SEDIMENT CONTROL AT A HEADWORKS USING GUIDE VANES

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SYNOPSIS

The Bureau of Reclamation has in progress a general study program concerning the control at canal headworks of coarse sediments diverted from alluvial streams. The study described in this paper was conducted as one phase of the general program. Its purpose was to develop satisfactory arrangements of bottom and surface guide vanes, to compare the performance of each type, and to evaluate the effectiveness of each type in reducing sediment intake into a canal diverted from a large river. Thirty-seven tests were made on one type of canal entrance using a standard river and diversion discharge.

Tests indicated that both bottom and surface vanes, Figures 7 and 9, are effective in reducing sediment intake into a canal diverted from a large river. With either bottom or surface vane operation, it was possible to reduce the quantity of sediment entering the model canal to approximately 1/23 of the quantity entering without the vanes in place.

Because the vanes are not overly sensitive to the tested variables, including length, spacing, placement, and depth, the information in this paper should be of value in design work. For intake conditions similar to those used in these tests, guide vanes having dimensions proportional to those given in Figures 7 and 9 should prove beneficial. Results of these tests show that guide vanes to control sediment movement can be developed by means of model tests.

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INTRODUCTION

Sediment removal from canals, laterals, and farm ditches is costly maintenance, so that it is desirable, if possible, to exclude or reduce the amount of sediment going into a canal headworks which takes water from a sediment-laden stream. Guide vanes placed near a headworks or sluiceway entrance have been studied1/ as one effective method of controlling sediment movement near the intake. They are used to control localized secondary currents, Figures 1 and 2, by diverting bottom water with its relatively heavy sediment load away from the canal headworks, and top water with its relatively light sediment load through the canal headworks.

Studies to develop and evaluate the effectiveness of bottom guide vanes for a particular arrangement of intake were made for the San Acacia Diversion Dam and are reported in the Bureau of Reclamation, Hydraulics Branch Report No. Hyd-479. 2/ A bottom vane arrangement, determined by model tests which resulted in satisfactory performance is described in this paper. At the conclusion of the San Acacia tests, the model was used to extend the data on surface and bottom guide vanes as a research project. Dimensions referred to in this paper are for the San Acacia Dam. Prototype dimensions are used in the narrative because they are easier to visualize. Some prototype dimensions are shown in terms of a model scale of 1:20, in parentheses on the figures, but most of the dimensions are model dimensions and show the actual size of the test facility.

Although the scope of these studies is limited, the research indicated that efficient guide vanes can be developed by means of model studies, and that additional research would provide valuable generalized design information.

1/M. Potapov and B. Pychkine, 1947, Methods of Transverse Circulation and Its Application to Hydrotechnics, Moscow Academy of Sciences, U.S.S.R. Translation No. 46 of Service des Etude et Recherches Hydrauliques, Paris.
2/Bureau of Reclamation, March 1962, Hydraulic Model Study to Determine a Sediment Control Arrangement for Socorro Main Canal Headworks--San Acacia Diversion Dam, Middle Rio Grande Project, New Mexico, Hydraulics Branch Report No. Hyd-479.

EXPERIMENTAL WORK AND DATA OBTAINED

The model, Figures 3 and 4, was constructed in a test box lined with sheet metal. The prototype spillway consisted of 12 river bays with 20-foot by 7-foot 6-inch gates and an adjacent sluiceway area. A movable bed extended approximately 600 feet upstream from the dam axis. The canal headworks was approximately 160 feet upstream from the dam axis and discharged into a canal of 8-foot bottom width and 2:1 side slopes. The low-flow channel used in the San Acacia study, shown in Figure 3 as having 5 entrance conduits, was not operated in these tests.

Major features such as river gates, conduits, slide gates, and sampling equipment were generally constructed of sheet metal. Treated wood was used for piers between radial gates, and a portion of the canal was constructed of metal lath covered with concrete.

A fine sand of near uniform size gradation, Figure 5a, was used to form the movable bed and to represent sediment bedload in the model. The average diameter of the model sediment was approximately 0.2 mm (millimeters). Figure 5b shows the settling velocities of the model sand.

Two pumps were used to supply water and sediment to the model. No. 1 pump positioned at the downstream end of the model, Figure 3, recirculated sediment-laden water through the model. No. 2 pump drew clear water from a laboratory reservoir and supplied a small amount of water to replace sampling and other losses. This water was introduced into the upstream end of the model and maintained a constant head on Pump No. 1. Excess water discharged over a weir at the downstream end of the model. Discharges and water surface elevations in the canal were maintained constant by the use of slide gates at the downstream end of the canal. Backwater was maintained on the radial river gates by the use of the slide gates installed for this purpose downstream from the diversion dam spillway, Figures 3 and 4.

Samples of water and sediment discharging from the canal, the sluiceway, and the river gates were obtained by passing a hand-operated sediment sampler through the discharging water, Figure 4b. The sediment-laden water flowed through the sampler to a volumetric collector calibrated to indicate the amount of water and sediment in liters. After the sediment had settled into the small funnel at the bottom of the collector, its volume was determined. Thus, the concentrations of sediment passing through the sluiceway or the canal could be readily determined at any time during a test.

During a test some sediment deposited and remained in the canal. To account for these deposits which had entered the canal but had not been accounted for in the sampling process, the volume of sediment remaining in the canal was also measured. The sediment concentration was therefore based on the discharge and the average sediment concentrations which passed through various parts of the model, taking into account the amount of sediment deposited in the canal.

For all tests, the water surface elevation just upstream from the dam was held at 4668.7; the tailwater elevation below the radial river gates was held at 4667.6 to correspond to the tailwater used in the San Acacia model study. The canal intake gate was calibrated while holding the headwater at normal elevation 4668.7 and maintaining the canal water surface at the calculated normal elevation for the discharge. A standard test discharge, similar to that used on the San Acacia model study, consisting of 8,760 cubic feet per second in the river and 174 cubic feet per second diverted to the canal was used throughout the study (1:20 model scale).

When contours of the movable bed configuration at the end of a test were desired, levels were obtained and appropriate plots made. To help evaluate results, both black and white and color photographs of sediment deposits and bed conditions were obtained for each test. Tests were compared on the basis of a ratio of the concentration of sediment entering the canal headworks to that moving in the river upstream from the headworks:

$$R = \frac{C_c}{C_{rus}}$$

where:

R = Concentration ratio
C_c = Concentration in parts per million, by weight, of sediment in water entering the canal headgates
C_{rus} = Concentration in parts per million, by weight, of sediment in the river water upstream from the canal headworks

Thus, lower values of the ratio indicate a more satisfactory sediment exclusion device.

To develop a satisfactory set of vanes for the standard test discharge, it was assumed that for a given number of vanes having an established cross section, a satisfactory vane spacing for a given vane angle, location, length, and elevation, would still be satisfactory if one of the other factors was varied. Accepting this assumption for all the variables involved allowed the following test plan to be adopted:

1. Determine satisfactory vane spacing.

2. Determine satisfactory vane angle.

3. Determine satisfactory placement of vanes with respect to canal headworks.

4. Determine satisfactory vane length.

5. Determine satisfactory vane elevation or vane depth.

6. Determine effect of the number of vanes.

7. Determine effect of vane cross section.

A graphical method of correlation analysis presented by Ezekiel3/ was used in analyzing results. In this method, a number of variables, such as the concentration ratio, any of the vane variables, concentration of total sediment moving in the river, and concentration of sediment moving near the headworks, are considered in the evaluation of a particular arrangement. The concentration ratios are first plotted as a function of the variable of immediate interest, for example, depth of vane, Figure 6. All points on the plot are numbered for future reference. The best average straight line is fitted to the points in Graph 1, solid line. Deviations of Points 1, 2, 3, and 4 from the fitted line (Deviation 1) are then plotted as a function of the next most important variable; in this example, concentration of sediment moving in the river, C_{rus}. From this plotting, a new curve is fitted to the points, Graph 2 of Figure 6, which is a correction curve to indicate the effect of the river concentration on the concentration ratio. Deviations from Graph 2 (for example Deviation 2) are then plotted as a function of the variables of next importance; in this example, concentration of sediment in the sluiceway is C_s. From the resulting correction curve, C_s is shown to be of minor importance. This process is continued until all the independent variables desired have been introduced.

