CHAPTER 37
MODEL TESTS OF ENLARGED NAVIGATION CHANNEL AT MILLER SANDS BAR, COLUMBIA RIVER ESTUARY

Frank A. Herrmann, Jr.
U. S. Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

ABSTRACT

The paper describes a series of tests made in the Columbia River Estuary model at the U. S. Army Engineer Waterways Experiment Station concerning enlargement of the navigation channel at Miller Sands Bar. Tests were conducted to determine the effects of enlarging the channel and to determine the effectiveness of various combinations of proposed improvement works.

Test results indicated that enlarging the navigation channel from 35x500 ft to 40x600 ft with no improvement works will cause about a 40 percent increase in channel shoaling. Plan 8 was found to be the most effective plan tested. It consisted of six pile dikes spaced 1800 ft apart and placed normal to the predominant flow direction and an 8700-ft dredge fill. The elements of this plan caused a 56 percent reduction of shoaling in the 40x600-ft channel.

The paper also describes the purpose of the model study, the prototype, the model, and model testing procedures.

THE PROTOTYPE

The Columbia River has its source in Columbia Lake, British Columbia, and flows 1,210 miles to the Pacific Ocean. The final 309 miles of the river forms the boundary between the states of Washington and Oregon. The total area of the Columbia River basin is about 259,000 square miles. The river broadens from about 1 mile wide in the narrow reaches below Bonneville Dam, 145 miles above the mouth, to about 2 miles wide at river mile 30. Thence the estuary rapidly broadens to about 9 miles wide at river mile 20, and then narrows to 2 miles wide between the jetties at the entrance.

During periods of low river discharge, the tidal effect extends upstream a distance of about 141 miles. The tides display a diurnal inequality typical of the Pacific Ocean. The mean tide range at Ft. Stevens (river mile 9) is 6.4 ft; however, the diurnal range (from mean higher high water to mean lower low water) is 8.3 ft. The mean and diurnal ranges at Portland are 1.8 ft and 2.4 ft for periods of low river discharge. The extreme tides at the entrance are -2.6 ft MLLW and +11.6 ft MLLW.

The mean freshwater discharge at the mouth of the river is about 260,000 cfs, with a maximum flow of record of about 1,300,000 cfs and a minimum flow of about 70,000 cfs. The annual hydrograph at the mouth shows two peaks. The highest flows occur in May and June, resulting from snow melt. The second peak, considerably lower than the summer freshet, reaches its maximum in December and January, and results from winter rains, mainly in the Willamette River basin.

821
Maximum ebb current velocities encountered in the main channel during an average freshet (600,000 cfs) are about 12 fps. Maximum flood current velocities encountered in the main channel during an average low flow period (120,000 cfs) are about 6 fps. Flood and ebb current velocities from surface to bottom vary appreciably in both magnitude and duration throughout the reach affected by saltwater intrusion, which lies generally between the entrance and Tongue Point (river mile 17). These differences decrease progressively upstream from the entrance and disappear in the freshwater reaches of the river. As a result of these density effects, bottom flood currents predominate over bottom ebb currents through the center of the entrance channel and up the naturally-deep channel on the Washington side to about river mile 17 during average flow periods. Surface ebb currents predominate over surface flood currents for all flows and at all locations throughout the estuary, except in the area between the north jetty and jetty A which is under the influence of a large eddy.

The water in the upper portions of the Columbia River Estuary is fresh, while that near the ocean entrance is essentially sea water at the lower depths. The variation in the density of the water in the vertical plane causes a difference in the magnitude and phase of surface and bottom current velocities as discussed in the preceding paragraph. The difference is most pronounced between the jetties and decreases progressively upstream until the water becomes completely fresh. The degree of mixing of saltwater and fresh water and the extent of saltwater intrusion vary with the range and elevation of tides and the amount of freshwater discharge. The upstream limit of saltwater intrusion for a low freshwater discharge and an average tide is about Harrington Point (river mile 24).

Existing improvements maintained by the Corps of Engineers for the purpose of providing a navigation channel include 3 stone jetties in the entrance, a 48x2640-ft channel through the entrance to river mile 3, a 35x500-ft channel from river mile 3 to Portland, Ore., and pile dikes located at strategic points to train the currents and produce scouring velocities. Congress recently authorized enlargement of the 35x500-ft channel to a 40x600-ft channel.

