ANALYSIS FOR OBTAINING UNIFORM FLOW FROM EQUALLY SPACED ORIFICES IN IRRIGATION PIPE

by 45

HUGO RAMIREZ-GUZMAN

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Approved by:

J O Hodges
Major Professor

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INTRODUCTION

The need for increased food supplies to feed a rapidly growing world population is leading to a rapid expansion of irrigation. New irrigation development is taking place not only in arid regions but in humid regions as well.

Flood irrigation has been practiced for centuries. Traditionally, water has been delivered to irrigated lands by open ditches resulting in large water losses due to evaporation and seepage. This introduction of pipelines to transport irrigation water has greatly reduced water losses.

Light weight gated pipe is a relatively new development for distributing water to fields under heads ranging from 0.5 to 8.0 feet of water. This method of water delivery is common for furrow irrigating row crops. An orifice is cut in the pipe wall on a spacing equal to the row width of the growing crop. A gate is placed in the orifice to control the size of the opening.

Water, one of the basic elements for plant life, is becoming a scarce resource. The available water supply for irrigation must be evenly distributed on the land for maximum crop production per unit of water. In addition to conserving water, costs of production will be held to a minimum.

Uniform distribution of irrigation water prevents over irrigation of some areas and insufficient moisture for others. Run-off losses are reduced to a minimum.

STATEMENT OF THE PROBLEM

Present gated pipe systems have adjustable orifices to give a wide range of flows. As a result, the gate must be set by the irrigator for the desired flow.

Approximately equal discharge from orifices in a perforated pipe with holes of equal sizes and equal spacing may be secured if the total area of orifices is small in relation to the cross section area of the pipe and if the pipe is of large diameter in relation to its length. However, the economy of design and the conditions in the field require numerous and relatively large orifices to minimize the pressure drop through them and a pipe not too large in size to keep down its cost. Thus, to secure both economy and uniformity of discharge a variation of the holes either in spacing or in size may be necessary.

The purpose of this study was to determine if the slope for a pipe of equally spaced orifices can be designed so that equal discharge through the orifices can be secured.

REVIEW OF LITERATURE

Flow of water from a perforated pipe has been analysed both theorically and experimentally. Enger and Levy (2) considered the variation of pressure in a long narrow slot. By neglecting pipe friction and assuming straight pipe with uniform cross-sectional area, they wrote a momentum equation for an elemental length of pipe:

$$\left[w\,A(h + dh) - w\,Ah\right]dt = w\,\frac{VA}{g}\left[(V-dV) - V\right]dt$$

$$dh = -\frac{V}{g}\,dV$$

$$\int dh = -\frac{1}{g}\int V\,dV$$

$$h = -\frac{V^2}{2g} + h_o \qquad (1)$$

where w = specific weight of fluid in pounds per cubic foot.

A = cross-sectional area of pipe in square feet.

h = static pressure head in feet of fluid.

t = time in seconds.

V = velocity in feet per second.

g = acceleration of gravity in feet per second squared.

h_o= static pressure at dead end in feet of fluid.

They found that neglecting pipe friction, the pressure at any point along the slot is equal to the static head at the dead end minus the velocity head at the given point. Assuming that the coefficient of discharge in the flow equation, $q = C_d\, b\, dx \sqrt{2gh}$, remains constant, they derived the following equation for pressure at any point along the slot ,

$$h = \frac{h_o}{2} \text{Vers} \left(\pi - 2\, \frac{C_d\, b\, x}{\cdots} \right) \qquad (2)$$

where C_d = coefficient of discharge.

b = slot width.

x = distance from dead end of main line in feet.

Enger and Levy found that the coefficient of discharge decreased with an increase in velocity in the pipe and proposed the empirical formula after experimentation with ten 3/8 " openings in a two inch water pipe,

$$C_d = \frac{h - V^2/2g}{h}\, C_{do} \qquad (3)$$

where $V^2/2g$ = velocity head of water in the pipe approaching the opening.

C_{do} = coefficient of discharge for the last opening.

A tabulation by Enger and Levy for one set of experiments showed close agreement between observed and calculated values of pressure head using equation (1) with a pressure range of 3.22 feet at the inlet to 3.38 feet of water at the dead end.

Gladding (3) considered the loss of head in a uniformly tapped pipe. He assumed that uniform outlets evenly spaced along a main line would discharge an equal amount of fluid.

Edwards (1) explained that the velocity in the direction of flow decreases after passing each orifice and that this fact brings as consequence a corresponding increase in pressure. The decrease in transfacial velocity is responsible for the increase in efficiency of each succeeding orifice resulting in a greater discharge from each successive opening downstream. Edwards concluded that Gladding's assumption was not possible and does not represent an accurate approximation of actual conditions except for a pipe having a large cross-sectional area compared to the total area of orifices.

Keller (7) in studying the manifold flow, stated that only inertia and friction forces determine the distribution of flow from manifolds. Inertia corresponds to the change in velocity head and when the fluid moves along the pipe its longitudinal velocity decreases because a part of the fluid volume is being discharged through the holes. Then, the fluid in the manifold is decelerated and causes an increase in pressure as predicted by Bernoulli's equation. Friction causes reduction in pressures. Thus, the relative magnitudes of these two forces determine whether there will be an increase or decrease of static pressure at the dead end of the pipe.

Keller wrote the following basic equation of pressure rise in the direction of flow:

$$\frac{dP}{w} = - d(V^2/2g) + f \frac{dx}{D} \frac{V^2}{2g} \tag{4}$$

where P = pressure of fluid in pounds per square foot.

w = specific weight of fluid in pounds per cubic foot.

V = velocity in feet per second.

f = Darcy's friction factor defined by $h = f \frac{l}{D} \frac{V^2}{2g}$

D = diameter of pipe in feet.

g = acceleration of gravity in feet per second squared.

x = distance from dead end of main line in feet.

The deceleration term is negative since an increase in pressure results from a decrease in velocity. Although the friction factor causes a reduction in pressure in the direction of flow, it is positive because x is measured from the dead end in the direction opposing flow as shown in Fig.1.

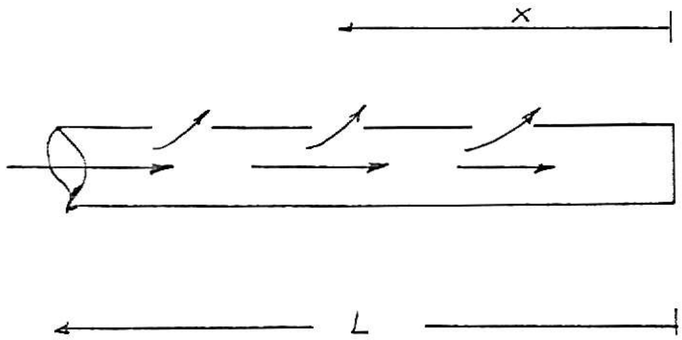


Fig. 1 Inlet manifold.

To determine the pressure P at any distance from the dead end for an inlet manifold, Keller integrated equation (4) and wrote,

$$P = P_L + w\left(\frac{V_L^2 - V^2}{2g}\right) + \int_L^{l-x} f\,\frac{w}{D}\,\frac{V^2}{2g}\,dx \qquad (5)$$

where subscript L represents inlet end of main line.

For uniform discharge the velocity decreases linearly from its initial velocity to zero at the dead end. So

$$V = V_L\,(x/L) \qquad (6)$$

Substitution of equation (6) in equation (5) gives,

$$P = P_L + w\left[\frac{V_L^2 - V_L^2\,(x/L)^2}{2g}\right] + \int_L^{L-x} f\,\frac{w}{D}\,\frac{V_L^2}{2g}\,\frac{x^2}{L^2}\,dx$$

$$= P_L + \frac{w}{2g}\,V_L^2\,(1-(x/L)^2) - f\,\frac{wL}{3D}\,\frac{V_L^2}{2g}\left[1-(1-x/L)^3\right] \qquad (7)$$

Oakey (8) analysed the flow of a fluid from a short tube in the side of a pipe. He began with the energy equation

$$Qu\,w\left(\frac{Vu^2}{2g} + hu\right) = Qd\,w\left(\frac{Vd^2}{2g} + hd\right) + q\,w\left(\frac{q}{Qu}\,\frac{Vu^2}{2g} + hu\right)$$

and then he reduced this equation to:

$$(hd - hu) = \left[3 \frac{q}{Qu} - (q/Qu)^2\right]\frac{Vu^2}{2g} \quad (8)$$

where Qu = flow rate in upstream cross-section of main line, in cubic foot per second.

w = specific weight of fluid.

Vu = velocity in upstream cross-section of main line in feet per second.

hu = pressure head upstream.

Qd = flow rate in downstream cross-section of main line.

Vd = velocity in downstream cross-section of main line in feet per second.

hd = pressure head downstream.

q = rate of flow in branch pipe in cubic feet per second.

From his analysis, he assumed the head on the discharging tube to be:

$$\frac{q}{Qu}\frac{Vu^2}{2g} + hu$$

For the determination of the coefficient of discharge he proposed the following equation:

$$q = Cd\ a\sqrt{2g\left(\frac{q}{Qu}\frac{Vu^2}{2g} + hu\right)} \quad (9)$$

x As one can observe, in the case of a long pipe with numerous orifices the ratio $q/Qu(Vu^2/2g)$ becomes negligible and may be disregarded. If on the contrary q/Qu is not insignificant one should consider the effect of $\frac{q}{Qu}\frac{Vu^2}{2g}$.

Howland (6) used the following Bernoulli's type equation in designing a perforated pipe for uniform discharge,

$$h = \frac{P}{w} = \frac{P_o}{w} - \frac{V_L^2}{2g}\left[(x/L)^2 - f\frac{L}{3D}(x/L)^3\right] \quad (10)$$

Values for the coefficient of discharge Cd were determined experimentally by him and used in his calculations. He compared the observed discharge from each orifice with that predicted by the equation,

$$q = Cd\ a\sqrt{2gh} \tag{11}$$

Hansen (4) in trying to obtain uniform discharge from gated irrigation pipe experimented with two 20 foot lengths of four-inch gated pipe with gate spacing of 22 inches and two 20-foot lengths with 36-inch gate spacing. Equal flow was achieved from every gate when he placed the pipe on a slope of 1 in 300.

Tovey (10) analysed the hydraulic losses of four-inch pipe using the 1 in 300 slope recommended by Hansen (4). He measured the discharge from all the gates and from these measurements calculated the average discharge per gate. He also determined the average head loss per gate by measuring the piezometric head at the inlet and at the last gate and dividing by the total number of gates. Tovey said that when the average head loss per gate exceeded 0.1 foot for a gate opening of 0.55", 0.15 foot for gate opening of 0.95 inches and 0.17 foot for gate opening of 1.7 inches, it was not possible to obtain equal flow.

Spomer (9) experimenting with 6-inch irrigation pipe with uniformly spaced orifices pointed out that he did not get the same discharge of all orifices when he used the slope recommended by Hansen. In his experiment for a falling slope of 1 in 300, an increase in discharge per orifice was measured as the dead end was approached. With a rising slope of 1 in 300, a decrease in discharge per orifice was measured as the dead end was approached. He concluded that it may be possible to provide uniform discharge in a level pipe within a discharge range of 4 to 15 gallons per minute per gate.

Hazen and Williams (5), by measuring flow velocities within circular pipes,found that the velocity is a function of the hydraulic radius, the hydraulic slope, and of a friction coefficient C_H. By selection of exponents for the hydraulic radius and the slope they concluded that in their equation the coefficient C_H may be considered approximately constant for a pipe of a specific diameter and material. The given equation is :

$$V = 1.318\, C_H\, R^{0.63}\, S^{0.54} \qquad (12)$$

where V = velocity within the pipe in feet per second.

C_H = Hazen-Williams friction coefficient.

R = hydraulic radius = diameter of pipe over four = D/4.

S = hydraulic slope = pressure loss/length.

They tabulated different values of C_H for different sizes and materials.

ANALYSIS OF THE PROBLEM

This study was directed to find the same discharge from equally spaced orifices in irrigation pipe. The discharge from an orifice is expressed by the flow equation:

$$q = Cq\, a\sqrt{2gh} \qquad (13)$$

where q = discharge in cubic feet per second.

Cq = coefficient of discharge.

a = area of orifice in square feet.

h = pressure head at a given point in the pipe in feet of water.

g = acceleration of gravity, in feet per second squared.

Application of Bernoulli's equation between the dead end of the pipe and any other point, gives:

$$h + \frac{V^2}{2g} + z = h_o + \frac{V_o^2}{2g} + z_o + h_L \qquad (14)$$

where h = pressure head at any point in the pipe in feet of water.

$\frac{V^2}{2g}$ = velocity head at the point in feet.

$\frac{Vo^2}{2g}$ = velocity head at the dead end = 0.

z = elevation of the point in feet.

zo = elevation of the dead end in feet.

h_L = pressure loss between the considered points.

Therefore,

$$h = h_o - \frac{V^2}{2g} + h_L + (z_o - z) \qquad (15)$$

Fig.2 shows the distribution of velocity that occurs along the pipe. The velocity within the pipe decreases as the flow of water within the pipe does. The velocity has its maximum value at the entrance and is zero at the dead end. After passing each orifice a drop in velocity within the pipe is observed caused by the disminution of flow within the pipe. If an infinite number of orifices is considered the velocity distribution for uniform discharge would be a straight line. By assuming such straight line as the velocity distribution within the pipe the following relationships are obtained :

$$\frac{V}{V_1} = \frac{X}{X_1} \qquad (16)$$

$$\frac{z_o}{X_1} = \frac{z}{X_1 - X} \qquad (17)$$

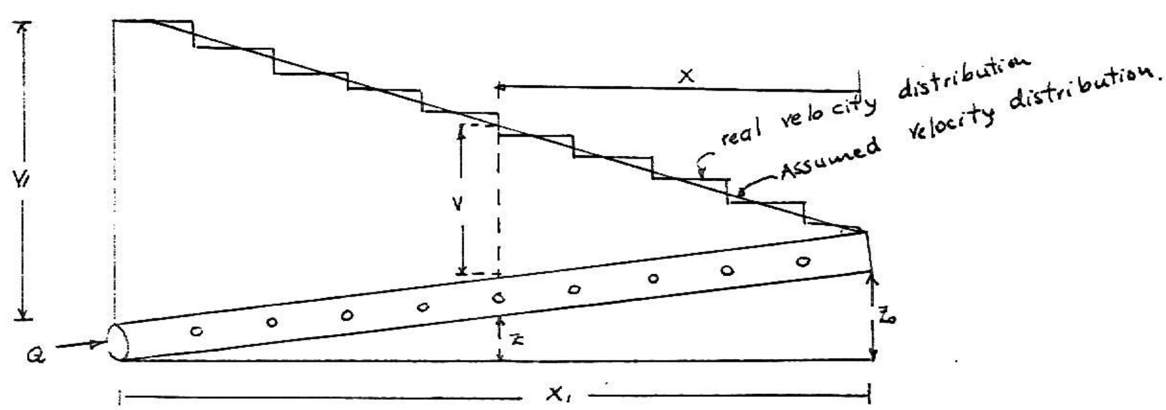


Fig.2 Velocity distribution.

$$z_o (X_1 - X) = zX_1$$

$$(z_o - z) = z_o (X/X_1) \quad (18)$$

Substitution of equations (16) and (18) in equation (15) gives:

$$h = h_o - \frac{V_1^2}{2g} (X/X_1)^2 + h_L + z_o (X/X_1) \quad (19)$$

With the consideration that the head loss between the point and the dead end is equivalent to the sum of all the small head losses between the point and the dead end in a pipe whose velocity distribution is a straight line, the following relationship is observed:

$$h_L = \int_0^X h' \, dx$$

where h' = head loss per unit length = $\frac{\Delta h}{\Delta x}$

From any flow equation one can observe that the head loss is a function of the velocity within the pipe to some exponent n. Therefore,

$$h' = h_1 (V/V_1)^n \quad (20)$$

where h_1 = value of h' at the entrance of the pipe.

n = exponent. (Experimentally equal to 1.85 from Hazen-Williams eq.).

Thus,

$$h_L = h_1 \int_0^X (V/V_1)^n \, dx$$

$$= h_1 \int_0^X (X/X_1)^{1.85} \, dx$$

$$h_L = \frac{h_1 X_1}{2.85} (X/X_1)^{2.85} \quad (21)$$

Substitution of equation (21) in equation (19) gives:

$$h = h_o - \frac{V_1^2}{2g} (X/X_1)^2 + \frac{h_1 X_1}{2.85} (X/X_1)^{2.85} + z_o(X/X_1) \quad (22)$$

From Hazen-Williams velocity formula,

$$V = 1.318 \, C_H \, R^{0.63} \, S^{0.54}$$

$$S = h_1 = \left[\frac{V}{1.318\ C_H}\right]^{1.85} \frac{1}{R^{1.17}}$$

Therefore,

$$h_1 X_1 = \left[\frac{V}{1.318\ C_H}\right]^{1.85} \frac{X_1}{R^{1.17}} \qquad (23)$$

Substitution of equation (23) in equation (22) gives:

$$h = h_o - \frac{V_1^2}{2g} (X/X_1)^2 + \left[\frac{V_1}{1.318\ C_H}\right]^{1.85} \frac{X_1}{2.85\ R^{1.17}} (X/X_1)^{2.85} + z_o (X/X_1) \qquad (24)$$

Let s=slope = z_o/X_1

Then, $z_o(X/X_1) = sX = s(X/X_1)\ X_1$ (25)

Substitution in equation (24) gives:

$$h = h_o - \frac{V_1^2}{2g} (X/X_1)^2 + \left[\frac{V_1}{1.318\ C_H}\right]^{1.85} \left[\frac{X_1}{2.85\ R^{1.17}}\right] (X/X_1)^{2.85} + s\frac{X}{X_1} X_1 \qquad (26)$$

Finally,

$$q = C_q\ a\sqrt{2gh} \qquad (27)$$

PROCEDURE AND COMPUTATIONS

By using the derived formula (26) and (27) the problem was started by application to known values. Spomer's experimental results were applied in this case and after the respective calculations a similarity between the expeimental and calculated values was observed. A C_H equal to 120 was assumed. This value is commonly used for smooth aluminum pipe with couplers. Spomer's results in tests 1, 2,and 3 with zero slope were compared with discharge calculated by the above formula. Calculated discharge and the experimentally measured discharge for tests 1, 2,and 3 are compared in Tables 1, 2 and 3 respectivelly.