In the example, the concentration of sediment in the sluice was the last variable considered. A second approximation of the relationship of the concentration ratio to the depth of vane may be determined by plotting the deviations from the last correction curve as deviations from the first approximation curve. A curve is fitted to the new points and if considerable change results, or if a large number of points are available, it may be desirable to repeat the entire evaluation process.

While a straight line of best fit can usually be drawn to fit the points, this method is not limited to straight lines. If only a few points are involved a straight-line curve is easy and rapid to use. However, if

3/Ezekiel, Mordecai, 1941, Methods of Correlation Analysis, Second Edition, John Wiley and Sons, Inc.

too few points are involved results may be inconclusive. As only a limited number of points were available for these analyses (usually three or four) the conclusions drawn are necessarily limited.

CONTROL TESTS

Five tests were conducted without vanes but with a 160-foot by 40-foot 3-inch slab, at elevation 4661.0, near the canal headworks on which the bottom vanes were later constructed. The standard discharges were used in the control tests and the river discharge was passed through all the river gates which were opened equally. The duration of the five control tests averaged approximately 6 hours, and the control tests were spaced throughout the overall testing period. The control tests are Tests 4 and 19 in the bottom guide vane series and Tests 20, 24, and 36 in the surface guide vane series. Results are shown in Table 1.

Table 1

Test	Number hours test was conducted	Concentration of sediment entering canal headworks, ppm	Concentration of sediment in the river ppm	Concentration ratio $\frac{C_c}{C_{rus}}$
4	7.0	1,601	385	4.16
19	4.4	1,635	345	4.74
20	8.4	1,589	1,331	1.20
24	4.1	886	835	1.06
36	5.0	622	861	0.72

The average concentration ratio obtained from the control tests was 2.38. This value is therefore the datum used to determine the improvement resulting from the various guide vane arrangements. In the control tests, sediment deposits in the canal decreased the effective cross section of the canal and resulted in a gradual decrease in discharge as the test progressed. The average decrease in discharge was approximately 34 percent. When the vanes were in place, no appreciable decrease in canal discharge occurred.

TESTS CONDUCTED WITH BOTTOM VANES

Bottom Vane Spacing

Four tests were made to determine a satisfactory vane spacing for tests using bottom vanes. These are shown in Table 2 as Tests 1, 2, 3, and 5 (Test 4 was a control test). Vane arrangements for the tests are shown in Figure 7, and the test data are summarized in Table 2.

Table 2

Test	Number hours test was conducted	Vane spacing feet and inches	Concentration of sediment entering canal headworks, ppm	Concentration of sediment in the river ppm	Concentration ratio $\frac{C_c}{C_{rus}}$
1	26.2	16-8	41	233	0.176
2	51.2	12-0	15	161	.093
3	31.2	26-0	34	349	.097
5	31.2	20-0	44	262	.168

For these tests the four vanes used were 50 feet long, their top elevation was at 4665.0 feet, and they were placed at an angle of 40° to the direction of flow with the downstream end of the downstream vane on the canal headworks centerline.

In these tests the concentration ratio was considerably improved from the 2.38 average of the control tests. A multiple correlation of the data indicated the spacing of 26 feet on centers in Test 3 to be most satisfactory. For this spacing the concentration ratio was reduced to 0.097 for 349 ppm sediment concentration in the river. The 26-foot spacing was used in all following tests.

Although the value 0.093 in Table 2 appears to be more satisfactory than the value 0.097, the multiple correlation method indicates 0.097 to be better. This results from a number of variables being involved in the correlation. For instance, although the concentration in the river was 349 ppm for Test 3, it was only 161 ppm for Test 2. However, even the difference between 0.093 and 0.176, the highest concentration ratio obtained in this test series, is not great when compared to the control concentration ratio of 2.38.

Angle Between Bottom Vanes and Direction of Flow

Tests 3, 6, and 8 were utilized to determine a satisfactory angle between the vanes and the direction of flow. The standard test discharge was set, and the multiple correlation method was used for analyzing results. For all three tests the vane length was 50 feet, vane spacing was 26 feet on centers, the tip of the downstream vane was on the canal centerline, and vane top elevation was 4665.0 feet, Figure 7. No noticeable decrease in discharge occurred in the canal for these tests. Results of the tests are shown in Table 3.

Table 3

Test	Number hours test was conducted	Vane angle to river-flow	Concentration of sediment entering canal headworks, ppm	Concentration of sediment in the river ppm	Concentration ratio $\frac{C_c}{C_{rus}}$
3	31.2	40°	34	349	0.097
6	29.0	35°	65	367	.177
8	51.4	45°	33	310	.106

In the previous series of tests the concentration ratio was not sensitive to vane spacing; in these tests the concentration ratio was not overly sensitive to the angle at which the vanes were placed in the river. However, from a multiple correlation analysis of the data, the 45° angle was considered to be most satisfactory. All angles tested indicated considerable improvement in the concentration ratio compared to the ratio obtained when no vanes were installed. The 45° angle indicated an improvement in $\frac{C_c}{C_{rus}}$ from 2.38 to 0.106.

Bottom Vane Location

Tests 7, 8, and 9 were utilized to determine a satisfactory placement or location of vanes with respect to the canal headworks. The standard test discharges of 8,760 cubic feet per second in the river and 174 cubic feet per second in the canal were used, and the multiple correlation method was used in analyzing results. For all tests, the vane length was 50 feet, vane spacing 26 feet, vane elevation 4665.0 feet, and the angle of the vane with the direction of flow was 45°. Test results are summarized in Table 4.

Table 4

Test	Number hours test was conducted	Tip location of downstream vane*	Concentration of sediment entering canal headworks, ppm	Concentration of sediment in the river ppm	Concentration ratio $\frac{C_c}{C_{rus}}$
7	26.8	5'-7" U.S.** from canal ℄	22	467	0.047
8	51.4	At canal ℄	33	310	.106
9	27.9	7'-11" D.S.** from canal ℄	28	380	.074

*See Figure 7.
**U.S. indicates upstream; D.S. indicates downstream.

Visual observations of trial locations indicated that placing the vanes either farther upstream or downstream from the canal headworks would reduce the efficiency of the vanes. The multiple correlation analysis of the three tests indicated that placing the vanes 5 feet 7 inches upstream from the canal centerline was the most satisfactory arrangement.

Bottom Vane Length

Tests 7, 10, and 11 were used to determine a satisfactory vane length. The standard test discharge was set and the following conditions were constant for the three tests: vane spacing 26 feet on centers, vane elevation 4665.0 feet, angle of vane with direction of flow 45°, and the tip of the downstream vane 5 feet 7 inches upstream from the centerline of the canal headworks. Table 5 summarizes results of these tests.

Table 5

Test	Number hours test was conducted	Vane length feet	Concentration of sediment entering canal headworks, ppm	Concentration of sediment in the river ppm	Concentration ratio $\frac{C_c}{C_{rus}}$
7	26.8	50	22	467	0.047
10	30.6	40	16	303	.053
11	29.8	30	34	333	.102

Plots and analysis of data indicated the 50-foot vane length to be most satisfactory. The results showed a considerable improvement over the average concentration ratio of 2.38 with no vanes in place.

Vane Top Elevation

Tests 7, 12, 13, 14, and 15 were utilized to establish a satisfactory vane top elevation for the test discharge. For this series of tests, vane length was 50 feet, vane spacing was 26 feet on centers, angle of vane with direction of flow was 45°, and the tip of the downstream vane was placed 5 feet 7 inches upstream from the centerline of the canal headworks. Four vanes were used in all tests. Table 6 summarizes results of these tests.

Table 6

Test	Number hours test was conducted	Vane top elevation	Concentration of sediment entering canal headworks, ppm	Concentration of sediment in the river ppm	Concentration ratio $\frac{C_c}{C_{rus}}$
7	26.8	4665.0	22	467	0.047
12	29.0	4663.9	90	362	.249
13	29.5	4664.5	26	175	.149
14	49.0	4666.2	4	319	.013
15	23.9	4666.8	41	456	.090

The vanes installed for Test 12 appeared to be too low and allowed considerable sediment to pass over them. An average decrease in discharge of approximately 5 percent occurred in the canal during Test 12. No significant decrease in discharge occurred during the other tests of this series.

