UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF THE MAIN CANAL OUTLET WORKS NAVAJO INDIAN IRRIGATION PROJECT, NEW MEXICO

Report No. Hyd-536

Hydraulics Branch
DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

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ABSTRACT

Hydraulic model studies showed the original design of the underground stilling basin and chute for the Navajo Main Canal headworks structure to be unsatisfactory. A number of modifications were developed to assure good energy dissipation, freedom from violent backwater flows against the 2 radial gates, and smooth flow conditions into the 17-1/2-ft, 2-mi-long horseshoe tunnel. Heads varied from 15 to 126.5 ft and discharges from 0 to 1800 cfs. Use of 15-deg sloping chutes extending from gate chamber invert to basin floor instead of parabolic chutes eliminated most heavy surging. The horizontal gate chamber inverts were joined to the chutes with 16-ft radii of curvature. The change in floor alinement occurred in the high pressure region upstream from the gate seats. A basin length of 89 ft provided the necessary energy dissipation. Vertical curtain walls to prevent excessive backflow against downstream sides of the radial gates were placed with bottoms about 7 ft above the chutes and faces almost 31 ft downstream from the projected intercept of horizontal gate chamber inverts and the chutes.

Maximum flows at minimum reservoir elevation are attained by allowing a part of the flow to overtop the cutain walls. Four large baffle piers effectively turned the flow upward and increased energy dissipation rate without danger of cavitation. An underpass-type wave suppressor located at downstream end of the basin provided excellent flow conditions in the downstream tunnel.

DESCRIPTORS-- *stilling basins/ *radial gates/ laboratory tests/ hydraulic jumps/ research and development/ gate seals/ cavitation/ baffles/ hydraulic gates and valves/ *energy dissipation/ instrumentation/ hydraulics/ canals/ high pressures/ discharges/ hydraulic structures// transitions/structures// wave velocity/ piers/ model tests/ hydraulic models/ chutes/ tunnels

IDENTIFIERS-- *headworks/ curtain walls/ chute blocks/ backflows/ center piers/ design modifications/ horseshoe transitions/ *underground stilling basins/ wave suppressors/ spoilers

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Report No. Hyd-536
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PURPOSE

Model studies were made to obtain head discharge relationships and to develop a radial gate controlled, underground stilling basin that would provide satisfactory energy dissipation, smooth flow in the downstream tunnel, and trouble-free operation.

CONCLUSIONS

1. The performance of the initial basin was unsatisfactory. Large, objectional surges occurred in the downstream portion of the basin and in the horseshoe tunnel (Figure 9).

2. The initial center dividing wall, extending the full length of the basin to the start of the horseshoe transition, caused lateral differential heads to exist as the flow reached the downstream end of the basin, and a swinging motion was imparted to the flow in the tunnel.

3. The initial parabolic chute did not provide a stable hydraulic jump (Figure 9). Upstream and downstream movement of the toe of the jump caused heavy surging in the stilling basin, and backflow struck the downstream side of the radial gates.

4. Raising the invert of the gate chamber from elevation 5969 to elevation 5975, and using a longer parabolic chute did not eliminate the unstable jump nor the backflow onto the radial gates.

5. Elimination of the chutes by using 12-foot vertical drops extending to the basin floor just downstream from the radial gates produced very unstable and undesirable flow conditions (Figure 11).

6. The use of 15° sloping chutes elimated most of the heavy surging that was characteristic of the flow with either parabolic chute (Figure 18). Although reduced in intensity, backflow still struck the radial gates.

7. The use of a 16-foot radius of curvature to join the gate chamber horizontal invert to the 15° sloping chutes, and starting the curvature in the high-pressure region upstream from the radial gates, eliminated cavitation pressures and provided a well-directed jet along the chute (Figures 14 and 15).

8. Four baffle piers located 48 feet downstream from the chutes effectively turned a portion of the flow upward to aid in forming the jump (Figure 19B). The pressures acting on the baffle piers are sufficiently high to prevent cavitation damage under normal operating conditions (Figure 21). However, single-gate operation at high heads with discharges above 900 cubic feet per second (cfs) will result in cavitation pressures and should be avoided.

9. Vertical curtain walls placed a short distance downstream from the gates, with the wall inverts far enough above the chute to allow passage of the jets, prevented backflow from striking the downstream sides of the radial gates (Figure 18).

10. Within design discharge requirements and at all gate openings, the jets resulting with reservoir heads between 126.5 and 36 feet sweep the backwater free of the gates and the gates operate under free discharge conditions (Figure 18).

11. With reservoir heads below 36 feet, the flows from the gates become intermittently and then completely submerged (Figure 19A).

12. To pass the maximum discharge at the minimum reservoir head, the curtain walls must be overtopped (Figure 19A). A higher head loss than that calculated for the upstream conduit, transitions, and gate chamber will result in a discharge lower than 1,800 cfs at the minimum reservoir head. This occurrence is not expected.

13. An underpass wave suppressor with a solid upstream headwall and a slotted horizontal surface produced the necessary, almost smooth, water surface in the downstream tunnel (Figures 18 and 22).

14. Balanced gate operation will provide the best basin performance and should be used for high-velocity, high-discharge releases.

15. Regulation of the flow by the fixed-wheel gates located upstream from the radial gates should be restricted to low reservoir discharges or to emergency situations because severely subatmospheric pressure conditions may occur along the curved invert between the gate chambers and the 15° sloping chutes.

ACKNOWLEDGEMENT

The results achieved through this test program resulted from the cooperation of the Canals Branch, the Mechanical Branch, and the Hydraulics Branch of the Chief Engineer's Office in Denver.

INTRODUCTION

The Navajo Indian Irrigation Project is located in the northwestern corner of New Mexico (Figure 1). The headworks structure (Figures 2 and 3), the subject of this report, will draw water from the southwest side of the reservoir created by Navajo Dam. The structure will pass discharges up to 1,800 cfs with reservoir heads varying from 15 to 126.5 feet. Control will be maintained by two 9-foot-wide by 12-foot-high radial gates which discharge into an underground stilling basin.

Two 9- by 12-foot fixed-wheel gates will be located just upstream from the radial gates to provide for emergency closures and to isolate the radial gates for normal maintenance work. A transition on the downstream end of the stilling basin will direct the flow into a tunnel.

The tunnel will be approximately 2 miles long and may be either an 18-foot-diameter circular tunnel or a 17-1/2-foot horseshoe tunnel. A Parshall flume will be located at the downstream end of this tunnel to measure the discharge. To increase the accuracy of the flume measurements, a smooth, relatively wave-free water surface must be provided in the tunnel. An upslope just downstream of the first tunnel section will cause a backwater effect in the tunnel at all but the maximum discharge (Figure 7).

Releases through the headworks will supply water to approximately 110,000 acres of irrigable land. The water will travel through an intricate distribution system approximately 150 miles in length. The system will be composed of tunnels, siphons, and lined and unlined canal reaches. Approximately 75 percent of the land will be supplied by gravity flow and the remaining portion by pumped flow.

THE MODEL

The tests were conducted in a 1:16 scale model of the outlet works (Figures 4, 5, and 6). The model included a 13-1/2-inch-inside-diameter inlet pipe 16 diameters long, a 3-foot-long, round-to-rectangular transition, the gate chamber which included slots for the fixed-wheel gates, two radial gates (9- by 12-foot prototype), a divided stilling basin, a transparent plastic transition from the basin to the downstream horseshoe tunnel, 6 diameters of horseshoe tunnel, and a tailgate for regulating the water surface elevation.

Flow was supplied by the main laboratory pumping system through calibrated 4- and 6-inch Venturi meters.

The radial gates were made of sheet metal with gages chosen to correspond in scale to the approximate dimensions of the prototype gates (Figures 4 and 6). The bottom surface of each gate was equipped with a 1/16-inch-thick solid rubber seal. The side and top seals were attached to the gate seat structure. The side and top seals were made of hollow refrigerator door rubber gasket material and were air inflatable to simulate pressurized seals on the prototype. After repeated seal ruptures, solid neoprene seals were used in place of the inflatable seals. Two stem lifting screws controlled the position of the gates.

The gate chamber was made of brass plate and was flanged to fit the rectangular end of the transition and the stilling basin (Figure 5).

The right side of the stilling basin and the downstream transition were made of transparent plastic to provide visual inspection and to permit obtaining photographic records of flow conditions. The basin was contained in an open, rectangular box. Chutes leading from the gate chamber to the basin floor were separately fabricated and inserted within the main box.

The model, as initially designed, conformed in most details to the first prototype design. Later modifications to the model and to the prototype resulted in several minor deviations. The configuration of the final gate chamber roof and the roof of the model between the fixed-wheel gates and the radial gates differed as shown in Figure 17. The 19-foot diameter of the initial model horseshoe tunnel on the downstream end of the basin was retained as compared to the 17-foot 6-inch diameter selected after the maximum discharge requirement was reduced from 2,120 to 1,800 cfs. The arched roof of the stilling basin was not installed for final testing because previous tests showed that no adverse effects resulted from its use.

INSTRUMENTATION

Piezometers were placed in the model at various locations to obtain desired pressure head readings and to detect adverse pressure conditions. Most of the pressure measurements were made with single-leg, water-filled manometers. Diaphragm-type pressure cells and electronic recording equipment were used to obtain instantaneous pressures at critical piezometer locations.

The upstream head was measured with a single-leg water manometer set so that the zero head level was at the gate invert elevation. The column was attached by a ring of four piezometers to the circular inlet pipe

1 diameter upstream (Station 4+18.50) from the round-to-rectangular transition.

Records of water surface conditions in the downstream tunnel were obtained with a capacitance-type wave probe and electronic recording equipment.

INVESTIGATION

Most of the tests were made with the most severe operating conditions that could occur. These conditions were maximum discharges for either double- or single-gate operation at maximum head. Tests were also made at lesser discharges and heads. The tailwater elevation was adjusted to conform to Curve A supplied by the Division of Design (Figure 7).

During the course of the study, the maximum design discharge was changed from 2,120 to 1,800 cfs. This changed the operating range of Froude numbers from initial values between 14.4 and 1.36 to final values between 10.7 and 2.16.

Performance of the basin as initially designed was unsatisfactory (Figure 9). The jump was very unstable and large objectional oscillations or surges from the jump carried into the downstream tunnel. Also, intermittent heavy backflow struck the downstream sides of the radial gates. A number of modifications to the basin were made to correct these operating deficiencies.

Chute Design

Parabolic Chute with 6-foot Vertical Drop. --The original chute was of parabolic shape and followed the equation $x^2 = 530\ y$. The elevation change from gate invert to basin floor along the parabolic chute was 6 feet (Figure 2). The position of the toe of the jump for heads at or above the normal reservoir water surface was very unstable. The toe occurred along the nearly horizontal portion of the chute and slight changes in head resulted in considerable upstream and downstream movement of the toe of the jump. The jet did not continually penetrate to the full depth of the basin pool and this resulted in variations in the sweepout force, or time rate of change of linear momentum. These characteristics resulted in heavy surges which carried into the downstream portion of the basin and into the tunnel (Figure 9). The magnitude of the surging was sufficient to cause the tunnel to intermittently flow full.

Horizontal Floor Extending from Gates through Basin.--A horizontal floor extending from the gates through the stilling basin at elevation 5969 was placed in the model in an attempt to provide a more stable jump (Figure 10). This eliminated the use of a chute entirely. However, the modification was unsatisfactory because insufficient tailwater was available without the addition of large baffle piers to confine the jump to the basin.

Parabolic Chute with 12-foot Vertical Drop.--In an attempt to eliminate the backflow onto the radial gates, the gate structure and upstream tunnel were raised the maximum allowable distance of 6 feet (Figure 4C). With the head on the gate invert decreased by 6 feet, the equation of the parabolic chute was modified to $x^2 = 506\ y$ (Figure 3).

Upstream and downstream movements of the toe of the jump were greater with this design than with the previous parabolic design. The horizontal length of the chute was approximately 21-1/2 feet greater than the initial parabolic chute, providing a greater length and depth for movement of the toe of the jump. As with the previous chute design, the jet did not consistently penetrate the full depth of the basin, causing a variation in the sweepout force. With reservoir heads of approximately 80 feet, the toe of the jump had a total upstream and downstream movement of 45 feet. Large surging waves appeared to occur at resonance in the basin and occasionally overtopped the walls of the model or reached a height of 40 feet (prototype) above the basin floor. The resonance effect also caused extremely heavy back surges to strike the downstream sides of the radial gates.

Horizontal Floors with 12-foot Vertical Step.--Studies were made of the flow conditions resulting from a 12-foot vertical drop just downstream from the gate lower seal plate. An extremely unstable type of flow resulted, similar to that reported earlier by Bakhmetaff1/ and observed by Colgate2/. With the tailwater lowered 1.6 feet below normal, the flow from the gates was directed downward into the basin (Figure 11A). However, with normal tailwater the flow was redirected, first horizontally (Figure 11B), and subsequently upward (Figure 11C). With identical gate settings, flow from one gate was occasionally directed downward and flow from the other was directed upward (Figure 11D).

15° Sloping Chute.--In the designs with parabolic slopes the toe of the jumps moved upstream and downstream along the curvature where the slope varied from 0° to approximately 6°. By making the chute considerably steeper at the upstream end, movement of the jump would be greatly restricted because any incremental upstream and downstream movement would involve an appreciable change in elevation. Better,

1/Numbers refer to items in bibliography.

smoother flow conditions would then result. Therefore, a slope of 15° was tested. With this design the movement of the jump was much less than observed with other designs, the surge waves were considerably reduced in size, and the jet penetrated to the full depth of the basin at moderate and high heads. Records of chute and floor pressures are contained in Figure 12. The records indicate rapidly fluctuating pressures on the chute in the neighborhood of the curtain wall. However, these pressures do not go below atmospheric more than a small percentage of the time and never reach the cavitation region. No damage is expected from the rapidly fluctuating pressures.

Center Dividing Wall

The original design contained a 188-foot-long center wall that extended the full length of the basin and into the downstream transition. With intense, random surging in the stilling basin, and with the surging on either side of the center wall not always in phase, head differentials often existed at the downstream end of the wall. These head differentials imparted a lateral swinging motion to the flow as it entered the tunnel and caused waves sufficiently high to intermittently seal the tunnel. The same swinging motion existed for single-gate operation.

To eliminate the swinging motion in the tunnel, the length of the wall was reduced to 52 feet. With the shorter wall, the flow in the downstream portion of the basin was more evenly distributed and no swinging motion was visible. The more even distribution also existed for single-gate operation. A large 45° chamfer was provided on the downstream end of the wall to prevent flow from clinging to the surface and causing adverse pressure conditions. Pressure cell traces obtained for selected positions on the chamfer showed that no adverse conditions existed (Figure 13).

A structural change to the roof of the prototype basin was necessitated by the shorter center wall. With the initial design, the center wall was utilized as a supporting member for a flat roof. With the wall shortened, the increased span required an arched roof.

Tunnel Transition

Flow conditions in the square-to-horseshoe transition just upstream of the tunnel were unsatisfactory. The transition contained intersection lines which extended from the top corners at the upstream end to the mid-height of the conduit at the downstream end (Figure 9). The flow near the water surface was restricted by the relatively abrupt transitioning to the extent that the air passage in the crown of the transition was nearly blocked off. The use of the arched roof over the basin made possible a more gradual transition which provided a smoother passage and more satisfactory flow conditions (Figure 18).

Pressures on Gate Chamber Walls Near Seals

Pressure data were obtained on the gate chamber walls just upstream from the gate seals (Figure 8) to study possibilities for venting or relieving seal actuating pressures that might overextend the portions of the seals that become exposed as the gates are raised. The data were obtained at a discharge of 2,120 cfs and show that locations near the floor close to the seals will be subjected to significantly lower pressures than surrounding areas whenever appreciable flows are occurring through the gates.

