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HYDRAULIC MODEL STUDIES OF THE RESERVOIR INLET-OUTLET STRUCTURE FOR HORSE MESA PUMP-STORAGE UNIT SALT RIVER PROJECT, ARIZONA

P. L. Johnson
Engineering and Research Center
Bureau of Reclamation

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16. ABSTRACT

Hydraulic model studies were performed to assure satisfactory flow conditions through the reservoir inlet-outlet structure for a pump-storage unit at Horse Mesa Dam, Ariz. The studies were considered necessary because of unsymmetrical approach flow caused by the penstock configuration. The main purpose for the studies was to develop a design to provide a uniform velocity distribution at the trashrack. Uniform velocity distribution would eliminate any chance of forming strong vortex shedding and ensure a trashrack free from the danger of fatigue failure. The model was at a 1:24 scale and included the inlet-outlet structure, a rectangular-to-circular transition, and the penstock down to the spiral case. Velocity distribution and head loss measurements were made for the penstock and inlet-outlet structure. Two vertical walls were placed in the structure to improve the horizontal velocity distribution at the trashrack position. A low-velocity area was removed by making the floor of the structure nondivergent. The structure was then lengthened to restore the initial trashrack area.

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Hydraulics Branch
Division of General Research
Engineering and Research Center
Denver, Colorado

UNITED STATES DEPARTMENT OF THE INTERIOR
Rogers C. B. Morton
Secretary

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PURPOSE

These studies were made to develop a satisfactory reservoir inlet-outlet structure for the new pump-storage unit to be installed at Horse Mesa Dam, Arizona.

RESULTS

1. The centrifugal force of the flow in the two vertical bends and the single horizontal angular displacement in the penstock caused assymetrical flow concentrations in the penstock and the reservoir inlet-outlet structure. These flow concentrations resulted in high- and low-velocity areas in sections where velocity distribution data were taken.

2. Interior walls placed in the reservoir inlet-outlet structure significantly improved the horizontal velocity distribution at the trashrack section for pumped flow. Two interior walls, in an unsymmetrical arrangement, were found to be most effective.

3. A floor parallel with the centerline, replacing the diverging floor of the preliminary structure, eliminated a low-velocity area in the bottom of the trashrack section. The structure was lengthened to restore the original trashrack section area.

4. Because of a concern that actual penstock flow conditions may not have been duplicated and the knowledge that an unsymmetrical structure may intensify uneven flow distributions, a structure with symmetrical interior wall placement was tried. The resulting velocity distribution was not as good as with the unsymmetrical arrangement.

5. A tendency for vortex formation was observed during generating flow at minimum reservoir water surface. Topography surrounding the inlet-outlet structure appeared to have little effect on this vortex formation tendency. No air intake through the vortices was observed.

6. The observed head loss through the penstock and reservoir inlet-outlet structure for Alteration 5 at the maximum design discharge was found to be 4.19 feet (1.28 m) of water for the pumped cycle and 5.15 feet (1.57 m) of water for the generating cycle. Corresponding resistance coefficient values in terms of velocity head are 0.53 and 0.47, respectively. The observed head loss throughout the inlet-outlet structure for Alteration 5 at the maximum design discharge was found to be 1.72 feet (0.52 m) of water for the pumped cycle and 1.77 feet (0.54 m) of water for the generating cycle. Corresponding resistance coefficient values are 0.21 and 0.15, respectively.

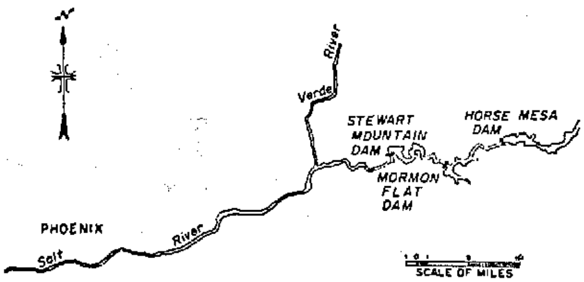
7. Alteration 5 develops the most satisfactory velocity distribution of those alterations considered with a trashrack area equal to the trashrack area of the preliminary design. The unsymmetrical interior wall arrangement can be justified through a consideration of the penstock configuration and the effect of this configuration on the flow distribution.

APPLICATION

The results of these studies are generally applicable only to structures with similar geometrical configuration and therefore similar flow conditions. These studies may be useful in initial evaluations of similar problems.

INTRODUCTION

Horse Mesa Dam and Powerplant, two facilities of the Salt River Project in central Arizona, are located on the Salt River about 65 miles (104 km) northeast of Phoenix. The dam is a 305-foot-high (93.0 m) concrete thin-arch structure, built by the Salt River Valley Water Users Association in 1927. It contains 162,000 cubic yards (124,000 cu m) of concrete and creates a reservoir of 245,100-acre-foot (3,020,000-cu m) capacity. In 1936-37, a 47,000-cubic-foot-per-second (1,330 cu m/sec), 30-foot-diameter (9.14 m) tunnel spillway was added to the structure by the Bureau of Reclamation.



The powerplant, also built in 1927, contains three 25-hz generating units, each with a maximum capability of 10 megawatts. These units have not only been an operational and maintenance burden on the Salt River Project, but they also do not develop the full power-generating capacity that is available.

In 1966, after a preliminary evaluation of the Horse Mesa, Theodore Roosevelt, and Morman Flat

Powerplants, the Salt River Project initiated a more detailed study looking toward reconstruction and expansion of the generating facilities. In 1967, Bechtel Corporation was authorized to investigate the cost of replacement of these generating facilities. This investigation recommended, in part, an overhaul and rehabilitation of the three existing hydraulic turbines, the spiral cases, draft tubes, penstocks, and ancillary equipment at the Horse Mesa Powerplant. The existing 25-hz generators would be rebuilt as 60-hz units, each with a 10-Mw maximum capability.

It was also recommended that an additional reversible-generator/motor facility be installed at the Horse Mesa site (Figure 1). The new 96,500-kva/113,000-hp 60-hz

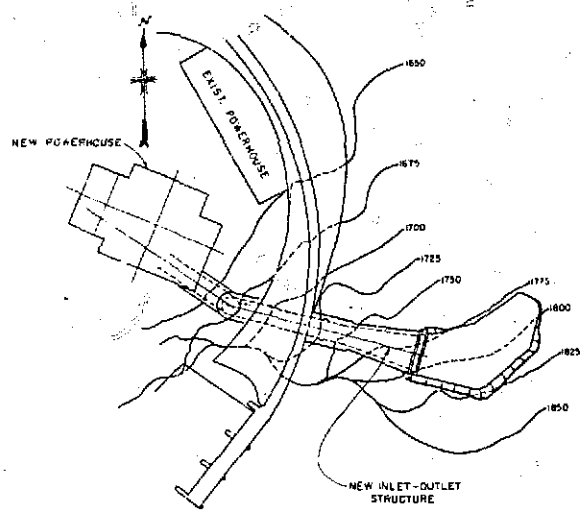


Figure 1. Dam and powerplant plan.

unit would be of the indoor type. A new penstock (Figure 2) would penetrate the existing dam and connect with the new powerhouse. The penstock would be 15.5 feet (4.72 m) in diameter and would contain two vertical curves, one of 90° and one of 75°. The radii of curvature would be 58.25 feet (17.85 m) and 46.50 feet (14.17 m), respectively. The penstock would also contain a horizontal angular deflection of 19°. The reservoir inlet-outlet structure for the new penstock is the subject of this report. (The structure is referred to as the "inlet-outlet structure" throughout the report.)

Because of the vertical curves and the horizontal angular displacement in the penstock, hydraulic model studies were considered necessary to thoroughly investigate the flow conditions in the inlet-outlet structure. Bechtel, through Salt River Project officials, requested the Bureau of Reclamation to conduct hydraulic model studies of the inlet-outlet structure and penstock. The studies were performed at the Bureau's Engineering and Research Center in Denver, Colorado. The main purpose for the model testing was to obtain a design which would provide the most uniform velocity distribution at the trashracks. This would eliminate any chance for formation of strong vortex shedding, thus ensuring a trashrack which would be free from the danger of fatigue failure.

THE MODEL

The maximum reservoir head of 286.25 feet (87.25 m) of water above the invert of the penstock was found to be the controlling physical dimension in selecting the model scale. Considering this, it was decided that a model scale ratio of 1:24 was satisfactory. The 15.5-foot-diameter (4.72 m) prototype penstock was, therefore, represented by a 7.75-inch (19.0-cm) inside diameter, clear plastic pipe (Figure 3). The maximum discharge of 5,000 cubic feet per second (141.5 cms) was represented in the model by 1.77 cubic feet per second (0.050 cms).

The model included the inlet-outlet structure (Figure 4), the rectangular-to-circular transition, and the penstock down to the spiral case (Figure 3). The spiral case was not represented in the model. The model was arranged so that both pumping and generating flow could be simulated. Discharges were measured with venturi and venturi-orifice meters. The amount of swirl induced in the pumped flow was controlled by varying the opening of the control valve in the pumped flow supply line.

THE INVESTIGATION

Test Procedure

In the analysis of the inlet-outlet structure, velocity distribution data were taken at three sections in the system, all of which were perpendicular to the centerline of the penstock or of the inlet-outlet structure. The first section was in the penstock 11.68 feet (3.56 m) from the section where the spiral case joins the penstock. The second section was between the gate slots and the circular-to-rectangular transition (Figure 2). In these two sections a pitot cylinder was used for the velocity sensor. Total energy heads and static pressure heads were observed on a manometer board. The differential between these two heads is the velocity head. Because of the extreme damping in this system, the data indicated only established average

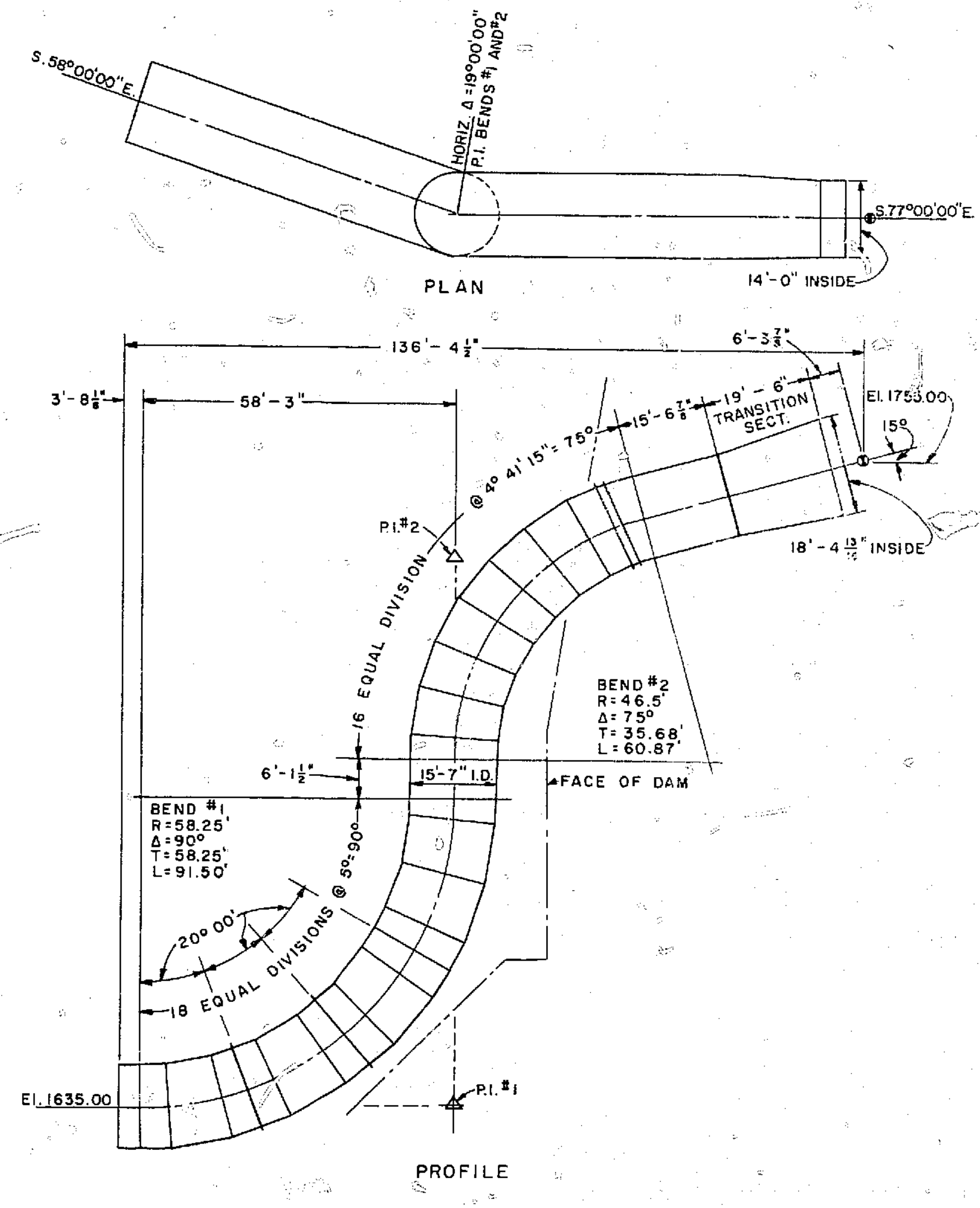


Figure 2. Penstock, plan and profile

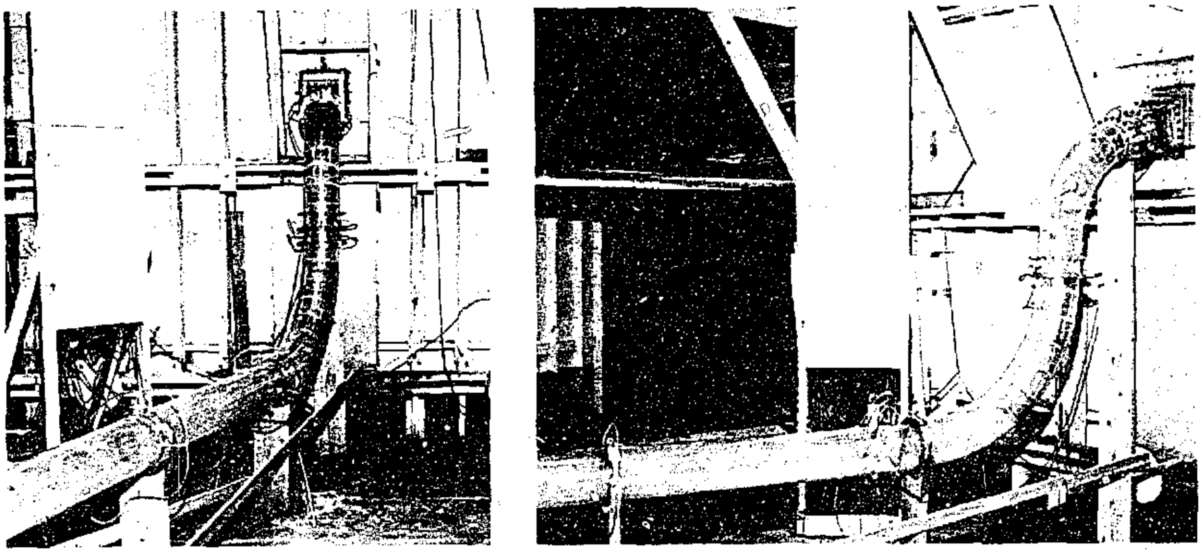


Figure 3. 1:24 scale penstock model. Left photo P25-D-69544 and right photo P25-D-69545.

flow patterns but did not indicate the amount of turbulence in the flow. However, the flow patterns that were obtained did show the effects of both induced swirl in the flow and penstock configuration. The third section at which velocity distribution data were taken was at the trashrack location in the structure. The uniformity of the velocity distribution at this section was the major criterion in the study. Head differentials equal to the velocity head were measured with a system consisting of a Prandtl tube connected to a 0.03-psi (0.002-ksc) diaphragm-type differential pressure cell. This cell was in turn connected to a transducer indicator and recorder, an integrating digital voltmeter and a printer. Data from this system consisted of a printout of average velocity heads and a graph recording of instantaneous velocity heads. The instantaneous data were partially damped by the system.

