UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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MODEL STUDY OF ALAMOGORDO OUTLET NEEDLE VALVE TO ELIMINATE DAMAGE BY CAVITATION CARLSBAD PROJECT, NEW MEXICO

By

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Branch of Design and Construction
Engineering and Geological Control
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Laboratory Report No. 147
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Subject: Model study of Alamogordo outlet needle valve to eliminate damage by cavitation - Carlsbad project, New Mexico.

INTRODUCTION

1. Damage to needle valves at Alamogordo Dam. The needles and the nozzles of the two interior, differential needle valves in the outlet works at Alamogordo Dam of the Carlsbad project in New Mexico (figure 1) have been damaged by a pitting action produced by cavitation. The condition of one valve is not serious, but that of the other, which no doubt has been operated much more, is similar in nature and extent to that observed on needle valves at Boulder, Alcova, and other Bureau dams, described in hydraulic laboratory reports Nos. 42, 49, and 133. The cause is attributed to the unfavorable profile of the water passage over certain ranges of opening. The curvature of the nozzle exit of these valves is such that the flow tends to separate from the boundary, producing severe negative pressures that result in the formation of cavitation cavities which collapse on the surface of the nozzle near the exit to produce the pitting. The pitting of the needle results from the same phenomenon, but it is influenced also by the slight divergence of the flow passage at certain openings. It was for the purpose of determining the adequacy of a proposed modification in the elimination of severe subatmospheric pressures believed to be the cause of this destructive action that model tests were instigated in June 1944. The study was made using an aerodynamic model constructed of plaster to a scale of 1 to 5-1/2. The tests on this model, which represented a one-eighth sector of the valve and the downstream portion of the outlet conduit, were completed July 10, 1944. The proposed alterations were found to be satisfactory.

PURPOSE OF MODEL STUDIES

2. Scope of tests. The purpose of the model tests was to investigate the adequacy of proposed changes in the Alamogordo outlet valves to prevent damage to the needles and the nozzles by cavitation. The investigation included a study of the pressure distribution on critical portions of the proposed modification, a comprehensive calibration of the modified design, and computations to establish the outlet capacity with

one valve modified and the other repaired only. Consideration was given to making the study of the Alamogordo valves by using either a 5-inch hydraulic model valve that was tested at Boulder Dam in 1938 or an 8-1/4-inch model of the 86-inch Bartlett valves tested in the Denver laboratory. However, the 5-inch valve was not available immediately and both valves required changes which would have delayed the test program. As a result, it was decided to use an aerodynamic model which could be constructed and tested in a reasonably short period. Whether or not the construction of the intricate points on the needle tips of air model needle valves is essential in pressure and calibration tests has been questionable; therefore tests were made to ascertain their necessity.

3. Summary of results. Pressures on the nozzle and the needle were positive for all valve openings. Although they decreased and became very small at some points as the needle approached the closed position, none became negative; thus the cavitation so prevalent in the original design should not be present in the modified valve. Discharge coefficients and capacity curves for the modified design indicated a decrease in capacity of approximately 18-1/2 percent due to the change, a characteristic which is unavoidable when the source of cavitation in these valves is eliminated.

Discharge curves based on the data taken from the 1:5-1/2 scale aerodynamic model, and from tests on the 72-inch Boulder valves and a 5-inch hydraulic model of the Boulder valves, should prove useful in determining the amount of water being released from the outlet structure.

THE INVESTIGATION

4. Description of 1:5-1/2 scale aerodynamic model. A model having a scale of 1 to 5-1/2, representing a one-eighth sector through the valve and a portion of an outlet conduit, using air as a test medium, was employed to ascertain the feasibility of the proposed modifications to the 54-inch needle valves in the outlet works at Alamogordo Dam. The model consisted of a length of 6-inch-diameter metal pipe; a transition from 6-inch-diameter to a 45-degree, 6-inch radius, circular segment; a 45-degree V-shaped channel with one side of fiber wood and the other of transparent plastic; and 45-degree plaster sectors of the valve needle and the nozzle (figure 2A).