Gate Chamber Invert Modifications

To prevent flow separation and possible cavitation pressures at the point of intersection of the horizontal invert of the gate chamber and the 15° chutes, the slope was extended upstream from the gates into the high-pressure region. To determine the optimum position and shape for the intersecting point, two piezometer-equipped 12-inch-high (3/4-inch model) false floor sections were utilized. In one section the change from the level floor of the gate chamber to the 15° slope of the chute occurred abruptly (Figure 14A). In the other section, the horizontal and sloping sections were connected by a 16-foot radius curve (12-inch model) (Figure 14B). By placing special shims under the sections, the sections and hence the point of intersection, was moved upward and upstream in increments (Figure 14A). Each shim was 4 inches thick (1/4-inch model) and the addition of a single shim moved the intersecting point upstream approximately 15 inches (0.933-inch model). Readings of pressures occurring along the floor were taken for each shape and shim combination throughout the range of reservoir heads and gate openings (Figure 15). From these data, a 16-foot radius of curvature was selected to join the horizontal gate invert with the 15° sloping chute. The projected intercept of the two surfaces was located 41.19 inches upstream from, and 11 inches above, the new gate seal point. With this configuration, positive pressures resulted throughout the curvature for all operating conditions (Figure 15H).

Backflow on the Radial Gates

Backflow of water against the downstream sides of the radial gates presented a difficult problem because the elevation of the gate inverts was only 2.68 feet (prototype) above the invert of the upstream portion of the horseshoe tunnel and was considerably below all tailwater elevations resulting from tunnel friction and the backwater effect of the Parshall flume located at the downstream end of the tunnel. The dynamic forces of the backflow against the gates were undesirable because they would cause pounding on the gates and excessive wear and loading on the seals, gates, gate-operating equipment, and gate trunions. The gate structure and upstream tunnel could not be raised further because placing them at any higher elevations would reduce the capacity of the system particularly at the lowest operating reservoir levels. The decision was made to develop curtain walls[4] which would allow the passage of the jets under the walls, and would restrict movement of the tailwater toward the gates (Figures 16 and 18).

Curtain Wall Location. --The selected location for the curtain walls was a compromise to obtain satisfactory flow conditions for high-head and for low-head discharges. For high-head discharges and thinner jets, a curtain wall position slightly above the jet provided excellent flow conditions. However, with intermediate- and low-head discharges, the opening between the chute and the curtain wall became the control point, and the maximum discharge could not be passed. Raising the wall resulted in an improvement of the low-head flow conditions, but impaired the higher head flow conditions by allowing flow to pass from the downstream side of the curtain walls to the upstream side between the jets and the lower face of the walls. To eliminate as much as possible the upstream movement of the flow and to maintain the control point at the gates for all but extremely low-velocity flows, the curtain walls were placed 6 feet, 11-9/16 inches above the chutes and 30 feet, 10-3/8 inches downstream from the projected intercept of the horizontal gate chamber inverts and the 15° chutes (Figure 16). The top of the walls was placed at elevation 5987.55 so that overtopping could occur in order that the outlet works could pass 1,800 cfs at a 15-foot reservoir head (Figure 19A). With this configuration and high-head flows, occasional overtopping of the wall in the upstream direction results; however, the magnitude is slight and the flow does not reach the gates (Figure 18).

Shape of the Bottom of the Curtain Walls. --The inital shape of the bottom of the curtain wall was horizontal with sharp 90° corners at the upstream and downstream wall faces. A low-pressure area existed immediately downstream from the upstream corner of the wall along the horizontal bottom. By means of dyes, flow from the downstream side of the wall was observed to move around the downstream corner of the wall in an upstream direction into the low-pressure area. The momentum was sufficient to carry the flow past the upstream face of the wall where it impinged on the jets from the gates. To improve the flow conditions, the bottom of the wall was cut at a 15° angle to parallel the sloping chute. This greatly reduced the amount of flow moving from the downstream side to the upstream side of the wall, and hence the amount of water impinging on the jets from the gates. Instantaneous pressures obtained at selected points along the bottom were found to rapidly fluctuate and to reach one-half atmosphere subatmospheric. In an attempt to eliminate the rapidly fluctuating pressures, a 195°, 6-inch-radius lip was placed on the downstream lower side of the wall to act as a spoiler (Figure 16). Instantaneous pressure traces revealed that a stabilizing effect resulted from this modification. The 6-inch-radius lip was then replaced by a larger 195°, 12-inch-radius lip. Instantaneous pressure traces still showed rapidly fluctuating pressures (Figure 20); however, the lowest pressures were sufficiently high to prevent cavitation and ensuing damage.

Chute Blocks

Chute blocks were used in the initial design (Figure 2); however, they were ineffective. Even with maximum reservoir heads the jets seldom penetrated to the position of the chute blocks at the downstream end of the parabolic chute. The chute blocks used with the subsequent parabolic chute design also were ineffective. With the 15° sloping chutes, chute blocks are undesirable because they help break up the high-velocity jets with the result that greater depths of water would occur in the upstream portion of the basin. This would cause greater backflows against the gates at most operating conditions and overtopping of the curtain walls from downstream when maximum flows were passed at high reservoir elevations. For these reasons, chute blocks are not recommended for the final design (Figure 16).

Baffle Piers

The initial stilling basin contained four large baffle piers at the downstream end of the basin (Figure 2). The jump formed approximately 75 to 100 feet upstream from the baffles; and thus, the baffle piers were completely ineffective. Much better results were obtained with baffle piers placed nearer the upstream end of the basin. For initial pressure evaluation, the baffle piers were located 16 feet downstream from the end of the chutes. Instantaneous pressure traces showed that severe cavitation pressures existed on the baffle piers at this location. The piers were moved downstream to a point 32 feet from the end of the chute, and additional instantaneous pressures were obtained. The traces revealed an improvement in the pressures; however, they were still sufficiently low to cause damage. Further movement of the baffle piers to 48 feet downstream from the end of the chute eliminated the severe subatmospheric pressures on the baffle piers while still maintaining most of their effectiveness (Figures 19B and 21). The baffle piers conform in shape to those specified in Engineering Monograph No. 25 3/; however, they are considerably larger. The piers contained sharp corners so as to increase the turbulence generating capacity and improve the basin performance.

Single-gate operation at high heads and discharges above 900 cfs will result in undesirable pressures on the baffle piers and prolonged operation should be avoided.

Underpass Wave Suppressor

An underpass wave suppressor (Figure 16) was found necessary to provide a smooth water surface in the downstream tunnel. The wave heights in the tunnel with the recommended stilling basin but without the suppressor were 3.2 feet maximum, measured from trough to crest. By adding the recommended suppressor, the wave heights were reduced to approximately 0.8 foot (Figure 22). The undersurface of the recommended wave suppressor was slotted to reduce the size of surges and also reduce the differential head acting on the suppressor.

Gate Calibration

The two radial gates were calibrated for single- and double-gate operation for piezometric heads in the approach tunnel (Station 4+18.50) ranging from 14 to 130 feet (Figures 23 and 24). Discharge curves were prepared in increments of 5 percent to a 30 percent gate opening and in increments of 20 percent from 40 percent to full open. For the calibration the gates were set to the desired opening, as measured vertically from the bottom of the gates to the surfaces of the chutes. A vernier caliper maintained in the vertical position with the aid of a bubble level was used to set the model gate openings. The upstream head on the radial gate was adjusted by a gate valve on the upstream end of the model inlet pipe. The tailwater was adjusted to provide depths specified by the tailwater curve prepared by the design section for the 17-foot, 6-inch horseshoe tunnel with backwater from the Parshall flume and based on Manning's "n" of 0.013 (Figure 7, Curve A).

Operating Restrictions

All normal regulation of the flow will be accomplished with the radial gates. If, however, control of the flow is attempted by the fixed-wheel gates located upstream of the radial gates, the control should be restricted to discharges at low reservoir heads. Higher head operation may cause severely subatmospheric pressure conditions along the 16-foot-radius curve from the horizontal invert of the gate chamber to the 15° sloping chute.

Balanced gate operation will provide the best basin performance and should be used for high-velocity, high-discharge releases.

Single-gate operation at high reservoir heads and discharges above 900 cfs will result in undesirable pressures on the baffle piers and should be avoided for prolonged operation.

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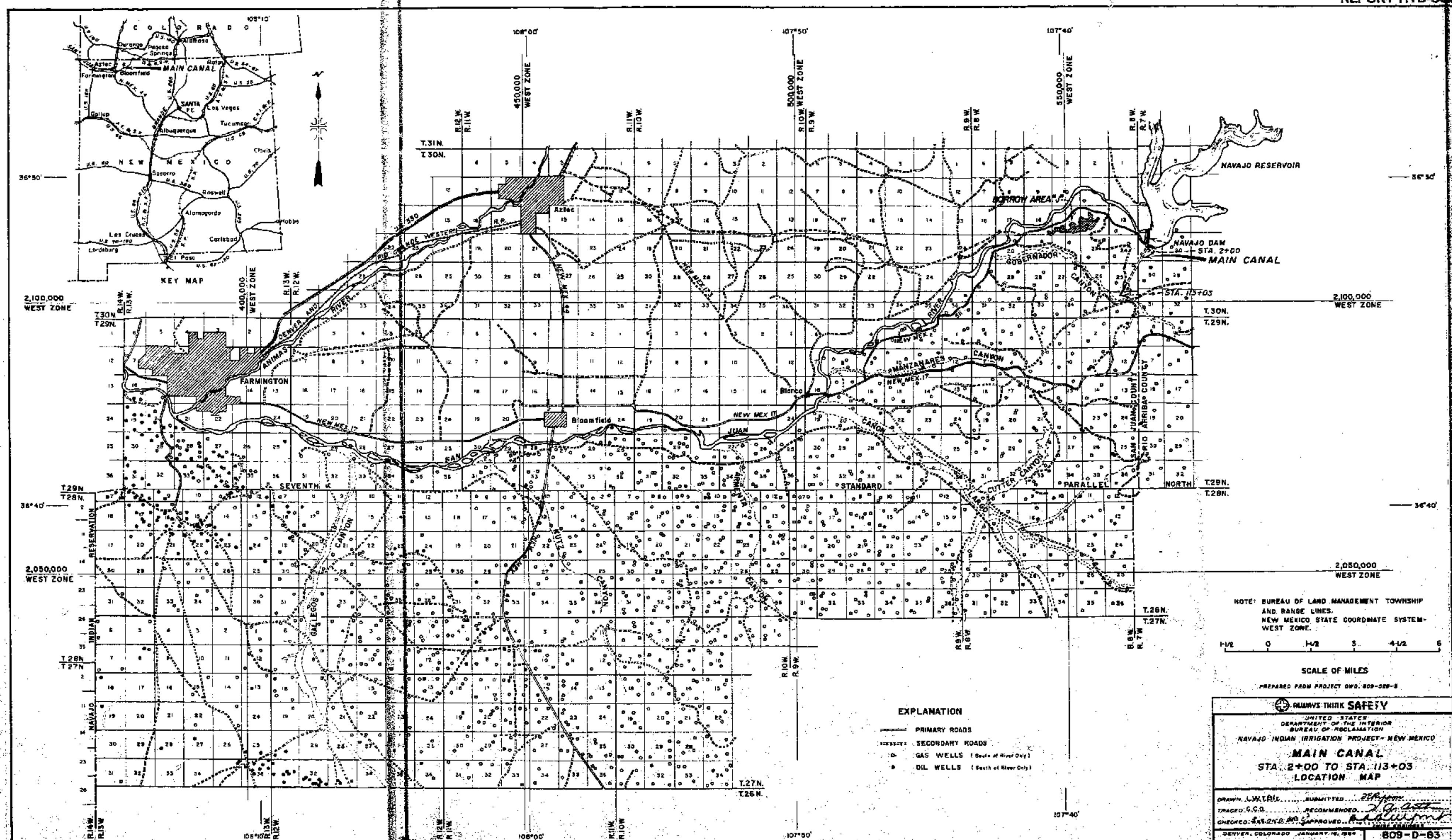
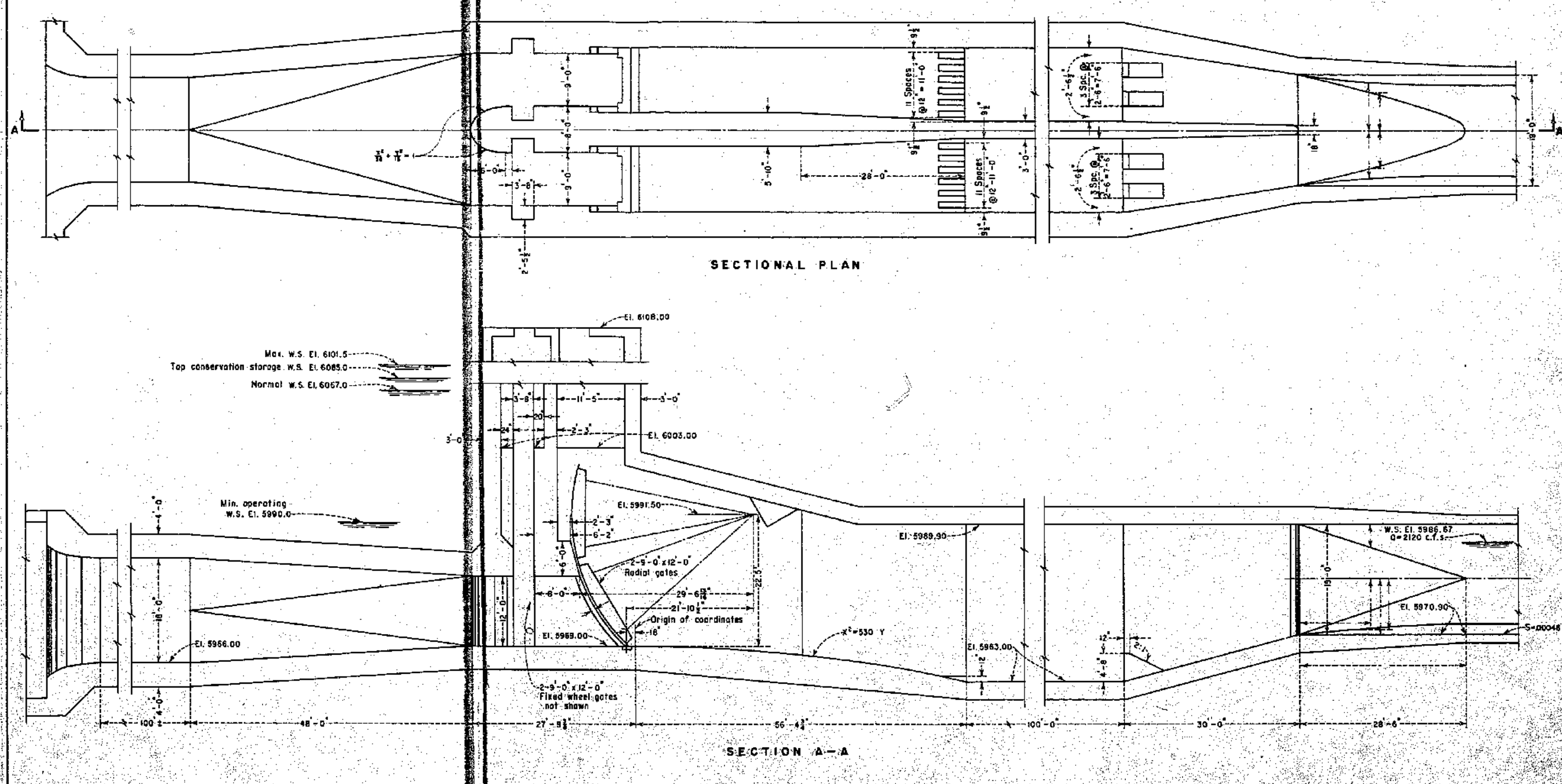
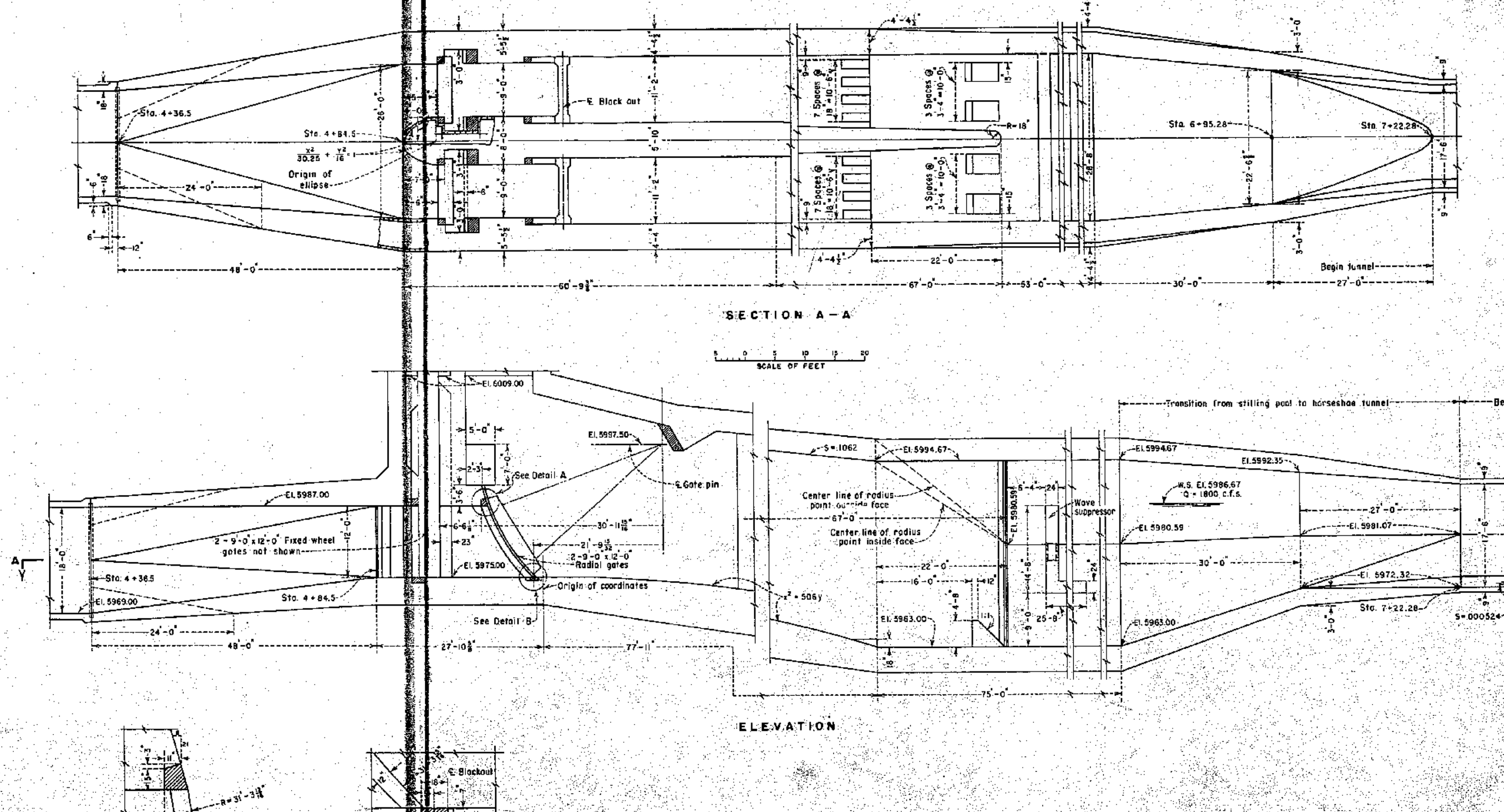