Appendix A contains the computer program, measured discharge and calculated discharge. The values of the parameters used in this comparison were:

X_1 = length of pipe = 60 feet.

D = Pipe diameter = 6 inch.

Number of orifices = 18

Spacing between orifices = 40 inch.

C_H= 120.

R_H= hydraulic radius = D/4.

Delta = relative distance from the dead end = X/X_1

X = distance from the point considered to the dead end.

A = pipe cross-sectional area in square feet.

HP= pressure at a given point, determined by equation (26).

Q = total inlet flow, in cfs.

Aorif= orifice area (3/4" orifice diameter).

V_1= velocity within the pipe at entrance.

HO= pressure head at the dead end.

CD= coefficient of discharge.

QGPM= value of inlet flow in gallons per minute.

S = slope. (from 0.000 to - 0.003).

The maximum difference between the measured discharge and the calculated by formula was found in orifices 3 and 4. In those orifices, the difference with the calculated discharge is close to 5%.

The next step was to compare the discharge calculated by the formula with measured discharge for falling and rising slopes. Spomer's experimental results for the specific case of 1 in 300 slope were the measured values used for the comparisons. Tests(a) and (b) for falling slope and (c) and (d) for rising slope were compared.

The general programming for these tests is similar to the one used before and appears in Appendix B. The values of QGPM and HO for these cases are given in Table 4.

Table 1 Table of comparison between calculated values and experimental results. Slope = 0.

TEST 1-. HO = 0.257 ft.
Q = 70.16 gpm.

Orifice	Experimental values gpm	Calculated values gpm
1	3.89	3.896
2	3.89	3.896
3	* 4.06	3.896
4	* 4.00	3.894
5	3.93	3.893
6	3.89	3.893
7	3.87	3.892
8	3.88	3.892
9	3.89	3.892
10	3.92	3.892
11	3.91	3.893
12	3.89	3.894
13	3.90	3.896
14	3.91	3.899
15	3.85	3.903
16	3.82	3.907
17	3.79	3.913
18	3.87	3.919
total	70.16	
Mean	3.90	

Table 2 Table of comparison between calculated values and experimental results. Slope=0.

TEST 2-. HO = 0.528 ft.
Q = 95.47 gpm.

Orifice	Experimental values gpm	Calculated values gpm
1	5.32	5.3034
2	5.30	5.3029
3	* 5.58	5.3021
4	5.53	5.3011
5	5.41	5.3000
6	5.34	5.2990
7	5.34	5.2981
8	5.34	5.2974
9	5.33	5.2971
10	5.38	5.2973
11	5.33	5.2980
12	5.33	5.2994

Table 2 (Continuation)-.

Orifice	Experimental values gpm	Calculated values gpm
13	5.37	5.3015
14	5.35	5.3045
15	5.33	5.3084
16	5.29	5.3134
17	5.26	5.3195
18	5.34	5.3269
Total	95.47	
Mean	5.30	

Table 3 Table of comparison between calculated values and experimental results.- Slope = 0.

TEST 3-. HO = 0.674 ft.
Q = 107.37 gpm.

Orifice	Experimental values gpm	Calculated values gpm
1	5.91	5.9650
2	5.86	5.9645
3	6.21	5.9636
4	6.15	5.9625
5	6.03	5.9613
6	5.98	5.9601
7	5.95	5.9590
8	5.97	5.9582
9	5.90	5.9578
10	5.99	5.9579
11	5.97	5.9585
12	5.94	5.9599
13	5.97	5.9621
14	5.94	5.9653
15	5.92	5.9694
16	5.90	5.9747
17	5.84	5.9812
18	5.94	5.9891
Total	107.37	
Mean	5.97	

Table 4 Pressure heads and discharges used for the specific slope 1 in 300.

	QGPM	HO (ft.)
1-. Falling Slope.		
Test (a)	94.83	0.611
Test (b)	112.22	0.841
2-. Rising Slope.		
Test (c)	84.25	0.338
Test (d)	87.86	0.558

The calculated discharge is compared with the measured discharge in Tables 5, 6, 7 and 8. The similarity between the results obtained from calculation by the formula and the experimentally determined, prove the accuracy of the formula and the application for any case: horizontal, falling and rising slope. For this specific slope of 1 in 300 close agreement between the calculated values and the measured discharge was found. In test (a), the maximum difference was found in orifice 1 ; such a difference was 3.65%. In test (b) the maximum difference between calculated and measured discharge occured in orifice 2 with a value of 2.7%. For test c) this occurred at orifice 3 (6.5%) and in test (d) at orifice 3 (5.6%).

For a general case and as an example of the use of the formula, a pipe of 300 feet of length was studied. For this case no spacing between orifices was fixed. The computations were made at each tenth of the total length. The parameter $\frac{\text{discharge per orifice}}{\text{area of orifice}}$ was calculated so that the values could be applied to any size and spacing of orifices. Pressure heads at the entrance of 5.0 feet of water and 2.0 feet of

Table 5 Comparison between measured and calculated discharge for Test (a).

HO = 0.611 ft.
Q = 94.83 gpm.

Orifice	Experimental values	Calculated discharge
1	5.53	5.7428
2	5.50	5.6894
3	5.72	5.6352
4	5.64	5.5803
5	5.51	5.5248
6	5.40	5.4687
7	5.38	5.4122
8	5.30	5.3553
9	5.27	5.2982
10	5.24	5.2409
11	5.21	5.1836
12	5.11	5.1264
13	5.08	5.0692
14	5.08	5.0124
15	5.07	4.9559
16	4.99	4.8999
17	4.90	4.8446
18	4.90	4.7899

Table 6 Comparison between measured and calculated discharge for Test (b).

HO = 0.841 ft.
Q = 112.22 gpm.

Orifice	Experimental values	Calculated discharge
1	6.47	6.6249
2	6.40	6.5802
3	6.70	6.5348
4	6.59	6.4890
5	6.45	6.4425
6	6.33	6.3958
7	6.25	6.3489
8	6.22	6.3019
9	6.19	6.2550
10	6.22	6.2082
11	6.25	6.1616
12	6.07	6.1155
13	6.07	6.0699
14	6.10	6.0249
15	6.12	5.9807
16	5.97	5.9374
17	5.90	5.8951
18	5.92	5.8539

Table 7 Comparison between calculated and measured discharge for test (c).

HO = 0.338 ft.
Q = 84.25 gpm.

Orifice	Measured discharge	Calculated discharge
1	4.24	4.1538
2	4.27	4.2200
3	4.56	4.2849
4	4.57	4.3487
5	4.53	4.4114
6	4.51	4.4734
7	4.67	4.5346
8	4.60	4.5952
9	4.60	4.6553
10	4.67	4.7151
11	4.62	4.7746
12	4.76	4.8339
13	4.87	4.8931
14	4.90	4.9523
15	4.94	5.0116
16	4.99	5.0710
17	4.93	5.1306
18	5.02	5.1904

Table 8 Comparison between calculated and measured discharge for test (d).

HO = 0.558 ft.
Q = 87.86 gpm.

Orifice	Measured discharge	Calculated discharge
1	4.56	4.5212
2	4.56	4.5653
3	4.87	4.6087
4	4.84	4.6515
5	4.76	4.6940
6	4.99	4.7360
7	4.76	4.7778
8	4.81	4.8194
9	4.78	4.8609
10	4.89	4.9023
11	4.86	4.9438
12	4,91	4.9853
13	4.99	5.0269
14	5.05	5.0687
15	5.01	5.1107
16	5.05	5.1531
17	5.02	5.1958
18	5.15	5.2388

water were used. The purpose was to study which slope in those cases would give the most uniform discharge for inlet flows of 1.0 , 2.0 and 3.0 cfs. Discharges were computed for zero slope and for rising and falling slopes of 0.001 to 0.005.

The general programming and results appear in Appendix C. The parameters used were:

X_1 = total length of pipe = 300. ft.

Q = inlet flow = 1.0 to 3.0 cfs.

D = pipe diameter = 8 inch.

VI = inlet velocity = Q/A.

A = pipe cross-sectional area in square feet.

C_H = 120. for aluminum pipe.

C_Q = coefficient of discharge assumed equal to 0.6

S = slope. (From 0.000 to 0.005 for falling and rising slopes.).

FLOW = discharge per orifice/area of orifice.

HO = pressure head at the dead end in feet.

HE = pressure head at the entrance in feet.

HP = pressure head at any point in feet.

DELTA = relative distance from the dead end = X/X_1

X = distance from the point to the dead end in feet.

From the results of these computations, figs. 3, 4, 5, and 6 were drawn. Figure 3 represents the obtained values for zero and positive slopes for HE = 5.0 ft of water and Q= 1.0 and 2.0 cfs. For both cases one can observe that positive slopes do not improve uniformity but on the contrary the variation of discharges increases as the slope is increased. Figure 4 represents the obtained values for positive slopes with a pressure head at entrance of 2.0 ft. The same conclusion as above is observed. This head at the

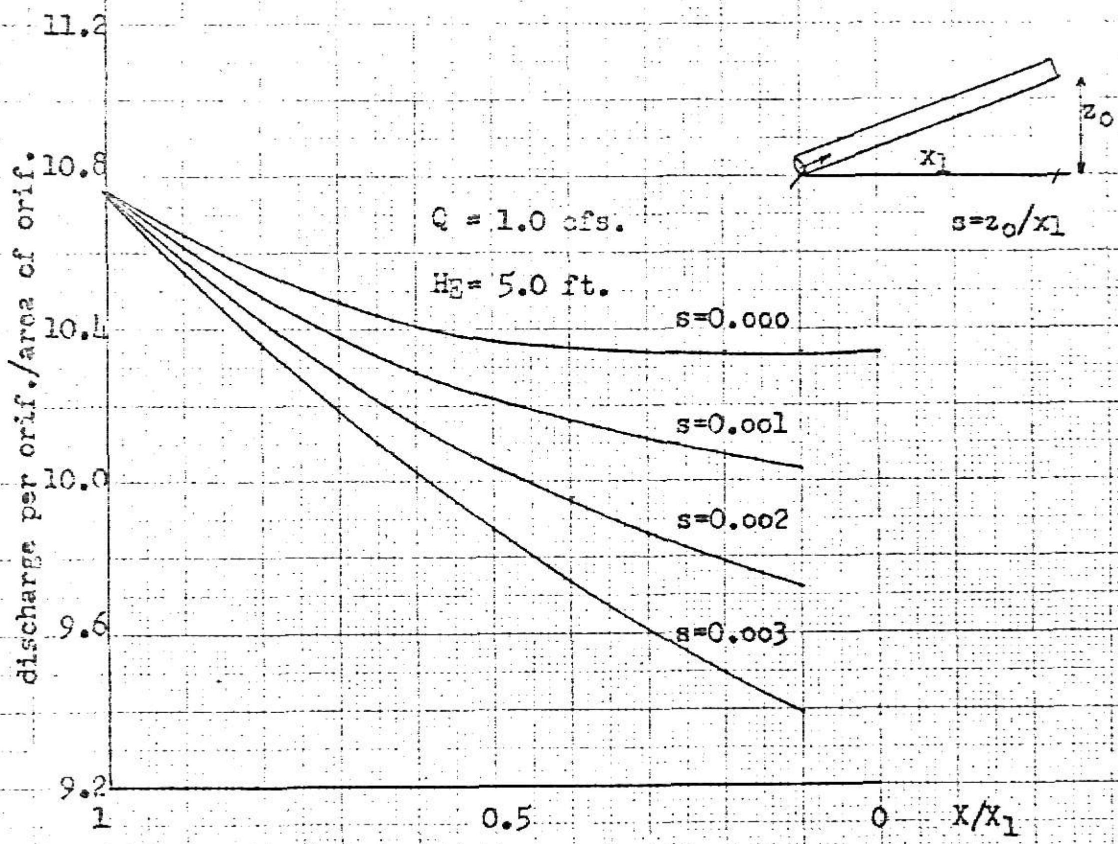
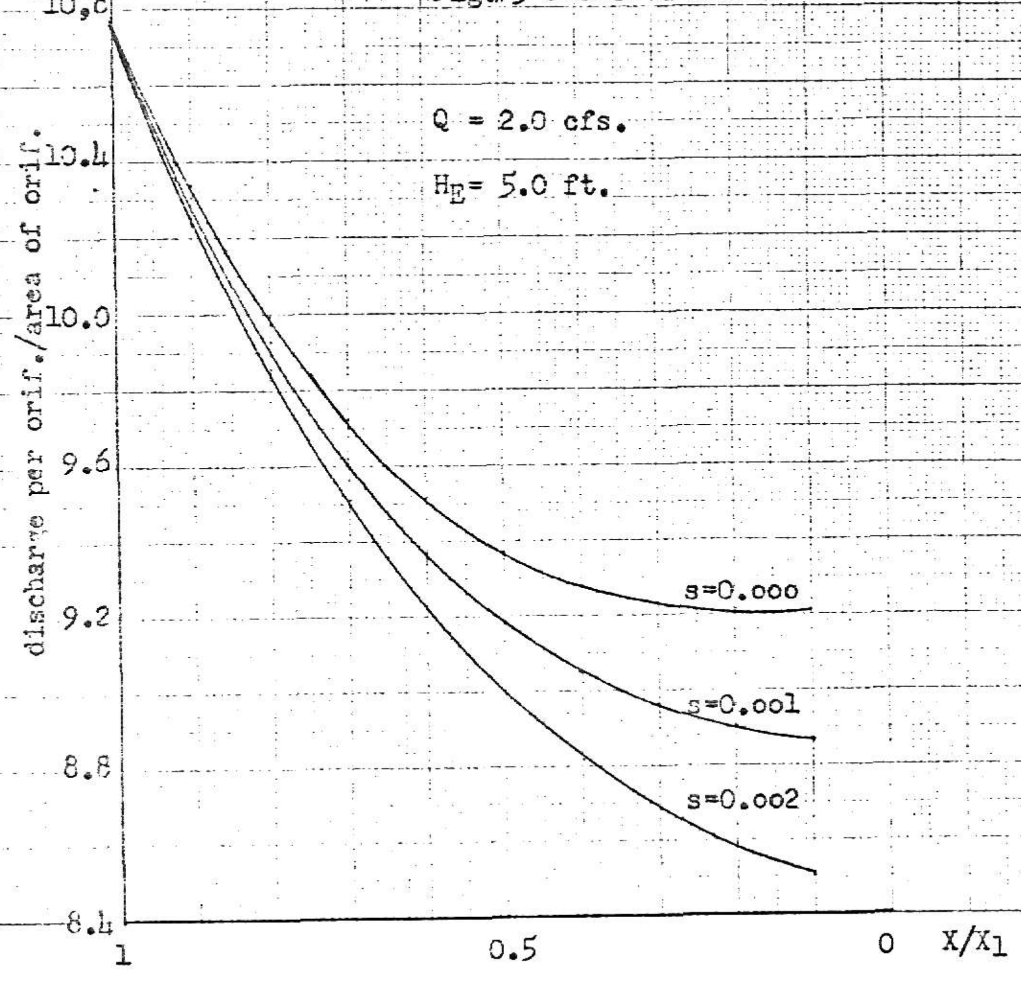


