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Appendix C.4

Primary Solution Collection Pipe Flow Calculations

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CALCULATION TITLE PAGE

CLIENT Cripple Creek & Victor Gold Company	JOB NO. 1125	TASK NO. A100	PAGE 1 OF 2
PROJECT Arequa VLF	CALCULATION No. 1	REV. No. 1	
SUBJECT/ TITLE Primary Pipe Flow Design			

REV. NO.	PREPARER/ DATE	REVIEWER/ DATE	QA REVIEWER/ DATE	CONFIRMATION REQUIRED (Y/N)
1	Derek T. Wittwer 1/9/08	Amanda L. Dolezal 2/19/08	JF Lupo 2/19/08	

CALCULATION OBJECTIVE

Design primary pipe to collect and route design flow.

CALCULATION METHODOLOGY/ LIST of ASSUMPTIONS

- Q_{total} = 14,400 gpm, distribute flow to 3 pipes
- Add factor of safety of 25% for flow of 18,000 gpm
- Distribute flow evenly between the three pipes for design flow in each pipe of 6,000 gpm
- Perforation size based on "self filter" development using Johnson Screen controls criteria where hole size should contain 40% to 60% of the material size (Cresson Ore and DCF material gradations attached).

REFERENCES

Driscoll, F.G., "Groundwater and Wells", 1995, Johnson Screens.
Brater et. al, "Hand book of Hydraulics", 7th ed., 1996, McGraw-Hill Companies, Inc.

CONCLUSIONS

- Perforation size determined to be 0.5 inches and 8 holes are required per foot of pipe.

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PROJECT: Arequa VLF	JOB NO: 1125	SHEET 2 OF 2
FEATURE: Primary Solution Collection Pipe	BY: DTW	DATE: 1/9/08
DETAILS: Perforation Size and Quantity	CHKD BY: ALD	DATE: 2/19/08

Hole perforation and quantity calculation

- Criteria:

1)Use Johnson screen criteria for hole size and flow rate of 6,000 gpm in each pipe

- Analysis:

Based on attached gradations a perforation size 0.5" should be acceptable for the 40% to 60% criteria.

Area of single perforation:
$A=\pi r^2 = \pi(0.25)^2 = 0.196\ in^2$ / perforation

Desired yield per foot of pipe:
Pipe needs a capacity of 6,000 gpm. Assume flow enters in 600 feet of pipe length. Yield = 6,000/600 = 10 gpm / ft

