Commonwealth of Kentucky
Department of Highways

Highway Materials Research Laboratory
132 Graham Avenue, Lexington 29, Kentucky

July 15, 1952

D.1.6.
D.2.3.

MEMO TO: J. O. Cornell
Assistant Zone Engineer
Zone C

SUBJECT: Calculations of Head on Structure Near Greenup

Attached is a memo report and set of calculations pertaining to five structures on U.S. 23, which would be affected by changes in the pool behind the proposed Greenup Lock and Dam. Originally, there were seven structures mentioned, but we received information on only six and one of those was voided on the sketch plan.

The calculations, of course, apply to the effects of anticipated runoff from the contributing drainage areas and not to any effects of flood stages in the Ohio River itself. Each structure is treated individually under Part III, which includes the last eleven pages of the report. These represent the information you requested.

Parts I and II deal with the fundamental concepts and approaches taken toward solution of the problems, and inasmuch as these preliminary analyses may be of value in dealing with future problems of a similar nature, they are recorded here.

L. E. Gregg
L. E. Gregg
Assistant Director of Research

LEG:DDC
Attached

Commonwealth of Kentucky
Department of Highways

Highway Materials Research Laboratory
132 Graham Avenue, Lexington 29, Kentucky

July 14, 1952

D.2.1.1.

MEMO TO: L. E. Gregg
Assistant Director of Research

SUBJECT: Head Determinations for Structures on U.S. 23 That Are Affected By Raising The Normal Pool Elevation of Ohio River Lock and Dam No. 30 at Greenup, Kentucky.

During a visit to this office on July 3, 1952, Mr. J. O. Cornell requested the assistance of the Hydraulics Section of the Research Laboratory in investigating the possible head to be expected on the drainage structures on U.S. 23, that would be influenced by the proposed raising of the normal pool elevation of Ohio River Lock and Dam No. 30 at Greenup, Kentucky.

In order to better evaluate the head to be expected, I have approached the problem from an analytical standpoint, outlining and comparing the results from three suggested methods. The results of the analysis of the three separate approaches are very similar which indicates that the resulting values are reliable. -

For estimating the discharge to be expected in these calculations, I have used the formulas now in existance and have not included any new concepts for estimating runoff or expected discharge. In the calculations for the structure at Coals Branch, the head was recalculated using the discharge obtained by the Jarvis Formula, this giving a larger value than Talbot's Formula or the method presented by W. D. Potter in his report, "Peak Rates of Runoff for the Alleghaney-Cumberland Plateau." Since the head varies as the square of the discharge, an error in estimating the discharge will be raised to the second power in the head determination.

With this in mind, it is suggested that an investigation be made of the existing structures to determine if the size of the structure has been ample in the past or if it is oversized.

Calculations for the head at each of the stations are included, using a value of "Q" obtained from Talbot's report and using a widely accepted average velocity of 3 ft. per sec. Also, using "Q" from Jarvis's Formula with values of "P" as suggested by the U.S.G.S., the values of "Q" from Potter's Chart are included for comparison, with the frequency interval specified.

It should be considered that these calculations are made with the assumption that the culvert is clear and that in submerged flow, as is the case in each of these structures, there might be an even greater tendency for silting.

Eugene M West
Eugene M. West
-istant Research Engineer

Suggested Method No. 1

The structure will be subjected to submerged flow at all times thus, treating it as a submerged tube*:

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

Q = Discharge
C = Coefficient of discharge for suggested values. See King's Handbook** of Hydraulics. Values based on 3000 experiments***.
A = Area of Opening
g = Use 32.2
H = Difference in elevation of water surface at inlet and outlet side of culvert.

To determine "C" by the expressions developed from experimental data*** for different flow conditions:

Condition 1: "C" for concrete pipe, beveled-lip entrance

$$C = \left(1.1 + \frac{0.026L}{d^{1.2}}\right)^{-\frac{1}{2}}$$

Condition 2: "C" for concrete pipe, square-cornered entrance

$$C = \left(1 + 0.31d^{0.5} + \frac{0.026L}{d^{1.2}}\right)^{-\frac{1}{2}}$$

Condition 3: "C" for concrete box culvert, round-lip entrance

$$C = \left(1.05 + \frac{.0045L}{r^{1.25}}\right)^{-\frac{1}{2}}$$

Condition 4: "C" for concrete box culverts with square cornered entrance

$$C = \left(1 + 0.4r^{0.3} + \frac{0.0045L}{r^{1.25}}\right)^{-\frac{1}{2}}$$

* King, Wisler, and Woodburn; "Hydraulics" John Wiley and Sons, 1948, Chapter VI.

** King; "Handbook of Hydraulics" McGraw-Hill Company, Ltd., 1939, Chapter III.

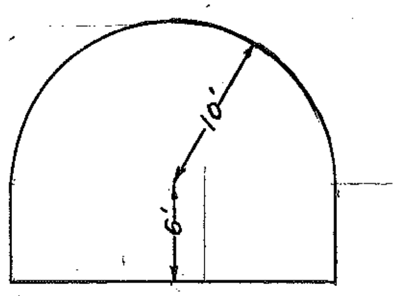
*** D. L. Yarnell, F. A. Nagler, and S. M. Woodward; "Flow of Water Through Culverts," Studies in Engineering, University of Iowa, 1926.

