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The Effect of Wave Formation on Open Channel Flow in a Triangular Closed Conduit

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THE EFFECT OF WAVE FORMATION ON OPEN CHANNEL FLOW IN A TRIANGULAR CLOSED CONDUIT

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

_______________________ April 16, 1964
Thesis Adviser — Date

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Head, Agricultural Engineering Department — Date

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CHAPTER I

INTRODUCTION

In the fields of Civil, Hydraulic, and Agricultural Engineering, it is common for water to be delivered by means of open or closed conduits. Analysis of the flow within these conduits is divided into two categories, open-channel flow and pipe flow. These two kinds of flow are similar in many ways but differ in one important respect. Open-channel flow must have a free surface, whereas pipe flow has none, since the water must fill the whole conduit. A free surface is subject to atmospheric pressure. Pipe flow, being confined in a closed conduit, exerts no direct atmospheric pressure but hydraulic pressure only. When water flows partly full within a closed conduit, due to the existence of a free surface, it will have open-channel flow characteristics. If the rate of flow is gradually increased, the water surface in this closed conduit will gradually get higher. Finally, as the water surface touches the top of the closed conduit, there will no longer be a free surface. Consequently, with full flow in the closed conduit, pipe flow characteristics will result. The shape of the closed conduit may be divided into two kinds: one suddenly closed at the top, such as a channel with a flat slab cover; another closed at the top by following some geometrical relationship such as circular, triangular, or other special shapes used in sewer design. The circular closed conduit is most often found in ordinary engineering practices. Therefore the phenomena of flow in circular closed conduits have attracted the interest of many hydraulic engineers and hydraulicians.

Lembke (13) observed the transition from part-flow to full-flow in steep circular drains; he noted five flow regimes for this transition. Flow Regimes I, II, III, and IV were related to the hydraulic jump. For Flow Regime III, the air pockets formed by the entrained air from the jump had the effect of expanding. This expansion reduces the capacity of the conduit to carry water. This is analogous to Roberson's studies (17) in that water hammer action would be developed, resulting in the breakage of the drain pipe and reduction of the flow.

Flow Regime V of Lembke's research was different from the others in that there was no stationary hydraulic jump concerned, but slug flow occurred in the circular conduit with a free outlet condition. Lembke concluded that this Flow Regime V was dependent primarily on the dimensionless parameters of slope and the ratio of the critical depth of flow to the diameter of the circular conduit. In other words, it is primarily dependent on the slope and discharge. Since slugs are surface waves, the activities of the surface waves in the circular conduit are significant for changing the flow condition from open-channel flow to pipe flow. In the field it is common engineering practice for a pipe line laid underneath an earth embankment or fill to serve as a spillway or drain. Some failures may result when slug flow occurs to change the flow condition from open-channel flow to pipe flow. These failures may result from reduction of flow by air bubble formation. They may also result from the pipe body itself shaking, due to the action of water waves. The former case of reduction of flow will increase the relative cost by requiring a larger size of pipe. The latter case of shaking the pipe body will cause breakage of the pipe line and also will loosen the earth fill so as to endanger the earth structure. If the transition from open-channel flow to pipe flow can be obtained smoothly within the pipe line, the aforesaid failures will be eliminated. Therefore, it is interesting to learn the relationship between the slope and the discharge for the condition just before the change from open-channel flow to pipe flow and how surface waves occur.

The wave surface in open-channel flow involves steady varied flow characteristics and the phenomena of wave motion which will be discussed in Chapter III and IV respectively. The flow within a circular or triangular closed conduit is in many ways alike. This will be shown in Chapter II. An appropriate triangular closed conduit will be chosen instead of the circular one. This will have the advantage that the phenomena of flow may be expected to be approximately the same, and the water wave activities will be more clearly observed and analyzed.

The main object of this research is to find some relationship between the slope and discharge for a triangular closed conduit at the transition from open-channel flow to pipe flow. This is the maximum stage of open-channel flow in this triangular closed conduit. If it is possible, the cause of the wave surface of the flow will be found and explained. This will permit a more clear explanation of wave phenomena in other conduit shapes.

CHAPTER II

THE SIGNIFICANCE OF CONDUITS WHICH ARE GRADUALLY CLOSED AT THE TOP

In open-channel hydraulics, Manning's formula for uniform flow states that (refer to Appendix A for all notations)

$$V = \frac{1.486}{n} R^{2/3} S_o^{1/2} \qquad (1)$$

or

$$Q = AV = \frac{1.486}{n} AR^{2/3} S_o^{1/2} \qquad (2)$$

$$\frac{Q}{\sqrt{S_o}} = \frac{1.486}{n} AR^{2/3}$$

Designating

$$\frac{1.486}{n} AR^{2/3} = K \qquad (3)$$

$$Q = K \cdot \sqrt{S_o} \qquad (4)$$

where "K" is called conveyance (2). For a given channel of uniform section and roughness, "n," the value of "K" is a function of the normal depth, "y_n," of flow. It may be expressed as

$$K = f(y_n) \qquad (5)$$

Cases for the Differential of the Conveyance With Respect to the Normal Depth

Since "A" and "R" are the function of "y_n," from equation (3), it is evident that the variations between "K" and "y_n" are non-linear. In other words, "K" and "y_n" are in curvilinear variation. Differentiating equation (5) with respect to "y_n," we have $\frac{dK}{dy_n} = \frac{d}{dy_n}\left[f(y_n)\right] = f'(y_n)$. Therefore, $\frac{dK}{dy_n}$, the change of rate of "K" with respect to "y_n" depends upon the geometry of the cross-section of the channel or conduit entirely. From mathematics, the differential $\frac{dK}{dy_n}$ may be evaluated for a given value of "y_n," the water depth. "y_n" will always be a positive value. So the value of "K" will never be negative. Besides at $y_n = 0$, $K = 0$. It can be verified, by plotting, that the curves of "K" over "y_n" are certainly in the first quadrant and pass through the origin. To evaluate the differential $\frac{dK}{dy_n}$, the possible cases will be as follows:

(1) It may always be positive for all values of "y_n" -- this is some type of ascending curve and it may be extended freely as shown in Figure 1a and Figure 1b. This is the case for ordinary open-channel sections such as rectangular, trapezoidal, triangular, and parabolic, etc. or generally as those sections which have the geometrical property of side walls divergent or in parallel.

(2) It may always be positive but definitely stop at some point -- this is a similar curve to case (1) only it cannot be extended as shown in Figure 2a and Figure 2b. It is the case for those channel sections in case (1) which are covered by a flat slab.

(3) It may gradually change from positive, approaching zero as a limit -- this is a special case of an ascending curve. Figure 3 shows this type of curve.

