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Model study of corrective design for the little pine creek outlet structure, March 1952

M. B. McPherson

H. S. Strausser

J. O. Liebig

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MODEL STUDY OF A CORRECTIVE DESIGN
FOR THE LITTLE PINE CREEK OUTLET STRUCTURE

by

M. B. McPherson, with H. S. Strausser and J. O. Liebig

for

Justin and Courtney, Consulting Engineers,
Philadelphia

The Hydraulic Laboratory
Fritz Engineering Laboratory
Dept. of Civil Engineering & Mechanics
Lehigh University
Bethlehem, Penna.

F. L. Project No. 228 1 March 1952
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I - INTRODUCTION

In October of 1948, Professor William J. Eney, Head of the Department of Civil Engineering and Mechanics and Director of Fritz Laboratory, was contacted by Mr. C. E. Ryder of Gannett, Fleming, Corddry and Carpenter, Inc. and requested to make a model study of the Little Pine Creek outlet structure which had been designed by this consulting firm. Since construction of the prototype was to begin in a short time, only certain characteristics of the model could be investigated. A report was submitted to the consultants on November 29, 1949 entitled, "Model Study of the Little Pine Creek Dam Outlet Structure" by M. B. McPherson, hereinafter referred to as "the 1949 Tests". This study was confined to the determination of the effect of the trash rack on the control tower orifice discharge. A summary of these test results appeared in the August 1950 issue of CIVIL ENGINEERING Magazine entitled, "Design of Dam Outlet Trash Rack Verified by Model Tests", by M. B. McPherson.

Damage to the outlet tower was sustained during two large floods in the Winter of 1950. (Dam Completed in 1950). A discussion of the cause and extent of damage, and suggested remedial measures are included in a report to Gannett, Fleming, Corddry and Carpenter, Inc. on 6 August 1951 entitled "Comprehensive Model Study of the Little Pine Creek Dam Outlet Structure", by M. B. McPherson, hereinafter referred to as"the 1951 Tests". The immediate cause of damage to the tower in 1950 was shown to result from the action of cavitation. Prevailing
pressures within the tower ("back-pressure") were insufficient, in combination with the high velocity of flow leaving the control orifice (where it entered the tower), to prevent vaporization. The objective of remedial measures sought in the 1951 tests was the elimination, or at least a substantial minimization, of future damage at all rates of flow consistent with economy. The resultant proposal, made jointly by the writer and the sponsoring firm, featured an 11-foot diameter orifice plate at the end of the outlet conduit, and moderate revision to the outlet stilling pool necessitated by the higher velocities emerging from an orifice-plate. (See report by Mr. C. E. Ryder, dated July 1951 to the General State Authority).

The probably unprecedented revision thus proposed was received with a certain degree of understandable skepticism by the engineers representing the Commonwealth. As a result, Justin and Courtney were retained to review the proposed revision. A design proposed as a result of their study includes a steel conduit of 8.5-foot diameter centered within the present 15-foot diameter conduit, joined to the tower control orifice by an eccentric elbow located within the tower. As pointed out by Mr. Courtney, ("Welded Steel Penstocks—Design and Construction", by C. J. Bier, U. S. Dept. of Interior Engin. Monogram No. 3), there is proven precedent for this latter design. This design was considered to be better hydraulically and would actually increase the safety of the present concrete conduit as opposed to the 1951 proposal in which the concrete conduit would have been subjected to greater hydrostatic loading than previously existed. The estimated cost of the 1952 proposal is approximately twice the estimated cost of the 1951 proposal.
II - SYNOPSIS

The main objective of the model study outlined in this report was to determine the trend and magnitude of minimum pressures within the proposed eccentric bend. Necessary corollaries were the determination of the losses within the bend and visual confirmation of the presence or absence of vaporization. The performance of a 21° bend, located at the terminus of the conduit (modification of 1951 orifice-plate alignment), plus the effect of the high kinetic energy emanating from this bend were investigated using the scaled 1:24 model stilling pool built for the 1951 tests.

