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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

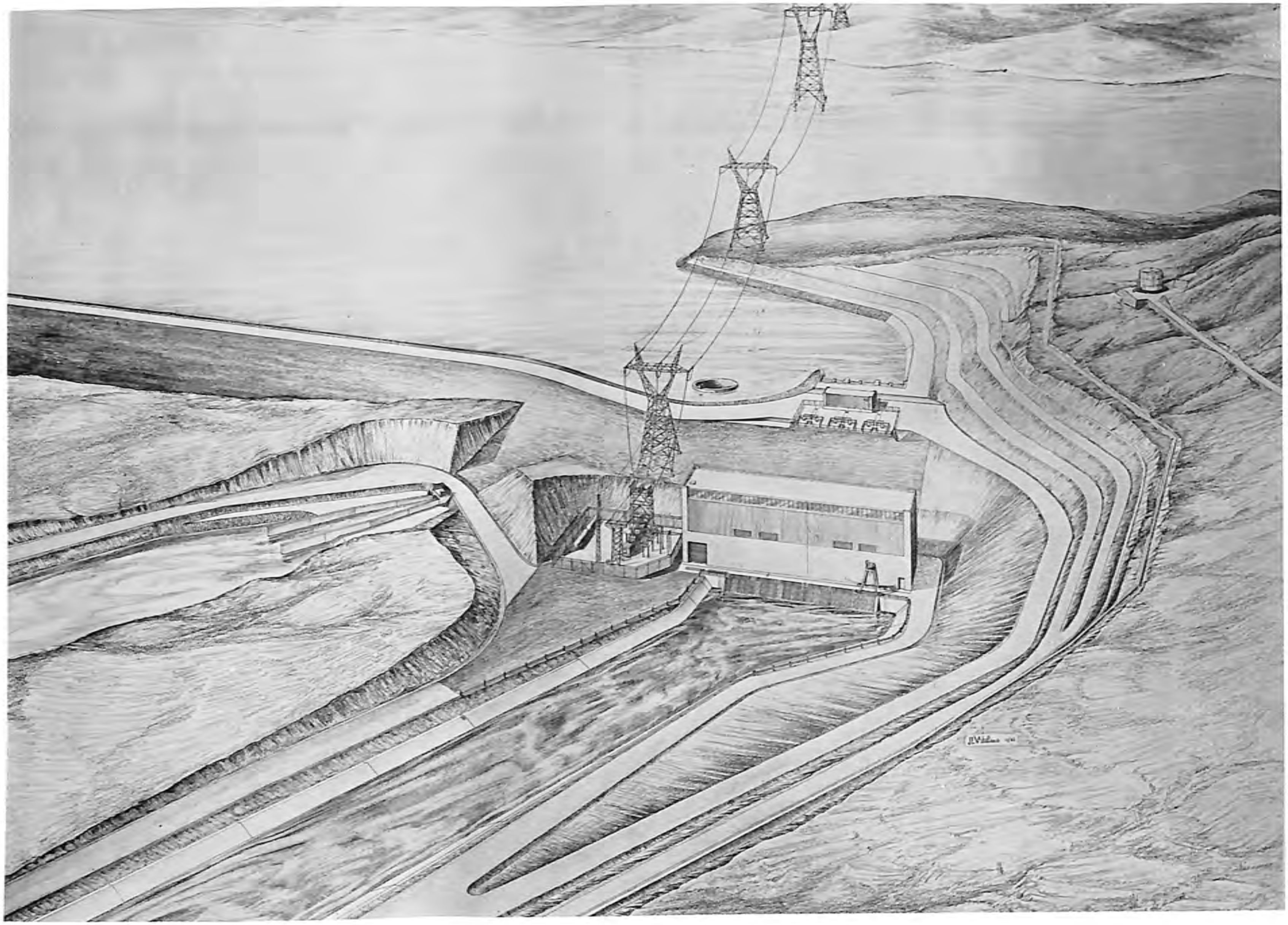
HYDRAULIC MODEL STUDIES OF THE CANAL TRANSITION AT THE FOREBAY PUMPING PLANT, SAN LUIS UNIT CENTRAL VALLEY PROJECT, CALIFORNIA

Report No. Hyd-542

Hydraulics Branch
DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

June 15, 1965



FOREBAY PUMPING PLANT
SAN LUIS UNIT - CALIFORNIA

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ABSTRACT

Hydraulic model studies of 2 intake channel transition designs for the Forebay Pumping Plant in San Luis Unit, CVP, showed that the hydraulic advantages of a symmetrical transition were not great enough to outweigh the economic advantages of an angled transition. Because the pumping plant location and alinement were fixed by geologic conditions a straight-in approach could not be used; therefore 2 alternative schemes for the Forebay Canal alinement and transition configuration were studied by comparing velocity distributions, head losses, and surface flow patterns on a 1:15-scale model. Velocity distribution comparison indicated that a symmetrical transition with curved approach was preferable to an angled transition with straight canal alinement. Although the symmetrical transition showed slightly more desirable flow patterns, the strength of eddy currents occurring along the transition sides appeared to be the same for both types. Head loss difference between the 2 types was too small to justify comparison on this basis. The symmetrical transition exhibited less tendency to form vortices between the intake piers. Both types could possibly be improved by modifying the design--that is, widening the canal bottom or including vertical sidewalls at the pumping plant. The symmetrical transition, although hydraulically preferable, would require additional excavation and a longer approach canal, resulting in higher costs.

DESCRIPTORS-- *pumping plant// *transitions/structures// *canals/ velocity distribution/ head losses/ eddies/ angle of approach/ instrumentation/ model tests/ data reduction/ curve fitting/ computers/ research and development/ economics/ hydraulics/ hydraulic models/ pumped storage/ hydraulic structures/ intake structures/ turbulent flow/ digital computers/ computer programming/ design/ velocity meters
IDENTIFIERS-- Central Valley Project/ California/ San Luis Forebay Pumping Plant/ hydraulic design

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Office of Chief Engineer
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Author: D. L. King
Checked by: T. J. Rhone
Reviewed by: W. E. Wagner
Submitted by: H. M. Martin

HYDRAULIC MODEL STUDIES OF THE CANAL TRANSITION AT THE FOREBAY PUMPING PLANT--SAN LUIS UNIT CENTRAL VALLEY PROJECT, CALIFORNIA

PURPOSE

Model studies were conducted to compare the hydraulic performance of two configurations of the transition between the Forebay Canal and the Forebay Pumping Plant intake. Effects of modifications to the major design schemes were evaluated and the relative effects of approach alinement were determined for one configuration.

CONCLUSIONS

1. Comparison of the transition designs on the basis of velocity distribution in the transition and pumping plant intakes indicated that the symmetrical transition with a curved canal approach is somewhat preferred over the angled transition with straight canal alinement, Figures 7, 8, 9, 12, and 13. A symmetrical transition with straight approach showed no improvement over the curved approach, Figures 9, 14, and 15.

2. The difference in head losses between the transition types was too small to justify comparison on this basis.

3. On the basis of flow appearance the symmetrical transition is somewhat more desirable, Figure 10. However, the strength of eddy currents which occurred along the sides of the transition appeared to be the same for both types.

4. The effect of the curved canal alinement was apparently small and the downstream tangent and transition were effective in recovering symmetrical velocity distribution, Figure 13.

5. The symmetrical transition exhibited less tendency for formation of vortices between the intake piers than the angled transition.

6. Installation of a trashrack with twice the bar depth of the previous rack on one bay of the angled transition did not change the velocity distribution. Operation of a bay with no trashrack indicated a higher average velocity. All bays were operating during these tests.

7. Both transition types could possibly be improved through modifications to the design, such as widening the canal bottom or including vertical sidewalls at the pumping plant, Figures 11 and 12.

8. Although the symmetrical transition might be preferred according to hydraulic factors, the angled transition was considered more practicable when economic factors were considered. The symmetrical transition would require additional excavation and a longer approach canal, resulting in additional costs which precluded the slight advantage in hydraulic performance.

ACKNOWLEDGMENT

The studies described in this report were accomplished through cooperation between the Hydraulics Branch, Division of Research, and the Canals Branch, Division of Design. Suggestions from the Hydraulic Machinery Branch, Division of Design, materially aided the investigation. Laboratory photography was by W. M. Batts, Office Services Branch.

INTRODUCTION

The San Luis Forebay Canal is a feature of the San Luis Unit of the Central Valley Project in California. The Forebay Canal, which supplies water to the Forebay Pumping Plant and Forebay Dam Reservoir, is located near Los Banos approximately 75 miles northwest of Fresno, Figure 1. The Forebay Pumping Plant is an important feature in the plan to store surplus water for subsequent releases. Water will be diverted from the existing Delta-Mendota Canal into the 80-foot-wide, 15-foot-deep, Forebay Canal, where a maximum of 4,200 cfs (cubic feet per second) will be lifted by the six-unit plant into the Forebay Reservoir. The water is then pumped by pump-generator units into San Luis Reservoir for storage. Later, the water may be released back into the Forebay Reservoir to generate power and supply flows for downstream irrigation. The features are shown in Figure 2.

The subject transition connects the Forebay Canal to the Forebay Pumping Plant. The location and alinement of the pumping plant were fixed by geologic conditions and could not be changed. Two alternative schemes for the canal alinement and transition configuration were considered. The first alternative consisted of a straight canal alinement approaching the pumping plant at a 30° angle, resulting in an angled transition. The second alternative included a curved canal alinement with a symmetrical transition leading straight into the pumping plant. Because of high costs of pumping it was requested that head losses in the two transition designs be compared. Also, velocity measurements in the transition and pumping plant intake bays were required to determine the velocity distribution at the pump intakes. An asymmetrical velocity distribution, if carried through the intake tubes, could result in a velocity vector which would affect the rotational velocity of the impeller. Also, any difference in velocities entering the intake bays would result in unequal pump loads to maintain the required rate of discharge. In either case, the affected pumps would operate at less than optimum efficiency. The model data did not permit a quantitative evaluation of these effects.

The angle at which the flow approaches the plant is also a factor in the formation of eddy currents in the intake bays which could result in deposition of sediment and retention of small debris that had passed the trashracks.

THE MODEL

The 1:15 scale model consisted of approximately 500 feet of canal section, the transition, trashracks, and pumping plant intake bays, Figure 3, and a portion of the intake elbows down to the downstream end of the converging transition section, immediately upstream from the vertical elbow. Slide gates at the ends of the transition sections controlled the rate of flow through each unit.

The canal section and transition, excluding the warped sections, were fabricated with plywood. The warped transition sections were formed in concrete. The trashracks and wide flange beam supports were nearly exact duplicates of the prototype structures and were fabricated from sheet metal. The piers which separated the individual bays were made of wood and the converging transition sections of the intake tubes were formed in sheet metal.

Water entered the canal through a rock stilling baffle in a headbox. The rate of flow was measured with volumetrically calibrated Venturi meters which are permanently installed in the laboratory.

Water surface elevations were measured with point gages mounted on aluminum structural channels. Velocities were measured with a minature propeller meter, Figure 4, connected to an electronic counting device which yielded the velocity in feet per second from a calibration curve.

The configurations of the three transitions and intake channel arrangements are shown in Figure 5. The angled transition with the straight canal alinement, Figure 5A, was tested first. After testing of the angled transition the model was modified to include the curved canal alinement and symmetrical transition, Figure 5B. The pumping plant intake portion of the model remained the same as before. Finally, tests were made with a straight canal alinement and symmetrical transition, Figure 5C.

THE INVESTIGATION

The investigation was concerned with comparing velocity distribution and head loss characteristics of the two transition designs. During the course of the study, surface flow patterns were observed and effects of modifications to the basic designs were determined. To facilitate evaluation of the two transitions, intake velocity distributions and surface flow patterns for each design are presented simultaneously in the appropriate figures of this report.

A digital computer program was developed to calculate prototype velocities using data from the electronic counter and was later expanded to include a numerical integration of the velocity distribution curves to determine computed rate of discharge through each bay (see Appendix).

A discharge of 700 cfs through each bay was maintained by adjusting the control gates to give equal pressure heads in the conduits. This method is acceptable if the difference in conduit head loss between any two of the six conduits is of negligible magnitude. Measurements showed that the conduit loss was approximately 0.004 foot (model), indicating that the difference in head loss between conduits was negligible.

The day-to-day variation in the calibration of the miniature propeller meter used to measure velocities was an important problem. Deposits of fine waterborne materials on the apparatus resulted in recording velocities lower than the correct value. By computing the average velocity from the recorded data and by presenting the velocity data in dimensionless form (recorded point velocity divided by computed average velocity) the calibaration errors are considered.

Straight Canal Alinement with 30° Angled Transition

Initial tests were made with a prototype water depth of approximately 20 feet at the intakes based on the depth of flow in the Delta-Mendota Canal. Data taken to determine the variation in velocity distribution through the canal section indicated that the section was sufficiently long to ensure full development of turbulent flow at the upstream end of the transition, with no influence from the model entrance.

Reasonably symmetrical velocity distribution prevailed in the transition upstream from the intakes, Figure 6, except for large areas of reverse flow along the diverging sidewalls of the transition, especially the right side. These side eddies resulted in retardation of the flow entering the outside bays (1 and 6) and, to a lesser extent, Bay 5. As described in the introduction, the true effect of this asymmetrical flow distribution is unknown; however, the result would probably be operation of some pumps at higher speeds than others with some loss in efficiency. The eddy currents are also likely to result in accumulation of trash and deposition of sediment along the banks of the transition.

Following the above-described tests, new information was received concerning the depth of flow in the Delta-Mendota Canal and all subsequent data were taken for a depth of approximately 17 feet at the intakes. Visual observations indicated that surface flow conditions were improved but velocity measurements in the transition, Figure 7, showed that velocities were less uniform than those observed with the 20-foot depth, probably because of the higher average velocity.

A shift in the velocity distribution, with higher velocities toward the left side of the transition, is apparent in Section C-C, Figure 6, with the flowmeter axis parallel to the intake centerline. This velocity distribution indicates that the flow has begun to turn toward the intakes in the left portion of the transition, but is continuing parallel to the canal centerline in the right portion. The velocity distribution recorded with the flowmeter axis parallel to the canal centerline shows slightly higher velocities on the left side of the transition.

Velocities were measured at the three one-quarter vertical sections of each bay at 6, 20, 40, 60, and 80 percent depth, measured from the water surface. Symmetrical operation of the pumping plant and several representative conditions of asymmetrical operation were investigated. The data were processed by electronic digital computer and plotted by machine, Figure 8. Following is a guide to the data presented in Figure 8:

One-bay operation	Sheets 1 and 2
Two-bay operation	Sheets 2, 3, and 4
Three-bay operation	Sheets 5, 6, 7, and 8
Four-bay operation	Sheets 9, 10, and 11
Five-bay operation	Sheets 11, 12, and 13
Six-bay operation	Sheets 13, 14, and 15

Sheets 13 to 15 of Figure 8 show that for six-bay operation higher velocities generally occurred in the right half of each bay. This condition was due to the angle of approach. Figure 9A also demonstrates the asymmetrical velocity distribution in the intake bays.

Head loss between the upstream end of the transition and the gate slots downstream from the trashracks was measured as 0.105 foot (prototype) with a depth of 17 feet, and all bays operating. Most of this loss was apparently produced by the trashrack, as indicated by a noticeable drop in the water surface as the flow passed through the rack. Head loss between the bulkhead gate slots and model piezometers (near the start of the vertical elbow) was 0.054 foot (prototype).

No attempt was made to evaluate the energy (Coriolis) coefficient due to nonuniform velocity distribution because of inability to obtain accurate velocity data near the boundaries. This coefficient varies from unity at sections of uniform velocity distribution to larger values dependent on the degree of nonuniformity. It is expected that the coefficient should be much higher at the intakes than at the upstream end of the transition. Application of appropriate coefficients to the velocity head in each of the two sections would result in a head loss value lower than that stated in the preceding paragraph.

Velocity distribution data for asymmetrical operation of the pumping plant indicated a pronounced effect of the angled approach, as shown on Sheets 9 and 10 of Figure 8, Units 1, 2, 5, and 6 operating. Surface flow patterns were observed for several operating conditions, Figure 10. Comparison of the surface flow patterns with Units 1, 2, 5, and 6 operating in Figure 10D with the corresponding velocity distributions illustrates the effect of the angled approach. Flow entering Bays 1 and 2 is fairly symmetrical, as evidenced by both the surface pattern and the velocity distribution. The flow generally approaches Unit 5 from the left, which results in higher velocities on the right side of the intake bay. The velocity distribution in Bay 6 is nearly symmetrical except for a high velocity on the left side near the surface. The surface flow pattern shows a slight curvature to the left which may be more pronounced downstream from the trashrack. Similar conclusions can be drawn for operation of Units 2, 3, 4, and 5 by comparing the velocity distributions on Sheets 10 and 11 of Figure 8 with the corresponding surface flow pattern in Figure 10E.

Head loss data showed a wide variation but indicated that the loss between the upstream end of the transition and the intakes varied from approximately 0.05 foot (prototype) for single-bay operation to approximately 0.10 foot for five-bay operation.

Several modifications were made to the transition to determine possible improvements in the flow conditions by relatively minor changes in the basic design. Surface flow patterns and intake velocity distributions are shown in Figures 11 and 12, respectively.

Modification No. 1.--The right bank of the canal approach section was extended downstream to a point closer to the plant, thus reducing the length of one side of the transition, Figure 11A. This change resulted in a reduction of the size of the reverse current on the right side of the transition. Velocity distribution in the intake bays remained essentially unchanged. Compare Sheets 13, 14, and 15 of Figure 8 with Sheet 1 of Figure 12.

Modification No. 2. --The transition was further modified by warping the 1-1/2:1 side slopes to vertical walls at each side of the pumping plant, Figure 11B. This modification resulted in noticeable reduction in the size of the reverse current on the left side of the transition but little change in the velocity distribution. Velocity distribution in Bay 6 was unchanged because of the abrupt offset in alinement of the right sidewall of the transition. Compare Sheets 13, 14, and 15 of Figure 8 with Sheet 2 of Figure 12.

Modification No. 3. --Widening the bottom of the canal from 60 to 80 feet was simulated by blocking off Bay 6 and reshaping the warped transition on the right side so that it terminated in a 1:1 slope at the plant, Figure 11C. The reverse current still prevailed but the distribution in the right outside bay (now Bay 5) and in Bay 4 appeared to be improved. Widening the prototype canal would result in lowering the average velocity in the transition and consequently reduce the strength of eddies formed along the sides. The effect of shifting the canal to the right was simulated by moving the left side of the transition 8 feet (prototype) toward the centerline and warping the side slopes from 1-1/2:1 to vertical on the left side. The reverse current was slightly increased in size, and the velocity distribution in Bay 1 showed only slight improvement. Compare Sheets 13, 14, and 15 of Figure 8 with Sheet 3 of Figure 12.

Modification No. 4. --The final and most effective modification combined simulation of widening the canal and transition and warping both side slopes to vertical walls at the pumping plant, Figure 11D. This test showed that vertical walls and a wider canal were undoubtedly the most effective way of ensuring good transition flow conditions and symmetrical velocity distribution in each of the pump intakes. However, even with the vertical walls, some effect of the angle of the plant was still apparent in the velocity distributions. Sheet 3 of Figure 12 is very similar to Sheet 4. The most apparent improvement was the reduction of the eddies on each side of the transition.

Curved Canal Alinement with Symmetrical Transition

The model was revised to include an approach canal having a 30° horizontal curve with a radius of 970.3 feet and a 110-foot-long symmetrical transition, Figure 3B, as shown in the preliminary alternative design. Data identical to those recorded for the angled transition were recorded to facilitate easy comparison between the two types.

The studies indicated a somewhat improved velocity distribution at the pump intakes, Figures 8 and 9B, compared to that observed for the angled transition. Compare the left half of each sheet of Figure 8 with the right half. Very good distribution prevailed in the transition upstream from the intakes, Figure 13. Bays 1 and 6 continued to exhibit the retarding effect of the eddies, Sheets 13 and 15, Figure 8. The symmetry of the transition alleviated the higher velocities on the right side of the remaining intake bays.

The effect of the curved canal alinement on the velocity distribution was apparently small, Figure 13, and the downstream tangent and transition were effective in recovering symmetrical velocity distribution. Slightly higher velocities on the outside of the curve were observed but the distribution was nearly symmetrical in the transition.

The appearance of flow in the symmetrical transition, Figure 10A, was improved over the angled transition and the intensity of the eddy currents appeared to be somewhat less than those observed in the angled transition. The reduced eddy currents affected only Bays 1 and 6 while Bays 1, 5, and 6 were affected in the angled transition.

Head loss between the upstream end of the transition and the gate slots downstream from the trashracks was 0.06 foot (prototype). Loss between the bulkhead gate slots and the start of the vertical elbow was also 0.06 foot, which is nearly the same as the angled transition, as expected. The slight difference of 0.045 foot between transition losses in the two types does not warrant preference of the symmetrical type on this basis. Head loss data were not taken during asymmetrical operation of the plant.

Surface flow patterns for asymmetrical operation of the plant were observed, Figure 10, as for the angled transition. The patterns were very similar in each of the two transitions, except that curvature of the flow lines was more pronounced in the angled transition, particularly with flow through the outside bays.

Straight Canal Alinement with Symmetrical Transition

The primary purpose of the study was to compare hydraulic characteristics of the two transition types previously described. Data were also obtained on operation of an "ideal" configuration consisting of a straight canal alinement with a symmetrical transition, Figure 3C. It was expected that this test would provide additional information to more adequately evaluate the performance of the two transition types. The model was revised by replacing the curved canal approach with a straight section. The transition section remained unchanged from the curved approach tests.

Data were taken identical to those recorded for the other two model arrangements. As in the angled transition, the velocity distribution at the upstream end of the transition was checked to ensure that the model adequately represented the prototype distribution. After some modification to the model entrance, the measured velocity distribution was as shown in Section A-A, Figure 14.

At a section approximately 125 feet downstream from the beginning of the transition the distribution was reasonably symmetrical although slightly higher velocities occurred in the left half of the canal, Section B-B, Figure 14. No obvious explanation can be offered for this result. The unstable eddy areas, observed in the other two transition types, were also observed in this transition. The influence of these eddies was apparent approximately 45 feet either side of the centerline near the intersection of the sloping banks with the canal bottom.

Velocity distribution in the intake bays, Figures 9C and 15, was very similar to that in the symmetrical transition with curved approach except for asymmetrical operation with three and four bays, Sheets 3, 4, and 5, Figure 15. Extremely low velocities were noted at 6 and 20 percent depth, and in several cases, an accompanying large distortion of the velocity distribution was observed toward one side of the bay. Some difficulty was experienced with the miniature propeller meter, which accounts for the zero and negative velocities. However, the distribution indicates that the piers between the bays and the curving surface flow induced a contraction on the leeward side of the pier which resulted in the described distortion. The question remains as to why a similar effect was not observed with the curved approach. Inspection of the velocity distributions for the two transitions, Figures 8 and 15, shows that the only appreciable differences were at 6 and 20 percent depth; thus, the particular combination of transition geometry and mode of operation has some effect on the flow pattern at or near the surface. A careful measurement of secondary currents in the transition would be necessary to properly evaluate these effects.

Time-lapse photographs of surface flow patterns were essentially identical to those for the curved approach alinement, Figure 10. The quality of the photographs was not suitable for reproduction and are not included in this report.

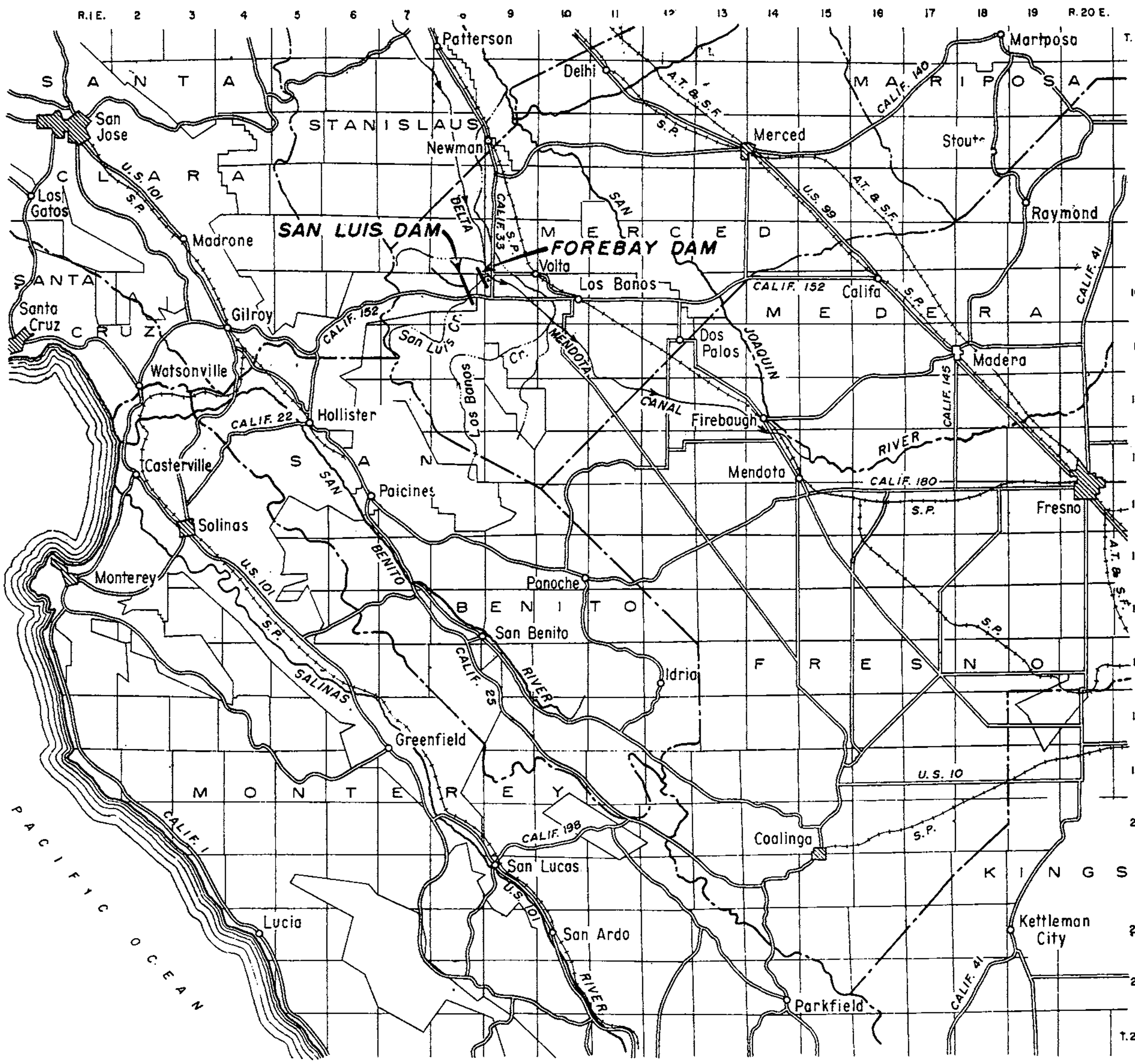
Head loss between the upstream end of the transition and a measuring section downstream from the trashracks was measured as 0.02 foot (prototype). This loss is less than the losses observed for the other two transitions (0.105 and 0.060 foot, respectively) but as mentioned before, does not warrant comparison of the transitions on this basis. The trend is as expected, with the largest loss being measured in the angled transition.

Miscellaneous Tests

Observations were made of the formation of vortices in the intakes downstream from the trashracks resulting from contraction of the flow due to the influence of the piers between the bays. The symmetrical transitions, Figure 16, exhibited less tendency for the formation of these vortices; in no case did the vortices develop to such an extent as to take large quantities of air. Photographs of similar action in the angled transition are not available. The piers included in the prototype design have a 60° chamfer on the upstream end as compared with 45° on the model piers. This additional streamlining should result in better flow conditions than those exhibited in the model.

Installation of a trashrack with twice the bar depth of the previous rack in one bay of the angled transition showed no change in the velocity distribution. Operation of a bay with no trashrack indicated a higher average velocity. All six bays were operating during these tests.

A 12-foot-long extension of the center dividing pier (between Bays 3 and 4), extending above the water surface and perpendicular to the line of pumps, improved the velocity distribution in Bays 3 and 4. The pier extension was in the form of a thin wall. A similar extension placed parallel to the entering flow (or 30° to the line of pumps) showed no improvement in the velocity distribution. The influence of the piers on the flow lines along the bottom is indicated by dye traces in Figure 17.