(4) It may gradually change from positive to zero and then to negative -- this kind of curve is shown in Figure 4. It is significant that after some point, as water depth increases the conveyance decreases. From equation (4), for the same bottom slope, discharge is proportional

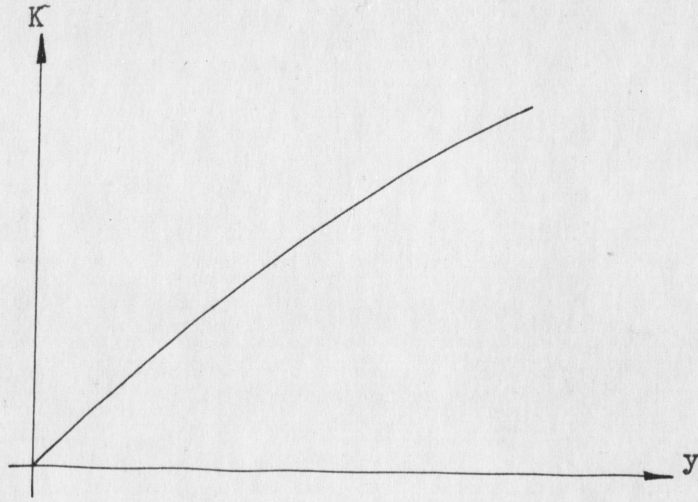


Fig. 1_a.

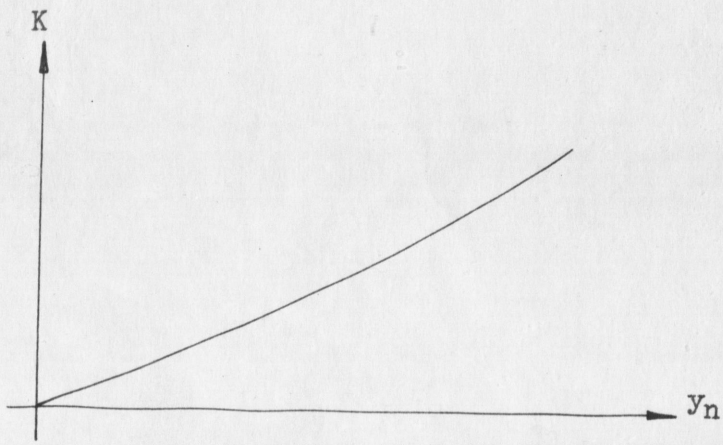


Fig. 1_b.

K vs. y_n Curves for the Value of $\frac{dK}{dy_n}$ always Positive.

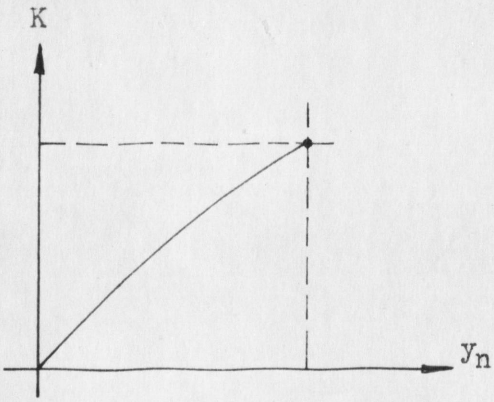


Fig. 2_a

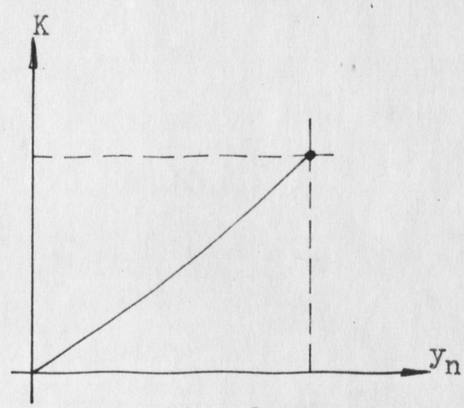


Fig. 2_b

K vs. y_n Curves of the Value of dK/dy_n always Positive but Stop at some Point.

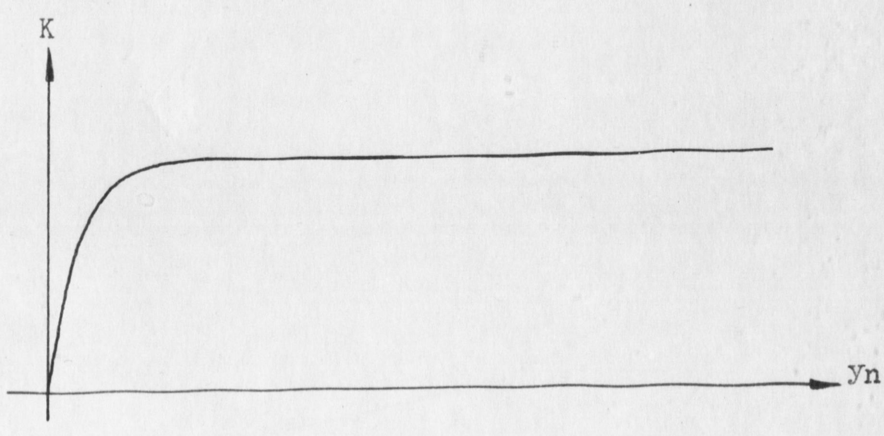


Fig. 3. K vs. y_n Curve for the Value of dK/dy_n from Positive to Zero.

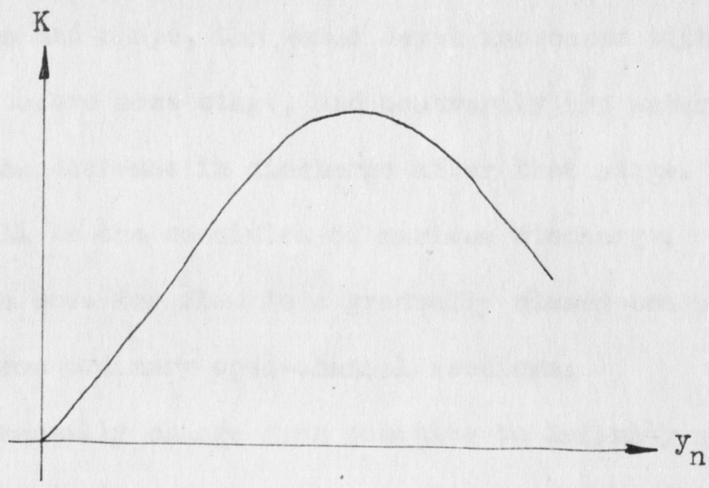


Fig. 4. K vs. y_n Curve for the Value of dK/dy_n from Positive to Zero and then to Negative.

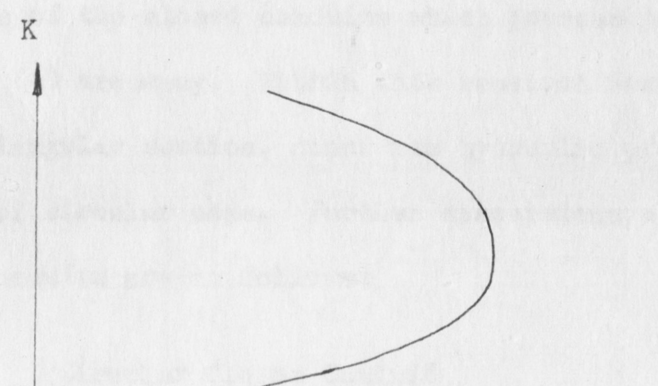


Fig. 5. K vs. y_n Curve for the Value of dK/dy_n from Positive to Infinity and then to Negative.

