UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF THE AZOTEA TUNNEL INLET JUNCTION SAN JUAN-CHAMA PROJECT, COLORADO

Report No. Hyd-551

Hydraulics Branch
DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

December 17, 1965

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ABSTRACT

Hydraulic model studies were performed on a 1:12 scale model of the Azotea Tunnel Inlet Junction to find a configuration which would minimize head losses through the junction, to determine critical dimensions of the structure, and to establish canal water depths. The purpose of the junction is to combine the flow from a feeder canal with that from the Oso Tunnel inverted siphon and direct this combined flow into the Azotea Tunnel. The recommended design minimized head losses between the siphon and the tunnel by means of a bearing wall placed in the flow stream which accelerated the flow leaving the canal, thereby making the uniting flow velocities from the canal and the siphon almost equal. This significantly reduced eddy formation and tended to eliminate retardation of the siphon flow. The bearing wall also reduces the span length of a roof over the inlet junction. The flow conditions with this configuration were good over a large range of siphon, canal, and tunnel discharges. Fairly accurate estimates of losses through a system which is not geometrically similar to the Azotea inlet junction can be obtained by application of momentum and energy equations over two control sections. An example of this procedure is given in the appendix to the report.

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PURPOSE

A model study of the Azotea Tunnel Inlet Junction was conducted to develop a configuration which would minimize the loss between the siphon and the canal, to accurately determine critical dimensions of the junction, and to obtain information to establish the invert elevation for a measuring flume in the feeder canal.

CONCLUSIONS

1. Design A, which provided a straight flow path from the siphon barrel to the tunnel, produced lower losses between the siphon and tunnel than Design B, which required the siphon flow to turn through an angle of 15° (Figure 4).

2. Minimum losses between the siphon and the tunnel were obtained with Design A having a bearing wall 12 feet long placed between the siphon and the canal at an angle of 7-1/2° relative to the tunnel centerline (the recommended design) (Figure 9E).

3. The maximum water depth in the junction was 11.4 feet with the recommended design.

4. Design B produced lower losses between the canal and the siphon than Design A which required the flow to be turned through 30° instead of only through 15° as in Design B (Figure 10).

5. A method for estimating the losses through similar junction configurations is described.

ACKNOWLEDGMENT

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INTRODUCTION

The San Juan-Chama Project is a participating project of the Colorado River Storage Project and will make possible the diversion of about 110,000 acre-feet annually from the upper tributaries of the San Juan River in the Upper Colorado River Basin, through the Continental Divide, into the Rio Grande Basin in New Mexico (Figure 1). The diverted water will provide an irrigation water supply to the land in the Rio Grande Basin and serve as a supplemental water supply for the Middle Rio Grande Conservancy District.

The project's diversion facilities will consist of three concrete diversion dams, one on the Rio Blanco, one on the Little Navajo River, and one on the Navajo River; feeder canals from the headworks of the diversion dams to the tunnel inlet structures; and the Blanco and the Oso Tunnels which collect the diverted water and pass it under the Continental Divide through the Azotea Tunnel (Figure 2).

The inlet junction structure to the Azotea Tunnel serves to combine the flow brought by the feeder canal from the diversion dam on the Navajo River with the flow coming from the Oso Tunnel (Figure 3). The inlet junction structure consists of a transition from the Oso Tunnel inverted siphon, the end of the feeder canal, a junction combining these two flow passages, and a transition into the Azotea Tunnel (Figure 4).

A model study of the tunnel inlet structure was necessary to develop a junction configuration which would minimize the losses between the siphon and the tunnel, as well as to investigate the combined flow conditions. In addition, the model study was used to obtain canal water depths. Knowledge of the canal depths was necessary so that the invert of a measuring flume in the feeder canal could be placed sufficiently high to prevent backflow into the Navajo River during low river stages.

Model tests were performed on two basic designs. In Design A, water from the siphon passed in a straight line through the junction and into the tunnel (Figure 4A). In Design B, the water was turned through a horizontal angle of 15° before entering the tunnel (Figure 4B). In both cases, the included angle between the canal and the siphon was maintained at 30°.

Depending upon the quantity of upstream rainfall and the downstream water commitments, discharge can vary from zero to a maximum of 550 cfs (cubic feet per second) through the siphon and from zero to a maximum of 65 cfs through the feeder canal. The maximum combined flow in the Azotea Tunnel is limited to 950 cfs.

THE MODEL

The studies were conducted on a 1:12 scale model. Included in the model were about 20 diameters of siphon piping, the siphon transition, a length of diversion canal equivalent to 72 feet of prototype canal, the junction, a transition from the junction to the tunnel, and about 13 diameters of circular tunnel downstream from the junction (Figure 5). Although the contractor has the option of constructing either a circular or a horseshoe tunnel, only the circular tunnel was tested in the model (Figure 14).

Discharges through the siphon were measured with calibrated Venturi meters located permanently in the laboratory. The discharge through the canal was measured with a portable Orifice-Venturi meter which was placed about 22 pipe diameters downstream from a portable pump and about 30 pipe diameters upstream from the head box which led into the canal. Swirl from the portable pump was minimized through the use of a flow straightener which consisted of parallel plates about 3 feet long that were welded to the inside of the 8-inch-diameter pipe immediately downstream from the pump. The water depth or piezometric head was determined in the canal, siphon, and tunnel by connecting stilling wells to piezometer stations in these sections and by measuring the depth of water in each of three stilling wells with a point gage (Figures 4, 5, and 6). Velocity traverses at the tunnel and the canal measuring stations were made with a boundary-layer-type, total head tube. At the siphon measuring station a three-hole cylindrical probe was utilized (Figure 7).

THE INVESTIGATION

Test Procedures

The testing was begun with Design A and a tailwater depth of 8.78 feet (prototype) at the tunnel measuring station. This depth corresponded to that which was computed to occur at the maximum tunnel discharge of 950 cfs in a circular tunnel (Figure 3). The ratio of the flow rate in the canal to the flow rate in the siphon was varied between 0 and 1.0 in increments of about 0.2. For each increment, the combined flow was adjusted to total 950 cfs and then the piezometric elevation at each of the three measuring stations was read. This procedure was repeated with various modifications in the junction structure until one was found which resulted in the minimum head loss between the siphon and the tunnel. For this optimum condition, the increments were repeated for a combined flow rate of 475 cfs in the tunnel. The testing with Design B was begun in a similar manner; however, it was quickly seen that the addition of walls, etc., would neither decrease the losses between the siphon and the tunnel nor improve the flow conditions. Therefore, the complete range of loss values was obtained for the original configuration only.

Test Results

Loss Coefficients.--The loss coefficients for Designs A and B are presented in Figures 9 and 10, which are plots of ξ versus α,

where ξ_1 = head loss coefficient between the canal and the tunnel

ξ_2 = head loss coefficient between the siphon and the tunnel

α = ratio of flow rate in canal to total combined flow rate in tunnel.

The coefficients are defined by Bernoulli's Equation, when written between the various points in question, as:

a. Canal to tunnel

$$\left(\frac{V^2}{2g} + \frac{p}{\gamma} + Z\right)_{canal} = \left(\frac{V^2}{2g} + \frac{p}{\gamma} + Z\right)_{tunnel} + \xi_1\left(\frac{V^2}{2g}\right)_{tunnel}$$

b. Siphon to tunnel

$$\left(\frac{V^2}{2g} + \frac{p}{\gamma} + Z\right)_{siphon} = \left(\frac{V^2}{2g} + \frac{p}{\gamma} + Z\right)_{tunnel} + \xi_2\left(\frac{V^2}{2g}\right)_{tunnel}$$

Actually, the velocity head terms in these energy equations should be multiplied by a kinetic energy correction factor which accounts for the nonuniform velocity distribution. The correction factors for the siphon, canal, and tunnel were measured in the model and amounted to 1.020, 1.014, 1.024, respectively. The siphon factor was determined with

950 cfs in the siphon and no flow through the canal; the canal and tunnel factors were determined with 950 cfs in the canal and no flow through the siphon. Since these values were so close to 1.000, and since their inclusion in the equations would add an unwarranted refinement to the measured head loss values, all were assumed equal to unity.

The value α is a dimensionless flow parameter, and is defined as

$$\alpha = \frac{Q_{canal}}{Q_{tunnel}}$$

In all loss determinations, the tunnel discharge is 950 cfs unless otherwise noted. Since $Q_{tunnel} = Q_{canal} + Q_{siphon}$, the dimensionless flow parameter can also be expressed as

$$\alpha = 1 - \frac{Q_{siphon}}{Q_{tunnel}}$$

For the Azotea Tunnel Inlet Junction the maximum flow rates are Q_{tunnel} = 950 cfs, Q_{siphon} = 550 cfs, and Q_{canal} = 650 cfs. These values correspond to a range of α = 0.421 to α = 0.684 when the tunnel is flowing at maximum capacity. The range α = 0 to α = 1.0 was tested in order to more accurately determine the shape of the loss curve, and to generalize the results for broader application. In the following discussions, the remarks are limited to the range of α values between 0.421 and 0.684.

Design A.--The original design contained no appurtenances within the junction box and the only streamlining consisted of a rounded corner at the intersection of the left canal wall with the tunnel inlet (Figure 4A). The loss coefficients obtained with this configuration were used as an arbitrary reference upon which to evaluate the effects of modifications and the performance of other designs (Figure 9A).

Effects of Modifications to Design A.--The first modification made to Design A was to replace the curve at the intersection of the left wall of the canal and the tunnel with a sharp corner to determine whether this simplification in construction would be detrimental so far as the hydraulic losses are concerned. The sharp corner created a distinct zone of separation at the inlet to the tunnel transition which resulted in increased losses from the siphon to the tunnel and from the canal to the tunnel (Figure 9A).

It was anticipated that a roof would be placed over the inlet junction. To keep the spans within tolerable limits, some type of supporting member in the flow stream was deemed necessary. The second modification consisted of a 1-foot 4-inch diameter post located within the junction (Figure 9B). The intersection between the canal and siphon wall was rounded with a 9-inch radius. The losses with the post were much greater than with the original design because of flow separation behind the post.

The third modification consisted of a bearing wall 12 feet 0 inch long (Figure 9C). The length of wall was chosen for structural reasons and consequently no other lengths were tested. This wall tended to slightly increase the loss between the canal and the tunnel because the wall acts as a restriction to the canal flow. However, the loss between the siphon and the tunnel was substantially decreased. The effect of the wall was to accelerate the flow leaving the canal, thereby making the flow velocities from the canal and the siphon almost equal where they unite. Making the flow velocities approximately equal significantly reduces the eddy formation in the junction and tends to eliminate the retardation of the siphon flow. These effects account for the reduction in loss between the siphon and the tunnel with a bearing wall. A wall placed at 7-1/2° relative to the tunnel centerline resulted in the lowest losses for this type of modification (Figure 9C).

Consideration was given to the possibility that a wall whose top was sloped in the downstream direction might provide a better matching of the two flows entering the junction. The tests showed that the opposite occurred, and the sloped wall produced higher losses (Figure 9D).

Design B. --Tests with this design indicated an increase in the loss coefficient between the siphon and the tunnel with respect to the unmodified Design A (Figure 10). Spot checks with a wall such as that used in Design A indicated a further increase in this loss coefficient. Therefore, this design was rejected even though a decrease in the loss coefficient between the canal and the tunnel was noted.