SCALE OF MILES (10 0 10 20 30)

KEY MAP

ALWAYS THINK SAFETY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT
WEST SAN JOAQUIN DIV. - SAN LUIS UNIT - CALIFORNIA

SAN LUIS DAM AND FOREBAY DAM
LOCATION MAP

DRAWN W.W.G. SUBMITTED R. J. Larsen
TRACED W.W.G. RECOMMENDED [signature]
CHECKED [signature] APPROVED [signature]
ACT. ASST. COMM. AND CHIEF ENGINEER

DENVER, COLORADO SEPT. 22, 1962 805-D-111

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FIGURE 2
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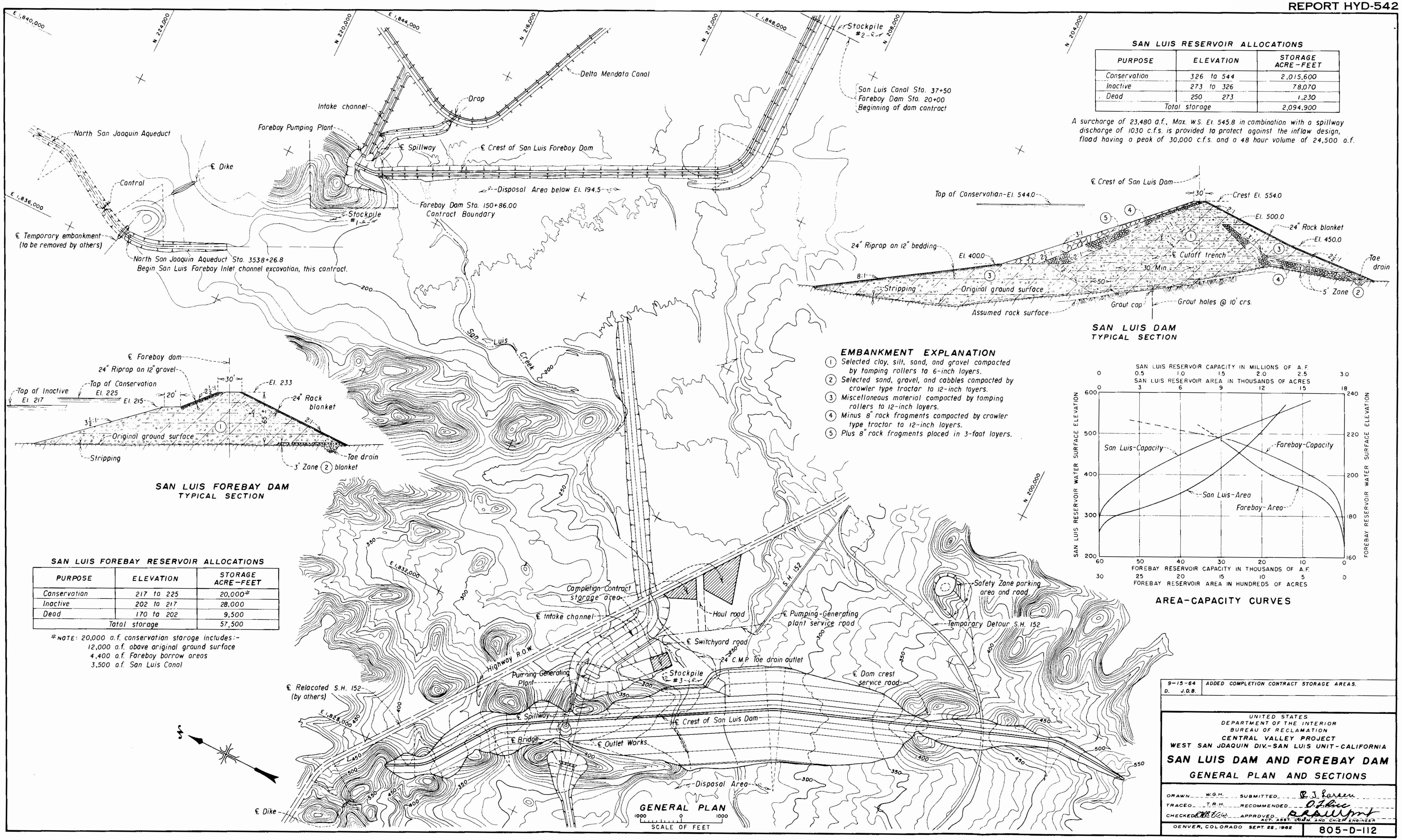


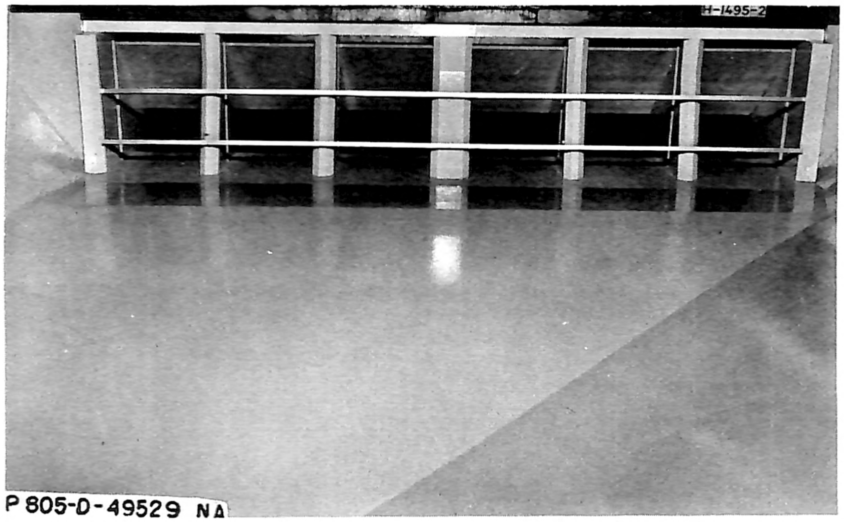
SAN LUIS RESERVOIR ALLOCATIONS

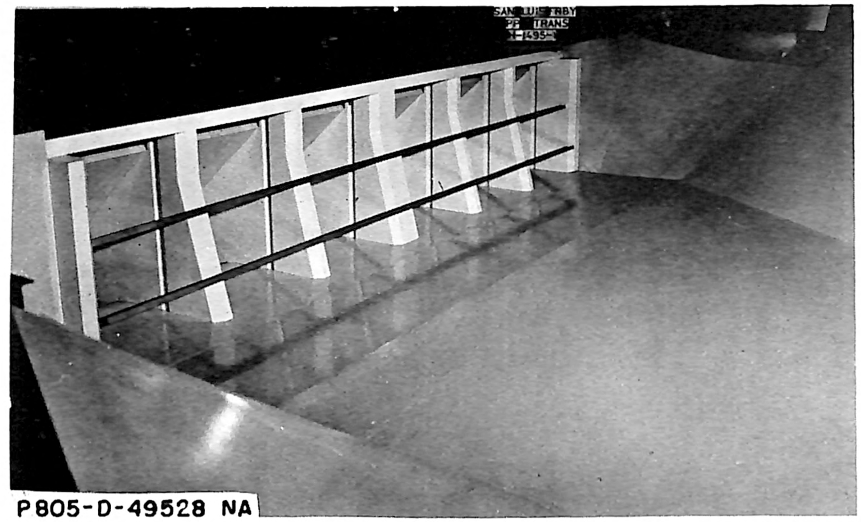
PURPOSE	ELEVATION	STORAGE ACRE-FEET
Conservation	326 to 544	2,015,600
Inactive	273 to 326	78,070
Dead	250 273	1,230
Total storage		2,094,900

SAN LUIS FOREBAY RESERVOIR ALLOCATIONS

PURPOSE	ELEVATION	STORAGE ACRE-FEET
Conservation	217 to 225	20,000*
Inactive	202 to 217	28,000
Dead	170 to 202	9,500
Total storage		57,500

*NOTE: 20,000 a.f. conservation storage includes:-
12,000 a.f. above original ground surface
4,400 a.f. Forebay borrow areas
3,500 a.f. San Luis Canal





SAN LUIS FOREBAY PUMPING PLANT
CANAL TRANSITION STUDIES

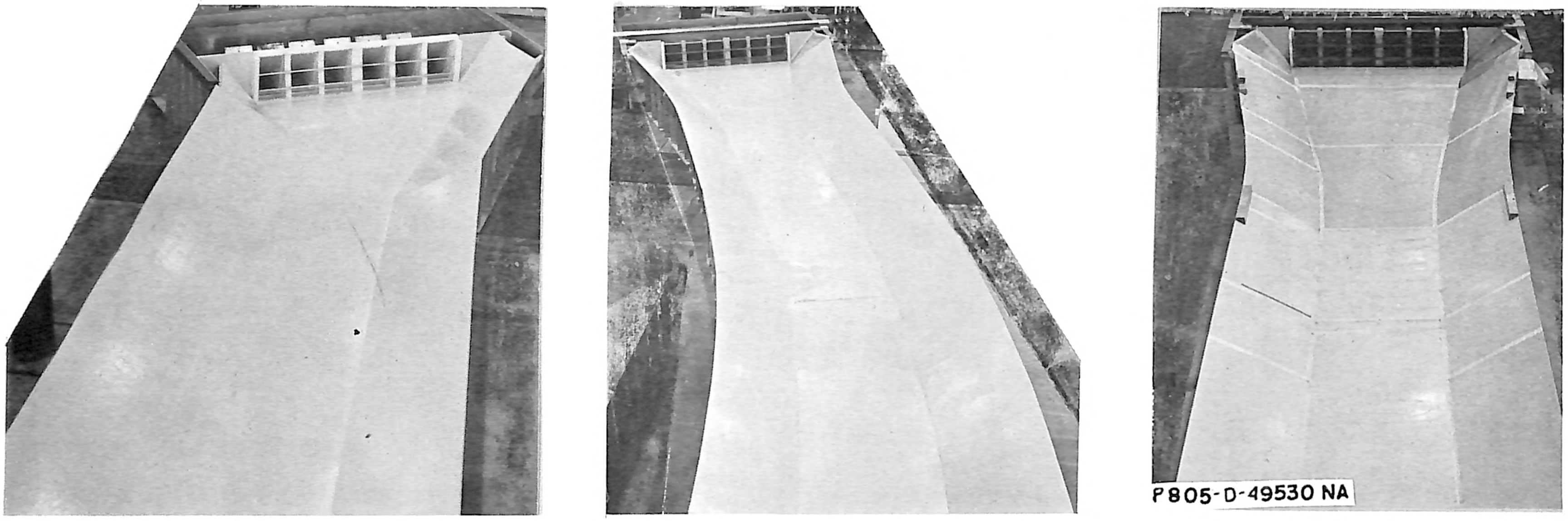
1:15 scale model

Pumping plant intake bays
trashracks not shown

SAN LUIS FOREBAY PUMPING PLANT
CANAL TRANSITION STUDIES

1:15 scale model

Measurement of flow velocities with
miniature propeller meter



A. Angled transition with straight approach alinement.

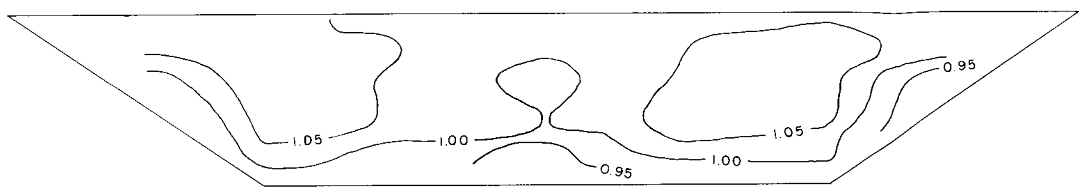
B. Symmetrical transition with curved approach alinement.

C. Symmetrical transition with straight approach alinement.

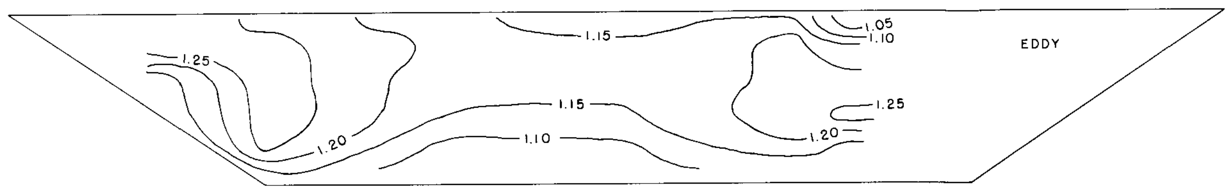
SAN LUIS FOREBAY PUMPING PLANT
CANAL TRANSITION STUDIES

1:15 scale model

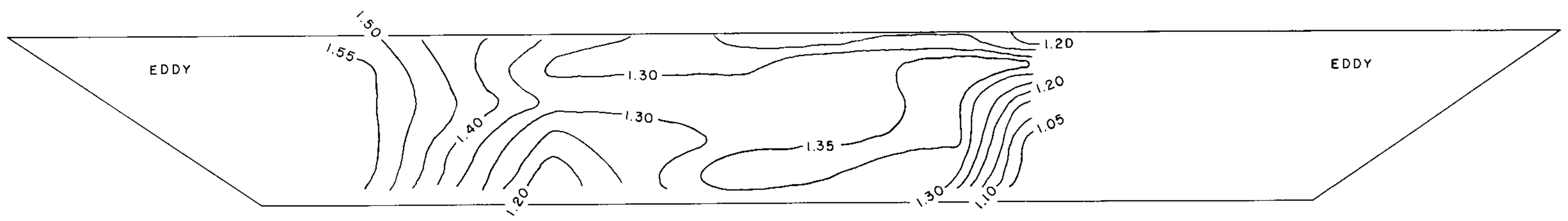
Model configurations



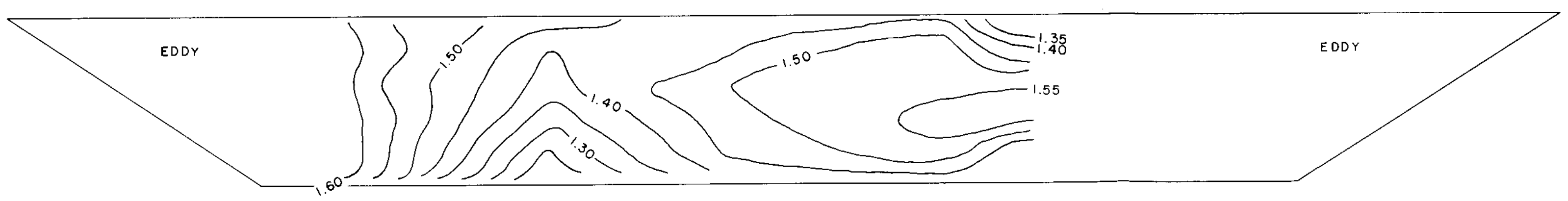
VELOCITY CONTOURS
SECTION A-A
FLOWMETER AXIS PARALLEL TO CANAL ℄



VELOCITY CONTOURS
SECTION B-B
FLOWMETER AXIS PARALLEL TO CANAL ℄



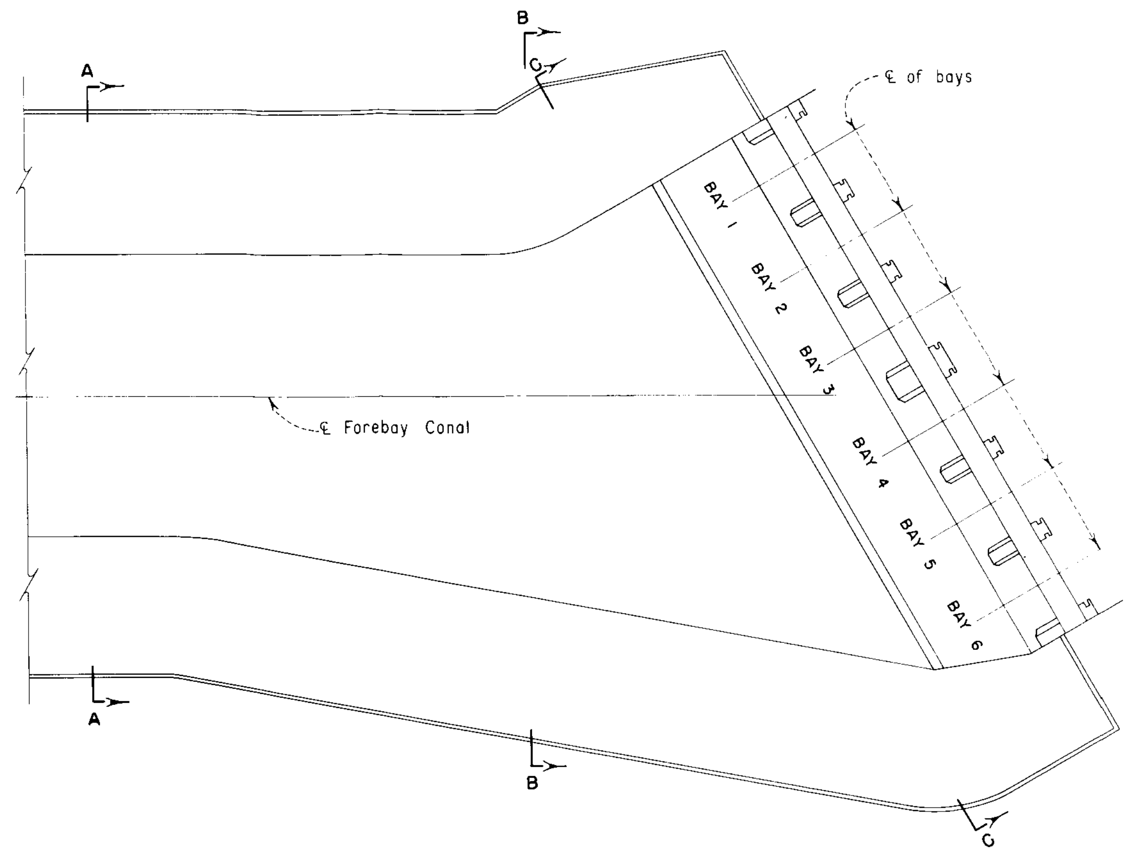
VELOCITY CONTOURS
SECTION C-C
FLOWMETER AXIS PARALLEL TO INTAKE ℄



VELOCITY CONTOURS
SECTION C-C
FLOWMETER AXIS PARALLEL TO CANAL ℄

0 5 10 20 30 40 50
LENGTH SCALE IN FEET (PROTOTYPE)

NOTE
Velocities are in the dimensionless form of measured velocity divided by the average velocity, where the average velocity is the discharge (4200 cfs) divided by the entire cross-sectional area of the flow.



PLAN OF TRANSITION SECTION
AND PUMPING PLANT INTAKES

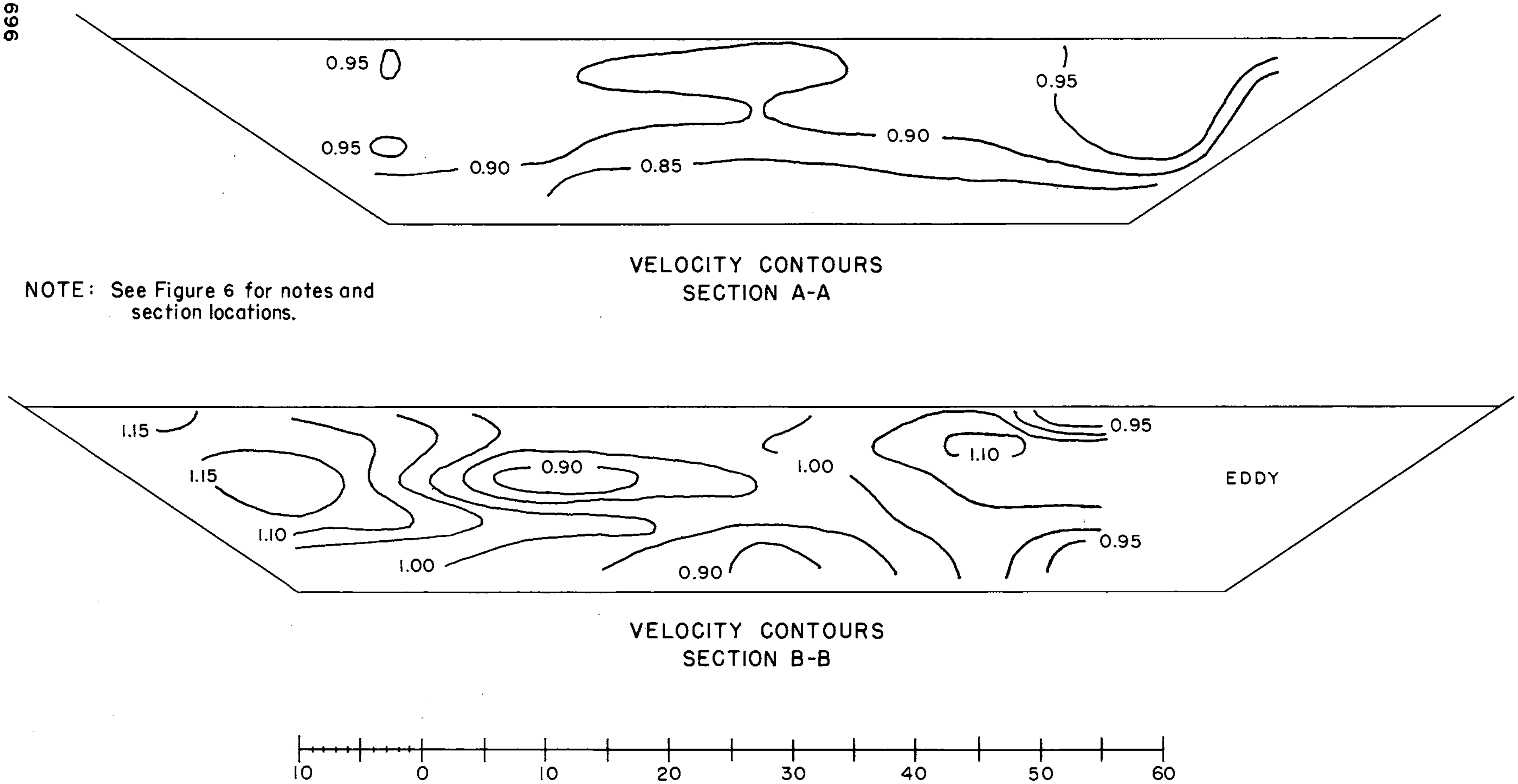
10 0 10 20 30 40 50 60 70 80 90
LENGTH SCALE IN FEET (PROTOTYPE)

SAN LUIS FOREBAY PUMPING PLANT
CANAL TRANSITION STUDIES

1:15 SCALE MODEL

VELOCITY DISTRIBUTION IN ANGLED TRANSITION
DEPTH = 20 FEET AT INTAKES

969



SAN LUIS FOREBAY PUMPING PLANT
CANAL TRANSITION STUDIES

1:15 SCALE MODEL

VELOCITY DISTRIBUTION IN ANGLED TRANSITION
DEPTH = 17 FEET AT INTAKES

FIGURE 7
REPORT HYD-542

Figure 8
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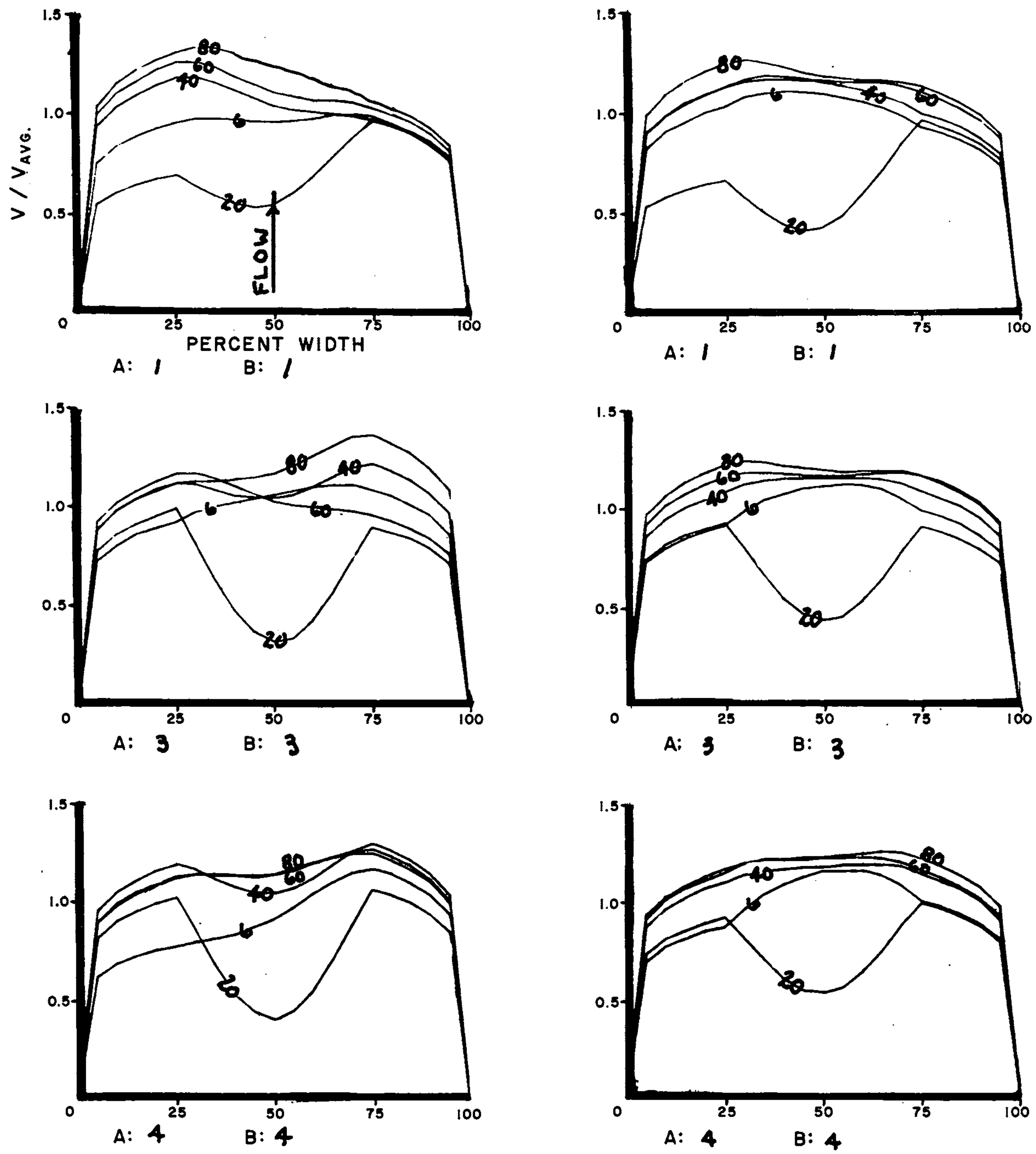


ANGLED TRANSITION WITH STRAIGHT APPROACH

SYMMETRICAL TRANSITION WITH CURVED APPROACH

NOTES

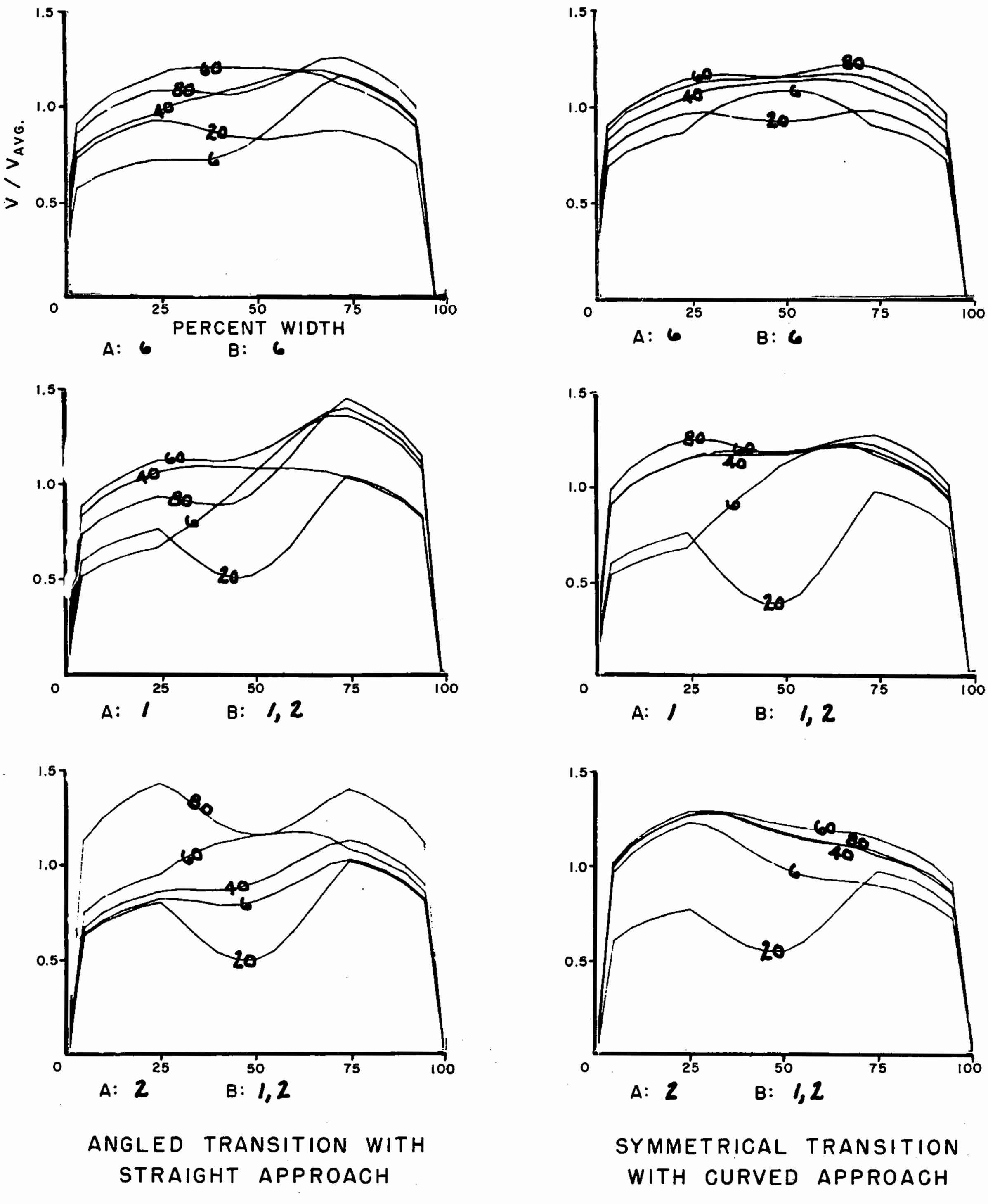
A: Bay measured
B: Bays operating
6, 20, 40, etc.: Percent of total depth measured from surface. Plane of velocity measurement at stop log slots.

