PAP-580

RESOURCE CONSULTANTS INC

ENGINEERING REPORT

HYDRAULIC INVESTIGATION OF OUTLET WORKS AND STILLING BASIN

TAYLOR DRAW DAM/KENNEY RESERVOIR, RANGELY, COLORADO

For

Water Users' Association No. 1
Rangely, Colorado

by

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1.0 INTRODUCTION

1.1 Background

Taylor Draw Dam and Kenney Reservoir are located on the White River, six miles northeast of Rangely in Rio Blanco County, Colorado. The dam and reservoir are owned and operated by Water Users' Association No. 1 in the Colorado River Water Conservation District to provide recreational, municipal, industrial, and agricultural water to the Western White River Basin.

Taylor Draw Dam was completed in October 1984 and is a five-zoned earthfill structure with a reinforced earth panel spillway face. The dam is 74 feet high with a maximum base width of 190 feet and a crest width of 20 feet. The crest length is 1,150 feet at an elevation of 5,329 feet (MSL). Kenney Reservoir has a capacity of 22,230 acre-feet (elevation 5,329 feet) with a surface area of 878 acres. Capacity at normal water surface (elevation 5,317.5 feet) is 13,800 acre-feet with a surface area of 615 acres.

Flow can be conveyed past the dam over an overflow spillway on the right (west) side of the dam or through a gated outlet works structure. The spillway has a concrete uncontrolled ogee crest at an elevation of 5,317.5 feet and a length of 505 feet. Spillway capacity is 69,426 cfs at an elevation of 5,329 feet. The outlet works consists of two separate conduits, a 96-inch conduit which will ultimately serve a hydroelectric powerplant (approximately 2 megawatts) and a 24-inch conduit that may be used for municipal or industrial purposes. Water enters the 96-inch and 24-inch pipes after passing through an intake structure consisting of a concrete box 17 feet by 18 feet with three sides covered by 12'x12' trashracks. The water then travels through 330 feet of pipe. The end of the 96-inch pipe culminates in a wye where the water can be discharged either through a 78-inch pipe into a stilling basin or, in the future, directly into the powerplant.

The 96-inch conduit to the future powerplant is presently blind flanged about 100 feet downstream from the bifurcation. Flow through the 78-inch conduit is controlled by a 6.5'x6.5' slide gate located at the downstream end. During construction a blockout wider than the control gate was formed to provide room to install the gate. After gate installation the remaining blockout area was not grouted. Thus, the conduit walls immediately upstream of the gate frame contain large vertical slots (roughly 1.25 feet wide by 1.0 foot deep). After passing through the stilling basin, the water flows through a riprapped channel before emptying into the original river channel. The stilling basin is similar to a USBR Type III basin (see Figure 1.1).

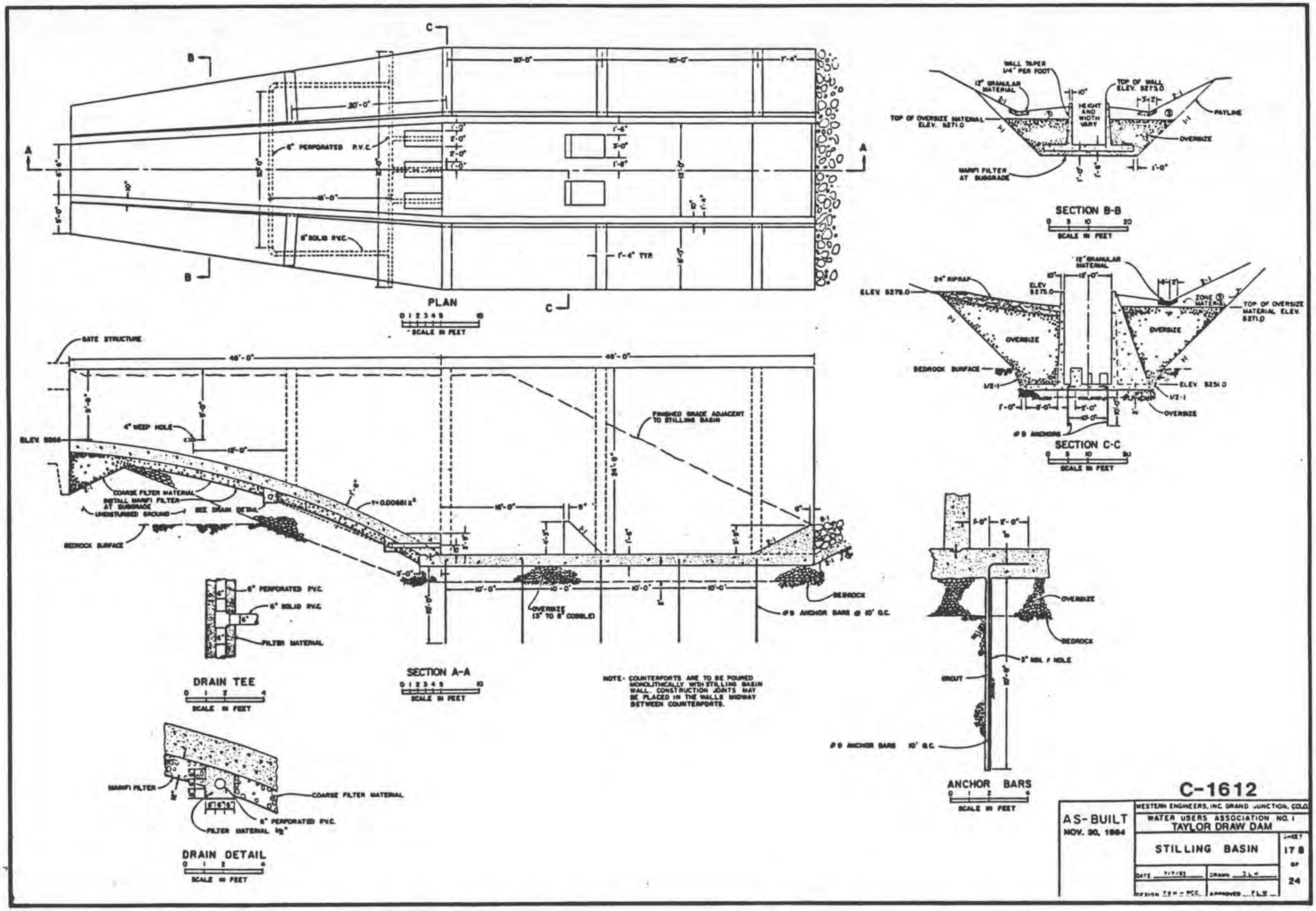


Figure 1.1: AS-BUILT STILLING BASIN PLAN & PROFILE

During an inspection in 1987 it was found that significant damage had occurred to the concrete walls and floor of the stilling basin. The damage was attributed to the abrasive action of rocks churning in the flow. It was suspected that rocks were entering the basin by falling or being thrown into the stilling basin. The basin was dewatered, the concrete was repaired with silica fume concrete, and a cover was placed over the stilling basin. In September 1989, a subsequent inspection by divers revealed that similar damage to the concrete surface had occurred again.

The Water Users' Association No. 1 (WUA#1), through the Colorado River Water Conservation District (River District), retained Resource Consultants, Inc. (RCI) to determine the cause(s) of the damage to the stilling basin and recommend corrective measures. After an initial site reconnaissance, RCI recommended that a physical hydraulic model study be conducted to determine the cause(s) of damage sustained by the stilling basin and as a basis for developing an engineering solution. The River District contacted the U.S. Bureau of Reclamation (USBR) and a contract was negotiated to perform the recommended hydraulic model study at the Bureau's Hydraulics Laboratory at the Denver Federal Center, Denver, Colorado.

This report summarizes the site investigations necessary to support the USBR hydraulic model study and the results of the Bureau's model study. Based on the USBR model study, engineering recommendations are provided for corrective actions necessary to prevent occurrence of similar damage to the stilling basin in the future. A scope of work and cost estimate for design and construction supervision of the recommended corrective measures are also provided.

1.2 Objectives and Scope of Work

The objectives of this investigation were:

1. To conduct a hydraulic engineering analysis, including hydraulic model study at the USBR's Hydraulics Laboratory to determine the cause(s) of damage being sustained by the concrete lining of the outlet works energy dissipator/stilling basin, and

2. To develop conceptual plans for a solution.

For purposes of cost estimation and project control the investigation was completed under the following tasks:

Task 1 - Develop a Scope of Work for the investigation and coordinate with USBR on a scope of work for the hydraulic model study.

Task 2 - Site visit and inspection (with USBR).

Task 3 - Obtain general background data and site specific sediment data to support modeling and analysis.

Task 4 - Coordinate the hydraulic model study at USBR's Denver laboratory.

Task 5 - Prepare an Engineering Report identifying the cause(s) of damage to the stilling basin/outlet works, recommend a conceptual plan for a solution, and prepare a scope of work and cost estimate for the design and construction supervision of repairs.

Chapter 2.0 of this report presents the results of site visits and field work. Chapter 3.0 summarizes the results of the USBR hydraulic model study of the outlet works and stilling basin. (The USBR report, "Physical Hydraulic Modeling Study of Taylor Draw Outlet Works," is attached as Appendix B.) Chapter 4.0 presents a conceptual plan for repair of the outlet works and stilling basin, and summarizes the results of an assessment of operability of the facility during the interim period prior to repair. Finally, Chapter 5.0 provides a scope of work and cost estimate for the design and construction supervision of the repairs.

2.0 SITE INVESTIGATION

2.1 Introduction

Several site reconnaissance visits were required to determine the extent of damage to the outlet works and as a basis for developing the project scope and model study requirements.

These site visits included:

September 28, 1989	Observe outlet works in operation, review as-built drawings, and obtain photographs of the damage and repairs in 1987. Discuss original design and repairs with representatives of Water Users' Association No. 1 and Western Engineers, Inc. of Grand Junction, Colorado.
October 25, 1989	Visit site with representative from Colorado State University to discuss requirements for hydraulic model study, and inspect damages with outlet works partially dewatered.
November 14, 1989	Attend Operating Commission meeting in Rangely, Colorado to provide recommendations on scope of investigation and answer questions on the model study recommendation.
March 12, 1990	Site visit with USBR representative to observe outlet works in operation and obtain video and still photography for a range of gate openings.
May 8-10, 1990	Field work and analyses to establish hydraulic control for the hydraulic model and obtain data on sediment and rip rap conditions.

Field data collection was necessary to evaluate sediment deposition in the reservoir near the inlet gate, and to provide information for the physical model study. The Soil Conservation Service (SCS)completed reservoir surveys in 1988; however, the sediment range nearest to the dam was about 1 mile upstream of the dam axis. In order to evaluate the significance of sediment abrasion to concrete erosion in the outlet works, better information on sediment deposition near the intake structure was required. Therefore, additional reservoir surveys concentrated in the vicinity of the dam and intake structure were completed.

For the physical model study an accurate stage-discharge relation in the tailwater area, downstream of the stilling basin, was required. Given the complexities introduced by different downstream hydraulic control points, as created by the multiple channel network and confluences immediately downstream of the stilling basin, a unique (single-valued) stage-discharge relation was thought not to exist (see Figure 2.2). In order to define the stage-discharge relationships, direct field measurements were combined with limited-analytical studies. Additionally, cross section data were collected and riprap sizes were evaluated to support or supplement information on the as-built drawings.

2.2 Reservoir Surveys

Sediment deposition in the vicinity of the intake structure was evaluated by depth sounding measurement techniques. Using the Water Users' boat and depth sounder, concentric profiles were completed by tethering the boat from a fence post located at the water's edge, approximately in-line with the intake structure. The location of the fence post was surveyed and a low stretch floating rope was utilized to tether the boat. Concentric profiles were completed at 25 ft intervals up to about a 300 ft radius.

Results of the survey are given in Figure 2.1, with spot elevations at various locations plotted on the as-built topography for the dam. Inspection of these results indicates that 1990 topography matches the as-built topography in all locations, except in the channel approaching the intake structure. At the intake structure the elevation is identical; however, within a short distance upstream sediment deposition up to about 2.5 feet has occurred in the channel.

This result suggests that sediment has been following a path along the thalweg (deepest part) of the original channel from the upper pool area, where significant sediment deposition was documented by the SCS, to the intake structure. The lack of any deposit at the entrance itself indicates that when the outlet works are open sediment is not accumulating around the entrance, but is being passed downstream. A sample of this deposit was not collected; however, considering the sediment characteristics of the upstream watershed and the nature of the deposit in the upper pool, it is thought to be primarily fine-grained material. Nonetheless, this sediment could have a minor contribution to abrasion in the outlet works.

2.3 Stage-Discharge Relation

The stage-discharge relation at the outlet of the stilling basin was evaluated by a combination of direct field measurement and water surface profile analysis. Direct measurements of discharge and water surface elevation

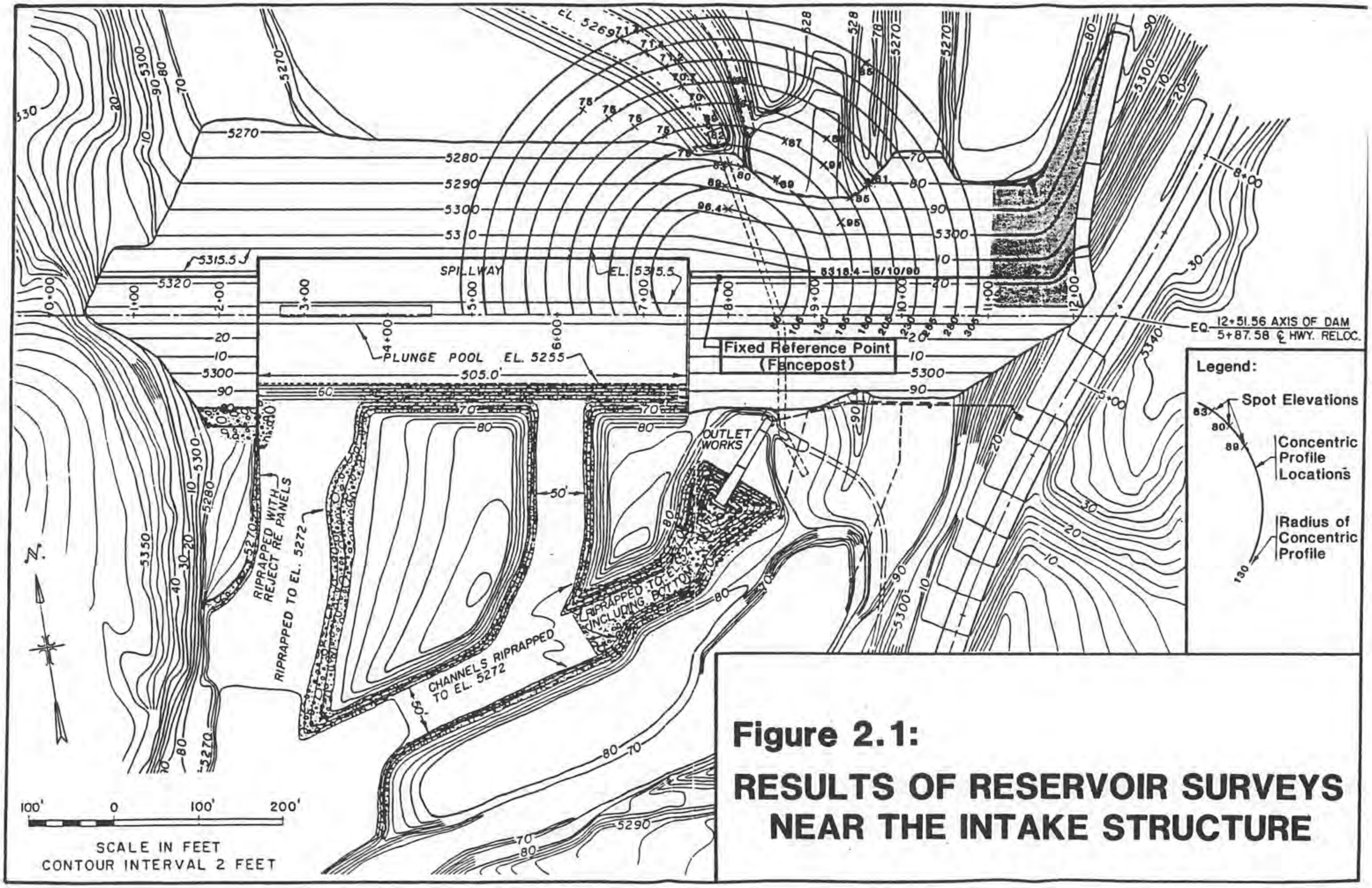


Figure 2.1:

RESULTS OF RESERVOIR SURVEYS NEAR THE INTAKE STRUCTURE

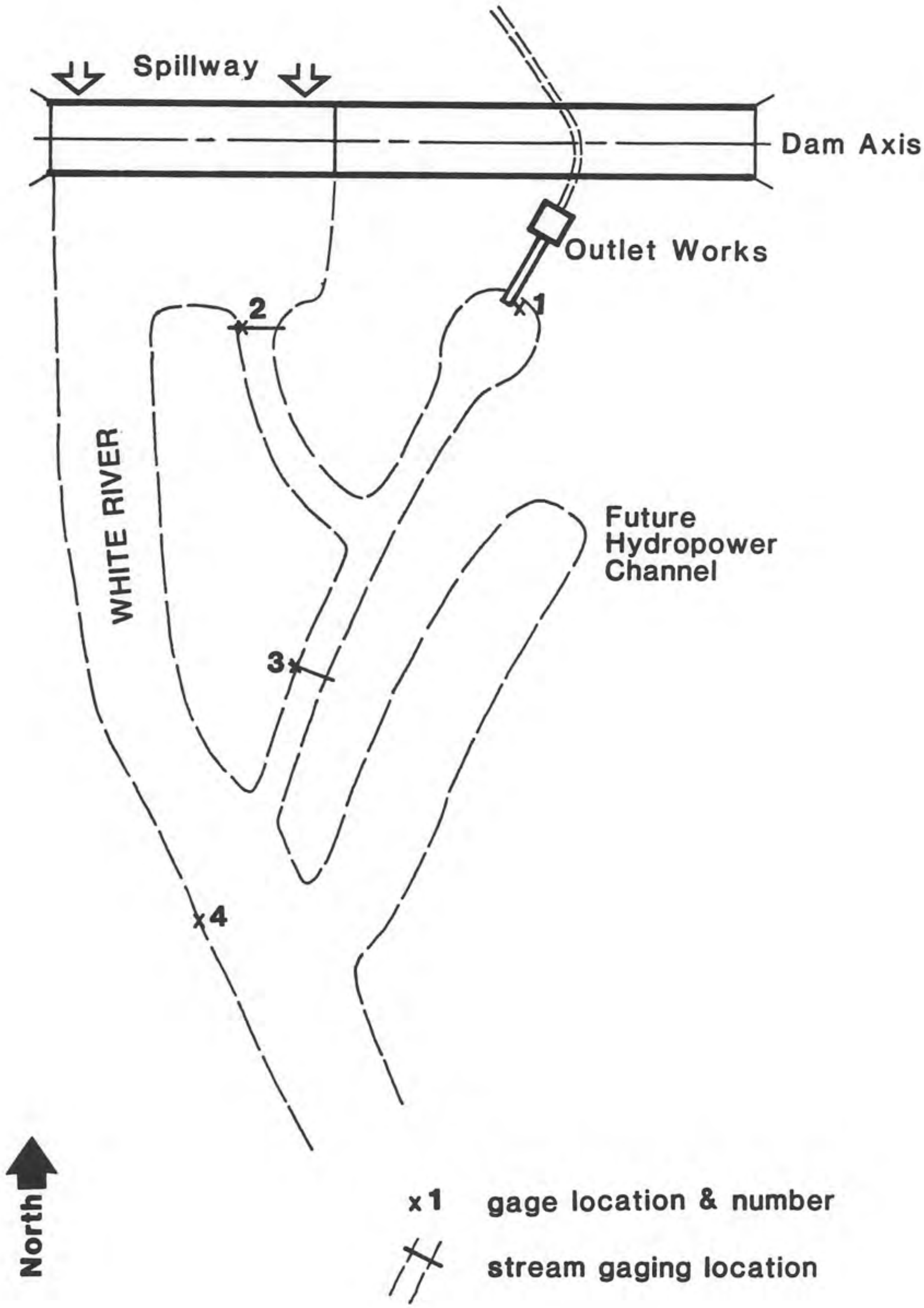


Figure 2.2

STREAM & STAFF GAGING LOCATIONS AT TAYLOR DRAW RESERVOIR

were completed for gate openings of 6, 12, 18, 24, 30 and 36 inches. Due to the turbulence in the outlet channel immediately below the stilling basin, discharge measurements in this reach would not have been reliable; therefore, the channel was gaged in two locations and the discharge at the outlet determined from the continuity equation. One location was in the spillway channel (location 2 in Figure 2.2) and the other was in the outlet channel below the confluence of the spillway channel (location 3 in Figure 2.2). Figure 2.2 also identifies the locations where water surface elevation measurements were made. These measurements were completed by staff gages that were installed and surveyed to a common datum.

As expected, the variety of channels and confluences created different hydraulic control points at various flow conditions depending on the flow through the outlet works and over the spillway. In fact, flow in the smaller spillway channel reversed direction for gate openings larger than 18 inches. Below the 18 inch gate opening the flow direction was downstream; at the 18 inch opening virtually no flow occurred in this channel, and above an 18 inch opening the flow direction was upstream towards the dam. The location of reverse flow will likely vary with the quantity of water flowing over the spillway, which was relatively small during the field measurements.

The field measured data defined the stage-discharge relationship for a given set of downstream conditions. To evaluate other scenarios the measured data were utilized to calibrate a HEC-2 water surface profile model. Field measured cross sections (see Section 2.4) were used in the analysis. Calibration was based on matching the measured water surface elevations for the six measured flow conditions by adjusting the channel Manning n value. The resulting n value was 0.045, which is consistent with the roughness created by the large riprap in the outlet channel.

Results of this analysis are summarized in Figure 2.3. The low tailwater (TW) condition was based on the conditions in the White River the day the measurements were completed, while the high TW condition assumed that the stage on the White River was 2.0 feet higher, which was considered indicative of a significantly greater amount of water passing over the spillway. As would be expected, the influence of the downstream tailwater condition diminished with higher discharge through the outlet works. The band width defined by the low and high tailwater conditions defines the expected operating range of tailwater conditions in the outlet works for given discharges. These results were then used to define expected prototype conditions for the physical model study.

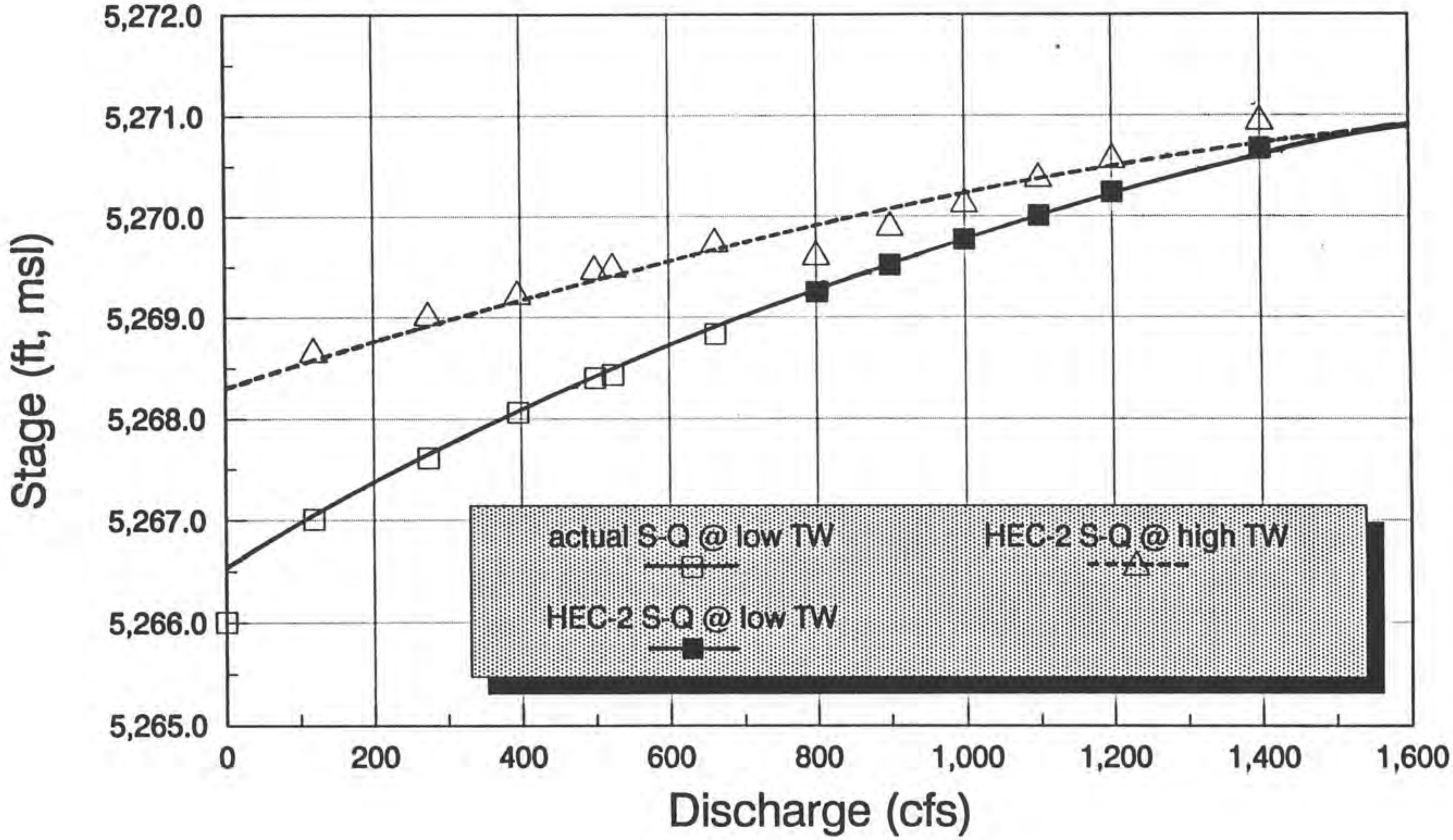
A secondary benefit of the field measured stage-discharge was confirmation of the rating curve relationship for the outlet gate. Determination of discharge through the outlet works has been based on the gate opening, as defined by a graduated rod attached to the gate in the gatehouse. There were

Figure 2.3

Taylor Draw Outlet Canal

Stage-discharge Relationship

HEC-2 cross section #5



some questions as to the accuracy of this method, and consideration that the staff gages installed for the field measurements in the various channels might provide an alternate gaging method. Review of the measured data indicate that the gate opening method is accurate to about +/- 15%, which is not unreasonable for a simplified rating procedure (see Table 2.1). Given the complexities of the downstream flow conditions as determined by field measurement, including the reverse flow effect, development of a rating method based on the staff gages would not provide any better accuracy than the current method based on gate opening.