Analyses of the data indicated the most satisfactory surface elevation to be between 4665.9 and 4666.2 feet. The elevation selected as most satisfactory, after these and additional test data were analyzed, was 4666.1 feet. However, in some succeeding tests the value 4665.9 was used.

Number of Vanes

Test 16 was used to establish whether fewer than four vanes would produce sufficiently strong secondary currents to reduce sediment intake into the canal.

Three vanes were tested in a manner similar to that for four vanes. The 50-foot-long vanes were placed with the tip of the downstream vane 5 feet 7 inches upstream from the canal headworks. Vane top elevation was 4665.9; the vanes were 26 feet on centers, and placed at an angle of 45° with the direction of flow. The standard discharges were set, and tests of 18.5 and 7.0 hours were conducted. The canal discharge remained constant during the tests, and the resulting average concentration ratio was 0.067.

From visual observations and comparison of Tests 16 and 14, it was concluded that four vanes produced a more satisfactory concentration ratio that three vanes.

Effect of Vane Cross Section

Tests 17 and 18 were utilized to determine the effect of vane cross section on the concentration ratio. In previous tests, the vanes in the model were constructed of sheet metal, equivalent to a thickness of approximately 1 inch in a prototype structure 20 times as large as the model. A prototype vane would be somewhat thicker, particularly a concrete vane, and tests were required to evaluate the effect of vane thickness. Vanes 8 inches thick were therefore investigated. Figure 7 shows cross sections of the vanes used in these tests.

Four 50-foot-long vanes were used in these tests, spaced 26 feet on centers, placed at an angle of 45° with the direction of flow, and with the tip of the downstream vane 5 feet 7 inches upstream from the canal headworks centerline. Vane top elevation for Test 17 was 4665.9 feet and for Test 18 was 4666.1 feet. The test discharges of 8,760 cubic feet per second in the river and 174 cubic feet per second in the canal were used for the tests.

In Test 17, a set of four bottom vanes with sharp-edged lips extending 2 feet 6-13/32 inches upstream, shown in Figure 7, were tested during runs of 18.7, 6.2, 17.0, and 6.9 hours. The canal discharge remained constant, but no significant improvement was shown over vanes made with a rectangular cross section. The average concentration ratio was 0.110.

Rectangular vanes 8 inches thick, Figure 7, were installed for Test 18, and runs of 16.9 and 6.7 hours were conducted.

The canal discharge remained constant during both runs and the resulting average concentration ratio was 0.094. The rectangular vane cross section used for this test appeared to be more satisfactory than the cross section used in Test 17 and would certainly be easier to construct in a field installation.

Photographs of the sediment deposits which resulted in the canal when no control was used, and when the vanes of Test 18 were used are shown in Figure 8.

Summary of Bottom Vane Tests

From these tests it was concluded that bottom vanes are effective in reducing heavy sediment intake into a canal supplied by water diverted from a large river. The most efficient bottom vanes developed were a group of four 50-foot-long vanes installed upstream from the intake at an angle of 45° to the direction of flow. The vanes were spaced 26 feet on centers, the downstream tip of the downstream vane was located 5 feet 7 inches upstream from the canal headworks centerline, and vane top elevation was at 4666.1. This arrangement reduced the concentration ratio for the test discharge from 2.38, the average for the five control tests with no vanes in place, to less than 0.1. This ratio reduction means, in effect, that the vanes allowed only 1/23 of the usual amount of heavy sediment to enter the canal. Tests conducted during the San Acacia model study2/ indicated that the vanes were also of benefit when the ratio of river to canal discharge was varied.

Considering only the standard test discharge used in these tests, the dimensions of the variables, location, spacing, angle, length, depth number, and cross section were not critical with respect to performance. Minor changes in the dimensions tested could be made, therefore, without changing performance significantly. Surface vanes were next investigated to determine whether they were more or less efficient than bottom vanes.

TESTS WITH SURFACE VANES

Surface Vane Spacing

Tests 21, 22, 23, and 25 were used to determine the effect of spacing of surface vanes (Tests 20 and 24 were control tests). Vane arrangements for the tests are shown in Figure 9 and the test data are shown in Table 7.

Table 7

Test	Number hours test was conducted	Vane spacing feet and inches	Concentration of sediment entering canal headworks, ppm	Concentration of sediment in the river ppm	Concentration ratio $\frac{C_c}{C_{rus}}$
21	29.9	16-8	59	944	0.062
22	4.8	12-0	113	953	.119
23	5.8	26-0	87	917	.095
25	3.0	20-0	118	1,030	.114

Four vanes 50 feet long and 2 feet 8-1/2 inches deep were placed with their bottoms at elevation 4667.68; vane tops were at the normal water surface. The vanes were placed at an angle of 140°, (measured from the same reference as the bottom vanes), with the downstream end of the downstream vane of the canal headworks centerline. In this test, and all tests conducted with surface vanes, the vane thickness was 8 inches. The vane spacing was varied in each test as indicated in Column 3 of Table 7.

The test ratios all showed considerable improvement over the 2.38 average concentration ratio of the control tests, and indicated that the concentration ratio was not greatly affected by the spacing of the vanes. However, a multiple correlation of the data showed that a spacing of approximately 18 feet 4 inches would be the most efficient for these vanes. From this series of tests it was concluded that surface vanes could be used to effectively reduce the sediment entering a canal headworks.

Surface Vane Angle

In the bottom vane tests, the vanes were installed to guide bottom water away from the right bank into the river. When surface vanes are used to produce the same flow conditions they must be pointed toward the bank (looking downstream). In this position the vanes create secondary currents which move the bottom water away from the river bank into the river. This action helps to exclude sediment from the headworks, Figure 2. Tests 23, 26, 27, and 28 were used to test various vane angles.

For all four tests the vanes were 50 feet long, vane spacing was 26 feet on centers, the downstream tip of the downstream vane was at the canal centerline, and the vane was 2 feet 8-1/2 inches deep with bottom elevation at 4667.68 feet, Figure 9. Tests were made using the standard test discharges, and the multiple correlation method was used for analyzing results. Results of the tests are shown in Table 8.

Table 8

Test	Number hours test was conducted	Vane angle	Concentration of sediment entering canal headworks, ppm	Concentration of sediment in the river ppm	Concentration ratio $\frac{C_c}{C_{rus}}$
23	5.8	140°	87	917	0.095
26	4.8	145°	97	875	.111
27	3.0	135°	76	936	.081
28	5.0	130°	48	1,007	.047

Although the concentration ratio was not very sensitive to the angle at which the vanes were placed, a correlation analysis indicated the 130° angle to be most satisfactory.

Surface Vane Location

Tests 27, 29, and 30 were used to test surface vane placement (location). For all tests, the vane length was 50 feet, vane spacing was 26 feet on centers, angle of the vane was 135°, vane depth was 2 feet 8-1/2 inches, and vane bottom elevation was 4667.68 feet, Figure 9. The standard test discharges of 8,760 cubic feet per second in the river and 174 cubic feet per second in the canal were used and the multiple correlation method was used in analyzing data. Test results are summarized in Table 9.

Table 9

Test	Number hours test was conducted	Tip location of downstream vane	Concentration of sediment entering canal headworks, ppm	Concentration of sediment in the river ppm	Concentration ratio $\frac{C_c}{C_{rus}}$
27	3	At canal ℄	76	936	0.081
29	5	5'-7" U.S. from canal ℄	83	1,052	.079
30	5	7'-11" D.S. from canal ℄	62	824	.075

These three tests indicated that the vanes were remarkably insensitive to exact location. Concentration ratios were very similar for all three tests. However, visual observations indicated that moving the surface vanes farther upstream or downstream would have reduced their efficiency.

Surface Vane Lengths

Tests 29, 31, and 32 were used to show the effect of varying the length of surface vanes on their efficiency in controlling sediment movements. The standard test discharges were used and the following conditions were maintained constant: Vane spacing was 26 feet on centers, angle of vane was 135°, the tip of the downstream vane was placed 5 feet 7 inches upstream from the canal centerline, the vanes were 2 feet 8-1/2 inches deep, and vane bottom elevation was 4667.68 feet, Figure 9. Table 10 summarizes results of these tests.