SAN LUIS FOREBAY PUMPING PLANT CANAL TRANSITION STUDIES

1:15 SCALE MODEL

PLAN VIEW OF VELOCITY DISTRIBUTION IN PUMP INTAKE BAYS

Sheet 4 of 15



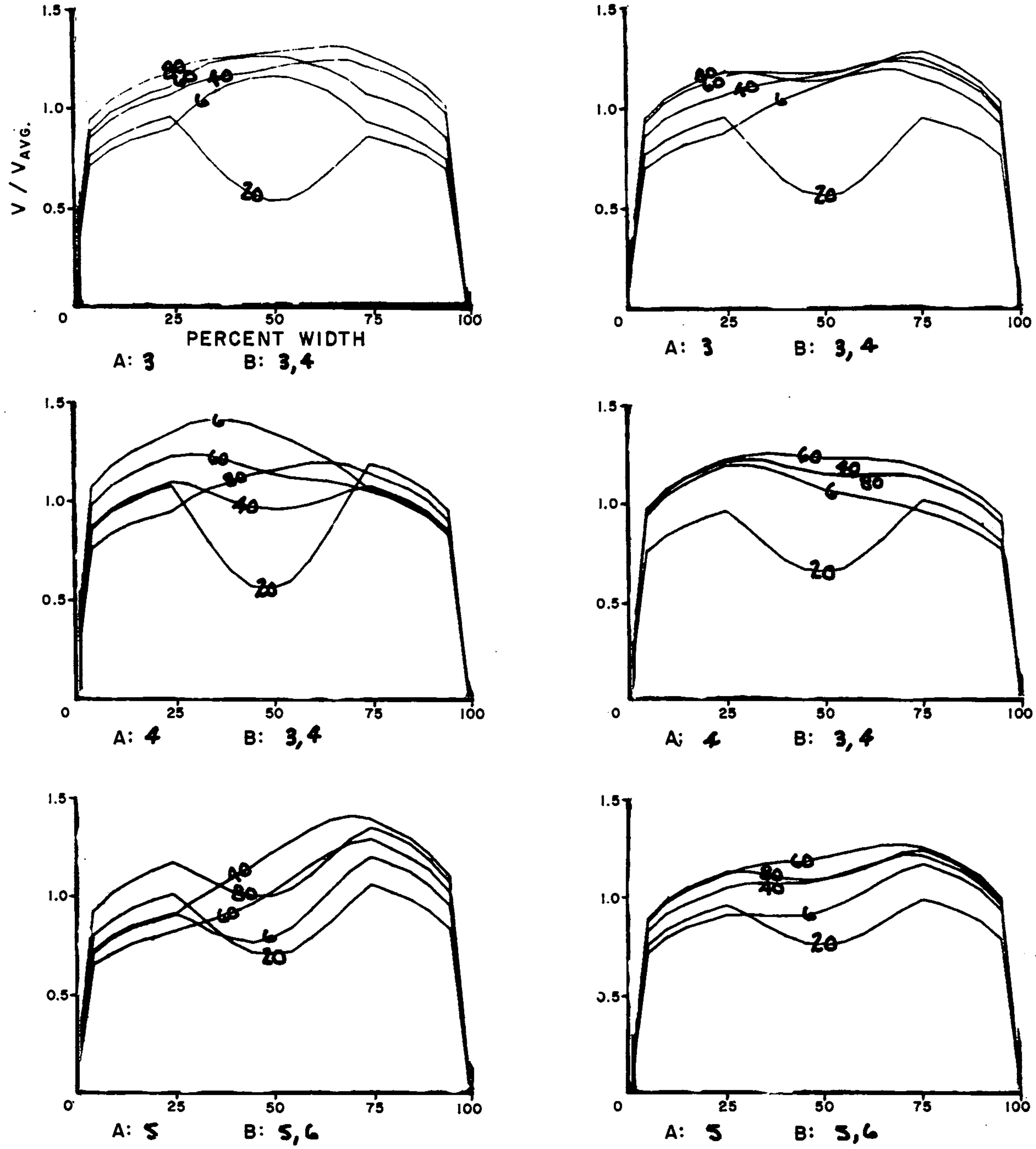
NOTES

A: Bay measured
B: Bays operating
6, 20, 40, etc.: Percent of total depth measured from surface.
Plane of velocity measurement at stop log slots.

SAN LUIS FOREBAY PUMPING PLANT CANAL TRANSITION STUDIES

1:15 SCALE MODEL

PLAN VIEW OF VELOCITY DISTRIBUTION IN PUMP INTAKE BAYS



ANGLED TRANSITION WITH STRAIGHT APPROACH

SYMMETRICAL TRANSITION WITH CURVED APPROACH

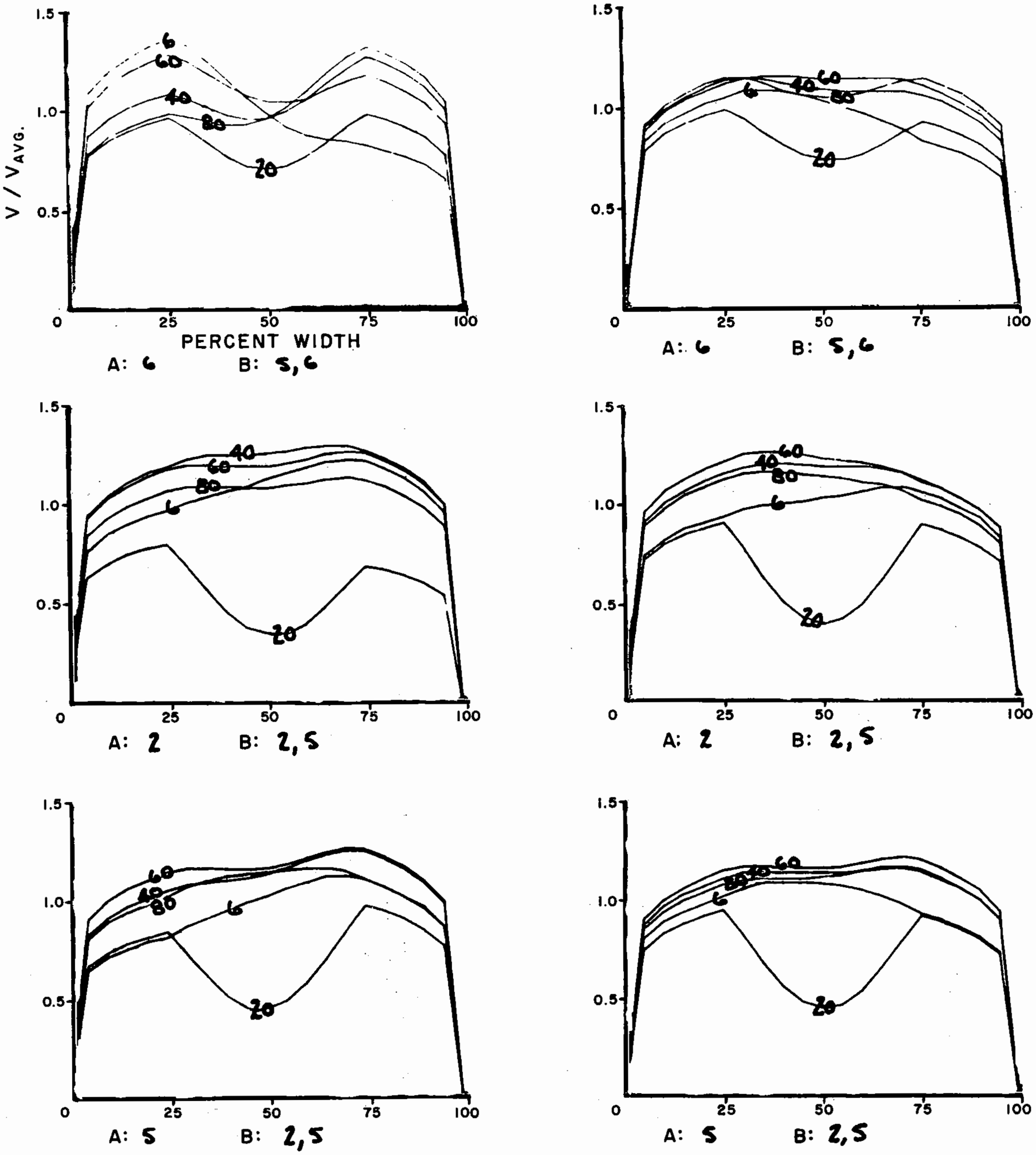
NOTES

A: Bay measured
B: Bays operating
6, 20, 40, etc.: Percent of total depth measured from surface. Plane of velocity measurement at stop log slots.

SAN LUIS FOREBAY PUMPING PLANT
CANAL TRANSITION STUDIES

1:15 SCALE MODEL

PLAN VIEW OF VELOCITY DISTRIBUTION IN PUMP INTAKE BAYS



ANGLED TRANSITION WITH STRAIGHT APPROACH

SYMMETRICAL TRANSITION WITH CURVED APPROACH

NOTES

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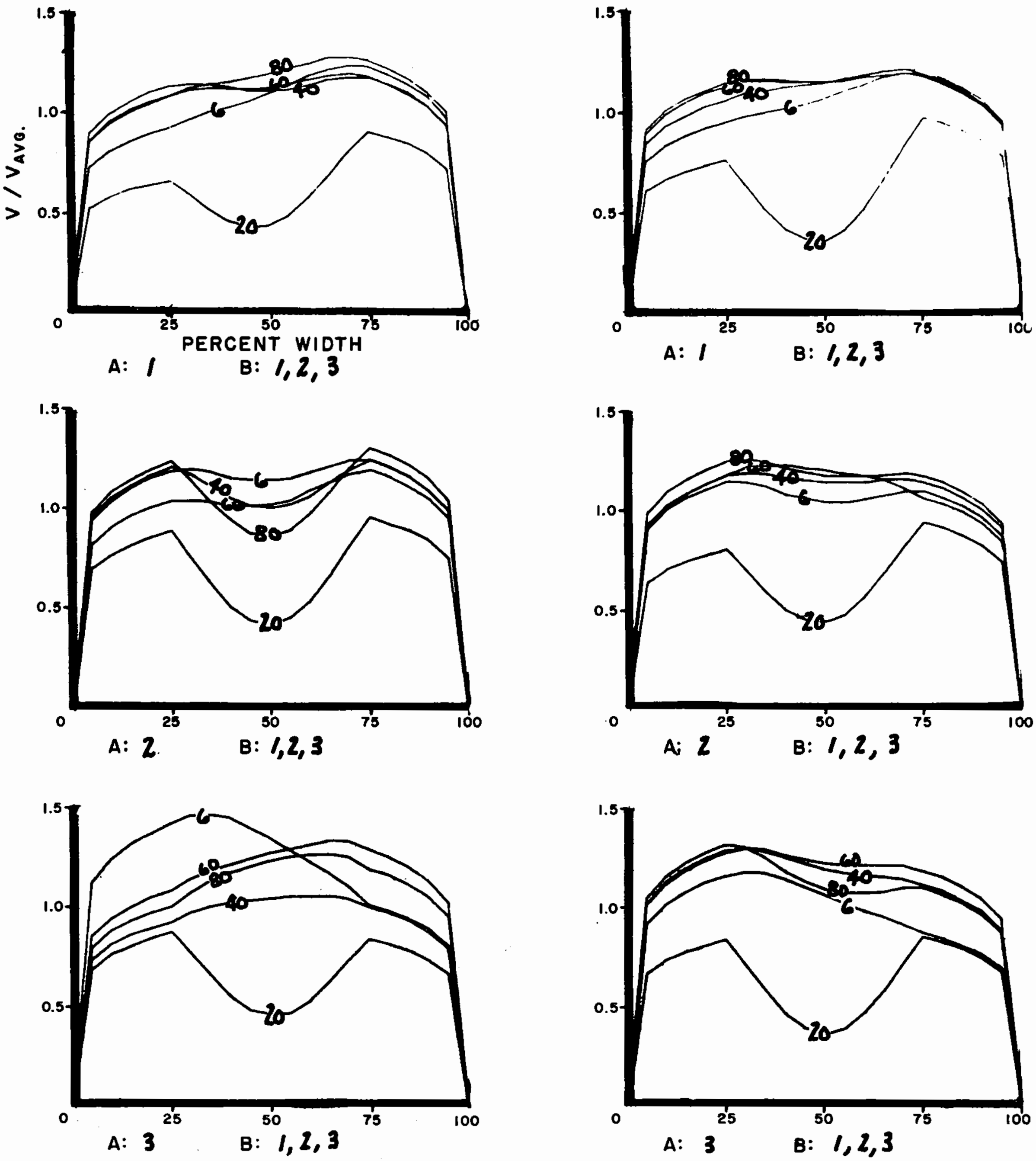
SAN LUIS FOREBAY PUMPING PLANT
CANAL TRANSITION STUDIES

1:15 SCALE MODEL

PLAN VIEW OF VELOCITY DISTRIBUTION IN PUMP INTAKE BAYS



ANGLED TRANSITION WITH STRAIGHT APPROACH

SYMMETRICAL TRANSITION WITH CURVED APPROACH

NOTES

A: Bay measured
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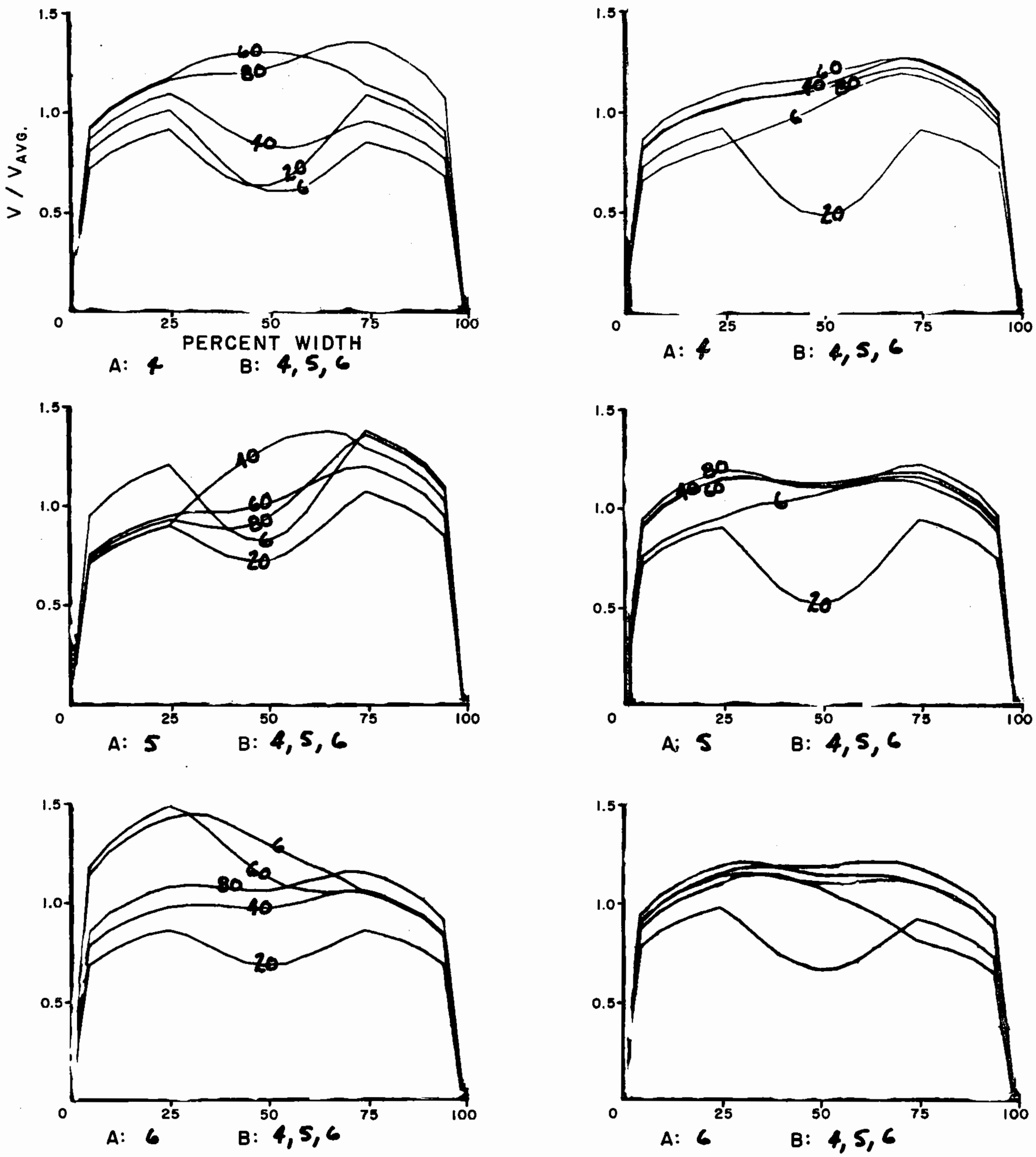
SAN LUIS FOREBAY PUMPING PLANT CANAL TRANSITION STUDIES

1:15 SCALE MODEL

PLAN VIEW OF VELOCITY DISTRIBUTION IN PUMP INTAKE BAYS



ANGLED TRANSITION WITH STRAIGHT APPROACH

SYMMETRICAL TRANSITION WITH CURVED APPROACH

NOTES

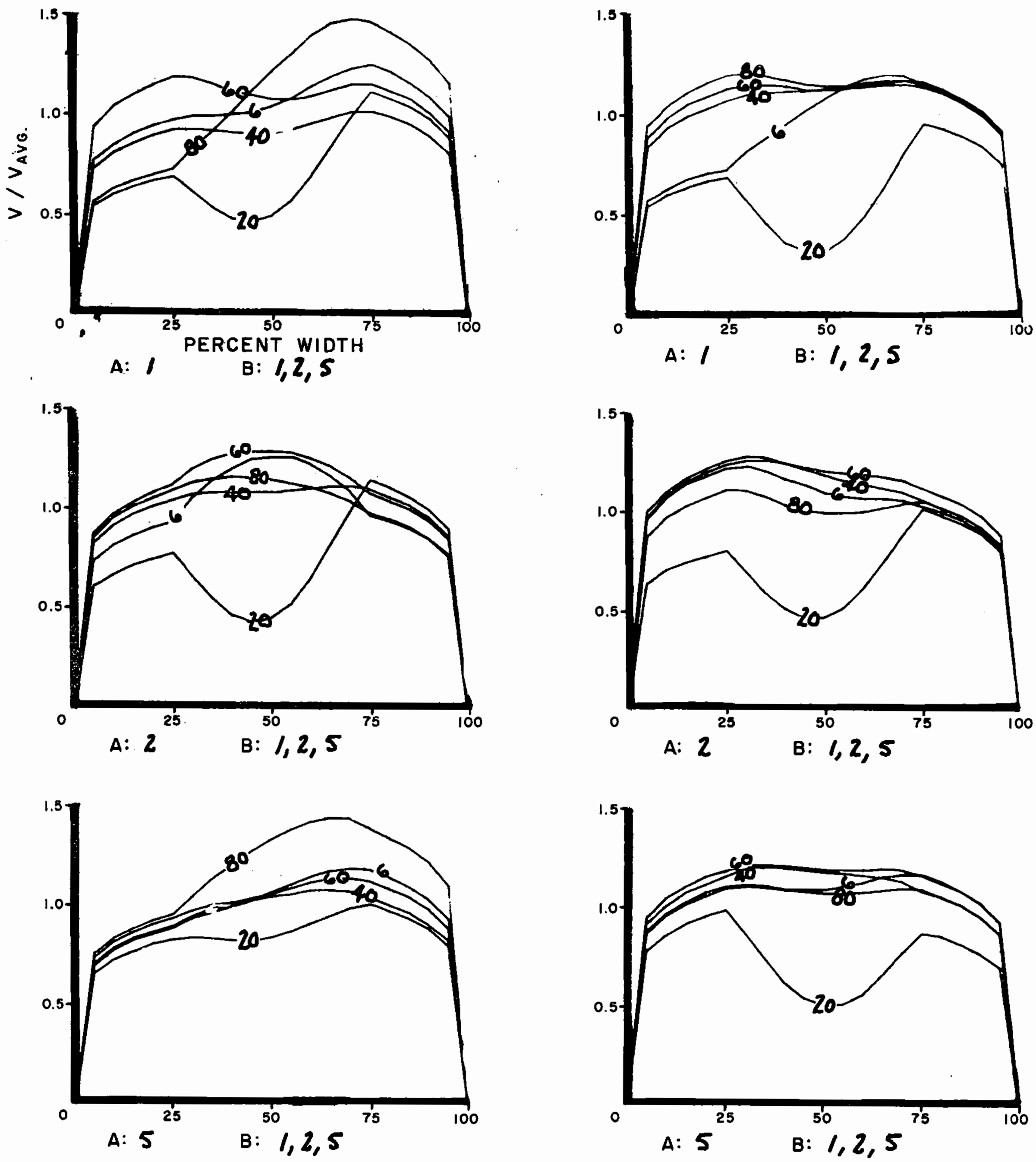
A: Bay measured
B: Bays operating
6, 20, 40, etc.: Percent of total depth measured from surface. Plane of velocity measurement at stop log slots.

SAN LUIS FOREBAY PUMPING PLANT CANAL TRANSITION STUDIES

1:15 SCALE MODEL

PLAN VIEW OF VELOCITY DISTRIBUTION IN PUMP INTAKE BAYS

Figure 8
Report Hyd-542



ANGLED TRANSITION WITH STRAIGHT APPROACH

SYMMETRICAL TRANSITION WITH CURVED APPROACH

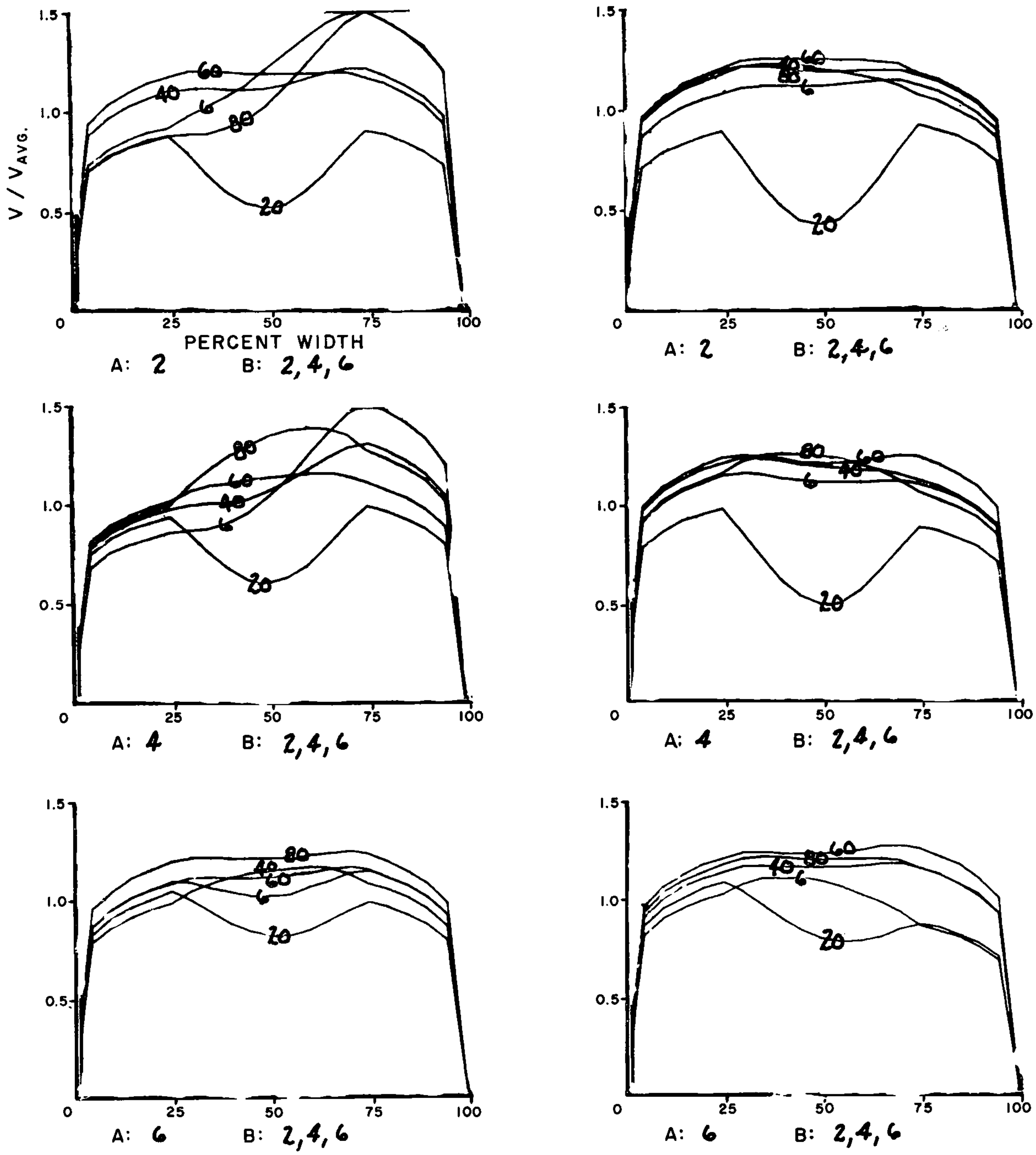
NOTES

A: Bay measured
B: Bays operating
6, 20, 40, etc.: Percent of total depth measured from surface.
Plane of velocity measurement at stop log slots.