Where "d" is the diameter of pipe culvert, r is the hydraulic radius and "L" is the length of the culvert.

Values of "C" have been determined and by use of above expressions, the experimental data have been extrapolated and are listed in Table 36 of King's "Handbook" for diameters up to 8 feet and lengths up to 200 feet.

The structure at Coal Branch R.M. 337.3, has a length of 260 feet and a diameter greater than 8 feet as given in Table 36. Assuming that this structure is within the limitations of the experimental expressions, it will be necessary to solve for values of "C" from the equations.

Since the structure under consideration is an arch, a value somewhere between that of a circular pipe and that of a box culvert is assumed. Also, since the experimental expressions for "C" were determined for round-lip entrance and square-cornered entrance conditions, it will be necessary to assume a conservative value of "C" that falls within these two conditions. Experimental data has shown that where 45° wing walls are used in connection with pipe culverts there will be an increase of from 1% to 10% in the discharge.



$$\text{Area} = \frac{\pi d^2}{4} \times \frac{1}{2} + (6 \times 20)$$

$$A = 157.08 + 120 = 277.08 \text{ Sq. Ft.}$$

__Condition 1:__ Treating the structure as a circular pipe, beveled-lip entrance.

$$C = \left(1.1 + \frac{0.026L}{d^{1.2}}\right)^{-\frac{1}{2}}$$

Solving for an equivalent diameter:

$$A = \frac{\pi d^2}{4} = 277.08 = \frac{3.1416 d^2}{4}$$

$$d^2 = \frac{1108.32}{3.1416} = 352.788$$

$$d = 18.78 \text{ Ft.}$$

Using the equivalent diameter in the equation:

$$C = \left(1.1 + \frac{0.026L}{d^{1.2}}\right)^{-\frac{1}{2}}$$

$$C = \left[1.1 + \frac{0.026\ (260)}{18.78^{1.2}}\right]^{-\frac{1}{2}}$$

$$C = \left[1.1 + \frac{6.76}{18.78^{1.2}}\right]^{-\frac{1}{2}}$$

$$C = \left[1.1 + \frac{6.76}{33.76}\right]^{-\frac{1}{2}}$$

$$\log 18.78 = 1.27370$$
$$\underline{x1.2 \quad = 1.52844}$$
$$18.78^{1.2} = 33.76$$

$$C = (1.1 + .20024)^{-\frac{1}{2}}$$

$$C = (1.30024)^{-\frac{1}{2}}$$

$$\log \frac{1.30024}{2} = \frac{0.11394}{2} = 0.05697$$

$$C = \frac{1}{1.140} = \underline{\underline{.877}} = \underline{\underline{.88}}$$

$$\sqrt{1.30024} = 1.140$$

<u>Condition 2:</u> Treating the structure as a concrete pipe, square-cornered entrance.

$$C = \left[1 + 0.31d^{0.5} + \frac{0.026L}{d^{1.2}}\right]^{-\frac{1}{2}}$$

$$C = \left[1 + 0.31\ (18.78)^{\frac{1}{2}} + .20024\right]^{-\frac{1}{2}}$$

$$C = \left[1 + 0.31\ (4.334) + .20024\right]^{-\frac{1}{2}}$$

$$C = \left[1 + 1.34354 + .20024\right]^{-\frac{1}{2}}$$

$$C = \left[2.54378\right]^{-\frac{1}{2}}$$

$$C = \frac{1}{\sqrt{2.54378}} = .627 \qquad \text{Use } \underline{\underline{.63}}$$

Condition 3: Treating the structure as a concrete-box culvert with round-lip entrance.

$$C = \left[1.05 + \frac{0.0045L}{r^{1.25}}\right]^{-\frac{1}{2}}$$

$$C = \left[1.05 + \frac{.0045(260)}{r^{1.25}}\right]^{-\frac{1}{2}}$$

$$r = \text{Hydraulic Radius} = \frac{\text{Area of the cross-section}}{\text{Wetted perimeter}} =$$

$$\frac{277.08}{63.416} = 4.37$$

$$C = \left[1.05 + \frac{.0045(260)}{4.37^{1.25}}\right]^{-\frac{1}{2}}$$

$$C = \left[1.05 + \frac{1.1700}{4.37^{1.25}}\right]^{-\frac{1}{2}}$$

$$\log 4.37 = 0.64048$$
$$\times 1.25 = 0.80060$$
$$6.318$$

$$C = \left[1.05 + \frac{1.1700}{6.318}\right]^{-\frac{1}{2}}$$

$$\log 1.2352 = 0.09167$$
$$-2 = 0.045835$$
$$1.1113$$

$$C = \left[1.05 + .1852\right]^{-\frac{1}{2}} = (1.2352)^{-\frac{1}{2}} = \frac{1}{\sqrt{1.2352}}$$

$$C = \frac{1}{1.1113} = .8998 = \underline{\underline{.90}}$$

Condition 4: Treating the structure as a concrete-box culvert, with square-cornered entrance.

