REC-OCE-70-3

HYDRAULIC MODEL STUDIES OF SILVER JACK DAM SPILLWAY STILLING BASIN, BOSTWICK PARK PROJECT, COLORADO

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Division of Research
Office of Chief Engineer
Bureau of Reclamation

January 1970

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16. Abstract

A massive landslide destroyed the nearly completed spillway stilling basin at Silver Jack Dam in Colorado. A circular curve in an inclined plane was used to connect the undamaged approach conduit and the relocated stilling basin. Hydraulic model studies were performed to assure satisfactory flow conditions in the conduit and stilling basin under limited tailwater conditions and with unsymmetrical approach flow resulting from a circular curve in the upstream conduit. A deflector vane was installed in the crown of the tunnel downstream from the curve to prevent the flow from crossing over the top and sealing the portal. Vanes were developed for the stilling basin approach chute to improve flow distribution in the basin. Unique baffle blocks were developed to provide good energy distribution in a basin that had insufficient tailwater depth to form a conventional hydraulic jump. Pressure measurements were made on the conduit bend, conduit vane, chute vanes, and baffle blocks.

17. Key Words

DESCRIPTORS--/ *model tests/ *hydraulic models/ * stilling basins/ conduits/ pipe bends/ piezometers/ measurement/ Colorado/ air demand/ *energy dissipation/ hydraulics/ spillways/ laboratory tests/ hydraulic design

IDENTIFIERS--/ Silver Jack Dam, Colo/ Bostwick Park Project, Colo/ deflectors/ baffle blocks

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by

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HYDRAULICS BRANCH
DIVISION OF RESEARCH

UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF RECLAMATION
Office of Chief Engineer . Denver, Colorado

ACKNOWLEDGEMENTS

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CONTENTS

PURPOSE

These studies were made to develop a satisfactory stilling basin under limited tailwater conditions and with unsymmetrical approach flow resulting from a circular curve in the upstream conduit.

RESULTS

1. The centrifugal force of the high-velocity flow in circular curve caused the flow to rise over the top of the conduit at maximum discharge. The flow appeared to fill the conduit at the portal, apparently sealing off the air to the conduit.

2. A guide vane suspended normal to the conduit roof and 28-1/2° to right of center, Figure 4, prevented the flow from crossing over the conduit crown. Pressures measured along the vane indicated nominal impact forces.

3. Flow entered the stilling basin approach chute at an angle, resulting in very uneven flow distribution in the stilling basin. Deflector vanes developed and placed in the chute greatly improved the flow distribution in the basin.

4. Pressure measurements and air demand tests indicated that air vents should be placed on the lee side of the deflector vanes in the chute and the vanes should be clad with steel plates for protection.

5. The location of the basin and the need to minimize the amount of excavation resulted in a basin limited in length and with insufficient tailwater depth for standard hydraulic jump basin design. Large baffle blocks with concave upstream faces were developed that provided excellent energy dissipation. The location, spacing, and size of the blocks were developed by trial and error methods specifically for the unusual flow conditions in this basin.

6. Pressure measurements on critical areas of the blocks indicated that in some locations pressures as high as 75 feet (22.85 m) of water above atmospheric and as low as 19 feet (5.79m) of water below atmospheric could be expected.

7. Because of the large range in pressures and the turbulence in the flow, the blocks should be armored with steel plates.

APPLICATION

The results of these studies are generally applicable only to structures having flow conditions and construction limitations similar to those found at Silver Jack Dam.

INTRODUCTION

Silver Jack Dam, a feature of the Bostwick Park Project in western Colorado, is located on Cimarron Creek about 25 miles (40.25 km) southeast of Montrose, Figure 1. The earthfill dam has a height of 150 feet (45.7 m) above the creekbed, a length of 1,070 feet (326.2 m) at the crest, and a fill volume of 1,260,000 cubic yards (963,500 cu. m). The principal hydrualic features are a spillway and an outlet works. The spillway is the subject of this report.

The spillway is a 41-foot-diameter (12.48 m) morning glory with its crest at elevation 8925.60, 136 feet (41.50 m) above the creek channel, Figure 2. Flow from the spillway crest falls about 44 feet (13.4 m) into a 16.5-foot-diameter (5.03 m) circular conduit. The circular conduit is about 563 feet (171.5 m) long and terminates in an open channel chute leading to the stilling basin. The conduit flares and connects to a diverging chute leading to the stilling basin. The stilling basin floor is about 147 feet (44.8 m) below the spillway crest.

In the spring of 1969, the morning glory crest and circular conduit had been completed down to Station 7+26. A massive landslide engulfed and destroyed parts of the nearly completed stilling basin and chute, and cracked about 38 feet (11.6 m) of the completed circular conduit. A new site for the stilling basin was selected to the left of the initial location, adjacent to and parallel to the outlet works stilling basin, Figure 2. A conduit bend having a 165-foot (50.4 m) radius and a deflection angle of 17-1/2° to connect the existing undamaged conduit with the relocated stilling basin. The floor of the relocated stilling basin is 16.5 feet (5.04 m) higher than the original basin floor.

Because of the curved approach conduit and the very shallow basin, hydraulic model studies were initiated to thoroughly investigate the flow conditions in the curved conduit and basin.

THE MODEL

To conserve time, some readily available 11.5-inch (29.2 cm) inside-diameter, clear plastic tubing was selected to represent the 16.5-foot-diameter (5.03 m) prototype conduit, resulting in a model scale ratio of 1:17.22. The maximum discharge of 6,280 cfs (177.8 cms) was represented in the model by 5.10 cfs (0.14 cms).

The model included a 5-foot (1.52 m) length of circular conduit approaching the conduit bend, the bend, the circular-to-horseshoe transition, the open-channel chute, the stilling basin, and a section of the excavated channel downstream from the stilling basin. The correct flow depth and velocity in the circular conduit were obtained by regulating the flow with a slide gate at the upstream end of the circular conduit.

THE INVESTIGATION

Conduit Bend

The theoretical flow velocity at the start of the vertical curve is expected to be about 74 fps (22.55 mps), 77 fps (23.46 mps), and 80 fps (24.38 mps) for the three test discharges of 1,650 cfs (46.75 cms), 3.140 cfs (89.0 cms), and 6,280 cfs (177.8 cms). The 1,650 cfs is the discharge resulting from routing the computed 100-year flood through the reservoir, spillway and outlet works. The 6,280 cfs is the discharge resulting from routing the computed inflow design flood.

For the inflow design flood, the flow climbed the outside of the conduit bend starting a short distance downstream from the P.C. The flow crossed over the top of the conduit in the transition and seemed to completely fill the conduit at the portal, Figure 3. The flow appearance was similar for discharges of 1,650 cfs (46.75 cms) and 3,140 cfs (89.0 cms), but did not cross over the top.

Several deflectors were tried to prevent the flow from crossing over the top of the conduit. The first trial was a deflector normal to the side of the conduit along the spring line. The deflector extended from about the midpoint of the bend downstream to a point about 10 feet (3.05 m) beyond the end of the bend. This deflector did not intercept a sufficient amount of the flow so it was lengthened about 5 feet (1.52 m) in the upstream direction. The deflector still was ineffective and a further increase in length would result in an impractical structure from the construction viewpoint.

A narrow wall suspended from the conduit crown was next installed. The initial deflector wall was 1 foot (.3 m) wide, 6 feet (1.83 m) high and extended from the P.T. of the bend downstream to the end of the transition. The wall prevented the flow from crossing over the crown of the conduit. However, it deflected the flow vertically downward into the part of the flow moving along the conduit invert and the merging of the two high-velocity flows resulted in an excessive amount of splashing and spray downstream from the conduit portal.

To prevent the direct impingement of the deflected flows, the wall was moved to the right of the crown. Three trials were made with the wall off center 15° 28-1/2° and 45° from vertical. All of the off-center locations reduced the splash and spray, but the 28-1/2° location, Figure 4, caused the minimum amount of disturbance and also improved the flow distribution at the tunnel portal.

Moving the deflector to the off-center position also required that it be extended upstream 7.5 feet (2.29 m) into the curved portion of the conduit to intercept all of the flow crossing over the top of the tunnel. Tests were made to determine the minimum slant height for the deflector wall. These tests showed that the slant height could be reduced to 4 feet (1.22 m) without reducing the wall's effectiveness.