KEY MAP
MAIN CANAL
NAVAJO RESERVOIR
NAVAJO DAM
STA. 2+00
STA. 113+03
FARMINGTON
Aztec
Bloomfield
Blanco
NOTE: BUREAU OF LAND MANAGEMENT TOWNSHIP AND RANGE LINES.
NEW MEXICO STATE COORDINATE SYSTEM-WEST ZONE.
SCALE OF MILES
PREPARED FROM PROJECT DWG. 809-529-8
EXPLANATION
PRIMARY ROADS
SECONDARY ROADS
GAS WELLS (South of River Only)
OIL WELLS (South of River Only)
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
NAVAJO INDIAN IRRIGATION PROJECT - NEW MEXICO
MAIN CANAL
STA. 2+00 TO STA. 113+03
LOCATION MAP
DENVER, COLORADO JANUARY 16, 1964
809-D-83

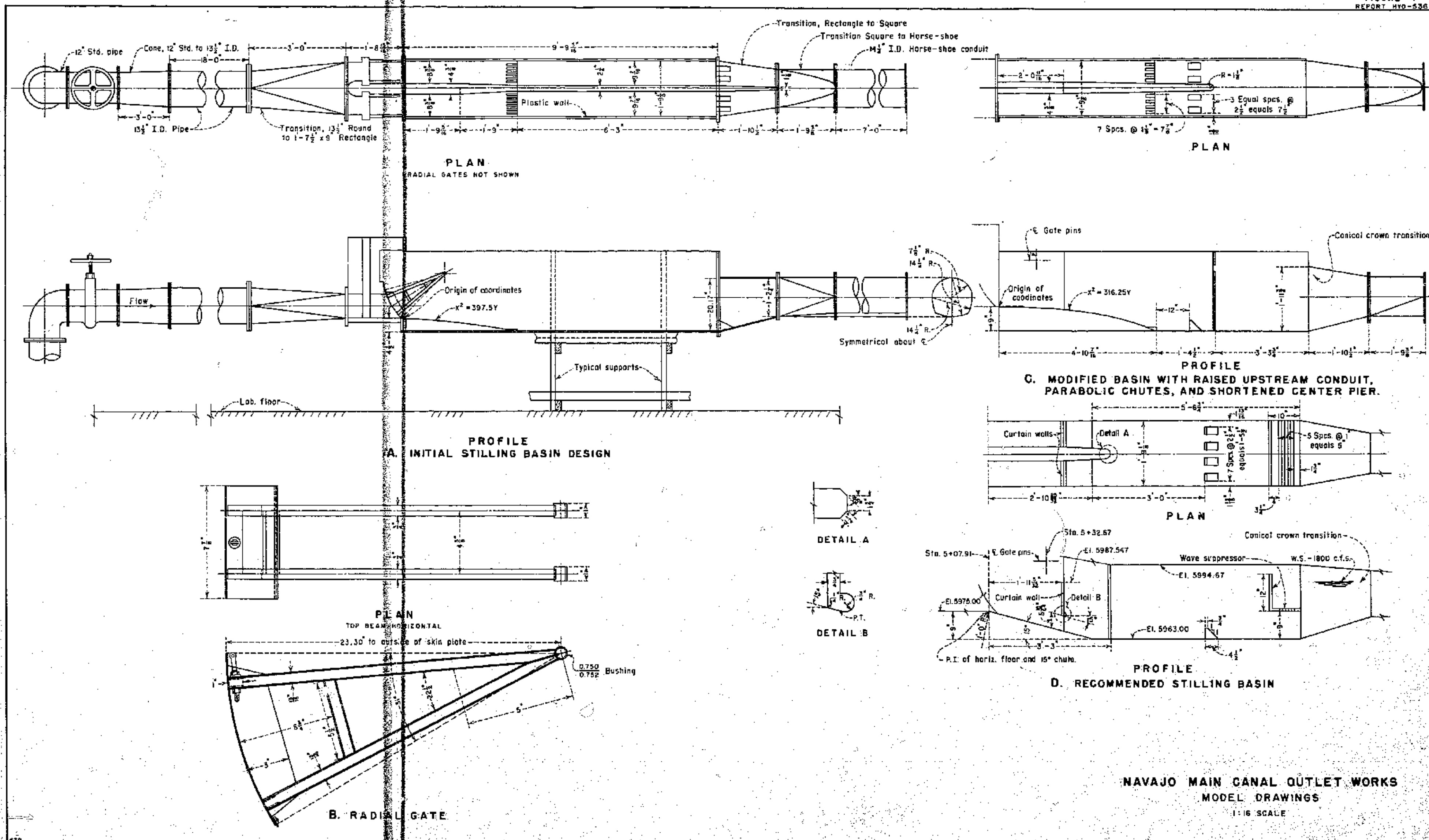
FIGURE 2
REPORT HYD-536



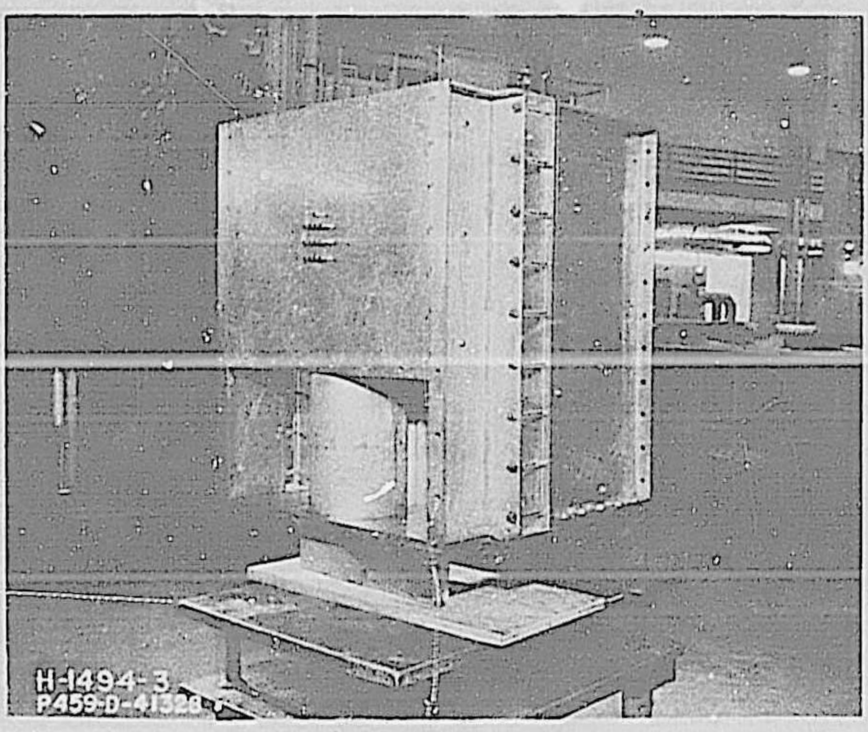
NAVAJO MAIN CANAL OUTLET WORKS
INITIAL STILLING BASIN DESIGN



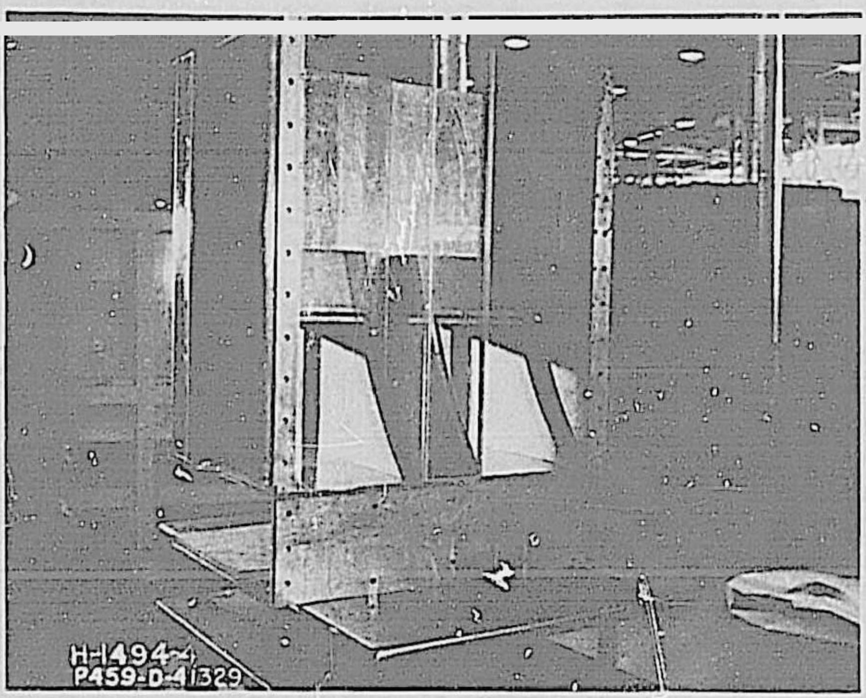
NAVAJO MAIN CANAL OUTLET WORKS
MODIFIED BASIN WITH RAISED UPSTREAM CONDUIT, PARABOLIC CHUTES, AND SHORTENED CENTER PIER