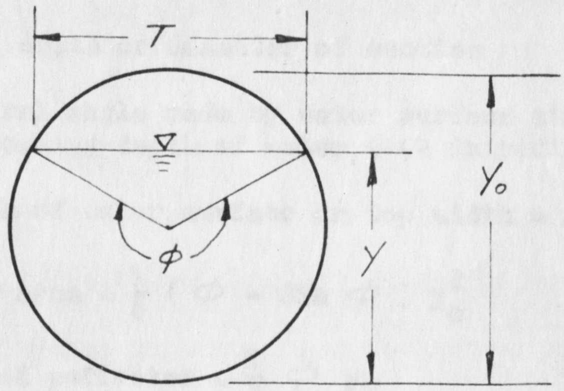
to conveyance. It can be said in this way that for a special conduit of the same roughness and slope, the water depth increases with an increase in discharge before some stage, and contrarily the water depth increases to cause the decrease in discharge after that stage. The stage for $\frac{dK}{dy_n} = 0$ will be the condition of maximum discharge. This phenomena is only the case for flow in a gradually closed conduit which is quite different from ordinary open-channel sections.

(5) It may gradually change from positive to infinity and then to negative -- this kind of curve is shown in Figure 5. It is significant since $\frac{dK}{dy_n}$ changes from positive to negative. However, as it passes the point, $\frac{dK}{dy_n} = \infty$. Physically it is impossible for a conduit, at same water depth, to have two different conveyances under the condition of the same slope and roughness.

The geometries of the closed conduits which possess the property as mentioned in case (4) are many. Within this research work, attention is paid only to a triangular section, since its hydraulic properties are similar to that of circular ones. Further discussions about circular and triangular conduits are as follows:

Circular Closed Conduit

In analysis for flow in a conduit the hydraulic elements regarding the geometry of the section of this conduit are very important. For the circular section, as shown in Figure 6, its hydraulic elements are as follows:



$$A = \frac{1}{8} (\phi - \sin \phi) y_o^2$$

$$p_w = \frac{1}{2} \phi y_o$$

$$R = \frac{1}{4} (1 - \frac{\text{Sin } \phi}{\phi}) y_o = \frac{A}{p_w}$$

$$T = (\text{Sin } \frac{\phi}{2}) y_o = 2 \sqrt{y(y_o - y)}$$

$$D_m = \frac{1}{8} (\frac{\phi - \sin \phi}{\sin \frac{\phi}{2}}) y_o = A/T$$

$$Z = \frac{\sqrt{2}}{32} \frac{(\phi - \sin \phi)^{3/2}}{(\sin \frac{\phi}{2})^{1/2}} y_o^{5/2} = A \sqrt{A/T} = A \sqrt{D_m}$$

ϕ in radians

Fig. 6. Hydraulic Elements for a Circular Section in Terms of ϕ and y_o

y = water depth

y_o = full depth or diameter of section

ϕ = central angle made by water surface at its corresponding depth of water (ϕ in radians)

T = width of water surface or top width = $(\text{Sin } \frac{\phi}{2})\, y_o$

A = flow area = $\frac{1}{8}(\phi - \text{Sin } \phi)\, y_o^2$

p_w = wetted perimeter = $\frac{1}{2}\phi\, y_o$

R = Hydraulic radius = $\frac{A}{p_w}$

$= \frac{1}{4}\left(1 - \frac{\text{Sin } \phi}{\phi}\right) y_o$

D_m = mean or hydraulic depth

$= A/T = \frac{1}{8}\left(\frac{\phi - \text{Sin } \phi}{\text{Sin } \frac{\phi}{2}}\right) y_o$

Z = section factor = $A\sqrt{A/T}$

$$= \frac{\sqrt{2}}{32} \frac{(\phi - \text{Sin } \phi)^{3/2}}{(\text{Sin } \frac{\phi}{2})^{1/2}}\, y_o^{5/2}$$

All of the above elements are in terms of " ϕ " and "y_o." They can be found from Chow (4).

As water flows in a given circular conduit of constant slope and roughness, the normal depth of flow can be computed by Manning's formula if the discharge is known.

$$Q = \frac{1.486}{n} AR^{2/3}S^{1/2}$$

$$Q = \left(\frac{1.486}{n} S^{1/2}\right) \left[\frac{1}{8}(\phi - \sin \phi)\, y_o^2\right] \left[\frac{1}{4}\left(1 - \frac{\text{Sin } \phi}{\phi}\right) y_o\right]^{2/3}$$

$$Q = \left[\frac{1.486}{8n} (\tfrac{1}{4})^{2/3} S^{1/2} y_o^{8/3} \right] (\phi - \sin \phi)(1 - \frac{\sin \phi}{\phi}) \qquad (6)$$

In the above equation, "n," "S" and "y_o" are known. Then for a given discharge "Q," the value of "ϕ" can be solved and its corresponding depth will be obtained. To solve equation (6) for "ϕ" is complicated. However, if different values of "ϕ" corresponding to their depths are substituted into equation (6) respectively, their corresponding values of "Q" will be computed easily. A curve of "Q" over "y_n" can be plotted. From this curve, if either of them is known, the other will be read directly. In general application, this kind of curve is prepared in dimensionless plotting. Many tables of dimensionless construction in this respect are available from ordinary books on open channel hydraulics (4,18,10). The dimensionless plotting for circular conduit flow is that the depth "y" refers to its full depth "y_o," and the discharge "Q" and velocity "V" also refer to its full flow case under the condition of no pressure head added to the energy gradient, which means that the flow is merely gravitational in nature. For the same slope and roughness,

full flow discharge $Q_o = \left[\frac{1.486}{n} S_o^{1/2} \right] A_o R_o^{2/3}$