PURPOSE OF THE MODEL STUDY

In 1960 the Committee on Tidal Hydraulics recommended construction of a comprehensive hydraulic model of the Lower Columbia River Estuary. In general terms the purposes of the model study are as follows: to determine the need for and to develop optimum plans for rehabilitation of existing jetties; to determine the most effective means of reducing the cost of maintenance dredging in the navigation channels; and to determine the effects of the proposed enlargement of the 35x500-ft channel to 40x600 ft.

Specific investigations concerning the proposed 40x600-ft channel include: determination of existing hydraulic, salinity, and shoaling characteristics at each bar included in the Columbia River Estuary model; determination of the changes in hydraulic, salinity, and shoaling characteristics caused by enlarging the channel; development of optimum control structures to minimize dredging; and location of suitable dredge-spoil disposal areas.

This paper covers the 40x600-ft channel studies made at Miller Sands Bar.
MODEL TESTS

THE MODEL

DESCRIPTION

The Columbia River model was constructed at U. S. Army Engineer Waterways Experiment Station in 1962. The model reproduces approximately 350 square miles of the prototype area, including the Pacific coast from 9 miles north of the north jetty to 6 miles south of the south jetty and offshore areas well beyond the -120 ft contour; the Columbia River to river mile 52; Youngs, Baker, and Grays Bays; Youngs, Lewis and Clark, Grays, and Deep Rivers; and the extensive system of sloughs and other tidal tributaries which affect tidal action through the model area. The limits of the area reproduced are shown in fig. 1.

The model is constructed to linear scale ratios, model to prototype, of 1:500 horizontally and 1:100 vertically. From these basic ratios the following scale relations were computed according to the Froudian relationship: velocity, 1:10; time, 1:50; discharge, 1:500,000; volume, 1:25,000,000; and slope, 1:5. The salinity ratio for the study is 1:1. One prototype cycle (diurnal tide) of 24 hours and 50 minutes is reproduced in the model in 29 minutes and 48.5 seconds. Lambert Grid coordinates are used for horizontal control, and mean lower low water, the Columbia River datum, and mean sea level (USC&GS Datum - 1947 Adjustment) are used for vertical control. The model is approximately 560 ft long, 130 ft wide at its widest point, and covers an area of about 48,000 square feet. It is completely inclosed to protect it and its appurtenances from the weather, and to permit uninterrupted operation.

The model is a combination fixed-bed and movable-bed model. It was initially constructed as a fixed-bed model throughout; however, provisions were made to convert the entrance area to a movable-bed model at a later date, when such studies are deemed necessary. The model is molded to conform to the prototype conditions that existed in 1959. The navigation channel is molded in removable blocks so that desired alterations can readily be made.

The permanent model roughness employed consists of metal strips, varying in width from ½ inch to 1 inch, and cut off below the low-water elevation. All the strips installed in the navigation channel are mounted on wires to prevent excessive turbulence adjacent to the bottom of the strips. The use of these metal strips as roughness is necessary because proper adjustment of velocity and distribution of currents, both horizontally and vertically, in any given cross section, could not be obtained through the use of boundary roughness alone, especially in the deep areas of the model.

APPURTENANCES

The model is equipped with the necessary appurtenances to reproduce and measure all pertinent phenomena such as tidal elevations, saltwater intrusion, current velocities, freshwater inflow, littoral current, waves, dispersion characteristics, and shoaling distribution. Apparatus used in connection with the reproduction and measurement of these phenomena include a primary tide generator and recorder, secondary tide generator, tide gages, continuous recording salinity meters, salinity samplers, chemical titration equipment, current velocity meters, freshwater inflow measuring devices, skimming and measuring weirs, littoral current generator, wave generators,
Fig. 1. Layout of Columbia River Estuary model
dye injection and measurement equipment, and shoaling injection and recovery apparatus.

The reproduction of the tidal action in the model is accomplished by means of a primary tide generator located in the model ocean and a secondary tide generator located at the upstream limit of the model (Beaver Army Terminal). The primary tide generator maintains a differential between a pumped inflow of saltwater to the model ocean and a gravity outflow of saltwater from the model ocean as required to reproduce all characteristics of the prototype tides at the model control station (Ft. Stevens). The primary tide generator is equipped with a continuous tide recorder so that the accuracy of the model tide reproduction can be checked visually at any time. The secondary tide generator, synchronized with the primary tide generator, reproduces the proper ebb and flood tidal discharges at Beaver Army Terminal throughout the tidal cycle.