Fig.#3 POSITIVE SLOPES



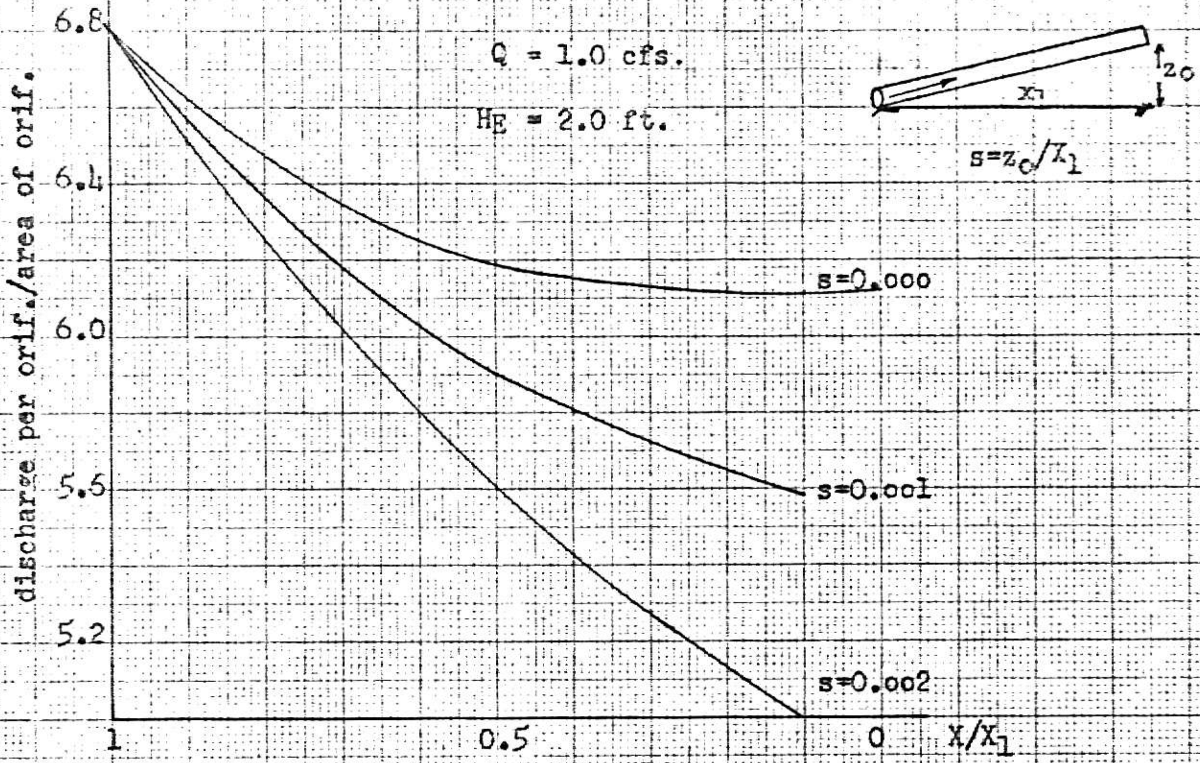
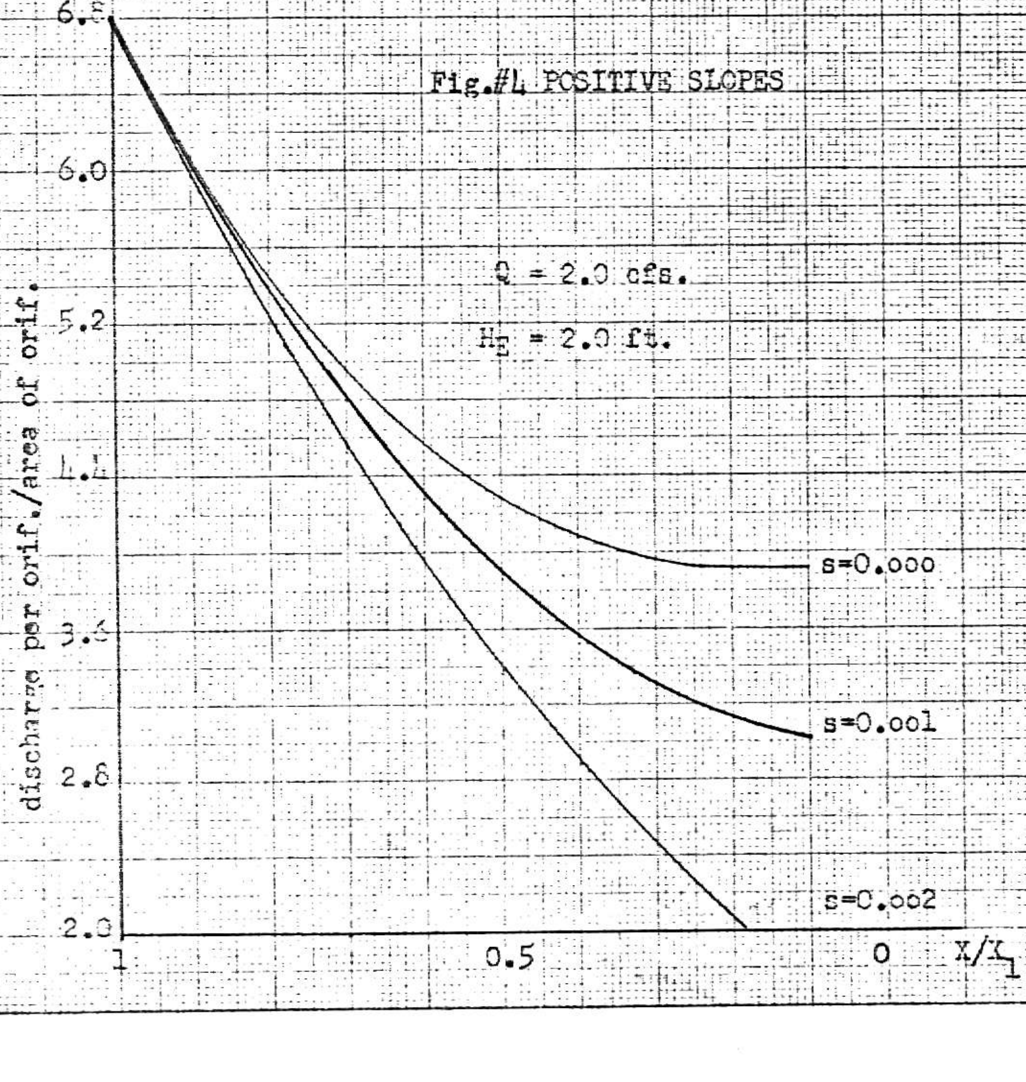


Fig.#4 POSITIVE SLOPES



entrance of 2.0 feet of water is not enough to put 3.0 cfs through the pipe due to losses. Figure 5 represents the calculated values for negative slopes with HE = 5.0 feet and Q= 1.0 and 2.0 cfs. For the first case, Q= 1.0cfs, more uniformity is attained with a slope between -0.001 and -0.002 (probably -0.0015). With the pipe placed on this slope more uniformity of discharge is attained than with the pipe placed horizontally. In the second case, Q= 2.0 cfs., at a slope of -0.005 more uniformity is attained than at zero slope. Figure 6 shows the obtained discharges for falling slopes for HE=2.0 feet and Q=1.0 and 2.0 cfs. In the first case, Q=1.0 cfs., better uniformity is attained with a slope between -0.001 and -0.002 (probably -0.0015 as before) than it is with leveled pipe. For Q=2.0 cfs., a slope of -0.005 gives best uniformity.

For this pipe, 300 feet long, with 5.0 feet of pressure head at entrance, the discharge per orifice can be obtained fom fig.5. For example, if in this case and an inlet flow of 1.0 cfs one wants to know the discharge from an orifice located at mid-way in the pipe ($X/X_1 = 0.5$) and if the pipe is placed on a slope of -0.002, by reading on the ordinate of this graph , one finds:

$$q_1 = \frac{\text{discharge per orifice}}{\text{area of orifice}} = 10.71 \text{ ft/sec.}$$

$\sum q$ =summation of terms q_1 times area of orifice.

$$\text{Actual disch.} = 10.71 \text{ (area of orifice) } \left(\frac{1}{\sum q} \right)$$

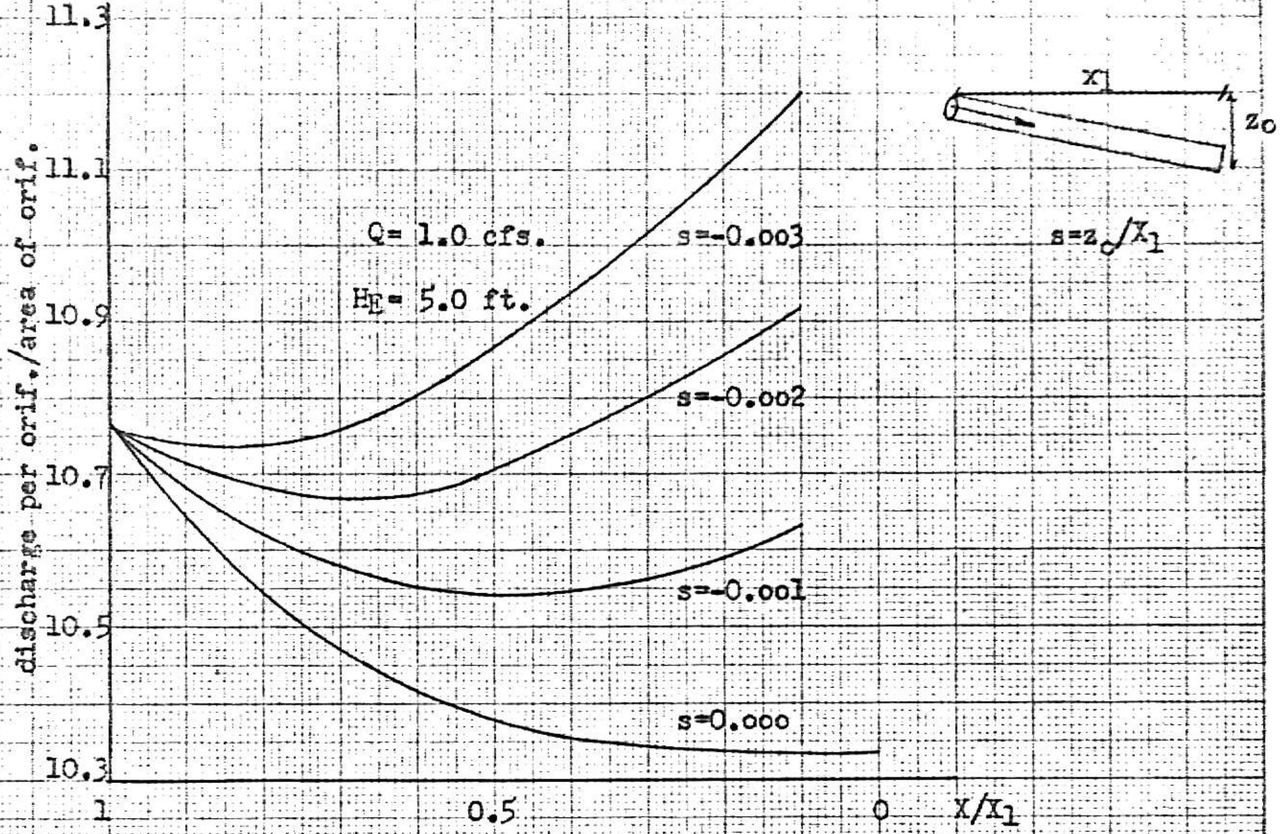
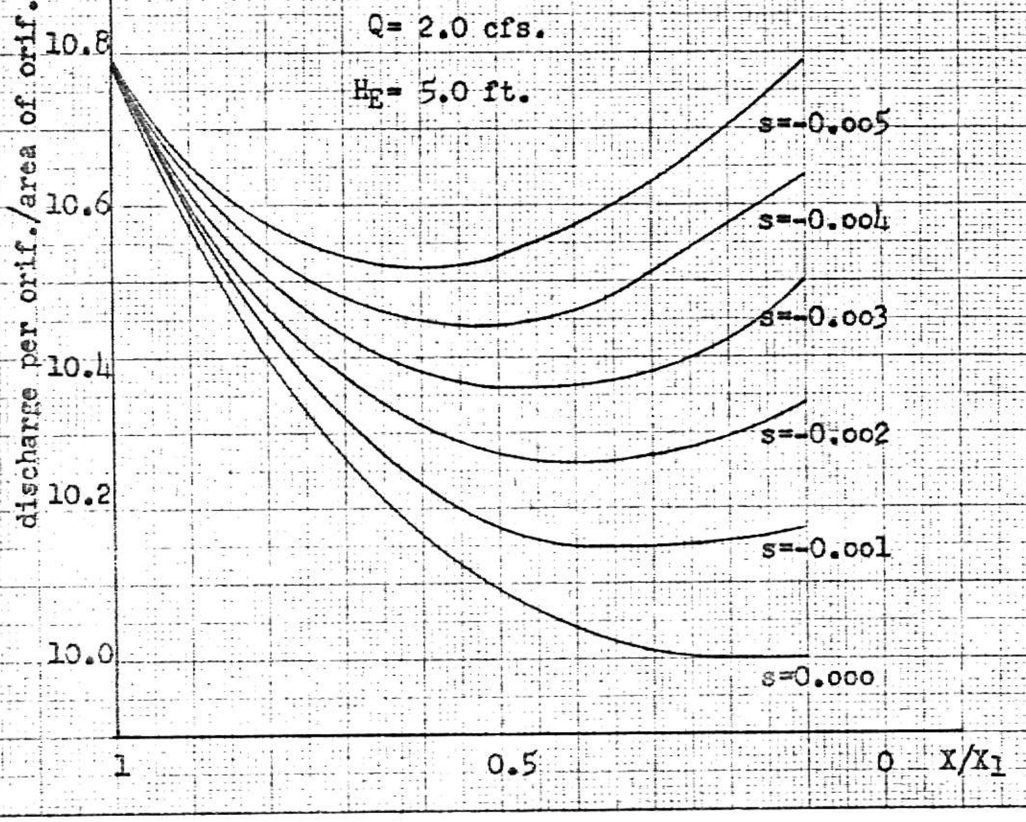


Fig.#5 NEGATIVE SLOPES



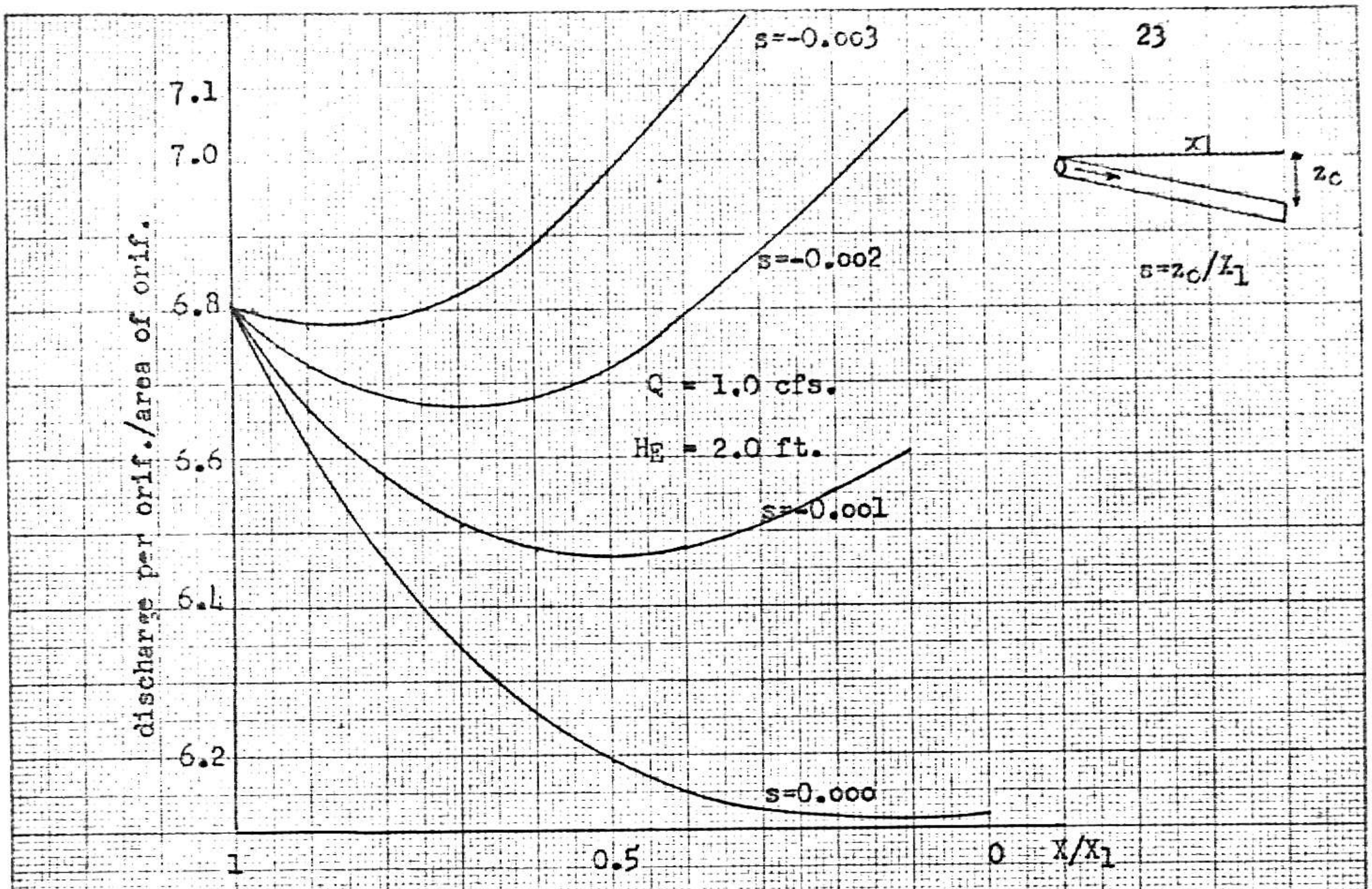
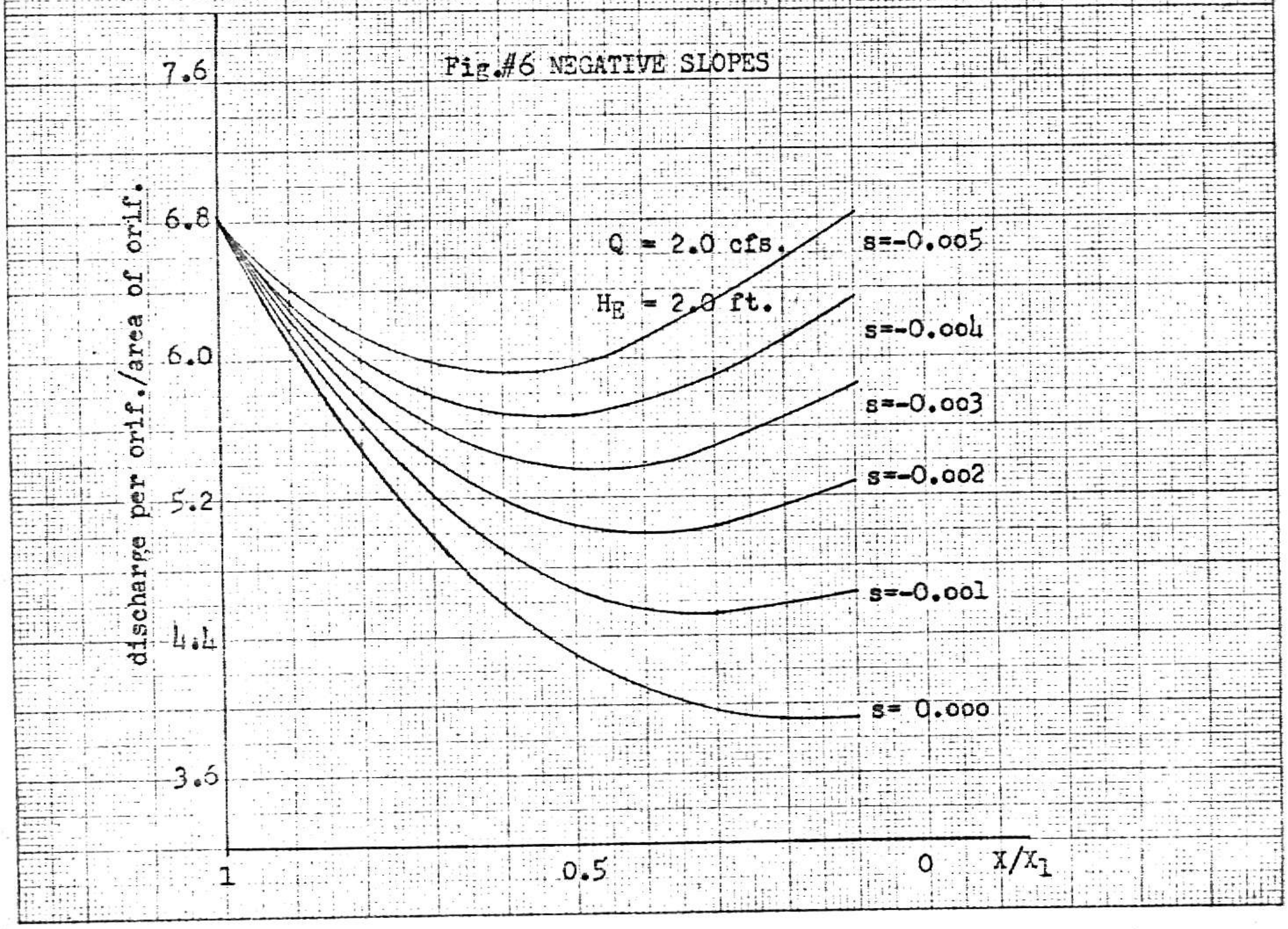


Fig.#6 NEGATIVE SLOPES



SUMMARY AND CONCLUSIONS

Pipes with equally spaced orifices are commonly used in irrigation systems. They offer good efficiency by eliminating evaporation and infiltration losses which occur when water is transported in open earth ditches.