Recommended Design. --The optimum design from the standpoint of reducing the losses between the siphon and the tunnel, is Design A with a 12-foot-long bearing wall which is placed at an angle of 7-1/2° relative to the tunnel centerline and whose top is horizontal. This design was also tested with one-half of maximum discharge, or 475 cfs, in the tunnel to determine the dependence of the loss coefficients on the flow rate (Figure 9E). This dependence is due to the changes in Manning's "n" and to changes in the momentum correction factor β as the depth of flow (or flow rate) varies.

Flow Conditions with the Recommended Design. --The reason for the decrease in loss between the siphon and the tunnel when a bearing wall was inserted into the junction was explained in a previous section. In general, the flow conditions were very good with a bearing wall placed at 7-1/2° to the tunnel centerline. A very graphic picture of the improved flow conditions due to the wall can be obtained by comparing the flow conditions in Figure 11. The water surface throughout the junction and tunnel inlet transition was relatively smooth. No large standing waves were observed in the downstream section of tunnel although a tendency for their formation was noted in the velocity traverse at the tunnel measuring station. The zone of separation at the end of the bearing wall might be decreased somewhat by rounding the end of the wall. Although tests were not made with the end of the wall rounded, it is reasonable to expect that no significant changes in the water surface roughness or loss coefficients will be observed by making this change.

A slight tendency toward separation and drawdown of the water surface was noted at the curved portion of the left wall of the junction where the canal joins tunnel inlet (Figure 12). This drawdown could be reduced by using a curve whose radius was larger than the 18-foot 8-inch radius used in the studies. The amount of drawdown and separation is not large enough to cause concern, but it indicates that a smaller radius should not be used.

Water Depths in Canal and Junction. --The depth of water in the canal at the station from which the losses were determined can be computed from

$$y_{canal} = y_{tunnel} + \frac{Q^2_{tunnel}}{2g}\left[\frac{(1+\xi_1)}{A^2_{tunnel}} - \frac{\alpha^2}{4(by)^2_{canal}}\right] - \Delta Z$$

where y = flow depth at station (ft)

Q = discharge in tunnel (ft^3/sec)

ξ_1 = loss coefficient between canal and tunnel

A = cross-sectional area of the flowing water in the tunnel (ft^2)

α = flow ratio

b = one-half canal width (ft)

ΔZ = difference in invert elevation between canal station and tunnel station (ft).

The canal depth has been computed on this basis for the junction with a bearing wall at 7-1/2° to the tunnel centerline for the maximum discharge in the tunnel (Figure 13). This canal depth can also be used as the depth at the siphon outlet for the determination of freeboard requirements.

The depth at the inlet to the tunnel transition can be obtained approximately by solving the third degree equation

$$y^3_{inlet} - \left[y^2_{tunnel} \cdot b_2 + \frac{1}{g}\left(\frac{Q^2}{A}\right)_{tunnel} \right] y_{inlet} + \frac{Q^2_{tunnel}}{2g\ b_2} = 0$$

where b_2 = one-half width of inlet transition.

A discussion of the assumptions used in deriving the equation is presented in the Appendix. With a discharge of 950 cfs in the Azotea Tunnel, the computation yields a depth of 9.8 feet. This agrees favorably with depths obtained in the model (note flow depth at inlet to tunnel transition in the photographs in Figure 12).

Prediction of Energy Losses through Similar Junctions

These results can be directly applied only to junctions which are geometrically similar to the Azotea Inlet Junction and whose discharges are related to the Azotea discharges by the length scale to the five-halves' power. Normally, such ideal conditions will not be encountered.

Fairly accurate estimates of losses through a system which is not geometrically similar to the Azotea Inlet Junction can be obtained by the application of momentum and energy equations over two control sections. An example of this procedure is given in the Appendix.

Example of Head Loss Computations

The method for computing head loss through the junction is illustrated by the following example:

Given: Q_{siphon} = 550 cfs

Q_{canal} = 400 cfs

Q_{tunnel} = 950 cfs

Bearing wall at 7-1/2° to tunnel centerline in junction Design A.

Find: (a) Head loss between canal and tunnel stations

(b) Head loss between siphon and tunnel stations.

Solution:

For this case $\alpha = \frac{400}{950} = 0.421$

From Figure 9E the loss coefficients are found to be:

$$\xi_1 = 0.05, \text{ and } \xi_2 = 0.25$$

The water depth in the tunnel with a discharge of 950 cfs is 8.78 feet (Figure 8). Entering King's Handbook* with a d/D = 8.78/10.916 = 0.804, one can obtain an expression for the flow area in a circular pipe. This value is Area/D^2 = 0.674 or A = 80.32 ft^2.

Thus the tunnel velocity is

$$V = \frac{Q}{A} = \frac{950}{80.32} = 11.83 \text{ ft/sec}$$

and the velocity head is

$$\frac{V^2}{2g} = 2.17 \text{ ft}$$

The required head losses can now be computed.

(a) Head loss from canal to tunnel

$$h_L = \xi_1 \left(\frac{V^2}{2g}\right)_{tunnel} = (0.05)(2.17) = 0.11 \text{ ft}$$

(b) Head loss from siphon to tunnel

$$h_L = \xi_2 \left(\frac{V^2}{2g}\right)_{tunnel} = (0.25)(2.17) = 0.54 \text{ ft}$$

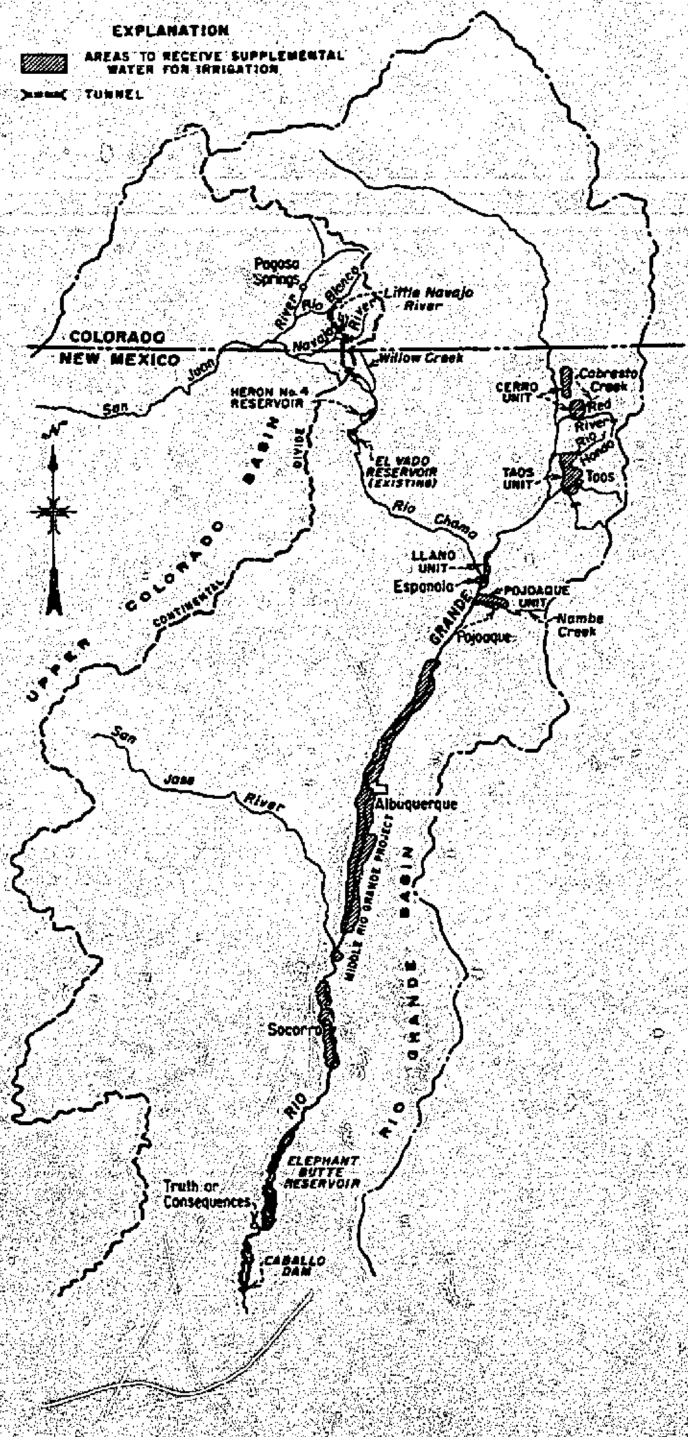
Separation of Losses through the Structure

Separating the losses into individual components through the structure was not attempted because a detailed knowledge of the turbulence intensities and velocity distributions through the structure would be

*King, H. W., Handbook of Hydraulics, McGraw-Hill Book Company, Inc., New York, 1954, p 7-41, Table 84 required. In addition, the total magnitude of the loss through the model is relatively small. Further division of this loss into individual losses would have resulted in questionable results since the experimental errors would have been large relative to the values being measured.