SAN LUIS FOREBAY PUMPING PLANT CANAL TRANSITION STUDIES

1:15 SCALE MODEL

PLAN VIEW OF VELOCITY DISTRIBUTION IN PUMP INTAKE BAYS



ANGLED TRANSITION WITH STRAIGHT APPROACH

SYMMETRICAL TRANSITION WITH CURVED APPROACH

SAN LUIS FOREBAY PUMPING PLANT CANAL TRANSITION STUDIES

1:15 SCALE MODEL

PLAN VIEW OF VELOCITY DISTRIBUTION IN PUMP INTAKE BAYS

NOTES

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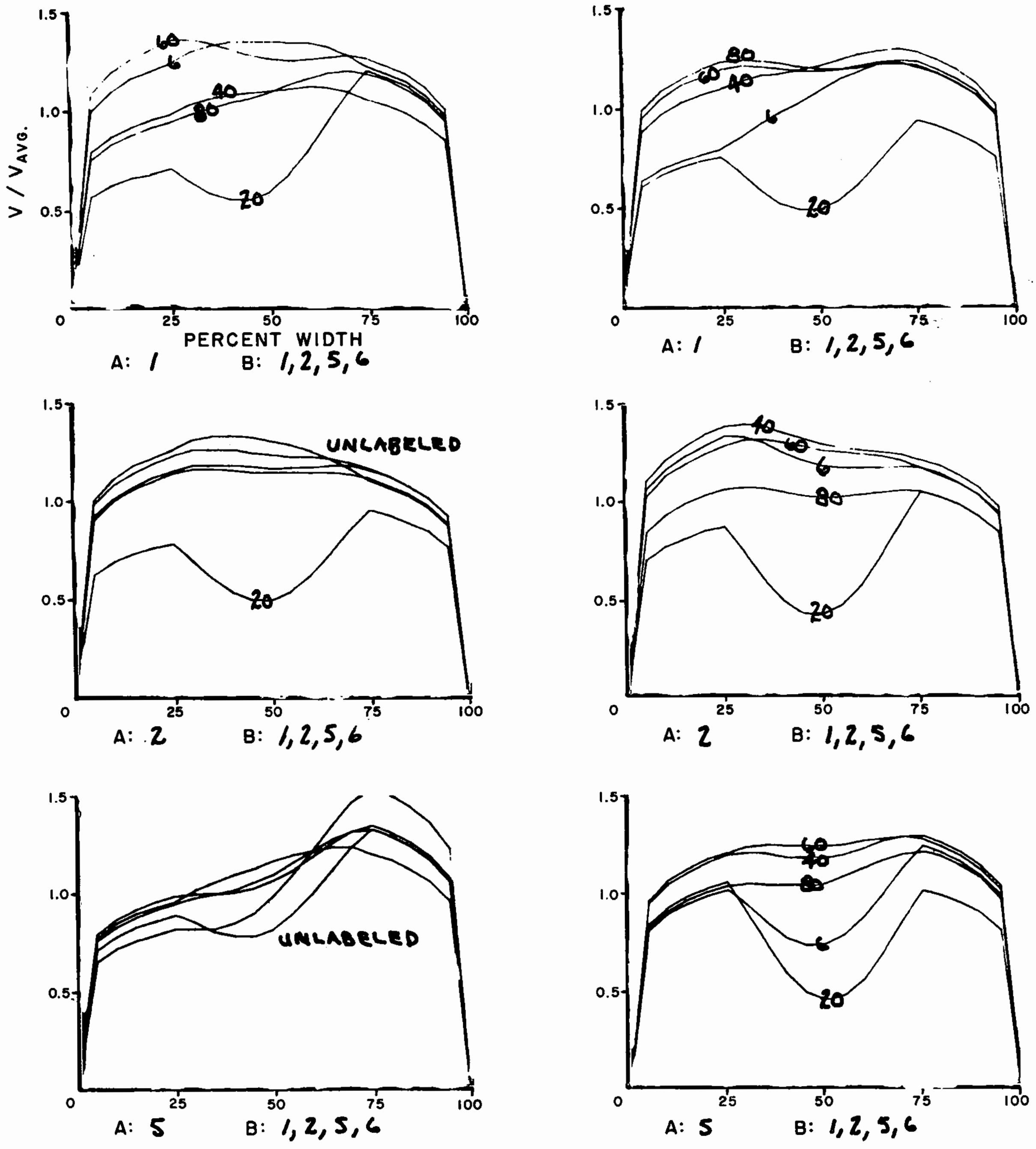

ANGLED TRANSITION WITH STRAIGHT APPROACH

SYMMETRICAL TRANSITION WITH CURVED APPROACH

NOTES

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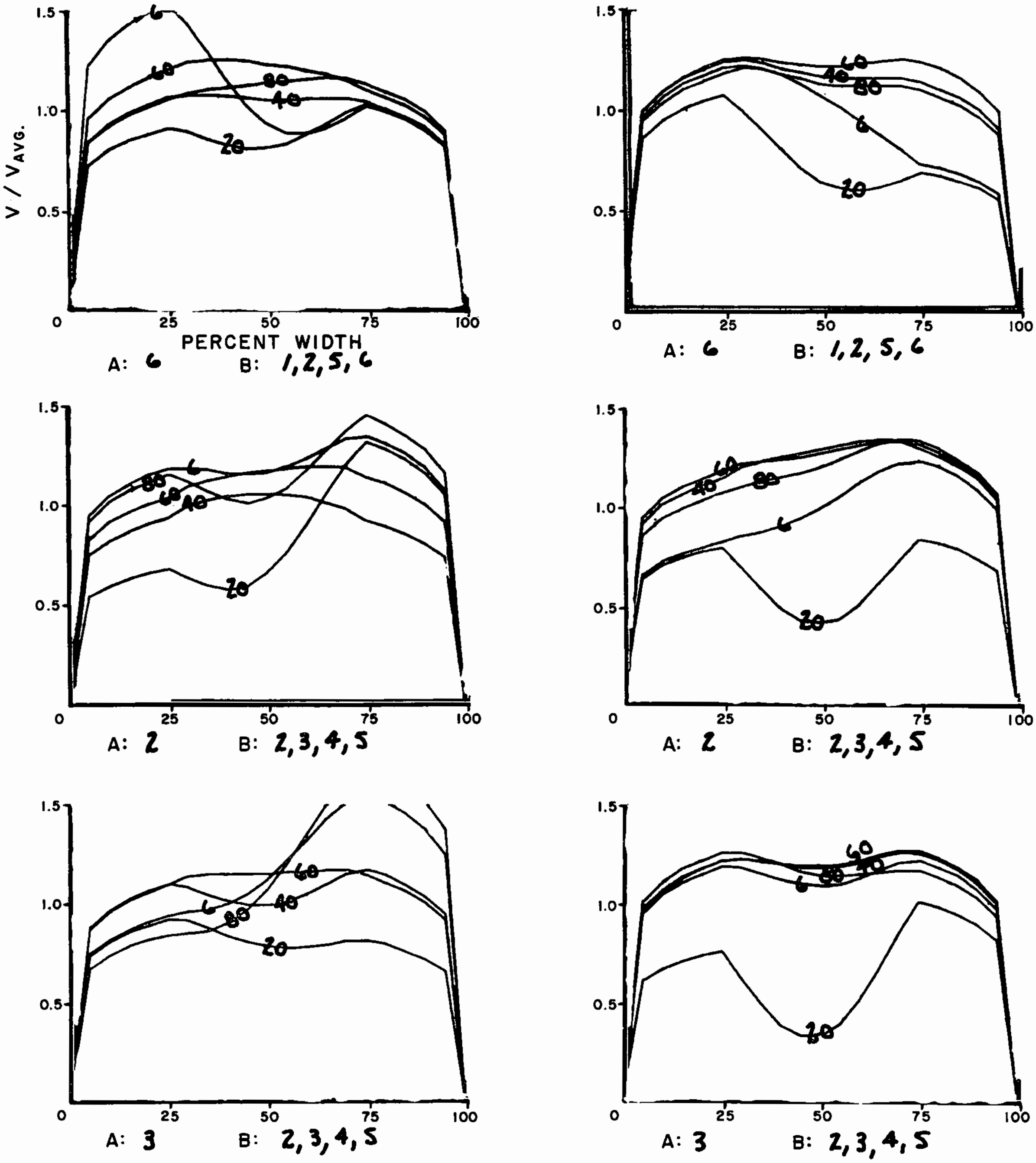
SAN LUIS FOREBAY PUMPING PLANT CANAL TRANSITION STUDIES

1:15 SCALE MODEL

PLAN VIEW OF VELOCITY DISTRIBUTION IN PUMP INTAKE BAYS



ANGLED TRANSITION WITH STRAIGHT APPROACH

SYMMETRICAL TRANSITION WITH CURVED APPROACH

NOTES

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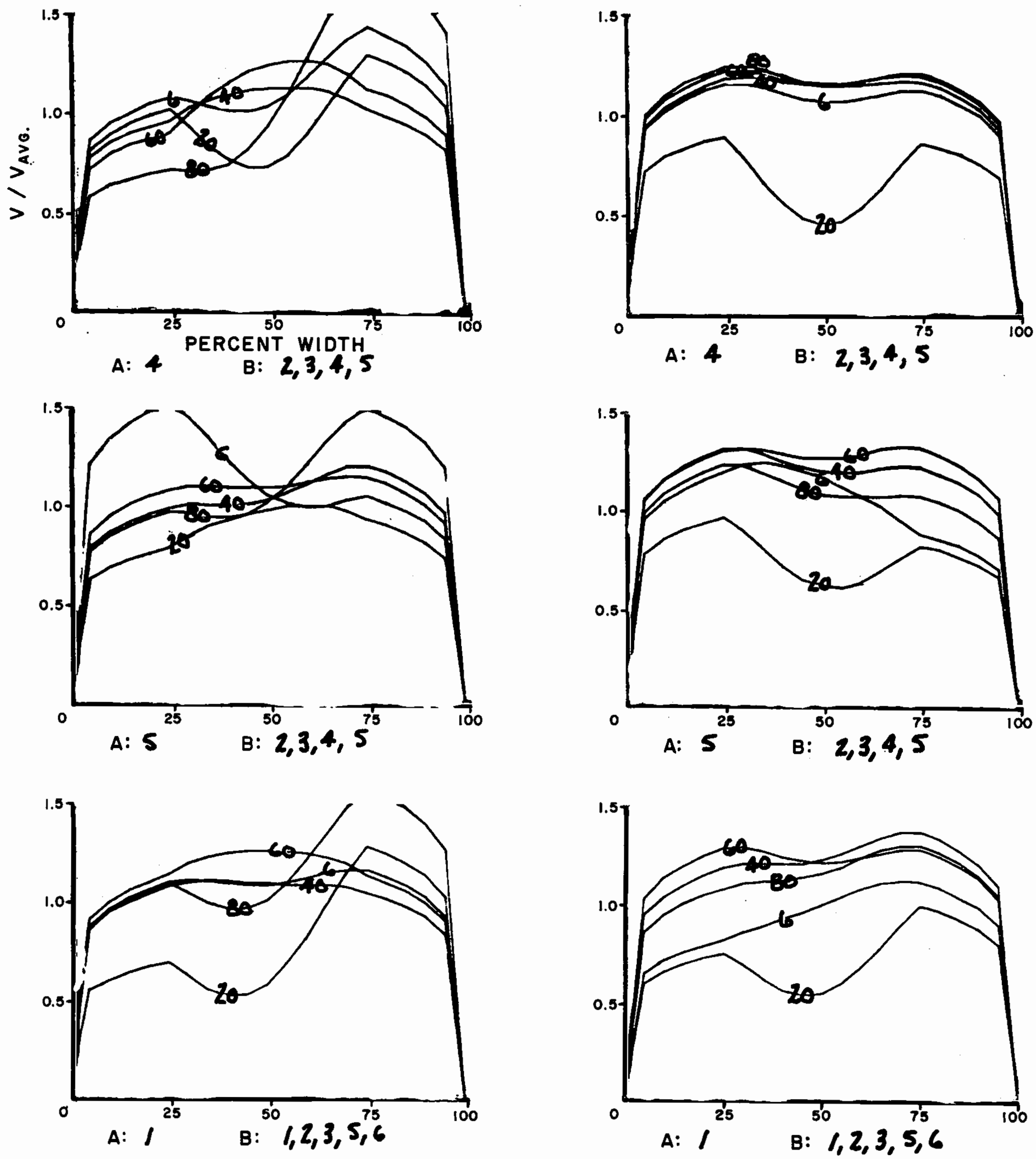
SAN LUIS FOREBAY PUMPING PLANT CANAL TRANSITION STUDIES

1:15 SCALE MODEL

PLAN VIEW OF VELOCITY DISTRIBUTION IN PUMP INTAKE BAYS



ANGLED TRANSITION WITH STRAIGHT APPROACH

SYMMETRICAL TRANSITION WITH CURVED APPROACH

NOTES

A: Bay measured
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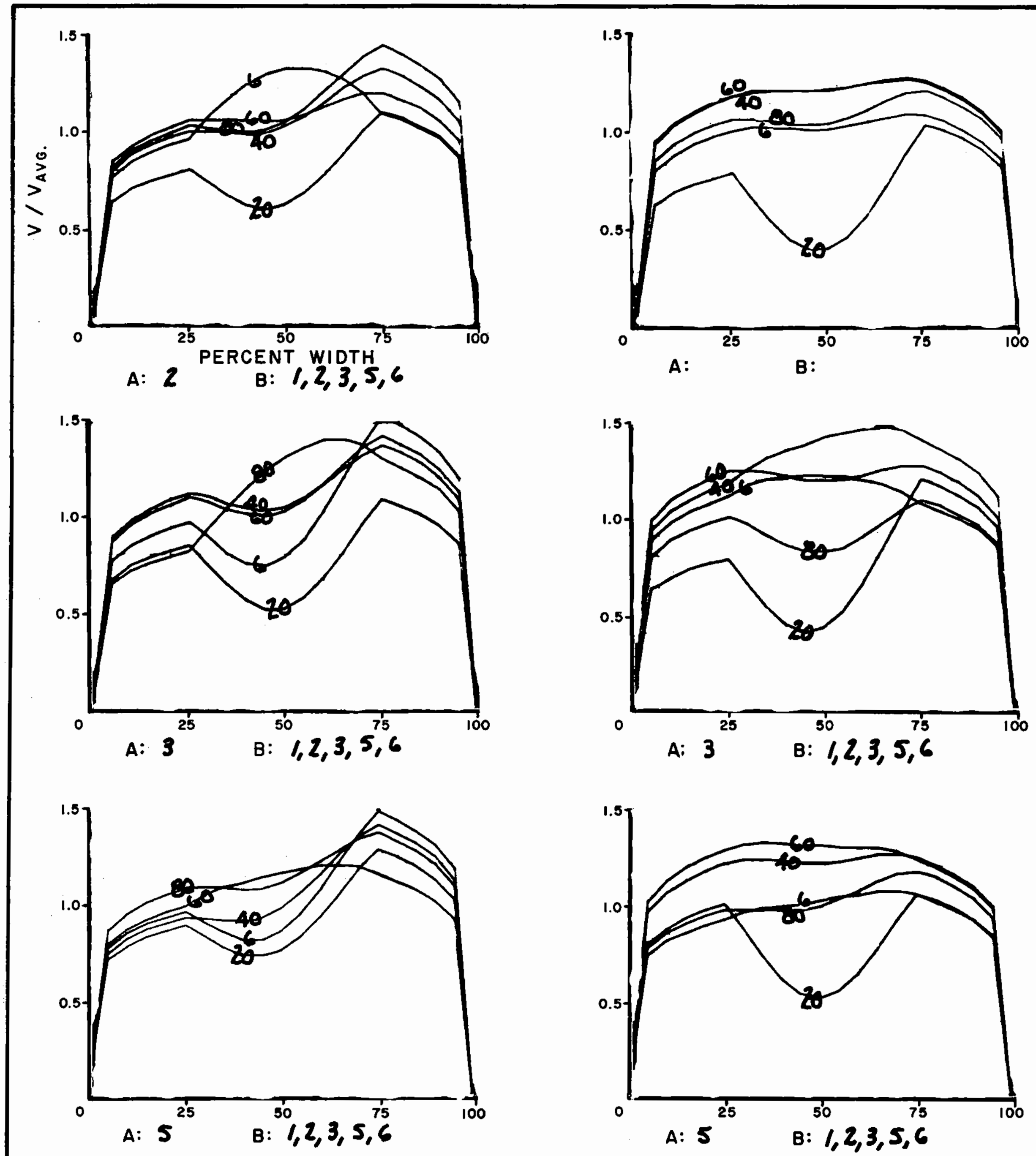
SAN LUIS FOREBAY PUMPING PLANT CANAL TRANSITION STUDIES

1:15 SCALE MODEL

PLAN VIEW OF VELOCITY DISTRIBUTION IN PUMP INTAKE BAYS

Sheet 11 of 15



ANGLED TRANSITION WITH STRAIGHT APPROACH

SYMMETRICAL TRANSITION WITH CURVED APPROACH

NOTES

A: Bay measured
B: Bays operating
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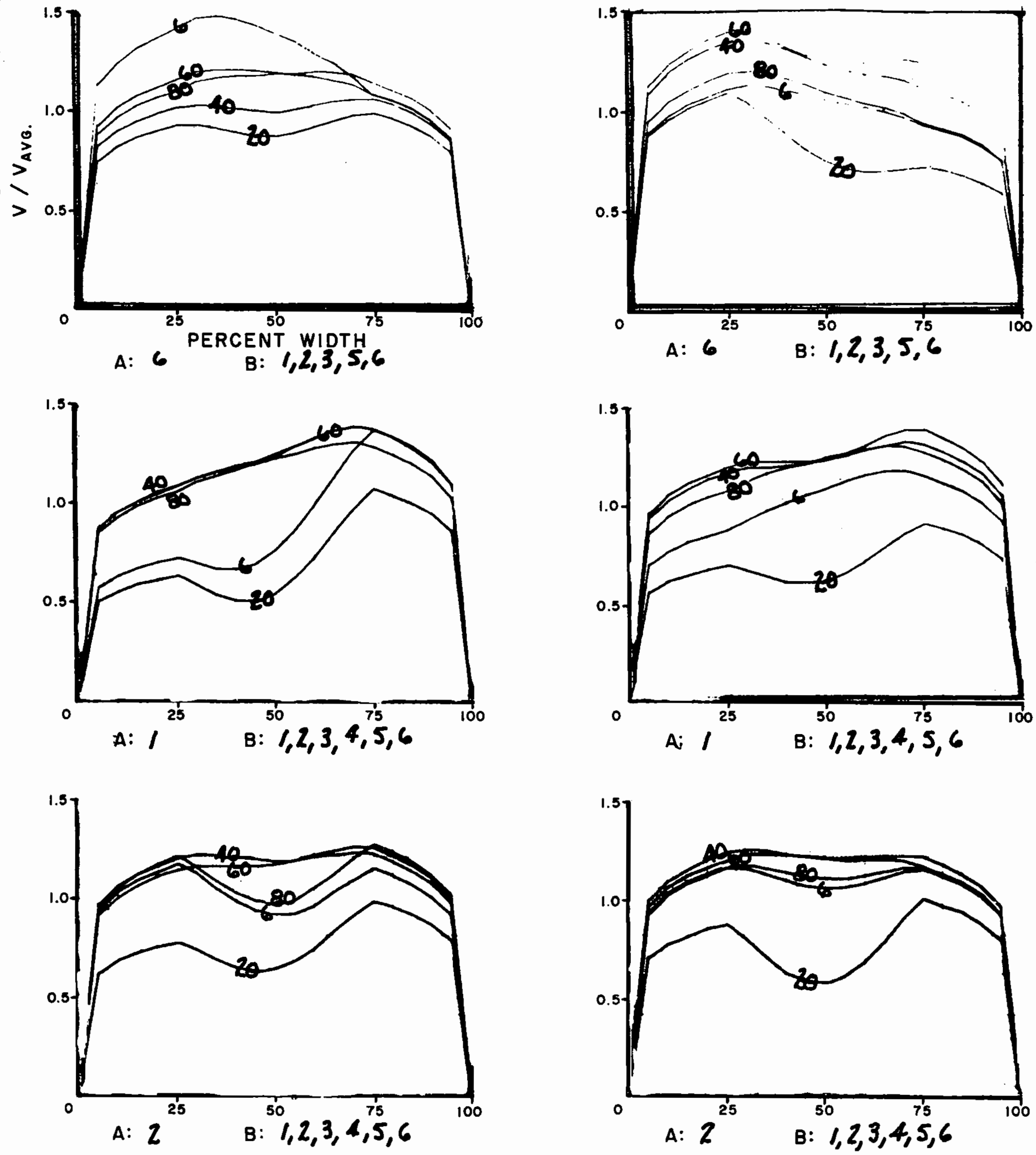
SAN LUIS FOREBAY PUMPING PLANT CANAL TRANSITION STUDIES

1:15 SCALE MODEL

PLAN VIEW OF VELOCITY DISTRIBUTION IN PUMP INTAKE BAYS



ANGLED TRANSITION WITH STRAIGHT APPROACH

SYMMETRICAL TRANSITION WITH CURVED APPROACH

SAN LUIS FOREBAY PUMPING PLANT CANAL TRANSITION STUDIES

1:15 SCALE MODEL

PLAN VIEW OF VELOCITY DISTRIBUTION IN PUMP INTAKE BAYS

NOTES

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B: Bays operating
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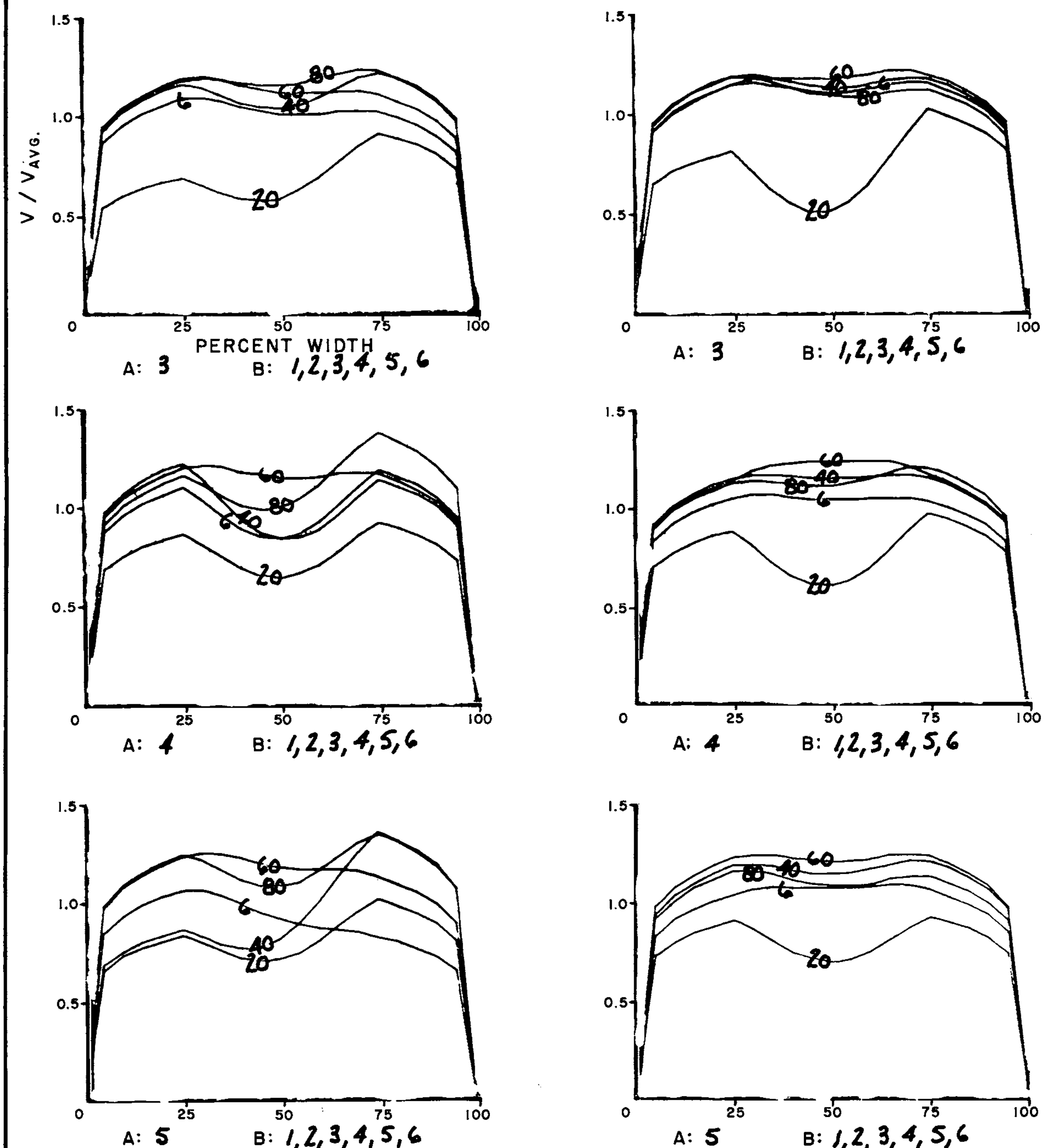

ANGLED TRANSITION WITH STRAIGHT APPROACH

SYMMETRICAL TRANSITION WITH CURVED APPROACH

SAN LUIS FOREBAY PUMPING PLANT
CANAL TRANSITION STUDIES

1:15 SCALE MODEL

PLAN VIEW OF VELOCITY DISTRIBUTION IN PUMP INTAKE BAYS

NOTES

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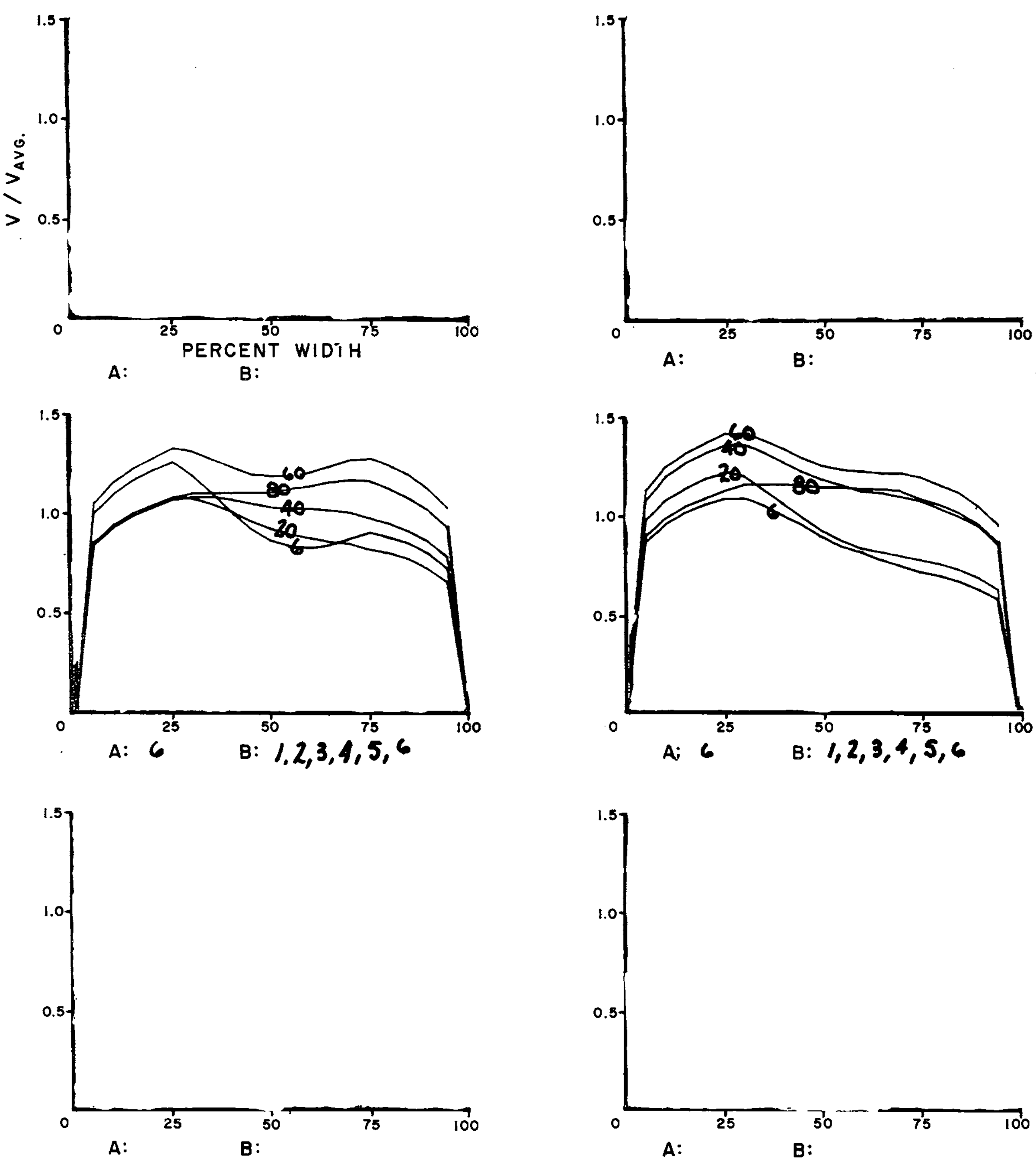

ANGLED TRANSITION WITH STRAIGHT APPROACH

SYMMETRICAL TRANSITION WITH CURVED APPROACH

NOTES

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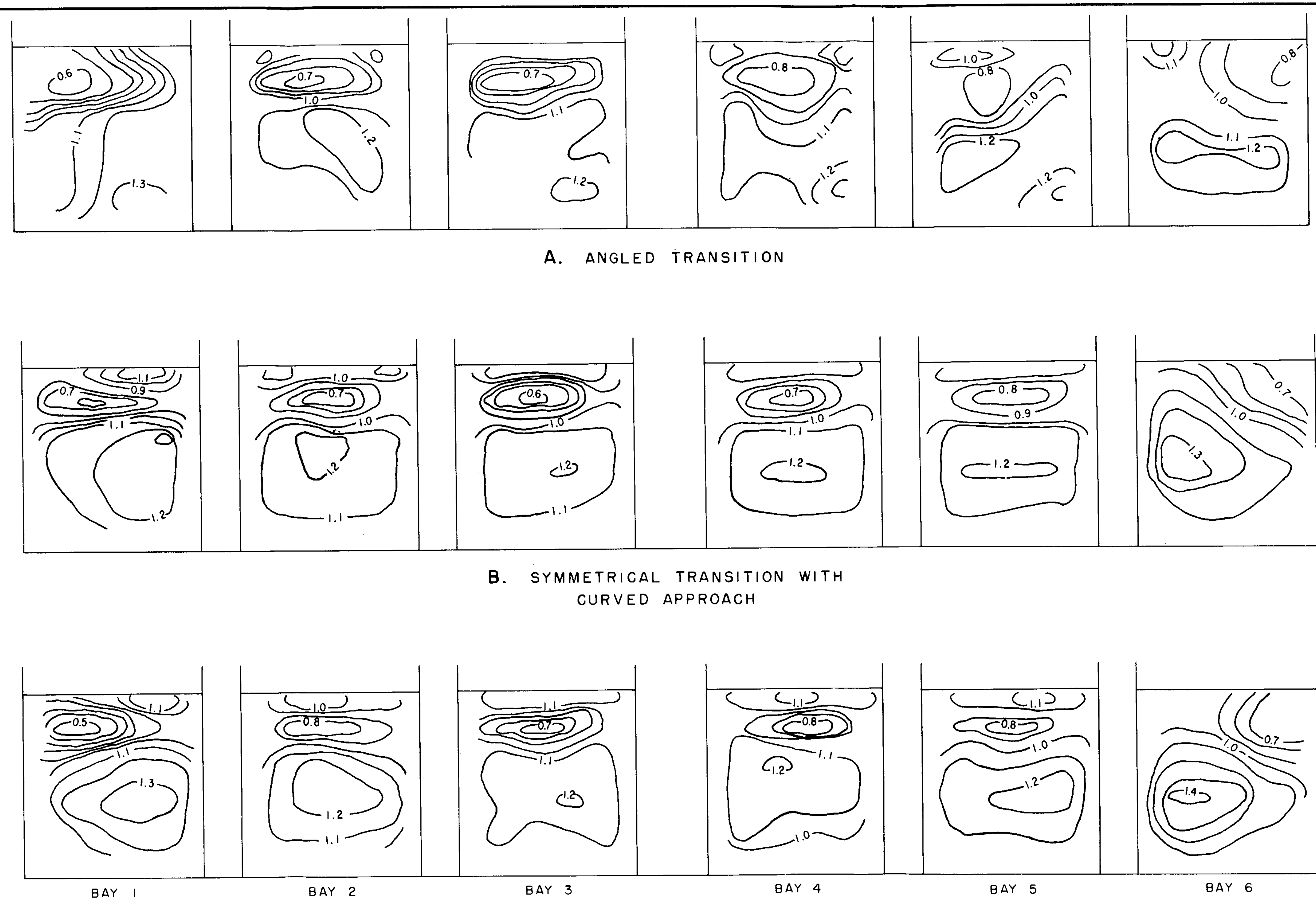
SAN LUIS FOREBAY PUMPING PLANT CANAL TRANSITION STUDIES