Within the predictable accuracy of prototype performance no overall cavitation is anticipated with this design. Local cavitation would probably occur at any predominant malalignments in the fabricated steel bend and conduit. If the stilling pool revision proposed as a result of the 1951 tests is used with this design, no functional difficulties are anticipated.

Whereas the design arising from the 1951 tests was less costly, it was admittedly marginal with respect to a satisfactory hydraulic performance. The safety, hydraulically, of the present design is inherently greater. The maximum discharge anticipated for the 1951 design was 3,800 c.f.s.; the maximum anticipated discharge for this design is about 2900 c.f.s. The original design maximum discharge was 5,000 c.f.s.
III - 1:34 SCALED MODEL

A. Description.

A drawing of the proposed design is given in Figure 22. Details of the model tower, orifice, bend and conduit in relation to the entrance tank used are shown in Figure 1. Photographs of the model installation are included in Figures 2 and 3. The scale ratio used was determined by consideration of laboratory piping losses and available plastic pipe sizes.

The only departure from prototype conditions was a concession to facility of construction: the tower proper was replaced with a diaphragm-plate. No currents could originate below El.710 and travel in an upwards direction. However, the velocities through the trash rack piers are so small that this effect is negligible.

The model was made to scale, but full prototype heads (and hence velocities) were obtained. The maximum difference in elevation in the model was therefore a negligible quantity, and the model tower was positioned on its side for convenience in testing.

The length of conduit used was equal to only 300-feet (9' x 34) of the prototype 620-feet of 8.5-foot diameter conduit. This short length was used so that all reasonable values of prototype pipe friction could be simulated (for a given velocity, model head loss per foot would be higher, even though the model conduit was much smoother). This nine-foot model pipe length was equivalent to a prototype length of about 400-feet in terms of prototype pipe friction loss, for a medium-smooth surface. A gate valve near the end of the line provided a means of adjusting the conduit head loss to any value which...
might be anticipated for the prototype.

From the gate valve flow entered the side of a weir tank upstream from a series of baffles. Since the conduit velocities were as high as 53 feet-per-second, some disturbance occurred in the area immediately upstream from the weir used to determine discharge. This disturbance was not great and the rates of flow thus measured should be within an accuracy of plus or minus 5-percent.

A specially cast bronze elbow, carefully polished inside, was equipped with 20 piezometer taps located on the inside, outside, and either side of the center-line of the elbow. Six taps were provided in the conduit proper. These taps were connected to a manometer manifold built for the 1951 tests.

The conduit, trash rack and plate containing the control orifice were made of plastic so that the presence of vapor, if any, could be observed.

Each part was fabricated in such a way that major changes in design could be accommodated with a minimum of time and effort.

The 4-foot diameter header tank was used to provide conditions of flow as quiescent as possible near the trash rack.

B. Preliminary Tests.

Seven runs were made on the 26th of January to check model performance. Two additional runs were made on the 30th of January. During these latter tests one member of the header tank gave way and had to be replaced. These latter runs were made to determine the minimum head loss for the model (control gate-valve wide open). These nine runs were essential to more accurate setting of future runs, since the head loss through the
bend was thus established.

In a non-eccentric 90-degree bend the minimum pressure usually occurs on the inside radius at the 45° point. The preliminary tests indicated that the minimum pressure would always occur at the 60-degree point (60-degrees from lip of orifice – El.704).

On January 31 and February 2 nine runs were made, in an attempt to obtain average conditions of pipe friction losses anticipated by Justin and Courtney in their report to the Commonwealth on 27 September 1951. The most important data of these tests are given in the following table:

**TABLE ONE**

<table>
<thead>
<tr>
<th>Run</th>
<th>Q (prot.) c.f.s.</th>
<th>Total Head above El.686</th>
<th>Prototype Minimum Pressure Head at 60-degree point, El.695.1</th>
</tr>
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<tbody>
<tr>
<td>10</td>
<td>1975</td>
<td>42.5 feet</td>
<td>- 1.7 feet</td>
</tr>
<tr>
<td>11</td>
<td>2140</td>
<td>50.4</td>
<td>- 1.5</td>
</tr>
<tr>
<td>12</td>
<td>2220</td>
<td>54.5</td>
<td>- 0.9</td>
</tr>
<tr>
<td>13</td>
<td>2310</td>
<td>61.0</td>
<td>- 0.1</td>
</tr>
<tr>
<td>14</td>
<td>2480</td>
<td>67.0</td>
<td>- 0.5</td>
</tr>
<tr>
<td>15</td>
<td>2520</td>
<td>~71.</td>
<td>+ 1.0</td>
</tr>
<tr>
<td>16</td>
<td>2620</td>
<td>~78.</td>
<td>+ 1.5</td>
</tr>
<tr>
<td>17</td>
<td>2790</td>
<td>~89.</td>
<td>+ 2.5</td>
</tr>
<tr>
<td>18</td>
<td>3000</td>
<td>~99.</td>
<td>+ 3.2</td>
</tr>
</tbody>
</table>
IV - UPPER LIMIT TESTS ON 1:34 MODEL

A. Justin and Courtney Upper Limit.

The bend loss (see next section) was found to be quite close to that assumed as an average by Justin and Courtney in their report of 27 September 1951. Calculations of prototype pipe friction for quite smooth surfaces indicated that the prototype discharge could not conceivably exceed the upper limit which they had calculated. Test Runs 19 to 26 were made on the 9th of February, tracing this Upper Limit (see Figure Four), to determine the lowest conceivable values of pressure head in the bend. (Total Head is the height to reservoir water surface above El.686, the center-line of the conduit at exit.)

(At a high head, gross deflection of the rear header tank diaphragm interrupted tests at Run 27. Run 18 was pertinent to the trace, however, and duplication was not deemed necessary. The diaphragm was reinforced on the 12th of February.)

Plots of pertinent data for Runs 18 to 26 are given in Figures 9 to 17.

B. Bend Loss.

The loss of head attributable to change of direction of flow is plotted against discharge in Figure Five. For each point plotted a deduction from the gross head loss has been made for a length of 8.5-foot diameter pipe equal to the center-line arc length of the bend. In computations, therefore, the length of 8.5-foot conduit subjected to pipe friction loss becomes approximately 640-feet. Inasmuch as the bend reduces in diameter from 9.5-feet to 8.5-feet, the head loss was expressed in terms of discharge rather than the velocity at a given cross-section.
C. Probable Prototype Discharge.

In Figure Six are plotted the upper limit curve and five curves calculated for various degrees of pipe roughness. (Total head is the height to reservoir water surface above El.686, the center-line of the conduit at exit.) For pipe friction, a length of 8.5-foot conduit of 640-feet was used, as noted in Section B, above. The relationship for loss of head through the trash rack and control orifice was determined in the 1949 tests. To be on the ultra-conservative side, no loss was included for the 22-degree bend located at the terminus of the conduit.

These curves compared to the curve for the Upper Limit (Runs 18 to 26) prove that should the prototype conduit roughness as installed equal or exceed that for wrought iron the resulting discharge will be less than that defined by the Upper Limit. Since the minimum pressures in the bend are directly related to the magnitude of total losses, and hence discharge, it becomes evident that the lowest pressures measured in the model for Upper Limit discharges should not be exceeded in the prototype. The eccentric bend loss will be lower in the prototype than in the model, but even if this loss is assumed to be zero, the Upper Limit remains as a reasonable envelope of prototype discharge.

(The Curve for Maximum Discharge Possible with Model is included to show that any conceivable combination of losses could have been duplicated in the model.)

