SHEET 534-1

LOCK CULVERTS

REVERSE TAINTER VALVES

LOSS COEFFICIENTS

1. The head loss across a lock culvert valve can be determined from the equation:

$$H_L = K_v V^2/2g$$

where

H_L = head loss across the valve in ft of water
K_v = valve loss coefficient
V = mean culvert velocity in ft/sec
g = acceleration of gravity in ft/sec^2.

2. Hydraulic Design Chart 534-1 shows valve loss coefficients vs the ratio of the area of the valve opening to the area of the culvert for reverse tainter valves. The Weisbach curve(1) is based on data for a vertical gate in a rectangular conduit. The data shown were computed from model and prototype tests. A complete list of data sources is given in paragraph 3. The graph is similar to plate 6 of Engineer Manual 1110-2-1604. However, experimental data are plotted on Chart 534-1, to emphasize the excellent agreement of various test results.

3. Data Sources.

(1) Weisbach. "Hydraulics and Its Application" by A. H. Gibson, D. Van Nostrand Co., Inc., New York, N. Y., 4th ed., 1930, p 249.

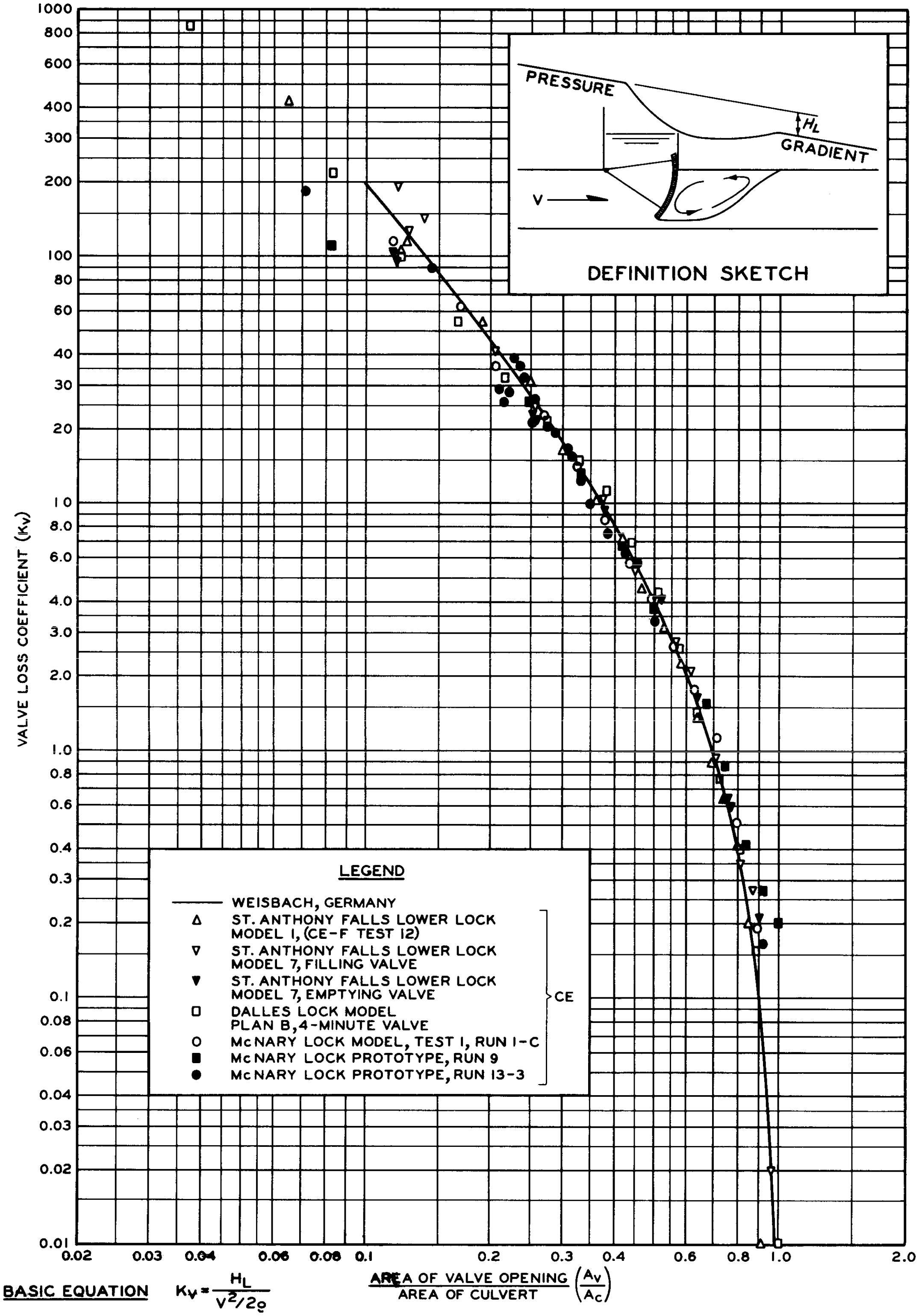
(2) St. Anthony Falls Lower Lock Models 1 and 7. Unpublished data computed by U. S. Army Engineer District, St. Paul, Minnesota, under CW 820, December 1953.