Table 10

Test	Number hours test was conducted	Vane length feet	Concentration of sediment entering canal headworks, ppm	Concentration of sediment in the river ppm	Concentration ratio $\frac{C_c}{C_{rus}}$
29	5	50	83	1,052	0.079
31	5	40	57	861	.066
32	5	30	62	863	.072

The analysis indicated that a surface vane longer than 40 feet did not improve the concentration ratio, and that a vane less than 40 feet long was slightly less efficient.

Surface Vane Height

Tests 29, 33, 34, and 35 were utilized to establish a satisfactory height of surface vanes. For this series of tests the vane length was 50 feet, vane spacing was 26 feet on centers, and the angle of the vanes was 135°. Four vanes were used, and the tip of the downstream vane was placed 5 feet 7 inches upstream from the centerline of the canal headworks. Table 11 summarizes results of these tests.

Table 11

Test	Number hours test was conducted	Vane height feet and inches	Concentration of sediment entering canal headworks, ppm	Concentration of sediment in the river ppm	Concentration ratio $\frac{C_c}{C_{rus}}$
29	5	2-8-1/2	83	1,052	0.079
33	5	3-1-1/2	61	903	.067
34	5	3-11-1/2	84	1,018	.084
35	5	1-11-3/4	59	988	.060

In all cases, the vanes were effective, but analysis indicated the most effective depth to be 1 foot 11-3/4 inches.

Number of Surface Vanes

Test 37 was conducted to establish the effect of fewer than four vanes (Test 36 was a control test). Three 50-foot-long vanes were placed with the tip of the downstream vane 5 feet 7 inches upstream from the canal headworks. Vane depth was 2 feet 8-1/2 inches, spacing was 26 feet on centers, and they were placed at an angle of 135°. The standard discharges were tested and the resulting concentration ratio was 0.074, almost identical with the ratio 0.079 of Test 29 in which four vanes were used.

Summary of Surface Vane Tests

From the tests with surface vanes, it was concluded that surface vanes are effective in reducing heavy sediment intake into a canal supplied with water diverted from a large river, and are about as efficient as bottom vanes. The dimensions of the vane variables, location, spacing, height, angle, length, and number were not critical with respect to the performance of the set of vanes. Installed in the same relative position as the bottom vanes, but angled so as to divert top water into the canal headworks (bottom vanes are angled so as to divert bottom water away from the headworks) they produced approximately equivalent results, and reduced the concentration ratio for the test discharge from 2.38, the average for the control tests, to less than 0.1. All tests on the surface vanes were conducted at standard discharges of 8,760 cubic feet per second in the river and 174 cubic feet per second diverted to the canal.

Photographs showing the surface vanes in place for Test 21 and the resulting deposits in the canal following the test are shown in Figures 10a and 10b.

COMPARISON OF VANES AND DISCUSSION

Both surface and bottom guide vanes reduced the concentration ratio $\frac{Cc}{Crus}$, (concentration of sediment entering the canal to concentration of sediment in the river upstream), from 2.38, the average of the control tests, to less than 0.1. In other words, the sediment entering the headworks was only 1/23 the amount which entered when no vanes were used. A comparison of the vane variables which produced the most satisfactory results for the bottom and surface vanes is shown in Table 12 and results of all tests are summarized in Table 13. Although the results of tests with both types of vanes showed that the vanes were not overly sensitive to the variables tested (within the test range), the surface vanes appeared to be the least sensitive to location, length, and numbers of vanes. The angle at which the bottom vanes worked best was 45°. Also, the ratio, height of vane divided by the water depth above the slab, may be less for the surface vanes. The lesser height of the surface vanes appears to result in less total projected vane area in the flow prism. However, as some sediment was always present on the supporting slab when the bottom vanes were in place, Figure 11, the y/d ratio and projected area shown for the bottom vanes in Table 12 is no doubt too large. Few generalizations can be made from these tests because only one arrangement of canal intake and only one discharge were tested. The tests demonstrated, however, that satisfactory vane arrangements can be developed using the testing and analysis principles discussed.

Table 12

OPTIMUM DIMENSIONS OF VARIABLES OF BOTTOM AND SURFACE VANES

	Best spacing (feet and inches)	Best angle tested	Best placement tested	Best vane length tested (feet)	Best y/d ratio tested*	Effect on concentration ratio from reducing number of vanes from 4 to 3	Total vane surface in flow above slab at best condition ft^2
Bottom	26	45°	Tip of D.S. vane 5'-7" U.S. from canal ℄	50	0.544	Increases	83.3
Surface vanes	18'-4"	130°	Tip of D.S. vane from 7'-11" D.S. from canal ℄ to 5'-7" U.S. from canal ℄	30 to 50	0.257	No significant change	33.3

*y = height of vane; d = depth of water above slab.

The most effective set of bottom vanes tested consisted of four 50-foot-long vanes installed upstream from the canal headworks. The vanes were placed along the right bank of the river model at an angle of 45° to the direction of flow. Vane spacing was 26 feet on centers, vane top elevation was 4666.1 feet, and the downstream tip of the downstream vane was located 5 feet 7 inches upstream from the canal headworks centerline. The bottom vanes tested are shown in Figure 7.

The most effective set of surface vanes, indicated by the tests, included either three or four vanes 40 to 50 feet long placed near the canal headworks, Table 12. The vanes were installed along the right bank of the river model at an angle of 140° (same reference datum as bottom vanes). Vane spacing was 18 feet 4 inches on centers and vane height was 1 foot 11-3/4 inches. The surface vanes tested are shown in Figure 9.

Both bottom and surface vanes were found to be extremely valuable in helping to gain control of heavy sediments by creating localized secondary currents to reduce the sediment intake into a canal. Consideration should be given to their use where flow conditions are similar to those tested in this study. For example, where a relatively small discharge is being diverted from a relatively large flow, and it is desired that the small discharge have a relatively light sediment load, either bottom or surface vanes may be employed using the dimensions (or proportional dimensions) given in this paper. Further investigation in a model should be made, however, if discharges are significantly different than those tested.

Further research should be conducted to determine the general performance of vanes in confined spaces and their possible use in increasing sediment loads in canal sluiceways. The effect of varying discharges should also be investigated.