Six piezometers were placed along the right side of the deflector wall near the roof. Pressure measurements at the maximum discharge indicated that at the upstream end where the wall intercepted most of the flow, the pressure would be equivalent to about 14 feet (4.27 m) of water, Figure 4. All of the other piezometers indicated pressures near atmospheric.

One piezometer was placed on the outside of the bend near the spring line about 20 feet (6.1 m) upstream from the P.T. of the bend. This piezometer was used to determine if excessive pressures due to the centrifugal force of the water should be considered in the structural design of the bend. Pressure measurements showed that the pressures in this area were about hydrostatic at all discharges. At 1,650 cfs (46.75 cms) the pressure was atmospheric, at 3,140 cfs (89.0 cms) the pressure was about 1 foot (0.3 m) of water above atmospheric, and at 6,280 cfs (177.8 cms) the pressure was about 8 feet (2.44 m) of water above atmospheric.

Open Channel Chute

Flow entering the diverging chute leading to the stilling basin was very unsymmetrical and the unequal distribution carried into the stilling basin. In the preliminary design, the flow was concentrated on the left side of the basin with the 1,650 cfs (46.75 cms) and 6,280 cfs (177.8 cms) discharges, but with the 3,140 cfs (89.0 cms) discharge the flow was more concentrated on the right side, Figure 5. The deflector wall in the conduit did not affect the flow at the two low test discharges; at the maximum discharge, the deflector wall slightly improved the flow distribution, but the flow still tended to concentrate along the left side.

Longitudinal guide vanes dividing the chute in thirds were developed to provide symmetrical distribution of the flow entering the stilling basin. Both vanes are 2 feet (.61 m) wide and extend between Station 7+99.50 and Station 8+50.00. The height of each vane and the configuration at the upstream end were developed by cut and fit until the optimum distribution of the flow entering the stilling basin and the minimum amount of disturbance near the upstream end of the vane were obtained for all three test discharges. The configurations of the vanes are shown on Figure 6 and the flow appearance in the basin is shown on Figure 7.

Piezometers were installed in the floor on both sides of each vane and two air vents were placed on the left side of each vane. The location of the piezometers and air vents is shown on Figure 8. The general direction of the flow at the upstream end of the chute was diagonally from right to left. The piezometers on the right side of the vanes were to determine the magnitude of the impact forces, the piezometers on the left side of the vanes were to detect any potential subatmospheric pressure areas and to determine the pressure differential across each vane. The air vents were to determine if air was demanded on the lee side of the vanes and, if so, the effect that supplying air would have on the pressures.

The lowest pressure occurred on the left side at the upstream end of the right vane, Figure 8. The pressure, equivalent to about 11 feet (3.35 m) of water below atmospheric, was measured at the maximum discharge. The lowest pressure at the left vane was about 8 feet (2.44 m) of water below atmospheric, also measured at the maximum discharge. The greatest pressure differential was measured at the upstream ends of the vanes during the maximum discharge. On the left vane, the differential was equivalent to about 19 feet (5.79 m) of water, and on the right vane, the differential was about 22 feet (6.71 m) of water.

The upstream air vents supplied air at all discharges. However, occasionally the downstream vents would fill with water and once filled, they would not voluntarily empty and start drawing air again. There was no significant difference in the piezometer readings with the air vents open or closed.

The air vents were connected to water manometers to determine the pressure on the side of the vanes. At the maximum discharge, the upstream vent on the lee side of the right vane indicated a pressure equivalent to vapor pressure when both vents were closed; when the downstream vent was opened, the pressure at the

upstream vent was about 10 feet (3.05 m) of water below atmospheric. The downstream vent in the left vane indicated a pressure of about 4 feet (1.22 m) of water below atmospheric when no air was supplied; when air was supplied through the upstream vent, the pressure at the downstream vent was about 2 feet (.61 m) of water below atmospheric. The results of the pressure measurements have been tabulated on Figure 8.

Based on these studies, it was recommended that air vents be provided on the left side of both vanes and that the vanes be steelclad as shown on Figure 6.

Stilling Basin

The theoretical flow velocity and depth at the toe of the chute are 90 feet (27.43 m) per second and 1.99 feet (.61 m), respectively. These values assume uniform flow distribution on the chute and a Manning's roughness coefficient n = 0.008. Ideally, for these entrance conditions, a Type II[1] stilling basin should be 128 feet (39 m) long with a tailwater depth of 29.5 feet (8.99 m) and a Type III stilling basin should be 70 feet (21.32 m) long with a tailwater depth of 25 feet (7.63 m). Due to the landslide on the right side and the space limitations caused by the proximity of the outlet works stilling basin and discharge channel, the basin length was restricted to 84.50 feet (25.75 m) and to a tailwater depth of only 19 feet (5.29 m).

To compensate for the inadequate tailwater depth, large baffle blocks with concave upstream faces were installed in the basin. These blocks were patterned after blocks that had been used successfully in another structure where sufficient tailwater depth was not available.[2]

In the initial arrangement, two rows of blocks were installed. The first row contained three 3-foot-wide (.91 m) and two 2-foot-wide (.61 m) blocks with their upstream faces about 10 feet (3.05 m) downstream from the toe of the slope. The second row contained four 3-foot-wide blocks 14 feet (4.27 m) downstream from the first row. All blocks were 7 feet (2.13 m) high.

This arrangement provided unsatisfactory stilling action in the basin. The lack of energy dissipation was evident whether or not the deflector vanes were installed on the approach chute, Figures 5 and 7. A similar block arrangement was tried with 5-foot-high (1.52 m) blocks in both rows and with 5-foot-high blocks in the first row and 7-foot-high (2.13 m) blocks in the second row. There was very little improvement in the energy dissipation with any of these symmetrical arrangements of blocks.

The flow entering the basin was not truly symmetrical and the flow concentration changed from the left side to the right side and then back to the left side as the discharge increased. These flow conditions indicated that an unsymmetrical block arrangement might be necessary to obtain adequate energy dissipation. On this premise, the tests were continued on a "trial and error" basis to develop an effective block arrangement. The location of the rows and the spacing and location of individual blocks were adjusted and changed many times in arriving at the recommended arrangement with three rows of blocks as shown in Figure 9. The flow appearance with the recommended arrangement for the stilling basin is shown on Figure 10. The excellent flow conditions were prevalent for all discharges and the tailwater could be lowered about 3 feet (0.92 m) at which point the model channel became the control, without adversely affecting the basin efficiency.