Table 2.1. Measured stage-discharge data compared to gate rating curve for a reservoir pool elevation of 5,018.

Gate Opening (inches)	Gate Rating (cfs)	Gaged Value (cfs)
6	132	116
12	263	274
18	393	396
24	521	500
30	646	524
36	767	662

2.4 Other Data Collection

Other data collection included cross section surveying of the outlet channel, and surveying the size of the outlet channel riprap. Cross section surveying was completed to support the HEC-2 analysis and to confirm the as-built cross sections immediately downstream of the outlet works for use in constructing the physical model. The location of the surveyed cross sections and the measured cross sections are shown in Appendix A.

Riprap sizing was completed based on four 100 foot transects, two along each bank just below the outlet works. The objective of the survey was to define the d_{50} size so that the model study gravels could be appropriately sized. Based on field observations, the rock tended to be flat in shape and appeared poorly graded. The sizing was completed based on the axis controlling how the rock would fall through a square mesh sieve. Results of the survey are summarized in Table 2.2, and indicate that the average size is 2-3 feet. The right bank (looking downstream) is slightly finer, which was visually apparent in the field when comparing one bank to the other.

Table 2.2 Riprap measurements.

Distance	Left Bank upper	Left Bank lower	Right Bank upper	Right Bank lower
0	2.50	2.00	2.50	2.25
10	0.75	2.00	2.50	1.50
20	2.25	2.75	2.00	1.50
30	4.25	1.25	1.25	1.00
40	3.50	3.75	1.50	1.75
50	2.00	3.50	2.00	4.75
60	4.50	5.00	1.50	1.00
70	2.00	6.50	--	2.00
80	3.50	3.75	2.50	2.25
90	1.50	2.25	1.75	2.25
100	2.00	1.50	2.25	1.50
average	2.6	3.1	2.0	2.1

2.5 Damage to the Stilling Basin

The as-built plan and profile of the stilling basin are shown in Figure 1.1. A survey of the extent of damage sustained during operations 1984-1989 is provided by Figures 2.4 - 2.6. Figures 2.4 a and b show the extent of damage visible during the 1987 inspection. Figure 2.4a looks upstream from below the baffle blocks toward the outlet gate. Abrasion of the basin chute floor and rounding of the chute blocks is apparent. The reinforcing bar is exposed on the chute floor and at the junction of the floor and left wall. The asymmetrical characteristic of the abrasion damage is also apparent, with a tendency for greater damage to the left of the basin. Figure 2.4b is looking downstream at the junction of the left wall and chute floor. Exposure of the reinforcing bar is apparent.

Figures 2.5 a and b show an overview of the repairs in 1987 and typical material removed from the basin floor. Figure 2.5a is looking upstream from below the baffle blocks toward the outlet gate (see Figure 2.4a for comparison). Reinforcing bars for resurfacing the chute floor and forming for the central and left chute blocks are shown. Figure 2.5b shows material taken from the basin floor prior to repairs in 1987. The material ranges in size from sand and fine gravel up to eight inch cobbles.

Figure 2.4a. 1987 Inspection - Looking upstream from below the baffle blocks.

Figure 2.4b. 1987 Inspection - Looking downstream at the left wall and floor.

Figure 2.5a. 1987 Repair - Looking upstream from below the baffle blocks.

Figure 2.5b. 1987 Repair - Material removed from basin floor.

Figure 2.6a. 1989 Inspection - Looking upstream toward the chute blocks.

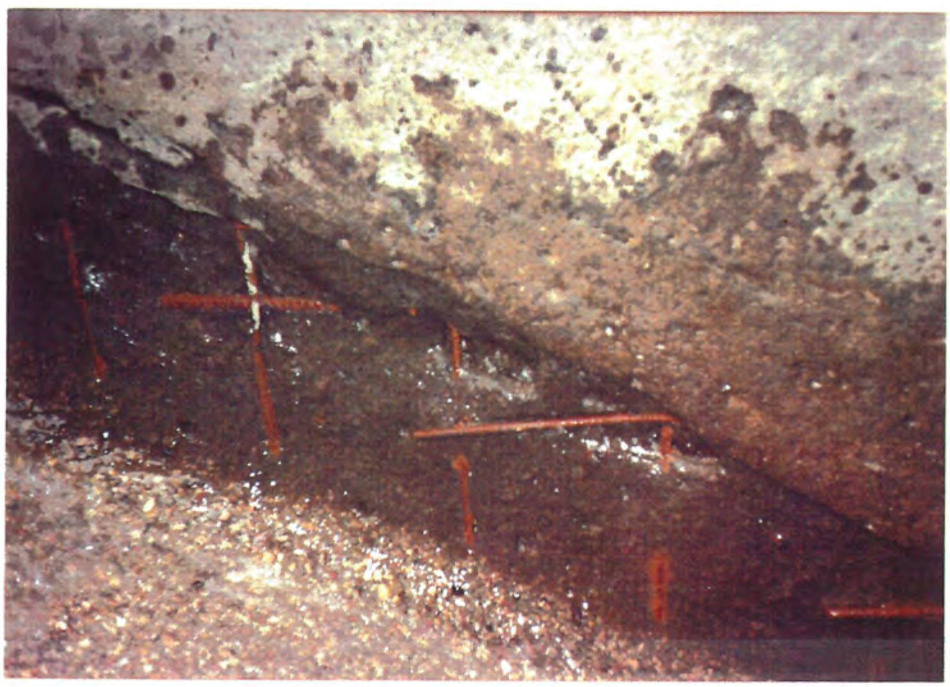


Figure 2.6b. 1989 Inspection - Close up of junction of chute floor and left wall of basin.

Figures 2.6 a and b show the extent of damage visible during the 1989 inspection. The basin was only partially dewatered at the time of the inspection. Figure 2.6a is looking upstream toward the chute blocks and Figure 2.6b is a close-up of the junction between the chute floor and the left basin wall. While the damage has a pattern similar to that observed in 1987, it is apparent that the extent of damage is less than what occurred between 1984 and 1987. A complete underwater inspection of damage was conducted in 1990 (see Appendix D).

3.0 USBR HYDRAULIC MODEL STUDY

3.1 Objectives and Scope

The objectives of the hydraulic model study were:

1. To conduct the necessary hydraulic model studies to determine the most probable cause(s) of damages experienced at the Taylor Draw Dam outlet works and stilling basin during operations from 1984 to present, and

2. To recommend possible corrective measures in terms of outlet works/stilling basin configuration or operations as a basis for rehabilitation or redesign of the facility.

The scope of the hydraulic model study was to duplicate existing conditions as a baseline and address (as a minimum) the following possible causes or contributors to the damages experienced:

1. Cavitation.

2. Abrasion due to sediment content of the inflow or sediment carried into the stilling basin from below.

3. Non-uniform flow patterns related to the configuration of the inflow conduit or the downstream control gate.

4. Undesirable flow patterns related to gate operations, the configuration of the stilling basin, or improper tailwater elevations.

To the extent a model study or the expertise of the USBR Hydraulics Laboratory could support recommendations, the study was also to address:

1. The configuration of the upstream inlet structure and gate in relation to sediment issues.

2. The configuration of the downstream control gate and the potential for cavitation at that gate (particularly in view of problems experienced with control gate operations and the gate seals).

3. The possible contribution of water quality (chemical) characteristics of the inflow water to deterioration of the concrete.

It was anticipated that about 300 feet of the prototype would be included in the model, from the bend in the conduit above the conduit bifurcation (wye) to include as much of the riprapped basin as necessary to address sediment/abrasion concerns. A model scale of about 1:10 was considered appropriate (within the constraints of the USBR's laboratory facility). Documentation would include high quality still photography (35 mm) and video where appropriate, and hydraulic data would include stage and the distribution of velocity and pressure at appropriate locations in the model. A qualitative evaluation of potential sediment interactions between the riprapped and concrete portions of the stilling basin was to be made.

The end product of the hydraulic model study would be a technical report documenting model design, model operation, and model results, including:

1. Identification of the most probable cause(s) of the damages experienced.

2. Recommendations for corrective measures in terms of outlet works/stilling basin configuration or operations as a basis for rehabilitation or redesign of the facility.

3.2 The USBR Hydraulic Model

Initial discussions at the Bureau centered on two possible causes of the basin concrete damage:

1. Abrasion caused by rock, gravel and sand brought into the basin by backflow over the end sill. The turbulent action of the flow erodes the concrete surfaces by continually moving material about the surfaces. This process is commonly referred to by the USBR as ball milling.

2. Erosion caused by the formation of cavitation along the walls and floor.

Abrasion damage was considered by the Bureau to be the most probable cause of damage. Previous investigations had indicated that rock and debris from downstream of hydraulic jump stilling basins can be moved into the basin by return flows moving upstream along the basin apron and floor under some operating conditions. It appeared much less likely the damage was the result of flow cavitation, as large areas of the chute, basin walls and floor were eroded. Most of the erosion pattern showed no apparent dependency on boundary geometry. (See Figures 2.4 a and b). It was also suspected that the large slots remaining in the conduit walls upstream of the gate (see Section 1.1) create vertical eddies that could add to the skewness of the jet observed downstream of the control gate.

A 1:10 Froude scale hydraulic model of the outlet-works structures was constructed to study the problem. (See Appendix B.) The model represented about 100 feet of the upstream 96-inch pipe, wye branch, outlet pipe, control gate, chute, basin and downstream topography. The 96"x78" pipe wye branch, the 6.5'x6.5' outlet control gate, and the stilling basin were constructed using clear acrylic plastic to allow flow visualization. The transition from the pipe to square gate approach and the gate leaf were constructed of metal. The riprap protection and topography of the downstream outlet channel were contoured down to station 6+51 using 7.5- to 15-inch rock. For the model, instead of simulating the complete outlet works system, discharge from the laboratory pumping system was passed directly into a pressure tank. The tank contained baffles to dampen out large scale flow turbulence before it entered into the 9.6 inch (model) outlet pipe. A piezometer ring was placed on the model outlet conduit to measure the piezometric head for setting the model reservoir elevation. Energy losses upstream of the piezometer tap were calculated for a range of discharges based on the prototype geometry. True reservoir elevation was then calculated by the sum of the upstream losses and the measured piezometric head.

The tailwater elevation downstream of the basin was determined for the model by the stage-discharge curve given in Figure 2.3. The low tailwater curve (flow only through the outlet works) as indicated by the squares on Figure 2.3 was used predominantly throughout the model studies. The model was tested at tailwater elevations above these levels as needed to determine the sensitivity of the flow to tailwater elevation.

Cavitation was investigated as a possible contributor to the stilling basin damage through the measurement and evaluation of pressures in the model. Static pressures were measured at 10% increments of discharge. Stilling basin damage resulting from abrasion was studied in the model to determine if and under what operating conditions material is drawn into the basin from downstream. Also, material was placed in the basin to determine its movement and retention as a function of operating conditions. The apparent non-uniformity of the flow entering the basin was investigated by measuring invert pressures, velocity and water surface profiles within the chute for 25% increments of discharge. An evaluation of the characteristics of the flow as attributed to the pipe junction or control gate was made. For details on flow similitude, measurement techniques, model documentation, and the range of testing conditions, see Appendix B.

3.3 Conclusions and Recommendations from the USBR Study

The USBR conclusions from the hydraulic model study were:

1. Model tests of the as-built outlet works geometry show that the jet leaving the control gate becomes highly skewed within the basin chute for flows up to roughly 50% of the gate opening. The flow is concentrated to the left side of the chute and lifts off the chute floor. Downstream of the hydraulic jump the flow remains concentrated along the upper left side of the basin. This creates a strong reverse flow (into the basin) along the floor with highest velocities on the right side. The horizontal skewness of the jet is largely a result of the close proximity of the outlet works wye branch to the control gate, the offset centerline of the branch, and the open wall slots remaining after construction from the gate frame blockout.

2. For gate openings of approximately 15% to 40% upstream flow velocities on the basin end sill are sufficient to move material from the riprap apron over the end sill and into the basin. Gate openings from about 17% to 25% create upstream velocities sufficient to move material on the order of 9-inch diameter (prototype) rock into the basin. This material generally moves about on the basin floor. Smaller material (rocks up to roughly 4 inch diameter) can be moved up and down the chute to approximately the toe of the hydraulic jump by the action of the horizontally skewed jet. Material is moved up the left side of the chute floor and thrust down the right side.

The USBR recommended that the poor flow distribution within the basin that causes the strong return flows near the basin end sill be corrected by making the following modifications:

1. The open slots on each wall upstream of the gate frame should be filled. These slots enhance jet skewness as they promote the formation of vortices immediately upstream of the control gate.

2. Installing two flow deflectors (one in the chute and one in the basin). Deflectors can be used to greatly improve the flow distribution rather than modify the wye branch or basin geometry. If possible the upstream curved deflector should be supported from above so as not to interfere with needed flow spreading action.

3. Pressure measurements on the chute and basin floor do not indicate a significant potential for cavitation damage. Cavitation in the model was noted along the wye branch crotch with gate openings above 5.5 feet (reservoir elevation = 5,317.5). Although cavitation damage has not

occurred in the prototype under normal operating conditions, the outlet pipes downstream of the wye branch should be inspected for damage after running for extended periods of time at gate openings above 4 feet.

4. The rip rap portion of the stilling basin should be restored to its original configuration and gradation with some modifications in the vicinity of the end sill. (See Figure 1.1.) In particular, the basin floor should have a slope no steeper than 1:5(V:H) as designed, and in the vicinity of the concrete basin end sill, this flatter slope should extend laterally to move the steeper side slope away from the end sill. (See Appendix B.)

As a basis for structural design of the recommended flow deflectors (see Item 2, above), pressure measurements at 100% gate opening were obtained on both sides of both deflectors. The lower side of the curved chute deflector is subjected to positive pressures while on the top side the pressures are largely negative. The measured maximum net differential pressure acting across the chute deflector expressed as net unit load is 1,630 lb/ft^2. The pressure on the flat basin deflector is positive on both sides. The measured maximum net differential pressure acting downstream on the basin deflector expressed as net unit load is 421 lb/ft^2. (See Appendix B.)

4.0 CONCEPTUAL DESIGN RECOMMENDATIONS

4.1 Conceptual Design

The conceptual plan for repair of the Taylor Draw stilling basin/outlet works is primarily based on the findings and recommendations resulting from the USBR hydraulic model study. Modifications or repair will be required to:

1. Restore the existing basin and outlet works to original (as-built) conditions.

2. Add deflectors (guide vanes - see Chapter 3.0).

3. Fill the gate blockout areas (voids) to correct the poor hydraulic/energy dissipation conditions in the existing basin.

4. Restore the as-built conditions of the rip rap portion of the stilling basin to minimize the possibility of rip rap being swept back into the concrete portion of the stilling basin.

Specifically, the conceptual design for repair and modification of the outlet works and stilling basin includes:

1. Repairs necessary to restore the stilling basin floor, walls, baffle blocks, and chute blocks to original (as-built) conditions. Based on the extent of damage, as determined when the stilling basin is dewatered, a level of effort and approach similar to the 1987 repairs should be anticipated. The conceptual design and the scope and cost estimate of Chapter 5.0 are based on the assumption that the damages sustained by the outlet works/stilling basin are <u>no</u> <u>worse</u> than that sustained prior to the 1987 repair. (See Figures 2.4 a-b and 2.5 a-b.)

2. Fill the gate block out areas (voids) in the walls upstream of the 6.5'x6.5' slide gate. If access to these blockout areas is not required for gate maintenance or adjustment, this repair could be accomplished by grouting.

3. Fabricate and install, based on loadings and locations from the hydraulic model study, a curved upstream deflector (chute deflector) and a flat downstream deflector (basin deflector). (See Figure 4.1.) Initial consultation with a structural engineering consultant (Russell M. Miller Consulting Engineers of Timnath, Colorado) indicates that the structural loadings derived from the hydraulic model do not present insurmountable design problems. Preliminary structural analysis resulted in a recommendation that the deflectors be fabricated from stainless steel or

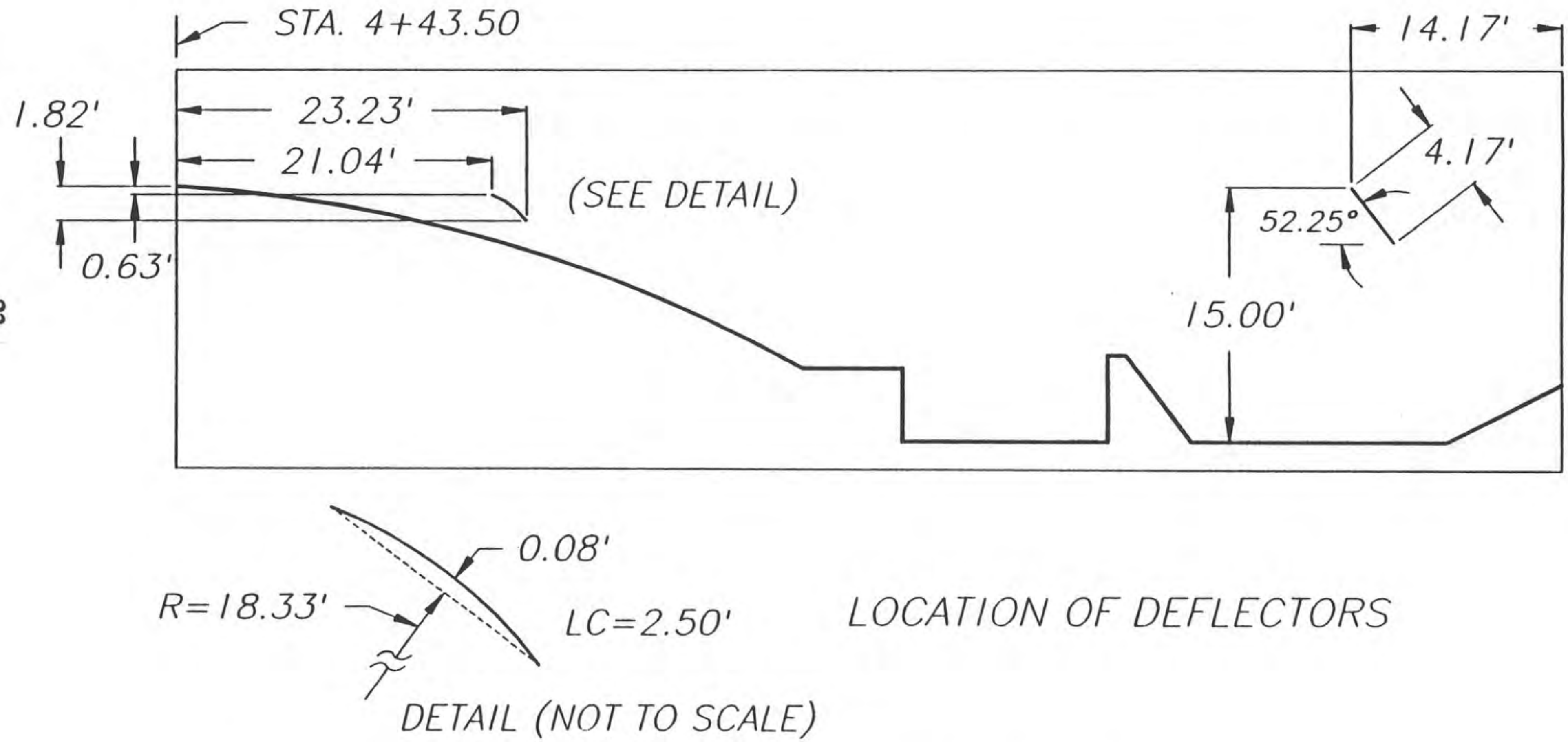


Figure 4.1: POSITION OF FLOW DEFLECTORS FOR THE CHUTE AND STILLING BASIN (FROM USBR REPORT, APPENDIX B)

other corrosion resistant end product, with a strutted interior section (i.e., hollow with interior struts similar to an aircraft wing). Structural modification to the concrete basin walls (and possibly floor) may be required to withstand static and dynamic loading from the outlet jet on the deflectors.

4. Restore the configuration and gradation of the rip rap portion of the stilling basin to its original (as-built) conditions except in the immediate vicinity of the end sill. The basin floor should have its original designed 1:5(V:H) slope. Near the concrete basin end sill this flatter shape of the floor should extend laterally to move the steeper side sloped away from the end sill. Depending on the existing gradation of the rip rap, as determined by site investigation during the repair project, it may be necessary to remove, sort, clean and replace the rip rap to original as-built conditions.

While it is not necessary for proper hydraulic operation of the outlet works and stilling basin, it is recommended that a downstream gate structure (stop log) be installed below the rip rapped portion of the stilling basin. Such a structure would facilitate dewatering of the stilling basin for inspection and maintenance in the future and eliminate the need for repeated construction of a coffer dam with its associated expense, environmental concerns, and impacts on the gradation and stability of the rip rap in the basin.

During the initial phases of the investigation it was considered possible that sediment in the inflow water might be contributing to the abrasion problem in the outlet works. Based on the results of the reservoir deposition survey in the vicinity of the inlet gate (see Section 2.2), and the small size of sediments deposited in the reservoir, sediment in the inflow water would not appear to be a significant contribution to the abrasion problem. This conclusion is supported by the magnitude of the problem revealed by the hydraulic model study; that is, the tendency to sweep large quantities of up to rip rap size material into the concrete basin under certain operating conditions. (See Sections 3.3 and 3.4.) Consequently, no corrective action is required at the inlet gate in relation to the abrasion problem.

4.2 Stilling Basin Operability Assessment

This section summarizes the results and conclusions of a limited investigation of the operability of the Taylor Draw outlet works for another season, and/or for water quality control in the reservoir. The two major components of the scope of work for this investigation were structural analysis by Mr. Russ Miller (Russell M. Miller Consulting Engineers, RMCE) and evaluation of hydraulic issues and recommendations for an operational strategy and/or a monitoring system.

A letter report by Mr. Russ Miller with supporting exhibit is attached as Appendix C. This report concludes that if the concrete erosion were allowed to continue, partial or complete collapse of the structure would occur. An assessment of the extent of short term erosion allowable, defined as erosion during the remainder of 1990, is detailed in Exhibit A (Appendix C). The allowable erosion is defined by either the average allowable erosion over a broad area, or a maximum amount over a smaller portion of that same area. It is concluded that with appropriate monitoring, the risk of complete failure is remote; however, if the allowable erosion amounts do occur, the structure would be very difficult and expensive to repair.

The analysis of hydraulic issues relied primarily on observations of the USBR's hydraulic model as a basis for recommending corrective measures. The evaluation of operability benefited from the model being near completion. As a result, some initial runs investigating the operability issue were completed by the Bureau prior to initiating their defined scope of work.

Preliminary observations (June 14, 1990) found that at the normal range of gate operation (1-2 feet) rock from the tailwater area was brought into the basin and onto the chute. This phenomenon appeared to be the result of jet separation and nonuniform flow under the gate, with more flow being directed to the left side (looking downstream) of the basin. The impingement of the jet on the left wall caused vertical vortices to form underneath the jet, which moved in a circular motion from the left wall downstream past the blocks at the end of the chute, and then across to the right side of the model and back upstream approximately one-third of the way up the chute. These vortices were able to pick up 1-2 inch gravel from the tailwater region of the model (equal to riprap size material in the prototype) and impact them against the chute and the walls of the stilling basin, with the greatest impact occurring along the base of the left wall and the left block at the base of the chute. The addition of smaller sized gravel (1/4 inch) to the flow showed the same patterns, only much more vigorously. The model was being run at low tailwater conditions typical of summertime conditions. Increases in the tailwater condition tended to aggravate the problem. These preliminary observations were later confirmed by more detailed observations during subsequent phases of the model study. (See Chapter 3.0 and Appendix B.)

At a 3.0 foot gate opening the jet tended to follow the chute profile more closely and the phenomenon discussed above disappeared. At a 0.5 foot opening the jet separated, but the level of turbulence was low enough that rock entrainment was not a problem. Based on these preliminary observations, it was concluded that a low gate opening during an interim period would be acceptable. This flow condition may release enough water to help alleviate dissolved oxygen (DO) problems in the lower portions of the the reservoir.

After some adjustment of the tailwater ground contours in the model, to better reflect the measured data, rather than the as-built data, a second set of observations were completed on June 28, 1990. The above observations were confirmed and it was concluded that the 1.5 foot gate opening was the most damaging position and that a 0.5 foot gate opening was relatively safe. Apparently as a result of the slightly modified tailwater contours, a 2.0 foot opening was now found to be generally acceptable in performance. However, given the severity of the problem at a gate opening only 6 inches lower, it was concluded that a 0.5 foot opening was still the preferred operation.

