UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF THE EL VADO OUTLET WORKS FLIP BUCKET

Report No. HYD-567

HYDRAULICS BRANCH
DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

FEBRUARY 1968

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. A table of conversion factors--BRITISH TO METRIC UNITS OF MEASUREMENT--is provided at the end of this report.

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by

T. J. Isbester

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ACKNOWLEDGEMENTS

The study was conducted by the writer and reviewed by Mr. W. P. Simmons, under the supervision of the Structures and Equipment Section Head, Mr. W. E. Wagner, and the direction of the Hydraulics Branch Chief, Mr. H. M. Martin. The recommended design evolved through cooperation between the Spillways and Outlet Works Section of the Dams Branch, Division of Design, and the Hydraulics Branch, Division of Research. Photography was by Mr. W. M. Batts, Office Services Branch.

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FIGURES

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ABSTRACT

A flip bucket was developed from model studies to minimize river channel erosion and provide satisfactory dispersion of flows for the new, enlarged-capacity outlet works at El Vado Dam. The outlet works will utilize a plunge pool in the river channel created by past spillway flows. Normal discharges will range from 2,000 to 4,000 cfs, (56.634 to 113.268 cms) with an overall range of 0 to approximately 6,700 cfs (189.724 cms). Reservoir water surfaces will range between elevation 6775 and 6902. The initial bucket design proved unsatisfactory and resulted in considerable erosion in the river channel. The recommended bucket was constructed with 2 vertical, slightly converging sidewalls and 2 sloping plane surfaces. An offset opening was provided in the right wall for discharging small, low-velocity flows. River channel erosion caused by outlet works operation will be moderate. Erosion from combined spillway and outlet flows will be significant, but combined operation will be necessary only under extreme flood conditions. Operation of the spillway alone is not anticipated.

DESCRIPTORS-- *flip buckets/ hydraulic jumps/ erosion/ head losses/ *outlet works/ slide gates/ intake structures/ *hydraulic models/ model tests/ dispersion/ *energy dissipation/ movable bed models/ *spillways
IDENTIFIERS-- plunge pool/ El Vado Dam, New Mexico/ New Mexico/ San Juan Chama Project

PURPOSE

Studies were made to develop a flip bucket for the larger capacity outlet works at El Vado Dam to provide well dispersed flow, free from impingement on the canyon walls, and resulting in a minimum of river channel erosion.

CONCLUSIONS

1. The preliminary design of the flip bucket was unsatisfactory for the large range of heads and discharges. A large flow concentration existed along the left wall, and no vertical lift was imparted to the flow leaving the right side of the bucket (Figure 9).

2. A bucket designed for the normal discharge range of 2,000 to 4,000 cfs (56.634 to 113.268 cms) provided satisfactory flow conditions for discharges from 0 to 7,400 cfs (209.546 cms) throughout the range of heads to be encountered (Figure 12).

3. An offset opening in the right wall of the flip bucket provided a passage for small, low-velocity discharges, and allowed self-draining of the flip bucket area (Figure 10).

4. The dispersion characteristics of the flip bucket vary with depth and velocity of the approaching flow (Figure 12). A flip bucket could not be developed which provided optimum flow dispersion for all discharges and head conditions.

5. With minimum assumed tunnel losses, and balanced gate operation, a hydraulic jump will form at the tunnel portal at a release of 900 cfs (25.485 cms) with a reservoir water surface elevation of 6785, and at a release of 600 cfs (16.990 cms) with a reservoir water surface elevation of 6902. With higher tunnel losses, the jump will move upstream into the tunnel (Figure 13).

6. With maximum assumed tunnel losses and balanced gate operation, a hydraulic jump will form at the tunnel portal at a release of 1,600 cfs (45.307 cms) with a reservoir water surface elevation of 6785, and at a release of 1,000 cfs (28.317 cms) with a reservoir water surface elevation of 6902. With higher tunnel losses, the jump will move upstream into the tunnel (Figure 13).

7. Single gate operation resulted in slightly different flip bucket dispersion characteristics at high heads. The pattern appeared best for right gate operation. Dispersion at low heads appeared identical for either gate (Figure 14).

8. The flip bucket will perform satisfactorily with excess tailwater up to the elevation 6735 (Figure 15).

9. Spillway flows caused considerably deeper erosion than outlet works flows of the same magnitude (Figures 16 and 17).

10. The worst erosion for outlet works flows was produced by low head, high volume releases that struck near the downstream end of the apron (Figure 18).

11. Dynamic pressure measurements obtained on the left and right walls of the flip bucket revealed fairly steady loading, with no negative pressures encountered (Figure 19).

APPLICATIONS

The scope of the study was specific, dealing with a particular facility with definite and unusual operational and topographical conditions. Therefore, no further application can be anticipated for the study.

INTRODUCTION

El Vado Dam is an existing facility built in the 1930's and located on the Rio Chama in North Central New Mexico (Figure 1). The present outlet works at El Vado is too small to adequately meet water requirements of the San Juan-Chama Project. A new, larger outlet works will be built and the dam will become a regulating facility for the project in which water is diverted from the western slope of the Rocky Mountains and transported through the Continental Divide for beneficial use on the eastern slope.

The new outlet works will have a capacity of 6,700 cfs (189.724 cms) and will operate with reservoir water surface elevations ranging from 6775 to 6902. The new outlet works tunnel will approximately parallel the existing spillway. A plunge pool, created by past spillway flows striking the river channel will serve as the energy dissipator for outlet works flows that are directed into the pool by a flip bucket (Figure 2).

Releases will be controlled by the crest of the outlet works intake structure for reservoir water surfaces between elevation 6775 and approximately 6780. Flow leaving the outlet works tunnel will be directed by a flip bucket designed to cast the water beyond the structure for most operating conditions and at the same time spread the flow to obtain good energy dissipation as it falls into the river channel.

The model study was required to develop a flip bucket which would satisfactorily disperse flows for a wide range of operating conditions and minimize river channel erosion in the rather confined canyon area.

THE MODEL

A 1:30 scale model was constructed for the tests (Figure 3). The model contained two sheet metal outlet works slide gates, a section of outlet works tunnel, the flip bucket and spillway rehabilitation area, the downstream portion of the spillway, and a section of river channel.

Flow was supplied to the outlet works through a 3-foot-diameter (91.44 cm), baffled head tank located immediately upstream of the slide gates. A 10-foot-long sheet metal tunnel section (3.048 meter) was used to convey flow from the slide gates to the flip bucket. The tunnel shape was a modified horseshoe with vertical side walls and a 6-inch (15.24 cm) center rise (prototype) in the floor. The upstream portion of tunnel was of constant cross section. The downstream portion varied in cross section with the invert sloped away from the tunnel centerline to a maximum of 2 feet (60.96 cm) (prototype) at the tunnel portal. The flip bucket and associated structure were made of wood for ease of modification. Outlet works flow was supplied by a portable 8-inch pump and was measured with an orifice-venturi meter.

The downstream end of the existing spillway was represented to determine the effects of flows from the spillway structure alone, or with the spillway in conjunction with outlet works flows. The upstream end of the spillway section was connected to a head box. Adjustments to spillway flow velocities were made by adding or removing wooden slats at the head box outlet to change the water depth. The downstream end of the spillway was connected to the river channel tail box and the flip bucket structure (Figure 3).

Seven hundred feet of river channel were represented in the model (Figure 4) beginning at Station 5+85 (Figure 5) and extending approximately 450 feet (137.160 meters) downstream from the plunge pool. The canyon walls were constructed of concrete on wire mesh, and extended from elevation 6800 down to elevation 6680. Movable bed material consisting of 3/8- to 1-3/4-inch (0.953 to 4.445 cm) rounded gravel was used for the river bottom. A tailgate located at Station 12+85 provided a means of adjusting the tailwater to depths obtained from computed water surface profiles at Station 12+00 (Figures 5 and 6).

In order to provide correct pressure head settings for the model outlet works head tank, calculations were made to determine the losses in the prototype structure upstream of the gates for various discharges. Included in the computations were intake, bend, transition, and conduit friction losses. Two overall loss coefficients were used, one providing slightly higher losses than anticipated, and one providing slightly lower losses than anticipated. These coefficients were multiplied by the velocity head in the 11-foot 6-inch (3.505-meter) diameter conduit, and the resulting loss subtracted from the reservoir elevation leaving an available head which was set on the model head tank.

Model Deviations from Prototype

The model outlet works tunnel was constructed prior to the determination of the bottom slope for the portion of the tunnel with varying cross sections. The model invert was on a slope of 0.02667, whereas the final prototype invert section was on a slope of 0.008171. The greater relative roughness in the model1/ compensated for the steeper slope and provided specific energy at the tunnel exit portal comparable to the specific energy of the prototype for minimum assumed tunnel losses (n = 0.008). In order to obtain specific energy comparable to maximum assumed prototype tunnel losses (n = 0.014), wire mesh was added along the invert and side walls of the model tunnel (Figure 11).

THE INVESTIGATION

Preliminary Design

The preliminary flip bucket design was based on the best empirical data available, but proved to be unsatisfactory for the large range of heads and discharges. The bucket

1/Numbers refer to items in Bibliography contained a single laterally inclined, upwardly sloping, triangular-shaped plane surface (Figures 7, 9A and 9B). The right edge of the plane lay along the floor (elevation 6735), starting at the left wall at Station 16+50.00 and extending downstream to the right. The left edge began in the corner formed by the floor and wall and sloped upward along the left wall to elevation 6750 (Figure 7).

Small, low head releases flowed along the floor to the right of the flip bucket and then moved down a baffled apron to the river channel. Larger flows were directed by the flip bucket with varying trajectories, depending on the lateral position of the flow leaving the bucket (Figure 9B). Flow on the left side of the plane surface was lifted vertically, as well as turned downstream to the right. Flow on the right side was not lifted, but only turned downstream. For large high head releases, a heavy flow concentration developed along the left wall of the bucket, and struck the river bed near the channel center. Flow leaving the right portion of the inclined flip bucket plane surface struck the river channel near the end of the horizontal apron at the foot of the structure. To eliminate the heavy flow concentration along the left wall, and to prevent flow from the right side striking near the foot of the structure, the study was directed toward a design which would lift the flow evenly across the lip of the bucket for the larger releases2/3/4/ and pass small releases through an offset opening in the right wall.

First Modification

The first modification consisted of right and left confining walls and a large inclined plane surface with a second steeper inclined plane surface at the downstream end (Figure 8A). The left confining wall was an extension of the left approach channel wall which turned 15° to the right with a 30-foot (9.144-meter) radius of curvature beginning at Station 16+50.00. The upstream plane surface was used to lift and turn the flow as it approached the end of the bucket. The small downstream plane surface served as the lip of the bucket and imparted the final lift and direction to the flow. An offset opening for passing small flows was provided in the right confining wall of the bucket.

This design handled flows from 4,000 to 7,400 cfs (113.268 to 209.546 cms) very well; however, in the normal range of releases (2,000 to 4,000 cfs) (56.634 to 113.268 cms) a relatively large portion of the flow was turned toward the right canyon wall. The flow appeared to be following a projected line from the intersection of the two inclined plane surfaces. Also, the offset opening for passing small flows out the right side of the bucket was too small and allowed water to back up and cause a hydraulic jump to form upstream of the bucket and in the outlet works tunnel for releases in the 2,000 cfs (56.634 cms) flow range.

Second Modification

To prevent flow in the 2,000 to 4,000 cfs (56.634 to 113.268 cms) range from being directed toward the right canyon wall, two plane surfaces intersecting in a line directed to the left of the right canyon wall were installed (Figure 8B).

Dispersion of normal releases (2,000 to 4,000 cfs) (56.634 to 113.268 cms) was greatly improved with the new arrangement, and the flow cleared the right canyon wall. Larger releases were not as well dispersed as with the first modification but were satisfactory. As before, small flows were backed up by the offset opening in the right wall causing a hydraulic jump to form in the outlet works tunnel.

Recommended Design

To prevent the occurrence of a hydraulic jump in the outlet works tunnel for all but very small releases, two steps were undertaken. The first was to increase the size of the low flow offset opening in the right hand wall. This allowed the low flows to pass more easily from the structure, lowered the water surface elevation in the tunnel, and helped retard the formation of the jump for small releases. However, with large releases, a portion of the flow changed direction almost immediately after leaving the right approach channel wall (Station 16+50.00), flowed through the offset opening, and struck the right low-flow bypass channel wall with considerable force. This condition became worse when wire mesh was added to the tunnel to increase the losses and lower flow velocities.

The second step was to decrease the overall flip bucket height as much as possible without adversely affecting its performance. The flip bucket lip and right confining wall were lowered in small increments while making slight adjustments to the plane surfaces so as to maintain the same dispersion characteristics.

For the recommended design, the point of intersection of the downstream end of the flip bucket and the left wall was lowered from elevation 6751 to elevation 6745 (Figure 10). The point of intersection of the downstream end of the flip bucket and the right confining wall was lowered from elevation 6745 to elevation 6742.5. The high point of the left confining wall was lowered from elevation 6755 to elevation 6753.75.

