshore from the present shore line. In that area the 18-foot contour moved shoreward generally from 1,500 to 3,000 feet and the 24-foot contour from 500 to 3,000 feet. Beyond 2 miles offshore, however, shoaling took place over a distance of about 4 miles northward from the line of the south jetty produced. The 30-foot contour moving seaward from 500 to 1,500 feet, the 36-foot and 42-foot contours from a few hundred to 1,800 feet, and the 50-foot contour from 600 to 1,800 feet.

(d) South of the South Jetty. Deepening occurred over the entire offshore area coincident with the recession of the shore line already mentioned. The maximum scour was roughly along the bisector of the angle between jetty and shore. Along this line the 12-foot and 18-foot contours approached the shore by about 2,000 feet, the 24-foot contour by 2,600 feet, the 30-foot contour by 3,400 feet, the 36-foot contour by 3,000 feet and the 42-foot contour by 3,400 feet. The extent of this scouring, and the great depth at which it continued to be manifested, make it evident that there has been some general and deep seated current action in that area not caused by surface wind and wave effects alone.

46. Jetties at Charleston Harbor, S. C.

a. Jetties with Submerged Inner Sections. The jetties at Charleston Harbor, S. C., afford an instance of the use of submerged shore ends designed to permit the ready inflow of flood-tide currents while confining and directing a large part of the ebb-tide flow upon a restricted section of the offshore bar to assist in creating and maintaining by scour a channel through the bar. The vicinity is shown on U. S. Coast and Geodetic Survey Chart No. 470 and on the map herewith.

b. Description.

(1) Charleston Harbor is formed by the confluence of the Cooper River, flowing south, and the Ashley River, flowing southeast. The city of Charleston occupies the peninsula between the two rivers. From the southerly tip of the peninsula, where the rivers come together, the harbor extends easterly about 3½ miles, with a width of about 2 miles. It then narrows and turns southeasterly to pass into the ocean between Sullivan Island on the north and Morris Island on the south. The high water shore lines of the two land points are about 8,000 feet apart. Fort Moultrie is situated on the south tip of Sullivan Island and Fort Sumter occupies an artificial island about half-way across the entrance

near its harbor end.

(2) The inner harbor possesses several channels separated by shoals bare or nearly bare at low tide. These converge as the entrance is approached. Between the land points a single channel about 3,000 feet wide between 18-foot contours, and with general depths of 25 to 50 feet and maximum depths of 80 feet, passes north of Fort Sumter and through the throat of the entrance.

c. Conditions Prior to Improvement.

(1) Prior to the construction of the jetties, the configuration of the waterway was such that the eastward-moving ebb current concentrated by the several channels of the inner harbor passed north of Fort Sumter to impinge upon the south tip of Sullivan Island west of Fort Moultrie. It was then deflected southeast and south into the ocean to form the main channel, almost parallel to the shore of Morris Island. The channel was about 3,000 feet offshore as it enters the ocean and about 8,000 feet 4 miles south of the entrance. South of the main channel, between Fort Sumter and the south land point there was a wide flat shoal much of which was bare at low water.

(2) Between the main outer channel and deep water in the ocean, a long tapering shoal extended from the shore of Sullivan Island, north of the entrance, southward about 10 miles to swing over to the beach again on Morris Island. The shoal was about 1.75 miles wide between 18-foot contours. It had a steep western or channelward face and a flat eastern or oceanward face. The main channel skirted

the western edge of the shoal, becoming more and more shallow until it finally passed over the bar to sea with usual depths of 12 to 13.5 feet. From 4 to 6 secondary channels usually departed eastward and southeastward from the main channel, and crossed the bar with usual depths of 10 to 12 feet. Between these channels there were depths of 3 to 9 feet over the crest of the bar. The predominant littoral drift is from northeast to southwest.

(3) The ebb-tide flow, issuing from between the land points in a confined and directed current, followed chiefly the main channel southward behind the bar, with side currents through the secondary channels. The flood-tide flow, on the other hand, was gathered in by the wide funnel shape of the shore and approached the entrance more or less uniformly over the bar. It was thus forced out to the sides against the shores of both islands to form flood channels near shore. The flood velocities in these channels were greater than elsewhere in the entrance.

d. Plan of Improvement.

(1) The project for the improvement of the entrance to Charleston Harbor to give a depth of 21 feet through the offshore bar by the construction of two converging jetties and by dredging was adopted by the River and Harbor Act of June 18, 1878 (An.Rep. for 1878, pp. 553-572). Construction began in 1878 but proceeded slowly owing to insufficient annual appropriations. It was not completed until 1896. The jetties were constructed of granite on log and brush mattresses,

placed from barges instead of a trestle. The method departed from the usual plan in that the mattress foundations were extended to full length as rapidly as possible and the jetties were then raised to full height beginning at their outer ends and progressing shoreward.