Based on the observation that a 0.5 foot opening appeared to minimize the abrasion and water quality concerns, it was recommended as an acceptable gate opening during the interim period prior to implementation of a solution to correct the underlying problems of the structure. Due to the difficulty and concerns with repeated adjustment of the gate opening, it was suggested that a 0.5 foot opening could be set and left in that position, except at times of monitoring. While the model study suggested that the risk of erosion would be minimal at the 0.5 foot opening, a monitoring program was recommended.

It was suggested that until corrective measures are implemented, a diver (underwater) monitoring program be initiated. An initial inspection was recommended within 2-3 months of the start of interim operations. Depending on the results of that inspection, an appropriate interval for subsequent inspections would be recommended. If possible, subsequent monitoring should be completed by the same diver and should include a report of the estimated erosion depths at specific locations in the structure (as shown in Exhibit A to Appendix C), so that a quantitative comparison of subsequent inspections may be completed. The inspection should concentrate on areas where the most serious erosion was experienced in the past, and measure the depth of erosion below any reinforcing bar exposure. If the erosion continues and approaches the allowable limits defined in Appendix C, the use of the outlet works should be discontinued. The first diver inspection was performed on August 13-15, 1990 by Inland Marine Services of Aurora, Colorado (see Appendix D).

5.0 SCOPE AND COST ESTIMATE FOR REPAIRS

5.1 Scope of Services

The conceptual design of Chapter 4.0 focuses on three areas of modifications to be constructed during repair of the Taylor Draw outlet works and stilling basin. The first area concerns filling voids in the outlet conduit at the control gate. The second concerns the installation of deflectors (guide vanes) in the stilling basin, and the last concerns modifications to the outlet channel. In addition, repair of existing abrasion damage must also be designed. Specific tasks of the scope of services are outlined below.

Task 1 - Field Surveys. This task will involve collecting more data downstream of the stilling basin. Included will be additional cross sections of the river and outlet channel, and a detailed survey of the riprap portion of the stilling basin. In addition we will try to determine the level of silt and debris accumulation in the concrete portion of the stilling basin. (This task was completed based upon previous authorization from River District Staff.)

Task 2 - Preliminary Design. This task will consist of developing preliminary design alternatives and construction cost estimates of the stilling basin renovation.

1. Meeting with State Engineer's Office. Before the design of the improvements begins, a meeting will be arranged with the State Engineer's Office to review the physical modeling results, determine how they are going to review the proposed improvements, and determine their submittal requirements for this project.

2. Hydraulic Analysis. A hydraulic analysis will be conducted to determine the existing hydraulics of the outlet channel and river. This will be used as a baseline to compare how the proposed design alternatives will effect the river and outlet channel.

3. Renovation of Concrete in Stilling Basin. Alternatives for repairing the damage to the concrete in the stilling basin will be explored. Since the stilling basin can not be emptied to provide visual observation of the damage to the concrete, the previous repair drawings will be used as a guide to determine the extent of the damage.

4. Construction and Installation of the Deflectors. Alternative designs will be developed for the construction and installation of the deflectors. Depending on the type of designs developed, it may be necessary to try

these designs in the physical model to determine how they perform and which one is the preferred design alternative. Costs for the physical modeling of these designs is not included in this proposal. It is expected that the design alternative will be supplied to the USBR which will conduct the study and provide the results.

5. Filling the Void Behind the Gate Structure. Alternatives will be investigated to determine how to fill the void behind the gate structure. The manufacturer of the gate structure will be contacted for its recommendations.

6. Renovation of Riprap Basin. The USBR recommended returning the riprap basin to its original shape and to provide the proper gradation of the riprap. Alternative methods for reshaping the basin and correcting the riprap gradation problem will also be explored and a preferred method will be selected.

7. Downstream Gate Structure. To facilitate inspection of the stilling basin in the future without installing an earthen coffer dam we are proposing to construct a gate structure to isolate the stilling basin from the river and spillway channel for dewatering. Alternative designs will be developed and analyzed with the most viable design recommended for construction.

8. Preliminary Drawings. Preliminary drawings will be developed for the selected alternatives. These drawings will include plan, profile, elevation, and typical details of the structures proposed. The drawings will follow the format of the final drawings, but in less detail.

9. Cost Estimates. Cost estimates will be prepared for each alternative considered. Included in this task will be a cost analysis to determine the most economical alternative.

10. Preliminary Design Report. A report will be prepared summarizing the investigations made during the preliminary design, and a cost estimate of the alternatives will be prepared. The preliminary design report and preliminary drawings will be submitted to WUA#1 for review and comments. The preliminary drawings will also be submitted to the State Engineer's Office for preliminary review.

Task 3 - Construction Documents. The construction documents will be developed after the WUA#1 has selected the preferred alternatives.

1. Final Design Report. A final design report will be prepared which will summarize the engineering analysis and investigations which were utilized in preparation of the final design. This report will be provided to the

State Engineer's Office for review and approval of the modifications.

2. Construction Drawings and Specifications. The construction drawings and specifications will be developed in a standard format acceptable to the WUA#1 and State Engineer's Office.

3. Cost Estimates. Based on the quantity takeoffs on the plans, final cost estimates will be developed for each phase of the construction. Where available, unit prices will be taken from recent bids for similar construction. Area contractors will also be contacted to provide additional construction cost comparisons.

4. Review. Upon completion of the construction drawings, construction specifications and construction cost estimates, these documents will be submitted to WUA#1 for review and comments. In addition the construction plans and specifications will be submitted to the State Engineer's Office for final review and approval. Review fees charged by the State Engineer's Office are not included in this proposal.

5. Permitting. The design team will assist WUA#1 in the permitting process. Included will be the U.S. Army COE's 404 permit, Colorado Department of Health's NPDES permit and any local government permits. The fees charged by these governmental agencies are not included in this proposal.

6. Contract Documents. The contract documents will be prepared in the Engineer's Joint Contract Documents Committee (1983) format.

Task 4 - Construction Administration and Observation. To assist WUA #1 in assuring that the contractor completes the modifications as designed, the following tasks will be performed by the design team:

1. Preconstruction Meeting and Contract Award. The design team will assist WUA#1 in obtaining a construction contractor to perform the required work. This assistance will include:

   a. Prepare advertisement for bids.

   b. Prequalify prospective bidders.

   c. Prepare and distribute construction contract documents.

   d. Prepare and distribute required addenda.

e. Conduct pre-bid meeting at the site and prepare and distribute meeting summary.

f. Address contractor's questions during the bidding process.

g. Conduct the bid opening.

h. Prepare a bid analysis and recommend a best bid for award.

i. Prepare construction contract for WUA#1 review and contractor execution (including insurance, bonds, etc.).

2. Construction Observation and Contract Administration. The design team will provide on-site personnel during construction to observe the construction of the improvements. Design engineers from RCI and RMCE will make periodic observations at critical times in the construction. In addition the design team will administer the construction contract, process change orders, pay requests, and review submittals required of the contractor.

3. Construction Engineering. It was not economically justifiable to dewater the stilling basin before construction begins in order to review the extent of the damage to the concrete. Therefore the design team will review the stilling basin when the contractor has the basin dewatered and cleaned. The design team will then review the extent of the damage and modify the construction documents to reflect the actual conditions found.

4. Record Drawings. A complete set of record drawings will be prepared and submitted to the WUA#1 and the State Engineer's Office at the completion of the construction. Our construction engineer working with the contractor will provide the necessary information to update the construction drawings to the actual field constructed conditions.

5.2 Cost Estimate - Design and Construction Supervision

The estimated project budget is presented by Task in Table 5.1.

TABLE 5.1

TAYLOR DRAW STILLING BASIN RENOVATION

BUDGET

TASK	LABOR	EXPENSES	TOTAL
1. Field Surveys	$1,160	$442	$1,602
2. Preliminary Design	$11,202	$6,247	$17,448
3. Construction Documents	$10,333	$5,888	$16,221
4. Construction Observation and Administration	$16,168	$18,801	$34,969
TOTAL	$38,863	$31,378	$70,241

5.3 Rough Estimate - Total Project Cost

The following is a rough estimate of the construction costs for the repairs and modification of the concrete stilling basin, reshaping the riprap basin, and constructing a structure downstream of the stilling basin to facilitate dewatering the stilling basin for future inspections:

Task 1 Dewater Stilling Basin. $30,000
The work includes constructing coffer dam, pumping water out of the basin, removal of silt and debris in concrete basin floor and cleaning basin for inspection.

Task 2 Concrete Stilling Basin. $150,000
The work includes removal of covers, renovation of baffle and chute blocks, repair and reinforcing of floor and walls, fabrication of and installation of deflectors, grouting behind gate, and replacement of covers.

Task 3 Pumping Gate Leakage around Basin. $10,000
The work includes building coffer dam in outlet works and 24-hour operation and maintenance of pumping station to pump the leakage from outlet gate structure around stilling basin.

Task 4 Renovation of Riprap Basin. $75,000
The work includes removing riprap, cleaning and sorting riprap, regrading 1:5(V:H) slope of basin floor, and replacing riprap.

Task 5 Downstream Gate Structure. $30,000
The work includes construction of a gate structure to prevent water from draining back to the stilling basin from the river when the stilling basin is being dewatered.

Task 6 Removal of Coffer Dam and General Cleanup. $5,000
The work includes removal of coffer dam, repairing riprap blanket damaged by coffer dam and general cleanup of the stilling basin site.

A rough estimate of the engineering fee is $70,000 (see Section 5.1), which includes design of the construction listed above, submittal to the State Engineer's Office, assistance with the permitting required, construction observation and administration, testing, and record drawings.

The total construction requirement is $300,000 as a rough estimate.

APPENDIX A

Taylor Draw Outlet Canal

Cross Section Locations

Figure A.1: CROSS-SECTION LOCATIONS

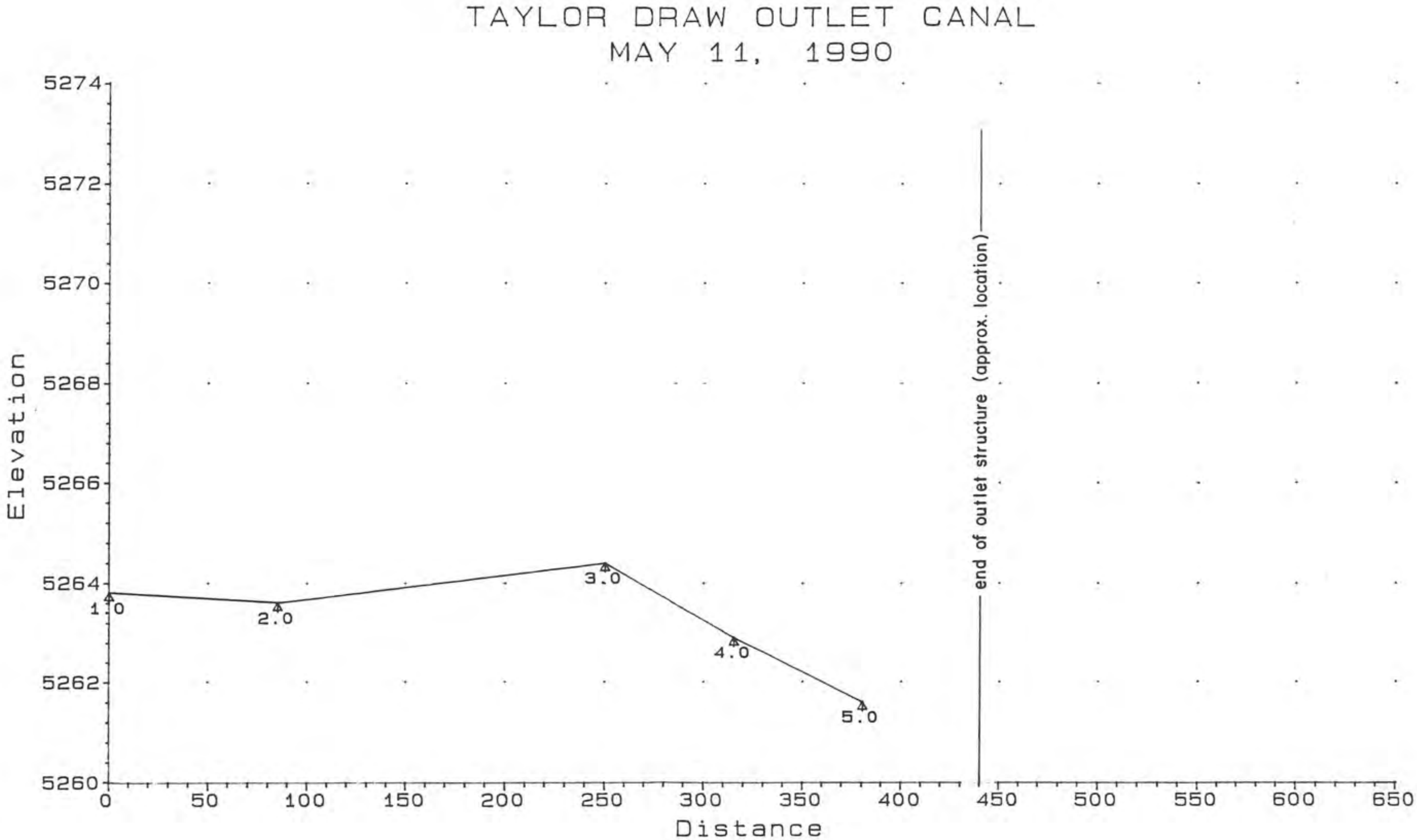


Figure A.2

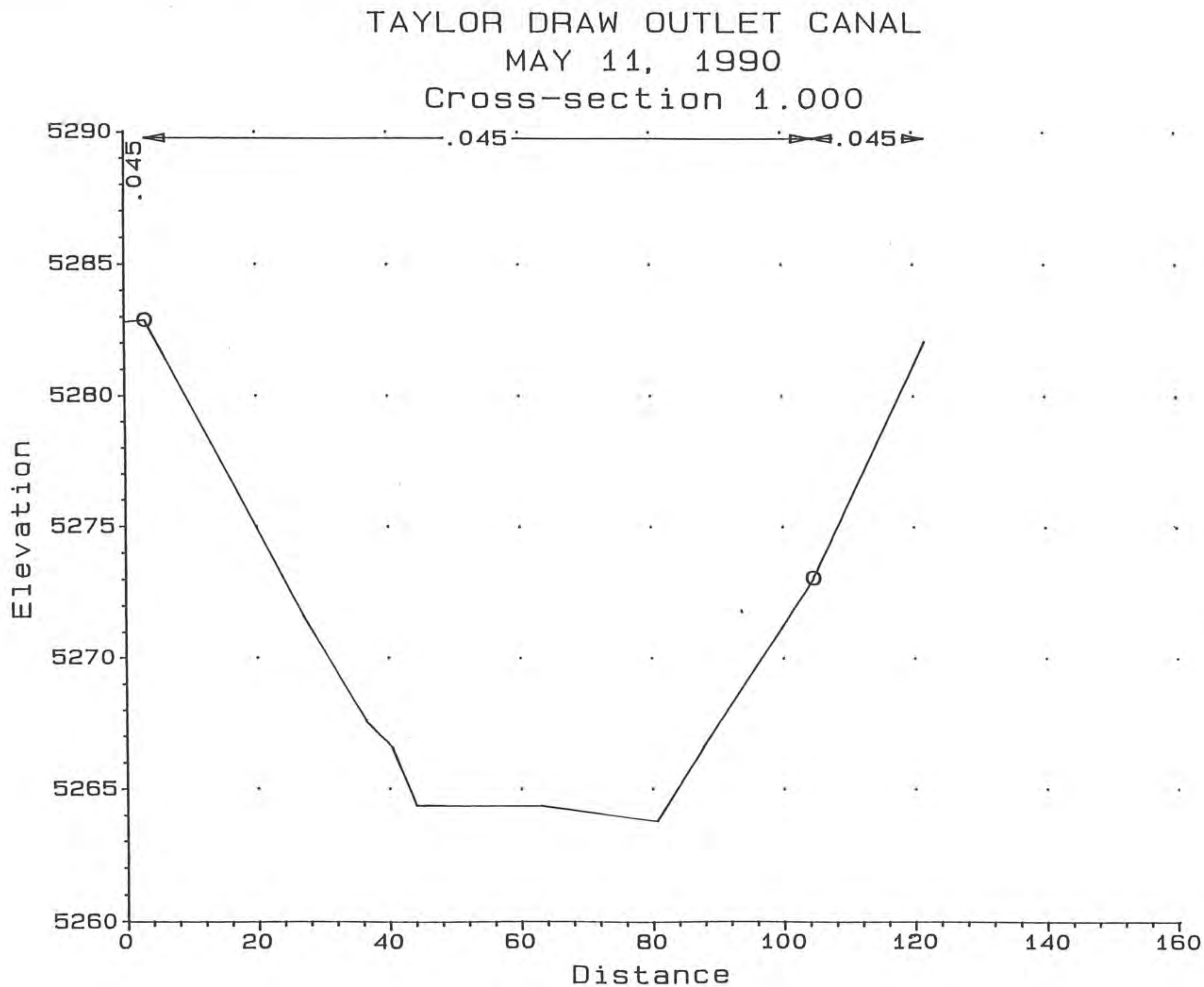
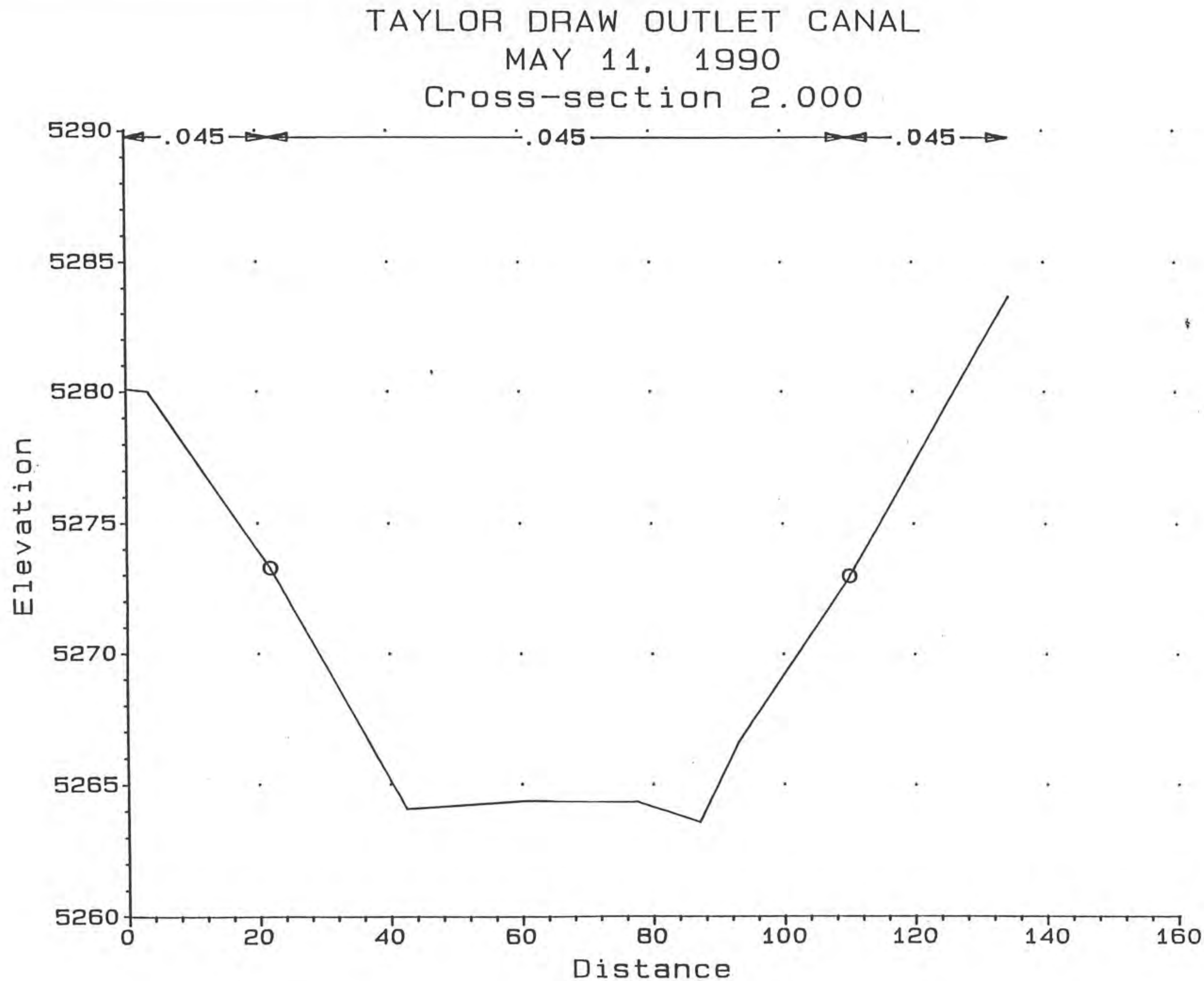

TAYLOR DRAW OUTLET CANAL
MAY 11, 1990
Cross-section 1.000
.045
.045
.045
Elevation
5290
5285
5280
5275
5270
5265
5260
0
20
40
60
80
100
120
140
160
Distance

Figure A.3


TAYLOR DRAW OUTLET CANAL
MAY 11, 1990
Cross-section 2.000
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Elevation
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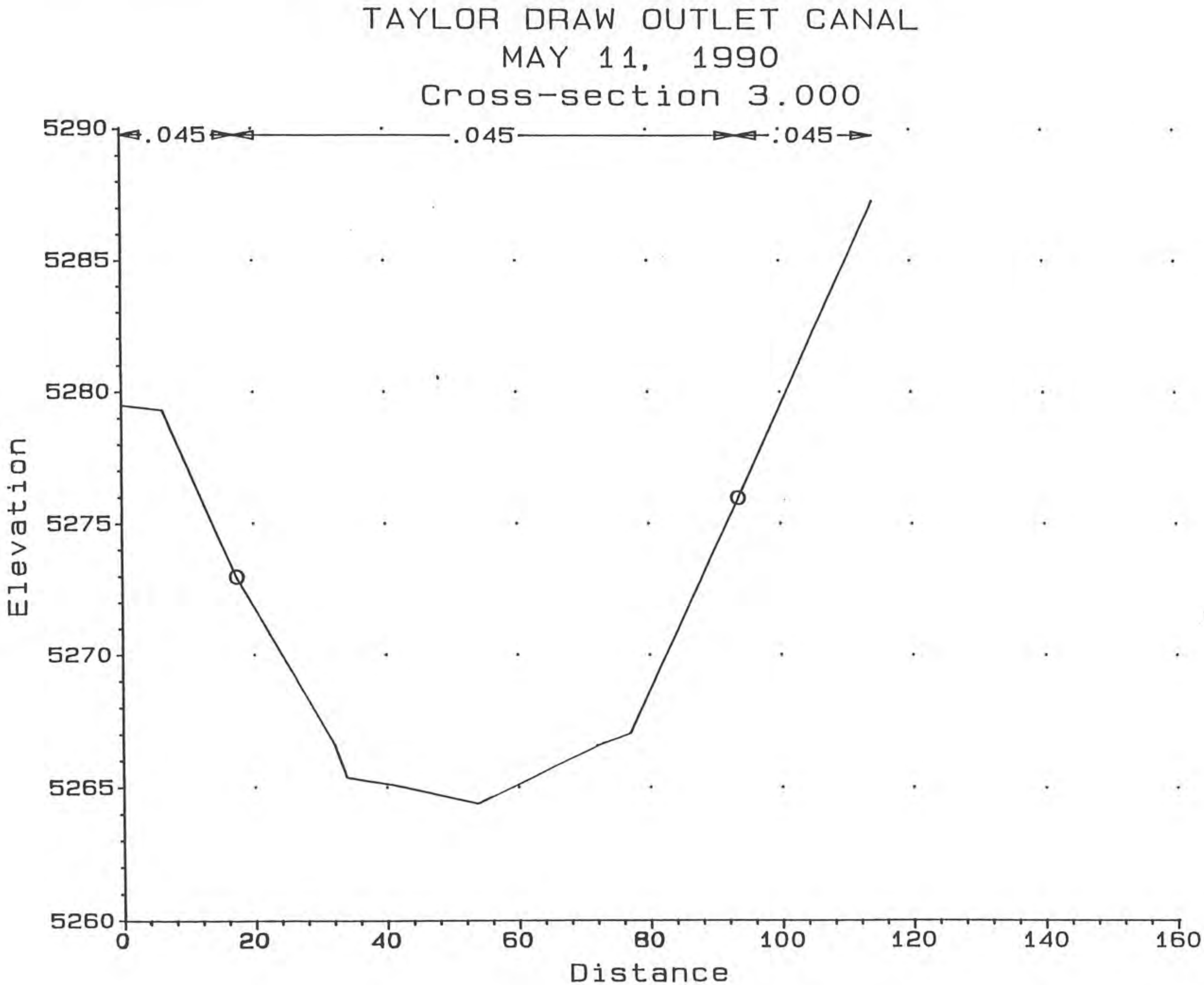
Distance