The low-flow offset opening began at Station 16+50.00 and extended 8.71 feet (2.6548 meters) downstream to the right confining wall. A 2-foot-high (60.96-cm) curb, which began at Station 16+54.06 and extended to the right confining wall (Figure 10, Section C-C), prevented lower velocity flows from striking the low-flow bypass channel right-hand wall. The bucket area was self-draining at elevation 6735 through a 1-foot 3-inch (38.100-cm) opening between the end of the right approach channel wall and the beginning of the upstream plane surface of the flip bucket.

Operation of Recommended Bucket

Outlet Works Gates Equally Open.--The dispersion characteristics of the recommended flip bucket vary considerably with depth and velocity of flow through the bucket (Figures 9C, 9D and 12). High-velocity, relatively shallow flows produce the best dispersion with the jet striking slightly beyond the center of the river channel. Deeper flows resulting from lower head operation or higher friction losses produce a more concentrated pattern with the jet striking the river channel near the end of the flip bucket structure. By using wire mesh in the outlet works tunnel to increase friction losses, any flow velocity condition resulting from between minimum and maximum assumed tunnel friction could be duplicated (Figure 11). For the dispersion tests, no unsatisfactory flows resulted, although the higher velocity flows resulted in better jet dispersion.

Single Outlet Works Gate.--Releases through a single gate resulted in slightly different flip bucket dispersion patterns at high heads. No significant difference was noted in dispersion for one- or two-gate operation when the heads were low or moderate (Figure 14B). The right gate appeared to provide the best flow dispersion at the flip bucket; however, the left gate flows were satisfactory. With low-head operation, no detectable difference was observed between left or right gate releases. No difficulty should be expected from single gate releases.

Hydraulic Jump Upstream of the Flip Bucket.--For small releases a hydraulic jump occurs at, or upstream from, the flip bucket, or in the outlet works tunnel (Figure 13). With minimum anticipated tunnel losses, a jump occurs at the tunnel portal at a release of 900 cfs (25.485 cms) with a reservoir water surface elevation of 6785, and at a release of 600 cfs (16.990 cms) with a reservoir water surface elevation of 6902. With maximum anticipated tunnel losses, a hydraulic jump occurs at the tunnel portal at a release of 1,600 cfs (45.307 cms) with a reservoir water surface elevation of 6785, and at a release of 1,000 cfs (28.317 cms) with a reservoir water surface elevation of 6902.

Effects of Increased Tailwater.--The flip bucket can be expected to perform satisfactorily until the tailwater near the bucket reaches elevation 6735. With the tailwater above elevation 6735, the backwater effect will cause the hydraulic jump to form upstream from the flip bucket more quickly and will move upstream into the tunnel for lower releases than with normal tailwater. If an accumulation of erodible material occurs in the river channel which would cause tailwater sufficiently high to prevent aeration of the flip bucket lip, the riverbed material should be removed. Photographs of flip bucket operation with high tailwater are shown in Figure 15.

Erosion Studies.--Previous operation of the prototype spillway has resulted in the formation of a plunge pool in the river channel. The spillway terminates at elevation 6780.16 with a short, nearly horizontal trapezoidal section. Flow leaves the spillway and strikes the river channel in a concentrated jet causing considerable erosion. As a result, the river channel bottom has been lowered to elevation 6709.5 in the area of the impinging spillway jet (Figure 5).

The model erosion tests were qualitative in nature. The material used in the movable bed portion of the model consisted of 3/8- to 1-3/4-inch (.953- to 4.445-cm) rounded gravel placed to a scaled depth of 30 feet (9.144 meters) below elevation 6710. Tailwater for the erosion tests was adjusted to conform to elevations shown on water surface profiles prepared by the Hydrology Branch and applied at Station 12+00.00 in the model (Figures 4 and 5).

Spillway Erosion .--Spillway flows of 12,000 cfs, or above, eroded the model bed to the floor of the box (El.6680) in less than 1 hour of operation (prototype time). The movement of material in the model was so rapid that to prevent the gravel from filling the sand trap and spilling into the laboratory channel, large discharge spillway operation was restricted to short time periods. The only timed spillway erosion test performed in the model was a 4,000 cfs (113.268 cms) release for a 20-hour prototype time period (Figure 16). The tests showed the model bed underwent considerably heavier erosion than had been experienced in the prototype in that the model bed was eroded from elevation 6720 to 6695 in the 20-hour time period. Spillway releases result in much heavier erosion than outlet works releases of the same size. With the increased release capability of the new outlet works, operation of the unaltered spillway is not anticipated. However, if use of the spillway should become necessary under flood conditions, the portion of the flood release passed by the outlet works should materially reduce the amount of erosion which would have resulted through spillway operation alone. Photographs of simultaneous operation of the outlet works and spillway are shown in Figure 17.

Outlet Works Erosion.--Early outlet works erosion studies resulted in a major change to the horizontal apron and cutoff wall. The initial apron was located at elevation 6720, and was cantilevered from a vertical cutoff wall. The apron extended horizontally 10 feet (3.048 meters) downstream, and rested on a riprap bed. Erosion tests revealed removal of the riprap material, leaving the apron unsupported back to the cutoff wall. The apron was lowered to elevation 6715 and the vertical cutoff wall was replaced with a heavy wedge-shaped foundation key. The key was placed to a depth of 10 feet (3.048 meters) below the apron, and minimized the danger of undercutting. The change provided an additional 5 feet (1.524 meters) of tailwater over the apron to aid in dissipating the energy of flow striking in that area.

The most adverse erosion condition for the recommended design resulted from large low-energy flows which were not well dispersed by the flip bucket and which struck near the intersection of the apron with the surrounding bed material. The erosion under these conditions was not severe enough to undercut the apron and key, but did penetrate to elevation 6710 (Figure 18).

In the model, a buildup of erodible material immediately downstream of the impact point of the jet caused more severe and deeper erosion than resulted with a level bed at the same elevation. If an erosion buildup occurs near the prototype structure, it should be removed. Removal may be accomplished hydraulically by raising the reservoir head level and allowing the jet to strike near the top of the buildup forcing it downstream.

Erosion patterns for various outlet works releases are shown in Figure 18. These tests were performed for 100 hours (prototype time) and resulted in a completely stabilized bed condition. The results of the tests were satisfactory and no detrimental erosion should occur in the prototype.

Pressures on Walls of Flip Bucket.--Dynamic pressure measurements were obtained along the left and right walls of the flip bucket (Figure 19). These pressures were reasonably steady, with the highest occurring where the flow direction was changed rapidly. The maximum fluctuations occur near the flip bucket-wall intersections where the mass and structural damping are the highest. Also, the frequency of pressure fluctuations were sufficiently high to minimize the possibilities of a resonant condition. No negative pressures were encountered in the model investigation.

Minimum Head Prototype Operation

When operating the prototype at near minimum heads, care must be taken by the operator to prevent an intermittent shifting of control between the crest of the intake structure and slide gates. Large quantities of air would be entrained as crest-controlled flows move through the vertical shaft of the intake structure. This air would collect in the crown of the 11-foot 6-inch- (3.505-meter) diameter conduit, and if flow control should shift to the gates, the accumulations of air would be compressed, move back upstream, and be released in an explosive manner in the vertical shaft.