(2) The jetties spring about normally from the shores of the land points about 13,000 feet apart and converge to become parallel and 2,900 feet apart for the seaward 4,000 feet or more of their lengths. The north jetty is 15,443 feet long. The south jetty is 19,104 feet long. They were originally brought to an average height of 8 to 10 feet above mean low water, except that the shoreward 5,800 feet of the north jetty and 6,000 feet of the south jetty were raised only a few feet above the bottom. These submerged sections were designed to permit the inflow of flood-tide currents without a corresponding escape of the ebb-tide currents. That this has been accomplished is evident from the fact that the flood-tide current velocities between the jetties range from 1.5 to 2.5 feet per second, whereas the ebb tide velocities are between 2.5 and over 4.0 feet per second. The cost of the jetties was $3,906,869.78.

e. Changes since Construction of Jetties.

(1) North of the North Jetty. The angle between jetty and shore has generally filled in out to and beyond the 18-foot contour. Over a distance of 2 miles or more, the shore line has advanced from 15 to 30 feet. The 6-foot contour has advanced about 500 to 1,000 feet, the 12-foot contour up to as much as 5,000 feet in places, and the 18-foot contour by 1,000 to 2,000 feet. The only material exception to the

general shoaling of that area is along and near the shoreward end of the jetty. There a gap was left over the crest of Drunken Dick Shoal during the construction. In this gap scouring of the crest of the shoal took place on both sides of the jetty before it was closed. This area is still deeper than it was originally. Sand has been carried over the crest of the submerged shoreward section and also around the seaward end of the north jetty over a distance of about 8,000 feet along the jetty line produced. It has encroached upon the channel area from the north.

(2) Between the Jetties. Active scouring has taken place over most of the interjetty area. During the construction period (1878-1896), 2,205,554 cubic yards of material were removed from the interjetty area by dredging and 4,094,247 cubic yards by scour. The shoals which originally occupied portions of the area, with depths of 9 feet or less over their crests, have been moved seaward and largely dissipated beyond the jetty ends. By this scouring and dredging, a channel 21 feet deep was finally secured. At first some shoaling occurred between the jetties, necessitating some maintenance dredging. Since the adoption of the 30-foot project in 1917, no maintenance dredging between the jetties has been required. In the entrance channel seaward of the jetty ends gradual shoaling, chiefly from the north side, has necessitated some maintenance dredging at the rate of about once every two years. A total of 3,490,070 cubic yards has been so removed at a cost of $273,121.26. The shore line of the north land point has changed little west of Fort Moultrie. Between Fort Moultrie and the

jetty it has advanced from about 40 feet at Fort Moultrie to about 400 feet at the shore end of the north jetty. These changes occurred chiefly prior to 1921 and little change has been noted since then. Flood-tide currents entering the harbor over the submerged shore end of the south jetty have scoured a channel 20 to 30 feet deep and 500 to 1,000 feet wide between 18-foot contours, extending past the north tip of Morris Island and the east side of Fort Sumter. The north tip of Morris Island has receded during this process by from 600 to 800 feet. Much of the material removed appears to have been carried onto the shoal between Fort Sumter and the south land point, where considerable shoaling has occurred. Another large part of the material removed has been deposited in a long narrow shoal separating the flood channel from the main ship channel.

(3) South of the South Jetty. Scouring has taken place over the entire area except the deeper trenches of the original main channel and a secondary channel which formerly crossed the bar south of and parallel to the jetty. These former channels, originally deeper than the surrounding shoals, have been partially filled. The filling of the original main channel had been accelerated by the deposit of spoil therein during the early dredging in the present ship channel. The ocean shore of Morris Island has continued to recede slowly except in the immediate vicinity of the shore end of the south jetty, where an advance of 100 to 200 feet has taken place. The general recession of the shore line of Morris Island has been about 100 to 150 feet. Offshore

the erosion has been much greater. The 6-foot contour has moved landward by from 1,000 to 1,500 feet, the 12-foot contour by 500 to 4,500 feet and the 18-foot contour on the seaward face of the bar by from 1,000 to 3,000 feet.

f. Economic Justification.