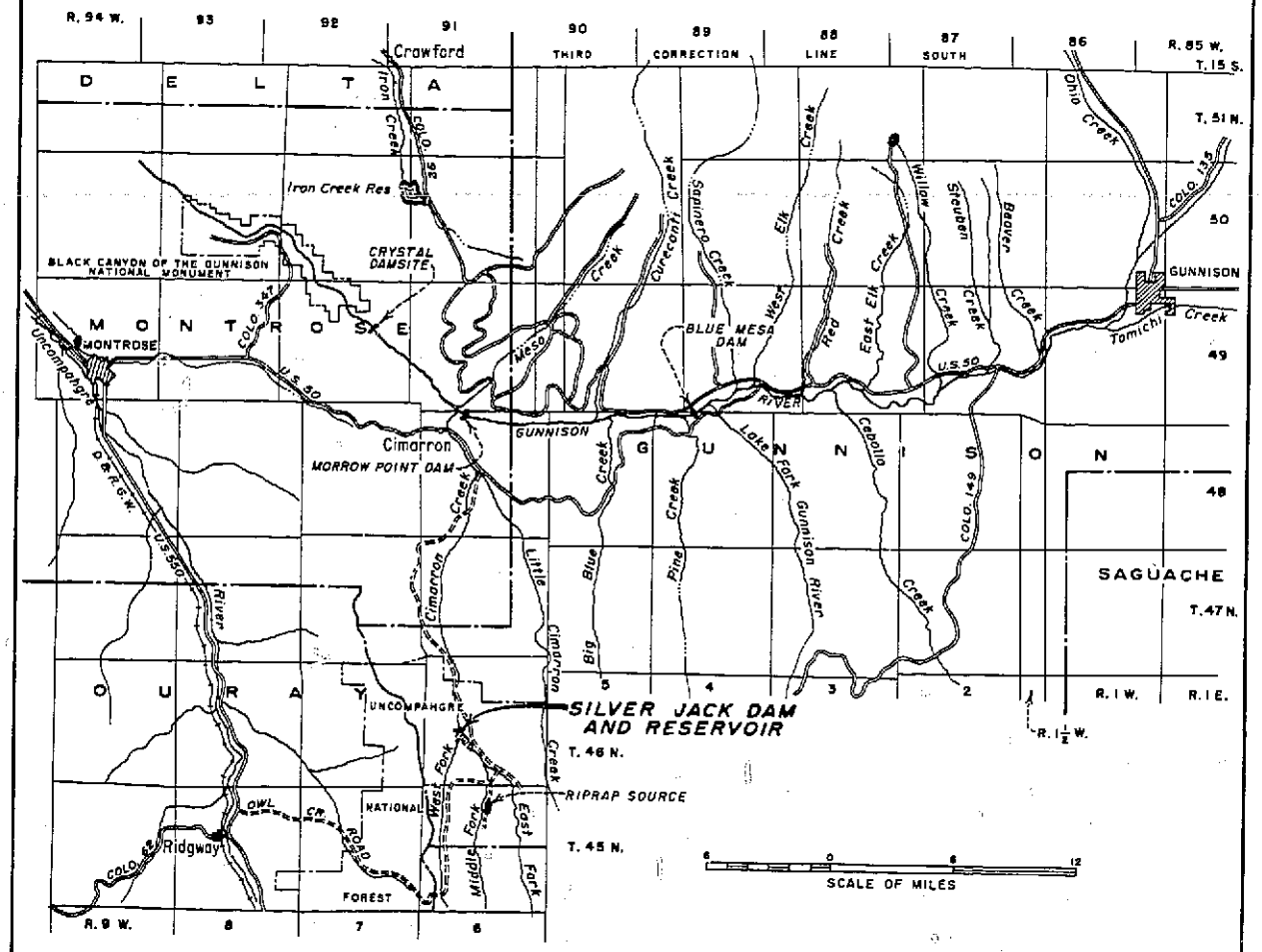
Eleven piezometers were installed in critical locations in one block to determine if dangerous subatmospheric pressures or exceptionally high impact pressures could be detected, Figure 11. Pressures were measured with the block in each of the four positions in the first two rows and in the centerline position of the third row.

The highest pressure was measured with the block in the two first row positions on the left second-row position. These pressures, located in the center of the concave face, were equivalent to 70 to 75 feet (21.3 to 22.8 m) of water. The lowest observed pressure was equivalent to about 19 feet (5.79 m) of water below atmospheric. The low pressures occurred on the sides of the block near the top, with the block in the left second-row position. The pressure readings have been tabulated on Figure 11.

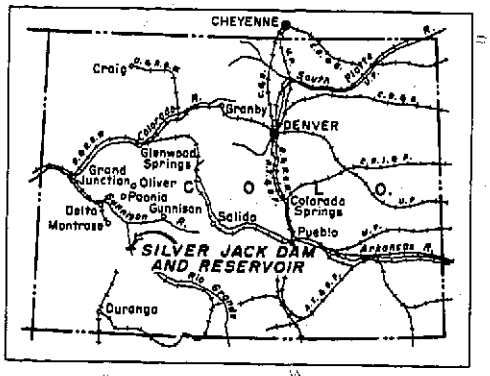
Dynamic pressure readings were not taken; however, due to the turbulence of the hydraulic jump and the low pressures that were measured with water manometer, it was recommended that the blocks be protected with steel plates as shown on Figure 9.

[1] USBR Engineering Monograph No. 25 "Hydraulic Design of Stilling Basins and Energy Dissipators."
[2] Beichley, G. L., Report HYD-394, "Hydraulic Model Studies of the Outlet Works at Carter Lake Reservoir Dam No. 1 Joining the St. Vrain Canal."

Figure 1
Report REC-OCE-70-3



NOTE: Cimarron Creek is also known as Cimarron River and Big Cimarron River.



KEY MAP

SAFETY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

BOSTWICK PARK PROJECT - COLORADO

SILVER JACK DAM

LOCATION MAP

DRAWN R.W.K. SUBMITTED
TRACED RECOMMENDED
CHECKED APPROVED
ACTING CHIEF ENGINEER

DENVER, COLORADO, FEB. 1, 1968

860-D-3

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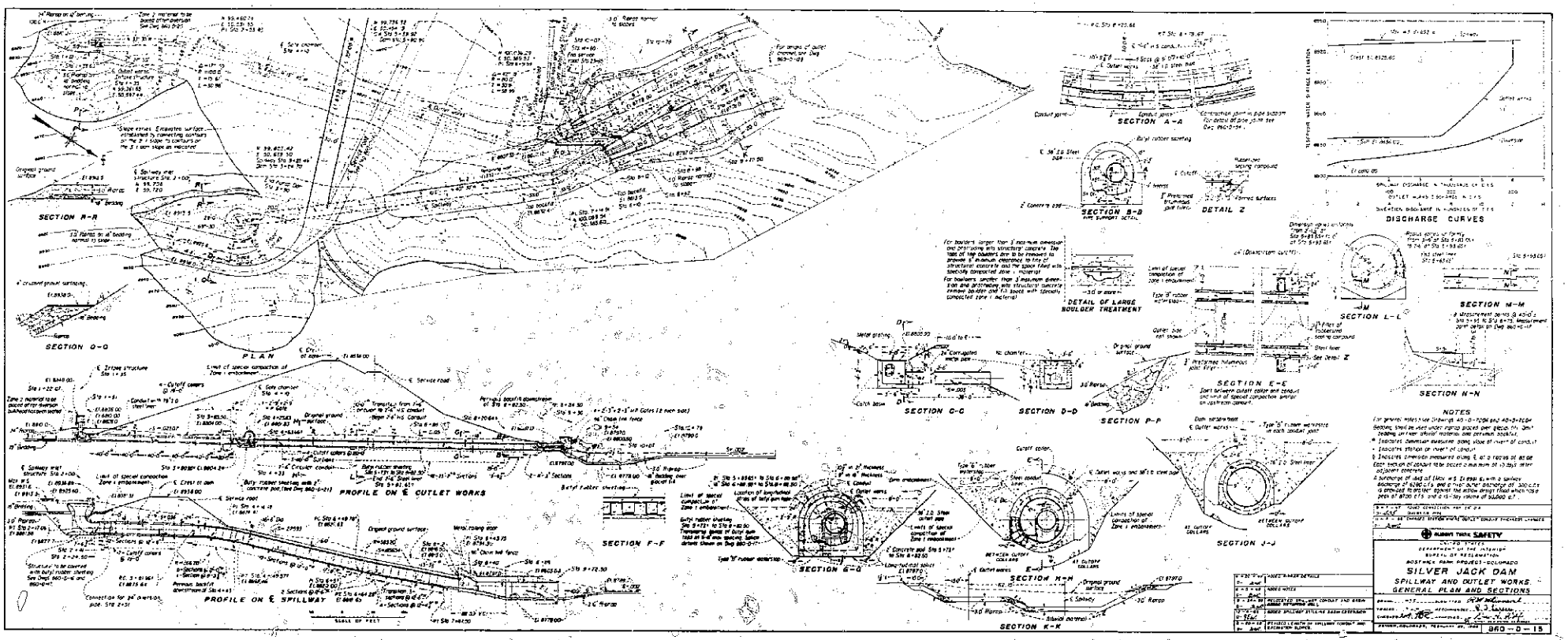
Figure 2
Report REC-OCE-70-3



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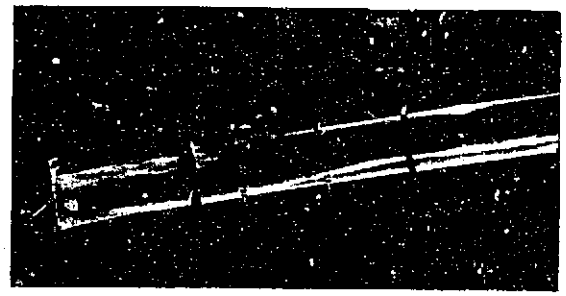