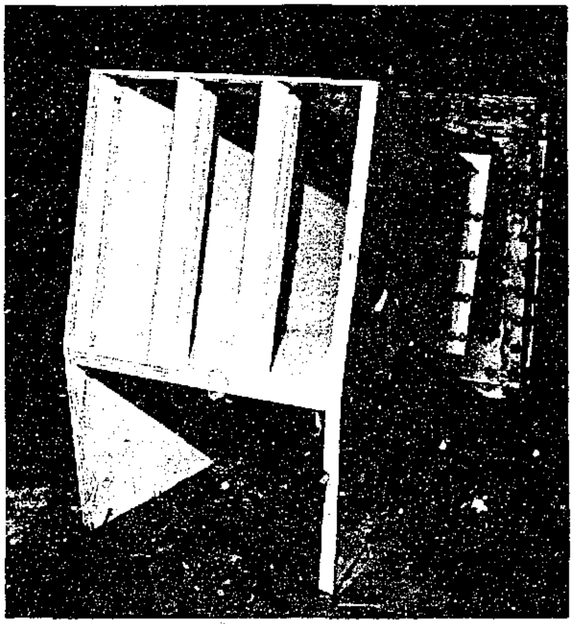
Head loss data were obtained for the penstock and the inlet-outlet structure through the use of two piezometer manifolds that tapped the penstock, one single piezometer that tapped the reservoir, and three associated manometers. One piezometer manifold was located in the circular penstock 5 feet (1.52 m) from the start of the circular-to-rectangular transition and the other was located approximately at the spiral case.

The reservoir water surface elevation was held at 1,884 feet (574.2 m) above sea level, the minimum pumping elevation, when pumping cycle data were taken and at 1,869 feet (569.7 m) above sea level, the minimum generating elevation, when generating cycle data were taken. Past experience has proven these to be the critical reservoir elevations with respect to vortex formation and velocity distribution.

Pumped Cycle

Preliminary structure.—Velocity distribution and head loss data were taken at prototype discharges of 4,620 cubic feet per second (130.7 cu m/sec) and 4,250 cubic feet per second (120.3 cu m/sec). Corresponding average prototype velocities at the trashrack section in the initial structure were 6.47 feet per second (1.97 m/sec) and 5.94 feet per second (1.81 m/sec). Prototype swirls of 0.8 radian per second, 0.3 radian per second, and 0.0 radian per second, were induced at the two discharges. Swirl is defined as an angular velocity or an angular displacement in the flow, with respect to time, about the axis of the penstock. Initially, it was speculated that the pumped discharge from the pump-turbine unit could possibly contain swirl; therefore, swirl was induced into the flow in an attempt to determine how it affected the velocity distribution. The velocity distribution at the trashrack section was affected significantly by the induced swirl of 0.8 radian per second. However, the distribution was controlled by the penstock configuration only when the induced swirl was 0.3 and 0.0 radian per second.

Data were taken at the trashrack location to correlate velocity distributions for the two discharges. It was concluded that the two distributions were similar and that they varied only by the linear factor of the ratio



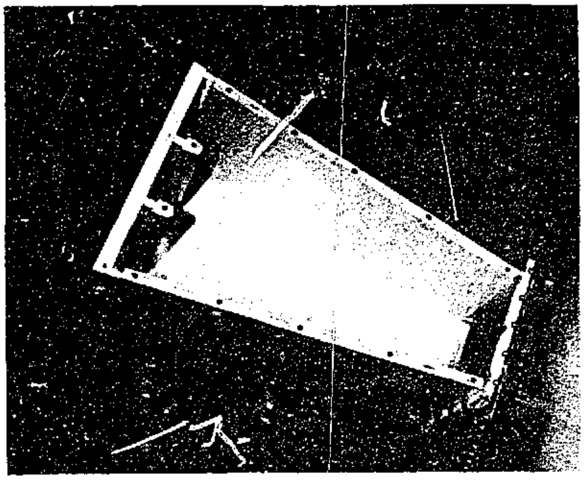
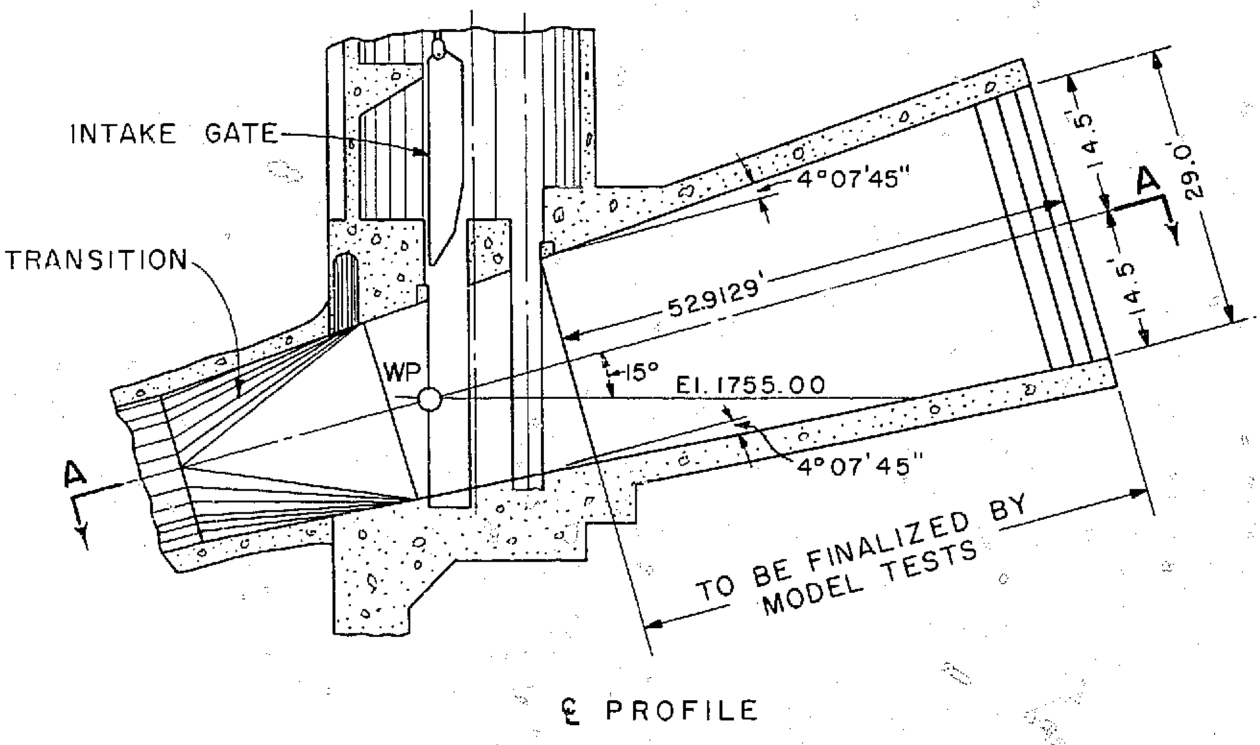


Figure 4. 1:24 scale model of preliminary inlet-outlet structure. Left photo P25-D-69543 and right photo P25-D-69542.

of their average velocities. Velocities at the trashrack section which are given in this text are, except where noted, for a prototype discharge of 4,250 cubic feet per second (120.3 cu m/sec). It is believed that the 0.0-radian-per-second case (no swirl) is the most representative of actual prototype flow conditions. This belief is supported by the observation that pumped flow leaves the spiral case tangentially, which is not conducive to the formation of a swirling flow. From considering the mechanics of the flow in the spiral case, it was concluded that secondary flows will not be a significant factor.

Flow through the preliminary inlet-outlet structure (Figure 5) was observed at a discharge of 4,620 cubic feet per second (130.7 cu m/sec) and at induced swirls of 0.8, 0.3, and 0.0 radian per second. In all three cases there was less flow in the left bay of the structure (looking in the direction of pumped flow). Prototype velocities at the trashrack varied from 0.16 foot per second (0.052 m/sec) near the upper left corner to 11.05 feet per second (3.37 m/sec) at the right center for the 0.8-radian-per-second case (Figure 1A, Appendix I). The effects of the angular velocity were also apparent in that the flow was concentrated near the sides of the structure with a low flow condition in the center. With a swirl flow of 0.3 radian per second (Figure 2A, Appendix I), the prototype velocity at the trashrack section varied from 0.93 foot per second (0.26 m/sec) at the lower left corner to 10.70 feet per second (3.26 m/sec) at the upper center of the section. Velocities were in general lower at the left and bottom of the structure but the distribution was better than for the 0.8-radian-per-second case. With no swirl (Figure 3A, Appendix I), the velocity distribution was similar to that of the 0.3-radian-per-second condition. The minimum observed prototype velocity with no swirl was 0.60 foot per second (0.18 m/sec) at the lower left corner and the maximum was 10.20 feet per second (3.11 m/sec) at the upper center.

Velocity distribution data were obtained at the two sections in the penstock for the above operating conditions. Data taken at the section near the gate slots showed velocity distribution similar to, but not as unsymmetrical as, the counterpart distribution at the trashrack section (Figures 4A, 5A, and 6A, Appendix I). The 0.8-radian-per-second swirl condition had lower velocities in the lower left corner and higher velocities along the right side; the 0.3-radian-per-second swirl condition had lower velocities in the lower left corner and higher velocities near the right center; and the no-swirl condition had lower velocities in the lower left corner and higher velocities in the right and top. The section near the spiral case showed a fairly symmetrical distribution with no extreme flow concentrations for the no-swirl condition (Figure 7A, Appendix I). This section did, however, show a strong flow deficiency in its upper center for the



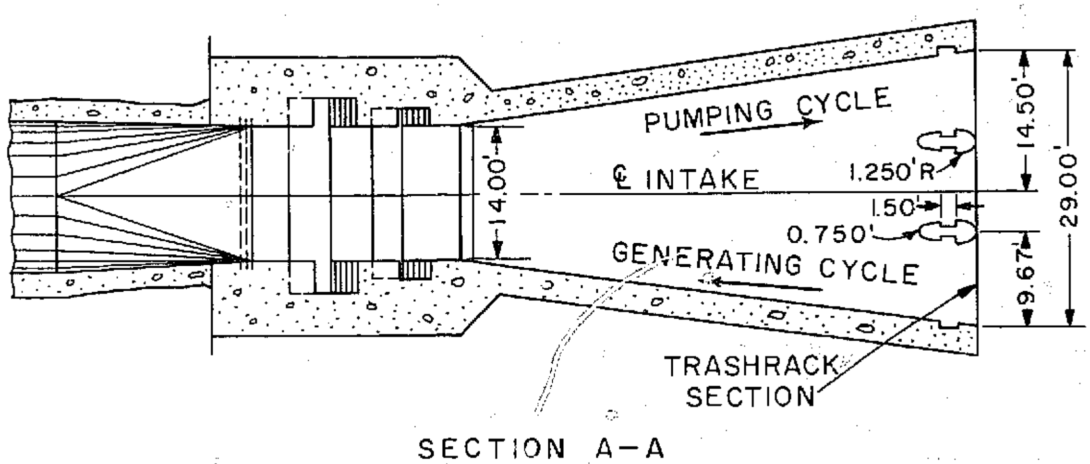


Figure 5. Preliminary initial inlet-outlet structure.

0.8-radian-per-second condition (Figure 8A, Appendix I).

These measurements indicated that for the no-swirl condition, as the flow left the upper vertical curve of the penstock a flow concentration was created at the top and somewhat to the right. This distribution can be directly inferred from momentum changes due to penstock configuration. If an angular velocity initially exists in the flow, a tendency for the flow to concentrate near the boundaries and away from the axis of rotation can be observed (Figures 4A and 8A, Appendix I). This flow is still affected by the penstock configuration and therefore unsymmetrical distribution will be created as before. The effect of the angular velocity depends completely on its initial magnitude.

Modifications.—The first alteration to the design of the inlet-outlet structure consisted of two vertical walls standing the full height of the structure. The walls began at the penstock end of the inlet-outlet structure and were 26.45 feet (8.063 m) in length, 1-foot (0.3-m) thick, and were rounded on both ends. The walls were unequally spaced at the penstock end of the structure in such a manner that they equally divided the flow into thirds based on the distribution measured at Section 3, shown on Figure 4A, Appendix I. At the downstream end the walls were in line with the centerlines of the piers located at the reservoir end of the structure.

The first alteration improved the velocity distribution at the trashrack section significantly. The minimum observed velocity for the no-swirl condition and a discharge of 4,620 cubic feet per second (130.7 cu m/sec) was 1.88 feet per second (0.574 m/sec) at the bottom right and the maximum was 9.41 feet per second (2.87 m/sec) at the top left (Figure 9A, Appendix I).