(1) If the original cost of the jetties be considered merely as the cost of securing the original 21-foot channel, the unit cost of the removal of material from between the jetties by scouring would have been nearly 95½ cents a cubic yard. If, however, it be considered that the unit cost of removing the scoured material from between the jetties by dredging would have been 15 cents, then $614,137 of the original cost of the jetties might be considered as having been expended for the creation of the deeper channel, leaving a balance of about $3,292,700 to be considered as having been invested in securing reduced maintenance of the ship channel. At 3½ per cent, that sum would yield an annual income of about $115,250. This would have paid for the dredging from the channel of about 770,000 cubic yards of material annually as maintenance at 15 cents a cubic yard. If it had been practicable to provide the ship channel by dredging only, without jetties, at a cost of not over $614,137 more than has been spent for new work dredging, and if the channel, once dredged, could have been maintained by dredging with a seagoing hopper dredge at an annual cost of not over $140,000 ($115,000 interest on cost of jetties plus $25,000 annually actually spent in dredging in the entrance channel), the con-

struction of the jetties as a measure of channel provision and maintenance was not justified.

VI. MISCELLANEOUS TYPES.

47. Jetties at Port Aransas (Aransas Pass), Texas.

a. Location. Aransas Pass, the entrance to Port Aransas and the harbor at Corpus Christi, is on the southerly portion of the coast of Texas, 180 miles southwest of Galveston and 132 miles north of the mouth of the Rio Grande. (See U. S. Coast and Geodetic Survey Chart No. 1285 and the map herewith).

b. Description.

(1) Aransas Pass separates too long, narrow barrier islands which form part of the Gulf coast of Texas. St. Josephs Island extends northeasterly from the Pass about 23 miles. Mustang Island extends southwesterly about 18 miles. Between the islands and the mainland are a number of interconnected tidal sounds, including Corpus Christi Bay and Aransas Bay. At the bayward entrance to the Pass, Harbor Island extends completely across the alignment of the Pass. The channel from Corpus Christi Bay passes northeasterly between Harbor Island and Mustang Island, and the channel from Aransas Bay passes southerly between Harbor Island and St. Josephs Island. These channels unite at Aransas Pass which extends southeasterly between St. Josephs and Mustang Islands into the Gulf. The normal tidal range is about 1.1 foot. During severe storms the extreme range may be as much as 5 feet or more.

c. Conditions Prior to Improvement.

(1) St. Josephs and Mustang Islands are composed of fine sand. Under the predominant littoral drift from northeast to southwest, the point of St. Josephs Island was extended southwestward, and the north point of Mustang Island correspondingly eroded. The Pass thus moved toward the southwest. Between 1868 and 1878, this migration had been at the rate of about 260 feet a year. In the throat of the Pass a channel existed from 300 to 500 feet wide between 24-foot contours, and with usual depths of 27 to 35 feet. A crescent-shaped offshore bar across the Gulf entrance, reduced the best navigable depths over the bar to between 7 and 9½ feet.

d. Plan of Improvement.

(1) The improvement of the harbor took place in 3 successive stages, namely:-

(a) Original Federal project.

(b) Improvement by the Aransas Pass Harbor Co.

(c) Existing Federal project.

(2) Original Federal Project. Between 1880 and 1890, the improvement of the Pass was accomplished by the United States. Beginning in 1880, a breakwater 450 feet long was constructed offshore from Harbor Island. A seawall or revetment 870 feet long was constructed along the shore of the north tip of Mustang Island, and 7 spur dikes were extended normal to the revetment into the Pass to lengths varying between 124 and 280 feet, into water generally about 20 feet deep. The

purpose of these structures was to hold the channel in the Pass off the north end of the island and prevent further erosion of that shore. In 1881, a south jetty was started, extending from the shore of Mustang Island into the Gulf. Work on this jetty, often referred to in subsequent reports as the Mansfield jetty, was completed in 1885, at which time it extended straight out from shore 2,352 feet, then curved toward the north and toward the channel an additional 1,698 feet. The jetty was constructed of brush and log mattresses weighted with stone. By 1888, the revetment and groins along the north end of Mustang Island had been largely undermined and washed away. In 1888 and 1889 about 2,700 linear feet of the north tip of the island were revetted anew with an apron of rock 18 inches thick. This was intended to hold the shore and prevent further migration of the pass. In 1890, the improvement of the Pass was turned over by the United States to the Aransas Pass Harbor Company.

(3) Work by Harbor Company. The Aransas Pass Harbor Company carried on improvement work at the Pass from 1890 to 1899. The first construction was started in 1892, when a new south jetty, known as the Nelson jetty, was begun. This jetty was from 600 to 1,000 feet north of the original government south jetty. It was about 1,800 feet long and concave toward the channel. It consisted of a row of light cylindrical wood caissons 7 feet in diameter, filled with sand and stone and riprapped to a certain extent. Construction of this jetty was suspended owing to exhaustion of funds. Between August 1895 and

September 1896, the north jetty was built. As planned, this jetty started at the 6-foot contour, about 1,500 feet offshore from St. Josephs Island, extended thence seaward for 2,000 feet on a curve of 3,000-foot radius convex toward the channel, then on a reverse curve 2,200 feet long with a 6,000-foot radius compounded with a second curve 2,000 feet long on a 4,000-foot radius, both concave toward the channel. This north jetty was only partly finished by the Harbor Company when their rights were turned back to the United States in 1899.