The valve needle and the nozzle were shaped by revolving metal templates about fixed centers. A plaster mortar, prepared by sifting dry molding plaster into a vessel of water until it was just covered by the water and stirring in a manner to prevent entrainment of air, was placed in V-troughs with sides shaped approximately to the section profiles of the needle and the nozzle; and the templates, centered at the ends, swung back and forth across the troughs. The segments were shaped through a process of building up with plaster and scraping off the surplus as it obtained its set.

The segments, except for the downstream needle tip, were fitted and bolted to the sides of the V-shaped channel. The needle was made adjustable and was controlled by a rod passing through a slot in the plastic wall. Airtight joints were made by placing a fillet of modeling clay along the seams inside the model. Air was supplied to the model by a 4-inch positive displacement blower.

Piezometers were installed by drilling small holes into the model segments and inserting small copper tubes for attaching to a water manometer. The connections between the model and the metal tubes were made airtight by placing plaster mortar around them.

The needle profile for each 10-percent increment of opening was etched on the inside of the transparent wall of the V-shaped channel to enable accurate setting of the valve at these openings.

A water manometer was used to measure the piezometer pressures.

5. Study of pressure distribution on needle and nozzle of modified design. Since model studies made previously on the Boulder, Alcova, and Bartlett valves had disclosed regions of subatmospheric pressure in the vicinity of the pitted areas, it was not believed essential to construct and test a model of the present installation. The proposed modification, consisting of replacement of the 42-degree needle tip with one having an angle of 36° 22' with the axis of the valve (the same as that of the present nozzle) and the alteration of the nozzle exit from the rounded to the sharp-edged type, was based on brief tests of similar changes to the Boulder design conducted on a 5-inch hydraulic model at Boulder Dam in 1938.

When the proposed modification was tested and the data transferred to prototype by using pressure factors, based on the total model head, expressed as a ratio of the head differential from a piezometer to the control at the exit to the total head differential from a point one diameter upstream to the control, the pressures in the region of the seat on both the needle and the nozzle were found to be positive. Although the magnitude decreased and became very small as the needle approached the closed position, the pressures at all points remained positive (figure 2B). Cavitation, therefore, should not be present on the modified design.

To ascertain the effect of the support ribs on the pressures on the needle and the nozzle and on the valve capacity, tests were made with and without one of the ribs. No effect was observed, and the rib was omitted for the remainder of the tests.

Upon completion of the pertinent studies, tests were conducted to ascertain the necessity for constructing the intricate tips of needle valves for aerodynamic tests. The tip of the operating needle was removed, making it a 36° 22' cone (test 3, figure 2A). When this change did not influence the pressures or the capacity, the end of the needle extending beyond the end of the nozzle, with the valve fully open, was removed (test 4, figure 2A). As this produced no change, an additional portion of the valve needle (1 inch, measured along the slope) was removed (test 5, figure 2A). No perceptible change was recorded; thus it was concluded that construction of the intricate needle tips on aerodynamic models of needle valves is not essential unless pressures on them are required for preparing thrust diagrams.

6. Calibration of the modified design. The reliability of air tests in calibrating hydraulic devices, when care is taken to have conditions representative of the prototype, has been verified by tests in the hydraulic laboratory; hence the proof that the results from air tests are as reliable as those from hydraulic tests was not a part of this study.

The quantity of air passing through the model was measured by an orifice located on the intake of the air blower. The quantity of air was computed by using the equation

$$Q = CA\sqrt{2gh}$$

where

- Q is the quantity of air in cubic feet per second,
- C is the orifice coefficient (0.60 in the case of an intake orifice with a small head differential),
- A is the area of the orifice in square feet,
- g is the acceleration due to gravity, and
- h is the head differential in feet of air.