Improvement in the design of such pipes to obtain uniformity of discharge would reduce run-off losses that occur as a result of unequal flow through the rows in a field.

The purpose of this study was to determine the effects of slope of the pipe on uniformity of orifice discharge.

In this study, water velocity within the pipe was assuming to vary linearly as would occur in an infinitely perforated pipe. This linear variation is justified when equal discharge per orifice is obtained since the average velocity within the pipe decreases directly as the flow in the pipe decreases.

Bernoulli's equation was applied between any arbitrary point and the dead end of the pipe to obtain the pressure head at that point and therefore to obtain the theoretical discharge per orifice. The head loss between any point and the dead end was considered as the sum of all the small head losses between the same point and the dead end in a pipe whose velocity distribution is linear.

The equations basically used in this deduction were Bernoulli's equation and Hazen-Williams velocity formula.

Further on, the equation was applied to available experimental values in order to compare it's accuracy. This comparison was made for zero slope and falling and rising slopes of 1 in 300. The discharge computed with the equation was in close agreement with the measured values. This fact was considered as a proof of the accuracy of the formula.

The next step was to apply the formula to a pipe 300-foot long for inlet flows of 1.0, 2.0 and 3.0 cfs. with pressure heads at entrance of 5.0 feet and 2.0 feet of water. This was done for zero slope and for falling and rising slopes in a range of 0.000 to 0.005.

As a conclusion of the results, best uniformity is attained for this pipe if Q= 1.0 cfs. and H_E= 5.0 feet at a falling slope between 0.001 and 0.002 (at 0.0015 probably). It also was concluded that a positive slope does not contribute to better uniformity.

The following table shows the slopes at which the above mentioned pipe would give better uniformity of discharge.

Table 9 Conditions for best uniformity of discharge in a pipe 300- foot long.

H_E (ft)*	Q (cfs.)	Falling Slope.
5.0	1.0	between 0.001 and 0.002
5.0	2.0	0.005
2.0	1.0	between 0.001 and 0.002
2.0	2.0	0.005

* H_E is pressure head at entrance.

Therefore, for inlet flows of 1.0 cfs. and more there is a specific falling slope that will produce better uniformity of discharge than the commonly used horizontally level.

SUGGESTIONS FOR FUTURE RESEARCH

The computed and measured values were in close agreement. However, as not many values were available, this theoretical approach might well be considered as a basis for future research applicable to experimental comparisons with the formula derived.

The writer suggests research upon the following points:

1.- Determination of the Hazen-Williams coefficient C_H for an aluminum pipe.

2.- Does a slight reduction in the area of the orifices situated between the dead end and the middle of the pipe aid in better uniformity when the pipe is placed on the most favorable falling slope?

3.- Does an increase in area in the orifices of the same zone as above aid in better uniformity when the pipe is placed horizontally?

4.- What is the coefficient of discharge for each orifice?

5.- Determination of the pressure head and velocity head at each orifice.

ACKNOWLEDGMENT

The author expresses sincere appreciation to the Government of the United States, the Fullbright Program, and the Comision para Intercambio Educativo in Colombia, for the opportunity given to him to take graduate studies in this country.

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APPENDIX

appendix A

```
340003200701360003200702         11540020000000    FORGO COLD START
C  C
C       COMPUTER PROGRAM FOR UNIFORM DISCHARGE IN AN IRRIGATION PIPE.
C       COMPARISON WITH EXPERIMENTAL DATA (SPOMER,S THESIS)
C       BY HUGO RAMIREZ-GUZMAN.
C       FALLING SLOPE
C       TEST 1
10      READ,CH,G,X1,RH
        HO=0.257
        Q=70.16/450.
        QGPM=70.16
        QT=0.
        AORIF=(3.1416*0.75**2.)/576.
        A=(9.*3.1416)/144.
        V1=Q/A
        CD=1.
15      S=0.
16      M=0
17      DELTA=20./720.
        N=0
33      N=N+1
        M=M+1
35      H=HO+((V1/(1.318*CH))**1.85)*(X1/(2.85*RH**1.17))*DELTA**2.85
36      HP=H-((V1**2)/(2.*G))*(DELTA)**2+S*DELTA*X1
38      YYY=(2.*G*HP)**0.5
        QOR=CD*AORIF*YYY*450.
        QT=QT+QOR
        IF(M-18)41,50,60
50      PUNCH,QT
        CD=QGPM/QT
        PUNCH,CD
        QT=0.
        GO TO 17
60      PUNCH,S,DELTA,HO,HP,QOR,N
41      DELTA=DELTA+40./720.
        IF(DELTA-1.)33,33,70
70      S=S-0.001
        QT=0.
        CD=1.
        IF(S+0.003)80,16,16
80      STOP
        END
120.    32.17  60.   0.125
```

TEST 1

SLOPE	DELTA	HO	HP	QOR
C C				
1.0109E+02				
6.9402E-01				
0.0000	2.7778E-02	2.5700E-01	2.5699E-01	3.8962
0.0000	8.3333E-02	2.5700E-01	2.5694E-01	3.8958
0.0000	1.3889E-01	2.5700E-01	2.5686E-01	3.8952
0.0000	1.9444E-01	2.5700E-01	2.5676E-01	3.8944
0.0000	2.5000E-01	2.5700E-01	2.5664E-01	3.8935
0.0000	3.0556E-01	2.5700E-01	2.5654E-01	3.8927
0.0000	3.6111E-01	2.5700E-01	2.5646E-01	3.8921
0.0000	4.1667E-01	2.5700E-01	2.5640E-01	3.8917
0.0000	4.7222E-01	2.5700E-01	2.5639E-01	3.8916
0.0000	5.2778E-01	2.5700E-01	2.5643E-01	3.8919
0.0000	5.8333E-01	2.5700E-01	2.5654E-01	3.8928
0.0000	6.3889E-01	2.5700E-01	2.5673E-01	3.8942
0.0000	6.9444E-01	2.5700E-01	2.5701E-01	3.8963
0.0000	7.5000E-01	2.5700E-01	2.5738E-01	3.8991
0.0000	8.0556E-01	2.5700E-01	2.5786E-01	3.9028
0.0000	8.6111E-01	2.5700E-01	2.5847E-01	3.9073
0.0000	9.1667E-01	2.5700E-01	2.5920E-01	3.9129
0.0000	9.7222E-01	2.5700E-01	2.6008E-01	3.9195
9.4950E+01				
7.3891E-01				
-1.0000E-03	2.7778E-02	2.5700E-01	2.5533E-01	4.1347
-1.0000E-03	8.3333E-02	2.5700E-01	2.5194E-01	4.1072
-1.0000E-03	1.3889E-01	2.5700E-01	2.4853E-01	4.0793
-1.0000E-03	1.9444E-01	2.5700E-01	2.4509E-01	4.0510
-1.0000E-03	2.5000E-01	2.5700E-01	2.4164E-01	4.0224
-1.0000E-03	3.0556E-01	2.5700E-01	2.3821E-01	3.9937
-1.0000E-03	3.6111E-01	2.5700E-01	2.3479E-01	3.9649
-1.0000E-03	4.1667E-01	2.5700E-01	2.3140E-01	3.9362
-1.0000E-03	4.7222E-01	2.5700E-01	2.2806E-01	3.9077
-1.0000E-03	5.2778E-01	2.5700E-01	2.2477E-01	3.8794
-1.0000E-03	5.8333E-01	2.5700E-01	2.2154E-01	3.8515
-1.0000E-03	6.3889E-01	2.5700E-01	2.1840E-01	3.8240
-1.0000E-03	6.9444E-01	2.5700E-01	2.1534E-01	3.7972
-1.0000E-03	7.5000E-01	2.5700E-01	2.1238E-01	3.7710
-1.0000E-03	8.0556E-01	2.5700E-01	2.0953E-01	3.7456
-1.0000E-03	8.6111E-01	2.5700E-01	2.0680E-01	3.7211
-1.0000E-03	9.1667E-01	2.5700E-01	2.0420E-01	3.6977
-1.0000E-03	9.7222E-01	2.5700E-01	2.0175E-01	3.6754
8.8188E+01				

SLOPE	DELTA	HO	HP	QOR
7.9557E-01				
-2.0000E-03	2.7778E-02	2.5700E-01	2.5366E-01	4.4372
-2.0000E-03	8.3333E-02	2.5700E-01	2.4694E-01	4.3781
-2.0000E-03	1.3889E-01	2.5700E-01	2.4019E-01	4.3178
-2.0000E-03	1.9444E-01	2.5700E-01	2.3342E-01	4.2565
-2.0000E-03	2.5000E-01	2.5700E-01	2.2664E-01	4.1943
-2.0000E-03	3.0556E-01	2.5700E-01	2.1987E-01	4.1311
-2.0000E-03	3.6111E-01	2.5700E-01	2.1312E-01	4.0672
-2.0000E-03	4.1667E-01	2.5700E-01	2.0640E-01	4.0026
-2.0000E-03	4.7222E-01	2.5700E-01	1.9972E-01	3.9373
-2.0000E-03	5.2778E-01	2.5700E-01	1.9310E-01	3.8715
-2.0000E-03	5.8333E-01	2.5700E-01	1.8654E-01	3.8052
-2.0000E-03	6.3889E-01	2.5700E-01	1.8006E-01	3.7385
-2.0000E-03	6.9444E-01	2.5700E-01	1.7367E-01	3.6715
-2.0000E-03	7.5000E-01	2.5700E-01	1.6738E-01	3.6044
-2.0000E-03	8.0556E-01	2.5700E-01	1.6120E-01	3.5372
-2.0000E-03	8.6111E-01	2.5700E-01	1.5513E-01	3.4701
-2.0000E-03	9.1667E-01	2.5700E-01	1.4920E-01	3.4031
-2.0000E-03	9.7222E-01	2.5700E-01	1.4341E-01	3.3364
8.0504E+01				
8.7151E-01				
-3.0000E-03	2.7778E-02	2.5700E-01	2.5199E-01	4.8447
-3.0000E-03	8.3333E-02	2.5700E-01	2.4194E-01	4.7471
-3.0000E-03	1.3889E-01	2.5700E-01	2.3186E-01	4.6472
-3.0000E-03	1.9444E-01	2.5700E-01	2.2176E-01	4.5448
-3.0000E-03	2.5000E-01	2.5700E-01	2.1164E-01	4.4400
-3.0000E-03	3.0556E-01	2.5700E-01	2.0154E-01	4.3327
-3.0000E-03	3.6111E-01	2.5700E-01	1.9146E-01	4.2229
-3.0000E-03	4.1667E-01	2.5700E-01	1.8140E-01	4.1105
-3.0000E-03	4.7222E-01	2.5700E-01	1.7139E-01	3.9955
-3.0000E-03	5.2778E-01	2.5700E-01	1.6143E-01	3.8777
-3.0000E-03	5.8333E-01	2.5700E-01	1.5154E-01	3.7570
-3.0000E-03	6.3889E-01	2.5700E-01	1.4173E-01	3.6333
-3.0000E-03	6.9444E-01	2.5700E-01	1.3201E-01	3.5065
-3.0000E-03	7.5000E-01	2.5700E-01	1.2238E-01	3.3762
-3.0000E-03	8.0556E-01	2.5700E-01	1.1286E-01	3.2423
-3.0000E-03	8.6111E-01	2.5700E-01	1.0347E-01	3.1044
-3.0000E-03	9.1667E-01	2.5700E-01	9.4203E-02	2.9622
-3.0000E-03	9.7222E-01	2.5700E-01	8.5081E-02	2.8151

0 STOP END OF PROGRAM AT STATEMENT 0080 + 00 LINES

C TEST 2
HO=0.528
Q=95.47/450.
QGPM=95.47

SLOPE	DELTA	HO	HP	QOR
C C				
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6.5908E-01				
0.0000	2.7778E-02	5.2800E-01	5.2799E-01	5.3034
0.0000	8.3333E-02	5.2800E-01	5.2789E-01	5.3029
0.0000	1.3889E-01	5.2800E-01	5.2774E-01	5.3021
0.0000	1.9444E-01	5.2800E-01	5.2754E-01	5.3011
0.0000	2.5000E-01	5.2800E-01	5.2732E-01	5.3000
0.0000	3.0556E-01	5.2800E-01	5.2711E-01	5.2990
0.0000	3.6111E-01	5.2800E-01	5.2693E-01	5.2981
0.0000	4.1667E-01	5.2800E-01	5.2680E-01	5.2974
0.0000	4.7222E-01	5.2800E-01	5.2674E-01	5.2971
0.0000	5.2778E-01	5.2800E-01	5.2677E-01	5.2973
0.0000	5.8333E-01	5.2800E-01	5.2691E-01	5.2980
0.0000	6.3889E-01	5.2800E-01	5.2719E-01	5.2994
0.0000	6.9444E-01	5.2800E-01	5.2761E-01	5.3015
0.0000	7.5000E-01	5.2800E-01	5.2821E-01	5.3045
0.0000	8.0556E-01	5.2800E-01	5.2899E-01	5.3084
0.0000	8.6111E-01	5.2800E-01	5.2999E-01	5.3134
0.0000	9.1667E-01	5.2800E-01	5.3121E-01	5.3195
0.0000	9.7222E-01	5.2800E-01	5.3267E-01	5.3269
1.4066E+02				
6.7873E-01				
-1.0000E-03	2.7778E-02	5.2800E-01	5.2632E-01	5.4529
-1.0000E-03	8.3333E-02	5.2800E-01	5.2289E-01	5.4351
-1.0000E-03	1.3889E-01	5.2800E-01	5.1940E-01	5.4169
-1.0000E-03	1.9444E-01	5.2800E-01	5.1587E-01	5.3984
-1.0000E-03	2.5000E-01	5.2800E-01	5.1232E-01	5.3798
-1.0000E-03	3.0556E-01	5.2800E-01	5.0878E-01	5.3612
-1.0000E-03	3.6111E-01	5.2800E-01	5.0526E-01	5.3427
-1.0000E-03	4.1667E-01	5.2800E-01	5.0180E-01	5.3243
-1.0000E-03	4.7222E-01	5.2800E-01	4.9841E-01	5.3063
-1.0000E-03	5.2778E-01	5.2800E-01	4.9511E-01	5.2887
-1.0000E-03	5.8333E-01	5.2800E-01	4.9191E-01	5.2716
-1.0000E-03	6.3889E-01	5.2800E-01	4.8886E-01	5.2552
-1.0000E-03	6.9444E-01	5.2800E-01	4.8595E-01	5.2395
-1.0000E-03	7.5000E-01	5.2800E-01	4.8321E-01	5.2248
-1.0000E-03	8.0556E-01	5.2800E-01	4.8066E-01	5.2110
-1.0000E-03	8.6111E-01	5.2800E-01	4.7832E-01	5.1983
-1.0000E-03	9.1667E-01	5.2800E-01	4.7621E-01	5.1868
-1.0000E-03	9.7222E-01	5.2800E-01	4.7434E-01	5.1766
1.3629E+02				
7.0050E-01				

SLOPE	DELTA	HO	HP	QOR
-2.0000E-03	2.7778E-02	5.2800E-01	5.2465E-01	5.6188
-2.0000E-03	8.3333E-02	5.2800E-01	5.1789E-01	5.5825
-2.0000E-03	1.3889E-01	5.2800E-01	5.1107E-01	5.5456
-2.0000E-03	1.9444E-01	5.2800E-01	5.0420E-01	5.5082
-2.0000E-03	2.5000E-01	5.2800E-01	4.9732E-01	5.4705
-2.0000E-03	3.0556E-01	5.2800E-01	4.9045E-01	5.4326
-2.0000E-03	3.6111E-01	5.2800E-01	4.8360E-01	5.3945
-2.0000E-03	4.1667E-01	5.2800E-01	4.7680E-01	5.3565
-2.0000E-03	4.7222E-01	5.2800E-01	4.7007E-01	5.3185
-2.0000E-03	5.2778E-01	5.2800E-01	4.6344E-01	5.2809
-2.0000E-03	5.8333E-01	5.2800E-01	4.5691E-01	5.2436
-2.0000E-03	6.3889E-01	5.2800E-01	4.5052E-01	5.2068
-2.0000E-03	6.9444E-01	5.2800E-01	4.4428E-01	5.1706
-2.0000E-03	7.5000E-01	5.2800E-01	4.3821E-01	5.1351
-2.0000E-03	8.0556E-01	5.2800E-01	4.3233E-01	5.1005
-2.0000E-03	8.6111E-01	5.2800E-01	4.2665E-01	5.0670
-2.0000E-03	9.1667E-01	5.2800E-01	4.2121E-01	5.0345
-2.0000E-03	9.7222E-01	5.2800E-01	4.1601E-01	5.0033
1.3171E+02				
7.2485E-01				
-3.0000E-03	2.7778E-02	5.2800E-01	5.2299E-01	5.8049
-3.0000E-03	8.3333E-02	5.2800E-01	5.1289E-01	5.7486
-3.0000E-03	1.3889E-01	5.2800E-01	5.0274E-01	5.6914
-3.0000E-03	1.9444E-01	5.2800E-01	4.9254E-01	5.6334
-3.0000E-03	2.5000E-01	5.2800E-01	4.8232E-01	5.5746
-3.0000E-03	3.0556E-01	5.2800E-01	4.7211E-01	5.5153
-3.0000E-03	3.6111E-01	5.2800E-01	4.6193E-01	5.4555
-3.0000E-03	4.1667E-01	5.2800E-01	4.5180E-01	5.3954
-3.0000E-03	4.7222E-01	5.2800E-01	4.4174E-01	5.3350
-3.0000E-03	5.2778E-01	5.2800E-01	4.3177E-01	5.2744
-3.0000E-03	5.8333E-01	5.2800E-01	4.2191E-01	5.2139
-3.0000E-03	6.3889E-01	5.2800E-01	4.1219E-01	5.1534
-3.0000E-03	6.9444E-01	5.2800E-01	4.0261E-01	5.0932
-3.0000E-03	7.5000E-01	5.2800E-01	3.9321E-01	5.0334
-3.0000E-03	8.0556E-01	5.2800E-01	3.8399E-01	4.9741
-3.0000E-03	8.6111E-01	5.2800E-01	3.7499E-01	4.9154
-3.0000E-03	9.1667E-01	5.2800E-01	3.6621E-01	4.8575
-3.0000E-03	9.7222E-01	5.2800E-01	3.5767E-01	4.8006