(4) Work under Existing Federal Project. By 1899, the Nelson jetty was very dilapidated and had in large part disappeared, due to the ravages of the teredo and storms. Beginning in 1902, the north jetty was repaired and completed, the work continuing spasmodically to 1906. In 1909, the north jetty was connected with St. Josephs Island and the building of a straight south jetty approximately parallel to the north jetty was begun. The latter was completed about 1915. During that period, the Mansfield and Nelson jetties were partially removed in successive sections to clear the interjetty area of obstruction. Dredging in the channel began in 1912 and has been continued annually since then to include 1937. A total of 23,316,392 cubic yards have been dredged in securing and maintaining project dimensions, at a total cost of over $2,000,000, an average of about 9 cents per cubic yard. In 1922-23 four spur jetties were constructed in the concave curve of the reaction section of the north jetty, extending channelward to about the chord between the extremities of the curved section. These converted it

practically into a straight section. Dikes have also been constructed at right angles to the jetties on St. Josephs and Mustang Islands, to prevent breaching of the islands by storms. A dike has been run along the south tip of St. Josephs Island. In 1936, portions of the jetties were capped with concrete.

e. Effects of the Improvements.

(1) Revetment of Mustang Island. The original groins and revetment on the north tip of Mustang Island temporarily delayed the erosion of that tip. The structures were undermined by eddies, and by 1888 had largely disappeared, the shore line having receded 100 to 200 feet south of the original dike line. The paving of the entire slope with an 18-inch thick rock revetment in 1888 and 1889 successfully stopped the erosion of the point. Meantime, the south point of St. Josephs Island continued to grow southward, narrowing and deepening the throat of the Pass. Between 1887 and 1897, the width of the gorge channel decreased from 1,785 feet to 750 feet; the maximum depth decreased from 38 feet in 1887 to 31 feet in 1895. It then increased to 45 feet in 1897.

(2) Mansfield Jetty. Sand accumulated along both sides of the jetty. The shore line advanced along the jetty, particularly along the south side. By 1900 the shore line had advanced along the jetty 750 feet beyond its position in 1899. The offshore contours showed a corresponding advance. The first effect of the jetty upon the channel was to cause some reopening by scour through the bar. By 1885,

the depth in the bar channel had increased from 7 feet to about 11 feet, and the 12-foot contours had been shifted considerably seaward over the bar. In 1886 an unusually severe storm damaged the jetty, shifted the channel southward close to the jetty, and diminished the controlling depth in the channel to about 10 feet. By 1888, the curved outer portion of the jetty had practically disappeared. The main channel had shifted farther south and crossed the jetty near its outer end. The controlling depth had decreased to $8\frac{1}{2}$ feet. By 1898, the remains of the jetty were completely covered with sand.

(3) Nelson Jetty. This structure is reported to have caused some deepening and advance in the channel as it was extended, but within a few years it had largely disappeared, and it never produced the results expected of it.

(4) Curved North Jetty. This was designed as a "reaction" jetty, to produce scouring along its curved face by the deflected currents. The section completed by the Harbor Company was expected to produce a depth of 15 feet, and the jetty, if completed as planned, was supposed to produce a channel 20 feet deep. By 1900 there was reported a least depth of $15\frac{1}{2}$ feet in the channel, but the channel was so close to the jetty, so narrow and irregular, that it was not practicable for boats drawing more than 10 feet. By 1902 the least depth had decreased to $14\frac{1}{2}$ feet. With farther building up of the curved north jetty, considerable deepening of the channel took place, but it was still too narrow and too close to the jetty for convenient navigation.

(5) Present Jetty System.

(a) Channel Changes. With the connection of the curved north jetty with the shore and the construction of the present south jetty (1909-1915), increased scouring took place in the channel. By 1911, the last year in which no dredging was done and the effects were due to scouring alone, the channel was 20 feet deep with a least width of 100 feet. Since construction of the 4 spur dikes to straighten the channel (1922-23), it is reported that little shoaling takes place in the channel across the ends of the spurs, but some shoaling does occur between the shoreward spur and the gorge of the Pass. The fact that in 1935, 1936 and 1937 over 600,000 cubic yards were dredged each year in maintaining project dimensions indicates that the jetties are not entirely adequate to the maintenance of the existing channel.