The coefficient of the valve was then obtained by using the equation

$$Q = C_v A\sqrt{2gh_t}$$

where

- Q is the quantity determined as explained above,
- C_v is the coefficient of the valve,
- A is the area of the inlet or outlet of the valve, depending upon which it is desired to base the coefficient,

g is the acceleration due to gravity, and

h_t is the total effective head in feet of air one diameter upstream from the valve inlet.

The coefficient was computed for each 10-percent increment of valve opening (figure 20). That for the fully open position, based on the outlet diameter, was 0.63, which checked favorably with the value obtained from tests on the 5-inch model with a nozzle and a needle angle of 36° 22'. In this case, however, the needle tip was a right circular cone, which was not the case with the Alamogordo modification. When the calibration of the modified design for the Alamogordo valve was completed, the tip of the needle was changed to make it a cone having the same angle. This alteration produced no change; so the Boulder data was considered proof of the validity of air model tests. Discharge curves were prepared from these data, considering tunnel and pipe losses to the valve. The values were used as part of a discharge chart for the outlet structure (figure 3).

7. Preparation of calibration chart for outlet structure. Since one of the two valves in the Alamogordo outlet works had incurred little damage, due, no doubt, to infrequent operation at critical openings, the modification of both valves did not seem justified, particularly since it was possible to establish an operating schedule which would enable regulation of the outflow over the entire range of discharge without operating the unaltered valve at the most critical openings. Tests on the 5-inch model at Boulder Dam indicated that pressure conditions were less severe at large openings; thus the schedule of operation and the discharge chart for the outlet structure were prepared on this basis. With this plan, the modified or regulatory valve would be used to release water until the demand exceeded its capacity. When this situation existed, the modified valve would be closed and the unaltered valve, with approximately 23-percent more capacity, would be opened to release the required quantity. Operation of the unaltered valve would thus be limited to openings of 70 to 100 percent (figure 3). When the demand for water increased beyond the capacity of this valve, the modified design would be operated to release the quantity needed until the full capacity of the structure was reached.

A discharge chart, reservoir elevation versus discharge, was prepared for the altered valve only, discharging at various openings; for the unaltered valve only, discharging at 70, 80, 90, and 100 percent open; for the unaltered valve fully open, and the regulating valve at various openings. Trashrack, entrance, bend, friction, and contraction losses were considered in its preparation.

Head losses from the reservoir to the valves were computed for various discharges; and average values for the friction coefficients of the different conduit sizes, K in $h_f = K \frac{V^2}{2g}$, were obtained. Using these, it was possible to write expressions for the total head at the bifurcation from the tunnel to the pipes in terms of the pressure gradient through the pipes and the two valves.

For the modified valve,

$$h_b = \frac{V_p^2}{2g} + K_f \frac{V_p^2}{2g} + \left(\frac{1}{C_m^2} - 1\right) \frac{V_p^2}{2g}$$

For the unaltered valve,

$$h_b = \frac{V_p^2}{2g} + K_f \frac{V_p^2}{2g} + \left(\frac{1}{C_u^2} - 1\right) \frac{V_p^2}{2g}$$

where

h_b = total effective head at bifurcation,

V_p = velocity in 66-inch pipe leading to the valve being considered,

K_f = a friction coefficient assumed constant and equal to the average value for the range of discharge,

C_m and C_u = the discharge coefficients of the modified and the unaltered valves, respectively, for the valve opening in question.

By simplifying and equating these expressions, using $\frac{Q}{A}$ in place of V_p for the particular branch considered, a ratio of Q_m to Q_u is obtained, Q_m being the quantity passing through the modified valve and Q_u that through the unaltered valve.