$$C = \left[1 + 0.4r^{0.3} + \frac{.0045L}{r^{1.25}}\right]^{-\frac{1}{2}}$$

$$C = \left[1 + 0.4(4.37)^{0.3} + .1852\right]^{-\frac{1}{2}}$$

$$C = \left[1 + 0.4(1.5565) + .1852\right]^{-\frac{1}{2}}$$

$$\log 4.37 = 0.64048$$
$$\times 0.3 = 0.192144$$
$$(4.37)^{0.3} \quad 1.5565$$
$$\times .4$$
$$.62260$$

$$C = \left[1 + .62260 + .1852\right]^{-\frac{1}{2}}$$

$$C = \left[1.80780\right]^{-\frac{1}{2}}$$

$$\log 1.80780 = 0.257152$$

$$\div 2 = 0.128576$$

$$\sqrt{1.8078} = 1.3446$$

$$C = \frac{1}{\sqrt{1.80780}} = \frac{1}{1.3446} = .74371 = \underline{\underline{.74}}$$

Assuming a conservative value of "C" from the above calculations by considering square cornered entrance conditions only, a reasonable value would be .68.

Using a value of 700 cfs. for "Q" (discharge) as would be given by the Talbot Formula, and which is the discharge, it is assumed that the structure was designed for:

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

$$H = \frac{Q^2}{(CA)^2\ 2g} = \frac{700^2}{(.68 \times 277)^2 \times 64.4} = 0.214'$$

Suggested Method No. 2

Since the experiments by Yarnell, Nagler and Woodward were conducted on culverts of much smaller cross-sectional area, 30-inch diameter, and for lengths of up to 36 ft., it is questionable that the extrapolation of the data up to 18.76 ft. diameter and a length of 260 ft. would be reliable. As a check, a suggested method is to treat the structure as a short tube for the first 40 or 50 feet in order to stay within the range of the experimental values for "C" and to compute the head loss in the remainder by regular pipe flow methods.

$$H = h_1 + h_2$$

h_1 = Head due to first 40 ft. as short tube

$$h_1 = \frac{Q^2}{CA^2\ 2g}$$

h_2 = Head loss due to pipe flow $= f \frac{l}{d} \frac{V^2}{2g}$

$$H = \frac{Q^2}{CA^2\ 2g} + \frac{fl}{d} \frac{V^2}{2g}$$

Where: f = Coefficient of pipe friction - using a very conservative value of .01.
l = Length of pipe flow.
d = Diameter of pipe.
V = Velocity $= \frac{Q}{A} = \frac{700}{227} = 2.08$ ft. per sec.
C = Suggested value of discharge coefficient - Use conservative value of .71.

$$H = \frac{700^2}{(.71 \times 277)^2\ 64.4} + .01 \times \frac{220}{18.67} \times \frac{9}{64.4}$$

$$H = 0.1967 + .0165 = \underline{\underline{0.2132}}$$

This value of "H" checks that found in Method 1, which would indicate that the extrapolated values of "C" are adequate.

Suggested Method No. 3

The total head for a culvert flowing full and submerged can also be computed by:

$$H = (1 + Ke + \frac{fl}{d}) \frac{V^2}{2g}^{*}$$

in which:

H = Difference in elevation of headwater and tailwater pools in feet.

Ke = Entrance loss factor* using maximum value of .5.

f = Friction factor which is a function of Manning's "n" and the diameter of the conduit.

$$H = 1 + .50 + .01 \left(\frac{260}{18.87}\right) \frac{9}{64.4}$$

$$H = (1.639) \left(\frac{9}{64.4}\right) = \underline{\underline{.229}}$$

Conclusions:

This method checks with Methods 1 and 2 to within 7%. Therefore, it is assumed that either of the methods will be adequate in determining the head considering it unlikely that the discharge assumed will be within this tolerance.

* Mavis, F. T., "Hydraulics of Culverts," Penn. State Engineering Experiment Station, Bulletin No. 56, February, 1943.

PART II (STRUCTURES PARTIALLY SUBMERGED)

The structures that are partially filled by back water are assumed to become completely submerged and, therefore, act the same as was the case of a structure completely submerged by the Normal Pool of the Dam. Since it is assumed that the structure was originally designed to accommodate the flow under peak conditions, it is apparent that the back water will cause the structure to flow full. Only in the case where the structure is grossly overdesigned would it be possible for the structure to carry the peak discharges without flowing full.

Of the structures considered in every case, more than 50% of the cross-sectional area of the culvert is filled by back water, which would indicate that an assumption of full pipe flow would be correct.

PART III (CALCULATIONS FOR INDIVIDUAL STRUCTURES)

Coal Branch, R.M. 337.3

Calculations for "H" using a value of "Q" derived from Talbot's Formula are included in Part I.