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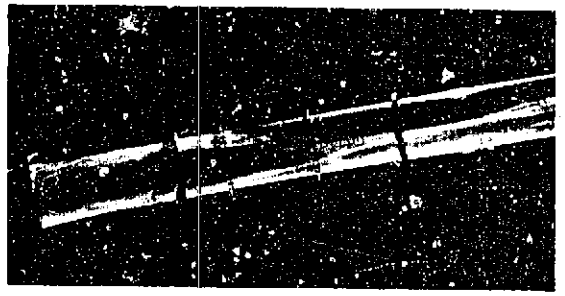

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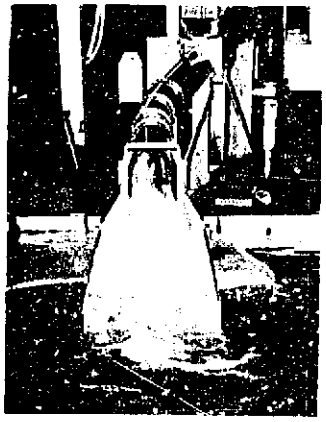
Discharge = 1650 cfs
Photo P860-D-65951



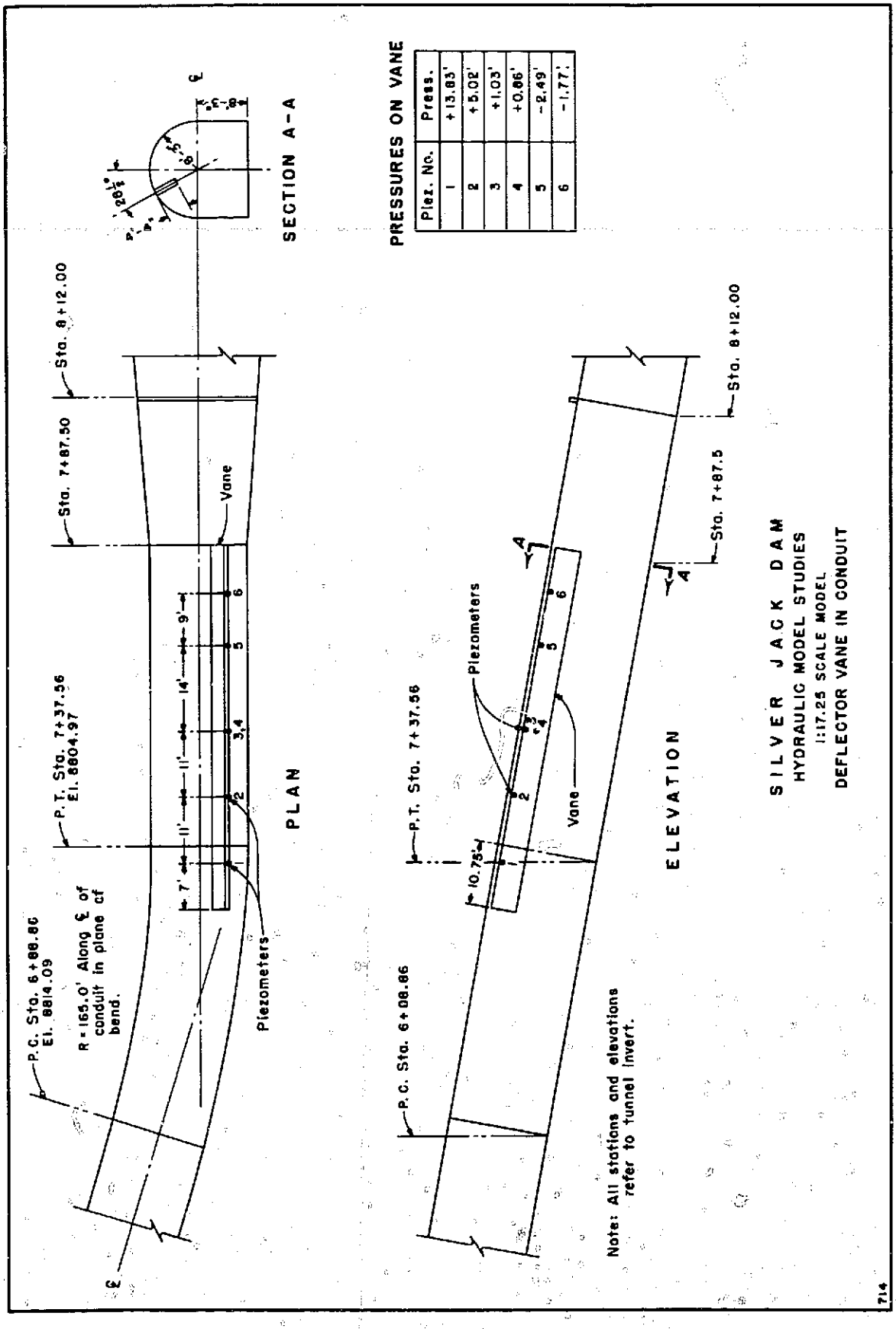
Discharge = 3140 cfs
Photo P860-D-65952

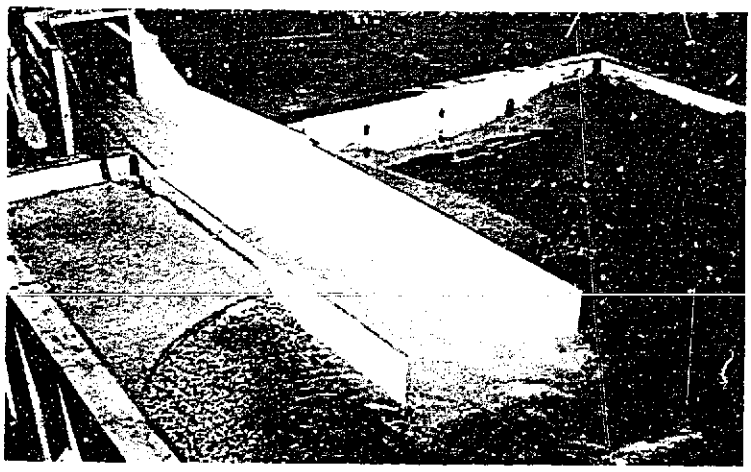
Discharge = 6280 cfs
Photo P860-D-65953

SILVER JACK DAM
Hydraulic Model Studies
1:17.25 Scale Model
Flow in Conduit, Chute
and Stilling Basin—Preliminary Design