NAVAJO MAIN CANAL OUTLET WORKS
MODEL DRAWINGS
1:16 SCALE



A. Upstream end of gate chamber showing elliptical flow divider and fixed wheel gate slots.

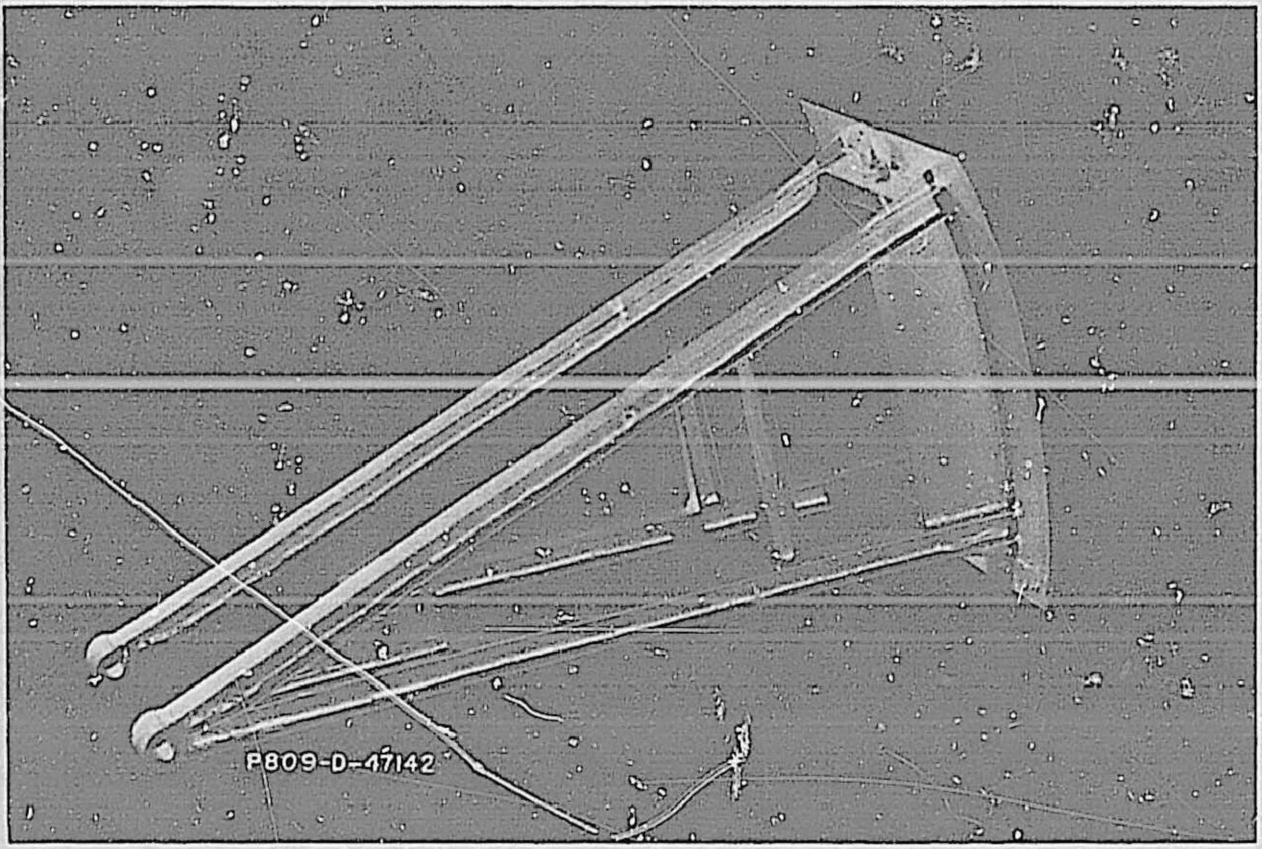


B. Downstream end of gate chamber showing gate seals attached to stationary structure.

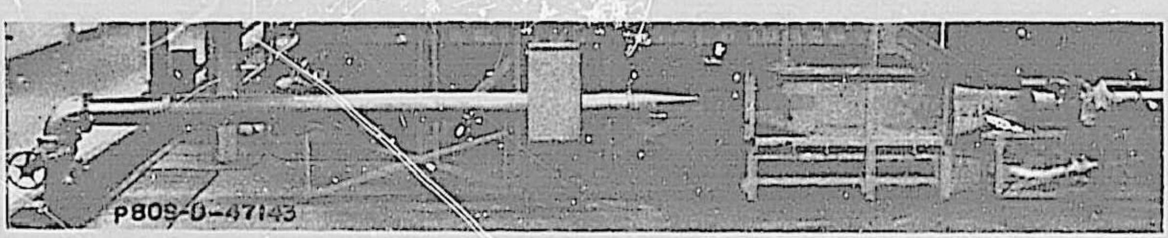
NAVAJO MAIN CANAL OUTLET WORKS

Model gate chamber

1:16 Model



A. Model of 9' x 12' radial gate showing structural details, lifting lug, and bottom seal.

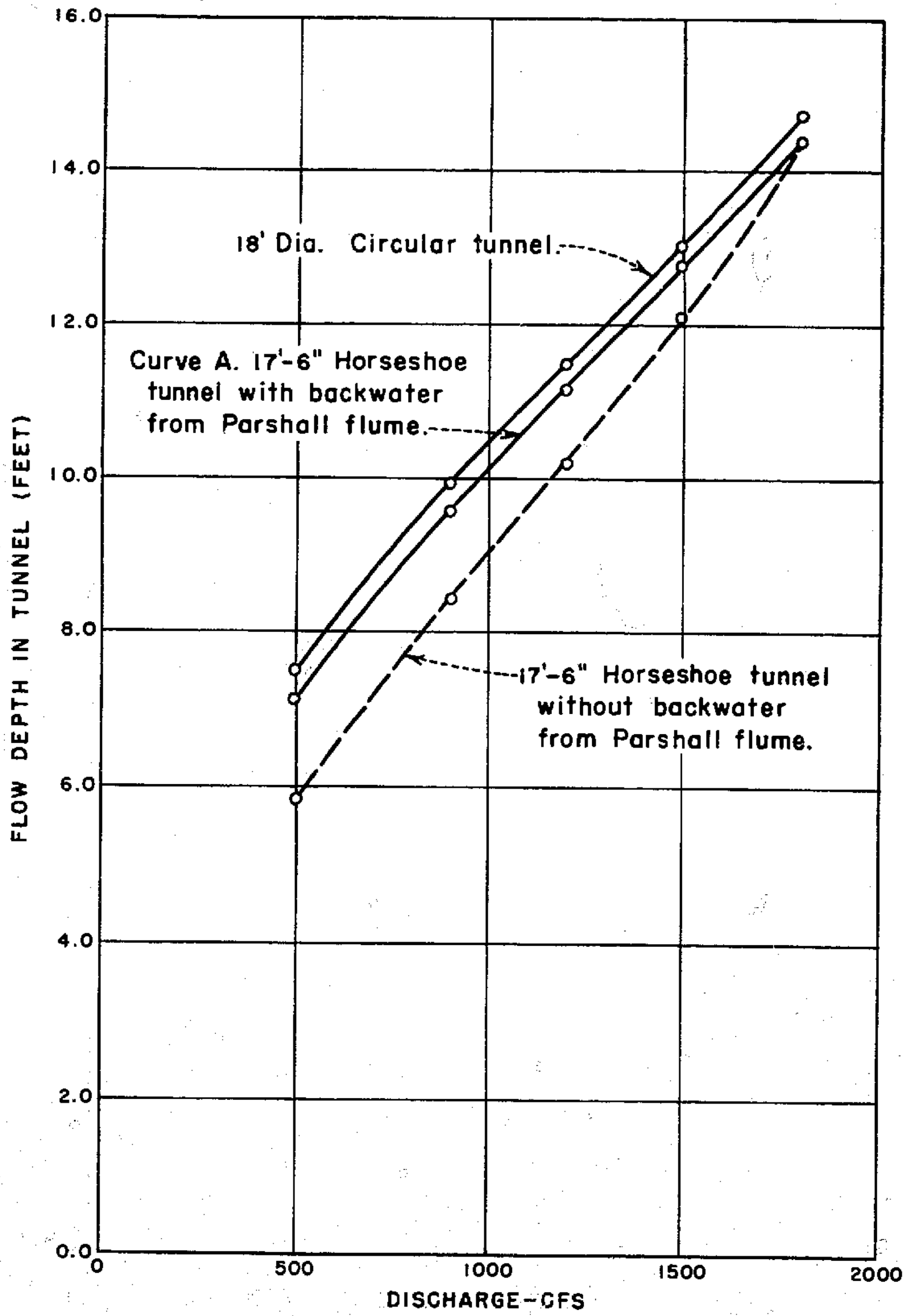


B. Overall view of the model showing inlet piping, gate structure, stilling basin, and horseshoe tunnel.

NAVAJO MAIN CANAL OUTLET WORKS

Radial gate and overall view of model

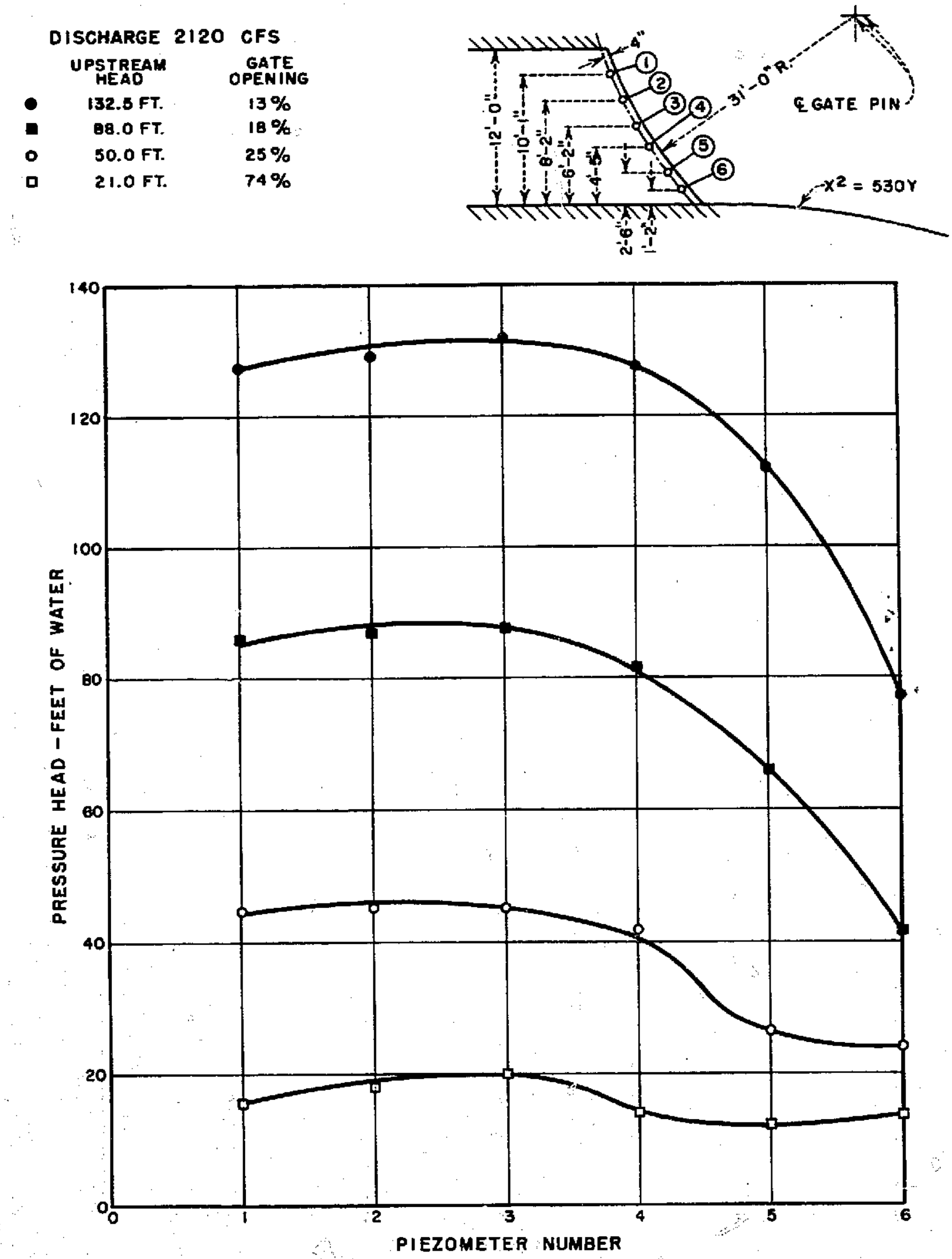
1:16 Model



NAVAJO MAIN CANAL OUTLET WORKS

TAILWATER CURVES

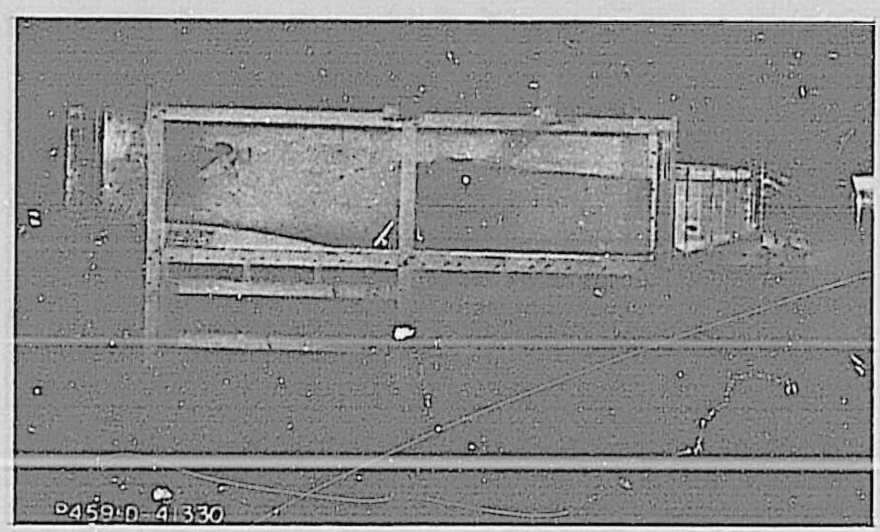
579



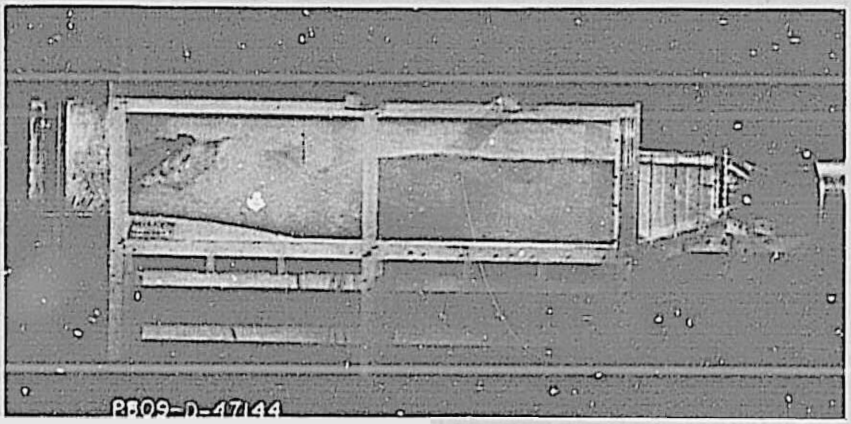
NAVAJO MAIN CANAL OUTLET WORKS

PRESSURES ON WALL UPSTREAM OF GATE SEALS

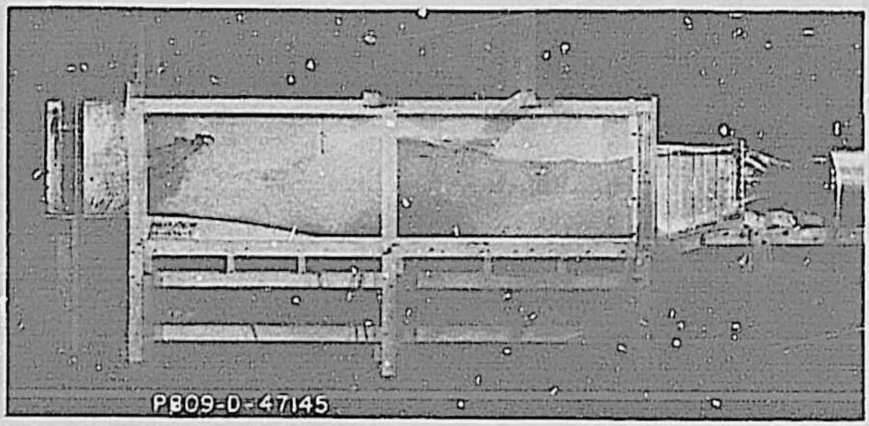
DATA FROM 1:16 MODEL



A. Note large splash over jump.



B. Note large wave followed by trough.



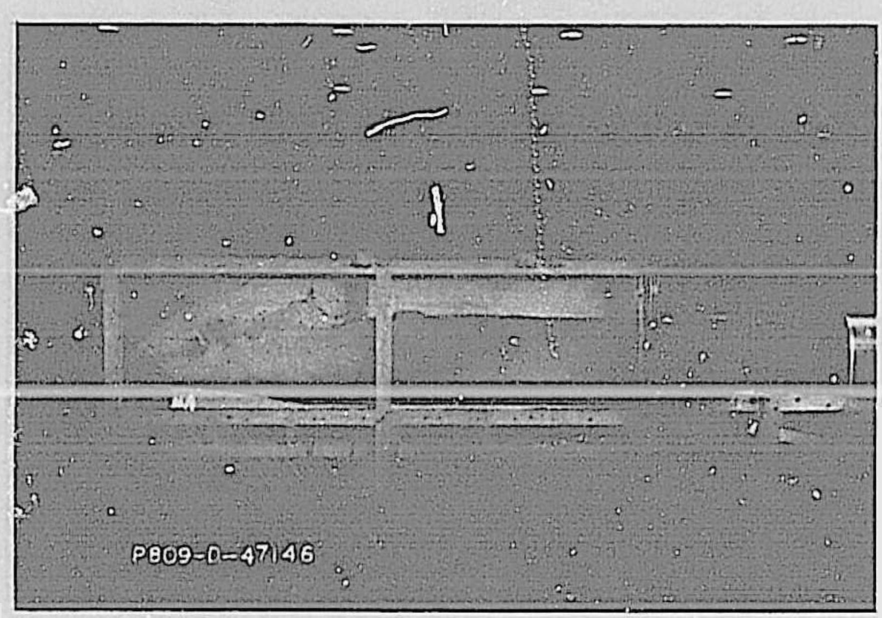
C. Note large surge wave.