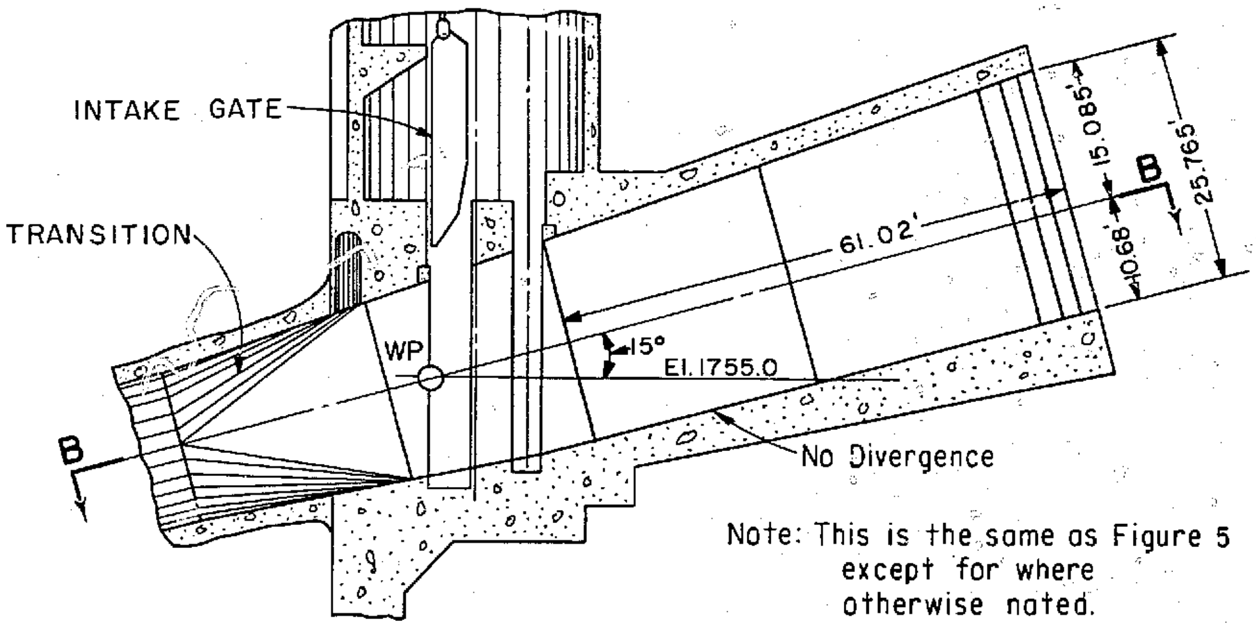
For Alteration 2, made to remedy the flow deficiency at the bottom and flow excess in the left bay at the trashrack section, the diverging floor was made parallel with the penstocks centerline and the upstream end of the interior walls were shifted a prototype distance of 3 inches (7.6 cm) to the left. The resulting data showed a significant increase in bottom velocities and a small improvement in average velocity distribution from bay to bay. For the no-swirl condition and a discharge of 4,620 cubic feet per second (130.7 cu m/sec) the minimum observed velocity was 1.69 feet per second (0.52 m/sec) at the lower left-hand corner and the maximum observed velocity was 9.53 feet per second (2.90 m/sec) at the upper left center of the section (Figure 10A, Appendix I).

The velocity distribution at the trashrack section obtained with Alteration 2 was considered satisfactory. However, because of a concern that actual penstock flow conditions might not have been duplicated and the knowledge that an unsymmetrical structure might intensify uneven flow distribution, a structure with symmetrical interior wall placement was tried for Modification 3. The initial tests had shown that velocity distribution at the gate slot section was more nearly uniform than at the trashrack section, indicating that the uneven velocity distribution was intensified in the intake structure. It was believed that the symmetrically spaced interior walls would intercept and stabilize the flow before the uneven velocity distribution intensified.

The velocity distribution with the symmetrical interior walls was better than in the preliminary structure but not as good as with Alterations 1 and 2. The maximum observed velocity at the trashrack section was 9.29 feet per second (2.83 m/sec) at the upper center, and the minimum was 1.75 feet per second (0.53 m/sec) at the lower left for the no-swirl flow condition. In the 0.8-radian-per-second flow condition, the lower velocity was 1.51 feet per second (0.46 m/sec) near the upper left corner while the maximum velocity of 12.02 feet per second (3.66 m/sec) was measured near the center of the right bay. The left bay showed a flow deficiency for both flow conditions (Figures 11A and 12A, Appendix I).

In Alteration 4, the inlet-outlet structure was lengthened 8.11 feet (2.47 m), to return the trashrack to its initial area and yet retain the nondiverging floor. The interior walls remained the same as for Alteration 3. This change did not improve the velocity distribution at the trashrack. The velocity distribution pattern was similar for Alterations 3 and 4 except for lower velocities along the invert of the structures, but the quantity of flow in each bay was nearly the same for Alterations 3 and 4. The maximum observed velocity was 9.47 ft/sec (2.89 m/sec) in the upper center of the section and the minimum observed velocity was 0.0 ft/sec (0.0 m/sec) in the lower left corner (Figure 13A, Appendix I).

The final inlet-outlet structure scheme to be studied, Alteration 5 (Figure 6), consisted of the same exterior structure as Alteration 4 with the symmetrical interior wall placement of Alteration 2. This outlet structure produced generally good flow distribution at the



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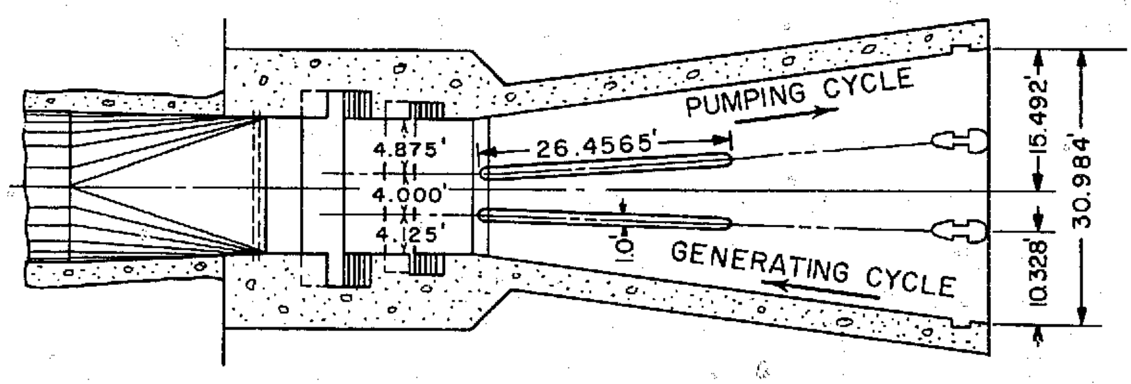

SECTION B—B

Figure 6. Inlet-outlet structure, Alteration 5

trashrack position with only moderate flow deficiencies at the left and bottom of the section. The minimum observed velocity was 1.67 feet per second (0.51 m/sec) in tne lower left corner and the maximum was 8.13 feet per second (2.48 m/sec) in the upper left center (Figure 14A, Appendix I).

Free jet outlet.—A free jet outlet was also tested (Figure 7). This consisted of the flow leaving the rectangular penstock just downstream from the gate slots with no expanding outlet structure to influence it. The resultant velocity distribution was observed at a section 52 feet (15.85 m) from the end of the penstock (Figure 15A, Appendix I), approximately the same location as the trashrack section in the preliminary design. The maximum observed velocity was 13.2 feet per second (4.02 m/sec), 23 feet (7.01 m) above the invert along the centerline of the outlet. The distribution was fairly symmetrical. An upward or vertical dispersion of the flow was observed as high as 40 feet (12.19 m) above the invert; in previous tests the outlet structure was 29 feet (8.84 m) high at this section. Lateral dispersion of flow was also observed 15 feet (4.57 m) to the left of (looking in direction of flow) and 18 feet (5.49 m) to the right of the centerline of the outlet. The preliminary inlet-outlet structure extended 14.5 feet (4.42 m) to both the left and right of the centerline at this section. This is an indication as to why the velocities were higher at the top and right boundaries in the previous tests.

Head losses.—Head loss data were taken for the Alteration 3 (symmetrical interior walls, floor parallel with centerline) inlet-outlet structure. The data were collected both with and without the interior walls in place. It was observed that for all practical purposes the interior walls did not increase the head loss. With the walls in place, the head loss coefficient (the ratio of head loss through the system or a portion of the system to the velocity head of the flow in the penstock) stabilized with respect to Reynolds number at 0.22 for the inlet-outlet structure and at 0.53 for the penstock and inlet-outlet structure combined (Figure 16A, Appendix I). With the interior walls removed, the resistance coefficients stabilized at approximately the same values (Figures 16A, Appendix I). The Reynolds number is a nondimensional number that consists of the ratio of the inertia forces to the viscous forces. Low Reynolds number values indicate an increased importance of the viscous forces. The Reynolds number values are related to the values of the resistance coefficients to show that above a certain value the resistance coefficient becomes constant. It was observed that, in general, the above resistance coefficients became

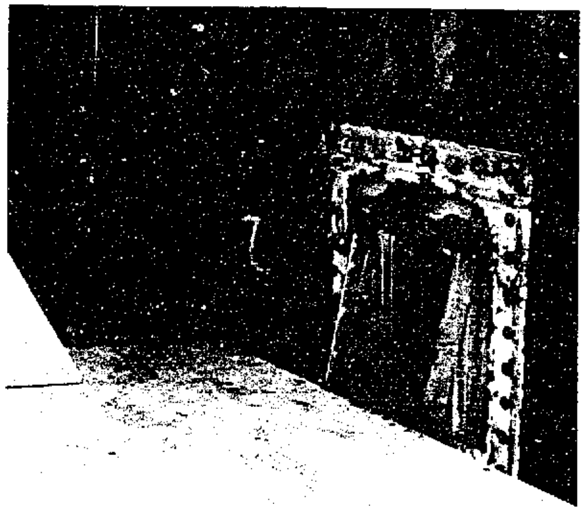

Figure 7. Free jet outlet. Photo P25-D-69546

constant at a Reynolds number of 5×10^5. Corresponding Reynolds numbers in the prototype will be several times greater than those at which the model loss coefficients became constant. Therefore, the obtained resistance coefficients are reliable indicators of roughness in the prototype.

Similar flow conditions were established for the Alterations 4 and 5 inlet-outlet structures with the interior walls in place. Head loss data were then collected for both the structures and the system. The findings corresponded with those for Alteration 3 (Figure 16A, Appendix I).

Generation Cycle

Velocity distribution.—Velocity distribution data were taken at a prototype discharge of 5,000 cubic feet per second (141.60 cu m/sec). For these tests, the reservoir water level was held at elevation 1869 feet (569.67 m). Velocity distribution data were taken at two sections in the penstock, the section near the gate slot, and the section near the spiral case (Figure 2).

The velocity distribution at the gate-slot section reflected the geometry of the interior wall placement. In general, the velocity distribution echoed the wall orientation with elongated vertical flow concentrations (Figure 17A, Appendix I). The velocity distribution at the section 11.68 feet (3.56 m) from the spiral case was found to be quite uniform with a small flow deficiency at the top of the section (Figure 18A, Appendix I). This flow deficiency may be directly *inferred from the momentum changes* due to the lower bend of the penstock.

Head losses.—The head loss data showed that for the generation cycle flow through *Alterations* 3, 4, *and* 5 the resistance coefficient stabilized at 0.15 for the inlet-outlet structure and at 0.47 for the entire system (Figure 19A, Appendix I).

It was also observed that for the Alteration 3 structure with no interior walls the resistance coefficient was 0.11 for the inlet-outlet structure and 0.43 for the entire system (Figure 19A, Appendix I). The system resistance coefficients appeared to stabilize at a Reynolds number of about 5×10^5 while the inlet-outlet structure resistance coefficients appeared to have stabilized at a Reynolds number of about 3×10^5.

APPENDIX I

Velocity Distributions in Penstock and At Trashrack Section, and Head-Loss Data

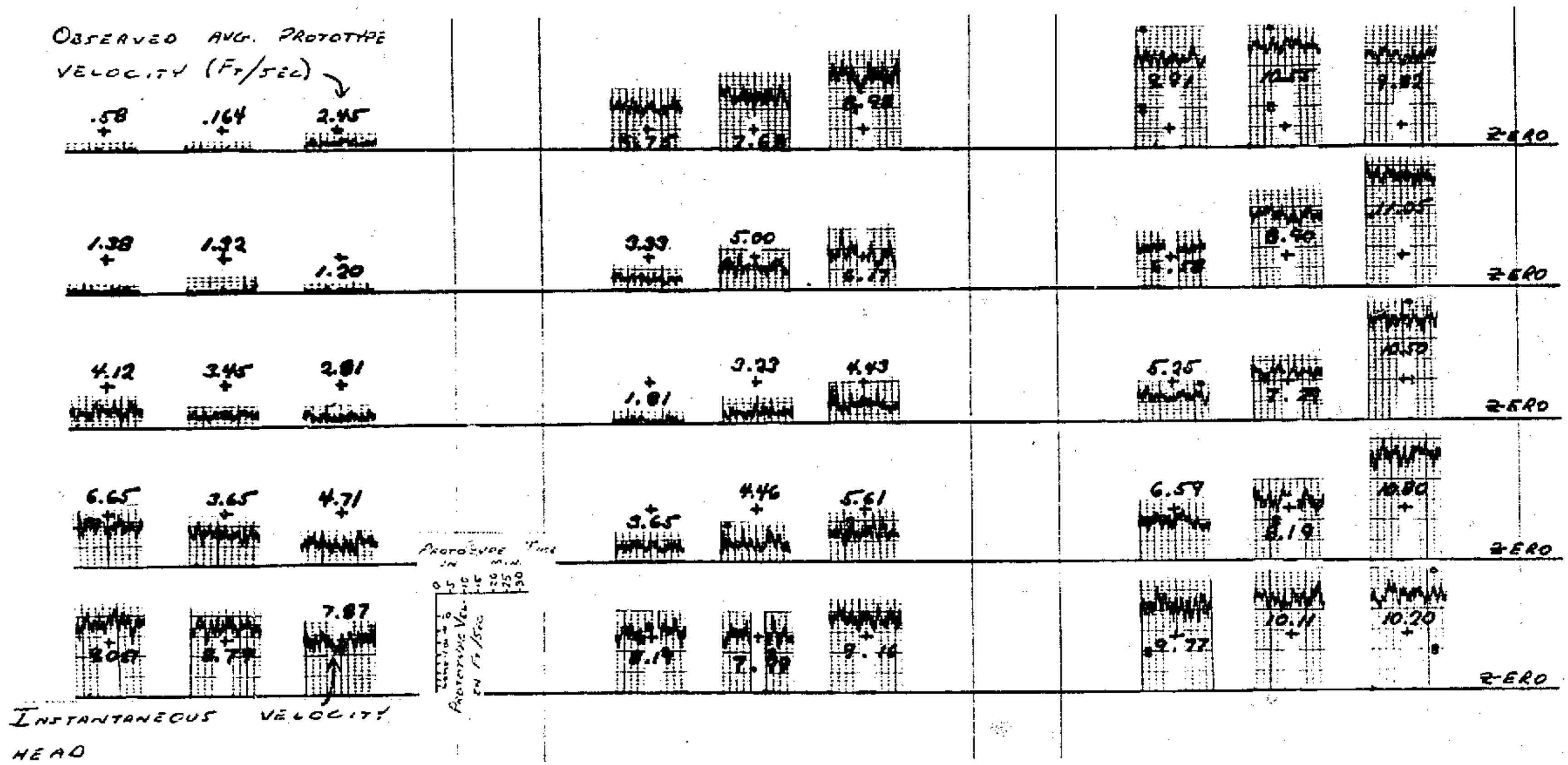

Figure 1A. Horse Mesa Hydroelectric Expansion Model Studies, velocity distribution at trashrack, preliminary inlet-outlet structure, angular velocity - 0.8rad/sec, discharge = 4620cfs, looking in direction of pumped flow.