D. Minimum Pressure Head.

The maximum head-discharge having been established as being closely represented by the Upper Limit, the pressures measured for Runs 18 to 26 should be reasonably close to those which
would occur in the prototype. The minimum piezometric head occurred at Run 19, -0.8-feet. Since the 60-degree point on the inside of the bend would be at Elevation 695.1, the pressure head at this point of lowest value would be the piezometric head less 9.1-feet. A plot of these values against total head is given in Figure Seven. It will be noted that the lowest value is -9.9 feet of water, at Water Surface El.717, which is a head of only seven feet over the face of the control orifice and the water surface would be situated one foot beneath the top slab of the tower. It is extremely doubtful that a pressure as low as -10 feet could occur at this low head in the prototype since the lower heads of the Upper Limit represent the most conservative conditions of range of discharge (see Figure Six). The point of transition between pipe flow and aerated flow could not be determined with the model tested.

Under the most extreme assumptions in calculation, the writer can find no realistic way in which the minimum pressure head could approach as much as -25 feet of water. Thus it becomes apparent that no cavitation as a direct result of curvature is conceivably possible. This does not preclude the absolute possibility of local cavitation and concurrent damage in the vicinity of malalignments in the bend or conduit. 

E. Witnessing of Model Performance.

Mr. Justin and Mr. Courtney witnessed the 1:34 model performance following the preliminary tests and the upper limit tests.

On Saturday, the 16th of February, the upper limit curve was traced to a total head of 70-feet in the presence of the following engineers:
Mr. Jones and Mr. Connelly of the General State Authority; Mr. Thomas, Mr. Spengler and Mr. Mathews of the Department of Forests and Waters; Mr. Ryder and Mr. Romano of Gannett, Fleming, Corddry and Carpenter, and Mr. Justin and Mr. Courtney.

These engineers also witnessed the performance of the 1:24 model stilling pool for conditions illustrated with photographs in this report and described in Section VI.
V - PREDICTION OF MINIMUM PRESSURE HEAD

The difference in piezometric head across an elbow at a given center-line station has been shown to be a function of the kinetic head of the average velocity. This relationship is the basis of formulation for an elbow meter, and is usually expressed as:

\[ \Delta h_e = C_k \frac{V_{ave}^2}{2g} \]

Using the velocity, average, for a diameter of 8.83-feet (2/3rds of difference between 9.5-foot and 8.5-foot diameter, at 60° from P.C. of bend), the average value of \( C_k \) at the 60-degree point was 1.51 for 25 runs. The divergence in value for any run did not exceed 4-percent of this average. If potential (frictionless) flow is assumed, where \( vr = K = \) a constant, and \( V_i \) is defined as the velocity at the inner wall and \( V_o \) as the velocity of the outer wall, then

\[ \Delta h_e = \frac{V_i^2 - V_o^2}{2g} \]

or

\[ C_k = \frac{\Delta h_e}{\frac{V_{ave}^2}{2g}} = \frac{V_i^2 - V_o^2}{2g} = \frac{V_{ave}^2}{2g} \]

or, in this instance, 1.51 \( V_{ave}^2 \) = \( \left( \frac{K}{R_1} \right)^2 - \left( \frac{K}{R_o} \right)^2 \)

where \( R_1 \) = the radius to the inside of the bend and \( R_o \) =
the radius to the outside of the bend. With \( R_1 = 9.75 \) -feet and \( R_o = 19.25 \) -feet, this reduces to \( \frac{K}{V_{8.83}} = 13.88 \), or

\[
V_1 = 1.425 \frac{V_{8.83}}{V_{8.83}} \quad (\text{and} \quad V_o = 0.720 \frac{V_{8.83}}{V_{8.83}})\]

For any discharge it is therefore possible to calculate the velocity head at the point of lowest pressure in the bend. Writing the energy equation between the point of minimum pressure (centerline station 16 + 38) and the point of exit from the conduit (about Sta. 22 + 58):

\[
\frac{V_1^2}{2g} + \frac{P_1}{\gamma} + \text{El.6951} = \frac{V_{8.83}^2}{2g} + h_L \text{ (friction for 620' pipe)} + h_L \text{ (bend)} + \frac{\text{El.686}}{3}.
\]