NAVAJO MAIN CANAL OUTLET WORKS

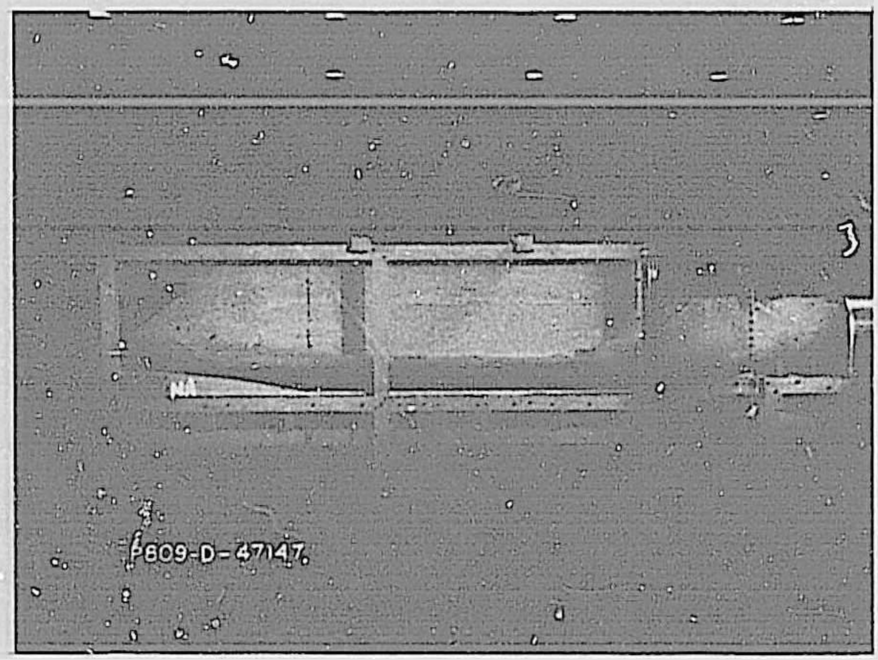
Unstable flow in initial stilling basin. Discharge 2120 cfs, head 132.5 ft., tailwater 15.75 ft.

1:16 Model

Figure 10
Report Hyd-536



A. Large baffle piers held jump in basin.



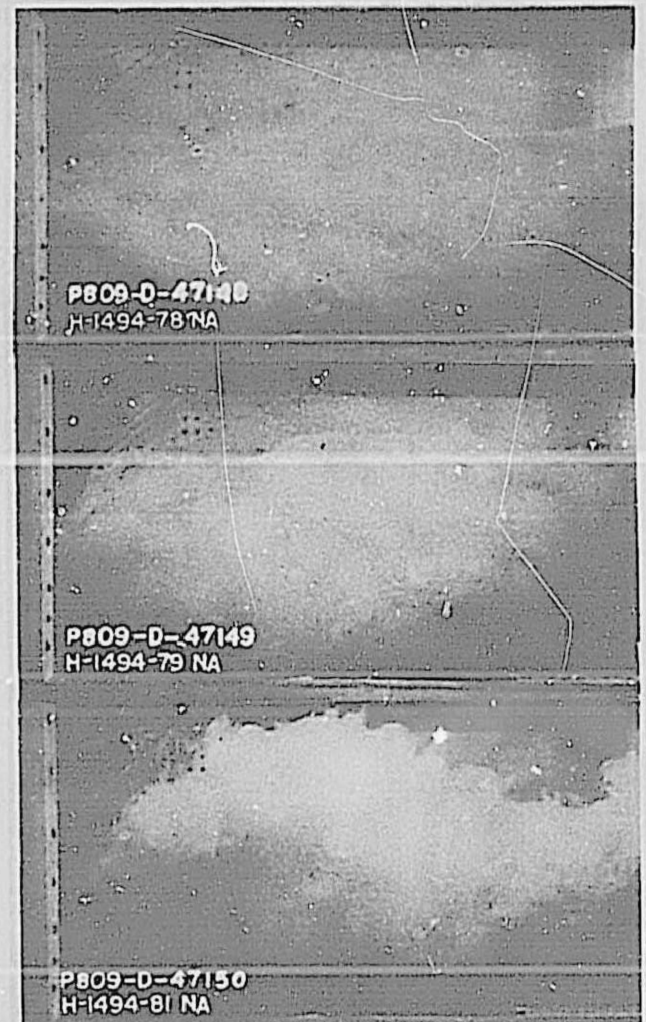
B. Jump swept from basin with baffle piers removed.

NAVAJO MAIN CANAL OUTLET WORKS

Unsatisfactory flow with gate invert level with basin floor. Discharge 2120 cfs, head 132.5 ft.

1:16 Model

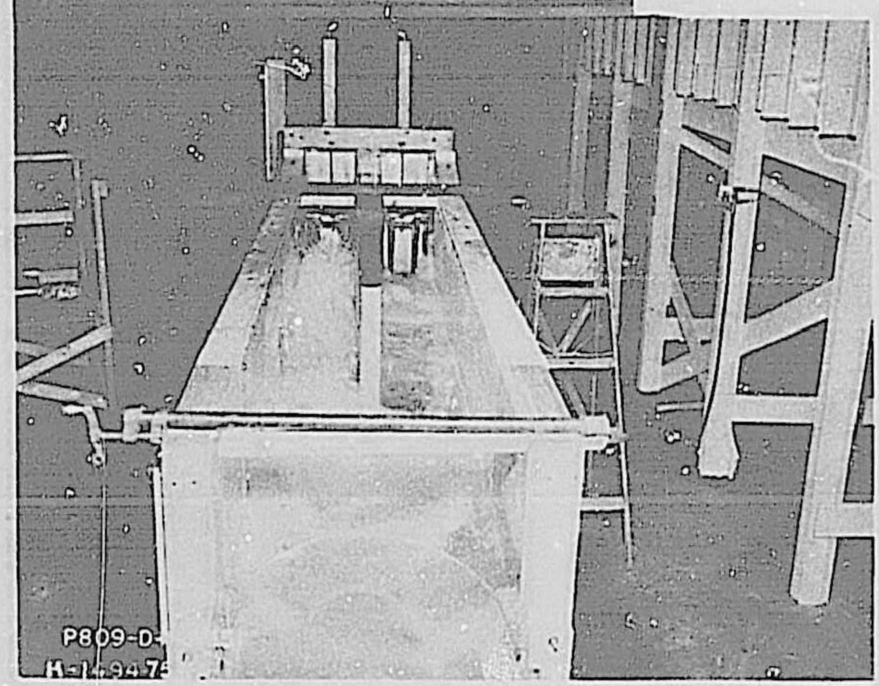
Figure 11
Report Hyd-536



A. Jet directed downward tail-water 1.60 feet below normal.

B. Jet horizontal tailwater approaching normal.

C. Jet directed upward tail-water normal.

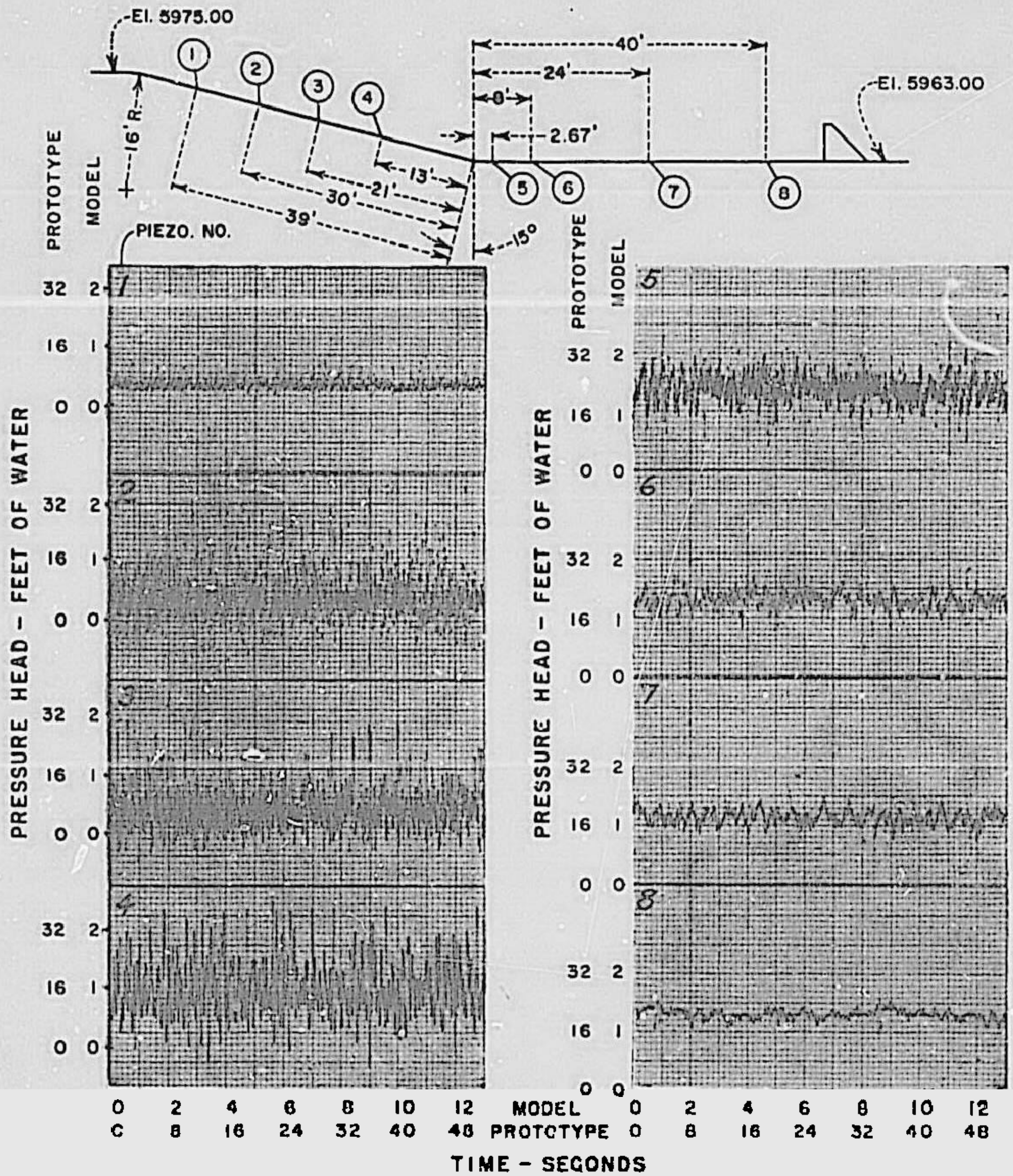


D. One jet directed upward, and the other downward. Gates equally opened, tailwater normal.

NAVAJO MAIN CANAL OUTLET WORKS

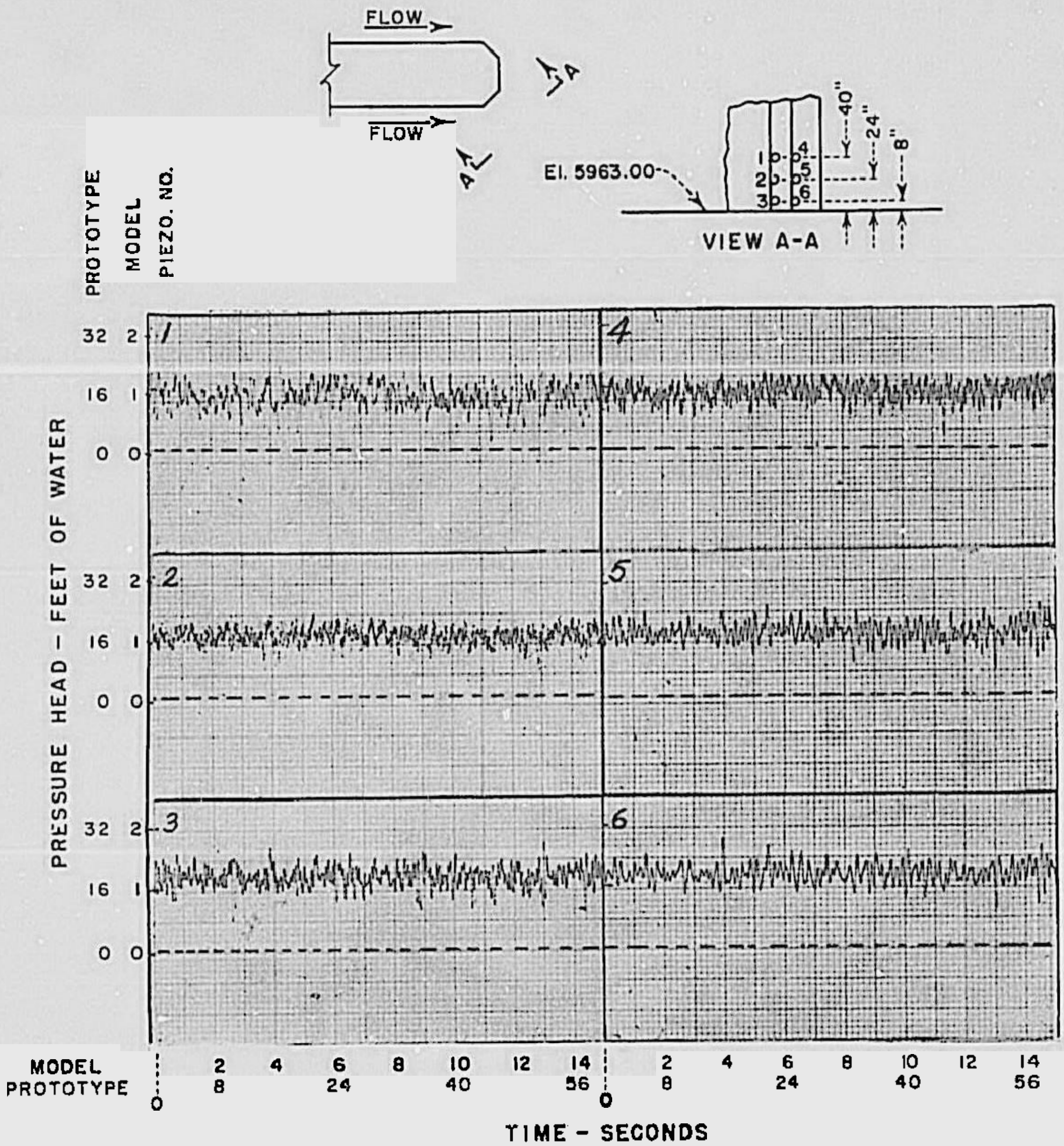
Unstable flow with 12 foot vertical step downstream from gates. Discharge 1800 cfs, head 89 ft., gate opening 17 percent.

1:16 Model



Instantaneous pressure head readings at points on the chute and on the floor of the basin. Discharge 1800 cfs., upstream head 126.5 ft., tailwater 14.35 ft.