Figure A.4



TAYLOR DRAW OUTLET CANAL
MAY 11, 1990
Cross-section 3.000
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Elevation
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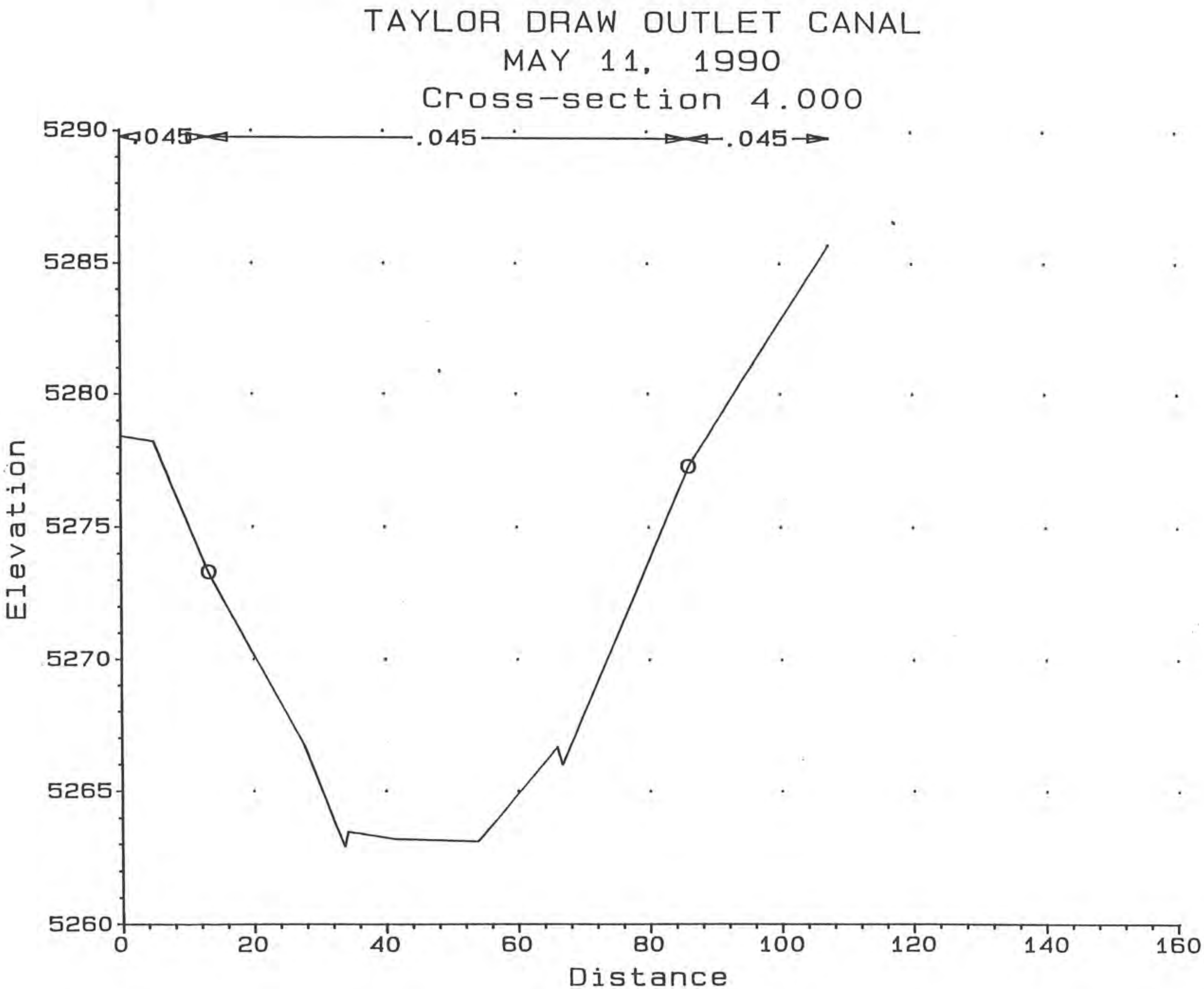
Distance

Figure A.5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Cross-section 4.000
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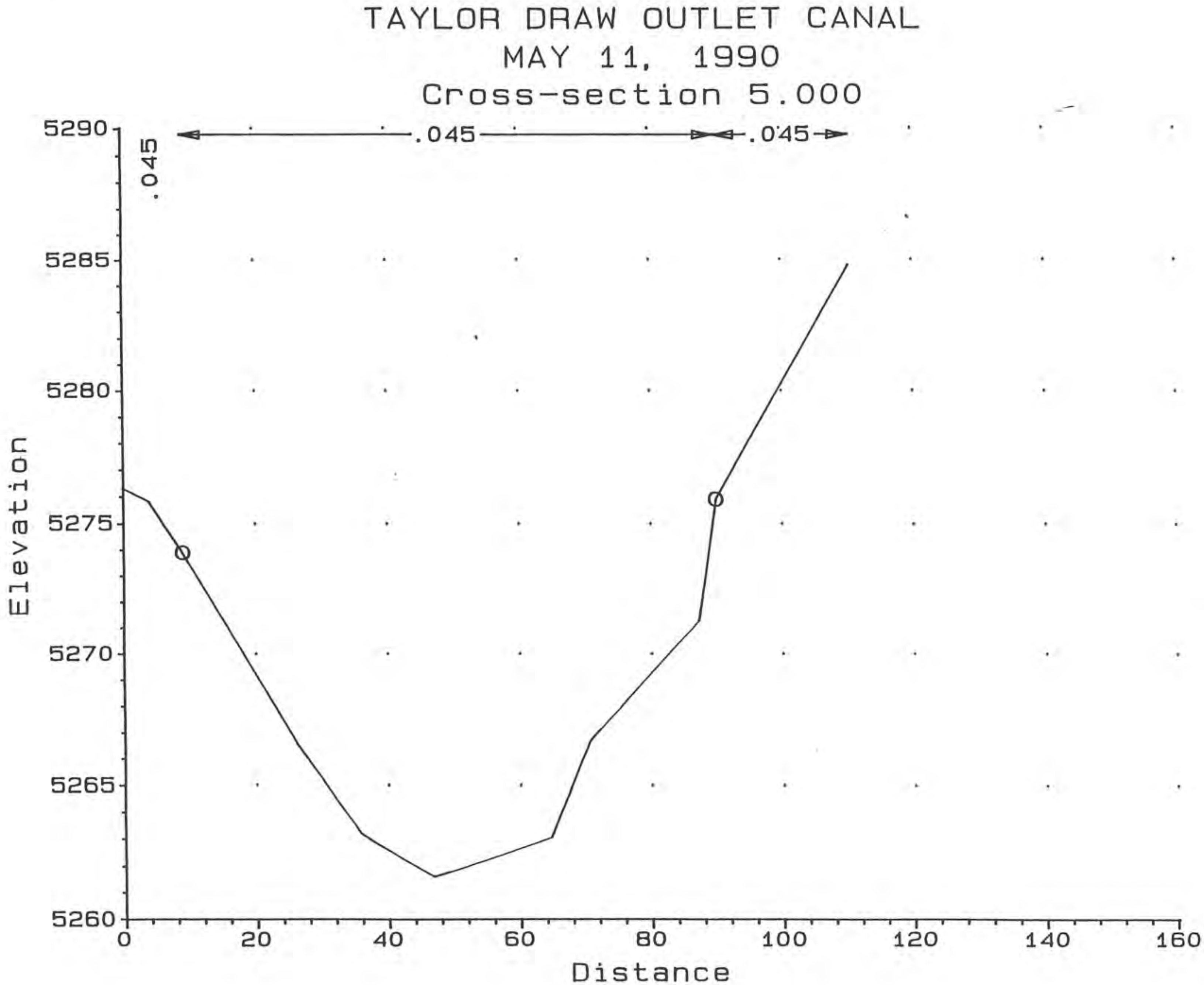
Figure A.6


TAYLOR DRAW OUTLET CANAL
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APPENDIX B

USBR Hydraulic Model Investigation Report

(PRELIMINARY)

PHYSICAL HYDRAULIC MODEL STUDY OF TAYLOR DRAW DAM OUTLET WORKS

BACKGROUND

Taylor Draw Dam and Kenney Reservoir are owned and operated by Water User's Association No.1 in Rio Blanco Country, Colorado. The dam is a five zoned earthfill structure on the White River located 6 miles northeast of Rangely, Colorado. The dam was completed October 1984 and provides recreational, municipal, industrial and agricultural water; especially during periods or prolonged drought, for the Western White River Basin. The dam is approximately 74 feet high with a maximum base width of 190 feet, a crest width of 20 feet, and a crest length of 1,150 feet. The crest elevation of the dam is 5,329 feet.

Flow can be conveyed past the dam through a overflow spillway on left side of the dam and through an outlet works structure. The spillway has an uncontrolled ogee crest extending 505.13 feet across the dam; with a discharge capacity of 69,426 ft^3/s at a water surface elevation 5,329. The outlet works consists of two separate conduits, a 24 inch conduit and a 96 inch conduit. The 24 inch conduit is used for municipal and industrial purposes. The 96 inch conduit bifurcates near the downstream end forming a 96 inch and a 78 inch conduit. The 96 inch conduit is presently blind flanged roughly 100 feet downstream of the bifurcation. It will eventually feed a hydroelectric powerplant. The 78 inch conduit serves the outlet works and stilling basin (similar to a Reclamation Type III basin). Flow through the 78 inch branch is controlled by a downstream 6.5- by 6.5-foot slide gate onto a parabolic chute down into the stilling basin. After passing through the stilling basin, the water flows over a riprapped transition back up to original river channel elevation.

During the relatively short operating history of Taylor Draw Dam, the outlet works chute and the stilling basin have experienced significant damage to the concrete walls and floor. In 1987 after an inspection of the basin, the damage was attributed to the abrasive action of rocks churning in the flow. It was suspected rocks were entering the basin by falling or being thrown into the stilling basin. The basin was de-watered, the concrete was repaired with silica fume concrete, and a cover was placed over the stilling basin. In September 1989, a subsequent inspection by divers revealed significant damage to the concrete surface had again occurred.

Following the discovery of the new basin damage engineers from the Colorado River Water Conservation District contacted Reclamation to determine if similar damage has occurred on Reclamation structures. Discussions centered on two possible causes of the basin concrete damage:

(1) Abrasion caused by rock, gravel and sand brought into the basin by back flow over the end sill. The turbulent action of the flow erodes concrete surfaces by continually moving material about the surfaces. This process is commonly referred to as ball milling.

(2) Erosion caused by the formation of cavitation along the walls and floor.

Abrasion damage was again considered to be the most probable cause. As investigated by Zeigler[1], rock and debris from downstream of hydraulic jump stilling basins can be moved into the basin by return flows moving upstream along the basin apron and floor under some operating conditions. It appeared much less likely the damage was the result of flow cavitation as large areas of the; chute and basin, walls and floor were eroded. Most of the erosion pattern showed no apparent dependency on boundary geometry.

It was decided that a physical model study was necessary to determine what causes the damage and how to prevent further occurrence.

CONCLUSIONS

Model tests of the as-built outlet works geometry show the jet leaving the control gate becomes highly skewed within the basin chute for flows up to roughly 50 pct gate opening. The flow is concentrated to the left side of the chute and lifts off the chute floor. Downstream of the hydraulic jump the flow remains concentrated along the upper left side of the basin. This creates a strong reverse flow (into the basin) along the floor with highest velocities on the left side. The horizontal skewness of the jet is largely a result of the close proximity of the outlet works wye branch to the control gate, the offset centerline of the branch, and the open wall slots remaining after construction from the gate frame blockout.

For gate openings of approximately 15 to 40 pct upstream flow velocities on the basin end sill are sufficient to move material from the riprap apron over the end sill and into the basin. Gate openings from about 17 to 25 pct create upstream velocities sufficient to move material on the order of 9 inch diameter rock into the basin. This material generally moves about on the basin floor.

[1]Eugene Zeigler, Abrasion Damage to Mason Dam Outlet Works Stilling Basin, R-90 (Draft report), USBR, Division of Research and Laboratory Services

Smaller material (rocks up to roughly 4 inch diameter) can be moved up and down the chute to approximately the toe of the hydraulic jump by the action of the horizontally skewed jet. Material is moved up the left side of the chute floor and thrust down the right side.

The riprap just downstream of the basin should be replaced with clean graded rock material to not greater than a 1 vertical to 5 horizontal slope up to the river channel. The width of the 1:5 sloped material should extend laterally to the base of the buttress walls. The riprap on the outside of the basin walls and back to the buttress should be placed on the horizontal, figure 1. The basin should be diver inspected periodically to check for and remove boulders. Rather than using coffer dams to de-water the basin for maintenance, a stoplog structure should be installed in the return river channel.

The poor flow distribution within the basin that causes the strong return flows near the basin end sill can be corrected by:

1. The open slots on each wall upstream of the gate frame should be filled. These slots enhance jet skewness as they promote the formation of vortices immediately upstream of the control gate.

2. Installing two flow deflectors (one in the chute and one in the basin). Deflectors can be used to greatly improve the flow distribution rather than modify the wye branch or basin geometry. The curved chute deflector should be supported if possible from above so as not to interfere with needed flow spreading action. Model pressure data indicated the structural unit load for the chute deflector is 1630 lb/ft^2 in the direction of flow (force measured normal to the surface) and the design unit load for the basin deflector is 421 lb/ft^2 in the direction of flow (measured normal to the surface). Without, modeling the final structural form of these deflectors to determine the dynamic fluctuation component of the hydraulic forces, a safety factor of at least 2 should be used.

Pressure measurements on the chute and basin floor do not indicate a significant potential for cavitation damage. The only potential for cavitation noted in the model occurred along the wye branch crotch with gate openings above 92 pct (reservoir elevation of 5317.5 ft). Although, cavitation damage has not occurred in the prototype under normal operating conditions, the outlet pipes downstream of the wye branch should be inspected for damage after running for extended periods of time at gate openings above 70 pct.

DESCRIPTION OF THE PHYSICAL MODEL

A 1:10 Froude scale hydraulic model of the outlet-works structures was constructed to study the problem, figure 2. The model represented about 100 feet of the downstream 96 inch pipe, wye branch, outlet pipe, control gate, chute, basin and downstream topography. The 96- by 78-inch pipe wye branch, the 6.5- by 6.5-foot outlet control gate, and the stilling basin, figure 3, were constructed using clear acrylic plastic to allow flow visualization. The transition from the pipe to square gate approach and the gate leaf were constructed of metal. The riprap protection and topography of the downstream outlet channel were contoured down to station 6+51 using 7.5- to 15-inch rock, figure 4. For the model, instead of simulating the complete outlet works system, discharge from the laboratory pumping system was passed directly into a pressure tank. The tank contained baffles to dampen out large scale flow turbulence before it entered into the 9.6 inch (model) outlet pipe. A piezometer ring was placed on the model outlet conduit (Sta. 3+69.5) to measure piezometric head for setting the model reservoir elevation. Energy losses upstream of the piezometer tap were calculated for a range of discharges based on the prototype geometry. True reservoir elevation was then calculated by the sum of the upstream losses and the measured energy head at Sta. 3+69.5.

The tailwater elevation downstream of the basin was determined for the model by the stage-discharge curve given in figure 5. Resource Consultants Incorporated, an engineering consulting firm developed the relationship for the water district. The low tailwater curve (flow only through the outlet works) as indicated by the squares was used predominantly throughout the model studies. The model was tested at tailwater elevations above these levels as needed to determine the sensitivity of the flow to tailwater elevation. Normal test conditions for each gate opening are listed in table 1.

Initial Proposed Scope of Study

Cavitation would be investigated as a possible contributor to the stilling basin damage through the measurement and evaluation of pressures in the model. Static pressures would be measured at 10 pct increments of discharge.

Stilling basin damage resulting from abrasion would be studied in the model to determine if and under what operating conditions material is drawn into the basin from downstream. Secondly, material would be placed in the basin to determine its movement and retention as a function of operating conditions.

The apparent non-uniformity of the flow entering the basin would be investigated by measuring invert pressures, velocity and water surface profiles within the chute for 25 pct increments of discharge. An evaluation of the characteristics of the flow as attributed to the pipe junction or control gate would be made.

Measurements and Observations

Permanently installed venturi meters are used in the hydraulic laboratory to measure discharge. Mercury manometers indicate the differential pressure across the venturi meters. The measured flow rates have a traceable accuracy based on volumetric tank calibrations of $\pm$ 1.0 pct. Velocities were measured using a electromagnetic current meter with a 3/4 inch ball shaped probe (measures average velocity of a 3 ball diameter area). A water surface probability probe was used to measure water surface profiles on the chute to document jet skewness. On a rough water surface, this instrument determines the percent of time that it is wet versus its elevation. The elevation at which it is 50 pct wet is taken as the water surface. Basin performance in terms of material transport was accentuated by replacing the design riprap (2 ft) with smaller material (3- to 4-inch prototype or No. 4 sieve size to 3/8 inch model) downstream of the basin end sill, as shown in figure 4. This material, being substantially smaller than the design riprap, was representative of the majority of material found in the basin during inspections. Pressure taps were placed on centerline along the curved chute bottom and downstream of chute blocks and floor blocks to determine the potential for cavitation within the basin.

MODEL SIMILITUDE

General

For a model to truly represent actual conditions, it must be geometrically, kinematically, and dynamically similar to the prototype. Geometric similarity exists when the ratios of all homologous dimensions between model and prototype are the same. The geometric scale ratio, or length ratio, is denoted by L_r which is the ratio L_m/L_p, where the subscripts m and p refer to the model and prototype, respectively. Kinematic similarity, or similarity of motion, implies that the ratios of velocities and accelerations between model and prototype are equal. Dynamic similarity requires that the ratios of homologous forces between the model and prototype be the same. If the model deviates from the prototype in any one of these three areas of similitude, then care must be taken to properly interpret the model results. However, if any one deviation is too large, or there are too many deviations, the model will not represent the prototype and no amount of interpretation will yield the correct results or conclusions.

Flow Similitude

Similitude analysis and model design are best started by finding valid homogeneous equations and dimensionless functional relationships that apply to both the model and prototype. Selection of a set of equations and functions includes the requirement that they be checked for their model and prototype application range and limits. Normalizing complete hydrodynamic equations for open channel flow opposed to tractive shear or friction and then extracting dimensionless parameters result in a Froude number squared (F^2) or ($V^2/R_h g$) and a product of the Darcy-Weisbach friction coefficient (f) times Froude number squared as the required parameters for scaling flow. The friction coefficient is a function of relative roughness ($k_s/4R_h$) and Reynolds number (R_e) expressed as:

$$f = \Phi(k_s/4R_h \, , \mathbf{R_e})$$

where:

$\mathbf{R_e}$ = $(4R_h V/\upsilon)$

f = Darcy Weisbach friction factor

R_h = hydraulic radius

V = velocity

g = gravitational constant

Φ = function operator

k_s = rugosity

υ = kinematic viscosity

Based on Froude law alone,

Length ratio	$L_r = 10$
Velocity ratio	$V_r = L_r^{1/2} = 3.16$
Time ratio	$T_r = L_r^{1/2} = 3.16$
Discharge ratio	$Q_r = L_r^{5/2} = 316$
Unit discharge ratio	$q_r = L_r^{3/2} = 31.6$
Tractive shear ratio	$t_r = L_r = 10$
Pressure ratio	$P_r = L_r = 10$

Having selected the Darcy-Weisbach equation to normalize friction loss in the complete flow equation, the ratio of friction factors in model and prototype (f_r) must be made equal to 1 to produce similar vertical velocity distributions and secondary flows. The Darcy-Weisbach equation for open channel flow in slope (S) form is expressed as:

$$S = f \frac{1}{4R_h} \frac{V^2}{2g} \qquad \textbf{(1)}$$

Since the friction factor (f) is a function of Reynolds number ($4R_hV/\nu$) and relative roughness ($k_s/4R_h$), the modeler must work within Moody-type friction curves. Kamphius [1972] found that (K_s) for river bed material is equivalent to $2D_{90}$ (twice the 90 pct sieve passing size). At a model scale of 1:10 and if the prototype D_{90} size is greater than 10 mm, then sediment can be scaled by the geometric scale for both transport and friction scaling provided the Reynolds number is large enough. Reynolds number and Froude number scaling cannot both be attained at the same time in models. However, if the Reynolds number and relative roughness are large enough then the Darcy-Weisbach friction factor (f) can be made the same for both the model and prototype river bed and riprap material. The model must be made to flow at water surface elevations according to a tailwater curve and produce the proper corresponding velocity. The modeler must check and/or make the both the model and prototype have the same (f) for the discharge range needed. Putting the previous scale relations into the Reynolds number results in a measure of Reynolds number distortion (R_{dr}) based on the selected model scale ratio expressed as:

$$R_{dr} = L_r^{3/2} = 31.6$$

Prototype to model friction ratios for the riprap modeled with 3/4- to 1.5-inch gravel varied from 0.97 to 1 for discharges ranging from 250- to 1400-ft^3/s. For No. 4 sieve size to 3/8-inch gravel the friction ratios were 1 over the same discharge range. Thus, the movable bed material scaled both in terms of friction and transport.

MODEL TESTS

Tests of As-built Structure

The jet exiting the control gate was visibly skewed across the chute. The horizontal skewness of the jet is a result of several factors; the close proximity of the outlet works wye branch to the control gate, the offset centerline of the branch, and the open wall slots remaining after construction from the gate frame blockout. With all the flow passing to the 78 inch branch (only condition presently possible) flow visually separates off the branch crotch and a strong longitudinal eddy is generated along the inside wall of the 78 inch leg. The eddy affects carry to the gate and effect the flow profile of the jet passing under it. The offset centerline of the 78 inch leg reduces the symmetry of the branch and acts to increase eddy strength. The open slots either side of the gate cause vertical eddies within the slots which are further sources of flow instability.

The lateral skewness of the jet downstream of the control gate was documented by measuring the water surface elevation across the chute using a water surface probability probe. Profiles were measured at three stations along the chute and for five gate openings from 16.7- to 66.7-percent. Profiles were measured at station 4+43.50 (located at PC), station 4+53.42, and station 4+62.13. Flow moving down the chute concentrated to the left side (looking downstream), figures 6-9. The unsymmetrical flow across the chute also causes the face of the hydraulic jump to be skewed from normal, figures 10-11.

During these tests some material moved from downstream of the basin into the basin. Large material generally moved about the basin floor while smaller material (roughly 3- to 4-inch) often traveled upstream to the chute where it moved in an oscillatory manner up the right side to nearly the face of the hydraulic jump and then down the left side, figure 12.

Static pressures measured along the chute and basin floor were greater than atmospheric at all pressure tap locations and for all discharges. Therefore, cavitation is not of significance to the concrete erosion problem.

Modifying the wye branch or installing vanes within the prototype conduit were considered difficult and less desirable than modifying the chute and basin. The only modifications considered upstream of the gate were the grouting of the slots upstream of the gate frame.

Tests With Slot Blocks

During construction a blockout wider than the control gate was formed to provide room to install the gate. After gate installation the remaining blockout area was not grouted. Thus, the conduit walls immediately upstream of the gate frame contain large vertical slots (roughly 1.25- wide by 1.0-foot deep). The large slots create vertical eddies that were suspected of adding to the skewness of the jet observed downstream of the control gate. The slots were filled in the model with removable blocks to investigate the influence of the slots on the chute flow.

Observations and surface profile data were again measured for the same stations and conditions as conducted previous.

Although, the flow still concentrated toward the left chute wall, the flow profile improved for the 16, 25, and 33 pct gate openings, figures 13-15. The increase in flow on the right side of the chute served to reduce the hydraulic jump skewness and the extent of the chute return flow. Some rock material was again drawn onto the stilling basin floor and moved onto the chute. Improvements in the flow skewness due to filling the slots were much less apparent at higher gate openings.

Observations With Deflectors

A curved flow deflector was placed in the chute and a second flat deflector was placed downstream in the stilling basin, figure 16. The location and angle of these deflectors were varied to determine if they could be used to adjust the flow profile. The chute deflector was designed to force the flow down along the chute floor and reduce the lateral skewness.

The location of the chute deflector was found by moving a straight deflector vertically, horizontally and rotationally, judging its effectiveness visually. The distance the jet traveled along the chute floor, the skewness of the jump face, and the location and lateral skewness of the bubbly-clear water interface were used as visual indicators of deflector performance. The deflector was positioned to obtain the greatest improvement in flow conditions between 16- and 33-pct gate openings. After the best position was determined, the deflector was then curved slightly (simple radius with 0.08 ft maximum deflection from its 2.5 ft chord) to reduce separation of flow and splash downstream from the deflector. The chute with the curved deflector installed is shown in figure 17 operating at 25 pct (1.62 ft) gate opening.

The chute deflector was observed with and without the slots upstream of the gate. These observations indicated that filling the slots noticeably improved the flow action downstream of deflector. The bubbly-clear water interface which provided a clear demarcation between the chute jet and the return flow eddy moved well upstream (size of the return flow eddy increased) toward the deflector when the filler blocks were removed.

The objective of the flat basin deflector was to force the flow to sweep the end sill and thus maintain a downstream velocity component over the basin end sill and adjacent apron. To find the best position and inclination for the basin deflector short strings were attached to downstream edge of the sloped stilling basin end sill to indicate the direction of flow. The deflector was first positioned for flow from a 25 pct gate opening. The deflector position was adjusted until all the strings were drawn steadily downstream as parallel with basin walls as possible. The positioning was then verified again by observing the action of the strings under flow conditions at all gate openings and over a range of increased tailwater elevations. The size and position of the basin deflector are shown in figure 16. The basin deflector tested in the model is shown in figure 18.

Effects of Deflectors on Velocity Over the Basin Outlet Sill

An evaluation of the modifications to the structure were conducted observing material movement and measuring flow velocities over the basin end sill as modifications were added. The basin flow in the as-built draws the most material into the basin at about 25 pct gate opening, therefore a 25 pct gate opening was chosen for velocity measurements. Velocity measurements were made of; (1) as-built with slots upstream of gate filled, (2) filled slots and upstream deflector, and (3) filled slots with both the upstream and downstream deflectors. Velocities were measured just above the interface between sill and the riprap apron. Velocities were measured at three positions across the end sill; near both the basin walls and at the center. A comparison of the velocity measurements are shown in Figure 19. Results of these tests were as follows.

Test 1) - With only the slot blocks installed, there was back flow over the entire sill-riprap interface with velocities ranging from 4.4 ft/s on the right side to 2.1 ft/s on the left side (looking downstream). Both the 3/4 inch and 3/8 inch (model) riprap material was moved into the basin.

Test 2) - After adding the chute deflector, there was still back flow over the sill-riprap interface on the left side and the middle, although the velocity was reduced by 76 pct on the left side and about 67 pct in the middle. On the right side the flow direction changed to downstream with a velocity of about 2.1 ft/s. Some small (3/8 inch) material came back into the basin.