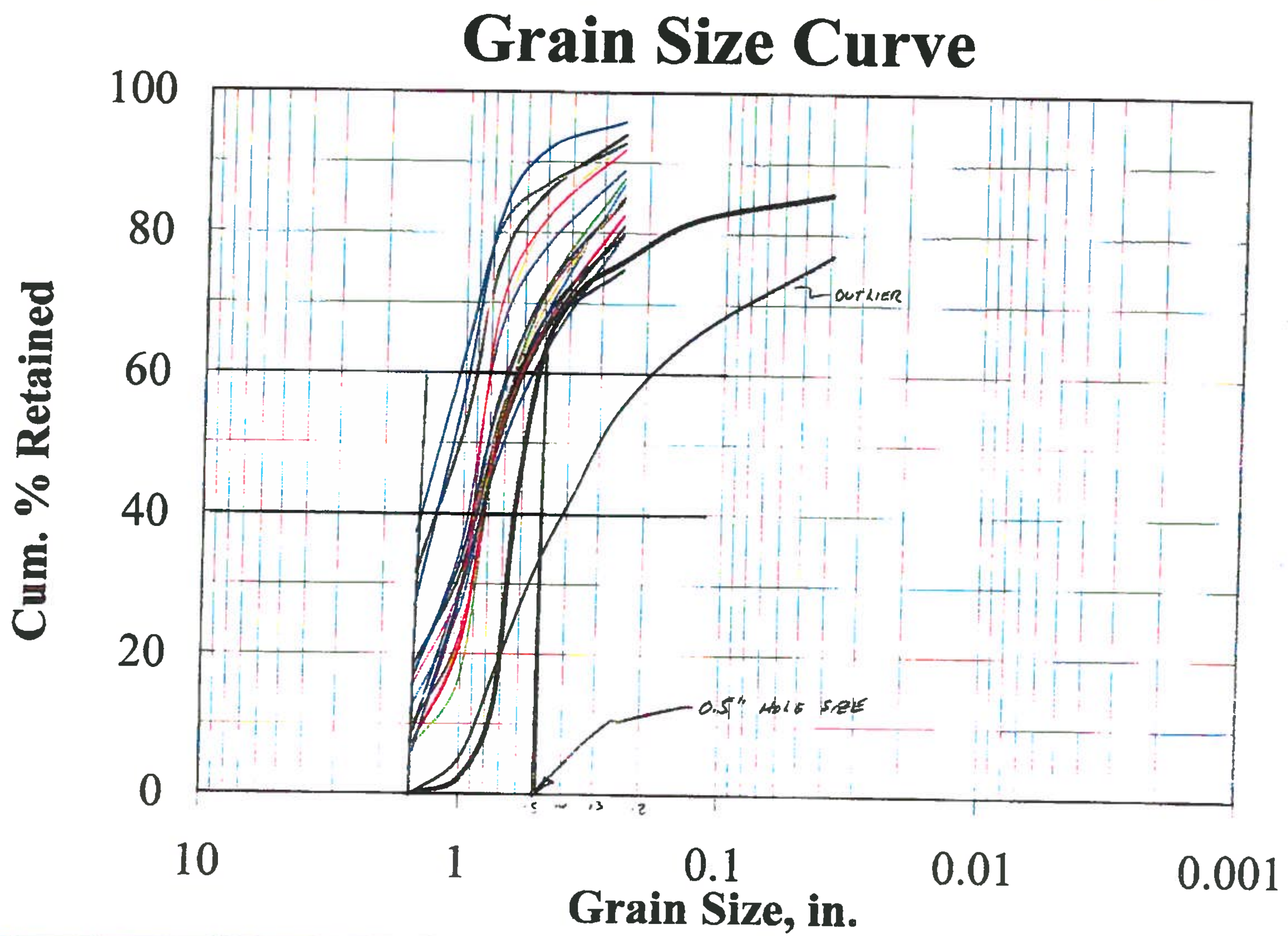
Perforation entrance velocity (Brater and King):
$Vp = c(2gh)^{0.5}$
6,000 gpm = 13.37 cfs
C=0.5
H = Head Differential, use 1-foot
$g = 32.2\ ft/s^2$
Note: This equation is for free flowing conditions - not pipe surrounded by fill
$Vp = 0.5(2\cdot 32.2\cdot 1)^{0.5} = 4$ fps per foot of differential
Apply a factor of safety of 2 to the number of perforations
V'p = 2 fps
Note: Vp will increase as differential head is increased

Find number of perforations:
$Q=AV = 13.37\ cfs = 2\ fps\cdot A$ $\qquad$ $A = 6.69\ ft^2$
$6.69\ ft^2 = 962.6\ in^2$ $\qquad$ $962.6\div 0.196 = 4911$ Holes
$4911\div 600 = 8$ holes per foot of pipe
8 holes/ft = $8 \cdot 0.196\ in^2/ft = 1.568\ in^2/ft$

Percent Open Area:
Solid Pipe = $2\pi R$ per ft = 26" on DR11 Pipe
$2\pi 13 = 81.7\ in^2/ft$
Open Area Percent = $1.568\div 81.7 = 2\%$ O.K. $\qquad$ Should be less than 5% to minimize stress

10050
10025
10000
9975
9725
9725
9750
9750
9725
9700
9675
9650

CRESSON ORE, DCF, & SELECT DCF GRADATIONS.



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Burington and May · Handbook of Probability and Statistics with Tables
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Huskey and Korn · Computer Handbook
Ireson · Reliability Handbook
Juran · Quality Control Handbook
Kallen · Handbook of Instrumentation and Controls
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Korn and Korn · Mathematical Handbook for Scientists and Engineers
Landee, Davis, and Albrecht · Electronic Designer's Handbook
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Mantell · Engineering Materials Handbook
Markus · Electronics and Nucleonics Dictionary
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Merritt · Standard Handbook for Civil Engineers
Perry · Engineering Manual
Perry · Chemical Engineers' Handbook
Rothbart · Mechanical Design and Systems Handbook
Streeter · Handbook of Fluid Dynamics
Truxal · Control Engineers' Handbook
Tuma · Engineering Mathematics Handbook
Tuma · Handbook of Physical Calculations
Tuma · Technology Mathematics Handbook
Urquhart · Civil Engineering Handbook