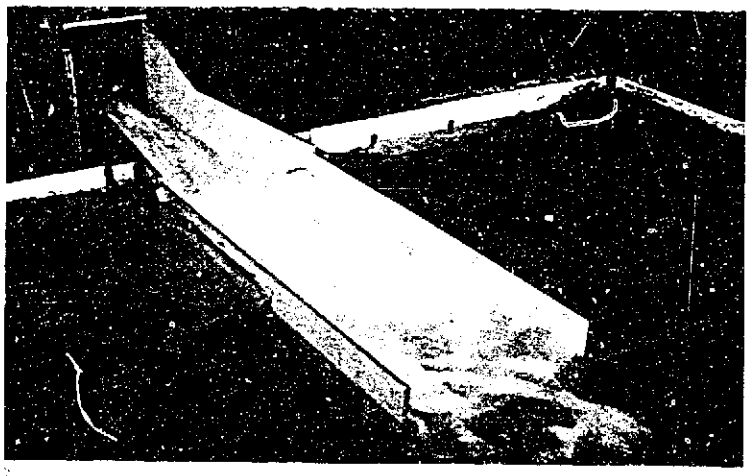
Figure 3
Report REC-OCE-70-3

Figure 4
Report REC-OCE-70-3

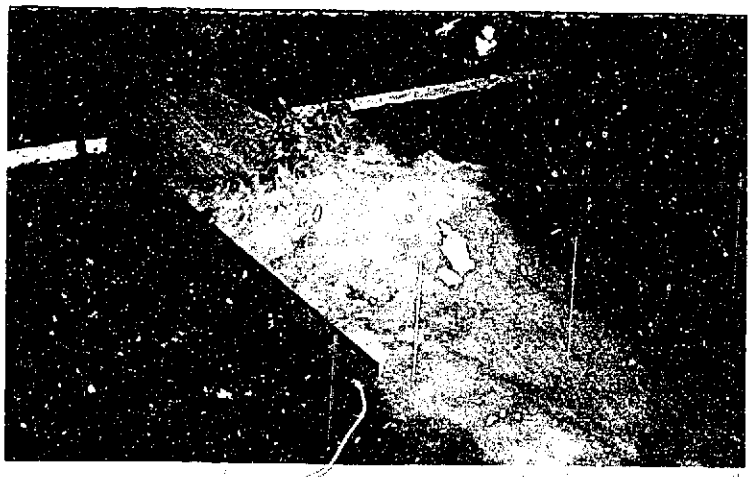




Discharge = 1650 cfs
T. W. Elev. = 8792.6
Photo P860-D-65954



Discharge = 3140 cfs
T. W. Elev. = 8793.8
Photo P860-D-65955



Discharge = 6280 cfs
T. W. Elev. = 8795.3
Photo P860-D-65956

SILVER JACK DAM
Hydraulic Model Studies
1:17.25 Scale Model
Stilling Basin Performance
Preliminary Design

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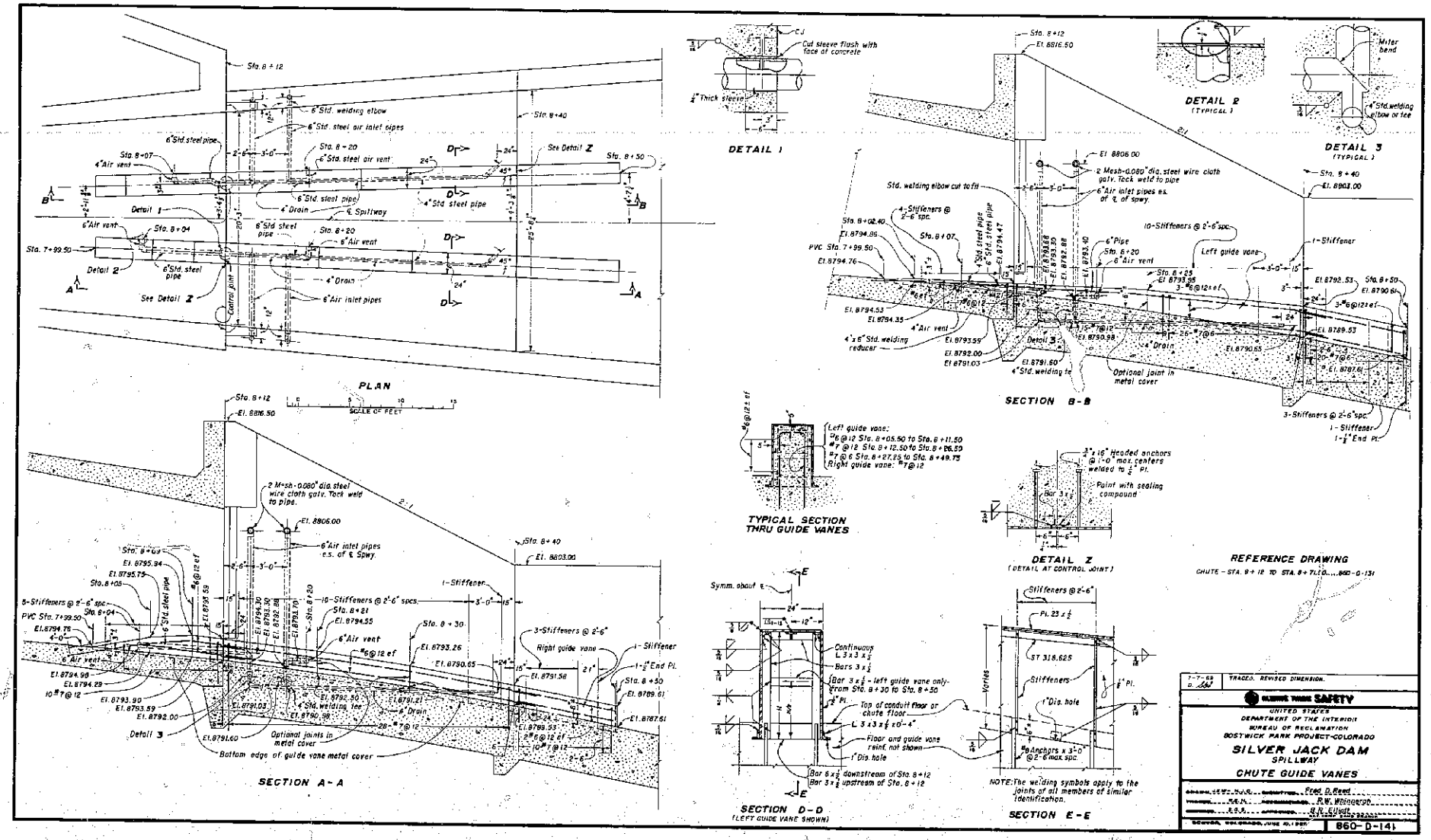
Figure 6
Report REC-OCE-70-3