Test 3) - With the addition of the basin deflector, all the flow over the sill-riprap interface moved downstream with velocities ranging from 3.75- to 4.15-ft/s (averaging about 4.0 ft/s). No material was drawn into the basin. After measurements were completed, the deflectors were removed and material again moved quickly into the basin.

Mavis's equation and Brooks' gravity slope stability correction equation as given by Vanoni [2] were used to estimate movement of prototype material based on the measured velocities for Test 1 (only the slots filled). These algorithms predict material up to 9 inch size cobbles could be moved back into the basin. This suggests flow in the as-built structure could move small or broken riprap material into the basin.

Following the fixed gate tests the performance of the three modifications (slots filled and deflectors) were monitored over extended lengths of time for all gate openings. During these tests no indication of reverse flow or movement of material over the end sill was observed. A single boulder in a stilling basin can cause considerable damage to concrete. The modifications recommended in this study should not be considered as 100 pct corrective. Thus, the basin should be diver inspected periodically to check for and remove boulders. Rather than using coffer dams to de-water the basin for maintenance, a stoplog structure should be installed in the return river channel.

Deflector Pressure Forces

Pressure measurements at 100 pct gate opening were obtained on both sides of both deflectors. The lower side of the curved chute deflector is subjected to positive pressures while on the top side the pressures are largely negative. The measured maximum net differential pressure acting across the chute deflector expressed as net unit load is 1630 lb/ft^2. The pressure on the flat basin deflector is positive on both sides. The measured maximum net differential pressure acting downstream on the basin deflector expressed as net unit load is 421 lb/ft^2. These units loads are average values and there are velocity fluctuations around their means. It is generally accepted that maximum turbulent intensity can approach about 10 pct before the flow becomes separate jets. Without, modeling the final structural form of these deflectors to determine the dynamic fluctuation component of the hydraulic forces, a safety factor of at least 2 should be used.

Discharge Calibration

A coefficient of discharge curve was determined for the outlet works. Discharge through the outlet works was measured over the full range of gate stroke at reservoir elevation of 5317.5 ft. Discharge was measured by the laboratory venturi meters. The values of coefficient of discharge are plotted versus gate opening in figure 20. This curve can be used with equation 2 to estimate discharge.

$$Q = C_d A (2g\Delta H)^{\frac{1}{2}} \tag{2}$$

The total hydraulic head (ΔH) is determined as the reservoir elevation minus elevation of the gate opening centerline. The area (A) is the full 6.5- by 6.5-foot open area of the gate. The equation can be rewritten as:

$$Q = 339 C_d (\Delta H)^{\frac{1}{2}} \qquad (3)$$

During the discharge calibration tests, cavitation occurred in the model along the crotch of the 96- to 78-inch wye branch for gate openings greater than 90 pct with reservoir elevation at 5317.5 ft. The prototype has not operated at large gate openings for extended periods of time due to gate vibration. No visible cavitation damage has been reported on the wye branch from normal operation (gate openings of less than 4.0 ft). Based on the past operating history a further investigation in the model of cavitation on the wye branch was not warranted. It should noted in the dam operation criteria that the prototype may experience cavitation on the wye branch at gate openings above 4 feet.

Acknowledgements

Pete Julius of the Hydraulics Branch and Jeff McLaughlin of the Boise Office did the drawings for the model. Brent Mefford supervised the study and did the head loss computations. Mel Sabay obtained most of the data for this study and wrote the introductory parts of this report.

Table 1

Gate Opening %	Energy Head Station 3+69.5 (Res. El. = 5317.5)	Tailwater (ft)	Discharge (ft^3/s)
16.68	5317.5	5267.8	321
25.01	5317.4	5268.2	427
33.34	5317.0	5268.5	533
50.03	5315.2	5269.2	771
66.67	5313.2	5269.8	997
91.72	5310.6	5270.5	1353

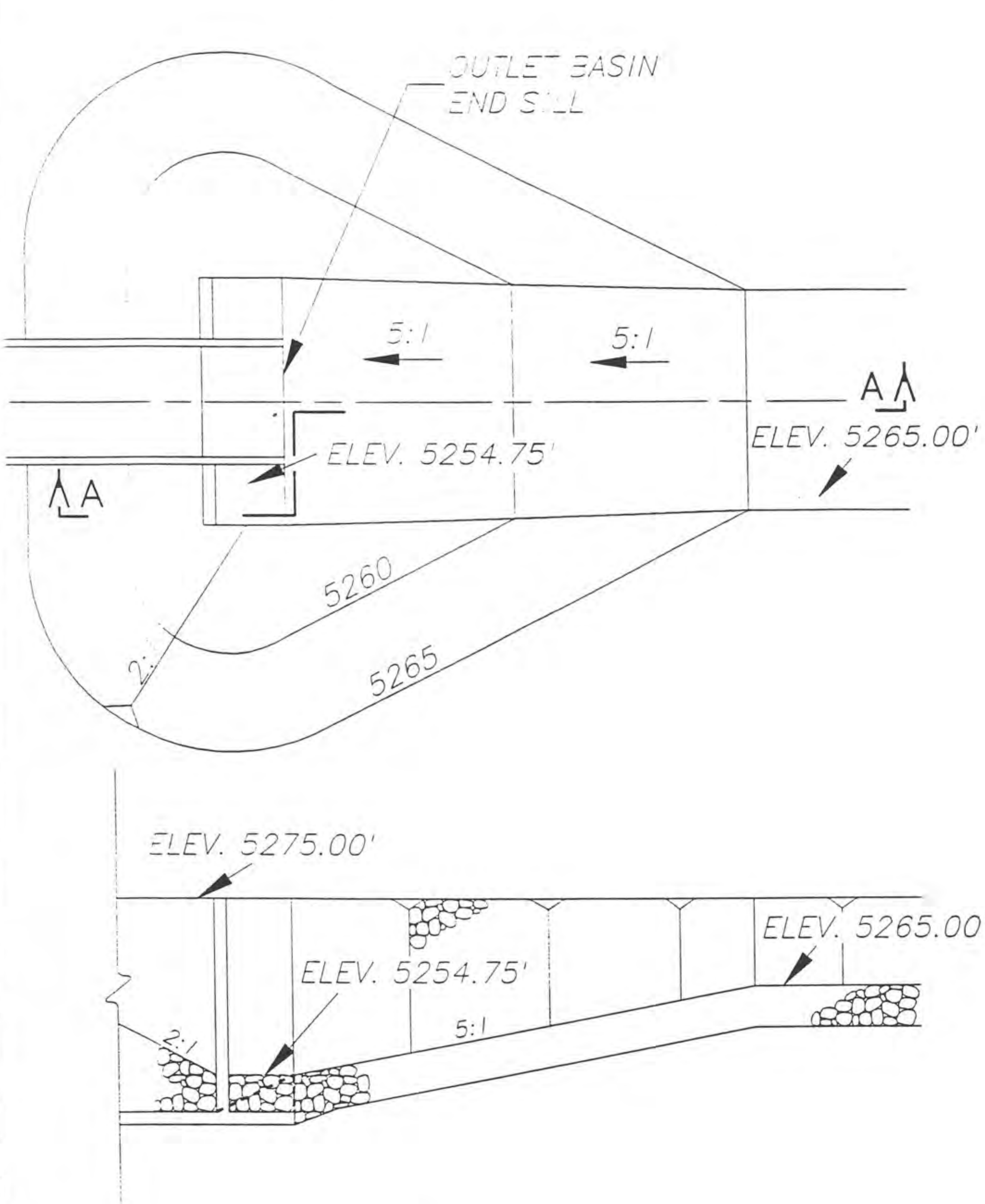


Figure 1. - Riprapped apron downstream of the stilling basin.