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for the Solution of Hydraulic Engineering Problems

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of the orifice. For a cylinder or prism with vertical axis, A is constant, and Eq. (4-18), after integration, becomes

$$t = \frac{2A}{Ca\sqrt{2g}}(\sqrt{h_1} - \sqrt{h_2}) \qquad (4\text{-}19)$$

Orifice Coefficients. One of the earliest experimenters on sharp-edged orifices was Hamilton Smith, Jr.[1] His values of the coefficient of discharge for round and square orifices are given in Table 4-3. There have been many subsequent investigations of circular orifices, not all of which are in agreement.

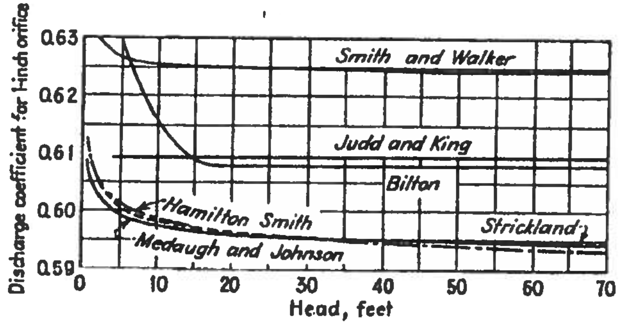

Fig. 4-6. Orifice coefficients.

Investigations by Medaugh and Johnson[2] check Smith's coefficients for orifices larger than ½ in. in diameter within ½ of 1 per cent. Values of the coefficient of discharge for a 1-in. orifice as determined by various investigators and plotted by Medaugh and Johnson are shown in Fig. 4-6. The differences between the values are undoubtedly not entirely due to experimental errors. Many other factors may contribute, as, for instance, the ratio of the orifice diameter to the dimensions of the tank wall, the sharpness of the edge of the orifice, the roughness of the inner surface, the orifice plate, and the temperature of the water. The effect of having the tank wall approach the orifice is to suppress contraction and therefore to make C approach the value of C_v.

[1] "Hydraulics," 1886.
[2] Medaugh and Johnson, Investigation of the Discharge and Coefficient of Small Circular Orifices, *Civil Eng. (N.Y.)*, July, 1940, pp. 422–424.

Smith and Walker[1] found values of C_v to vary from 0.954 to 0.991 for orifices varying in diameter from 0.75 to 2.5 in., respectively. They also found a small variation with head, the above values being averages for heads varying from 1 to 60 ft.

Values of C_c for circular sharp-edged orifices were found to vary from approximately 0.67 for ¾-in. orifices to 0.614 for 2.5-in. orifices when the head is 2 ft or more. Values are slightly larger for lower heads.

If there is suppression of contraction on one side and opportunity for complete contraction on the other sides, more water will approach with velocity components parallel to the face of the orifice on these sides and cause increased contraction. This to a large extent will compensate for loss of contraction on the other side. Williams[2] found, for rectangular orifices 30 in. wide and 2 to 4 in. high with full contraction at the top and completely suppressed contraction on the two sides and bottom, that the average coefficient of discharge was 0.607. This value corresponds closely to the coefficient for orifices with complete contraction. For orifices having full contraction at the top, one side a sharp edge 6 in. from the side of the channel, and contraction suppressed at one side and the bottom, Williams secured an average coefficient of 0.611. With the above orifices, except that the top was beveled to an angle of 45°, he obtained values of C of 0.776 and 0.755, respectively. Table 4-4, from results compiled by Smith,[3] indicates the effect of suppression of contraction for small orifices. In this table, "suppressed contraction" means that the edge of the orifice coincides with the side of the channel, and "partly suppressed" means that the distance of the edge of the orifice from the side of the channel was 0.066 ft. A special case of suppressed contraction is the pipe orifice, which will be discussed later.

When the inner edge of the orifice is rounded, as in Fig. 4-2, contraction is suppressed, C_c approaches 1, and C approaches the value of C_v. Values of C_v for such orifices are approximately the same as for sharp-edged orifices.