part flow discharge $Q = \left[\frac{1.486}{n} S_o^{1/2} \right] AR^{2/3}$

$$Q/Q_o = \frac{AR^{2/3}}{A_o R_o^{2/3}}$$

likewise $V/V_o = \frac{R^{2/3}}{R_o^{2/3}}$

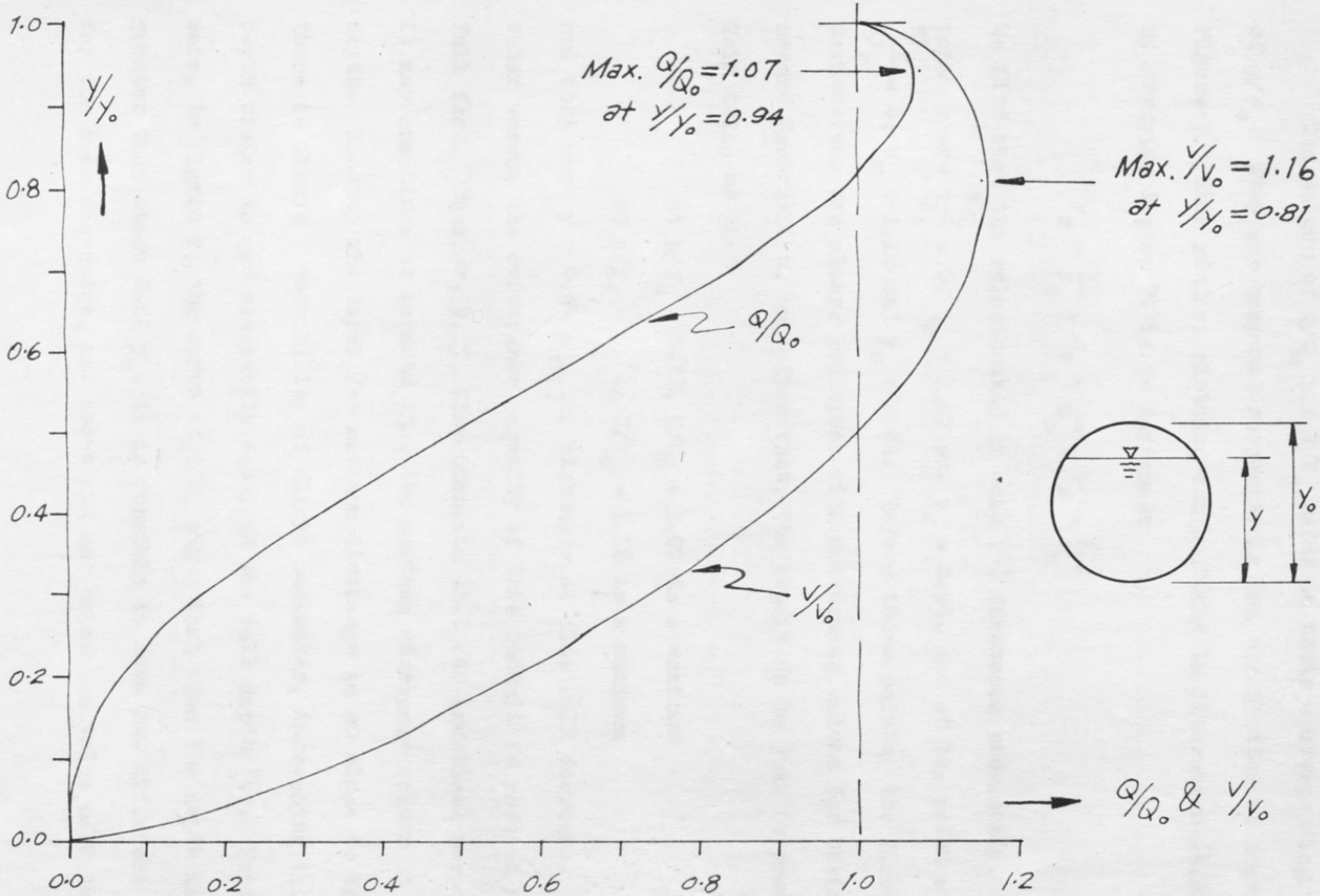


Fig. 7. Flow Characteristics of a Circular Section.

The values of Q/Q_o and V/V_o refer to their corresponding values of y/y_o. They are computed respectively and are plotted as shown in Figure 7. This kind of plotting can be found in literature (4,21,14). By studying Figure 7, if we designate

$$y_r = \frac{y}{y_o} , \quad Q_r = \frac{Q}{Q_o} , \quad V_r = \frac{V}{V_o}$$

We find that the relationship is case (4) discussed previously. At the point where $\frac{dQ_r}{dy_r} = 0$; $Q_r = 1.07$ and $y_r = 0.94$, and at the point where $\frac{dV_r}{dy_r} = 0$; $V_r = 1.16$ and $y_r = 0.81$. Before these points, the first derivatives are always positive; with decreasing values for their second derivatives, but after that, the condition is just reversed. This tells us that

at $y/y_o = 0.94$, $Q/Q_o = 1.07$ is a maximum

at $y/y_o = 0.81$, $V/V_o = 1.16$ is a maximum

and that when $y > 0.94\ y_o$, the discharge of flow will decrease. In other words, the conveyance capacity of this conduit is reduced near full flow. However, V. T. Chow comments that for practical purposes, it may sometimes be assumed that the maximum discharge occurs at full depth. Because the depth for maximum discharge is so close to the top there is always a possibility of slight backwater, increasing this depth closer to and eventually equal to the full depth (4). Furthermore, in Figure 7, the curve of Q/Q_o shows that when the depth is greater than about $0.82\ y_o$, it is possible to have two different depths for the same discharge, one above and one below the value of $0.94\ y_o$.

Similarly, the curve of V/V_o shows that when the depth is greater than $0.5\ y_o$, it is possible to have two different depths for the same velocity, one above and one below the value of $0.8\ y_o$. An isosceles triangular section to be used for this research work was sought so that the condition

$$\text{at } y/y_o = 0.94,\ Q/Q_o = 1.07$$

$$\text{at } y/y_o = 0.81,\ V/V_o = 1.16$$

would be reached as closely as possible.

Triangular Closed Conduit

The hydraulic elements regarding the geometry for an isosceles triangular section are, as shown in Figure 8, as follows:

y = water depth = $\beta\ y_o$

y_o = full depth $\quad (\beta = \frac{y}{y_o})$

θ = base angle,

B = bottom width = $2\ y_o \cot\theta$

A = flow area = $\beta\ y_o^2\ (2 - \beta)\cot\theta$

p_w = wetted perimeter

$= 2\ y_o\ (\cot\theta + \beta\csc\theta)$

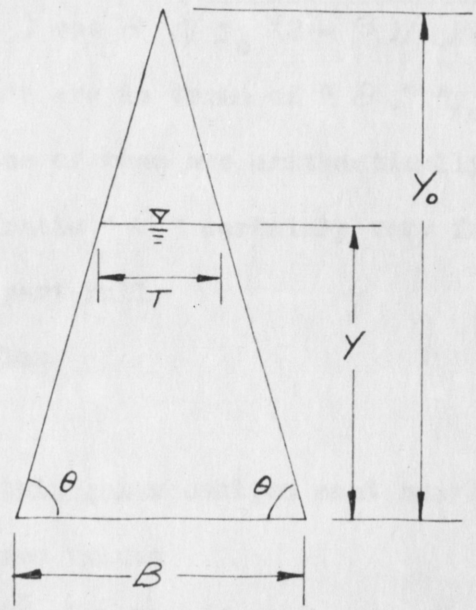
R = hydraulic radius = A/p_w

$= \left[\beta\ y_o\ (2 - \beta)\cot\theta\right] / \left[2(\cot\theta + \beta\csc\theta)\right]$

T = top width = $2\ y_o\ (1 - \beta)\cot\theta$

D_m = mean depth or hydraulic depth

$= A/T = \beta\ y_o\ (2 - \beta)/\left[2\ (1 - \beta)\right]$



$$\beta = \frac{y}{y_o}$$

$$B = 2\, y_o \cot\theta$$

$$A = \beta\, y_o^2\, (2 - \beta) \cot\theta$$

$$p_w = 2\, y_o\, (\cot\theta + \beta \csc\theta)$$

$$R = \left[\beta\, y_o\, (2 - \beta) \cot\theta\right] \Big/ \left[2\, (\cot\theta + \beta \csc\theta)\right]$$

$$T = 2\, y_o\, (1 - \beta) \cot\theta$$

$$D_m = \beta\, y_o\, (2 - \beta) / [2\, (1 - \beta)]$$

$$Z = A \sqrt{A/T} = \beta\, y_o^2\, (2 - \beta) \cot\theta \sqrt{\beta\, y_o\, (2 - \beta) / [2\, (1 - \beta)]}$$

Fig. 8. Hydraulic Elements for an Isosceles Triangular Section in Terms of y_o and $\beta = y/y_o$

$$Z = \text{section factor} = A\sqrt{A/T} = A\sqrt{D_m}$$

$$= \beta y_o^2 (2 - \beta) \cot\theta \sqrt{y_o (2 - \beta)/[2(1 - \beta)]}$$

All of the above elements are in terms of " θ ," " y_o " and the ratio $\beta = \frac{y}{y_o}$. The derivations of them are arithmetically simple and not shown. The values of the ratio " β " certainly vary from 0 to 1.