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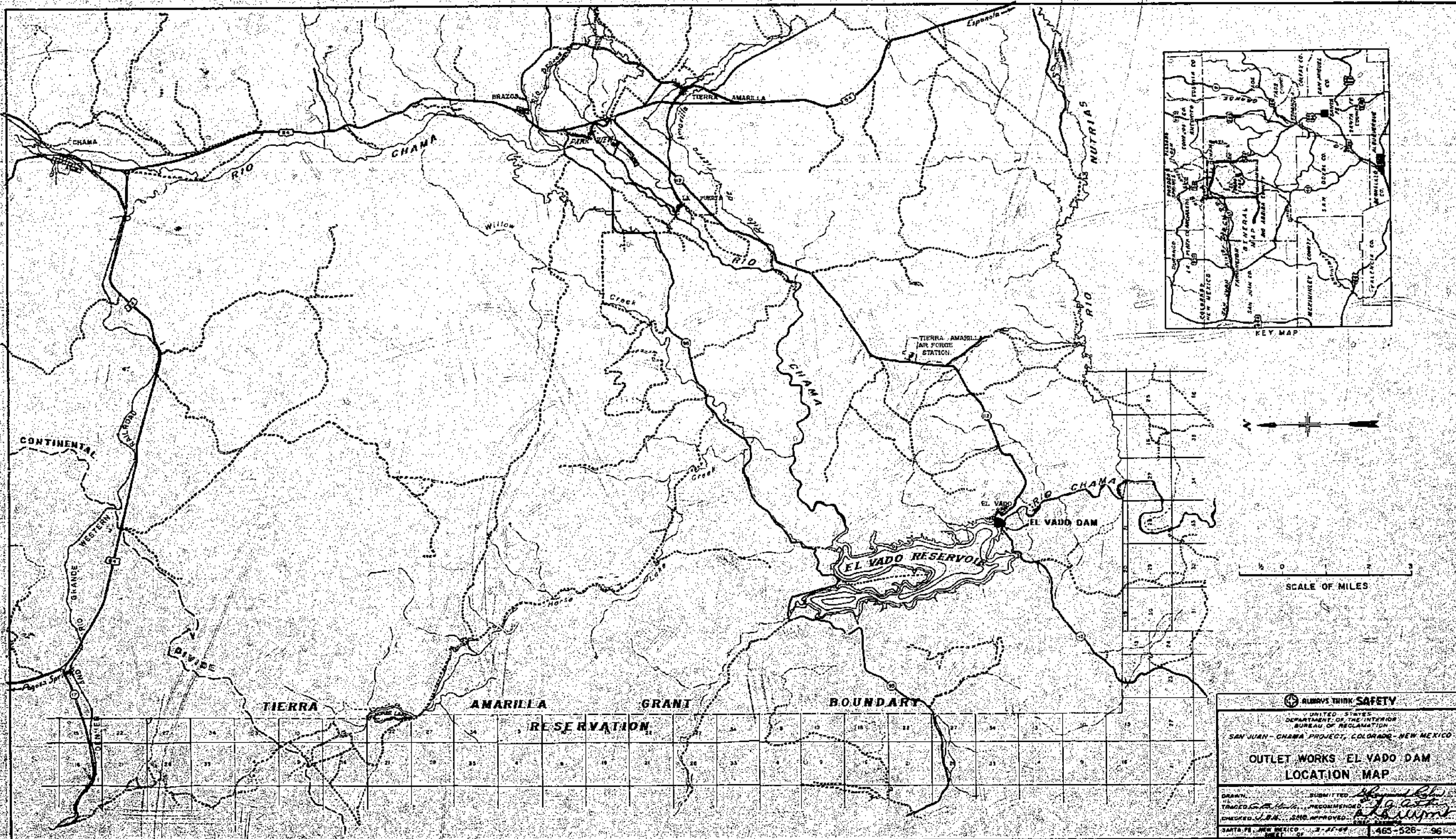
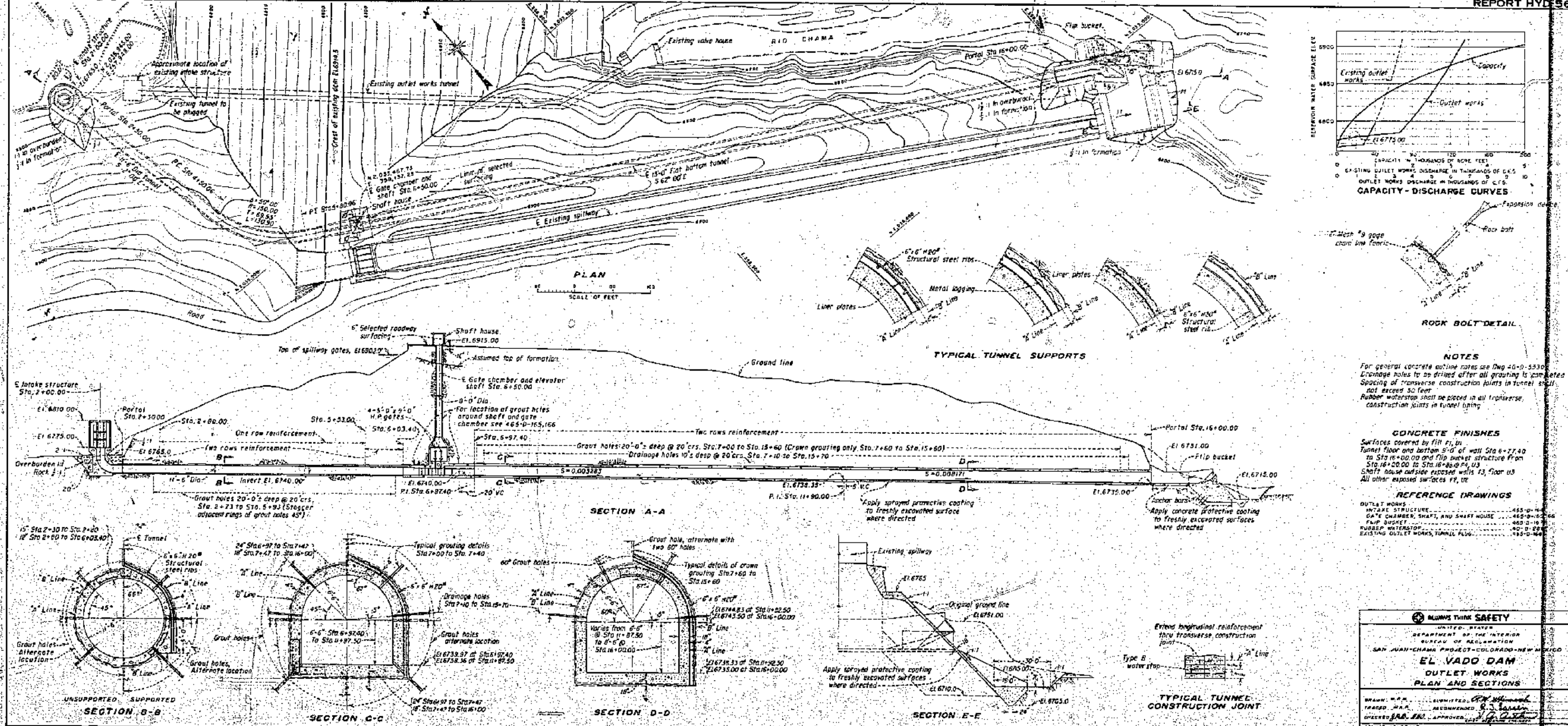
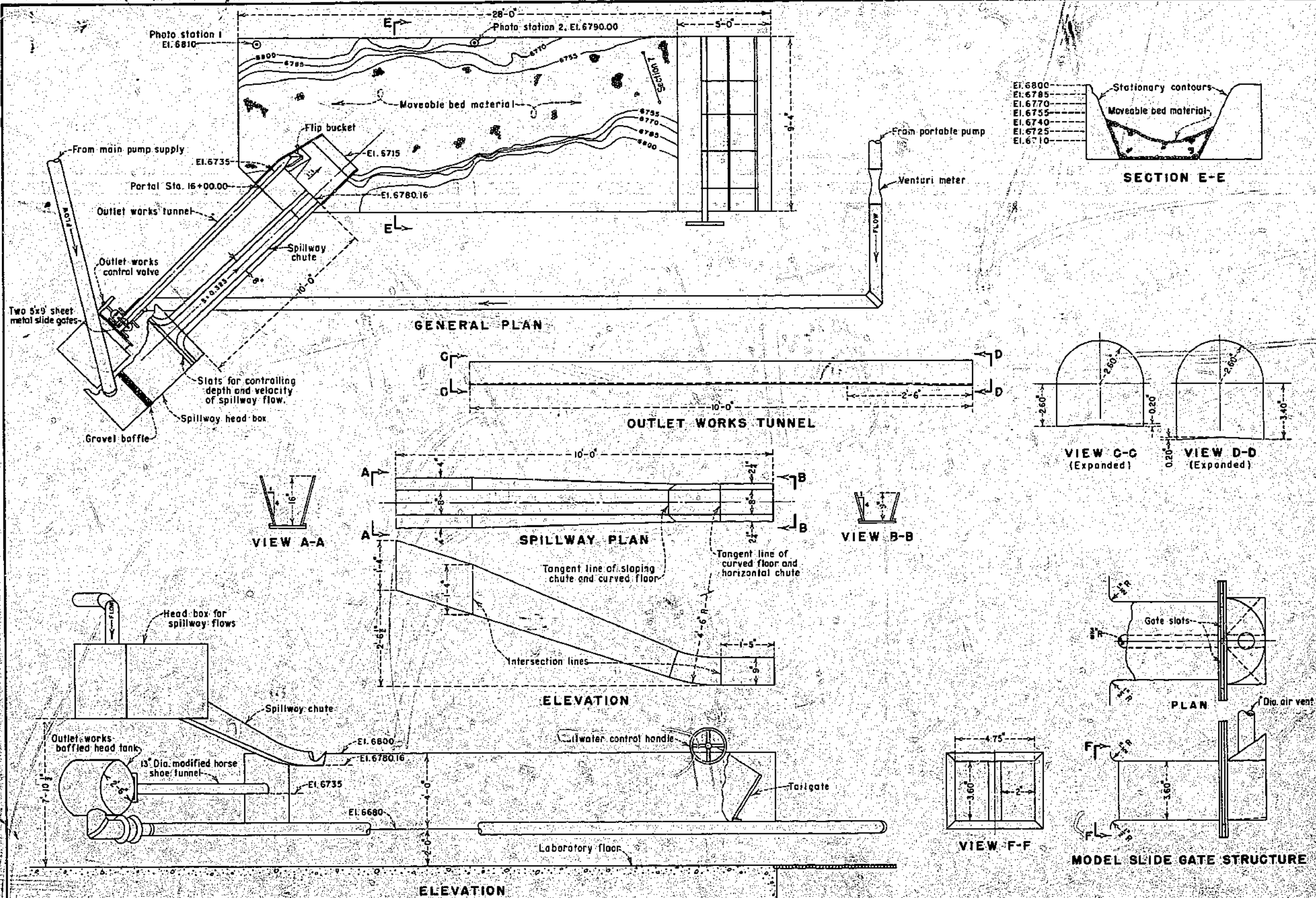
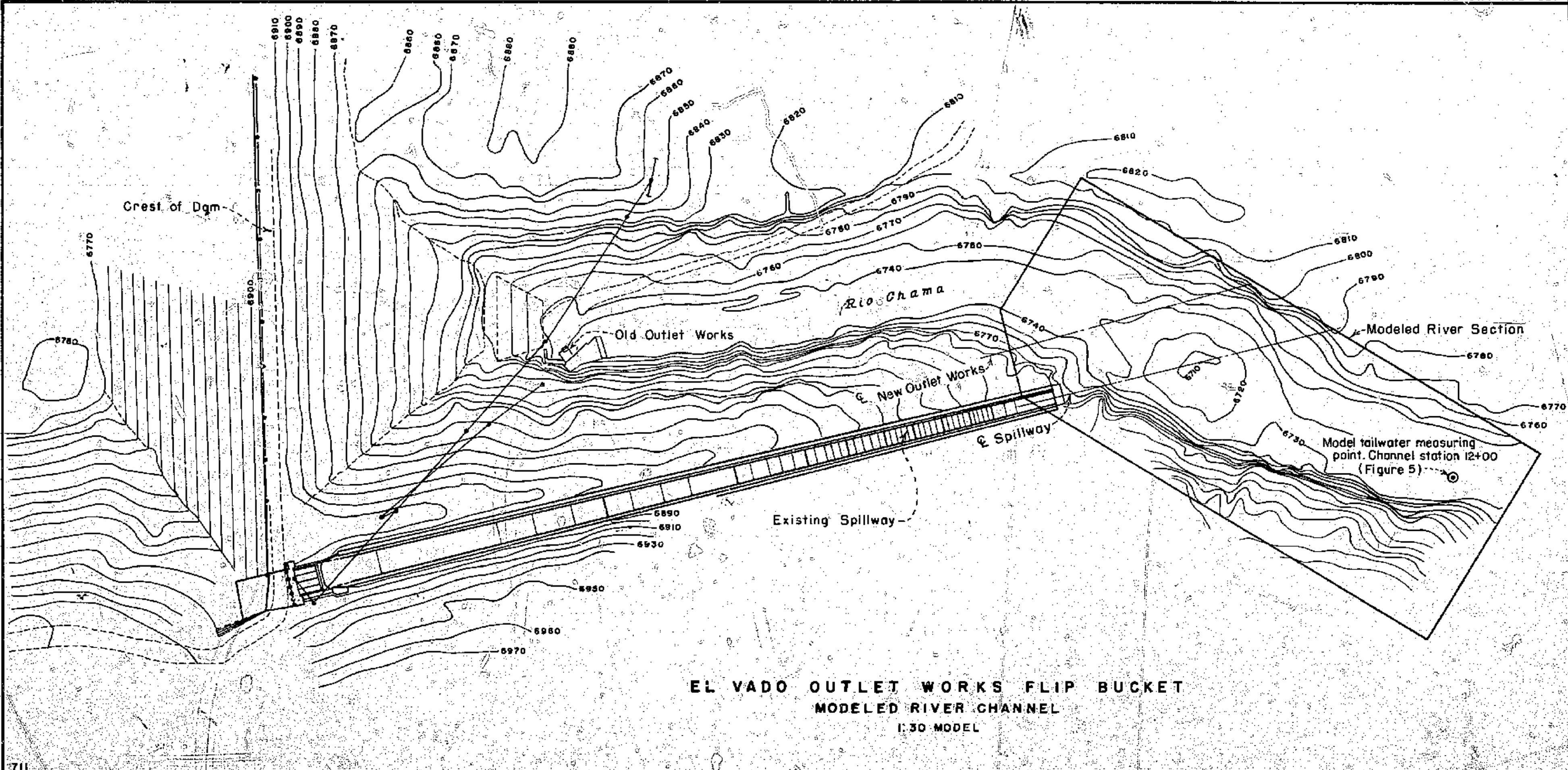
FIGURE 1
REPORT HYD 567



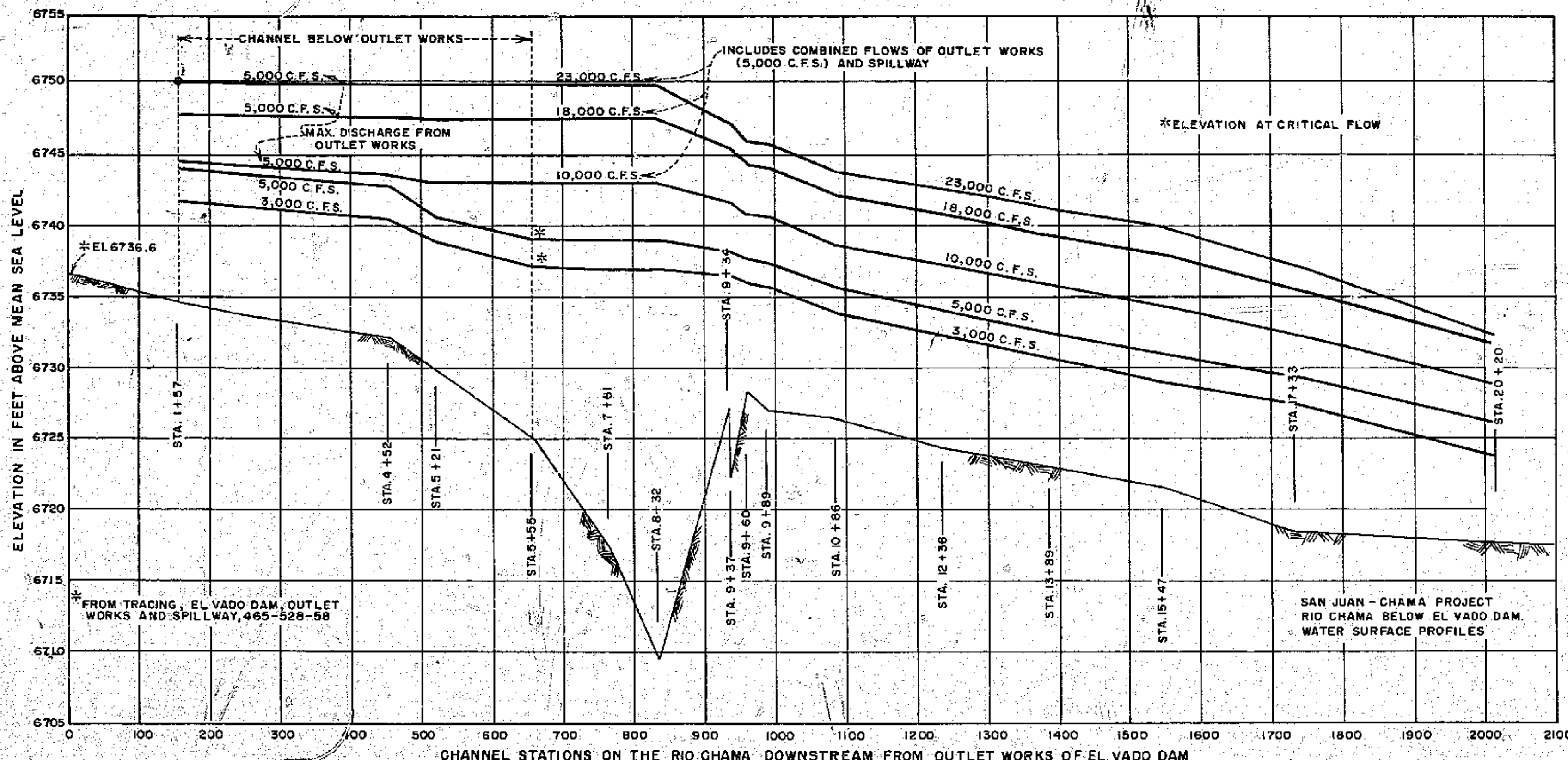

PLAN
SCALE OF FEET
RIO CHAMA
Existing valve house
Existing outlet works tunnel
Existing tunnel to be plugged
Approximate location of existing intake structure
Crest of existing dam El.6914.3
Existing spillway
Flip bucket
Portal Sta.16+00.00
Road
CAPACITY - DISCHARGE CURVES
Existing outlet works
Outlet works
Capacity
RESERVOIR WATER SURFACE ELEV.
CAPACITY IN THOUSANDS OF ACRE FEET
TYPICAL TUNNEL SUPPORTS
Structural steel ribs
Metal lagging
Liner plates
ROCK BOLT DETAIL
Expansion device
Rock bolt
SECTION A-A
Shaft house
Ground line
Two rows reinforcement
One row reinforcement
SECTION B-B
UNSUPPORTED SUPPORTED
SECTION C-C
SECTION D-D
SECTION E-E
Existing spillway
Original ground line
TYPICAL TUNNEL CONSTRUCTION JOINT
Extend longitudinal reinforcement thru transverse construction joint
Type B waterstop
NOTES
For general concrete outline notes see Dwg 40-D-5530.
Drainage holes to be drilled after all grouting is completed.
Spacing of transverse construction joints in tunnel shall not exceed 50 feet.
Rubber waterstop shall be placed in all transverse construction joints in tunnel lining.
CONCRETE FINISHES
Surfaces covered by fill F1, U1
Tunnel floor and bottom 5'-0" of wall Sta 6+77.40 to Sta 16+00.00 and flip bucket structure from Sta.16+00.00 to Sta.16+86.19 F4, U3
Shaft house outside exposed walls F3, floor U3
All other exposed surfaces F2, U2
REFERENCE DRAWINGS
OUTLET WORKS
INTAKE STRUCTURE
GATE CHAMBER, SHAFT, AND SHAFT HOUSE
FLIP BUCKET
RUBBER WATERSTOP
EXISTING OUTLET WORKS, TUNNEL PLUG
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN-CHAMA PROJECT-COLORADO-NEW MEXICO
EL VADO DAM
OUTLET WORKS
PLAN AND SECTIONS
DENVER, COLORADO
465-D-163