Roughening the inner surface of the orifice plate retards the

[1] D. Smith and W. J. Walker, Orifice Flow, *Proc. Inst. Mech. Engrs. (London)*, 1923, pp. 23–36.
[2] Unpublished experiments performed at the University of Michigan in 1928.
[3] *Op. cit.*, pp. 65–67.

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velocity components along the wall which cause contraction and thus tends to increase the values of both C_c and C. Similar effects would result from having the orifice plate differ from a perfectly plane surface. If it were slightly warped outward, C_c would be increased, whereas an inward curvature of the plate would have the opposite effect (see Standard Short Tubes, p. 4-19).

The effect of the water temperature is to change the viscosity and density. Taken in conjunction with the variation of C

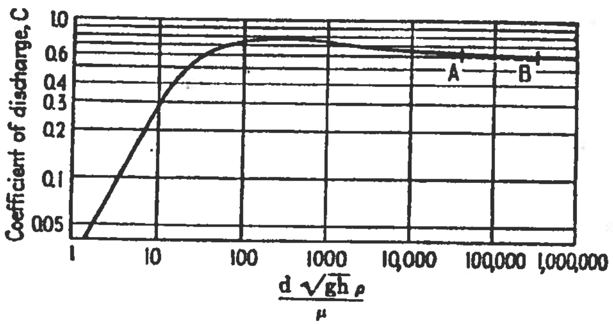

Fig. 4-7. Orifice coefficients.

with the velocity and orifice diameter shown in Table 4-3, it becomes clear that here again the Reynolds number is likely to be the coordinating factor. This was shown to be the case by Lea,[1] who plotted more than one hundred experimental values of C against R. The author's curve, derived from Lea's plotted points, is shown in Fig. 4-7. The fluids used in the tests were water, various mixtures of water and glycerin, and a number of oils. Flow is laminar for Reynolds number less than 12 and fully turbulent for R greater than 10,000, intervening values corresponding to a transition region. Except in the transition range, all points plotted by Lea show a spread of about 3 per cent. A spread of approximately 15 per cent occurs in the vicinity R equal to 1,000. The range of Reynolds numbers covered by the tests of Medaugh and Johnson is shown in Fig. 4-7 by the dashed line AB.

[1] F. C. Lea, "Hydraulics," 6th ed., Longmans, Green & Co., Inc., New York, 1942.

Investigations by Bilton[1] showed the coefficient of discharge of a circular orifice under any given head to be the same whether the jet is horizontal, vertical, or at any intermediate angle.

The extracts from tables by Fanning[2] and Bovey,[3] in Table 4-5, give coefficients of discharge for various shapes and arrangements of orifices with complete contraction. Fanning's table, compiled from experiments from several sources, contains coefficients for orifices 1 ft wide, of various heights, and under a wide range of heads. Bovey's table, prepared from his own experiments on orifices of different shapes, each with the area of a circle ½ in. in diameter, indicates the effect of shape of opening on the coefficient.

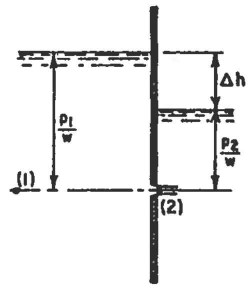

Fig. 4-8. Submerged orifice.

Submerged Orifices. Shown in Fig. 4-8 is an orifice in a tank with liquid on both sides. Application of the Bernoulli equation, taking the datum through the center of the orifice, yields Eq. (4-3) exactly in the same form as for free discharge (p. 4-2).

$$v_2 = \sqrt{2g\left(\frac{p_1}{w} - \frac{p_2}{w} + \frac{v_1^2}{2g} - h_l\right)} \qquad (4\text{-}3)$$

Noting that in this case

$$\frac{p_1}{w} - \frac{p_2}{w} = \Delta h \qquad (4\text{-}20)$$

neglecting $v_1^2/2g$, and introducing C to take care of the contraction and energy loss, the equation for discharge is

$$Q = Ca\sqrt{2g\,\Delta h} \qquad (4\text{-}21)$$

The few experiments for determining C for submerged orifices that are available indicate that the value of the coefficient is

[1] H. J. I. Bilton, Coefficients of Discharge through Circular Orifices, paper read before Victorian Institute of Engineers, April, 1908, *Eng. News*, July 9, 1908.