NAVAJO MAIN CANAL OUTLET WORKS
CHUTE AND BASIN FLOOR PRESSURE TRACES
WITH RECOMMENDED DESIGN
DATA FROM 1:16 MODEL



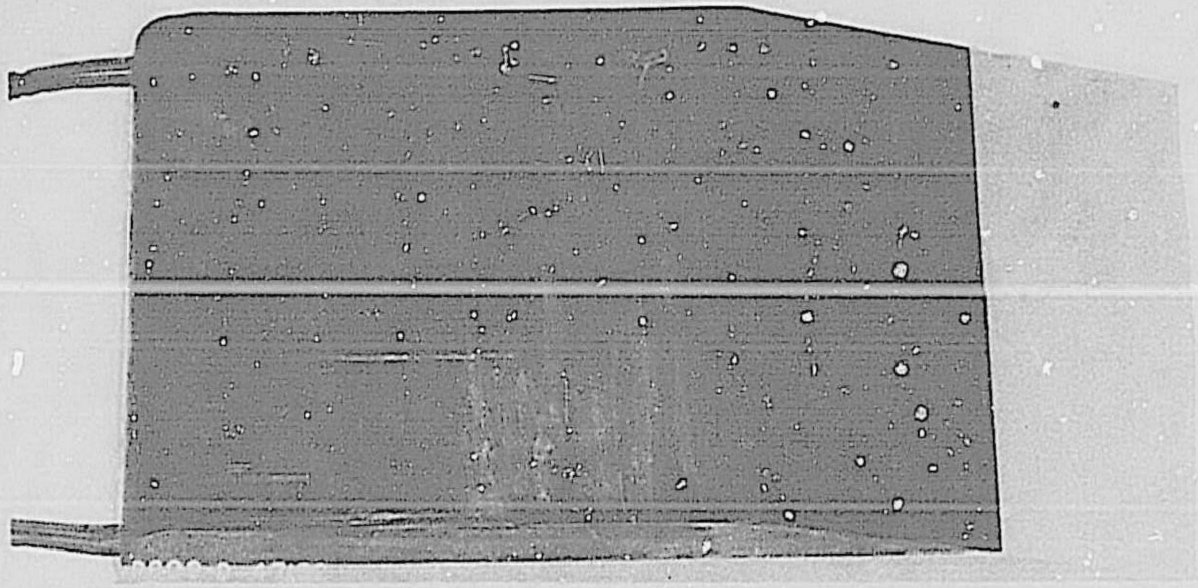
Instantaneous pressures head traces obtained at end of center pier. Discharge 1800 cfs., upstream head 126.5 ft., tailwater 14.35 ft.

NAVAJO MAIN CANAL OUTLET WORKS

PRESSURES AT END OF RECOMMENDED CENTER PIER

DATA FROM 1:16 MODEL

679 H-1494-95 NA



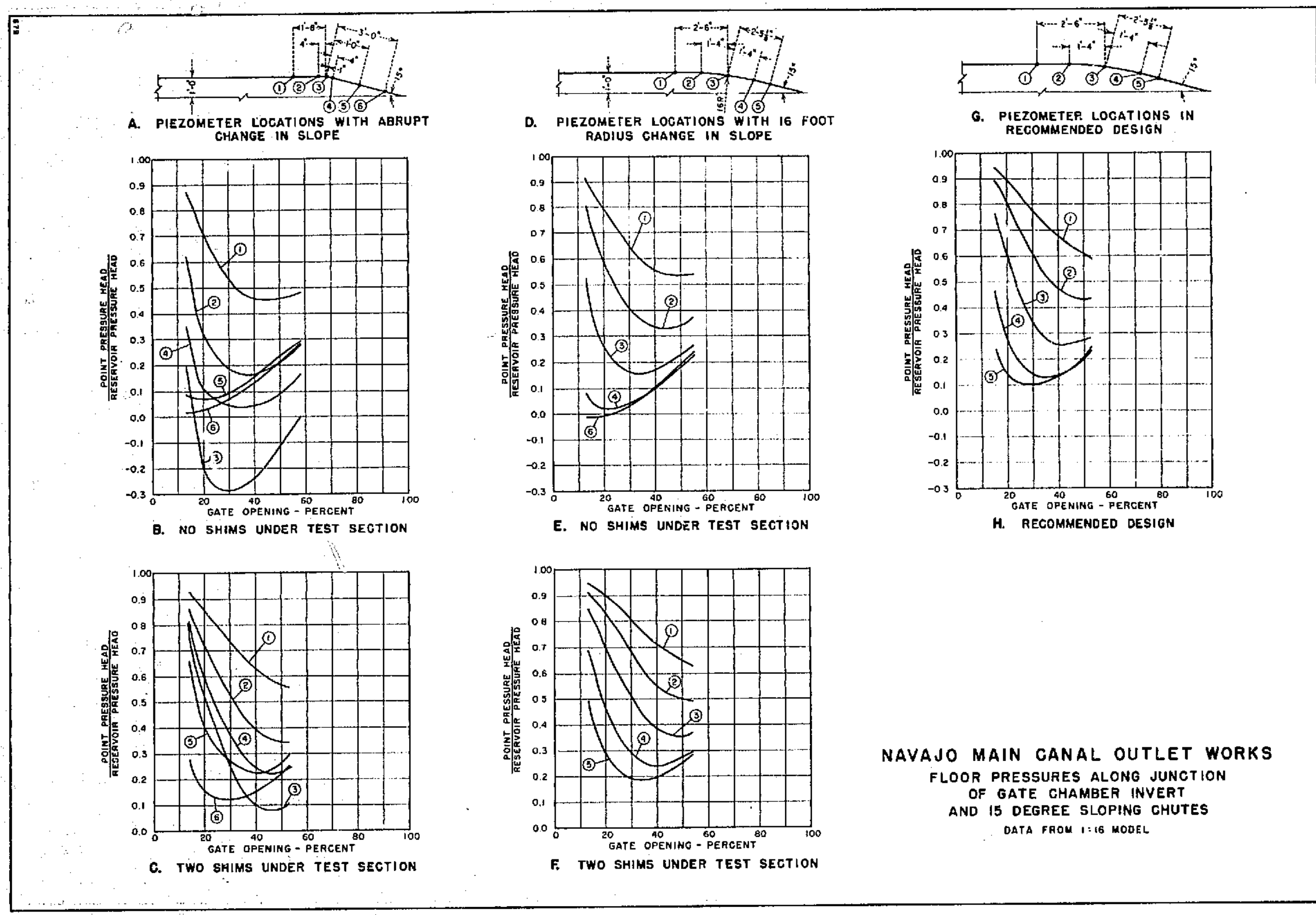
A. Section with abrupt change from horizontal gate chamber invert to 15° slope. Shims were used to raise sections and move point of intersection upstream.

B. Section with 16-foot-radius curve connecting gate chamber invert and 15° slope.

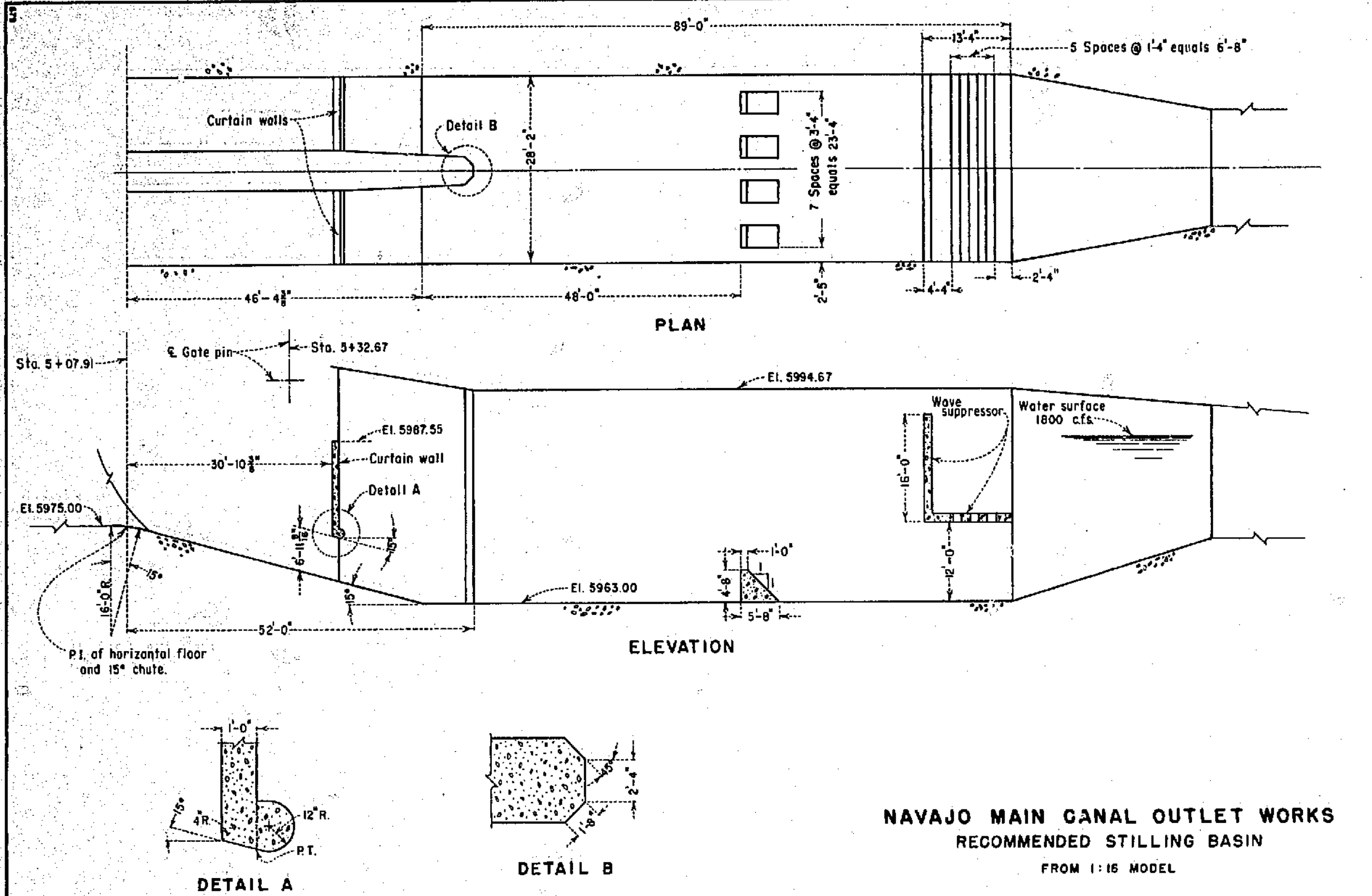
NAVAJO MAIN CANAL OUTLET WORKS

Sections used in determining position and shape of intersection of gate chamber floor and 15° sloping chutes.

1:16 Model

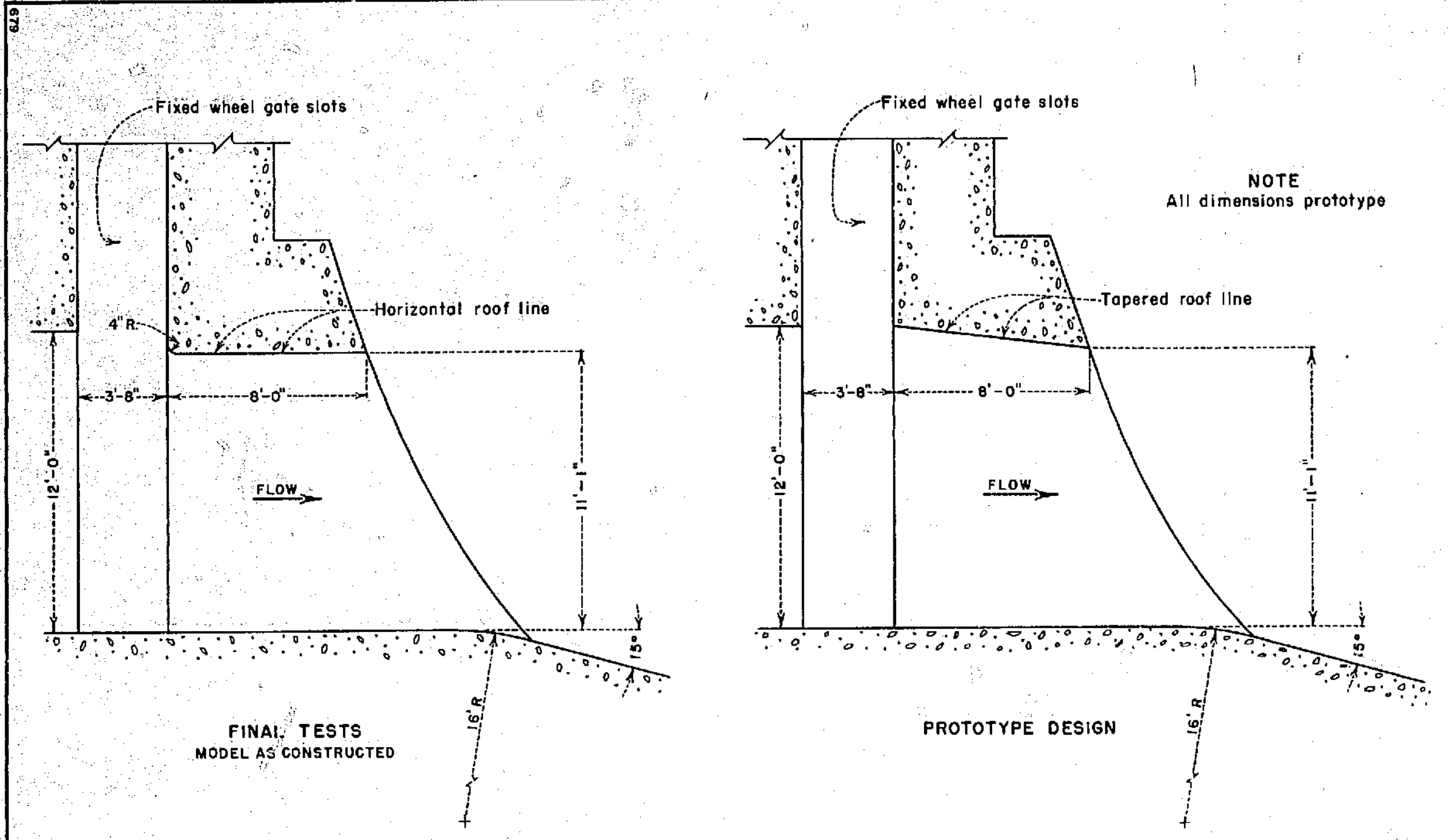


NAVAJO MAIN CANAL OUTLET WORKS
FLOOR PRESSURES ALONG JUNCTION OF GATE CHAMBER INVERT AND 15 DEGREE SLOPING CHUTES
DATA FROM 1:16 MODEL