(3) McNary Lock Model, Test 1, Run 1-C. Unpublished data computed by U. S. Army Engineer District, St. Paul, Minnesota, under CW 820, December 1953.

(4) McNary Lock Prototype, Run 13-3. Report on Model-Prototype Conformity-McNary Dam Navigation Lock, 1955 Tests. U. S. Army Engineer District, Walla Walla, Washington, March 1959.

(5) McNary Lock Prototype, Run 9. Unpublished data computed by U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss., from November 1957 tests.

(6) Dalles Lock Model. Report on Model-Prototype Conformity-McNary Dam Navigation Lock, 1955 Tests. U. S. Army Engineer District, Walla Walla, Washington, March 1959.



BASIC EQUATION $K_V = \frac{H_L}{V^2/2g}$

WHERE:

K_V = VALVE LOSS COEFFICIENT

H_L = HEAD LOSS ACROSS VALVE IN FT OF WATER

V = AVERAGE VELOCITY IN FT/SEC

g = ACCELERATION OF GRAVITY-FT/SEC^2

LOCK CULVERTS

REVERSE TAINTER VALVES LOSS COEFFICIENT

HYDRAULIC DESIGN CHART 534-1

PREPARED BY U. S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION, VICKSBURG, MISSISSIPPI

WES 5-59

HYDRAULIC DESIGN CRITERIA

SHEETS 534-2 AND 534-2/1

LOCK CULVERTS

MINIMUM BEND PRESSURE

RECTANGULAR SECTION

1. Laboratory flow studies have shown that, for a rectangular conduit section, the minimum pressure in circular bends of 90 to 300 deg occurs on the inside of the bend 45 deg from the point of curvature. Experimental turbulent flow pressure data, at this location, closely approximate values computed for two-dimensional potential flow. McPherson and Strausser[1] have suggested an analytical procedure for determining the magnitude of the minimum pressure in a circular bend of rectangular section.

2. Theory. The minimum bend pressure head can be computed from the equation

$$C_p = \frac{H - H_i}{\frac{V^2}{2g}} \qquad (1)$$

where

C_p = pressure-drop parameter

H = average pressure head, in ft, at the 45-deg point computed as a straight-line extension of the upstream pressure gradient