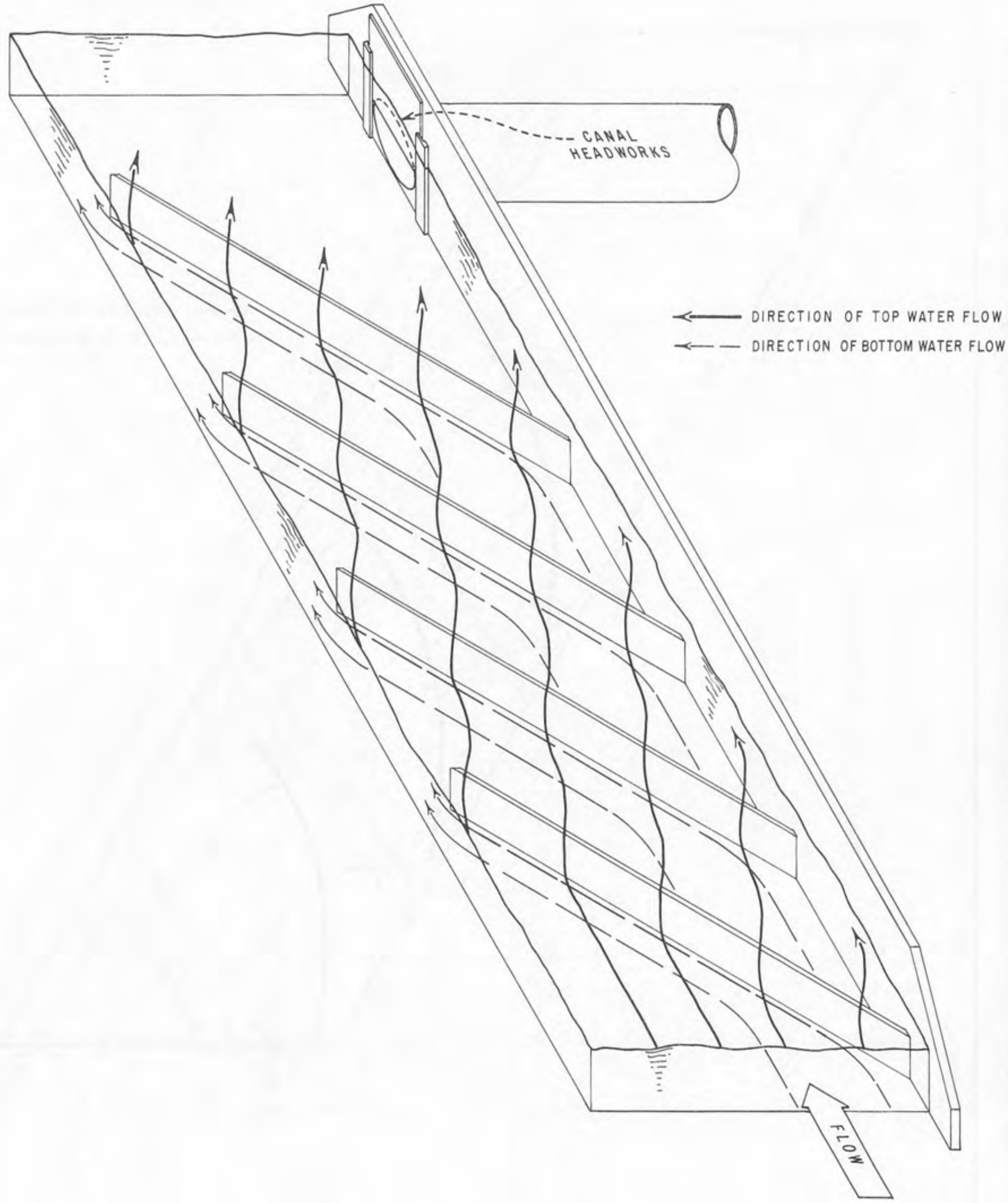
Table 13

SUMMARY OF VANE TESTS

Column

1 Test number
2 Total number of hours test was conducted
3 Average concentration of bed sediments in river in parts per million by weight (ppm)
4 Average concentration of bed sediments entering canal headworks, ppm
5 Ratio of sediments entering canal divided by sediments in river, $\frac{C_c}{C_{rus}}$
6 Short description

1	2	3	4	5	6
1	26.2	233	41	0.176	Four bottom vanes
2	51.2	161	15	0.093	Four bottom vanes
3	31.2	349	34	0.097	Four bottom vanes
4	7.0	385	1,601	4.16	Control test
5	31.2	262	44	0.168	Four bottom vanes
6	29.0	367	65	0.177	Four bottom vanes
7	26.8	467	22	0.047	Four bottom vanes
8	51.4	310	33	0.106	Four bottom vanes
9	27.9	380	28	0.074	Four bottom vanes
10	30.6	303	16	0.053	Four bottom vanes
11	29.8	333	34	0.102	Four bottom vanes
12	29.0	362	90	0.249	Four bottom vanes
13	29.5	175	26	0.149	Four bottom vanes
14	49.0	319	4	0.013	Four bottom vanes
15	23.9	456	41	0.090	Four bottom vanes
16	25.5	402	27	0.067	Three bottom vanes
17	48.8	337	37	0.110	Four bottom vanes
18	23.6	362	34	0.094	Four bottom vanes
19	4.4	345	1,635	4.74	Control test
20	8.4	1,331	1,589	1.20	Control test
21	29.9	944	59	0.062	Four surface vanes
22	4.8	953	113	0.119	Four surface vanes
23	5.8	917	87	0.095	Four surface vanes
24	4.1	835	886	1.06	Control test
25	3.0	1,030	118	0.114	Four surface vanes
26	4.8	875	97	0.111	Four surface vanes
27	3.0	936	76	0.081	Four surface vanes
28	5.0	1,007	48	0.047	Four surface vanes
29	5.0	1,052	83	0.079	Four surface vanes
30	5.0	824	62	0.075	Four surface vanes
31	5.0	861	57	0.066	Four surface vanes
32	5.0	863	62	0.072	Four surface vanes
33	5.0	903	61	0.067	Four surface vanes
34	5.0	1,018	84	0.084	Four surface vanes
35	5.0	988	59	0.060	Four surface vanes
36	5.0	861	622	0.720	Control test
37	5.0	952	70	0.074	Three surface vanes