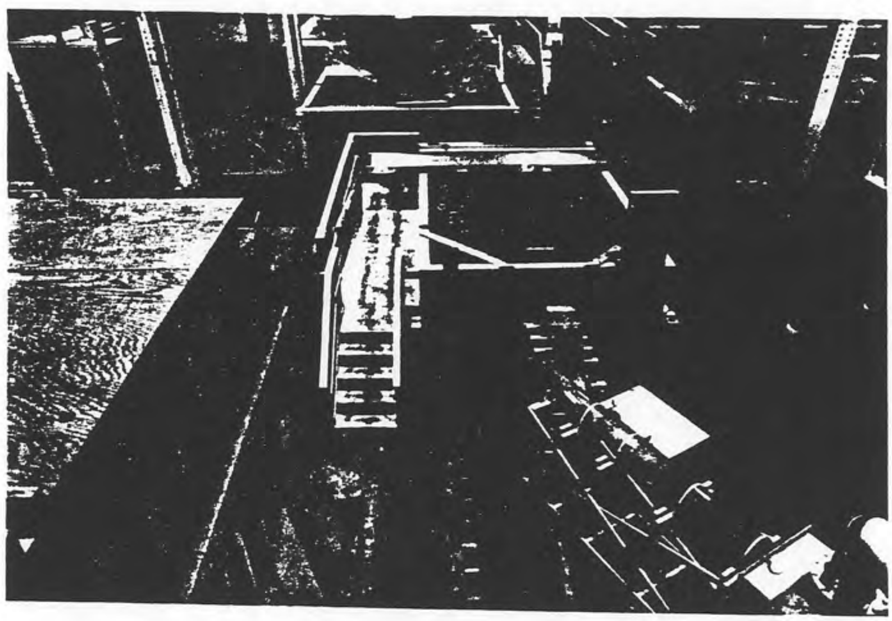


Figure 2. - View of Taylor Draw Outlet Works Model

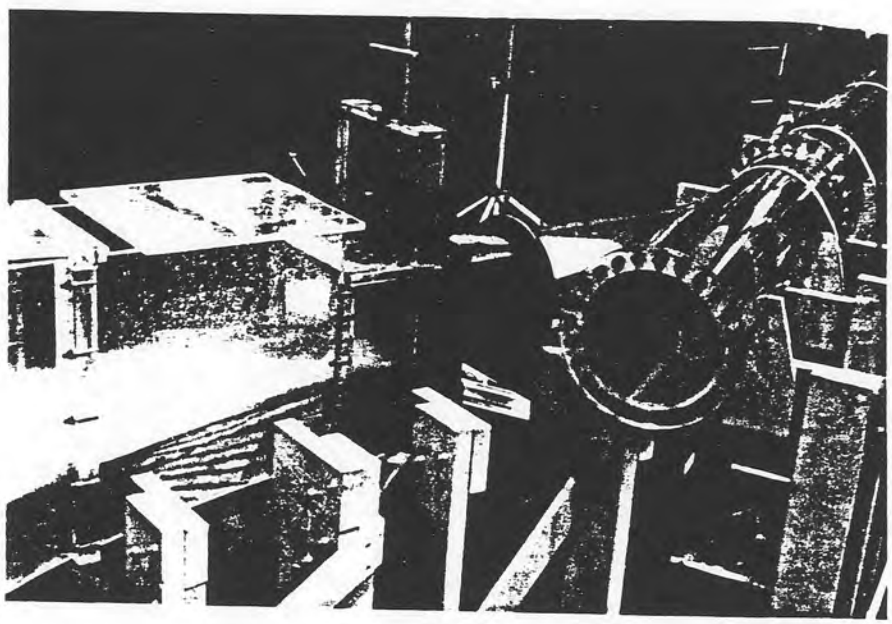


Figure 3. - The 96- by 78-inch wye branch

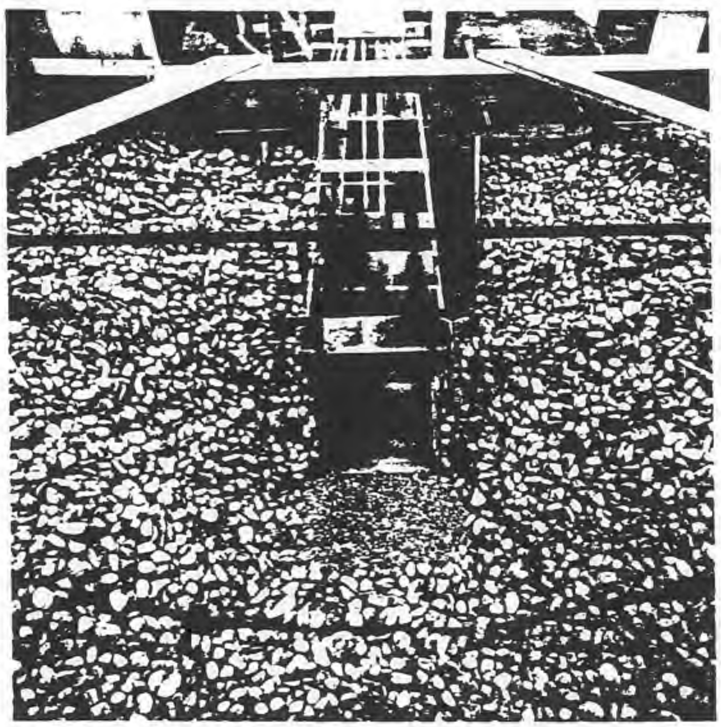


Figure 4. - Downstream model topography

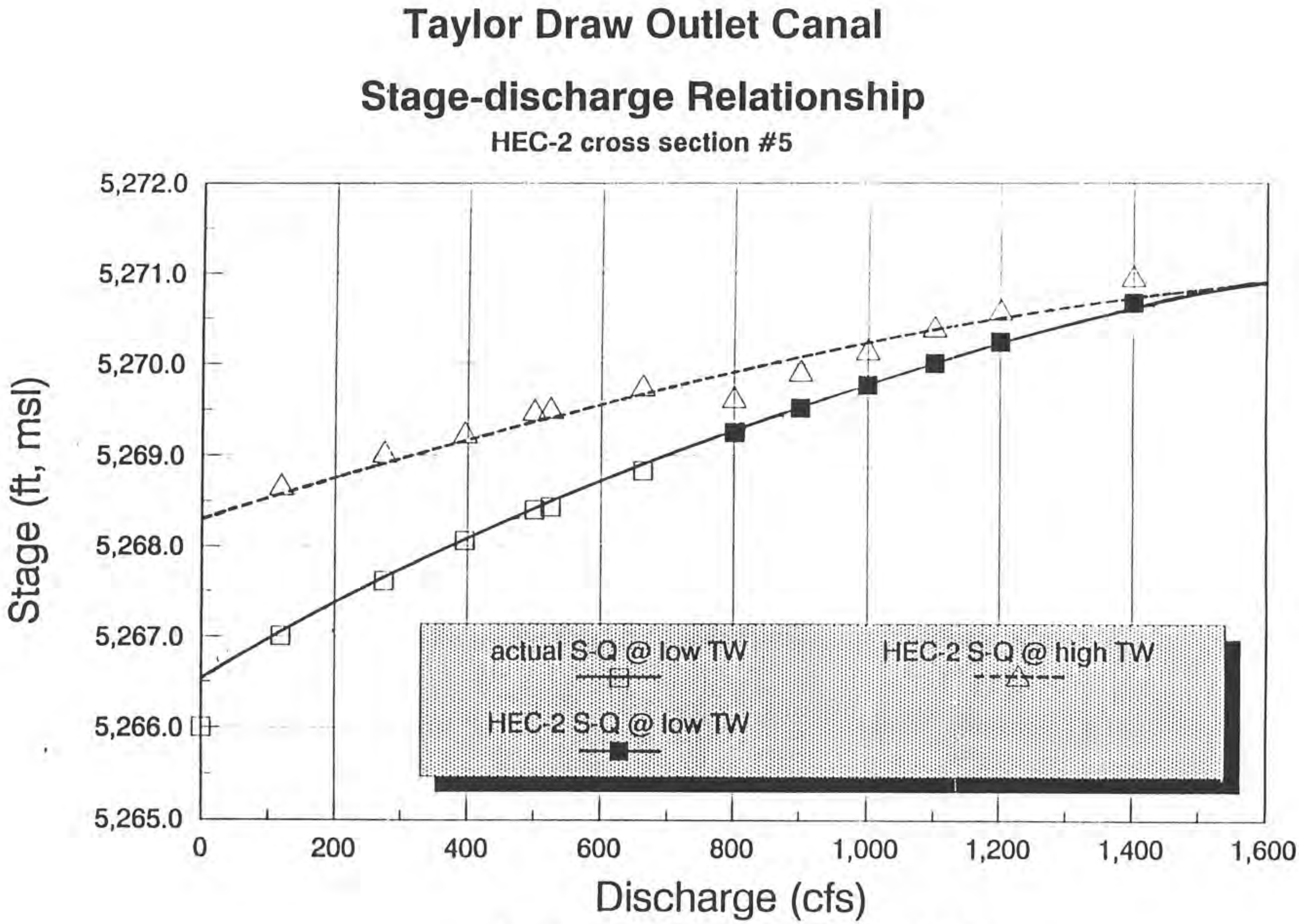


Figure 5. - Outlet works tailwater curve

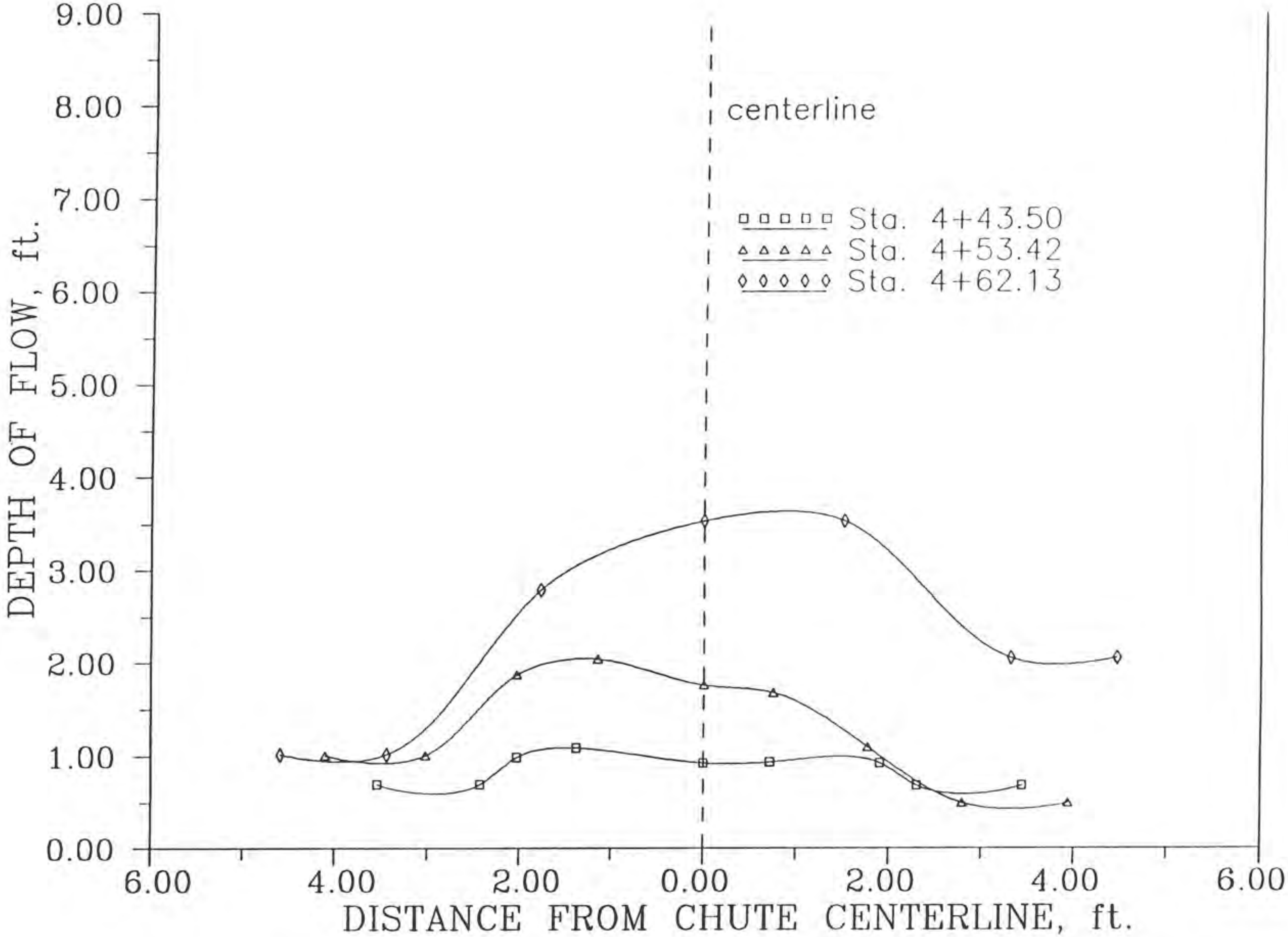


Figure 6. - Outlet works flow profile for As-Built, 16.7 percent gate opening

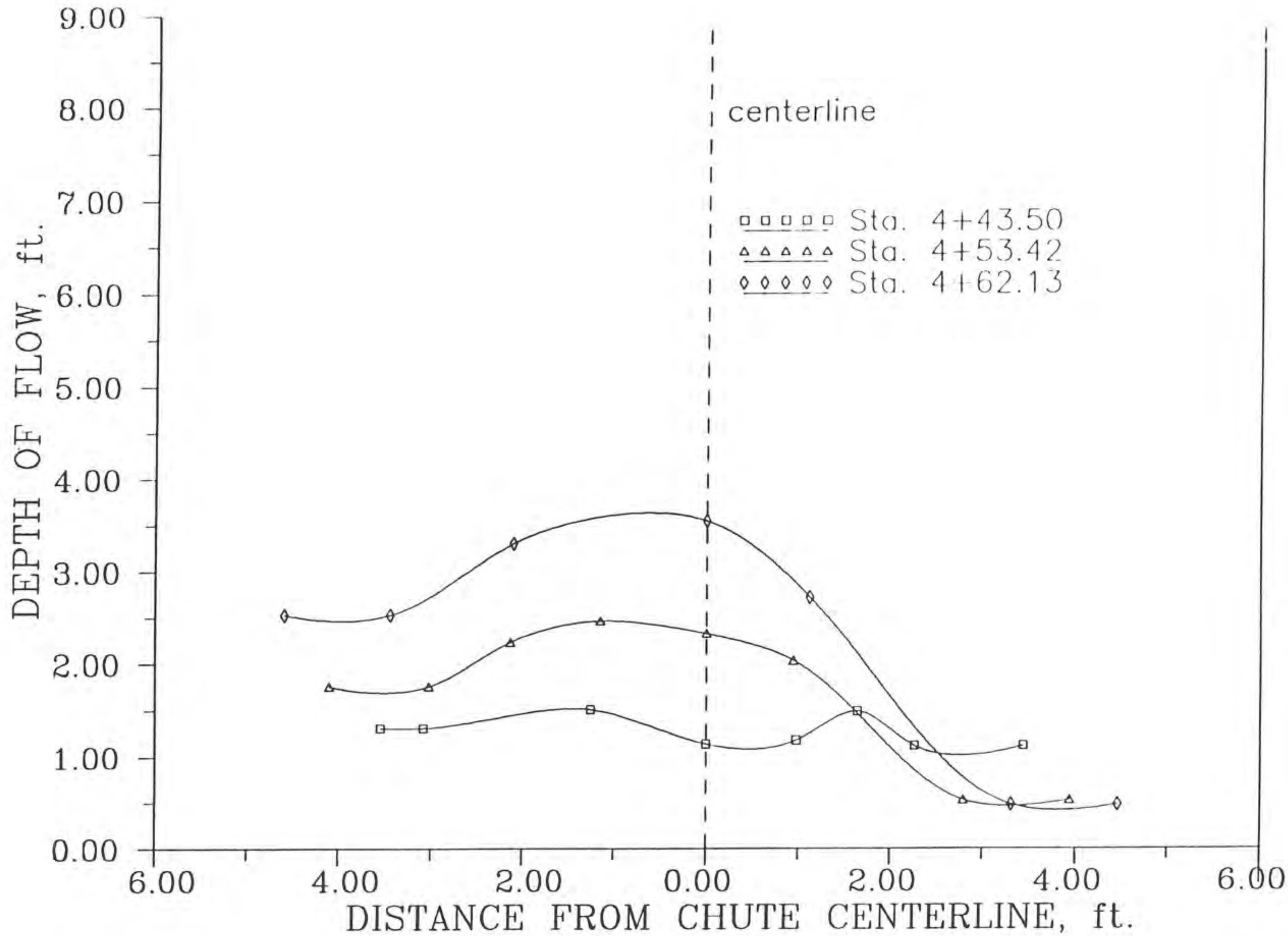


Figure 7. - Outlet works flow profile for As-Built, 25 percent gate opening

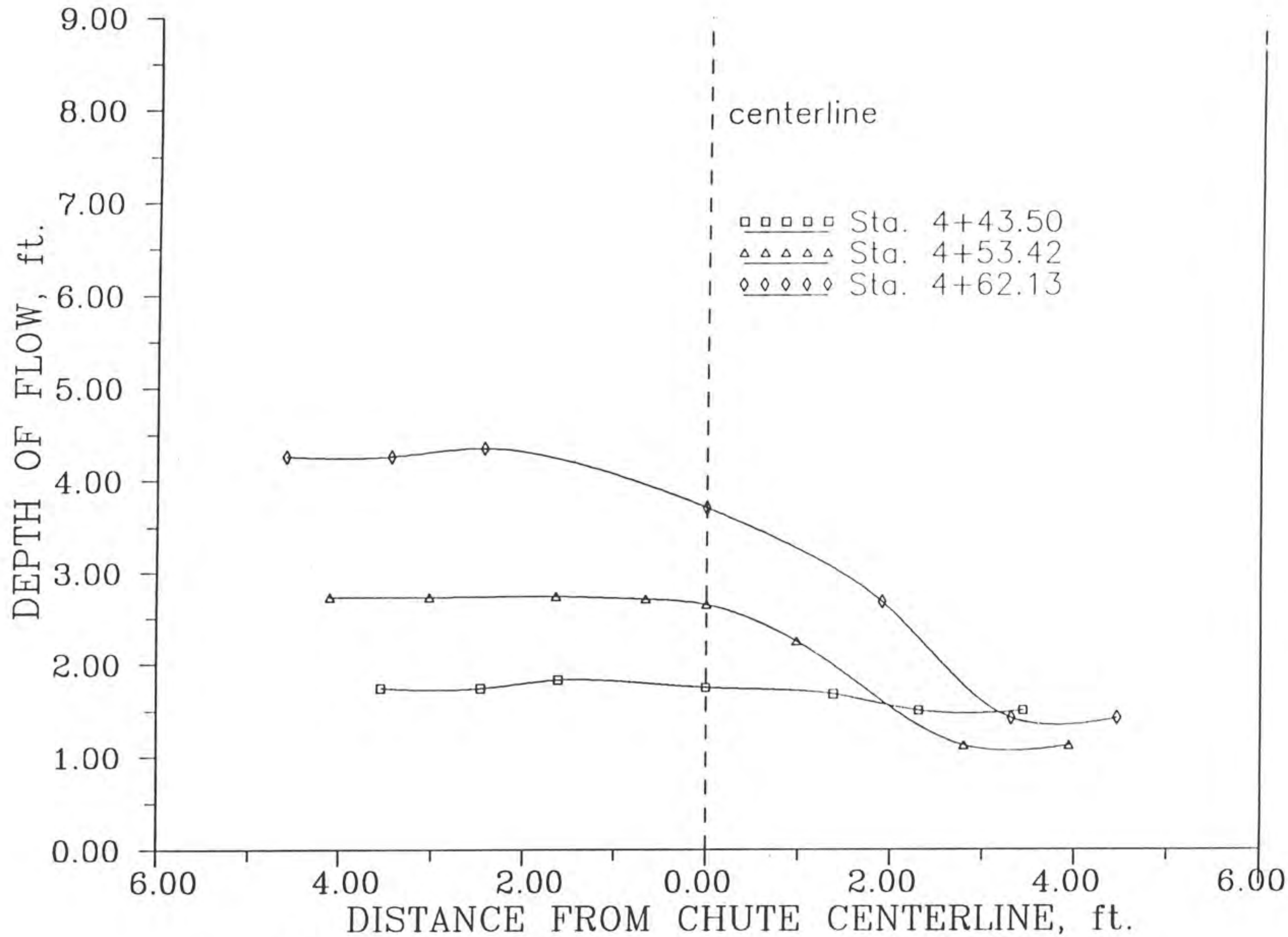


Figure 8.- Outlet works flow profile for As-Built, 33.3 percent gate opening

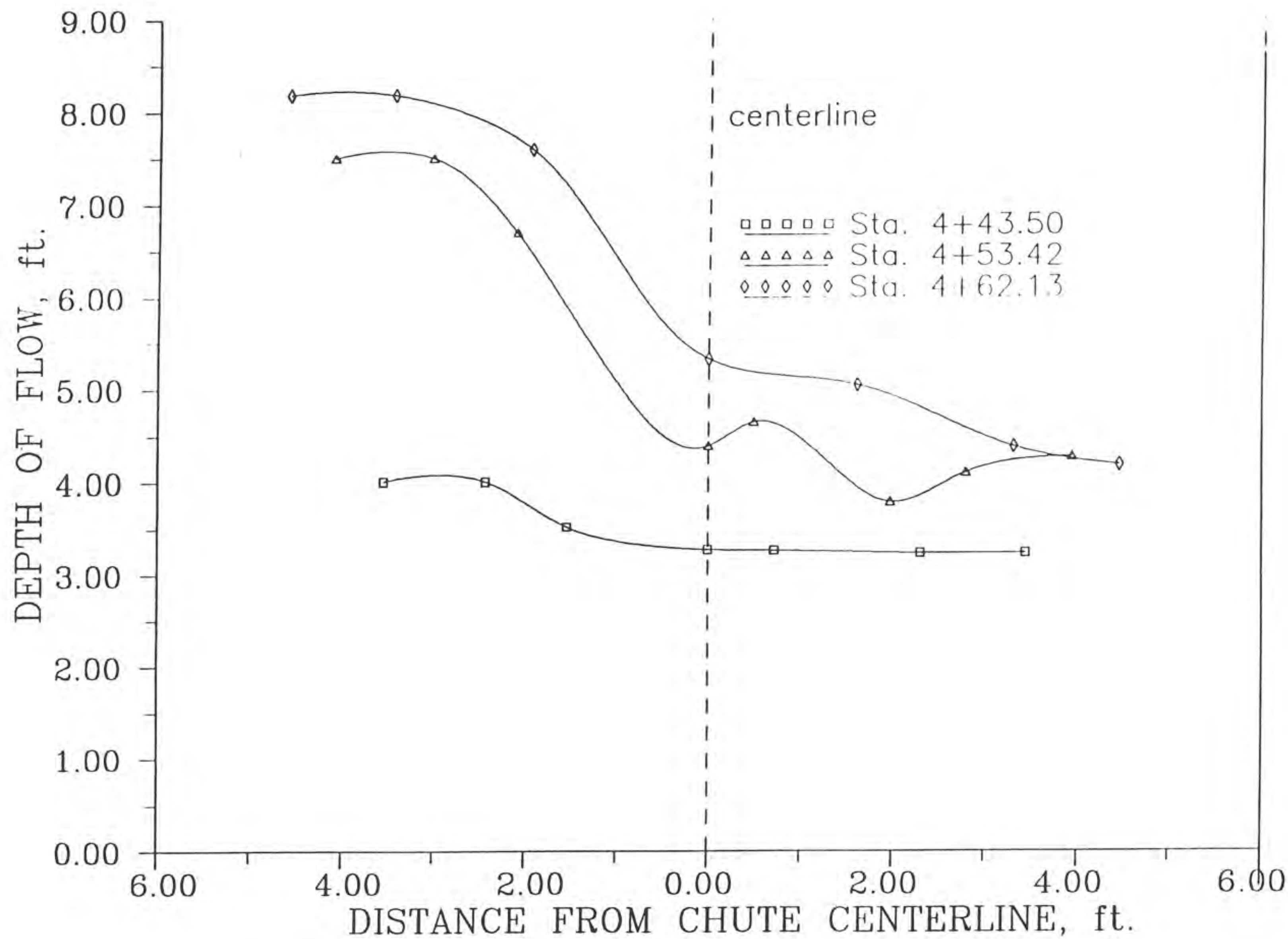


Figure 9. - Outlet works flow profile for As-Built, 66.7 percent gate opening

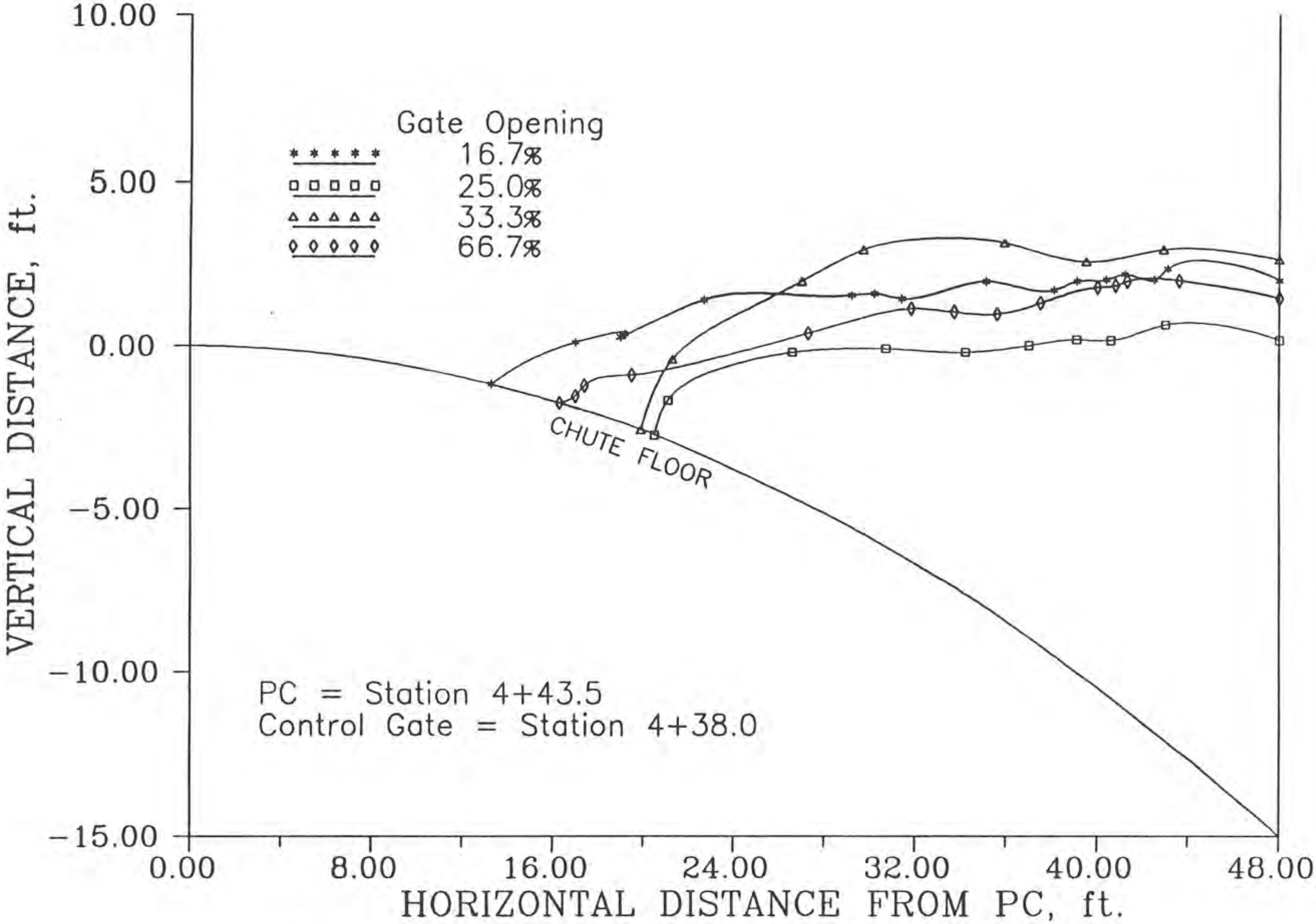


Figure 10 - Location of hydraulic jump on right wall of chute

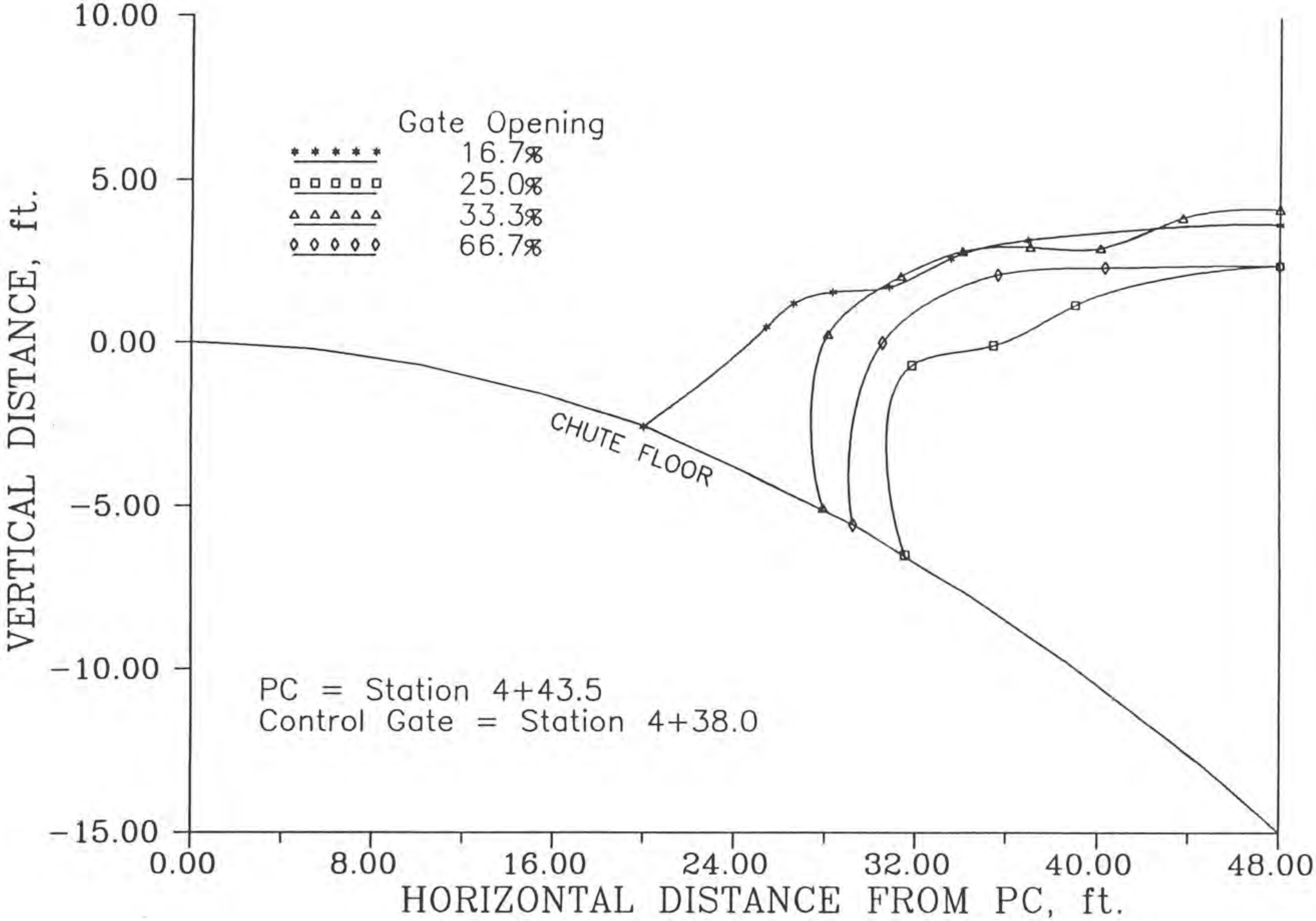


Figure 11. - Location of hydraulic jump on left wall of chute.

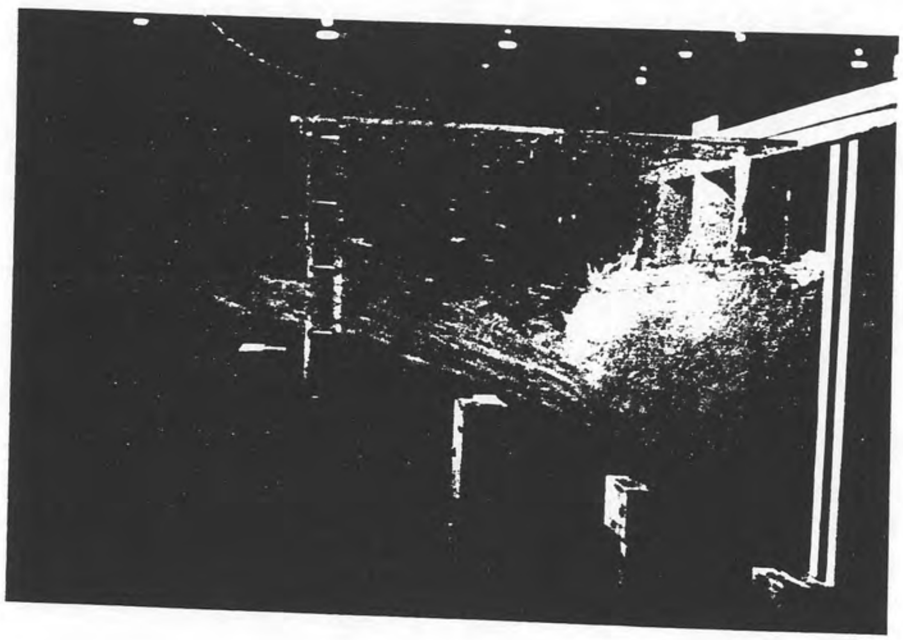


Figure 12. - As-Built outlet works operating at 16.7 percent gate opening. Note material on chute under the hydraulic jump.

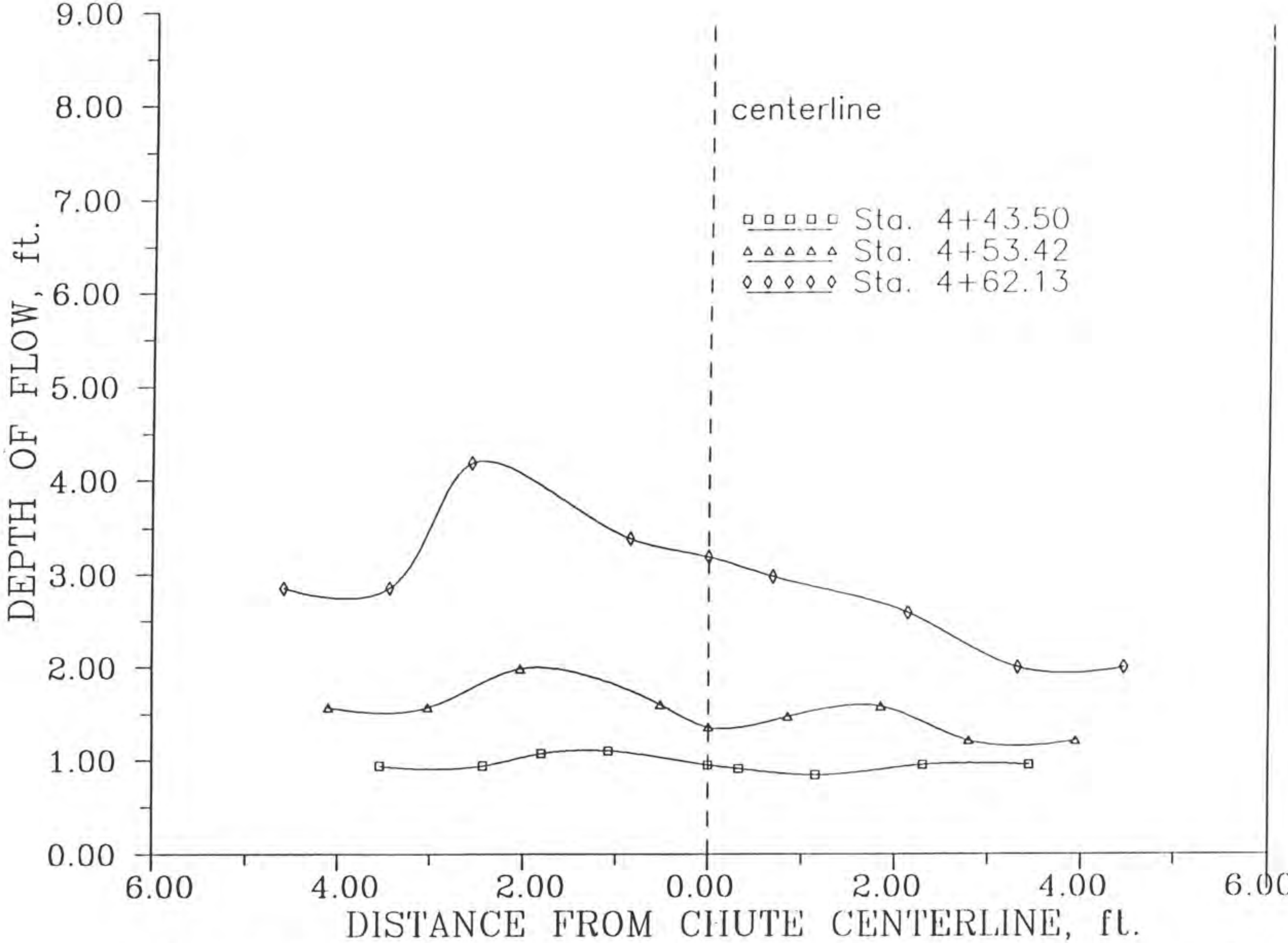


Figure 13. - Outlet works flow profile with slots upstream of the control gate filled, 16.7 percent gate opening.

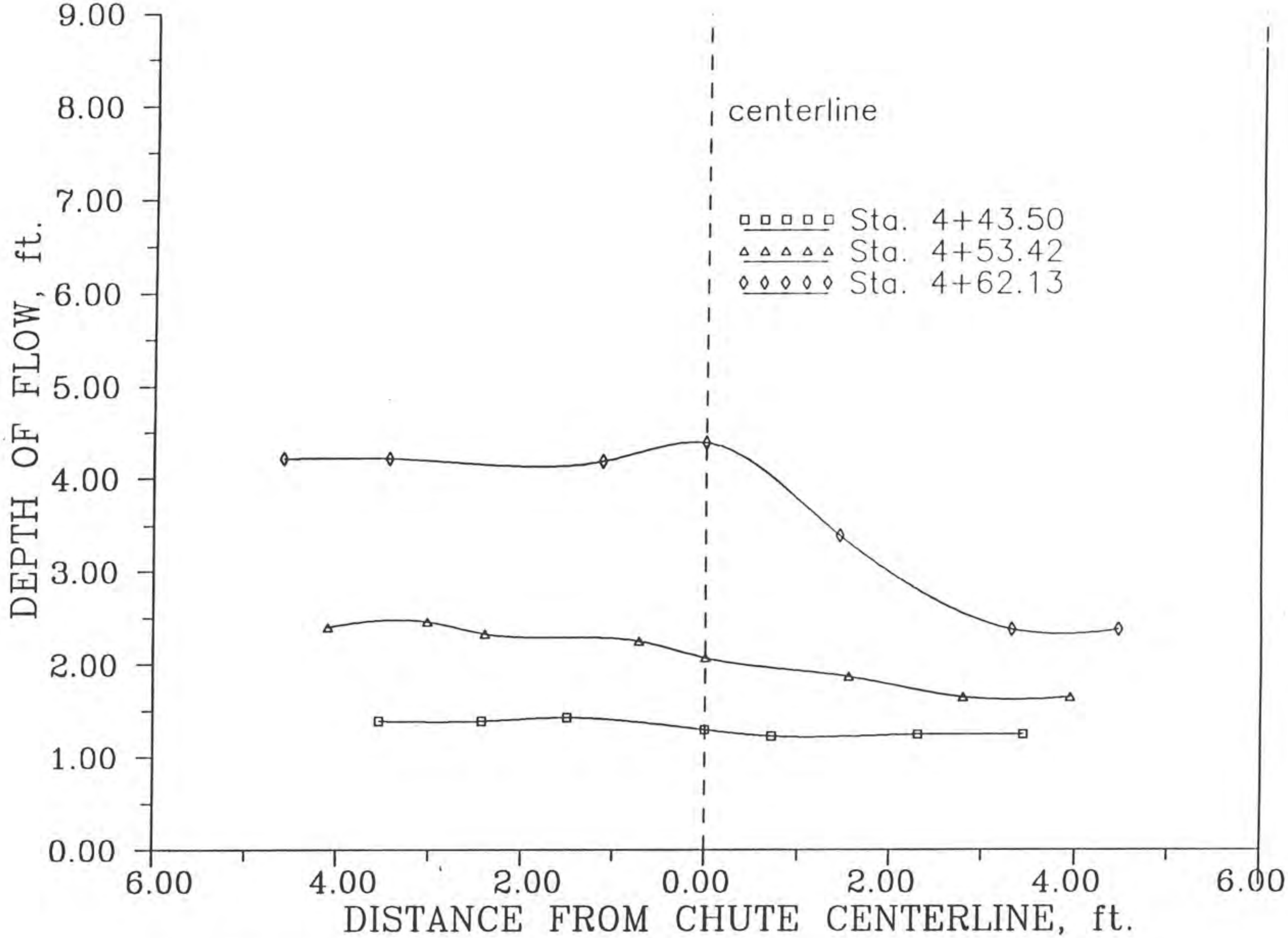


Figure 14. - Outlet works flow profile with slots upstream of control gate filled, 25 percent gate opening.