[2] J. T. Fanning, "Water-supply Engineering," pp. 205–206, D. Van Nostrand Company, Inc., Princeton, N.J., 1906.

[3] H. T. Bovey, "Hydraulics," p. 40, John Wiley & Sons, Inc., New York, 1909.

approximately ½ diameter downstream from the inner face of the orifice plate. The area at the vena contracta, a_2 in Fig. 4-1, is related to the area of the orifice a as follows:

$$a_2 = C_c a \tag{4-1}$$

where C_c is called the *coefficient of contraction*.

The contraction is caused by the fact that those elements of the fluid with approach from the side of the orifice have transverse velocity components directed toward the center of the orifice. Therefore the nearness of boundaries, as, for example, for orifices in pipes (p. 4-14), would tend to reduce the amount of contraction and increase C_c. If one edge of an orifice is flush with a wall, the contraction on that side will be entirely eliminated. However, the contraction from the other side will be increased by approximately the same amount. Increasing the roughness of the inner face of the orifice plate would also reduce the transverse velocity components slightly. Rounding the inner edge of the orifice reduces contraction, and the contraction can be eliminated completely by shaping the orifice to conform with the form of the contracting jet as shown in Fig. 4-2.

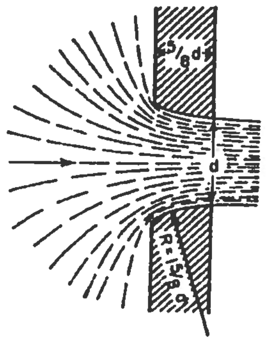

FIG. 4-2. Bell-mouthed orifice with rounded upstream edge.

Fundamental Equations. The Bernoulli equation (Sec. 3), written from any point in the liquid, such as 1 in Fig. 4-1, to the vena contracta (point 2), taking the datum plane through the center of the orifice, is

$$\frac{v_1^2}{2g} + \frac{p_1}{w} = \frac{v_2^2}{2g} + \frac{p_2}{w} + h_l \tag{4-2}$$

and

$$v_2 = \sqrt{2g\left(\frac{p_1}{w} - \frac{p_2}{w} + \frac{v_1^2}{2g} - h_l\right)} \tag{4-3}$$

Point 2 being located where the jet has ceased to contract, its pressure is that of the surrounding fluid. For discharge into

the atmosphere, p_2 is therefore zero on the gage scale. For large tanks, v_1 is so small that it may be neglected. Replacing p_1/w with h and dropping the subscript of v_2, Eq. (4-3) may now be written

$$v = \sqrt{2g(h - h_l)} \tag{4-4}$$

Neglecting energy losses, the equation for the theoretical velocity becomes

$$v_t = \sqrt{2gh} \tag{4-5}$$

or

$$h = \frac{v_t^2}{2g} \tag{4-6}$$

The expression $v_t^2/2g$ is termed the *velocity head.* Table 4-1 gives values of v_t for heads from 0 to 50 ft, and Table 4-2 gives h for velocities from 0 to 50 ft per sec.

It is convenient to take care of the energy loss by introducing a *coefficient of velocity* C_v. Thus, instead of subtracting the energy loss as in Eq. (4-4), the expression for the velocity at the vena contracta may be written

$$v = C_v \sqrt{2gh} \tag{4-7}$$

The discharge is the product of the velocity and area at the vena contracta as follows:

$$Q = a_2 v_2 \tag{4-8}$$

Inserting the value of a_2 from Eq. (4-1) and the value of v_2 from Eq. (4-7),

$$Q = C_c a C_v \sqrt{2gh} \tag{4-9}$$

The product of the coefficient of velocity C_v and the coefficient of contraction C_c is called the *coefficient of discharge* C. Equation (4-9) may then be written

$$Q = Ca\sqrt{2gh} \tag{4-10}$$

The energy loss may be expressed in terms of C_v by equating the expressions for v given in Eqs. (4-4) and (4-7) as follows:

$$\sqrt{2g(h - h_l)} = C_v \sqrt{2gh}$$

Then

$$h_l = (1 - C_v^2)h \tag{4-11}$$

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