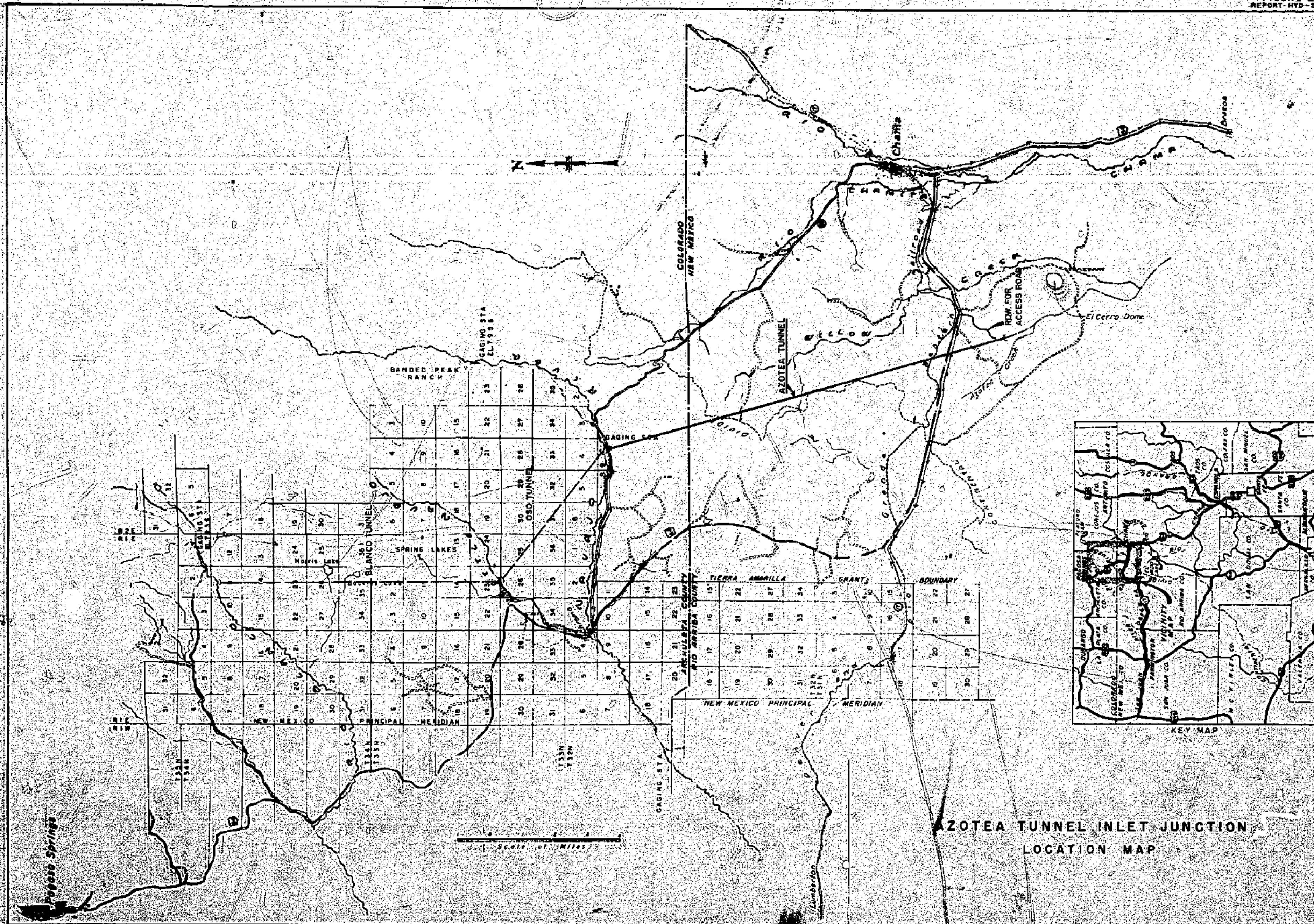
Prototype Design

The design of the field structure has a slightly different configuration from that which was recommended, (Figure 14). The rectangular access box has been moved downstream to occupy a position between the junction and the tunnel inlet transition. This additional 20 feet of run will tend to result in a better velocity distribution and a slightly smoother water surface at the inlet to the transition. The radius on the left wall between the canal and the tunnel has been increased from 18 feet 8 inches to 20 feet 0 inch, and all sharp breaks at the exit of the siphon outlet transition have been rounded with circular curves. These changes will result in slightly lower prototype losses than those predicted on the basis of model tests.