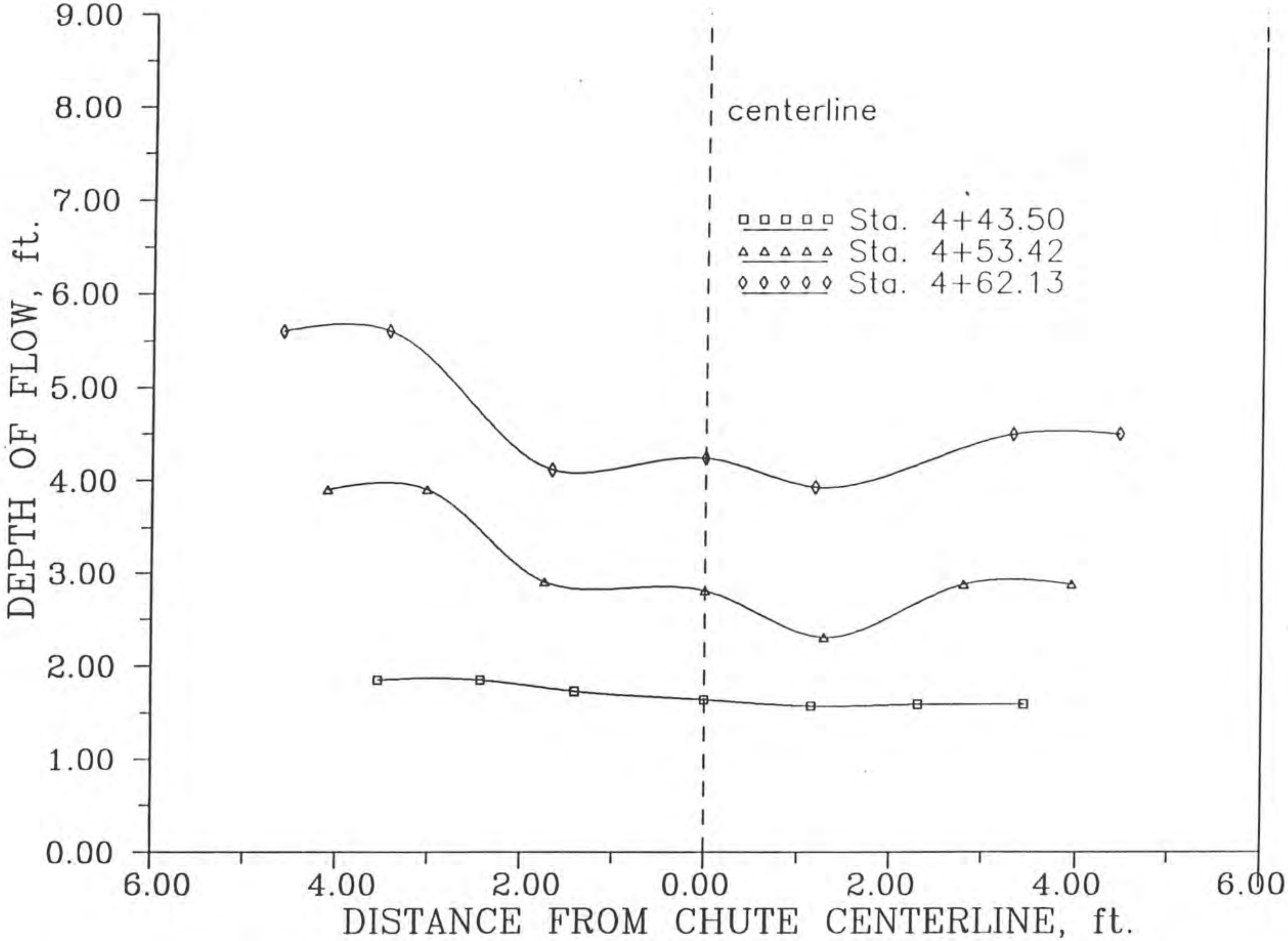


Figure 15. - Outlet works flow profile with slots upstream of control gate filled, 33.3 percent gate opening

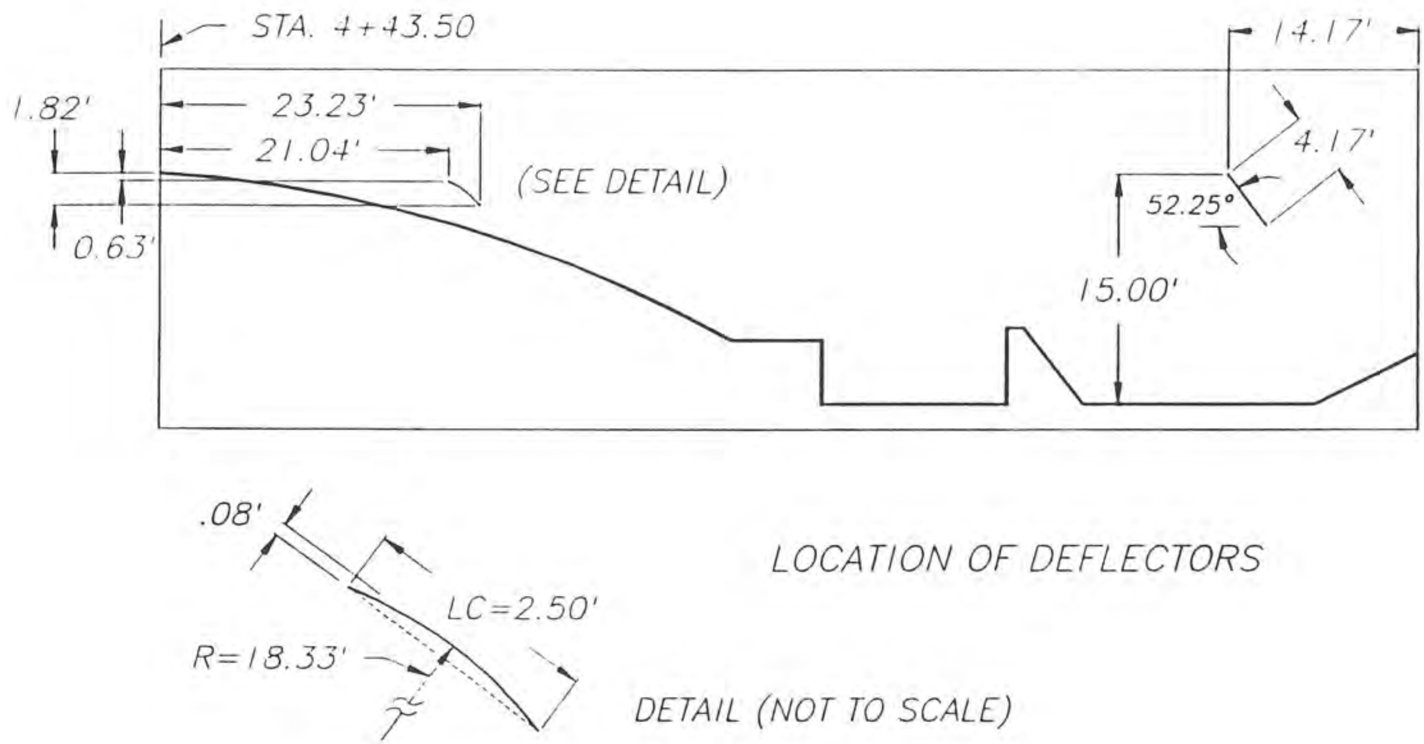


Figure 16. - Position of flow deflectors for the chute and stilling basin

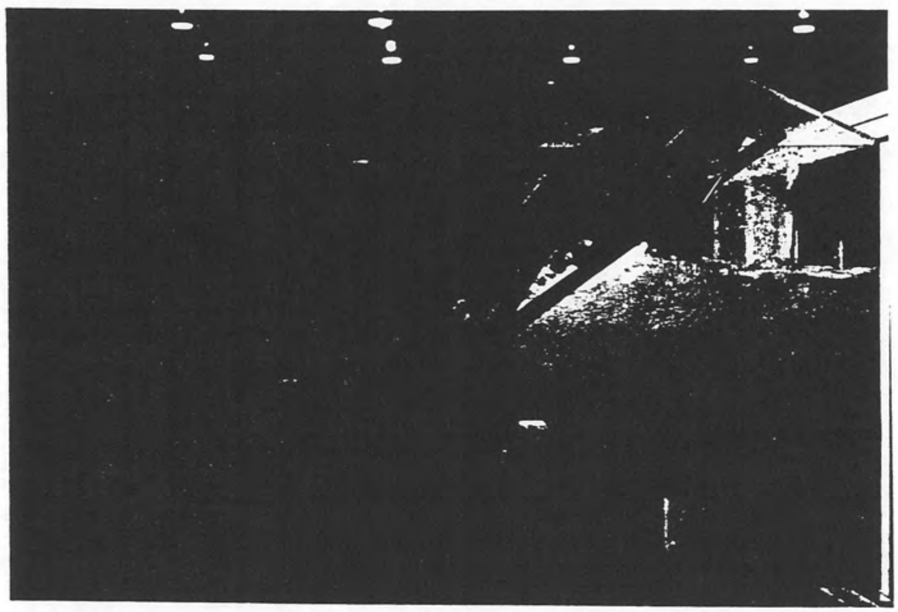


Figure 17. - Chute flow deflector operating at 25 percent gate opening

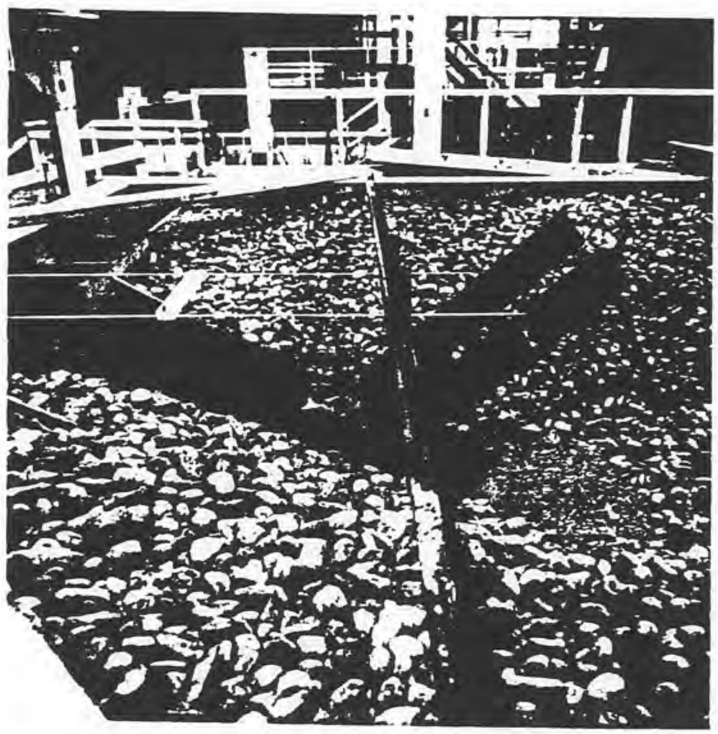


Figure 18. - Basin deflector mounted in the model

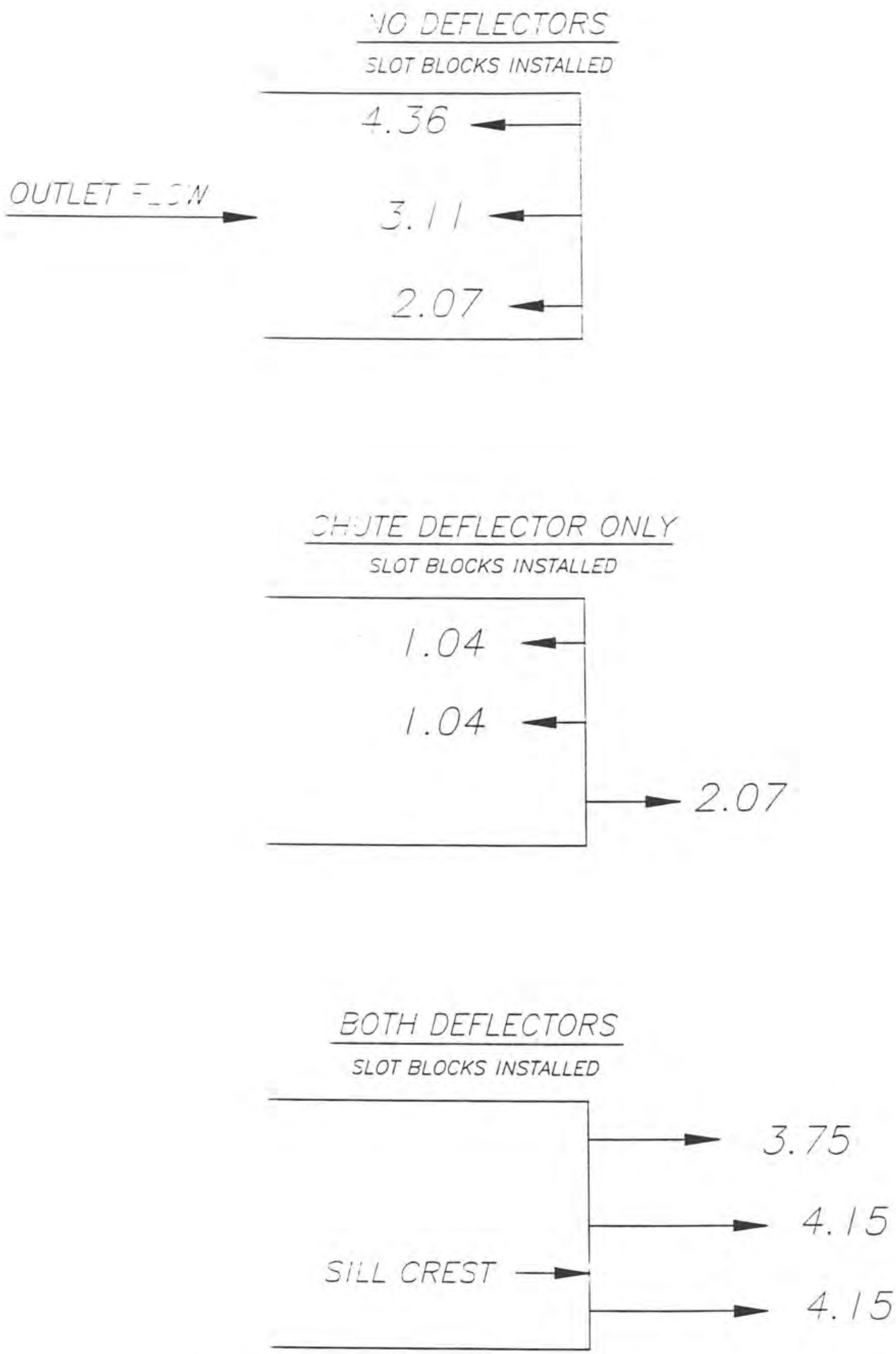


Figure 19. - Velocities measured above the end sill, ft/s

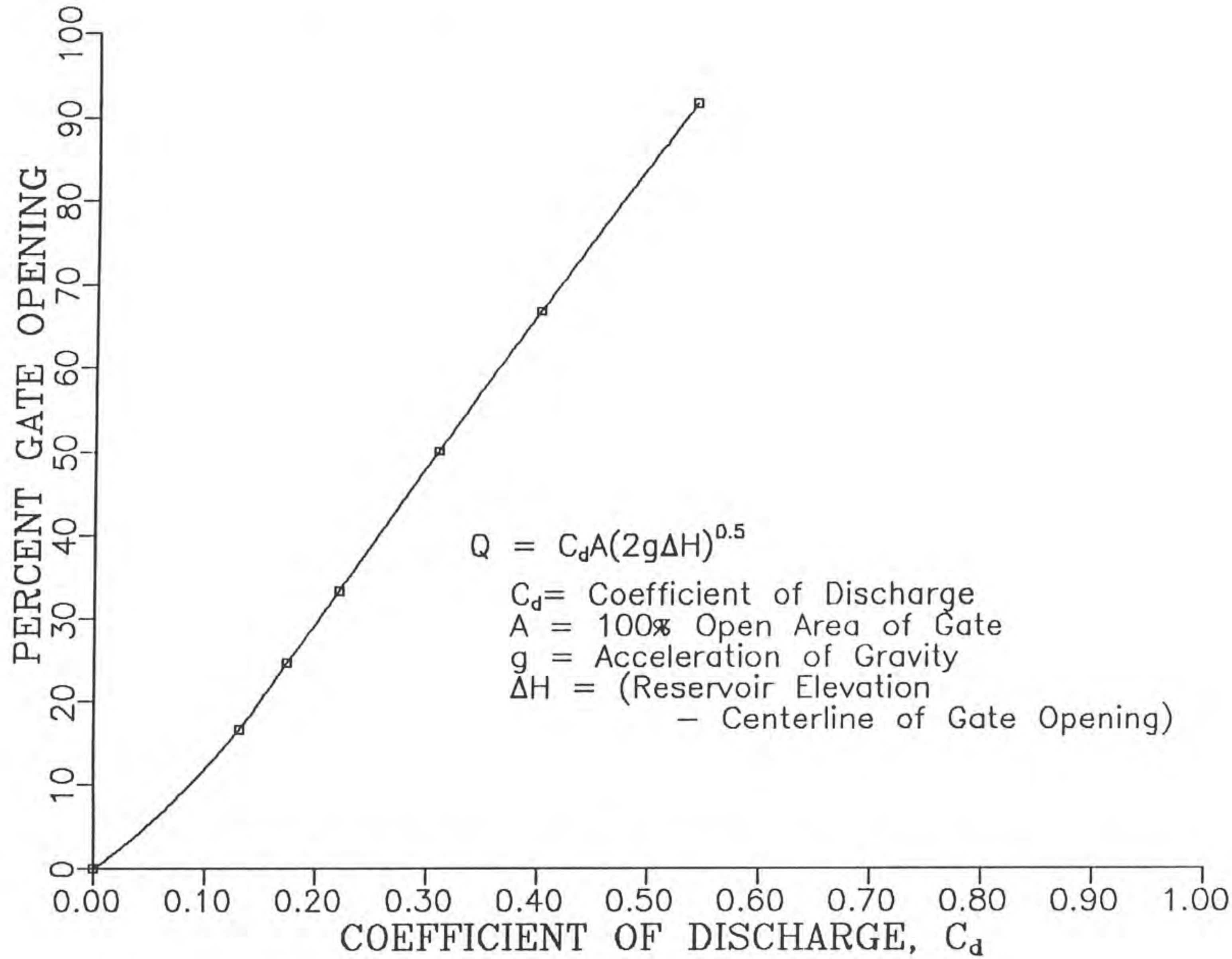


Figure 20. - Outlet works coefficient of discharge

APPENDIX C

Structural Engineer Report

Operability of Outlet Works

A STRUCTURAL ENGINEERING REPORT ON THE EVALUATION OF OPERABILITY OF THE TAYLOR DRAW OUTLET WORKS RANGELY, COLORADO

JUNE 18, 1990

PROJECT NO. 1890

PREPARED FOR:
DR. PETER F. LAGASSE, P.E.
RESOURCE CONSULTANTS, INC.
P.O. BOX Q
FORT COLLINS, COLORADO
80522

RUSSELL M. MILLER Consulting Engineers

P.O. Box 218 TIMNATH, COLORADO 80547 (303) 484-8375

June 18, 1990

Dr. Peter F. Lagasse, P.E.
Resource Consultants, Inc.
P.O. Box Q
Fort Collins, Colorado
80522

RE: Evaluation of operability of the Taylor Draw Outlet Works, Rangely, Colorado. Project #1490.

Dear Pete:

As per your request, I have reviewed relevant available subject project "as-built" drawings, and numerous photos. Further, I have visited the site and observed the stilling basin in operation. Here are my observations, comments and recommendations:

The current visual below water level structural condition of the subject project is primarily based on the photos that you supplied to me for review. There were several series of photos of different eras. The earlier series of photos indicated water related concrete erosion prior to any repairs. They showed severe erosion in the lower several feet of the walls above and at the chute blocks. The most severe wall erosion was in the south wall. It was on the order of several inches deep. In several cases, the steel reinforcement bars were fully exposed. The chute blocks were rounded off and also had sporadic exposed reinforcement bars. The chute floor and stilling basin floor in this zone was eroded from moderate to severe. The basin blocks also displayed a moderate degree of rounding off and erosion. This series of photos also displayed some of the remedial construction measures used in renovating the erosion damage.

The late 1989 photos showed the same general zones of previous renovation and how these zones have re eroded in the same general pattern as the erosion displayed in the earlier series of photos. The photo observed erosion does not appear to have advanced to the stage shown in the earlier photos. It is my opinion that if this erosion pattern is allowed to continue, over time this structure can, and will, continue to erode to the point of partial or complete collapse.

I found no specific indication that the subject portion of the outlet works is fully connected to the gate house. If they are connected and the subject structure was allowed to partially or fully collapse, the gate house could also suffer damage or possibility even collapse. This eventually must not be allowed to occur since significant gate house damage or failure would jeopardize the basic safety of the dam.

The original design calculations apparently are not available for review. We made our own spot check type structural overview calculations of the "as-built" structure indicated on the original drawings. I found no gross structural deficiencies of the specific items that I reviewed. I did not review the design of the total structure for all cases. My review was limited to determining what degree of erosion this structure could probably withstand for the remainder of 1990. Some of the reinforcement quantities appear to be on the light side for certain worst case loadings that I assumed for my review. One area of concern would be if this structure is completely emptied for repair. The wall steel is too light to accommodate the loads that I assumed for review. I would recommend that these walls be propped apart at the top if an empty basin condition is ever required. If I had been the structural engineer on this project, I would have designed it somewhat heavier, both in mass and reinforcement. This philosophical opinion is based on my personal feeling of the degree of permanence and life safety required for a civil structure of this type. No amount of structural design would have prevented the problems that are being experienced. The root problem is of a hydraulic nature.

As requested, we have determined what level of erosion we feel could be tolerated, without excessive risks, for the remainder of 1990. We have prepared a drawing (Exhibit A) to graphically display our findings. There is always a degree of calculated risk whenever a structure is altered by any means. However, we feel that with an orderly program of monitoring for damage, the risk of actual complete failure is remote. If during the monitoring process the erosion is found to have advanced beyond our indicated erosion tolerance levels, it is my opinion that the use of the outlet works should be discontinued until it is repaired, modified or replaced with a long term functional outlet works. The monitoring work could be handled by divers or some other method of your choice. Whatever method is used, I would recommend that, if possible, the same people do the work each time. All results should be recorded and compared to previous data. The exact methods and level of monitoring will need to be worked out between you and the CRWCD.

The level of erosion that is allowed to occur during the remainder of 1990 is directly related to the degree of difficulty and expense that will be needed to repair this structure. If this structure is eventually abandoned and replaced, the degree of erosion within the given limitations is not important. If the model and RCI studies determine that by modifying the structure, or operation of same, the structure can be made functional, the level of permitted erosion will be important. I would recommend that the outlet works be operated at the levels that minimize erosion, all as determined from the model, and RCI studies and recommendations. If major zones of the maximum levels of erosion are allowed to occur, this structure could become very difficult and prohibitively expensive to repair.

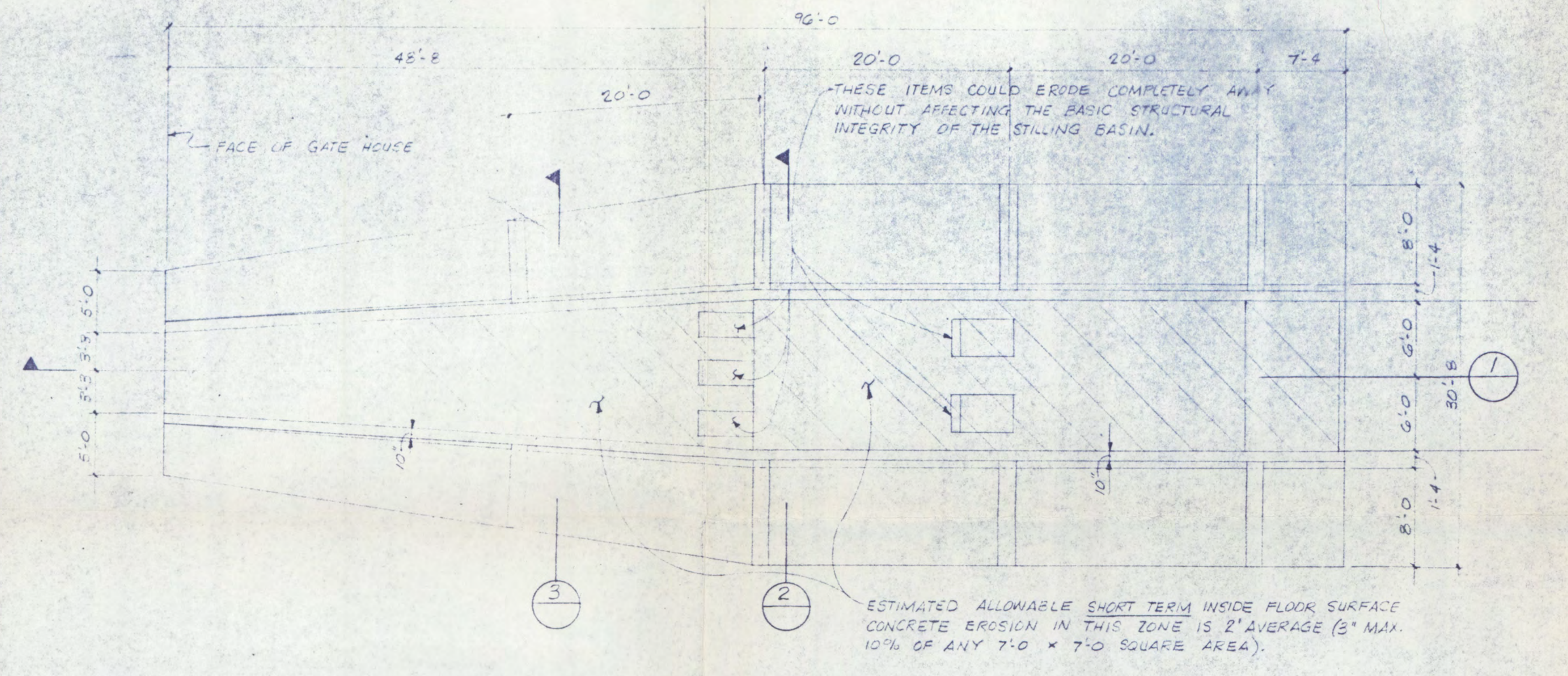
I believe that this brief report and the attendant Exhibit A covers the structural and relate aspects of the items that you wanted to be informed about at this time. Please contact me at any time if you or other interested parties have any questions or need additional data.