When $0 < \beta < 1$, flow is part full.

When $\beta = 0$, there is no flow.

When $\beta = 1$, flow is full.

In order to find an isosceles triangular section most nearly like that of a circular section for maximum values

$$Q/Q_o = AR^{2/3}/A_oR_o^{2/3} \doteq 1.07 \text{ and}$$

$$V/V_o = R^{2/3}/R_o^{2/3} \doteq 1.16$$

the trial method can be used to solve the problem, yet this takes time. By using an IBM 1620 computer to run the values of " θ " from 60° to 89° and values of $\beta = \frac{y}{y_o}$ from 0.1 to 1.0, the section of an isosceles triangle with a base angle of $\theta = 75°$ was found to be the best one. This section had a maximum value of $Q/Q_o = 1.049$ at $y/y_o = 0.82$ and a maximum value of $V/V_o = 1.157$ at $y/y_o = 0.50$. The detailed information about this section was obtained by using the computer again. Figure 9 shows the dimensionless curves of Q/Q_o and V/V_o over y/y_o for the 75° base angle or 30° vertex angle isosceles triangular section. The coordinates are as shown in Table I.

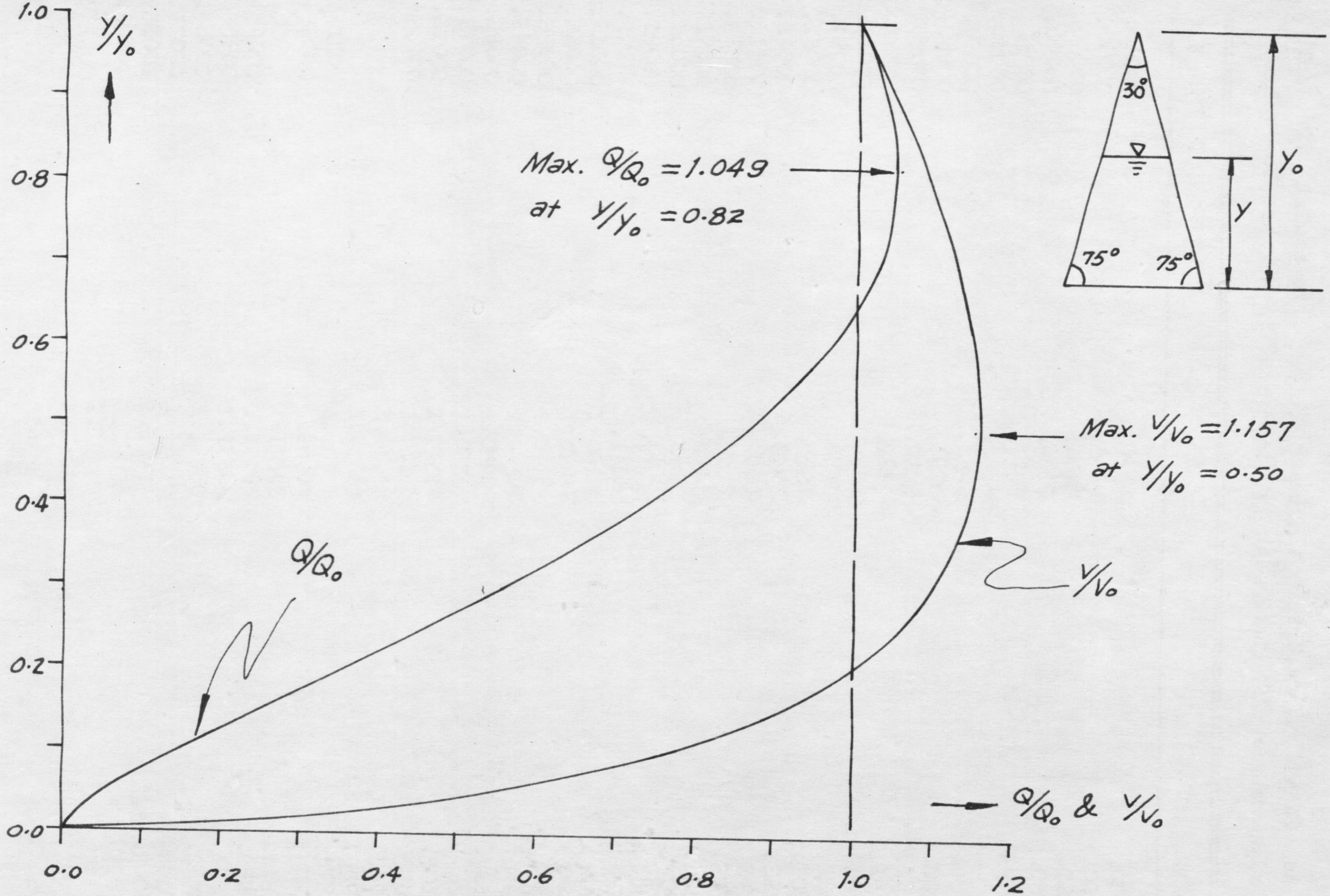


Fig. 9. Flow Characteristics of the 30° Vertex Angle Isosceles Triangular Section.

Table I. Values of y/y_o, Q/Q_o and V/V_o for Flow in the Closed Conduit of Section of Isosceles Triangle with 30° Vertex Angle

y/y_o	V/V_o	Q/Q_o
.01000	.20549	.00408
.02000	.31729	.01256
.03000	.40475	.02392
.04000	.47770	.03745
.05000	.54045	.05269
.06000	.59543	.06930
.07000	.64421	.08703
.08000	.68788	.10565
.09000	.72725	.12501
.1	.76294	.14495
.11000	.79543	.16537
.12000	.82512	.18614
.13000	.85232	.20720
.14000	.87732	.22845
.15000	.90034	.24984
.16000	.92157	.27131
.17000	.94118	.29280
.18000	.95932	.31427
.19000	.97611	.33568
.2	.99167	.35700
.21000	1.00610	.37819
.22000	1.01948	.39922
.23000	1.03189	.42008
.24000	1.04340	.44073
.25000	1.05409	.46116
.26000	1.06399	.48135
.27000	1.07318	.50128
.28000	1.08168	.52094
.29000	1.08955	.54031
.3	1.09683	.55938
.31000	1.10355	.57814
.32000	1.10974	.59659
.33000	1.11543	.61471
.34000	1.12065	.63249
.35000	1.12544	.64994
.36000	1.12980	.66703
.37000	1.13376	.68377
.38000	1.13735	.70015
.39000	1.14058	.71617
.4	1.14347	.73182
.41000	1.14604	.74710
.42000	1.14829	.76200