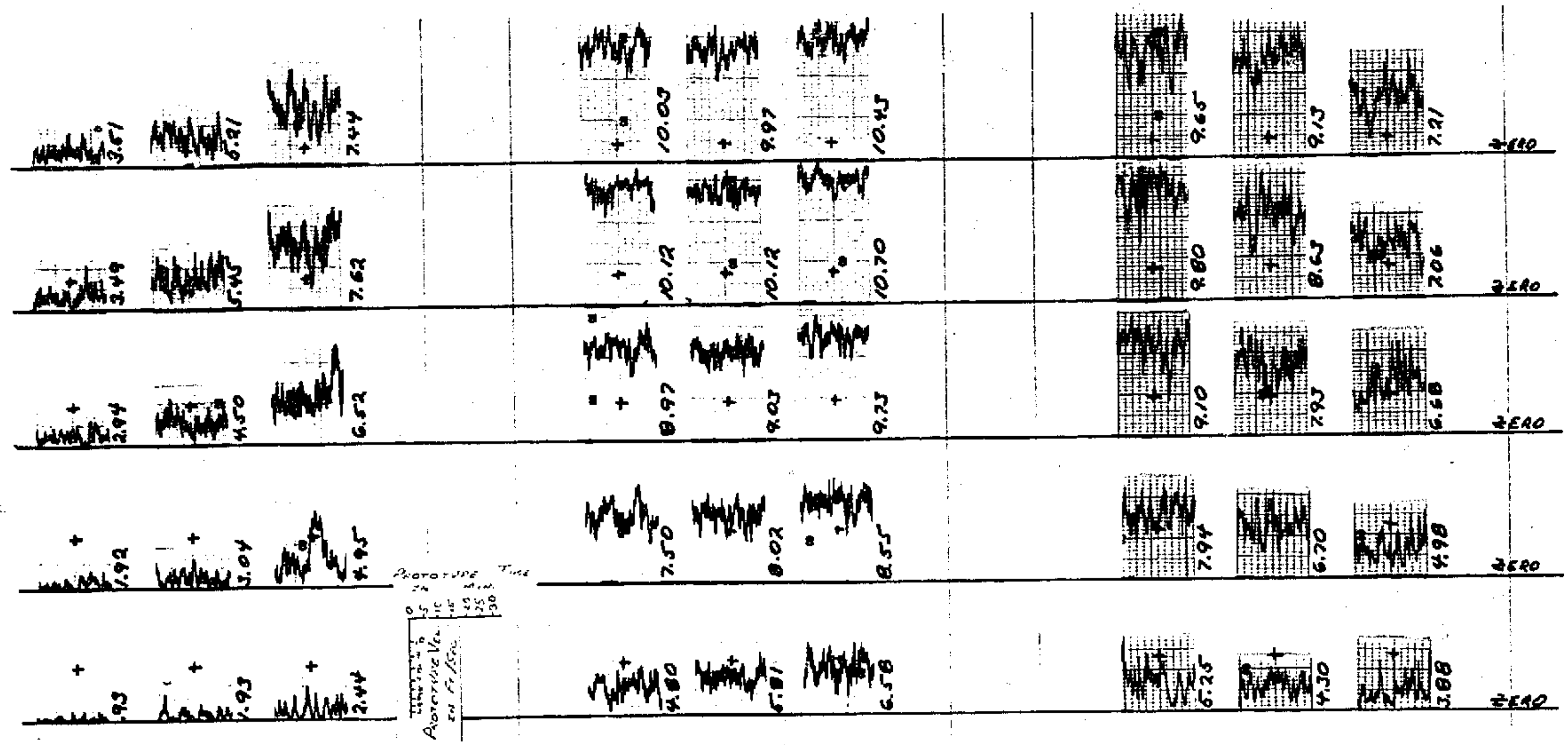

Figure 2A. Horse Mesa Hydroelectric Expansion Model Studies, velocity distribution at trashrack, preliminary inlet-outlet structure, angular velocity = 0.3rad/sec, discharge = 4620cfs, looking in direction of pumped flow.

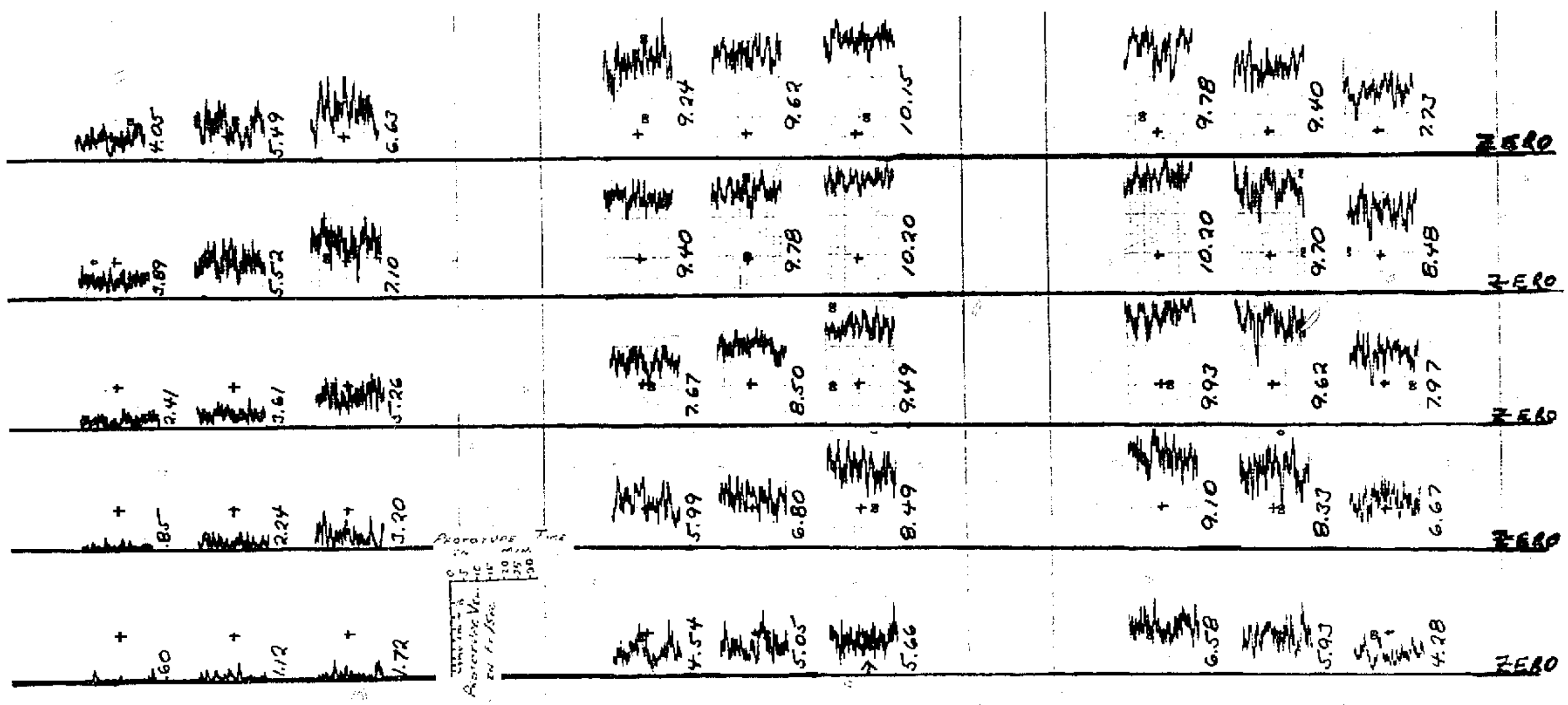

Figure 3A. Horse Mesa Hydroelectric Expansion Model Studies, velocity distribution at trashrack, preliminary inlet-outlet structure, angular velocity = 0.0rad/sec, discharge = 4620cfs, looking in direction of pumped flow.

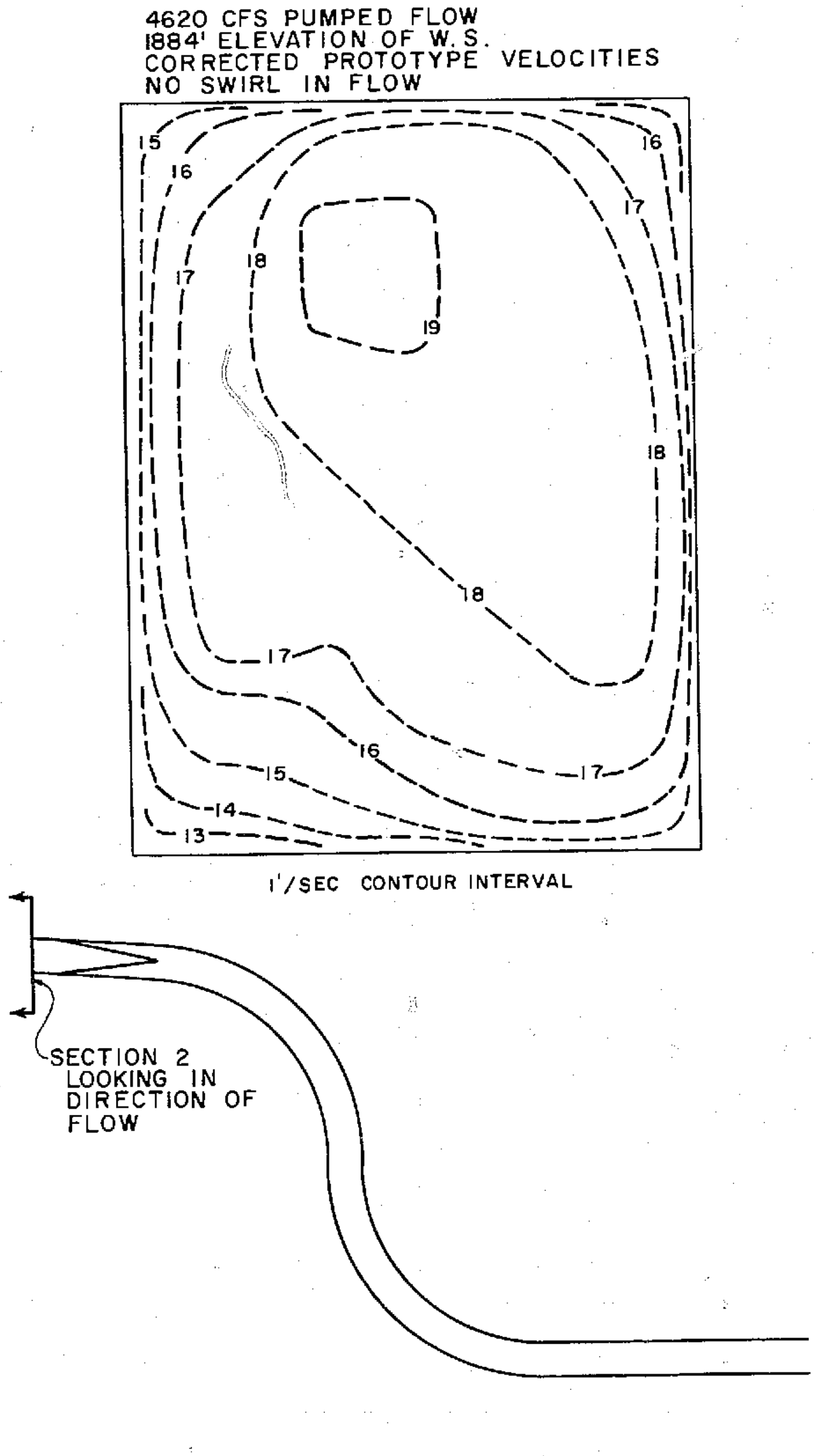

Figure 4A. Horse Mesa Hydroelectric Expansion Model Studies, Section 2 velocity distribution.

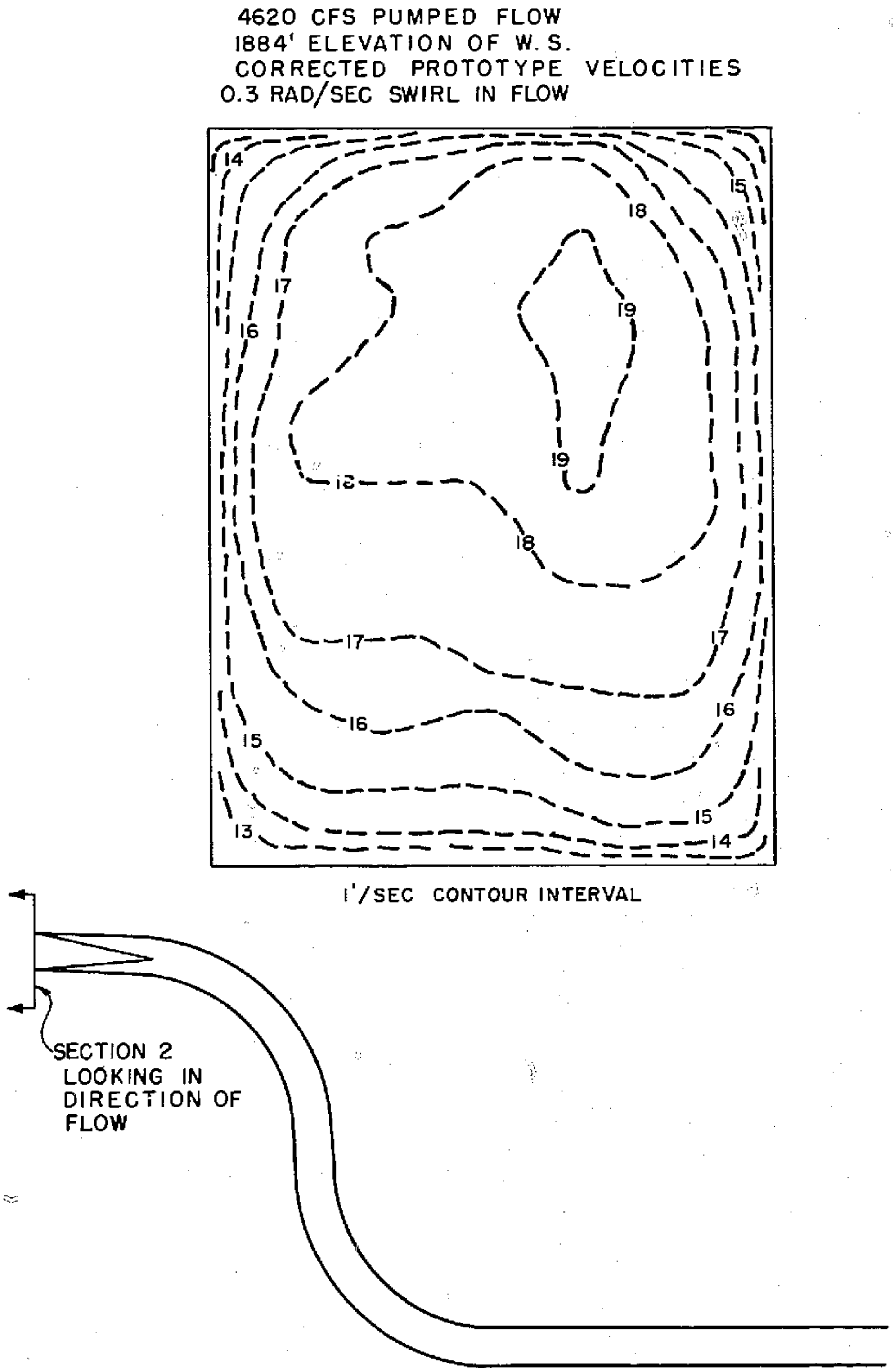

Figure 5A. Horse Mesa Hydroelectric Expansion Model Studies, Section 2 velocity distribution.