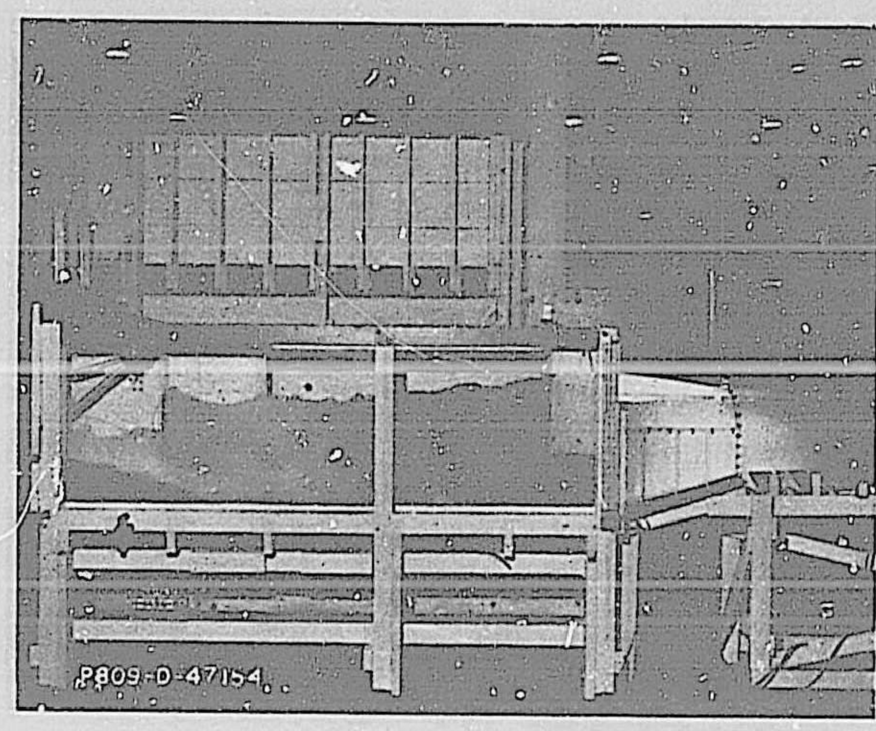
NAVAJO MAIN CANAL OUTLET WORKS
RECOMMENDED STILLING BASIN
FROM 1:16 MODEL

FIGURE 17
REPORT HYD-536

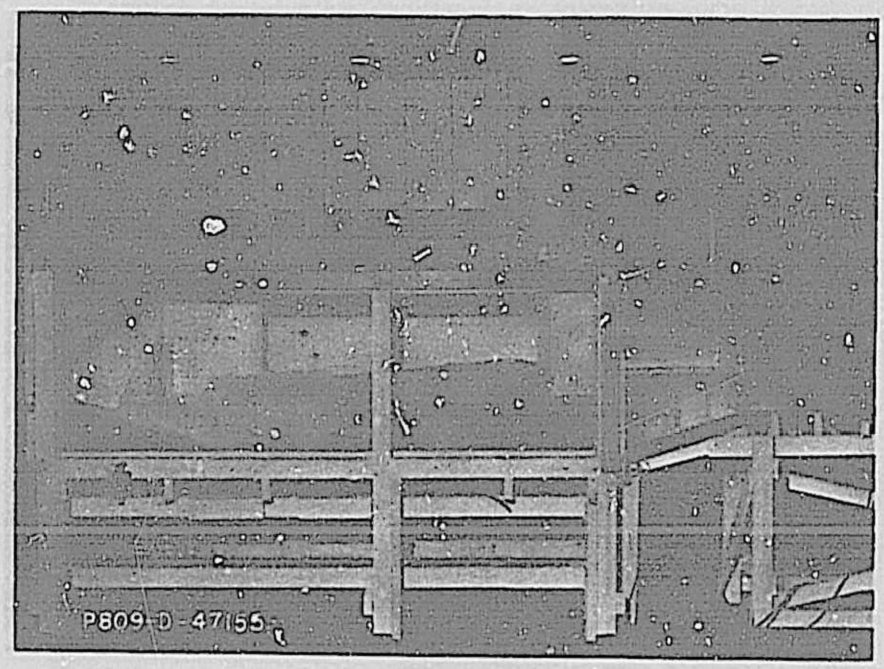


NAVAJO MAIN CANAL OUTLET WORKS
DEVIATIONS BETWEEN MODEL AND PROTYPE ROOF LINES OF GATE CHAMBER

Figure 18
Report Hyd-536



A. Double gate operation. Discharge 1800 cfs, head 126.5 ft., tailwater 14.35 ft. Note smooth water surface in tunnel.

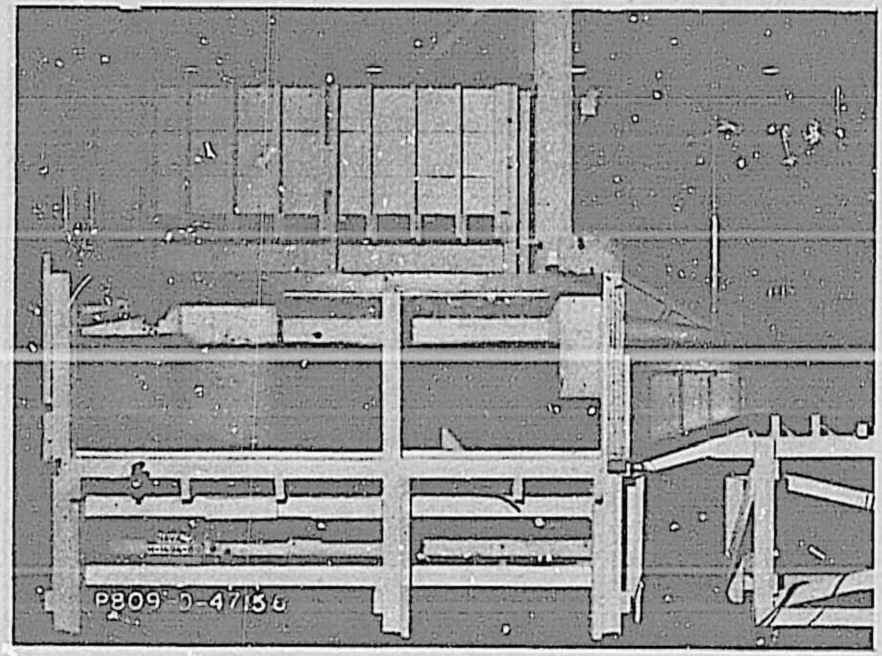


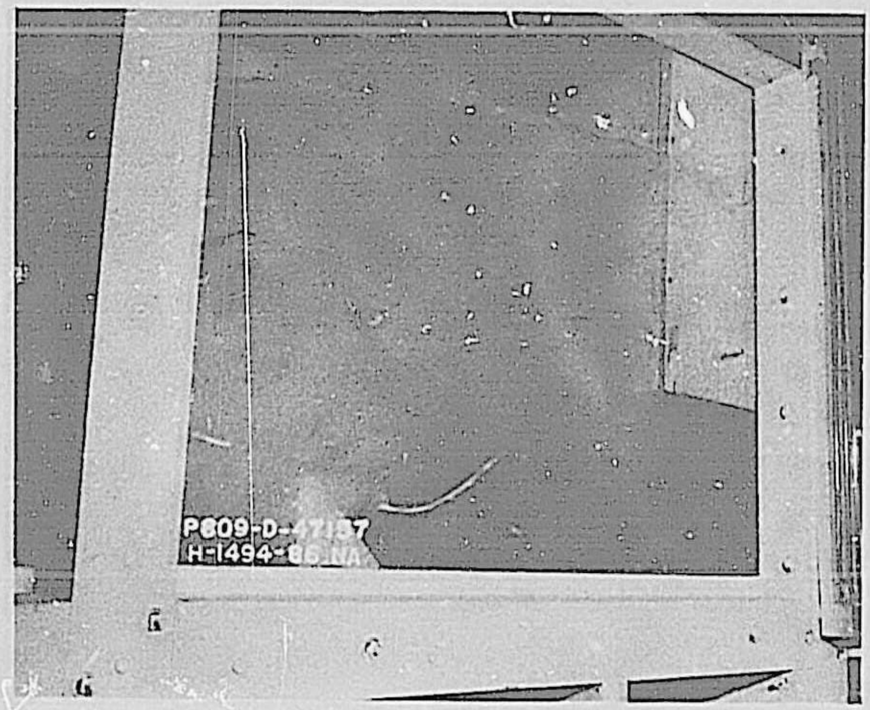
B. Single gate operation. Discharge 900 cfs, head 126.5 ft., tailwater 9.55 ft. Note smooth water surface in tunnel.

NAVAJO MAIN CANAL OUTLET WORKS

Flow in recommended stilling basin

1:16 Model





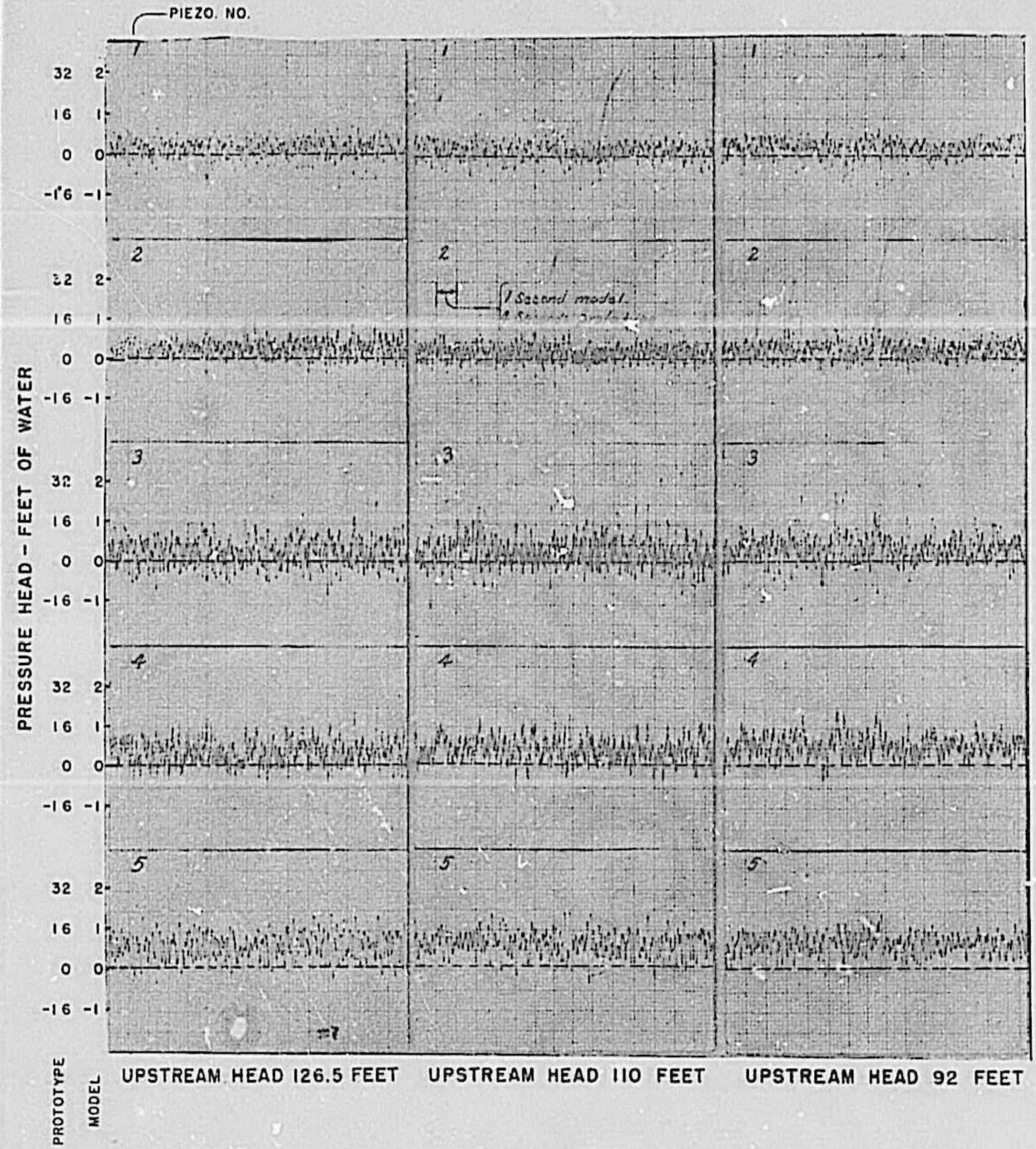
B. Baffle piers helped in turning the flow upward.
Discharge 1800 cfs, head 126.5 ft., tailwater 14.35 ft.

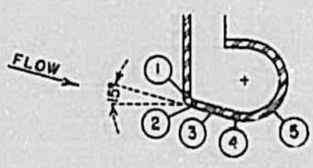
NAVAJO MAIN CANAL OUTLET WORKS

Flow with minimum head, and baffle pier effectiveness - Recommended Design

1:16 Model

FIGURE 20
REPORT HYD-536





CURTAIN WALL PIEZOMETER LOCATIONS

NAVAJO MAIN CANAL OUTLET WORKS

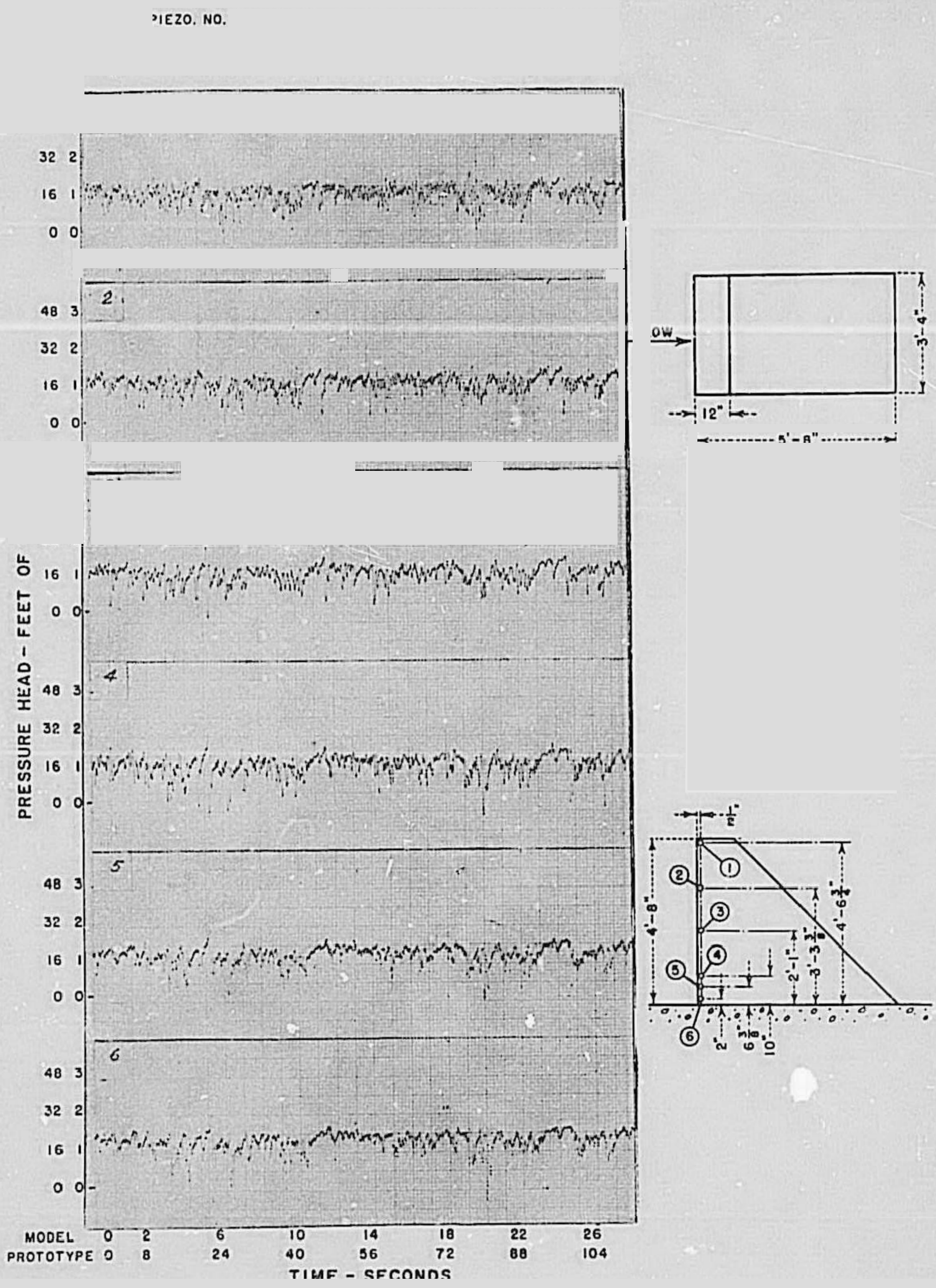
INSTANTANEOUS PRESSURES ON LOWER FACE OF CURTAIN WALL