EL VADO OUTLET WORKS FLIP BUCKET
MODEL ARRANGEMENT
1:30 MODEL

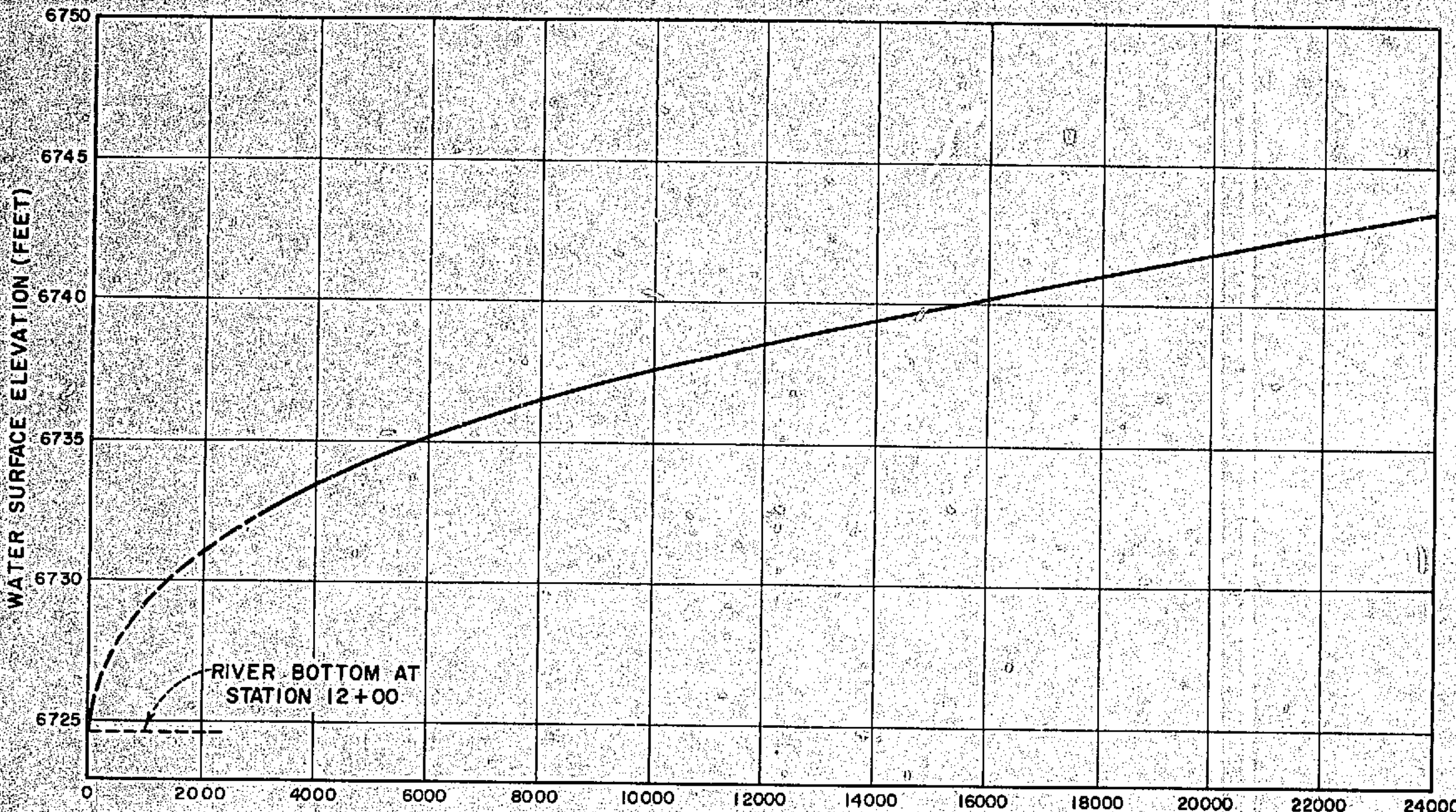


EL VADO OUTLET WORKS FLIP BUCKET
MODELED RIVER CHANNEL
1:30 MODEL



EL VADO OUTLET WORKS FLIP BUCKET
WATER SURFACE PROFILES

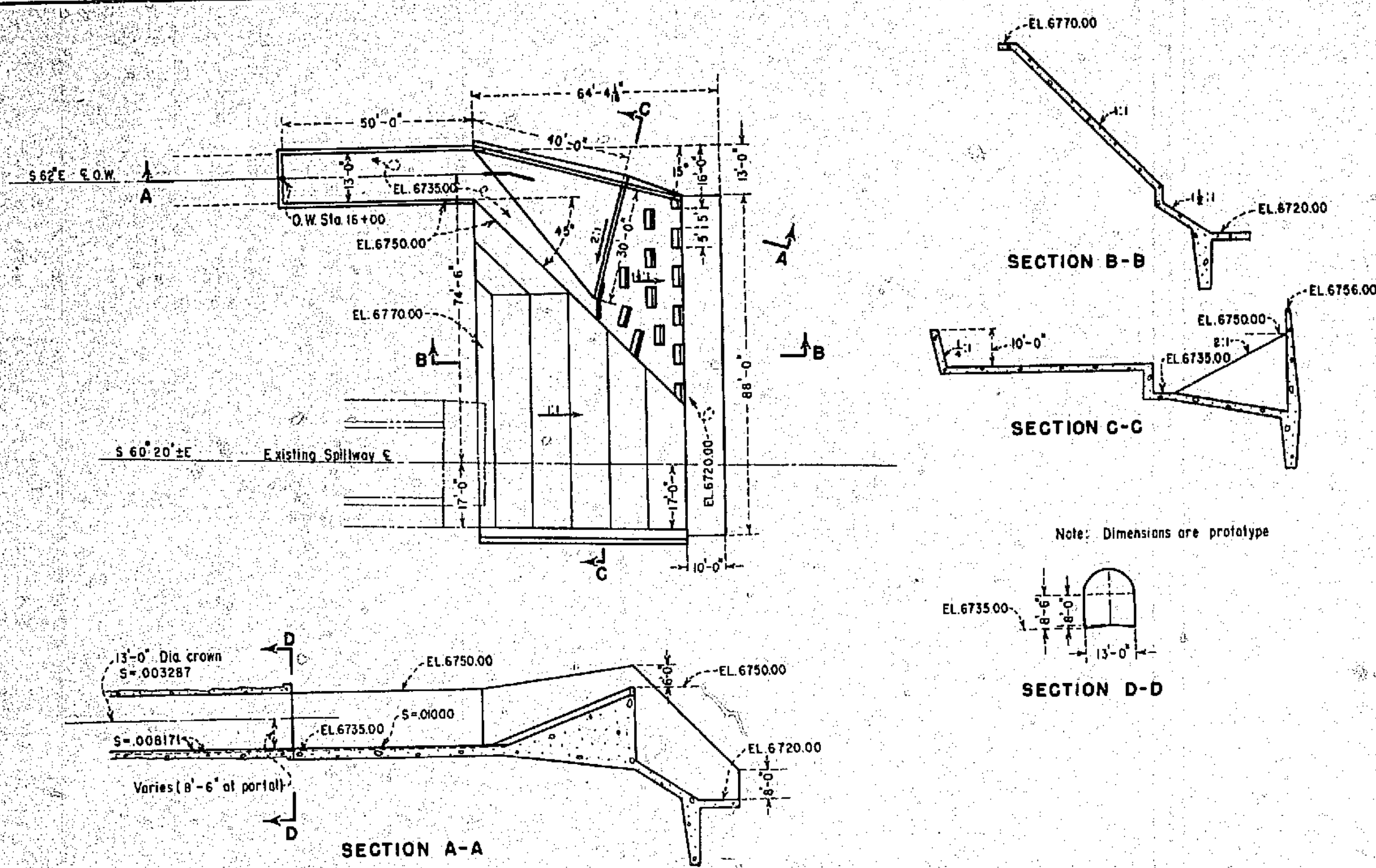
711



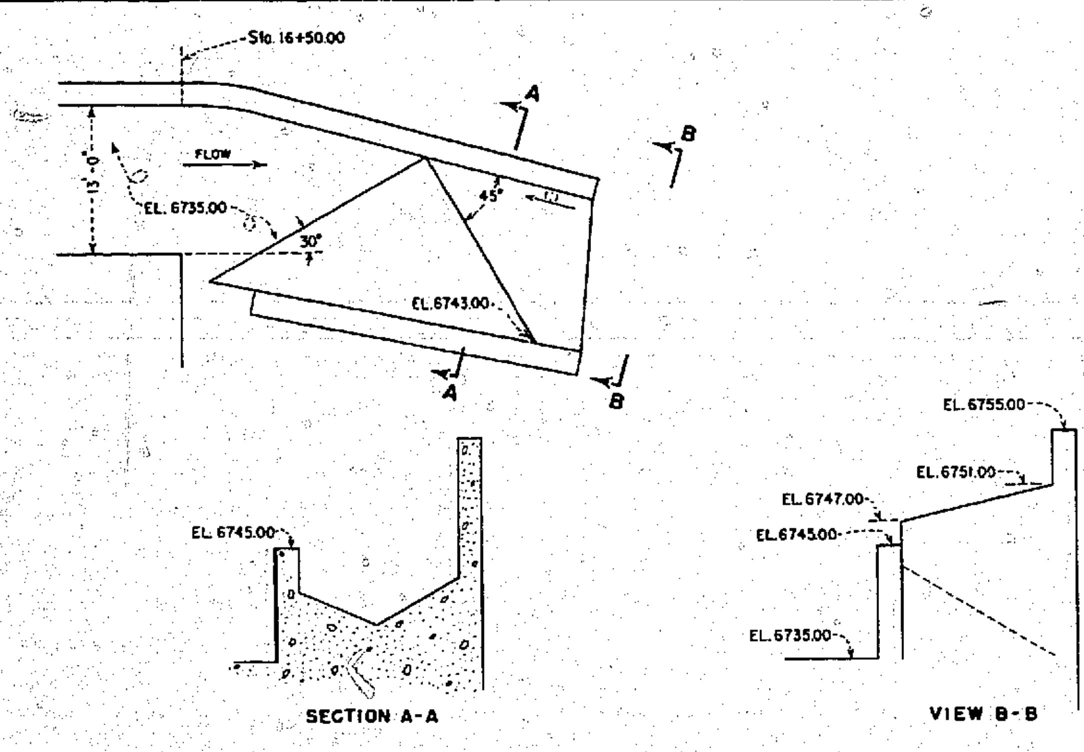
Tailwater curve prepared for river station 12+00, Figure 5