0 STOP END OF PROGRAM AT STATEMENT 0080 + 00 LINES

TEST 3

C C

SLOPE	DELTA	HO	HP	QOR
1.6364E+02				
6.5612E-01				
0.0000	2.7778E-02	6.7400E-01	6.7398E-01	5.9650
0.0000	8.3333E-02	6.7400E-01	6.7387E-01	5.9645
0.0000	1.3889E-01	6.7400E-01	6.7366E-01	5.9636
0.0000	1.9444E-01	6.7400E-01	6.7341E-01	5.9625
0.0000	2.5000E-01	6.7400E-01	6.7313E-01	5.9613
0.0000	3.0556E-01	6.7400E-01	6.7286E-01	5.9601
0.0000	3.6111E-01	6.7400E-01	6.7262E-01	5.9590
0.0000	4.1667E-01	6.7400E-01	6.7244E-01	5.9582
0.0000	4.7222E-01	6.7400E-01	6.7235E-01	5.9578
0.0000	5.2778E-01	6.7400E-01	6.7236E-01	5.9579
0.0000	5.8333E-01	6.7400E-01	6.7252E-01	5.9585
0.0000	6.3889E-01	6.7400E-01	6.7283E-01	5.9599
0.0000	6.9444E-01	6.7400E-01	6.7333E-01	5.9621
0.0000	7.5000E-01	6.7400E-01	6.7404E-01	5.9653
0.0000	8.0556E-01	6.7400E-01	6.7498E-01	5.9694
0.0000	8.6111E-01	6.7400E-01	6.7617E-01	5.9747
0.0000	9.1667E-01	6.7400E-01	6.7765E-01	5.9812
0.0000	9.7222E-01	6.7400E-01	6.7943E-01	5.9891
1.5995E+02				
6.7128E-01				
-1.0000E-03	2.7778E-02	6.7400E-01	6.7232E-01	6.0953
-1.0000E-03	8.3333E-02	6.7400E-01	6.6887E-01	6.0797
-1.0000E-03	1.3889E-01	6.7400E-01	6.6533E-01	6.0636
-1.0000E-03	1.9444E-01	6.7400E-01	6.6174E-01	6.0472
-1.0000E-03	2.5000E-01	6.7400E-01	6.5813E-01	6.0307
-1.0000E-03	3.0556E-01	6.7400E-01	6.5453E-01	6.0141
-1.0000E-03	3.6111E-01	6.7400E-01	6.5095E-01	5.9977
-1.0000E-03	4.1667E-01	6.7400E-01	6.4744E-01	5.9815
-1.0000E-03	4.7222E-01	6.7400E-01	6.4401E-01	5.9656
-1.0000E-03	5.2778E-01	6.7400E-01	6.4070E-01	5.9503
-1.0000E-03	5.8333E-01	6.7400E-01	6.3752E-01	5.9355
-1.0000E-03	6.3889E-01	6.7400E-01	6.3450E-01	5.9214
-1.0000E-03	6.9444E-01	6.7400E-01	6.3166E-01	5.9081
-1.0000E-03	7.5000E-01	6.7400E-01	6.2904E-01	5.8959
-1.0000E-03	8.0556E-01	6.7400E-01	6.2664E-01	5.8846
-1.0000E-03	8.6111E-01	6.7400E-01	6.2451E-01	5.8746
-1.0000E-03	9.1667E-01	6.7400E-01	6.2265E-01	5.8659
-1.0000E-03	9.7222E-01	6.7400E-01	6.2109E-01	5.8585
1.5613E+02				

SLOPE	DELTA	HC	HP	QCR
6.8769E-01				
-2.0000E-03	2.7778E-02	6.7400E-01	6.7065E-01	6.2365
-2.0000E-03	8.3333E-02	6.7400E-01	6.6387E-01	6.2049
-2.0000E-03	1.3889E-01	6.7400E-01	6.5706E-01	6.1727
-2.0000E-03	1.9444E-01	6.7400E-01	6.5008E-01	6.1401
-2.0000E-03	2.5000E-01	6.7400E-01	6.4313E-01	6.1072
-2.0000E-03	3.0556E-01	6.7400E-01	6.3619E-01	6.0742
-2.0000E-03	3.6111E-01	6.7400E-01	6.2929E-01	6.0411
-2.0000E-03	4.1667E-01	6.7400E-01	6.2244E-01	6.0082
-2.0000E-03	4.7222E-01	6.7400E-01	6.1568E-01	5.9755
-2.0000E-03	5.2778E-01	6.7400E-01	6.0903E-01	5.9431
-2.0000E-03	5.8333E-01	6.7400E-01	6.0252E-01	5.9112
-2.0000E-03	6.3889E-01	6.7400E-01	5.9616E-01	5.8800
-2.0000E-03	6.9444E-01	6.7400E-01	5.8999E-01	5.8495
-2.0000E-03	7.5000E-01	6.7400E-01	5.8404E-01	5.8199
-2.0000E-03	8.0556E-01	6.7400E-01	5.7831E-01	5.7913
-2.0000E-03	8.6111E-01	6.7400E-01	5.7284E-01	5.7638
-2.0000E-03	9.1667E-01	6.7400E-01	5.6765E-01	5.7377
-2.0000E-03	9.7222E-01	6.7400E-01	5.6276E-01	5.7129
1.5218E+02				
7.0554E-01				
-3.0000E-03	2.7778E-02	6.7400E-01	6.6898E-01	6.3904
-3.0000E-03	8.3333E-02	6.7400E-01	6.5887E-01	6.3419
-3.0000E-03	1.3889E-01	6.7400E-01	6.4866E-01	6.2926
-3.0000E-03	1.9444E-01	6.7400E-01	6.3841E-01	6.2427
-3.0000E-03	2.5000E-01	6.7400E-01	6.2813E-01	6.1922
-3.0000E-03	3.0556E-01	6.7400E-01	6.1786E-01	6.1414
-3.0000E-03	3.6111E-01	6.7400E-01	6.0762E-01	6.0903
-3.0000E-03	4.1667E-01	6.7400E-01	5.9744E-01	6.0391
-3.0000E-03	4.7222E-01	6.7400E-01	5.8735E-01	5.9878
-3.0000E-03	5.2778E-01	6.7400E-01	5.7736E-01	5.9367
-3.0000E-03	5.8333E-01	6.7400E-01	5.6752E-01	5.8859
-3.0000E-03	6.3889E-01	6.7400E-01	5.5783E-01	5.8354
-3.0000E-03	6.9444E-01	6.7400E-01	5.4833E-01	5.7855
-3.0000E-03	7.5000E-01	6.7400E-01	5.3904E-01	5.7363
-3.0000E-03	8.0556E-01	6.7400E-01	5.2998E-01	5.6879
-3.0000E-03	8.6111E-01	6.7400E-01	5.2117E-01	5.6405
-3.0000E-03	9.1667E-01	6.7400E-01	5.1265E-01	5.5941
-3.0000E-03	9.7222E-01	6.7400E-01	5.0443E-01	5.5491

0 STOP END OF PROGRAM AT STATEMENT 0080 + 00 LINES

appendix B

```
34000320070136000320070 2        11540020000000     FORGO COLD START
C  C
C       COMPUTER PROGRAM FOR UNIFORM DISCHARGE IN AN IRRIGATION PIPE.
C       COMPARISON WITH EXPERIMENTAL DATA (SPOMER,S THESIS)
C       BY HUGO RAMIREZ-GUZMAN.
C       FALLING SLOPE - SPECIFIC CASE
10      READ,CH,G,X1,RH
        HO=0.611
        QGPM=94.83
        Q=94.83/450.
        QT=0.
        AORIF=(3.1416*0.75**2.)/576.
        A=(9.*3.1416)/144.
        V1=Q/A
        CD=1.
15      S=0.
16      M=0
17      DELTA=20./720.
        N=0
33      N=N+1
        M=M+1
35      H=HO+((V1/(1.318*CH))**1.85)*(X1/(2.85*RH**1.17))*DELTA**2.85
36      HP=H-((V1**2)/(2.*G))*(DELTA)**2+S*DELTA*X1
38      YYY=(2.*G*HP)**0.5
        QOR=CD*AORIF*YYY*450.
        QT=QT+QOR
        IF(M-18)41,50,60
50      PUNCH,QT
        CD=QGPM/QT
        PUNCH,CD
        QT=0.
        GO TO 17
60      PUNCH,S,DELTA,HO,HP,QOR,N
41      DELTA=DELTA+40./720.
        IF(DELTA-1.)33,33,70
70      S=S-1./300.
        QT=0.
        CD=1.
        IF(S+0.004)80,16,16
80      STOP
        END
120.    32.17   60.   0.125
```

TEST a.

HO = 0.611 ft.
Q = 94.83 gpm

C C

	DELTA	HO	HP	QOR
1.5582E+02				
6.0858E-01				
0.0000	2.7778E-02	6.1100E-01	6.1099E-01	5.2679
0.0000	8.3333E-02	6.1100E-01	6.1090E-01	5.2675
0.0000	1.3889E-01	6.1100E-01	6.1074E-01	5.2668
0.0000	1.9444E-01	6.1100E-01	6.1054E-01	5.2660
0.0000	2.5000E-01	6.1100E-01	6.1033E-01	5.2650
0.0000	3.0556E-01	6.1100E-01	6.1012E-01	5.2642
0.0000	3.6111E-01	6.1100E-01	6.0995E-01	5.2634
0.0000	4.1667E-01	6.1100E-01	6.0982E-01	5.2628
0.0000	4.7222E-01	6.1100E-01	6.0976E-01	5.2626
0.0000	5.2778E-01	6.1100E-01	6.0979E-01	5.2627
0.0000	5.8333E-01	6.1100E-01	6.0993E-01	5.2633
0.0000	6.3889E-01	6.1100E-01	6.1021E-01	5.2645
0.0000	6.9444E-01	6.1100E-01	6.1063E-01	5.2663
0.0000	7.5000E-01	6.1100E-01	6.1122E-01	5.2689
0.0000	8.0556E-01	6.1100E-01	6.1199E-01	5.2722
0.0000	8.6111E-01	6.1100E-01	6.1298E-01	5.2764
0.0000	9.1667E-01	6.1100E-01	6.1418E-01	5.2816
0.0000	9.7222E-01	6.1100E-01	6.1563E-01	5.2879
1.4228E+02				
6.6648E-01				
-3.3333E-03	2.7778E-02	6.1100E-01	6.0543E-01	5.7428
-3.3333E-03	8.3333E-02	6.1100E-01	5.9423E-01	5.6894
-3.3333E-03	1.3889E-01	6.1100E-01	5.8296E-01	5.6352
-3.3333E-03	1.9444E-01	6.1100E-01	5.7165E-01	5.5803
-3.3333E-03	2.5000E-01	6.1100E-01	5.6033E-01	5.5248
-3.3333E-03	3.0556E-01	6.1100E-01	5.4901E-01	5.4687
-3.3333E-03	3.6111E-01	6.1100E-01	5.3772E-01	5.4122
-3.3333E-03	4.1667E-01	6.1100E-01	5.2649E-01	5.3553
-3.3333E-03	4.7222E-01	6.1100E-01	5.1532E-01	5.2982
-3.3333E-03	5.2778E-01	6.1100E-01	5.0424E-01	5.2409
-3.3333E-03	5.8333E-01	6.1100E-01	4.9327E-01	5.1836
-3.3333E-03	6.3889E-01	6.1100E-01	4.8243E-01	5.1264
-3.3333E-03	6.9444E-01	6.1100E-01	4.7174E-01	5.0692
-3.3333E-03	7.5000E-01	6.1100E-01	4.6122E-01	5.0124
-3.3333E-03	8.0556E-01	6.1100E-01	4.5088E-01	4.9559
-3.3333E-03	8.6111E-01	6.1100E-01	4.4075E-01	4.8999
-3.3333E-03	9.1667E-01	6.1100E-01	4.3085E-01	4.8446
-3.3333E-03	9.7222E-01	6.1100E-01	4.2119E-01	4.7899

0 STOP END OF PROGRAM AT STATEMENT 0080 + 00 LINES

TEST b.

HO = 0.841 ft.
Q = 112.22 gpm

C SLOPE	DELTA	HO	HP	QOR
1.8279E+02				
6.1393E-01				
0.0000	2.7778E-02	8.4100E-01	8.4098E-01	6.2347
0.0000	8.3333E-02	8.4100E-01	8.4085E-01	6.2342
0.0000	1.3889E-01	8.4100E-01	8.4063E-01	6.2334
0.0000	1.9444E-01	8.4100E-01	8.4035E-01	6.2323
0.0000	2.5000E-01	8.4100E-01	8.4005E-01	6.2312
0.0000	3.0556E-01	8.4100E-01	8.3975E-01	6.2301
0.0000	3.6111E-01	8.4100E-01	8.3948E-01	6.2291
0.0000	4.1667E-01	8.4100E-01	8.3928E-01	6.2284
0.0000	4.7222E-01	8.4100E-01	8.3917E-01	6.2279
0.0000	5.2778E-01	8.4100E-01	8.3918E-01	6.2280
0.0000	5.8333E-01	8.4100E-01	8.3933E-01	6.2286
0.0000	6.3889E-01	8.4100E-01	8.3966E-01	6.2298
0.0000	6.9444E-01	8.4100E-01	8.4019E-01	6.2317
0.0000	7.5000E-01	8.4100E-01	8.4094E-01	6.2345
0.0000	8.0556E-01	8.4100E-01	8.4195E-01	6.2383
0.0000	8.6111E-01	8.4100E-01	8.4323E-01	6.2430
0.0000	9.1667E-01	8.4100E-01	8.4482E-01	6.2489
0.0000	9.7222E-01	8.4100E-01	8.4673E-01	6.2560
1.7145E+02				
6.5452E-01				
-3.3333E-03	2.7778E-02	8.4100E-01	8.3543E-01	6.6249
-3.3333E-03	8.3333E-02	8.4100E-01	8.2419E-01	6.5802
-3.3333E-03	1.3889E-01	8.4100E-01	8.1285E-01	6.5348
-3.3333E-03	1.9444E-01	8.4100E-01	8.0146E-01	6.4889
-3.3333E-03	2.5000E-01	8.4100E-01	7.9005E-01	6.4425
-3.3333E-03	3.0556E-01	8.4100E-01	7.7864E-01	6.3958
-3.3333E-03	3.6111E-01	8.4100E-01	7.6726E-01	6.3489
-3.3333E-03	4.1667E-01	8.4100E-01	7.5594E-01	6.3019
-3.3333E-03	4.7222E-01	8.4100E-01	7.4472E-01	6.2550
-3.3333E-03	5.2778E-01	8.4100E-01	7.3362E-01	6.2082
-3.3333E-03	5.8333E-01	8.4100E-01	7.2267E-01	6.1616
-3.3333E-03	6.3889E-01	8.4100E-01	7.1188E-01	6.1155
-3.3333E-03	6.9444E-01	8.4100E-01	7.0130E-01	6.0699
-3.3333E-03	7.5000E-01	8.4100E-01	6.9094E-01	6.0249
-3.3333E-03	8.0556E-01	8.4100E-01	6.8084E-01	5.9807
-3.3333E-03	8.6111E-01	8.4100E-01	6.7101E-01	5.9374
-3.3333E-03	9.1667E-01	8.4100E-01	6.6149E-01	5.8951
-3.3333E-03	9.7222E-01	8.4100E-01	6.5229E-01	5.8539

0 STOP END OF PROGRAM AT STATEMENT 0080 + 00 LINES

TEST c.

HO = 0.338 ft.
Q = 84.25 gpm

C SLOPE	DELTA	HO	HP	QCR
1.1591E+02				
7.2683E-01				
0.0000	2.7778E-02	3.3800E-01	3.3799E-01	4.6794
0.0000	8.3333E-02	3.3800E-01	3.3792E-01	4.6789
0.0000	1.3889E-01	3.3800E-01	3.3780E-01	4.6780
0.0000	1.9444E-01	3.3800E-01	3.3764E-01	4.6770
0.0000	2.5000E-01	3.3800E-01	3.3748E-01	4.6758
0.0000	3.0556E-01	3.3800E-01	3.3732E-01	4.6747
0.0000	3.6111E-01	3.3800E-01	3.3719E-01	4.6738
0.0000	4.1667E-01	3.3800E-01	3.3709E-01	4.6732
0.0000	4.7222E-01	3.3800E-01	3.3706E-01	4.6729
0.0000	5.2778E-01	3.3800E-01	3.3710E-01	4.6732
0.0000	5.8333E-01	3.3800E-01	3.3723E-01	4.6741
0.0000	6.3889E-01	3.3800E-01	3.3747E-01	4.6758
0.0000	6.9444E-01	3.3800E-01	3.3782E-01	4.6782
0.0000	7.5000E-01	3.3800E-01	3.3832E-01	4.6816
0.0000	8.0556E-01	3.3800E-01	3.3896E-01	4.6861
0.0000	8.6111E-01	3.3800E-01	3.3978E-01	4.6917
0.0000	9.1667E-01	3.3800E-01	3.4077E-01	4.6986
0.0000	9.7222E-01	3.3800E-01	3.4196E-01	4.7068
1.3165E+02				
6.3996E-01				
3.3333E-03	2.7778E-02	3.3800E-01	3.4355E-01	4.1538
3.3333E-03	8.3333E-02	3.3800E-01	3.5458E-01	4.2200
3.3333E-03	1.3889E-01	3.3800E-01	3.6557E-01	4.2849
3.3333E-03	1.9444E-01	3.3800E-01	3.7653E-01	4.3487
3.3333E-03	2.5000E-01	3.3800E-01	3.8748E-01	4.4114
3.3333E-03	3.0556E-01	3.3800E-01	3.9843E-01	4.4734
3.3333E-03	3.6111E-01	3.3800E-01	4.0941E-01	4.5346
3.3333E-03	4.1667E-01	3.3800E-01	4.2043E-01	4.5952
3.3333E-03	4.7222E-01	3.3800E-01	4.3150E-01	4.6553
3.3333E-03	5.2778E-01	3.3800E-01	4.4266E-01	4.7151
3.3333E-03	5.8333E-01	3.3800E-01	4.5390E-01	4.7746
3.3333E-03	6.3889E-01	3.3800E-01	4.6524E-01	4.8339
3.3333E-03	6.9444E-01	3.3800E-01	4.7671E-01	4.8931
3.3333E-03	7.5000E-01	3.3800E-01	4.8832E-01	4.9523
3.3333E-03	8.0556E-01	3.3800E-01	5.0007E-01	5.0116
3.3333E-03	8.6111E-01	3.3800E-01	5.1200E-01	5.0710
3.3333E-03	9.1667E-01	3.3800E-01	5.2410E-01	5.1306
3.3333E-03	9.7222E-01	3.3800E-01	5.3640E-01	5.1904

0 STOP END OF PROGRAM AT STATEMENT 0080 + 00 LINES

TEST d.