By expressing both quantities in terms of the total outlet discharge and substituting in the expression for the total head, reservoir surface to center line of the valve,

$$H = K_1 \frac{V_1^2}{2g} + K_2 \frac{V_2^2}{2g} + h_b$$

Where

K_1 = loss coefficient to end of 12-foot section of tunnel,

V_1 = the velocity in the 12-foot tunnel,

K_2 = loss coefficient for 10-foot section,

V_2 = velocity in 10-foot section, and

h_b = total head at bifurcation from either of the two expressions above,

the total outlet discharge was computed for different reservoir elevations. These data were used to construct the outlet discharge chart, (figure 3).

The discharge coefficient for the unaltered valve was estimated by using that obtained from the Boulder valve studies having the same ratio of valve travel to outlet diameter as the Alamogordo valve. The value obtained in this manner was equal to that of the Boulder valve at 97-1/2 percent open, 0.76, or about 0.01 less than that recorded on the 5-inch model at Boulder. Prototype data, giving the ratio of discharge at partial opening as compared with that at full opening, obtained in operating the 72-inch valves at Boulder Dam, were used to establish the flow for partial opening. It is believed that any error resulting from the use of these data in this manner is negligible.

8. Conclusions. That positive pressures will exist throughout the modified valve having equal needle and nozzle angles of 36° 22' is indicated by the results obtained from the aerodynamic model. With such conditions the pitting of the valve needle and nozzle by cavitation should be eliminated. The maintenance of the Alamogordo valve, with the new 36° 22' needle tip and the nozzle exit changed to the sharp-edged type, should be a minimum.

In view of the results obtained from this study it was concluded that similar valves at other Bureau projects can be altered in the same manner to eliminate damage by cavitation, thereby reducing high maintenance costs.

From the tests in which sections of the needle tip was removed, it was concluded that the intricate tip of aerodynamic needle-valve models is not essential in determining the pressure distribution or discharge coefficient of the design unless the pressure distribution on the tip is needed to establish a thrust diagram.

Tests with and without the ribs supporting the upstream end of the needle indicated that such parts have little effect on the pressures and discharge coefficients when obtained by an aerodynamic model.

The capacity of a valve altered in this manner is substantially reduced, and consideration should be given this fact when similar changes are made. The capacity of the Alamogordo valve, with the reservoir surface at elevation 4265, will be reduced from 940 to 765 second-feet by the change, or about 18-1/2 percent.

The discharge chart prepared from this study will serve as a means of determining the outlet discharge when operation of the valves is as outlined in section 7 of this report.