(b) Shore Line Changes.

1. North of North Jetty. Beginning in 1907, the low-water shore line advanced at first rapidly, then at a decelerating rate. By 1909, the advance along the jetty had been about 1,400 feet, tapering off rapidly with increased distance from the jetty. By 1916, a farther advance of about 600 feet had occurred, and by 1936, another advance of about 500 feet. Between 1936 and 1938, a recession of 100 to 200 feet took place.

2. South of South Jetty. There has been an advance of the shore line, but on a much less extensive scale. Between 1907 and 1922, a general advance of about 700 feet along the jetty occurred, and of 250 to 350 feet along the more remote shore. Between

1922 and 1927, the shore line remained practically unchanged except for a slight recession immediately adjacent to the jetty. Between 1927 and 1929, the shore line advanced adjacent to the jetty, but receded by as much as 400 feet farther away from the jetty. There was a slight advance by 1930 and another slight recession by 1931. Between 1931 and 1932, the shore advanced little at the jetty, but by an increasing amount farther off, amounting to 400 feet 2,500 feet south of the jetty. It was almost as far out on the jetty as in 1922 and 1927. By 1936 it had again receded about 200 feet next the jetty and 500 feet 2,500 feet south of the jetty, and in the past 2 years has advanced again by from 50 to 200 feet.

VII. SUMMARY OF CHANGES.

48. Changes in Updrift Angle.

a. Shoreline.

(1) General. Of the 56 cases studied in some detail, 49 showed an advance of the low water shore line, ranging from slight in many cases to as much as 7,400 feet along the east jetty at Sabine Pass, Louisiana and Texas, and 9,500 feet along the north jetty at the mouth of the Columbia River, Oregon. Of the 7 remaining cases, one (Grays Harbor, Washington) advanced 2,500 feet along the south jetty while only one jetty existed, then receded 3,500 feet after the north jetty was built for a net recession of 1,000 feet, one (St. Andrews Bay, Florida) reported a slight recession on the updrift side, two had insufficient information as to changes, one showed no change due to the existence of

a bulkhead, and in two cases there was uncertainty as to the direction of the drift.

(2) Accretion. Of the 49 cases which definitely showed an advance of the shore line on the updrift side, ten are definitely known to have been affected by the deposit of dredged material in the updrift angle, whereby the amount of change due to the jetty alone is masked to some extent. In five of the 49 cases, the available information as to the amount of the advance is insufficient. The amount of the advance along the jetty for the remaining 44 cases is indicated in the following table.

Amount of Advance (Feet)	No. of Cases	Per Cent of Cases.
1-100	8	18.2
101-500	11	25.0
501-1000	11	25.0
1001-2000	6	13.6
2001-3000	1	2.3
3001-4000	5	11.4
Over 4000	2	4.5
	44	100.0

It therefore appears that in only 18.2 per cent of the cases was the advance 100 feet or less; that in 50 per cent of the cases the advance was more than 100 feet but not over 1,000 feet, and that in only 31.8 per cent of the cases did the shore line advance more than 1,000 feet. The maximum advance was about 9,500 feet, against the north side of the north jetty at the mouth of the Columbia River, Oregon.

(3) Variation between Accretion and Erosion. The distance along the shore over which the advance took place showed great variations. In many cases the surveys did not extend far enough to determine that distance, and no comprehensive comparison can be made. In the case of the St. Johns River, Florida, the accretion to the shore took the form of a long narrow beach along the side of the jetty, about 4,500 feet along the jetty but only 250 to 300 feet wide throughout most of its length except at the seaward tip, where a hooked point had built out to a distance of about 1,700 feet from the jetty. Dredged spoil had been deposited in the area, and it is uncertain how much of the accretion is due to that and how much to drift. The accretion north of the north jetty at the Columbia River entrance assumed a somewhat similar form, being 9,500 feet long along the jetty by about 2,000 to 5,000 feet wide. On the other hand, in many cases, such as Coos Bay and Coquille River, Oregon, the advance along the jetty was comparatively small, but its effect extended over many miles of the beach. Many intermediate gradations are found.

b. Offshore Changes.

(1) Nature of Change. The offshore changes on the updrift side cannot be so satisfactorily summarized as the shore line changes. In 33 of the 56 cases, no information was furnished by the districts. The data in the remaining 23 cases are tabulated below:-

Nature of Change	No. of Cases (Updrift)	No. of Cases (Downdrift)
General shoaling	13	7
Shoaling next to shore, little or slight deepening in intermediate area, shoaling farther out.	4	-
Shoaling next to shore, deepening farther out.	-	1
Shoaling next to jetty, deepening farther away.	4	-
Deepening next to shore, shoaling farther out.	-	2
Spotty deepening and shoaling	-	1
General deepening	2	13
	23	24

(2) Discussion. The general tendency toward accretion on the updrift side and erosion on the downdrift side is thus much more pronounced in the offshore area than along the shore line.