EL VADO OUTLET WORKS FLIP BUCKET
1:30 MODEL

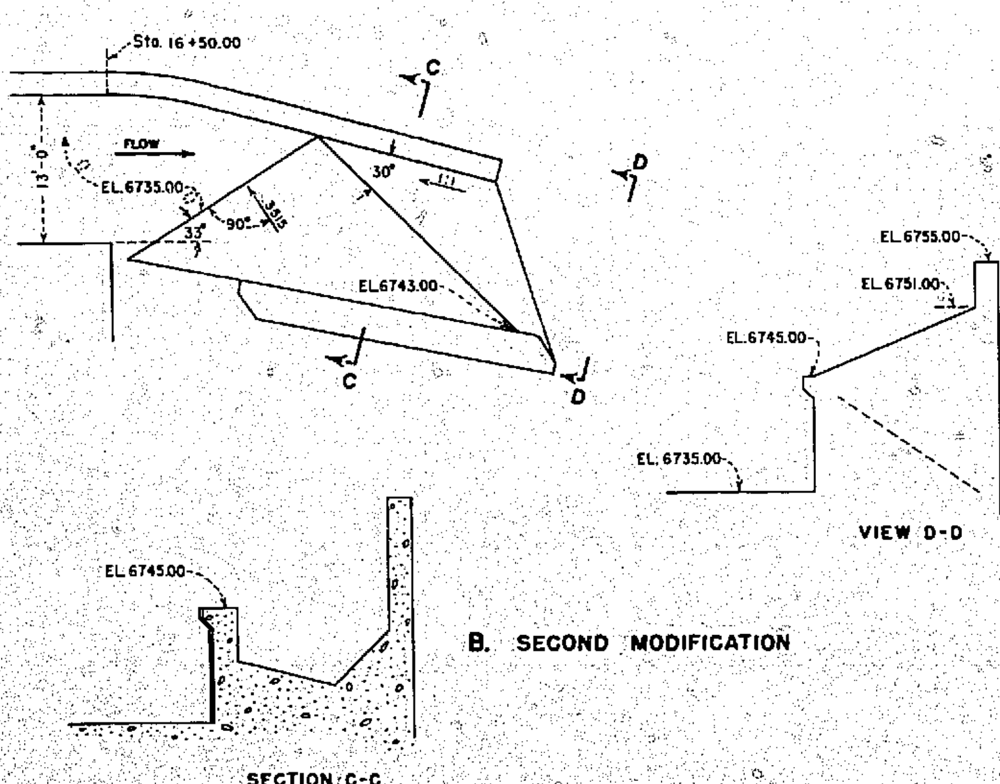
711



EL VADO OUTLET WORKS FLIP BUCKET
PRELIMINARY FLIP BUCKTET DESIGN

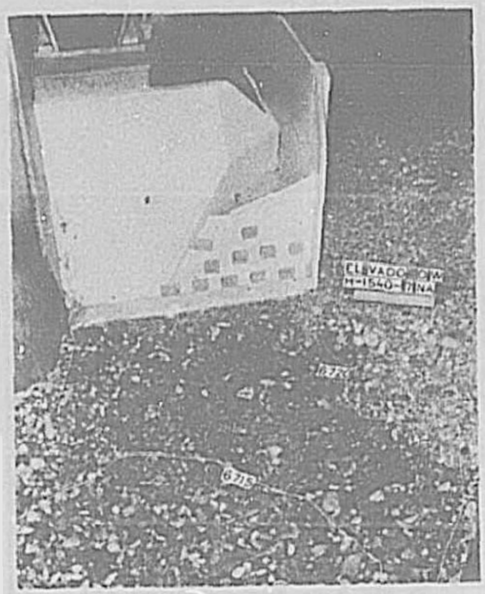


A. FIRST MODIFICATION



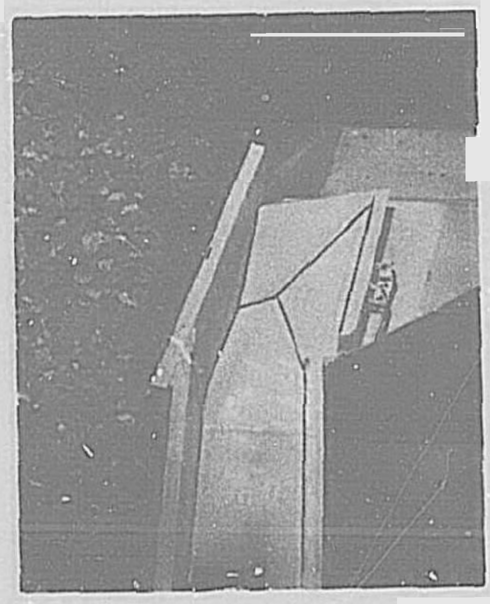
B. SECOND MODIFICATION

EL VADO OUTLET WORKS FLIP BUCKET
FLIP BUCKET MODIFICATIONS
1:30 MODEL

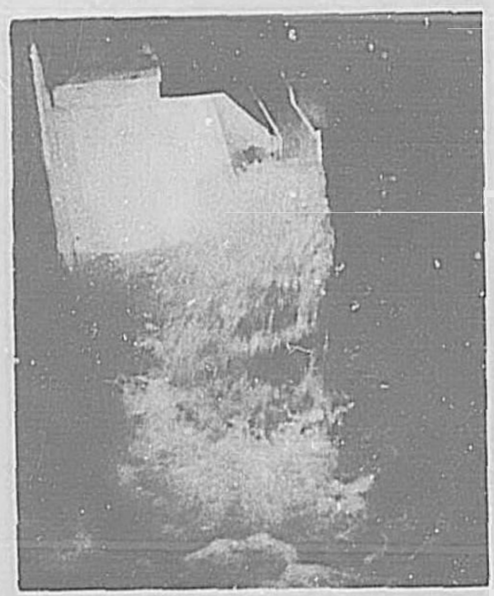


A. Preliminary flip bucket design, with single plane surface. Photo P163-D-60686

B. Flow from preliminary flip bucket. Q-4,000 cfs (56.634 cms), reservoir elevation 6880. Note flow striking at end of structure. Photo P163-D-60687



C. Recommended flip bucket with two plane surfaces, and left and right confining walls. Photo P163-D-60688

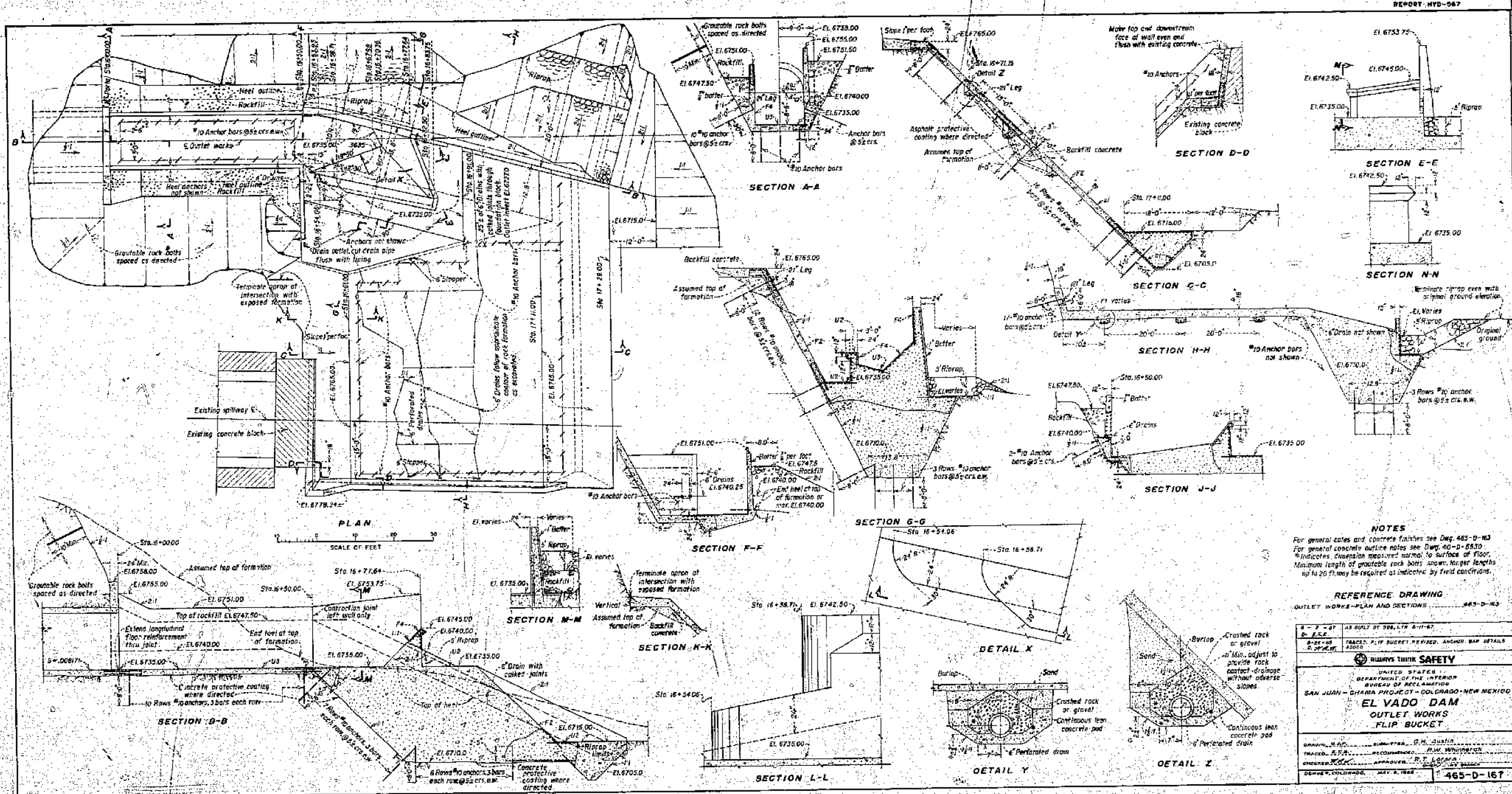


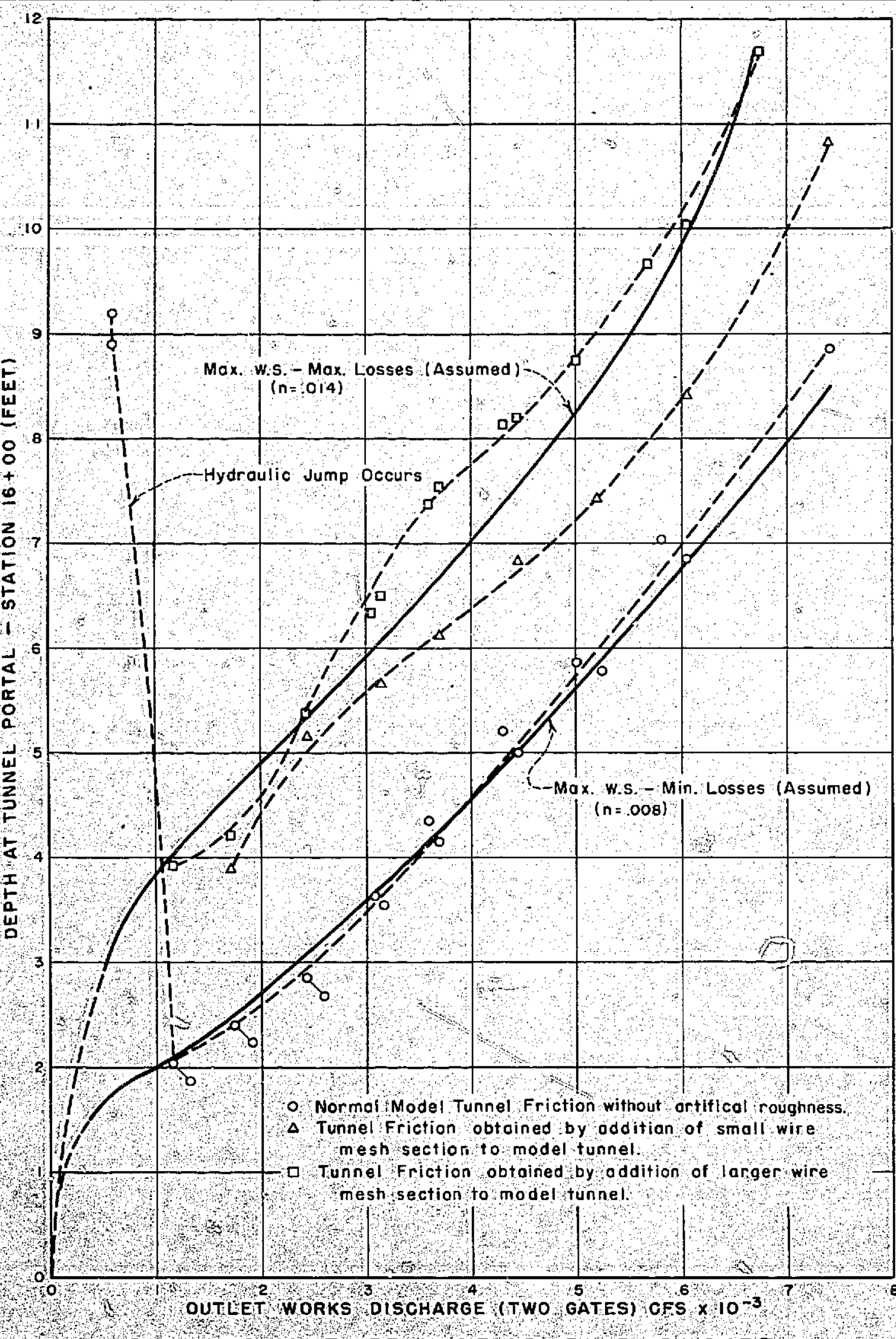
D. Flow from recommended bucket, Q-4,000 cfs (56.634 cms), reservoir elevation 6875. Note flow being cast beyond structure. Photo P163-D-60689

EL VADO OUTLET WORKS FLIP BUCKET

Comparison of preliminary flip bucket design and performance with recommended flip bucket