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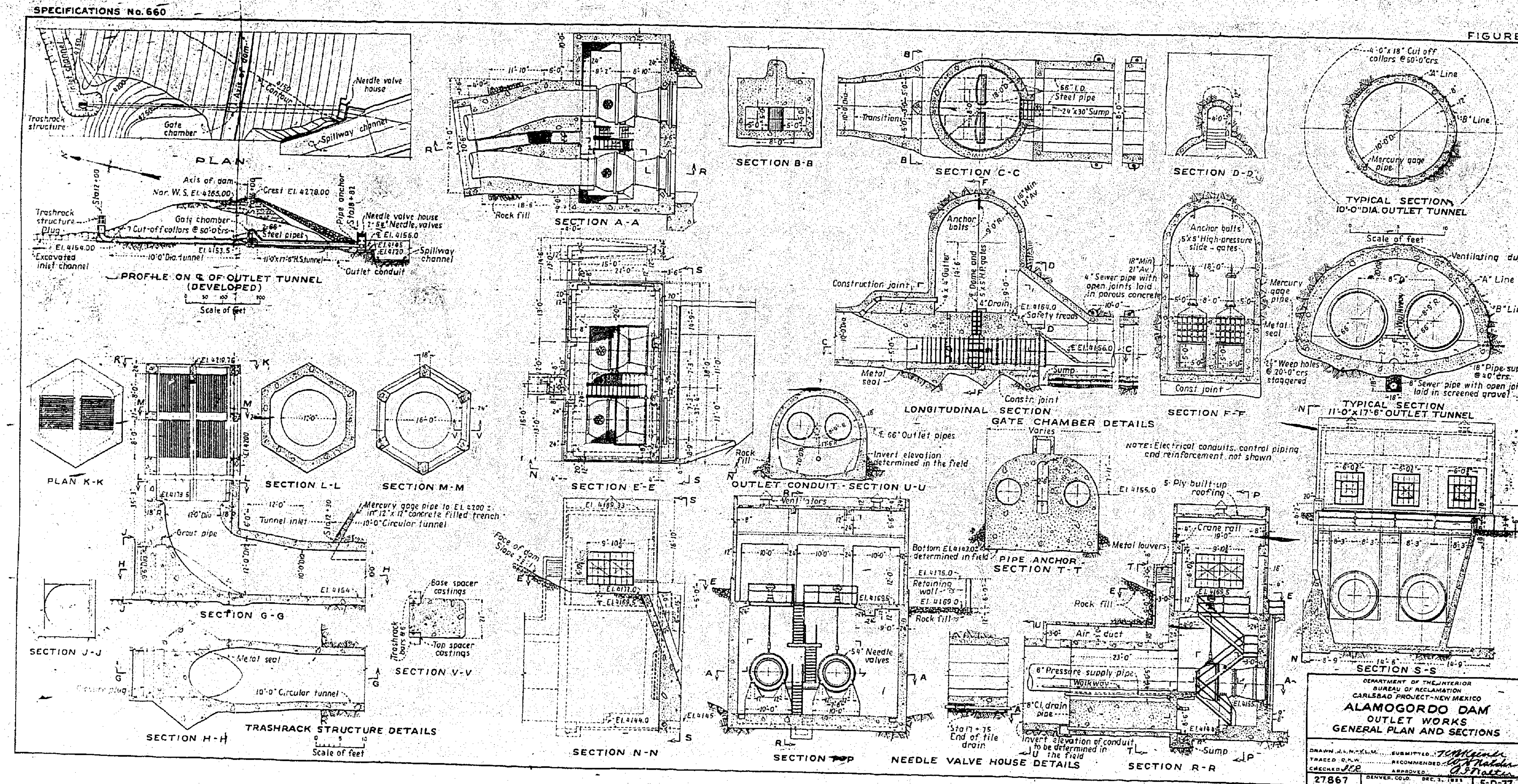