Permanently mounted point gages are installed on the model at the locations of the 5 recording tide gages used for collection of field tide data. The model gages are graduated in 0.001 ft (0.1 ft prototype) and are used to measure tidal elevations throughout the model. Portable point gages are used to measure tidal elevations at other points, as required.

Salinity concentrations are determined by chemical titrations with silver nitrate in all cases involving a large number of simultaneous measurements or requiring a high degree of accuracy. Water samples are taken from selected locations in the model by hand, or with a special sampler which can simultaneously draw samples at various desired depths. The samples are then titrated with equipment consisting of a graduated burette for measuring silver nitrate, a selected group of pipettes for measuring the volume of the salinity samples, sample jars, and potassium chromate for use as an end-point indicator in the titration process.

Current-velocity measurements are made in the model with miniature Price-type current meters. The meter cups are about 0.04 ft in diameter, representing 4.0 ft in the prototype. The center of the cups is about 0.045 ft from the bottom of the frame, representing 4.5 ft in the prototype. The meters are calibrated frequently to insure their accuracy and are capable of measuring velocities as low as about 0.05 fps (0.5 fps prototype).

A Van Leer or California-pipe weir is used to obtain precise measurements of the freshwater inflow of the Columbia River at Beaver Army Terminal for upstream discharges less than 300,000 cfs. For upstream discharges greater than 300,000 cfs, a Venturi meter is used. The freshwater discharge of the Youngs River and Lewis and Clark River is introduced into the model through a single, small Van Leer weir, as is that for the Grays River and Deep River.

The mixed saltwater and fresh water that accumulates in the model ocean has to be removed in order to maintain a constant source salinity. This is accomplished by means of a skimming weir which removes a quantity of mixed water from the surface layer equal to the freshwater inflow at the upper end of the model. Precise measurement of the discharge over the skimming weir is made by use of a V-notch weir.
Shoaling is reproduced in the model by injecting granulated synthetic sediments into the model. The equipment used for injecting the material into the model consists of a vacuum tank and a flexible hose with a flared nozzle. The material is sucked into the tank in a water mixture, then allowed to flow out of the tank by gravity through the hose and nozzle, and thus spread over the problem area. At the end of the model test, the shoaling material deposited within the limits of the navigation channel is removed with the flared nozzle connected by the hose to an aspirator or hydraulic ejector. The material is then separated from the water and measured volumetrically.

PROTOTYPE DATA

Prototype data collected for verification of the model included (a) continuously recorded tidal elevations at five locations; (b) current velocity, current direction, and salinity observations at five depths on each of 23 stations; (c) freshwater hydrograph; and (d) hydrographic and topographic surveys. All prototype data except hydrographic and topographic surveys were published by the U. S. Army Engineer District, Portland, in Interim Report 1 of 1 September 1960, entitled 1959 Current Measurement Program, Columbia River at Mouth, Washington and Oregon, in four volumes. These prototype data were obtained for three separate conditions of upland discharge and tide: low upland discharge and mean tide, intermediate upland discharge and mean tide, and high upland discharge and spring tide.

VERIFICATION OF THE MODEL

The accurate reproduction of hydraulic, salinity, and shoaling phenomena in an estuary model is an important phase in the preparation of the model for its ultimate use in evaluating the effects of proposed improvement works. Because of the wealth of prototype data available, and the degree of accuracy desired, verification of hydraulic and salinity phenomena required a series of elaborate tests extending over a period of 15 months. Shoaling verification is undertaken at each problem area when studies of that area are initiated. At least one month has been required to complete the shoaling verification of each problem area.

It should be emphasized that the worth of any model study is wholly dependent upon the proven ability of the model to produce with a reasonable degree of accuracy the results which can be expected to occur in the prototype under given conditions. It is essential, therefore, before any model tests are undertaken of proposed improvement plans, that the required similitude first be established between the model and prototype and that all scale relationships between the two be determined.

HYDRAULIC VERIFICATION

The first step in the hydraulic verification involved reproduction of the prototype tidal phenomena throughout the model, and was accomplished by adjusting the tide generators and the metal roughness strips in the model. The primary tide generator was adjusted to reproduce the proper tidal elevations and phases at the control tide station (Ft. Stevens), and then the secondary tide generator and the metal roughness strips throughout the model were adjusted until the proper tidal elevations and phases were reproduced at the remaining four tide stations. After completing the tidal adjustment, the maximum discrepancy in tidal range was in the order of 0.3 ft prototype (0.003 ft model), and the maximum discrepancy in the times of high water
and low water was in the order of one-half hour prototype (about 36 sec model).