Table I. (Continued)

y/y_o	V/V_o	Q/Q_o
.43000	1.15025	.77653
.44000	1.15193	.79068
.45000	1.15334	.80446
.46000	1.15450	.81784
.47000	1.15540	.83085
.48000	1.15607	.84347
.49000	1.15652	.85571
.5	1.15675	.86756
.51000	1.15676	.87902
.52000	1.15658	.89010
.53000	1.15620	.90080
.54000	1.15564	.91111
.55000	1.15490	.92103
.56000	1.15399	.93057
.57000	1.15291	.93973
.58000	1.15166	.94851
.59000	1.15026	.95690
.6	1.14872	.96492
.61000	1.14702	.97256
.62000	1.14519	.97982
.63000	1.14321	.98671
.64000	1.14111	.99322
.65000	1.13888	.99936
.66000	1.13652	1.00514
.67000	1.13404	1.01054
.68000	1.13144	1.01558
.69000	1.12873	1.02026
.7	1.12590	1.02457
.71000	1.12297	1.02853
.72000	1.11993	1.03213
.73000	1.11679	1.03538
.74000	1.11355	1.03827
.75000	1.11021	1.04082
.76000	1.10677	1.04302
.77000	1.10325	1.04488
.78000	1.09962	1.04640
.79000	1.09591	1.04758
.8	1.09211	1.04843
.81000	1.08823	1.04894
.82000	1.08426	1.04913
.83000	1.08021	1.04899
.84000	1.07608	1.04853
.85000	1.07187	1.04775

Table I. (Continued)

y/y_o	V/V_o	Q/Q_o
.86000	1.06758	1.04665
.87000	1.06321	1.04524
.88000	1.05877	1.04352
.89000	1.05425	1.04150
.9	1.04967	1.03917
.91000	1.04501	1.03654
.92000	1.04027	1.03362
.93000	1.03547	1.03040
.94000	1.03060	1.02689
.95000	1.02567	1.02310
.96000	1.02066	1.01903
.97000	1.01559	1.01468
.98000	1.01046	1.01005
.99000	1.00526	1.00516
1.0	1.00000	1.00000

By studying Figure 9, the curves of Q/Q_o and V/V_o show that respectively:

$y/y_o = 0.82$, $Q/Q_o = 1.049 = \text{max.}$

$y/y_o = 0.50$, $V/V_o = 1.157 = \text{max.}$

$y \geqq 0.65\, y_o$, two different depths possible for same discharge

$y \geqq 0.205\, y_o$, two different depths possible for same velocity.

For convenience in discussion, it is better to call the two possible depths for discharge "bounding depths." They change within some limit and depend on the shape of section. These depths will become unstable as the discharge approaches the maximum.

From the specific energy diagram, it is seen that for the same energy or specific head, there are usually two depths possible, known as alternate depths. By applying the so called "bounding depth", there would be four alternate depths for the same discharge. Furthermore, in case critical flow happens within the bounding region (the region to cause bounding depths), there also exists its corresponding bounding depth. Under this circumstance, it seems that for the same discharge the flow may be or may not be critical. This is quite different from ordinary open channel hydraulic knowledge. However, this is the significance of the gradually closed conduit.

CHAPTER III

STEADY VARIED FLOW IN OPEN CHANNELS

In this research the water was run in the triangular conduit with different discharges under different bed slopes. In some circumstances no waves were observed, and in some they were. All waves observed were stationary. No waves were observed in the case of steady, gradually varied flow. Waves were observed in the case of rapidly varied flow for which the property of steadiness was still kept as a result of the standing waves. The discussion about these two flow conditions follows.

Steady Gradually Varied Flow

In the field of gradually varied flow, a lot of research has been done to determine the water surface profiles. The basic theory and derivations are shown briefly below.

Surface Profiles Classification

Writing the total head at any cross section of an open channel as the sum of velocity head, water depth and elevation of the channel bottom (Figure 30, Appendix C)

$$E = \frac{V^2}{2g} + y + z \qquad (7)$$

differentiating with respect to "x," distance in the direction of flow

$$\frac{dE}{dx} = \frac{d}{dx}\left(\frac{V^2}{2g}\right) + \frac{dy}{dx} + \frac{dz}{dx} \qquad (8)$$

Because $\frac{dE}{dx}$ and $\frac{dz}{dx}$ always decrease as "x" increases, equation (8) may be written as

$$-\frac{dE}{dx} = \frac{d}{dx}\left(\frac{V^2}{2g}\right) + \frac{dy}{dx} - \frac{dz}{dx} \tag{9}$$

When the channel is rectangular and very large in width and Chezy's formula is used,

$$\frac{dE}{dx} = \frac{V^2}{C^2R} = \frac{Q^2}{C^2y(Ty)^2} = \frac{q^2}{C^2\ y^3} = S_f \tag{10}$$

$$\frac{d}{dx}\left(\frac{V^2}{2g}\right) = \frac{d}{dx}\left(\frac{Q^2}{2gA^2}\right) = \frac{d}{dx}\left[\frac{Q^2}{2g(Ty)2}\right]$$

$$= \frac{d}{dx}\left[\frac{q^2}{2g}\,\frac{1}{y2}\right] = \frac{q^2}{2g}\,\frac{d}{dx}\left(\frac{1}{y2}\right)$$

$$= \frac{q^2}{2g}\cdot(-2)\,\frac{1}{y^3}\,\frac{dy}{dx} = -\frac{q^2}{gy^3}\,\frac{dy}{dx} \tag{11}$$

and $$\frac{dz}{dx} = S_o \tag{12}$$

substituting equations (10), (11) and (12) into equation (9)

$$(-)\,\frac{q^2}{C^2y^3} = (-)\,\frac{q^2}{gy^3}\,\frac{dy}{dx} + \frac{dy}{dx} - S_o$$

$$\frac{dy}{dx} = \frac{S_o - (q^2/C^2y^3)}{1 - (q^2/gy^3)} \tag{13}$$

or $$\frac{dy}{dx} = \frac{S_o - S_f}{1 - (y_c/y)^3} \tag{14}$$

or $$\frac{dy}{dx} = S_o\left[\frac{1 - (y_n/y)^3}{1 - (y_c/y)^3}\right] \tag{15}$$

From equation (15), it can be shown that

when S_o is positive; $y > y_n > y_c$, mild slope,

then $\frac{dy}{dx}$ is positive or is increasing, this is classified as M_1 curve.

When S_o = positive; $y_n > y > y_c$, mild slope,

then $\frac{dy}{dx}$ is negative or is decreasing, this is classified as M_2 curve.

When S_o = positive; $y_n > y_c > y$, mild slope,

then $\frac{dy}{dx}$ is positive or is increasing, this is classified as M_3 curve. In the same way, the curves of S_1, S_2, S_3, C_1, C_3, H_2, H_3, A_2 and A_3 will be realized (3,4,5,6,7).