51. Changes in Area between Jetties.

a. Effect of Jetties on Channel.

(1) Of the 56 cases studied, 12 were cases of breakwaters which had no effect on a channel and 18 were cases in which no definite information has been furnished. The results, frequently incomplete, in the remaining 26 cases, are tabulated in a general way below:-

Amount of Scouring in Channel	No. of Cases	Per Cent of Cases.
Adequate scouring to maintain channel between jetties and through offshore bar with little or no dredging.	2	7.7
Adequate scouring to maintain channel between jetties, but not through bar, with little or no dredging.	3	11.5
Insufficient scour to maintain channel, but enough to diminish somewhat the maintenance dredging required.	11	42.3
Little or no scour	6	23.1
Scouring in some spots and shoaling in others	4	15.4
	26	100.0

(2) From the information now at hand, it thus appears that, insofar as the purpose of jetties may be taken as the caring for all or a large part of the provision and maintenance of a channel by the scouring effects of the confined and directed currents, those hitherto constructed have been largely successful in less than 20 per cent of the cases, and only moderately or little successful in over 80 per cent of the cases.

VIII. CONCLUSIONS.

52. In a general way, the study of the incomplete information so far collected indicates that the following results, having followed provision of the jetties hitherto constructed, are likely to follow the construction of future jetties.

a. Shore Line Changes.

(1) The shore line on both updrift and downdrift seaward

Nature of Change	No. of Cases	Per Cent of Cases.
General shoaling	13	56.5
Shoaling next to shore, little change or slight deepening in intermediate area, and shoaling farther out.	4	17.4
Shoaling next to jetty with deepening farther away.	4	17.4
General deepening.	2	8.7
	23	100.0

(2) Effect of Jetty Inclination. Of the 10 cases which evidenced more or less scouring in the updrift offshore area, two were cases in which the angle between jetty and shore was less than 90°, two in which the angle was about 90°, and six in which the angle was greater than 90°. In nine of the ten cases, there was an original offshore bar, the shifting of which after construction of the jetties caused or contributed to the deepening.

49. Changes in Downdrift Angle.

a. Shore Line.

(1) Nature of Change. Of the fifty-six cases studied, six had insufficient information and five were so masked by the disposal of spoil or other causes that the effect of the structures themselves could not be determined even approximately. The results in the other forty-five cases are tabulated as follows:-

Nature of Change	No. of Cases	Per Cent of Cases.
General advance	25	55.6
General recession	7	15.5
Advance at first, followed by smaller recession	5	11.1
Recession at first, followed by greater advance	1	2.2
Advance near jetty, recession farther away	4	8.9
No material change	3	6.7
	45	100.0

(2) Extent of Change. The amount of change, as represented by the amount of advance or recession along the jetty, varied from maximum advances of 13,500 feet along the south jetty of the Columbia River entrance and of 10,000 feet along the west jetty at the entrance to Galveston Harbor, to a maximum recession of less than 500 feet at a few of the jetties. It should be noted, however, that in a number of cases where initial recession was rapid, either protective works were provided which prevented the erosion from running its full natural course, or subsequent advance counteracted the initial effect. The amounts of the advance or recession along the jetty are tabulated below:-

Amount of Advance (+) or recession (-) (feet)	No. of Cases	Per Cent of Cases.
-500 to 0	7	15.5
No material change	3	6.7
0 to +100	10	22.2
+101 to +500	5	11.1
+501 to +1000	9	20.0
+1001 to + 2000	3	6.7
+2001 to +3000	3	6.7
+3001 to +4000	2	4.4
over 4000	3	6.7
	45	100.0

b. Offshore Changes. The available information as to offshore changes on the down drift side is incomplete. In 31 of the 56 cases, no information has been furnished, or the information is so scant as to be unreliable. Of the remaining 24 cases, a considerable number show only a single contour, or are in other respects incomplete. The available results are, however, tabulated below:-

Nature of Change	No. of Cases	Per cent of Cases
General deepening	13	54.2
Deepening next to shore, shoaling farther out	2	8.2
Shoaling next to shore, deepening farther out	1	4.2
General shoaling	7	29.2
Spotty deepening and shoaling	1	4.2
	24	100.0

50. Comparison of Updrift and Downdrift Sides.

a. Shore Line Changes.