HO = 0.558 ft.
Q = 87.86 gpm

C C

1.4892E+02	DELTA	HO	HP	QOR
5.8999E-01				
0.0000	2.7778E-02	5.5800E-01	5.5799E-01	4.8805
0.0000	8.3333E-02	5.5800E-01	5.5791E-01	4.8801
0.0000	1.3889E-01	5.5800E-01	5.5778E-01	4.8795
0.0000	1.9444E-01	5.5800E-01	5.5761E-01	4.8788
0.0000	2.5000E-01	5.5800E-01	5.5743E-01	4.8780
0.0000	3.0556E-01	5.5800E-01	5.5726E-01	4.8772
0.0000	3.6111E-01	5.5800E-01	5.5711E-01	4.8766
0.0000	4.1667E-01	5.5800E-01	5.5700E-01	4.8761
0.0000	4.7222E-01	5.5800E-01	5.5696E-01	4.8760
0.0000	5.2778E-01	5.5800E-01	5.5700E-01	4.8761
0.0000	5.8333E-01	5.5800E-01	5.5713E-01	4.8767
0.0000	6.3889E-01	5.5800E-01	5.5738E-01	4.8778
0.0000	6.9444E-01	5.5800E-01	5.5776E-01	4.8795
0.0000	7.5000E-01	5.5800E-01	5.5829E-01	4.8818
0.0000	8.0556E-01	5.5800E-01	5.5898E-01	4.8848
0.0000	8.6111E-01	5.5800E-01	5.5985E-01	4.8886
0.0000	9.1667E-01	5.5800E-01	5.6091E-01	4.8932
0.0000	9.7222E-01	5.5800E-01	5.6219E-01	4.8988
1.6155E+02				
5.4386E-01				
3.3333E-03	2.7778E-02	5.5800E-01	5.6354E-01	4.5212
3.3333E-03	8.3333E-02	5.5800E-01	5.7458E-01	4.5653
3.3333E-03	1.3889E-01	5.5800E-01	5.8555E-01	4.6087
3.3333E-03	1.9444E-01	5.5800E-01	5.9650E-01	4.6515
3.3333E-03	2.5000E-01	5.5800E-01	6.0743E-01	4.6940
3.3333E-03	3.0556E-01	5.5800E-01	6.1837E-01	4.7360
3.3333E-03	3.6111E-01	5.5800E-01	6.2933E-01	4.7778
3.3333E-03	4.1667E-01	5.5800E-01	6.4034E-01	4.8194
3.3333E-03	4.7222E-01	5.5800E-01	6.5141E-01	4.8609
3.3333E-03	5.2778E-01	5.5800E-01	6.6256E-01	4.9023
3.3333E-03	5.8333E-01	5.5800E-01	6.7380E-01	4.9438
3.3333E-03	6.3889E-01	5.5800E-01	6.8516E-01	4.9852
3.3333E-03	6.9444E-01	5.5800E-01	6.9665E-01	5.0269
3.3333E-03	7.5000E-01	5.5800E-01	7.0829E-01	5.0687
3.3333E-03	8.0556E-01	5.5800E-01	7.2009E-01	5.1107
3.3333E-03	8.6111E-01	5.5800E-01	7.3207E-01	5.1531
3.3333E-03	9.1667E-01	5.5800E-01	7.4425E-01	5.1958
3.3333E-03	9.7222E-01	5.5800E-01	7.5663E-01	5.2388

0 STOP END OF PROGRAM AT STATEMENT 0080 + 00 LINES

appendix C

```
340002400701360002400702115400200000000            FORGO COLD START
C   C
C       A MASTER,S REPORT
C       BY HUGO RAMIREZ-G
C       POSITIVE SLOPES
10      READ,HE,CH,G,XI,RH,DELTA
        Q=1.0
15      S=0.
        A=(16.*3.1416)/144.
        VI=Q/A
20      HOI=HE+(VI**2)/(2.*G)-((VI/(1.318*CH))**1.85)*(XI/(2.85*RH**1.17
25      HO=HOI-S*XI
35      H=HO+((VI/(1.318*CH))**1.85)*(XI/(2.85*RH**1.17))*DELTA**2.85
36      HP=H-((VI**2)/(2.*G))*(DELTA)**2+S*DELTA*XI
37      CQ=0.6
38      FLOW=CQ*(2.*G*HP)**0.5
40      PUNCH,S,DELTA,HO,HP,FLOW
50      DELTA=DELTA+0.1
55      IF(DELTA-1.)35,35,60
60      S=S+0.001
65      DELTA=0.1
70      IF(S-0.005)25,25,80
80      Q=Q+1.
        IF(Q-3.)15,15,90
90      STOP
        END
5.0     120.0    32.17    300.0    0.167    0.0
```

Rising Slope.
HE = 5.0 ft.
Q = 1.0 cfs

SLOPE	Delta		HP	FLOW
0.0000	0.0000	4.6159	4.6159	1.0340E+01
0.0000	1.0000E-01	4.6159	4.6153	1.0339E+01
0.0000	2.0000E-01	4.6159	4.6160	1.0340E+01
0.0000	3.0000E-01	4.6159	4.6210	1.0346E+01
0.0000	4.0000E-01	4.6159	4.6331	1.0359E+01
0.0000	5.0000E-01	4.6159	4.6550	1.0384E+01
0.0000	6.0000E-01	4.6159	4.6893	1.0422E+01
0.0000	7.0000E-01	4.6159	4.7385	1.0476E+01
0.0000	8.0000E-01	4.6159	4.8051	1.0550E+01
0.0000	9.0000E-01	4.6159	4.8915	1.0644E+01
0.0000	1.0000	4.6159	5.0000	1.0762E+01
1.0000E-03	1.0000E-01	4.3159	4.3453	1.0032E+01
1.0000E-03	2.0000E-01	4.3159	4.3760	1.0068E+01
1.0000E-03	3.0000E-01	4.3159	4.4110	1.0108E+01
1.0000E-03	4.0000E-01	4.3159	4.4531	1.0156E+01
1.0000E-03	5.0000E-01	4.3159	4.5050	1.0215E+01
1.0000E-03	6.0000E-01	4.3159	4.5693	1.0288E+01
1.0000E-03	7.0000E-01	4.3159	4.6485	1.0376E+01
1.0000E-03	8.0000E-01	4.3159	4.7451	1.0484E+01
1.0000E-03	9.0000E-01	4.3159	4.8615	1.0612E+01
1.0000E-03	1.0000	4.3159	5.0000	1.0762E+01
2.0000E-03	1.0000E-01	4.0159	4.0753	9.7157
2.0000E-03	2.0000E-01	4.0159	4.1360	9.7877
2.0000E-03	3.0000E-01	4.0159	4.2010	9.8643
2.0000E-03	4.0000E-01	4.0159	4.2731	9.9486
2.0000E-03	5.0000E-01	4.0159	4.3550	1.0043E+01
2.0000E-03	6.0000E-01	4.0159	4.4493	1.0152E+01
2.0000E-03	7.0000E-01	4.0159	4.5585	1.0276E+01
2.0000E-03	8.0000E-01	4.0159	4.6851	1.0417E+01
2.0000E-03	9.0000E-01	4.0159	4.8315	1.0579E+01
2.0000E-03	1.0000	4.0159	5.0000	1.0762E+01
3.0000E-03	1.0000E-01	3.7159	3.8053	9.3883
3.0000E-03	2.0000E-01	3.7159	3.8960	9.4995
3.0000E-03	3.0000E-01	3.7159	3.9910	9.6146
3.0000E-03	4.0000E-01	3.7159	4.0931	9.7368
3.0000E-03	5.0000E-01	3.7159	4.2050	9.8690
3.0000E-03	6.0000E-01	3.7159	4.3293	1.0014E+01
3.0000E-03	7.0000E-01	3.7159	4.4685	1.0174E+01
3.0000E-03	8.0000E-01	3.7159	4.6251	1.0350E+01
3.0000E-03	9.0000E-01	3.7159	4.8015	1.0546E+01
3.0000E-03	1.0000	3.7159	5.0000	1.0762E+01
4.0000E-03	1.0000E-01	3.4159	3.5353	9.0491
4.0000E-03	2.0000E-01	3.4159	3.6560	9.2023
4.0000E-03	3.0000E-01	3.4159	3.7810	9.3582
4.0000E-03	4.0000E-01	3.4159	3.9131	9.5203
4.0000E-03	5.0000E-01	3.4159	4.0550	9.6914
4.0000E-03	6.0000E-01	3.4159	4.2093	9.8741
4.0000E-03	7.0000E-01	3.4159	4.3785	1.0071E+01
4.0000E-03	8.0000E-01	3.4159	4.5651	1.0283E+01
4.0000E-03	9.0000E-01	3.4159	4.7715	1.0513E+01
4.0000E-03	1.0000	3.4159	5.0000	1.0762E+01

	SLOPE	DELTA	HO	HP	FLOW
	5.0000E-03	1.0000E-01	3.1159	3.2653	8.6967
	5.0000E-03	2.0000E-01	3.1159	3.4160	8.8951
	5.0000E-03	3.0000E-01	3.1159	3.5710	9.0946
	5.0000E-03	4.0000E-01	3.1159	3.7331	9.2987
	5.0000E-03	5.0000E-01	3.1159	3.9050	9.5104
	5.0000E-03	6.0000E-01	3.1159	4.0893	9.7323
	5.0000E-03	7.0000E-01	3.1159	4.2885	9.9666
	5.0000E-03	8.0000E-01	3.1159	4.5051	1.0215E+01
	5.0000E-03	9.0000E-01	3.1159	4.7415	1.0480E+01
	5.0000E-03	1.0000	3.1159	5.0000	1.0762E+01
Q=2.0 cfs	0.0000	1.0000E-01	3.6657	3.6632	9.2113
	0.0000	2.0000E-01	3.6657	3.6640	9.2124
	0.0000	3.0000E-01	3.6657	3.6794	9.2317
	0.0000	4.0000E-01	3.6657	3.7195	9.2818
	0.0000	5.0000E-01	3.6657	3.7939	9.3743
	0.0000	6.0000E-01	3.6657	3.9121	9.5192
	0.0000	7.0000E-01	3.6657	4.0831	9.7249
	0.0000	8.0000E-01	3.6657	4.3157	9.9981
	0.0000	9.0000E-01	3.6657	4.6185	1.0343E+01
	0.0000	1.0000	3.6657	5.0000	1.0762E+01
	1.0000E-03	1.0000E-01	3.3657	3.3932	8.8653
	1.0000E-03	2.0000E-01	3.3657	3.4240	8.9056
	1.0000E-03	3.0000E-01	3.3657	3.4694	8.9644
	1.0000E-03	4.0000E-01	3.3657	3.5395	9.0544
	1.0000E-03	5.0000E-01	3.3657	3.6439	9.1871
	1.0000E-03	6.0000E-01	3.3657	3.7921	9.3720
	1.0000E-03	7.0000E-01	3.3657	3.9931	9.6172
	1.0000E-03	8.0000E-01	3.3657	4.2557	9.9283
	1.0000E-03	9.0000E-01	3.3657	4.5885	1.0309E+01
	1.0000E-03	1.0000	3.3657	5.0000	1.0762E+01
	2.0000E-03	1.0000E-01	3.0657	3.1232	8.5053
	2.0000E-03	2.0000E-01	3.0657	3.1840	8.5878
	2.0000E-03	3.0000E-01	3.0657	3.2594	8.6888
	2.0000E-03	4.0000E-01	3.0657	3.3595	8.8212
	2.0000E-03	5.0000E-01	3.0657	3.4939	8.9960
	2.0000E-03	6.0000E-01	3.0657	3.6721	9.2225
	2.0000E-03	7.0000E-01	3.0657	3.9031	9.5082
	2.0000E-03	8.0000E-01	3.0657	4.1957	9.8581
	2.0000E-03	9.0000E-01	3.0657	4.5585	1.0275E+01
	2.0000E-03	1.0000	3.0657	5.0000	1.0762E+01
	3.0000E-03	1.0000E-01	2.7657	2.8532	8.1293
	3.0000E-03	2.0000E-01	2.7657	2.9440	8.2578
	3.0000E-03	3.0000E-01	2.7657	3.0494	8.4042
	3.0000E-03	4.0000E-01	2.7657	3.1795	8.5816
	3.0000E-03	5.0000E-01	2.7657	3.3439	8.8008
	3.0000E-03	6.0000E-01	2.7657	3.5521	9.0706
	3.0000E-03	7.0000E-01	2.7657	3.8131	9.3979
	3.0000E-03	8.0000E-01	2.7657	4.1357	9.7873
	3.0000E-03	9.0000E-01	2.7657	4.5285	1.0242E+01
	3.0000E-03	1.0000	2.7657	5.0000	1.0762E+01
	4.0000E-03	1.0000E-01	2.4657	2.5832	7.7351

	SLOPE	DELTA	HO	HP	FLOW
	4.0000E-03	4.0000E-01	2.4657	2.9995	8.3352
	4.0000E-03	5.0000E-01	2.4657	3.1939	8.6011
	4.0000E-03	6.0000E-01	2.4657	3.4321	8.9161
	4.0000E-03	7.0000E-01	2.4657	3.7231	9.2863
	4.0000E-03	8.0000E-01	2.4657	4.0757	9.7161
	4.0000E-03	9.0000E-01	2.4657	4.4985	1.0208E+01
	4.0000E-03	1.0000	2.4657	5.0000	1.0762E+01
	5.0000E-03	1.0000E-01	2.1657	2.3132	7.3197
	5.0000E-03	2.0000E-01	2.1657	2.4640	7.5547
	5.0000E-03	3.0000E-01	2.1657	2.6294	7.8040
	5.0000E-03	4.0000E-01	2.1657	2.8195	8.0812
	5.0000E-03	5.0000E-01	2.1657	3.0439	8.3967
	5.0000E-03	6.0000E-01	2.1657	3.3121	8.7588
	5.0000E-03	7.0000E-01	2.1657	3.6331	9.1734
	5.0000E-03	8.0000E-01	2.1657	4.0157	9.6443
	5.0000E-03	9.0000E-01	2.1657	4.4685	1.0174E+01
	5.0000E-03	1.0000	2.1657	5.0000	1.0762E+01
Q=3.0	0.0000	1.0000E-01	2.2426	2.2367	7.1977
	0.0000	2.0000E-01	2.2426	2.2365	7.1974
	0.0000	3.0000E-01	2.2426	2.2656	7.2441
	0.0000	4.0000E-01	2.2426	2.3457	7.3711
	0.0000	5.0000E-01	2.2426	2.4973	7.6055
	0.0000	6.0000E-01	2.2426	2.7401	7.9666
	0.0000	7.0000E-01	2.2426	3.0933	8.4645
	0.0000	8.0000E-01	2.2426	3.5755	9.1004
	0.0000	9.0000E-01	2.2426	4.2051	9.8692
	0.0000	1.0000	2.2426	5.0000	1.0762E+01
	1.0000E-03	1.0000E-01	1.9426	1.9667	6.7493
	1.0000E-03	2.0000E-01	1.9426	1.9965	6.8002
	1.0000E-03	3.0000E-01	1.9426	2.0556	6.9002
	1.0000E-03	4.0000E-01	1.9426	2.1657	7.0826
	1.0000E-03	5.0000E-01	1.9426	2.3473	7.3735
	1.0000E-03	6.0000E-01	1.9426	2.6201	7.7902
	1.0000E-03	7.0000E-01	1.9426	3.0033	8.3404
	1.0000E-03	8.0000E-01	1.9426	3.5155	9.0237
	1.0000E-03	9.0000E-01	1.9426	4.1751	9.8339
	1.0000E-03	1.0000	1.9426	5.0000	1.0762E+01
	2.0000E-03	1.0000E-01	1.6426	1.6967	6.2689
	2.0000E-03	2.0000E-01	1.6426	1.7565	6.3784
	2.0000E-03	3.0000E-01	1.6426	1.8456	6.5383
	2.0000E-03	4.0000E-01	1.6426	1.9857	6.7819
	2.0000E-03	5.0000E-01	1.6426	2.1973	7.1340
	2.0000E-03	6.0000E-01	1.6426	2.5001	7.6097
	2.0000E-03	7.0000E-01	1.6426	2.9133	8.2145
	2.0000E-03	8.0000E-01	1.6426	3.4555	8.9464
	2.0000E-03	9.0000E-01	1.6426	4.1451	9.7985
	2.0000E-03	1.0000	1.6426	5.0000	1.0762E+01
	3.0000E-03	1.0000E-01	1.3426	1.4267	5.7485
	3.0000E-03	2.0000E-01	1.3426	1.5165	5.9267
	3.0000E-03	3.0000E-01	1.3426	1.6356	6.1551

Q= 3.0 cfs

SLOPE	DELTA	HO	HP	QOR
3.0000E-03	4.0000E-01	1.3426	1.8057	6.4672
3.0000E-03	5.0000E-01	1.3426	2.0473	6.8862
3.0000E-03	6.0000E-01	1.3426	2.3801	7.4249
3.0000E-03	7.0000E-01	1.3426	2.8233	8.0866
3.0000E-03	8.0000E-01	1.3426	3.3955	8.8684
3.0000E-03	9.0000E-01	1.3426	4.1151	9.7630
3.0000E-03	1.0000	1.3426	5.0000	1.0762E+01
4.0000E-03	1.0000E-01	1.0426	1.1567	5.1760
4.0000E-03	2.0000E-01	1.0426	1.2765	5.4375
4.0000E-03	3.0000E-01	1.0426	1.4256	5.7464
4.0000E-03	4.0000E-01	1.0426	1.6257	6.1364
4.0000E-03	5.0000E-01	1.0426	1.8973	6.6292
4.0000E-03	6.0000E-01	1.0426	2.2601	7.2353
4.0000E-03	7.0000E-01	1.0426	2.7333	7.9567
4.0000E-03	8.0000E-01	1.0426	3.3355	8.7897
4.0000E-03	9.0000E-01	1.0426	4.0851	9.7273
4.0000E-03	1.0000	1.0426	5.0000	1.0762E+01
5.0000E-03	1.0000E-01	7.4263E-01	8.8667E-01	4.5318
5.0000E-03	2.0000E-01	7.4263E-01	1.0365	4.8997
5.0000E-03	3.0000E-01	7.4263E-01	1.2156	5.3063
5.0000E-03	4.0000E-01	7.4263E-01	1.4457	5.7867
5.0000E-03	5.0000E-01	7.4263E-01	1.7473	6.3617
5.0000E-03	6.0000E-01	7.4263E-01	2.1401	7.0406
5.0000E-03	7.0000E-01	7.4263E-01	2.6433	7.8246
5.0000E-03	8.0000E-01	7.4263E-01	3.2755	8.7103
5.0000E-03	9.0000E-01	7.4263E-01	4.0551	9.6916
5.0000E-03	1.0000	7.4263E-01	5.0000	1.0762E+01

0 STOP END OF PROGRAM AT STATEMENT 0090 + 00 LINES

Appendix C

Rising Slope.-
HE = 2.0 ft.
Q=1.0 cfs.