(In the above equation the loss for the 22-degree exit bend is neglected.) To use the model data, the piezometric head at Station 16 + 38 for pipe friction alone was used for convenience (see Figure Ten, *). Designating this head as \( \left( \frac{P}{\gamma} + h \right)_f \), the total energy at this point in the model is approximately:

\[
\frac{V_{8.83}^2}{2g} + \left( \frac{P}{\gamma} + h \right)_f + \frac{h_L \text{ (elbow)}}{3},
\]

and equals \( \frac{V_1^2}{2g} + \frac{P_1}{\gamma} + h_1 \)

or, \( \left( \frac{P_1}{\gamma} \right)_{\text{calc.}} = \frac{V_{8.83}^2}{2g} + \left( \frac{P}{\gamma} + h \right)_f + \frac{h_{Le}}{3} - \frac{V_1^2}{2g} \)

In Figure Eight are plotted actual versus calculated values of minimum piezometric head. The assumption of potential flow appears to be quite valid. In the model, piezometric head is
identical with pressure head because of the small differences in elevation. For prototype calculations, the prototype elevations cannot be likewise disregarded. Thus, calculated or actual minimum piezometric head values for the model must be corrected for elevation, or:

\[
\left( \frac{P_i + h_i}{\gamma} \right)_{\text{model}} = \left( \frac{P_i}{\gamma} \right)_{\text{model}} = \left( \frac{P_i}{\gamma} \right)_{\text{prot.}} + 695.1 - 686.0
\]

In Figure Seven, the pressure heads shown represent, therefore, the piezometric heads indicated in the plots of Figures 9-17 less 9.1-feet.
VI - PERFORMANCE OF STILLING POOL

The 1:24 scale model stilling pool made for the 1951 tests was connected to the laboratory piping system with a short length of 4-1/4-inch (8.5 feet) plastic pipe. (See Figure 18). A special plastic bend, a reproduction of the bend specified in Figure 22, was fabricated and mounted at the end of the conduit. This bend was oriented with a 20-degree horizontal angle and a 7-degree vertical angle. This corresponds to the angles at which the orifice-plate was set in the 1951 tests. The plumbing arrangement available at the time was tolerated since only flows at or near 2900 c.f.s. (1.025 c.f.s.) were to be investigated. It was expected that the stilling pool modification recommended as a result of the 1951 tests would be required for this design also, since the kinetic energy involved is of about the same magnitude.

Figure 19 shows the flow conditions with the existing (approximately as-built) stilling pool with an equivalent discharge of 2900 c.f.s. At an equivalent discharge of 1800 c.f.s. the conditions in the pool were not good, but the main body of water remained in the pool. At a discharge equivalent to 2400 c.f.s. the jet forced the stilled water out of the pool.

Figure 20 shows flow conditions with the stilling pool floor recommended in the tests of 1951 (see Figures 22, 38, 39 in 1951 Report, and compare Figure 20 of this report with Figures 40 and 41). The jet impinging on the auxiliary sill is quite strong. The flow over the end weir is not uniform. However, there is a tendency for the flow along the inner wall of the 22-degree bend to separate from the wall, precluding the
possibility of increasing this angle to obtain more uniformity of flow-depth over the weir. A comparison of photographs will indicate the necessity of excavating the stilling pool.

In Figure 21 the panel representing the auxiliary sill, and rock to within 3-feet of walls and end weir, were removed (excavation to El.667, three-feet from all known existing exposed concrete faces) at the request of Mr. Courtney to show what the flow might be like if the auxiliary sill were destroyed and the rock between El.667 and 672 was removed by the action of the jet. Were this to happen, it may be noted that the flow would still be in the pool, although the conditions will not be as satisfactory as those shown in Figure 20.