1:15 SCALE MODEL

PLAN VIEW OF VELOCITY DISTRIBUTION IN PUMP INTAKE BAYS

Sheet 15 of 15

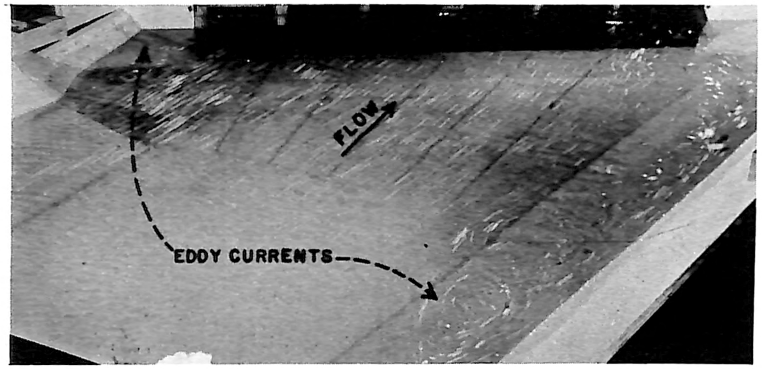


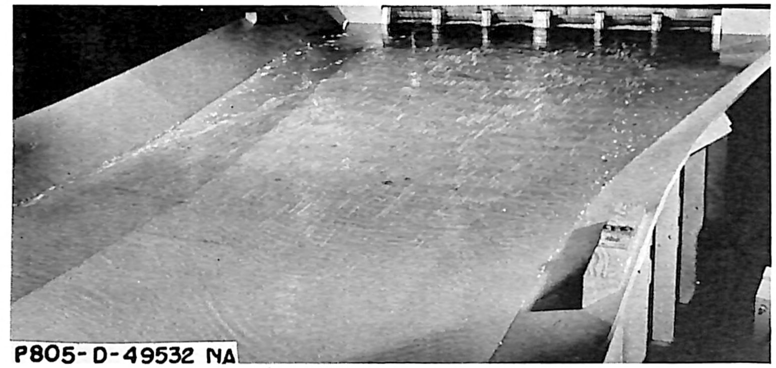
SCALE: 1" = 10'

Contours are labeled with values of dimensionless velocity, $V/V_{avg.}$

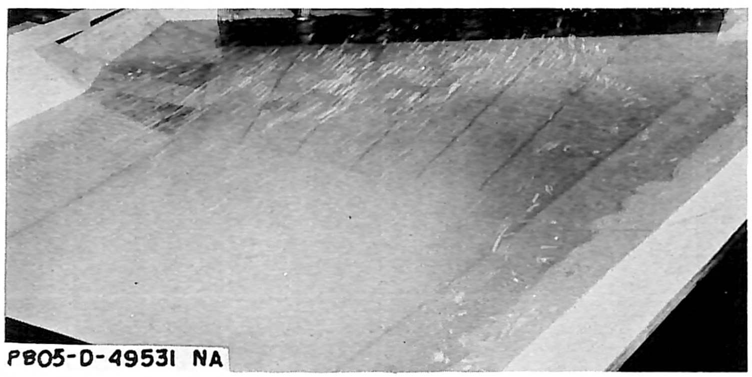
Looking downstream

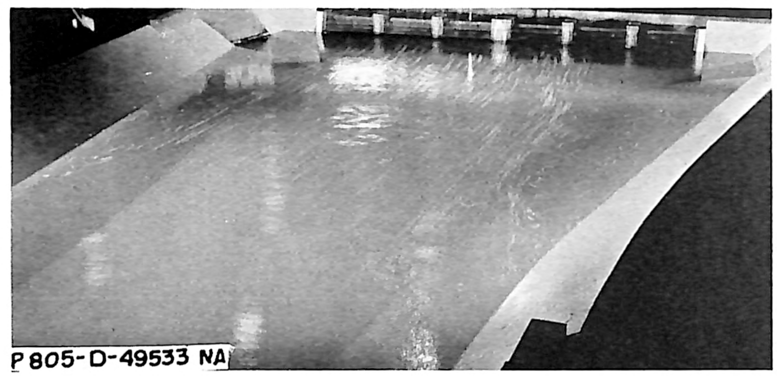
SAN LUIS FOREBAY PUMPING PLANT
CANAL TRANSITION STUDIES
1:15 SCALE MODEL
VELOCITY DISTRIBUTION IN THE INTAKE BAYS
Q = 4200 CFS, 700 CFS EACH UNIT





A. All six units operating





B. Units 1, 2, 3, 4, and 5 operating

ANGLED TRANSITION
STRAIGHT APPROACH

SYMMETRICAL TRANSITION
CURVED APPROACH

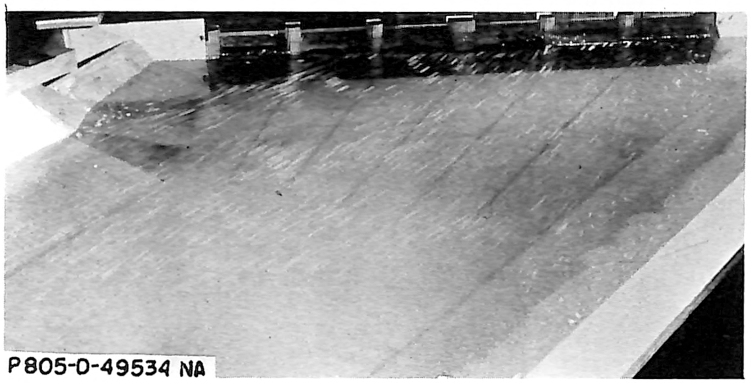
SAN LUIS FOREBAY PUMPING PLANT
CANAL TRANSITION STUDIES

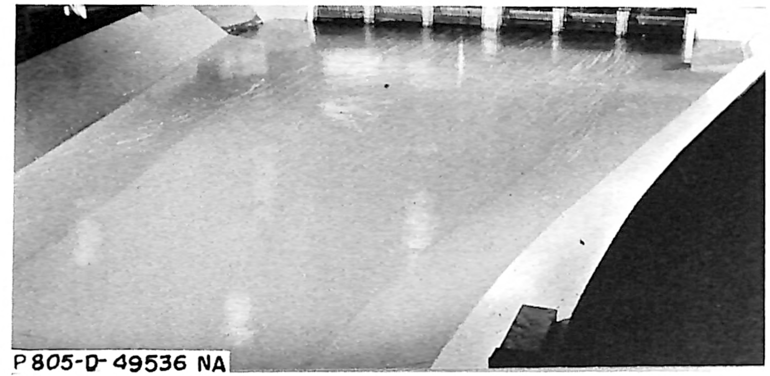
1:15 scale model

Surface flow patterns

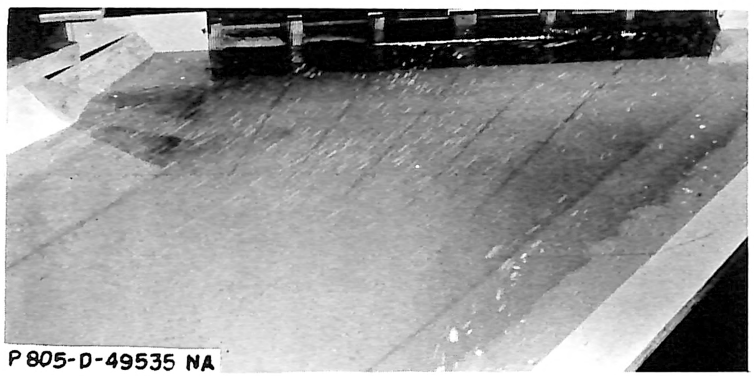
Sheet 1 of 6

Figure 10
Report Hyd-542





C. Units 2, 3, 4, 5, and 6 operating.



D. Units 1, 2, 5, and 6 operating.

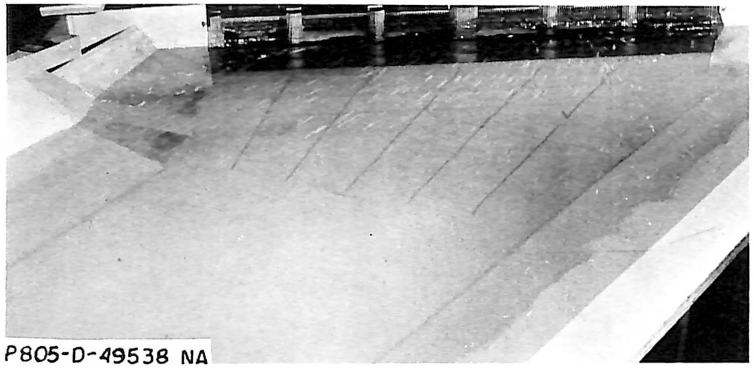
ANGLED TRANSITION
STRAIGHT APPROACH

SYMMETRICAL TRANSITION
CURVED APPROACH

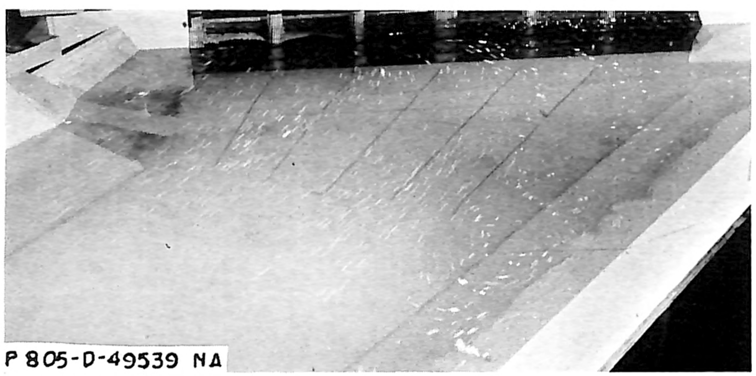
SAN LUIS FOREBAY PUMPING PLANT
CANAL TRANSITION STUDIES

1:15 scale model

Surface flow patterns



E. Units 2, 3, 4, and 5 operating.



F. Units 1, 2, and 3 operating.

ANGLED TRANSITION
STRAIGHT APPROACH

SYMMETRICAL TRANSITION
CURVED APPROACH

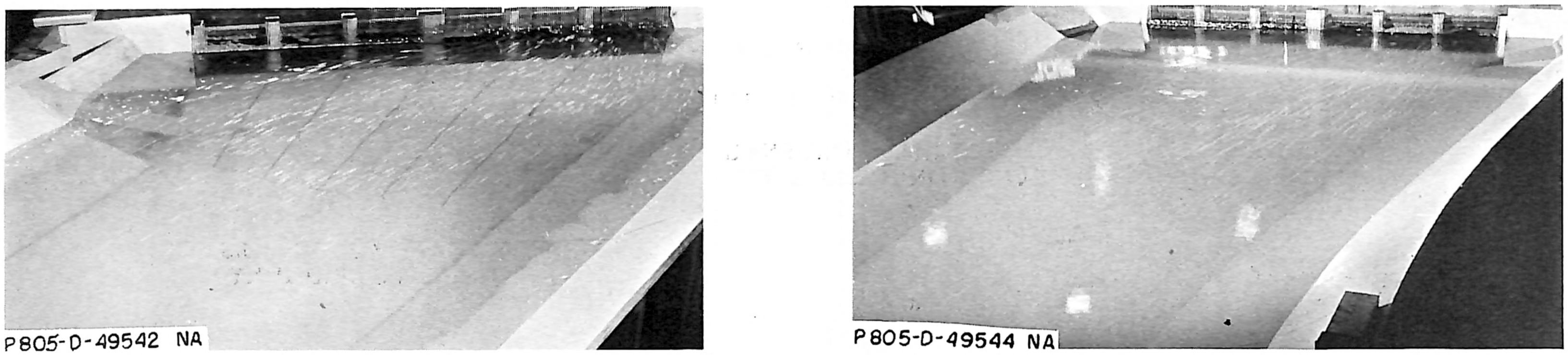
SAN LUIS FOREBAY PUMPING PLANT
CANAL TRANSITION STUDIES

1:15 scale model

Surface flow patterns

Sheet 3 of 6

Figure 10
Report Hyd-542



G. Units 4, 5, and 6 operating.

H. Units 1 and 6 operating.

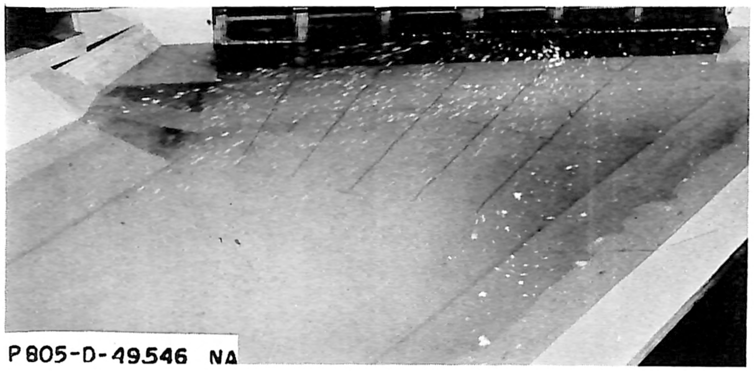
ANGLED TRANSITION
STRAIGHT APPROACH

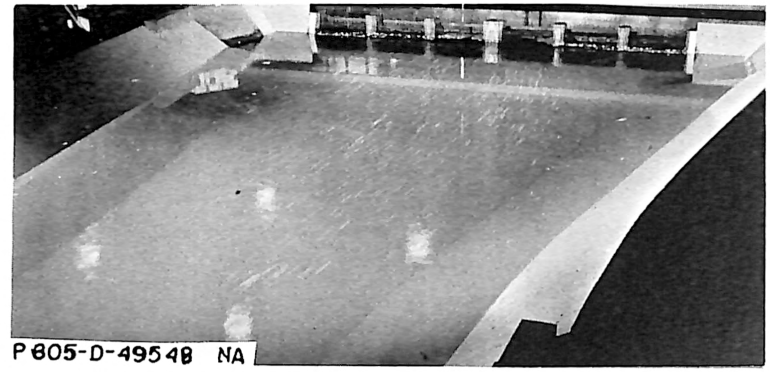
SYMMETRICAL TRANSITION
CURVED APPROACH

SAN LUIS FOREBAY PUMPING PLANT
CANAL TRANSITION STUDIES

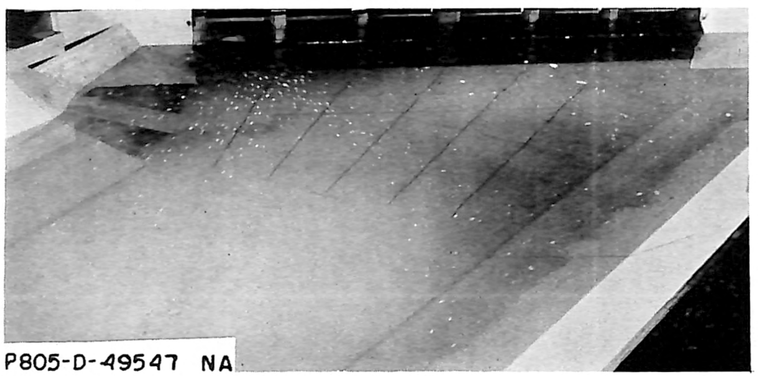
1:15 scale model

Surface flow patterns





I. Units 3 and 4 operating.



J. Unit 1 operating.

ANGLED TRANSITION
STRAIGHT APPROACH

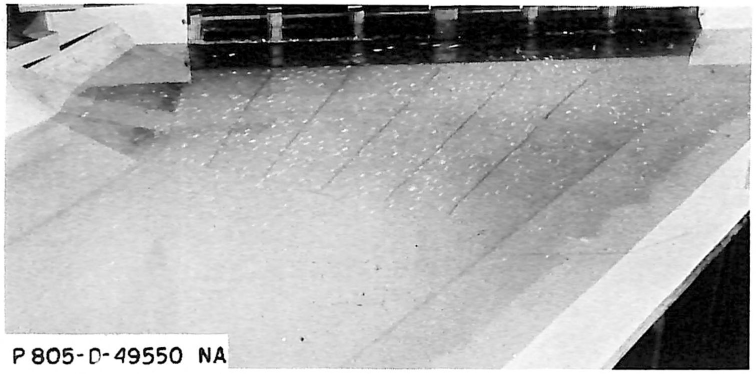
SYMMETRICAL TRANSITION
CURVED APPROACH

SAN LUIS FOREBAY PUMPING PLANT
CANAL TRANSITION STUDIES

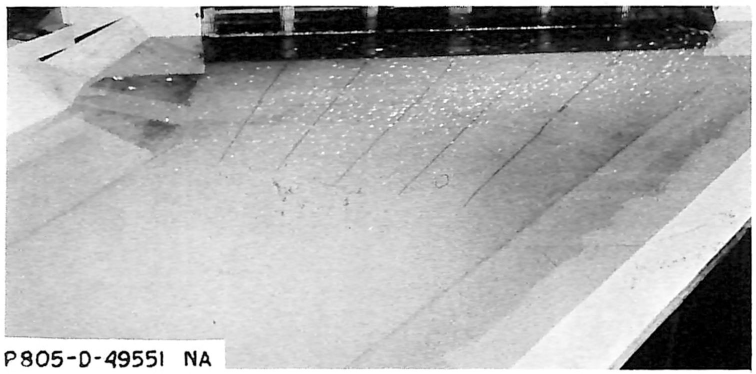
1:15 scale model

Surface flow pattern

Sheet 5 of 6



K. Unit 4 operating.



L. Unit 6 operating.

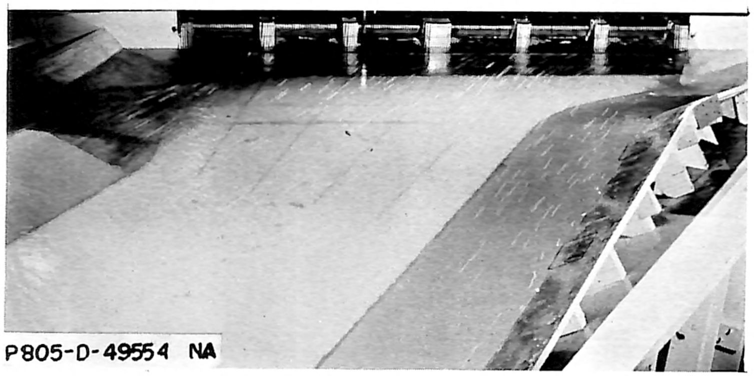
ANGLED TRANSITION
STRAIGHT APPROACH

SYMMETRICAL TRANSITIO
CURVED APPROACH

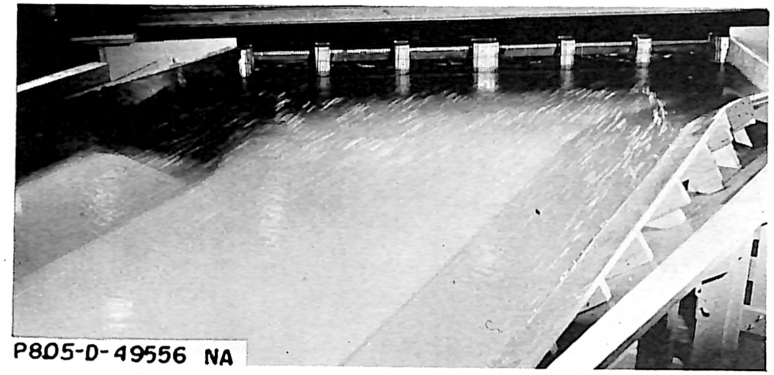
SAN LUIS FOREBAY PUMPING PLANT
CANAL TRANSITION STUDIES

1:15 scale model

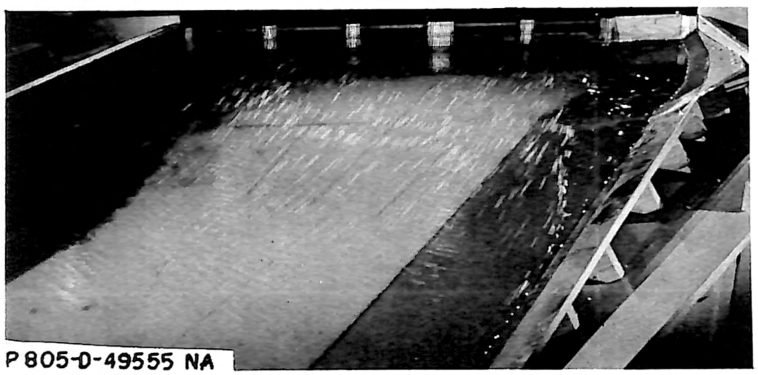
Surface flow pattern



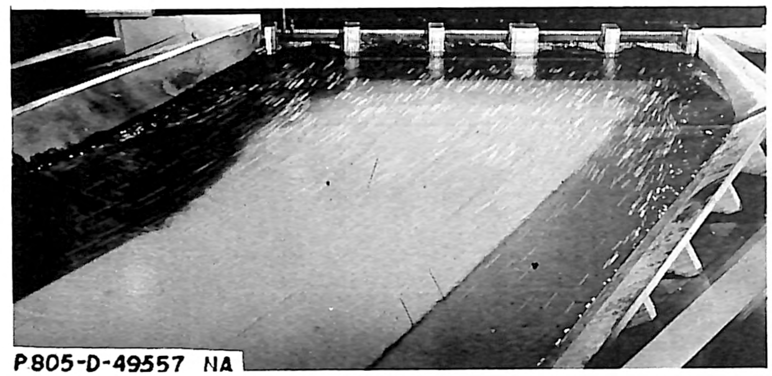
A. First modification. Reduced angle of divergence on right side.



B. Second modification. Vertical walls at pumping plant intakes.



C. Third modification. Simulated increased bottom width. 1:1 slope at pumping plant on right side. Vertical wall on left side.

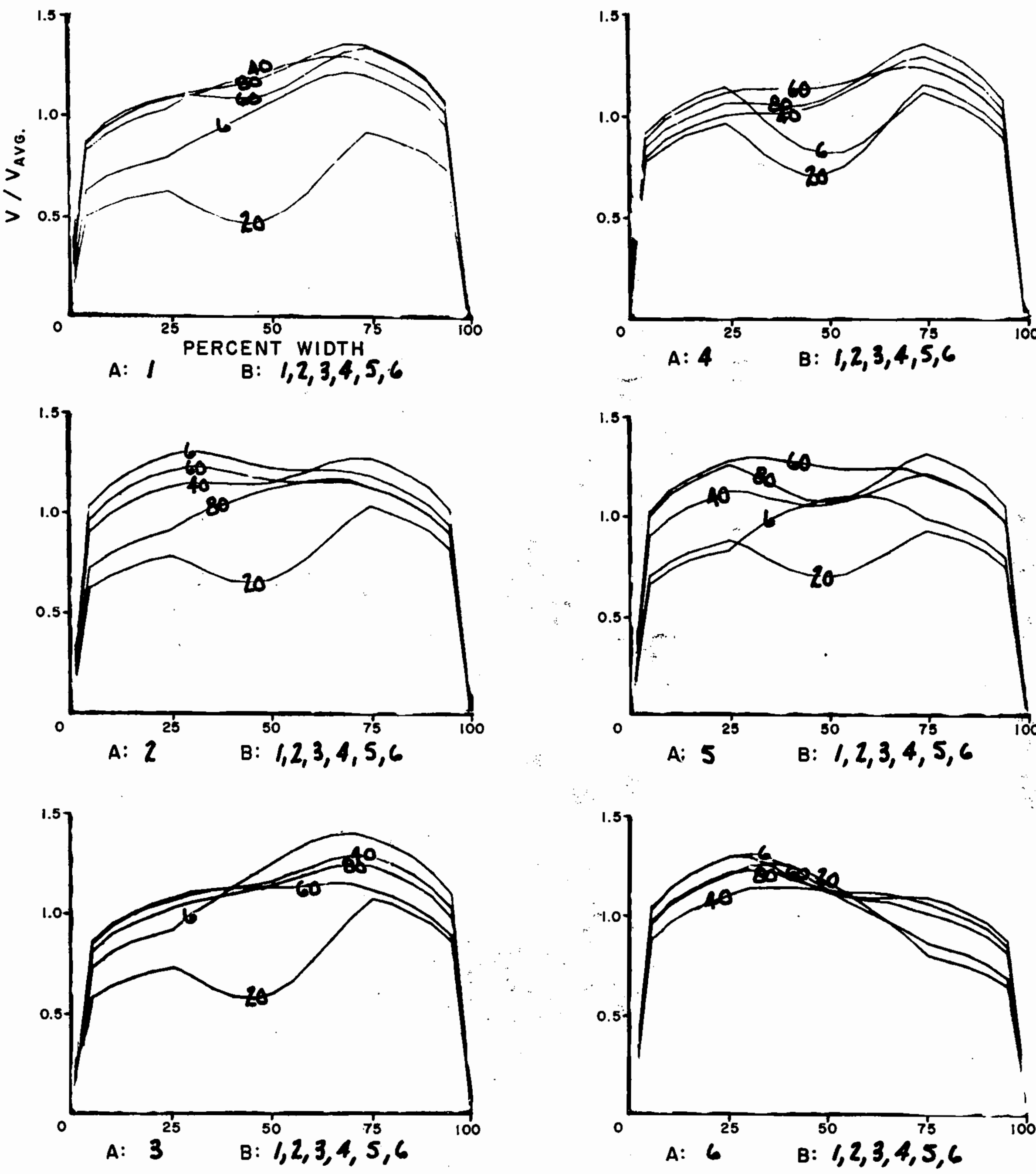


D. Fourth modification. Simulated increased bottom width and vertical walls at intakes.

SAN LUIS FOREBAY PUMPING PLANT
CANAL TRANSITION STUDIES

1:15 scale model

Modifications to angled transition



FIRST MODIFICATION TO ANGLED TRANSITION

NOTES

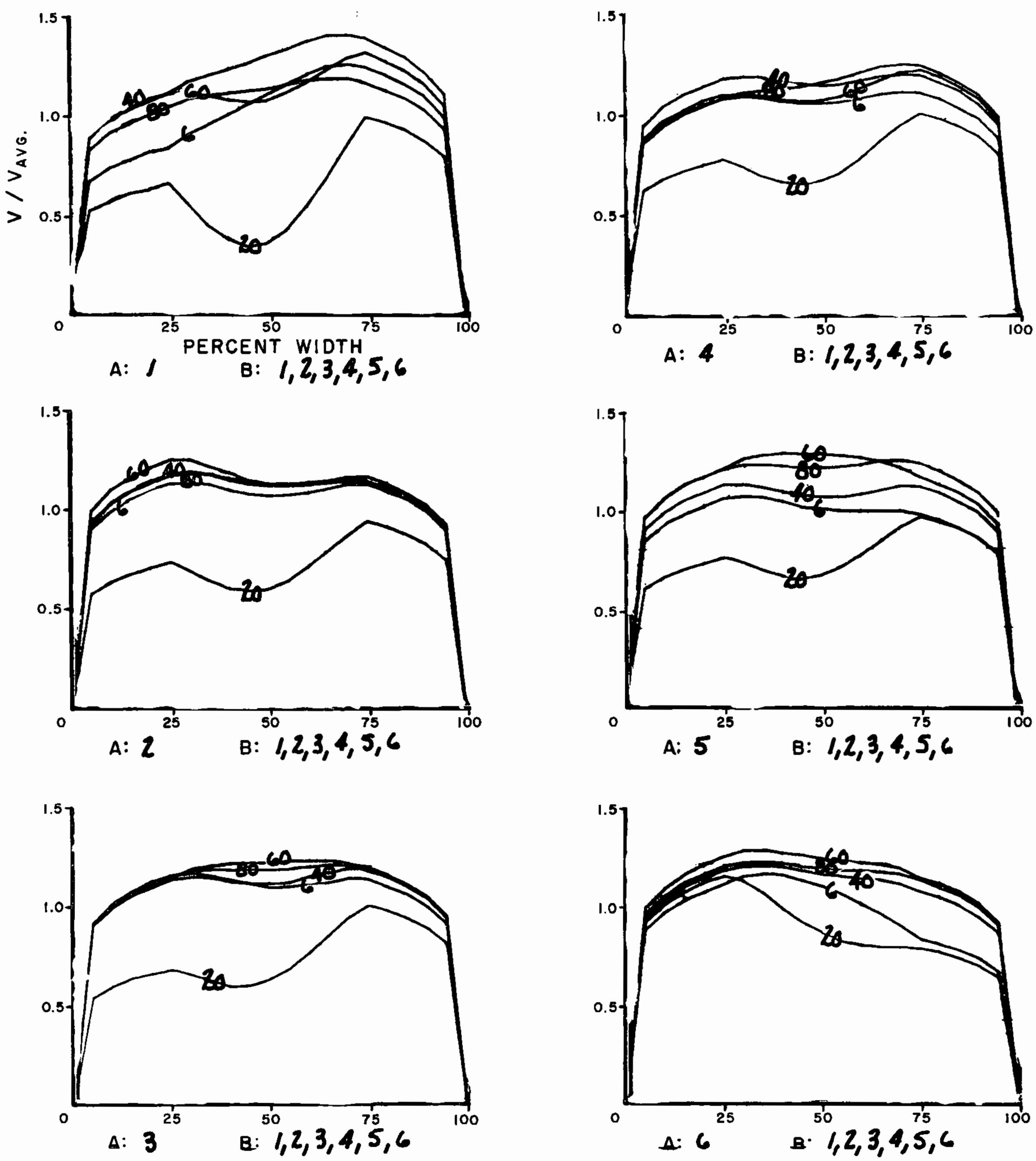
A: Bay measured
B: Bays operating
6, 20, 40, etc.: Percent of total depth measured from surface. Plane of velocity measurement at stop log slots.