C

SLOPE	DELTA	HO	HP	QOR
0.0000	0.0000	1.6159	1.6159	6.1178
0.0000	1.0000E-01	1.6159	1.6153	6.1168
0.0000	2.0000E-01	1.6159	1.6160	6.1180
0.0000	3.0000E-01	1.6159	1.6210	6.1274
0.0000	4.0000E-01	1.6159	1.6331	6.1502
0.0000	5.0000E-01	1.6159	1.6550	6.1914
0.0000	6.0000E-01	1.6159	1.6893	6.2552
0.0000	7.0000E-01	1.6159	1.7385	6.3458
0.0000	8.0000E-01	1.6159	1.8051	6.4662
0.0000	9.0000E-01	1.6159	1.8915	6.6191
0.0000	1.0000	1.6159	2.0000	6.8062
1.0000E-03	1.0000E-01	1.3159	1.3453	5.5822
1.0000E-03	2.0000E-01	1.3159	1.3760	5.6455
1.0000E-03	3.0000E-01	1.3159	1.4110	5.7167
1.0000E-03	4.0000E-01	1.3159	1.4531	5.8014
1.0000E-03	5.0000E-01	1.3159	1.5050	5.9041
1.0000E-03	6.0000E-01	1.3159	1.5693	6.0290
1.0000E-03	7.0000E-01	1.3159	1.6485	6.1793
1.0000E-03	8.0000E-01	1.3159	1.7451	6.3578
1.0000E-03	9.0000E-01	1.3159	1.8615	6.5664
1.0000E-03	1.0000	1.3159	2.0000	6.8062
2.0000E-03	1.0000E-01	1.0159	1.0753	4.9907
2.0000E-03	2.0000E-01	1.0159	1.1360	5.1296
2.0000E-03	3.0000E-01	1.0159	1.2010	5.2742
2.0000E-03	4.0000E-01	1.0159	1.2731	5.4302
2.0000E-03	5.0000E-01	1.0159	1.3550	5.6022
2.0000E-03	6.0000E-01	1.0159	1.4493	5.7939
2.0000E-03	7.0000E-01	1.0159	1.5585	6.0083
2.0000E-03	8.0000E-01	1.0159	1.6851	6.2476
2.0000E-03	9.0000E-01	1.0159	1.8315	6.5132
2.0000E-03	1.0000	1.0159	2.0000	6.8062
3.0000E-03	1.0000E-01	7.1589E-01	8.0533E-01	4.3190
3.0000E-03	2.0000E-01	7.1589E-01	8.9600E-01	4.5556
3.0000E-03	3.0000E-01	7.1589E-01	9.9096E-01	4.7909
3.0000E-03	4.0000E-01	7.1589E-01	1.0931	5.0317
3.0000E-03	5.0000E-01	7.1589E-01	1.2050	5.2830
3.0000E-03	6.0000E-01	7.1589E-01	1.3293	5.5488
3.0000E-03	7.0000E-01	7.1589E-01	1.4685	5.8322
3.0000E-03	8.0000E-01	7.1589E-01	1.6251	6.1353
3.0000E-03	9.0000E-01	7.1589E-01	1.8015	6.4597
3.0000E-03	1.0000	7.1589E-01	2.0000	6.8062
4.0000E-03	1.0000E-01	4.1589E-01	5.3533E-01	3.5213
4.0000E-03	2.0000E-01	4.1589E-01	6.5600E-01	3.8980
4.0000E-03	3.0000E-01	4.1589E-01	7.8096E-01	4.2531
4.0000E-03	4.0000E-01	4.1589E-01	9.1305E-01	4.5987
4.0000E-03	5.0000E-01	4.1589E-01	1.0550	4.9432
4.0000E-03	6.0000E-01	4.1589E-01	1.2093	5.2925
4.0000E-03	7.0000E-01	4.1589E-01	1.3785	5.6507

SLOPE	DELTA	HO	HP	QOR
4.0000E-03	8.0000E-01	4.1589E-01	1.5651	6.0210
4.0000E-03	9.0000E-01	4.1589E-01	1.7715	6.4057
4.0000E-03	1.0000	4.1589E-01	2.0000	6.8062
5.0000E-03	1.0000E-01	1.1589E-01	2.6533E-01	2.4791
5.0000E-03	2.0000E-01	1.1589E-01	4.1600E-01	3.1041
5.0000E-03	3.0000E-01	1.1589E-01	5.7096E-01	3.6366
5.0000E-03	4.0000E-01	1.1589E-01	7.3305E-01	4.1206
5.0000E-03	5.0000E-01	1.1589E-01	9.0496E-01	4.5783
5.0000E-03	6.0000E-01	1.1589E-01	1.0893	5.0230
5.0000E-03	7.0000E-01	1.1589E-01	1.2885	5.4631
5.0000E-03	8.0000E-01	1.1589E-01	1.5051	5.9045
5.0000E-03	9.0000E-01	1.1589E-01	1.7415	6.3512
5.0000E-03	1.0000	1.1589E-01	2.0000	6.8062
0.0000	1.0000E-01	6.6566E-01	6.6316E-01	3.9192
0.0000	2.0000E-01	6.6566E-01	6.6404E-01	3.9218
0.0000	3.0000E-01	6.6566E-01	6.7940E-01	3.9669
0.0000	4.0000E-01	6.6566E-01	7.1947E-01	4.0822
0.0000	5.0000E-01	6.6566E-01	7.9394E-01	4.2883
0.0000	6.0000E-01	6.6566E-01	9.1213E-01	4.5964
0.0000	7.0000E-01	6.6566E-01	1.0831	5.0087
0.0000	8.0000E-01	6.6566E-01	1.3157	5.5203
0.0000	9.0000E-01	6.6566E-01	1.6185	6.1227
0.0000	1.0000	6.6566E-01	2.0000	6.8062
1.0000E-03	1.0000E-01	3.6566E-01	3.9316E-01	3.0177
1.0000E-03	2.0000E-01	3.6566E-01	4.2404E-01	3.1340
1.0000E-03	3.0000E-01	3.6566E-01	4.6940E-01	3.2973
1.0000E-03	4.0000E-01	3.6566E-01	5.3947E-01	3.5349
1.0000E-03	5.0000E-01	3.6566E-01	6.4394E-01	3.8620
1.0000E-03	6.0000E-01	3.6566E-01	7.9213E-01	4.2834
1.0000E-03	7.0000E-01	3.6566E-01	9.9311E-01	4.7961
1.0000E-03	8.0000E-01	3.6566E-01	1.2557	5.3930
1.0000E-03	9.0000E-01	3.6566E-01	1.5885	6.0657
1.0000E-03	1.0000	3.6566E-01	2.0000	6.8062
2.0000E-03	1.0000E-01	6.5658E-02	1.2316E-01	1.6890
2.0000E-03	2.0000E-01	6.5658E-02	1.8404E-01	2.0646
2.0000E-03	3.0000E-01	6.5658E-02	2.5940E-01	2.4512
2.0000E-03	4.0000E-01	6.5658E-02	3.5947E-01	2.8855
2.0000E-03	5.0000E-01	6.5658E-02	4.9394E-01	3.3824
2.0000E-03	6.0000E-01	6.5658E-02	6.7213E-01	3.9457
2.0000E-03	7.0000E-01	6.5658E-02	9.0311E-01	4.5736
2.0000E-03	8.0000E-01	6.5658E-02	1.1957	5.2626
2.0000E-03	9.0000E-01	6.5658E-02	1.5585	6.0082
2.0000E-03	1.0000	6.5658E-02	2.0000	6.8062

Q= 2.0 cfs.

0 ERROR XX-4 IN STATEMENT 0038 + 00 LINES

Appendix C

Falling Slopes.

HO = 5.0 ft.

Q = 1.0 cfs.

C C

SLOPE	DELTA	HO	HP	QOR
0.0000	0.0000	4.6159	4.6159	1.0340E+01
0.0000	1.0000E-01	4.6159	4.6153	1.0339E+01
0.0000	2.0000E-01	4.6159	4.6160	1.0340E+01
0.0000	3.0000E-01	4.6159	4.6210	1.0346E+01
0.0000	4.0000E-01	4.6159	4.6331	1.0359E+01
0.0000	5.0000E-01	4.6159	4.6550	1.0384E+01
0.0000	6.0000E-01	4.6159	4.6893	1.0422E+01
0.0000	7.0000E-01	4.6159	4.7385	1.0476E+01
0.0000	8.0000E-01	4.6159	4.8051	1.0550E+01
0.0000	9.0000E-01	4.6159	4.8915	1.0644E+01
0.0000	1.0000	4.6159	5.0000	1.0762E+01
-1.0000E-03	1.0000E-01	4.9159	4.8853	1.0637E+01
-1.0000E-03	2.0000E-01	4.9159	4.8560	1.0605E+01
-1.0000E-03	3.0000E-01	4.9159	4.8310	1.0578E+01
-1.0000E-03	4.0000E-01	4.9159	4.8131	1.0558E+01
-1.0000E-03	5.0000E-01	4.9159	4.8050	1.0550E+01
-1.0000E-03	6.0000E-01	4.9159	4.8093	1.0554E+01
-1.0000E-03	7.0000E-01	4.9159	4.8285	1.0575E+01
-1.0000E-03	8.0000E-01	4.9159	4.8651	1.0615E+01
-1.0000E-03	9.0000E-01	4.9159	4.9215	1.0677E+01
-1.0000E-03	1.0000	4.9159	5.0000	1.0762E+01
-2.0000E-03	1.0000E-01	5.2159	5.1553	1.0927E+01
-2.0000E-03	2.0000E-01	5.2159	5.0960	1.0864E+01
-2.0000E-03	3.0000E-01	5.2159	5.0410	1.0806E+01
-2.0000E-03	4.0000E-01	5.2159	4.9931	1.0754E+01
-2.0000E-03	5.0000E-01	5.2159	4.9550	1.0713E+01
-2.0000E-03	6.0000E-01	5.2159	4.9293	1.0685E+01
-2.0000E-03	7.0000E-01	5.2159	4.9185	1.0674E+01
-2.0000E-03	8.0000E-01	5.2159	4.9251	1.0681E+01
-2.0000E-03	9.0000E-01	5.2159	4.9515	1.0709E+01
-2.0000E-03	1.0000	5.2159	5.0000	1.0762E+01
-3.0000E-03	1.0000E-01	5.5159	5.4253	1.1210E+01
-3.0000E-03	2.0000E-01	5.5159	5.3360	1.1117E+01
-3.0000E-03	3.0000E-01	5.5159	5.2510	1.1028E+01
-3.0000E-03	4.0000E-01	5.5159	5.1731	1.0946E+01
-3.0000E-03	5.0000E-01	5.5159	5.1050	1.0874E+01
-3.0000E-03	6.0000E-01	5.5159	5.0493	1.0815E+01
-3.0000E-03	7.0000E-01	5.5159	5.0085	1.0771E+01
-3.0000E-03	8.0000E-01	5.5159	4.9851	1.0746E+01
-3.0000E-03	9.0000E-01	5.5159	4.9815	1.0742E+01
-3.0000E-03	1.0000	5.5159	5.0000	1.0762E+01
-4.0000E-03	1.0000E-01	5.8159	5.6953	1.1486E+01
-4.0000E-03	2.0000E-01	5.8159	5.5760	1.1365E+01

SLOPE	DELTA	HO	HP	QOR	
-4.0000E-03	3.0000E-01	5.8159	5.4610	1.1247E+01	
-4.0000E-03	4.0000E-01	5.8159	5.3531	1.1135E+01	
-4.0000E-03	5.0000E-01	5.8159	5.2550	1.1033E+01	
-4.0000E-03	6.0000E-01	5.8159	5.1693	1.0942E+01	
-4.0000E-03	7.0000E-01	5.8159	5.0985	1.0867E+01	
-4.0000E-03	8.0000E-01	5.8159	5.0451	1.0810E+01	
-4.0000E-03	9.0000E-01	5.8159	5.0115	1.0774E+01	
-4.0000E-03	1.0000	5.8159	5.0000	1.0762E+01	
-5.0000E-03	1.0000E-01	6.1159	5.9653	1.1755E+01	
-5.0000E-03	2.0000E-01	6.1159	5.8160	1.1607E+01	
-5.0000E-03	3.0000E-01	6.1159	5.6710	1.1461E+01	
-5.0000E-03	4.0000E-01	6.1159	5.5331	1.1321E+01	
-5.0000E-03	5.0000E-01	6.1159	5.4050	1.1189E+01	
-5.0000E-03	6.0000E-01	6.1159	5.2893	1.1069E+01	
-5.0000E-03	7.0000E-01	6.1159	5.1885	1.0963E+01	
-5.0000E-03	8.0000E-01	6.1159	5.1051	1.0874E+01	
-5.0000E-03	9.0000E-01	6.1159	5.0415	1.0806E+01	
-5.0000E-03	1.0000	6.1159	5.0000	1.0762E+01	
0.0000	1.0000E-01	3.6657	3.6632	9.2113	Q=2.0cfs
0.0000	2.0000E-01	3.6657	3.6640	9.2124	
0.0000	3.0000E-01	3.6657	3.6794	9.2317	
0.0000	4.0000E-01	3.6657	3.7195	9.2818	
0.0000	5.0000E-01	3.6657	3.7939	9.3743	
0.0000	6.0000E-01	3.6657	3.9121	9.5192	
0.0000	7.0000E-01	3.6657	4.0831	9.7249	
0.0000	8.0000E-01	3.6657	4.3157	9.9981	
0.0000	9.0000E-01	3.6657	4.6185	1.0343E+01	
0.0000	1.0000	3.6657	5.0000	1.0762E+01	
-1.0000E-03	1.0000E-01	3.9657	3.9332	9.5447	
-1.0000E-03	2.0000E-01	3.9657	3.9040	9.5093	
-1.0000E-03	3.0000E-01	3.9657	3.8894	9.4915	
-1.0000E-03	4.0000E-01	3.9657	3.8995	9.5037	
-1.0000E-03	5.0000E-01	3.9657	3.9439	9.5578	
-1.0000E-03	6.0000E-01	3.9657	4.0321	9.6640	
-1.0000E-03	7.0000E-01	3.9657	4.1731	9.8315	
-1.0000E-03	8.0000E-01	3.9657	4.3757	1.0067E+01	
-1.0000E-03	9.0000E-01	3.9657	4.6485	1.0376E+01	
-1.0000E-03	1.0000	3.9657	5.0000	1.0762E+01	
-2.0000E-03	1.0000E-01	4.2657	4.2032	9.8669	
-2.0000E-03	2.0000E-01	4.2657	4.1440	9.7972	
-2.0000E-03	3.0000E-01	4.2657	4.0994	9.7443	
-2.0000E-03	4.0000E-01	4.2657	4.0795	9.7206	
-2.0000E-03	5.0000E-01	4.2657	4.0939	9.7378	
-2.0000E-03	6.0000E-01	4.2657	4.1521	9.8068	
-2.0000E-03	7.0000E-01	4.2657	4.2631	9.9370	
-2.0000E-03	8.0000E-01	4.2657	4.4357	1.0136E+01	
-2.0000E-03	9.0000E-01	4.2657	4.6785	1.0410E+01	