The second step in the hydraulic verification involved reproduction of the lateral distribution of prototype current velocities at the 23 stations metered in the prototype. The procedure followed consisted of progressively altering the arrangement of the model roughness strips until the lateral distributions of velocities were similar to those of the prototype velocity distributions at each of the velocity stations. During this verification phase, it was necessary to adjust the roughness in such a manner as to avoid significantly changing either the tidal elevations or tidal phases at any of the tide gages.

The verification efforts to this point were accomplished with fresh water only in the model; however, it was necessary to operate the model with both fresh water and saltwater for the detailed adjustment of vertical velocity distributions throughout the reach subject to saline intrusion. Accordingly, the model ocean was filled with water having a salinity of 33 parts per thousand, and further minor adjustments were made to the model roughness elements until the distributions of velocities from surface to bottom at all model velocity stations were in agreement with those observed in the prototype at corresponding stations.

SALINITY VERIFICATION

Once the adjustment of lateral and vertical velocity distributions had been accomplished, no further roughness adjustments were required to reproduce the prototype salinity distribution in both plan and vertical. Tests were made involving reproduction of the tides and river discharges that occurred during the measurements of prototype salinities, and the results of these tests showed that salinity phenomena in the model were in excellent agreement with those of the prototype.

SHOALING VERIFICATION

The model shoaling verification involves the reproduction of the prototype shoaling distribution pattern throughout the length of a given reach of the navigation channel. Prototype hydrographic surveys of the channel are analyzed to determine the amount of shoaling within the navigation channel from one year’s postdredge survey to the following year’s predredge survey. The channel is then divided into sections and the percent of total shoaling is determined for each section.

The basic objective of the model shoaling verification is to identify a synthetic sediment which will move and deposit under the influence of the model forces in the same manner that the natural sediments move and deposit under the influence of the natural forces. In the process of identifying a suitable sediment for use in the model, there are a great number of variables involved and each must be determined by trial and error in the model. A list of the most significant variables includes (a) shape, size, gradation and specific gravity of the artificial sediment, (b) method, location, duration and quantity of artificial sediment injection, (c) volume of freshwater discharge, (d) magnitude of tide, (e) length of model operation, (f) readjustment of model roughness, (g) magnitude and directions of waves, and (h) magnitude and
direction of littoral flow. Model temperature must be closely monitored, since similar shoaling tests run with different temperatures often give significantly different results.

DESCRIPTION OF THE MILLER SANDS AREA

Miller Sands Bar is 20,000 ft long and extends from about river mile 21.5 to about river mile 25.5. The upstream 6,000 ft of the navigation channel in this bar lie in the naturally-deep channel on the Washington side of the estuary. At about this location, the navigation channel leaves the Washington-side channel and crosses the estuary to the natural Oregon-side channel. The lower 14,000 ft of the bar forms the upper one-third of the river crossing. Saltwater intrusion extends into the bar during the flood phases of tide for upland discharges of 200,000 cfs or less. Reversal of current direction from ebb to flood occurs for upland discharges as great as 570,000 cfs. Ebb current velocities as great as 5.0 fps have been observed during the long ebb of a spring tide with an upland discharge of 570,000 cfs. Maximum flood velocities of about 2.0 fps have been observed with a mean tide and an upland discharge of about 160,000 cfs.

During the past four years, maintenance dredging in this bar has averaged about 860,000 cubic yards. During this period dredging operations have included 2 ft of overdepth dredging and an additional 3 ft of advance maintenance overdepth dredging. Dredging at Miller Sands Bar is accomplished by hopper dredge with the dredge-spoil disposed of in a sump and later re-handled by pipeline dredge. Unit cost of dredging is about $0.35 per cubic yard. It is possible that after the improvement works planned for the enlarged channel have been constructed, all dredging in this area can be accomplished by pipeline dredge with some reduction of cost. The sediment in this bar, as in the entire lower Columbia River Estuary, is fine sand with a grain size of 0.15 to 0.3 mm.