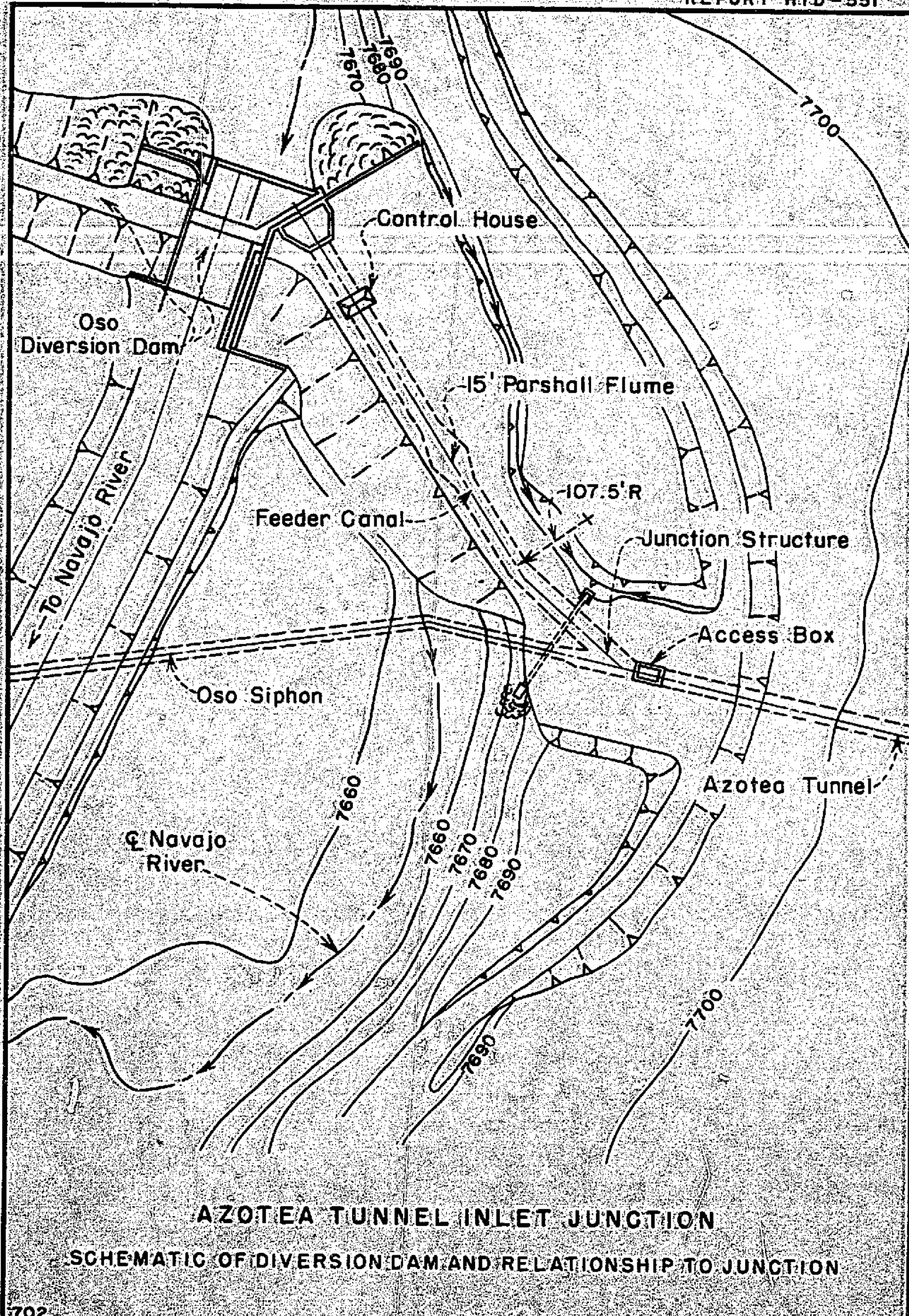


AZOTEA TUNNEL INLET JUNCTION

Location Map
San Juan-Chama Project

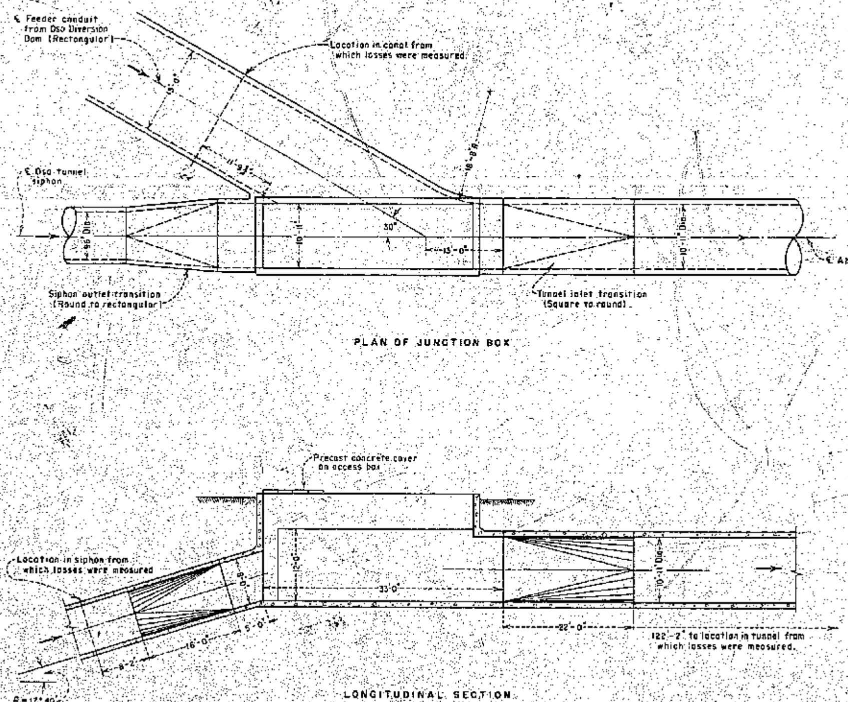


AZOTEA TUNNEL INLET JUNCTION
LOCATION MAP

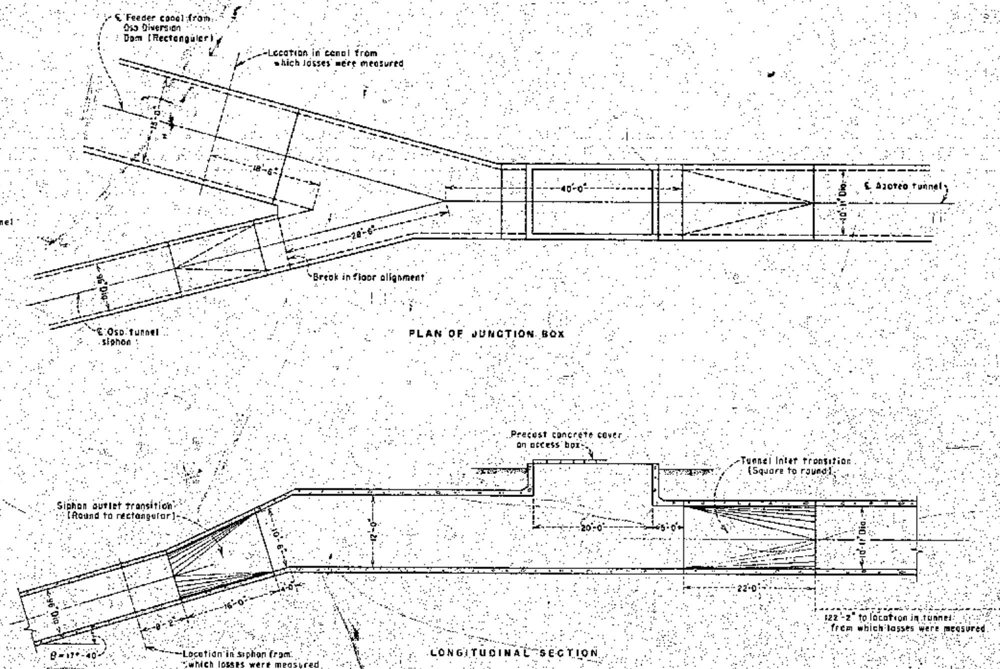


AZOTEA TUNNEL INLET JUNCTION

SCHEMATIC OF DIVERSION DAM AND RELATIONSHIP TO JUNCTION

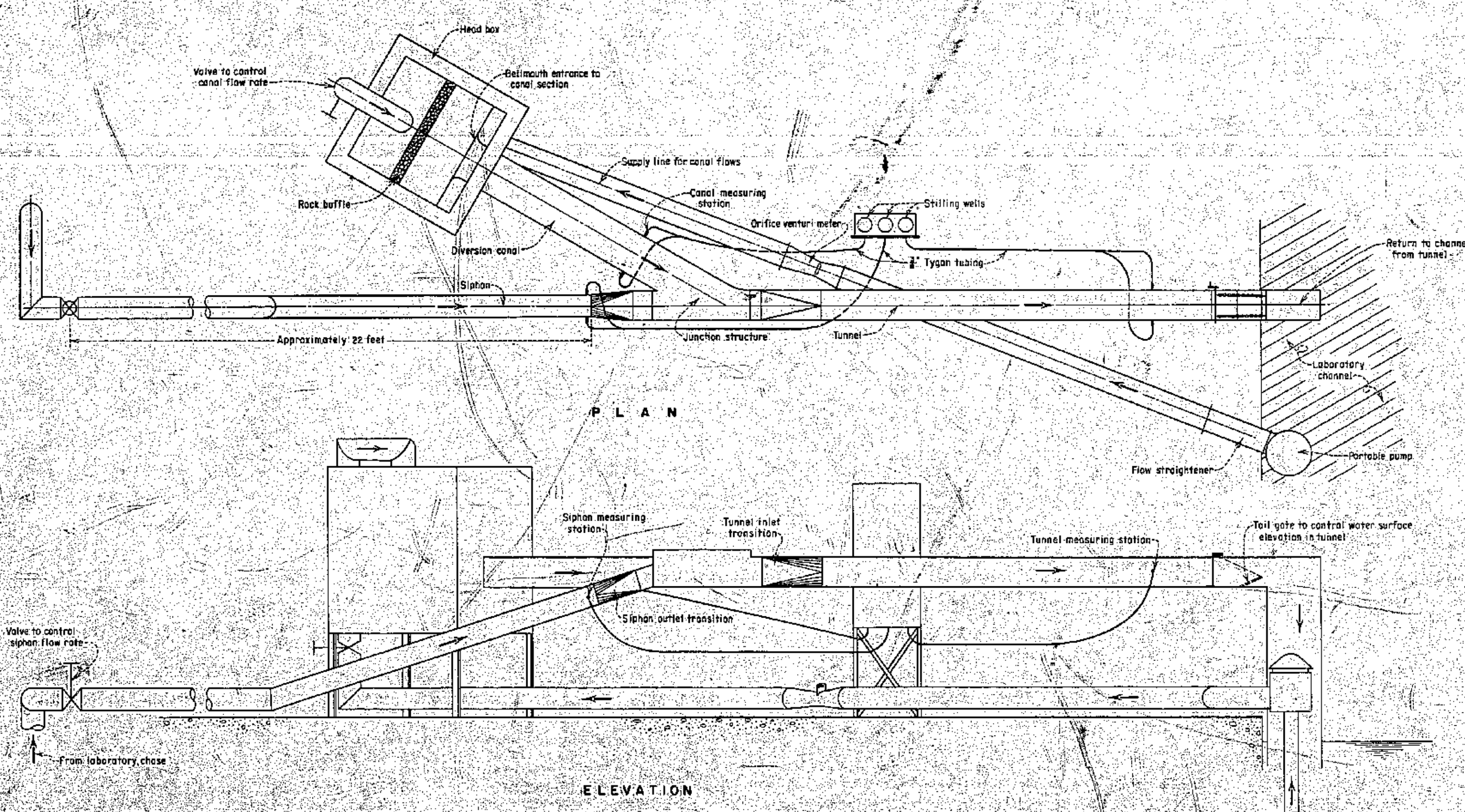


A. AZOTEA TUNNEL INLET JUNCTION
DESIGN A



B. AZOTEA TUNNEL INLET JUNCTION
DESIGN B

AZOTEA TUNNEL INLET JUNCTION
PRELIMINARY DESIGN CONFIGURATIONS
1:12 SCALE MODEL



AZOTEA TUNNEL INLET JUNCTION
MODEL LAYOUT, DESIGN A
1:12 SCALE MODEL

Figure 6
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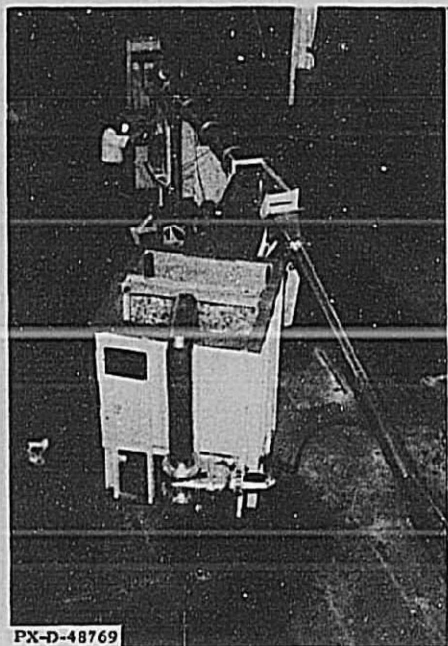
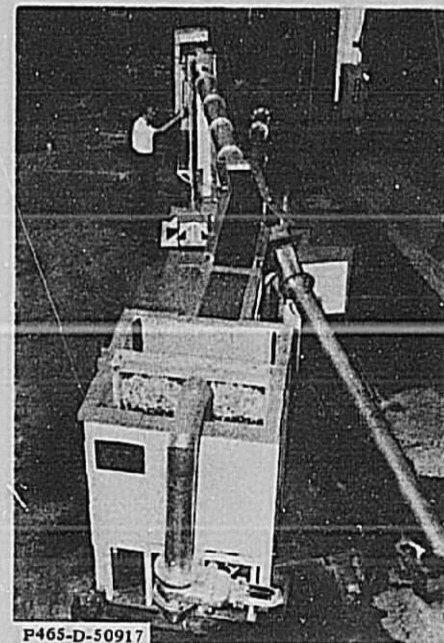
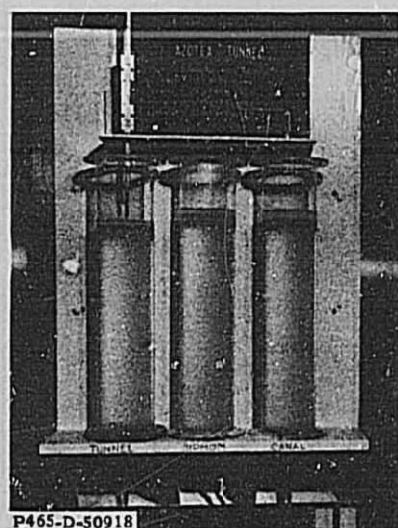


Design A



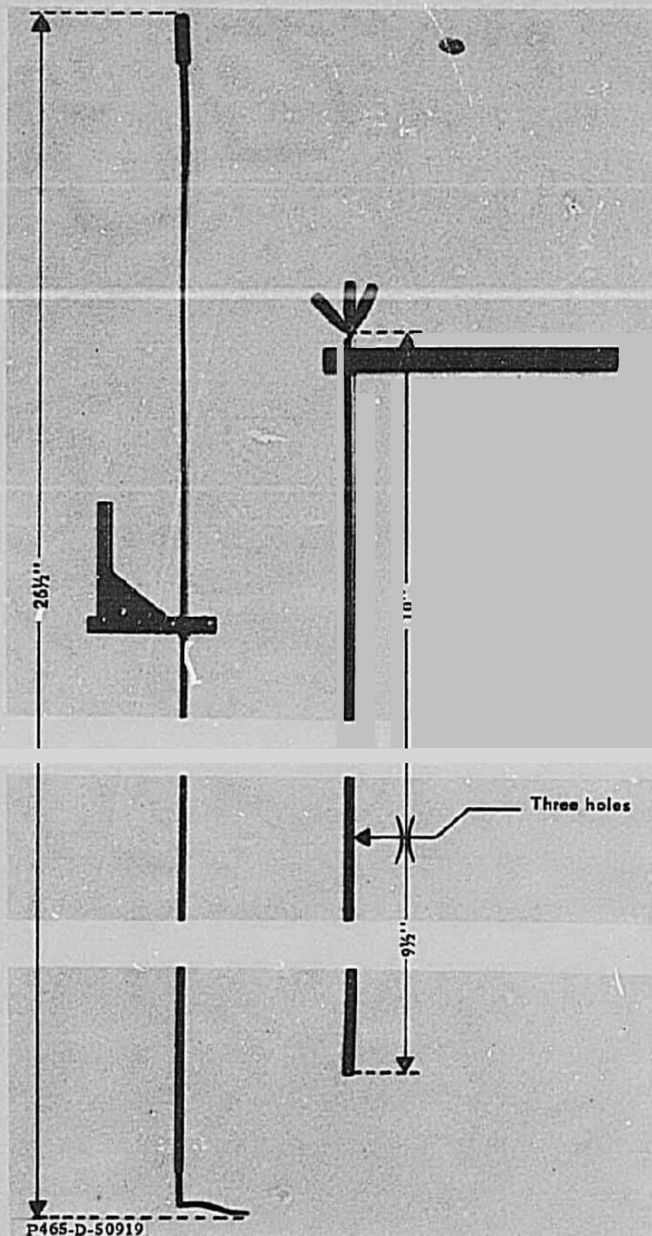
Design B



Stilling Wells for Piezometric Head Measurement

AZOTEA TUNNEL INLET JUNCTION

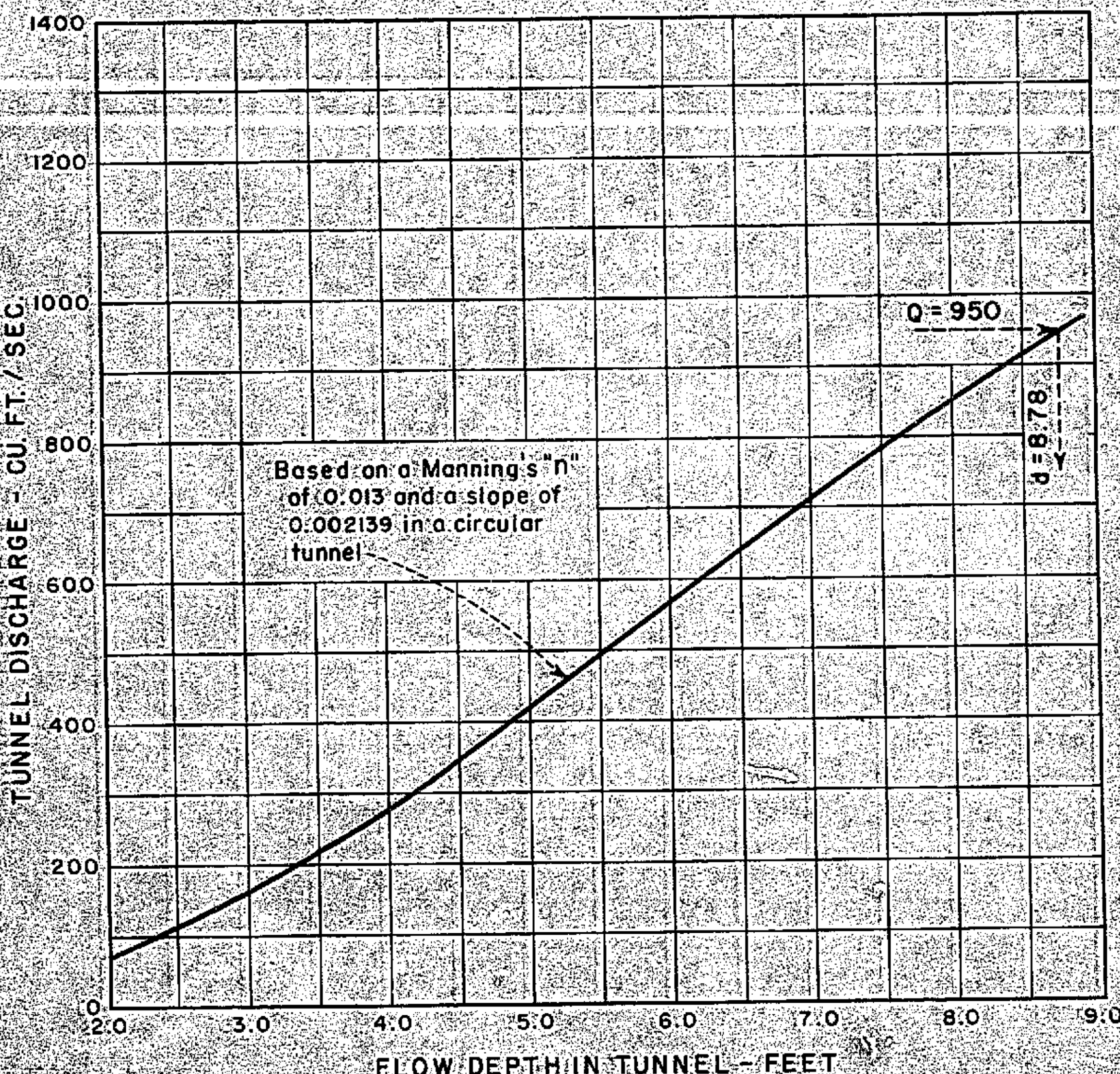
1:12 Scale Models



Boundary-layer Total-head Probe (left)
and Three-hole Cylindrical Velocity Probe (right)