1:30 Model

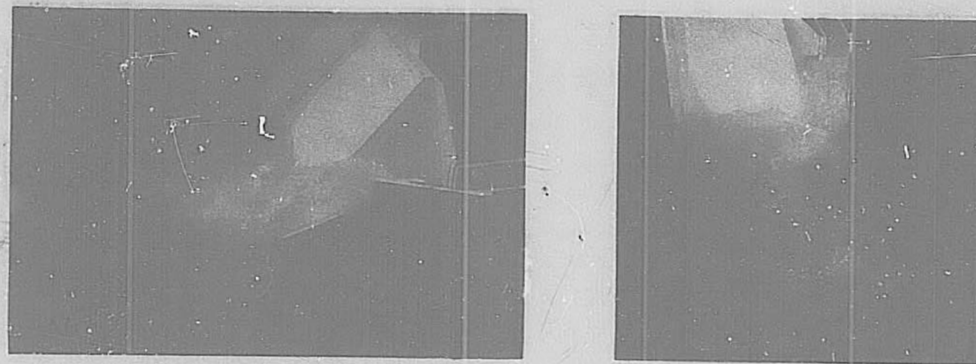

PLAN
SCALE OF FEET
SECTION A-A
SECTION B-B
SECTION C-C
SECTION D-D
SECTION E-E
SECTION F-F
SECTION G-G
SECTION H-H
SECTION J-J
SECTION K-K
SECTION L-L
SECTION M-M
SECTION N-N
DETAIL X
DETAIL Y
DETAIL Z
NOTES
For general cotes and concrete finishes see Dwg. 465-D-163
For general concrete outline notes see Dwg. 40-D-5530
# Indicates dimension measured normal to surface of floor.
Minimum length of groutable rock bolts shown, longer lengths up to 20 ft. may be required as indicated by field conditions.
REFERENCE DRAWING
OUTLET WORKS-PLAN AND SECTIONS 465-D-163
6-2-67 AS BUILT BY SEE. LTR 6-11-67.
TRACED, FLIP BUCKET REVISED, ANCHOR BAR DETAILS ADDED
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN JUAN-CHAMA PROJECT-COLORADO-NEW MEXICO
EL VADO DAM
OUTLET WORKS
FLIP BUCKET
SUBMITTED G.H. Austin
RECOMMENDED R.W. Whinnerah
APPROVED R.T. Larsen
DENVER, COLORADO, MAY 6, 1966
465-D-167



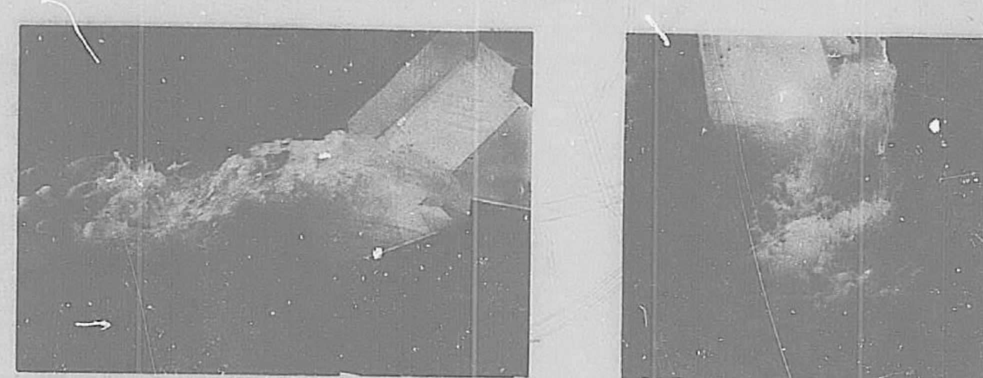
EL VADO OUTLET WORKS FLIP BUCKET
FLOW DEPTH AT TUNNEL PORTAL
FROM 1:30 MODEL

711

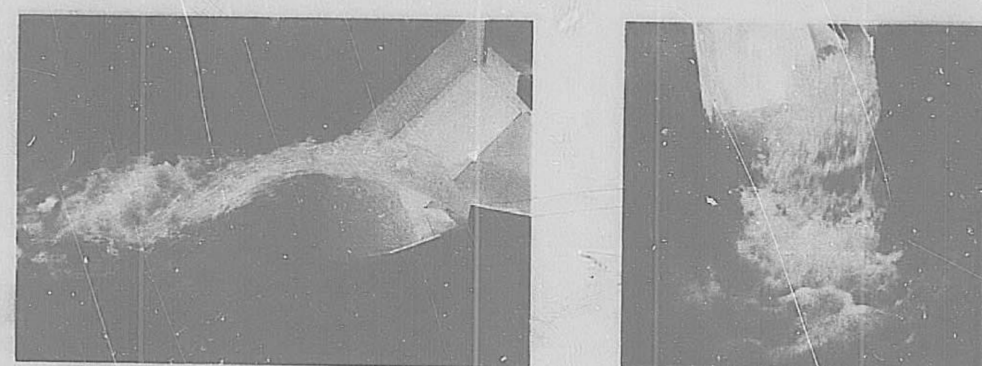
A. Discharge 800 cfs (22.654 cms), reservoir elevation 6812.
Photos P163-D-60697 and P163-D-60698



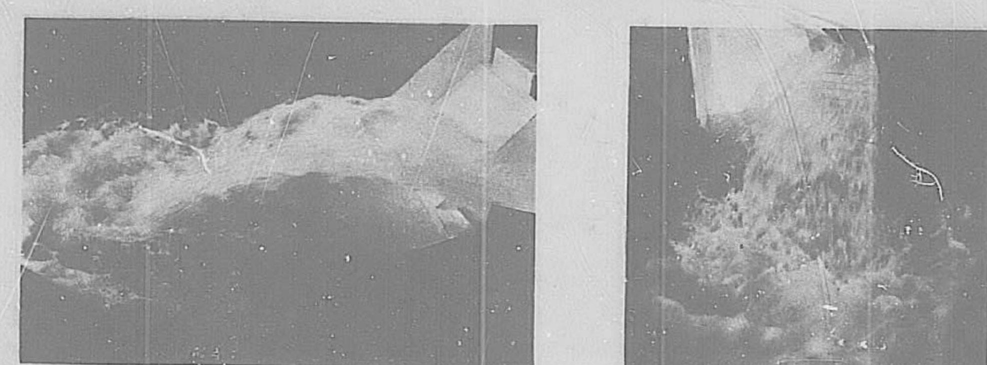
B. Discharge 2,000 cfs (56.634 cms), reservoir elevation 6787.
Photos P163-D-60695 and P163-D-60696



C. Discharge 3,000 cfs (84.951 cms), reservoir elevation 6902.
Photos P163-D-60693 and P163-D-60694



D. Discharge 4,000 cfs (113.268 cms), reservoir elevation 6875.
Photos P163-D-60692 and P163-D-60689

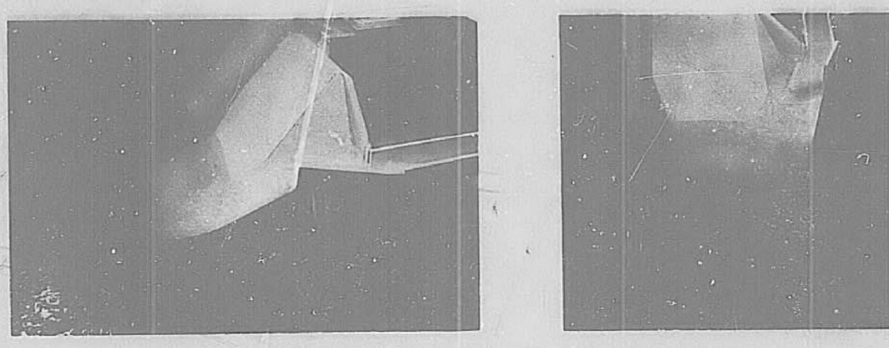


E. Discharge 7,400 cfs (209.546 cms), reservoir elevation 6902.
Photos P163-D-60690 and P163-D-60691

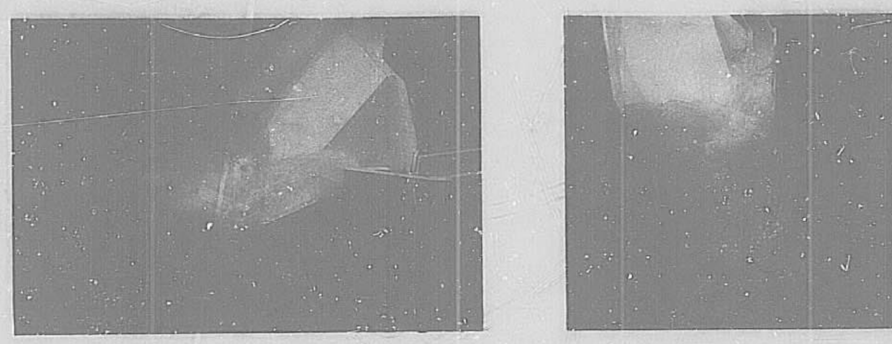
EL VADO OUTLET WORKS FLIP BUCKET

Flip bucket operation for various head-discharge relationships
Outlet gates equally opened - Recommended design

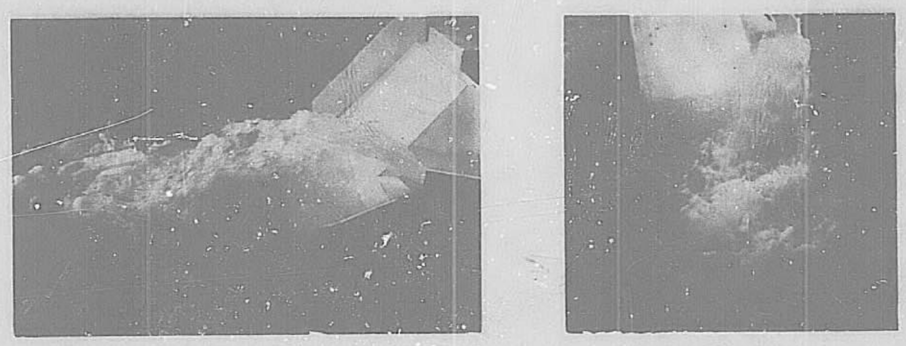
1:30 Model



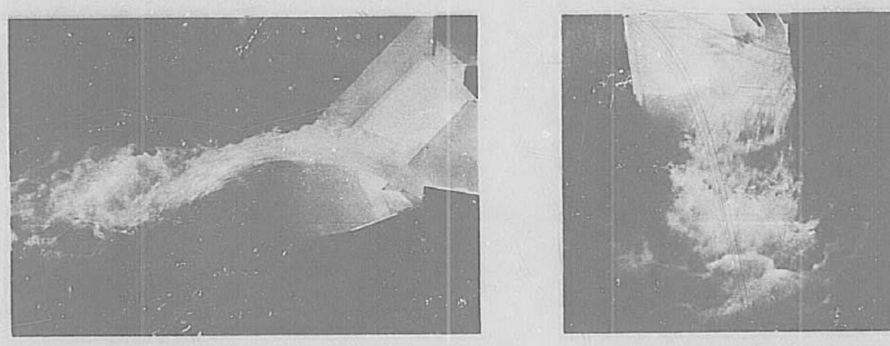
A. Discharge 800 cfs (22.654 cms), reservoir elevation 6812.
Photos P163-D-60697 and P163-D-60698



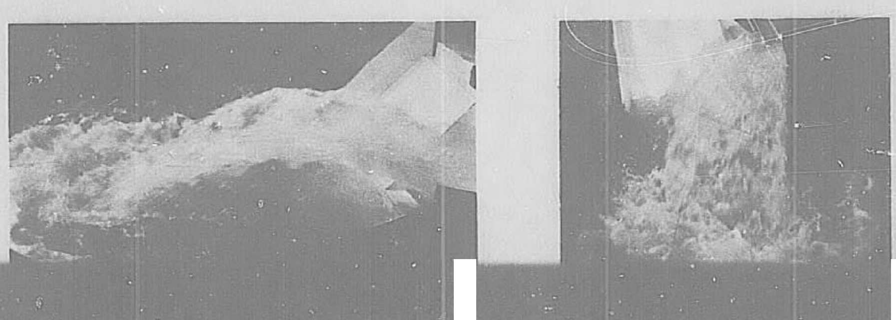
B. Discharge 2,000 cfs (56.634 cms), reservoir elevation 6787.
Photos P163-D-60695 and P163-D-60696