As in the 1951 tests, no consideration was allowed for backwater inasmuch as no field data is available.
VII - SUMMARY AND CONCLUSIONS

The minimum pressure head in the prototype may be calculated for any combination of circumstances, using information determined in these tests. The 90-degree bend loss has been determined also, although the prototype loss may be very slightly less than that determined with the model. The only significant unknown is the pipe friction head loss in the prototype; the results of calculations included in this report show that under worst conditions (smallest head loss, smoothest pipe, largest discharge) the minimum pressure in the 90-degree bend cannot approach -25 feet. Local cavitation is to be expected at all malalignments which might inadvertently be made in the fabricated prototype bends and conduit. No vaporization occurred during the runs at the "Upper Limit", although a slight cavitation noise was heard (safely attributed to gasket offsets at 90-degree bend connections). At the "Max. Discharge of Model" runs, vapor "puffs" were observed, but the prototype steel conduit would have to be constructed with a glass liner to approach the high head-discharge curve responsible for these low pressures.

The performance of the 1951 proposed stilling pool in conjunction with the 22-degree exit bend illustrated in Figure 22 is comparable to an equivalent discharge for the same pool modification and discharge as proposed with the terminal skewed orifice-plate in 1951. In any event, the terminal bend plus at least five feet of excavation accompanied by an auxiliary sill would appear to be essential qualifications to satisfactory flow conditions in the stilling pool.

The merits of the proposal under study are covered in the various sections of this report. In general, the proposed
design is conservative, on the side of safety, hydraulically. It was not an object of this study to evaluate or appraise the economic, structural, or flood-routing aspects of the proposed design.
VIII - ACKNOWLEDGMENTS

The writer wishes to thank the visiting engineers of the 16th of February for their patience and cooperation during the demonstration tests. Appreciation is due Mr. Justin and Mr. Courtney for the coordination which they made possible. Prompt initiation of the study was made possible by the early release of the space and equipment used in the 1951 tests, by Mr. Ryder.

Prof. W. J. Eney arranged the administrative program for the project. Mr. Gosztonyi was assisted by Mr. Taylor in setting up the apparatus. The elbow was patterned and cast by the Bridesburg Foundry of Fullerton. Most of the machining was performed by Mr. Schmidt and photos were taken by Mr. Harpel, of the Fritz Laboratory Shop.

All tests of this project were conducted in the Hydraulic Laboratory of the Department of Civil Engineering and Mechanic's Fritz Engineering Laboratory on the Lehigh University Campus, Bethlehem, Pennsylvania.

Mr. Harpel, Shop Superintendent, made several essential emergency repair welds to the header tank, a factor which substantially expedited the test program.

The original period requested last September for obtaining the first test runs was two months. Authorization was received on November 51 and the preliminary runs were completed on the 30th of January.

It is hoped that the Hydrologic Division of the Department of Forests and Waters will find it possible to take stream gaging records at flood peaks in conjunction with the existing stage recorder so that model-prototype verification may be made to the benefit of all concerned.
FIGURES ONE TO TWENTY-TWO
CROSS-SECTION THROUGH CENTER OF CONDUIT
1:34 Model - Note Plastic Flange, Bend, Plastic Pipe, Control Valve, Piezometer Connections to Manometer Manifold.
1:34 Model - Note Plastic Pipe,
Control Valve, Baffles
(Two banks used),
Measuring Weir.
ELEVATIONS

Q in 100 c.f.s.

22
21
20
19

TOTAL HEAD IN FEET

18
20
30
40
50
60
70
80
90
100
110

26x
25x
24x
23x

18x

RANGE COMPUTED
BY JAC - SEPT. 27, 1951

MAX. POOL
ELEV. 793.5

1:50 SCALE MODEL - LITTLE PINE CREEK

FOR JUSTIN & COURTNEY
FRITZ LABORATORY
FEB. 1952

DISCHARGE CURVES

X - TEST DATA
Justin & Courtney, Engineers  
121 South Broad Street  

Ref: LITTLE PINE CREEK  
DAM REPORT OF 1 MARCH 1952

Dear Sirs:

While working on a paper on bends, I discovered in calculating total energy lines that what I had called the "Head Loss in Elbow" was not correct. In my pains to provide close prediction of lowest pressures, I overlooked a very fundamental point. What has been called in the report "Head Loss in Elbow" is in truth the elbow loss plus the difference in velocity head between the 9.5 foot diameter and the 8.5 foot diameter. * The bend loss is extremely small, being only about 4 to 5 feet at 3000 c.f.s. instead of about 20 feet. This increases the maximum possible discharge to around 3300 c.f.s. For a discharge of 3300 c.f.s. and f = 0.01, the minimum pressure head would be about -9 feet at a head of 101 to 107 feet. This does not, I believe, drastically alter any conclusions reached in our report except to increase the probable maximum discharge to 3300 c.f.s. instead of 2900 c.f.s. Calculations should be made as indicated in the report, but instead of the loss being represented by $2.2 \frac{Q^2}{10^6}$, the loss is actually $0.5 \frac{Q^2}{10^6}$ affecting Figure Six. Calculations for Figure Eight are unaffected, since the term must still be used, where it is $2.2 \frac{Q^2}{10^6}$, but only a part of this quantity is a direct result of friction loss, and it thus becomes a misnomer.

I sincerely regret this error. Please add a copy of this letter to each of your copies of the report. The low bend loss was not expected, even though convective acceleration takes place in the bend.

Respectfully,

M. B. McPherson  
Assoc. Prof. of C. E.

* $h_{re} = (\text{Bend loss less equivalent pipe friction} + \frac{V_8.5^2}{2g} - \frac{V_9.5^2}{2g})$
1:34 Scale Model - Little Pine Creek
For Justin & Courtney
Fritz Laboratory
Feb. 1952

Discharge vs. Head Loss in Elbow
(Head loss for equivalent pipe friction,
\( L = 14.5R \times \frac{2\pi}{4} = 22.8' \) has been deducted
for \( D = 8.5' \))

26 Runs
**Note:**

**Calculated Curves Based On:**

\[ h_{L(ENT)} = Q^2 / 2,600,000 \]

\[ h_{L(BEND)} = 2.10 Q^2 / 7.0 \times 10^4 \]

\[ h_{L(FRICT)} = f (4.5 \times V^2) / 2g \]

\[ h_{L(BEND, 22^\circ EXIT)} \text{ Assumed} = 0 \]

**Test Data Runs Is: 1/268**

1. **Very Smooth (f = 0.007)**
2. **Wrought Iron (f = 0.009)**
3. **Galv. Iron (f = 0.011)**
4. **Concrete (f = 0.013)**
5. **Rough Steel (f = 0.015)**

**Max Discharge Possible With Model**

1:34 Scale Model - Little Pine Creek

For Justin & Courtney

Fritz Laboratory

Feb. 1952

**Probable Prototype Discharge**
Figure Seven

Plot of Minimum Pressure Head vs Total Head for Upper Limit J & C

(Prototype) Runs 18 to 26

Top of Orifice Elevation 710.0

1:34 Scale Model - Little Pine Creek

For Justin & Courtney

Fritz Laboratory
February 1952

Minimum Pressure Head - Ft of Water

At Inside of Bend, 60° from Lip of Orifice
FIGURE EIGHT

1:54 SCALE MODEL - LITTLE PINE CREEK DAM
FOR JUSTIN & COURTNEY - FEB 1952
FRITZ LAB, LEHIGH UNIVERSITY

NOTE: MINIMUM PRESSURE OCCURRED AT INSIDE OF BEND
AT POINT 60° FROM LIP OF TOWER ORIFICE -
* STA 16+38, EL 695.1

\[ D_{60°} = 8.33\text{ in} \quad A_{60°} = 61.25\text{ sq in} \]

THEORETICAL VELOCITY AT 60° INSIDE:
\[ V_{60°} = 1.425\sqrt{\frac{A}{0.63}} \]

\[ (\frac{P}{g} + h_t) = \text{PIEZ. HD. AT STA 16+38 FOR PIPE FRICTION AND EXIT LOSS ONLY} \]

\[ h_{le} = \text{ELBOW HEAD LOSS} = 2.20Q^2 \times 10^6 \]