MODEL TESTS AND RESULTS

TEST PROCEDURES

Information concerning hydraulic, salinity, and shoaling characteristics of each condition investigated was required as a basis for selecting the best improvement plan. Consequently, observations of surface and subsurface current velocities and patterns, as well as salinities, were made throughout the problem area for each condition tested, and each condition was subjected to identical shoaling tests.

Current velocities and salinities were measured at surface, middepth, and bottom at mile and half-mile stations along the navigation channel center line at one-half hour (prototype) intervals. Additionally, photographs were made at one hour (prototype) intervals of surface and bottom floats from which current velocities and current patterns could be determined. Hydraulic and salinity measurements and photographs were made for conditions of the tide of 20–21 September 1959, which was of approximately mean range (diurnal range of 8.2 ft at Ft. Stevens), and upland discharges of 200,000 cfs, 400,000 cfs, and 600,000 cfs.
The shoaling test procedure developed for the Miller Sands Bar study was as follows: (a) a granular plastic material with specific gravity of 1.04 and grain size of 1/8 inch diameter cylinders was used as the artificial sediment; (b) 100,000 cc of the material was initially spread over the entire problem area in a thin layer before model operation was begun; (c) after the model had been in operation for two complete tidal cycles, additional material was injected into the model across the channel about 3,500 ft upstream from Miller Sands Bar during the strength of ebb for the remaining 12 tidal cycles of the test; (d) throughout the test the model was operated alternately with an upland discharge of 600,000 cfs for 2 tidal cycles and 900,000 cfs for 1 tidal cycle; (e) 20,000 cc of material was injected during each cycle of 900,000 cfs discharge and 10,000 cc during each cycle of 600,000 cfs discharge; and (f) the model was operated for conditions of a mean tide. It was not found necessary to produce waves in the model during these tests. At the conclusion of each test, the material deposited within the navigation channel limits was picked up and measured by 2,000-ft channel sections. The shoaling distribution pattern was then computed as the percentage of material which had deposited in each section. The model technique was exactly the same for all tests.

DESCRIPTION OF PLANS

Shoaling tests were conducted for a total of 14 separate conditions. To date hydraulic and salinity observations have been completed for the existing (1965) conditions and partially completed for one of the proposed alignments of the enlarged channel. Additional hydraulic and salinity observations will be made only for plan 10. The shoaling distribution pattern was verified using prototype conditions existing prior to 1962, for which period extensive prototype shoaling data were available.

Navigation channel alignments - Shoaling tests were made of the existing (1965) 35x500-ft navigation channel and 2 proposed alignments of the enlarged navigation channel. The 35x500-ft channel base condition was the same as that for the shoaling verification except that Rice Island, a man-made dredge fill, was added to the model. Rice Island was built in 1962, is approximately 4,200 ft long, and is roughly parallel to and 2,000 ft north of the downstream portion of the navigation channel at Miller Sands Bar. In the first 40-ft channel alignment studied, the two bends in the existing alignment were replaced by a long radius curve. The width of this channel was increased to 800 ft in order to reduce the hazard of ships passing in a curve. This alignment was eliminated from consideration because of the high cost of initially dredging and maintaining a channel of this width; therefore, the 40x800-ft channel will not be discussed further. In the second alignment studied, the 40x800-ft channel alignment was slightly straightened and the width reduced to 600 ft. This alignment is referred to as the 40x600-ft channel base condition. Since 5 ft of over-depth dredging is authorized for this bar, the 35x500-ft channel was molded to -40 ft MLLW, and the 40-ft channels were molded to -45 ft MLLW. The alignments of the 35x500-ft and 40x600-ft channels are presented in fig. 2.

Plans 6-10 - Plans 6-10 constituted various combinations of improvement works with the 40x600-ft channel condition. For plan 6, an 8,700-ft dredge fill extending north from Rice Island was added to the model (fig. 3). The dredge fill varied from 1,000 ft north of the navigation channel at its upstream limit to 1,600 ft north of the navigation channel at its downstream limit. It was not located parallel to the predominant ebb current direction;
Fig. 2. Location of 35x500-ft and 40x600-ft navigation channels at Miller Sands Bar
Fig. 3. Elements of Plan 6 and model shoaling pattern
therefore, a significant amount of flow, which would normally have passed
north of Rice Island, was diverted into the navigation channel. The same
dredge fill was also included in plans 7-10. For plan 7, six pile dikes
perpendicular to and 200 ft north of the navigation channel were added to
the model (fig. 4). Spacing between the three upstream dikes was about
1,600 ft, and that between the remaining dikes was 2,250 ft. For plan 8,
the six pile dikes were realigned to be approximately normal to the pre-
dominant ebb current direction, and the spacing between the dikes was
1,800 ft (fig. 5). For plan 10, the upstream-most and downstream-most pile
dikes of plan 8 were removed from the model, and the lengths of the two
remaining downstream dikes were reduced by about 300 ft (fig. 6). This plan
was approved by the Portland District and will be constructed in 1966.
Elimination of the two pile dikes for this plan was an accommodation to local
commercial fishing and towboat interests.