Sincerely,

RUSSELL M. MILLER REGISTERED 4411 PROFESSIONAL ENGINEER STATE OF COLORADO

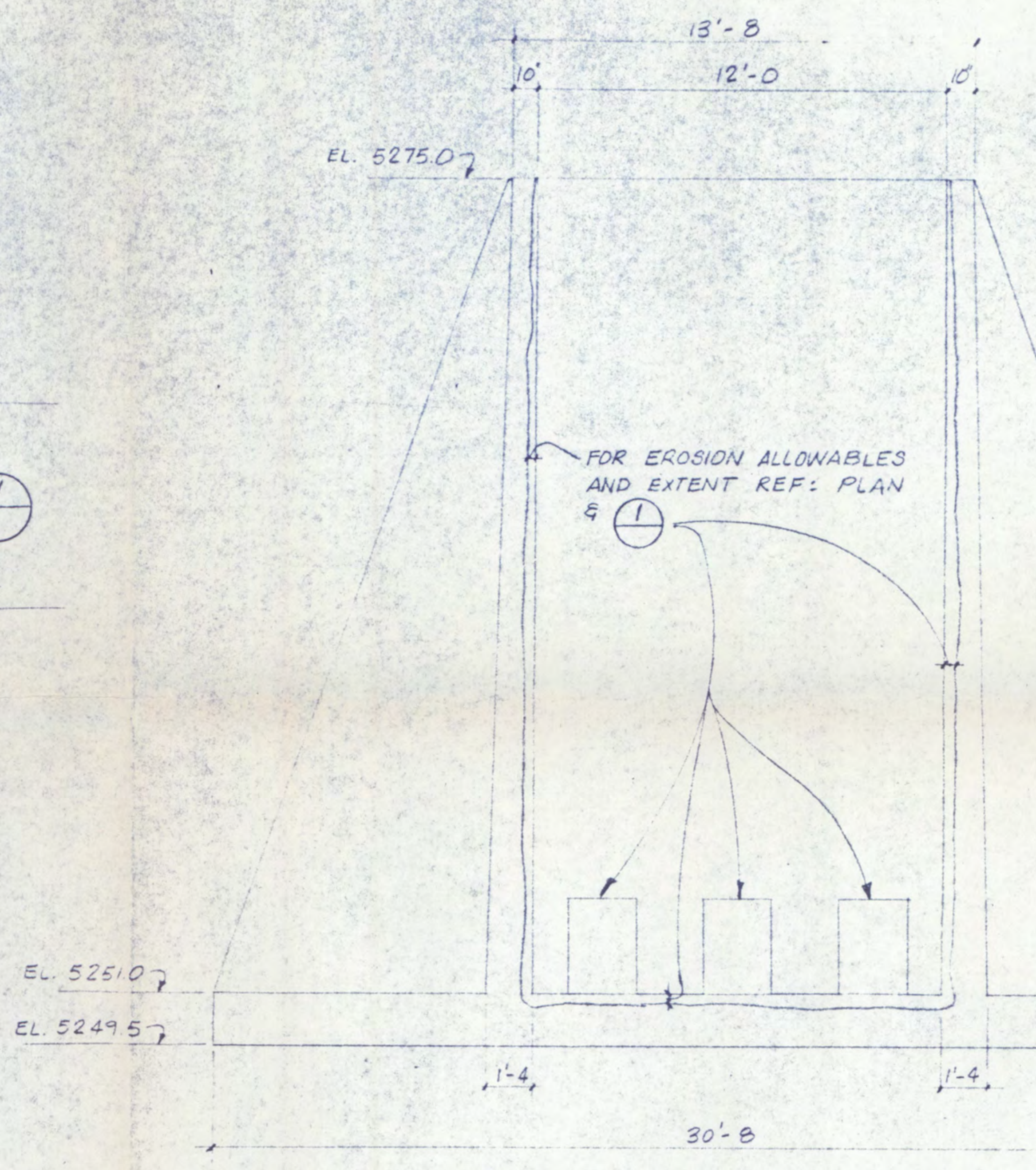
Russell M. Miller, P.E., C.C.E.
RMM/cb

Enclosures: Exhibit A (8 copies)

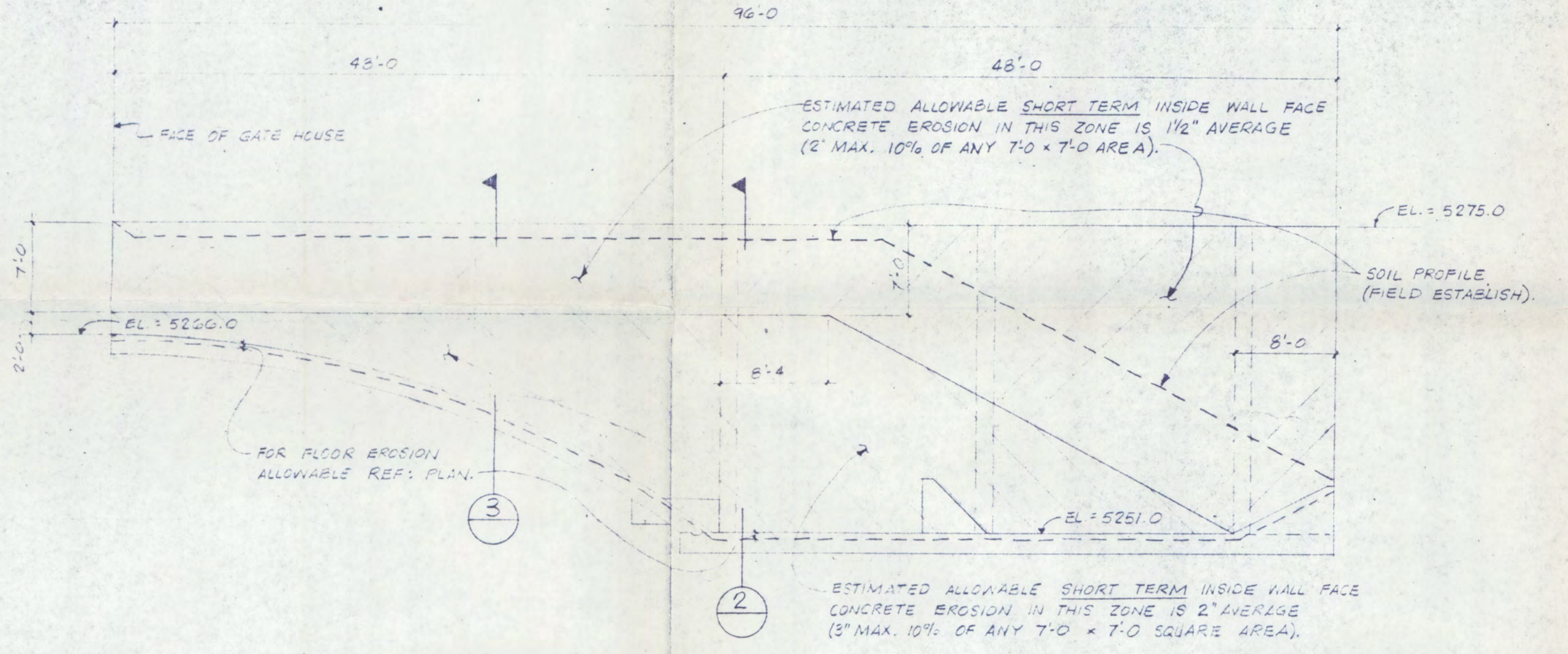


P L A N

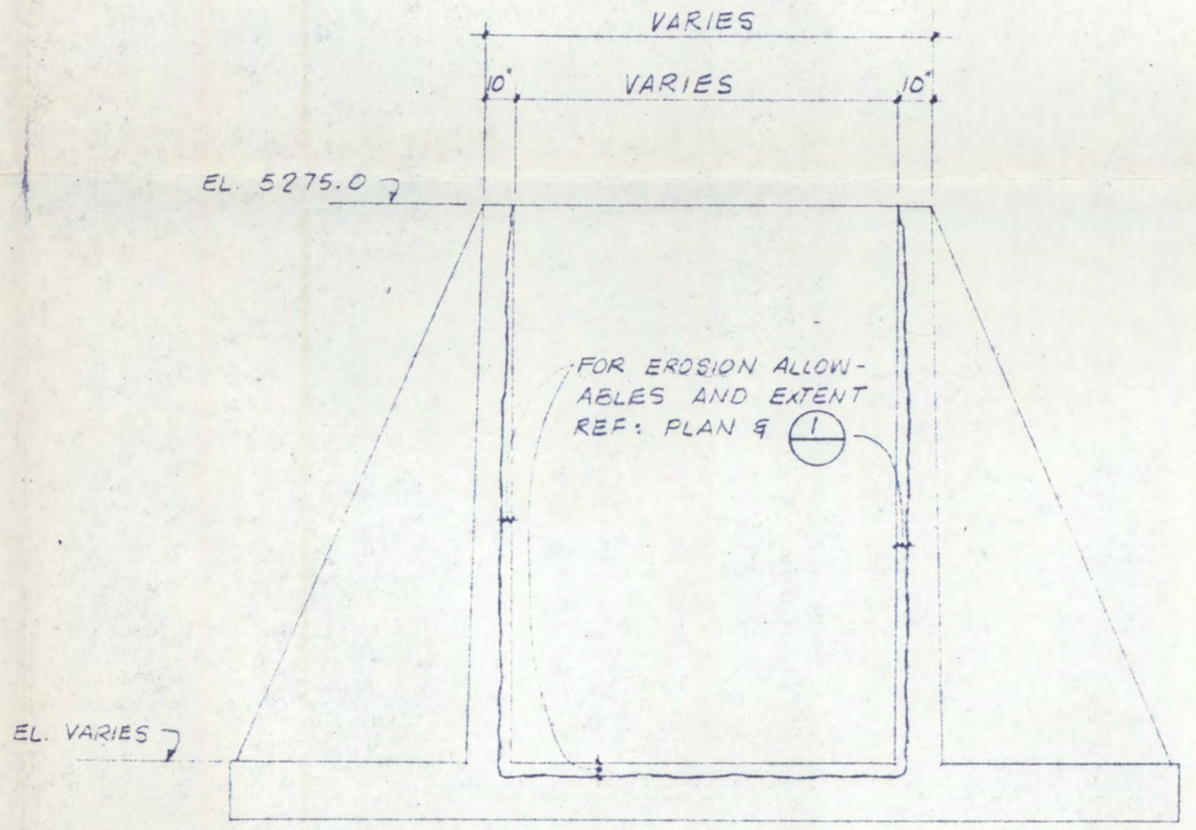
1/16" = 1'-0



2 1/4" = 1'-0



1 1/16" = 1'-0



3 1/4" = 1'-0

GENERAL NOTES:

1. THIS SHEET SHALL BE WORKED WITH OUR LETTER REPORT OF JUNE 18, 1990, CONTAINED IN THE RELATED REPORT PREPARED BY RESOURCE CONSULTANTS, INC., FORT COLLINS, COLORADO.
2. "SHORT TERM" IS DEFINED AS THE REMAINDER OF 1990.
3. THE DATA SHOWN ON THIS SHEET AND OUR RELATED ENGINEERING REPORT ENCOMPASSES THE TOTAL EXTENT OF THE DESIGN RESPONSIBILITY OF RUSSELL M. MILLER CONSULTING ENGINEERS.

DATE	SUBJECT	BY
6/20/90	GENERAL ISSUE (8 COPIES) WITH RELATED REPORT	RMM

TAYLOR DRAW DAM STILLING BASIN
RANGELY, COLORADO

RUSSELL M. MILLER REGISTERED 4411 PROFESSIONAL ENGINEER STATE OF COLORADO
JUN 20 1990

RUSSELL M. MILLER
CONSULTING ENGINEERS
4000 Kern, Timnath, CO 80547

DESIGNED	DRAWN	CHECKED	APPROVED
RMM	CS	RMM	R.M.M.

DATE JUNE 18, 1990
PROJECT NO. 1490
EXHIBIT "A"

STILLING BASIN ESTIMATED "SHORT TERM" ALLOWABLE CONCRETE EROSION DATA.

1 OF 1

APPENDIX D

Dive Inspection Report

Taylor Draw Dam

Dive Inspection Report

Taylor Draw Dam

August 13,14,15 1990

Inland Marine Services
17771 East Crestline Place
Aurora, Colorado 80015
(303) 699 - 2729

FACILITIES EXAMINED: Taylor Draw Dam outlet works stilling basin,
intake structure, and spillway stilling basin.

DATE EXAMINED: August 13, 14, 15, 1990

PERSONNEL: Inland Marine Services- Supervisor Barry Hughes
Diver #1 Steve Rupp
Standby diver Brad Matoush
Water Users Association- John Gibson

OBJECTIVE OF DIVE: To examine the outlet works and spillway stilling basins and the intake structure for structural stability during operation.

CONDITIONS: Weather - clear and warm
Water temperature - Approx. 50 degrees F.
Water visibility - 0 to 1 Feet
Water depth - Intake structure closed gate 47 feet
open gate 37 feet
Outlet works stilling basin 15 feet
Spillway stilling basin 15 feet

ACTION TAKEN:

INTAKE STRUCTURE

The diver entered the water from the crest of the dam, and walked to the intake. There is a point marked on the rip rap which enables surface personnel to aline the diver with the structure. The diver examined the gate hoisting cylinder and its mounting. The fittings where the hydraulic hoses connect to the hydraulic cylinder were all tight. The cylinder ram was free of corrosion. All bolts and brackets were tight and secure. The diver descended through the stop log slot in the top of the structure, and examined the gate area. The connection of the gate to the hydraulic ram was secure. The gate frame was in very good condition, and was stable.

The floor inside the structure was clean with only a thin layer of silt. All trash racks were firmly in place, with no corrosion.

The diver exited the structure and inspected the area around the outside of the trash racks. There was no silt, wood or trash built up in any quadrant. The silt level immediately around the intake was 47 feet below the water surface. This is the same elevation as the floor inside the intake structure.

Positioning himself at the hydraulic cylinder, the diver watched the gate and cylinder as surface personnel cycled the system from full closed to the open position. The lower outlet gate was closed during this operation. Everything operated properly. The diver noticed that the top two wedges on each side were not making proper contact with the gate frame. Surface personnel were lowering the gate to its original position when a hydraulic line ruptured.

A repair hose and fittings were obtained and installed on a subsequent dive. The system was operating properly when we left the dive site.

CONCLUSION: The intake structure is in good condition, with all components secure and operating properly. Some leakage is evident around the gate, probably due to improperly adjusted gate wedges.

RECOMMENDATIONS: There are no more spare hydraulic lines plumbed into the intake structure. Plans should be made to provide backup in case future hose failures occur. Once backup hydraulic lines are in place, the gate wedges should be adjusted.

OUTLET WORKS STILLING BASIN

For purposes of this report all left and right directions will be as though the observer is looking down stream. The upper and lower outlet gates were closed so that minor seepage was the only water flowing through the basin during our inspection.

Three dive inspections were made on the outlet and stilling basin. The initial examination was to determine the condition of the stilling basin since its last use, sometime prior to our inspection. The second inspection was done after the outlet works operated with the lower gate open 2.5 feet for five minutes. The third inspection was done after the outlet works operated with the lower gate open 2.5 feet for an additional fifteen minutes.

Dive Inspection Number One

The diver entered the basin at the extreme left down stream end. The visibility in the basin was zero feet.

The down stream quarter of the stilling basin had occasional 3 to 4 inch rounded cobble, scattered on the floor. The floor itself has sustained minor scour in this area. The walls in the down stream portion were covered with algae down to about one foot from the floor. Immediately down stream of the two center baffle blocks there is a build-up of 3 to 4 inch rounded cobble. The depth of the build-up on the left side is on the order of two feet deep, while the right side tapers off to approximately one foot deep. The build-up extends approximately four feet down stream from the down stream side of the baffle blocks. On the left side of the stilling basin the cobble deposit extends approximately four feet upstream of the upstream face of the left chute block. Its depth diminishes to zero at its upstream edge. In the center of the stilling basin between the center baffle blocks and the upstream chute blocks we found and removed a ten foot length of galvanized fence pole. Approximately four feet down stream of the down stream face of the chute blocks another cobble deposit started to build up across the entire width of the stilling basin floor. The composition of this deposit was on the order of 4" minus. The build-up increased in depth from its down stream margin upstream so as to cover all but the top four inches of all three chute blocks. The diver was able to dig down to the drains in the face of all three chute blocks and found them to be full of small rounded rocks. Upstream of the down stream face of the three chute blocks the gravel build-up continued for a distance of eight to nine feet. The cobble upstream of the chute blocks ranged to an occasional ten inch diameter, and was rounded in nature. On the left wall upstream of the left chute block the concrete was scoured deep enough to expose some portion of the rebar. In this same area apparently dowels had been put into the side wall. Small portions of the end of these dowels were exposed.

Scour was evident on both the left and right wall ranging from the floor up vertically approximately ten to twelve inches and running almost the entire length of the stilling basin.

In the past the stilling basin has been repaired with some type of epoxy. Occasional pieces of this epoxy were found in the stilling basin. Epoxy is peeling off the upstream face of the left baffle block. Both baffle blocks show evidence of scour on the upstream faces and corners.

Dive Inspection Number Two

The gravel and cobble deposits were diminished in quantity. The pattern of the deposits changed substantially.

Down stream of the left baffle block had a cobble build-up, but its depth was diminished to approximately ten inches. The right side of the stilling basin down stream of the right baffle block was completely clear of any cobble build-up. Upstream of the right baffle block six inch cobble had built up approximately one layer thick over the right half of the stilling basin floor.

The area of the chute block on the left side of the stilling basin was devoid of any cobble build-up. And the drain in the down stream face was clear so that the diver could put his arm the length of his forearm into the drain. The center and right chute block drains were full of small cobble. Six inch minus deposits were still on the right half of the stilling basin extending from four feet below the chute blocks to their upstream edge. The depth of the build-up at its deepest point, which was at the down stream face, was approximately one foot. The area upstream of the chute blocks was void of any cobble build-up enabling the diver to detect scour across the width of the stilling basin in this area.

Dive Inspection Number Three

The condition after an additional fifteen minutes of operation was essentially the same as dive inspection number two. The only difference being in each area of build-up the depths seemed to be slightly increased.

Inspection of the Stream Bed

We were curious about the composition of the stream bed immediately downstream of the downstream end of the stilling basin. The diver swam along the approximate center line of the stream and found the first thirty-nine feet to be almost totally void of any rocks larger than three inches. The further downstream he went the larger the size of rocks he encountered. That is to say, that approximately twenty-five feet downstream of the stilling basin occasional eight inch cobble was scattered on the stream bed. From thirty-nine feet to approximately fifty-five feet large cobble on the order of ten inches in diameter was encountered. As the diver continued to move down stream the character of the rock increased in size to small to medium boulders.

CONCLUSIONS: The outlet works stilling basin is sustaining substantial damage from rocks being pulled from the area downstream of the stilling basin. Various degrees of scouring are evident over one hundred percent of the stilling basin floor. Some scouring does exist on the stilling basin walls, with major damage on the left wall upstream of the chute blocks.

RECOMMENDATIONS: Inland Marine Services is aware that models of the stilling basin are being tested by the U.S. Bureau of Reclamation at their Engineering and Research Center in Lakewood, Colorado. We will defer any recommendations.

SPILLWAY STILLING BASIN

The reservoir was spilling over the right one-half of the spillway during our inspection. The diver entered at the downstream of the left wall of the stilling basin. He proceeded along the wall to the face of the dam and then across the face of the dam to the right wall. The entire left half of the stilling basin has uniform boulders placed there by the contractor along its bottom. The diver found occasional trash consisting of cable and sheets of plastic. The face of the dam in the area noted as the stilling basin is in excellent condition. Occasional two to three inch horizontal displacement of the blocks forming the face of the dam were noted. This displacement was apparently done during construction since no recent movement is noted. There is no vertical displacement on any blocks. Several wooden wedges remain in between the blocks. These were construction implements. On the bottom at the left side of the water coming over the top of the spillway there is a build-up of ten to twelve inch rock approximately ten feet out from the dam face and two feet high. These rocks are moss covered, thus do not appear to be moving. Over the length of the spilling water the rocks immediately adjacent to the abutment of the dam are excavated to a depth of approximately two feet below the mean elevation of the floor of the stilling basin and undisturbed areas. The excavated rocks appear to have been moved downstream from the face of the dam so as to create a mound of rocks approximately seven feet high approximately sixteen feet downstream from the face of the dam. There is also a build-up of rocks in the right corner of the stilling basin where the wall meets the face of the dam. These rocks are built-up approximately seven feet from the bottom and out approximately twelve feet from the corner.

CONCLUSION: The stilling basin seems to be operating properly. There is some minor displacement of rocks on the stilling basin floor. This displacement does not seem to be currently active.

RECOMMENDATIONS: The rock displacement should be monitored on future dives.

Inland Marine Services would like to thank the personnel of Water Users Association Number One for their help and cooperation during our inspection and repair of Taylor Draw Dam.

Barry Hughes
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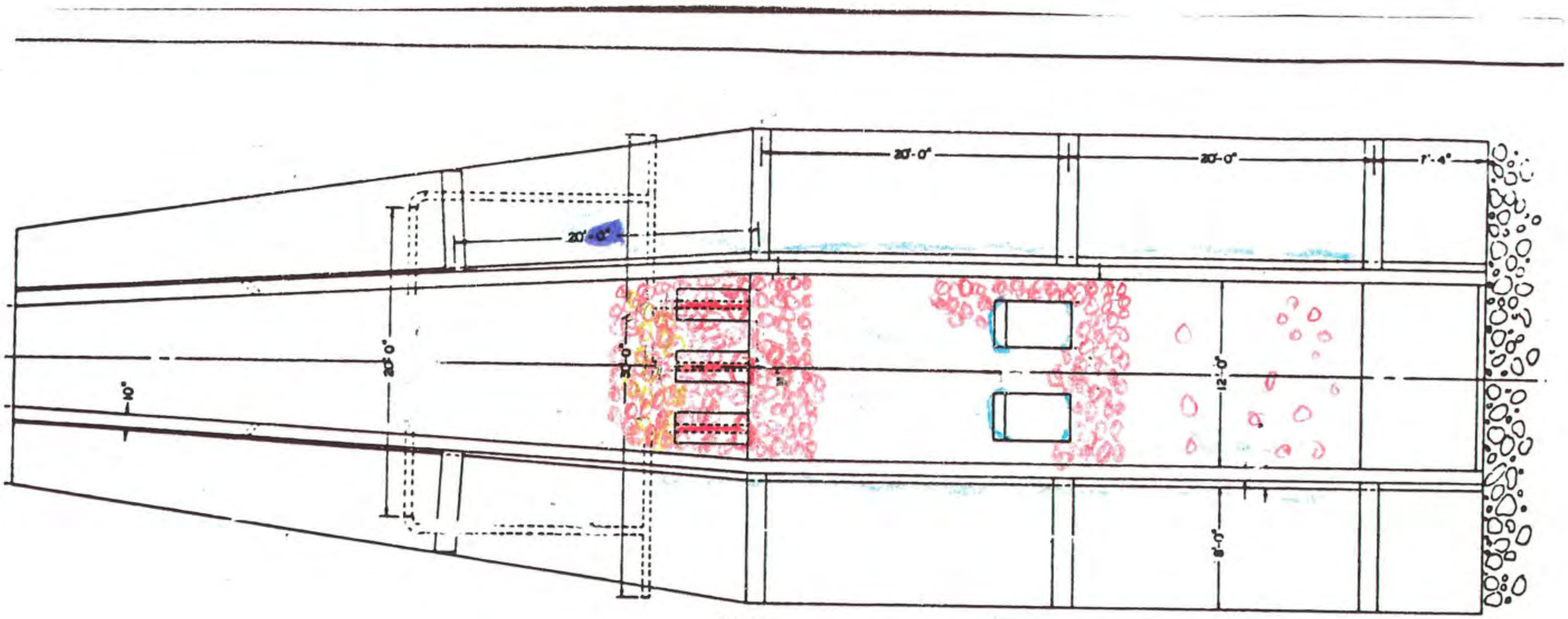
Exposed Rebar

6" minus Cobble

9"-10" Cobble

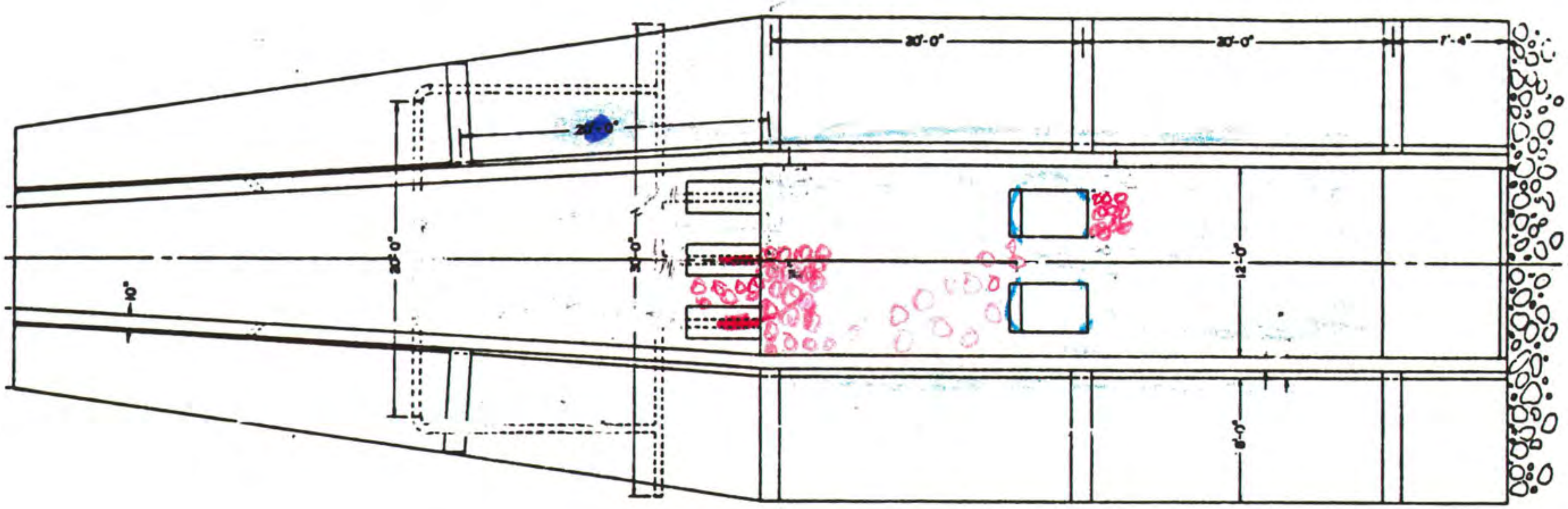
Scour



PLAN

0 1 2 3 4 5 10
SCALE IN FEET

Outlet work Stilling Basin
Dive Inspection #1 8-13-90



PLAN

0 1 2 3 4 5 10
SCALE IN FEET

Outlet Works Stilling Basin

Dive Inspection #2 8-15-90