Steady Rapidly Varied Flow

In rapidly varied flow, there is usually an abrupt change in surface profile, and the curvature of streamlines is formed. Owing to the complicated phenomena as related to wave activities, velocity distribution, pressure distribution, and other uncertain factors, there has been up to now no general theoretical approach in comparison with systematic analysis in gradually varied flow. Most research work done in this field has been conducted by hydraulic laboratory investigations and has been restricted to some assumed conditions or within some range of variations. Some ordinary cases of rapidly varied flow in open channel are discussed briefly as follows.

Hydraulic Jump

Hydraulic jump is the most usual case of a standing wave in rapidly varied flow. The derivation is based on the principle of momentum. Wherever the jump occurs, the flow changes from a supercritical to a sub-critical state. In other words, before jump the

Froude number must be greater than unity and after jump less than unity. Meanwhile, the flow must pass across the critical depth. The Froude number, "F," is defined as $F = V/\sqrt{gD_m}$,

where V = average velocity of flow

g = gravitational acceleration

$D_m = A/T$ = hydraulic or mean depth

= y = water depth for rectangular channel

The patterns of jump depend upon the Froude number. Bradley and Peterka classified five types of jumps on a horizontal floor (3):

Type 1, $F_1 = 1$ to 1.7, undular jump

Type 2, $F_1 = 1.7$ to 2.5, weak jump

Type 3, $F_1 = 2.5$ to 4.5, oscillating jump

Type 4, $F_1 = 4.5$ to 9, steady jump

Type 5, $F_1 > 9$, strong jump

Where $F_1 = V_1/\sqrt{gy_1}$, Froude number of the incoming flow with velocity "V_1," depth "y_1" and its sequent depth will be "y_2."

In hydraulic jump computation, the very simple case is for horizontal rectangular channels. The formula is

$$\frac{y_2}{y_1} = \frac{1}{2}\left[\sqrt{1 + 8\,F_1^2} - 1\right] \tag{16}$$

For a horizontal trapezoidal channel, Posey and Hsing worked out a table (23,16) which is very useful and time-saving in computation.

For a horizontal circular conduit, Lane and Kindsvater (12) observed the pressure-plus-momentum on the upstream side of the jump was slightly greater than that on the downstream side. This might be due to friction, non-uniform below the jump, or air bubbles. However, it is still close to the conventional hydraulic jump theory.

Argyropoulose (1) derived a general formula for hydraulic jump

$$2\left[y_2^{m+1} - y_1^{m+1}\right] - (y_2^m + y_1^m)(m + 1) \quad (X) \quad (y_2 - y_1) \sin\theta$$

$$= 2 \lambda_1 (m + 1)(y_2^m - y_1^m)(y_1^{m+1}/y_2^m) \qquad (17)$$

where $\lambda_1 = (F_1)^2$, θ = angle of channel slope

$X = \frac{Z}{y_2 - y_1}$, Z = jump length

m = a parameter (hydraulic exponent) = $\frac{Ty}{A}$

Figure 31, Appendix C, shows the general case of a hydraulic jump. This formula applies to any channel sections and any channel slopes. When jump occurs in a horizontal rectangular channel, $\sin\theta = 0$, $m = \frac{By}{By} = \frac{Ty}{Ty} = 1$, then this equation (17) is reduced to

$$(y_2/y_1)^2 + (y_2/y_1) = 2 \lambda_1 = 2F_1^2 \qquad (18)$$

and it can be changed to the form

$$\frac{y_2}{y_1} = \frac{1}{2}\left[\sqrt{1 + 8 F_1^2} - 1\right]$$

This is the same as equation (16).

Argyropoulos worked two tables for the factor "X" regarding parabolic and triangular flumes under different slopes (1).

Sudden Transitions

Transitions in a short distance to change the cross section of a channel will induce rapidly varied flow. The usual cases will be sudden contraction and sudden expansion. In general, for subcritical flow through a sudden contraction there will be a drop in water depth and for sudden expansion a rise in water depth. However, when supercritical flow is introduced through a contraction with symmetrical converging walls a cross wave will appear. Cross waves in a contraction are symmetrical with respect to the center line of the channel. This phenomena was originally studied by Ippen (7) and Dawson (8).

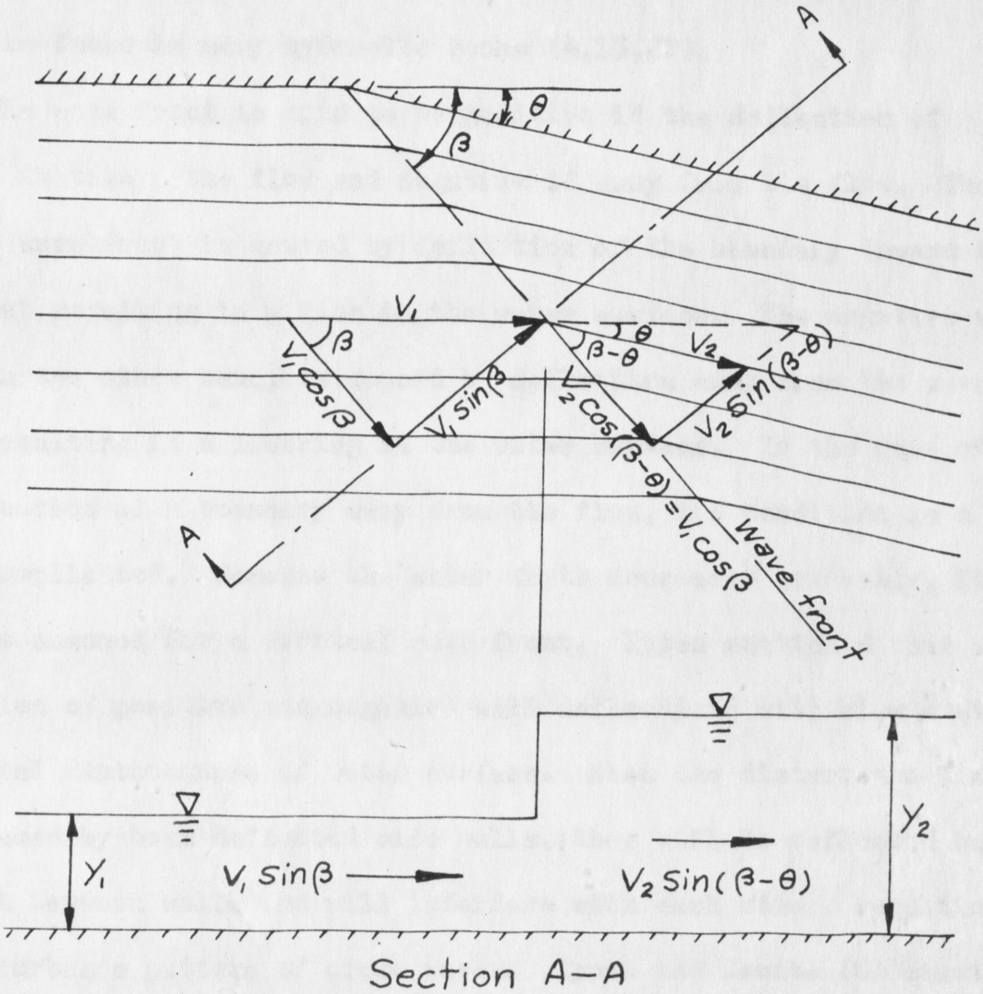
From Ippen's analysis (7), when a supercritical flow changes its direction because of the deflection of the side boundary, a shockwave front will be pronounced as shown in Figure 10. The wave angle "β" which the wave front or disturbance line makes with the initial direction, angle "θ," of flow can be shown as