(1) Comparison. In comparing the relative tendency

toward advance or recession of the shore line on the updrift and downdrift sides of the structures, the following tabulation of the results has been prepared:-

Nature and Amount of Change	No. of Cases (Updrift)	No. of Cases (Downdrift)
Recession	2	7
Advance of 1000 feet or less	30	27
Advance of over 1000 feet	14	11
	46	45

(2) Discussion. The foregoing tabulation indicates that, although there is a tendency toward less accretion and more erosion on the downdrift than on the updrift side of jetties and breakwaters, the tendency is not so marked, at least in the area immediately adjacent to the jetties, as might have been expected. It appears that even when, as in most cases, there is a pronounced predominant littoral drift in one direction, there are usually sufficient reversals of drift direction to cause accumulation of sand in the downdrift as well as the updrift angle, although in lesser amounts on the average.

b. Offshore Changes.

(1) Comparison. The relative tendency toward shoaling or deepening in the offshore area on the updrift and downdrift sides are indicated in the following comparison:-

sides of the jetties will advance, the amount of the advance, both along shore and along the jetty being greater, other things being equal, on the updrift than on the downdrift side.

(2) The advance will be comparatively rapid at first, decelerating until finally a condition of substantial equilibrium will be attained, with alternate periods of minor advance and recession about an average location.

(3) The advance will be greatest next to the jetty, tapering off rapidly at first, then more slowly with increasing distance from the jetty, so as to form a curved shore with curvature accentuated near the jetty. The position and form of the curve will be such that the incoming waves meet the beach line substantially normally at all points for as much of the time as may be.

(4) Beyond the sphere of action of the jetty on the updrift side, usually not over a mile or two, the beach will continue to build out or recede as it was doing before the structure was provided.

(5) Beyond the area of accretion on the downdrift side of the jetty, usually less than a mile, any previous tendency toward erosion will be intensified owing to the interception of sand from the updrift side.

(6) Any tendency toward scouring of the shore in the angle between jetty and shore is likely to be most pronounced in the case of an obtuse angle facing into the direction of the more severe storms, particularly if on the downdrift side.

b. Offshore Changes. The provision of jetties is likely to result in general shoaling of the offshore area on the updrift side and general deepening on the downdrift side, with the tendency toward shoaling slightly ascendant. If an offshore bar existed before the jetties were constructed, as is usually the case, the original crest of the bar will be planed down, and a new crest built up which will lie seaward of the original crest and of the ends of the jetties. Like the shore line changes, the offshore changes will proceed rapidly at first and then progressively more slowly until a new condition of equilibrium/is established. If the shifting bottom material is in large measure composed of sand moving along the shore, the bulk of the new bar will form on the updrift side of the jetties and erosion of the bottom on the downdrift side will more likely occur. If much material is scoured from the channel between the jetties, or brought down by rivers, particularly in flood, or if the jetties are too short to prevent the littoral drift from rounding their ends, the bulk of the bar is likely to build up on the downdrift side.

c. Changes in the Channel.

(1) It is almost axiomatic that the alignment and spacing of jetties should be such as to pass the tidal prism moving between them with velocities which will produce neither too much nor too little effect upon the channel. The cross sectional area between the jetties must then vary in large measure as the volume of the tidal prism, and be in some way proportioned to that volume. Indeed, one simple

approximate relationship for the two has been proposed - that the cross sectional area of the interjetty area in square feet should equal the volume of the tidal prism in acre-feet. This approximation has been found to work fairly well in some cases, but to fail in others, as might indeed be expected. Such a formula would require that the same cross sectional area of channel should be provided for a given tidal prism distributed over a large basin with a rise of one foot as for an equal tidal prism distributed over a basin of 1/10 the area with a rise of 10 feet, which is untenable.

(2) Instances of the dependence of jetty spacing upon tidal prism volume could be cited at length. Of the two cases heretofore listed as most successful, the jetties at Miami Harbor, Florida, are parallel and 1,000 feet apart, whereas those at the entrance to the Columbia River, Oregon, are converging and about 2 miles apart at their seaward ends, yet both have been successful. At Cold Spring Inlet, N. J., parallel jetties 850 feet apart have had very little effect in maintenance of a channel 25 feet deep and 400 feet wide between them; in fact, on June 30, 1937, the controlling depth was only 18.8 feet. On the other hand, jetties 800 feet apart at Lake Worth Inlet, Florida, and 900 feet apart at Fort Pierce Harbor, Florida, have diminished materially the maintenance dredging required in channels approximately 20 by 250 feet and 25 by 250 respectively, although neither has been completely successful. Of the cases heretofore tabulated in which the jetties have failed more or less completely to assist in maintaining a channel, most are small

installations at the entrances to small tidal basins, so that the tidal prism is insufficient to produce the necessary current velocities even in a channel only a few hundred feet wide.