Calculations for "H" using a "Q" of 1856 cfs. as found by use of the Jarvis Formula:

<u>Suggested Method No. 1:</u> $Q = CA\sqrt{2gH}$ $H = \frac{Q^2}{(CA)^2\ 2g}$

$$H = \frac{1856}{(.68x277)^2\ 64.4}$$

$$H = \underline{\underline{1.508\ Ft.}}$$

<u>Suggested Method No. 2:</u>

$$H = h1 + h2 \qquad \text{where: } h_1 = \frac{Q^2}{(CA)^2\ 2g}$$

$$H = \frac{Q^2}{(CA)^2\ 2g} + f\frac{l}{d}\frac{V^2}{2g} \qquad \text{and } h_2 = f\frac{l}{d}\frac{V^2}{2g} \qquad V = \frac{Q}{A} = \frac{1856}{277} = 6.70 \text{ ft/sec.}$$

$$H = \frac{1856^2}{(.71 \times 277)^2\ 64.4} + .01 \times \frac{220}{18.67} \times \frac{6.70^2}{64.4}$$

$$H = \underline{\underline{1.465\ Ft.}}$$

<u>Suggested Method No. 3:</u>

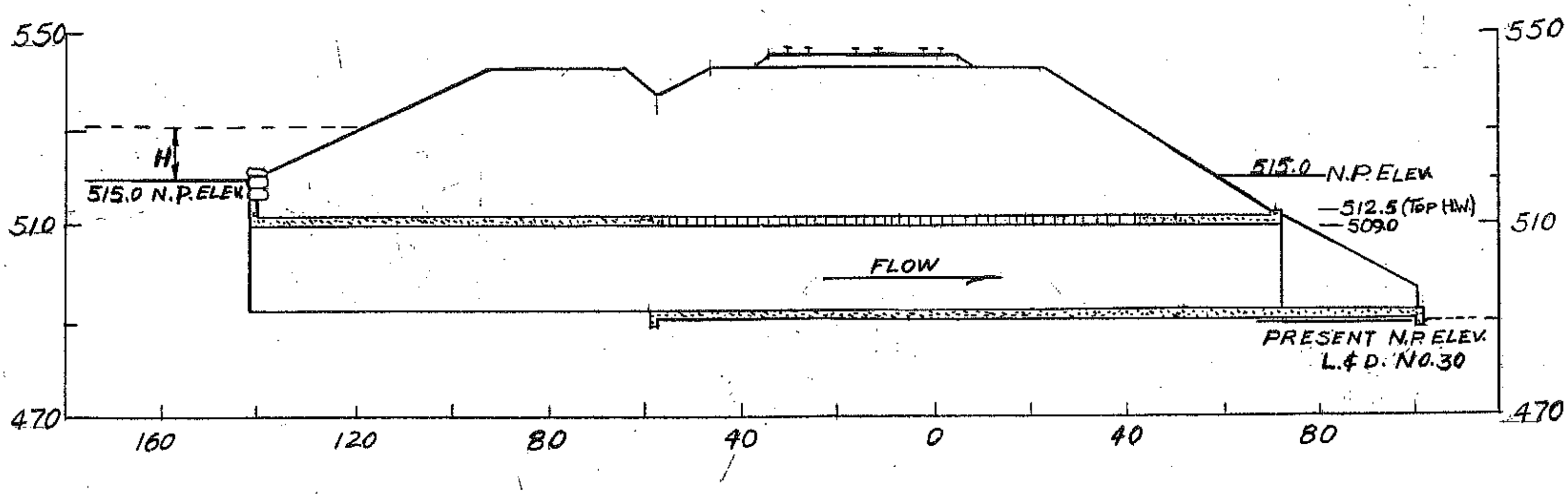
$$H = (1 + Ke + f\ \frac{l}{d})\ \frac{V^2}{2g}$$

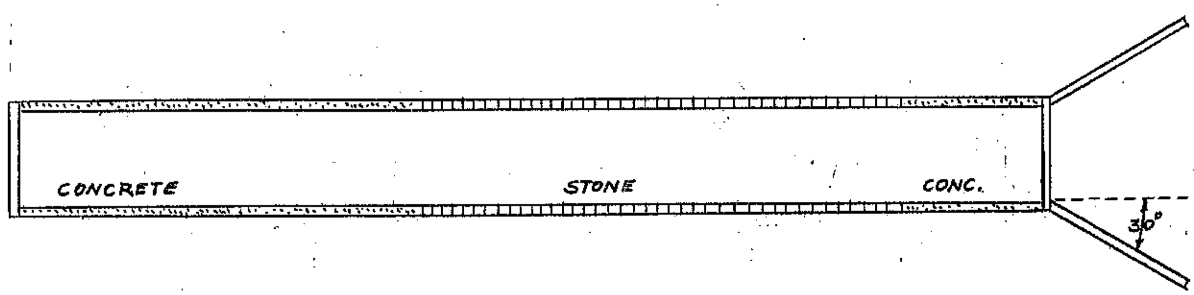
$$H = (1 + 0.5 + .01 \times \frac{260}{18.87})\ \frac{6.70}{64.4}$$