RECOMMENDED DESIGN

DATA FROM 1:16 MODEL

H-1494-96 NA

FIGURE 21
REPORT HYD-536



Discharge 1800 cfs, upstream head 126.5 ft., tailwater 14.35 ft

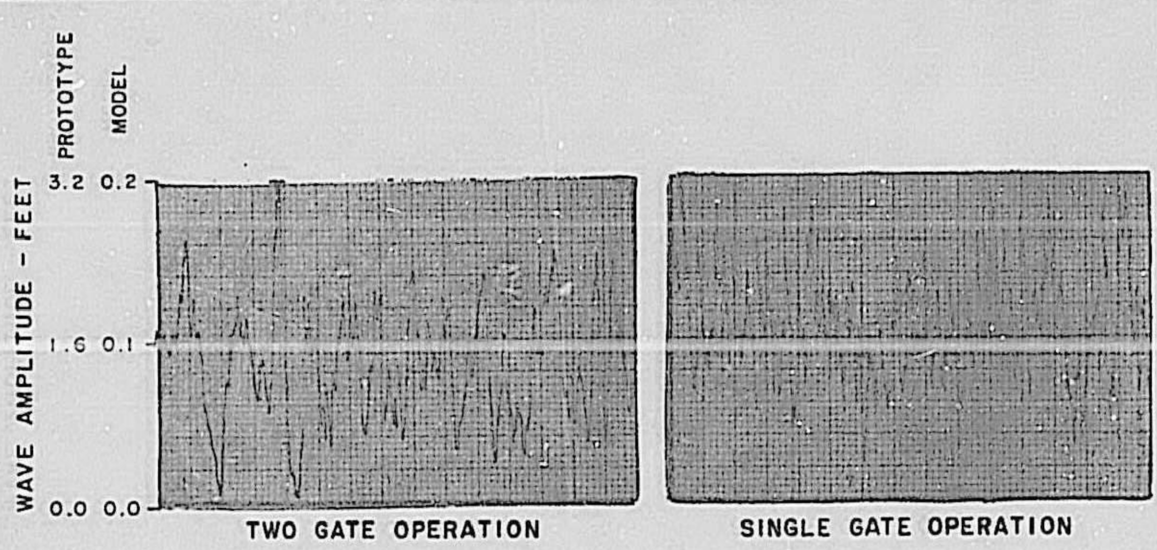
NAVAJO MAIN CANAL OUTLET WORKS

BAFFLE PIER PRESSURES - RECOMMENDED DESIGN

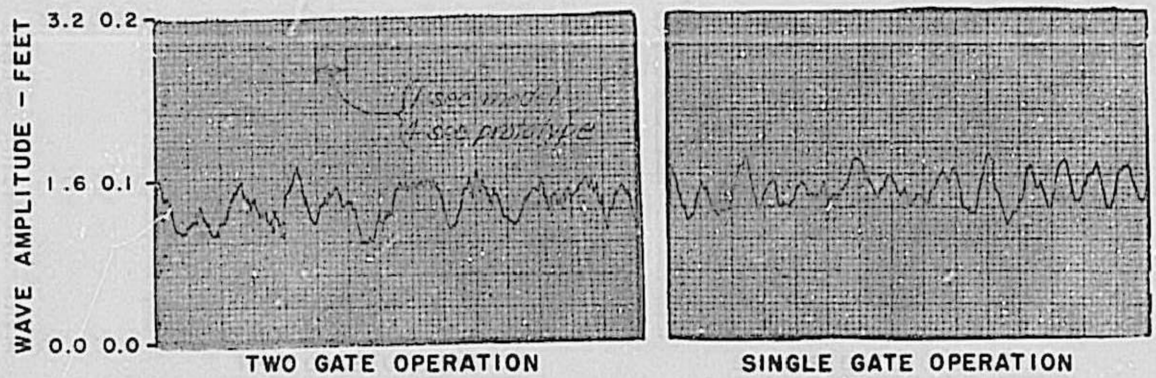
DATA FROM 1:16 MODEL

679 H-1494-97

FIGURE 22
REPORT HYD-536



A. WAVES IN HORSESHOE TUNNEL WITHOUT WAVE SUPPRESSOR

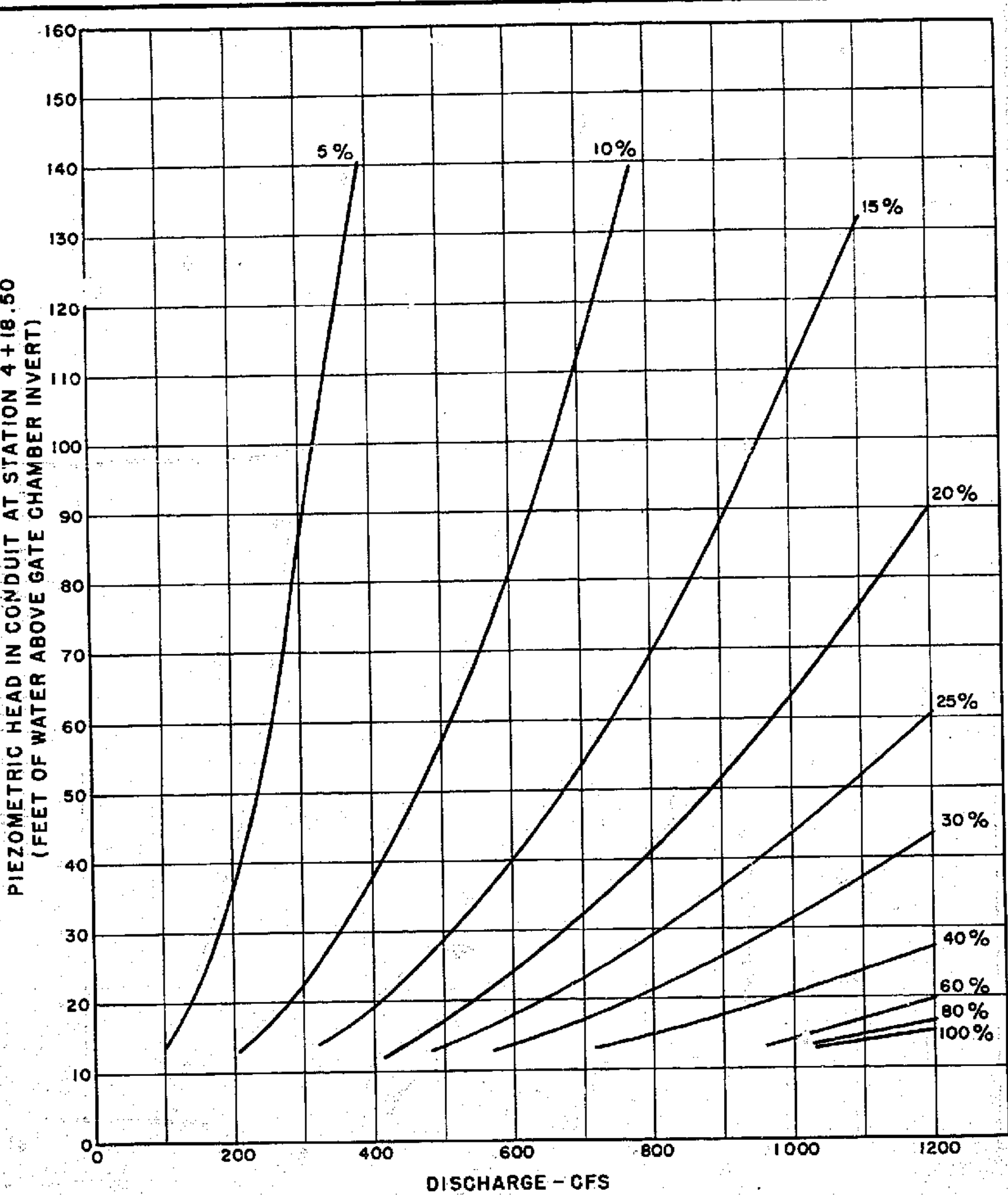


B. WAVES IN HORSESHOE TUNNEL WITH RECOMMENDED WAVE SUPPRESSOR

Two gate operation - 1800 c.f.s., 126.5 ft. head, 14.35 ft. tailwater
Single gate operation - 900 c.f.s., 126.5 ft. head, 9.55 ft. tailwater

NAVAJO MAIN CANAL OUTLET WORKS
WAVES IN HORSESHOE TUNNEL - RECOMMENDED BASIN
DATA FROM 1 : 16 MODEL

679 H-1494-98 NA

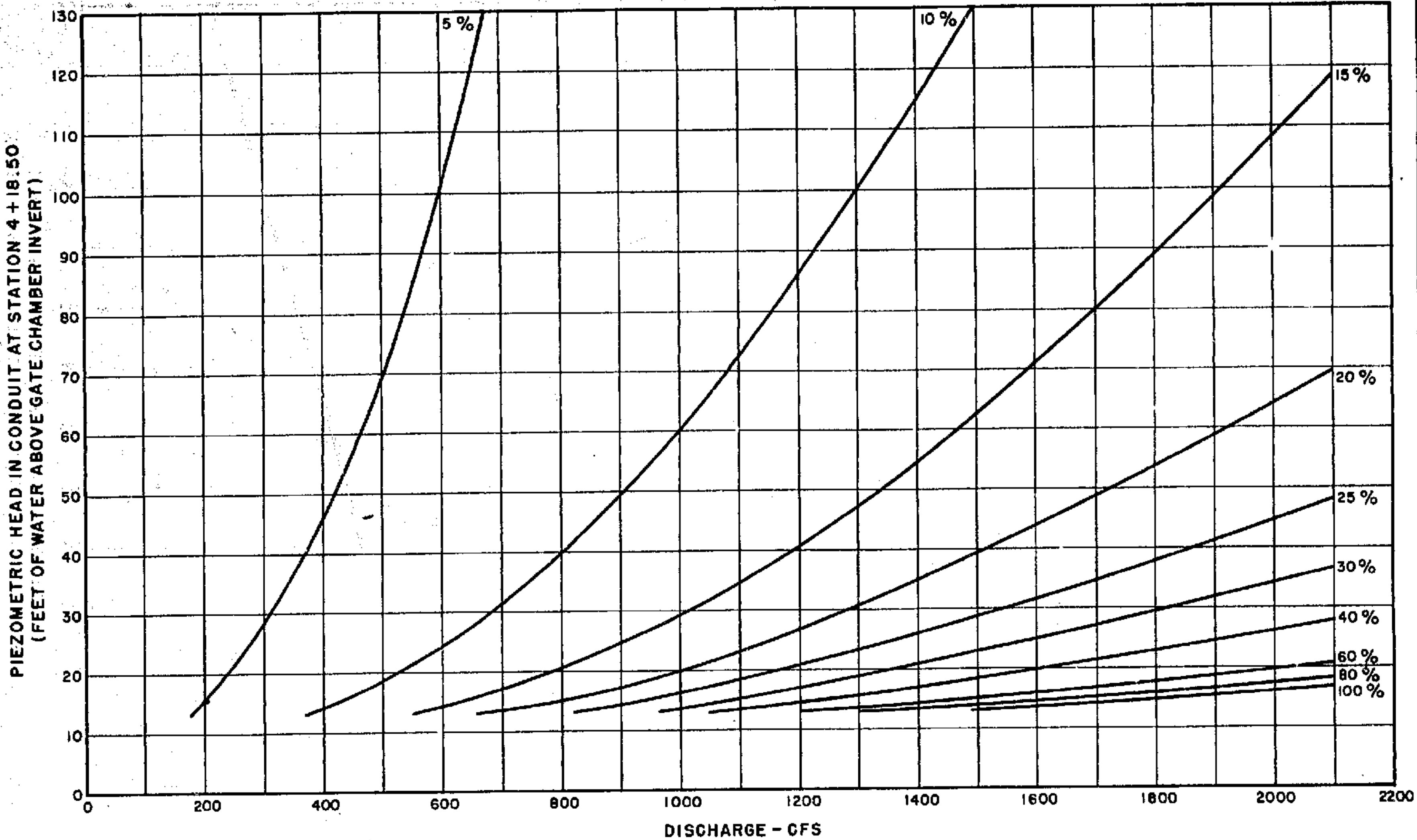


NAVAJO MAIN CANAL OUTLET WORKS

DISCHARGE THROUGH ONE RADIAL GATE

DATA FROM 1:16 MODEL

679



NAVAJO MAIN CANAL OUTLET WORKS
DISCHARGE THROUGH TWO EQUALLY OPENED RADIAL GATES
DATA FROM 1:16 MODEL

7-1750
(10-64)

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 1

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 (exactly)*	Square centimeters
	0.092903 (exactly)	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.)	9,463.58	Cubic centimeters
	0.946358	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
	1.12985×10^6	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
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)	0.02903* (exactly)	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	35.3147*	Millicuries per cubic meter
Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons per square yard	4.527219*	Liters per square meter
Pounds per inch	0.17858*	Kilograms per centimeter

ABSTRACT

Hydraulic model studies showed the original design of the underground stilling basin and chute for the Navajo Main Canal headworks structure to be unsatisfactory. A number of modifications were developed to assure good energy dissipation, freedom from violent backwater flows against the 2 radial gates, and smooth flow conditions into the 17-1/2-ft, 2-mi-long horseshoe tunnel. Heads varied from 15 to 126.5 ft and discharges from 0 to 1800 cfs. Use of 15-deg sloping chutes extending from gate chamber invert to basin floor instead of parabolic chutes eliminated most heavy surging. The horizontal gate chamber inverts were joined to the chutes with 16-ft radii of curvature. The change in floor alinement occurred in the high pressure region upstream from the gate seats. A basin length of 89 ft provided the necessary energy dissipation. Vertical curtain walls to prevent excessive backflow against downstream sides of the radial gates were placed with bottoms about 7 ft above the chutes and faces almost 31 ft downstream from the projected intercept of horizontal gate chamber inverts and the chutes.

Maximum flows at minimum reservoir elevation are attained by allowing a part of the flow to overtop the cutain walls. Four large baffle piers effectively turned the flow upward and increased energy dissipation rate without danger of cavitation. An underpass-type wave suppressor located at downstream end of the basin provided excellent flow conditions in the downstream tunnel.

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Hyd-536
Isbester, T J
HYDRAULIC MODEL STUDIES OF THE MAIN CANAL OUTLET WORKS--NAVAJO INDIAN IRRIGATION PROJECT, NEW MEXICO
Laboratory Report--Bureau of Reclamation, Denver, Colorado, 12 p, 24 fig, 4 ref, 1964

DESCRIPTORS-- *stilling basins/ *radial gates/ laboratory tests/ hydraulic jumps/ research and development/ gate seals/ cavitation/ baffles/ hydraulic gates and valves/ *energy dissipation/ instrumentation/ hydraulics/ canals/ high pressures/ discharges/ hydraulic structures// transitions/structures// wave velocity/ piers/ model tests/ hydraulic models/ chutes/ tunnels

IDENTIFIERS-- *headworks/ curtain walls/ chute blocks/ backflows/ center piers/ design modifications/ horseshoe transitions/ *underground stilling basins/ wave suppressors/ spoilers

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