(3) In the original planning of the jetties covered by this study, an attempt was made in most cases to derive a spacing of the jetties from considerations of the tidal prism or the cross sectional area of the original gorge, or both. Despite the good intentions of those attempts, however, the conclusion seems inescapable that jetties have been spaced too far apart much more often than too close together. Except where the currents have been deflected against the jetties by bends in the alignment, hardly a case is found where serious undermining of the jetties or other unfavorable result has arisen from too close spacing, whereas in the great majority of cases the results secured from jetty installations have been more or less disappointing due in part at least to excessive distance between them.

(4) This result has apparently been due to two principal causes. First, the fear of setting up currents with velocities unfavorable to navigation and sufficient to endanger the jetties by undermining, and of diminishing unduly the volume of the tidal prism by restricting the flood-tide inflow, has resulted in an unwarranted caution which has led to a spacing too great to realize even the results originally aimed at. Second, in practically all the more important cases, the original plans were drawn with channel dimensions in mind which were so increased by subsequent projects that, even had the jetties been adequately spaced

for their original purpose, they would have been inadequate to the modified project. It appears that, in planning jetties, it would be preferable to space them as closely together as may seem reasonably safe under the circumstances rather than as far apart as possible with any basis of hope that they will produce the desired results. It is doubtless preferable to secure a 30-foot deep channel on a 20-foot project than a 20-foot channel on a 30-foot project.

(5) With the incomplete information available, no opinion as to an approximate relationship between the cross sectional area between jetties and the volume of the tidal prism (or, more probably, the area of the tidal basin and the range of tide) can be hazarded. In a general way, it appears that jetties between 800 and 2,000 feet apart show a higher per centage of effectiveness than do those closer together or farther apart, but there are notable exceptions on both sides. The jetties at the entrance to the St. Johns River, Florida, 1,600 feet apart in their parallel section, have maintained a channel 30 feet deep and 800 feet wide between them with a minimum of maintenance dredging. By contrast, at Sabine Pass, Louisiana and Texas, with jetties 1,800 feet apart at their outer ends, over 25,000,000 cubic yards of material have been dredged from the channel in the past 15 years in the effort to secure and maintain depths of 34 to 36 feet and widths of 400 to 600 feet. With complete data and further study it may be possible to formulate some relationship between the varied and often complex factors involved which may determine with at least greater definiteness than is

now possible the spacing which should be adopted for jetties.

d. Economics.

(1) In attempting to analyze the economic justification for the provision of jetties as an aid to channel maintenance, many difficulties are encountered. For one thing, it is in the nature of the case impossible to prove whether or not in any given case, a channel could have been provided and maintained by dredging alone, and if so, at what cost for new work and average annual maintenance, inasmuch as the latter has usually not been tried. Then again, in computing the annual carrying charges on the jetty, the interest on the investment is usually computed on the "original cost for new work". In view of the fact that in a rock jetty, at least, there is only settlement and displacement of the material, with practically no loss thereof, and that "maintenance", so-called, consists in adding a permanent supply of rock necessary to produce a final stable structure, it would seem not illogical to base the comparable annual value of the jetty on its total cost of both "new work" and "maintenance" - in other words, in the provision of a final and stable jetty, so-called "maintenance" enrockment is as properly new work as the enrockment actually so-called. The acceptance of this point of view would considerably and justifiably increase the capital value of the finished jetty and the potential annual interest return thereon which may properly be balanced against the conjectural annual cost of maintenance by dredging, always assuming that the latter would have been practicable. Furthermore, in computing

maintenance costs by dredging, it is obvious that those costs many years ago, with less effective equipment, were higher than now. It may even be assumed that still further improvement of dredges and methods will be made, with a further decrease in the unit costs of dredging.

(2) Enough evidence is, however, available to indicate at least a strong probability that, solely from the standpoint of channel provision and maintenance by scour, the provision of many jetties appears to have been economically unjustified, if the channel could have been provided and maintained by dredging alone. It is indicated that those charged with planning inlet improvements in the future should exhaust every possibility of providing and maintaining a channel by dredging before providing jetties. In many if not most cases, it seems probable that dredging with a modern seagoing hopper dredge might profitably be attempted first, and, if that failed, the jetties could still be built. The experimental dredging would usually cost only a small part of the cost of jetties, and even if jetties were saved in only one case out of several, the elimination of the expenditure on a single jetty system would more than counterbalance the loss on a number of cases of unsuccessful experimental dredging.

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