SAN LUIS FOREBAY PUMPING PLANT CANAL TRANSITION STUDIES

1:15 SCALE MODEL

PLAN VIEW OF VELOCITY DISTRIBUTION IN PUMP INTAKE BAYS

Sheet 1 of 4



SECOND MODIFICATION TO ANGLED TRANSITION

NOTES

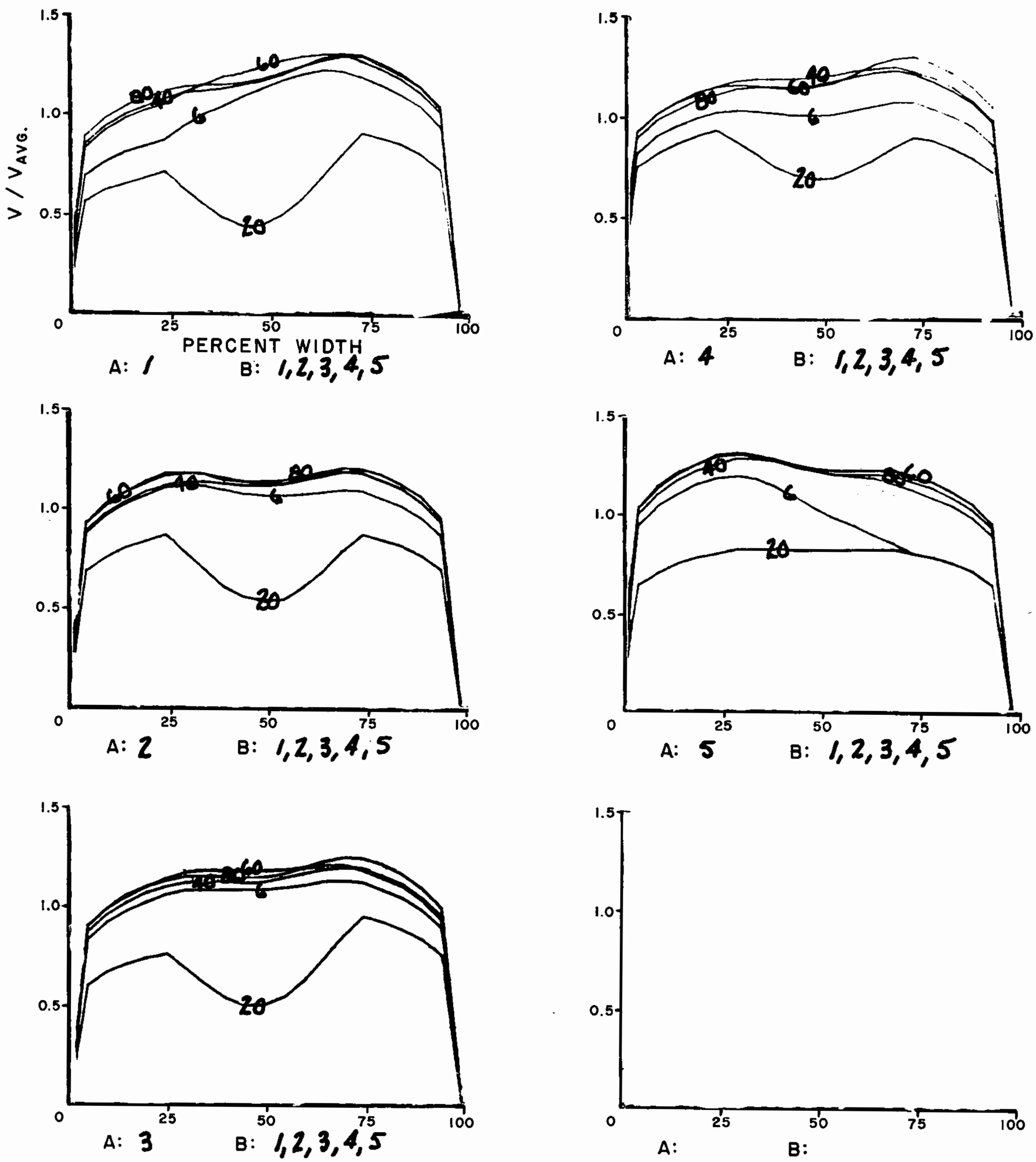
A: Bay measured
B: Bays operating
6, 20, 40, etc.: Percent of total depth measured from surface. Plane of velocity measurement at stop log slots.

SAN LUIS FOREBAY PUMPING PLANT CANAL TRANSITION STUDIES

1:15 SCALE MODEL

PLAN VIEW OF VELOCITY DISTRIBUTION IN PUMP INTAKE BAYS

Sheet 2 of 4



THIRD MODIFICATION TO ANGLED TRANSITION

NOTES

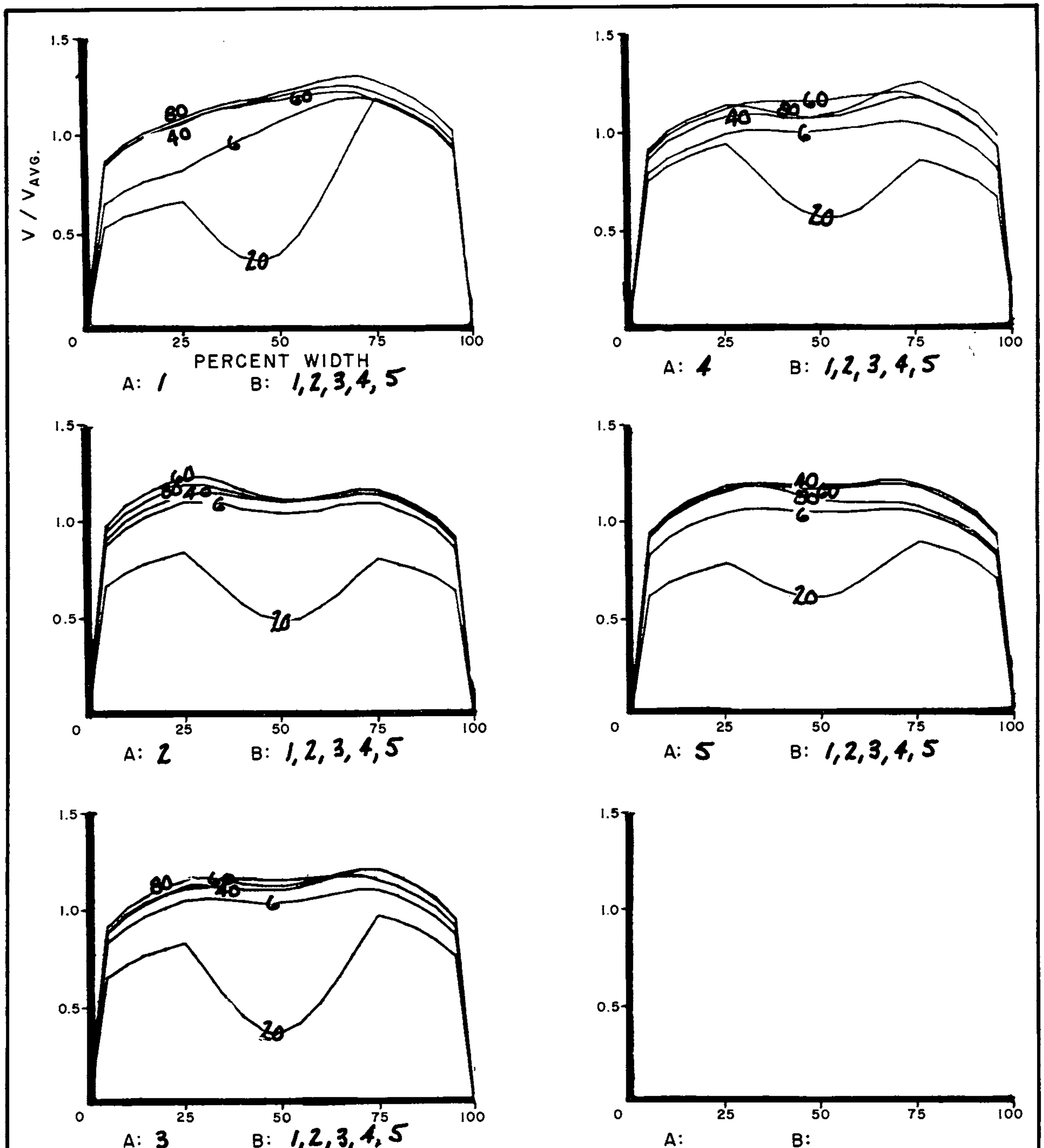
A: Bay measured
B: Bays operating
6, 20, 40, etc.: Percent of total depth measured from surface. Plane of velocity measurement at stop log slots.

SAN LUIS FOREBAY PUMPING PLANT CANAL TRANSITION STUDIES

1:15 SCALE MODEL

PLAN VIEW OF VELOCITY DISTRIBUTION IN PUMP INTAKE BAYS

Sheet 3 of 4



FOURTH MODIFICATION TO ANGLED TRANSITION

NOTES

A: Bay measured
B: Bays operating
6, 20, 40, etc.: Percent of total depth measured from surface. Plane of velocity measurement at stop log slots.

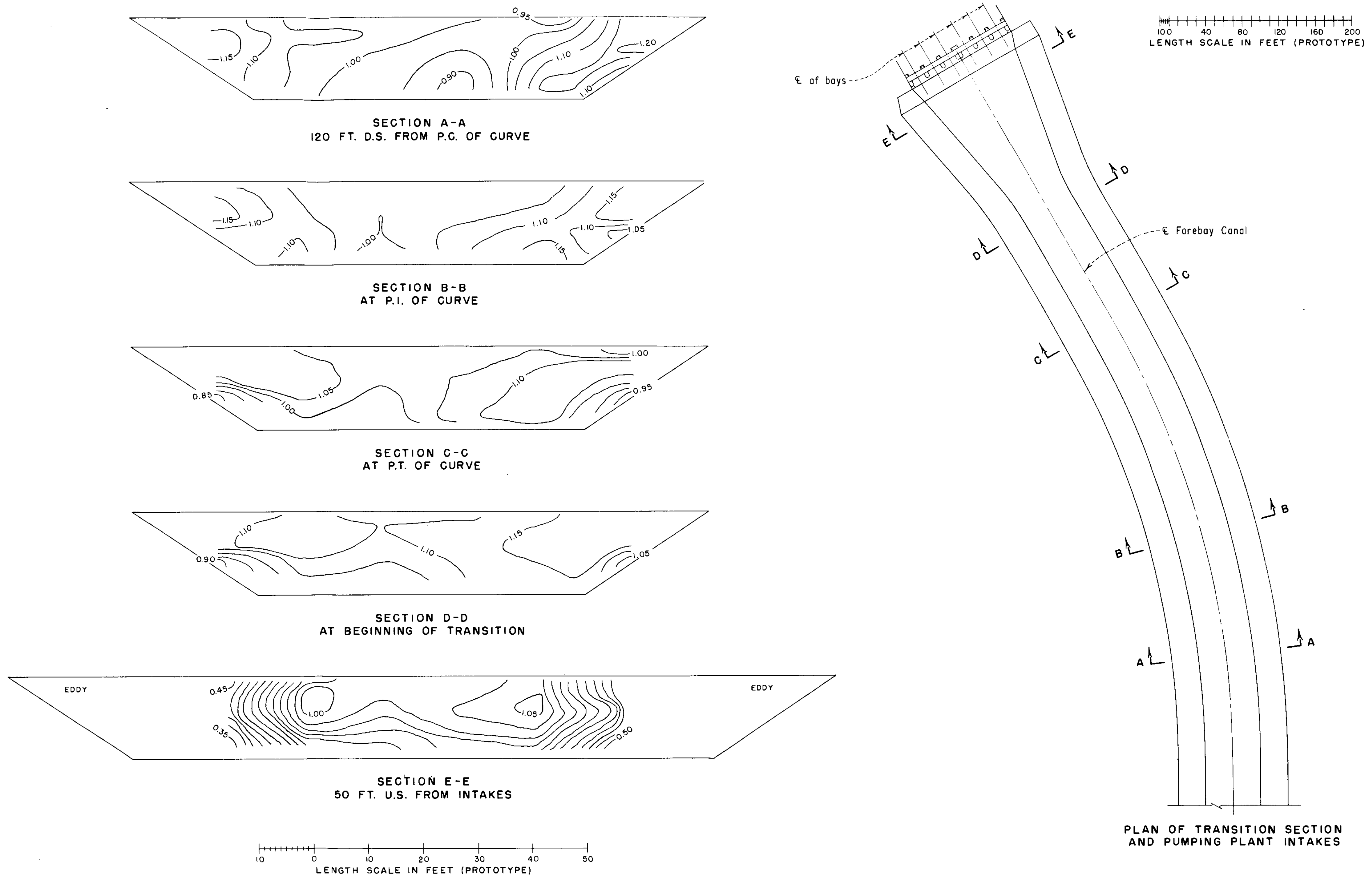
SAN LUIS FOREBAY PUMPING PLANT
CANAL TRANSITION STUDIES

1:15 SCALE MODEL

PLAN VIEW OF VELOCITY DISTRIBUTION
IN PUMP INTAKE BAYS

Sheet 4 of 4

FIGURE 13
REPORT HYD-542



NOTE

Velocities are in the dimensionless form of measured velocity divided by the average velocity, where the average velocity is the discharge (4200 cfs) divided by the entire cross-sectional area of the flow.

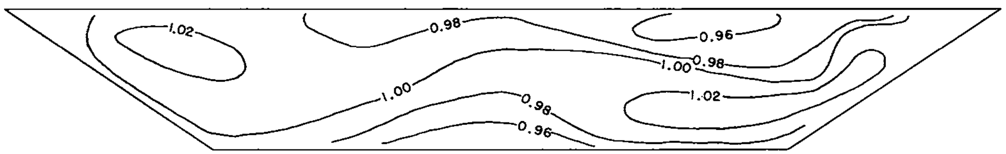
SAN LUIS FOREBAY PUMPING PLANT
CANAL TRANSITION STUDIES

1:15 SCALE MODEL

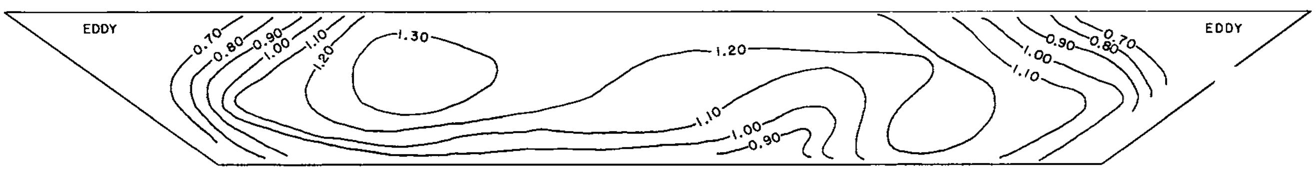
VELOCITY DISTRIBUTION IN SYMMETRICAL
TRANSITION WITH CURVED APPROACH

696

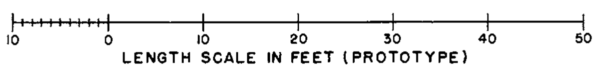
969

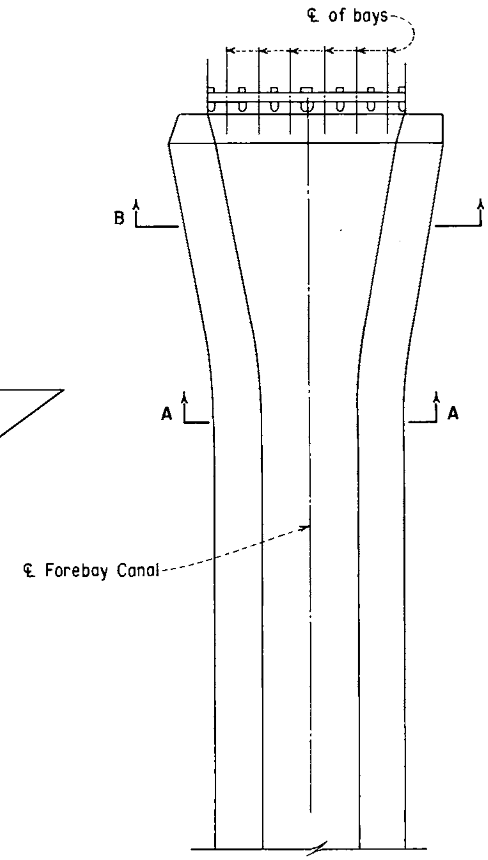


SECTION A-A
AT BEGINNING OF TRANSITION

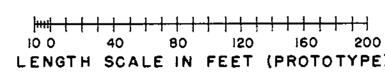


SECTION B-B
70 FT. U.S. FROM INTAKES





PLAN OF TRANSITION SECTION
AND PUMPING PLANT INTAKES



NOTE

Velocities are in the dimensionless form of measured velocity divided by average velocity where the average velocity is the discharge (4200 CFS) divided by the cross sectional area of the flow.

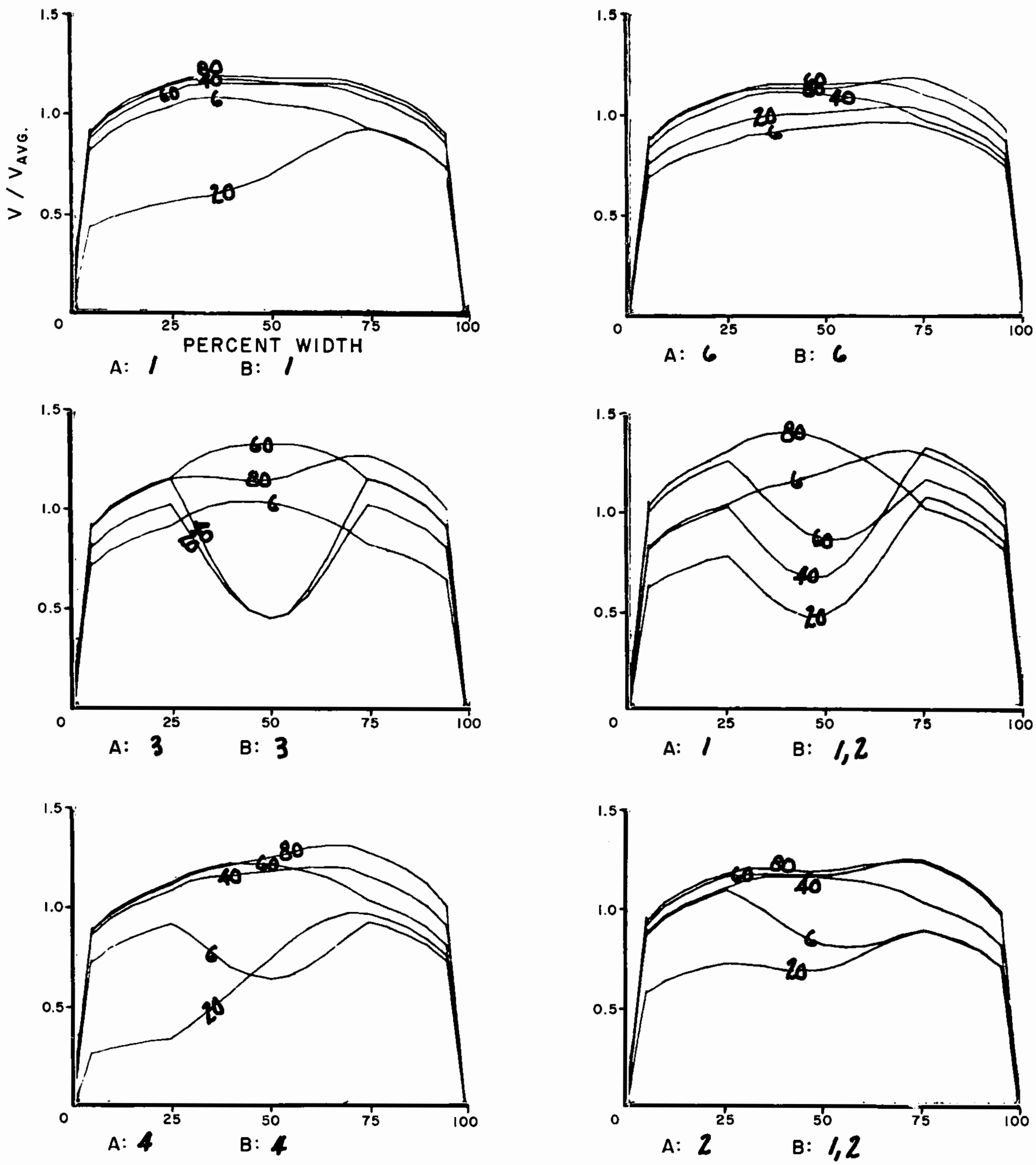
SAN LUIS FOREBAY PUMPING PLANT
CANAL TRANSITION STUDIES

1:15 SCALE MODEL

VELOCITY DISTRIBUTION IN SYMMETRICAL TRANSITION WITH STRAIGHT APPROACH

FIGURE 14
REPORT HYD. 542

Figure 15
Report Hyd-542



SYMMETRICAL TRANSITION WITH STRAIGHT APPROACH

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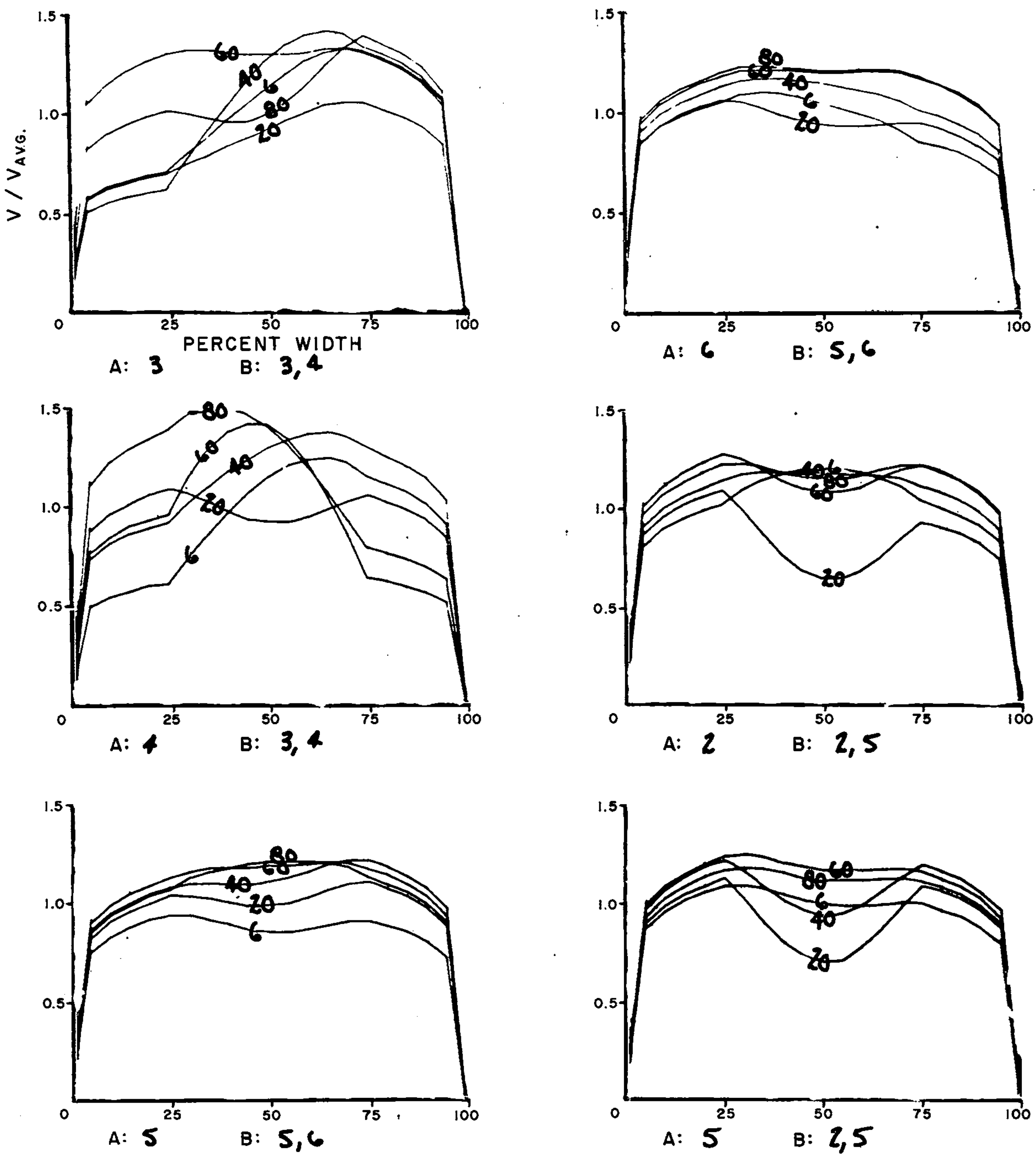
SAN LUIS FOREBAY PUMPING PLANT
CANAL TRANSITION STUDIES

1:15 SCALE MODEL

PLAN VIEW OF VELOCITY DISTRIBUTION
IN PUMP INTAKE BAYS

Sheet 1 of 8



SYMMETRICAL TRANSITION WITH STRAIGHT APPROACH

SAN LUIS FOREBAY PUMPING PLANT
CANAL TRANSITION STUDIES

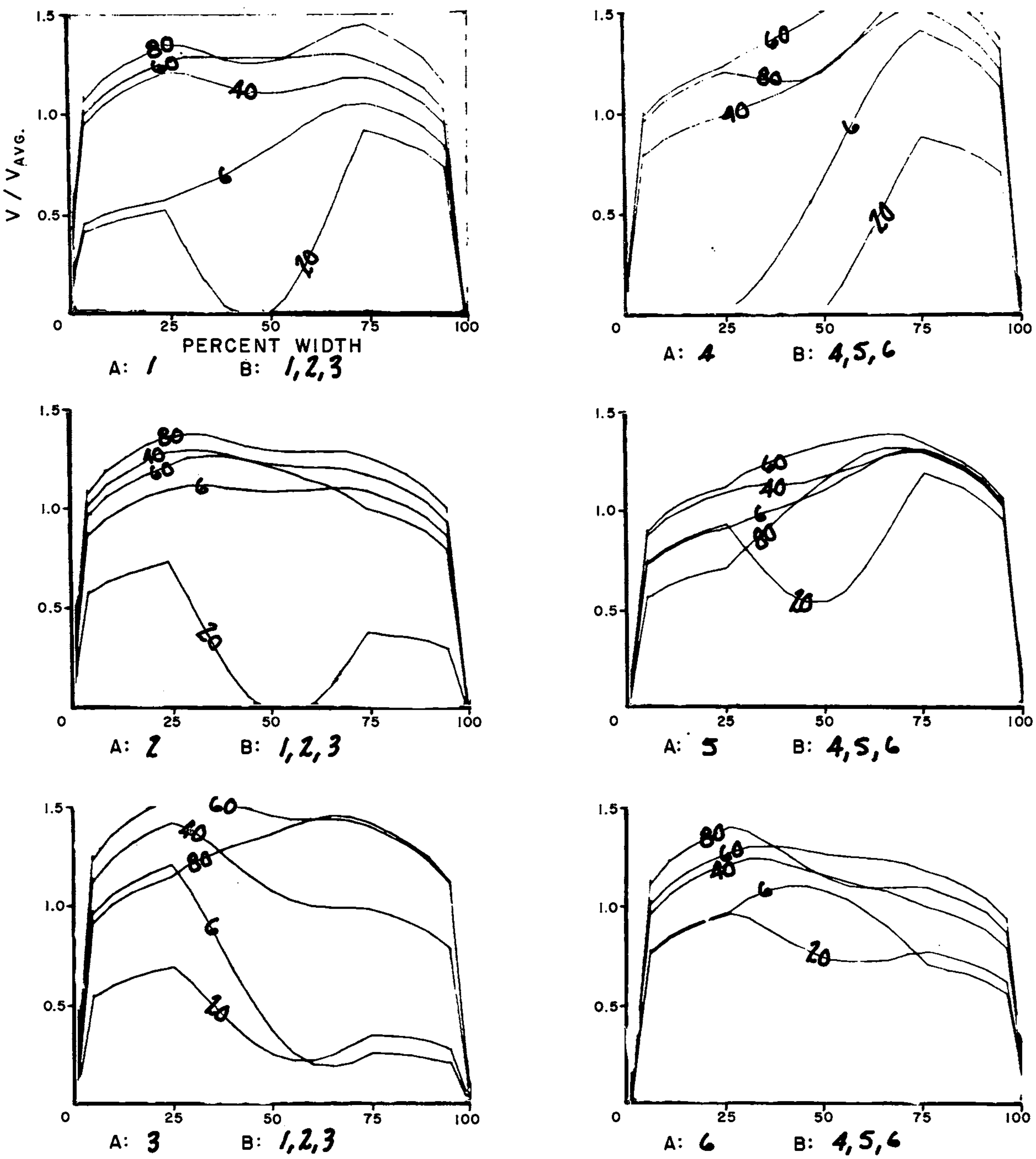
1:15 SCALE MODEL

PLAN VIEW OF VELOCITY DISTRIBUTION
IN PUMP INTAKE BAYS

NOTES

A: Bay measured
B: Bays operating
6, 20, 40, etc.: Percent of total depth measured from surface. Plane of velocity measurement at stop log slots.