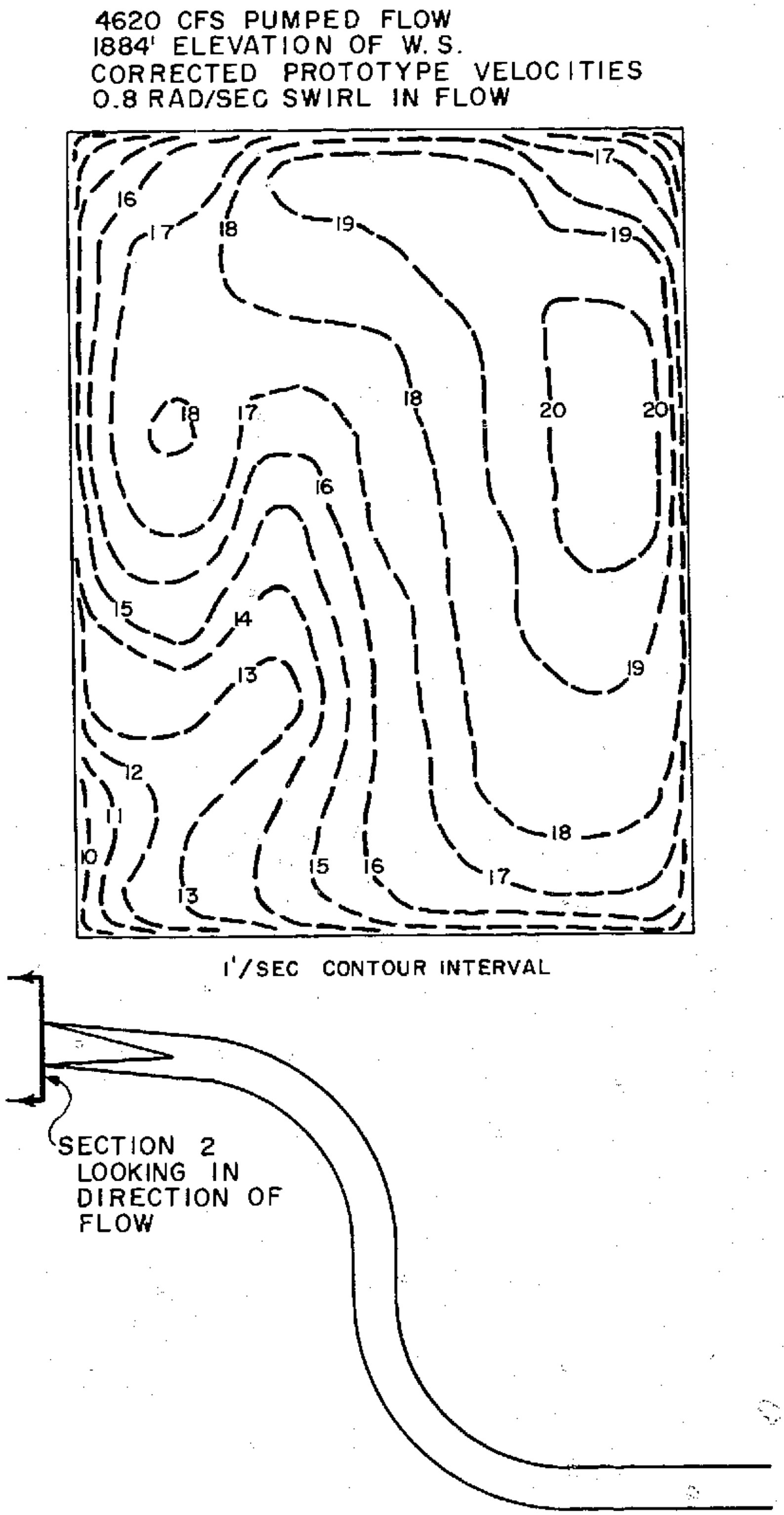

Figure 6A. Horse Mesa Hydroelectric Expansion Model Studies, Section 2, velocity distribution.

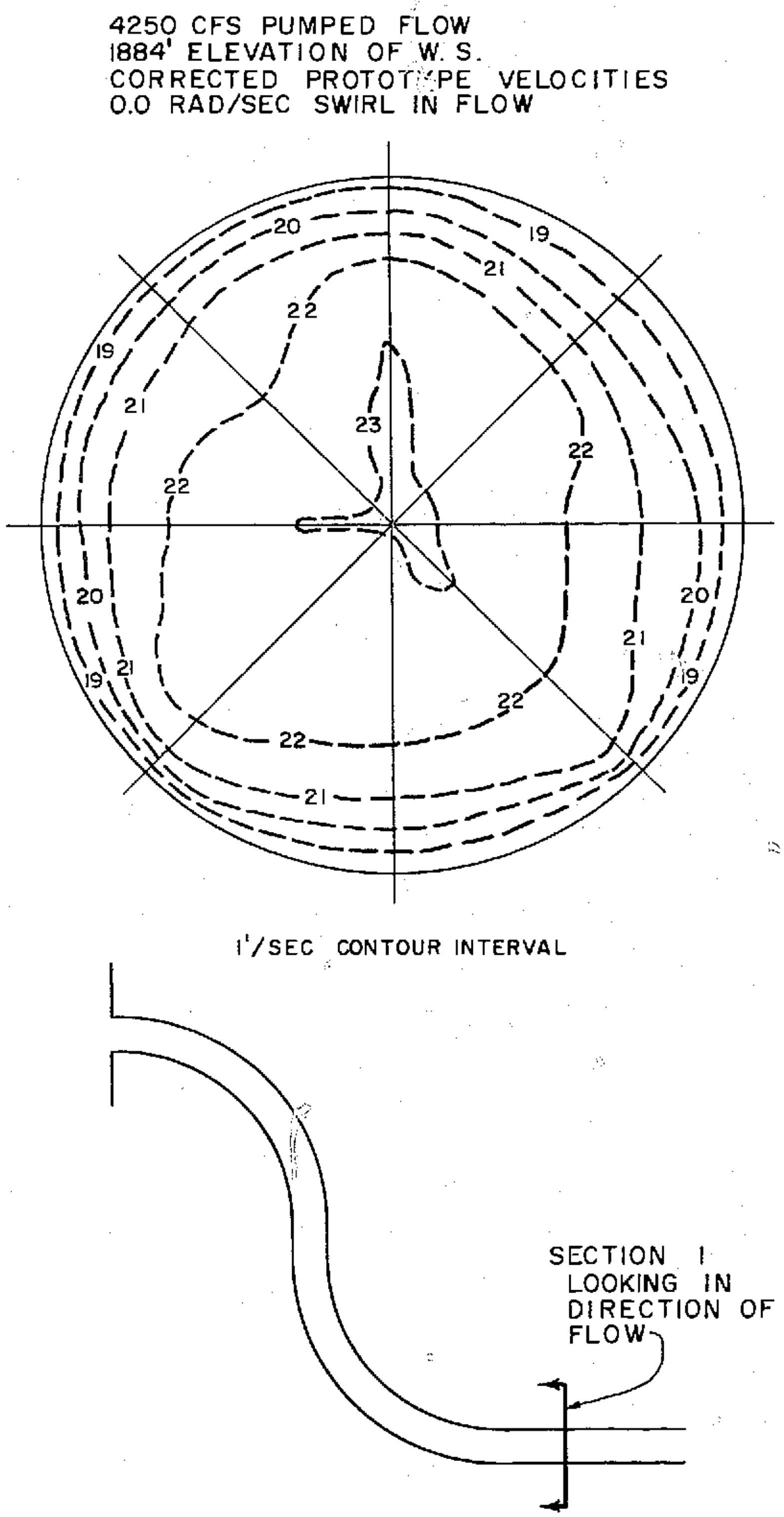

Figure 7A. Horse Mesa Hydroelectric Expansion Model Studies, Section 1 velocity distribution.

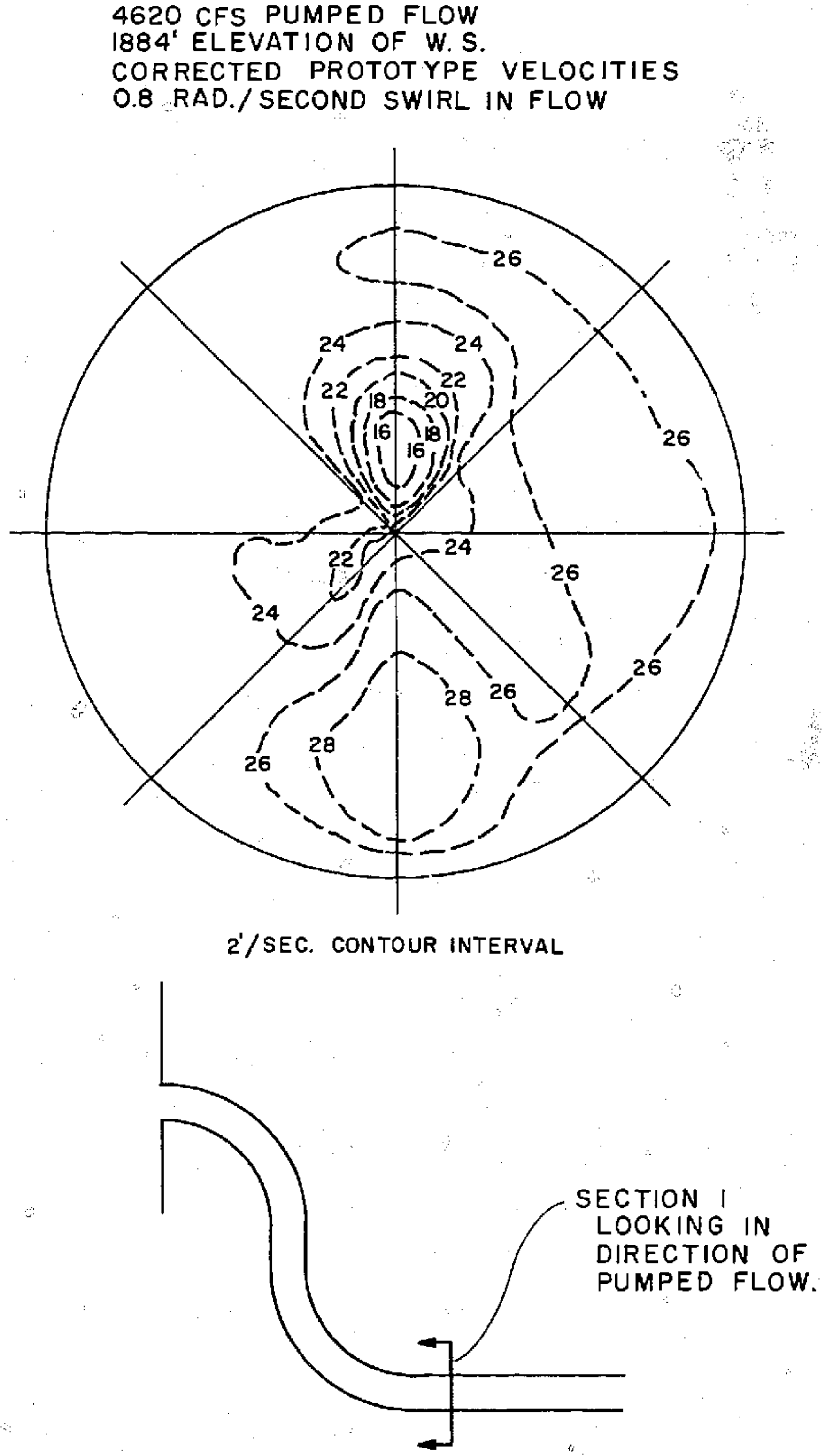

Figure 8A. Horse Mesa Hydroelectric Expansion Model Studies, Section 1 velocity distribution.

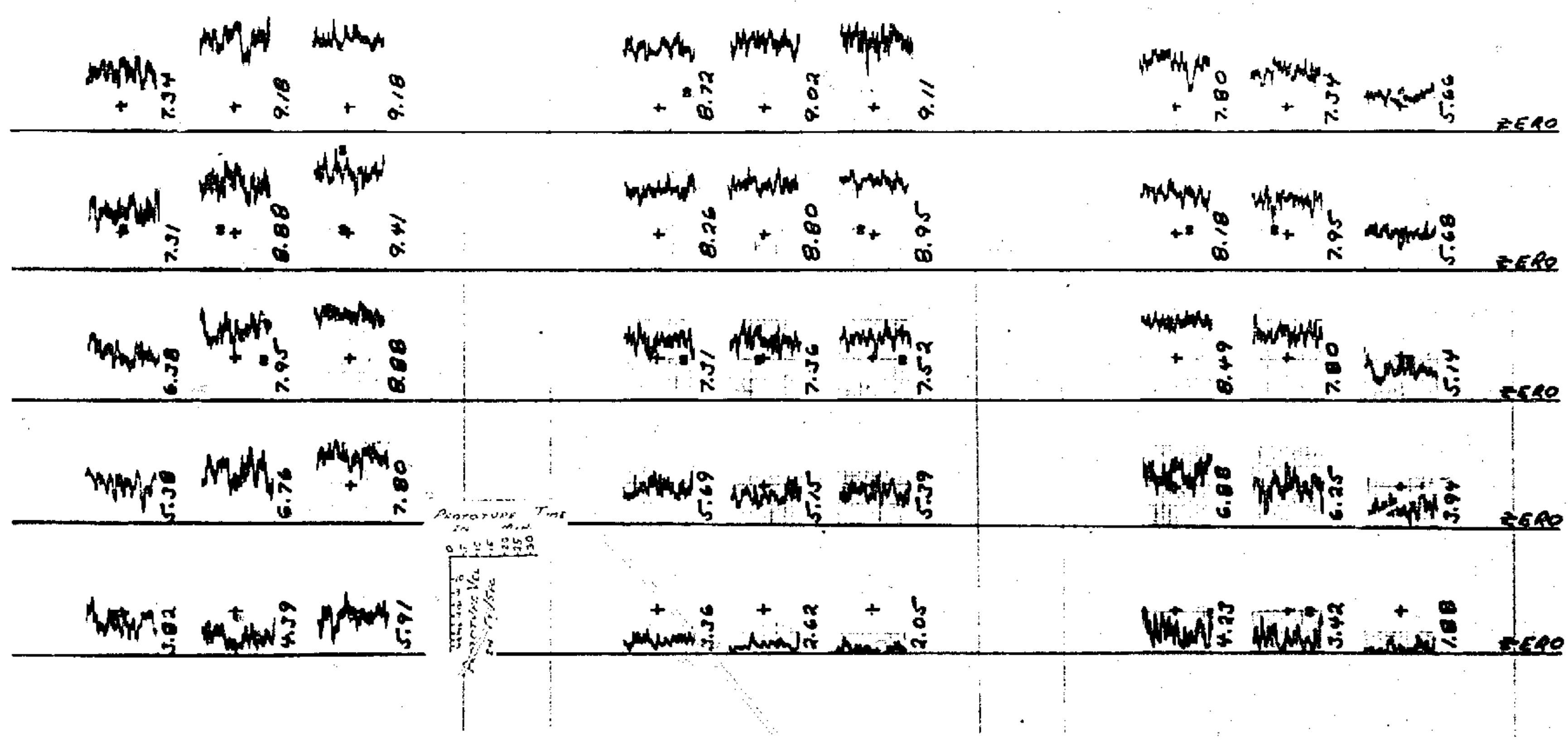

Figure 9A. Horse Mesa Hydroelectric Expansion Model Studies, velocity distribution at trashrack, Alteration 1, angular velocity = 0.0rad/sec, discharge = 4620cfs, looking in direction of pumped flow.