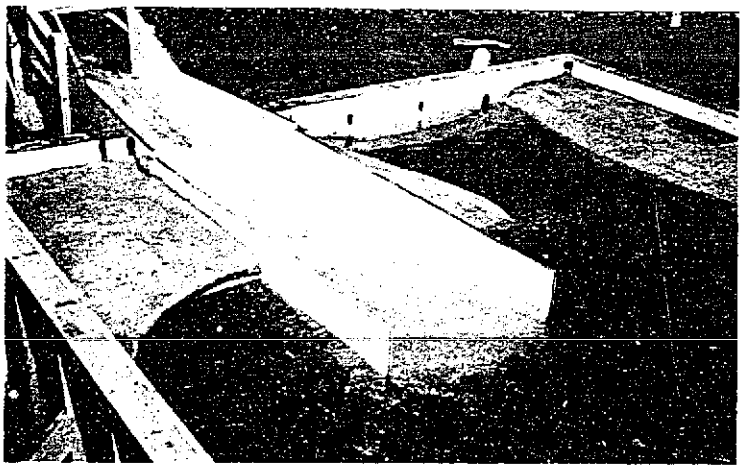


Photo P860-D-65957

Discharge = 1650 cfs
T. W. Elev. = 8792.6
Photo P860-D-65960

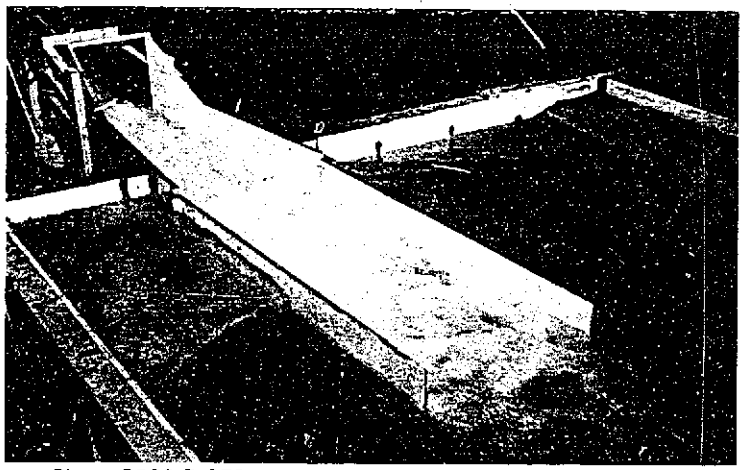


Photo P860-D-65958

Discharge = 3140 cfs
T. W. Elev. = 8793.8
Photo 860-D-65961

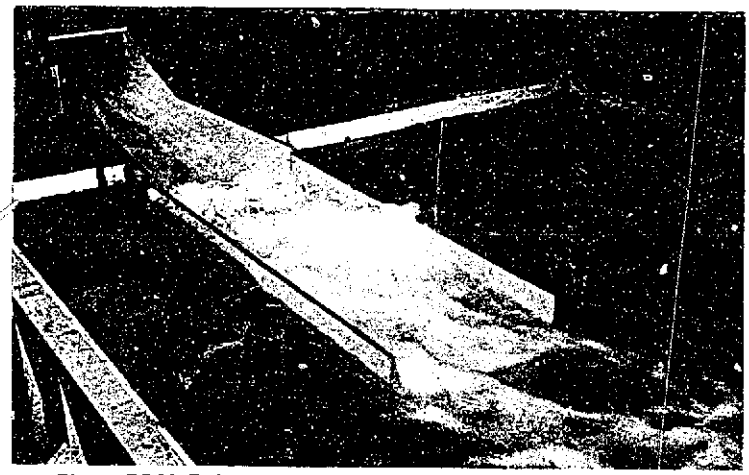
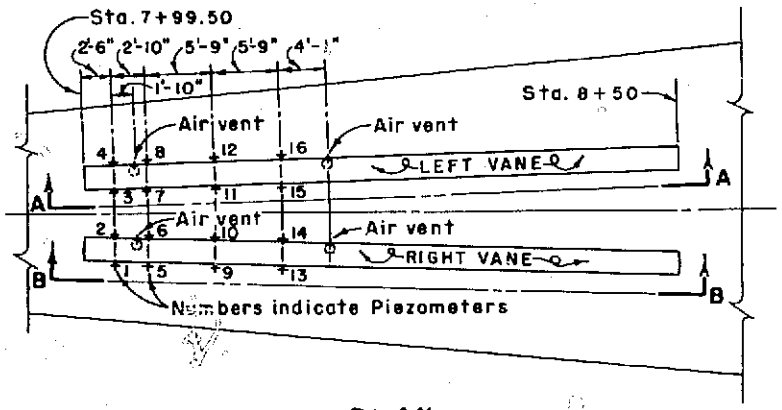


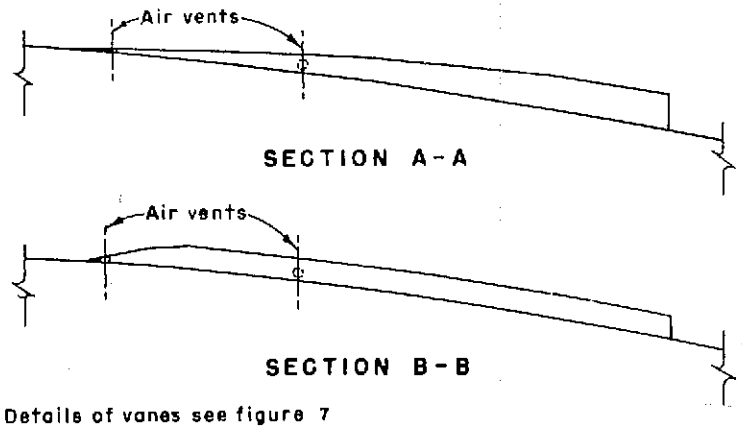
Photo P860-D-65959

Discharge = 6280 cfs
T. W. Elev. = 8795.3
Photo P860-D-65962

SILVER JACK DAM
Hydraulic Model Studies
1:17.25 Scale Model
Stilling Basin Performance
Recommended Vanes in Conduit and Chute-Preliminary
Baffle Block Arrangement



PLAN



For Details of vanes see figure 7

PRESSURES AT PIEZOMETERS AND AIR VENTS

Q = 6280cfs					Q = 3140cfs					Q = 1650cfs				
PIEZ. NO.	VENTS CLOSED	U.S. VENTS OPEN	D.S. VENTS OPEN	ALL VENTS OPEN	PIEZ. NO.	VENTS CLOSED	U.S. VENTS OPEN	D.S. VENTS OPEN	ALL VENTS OPEN	PIEZ. NO.	VENTS CLOSED	U.S. VENTS OPEN	D.S. VENTS OPEN	ALL VENTS OPEN
1	+11.8	+10.9	+11.2	+10.8	1	+7.3	+7.5	+7.8	+7.3	1	+6.8	+6.8	−6.0	+6.5
2	−10.6	−8.5	−10.7	−5.7	2	−2.3	−2.3	−2.4	−2.2	2	−0.3	−0.3	−0.3	−0.3
3	−0.9	+1.5	−0.8	+2.2	3	+3.4	+3.6	+3.6	+3.6	3	+5.9	+5.9	+6.0	+5.7
4	−7.2	−7.0	−7.3	−7.2	4	−0.5	−0.5	−0.6	−0.5	4	−4.1	−3.8	−4.0	−3.9
5	+1.2	+0.2	+1.4	+0.5	5	−1.2	−1.2	−1.5	−0.6	5	−4.0	−4.0	−4.0	−4.0
6	−2.8	−7.5	−2.8	−4.2	6	−1.9	−1.6	−1.4	−1.5	6	0	0	0	0
7	+0.6	+1.6	−0.7	+2.9	7	+3.9	+4.2	+4.0	+4.2	7	+5.9	+6.1	+6.8	+5.9
8	−2.9	−2.9	−2.9	−2.9	8	0	0	0	0	8	−1.9	−1.9	−2.0	−2.0
9	+8.7	+8.5	+8.7	+8.4	9	+7.2	+8.0	+7.6	+8.2	9	+2.4	+2.5	+2.5	+2.5
10	+1.7	−7.8	+1.8	−3.4	10	−1.0	−0.8	−0.9	−0.8	10	+0.2	+0.2	−0.2	+0.3
11	+4.2	+3.5	+3.9	+3.0	11	−3.4	+3.6	+3.4	+3.6	11	+2.1	+2.0	+2.0	+1.9
12	−1.1	−1.4	−1.2	−1.4	12	0	0	0	0	12	−1.6	−1.7	−1.6	−1.7
13	+3.5	+3.5	+3.5	+3.3	13	+3.9	+4.0	+3.9	+4.0	13	−1.8	−1.6	−1.8	−1.8
14	−2.0	—	−2.0	−3.3	14	−0.3	−0.3	−0.2	−0.3	14	0	0	0	0
15	+2.0	+3.7	+2.3	+1.1	15	0	0	0	0	15	−1.9	−1.9	−1.9	−1.9
16	−4.8	−4.8	−4.9	−4.9	16	−0.6	−0.6	−0.5	−0.5	16	−2.3	−2.2	−2.3	−2.0
	AIR VENTS					AIR VENTS					AIR VENTS			
U.S.RT.	−28.7	—	−10.0		U.S.RT.	−1.4	—	−0.7		U.S.RT.	−0.7	—	−0.7	
U.S.LT.	−5.8	—	−5.8		U.S.LT.	0	—	0		U.S.LT.	−1.4	—	−1.4	
D.S.RT.	+3.2	+2.9	—		D.S.RT.	0	0	—		D.S.RT.	0	0	—	
D.S.LT.	−4.3	−2.2	—		D.S.LT.	0	0	—		D.S.LT.	−5.7	0	—	