H_i = minimum pressure head, in ft, at the 45-deg point on inside of bend

V = average culvert velocity in ft per sec

g = acceleration, gravitational, in ft per sec^2

Equation 1 is similar to the bend coefficient equation developed by Lansford (reference 4, Sheet 228-3). Based on equation 3 of reference 1, it can also be shown that

$$C_p = \left[\frac{2}{\left(\frac{R}{C} - 1\right) \ln\left(\frac{\frac{R}{C} + 1}{\frac{R}{C} - 1}\right)} \right]^2 - 1 \qquad (2)$$

where

R = center-line radius of the bend

C = one-half the culvert width

3. Application. Hydraulic Design Chart 534-2 shows the relation between the theoretical pressure-drop parameter and ratio of the radius of curvature to one-half the conduit dimension in the direction concerned. Values of C_p computed from experimental results reported by Silberman[2] and Yarnell and Woodward[3] are also shown. These data indicate the effects of Reynolds numbers between 6.7×10^4 and 8.2×10^5 . Points computed from data summarized by McPherson and Strausser[1] from tests by Addison,[4] Lell,[5] Wattendorf,[6] and Nippert[7] and on the Waynesboro and Mt. Alto model studies at Lehigh University are included on the chart. The indicated Reynolds number is about 10^5 to 10^6. The chart is considered applicable to bends of 45 to 300 deg.

4. Cavitation occurs when the instantaneous pressure at any point in a flowing liquid drops to the vapor pressure. Vapor pressure varies with temperature of the liquid (see Sheet 000-2). Since turbulence in flow causes pressure fluctuations, an estimate should be made of the maximum expected fluctuation from the minimum computed bend pressure. The sum of the estimated pressure fluctuation, the vapor pressure, and a few feet of water for a margin of safety should be computed. The local barometric pressure (see Chart 000-2) should be subtracted from this total to obtain the minimum permissible bend pressure. This pressure can then be used to determine the necessary average conduit pressure or the permissible average conduit velocity to prevent cavitation. Cavitation damage has been found where the average pressure is relatively high but violent negative pulsations reach cavitation pressures. Such criteria as indicated here should therefore be used conservatively.

5. Chart 534-2/1 is a sample computation showing the application of Chart 534-2 to the minimum bend pressure problem. Computations to indicate the minimum permissible average conduit pressure and the maximum permissible average conduit velocity to prevent cavitation are included. Chart 534-2 can also be used for the design of bends in rectangular sluices and siphons and in circular conduits. Its application to the latter is shown in Chart 228-3.

6. References.

(1) McPherson, M. B., and Strausser, H. S., "Minimum pressures in rectangular bends." Proceedings, ASCE, vol 81, Separate Paper No. 747 (July 1955); vol 82, Separate Paper No. 1092 (October 1956), p 9, Closure.

(2) Silberman, E., The Nature of Flow in an Elbow. Project Report No. 5, St. Anthony Falls Hydraulic Laboratory, University of Minnesota, Minneapolis, prepared for David Taylor Model Basin, December 1947.