SLOPE	DELTA	HO	HP	QOR	
-2.0000E-03	1.0000	4.2657	5.0000	1.0762E+01	
-3.0000E-03	1.0000E-01	4.5657	4.4732	1.0179E+01	
-3.0000E-03	2.0000E-01	4.5657	4.3840	1.0077E+01	
-3.0000E-03	3.0000E-01	4.5657	4.3094	9.9908	
-3.0000E-03	4.0000E-01	4.5657	4.2595	9.9327	
-3.0000E-03	5.0000E-01	4.5657	4.2439	9.9146	
-3.0000E-03	6.0000E-01	4.5657	4.2721	9.9475	
-3.0000E-03	7.0000E-01	4.5657	4.3531	1.0041E+01	
-3.0000E-03	8.0000E-01	4.5657	4.4957	1.0204E+01	
-3.0000E-03	9.0000E-01	4.5657	4.7085	1.0443E+01	
-3.0000E-03	1.0000	4.5657	5.0000	1.0762E+01	
-4.0000E-03	1.0000E-01	4.8657	4.7432	1.0482E+01	
-4.0000E-03	2.0000E-01	4.8657	4.6240	1.0349E+01	
-4.0000E-03	3.0000E-01	4.8657	4.5194	1.0231E+01	
-4.0000E-03	4.0000E-01	4.8657	4.4395	1.0140E+01	
-4.0000E-03	5.0000E-01	4.8657	4.3939	1.0088E+01	
-4.0000E-03	6.0000E-01	4.8657	4.3921	1.0086E+01	
-4.0000E-03	7.0000E-01	4.8657	4.4431	1.0145E+01	
-4.0000E-03	8.0000E-01	4.8657	4.5557	1.0272E+01	
-4.0000E-03	9.0000E-01	4.8657	4.7385	1.0476E+01	
-4.0000E-03	1.0000	4.8657	5.0000	1.0762E+01	
-5.0000E-03	1.0000E-01	5.1657	5.0132	1.0776E+01	
-5.0000E-03	2.0000E-01	5.1657	4.8640	1.0614E+01	
-5.0000E-03	3.0000E-01	5.1657	4.7294	1.0466E+01	
-5.0000E-03	4.0000E-01	5.1657	4.6195	1.0344E+01	
-5.0000E-03	5.0000E-01	5.1657	4.5439	1.0259E+01	
-5.0000E-03	6.0000E-01	5.1657	4.5121	1.0223E+01	
-5.0000E-03	7.0000E-01	5.1657	4.5331	1.0247E+01	
-5.0000E-03	8.0000E-01	5.1657	4.6157	1.0340E+01	
-5.0000E-03	9.0000E-01	5.1657	4.7685	1.0509E+01	
-5.0000E-03	1.0000	5.1657	5.0000	1.0762E+01	
0.0000	1.0000E-01	2.2426	2.2367	7.1977	Q = 3.0 cfs.
0.0000	2.0000E-01	2.2426	2.2365	7.1974	
0.0000	3.0000E-01	2.2426	2.2656	7.2441	
0.0000	4.0000E-01	2.2426	2.3457	7.3711	
0.0000	5.0000E-01	2.2426	2.4973	7.6055	
0.0000	6.0000E-01	2.2426	2.7401	7.9666	
0.0000	7.0000E-01	2.2426	3.0933	8.4645	
0.0000	8.0000E-01	2.2426	3.5755	9.1004	
0.0000	9.0000E-01	2.2426	4.2051	9.8692	
0.0000	1.0000	2.2426	5.0000	1.0762E+01	
-1.0000E-03	1.0000E-01	2.5426	2.5067	7.6197	
-1.0000E-03	2.0000E-01	2.5426	2.4765	7.5737	
-1.0000E-03	3.0000E-01	2.5426	2.4756	7.5724	
-1.0000E-03	4.0000E-01	2.5426	2.5257	7.6486	
-1.0000E-03	5.0000E-01	2.5426	2.6473	7.8306	
-1.0000E-03	6.0000E-01	2.5426	2.8601	8.1392	
-1.0000E-03	7.0000E-01	2.5426	3.1833	8.5867	
-1.0000E-03	8.0000E-01	2.5426	3.6355	9.1765	
-1.0000E-03	9.0000E-01	2.5426	4.2351	9.9043	
-1.0000E-03	1.0000	2.5426	5.0000	1.0762E+01	
-2.0000E-03	1.0000E-01	2.8426	2.7767	8.0196	

SLOPE	DELTA	HO	HP	QOR
-2.0000E-03	2.0000E-01	2.8426	2.7165	7.9322
-2.0000E-03	3.0000E-01	2.8426	2.6856	7.8870
-2.0000E-03	4.0000E-01	2.8426	2.7057	7.9165
-2.0000E-03	5.0000E-01	2.8426	2.7973	8.0493
-2.0000E-03	6.0000E-01	2.8426	2.9801	8.3082
-2.0000E-03	7.0000E-01	2.8426	3.2733	8.7073
-2.0000E-03	8.0000E-01	2.8426	3.6955	9.2519
-2.0000E-03	9.0000E-01	2.8426	4.2651	9.9393
-2.0000E-03	1.0000	2.8426	5.0000	1.0762E+01
-3.0000E-03	1.0000E-01	3.1426	3.0467	8.4005
-3.0000E-03	2.0000E-01	3.1426	2.9565	8.2752
-3.0000E-03	3.0000E-01	3.1426	2.8956	8.1896
-3.0000E-03	4.0000E-01	3.1426	2.8857	8.1756
-3.0000E-03	5.0000E-01	3.1426	2.9473	8.2623
-3.0000E-03	6.0000E-01	3.1426	3.1001	8.4738
-3.0000E-03	7.0000E-01	3.1426	3.3633	8.8262
-3.0000E-03	8.0000E-01	3.1426	3.7555	9.3267
-3.0000E-03	9.0000E-01	3.1426	4.2951	9.9742
-3.0000E-03	1.0000	3.1426	5.0000	1.0762E+01
-4.0000E-03	1.0000E-01	3.4426	3.3167	8.7648
-4.0000E-03	2.0000E-01	3.4426	3.1965	8.6046
-4.0000E-03	3.0000E-01	3.4426	3.1056	8.4814
-4.0000E-03	4.0000E-01	3.4426	3.0657	8.4267
-4.0000E-03	5.0000E-01	3.4426	3.0973	8.4700
-4.0000E-03	6.0000E-01	3.4426	3.2201	8.6363
-4.0000E-03	7.0000E-01	3.4426	3.4533	8.9435
-4.0000E-03	8.0000E-01	3.4426	3.8155	9.4009
-4.0000E-03	9.0000E-01	3.4426	4.3251	1.0009E+01
-4.0000E-03	1.0000	3.4426	5.0000	1.0762E+01
-5.0000E-03	1.0000E-01	3.7426	3.5867	9.1146
-5.0000E-03	2.0000E-01	3.7426	3.4365	8.9217
-5.0000E-03	3.0000E-01	3.7426	3.3156	8.7634
-5.0000E-03	4.0000E-01	3.7426	3.2457	8.6706
-5.0000E-03	5.0000E-01	3.7426	3.2473	8.6727
-5.0000E-03	6.0000E-01	3.7426	3.3401	8.7957
-5.0000E-03	7.0000E-01	3.7426	3.5433	9.0593
-5.0000E-03	8.0000E-01	3.7426	3.8755	9.4745
-5.0000E-03	9.0000E-01	3.7426	4.3551	1.0044E+01
-5.0000E-03	1.0000	3.7426	5.0000	1.0762E+01

0 STOP END OF PROGRAM AT STATEMENT 0090 + 00 LINES

Appendix C

Falling Slopes.-

HØ = 2.0 ft.

Q = 1.0 cfs.

C SLOPE	DELTA	HO	HP	QOR
0.0000	0.0000	1.6159	1.6159	6.1178
0.0000	1.0000E-01	1.6159	1.6153	6.1168
0.0000	2.0000E-01	1.6159	1.6160	6.1180
0.0000	3.0000E-01	1.6159	1.6210	6.1274
0.0000	4.0000E-01	1.6159	1.6331	6.1502
0.0000	5.0000E-01	1.6159	1.6550	6.1914
0.0000	6.0000E-01	1.6159	1.6893	6.2552
0.0000	7.0000E-01	1.6159	1.7385	6.3458
0.0000	8.0000E-01	1.6159	1.8051	6.4662
0.0000	9.0000E-01	1.6159	1.8915	6.6191
0.0000	1.0000	1.6159	2.0000	6.8062
-1.0000E-03	1.0000E-01	1.9159	1.8853	6.6082
-1.0000E-03	2.0000E-01	1.9159	1.8560	6.5566
-1.0000E-03	3.0000E-01	1.9159	1.8310	6.5122
-1.0000E-03	4.0000E-01	1.9159	1.8131	6.4803
-1.0000E-03	5.0000E-01	1.9159	1.8050	6.4659
-1.0000E-03	6.0000E-01	1.9159	1.8093	6.4736
-1.0000E-03	7.0000E-01	1.9159	1.8285	6.5079
-1.0000E-03	8.0000E-01	1.9159	1.8651	6.5728
-1.0000E-03	9.0000E-01	1.9159	1.9215	6.6714
-1.0000E-03	1.0000	1.9159	2.0000	6.8062
-2.0000E-03	1.0000E-01	2.2159	2.1553	7.0656
-2.0000E-03	2.0000E-01	2.2159	2.0960	6.9677
-2.0000E-03	3.0000E-01	2.2159	2.0410	6.8756
-2.0000E-03	4.0000E-01	2.2159	1.9931	6.7944
-2.0000E-03	5.0000E-01	2.2159	1.9550	6.7292
-2.0000E-03	6.0000E-01	2.2159	1.9293	6.6848
-2.0000E-03	7.0000E-01	2.2159	1.9185	6.6662
-2.0000E-03	8.0000E-01	2.2159	1.9251	6.6776
-2.0000E-03	9.0000E-01	2.2159	1.9515	6.7232
-2.0000E-03	1.0000	2.2159	2.0000	6.8062
-3.0000E-03	1.0000E-01	2.5159	2.4253	7.4951
-3.0000E-03	2.0000E-01	2.5159	2.3360	7.3558
-3.0000E-03	3.0000E-01	2.5159	2.2510	7.2206
-3.0000E-03	4.0000E-01	2.5159	2.1731	7.0946
-3.0000E-03	5.0000E-01	2.5159	2.1050	6.9826
-3.0000E-03	6.0000E-01	2.5159	2.0493	6.8896
-3.0000E-03	7.0000E-01	2.5159	2.0085	6.8207
-3.0000E-03	8.0000E-01	2.5159	1.9851	6.7809
-3.0000E-03	9.0000E-01	2.5159	1.9815	6.7747
-3.0000E-03	1.0000	2.5159	2.0000	6.8062
-4.0000E-03	1.0000E-01	2.8159	2.6953	7.9013
-4.0000E-03	2.0000E-01	2.8159	2.5760	7.7244
-4.0000E-03	3.0000E-01	2.8159	2.4610	7.5499
-4.0000E-03	4.0000E-01	2.8159	2.3531	7.3826

SLOPE	DELTA	HO	HP	QOR	
-4.0000E-03	5.0000E-01	2.8159	2.2550	7.2271	
-4.0000E-03	6.0000E-01	2.8159	2.1693	7.0884	
-4.0000E-03	7.0000E-01	2.8159	2.0985	6.9719	
-4.0000E-03	8.0000E-01	2.8159	2.0451	6.8826	
-4.0000E-03	9.0000E-01	2.8159	2.0115	6.8258	
-4.0000E-03	1.0000	2.8159	2.0000	6.8062	
-5.0000E-03	1.0000E-01	3.1159	2.9653	8.2876	
-5.0000E-03	2.0000E-01	3.1159	2.8160	8.0762	
-5.0000E-03	3.0000E-01	3.1159	2.6710	7.8655	
-5.0000E-03	4.0000E-01	3.1159	2.5331	7.6597	
-5.0000E-03	5.0000E-01	3.1159	2.4050	7.4636	
-5.0000E-03	6.0000E-01	3.1159	2.2893	7.2819	
-5.0000E-03	7.0000E-01	3.1159	2.1885	7.1198	
-5.0000E-03	8.0000E-01	3.1159	2.1051	6.9828	
-5.0000E-03	9.0000E-01	3.1159	2.0415	6.8765	
-5.0000E-03	1.0000	3.1159	2.0000	6.8062	
0.0000	1.0000E-01	6.6566E-01	6.6316E-01	3.9192	**Q = 2.0 cfs.**
0.0000	2.0000E-01	6.6566E-01	6.6404E-01	3.9218	
0.0000	3.0000E-01	6.6566E-01	6.7940E-01	3.9669	
0.0000	4.0000E-01	6.6566E-01	7.1947E-01	4.0822	
0.0000	5.0000E-01	6.6566E-01	7.9394E-01	4.2883	
0.0000	6.0000E-01	6.6566E-01	9.1213E-01	4.5964	
0.0000	7.0000E-01	6.6566E-01	1.0831	5.0087	
0.0000	8.0000E-01	6.6566E-01	1.3157	5.5203	
0.0000	9.0000E-01	6.6566E-01	1.6185	6.1227	
0.0000	1.0000	6.6566E-01	2.0000	6.8062	
-1.0000E-03	1.0000E-01	9.6566E-01	9.3316E-01	4.6491	
-1.0000E-03	2.0000E-01	9.6566E-01	9.0404E-01	4.5760	
-1.0000E-03	3.0000E-01	9.6566E-01	8.8940E-01	4.5388	
-1.0000E-03	4.0000E-01	9.6566E-01	8.9947E-01	4.5644	
-1.0000E-03	5.0000E-01	9.6566E-01	9.4394E-01	4.6759	
-1.0000E-03	6.0000E-01	9.6566E-01	1.0321	4.8894	
-1.0000E-03	7.0000E-01	9.6566E-01	1.1731	5.2127	
-1.0000E-03	8.0000E-01	9.6566E-01	1.3757	5.6448	
-1.0000E-03	9.0000E-01	9.6566E-01	1.6485	6.1792	
-1.0000E-03	1.0000	9.6566E-01	2.0000	6.8062	
-2.0000E-03	1.0000E-01	1.2657	1.2032	5.2790	
-2.0000E-03	2.0000E-01	1.2657	1.1440	5.1477	
-2.0000E-03	3.0000E-01	1.2657	1.0994	5.0463	
-2.0000E-03	4.0000E-01	1.2657	1.0795	5.0003	
-2.0000E-03	5.0000E-01	1.2657	1.0939	5.0337	
-2.0000E-03	6.0000E-01	1.2657	1.1521	5.1659	
-2.0000E-03	7.0000E-01	1.2657	1.2631	5.4089	
-2.0000E-03	8.0000E-01	1.2657	1.4357	5.7666	
-2.0000E-03	9.0000E-01	1.2657	1.6785	6.2352	
-2.0000E-03	1.0000	1.2657	2.0000	6.8062	
-3.0000E-03	1.0000E-01	1.5657	1.4732	5.8414	
-3.0000E-03	2.0000E-01	1.5657	1.3840	5.6619	
-3.0000E-03	3.0000E-01	1.5657	1.3094	5.5072	
-3.0000E-03	4.0000E-01	1.5657	1.2595	5.4011	
-3.0000E-03	5.0000E-01	1.5657	1.2439	5.3677	
-3.0000E-03	6.0000E-01	1.5657	1.2721	5.4282	
-3.0000E-03	7.0000E-01	1.5657	1.3531	5.5983	

SLOPE	DELTA	HO	HP	QOR
-3.0000E-03	8.0000E-01	1.5657	1.4957	5.8859
-3.0000E-03	9.0000E-01	1.5657	1.7085	6.2907
-3.0000E-03	1.0000	1.5657	2.0000	6.8062
-4.0000E-03	1.0000E-01	1.8657	1.7432	6.3542
-4.0000E-03	2.0000E-01	1.8657	1.6240	6.1332
-4.0000E-03	3.0000E-01	1.8657	1.5194	5.9324
-4.0000E-03	4.0000E-01	1.8657	1.4395	5.7742
-4.0000E-03	5.0000E-01	1.8657	1.3939	5.6822
-4.0000E-03	6.0000E-01	1.8657	1.3921	5.6785
-4.0000E-03	7.0000E-01	1.8657	1.4431	5.7815
-4.0000E-03	8.0000E-01	1.8657	1.5557	6.0028
-4.0000E-03	9.0000E-01	1.8657	1.7385	6.3457
-4.0000E-03	1.0000	1.8657	2.0000	6.8062
-5.0000E-03	1.0000E-01	2.1657	2.0132	6.8286
-5.0000E-03	2.0000E-01	2.1657	1.8640	6.5708
-5.0000E-03	3.0000E-01	2.1657	1.7294	6.3291
-5.0000E-03	4.0000E-01	2.1657	1.6195	6.1246
-5.0000E-03	5.0000E-01	2.1657	1.5439	5.9801
-5.0000E-03	6.0000E-01	2.1657	1.5121	5.9182
-5.0000E-03	7.0000E-01	2.1657	1.5331	5.9591
-5.0000E-03	8.0000E-01	2.1657	1.6157	6.1174
-5.0000E-03	9.0000E-01	2.1657	1.7685	6.4002
-5.0000E-03	1.0000	2.1657	2.0000	6.8062

0 ERROR XX-4 IN STATEMENT 0038 + 00 LINES

ANALYSIS FOR OBTAINING UNIFORM FLOW FROM EQUALLY SPACED ORIFICES IN IRRIGATION PIPE

by

HUGO RAMIREZ-GUZMAN

B.S., Universidad Nacional de Colombia, 1966

AN ABSTRACT OF A MASTER'S REPORT

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requirements for the degree

MASTER OF SCIENCE

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1969

This study was performed with the purpose of determining whether a design equation could be developed to secure an equal discharge from uniformly spaced orifices in an irrigation pipe.

In the development of the theoretical analysis the following assumptions were made:

1.- Linear distribution of velocity within the pipe.

2.- Equal coefficient of discharge for each orifice.

The formula obtained was compared with experimental results from R. G. Spomer's Thesis K.S.U. 1961, and a close agreement was found. Differences between the experimental results and the calculated discharges did not exceed more than 6%. The results of this study indicated that there was an increase in discharge from the orifices as the dead end of the pipe was approached for a pipe placed on falling slope. In the case of rising slope (dead end high) a decrease in discharge from the orifices was noted as the dead end of the pipe was approached.

Since the discharge calculated by the formula agreed closely for the above 60-foot length of pipe, the same analysis and procedure was applied to a pipe 300-foot of length. Flow calculations were made for zero, falling, and rising slope at inlet flows of 1.0, 2.0, and 3.0 cubic feet per second. Calculations were made for points spaced at 30 foot intervals. Two pressure heads at the entrance were considered. In the first case the assumed value was 5.0 feet of water. In the second case 2.0 foot of entrance pressure head was considered.

It was found that for an inlet flow of 1.0 cubic feet per second, and an entrance pressure head of 5.0 feet, a falling slope between 0.001 and 0.002 (0.0015 probably) will produce the best uniformity of discharge from orifices. The same conclusion was observed for this flow at 2.0 foot of entrance pressure head.

For an inlet flow of 2.0 cubic feet per second, and pressure head of 5.0-foot of water, the falling slope that produced best uniformity was 0.005. Probably, for this case, a falling slope of more than 0.005 would produce the best uniformity. The same conclusion is observed for this inlet flow at an entrance pressure head of 2.0 feet.

As conclusion, for inlet flows of 1.0 cubic feet per second and more, there is an specific falling slope that will produce the best uniformity discharge.