SPECIFICATIONS No. 660
FIGURE 1
PLAN
Trashrack structure
Gate chamber
Needle valve house
Spillway channel
Axis of dam
PROFILE ON ℄ OF OUTLET TUNNEL (DEVELOPED)
Scale of feet
SECTION A-A
SECTION B-B
SECTION C-C
SECTION D-D
TYPICAL SECTION 10'-0" DIA. OUTLET TUNNEL
LONGITUDINAL SECTION
GATE CHAMBER DETAILS
SECTION F-F
TYPICAL SECTION 11'-0" x 17'-6" OUTLET TUNNEL
NOTE: Electrical conduits, control piping and reinforcement not shown
PLAN K-K
SECTION L-L
SECTION M-M
SECTION E-E
OUTLET CONDUIT - SECTION U-U
PIPE ANCHOR - SECTION T-T
SECTION G-G
SECTION J-J
SECTION V-V
SECTION H-H
TRASHRACK STRUCTURE DETAILS
SECTION N-N
SECTION P-P
NEEDLE VALVE HOUSE DETAILS
SECTION R-R
SECTION S-S
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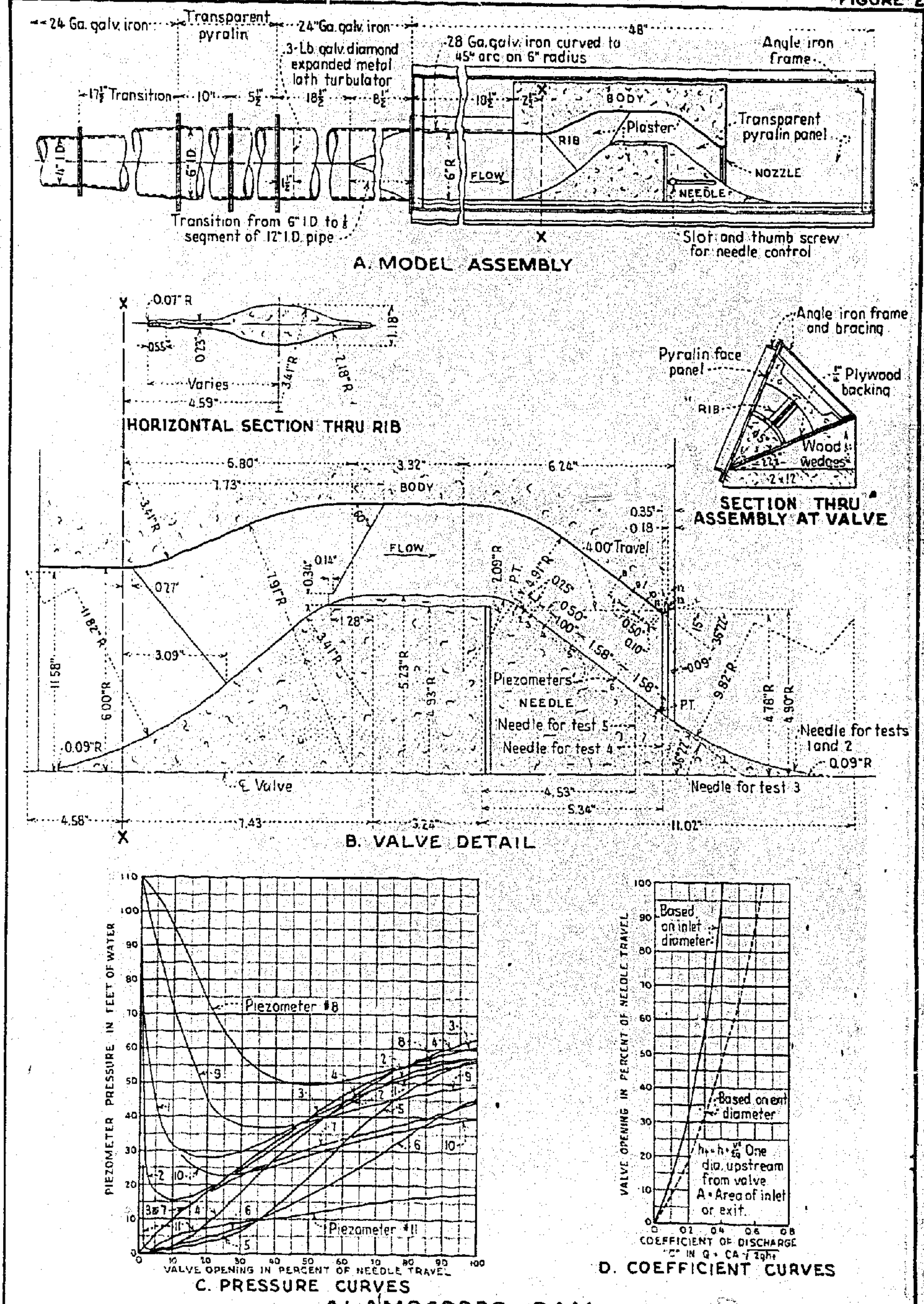