BOTTOM GUIDE VANE METHOD OF PRODUCING
SECONDARY CURRENTS FOR SEDIMENT CONTROL
HYDRAULIC MODEL STUDY

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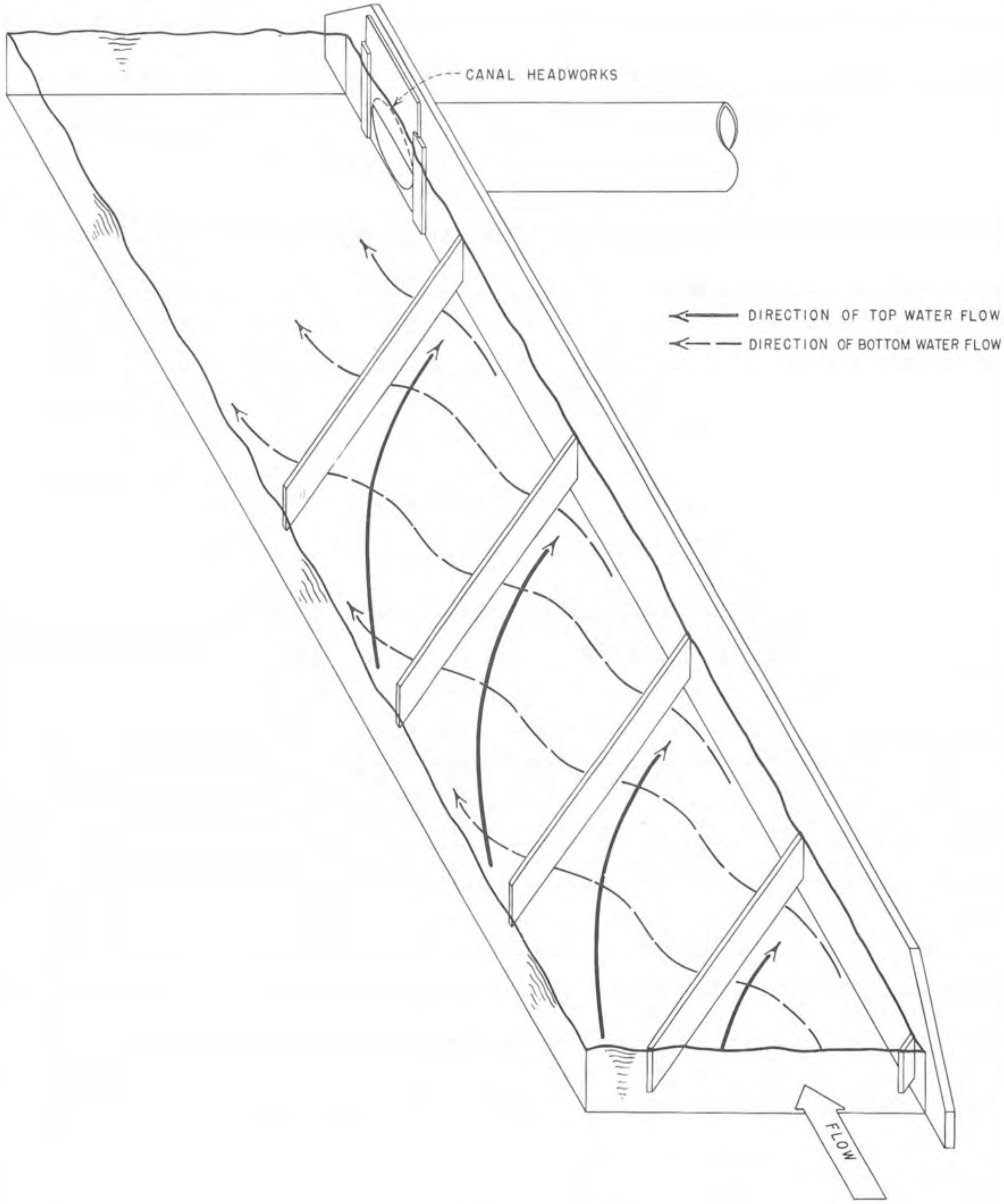
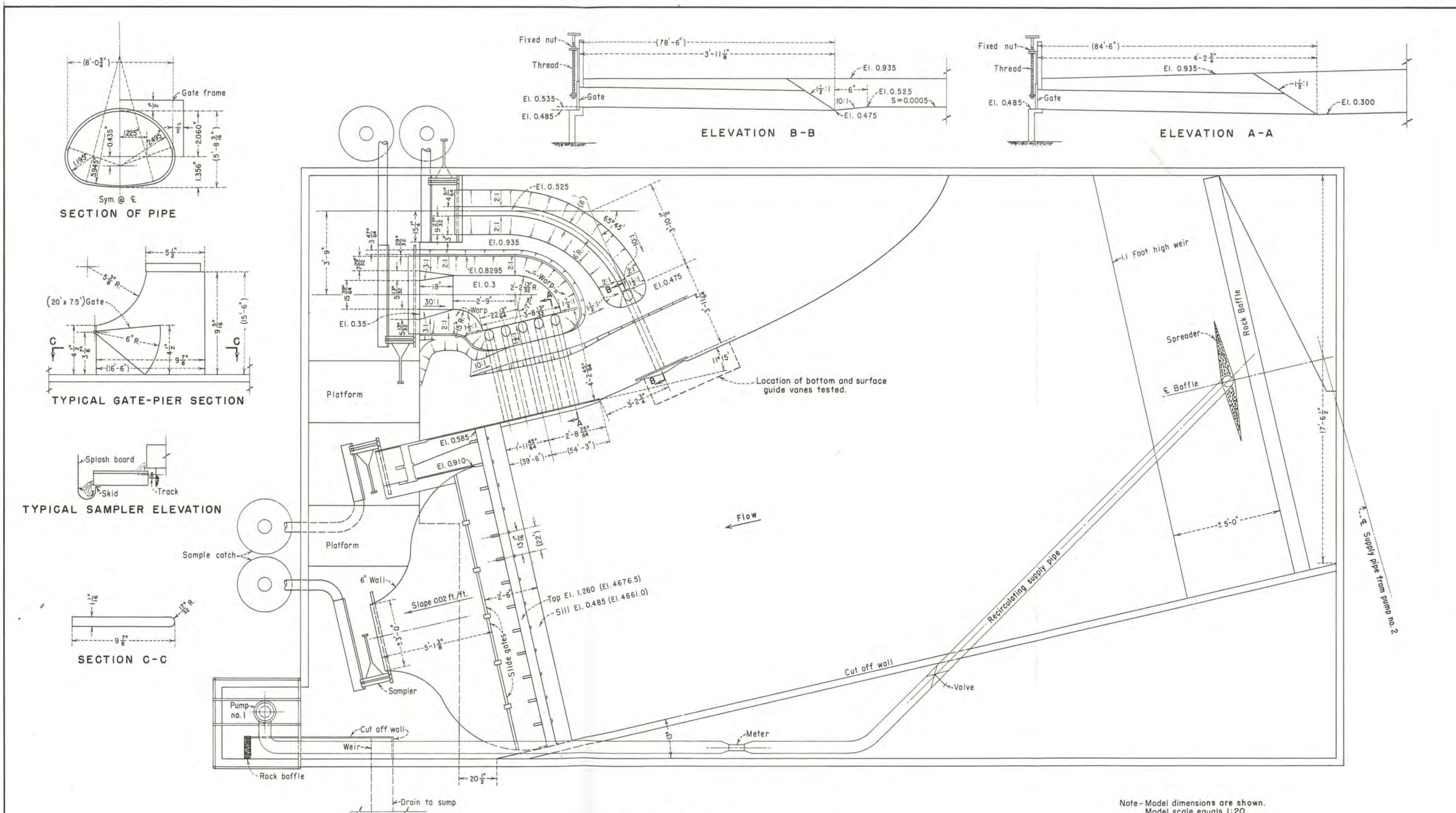
FIGURE 2



SURFACE GUIDE VANE METHOD OF PRODUCING SECONDARY CURRENTS FOR SEDIMENT CONTROL
HYDRAULIC MODEL STUDY



Note - Model dimensions are shown.
Model scale equals 1:20.
Prototype dimensions are shown in parentheses ( ).