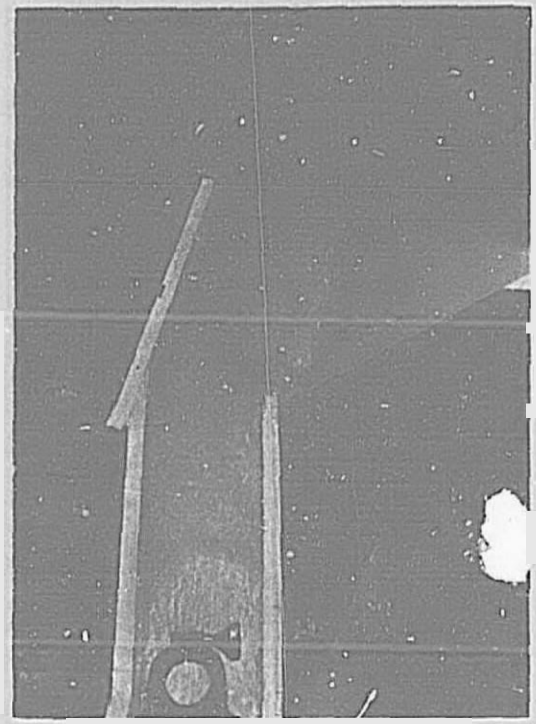


C. Discharge 3,000 cfs (84.951 cms), reservoir elevation 6902.
Photos P163-D-60693 and P163-D-60694

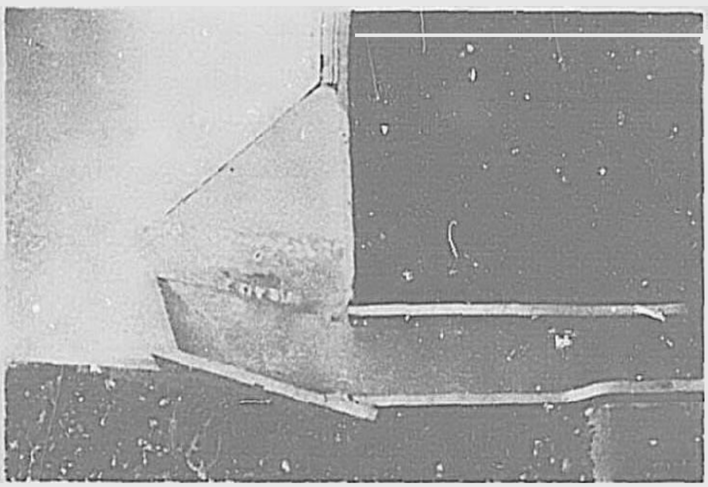


D. Discharge 4,000 cfs (113.268 cms), reservoir elevation 6875.
Photos P163-D-60692 and P163-D-60689





A. Hydraulic jump upstream of flip bucket. Discharge 820 cfs, reservoir elevation 6812.5. Photo P163-D-60699



B. Hydraulic jump at tunnel portal. Discharge 790 cfs, reservoir elevation 6805. Photo P163-D-60700

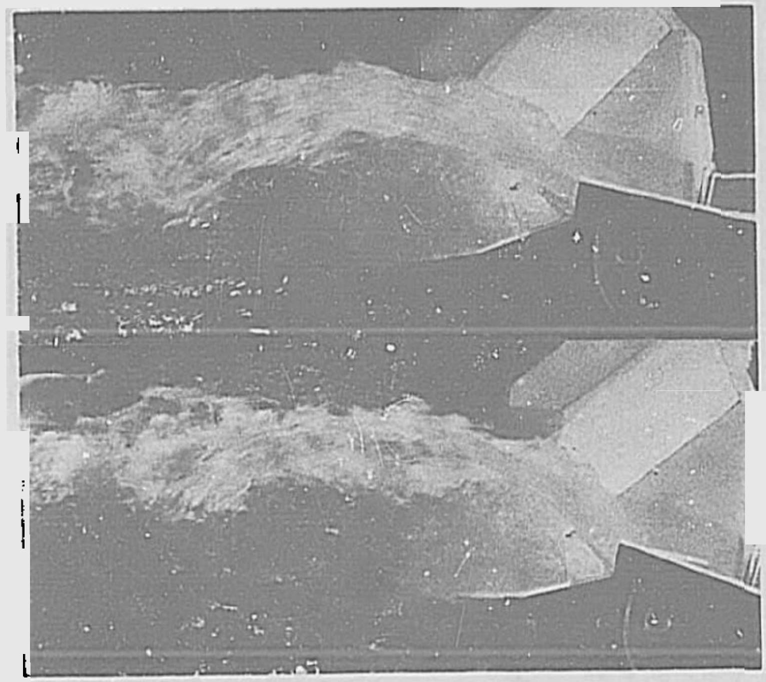
EL VADO OUTLET WORKS FLIP BUCKET

Hydraulic jump upstream of flip bucket for small releases. Outlet gates equally opened - Recommended design

1:30 Model

Right gate operation
Photo P163-D-60701

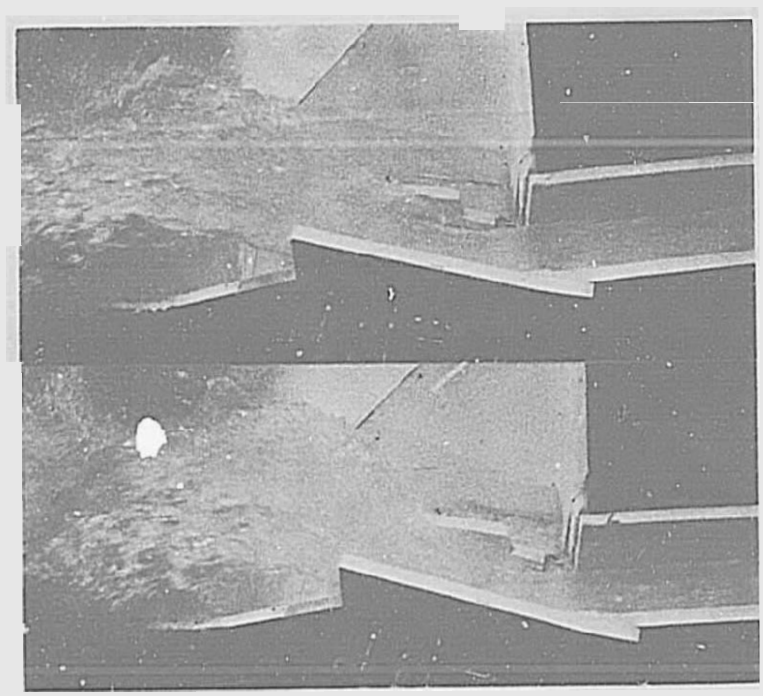
Left gate operation
Photo P163-D-60702



A. Discharge 2,000 cfs, reservoir elevation 6900

Right gate operation
Photo P163-D-60703

Left gate operation
Photo P163-D-60704



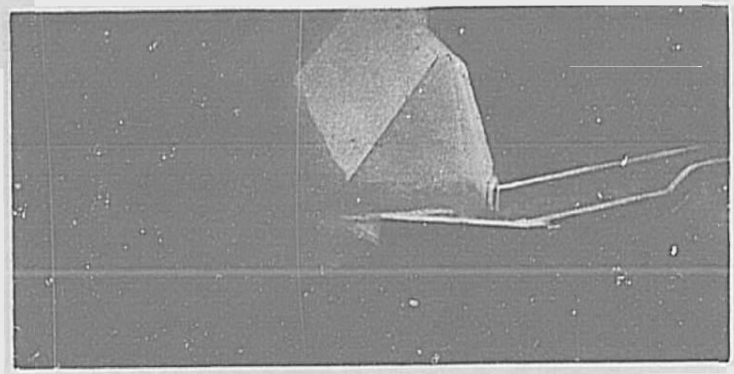
B. Discharge 1,800 cfs, reservoir elevation 6805

EL VADO OUTLET WORKS FLIP BUCKET

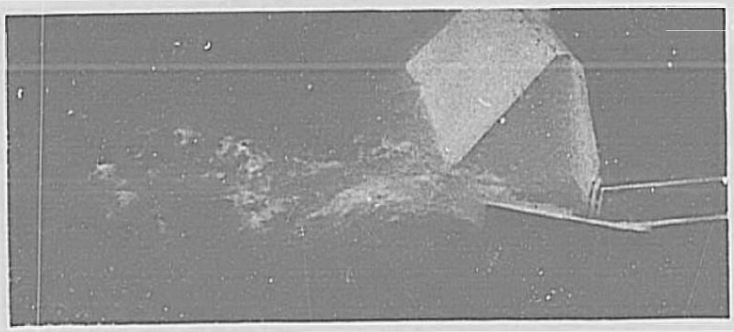
Flip bucket dispersion for single gate operation
Recommended design

1:30 Model

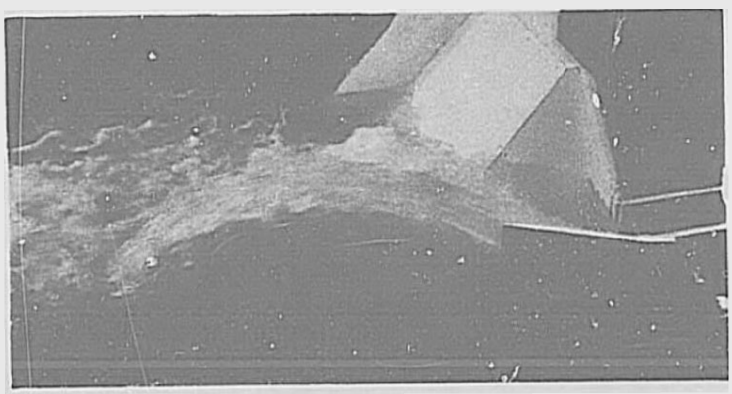
Figure 15
Report Hyd-567



A. Discharge 420 cfs, reservoir elevation 6835, tailwater 16 feet above normal. Photo P163-D-60705



B. Discharge 1,800 cfs, reservoir elevation 6835, tailwater 14 feet above normal. Photo P163-D-60706



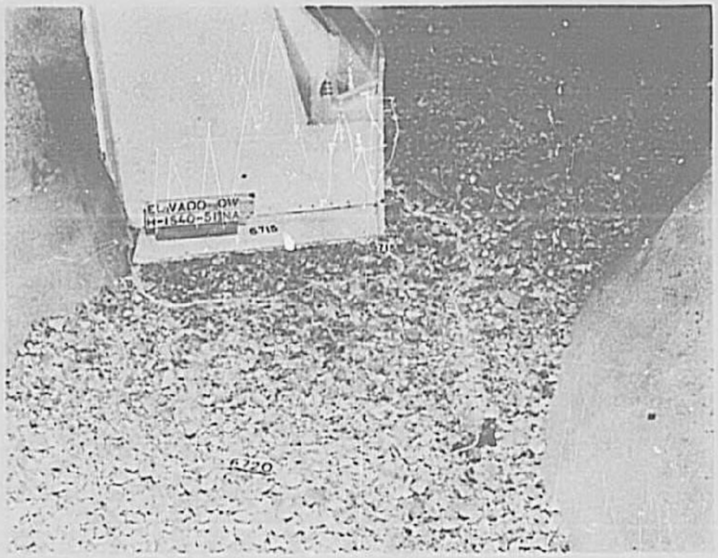
C. Discharge 5,200 cfs, reservoir elevation 6860, tailwater 12 feet above normal. Photo P163-D-60707

EL VADO OUTLET WORKS FLIP BUCKET

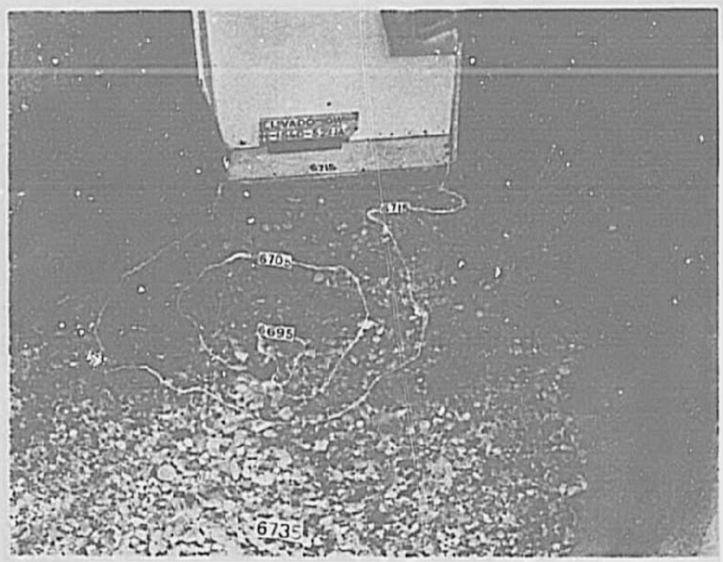
Flip bucket performance with high tailwater
Recommended design

1:30 Model

Figure 16
Report Hyd-567



A. River channel with contour lines prior to a 20-hour spillway erosion test. Photo P163-D-60708

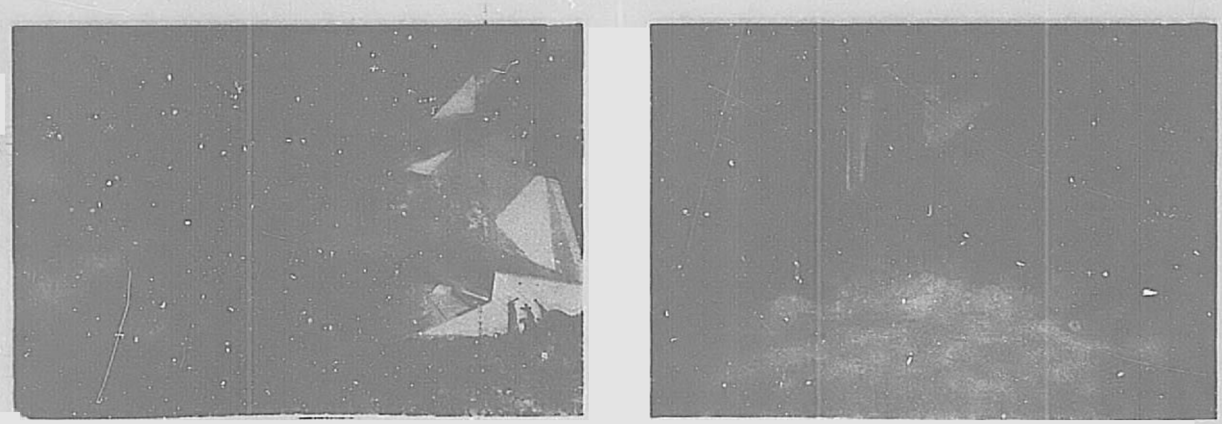


B. River channel with contour lines after 20 hours of spillway operation at 4,000 cfs (prototype time). Photo P163-D-60709