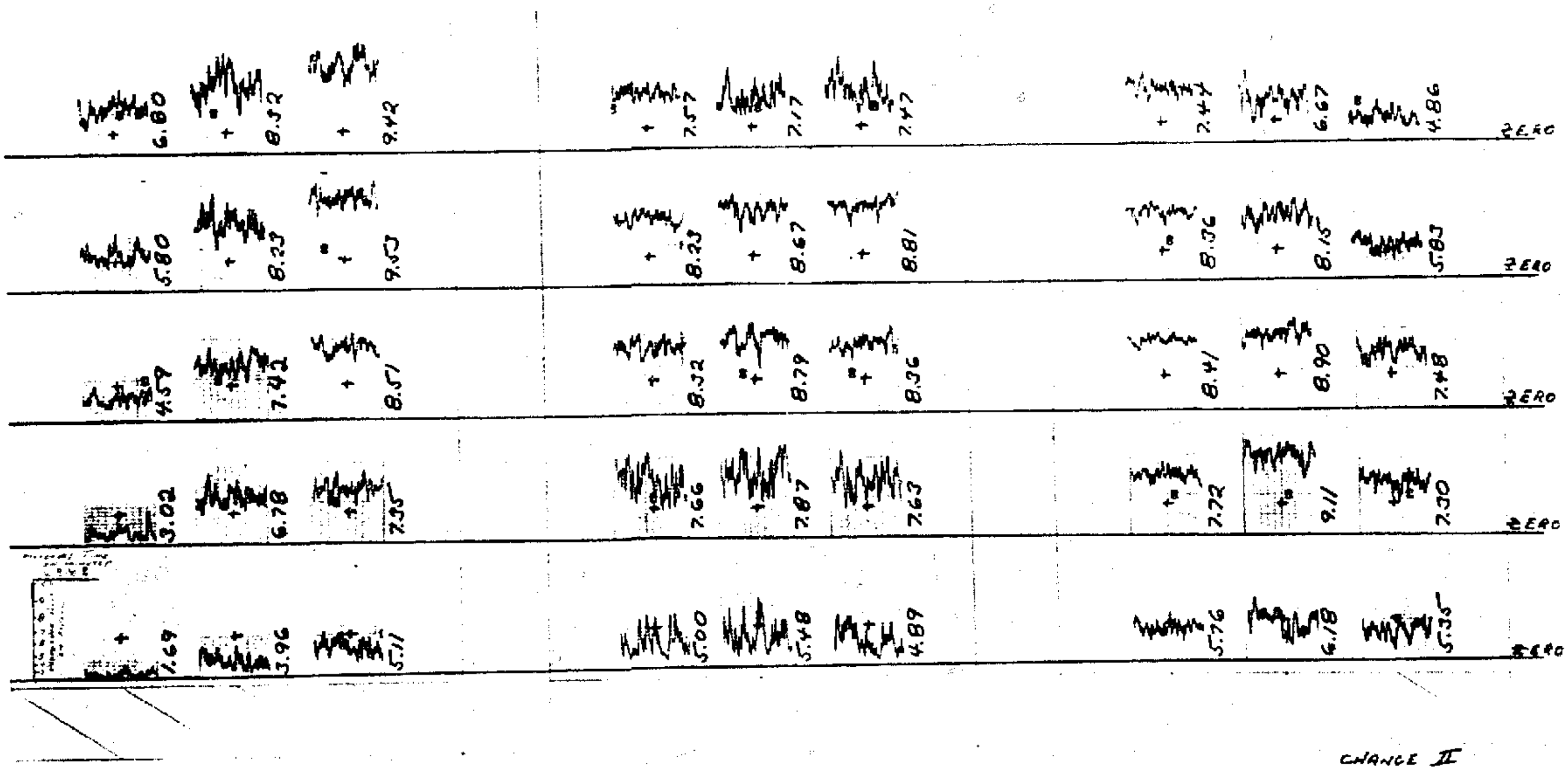

Figure 10A. Horse Mesa Hydroelectric Expansion Model Studies, velocity distribution at trashrack position, Alteration 2, angular velocity = 0.0rad/sec, discharge = 4620cfs, looking in direction of pumped flow.

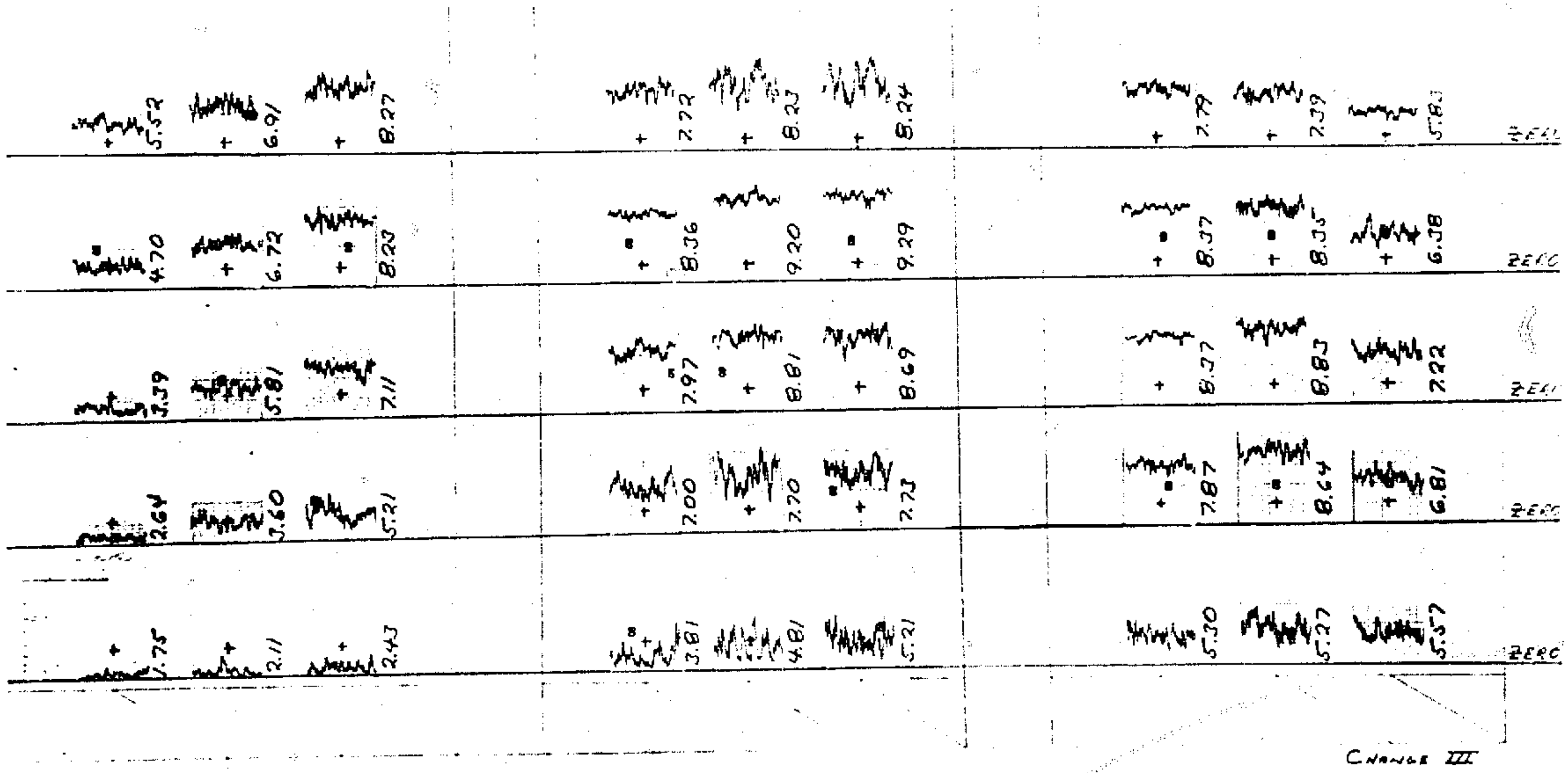

Figure 11A. Horse Mesa Hydroelectric Expansion Model Studies, velocity distribution at trashrack, Alteration 3, angular velocity = 0.0rad/sec, discharge = 4250cfs, looking in direction of pumped flow.

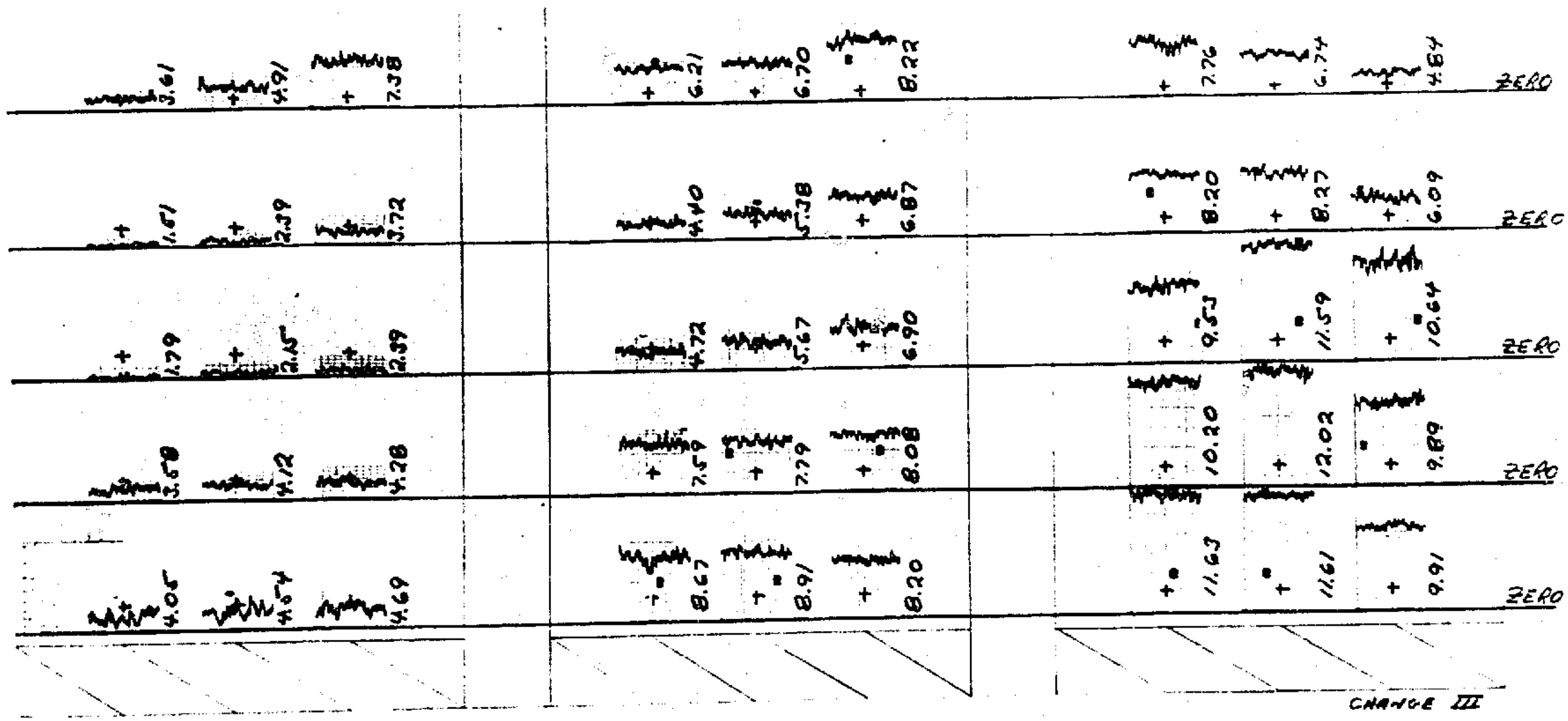

Figure 12A. Horse Mesa Hydroelectric Expansion Model Studies, velocity distribution at trashrack position, Alteration 3, angular velocity = 0.8rad/sec, discharge = 4250cfs, looking in direction of pumped flow.

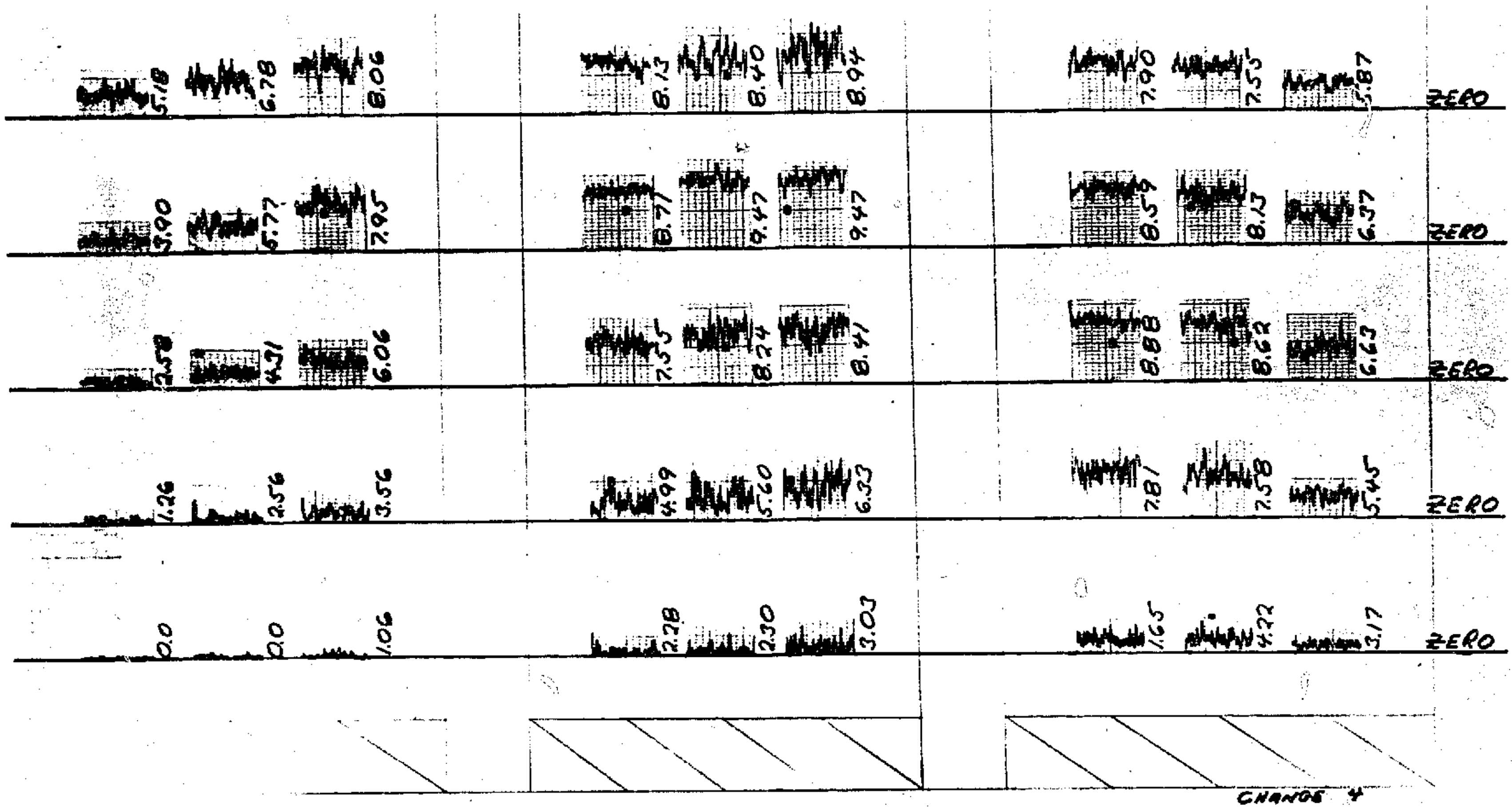

Figure 13A. Horse Mesa Hydroelectric Expansion Model Studies, velocity distribution at trashrack position, Alteration 4, angular velocity = 0.0rad/sec, discharge = 4250cfs, looking in direction of pumped flow.