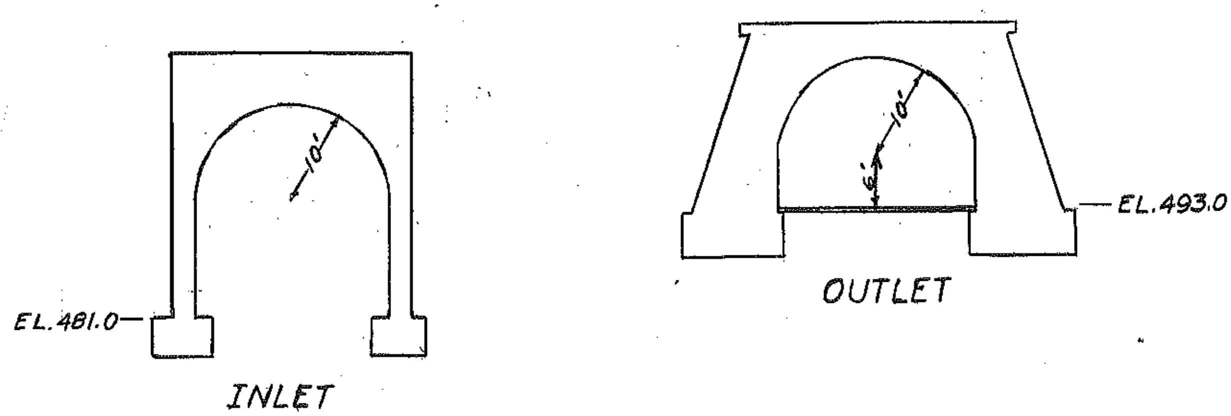
$$H = \underline{\underline{1.136\ Ft.}}$$

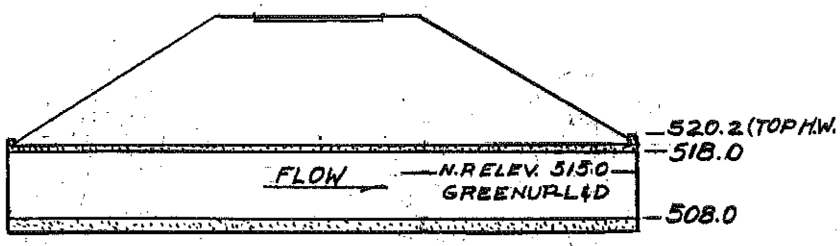
"Q" from Bureau of Public Roads Nomograph "Discharge in Alegheny-Cumberland Plateau" = 1460 cfs. based on a 10-year frequency.

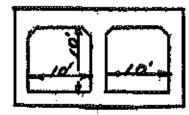
COAL BRANCH R.M. 337.3











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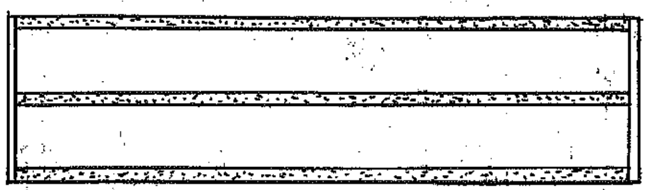


PLAN

<u>Suggested Method No. 2:</u> (Q from Talbot)

$$H = \frac{Q^2}{(CA)^2 \times 2g} + f \frac{l}{d} \frac{V^2}{2g}$$

where: Q = 840 cfs. (Talbot's Formula with c = 0.8)
Assume half the flow in each barrel or
Q = 420 cfs.

C = .80 assumed using King's Handbook Table 26.

A = 100 square ft.

f = .01

l = (98-40) = 58 ft.

d = 11.285 Ft. (Equivalent diameter for a 10 x 10 box culvert)

$$V = \frac{Q}{A} = \frac{420}{100} = 4.2 \text{ ft./sec.}$$

$$H = \frac{420^2}{(.80 \times 100)^2 \times 64.4} + .01 \times \frac{58}{11.285} \times \frac{4.2^2}{64.4}$$

H = <u>0.455 Ft.</u>

<u>Suggested Method No. 3:</u> (Q from Talbot)

$$H = (1 + Ke + f \frac{l}{d}) \frac{V^2}{2g}$$

where Ke = 0.5

f = .01

$l = 98$

$d = 11.285$

$V = 4.2$ Ft./Sec.

$$H = \left(1 + 0.5 + .01 \times \frac{98}{11.285}\right) \frac{4.2^2}{64.4}$$

$H = \underline{\underline{0.434 \text{ Ft.}}}$

Suggested Method No. 2: (Q from Jarvis)

$$H = \frac{Q^2}{(CA)^2 \times 2g} + f \frac{l}{d} \frac{V^2}{2g}$$

where; $Q = \frac{1676 \text{ cfs.}}{2} = 838$ cfs. per barrel

$V = \frac{Q}{A} = \frac{838}{100} = 8.38$ ft./sec.

$$H = \frac{838^2}{(.80 \times 100)^2 \times 64.4} + .01 \times \frac{58}{11.285} \times \frac{8.38^2}{64.4}$$

$H = \underline{\underline{1.76 \text{ Ft.}}}$

Suggested Method No. 3: (Q from Jarvis)

$$H = \left(1 + Ke + f\frac{l}{d}\right) \frac{V^2}{2g}$$

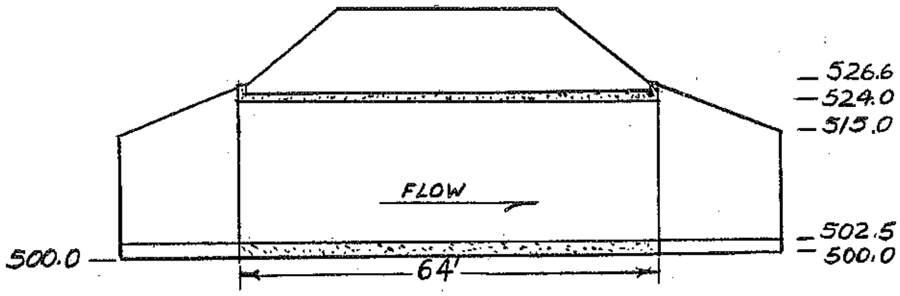
where; $V = \frac{Q}{A} = \frac{838}{100} = 8.38$ Ft/Sec.