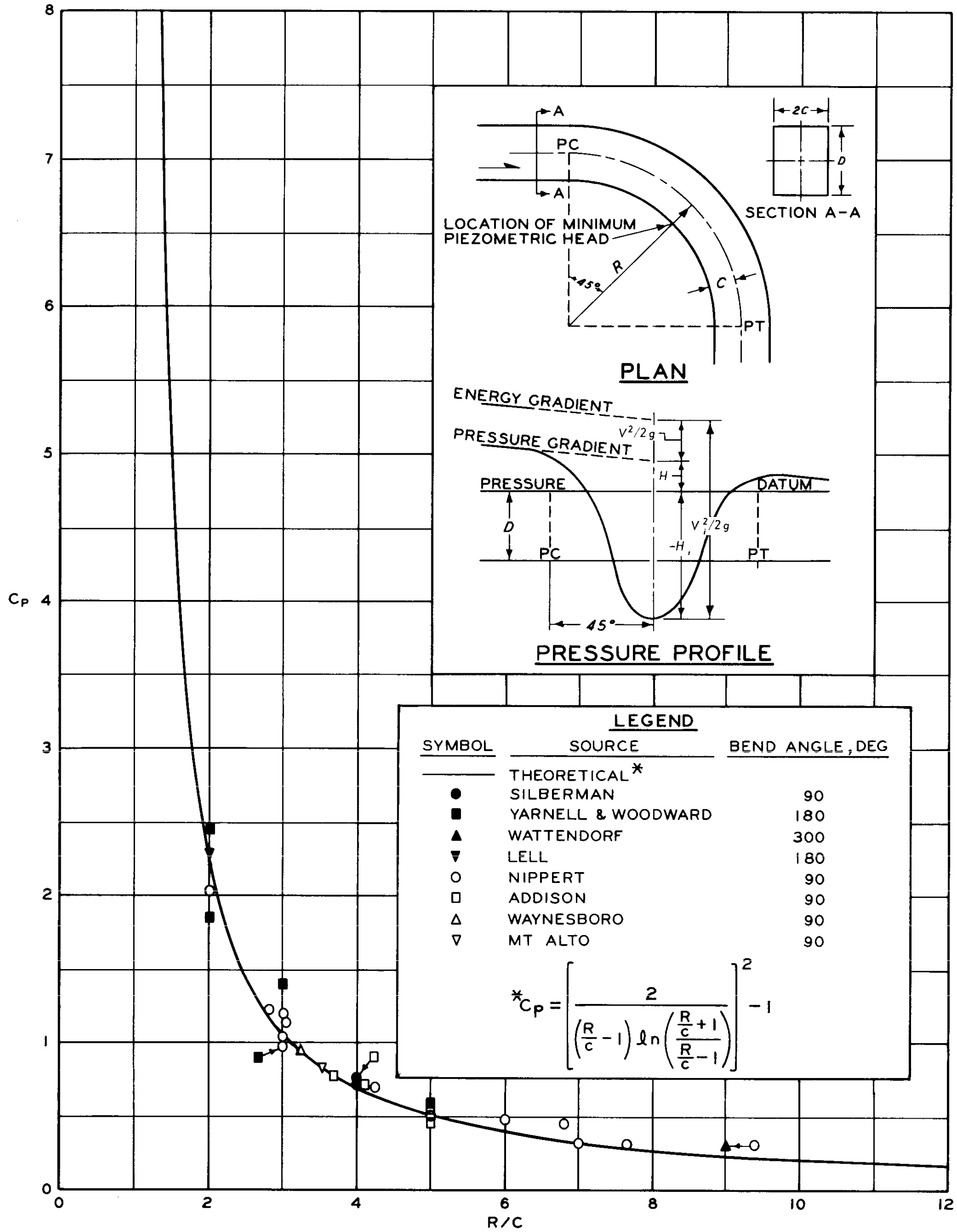
(3) U. S. Department of Agriculture, Flow of Water Around 180-Degree Bends, by D. L. Yarnell, and S. M. Woodward. Technical Bulletin No. 526, Washington, D. C., October 1936.

(4) Addison, H., "The use of bends as flow meters." Engineering, vol 145 (4 March 1938), pp 227-229 (25 March 1938), p 324.

(5) Lell, J., "Contribution to the Knowledge of Secondary Currents in Curved Channels (Beitrag zur Kenntnis der Sekundärströmungen in gekrümmten Kanälen)." Dissertation, R. Oldenbourg, Muchen, 1913. Also Zeitschrift für das gesamte Turbinenwesen, Heft 11, July 1914, pp 129-135, 293-298, 313-317, and 325-330.

(6) Wattendorf, F. L., "A study of the effects of curvature on fully developed turbulent flow." Proceedings, Royal Society of London, Series A, vol 148 (February 1935), pp 565-598.

(7) Nippert, H., "Über den Strömungsverlust in gekrümmten Kanälen." VDI, Forschungsarbeiten, Heft 320, Berlin (1929).