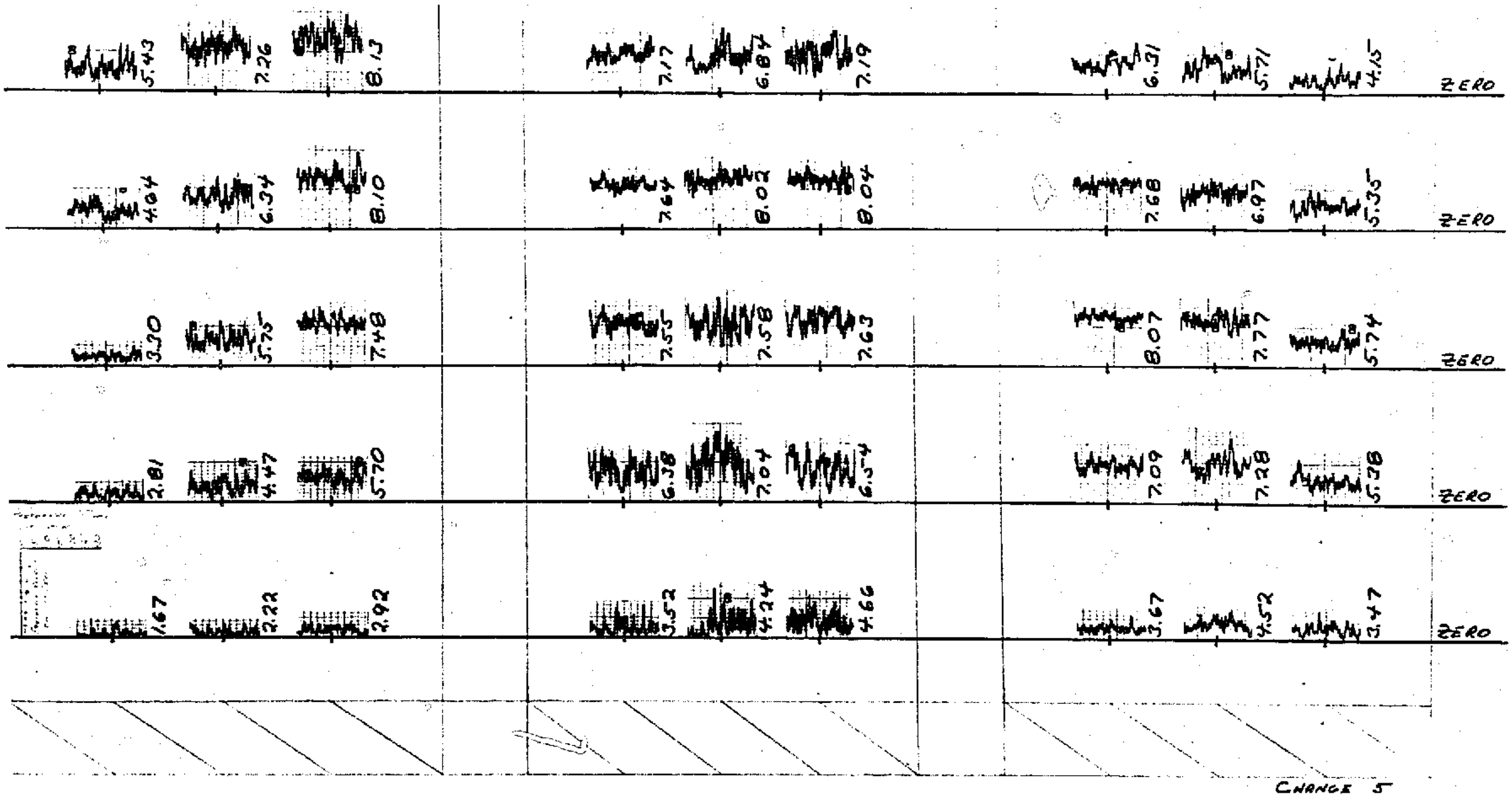

Figure 14A. Horse Mesa Hydroelectric Expansion Model Studies, velocity distribution at trashrack position, Alteration 5, angular velocity = 0.0rad/sec, discharge = 4250cfs, looking in direction of pumped flow.

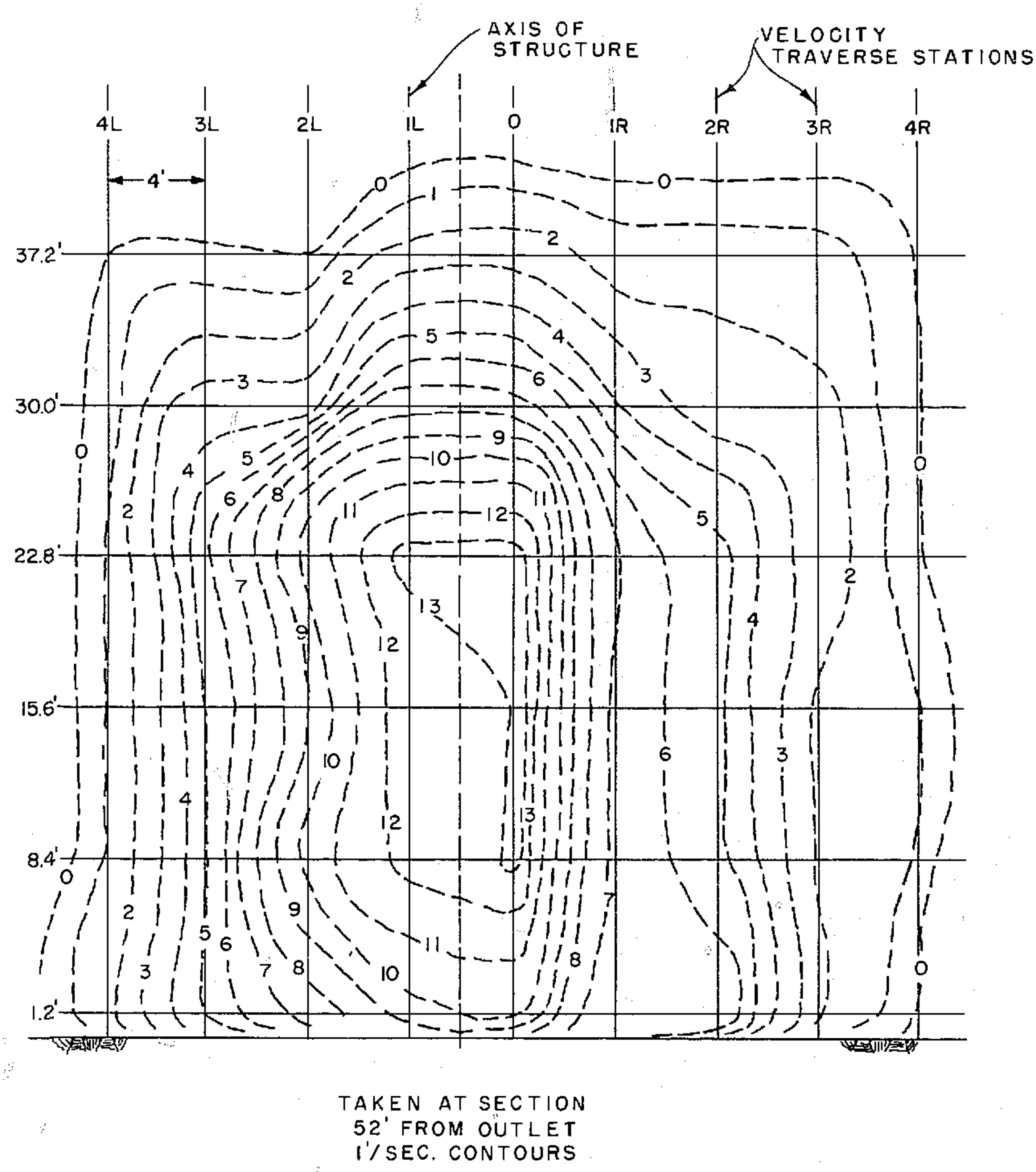

Figure 15A. Horse Mesa Hydroelectric Expansion Model Studies, free jet outlet velocity distribution.

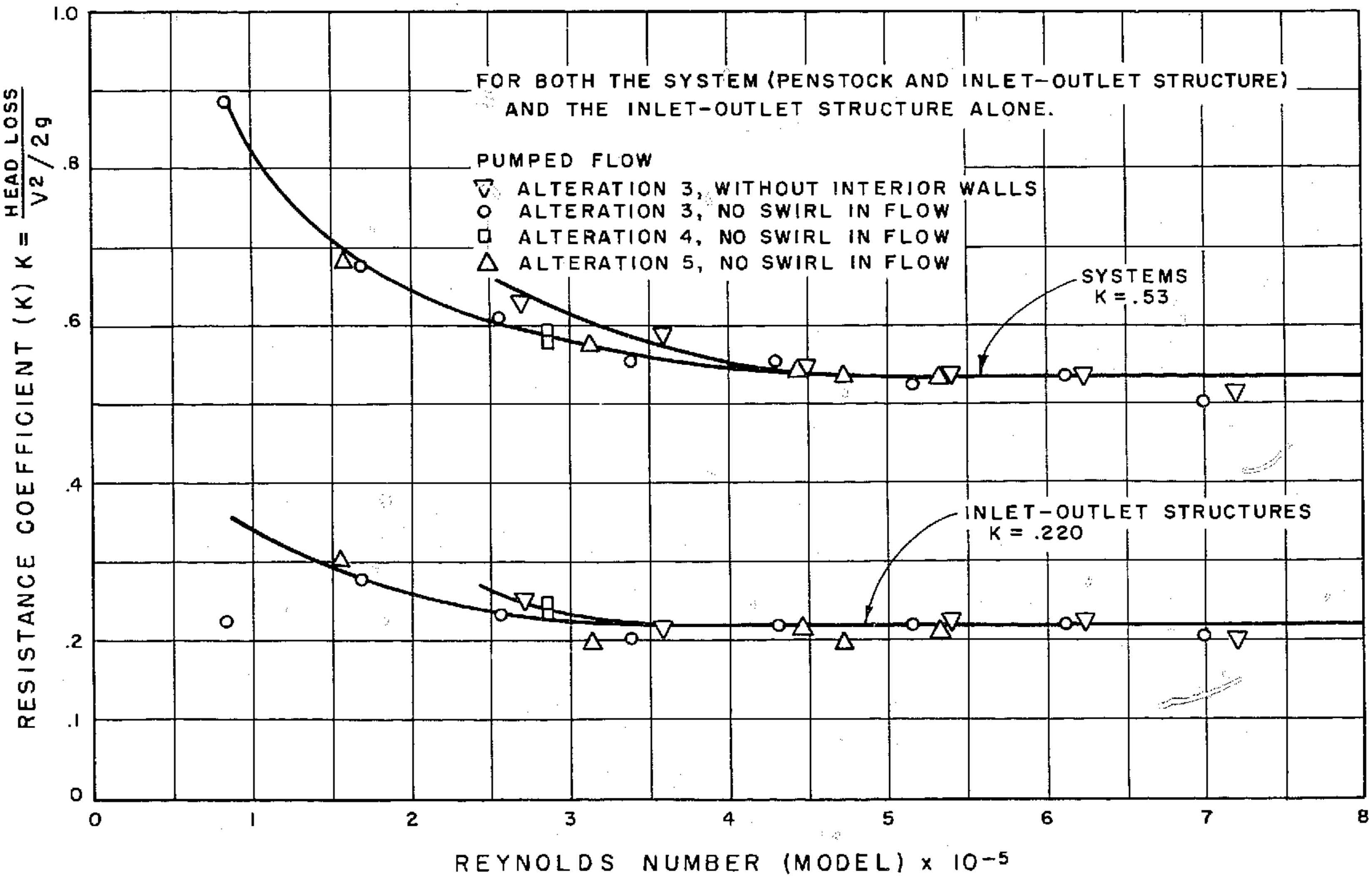

Figure 16A. Horse Mesa Hydroelectric Expansion Model Studies, Reynolds number vs. resistance coefficient.