AZOTEA TUNNEL INLET JUNCTION

[illegible]ad and Velocity Measurements



AZOTEA TUNNEL INLET JUNCTION

FLOW DEPTHS AT TUNNEL MEASURING STATION

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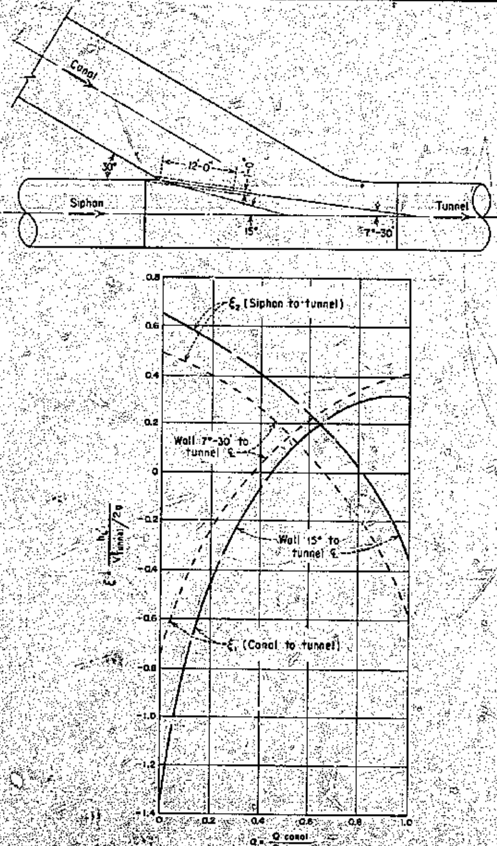
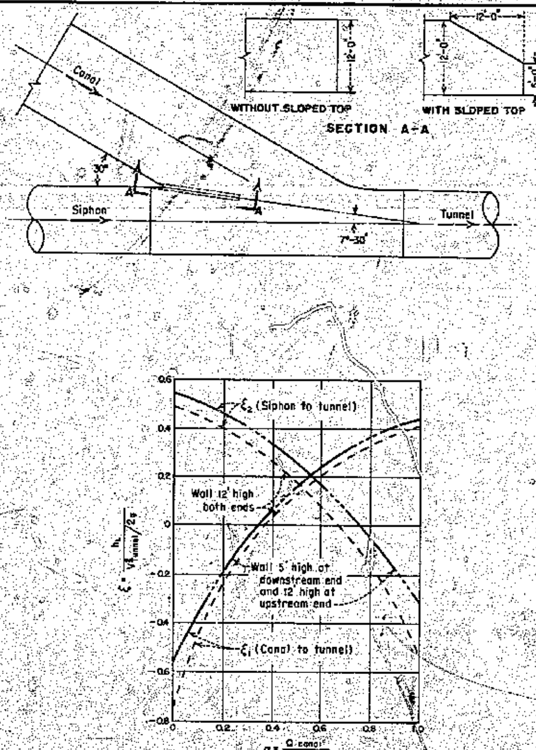
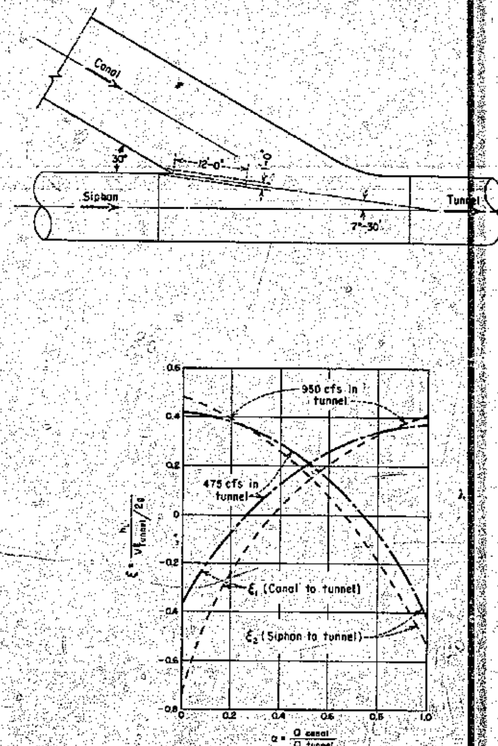