GENERAL PLAN AND SECTIONS OF MODEL

HYDRAULIC MODEL STUDY

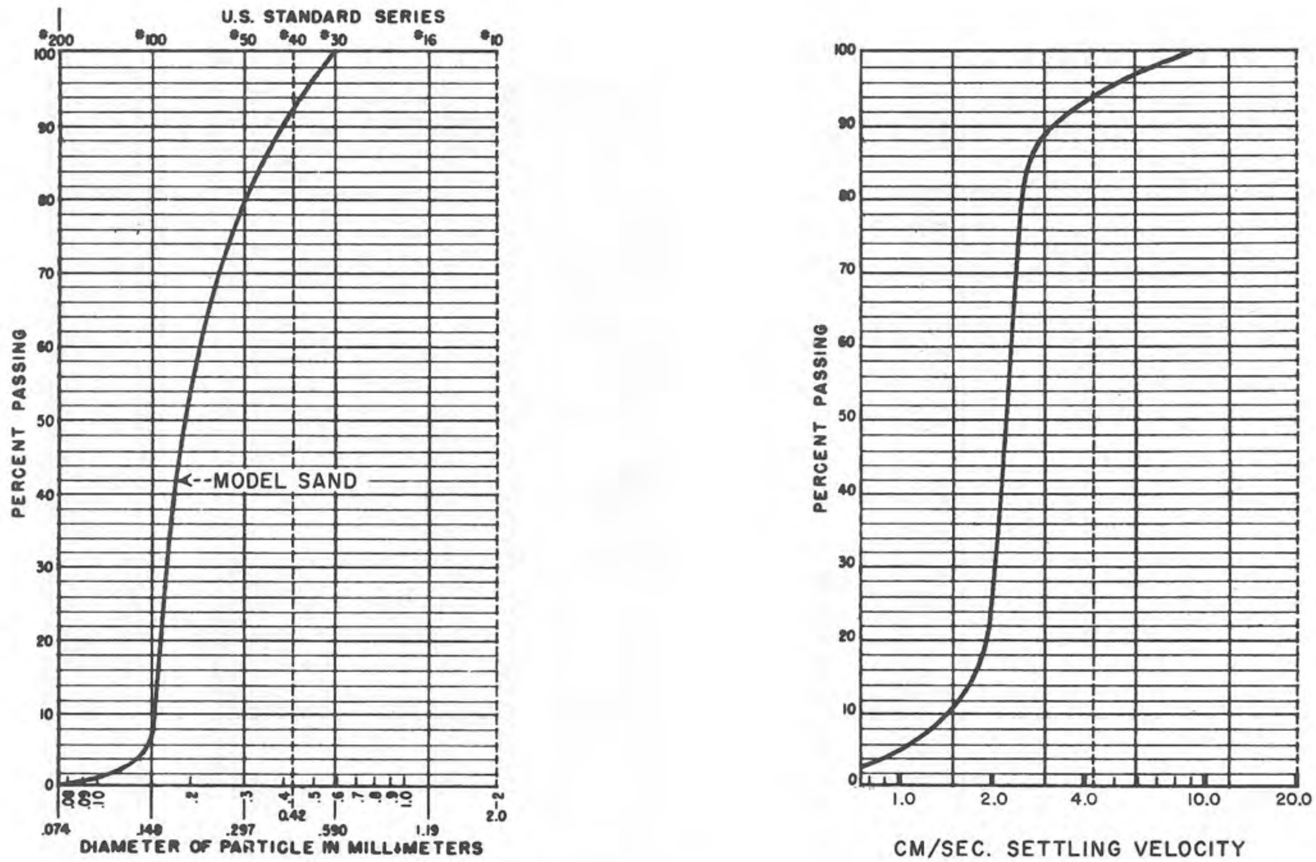
(a)
Overall View of Model

(b)
Sample Being Obtained from River Flow

THE MODEL AND SEDIMENT SAMPLING PROCEDURE

Hydraulic Model Study

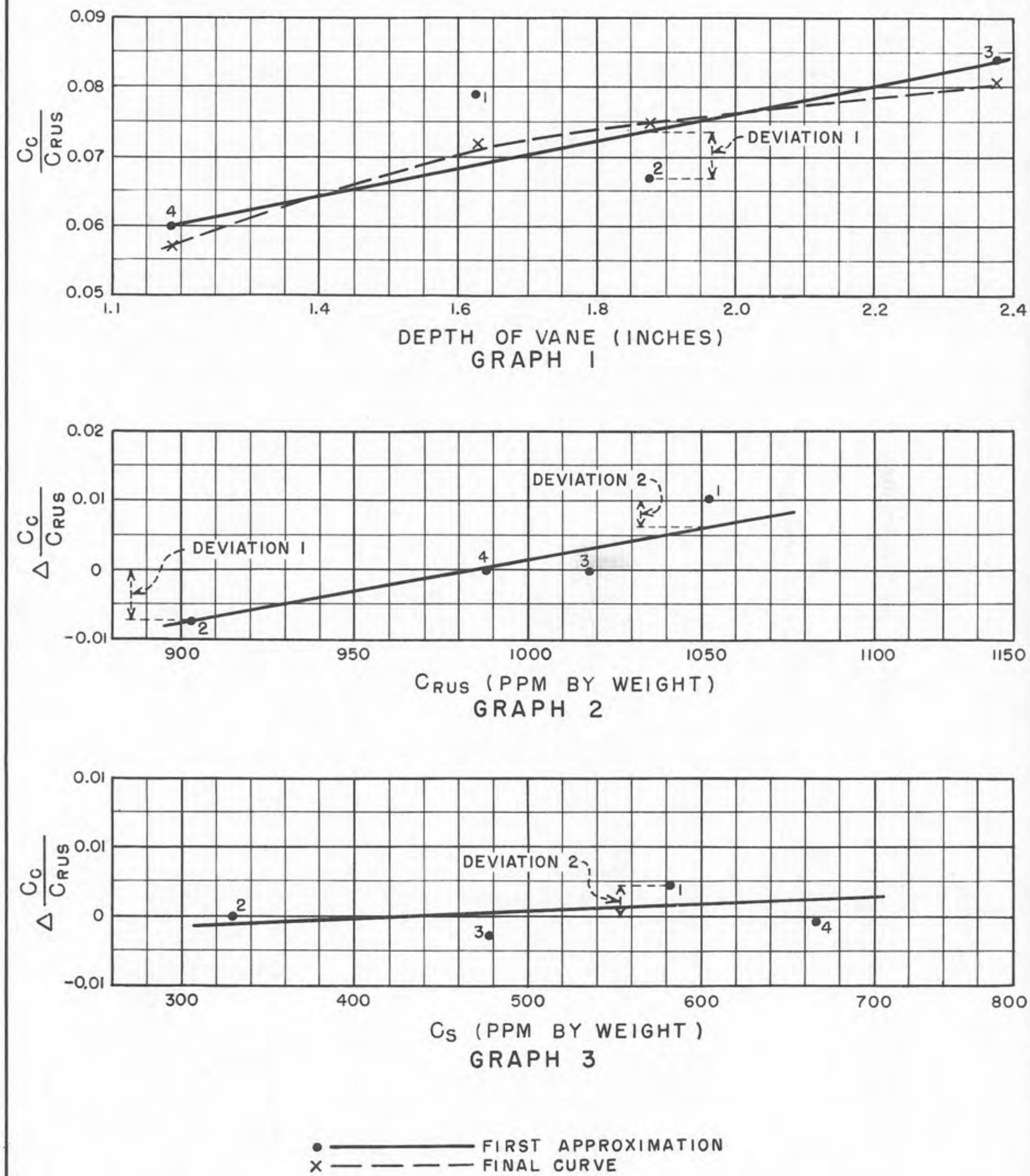
FIGURE 5



(a) (b)

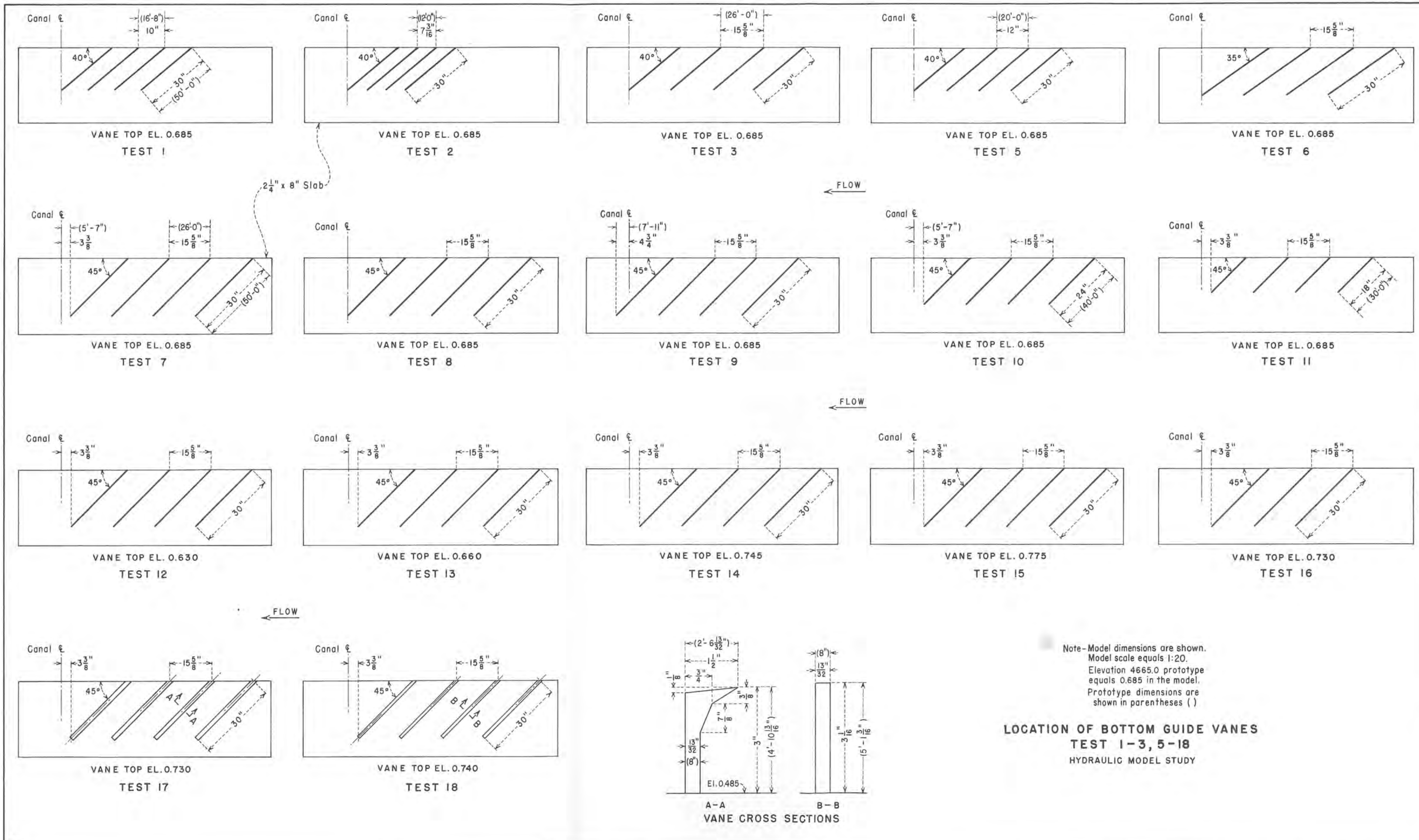
SAND GRADATION ANALYSIS AND SETTLING VELOCITIES