$$H = \left(1 + 0.5 + .01 \frac{98}{11.285}\right) \frac{8.38^2}{64.4}$$

$H = \underline{\underline{1.73 \text{ Ft.}}}$

"Q" from Bureau of Public Roads Nomograph, "Discharge in Alegheny-Cumberland Plateau."

Q = 1050 cfs.	10 yr. frequency
Q = 1323 cfs.	25 yr. frequency
Q = 1533 cfs.	50 yr. frequency



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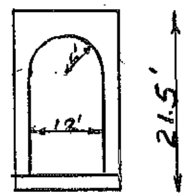

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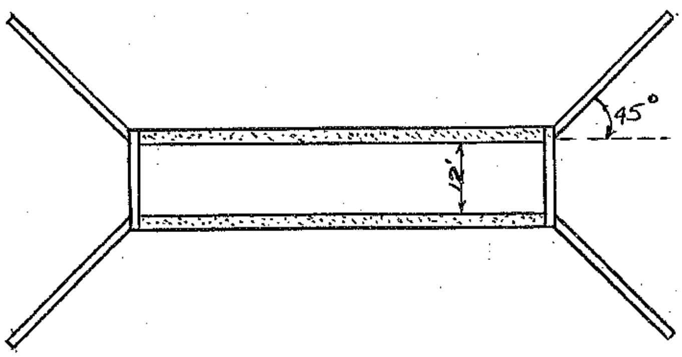

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Suggested Method No. 2: (Q from Talbot)

$$H = \frac{Q^2}{(CA)^2\ 2g} + f\ \frac{l}{d}\ \frac{V^2}{2g}$$

Q = 1173.6 cfs.

A = 242.55

d = Equivalent diameter = 17.575 Ft.

l = (64'-40') = 24 Ft.

C = .80

$$V = \frac{Q}{A} = \frac{1173.6}{242.55} = 4.84 \text{ Ft./Sec.}$$

f = .01

$$H = \frac{1173.6^2}{(.80 \times 242.5)^2\ 64.4} + .01 \times \frac{24'}{17.58}\ \frac{4.84^2}{64.4}$$

H = <u>0.573 Ft.</u>

Suggested Method No. 3: (Q from Talbot)

$$H = (1 + Ke + f \frac{l}{d}) \frac{V^2}{2g}$$

$$H = (1 + 0.5 + .01 \times \frac{64}{17.575}) \frac{4.84^2}{64.4}$$

$$H = \underline{0.559 \text{ Ft.}}$$

Suggested Method No. 2: (Q from Jarvis)

$$H = \frac{Q^2}{(CA)^2\ 2g} + f \frac{l}{d} \frac{V^2}{2g}$$

$$Q = 2087 \text{ cfs.}$$

$$V^2 = \frac{Q}{A} = \frac{2087}{242.5} = 8.61$$

$$H = \frac{2087^2}{(.80 \times 242.5)^2\ 64.4} + .01 \times \frac{24}{17.575} \times \frac{8.61^2}{64.4}$$

$$H = \underline{1.81 \text{ Ft.}}$$

Suggested Method 3: (Q from Jarvis)

$$H = (1 + Ke + f \frac{l}{d}) \frac{V^2}{2g}$$

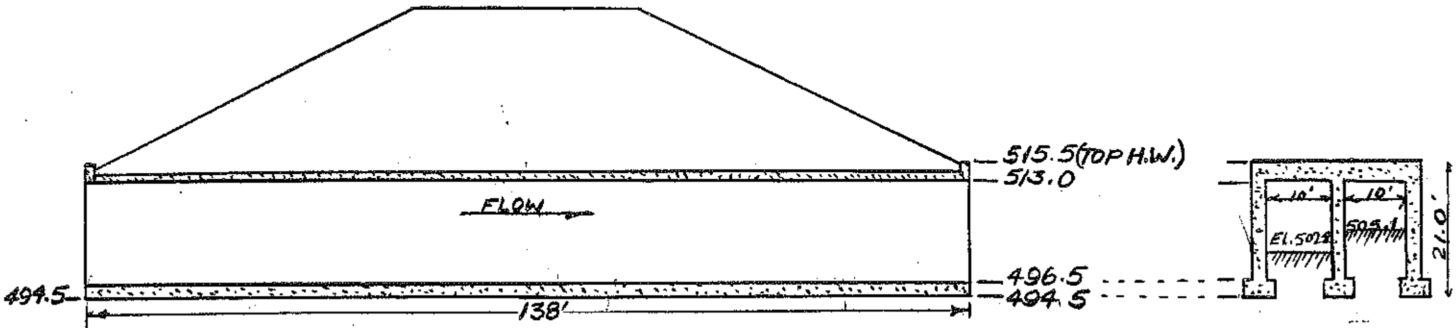
$$H = (1 + 0.5 + .01 \frac{64}{17.575}) \frac{861^2}{64.4}$$

$$H = \underline{1.77 \text{ Ft.}}$$

"Q" from Bureau of Public Roads Nomograph, "Discharge in Allegheny-Cumberland Plateau."