Sheet 2 of 8



SYMMETRICAL TRANSITION WITH STRAIGHT APPROACH

NOTES

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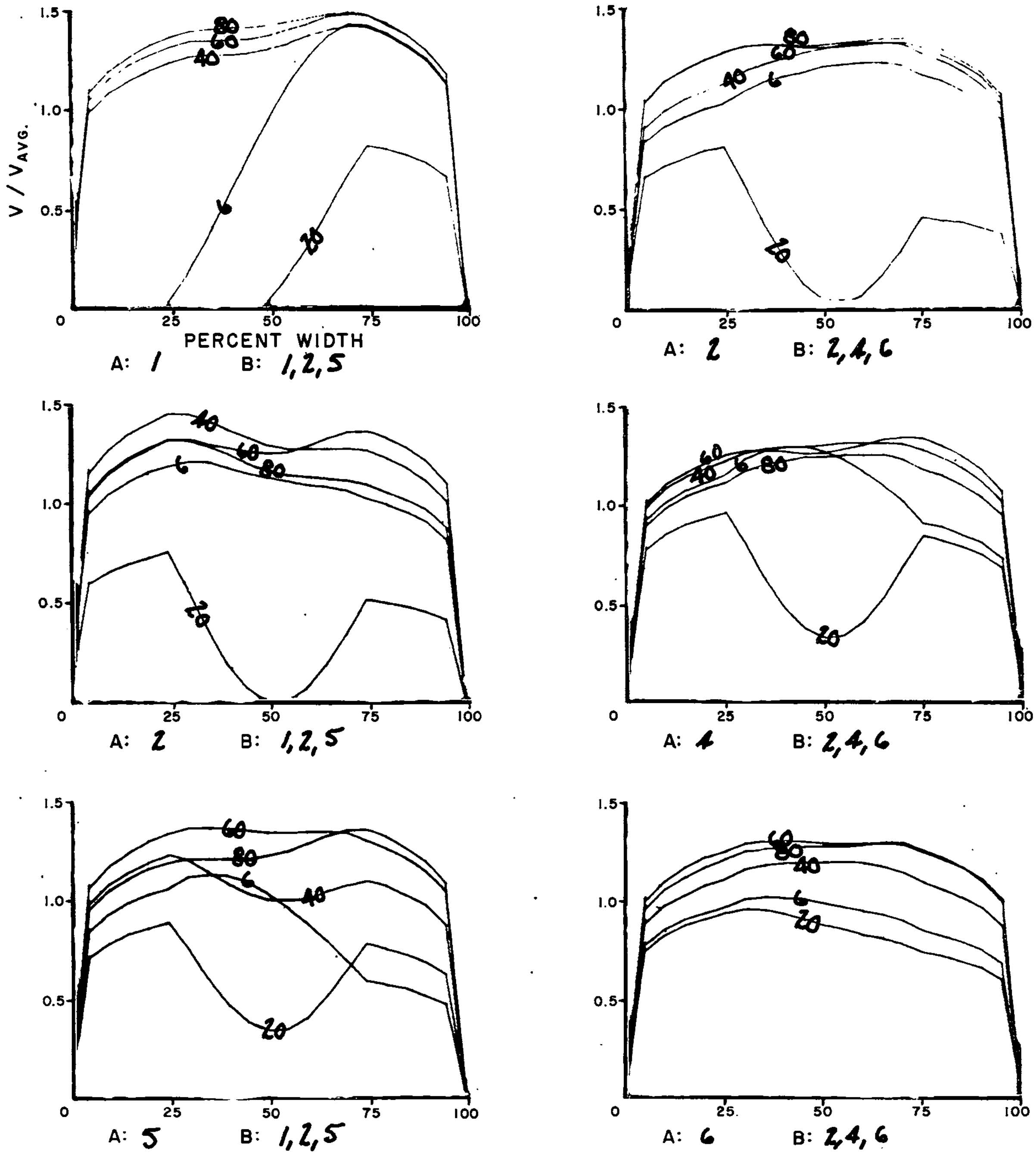
B: Bays operating
6, 20, 40, etc.: Percent of total depth measured from surface. Plane of velocity measurement at stop log slots.

SAN LUIS FOREBAY PUMPING PLANT CANAL TRANSITION STUDIES

1:15 SCALE MODEL

PLAN VIEW OF VELOCITY DISTRIBUTION IN PUMP INTAKE BAYS

Sheet 3 of 8



SYMMETRICAL TRANSITION WITH STRAIGHT APPROACH

SAN LUIS FOREBAY PUMPING PLANT
CANAL TRANSITION STUDIES

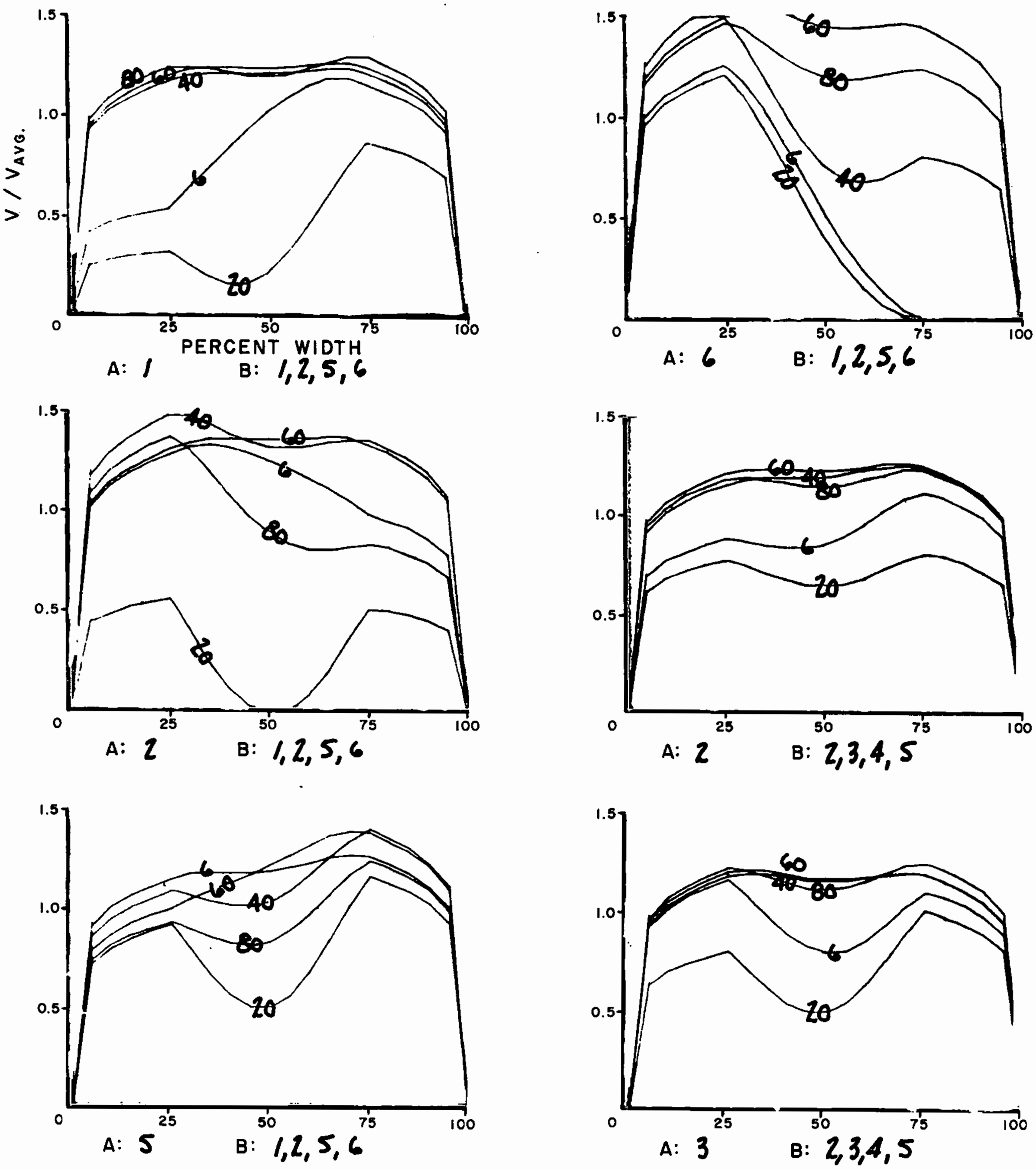
1:15 SCALE MODEL

PLAN VIEW OF VELOCITY DISTRIBUTION
IN PUMP INTAKE BAYS

NOTES

A: Bay measured
B: Bays operating
6, 20, 40, etc.: Percent of total depth measured from surface. Plane of velocity measurement at stop log slots.

Sheet 4 of 8



SYMMETRICAL TRANSITION WITH STRAIGHT APPROACH

SAN LUIS FOREBAY PUMPING PLANT
CANAL TRANSITION STUDIES

1:15 SCALE MODEL

PLAN VIEW OF VELOCITY DISTRIBUTION
IN PUMP INTAKE BAYS

NOTES

A: Bay measured
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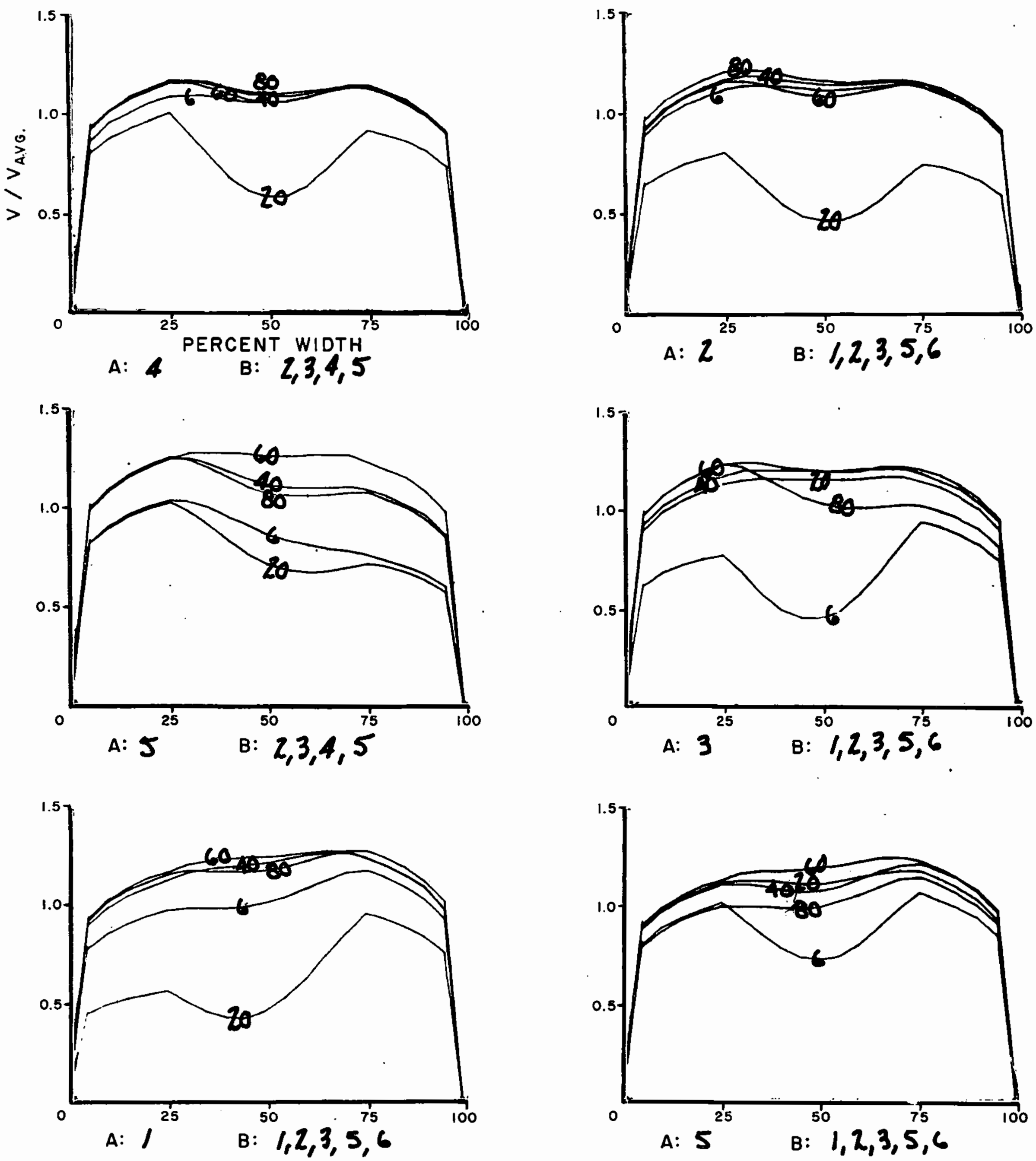

SYMMETRICAL TRANSITION WITH STRAIGHT APPROACH

NOTES

A: Bay measured
B: Bays operating
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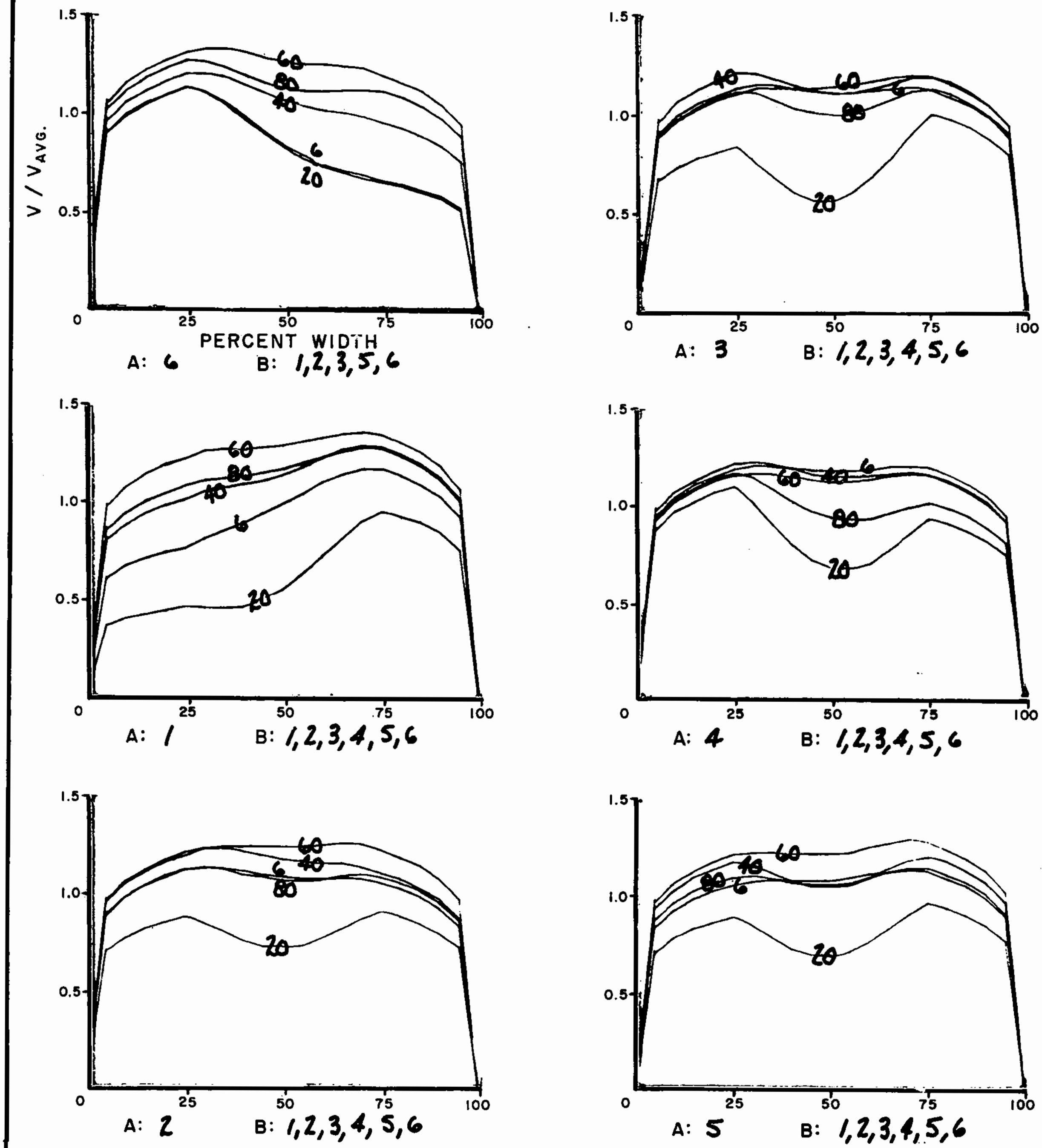
SAN LUIS FOREBAY PUMPING PLANT CANAL TRANSITION STUDIES

1:15 SCALE MODEL

PLAN VIEW OF VELOCITY DISTRIBUTION IN PUMP INTAKE BAYS

Figure 15
Report Hyd-542



SYMMETRICAL TRANSITION WITH STRAIGHT APPROACH

NOTES

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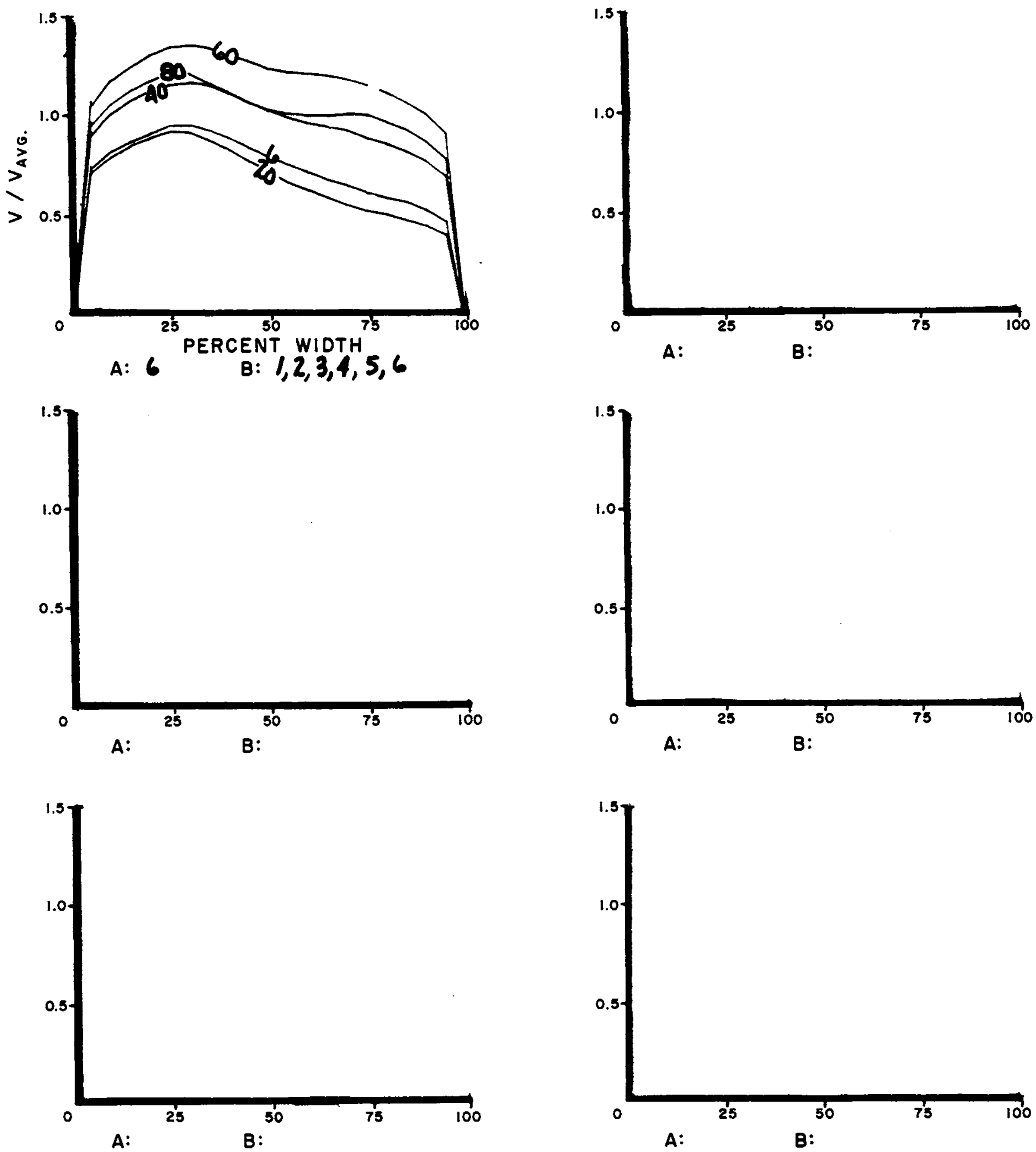
B: Bays operating
6, 20, 40, etc.: Percent of total depth measured from surface. Plane of velocity measurement at stop log slots.

SAN LUIS FOREBAY PUMPING PLANT CANAL TRANSITION STUDIES

1:15 SCALE MODEL

PLAN VIEW OF VELOCITY DISTRIBUTION IN PUMP INTAKE BAYS

Sheet 7 of 8



SYMMETRICAL TRANSITION WITH STRAIGHT APPROACH

SAN LUIS FOREBAY PUMPING PLANT
CANAL TRANSITION STUDIES

1:15 SCALE MODEL

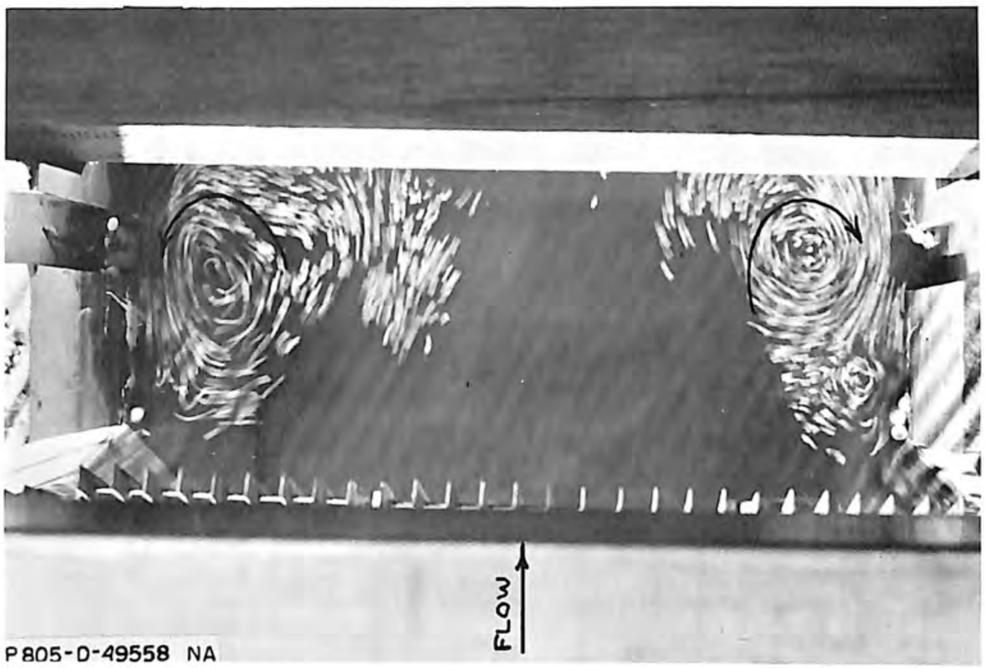
PLAN VIEW OF VELOCITY DISTRIBUTION IN PUMP INTAKE BAYS

NOTES

A: Bay measured
B: Bays operating
6, 20, 40, etc.: Percent of total depth measured from surface.
Plane of velocity measurement at stop log slots.

Sheet 8 of 8

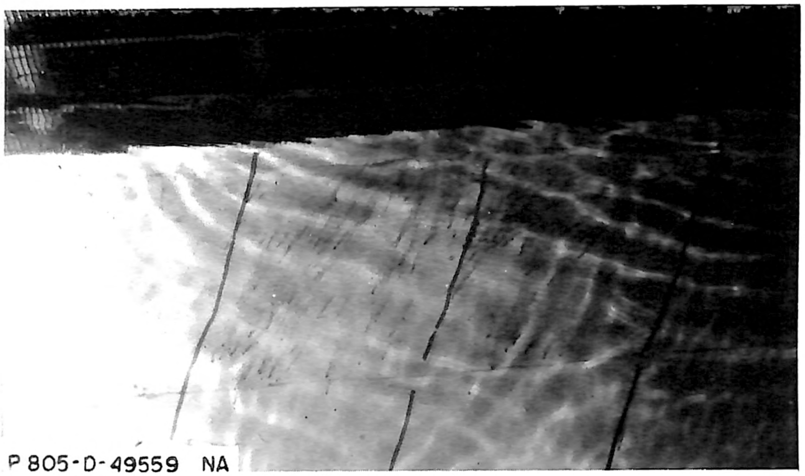
Figure 16
Report Hyd-542



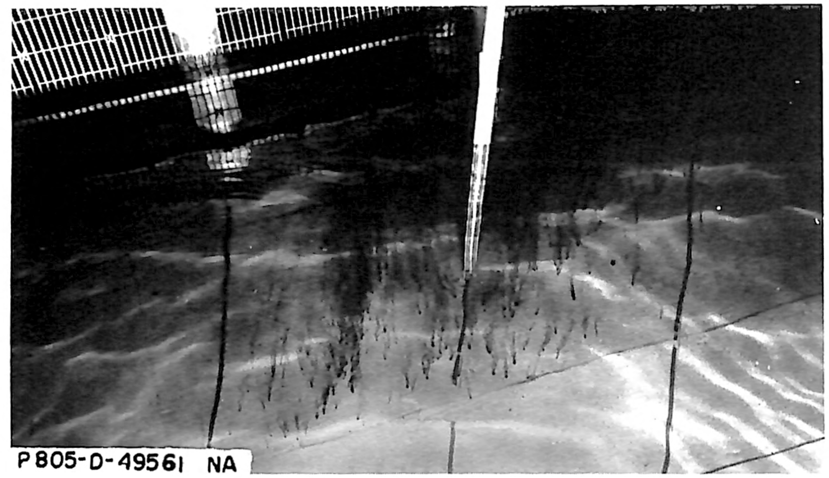
SAN LUIS FOREBAY PUMPING PLANT
CANAL TRANSITION STUDIES

1:15 scale model

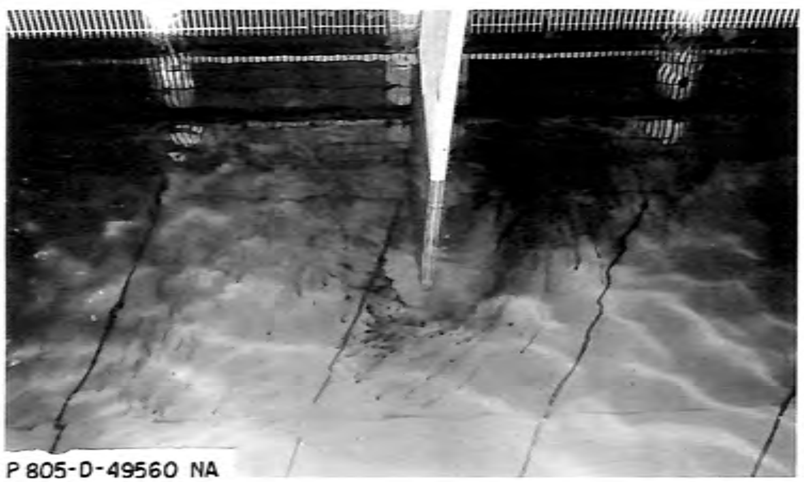
Eddy currents in vicinity of stoplog slots - total discharge = 4,200 cubic feet per second, Bay 3 shown, symmetrical transition with straight approach.