HYDRAULIC MODEL STUDY



EXAMPLE OF GRAPHICAL METHOD USED FOR ANALYSIS

HYDRAULIC MODEL STUDY



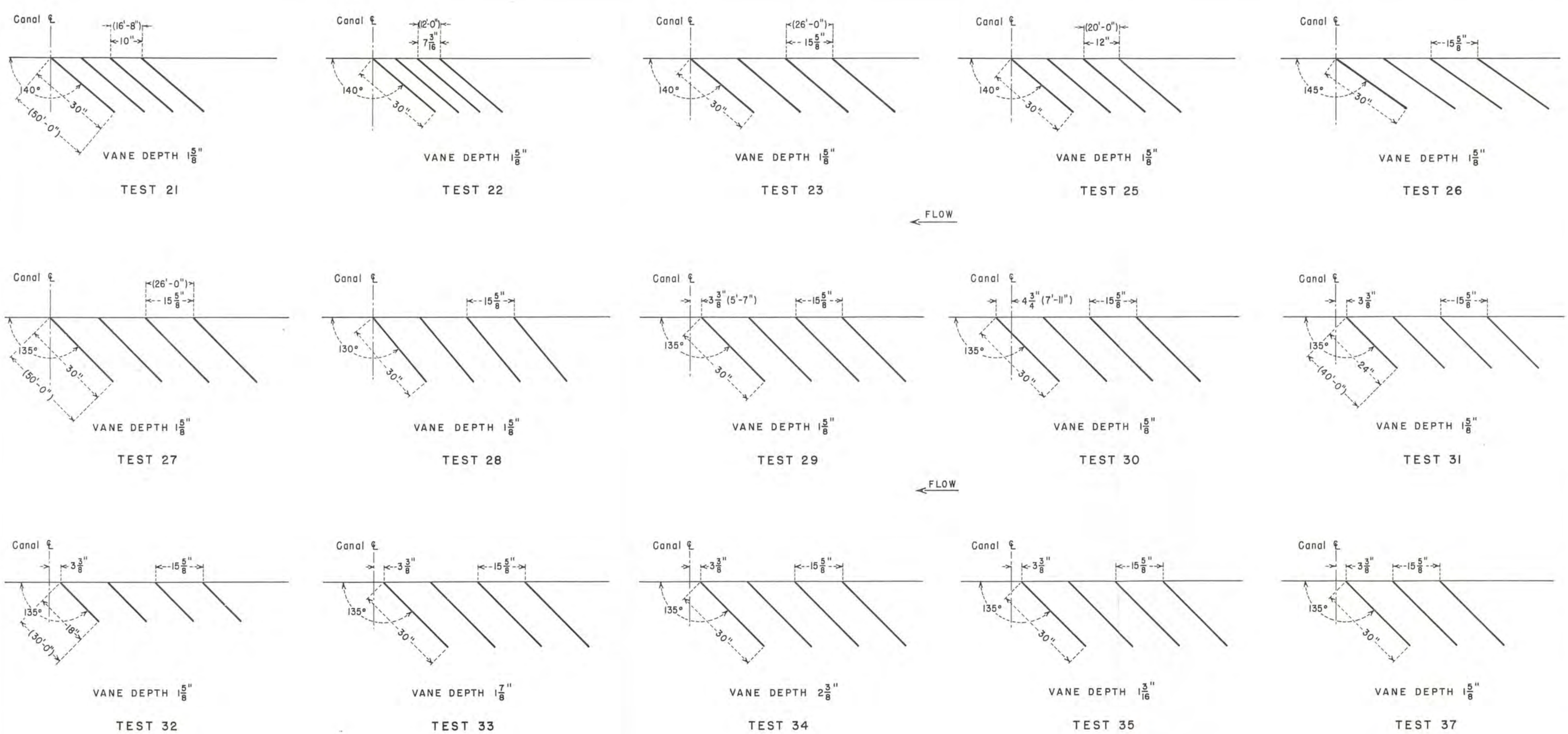
LOCATION OF BOTTOM GUIDE VANES
TEST 1-3, 5-18
HYDRAULIC MODEL STUDY

(a)
Without Bottom Guide Vanes

(b)
With Bottom Guide Vanes

SEDIMENT DEPOSITS IN CANAL WITHOUT AND WITH BOTTOM GUIDE VANES

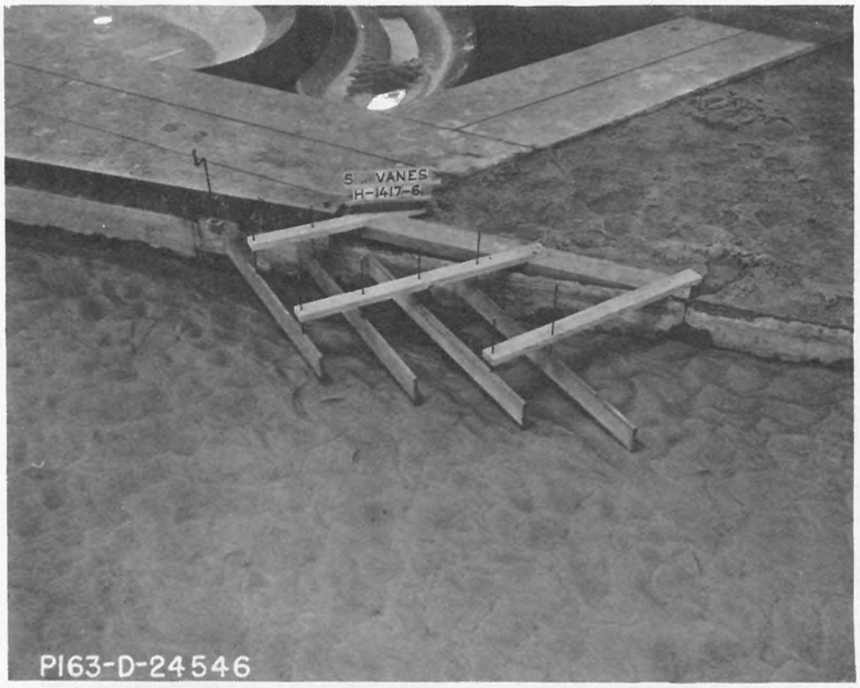
Hydraulic Model Study



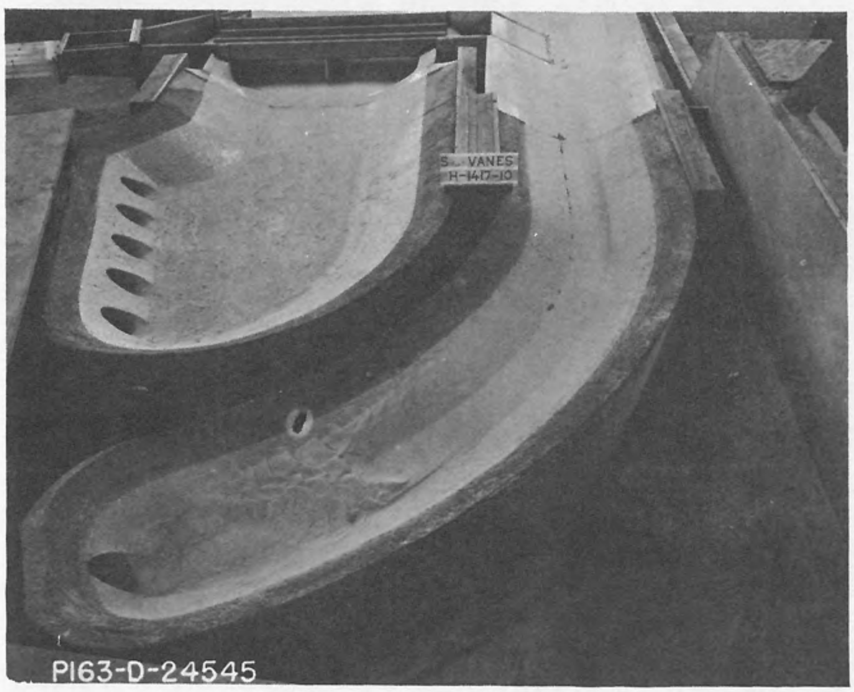
NOTES

All vanes were rectangular in cross section and were 0.4 inches wide.
Tops of all vanes were at normal water surface elevation.
Model dimensions are shown. Model scale equals 1:20
Prototype dimensions are shown in parentheses ()

LOCATION OF SURFACE GUIDE VANES
TESTS 21-23, 25-35, 37
HYDRAULIC MODEL STUDY



(a)
Surface Vanes in Place for Test 21



(b)
Sediment Deposits in Canal After Test 21

SURFACE VANES AND DEPOSITS FOR
TEST 21

Hydraulic Model Study

Figure 11

BOTTOM VANES AFTER TEST 18 SHOWING
SEDIMENT DEPOSITS PARTIALLY COVERING
VANE AREA

Hydraulic Model Study

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