C. EFFECT OF A BEARING WALL (NOT SLOPED) ON THE LOSS COEFFICIENTS 950 CFS IN TUNNEL



D. EFFECT OF SLOPED BEARING WALL ON THE LOSS COEFFICIENTS 950 CFS IN TUNNEL

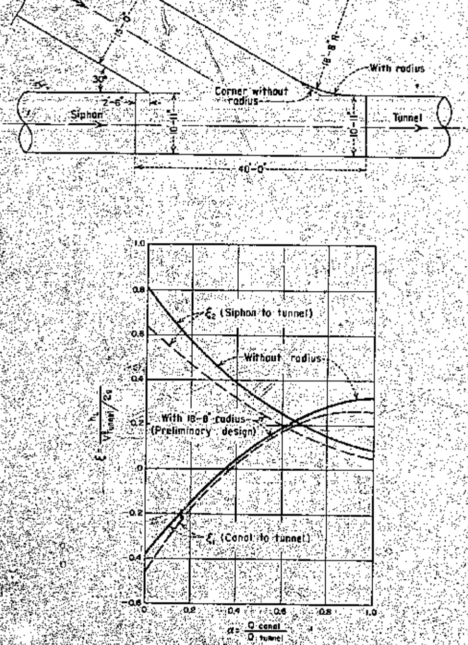


E. EFFECT OF TUNNEL DISCHARGE RATE ON THE LOSS COEFFICIENTS WITH A BEARING WALL (NOT SLOPED)

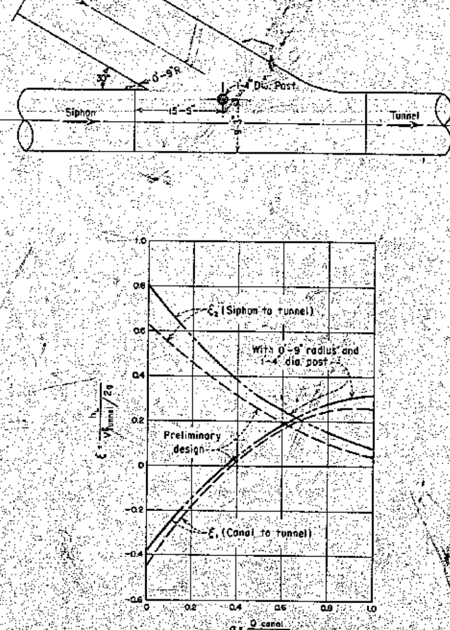
AZOTEA TUNNEL INLET JUNCTION

LOSS COEFFICIENT, DESIGN A

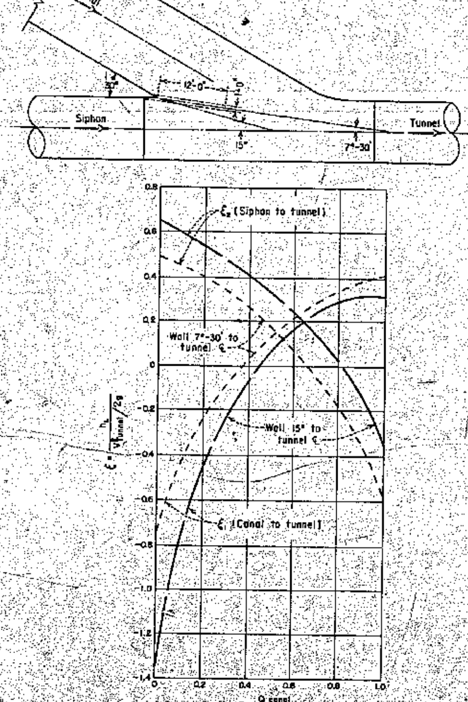
1:12 SCALE MODEL



A. EFFECT OF A SHARP CORNER BETWEEN THE TUNNEL AND THE CANAL ON THE LOSS COEFFICIENTS 950 CFS IN TUNNEL

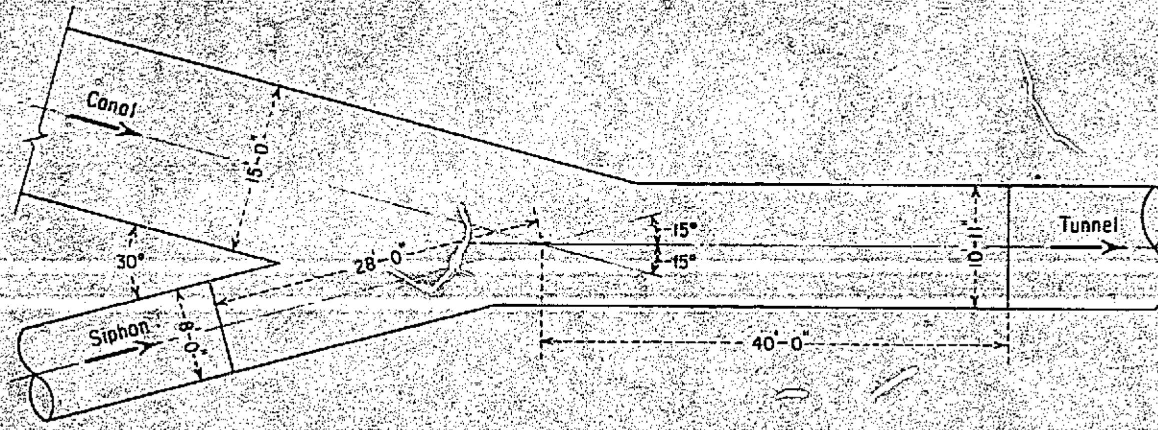


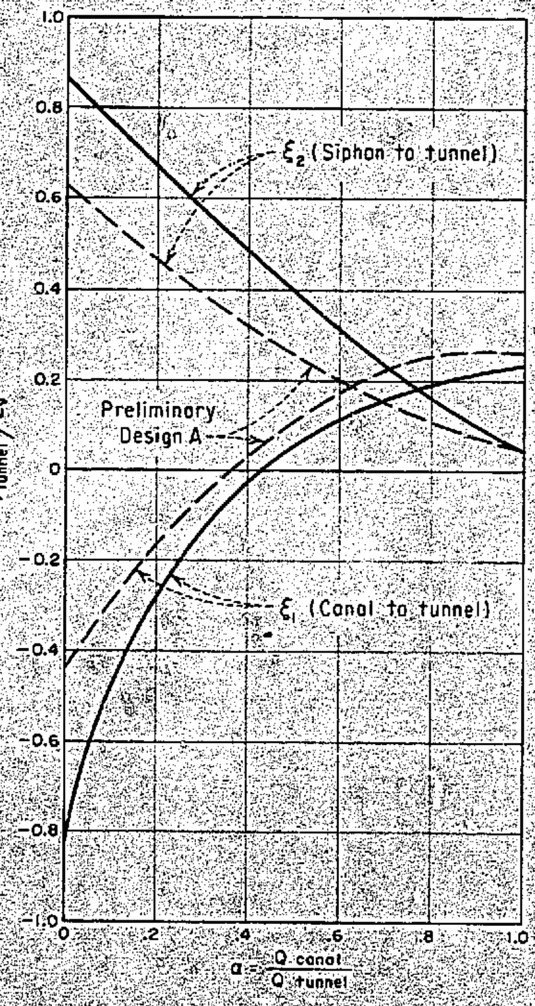
B. EFFECT OF A CIRCULAR BEARING POST ON THE LOSS COEFFICIENTS 950 CFS IN TUNNEL



C. EFFECT OF A BEARING WALL (NOT SLOPED) ON THE LOSS COEFFICIENTS 950 CFS IN TUNNEL

FRAME 2

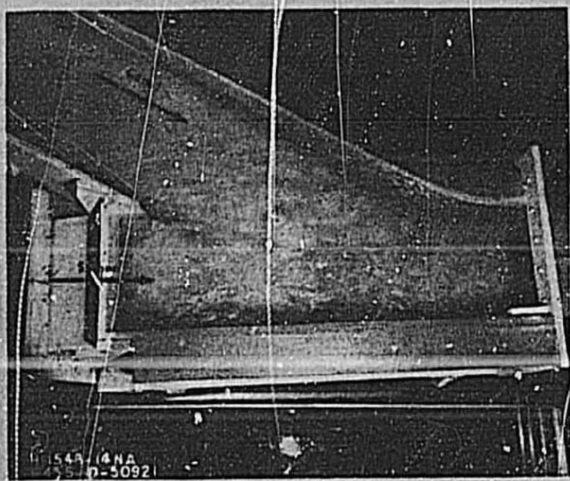




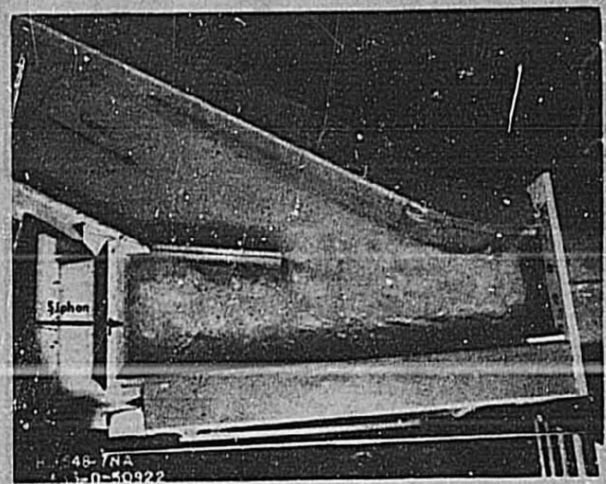
AZOTEA TUNNEL INLET JUNCTION

LOSS COEFFICIENTS, DESIGN B

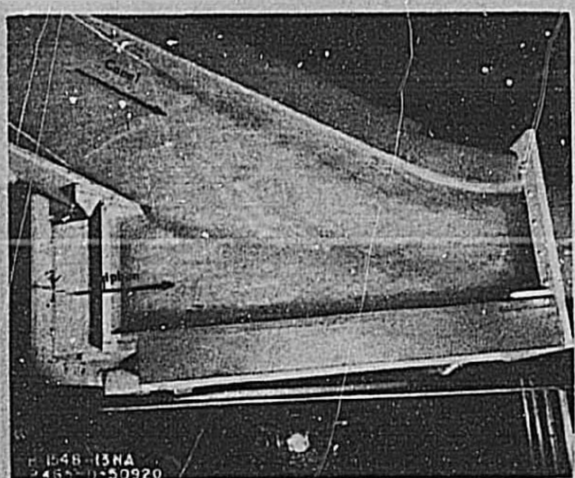
1:12 SCALE MODEL



A. Q_{canal} = 400 cfs; Q_{siphon} = 550 cfs; α = 0.421

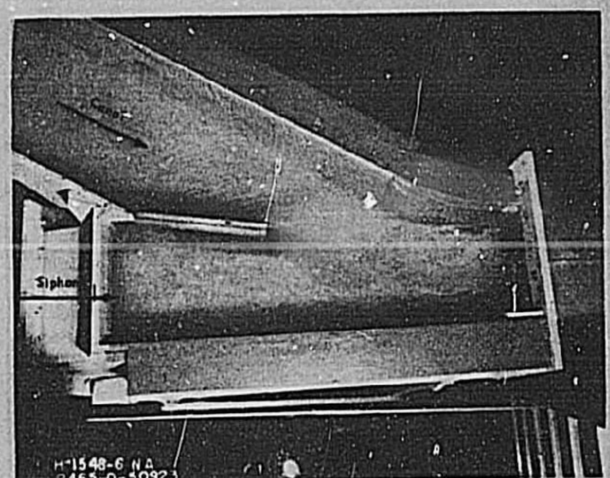


A. Q_{canal} = 400 cfs; Q_{siphon} = 550 cfs; α = 0.421



B. Q_{canal} = 650 cfs; Q_{siphon} = 300 cfs; α = 0.684

Design A



B. Q_{canal} = 650 cfs; Q_{siphon} = 300 cfs; α = 0.684

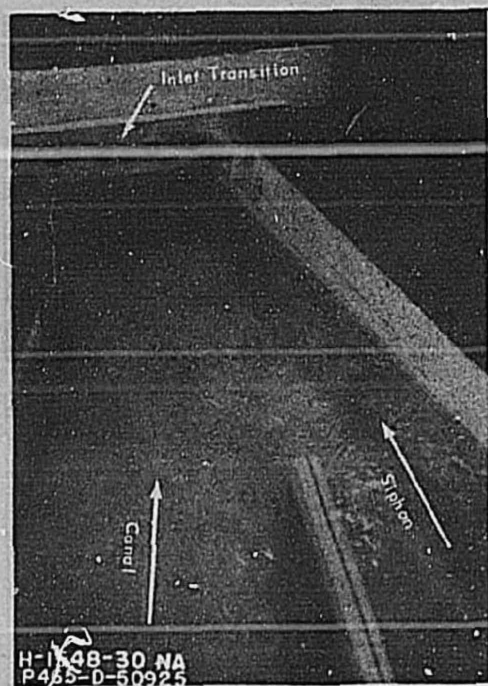
Design A with bearing wall 7-1/2° to tunnel ℄

AZOTEA TUNNEL INLET JUNCTION

Flow With and Without Bearing Wall - Design A

950 cfs in Tunnel

1:12 Scale Model



Q_{canal} = 650 cfs

Q_{siphon} = 300 cfs

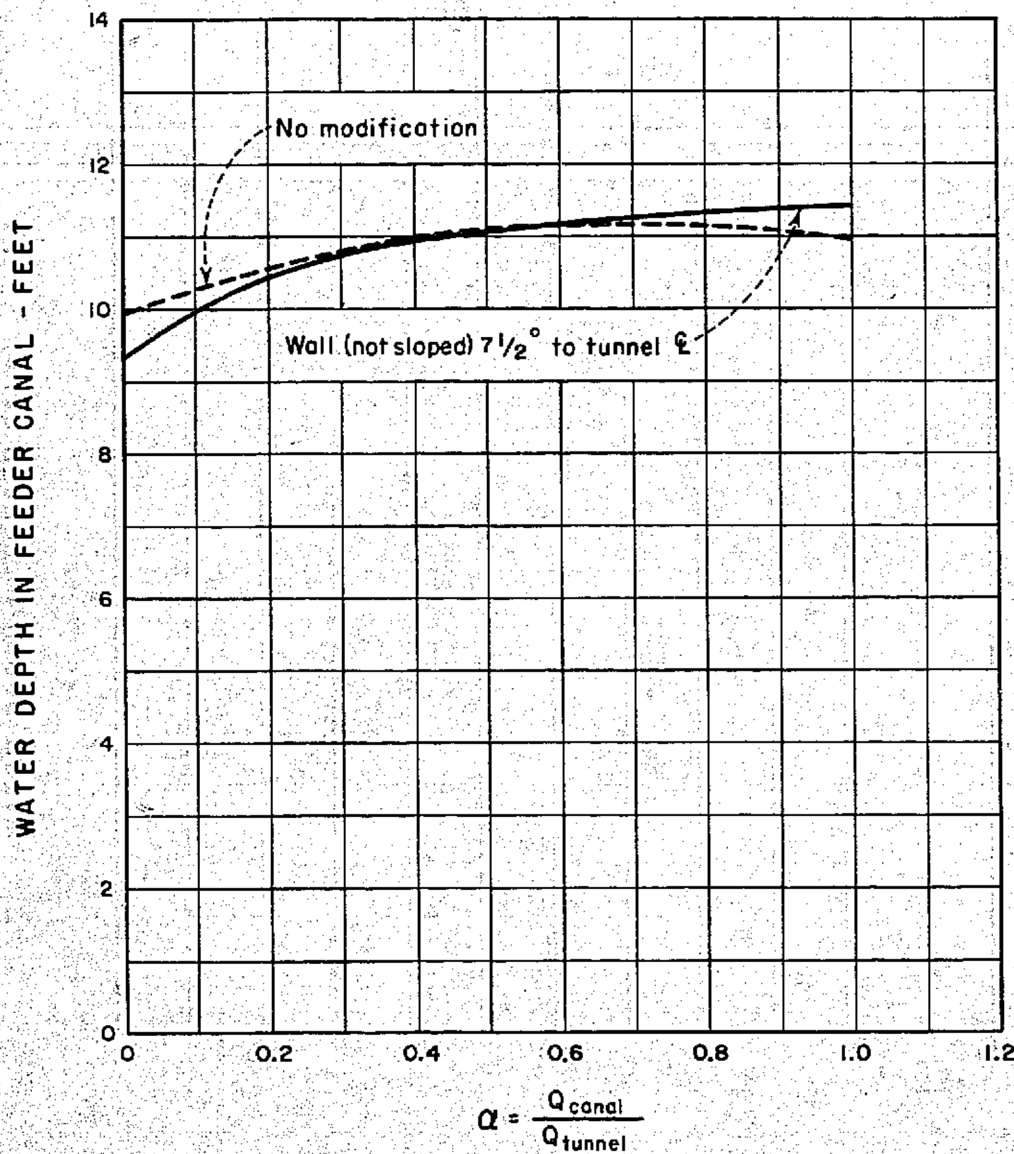
α = 0.684

AZOTEA TUNNEL INLET JUNCTION

Flow Conditions and Inlet Depth to Tunnel Transition
Design A with Bearing Wall at 15° to Tunnel