ALAMOGORDO DAM

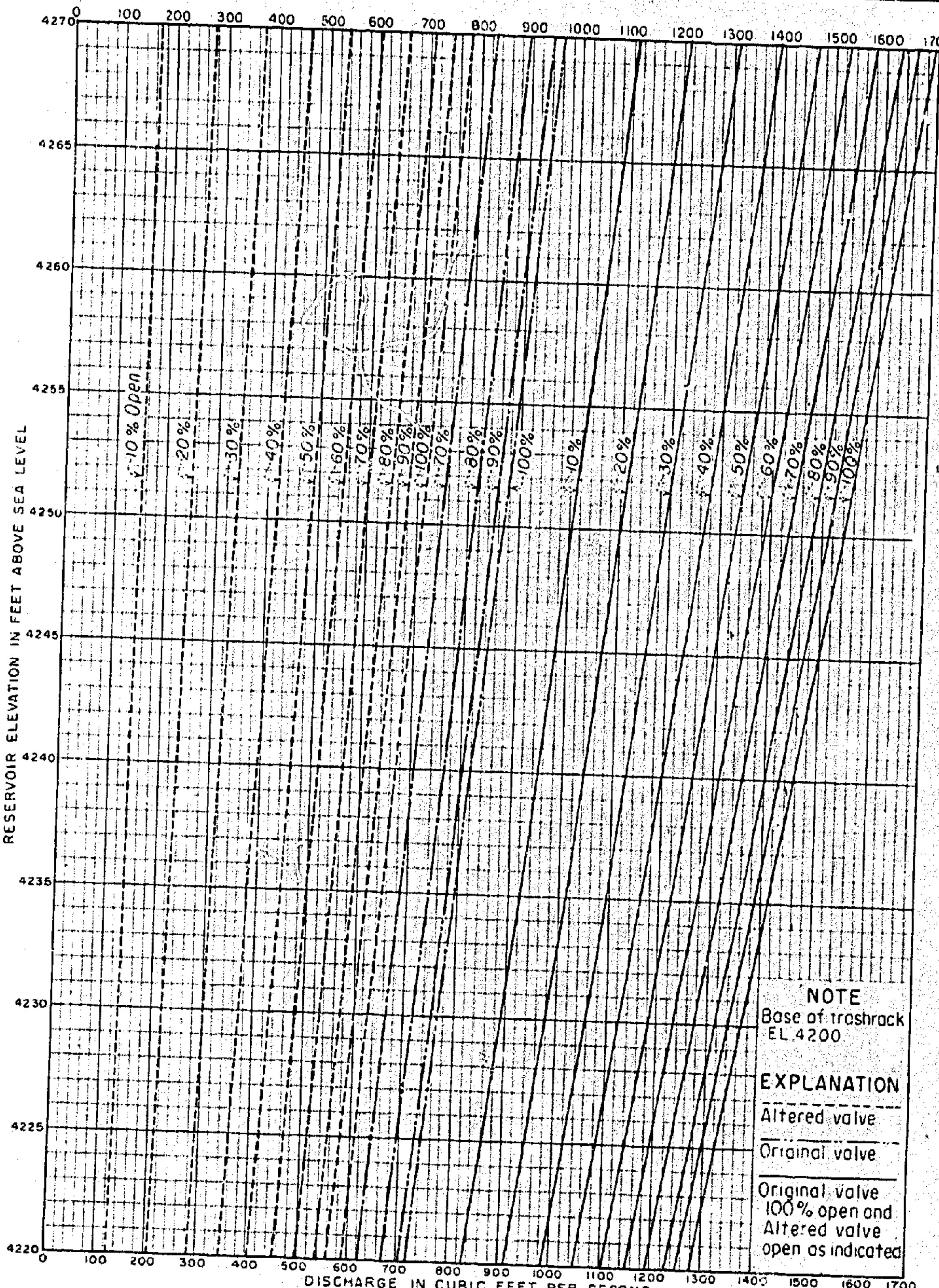
AERODYNAMIC STUDIES OF MODIFIED 54" NEEDLE VALVE

MODEL SCALE 1:5¼

MODEL DETAILS, DISCHARGE COEFFICIENTS, AND PRESSURE DISTRIBUTION

HYP-147

FIGURE 3



NOTE: Curves for altered valve based on 1:5½ air model tests, other curves based on valve tests at Boulder Dam

ALAMOGORDO DAM

DISCHARGE CURVES

54-INCH NEEDLE VALVES