MODEL:
\[ \frac{V^2}{2g} + (\frac{P}{g} + h_t) = \frac{V_{60°}^2}{2g} + (\frac{P}{g} + h_t) + \frac{h_{le}}{3} \]

\[ (\frac{P}{g})_{calc} = \frac{V^2}{2g} + (\frac{P}{g} + h_t) + \frac{h_{le}}{3} - \frac{V_{60°}^2}{2g} \]

CALCULATED \( (\frac{P}{g} + h_t) \) AT STA 16+38 (ELEV. 695.1)
Figure Nine

\[ \frac{P + h}{\delta} = \text{FT. OF WATER} \]

\[ X = \text{INSIDE OF ELBOW} \]
\[ O = \text{OUTSIDE OF ELBOW} \]
\[ A = \text{SIDE OF ELBOW} \]

Plot of piezometric head for equivalent water surface.

Elev. 785 and \( Q = 3000 \text{ cfs.} \)

Run 18

1:34 Scale model Little Pine Creek for Justin & Courtney

Fritz Laboratory
February 1952
Figure Ten

Plot of piezometric head for equivalent water surface at elev. 717.3, Q = 1880 cfs

Run 19

1:34 scale model Little Pine Creek for Justin & Courtney Fritz Laboratory
February 1952
FIGURE ELEVEN

$\frac{P + h}{\theta}$ (FEET OF WATER)

PLOT OF PIEZOMETRIC HEAD
FOR EQUIVALENT WATER SURFACE
ELEV. 726.4 $Q = 2080$ cfs

RUN 20

1.34 SCALE MODEL LITTLE PINE CREEK
FOR JUSTIN & COURTNEY
FRITZ LABORATORY
FEBRUARY 1952

STATIONS - FEET FROM LIP OF ORIFICE EL. 704
PLOT OF PIEZOMETRIC HEAD FOR EQUIVALENT WATER SURFACE ELEV. 733.5 $Q = 2230$ cfs

RUN 21

1.54 SCALE MODEL LITTLE PINER CREEK FOR JUSTIN & COURTNEY FRITZ LABORATORY FEBRUARY 1952

$P + h \over \gamma$ (FEET OF WATER)
PLOT OF PIEZOMETRIC HEAD
FOR EQUIVALENT WATER SURFACE
ELEV. 746.4  Q = 2490 cfs

1:34 SCALE MODEL LITTLE PINE CREEK
FOR JUSTIN & COURTNEY
FRITZ LABORATORY
FEBRUARY 1952

X = INSIDE OF ELBOW
O = OUTSIDE OF ELBOW
@ = SIDES OF ELBOW

\( \frac{P}{y} + h \) (FEET OF WATER)
X = INSIDE OF ELBOW
O = OUTSIDE OF ELBOW
A) = SIDES OF ELBOW

PLOT OF PIZZOMETRIC HEAD
FOR EQUIVALENT WATER SURFACE
ELEV. 754.4 Q = 2600 CFS

RUN 24

1:34 SCALE MODEL LITTLE PINE CREEK
FOR JUSTIN & COURTNEY
FRITZ LABORATORY
FEBRUARY 1952

$P + h \over \gamma$ (FEET OF WATER)

STATIONS- FEET FROM UP OF ORIFICE EL 704
Figure Seventeen

X = INSIDE OF ELBOW
O = OUTSIDE OF ELBOW
A = SIDES OF ELBOW

PLOT OF PIEZOMETRIC HEAD FOR EQUIVALENT WATER SURFACE
ELEV. 771.9 Q = 2880 cfs
RUN 26

1.34 SCALE MODEL LITTLE PINE CREEK
FOR JUSTIN & COURTNEY
FRITZ LABORATORY
FEBRUARY 1952

4 STATIONS FEET FROM LIP OF ORIFICE EL. 704
1:24 Model, Stilling Pool - Arrangement of Piping from Laboratory System.
FIGURE NINETEEN

1:24 Model -

Existing Stilling Pool.
1:24 Model -
Proposed Stilling
Pool of 1951.
1:24 Model - Entire Stilling

Pool Excavated to Elevation 667 -

2900 c.f.s.