SHOALING TEST RESULTS

35-ft channel - The results of the model shoaling verification are
presented in fig. 7. From experience with other models, it is believed that
the model reproduction of prototype shoaling is entirely satisfactory for a
detailed qualitative analysis of the effects of proposed plans. The results
of the 35x500-ft channel base test are presented in fig. 8. The shoaling
index, which appears in figs. 8-11, is defined as the total amount of material
recovered in the navigation channel for a particular test, divided by the amount
of material recovered in the navigation channel for some different test to
which the former is to be referenced. A shoaling index of less than 100 percent
indicates that the condition tested resulted in a reduction in shoaling, while an
index greater than 100 percent indicates the condition tested resulted in an
increase in shoaling. It can be seen in fig. 8 that the addition of Rice Island
to the model did not significantly change the shoaling distribution pattern,
but it did indicate a reduction in shoaling of about 10 percent.

40x600-ft channel - It can be seen from the data presented in fig. 9
that the proposed 40x600-ft channel caused an increase of channel shoaling of
about 41 percent, as compared to existing conditions. The shoaling distribution
pattern was not greatly changed, although a slight downstream shift was noted.
It should be pointed out that the area of the 40x600-ft channel is approximately
20 percent greater than that of the 35x500-ft channel, which would result in a
considerable increase in shoaling even without deepening the channel.

Plans 6 and 7 - Results of the shoaling tests of plans 6 and 7 give a
good indication of the relative merits of the proposed dredge fill and pile
dikes. It can be seen from the data presented in fig. 10 that the dredge fill
alone (plan 6) reduced channel shoaling by about 11 percent, as compared to the
40x600-ft channel base test, but caused a second peak to form in the shoaling
distribution pattern opposite the upstream end of the dredge fill. Addition
of the plan 7 pile dikes further reduced channel shoaling by about 38 percent,
or a total reduction of about 49 percent as compared to the 40x600-ft channel
base test. The pile dikes also reduced the second peak in the distribution
pattern which was caused by the dredge fill. It can be seen by comparing the
shoaling patterns shown in figs. 3 and 4, that the plan 7 pile dikes were
effective in forcing the northern limit of model shoaling about 200 ft south
as compared to plan 6. It was noted, however, that addition of the pile dikes
doubled the rate of model shoaling in the next bar downstream. Since this
next bar downstream is a minor one in terms of annual shoaling, and since it
Fig. 4. Elements of Plan 7 and model shoaling pattern
Fig. 5. Elements of Plan 8 and model shoaling pattern
Fig. 6. Elements of Plan 10 and model shoaling pattern
Fig. 7. Verification of model shoaling distribution
Fig. 8. Shoaling distribution - 35x500-ft channel base test
Fig. 9. Shoaling distribution - 40x600-ft channel base test
Fig. 10. Shoaling distribution - Plans 6 and 7
is difficult to determine the main source of shoaling material to this bar, the significance of the observed shoaling increase here is difficult to evaluate.

Plan 8 - The results of the plan 8 shoaling test are presented in figs. 5 and 11. It can be seen that by realigning the pile dikes so that they are normal to the flow direction and by reducing the spacing between the downstream four dikes, channel shoaling was further reduced by about 7 percent, or a total reduction of about 56 percent as compared to the 40x600-ft channel base test. This is equivalent to 62 percent of the existing shoaling rate with the 35x500-ft channel. It can also be seen that this alignment of the pile dikes completely eliminated the upstream peak in the shoaling distribution pattern, which was caused by the dredge fill. Examination of the shoaling pattern shown in fig. 5 indicates that the realignment of the pile dikes and the reduction of the spacing between them forced the northern limit of model shoaling about an additional 150 ft south, as compared to plan 7. Plan 8 was the most effective plan tested in terms of reducing shoaling in the navigation channel. The sharp increase in channel shoaling in the next bar downstream was observed for this plan as it was for plan 7.