Q = 1540 cfs. - 10 yr. frequency
Q = 1940 cfs. - 25 yr. frequency
Q = 2248 cfs. - 50 yr. frequency

TOWN BRANCH, R. M. 338.6



ELEVATION

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Suggested Method No. 2: (Q from Talbot)

$$H = \frac{Q^2}{(CA)^2\,2g} + f\,\frac{l}{d}\,\frac{V^2}{2g}$$

where;

A_1 = 10'x8½' = 85 Sq. Ft.

A_2 = 10'x10.8' = 108 Sq. Ft.

Q = Total = 576 cfs. x $\frac{85}{193}$ = 253.68

d = 10.41 (Equivalent diameter for 10x8.5' Box culvert)

l = 138 - 40 = 98 Ft.

C = .80 Assumed using King's Handbook, Table 26)

V = $\frac{Q}{A} = \frac{253.68}{85}$ = 2.98 Ft./Sec.

f = 0.01

$$H = \frac{253.68^2}{(.80x85)^2\;64.4} + 0.01 \times \frac{98}{10.41} \times \frac{2.98^2}{64.4}$$

H = .229 Ft.

Suggested Method No. 3: (Q from Talbot)

$$H = \left(1 + Ke + f\,\frac{l}{d}\right)\frac{V^2}{2g}$$

where;

Ke = 0.5

f = 0.01

l = 138 Ft.

d = 10.41 Ft.

V = 2.98 Ft./Sec.

$$H = \left(1 + 0.5 + .01 \times \frac{138}{10.41}\right) \frac{2.98^2}{64.4}$$

$$H = \underline{\underline{.216 \text{ Ft.}}}$$

<u>Suggested Method No. 2:</u> (Q from Jarvis)

$$H = \frac{Q^2}{(CA)^2\ 2g} + f\ \frac{l}{d}\ \frac{V^2}{2g}$$

$$Q = 1297 \times \frac{85}{193} = 571.2 \text{ cfs.}$$

$$V = \frac{Q}{A} = \frac{571.2}{85} = 6.72 \text{ Ft./Sec.}$$

$$H = \frac{571.2^2}{(.80 \times 85)^2\ 64.4} + .01 \times \frac{98}{10.41}\ \frac{6.72^2}{64.4}$$

$$H = \underline{\underline{1.172}} \text{ Ft.}$$

<u>Suggested Method No. 3:</u> (Q from Jarvis)

$$H = \left(1 + Ke + f\frac{l}{d}\right) \frac{V^2}{2g}$$

where; $V = \frac{Q}{A} = \frac{571.2}{85} = 6.72$ Ft/Sec.