EQUATIONS

$$H+\frac{V^2}{2g}=H_i+\frac{V_i^2}{2g}\ , \qquad \frac{H-H_i}{\frac{V^2}{2g}}=C_P$$

WHERE:

- H = PIEZOMETRIC HEAD FROM PRESSURE GRADIENT EXTENSION, FT
- V = AVERAGE VELOCITY, FT PER SEC
- g = ACCELERATION, GRAVITATIONAL, FT PER SEC^2
- H_i = MINIMUM PIEZOMETRIC HEAD, FT
- V_i = VELOCITY AT LOCATION OF H_i, FT PER SEC
- C_P = PRESSURE DROP PARAMETER

LOCK CULVERTS

RECTANGULAR SECTION MINIMUM BEND PRESSURE

HYDRAULIC DESIGN CHART 534-2

U. S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION

COMPUTATION SHEET

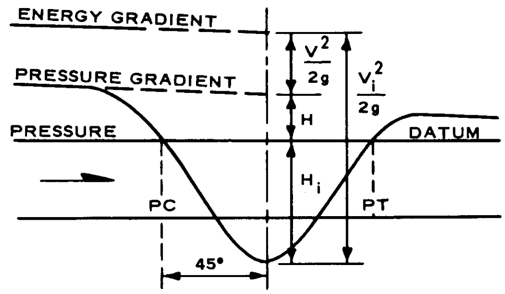
JOB CW 804 PROJECT John Doe Dam SUBJECT Lock Culverts

COMPUTATION Minimum Bend Pressure in a Rectangular Section

COMPUTED BY WTH DATE 4/30/59 CHECKED BY MBB DATE 5/4/59

GIVEN:

Rectangular culvert section
Horizontal bend
Elevation of roof = 500 ft msl
Deflection angle = 90°
Bend radius (R) = 10 ft
Width of culvert (2c) = 10 ft
Average velocity (V) = 20 fps
Temperature = 50 F
Average conduit pressure measured from pressure gradient extension (H) = 10 ft



PRESSURE PROFILE

REQUIRED:

H_i = minimum pressure (in ft) inside of bend.
$H_{i\ min}$ = minimum permissible bend pressure (ft).
H_{min} = minimum permissible average conduit pressure (in ft) to prevent cavitation (V = 20 fps).
V_{max} = maximum permissible average conduit velocity (in fps) to prevent cavitation (H = 10 ft).

COMPUTE:

1. R/c = 10/5 = 2
2. C_p = 2.30 for R/c = 2 (Chart 534-2)
3. Minimum bend pressure (H_i)

$$\frac{H - H_i}{V^2/2g} = C_p$$

$$\frac{10 - H_i}{20^2/64.4} = 2.30$$

$$H_i = -4.3 \text{ ft}$$

4. Minimum permissible bend pressure head ($H_{i\ min}$)

a. Estimated pressure head fluctuation = 10.0 ft
b. Vapor pressure head of water at 50 F = 0.4 ft (Sheet 000-2)
c. Pressure allowance for margin of safety = 5.0 ft
Total = 15.4 ft
d. Local barometric pressure head = 33.2 ft (Chart 000-2)
e. Minimum permissible bend pressure head ($H_{i\ min}$) = 15.4 - 33.2 = -17.8 ft

Note: Since $H_i > H_{i\ min}$ cavitation should not occur. However, this is not adequate to use as positive criterion since the values used for items 4a and 4c are dependent upon the judgement of the designer.

5. Minimum permissible average conduit pressure head (H_{min}) to prevent cavitation (V = 20 fps).

$$\frac{H_{min} - H_{i\ min}}{V^2/2g} = C_p$$

$$\frac{H_{min} - (-17.8)}{20^2/64.4} = 2.30$$

$$H_{min} = 2.3\ (400/64.4) - 17.8 = 14.3 - 17.8 = -3.5 \text{ ft}$$

6. Maximum permissible average conduit velocity (V_{max}) to prevent cavitation (conditions of step 4 and H = 10 ft).

$$\frac{H - H_{i\ min}}{V^2_{max}/2g} = C_p$$

$$\frac{10 - (-17.8)}{V^2_{max}/64.4} = 2.3$$

$$V^2_{max} = \frac{(10 + 17.8)\ 64.4}{2.3} = \frac{27.8 \times 64.4}{2.3} = 779$$

LOCK CULVERTS
RECTANGULAR SECTION
MINIMUM BEND PRESSURE
SAMPLE COMPUTATION
HYDRAULIC DESIGN CHART 534-2/1
WES 5-59

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