Plan 10 - The results of the plan 10 shoaling test are presented in figs. 6 and 11. It can be seen from this data that removal of the upstream-most and downstream-most pile dikes of plan 8 caused an increase in channel shoaling of about 8 percent as compared to plan 8, or a total reduction of about 48 percent as compared to the 40x600-ft channel base test. This increase in shoaling occurred primarily at the downstream end of the channel. The sharp increase in channel shoaling in the next bar downstream was observed for this plan as it was for plans 7 and 8.

HYDRAULIC TEST RESULTS

Results of current velocity measurements show that, for the 600,000 cfs and 400,000 cfs upland discharges, the proposed 40-ft channel caused general increases of about 0.5 - 1.0 fps in maximum surface and middepth ebb velocities throughout the length of the bar. Maximum bottom ebb velocities were generally increased by less than 0.5 fps for both discharge conditions. A velocity increase of this sort had not been anticipated, since it would normally be expected that an increase in cross-sectional area would be accompanied by a decrease in velocity. However, subsequent measurements in secondary natural channels south of the navigation channel revealed that velocities in these channels had been significantly reduced, indicating that the enlarged navigation channel carried a larger percentage of the total discharge than does the existing channel. There was no reversal of current direction from ebb to flood in the navigation channel for the 600,000 cfs discharge, and minimum ebb velocities were not changed. There was a slight reversal of current direction for the 400,000 cfs discharge, with maximum flood velocities of about 0.2 fps for both channel conditions. Current velocity data for river mile 24.0 are presented in figs. 12 and 13. The photographs of surface and bottom current patterns indicated that the 40-ft channel did not cause any great changes in either surface or bottom current patterns in the Miller Sands Bar area.
Fig. 11. Shoaling distribution - Plans 8 and 10
Fig. 12. Velocity observations on channel center line at mile 24.0 - Q = 600,000 cfs
Fig. 13. Velocity observations on channel center line at mile 24.0 - Q = 400,000 cfs
CONCLUSIONS

From the results of the tests described above, the following conclusions were reached:

1. Enlargement of the existing 35x500-ft channel to a 40x600-ft channel, without the construction of appurtenant works, would result in about a 41 percent increase in channel shoaling. The shoaling distribution pattern, however, would not be greatly changed.

2. The dredge fill of plan 6 would cause a significant reduction of channel shoaling; however, the combination of the dredge fill and pile dikes of plan 7 would prove to be far more effective, and would result in a reduction in channel shoaling of about 49 percent as compared to the 40x600-ft channel with no improvements. Either the dredge fill alone or the dredge fill and pile dikes would create a new peak in the shoaling distribution pattern opposite the upstream end of the dredge fill.

3. Placing the dikes normal to the predominant current direction and spacing them 1,800 ft apart (plan 8) would result in significantly less channel shoaling than would be obtained from placing them perpendicular to the channel and spacing them 2,250 ft apart (plan 7). The improvements of plan 8 would result in a reduction in channel shoaling of about 56 percent as compared to the 40x600-ft channel with no improvements.

4. Omission of the upstream-most and downstream-most pile dikes of plan 8 would result in a reduction of channel shoaling of about 48 percent as compared to the 40x600-ft channel with no improvements.

5. Velocity observations indicate that the 40x600-ft channel will be significantly more efficient hydraulically than the existing 35x500-ft channel. This will result in the diversion of a significant amount of flow from the secondary channels into the navigation channel, thus increasing current velocities in the navigation channel and reducing those in secondary channels.

CONCLUDING REMARKS

Since the present state of knowledge in the field of tidal hydraulics has not developed to the point where complex problems involving sedimentation can be solved analytically, the hydraulic model is a very valuable tool for the design engineer. It is not capable, however, of providing all the quantitative information necessary for the design of major projects and is, therefore, not suggested as a substitute for analytical design or the collection and examination of field data. In the hands of experienced laboratory personnel who are thoroughly familiar with the capabilities and limitations of hydraulic models, the cost and effort invested in the model study is usually returned with dividends in terms of lower costs and improved performance of the project in the field. The model may indicate that the best design will have either a lower or higher cost of construction than that of the proposed design; however, savings should result from improved efficiency of the design and lower maintenance costs.