$$H = \left(1 + 0.5 + .01 \times \frac{138}{10.41}\right) \frac{6.72^2}{64.4}$$

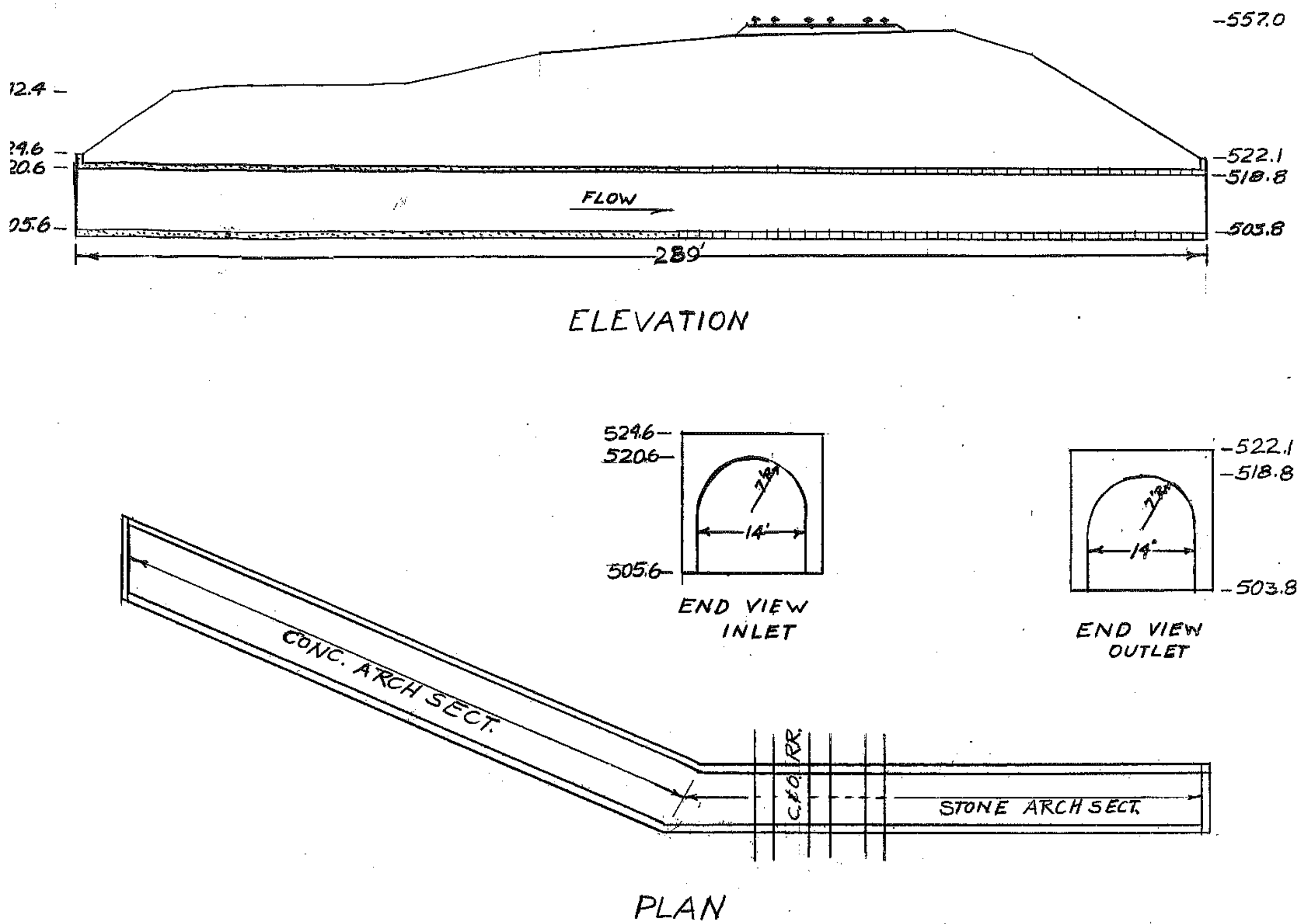
$$H = \underline{\underline{1.144}} \text{ Ft.}$$

"Q" from Bureau of Public Roads Nomograph "Discharge in Allegheny-Cumberland Plateau."

Q = 590 cfs. 10 yr. frequency

Q = 743 cfs. 25 yr. frequency

Q = 861 cfs. 50 yr. frequency



Due to the bend in the conduit it is necessary to include in Suggested Method No. 2 and No. 3, a factor for head to account for head loss due to flow around bends*:

$$h_b = K_b \frac{V^2}{2g}$$

Suggested Method No. 2: (Q from Talbot)

$$H = \frac{Q^2}{(CA)^2\ 2g} + f\frac{l}{d}\frac{V^2}{2g} + \frac{K_b\ V^2}{2g}$$

* King, Wisler and Brater "Hydraulics" Ch. VII.

Q = 532.8 cfs.

A = 188.97 Sq. Ft.

d = 15.51 Ft.

l = 292. Ft.

C = .80 Assumed using King's Handbook Table 26.

$V = \frac{Q}{A} = \frac{532.8}{188.97} = 2.82$ Ft./Sec.

f = .01

K_b = Use .42 estimated value well on the conservative side*.

$$H = \frac{532.8^2}{(.80 \times 188.97)^2\ 64.4} + .01 \times \frac{232.}{15.51} \times \frac{2.82^2}{64.4} + .42 \times \frac{2.82^2}{64.4}$$

H = <u>.260 Ft.</u>

Suggested Method No. 3: (Q from Talbot)

$$H = (1 + Ke + f\frac{l}{d}) \frac{V^2}{2g} + K_b \frac{V^2}{2g}$$

$$H = (1 + 0.5 + .01 \times \frac{292}{15.51}) \frac{2.82^2}{64.4} + .42 \times \frac{2.82^2}{64.4}$$

H = <u>.264 Ft.</u>

Suggested Method No. 2: (Q from Talbot)

$$H = \frac{Q^2}{(CA)^2\ 2g} + f\frac{l}{d} \frac{V^2}{2g} + \frac{K_b\ V^2}{2g}$$

Q = 1241

$V = \frac{Q}{A} = \frac{1241}{188.97} = 6.57$ Ft./Sec.

$$H = \frac{1241^2}{(.80 \times 188.97)^2\ 64.4} + .01 \times \frac{252}{15.51} \times \frac{6.57^2}{64.4} + .42 \times \frac{6.57^2}{64.4}$$

H = <u>1.44 Ft.</u>

* King, Wisler and Brater "Hydraulics" Ch. VII.

Suggested Method No. 3: (Q from Jarvis)

$$H = (1 + Ke + f\frac{l}{d}) + K_b \frac{V^2}{2g}$$

$$H = (1 + 0.5 + .01 \times \frac{292}{15.51}) \frac{6.57^2}{64.4} + .42 \times \frac{6.57^2}{64.4}$$

$$H = \underline{\underline{1.4075 \text{ Ft.}}}$$

"Q" from Bureau of Public Roads Nomograph, "Discharge in Allegheny-Cumberland Plateau."

Q = 380 cfs. - 10 yr. frequency

Q = 478.8 cfs. - 25 yr. frequency

Q = 554.8 cfs. - 50 yr. frequency