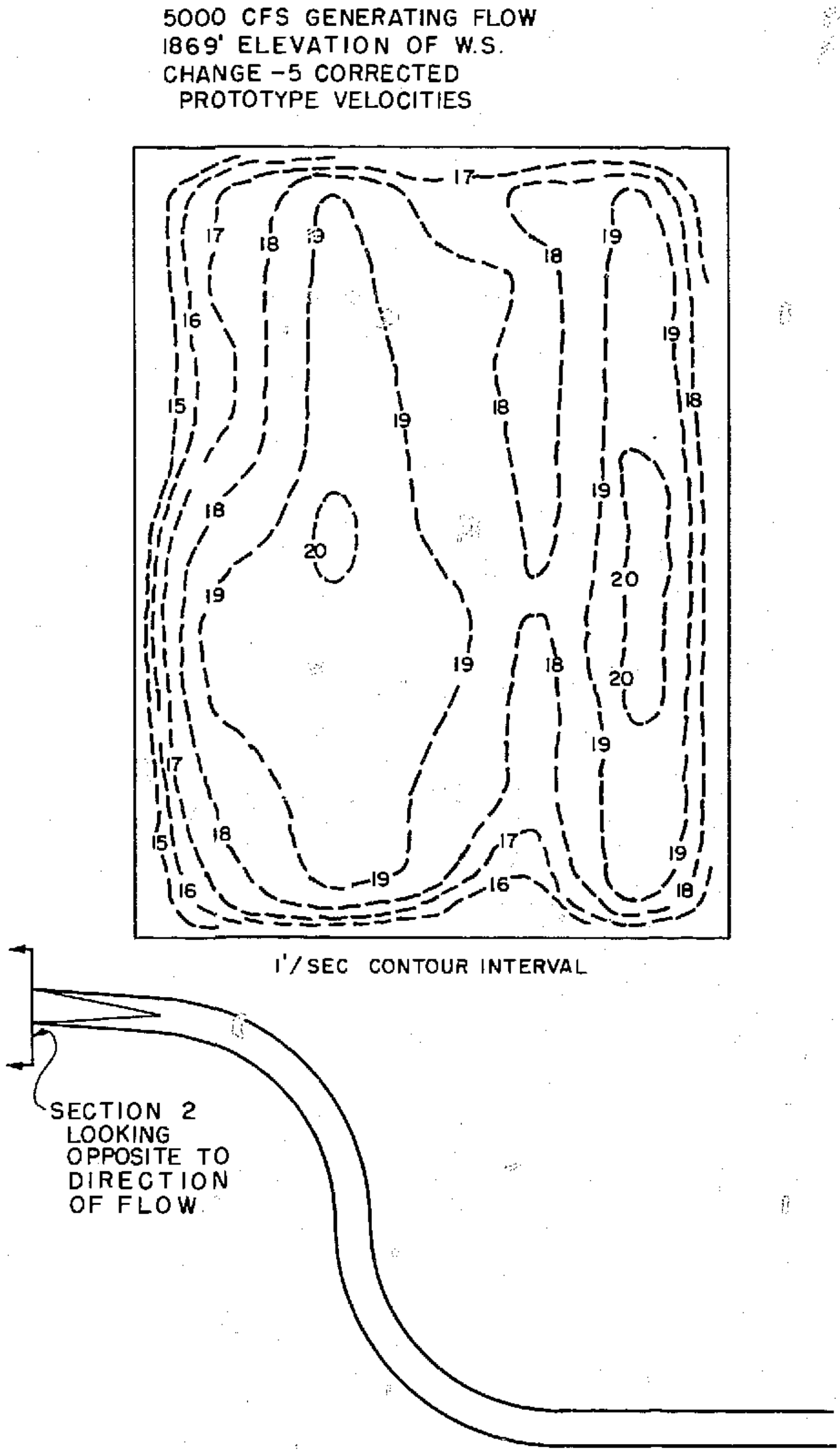

Figure 17A. Horse Mesa Hydroelectric Expansion Model Studies, Section 2 velocity distribution.

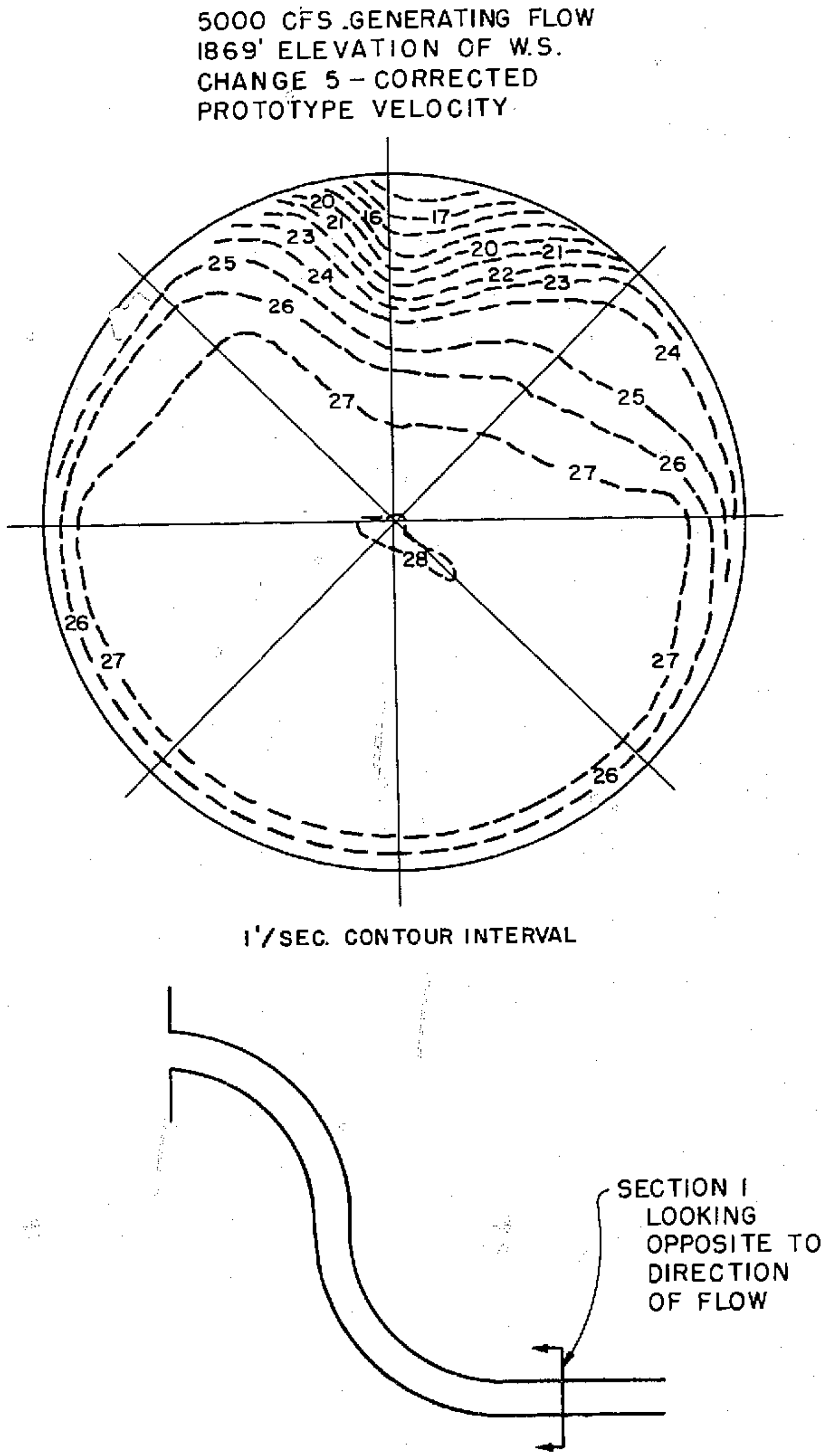

Figure 18A. Horse Mesa Hydroelectric Expansion Model Studies, Section 1 velocity distribution.

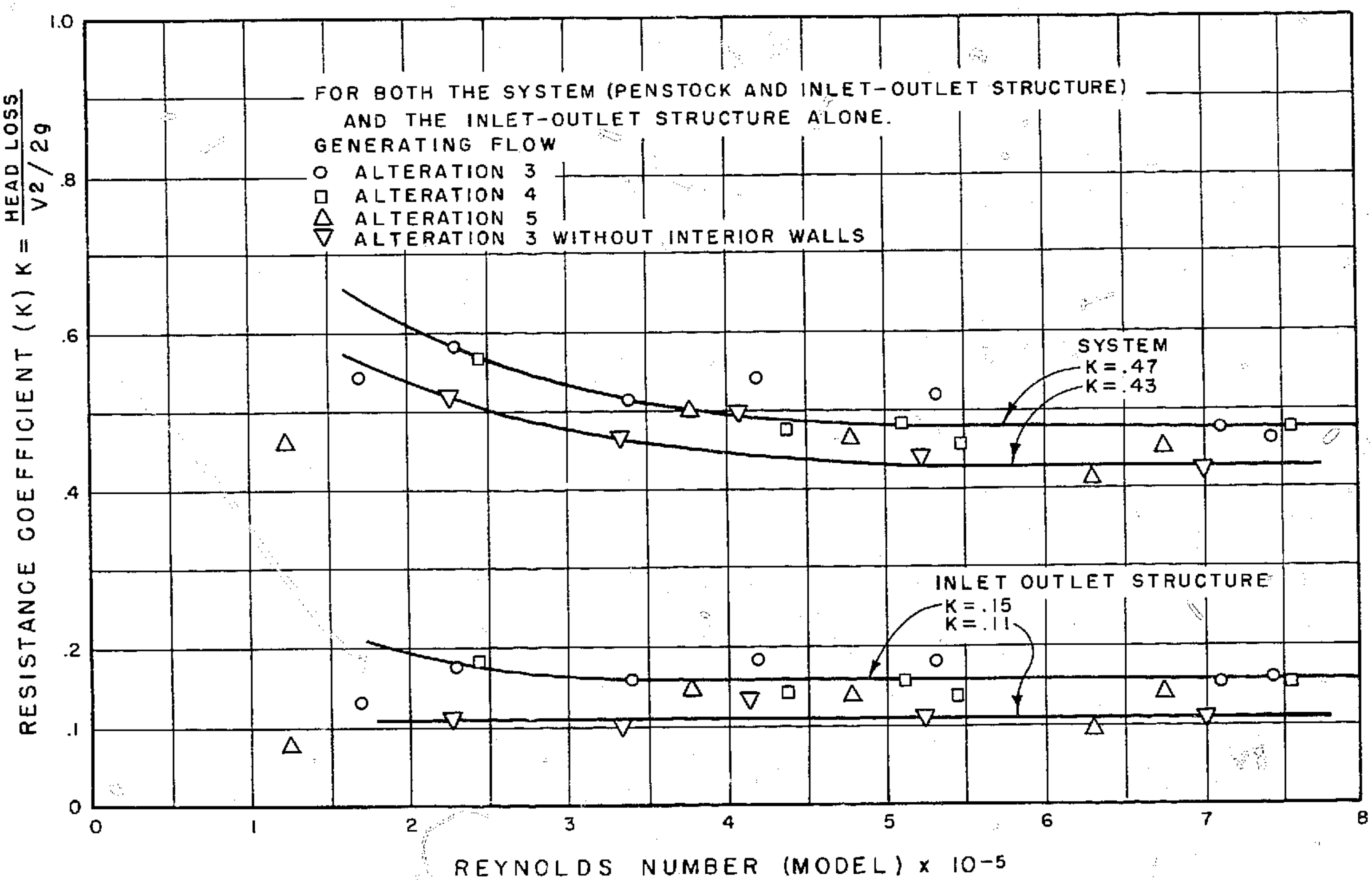

Figure 19A. Horse Mesa Hydroelectric Expansion Model Studies, Reynolds number vs. resistance coefficient.

7-1750 (3-71)
Bureau of Reclamation

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, E 380-68) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given in 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.

Where approximate or nominal English units are used to express a value or range of values, the converted metric units in parentheses are also approximate or nominal. Where precise English units are used, the converted metric units are expressed as equally significant values.

Table I

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
Inches	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
Feet	0.3048 (exactly)*	Meters
Feet	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
Miles	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	*929.03	Square centimeters
Square feet	0.092903	Square meters
Square yards	0.836127	Square meters
Acres	*0.40469	Hectares
Acres	*4,046.9	Square meters
Acres	*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
Fluid ounces (U.S.)	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
Liquid pints (U.S.)	0.473166	Liters
Quarts (U.S.)	*946.358	Cubic centimeters
Quarts (U.S.)	*0.946331	Liters
Gallons (U.S.)	*3,785.43	Cubic centimeters
Gallons (U.S.)	3.78543	Cubic decimeters
Gallons (U.S.)	3.78533	Liters
Gallons (U.S.)	*0.00378543	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
Gallons (U.K.)	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	*764.55	Liters
Acre-feet	*1,233.5	Cubic meters
Acre-feet	*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
Short tons (2,000 lb)	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
Pounds per square inch	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
Pounds per square foot	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
Pounds per cubic foot	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
Inch-pounds	1.12985×10^6	Centimeter-dynes
Foot-pounds	*0.138255*	*Meter-kilograms*
Foot-pounds	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
Feet per second	0.3048 (exactly)*	**Meters per second**
Feet per year	$*0.965873 \times 10^{-6}$	Centimeters per second
Miles per hour	1.609344 (exactly)	**Kilometers per hour**
Miles 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
Pounds	*4.4482	Newtons
Pounds	$*4.4482 \times 10^5$	Dynes

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Table II—Continued

Multiply	By	To obtain
WORK AND ENERGY*		
British thermal units (Btu)	*0.252	Kilogram cal
British thermal units (Btu)	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 degree F (k, thermal conductivity)	1.442	Milliwatts/cm degree C
Btu in./hr ft^2 degree F (k, thermal conductivity)	0.1240	Kg cal/hr m degree C
Btu ft/hr ft^2 degree F	*1.4880	Kg cal m/hr m^2 degree C
Btu/hr ft^2 degree F (C, thermal conductance)	0.568	Milliwatts/cm^2 degree C
Btu/hr ft^2 degree F (C, thermal conductance)	4.882	Kg cal/hr m^2 degree C
Degree F hr ft^2/Btu (R, thermal resistance)	1.761	Degree C cm^2/milliwat
Btu/lb degree F (c, heat capacity)	4.1868	J/g degree C
Btu/lb degree F	*1.000	Cal/gram degree C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
Ft^2/hr (thermal diffusivity)	*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)	*0.092903	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

ABSTRACT

Hydraulic model studies were performed to assure satisfactory flow conditions through the reservoir inlet-outlet structure for a pump-storage unit at Horse Mesa Dam, Ariz. The studies were considered necessary because of unsymmetrical approach flow caused by the penstock configuration. The main purpose for the studies was to develop a design to provide a uniform velocity distribution at the trashrack. Uniform velocity distribution would eliminate any chance of forming strong vortex shedding and ensure a trashrack free from the danger of fatigue failure. The model was at a 1:24 scale and included the inlet-outlet structure, a rectangular-to-circular transition, and the penstock down to the spiral case. Velocity distribution and head loss measurements were made for the penstock and inlet-outlet structure. Two vertical walls were placed in the structure to improve the horizontal velocity distribution at the trashrack position. A low-velocity area was removed by making the floor of the structure nondivergent. The structure was then lengthened to restore the initial trashrack area.

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REC-ERC-71-34
Johnson, P L
HYDRAULIC MODEL STUDIES OF THE RESERVOIR INLET-OUTLET STRUCTURE FOR HORSE MESA PUMP-STORAGE UNIT--SALT RIVER PROJECT, ARIZONA. Bur Reclam Rep REC-ERC-71-34, Div Gen Res, Sep 1971. Bureau of Reclamation, Denver, 30 p, 26 fig, 3 tab, append

DESCRIPTORS—/ pump turbines/ *head losses/ spiral cases/ jets/ Reynolds number/ *penstocks/ trashracks/ axial flow/ vortices/ turbulence/ design improvements/ pumping plants/ *flow distribution/ *model studies/ design modifications/ *hydraulic models/ hydraulic properties/ *pumped storage/ model tests/ flow control/ *outlet works.
IDENTIFIERS—/ Horse Mesa Dam, Ariz

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