950 cfs in Tunnel

1:12 Scale Model



AZOTEA TUNNEL INLET JUNCTION

FLOW DEPTHS IN FEEDER CANAL, 950 CFS IN TUNNEL

FROM 1:12 SCALE MODEL

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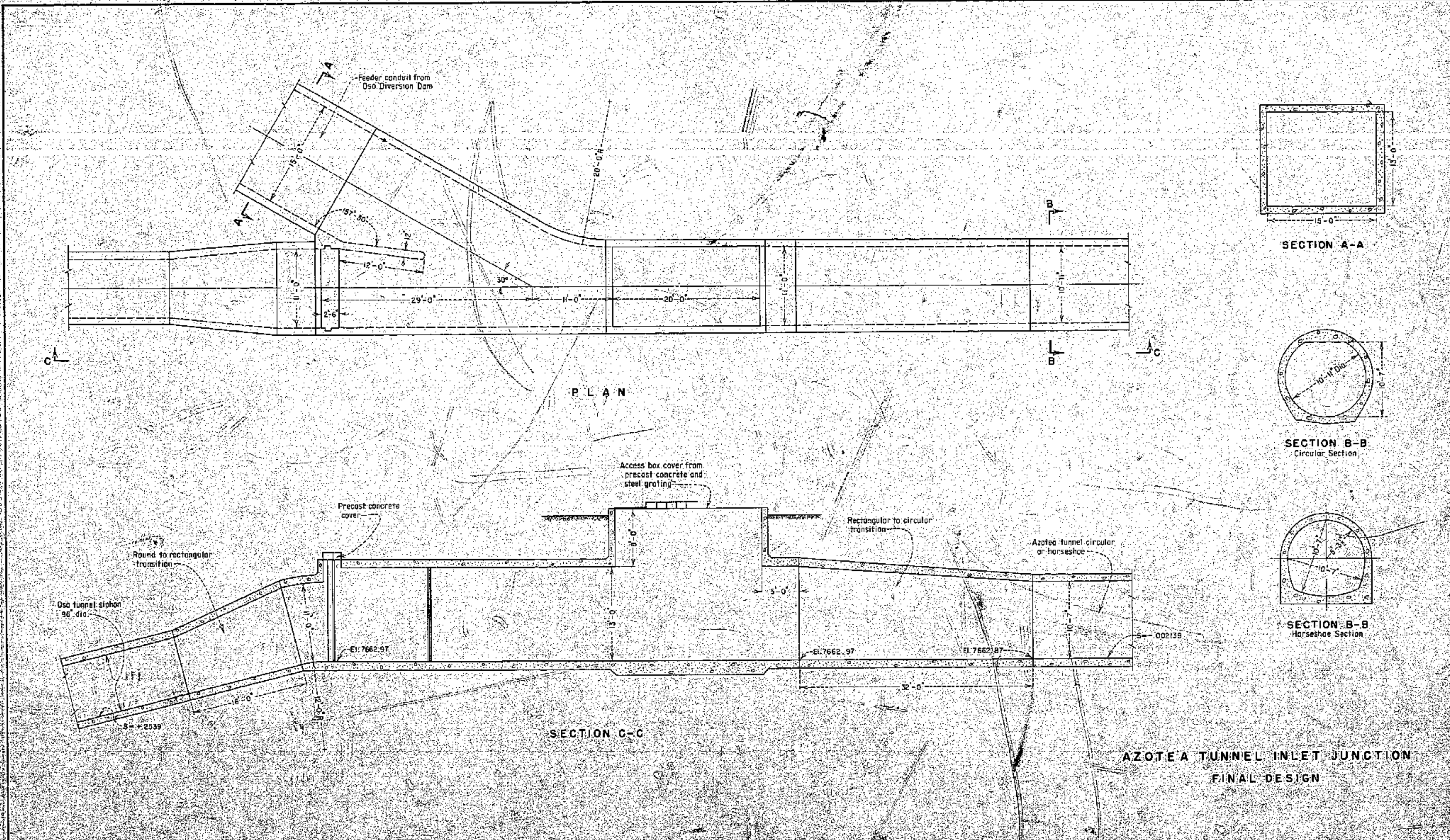


AZOTEA TUNNEL INLET JUNCTION
FINAL DESIGN

APPENDIX

APPENDIX

The energy loss through structures, which are in general similar to that of the Azotea Inlet Junction, can be approximately determined through the proper application of the Energy and Momentum Equations. The following example illustrates the method and compares the theoretical results with energy losses actually measured.

A sketch of the junction configuration and the control sections is given in Appendix Figure 1. For the purposes of this example only the loss between ① and ② will be investigated. Similar computations could be performed to determine the loss between the siphon and the tunnel or the losses with other junction geometries.

The equations which follow are restricted by the following assumptions:

1. The flow depth across AB is the same as the flow depth across BC.

2. Friction forces through the junction are negligible.

3. The water depth at the inlet to the tunnel transition can be determined from

$$y_{DE}^3 - \left[y_F^2 + \frac{Q_F^2}{g\ b_2\ A_F} \right] \cdot y_{DE} + \frac{Q_F^2}{2g\ b_2^2} = 0$$

where Y = depth

A = area

Q = discharge

g = acceleration of gravity

b = half width of rectangular section at transition inlet

The subscript refers to the station at which the quantities are measured.

This equation is obtained by writing the momentum balance between Section DE and F. To arrive at this expression one must assume:

a. The hydrostatic force in the tunnel plus the force of the transition on the water is equal to

$$\frac{1}{2} \cdot \gamma \cdot y_F^2 \cdot 2b_2$$

b. The momentum correction factor is equal to 1.0 for all combination of flows.

The problem might be stated:

Given: $b_1 = 7.50$ ft; $b_s = 5.46$ ft; $y_2 = 8.78$ ft; $d_s = 8.0$ ft

$Q_2 = 950$ cfs; tunnel dia = 10.92 ft

Find: y_F; y_{DE}; y_{AB}; y_{BC}; y_1 ; and the energy loss between ① and ② for all combinations of the flow ratio α.

The depth at y_F can be found by utilizing standard techniques for computing backwater curves. For instance the standard step method utilizing only one step gives

$$y_F = 9.21 \text{ ft}$$

when $n = 0.013$

The method is not outlined since typical examples can be found in most texts on fluid mechanics or open channel flow.

The second requirement is to find y_{DE} . This can be done by a trial and error solution of the equation given in Assumption 3. After placing the given quantities into the equation and solving for y_{DE}, one obtains

$$y_{DE} = 9.92 \text{ ft}$$

The depth at AB or BC is found by equating the momentum in the direction of the tunnel centerline to the forces in the same direction over the volume which is outlined by dashed lines.

Across AB

The momentum entering the section is

$$\frac{\beta_{AB} \cdot \rho \cdot (1-\alpha)^2 \cdot Q_2^2 \cdot \cos(17° - 40')}{2 \cdot b_s \cdot d_s}$$

where β_{AB} is the momentum correction factor at the section AB and is equal to

$$\frac{1}{A}\int\left(\frac{v}{V}\right)^2 dA$$

The force (acting downstream) on the section is

$$\frac{1}{2} \cdot 2\, b_s \cdot y_{AB}^2 \cdot \gamma$$

Across BC

The momentum entering the section is

$$\frac{\beta_{BC} \cdot \rho \cdot \alpha^2 \cdot Q_2^2 \cdot \cos 30°}{2 \cdot b_1 \cdot y_{BC}}$$

The force (acting downstream) on the section is

$$\frac{1}{2} \cdot 2\, b_1 \cdot \cos 30° \cdot \gamma \cdot y_{BC}^2$$

Across CD

Since no flow occurs across CD, the momentum is equal to zero.

The force (acting upstream) on the section is

$$\frac{1}{2} \cdot 2\, b_1 \cdot \sin 60° \cdot \left(\frac{y_{BC} + y_{DE}}{2}\right)^2 \cdot \gamma$$

Across DE

The momentum leaving the section is

$$\frac{\beta_{DE} \cdot \rho \cdot Q_2^2}{2\, b_s \cdot y_{DE}}$$

The force (acting upstream) on the section is

$$\frac{1}{2} \cdot 2\, b_s \cdot \gamma \cdot y_{DE}^2$$

The momentum and force along EA, in a direction parallel to the tunnel centerline, are equal to zero.

Thus, equating the momentum entering the control section plus the forces acting downstream with the momentum leaving the control section plus the forces acting upstream gives

$$\frac{\beta_{AB} \cdot \rho \cdot (1-\alpha)^2 \cdot Q_2^2 \cdot \cos\,(17^\circ - 40')}{2 \cdot b_s \cdot d_s} + b_s \cdot y_{AB}^2 \cdot \gamma$$

$$+ \frac{\beta_{BC} \cdot \rho \cdot \alpha^2 \cdot Q_2^2 \cdot \cos 30^\circ}{2 \cdot b_1 \cdot y_{BC}} + b_1 \cdot y_{BC}^2 \cdot \gamma \cdot \cos 30^\circ$$

$$= \frac{b_1 \cdot (y_{BC} + y_{DE})^2 \cdot \gamma \cdot \sin 60^\circ}{4} + \frac{\beta_{DE} \cdot \rho \cdot Q_2^2}{2 \cdot b_s \cdot y_{DE}}$$

$$+ b_s \cdot y_{DE}^2 \cdot \gamma \qquad \textbf{Equation (1)}$$

Substitution of the given dimensions into this equation and solving gives the de[illegible]ed depth, $y_{AB} = y_{BC}$. The only difficulty is encountered in the selection of the β values. These are dependent upon the velocity distribution in the control sections and are found to have a significant effect on the solution of Equation (1). This strong dependence upon β has several far-reaching implications. First, it shows that the loss through the junction is dependent upon the velocity distributions in the canal, the siphon, and entrance to the tunnel transition. If the distributions are significantly different from that which was produced in the model, significant variations in the loss coefficients can be expected.

Secondly, the strong dependence upon β indicates that the loss through a compound structure cannot be determined by summing the individual losses, since each component of the compound structure has an effect on the velocity distribution entering or leaving other components. Therefore, to determine the loss through compound structures, either prototype or model measurements are required; or the probable velocity distribution through the compound structure must be estimated.

In the model the following values for the momentum correction factor were obtained for Design A having no modifications

$$\beta_{AB} = 1.03; \ \beta_{BC} = 1.06; \ \beta_2 = 1.09$$

β_{DE} was found to be equal to $1.223\,(1.0 + .103\,\alpha)$ by solving Equation (1) for the ratios $\alpha = 0$ and $\alpha = 1.0$ when using depths determined from the model.

Substitution of the β values and the prototype dimensions into Equation (1) will yield the following equation after dividing by γ and simplifying:

$$11.955\, y_{AB}^2 - 1.624(y_{AB} + 9.92)^2 + 1{,}715.233\, \frac{\alpha^2}{y_{AB}}$$

$$= 537.299 + 316.491(1 + 0.360\alpha) - 314.860(1 - \alpha)^2$$

Solving this equation for y_{AB} with various values of α gives

α	0	0.25	0.50	0.75	1.00
y_{AB}	9.93	10.68	11.09	11.18	10.97

With Design No. 1 and the sharp corners on the wall between the tunnel and the canal, the momentum correction factors become:

$$\beta_{AB} = 1.03; \ \beta_{BC} = 1.06; \ \beta_{DE} = 1.338(1.0 + 0.189\,\alpha)$$

The increase in the value of β_{DE} with the sharp corner reflects the increased loss which occurred with this modification (see Figure 8).