A. Flow pattern without pier extension.
Q = 4, 200 cubic feet per second.



B. Flow pattern with 12-foot extension parallel to flow lines.



C. Flow pattern with 12-foot extension perpendicular to line of intakes.

SAN LUIS FOREBAY PUMPING PLANT
CANAL TRANSITION STUDIES

1:15 scale model

Effect of center pier extension on flow pattern in intake Bays 3 and 4 - angled transition

APPENDIX

Numerical Analysis and Electronic Digital Computer Program to Compute and Analyze Velocities from Data Obtained with a Miniature Propeller Meter

This computer program was developed to analyze data obtained during the course of the model study of pumping plant intake canal transitions for the San Luis Forebay Canal, Central Valley Project, California. With slight revision, the program is generally applicable to other problems of similar nature.

The program is coded in the FORTRAN II (FORmula TRANslation) language, and operates on data read directly from the model instrumentation. The program can be used on most digital computing equipment. No special operating procedures are required. The first phase of the program was written to compute prototype velocities from data obtained by an electronic counting device connected to a miniature propeller velocity meter. The program was later extended to include a numerical analysis of the resulting prototype velocities, with punched card output so that the large volume of results could be plotted on an X-Y plotting machine.

The velocity computation portion of the program reads the station, section, percent depth, and number of counts recorded in 10 seconds as input data (flow diagram, program listing, definition of variables, and sample input data sheet are included at the end of this appendix), and solves the equations of the calibration curves for the model velocity. In addition each set of data is identified by the date, the orientation of the velocity meter (normal or reverse), and the velocity scale ratio. The model velocity is multiplied by the velocity scale ratio (square root of the length ratio) to obtain the prototype velocity. The prototype velocities are stored in a two-dimensional array for additional processing.

Numerical methods are utilized in the remaining portion of the program to fit an equation to the data points at a given depth, use this equation to interpolate for additional points, then solve for areas and volumes to obtain the rate of discharge based on the measured velocity distribution. The computed discharge is divided by the area to obtain the average velocity. Each point velocity is divided by the average velocity to obtain velocities in dimensionless form, which are printed and punched as results. A test problem using a least squares fit to the data points indicated a large variation from some points because of the asymmetrical shape of the profile. It was therefore decided to use a polynomial fit with the computed curve passing through all data points.

The polynomial equation is fitted to five horizontal data points at a given percent of depth in the intake bay. Data were recorded at the three one-quarter vertical sections and zero velocities at the boundaries are included to give five points. Finite differences are employed to find the polynomial equations of a curve which passes through all the points. A table is constructed using forward difference notation where the V's are recorded (or, at the boundaries, set to zero) point velocities in a single bay at a given depth from left to right looking downstream. In the following notation x is a measure of the horizontal distance, with a magnitude of 1.0 between each quarter section, i.e., x = 0 at the left boundary, 1.0 at the one-quarter section, 2.0 at the centerline, 3.0 at the three-quarter section, and 4.0 at the right boundary.

x	f(x)		2	3	4
0	V_0				
		ΔV_0			
1	V_1		$\Delta^2 V_0$		
		ΔV_1		$\Delta^3 V_0$	
2	V_2		$\Delta^2 V_1$		$\Delta^4 V_0$
		ΔV_2		$\Delta^3 V_1$	
3	V_3		$\Delta^2 V_2$		
		ΔV_3			
4	V_4				

$\Delta V_0 = V_1 - V_0$ $\quad \Delta^2 V_0 = \Delta V_1 - \Delta V_0$ $\quad \Delta^3 V_0 = \Delta^2 V_1 - \Delta^2 V_0$ $\quad \Delta^4 V_0 = \Delta^3 V_1 - \Delta^3 V_0$

$\Delta V_1 = V_2 - V_1$ $\quad \Delta^2 V_1 = \Delta V_2 - \Delta V_1$ $\quad \Delta^3 V_1 = \Delta^2 V_2 - \Delta^2 V_1$

$\Delta V_2 = V_3 - V_2$ $\quad \Delta^2 V_2 = \Delta V_3 - \Delta V_2$

$\Delta V_3 = V_4 - V_3$

The five data points result in a fourth-degree polynomial equation of the form $V = a+bx+cx^2+dx^3+ex^4$

Solution for the coefficients a, b, c, d, and e using the differences shown above results in the equation

$$V = V_0 + x\Delta V_0 + \frac{x(x-1)}{2!}\Delta^2 V_0 + \frac{x(x-1)(x-2)}{3!}\Delta^3 V_0 + \frac{x(x-1)(x-2)(x-3)}{4!}\Delta^4 V_0$$

as derived by Newton.

By solving this equation for intermediate values of x, additional points can be determined. The computer program solves the equation in increments of x = 0.2, resulting in a total of 21 velocity values, including the 5 original data points. The process is repeated for other depths, finally producing a horizontal velocity profile for 6, 20, 40, 60, and 80 percent depth (6 is replaced by zero in the output listing as a matter of convenience).

To more closely approximate the true horizontal velocity distribution profile the velocities in the outside one-quarter portions of each bay are replaced by new values computed according to the "one seventh power law."

$$V = KX^{1/7}$$

where V is the velocity at the given distance (X) from the boundary. The computation proceeds toward the boundary with decreasing values of X. The constant of proportionality K is evaluated from the known values of V and X at the starting point.

To evaluate the accuracy of the numerical method, a velocity traverse was made in one bay to obtain a larger number of data points than was normally read during the model study. In Figure 1 of this appendix the measured velocity profiles are compared with profiles computed from the usual five data points using the polynomial equation fit.

The area of each horizontal velocity profile (at 6, 20, 40, 60, and 80 percent depth measured from the surface) is computed with the trapezoidal formula and the total volume included over the entire depth is computed using the average-end-area method where the horizontal profiles are assumed to be connected by straight lines. It is assumed that the horizontal velocity profiles are constant between the surface and 6 percent depth and between 80 percent depth and the bottom.

The formula is

$$\bar{V} = 0.06d\,(A6) + 0.14d\frac{(A6+A20)}{2} + 0.20d\frac{(A20+A40)}{2} + 0.20d\frac{(A40+A60)}{2} + 0.20d\frac{(A60+A80)}{2} + 0.20d(A80)$$

where

$\forall$ = volume,

A20 etc. = area of velocity distribution curve at specified depth.

The improved velocity traverse justified the use of the average-end-area method and the assumptions made in its application. Velocities close to the bottom showed little reduction from those at 80 percent depth. The low velocities at 6 and 20 percent depth made the use of more sophisticated methods of intergration undesirable.

The integration results in the discharge Q in cubic feet per second. Simplifying the equation and including the total depth d = 17.08 feet gives

$$Q = 1.025(A6)+1.196(A6+A20)+3.416(A20/2)+A40+A60+1.5(A80)$$

used in the computer program. The equation could have been further simplified.

The average velocity (Q/A) and the dimensionless velocity at each point (V/average V) are then computed. The dimensionless velocities are printed on the output listing and punched on cards for use on the X-Y plotter. An example of the output listing is included in this appendix. The punched cards contain the dimensionless velocities and the percent of width. Plotter control cards for pen lifts and stops are also generated by the program.

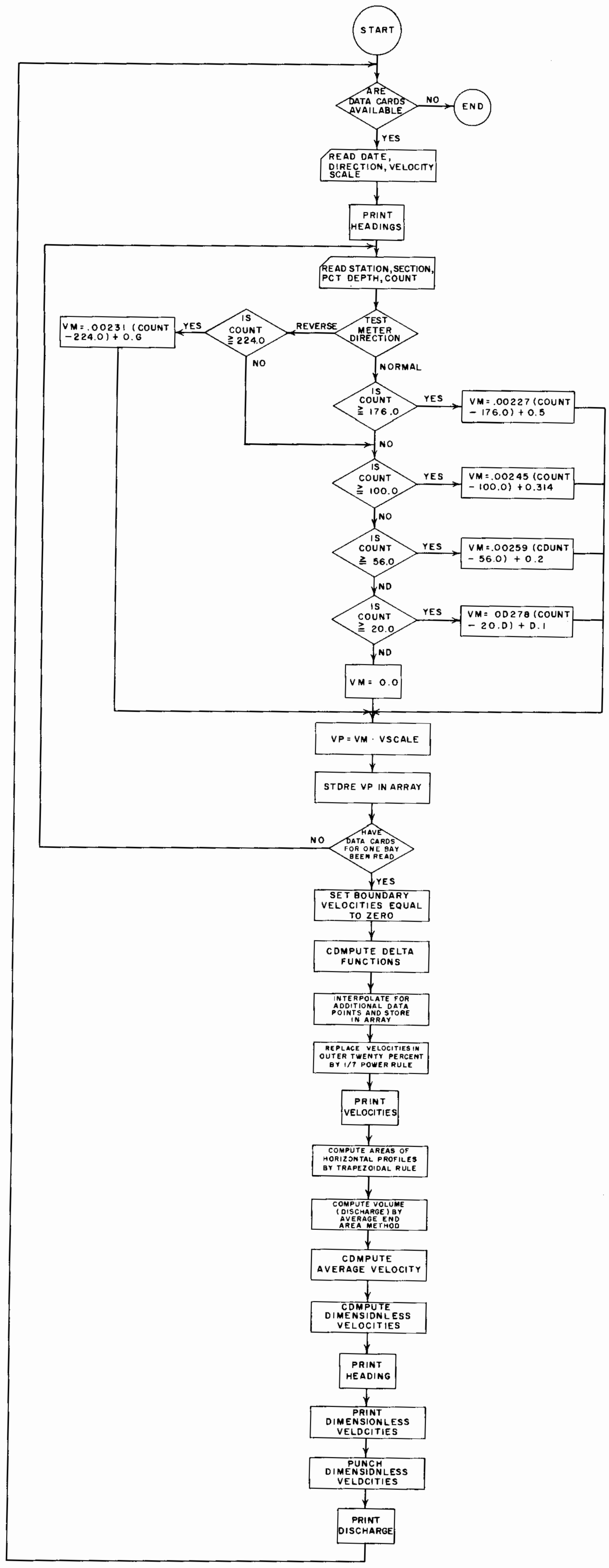
REFERENCES

1. Stanton, Ralph G., Numerical Methods for Science and Engineering. New Jersey: Prentice-Hall, Incorporated, 1963

2. Wylie, C. R., Jr., Advanced Engineering Mathematics. New York: McGraw-Hill Book Company, Incorporated, 1951

DEFINITION OF VARIABLES USED IN PROGRAM

A	--area of horizontal profile
COUNT	--total number of counts in 10 seconds from velocity meter
DATE	--calendar date of data recording
DELT	--delta (△) in difference notation for numerical analysis
DEPTH	--percent depth, measured from surface
DIREC	--orientation of flowmeter, normal or reverse
NLIFT	--plotter control term, lift pen
NSTOP	--plotter control term, stop pen
Q	--compute rate of discharge
SECT	--vertical section of velocity measurement
STA	--canal station of velocity measurement
SUM	--summing term in trapezoidal rule for integration of area
TOTAL	--unnecessary term, inadvertently left in program after modification
VAVE	--average velocity of flow, computed discharge divided by area of flow
VEL	--prototype or dimensionless velocity, stored in array
VLP	--velocity for punched card output
VM	--measured model point velocity
VP	--computed prototype point velocity
VSCALE	--velocity scale ratio
W	--percent width, punched card output
X	--width term, numerical analysis



FLOW DIAGRAM FOR VELOCITY DISTRIBUTION ANALYSIS PROGRAM

APPENDIX
REPORT HYD-542

PROGRAM LISTING


```
C     FOREBAY PUMPING PLANT INTAKE TRANSITIONS
      DIMENSION VP(5,5),DELT(5,5),VEL(21,21),A(21)
    1 FORMAT(2I8,F8.0)
   51 FORMAT(3I8,F8.0)
   20FORMAT(94H0 PCT                  PROTOTYPE VELOCITIES AT 1/20 POINTS
     1 FROM LEFT TO RIGHT LOOKING DOWNSTREAM)
    3 FORMAT   (111H DEPTH 0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40
     10.45 0.50 0.55 0.60 0.65 0.70 0.75 0.80 0.85 0.90 0.95 1.00)
    4 FORMAT(6H1DATE= I6)
    5 FORMAT(F5.0,1X,21F5.2)
  540FORMAT(85H0                  V/AVERAGE V AT 1/20 POINTS FROM LEF
     1T TO RIGHT LOOKING DOWNSTREAM)
   55 FORMAT(20H0COMPUTED DISCHARGE= F7.2)
    6 READ INPUT TAPE 5,1,DATE,DIREC,VSCALE
      WRITE OUTPUT TAPE 6,4,DATE
      WRITE OUTPUT TAPE 6,2
      WRITE OUTPUT TAPE 6,3
      DO 19 J=2,4
      DO 19 I=1,5
    7 READ INPUT TAPE 5,51,STA,SECT,DEPTH,COUNT
      IF (DIREC) 16,8,17
C     NORMAL FLOW
    8 IF (COUNT-176.0) 10,9,9
    9 VM=0.00227* (COUNT-176.0)+0.5
      GO TO 19
   10 IF (COUNT-100.0) 12,11,11
   11 VM=0.00245*(COUNT-100.0)+0.314
      GO TO 19
   12 IF (COUNT-56.0) 14,13,13
   13 VM=0.00259*(COUNT-56.0)+0.2
      GO TO 19
   14 IF (COUNT-20.0) 16,15,15
   15 VM=0.00278*(COUNT-20.0)+0.1
      GO TO 19
   16 VM=0.0
      GO TO 19
C     REVERSE FLOW
   17 IF (COUNT-224.0) 10,18,18
   18 VM=0.00231*(COUNT-224.0)+0.6
   19 VP(I,J)=VM*VSCALE
C     VELOCITIES FOR ONE BAY HAVE BEEN COMPUTED AND STORED
C     SET BOUNDARY VELOCITIES TO ZERO
      DO 20 I=1,5
      VP(I,1)=0.0
   20 VP(I,5)=0.0
C     ROUTINE TO COMPUTE POLYNOMIAL EQUATION OF HORIZONTAL PROFILE
      DO 25 I=1,5
      DO 21 J=1,4
   21 DELT(1,J)=VP(I,J+1)-VP(I,J)
      DO 22 J=1,3
   22 DELT(2,J)=DELT(1,J+1)-DELT(1,J)
```

```
      DO 23 J=1,2                                                       50
   23 DELT(3,J)=DELT(2,J+1)-DELT(2,J)                                   51
      DELT(4,1)=DELT(3,2)-DELT(3,1)                                     52
C     INTERPOLATE FOR ADDITIONAL POINTS                                 53
      X=0.                                                              54
      DO 24 K=1,21                                                      55
     0VEL(I,K)= VP(I,1)+DELT(1,1)*X+(DELT(2,1)/2.0)*(X*X-X)+(DELT(3,1)/6  56
     1.0)*(X*X*X-3.0*X*X+2.0*X)+(DELT(4,1)/24.0)*(X*X*X*X-6.0*X*X*X+11.0  57
     2*X*X-6.0*X)                                                       58
   24 X=X+0.2                                                           59
      X=0.0                                                             59A
      DO 26 K=1,5                                                       59B
      VEL(I,K)=VEL(I,6)*X**0.143/0.25**0.143                            59C
   26 X=X+0.05                                                          59D
      X=0.20                                                            59E
      DO 27 K=17,20                                                     59F
      VEL(I,K)=VEL(I,16)*X**0.143/0.25**0.143                           59G
      VEL(I,21)=0.0                                                     59HH
   27 X=X-0.05                                                          59H
   25 CONTINUE                                                          59I
      DEPTH=0.0                                                         79A
      DO 39 L=1,5                                                       80
      WRITE OUTPUT TAPE 6,5,DEPTH,(VEL(L,K),K=1,21)                     81
   39 DEPTH=DEPTH+20.0                                                  81A
C     COMPUTE AREAS OF HORIZONTAL PROFILES BY TRAPEZOIDAL RULE          82
      TOTAL=0.0                                                         83
      DO 33 L=1,5                                                       84
      SUM=0.0                                                           85
      DO 34 K=2,20                                                      86
   34 SUM=SUM+VEL(L,K)                                                  87
   33 A(L)=.413*(VEL(L,1)+2.0*SUM+VEL(L,21))                            88
C     COMPUTE VOLUME (DISCHARGE)                                        91
     0Q=1.025*A(1)+1.196*(A(1)+A(2))+3.416*((A(2)/2.0)+A(3)+A(4)+A(5)*1.  92
     15)                                                                92A
      VAVE=Q/(17.08*16.5)                                               93
      DO 36 L=1,5                                                       95
      DO 36 K=1,21                                                      96
   36 VEL(L,K)=VEL(L,K)/VAVE                                            97
      DEPTH=0.0                                                         97A
      WRITE OUTPUT TAPE 6,54                                            97B
      DO 38 L=1,5                                                       98
      WRITE OUTPUT TAPE 6,5,DEPTH,(VEL(L,K),K=1,21)                     99
      NSTOP=8                                                           99A
      NLIFT=3                                                           99B
  500 FORMAT (2F10.2)                                                   99C
  501 FORMAT (78X,I2)                                                   99D
      W=0.0                                                             99E
      DO 600 J=1,21                                                     99F
      VLP=VEL(L,J)                                                      99G
      WRITE OUTPUT TAPE 7,500,W,VLP                                     99H
  600 W=W+5.0                                                           99I
      WRITE CUTPUT TAPE 7,501,NLIFT                                     99J
```

```
38 DEPTH=DEPTH+20.0                                    99K
   WRITE OUTPUT TAPE 7,501,NSTOP                       99L
   WRITE OUTPUT TAPE 6,55,Q                            101
   GO TO 6                                             103
   END(1,0,0,0,0,0,1,0,0,0,0,0,0,0,0)
```

BUREAU OF RECLAMATION

LABORATORY PUNCH CARD DATA

USE BUFF COLORED CARDS	PROBLEM Forebay Pumping Plant Transition Studies	JOB NO.	Sample
	DETAIL Transition C	#	Data Sheet
	FEATURE One Bay Operation - Bay 1	RETURN TO	
	PROJECT CVP	ROOM	BLDG. PHONE

Date	Meter Direction	Velocity Scale	
091664	1	31.873	

Station	Section	Pct. Depth	Average Count
4	1	6	212.3
4	1	20	104.0
4	1	40	243.8
4	1	60	235.3
4	1	80	247.0
4	2	6	214.7
4	2	20	134.3
4	2	40	245.6
4	2	60	245.0
4	2	80	251.5
4	3	6	187.9
4	3	20	186.8
4	3	40	221.0
4	3	60	236.6
4	3	80	242.2

REMARKS

BY DLK DATE 9-16-64 CHECKED ✓ SHEET 1 OF 1

GPO 833969

SAMPLE OUTPUT

DATE= 91664

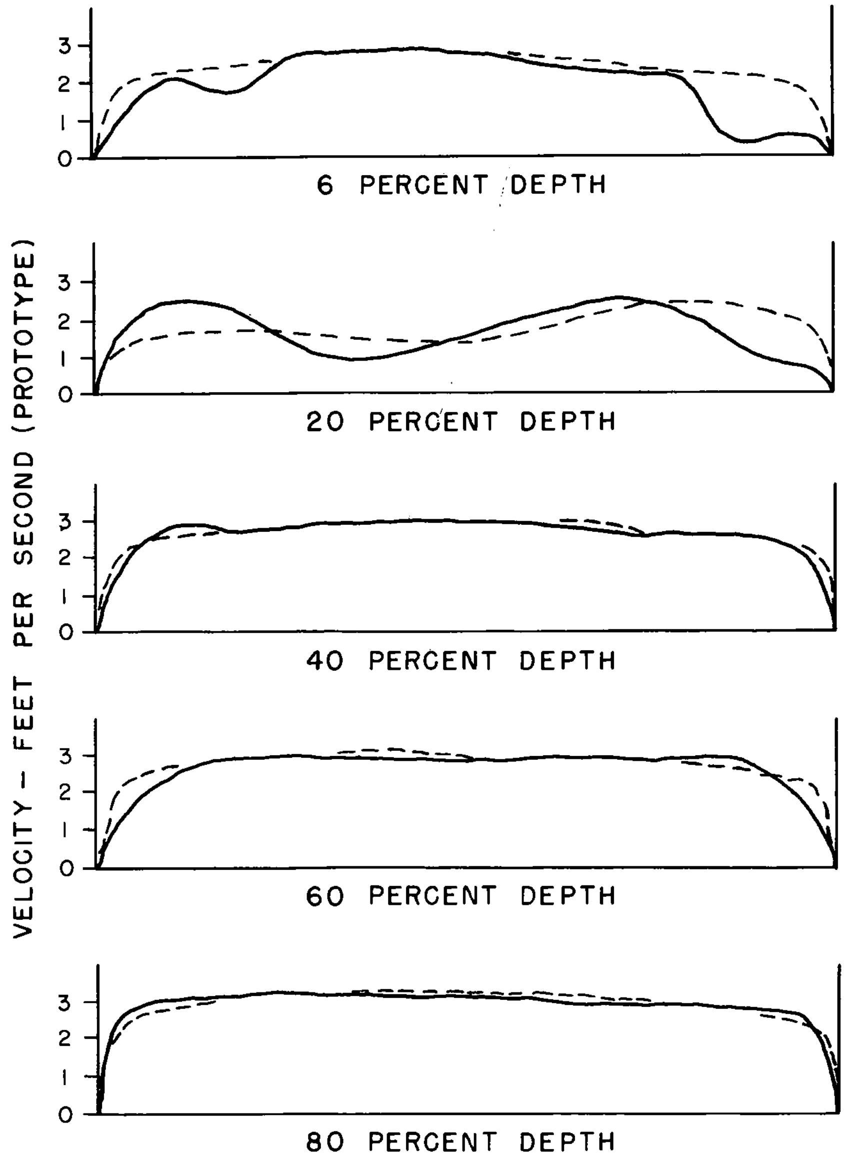
PROTOTYPE VELOCITIES AT 1/20 POINTS FROM LEFT TO RIGHT LOOKING DOWNSTREAM

PCT DEPTH	0.00	0.05	0.10	0.15	0.20	C.25	0.30	0.35	0.40	0.45	C.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.CO
0.	0.	1.81	2.00	2.12	2.21	2.28	2.35	2.37	2.36	2.34	2.30	2.27	2.24	2.20	2.15	2.05	1.99	1.91	1.80	1.63	0.
20.	0.	1.00	1.10	1.17	1.21	1.25	1.29	1.33	1.38	1.45	1.54	1.66	1.78	1.90	2.00	2.04	1.98	1.90	1.79	1.62	0.
40.	0.	1.99	2.19	2.32	2.42	2.50	2.57	2.58	2.56	2.54	2.52	2.50	2.49	2.48	2.44	2.36	2.29	2.20	2.07	1.88	0.
60.	0.	1.93	2.13	2.25	2.35	2.42	2.50	2.52	2.52	2.51	2.51	2.52	2.53	2.53	2.51	2.44	2.36	2.26	2.14	1.94	0.
80.	0.	2.01	2.22	2.35	2.45	2.53	2.59	2.61	2.60	2.58	2.57	2.57	2.57	2.58	2.56	2.49	2.41	2.31	2.18	1.98	0.

V/AVERAGE V AT 1/20 POINTS FROM LEFT TO RIGHT LOCKING DOWNSTREAM

0.	0.	0.86	0.95	1.01	1.05	1.08	1.12	1.13	1.12	1.11	1.09	1.08	1.07	1.05	1.02	0.97	0.94	0.91	0.85	0.77	0.
20.	0.	0.47	0.52	0.55	0.58	0.60	0.62	0.63	0.66	0.69	C.73	0.79	0.85	0.90	0.95	0.97	0.94	0.90	0.85	0.77	0.
40.	0.	0.94	1.04	1.10	1.15	1.19	1.22	1.22	1.22	1.21	1.20	1.19	1.18	1.18	1.16	1.12	1.09	1.04	0.99	0.89	0.
60.	0.	0.92	1.01	1.07	1.12	1.15	1.19	1.20	1.20	1.19	1.19	1.20	1.20	1.20	1.19	1.16	1.12	1.08	1.02	0.92	0.
80.	0.	0.95	1.05	1.12	1.16	1.20	1.23	1.24	1.23	1.23	1.22	1.22	1.22	1.22	1.21	1.18	1.14	1.10	1.04	0.94	0.

CCMPUTED CISCHARGE= 593.20



——— Curve fitted by hand through data of improved traverse.

- - - - Curve fitted by computer through data of normal traverse.

Symmetrical transition with curved approach, Bay 1 alone.

SAN LUIS FOREBAY PUMPING PLANT
CANAL TRANSITION STUDIES

1:15 SCALE MODEL

COMPARISON OF COMPUTER DERIVED VELOCITY DISTRIBUTION WITH MEASURED VELOCITY DISTRIBUTION

7-1750
(10-64)

CONVERSION FACTORS--BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, January 1964) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given on pages 10-11 of the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Table 1

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
	0.3048 (exactly)*	Meters
	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	929.03 (exactly)*	Square centimeters
	0.092903 (exactly)	Square meters
Square yards	0.836127	Square meters
Acres	0.40469*	Hectares
	4,046.9*	Square meters
	0.0040469*	Square kilometers
Square miles	2.58999	Square kilometers
	VOLUME	
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
	CAPACITY	
Fluid ounces (U.S.)	29.5737	Cubic centimeters
	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
	0.473166	Liters
Quarts (U.S.)	9,463.58	Cubic centimeters
	0.946358	Liters
Gallons (U.S.)	3,785.43*	Cubic centimeters
	3.78543	Cubic decimeters
	3.78533	Liters
	0.00378543*	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	764.55*	Liters
Acre-feet	1,233.5*	Cubic meters
	1,233,500*	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
	1.12985×10^6	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
	1.35582×10^7	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
	0.3048 (exactly)*	Meters per second
Feet per year	0.965873×10^{-6}*	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2	0.3048*	Meters per second^2
FLOW		
Cubic feet per second (second-feet)	0.028317*	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
FORCE*		
Pounds	0.453592*	Kilograms
	4.4482*	Newtons
	4.4482×10^{-5}*	Dynes
WORK AND ENERGY*		
British thermal units (Btu)	0.252*	Kilogram calories
	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	1.35582*	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 deg F (k, thermal conductivity)	1.442	Milliwatts/cm deg C
	0.1240	Kg cal/hr m deg C
Btu ft/hr ft^2 deg F	1.4880*	Kg cal m/hr m^2 deg C
Btu/hr ft^2 deg F (C, thermal conductance)	0.568	Milliwatts/cm^2 deg C
	4.882	Kg cal/hr m^2 deg C
Deg F hr ft^2/Btu (R, thermal resistance)	1.761	Deg C cm^2/milliwatt
Btu/lb deg F (c, heat capacity)	4.1868	J/g deg C
Btu/lb deg F	1.000*	Cal/gram deg C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
	0.09290*	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Pound-seconds per square foot (viscosity)	4.8824*	Kilogram second per square meter
Square feet per second (viscosity)	0.02903* (exactly)	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	35.3147*	Millicuries per cubic meter
Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons per square yard	4.527219*	Liters per square meter
Pounds per inch	0.17858*	Kilograms per centimeter

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ABSTRACT

Hydraulic model studies of 2 intake channel transition designs for the Forebay Pumping Plant in San Luis Unit, CVP, showed that the hydraulic advantages of a symmetrical transition were not great enough to outweigh the economic advantages of an angled transition. Because the pumping plant location and alinement were fixed by geologic conditions a straight-in approach could not be used; therefore 2 alternative schemes for the Forebay Canal alinement and transition configuration were studied by comparing velocity distributions, head losses, and surface flow patterns on a 1:15-scale model. Velocity distribution comparison indicated that a symmetrical transition with curved approach was preferable to an angled transition with straight canal alinement. Although the symmetrical transition showed slightly more desirable flow patterns, the strength of eddy currents occurring along the transition sides appeared to be the same for both types. Head loss difference between the 2 types was too small to justify comparison on this basis. The symmetrical transition exhibited less tendency to form vortices between the intake piers. Both types could possibly be improved by modifying the design--that is, widening the canal bottom or including vertical sidewalls at the pumping plant. The symmetrical transition, although hydraulically preferable, would require additional excavation and a longer approach canal, resulting in higher costs.

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King, D. L.
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Laboratory Report, Bureau of Reclamation, Denver, 16 p, 19 fig, 2 ref, 1965

DESCRIPTORS-- *pumping plant// *transitions/structures// *canals/ velocity distribution/ head losses/ eddies/ angle of approach/ instrumentation/ model tests/ data reduction/ curve fitting/ computers/ research and development/ economics/ hydraulics/ hydraulic models/ pumped storage/ hydraulic structures/ intake structures/ turbulent flow/ digital computers/ computer programming/ design/ velocity meters
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