SILVER JACK DAM

HYDRAULIC MODEL STUDIES

1:17.25 SCALE MODEL

PRESSURES AT CHUTE DEFLECTOR VANES

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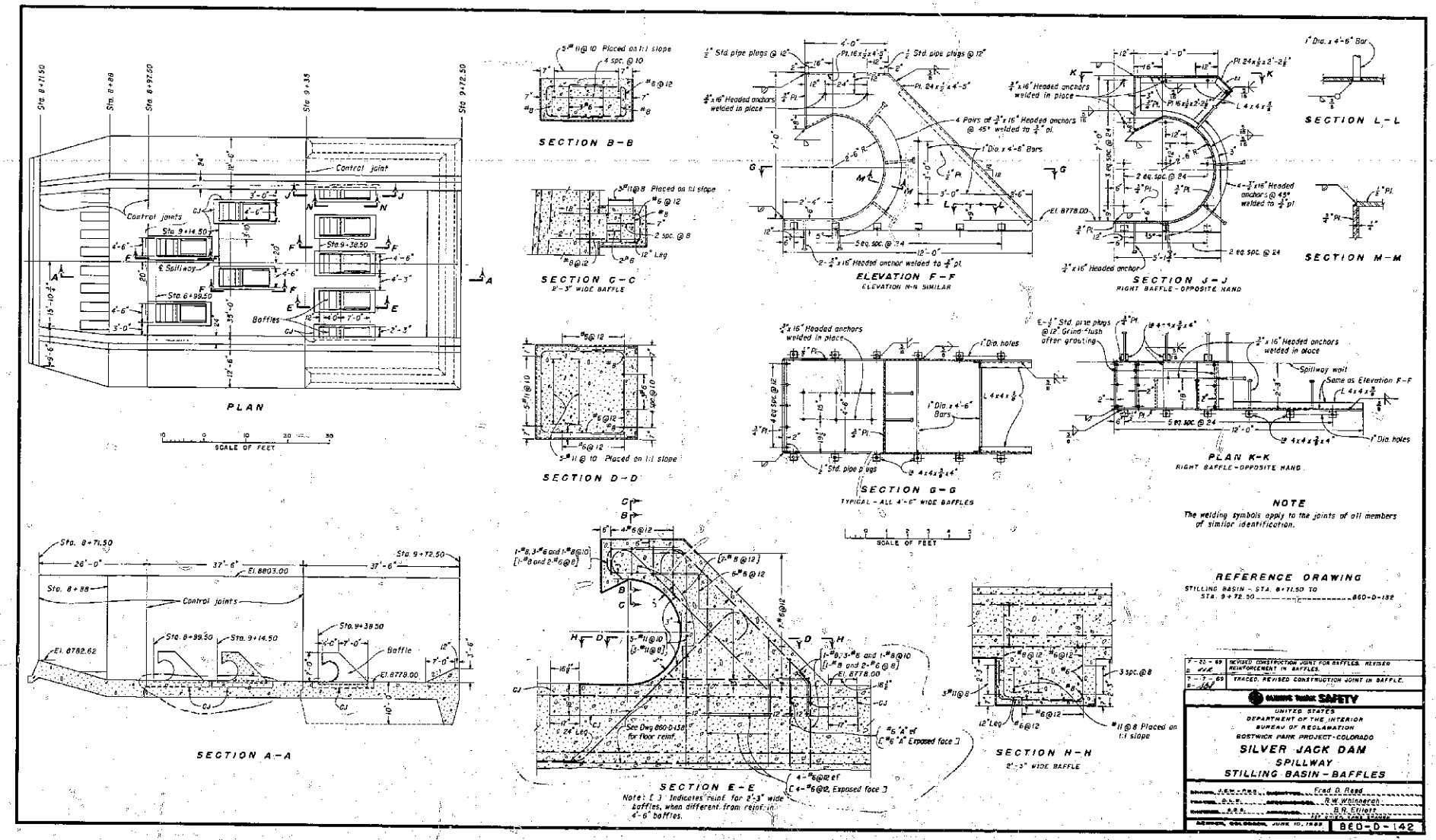
Figure 9
Report REC-OCE-70-3



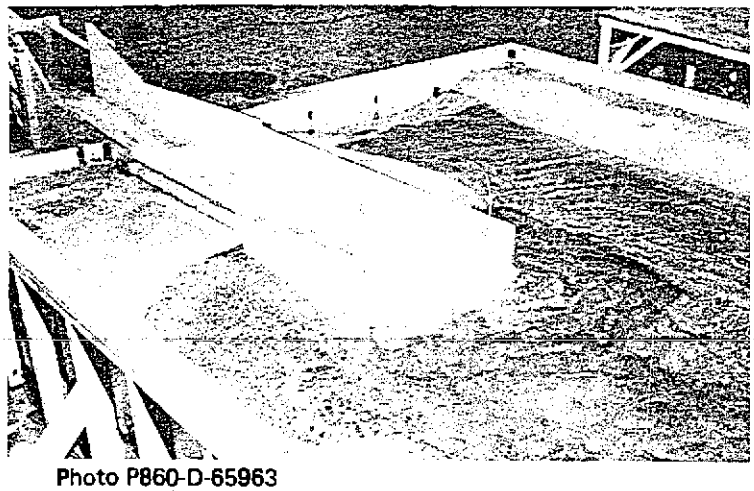


Photo P860-D-65963

Discharge = 1650 cfs
T. W. Elev. = 8792.6
Photo P860-D-65966

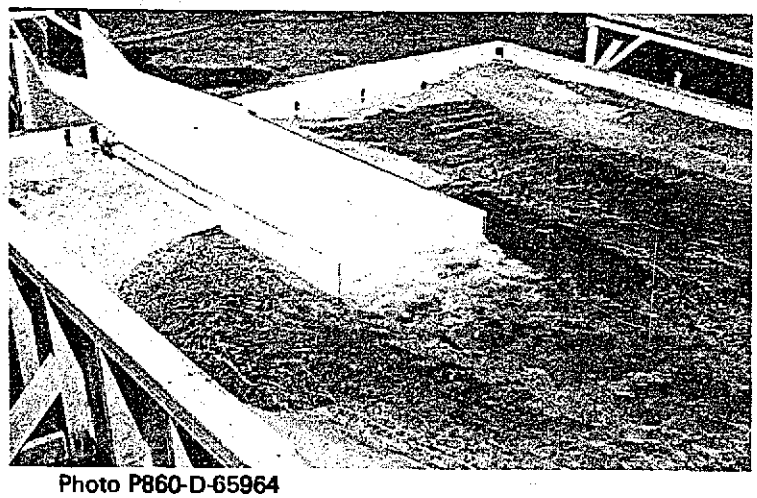


Photo P860-D-65964

Discharge = 3140 cfs
T. W. Elev. = 8793.8
Photo P860-D-65967

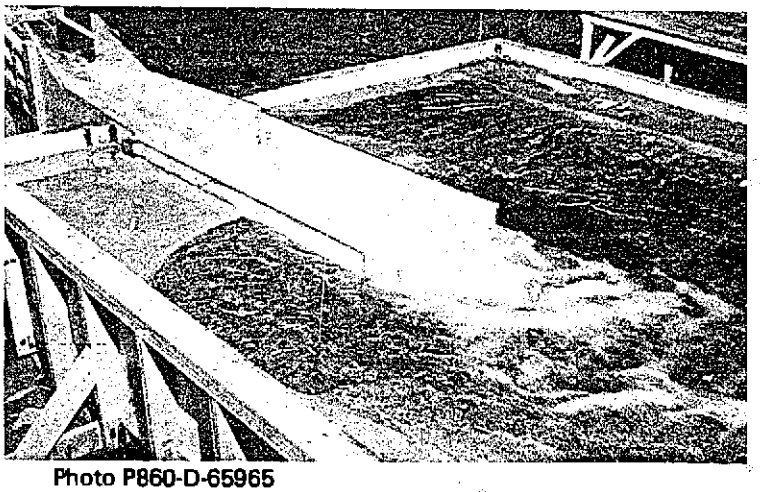
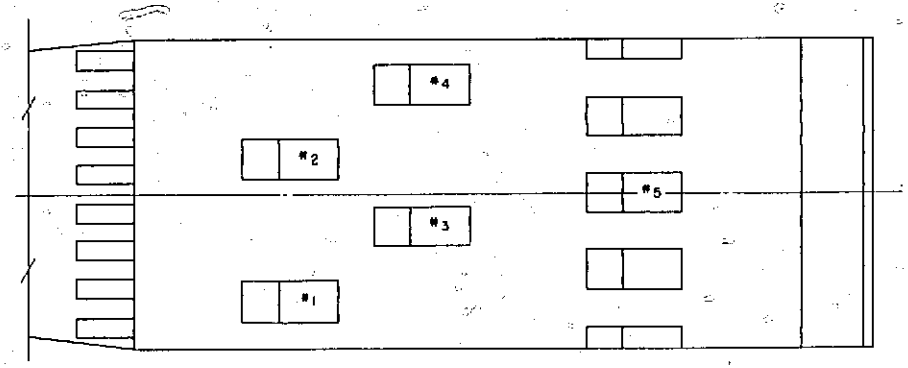