If the results of a model study are not available, the momentum correction factors must be estimated. Reference 1 is a good source for obtaining values for established flow in canals and pipes. The values of β_{DE} obtained in this study provide guide lines for the estimation of the combined flow momentum factor downstream from a junction which is similar to the Azotea Tunnel Inlet Junction.

The depth y_1 is obtained by standard backwater curve computations. However, the reach is so short and the velocities so low, that y_1 can be assumed equal to y_{BC}.

The energy loss between the canal and the tunnel can be determined from the computed quantities by writing Bernoulli's Equation between the two points. This is

$$y_1 + \frac{V_1^2}{2g} + Z_1 = y_2 + \frac{V_2^2}{2g} + \xi_1 \frac{V_2^2}{2g} + Z_2$$

Solving for ξ_1 and letting

$$V_2 = \frac{Q_2}{A_2} \quad \text{and} \quad V_1 = \frac{\alpha Q_2}{2\, b_1\, y_1}$$

one obtains

$$\xi_1 = \frac{2g\, A_2^2}{Q_2^2}\left[y_1 - y_2 + \frac{Q_2^2}{2g}\left(\frac{\alpha^2}{4\, b_1^2\, y_1^2} - \frac{1}{A_2^2}\right) + Z_1 - Z_2\right]$$

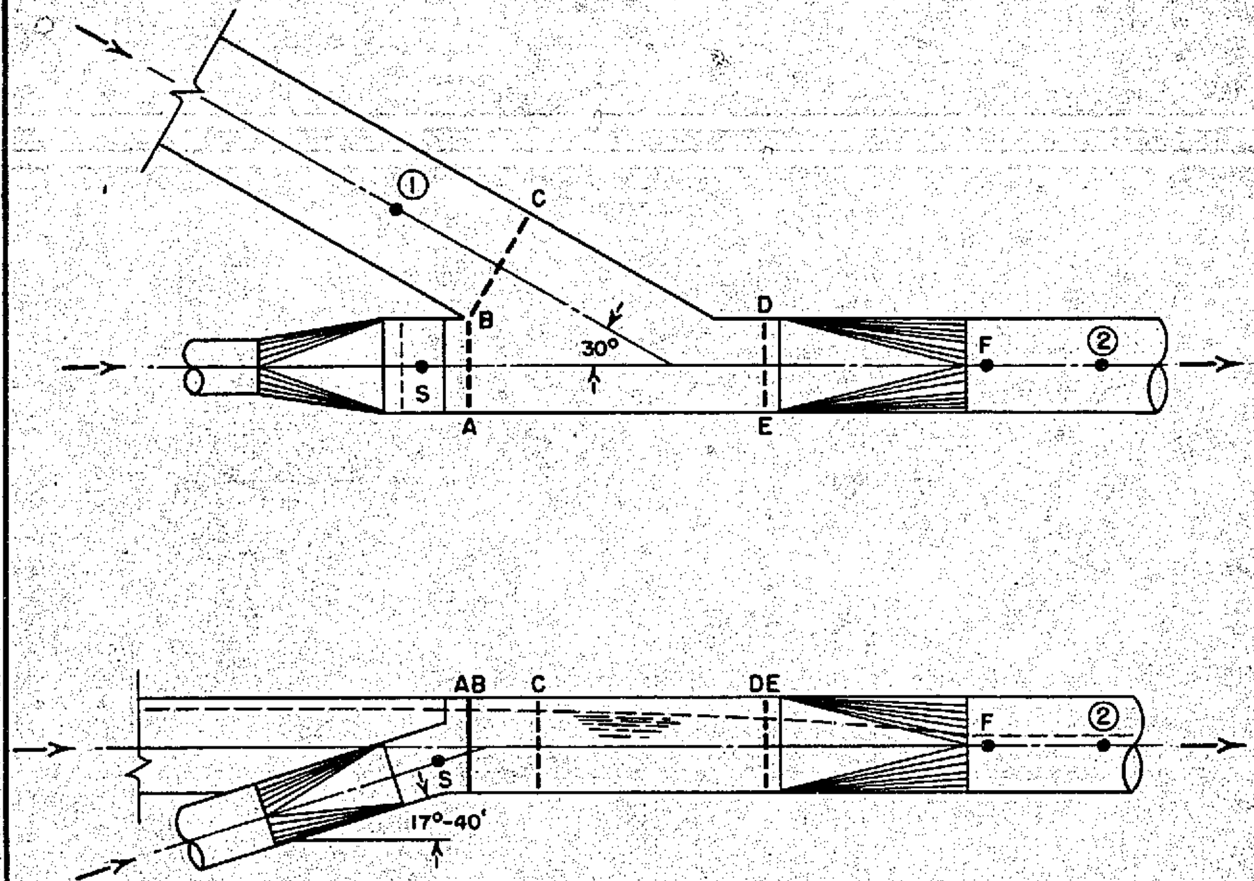
With $A_2 = 80.75\ \text{ft}^2$ and $Z_1 = Z_2$ the values of ξ_1 were determined as:

α	0	0.25	0.50	0.75	1.00
ξ_1	-0.465	-0.100	0.132	0.249	0.260

A plot of the curve as determined from these values and the experimental points for the given junction configuration are given in Appendix Figure 2. All of the experimental points fall rather close to the computed curve with one exception. No explanation for this aberration could be found.

References

1. Streeter, V. L., Kinetic Energy and Momentum Correction Factors for Pipes and for Open Channels of Great Width, Civil Engineering, Vol. 12, n4, April 1942, pp 212-213.



AZOTEA TUNNEL INLET JUNCTION

CONTROL SECTION DEFINITION SKETCH

DESIGN A, NO MODIFICATIONS

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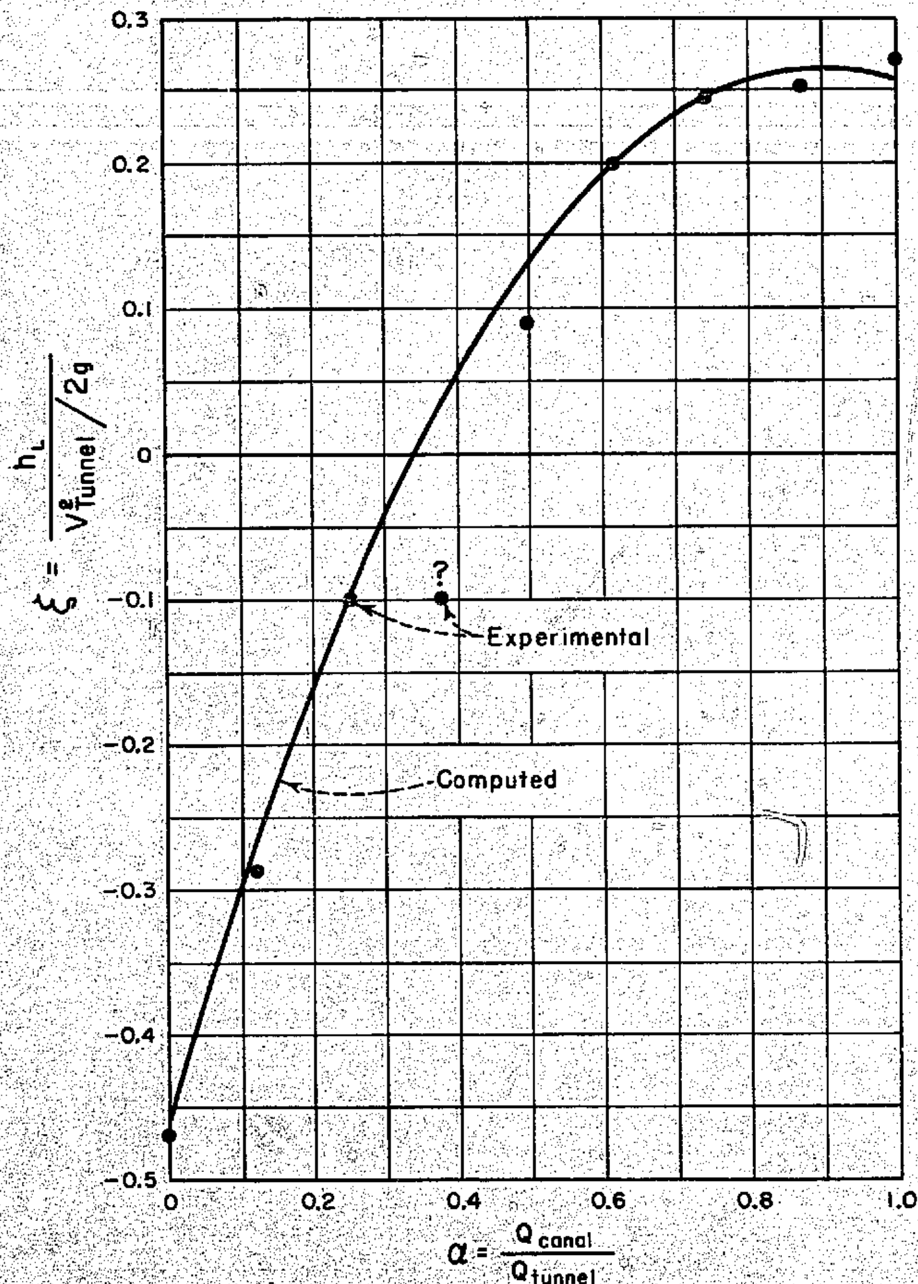

AZOTEA TUNNEL INLET JUNCTION

COMPARISON OF COMPUTED LOSS CURVE WITH EXPERIMENTAL DATA

DESIGN A, NO MODIFICATIONS

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CONVERSION FACTORS--BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, 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

GPO 845-237

ABSTRACT

Hydraulic model studies were performed on a 1:12 scale model of the Azotea Tunnel Inlet Junction to find a configuration which would minimize head losses through the junction, to determine critical dimensions of the structure, and to establish canal water depths. The purpose of the junction is to combine the flow from a feeder canal with that from the Oso Tunnel inverted siphon and direct this combined flow into the Azotea Tunnel. The recommended design minimized head losses between the siphon and the tunnel by means of a bearing wall placed in the flow stream which accelerated the flow leaving the canal, thereby making the uniting flow velocities from the canal and the siphon almost equal. This significantly reduced eddy formation and tended to eliminate retardation of the siphon flow. The bearing wall also reduces the span length of a roof over the inlet junction. The flow conditions with this configuration were good over a large range of siphon, canal, and tunnel discharges. Fairly accurate estimates of losses through a system which is not geometrically similar to the Azotea inlet junction can be obtained by application of momentum and energy equations over two control sections. An example of this procedure is given in the appendix to the report.

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Hyd-551
Falvey, H. T.
HYDRAULIC MODEL STUDIES OF THE AZOTEA TUNNEL INLET JUNCTION, SAN JUAN-CHAMA PROJECT, COLORADO
Bureau of Reclamation, Hydraulics Branch, Denver, 45 p, including 16 fig, 1 ref, append, November 1965

DESCRIPTORS-- hydraulics/ *model tests/ *hydraulic models/ *head losses/ *hydraulic structures/ canals/ siphons/ tunnels/ *water surface profiles/ open channel flow/ inlets/ velocity/ coefficients/ momentum/ discharges
IDENTIFIERS-- Azotea Tunnel, Colo/ San Juan-Chama Proj, Colo/ flow junctions

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