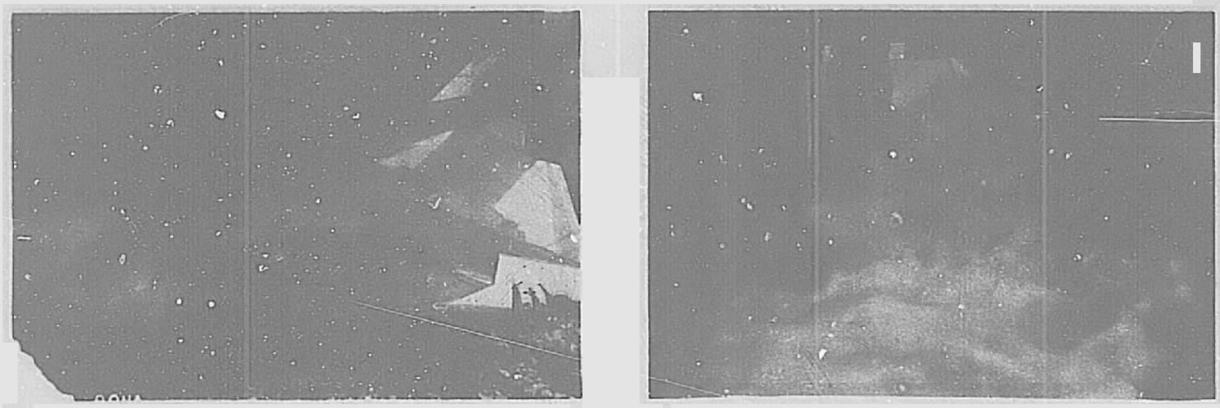
EL VADO OUTLET WORKS FLIP BUCKET

Spillway erosion studies

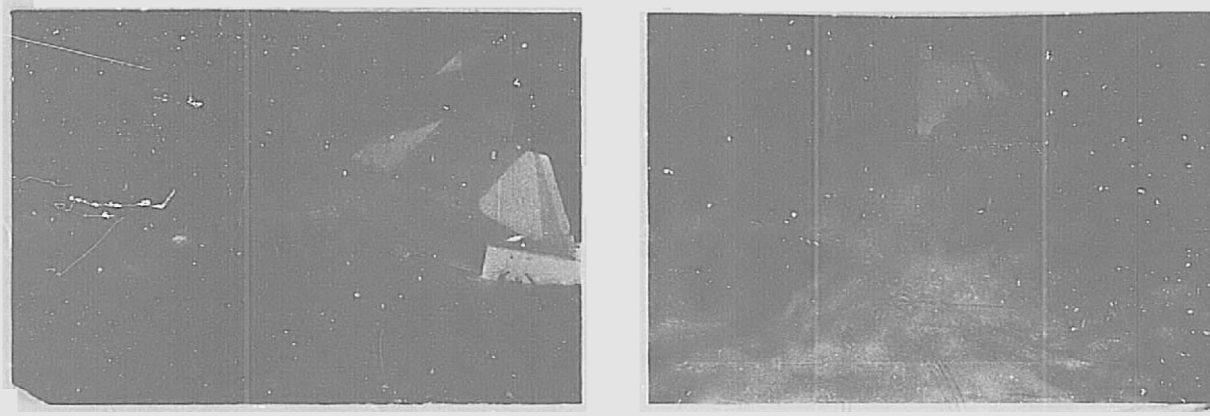
1:30 Model



A. Outlet works releasing 7,400 cfs, with a spillway flow of 5,500 cfs. Photos P163-D-60710 and P163-D-60711



B. Outlet works releasing 7,400 cfs, with a spillway flow of 11,000 cfs. Photos P163-D-60712 and P163-D-60713

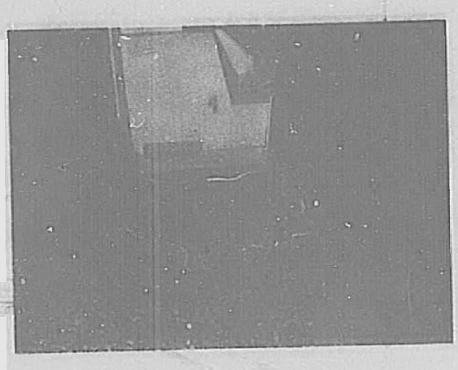


C. Outlet works releasing 7,400 cfs, with a spillway flow of 16,000 cfs. Photos P163-D-60714 and P163-D-60715

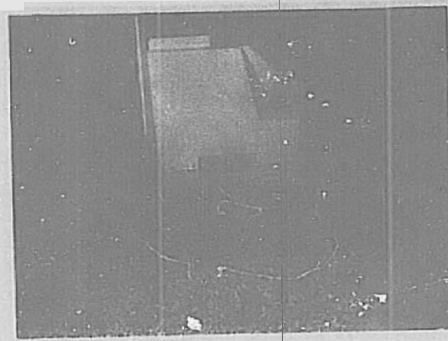
EL VADO OUTLET WORKS FLIP BUCKET

Combined spillway and outlet works operation, reservoir elevation 6902
Recommended design

1:30 Model



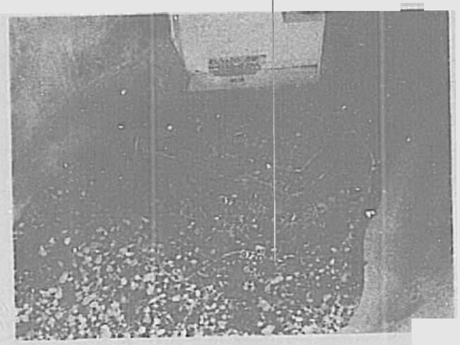
Before test



After 100 hours

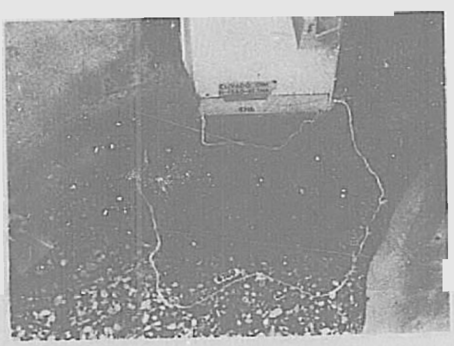
A. Test conditions: Discharge 4,000 cfs, reservoir elevation 6795, tailwater 6733.5. Photos P163-D-60716 and P163-D-60717

Before test

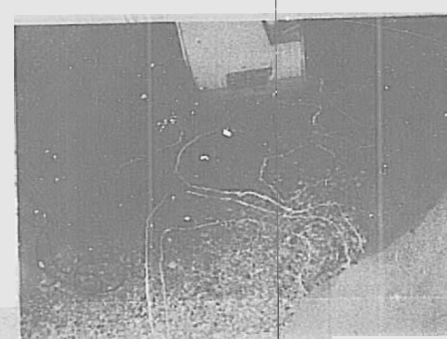


After 100 hours

B. Test conditions: Discharge 4,000 cfs, reservoir elevation 6848, tailwater 6733.5. Photos P163-D-60718 and P163-D-60719



Before test



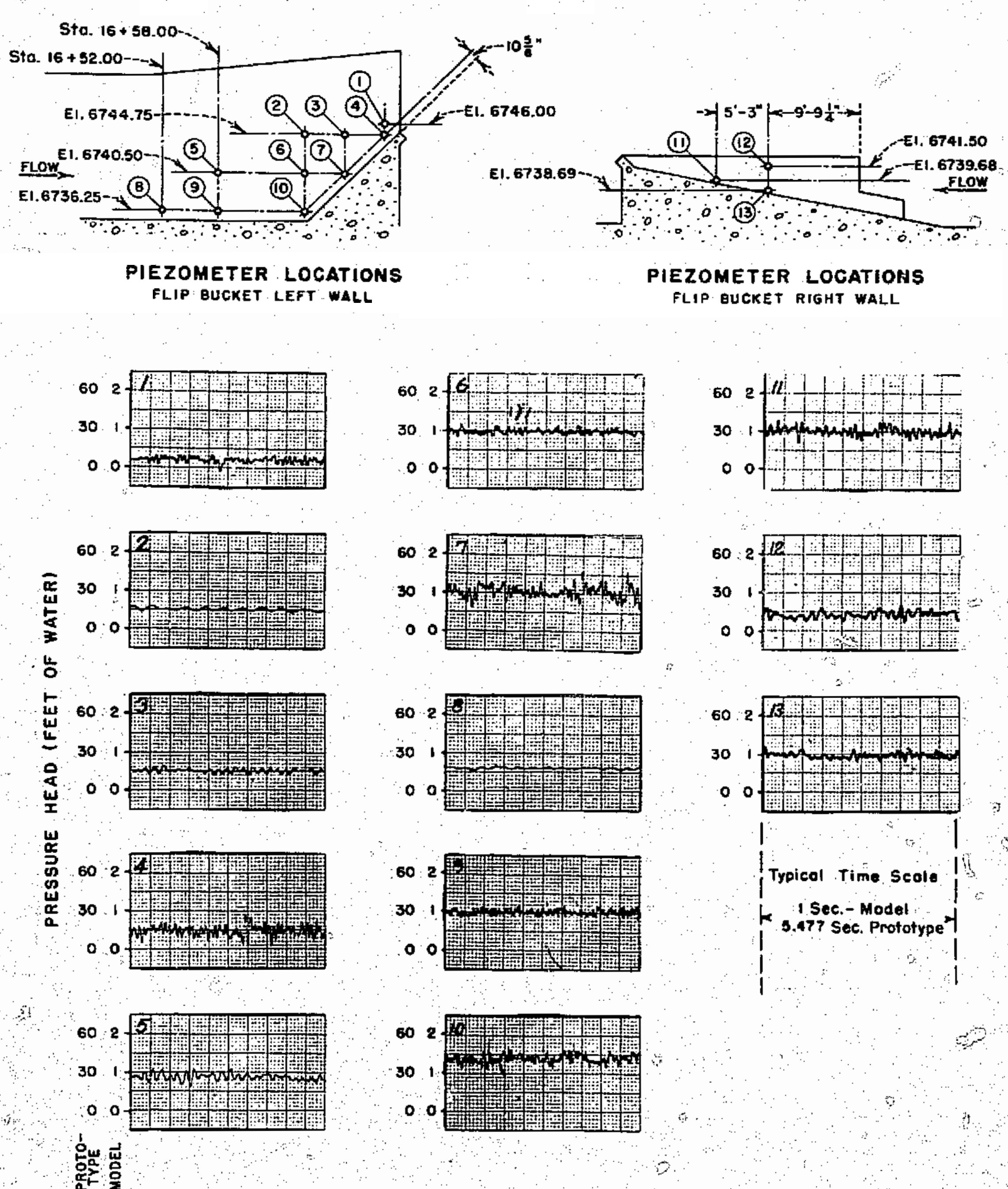
After 100 hours

C. Test conditions: Discharge 7,400 cfs, reservoir elevation 6902, tailwater 6736. Photos P163-D-60720 and P163-D-60721

EL VADO OUTLET WORKS FLIP BUCKET

Outlet works erosion patterns for various discharges
Recommended design

1:30 Model



Readings obtained for a 7,400 c.f.s. discharge, with a water surface elevation of 6902, and 100 percent gate opening, recommend design.

EL VADO OUTLET WORKS FLIP BUCKET
DYNAMIC PRESSURES ACTING ON WALLS
DATA FROM 1:30 MODEL

711

7-1750
(2-67)
Bureau of Reclamation

CONVERSION FACTORS--BRITISH TO METRIC UNITS OF MEASUREMENT

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

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

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

Table 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
	1.12985 x 10^6	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
	1.35582 x 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 x 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 x 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)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

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

ABSTRACT

A flip bucket was developed from model studies to minimize river channel erosion and provide satisfactory dispersion of flows for the new, enlarged-capacity outlet works at El Vado Dam. The outlet works will utilize a plunge pool in the river channel created by past spillway flows. Normal discharges will range from 2,000 to 4,000 cfs, (56.634 to 113.268 cms) with an overall range of 0 to approximately 6,700 cfs (189.724 cms). Reservoir water surfaces will range between elevation 6775 and 6902. The initial bucket design proved unsatisfactory and resulted in considerable erosion in the river channel. The recommended bucket was constructed with 2 vertical, slightly converging sidewalls and 2 sloping plane surfaces. An offset opening was provided in the right wall for discharging small, low-velocity flows. River channel erosion caused by outlet works operation will be moderate. Erosion from combined spillway and outlet flows will be significant, but combined operation will be necessary only under extreme flood conditions. Operation of the spillway alone is not anticipated.

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Hyd-567
Isbester, T J
HYDRAULIC MODEL STUDIES OF THE EL VADO OUTLET WORKS FLIP BUCKET
USBR Lab Rept Hyd-567, Hyd Br, April 1967. Bureau of Reclamation, Denver, 11 p, 19 fig, 3 tab
DESCRIPTORS-- *flip buckets/ hydraulic jumps/ erosion/ head losses/ *outlet works/ slide gates/ intake structures/ *hydraulic models/ model tests/ dispersion/ *energy dissipation/ movable bed models/ *spillways
IDENTIFIERS-- plunge pool/ El Vado Dam, New Mexico/ New Mexico/ San Juan Chama Project

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