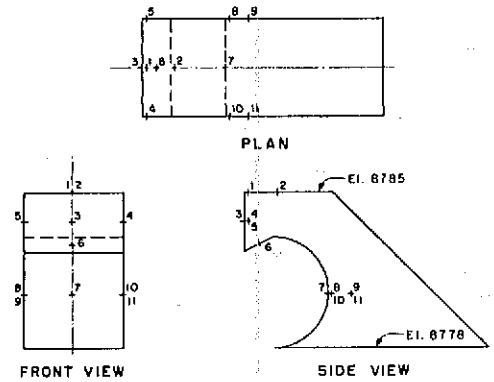
Photo P860-D-65965

Discharge = 6280 cfs
T. W. Elev. = 8795.6
Photo P860-D-65968

SILVER JACK DAM
Hydraulic Model Studies
1:17.25 Scale Model
Stilling Basin Performance
Recommended Design



BAFFLE BLOCK LOCATIONS



PIEZOMETER LOCATIONS

PRESSURES

BAFFLE #1

PIEZ. #	Q = 1650cfs	Q = 3140cfs	Q = 6280cfs
1	7.6'	4.7'	4.4'
2	7.6'	4.3'	4.0'
3	13.0'	12.5'	10.2'
4	8.3'	0.6'	-3.2'
5	7.5'	0.3'	-2.9'
6	11.4'	18.3'	28.5'
7	18.4'	50.0'	71.7'
8	10.0'	3.3'	1.6'
9	10.4'	4.4'	1.9'
10	11.5'	-2.8'	-6.3'
11	10.6'	-4.4'	-8.5'

BAFFLE #4

PIEZ. #	Q = 1650cfs	Q = 3140cfs	Q = 6280cfs
1	5.9'	8.4'	-5.3'
2	5.4'	8.5'	-5.6'
3	10.9'	12.6'	38.7'
4	5.2'	8.2'	-19.1'
5	7.1'	7.4'	-19.4'
6	10.7'	12.8'	34.5'
7	25.1'	21.1'	70.3'
8	0.7'	10.0'	-13.5'
9	4.1'	10.1'	-13.0'
10	11.0'	10.8'	-0.9'
11	11.0'	10.9'	-3.8'

BAFFLE #2

PIEZ. #	Q = 1650cfs	Q = 3140cfs	Q = 6280cfs
1	6.6'	6.6'	3.5'
2	6.7'	5.0'	3.1'
3	7.8'	10.4'	7.6'
4	8.0'	4.6'	1.7'
5	7.8'	4.8'	2.8'
6	9.0'	10.0'	13.9'
7	11.3'	43.2'	75.1'
8	10.9'	3.0'	-7.3'
9	11.0'	3.8'	-7.4'
10	10.9'	0.8'	-1.0'
11	11.3'	-0.9'	-2.7'

BAFFLE #5

PIEZ. #	Q = 1650cfs	Q = 3140cfs	Q = 6280cfs
1	8.3'	9.4'	9.6'
2	7.1'	8.3'	8.1'
3	10.1'	11.1'	11.7'
4	10.1'	11.1'	11.6'
5	9.8'	10.5'	11.3'
6	11.0'	12.2'	12.6'
7	13.3'	14.3'	17.3'
8	13.1'	13.6'	13.4'
9	13.0'	13.6'	13.6'
10	12.9'	14.0'	15.1'
11	13.0'	14.2'	14.9'

BAFFLE #3

PIEZ. #	Q = 1650cfs	Q = 3140cfs	Q = 6280cfs
1	7.4'	5.4'	6.4'
2	7.1'	3.0'	3.4'
3	7.5'	20.7'	31.8'
4	8.8'	0.4'	2.5'
5	8.6'	0.7'	2.2'
6	10.0'	14.6'	19.9'
7	12.2'	36.2'	56.0'
8	12.0'	8.1'	7.5'
9	12.0'	7.9'	7.4'
10	11.0'	9.3'	9.8'
11	11.6'	9.4'	9.9'

NOTES

Q = 1650 cfs T.W. El. = 8792.6
Q = 3140 cfs T.W. El. = 8793.8
Q = 6280 cfs T.W. El. = 8795.3
For details of baffles see Fig. 9

SILVER JACK DAM
HYDRAULIC MODEL STUDIES
1 : 17.25 SCALE MODEL
PRESSURES ON BAFFLE BLOCKS

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CONVERSION FACTORS--BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, E 380-68) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given in the ASTM Metric Practice Guide.

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

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

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

Table I

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
LENGTH		
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
	0.3048 (exactly)*	Meters
	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
	1.609344 (exactly)	Kilometers
AREA		
Square inches	6.4516 (exactly)	Square centimeters
Square feet	929.03*	Square centimeters
	0.092903	Square meters
Square yards	0.836127	Square meters
Acres	0.40469*	Hectares
	4,046.9*	Square meters
	0.0040469*	Square kilometers
Square miles	2.58999	Square kilometers
VOLUME		
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
CAPACITY		
Fluid ounces (U.S.)	29.5737	Cubic centimeters
	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
	0.473166	Liters
Quarts (U.S.)	946.358*	Cubic centimeters
	0.946331*	Liters
Gallons (U.S.)	3,785.43*	Cubic centimeters
	3.78543	Cubic decimeters
	3.78533	Liters
	0.00378543*	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	764.55*	Liters
Acre-feet	1,233.5*	Cubic meters
	1,233,500*	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
	1.12986×10^6	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
	1.35582×10^7	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
	0.3048 (exactly)*	Meters per second
Feet per year	0.965873×10^{-6}*	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2	0.3048*	Meters per second^2
FLOW		
Cubic feet per second (second-feet)	0.028317*	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
FORCE*		
Pounds	0.453592*	Kilograms
	4.4482*	Newtons
	4.4482×10^{-5}*	Dynes

Multiply	By	To obtain
WORK AND ENERGY*		
British thermal units (Btu)	0.252*	Kilogram calories
	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	1.35582*	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 deg F (k, thermal conductivity)	1.442	Milliwatts/cm deg C
	0.1240	Kg cal/hr m deg C
Btu ft/hr ft^2 deg F	1.4880*	Kg cal m/hr m^2 deg C
Btu/hr ft^2 deg F (C, thermal conductance)	0.568	Milliwatts/cm^2 deg C
	4.882	Kg cal/hr m^2 deg C
Deg F hr ft^2/Btu (R, thermal resistance)	1.761	Deg C cm^2/milliwatt
Btu/lb deg F (c, heat capacity)	4.1868	J/g deg C
Btu/lb deg F	1.000*	Cal/gram deg C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
	0.09290*	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.569	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Pound-seconds per square foot (viscosity)	4.8824*	Kilogram second per square meter
Square feet per second (viscosity)	0.092903*	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	35.3147*	Millicuries per cubic meter
Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons per square yard	4.527219*	Liters per square meter
Pounds per inch	0.17858*	Kilograms per centimeter

GPO 856-304

ABSTRACT

A massive landslide destroyed the nearly completed spillway stilling basin at Silver Jack Dam in Colorado. A circular curve in an inclined plane was used to connect the undamaged approach conduit and the relocated stilling basin. Hydraulic model studies were performed to assure satisfactory flow conditions in the conduit and stilling basin under limited tailwater conditions and with unsymmetrical approach flow resulting from a circular curve in the upstream conduit. A deflector vane was installed in the crown of the tunnel downstream from the curve to prevent the flow from crossing over the top and sealing the portal. Vanes were developed for the stilling basin approach chute to improve flow distribution in the basin. Unique baffle blocks were developed to provide good energy distribution in a basin that had insufficient tailwater depth to form a conventional hydraulic jump. Pressure measurements were made on the conduit bend, conduit vane, chute vanes, and baffle blocks.

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REC-OCE-70-3
Rhone, T J
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Bur Reclam Lab Rep REC-OCE-70-3, Hydraul Br, Jan 1970. Bureau of Reclamation, Denver, 20 p, 11 fig, 3 tab, 2 ref

DESCRIPTORS—/ *model tests/ *hydraulic models/ *stilling basins/ conduits/ pipe bends/ piezometers/ measurement/ Colorado/ air demand/ *energy dissipation/ hydraulics/ spillways/ laboratory tests/ hydraulic design
IDENTIFIERS—/ Silver Jack Dam, Colo/ Bostwick Park Project, Colo/ baffle blocks/ deflectors

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