$$\sin \beta = \frac{\sqrt{gy_1}}{V_1} \sqrt{\frac{1}{2} \left(1 + \frac{y_2}{y_1}\right) \frac{y_2}{y_1}} \qquad (19)$$

$$\frac{y_2}{y_1} = \frac{\tan \beta}{\tan (\beta - \theta)} = \frac{V_1 \sin \beta}{V_2 \sin (\beta - \theta)} \qquad (20)$$

$$\tan \theta = \frac{\tan \beta \left(\sqrt{1 + 8F_1^2 \sin^2 \beta} - 3\right)}{2 \tan^2 \beta + \sqrt{1 + 8F_1^2 \sin^2 \beta} - 1} \qquad (21)$$

A direct solution of the last equation for "β" in terms of "F_1" and "θ" is practically impossible. Ippen has prepared a four - quadrant graph showing all relationships expressed by equations (19),



$V_1 \sin\beta$ = Velocity V_1 Normal to Wave Front

$V_1 \cos\beta$ = Velocity V_1 Tangent to Wave Front

θ = Boundary Deflection Angle

β = Wave Angle

Fig. 10. Shock-Wave Front.

(20) and (21). This graph is self-explanatory for solving the problems and can be found in many hydraulic books (4,18,22).

The wave front is said to be positive if the deflection of boundary is toward the flow and negative if away from the flow. The positive wave front is caused by deflection of the boundary toward the wave front resulting in a rise in the water surface. The negative wave front, on the other hand, is caused by deflection away from the wave front, resulting in a lowering in the water surface. In the case of the deflection of a boundary away from the flow, the condition is a little complicated. Because the water depth decreases gradually, it cannot be assumed for a vertical wave front. Ippen mentioned that a combination of positive and negative wall deflections will always cause large total disturbances of water surface. When the disturbance lines are produced by both deflected side walls, they will be reflected back and forth between walls and will interfere with each other, resulting in a disturbance pattern of cross waves. Ippen and Dawson (8) studied the transition from a wide channel upstream to a narrow channel downstream. This is the case where the boundary changes from positive deflection to negative deflection. Pictures show very clearly the figure of the cross waves downstream (8).

The Effect of Curvature of the Flow

In ordinary analysis, the assumption is based on parallel flow with hydrostatic pressure distribution. Taking the effect of the curvature of the flow into consideration, Boussinesq (9, 20) derived the equation for the water surface as

$$\frac{d^3j}{dx^3} + \frac{3\alpha}{y_n}\left(\frac{1}{y_c^3} - \frac{1}{y_n^3}\right)\frac{dj}{dx} - \frac{9g}{C^2y_n^3}\, j = 0 \qquad (22)$$

where $j = \frac{y}{y_n} - 1$, α = coefficient

C = Chezy's coefficient

Let $p = \alpha\, y_n \left(\frac{1}{y_c^3} - \frac{1}{y_n^3}\right)$, $q = \frac{9g}{2C^2y_n^3}$

The general solution of equation (22) is

$$j = C_1 \exp(m_1x) + C_2 \exp(m_2x) + C_3 \exp(m_3x) \qquad (23)$$

Where $\exp(mx) = e^{mx}$ and

C_1, C_2 and C_3 are constant and m_1, m_2, and m_3 are the roots of the equation

$$m^3 + 3\,pm - 2q = 0 \qquad (24)$$

In the case of subcritical flow, $p > 0$, $q < 0$ and $q^2 + p^3 > 0$, the equation has one real root and a pair of complex roots. Accordingly, "j" may have a mathematically periodic solution and a wavy free surface is possible.

In the case of supercritical flow, $p < 0$, $q > 0$. As long as the difference between "y_c" and "y_n" is small and $q^2 + p^3 > 0$, a wavy free surface is possible. If the channel slope is steep and the difference between "y_n" and "y_c" is large, or $q^2 + p^3 < 0$, a wavy free surface is impossible because equation (24) is a mathematically irreducible case.

From the above discussion, it seems that the free surface is stable in supercritical flow if the discharge is constant and the Froude number is large. However, there is a limiting condition above which a supercritical flow of large Froude number may be unstable because the flow becomes unsteady. This limiting condition may be theoretically determined by the Vedermikov number "V_N" (20)

$$V_N = x\,f\,F \tag{25}$$

where $x = \frac{2}{3}$ if Manning's formula is used

F = Froude number

f = a shape factor of channel section

$$= 1 - R\,\frac{dp_w}{dA} \tag{26}$$

when $V_N < 1$, any waves in the channel will be depressed and the flow can be stable,

when $V_N > 1$, waves will be amplified so that stable flow becomes impossible and unsteady flow prevails.

According to the Vedernikow number,

when $1 \leqq F < 2$, there is roll waves.

$F > 2$, there is slug flow.

$F > 3.5$, there is air-entrained flow.

There are more cases to cause rapidly varied flow, such as curved channel flow, flow over weirs and spillways, flow through obstructions and channel junctions, etc. Since they are not related to this research work they are being omitted.

CHAPTER IV

WATER WAVES

Wave motion is a very broad and complex branch of hydraulic engineering. In analysis, a good deal of advanced mathematical techniques is applied. The discussions in this chapter are not going to involve a theoretical approach to wave motions mathematically. Some statements or descriptions in brief will be made.

General Conceptions of Water Waves

Before going on, we should be reminded first that whenever or wherever there is moving wave occurring, the flow will be unsteady and non-uniform. When waves are stationary or standing, the flow will be steady.

A wave may be defined as a temporal variation in fluid velocity which is propagated through a fluid medium. The speed of propagation of such a disturbance relative to the fluid is known as the wave celerity "c." If the fluid itself is in motion with a velocity "V," the absolute wave velocity "V_w" will be

$$V_w = V \pm c$$

In open channel waves these velocities are as a general rule, parallel to the channel axis. They are considered positive in the downstream direction and negative in the upstream direction. According to the complete analysis by Lamb (11), the celerity of the gravity surface wave of a small amplitude in water at any depth (Figure 13) is

$$c = \sqrt{\frac{\gamma}{\rho}\frac{\lambda}{2\pi}\tanh\frac{2\pi y}{\lambda}} \qquad (27)$$

For $\frac{\lambda}{y} < 2$, $\tanh\frac{2\pi y}{\lambda} \doteq 1$, and since $\frac{\gamma}{\rho} = g$

$$c = \sqrt{\frac{g\lambda}{2\pi}} \qquad (28)$$

This applies for deep-water waves. It can be seen that the celerity depends on the wave length only. Surface waves in the ocean belong to this category.

Where " λ " is moderately large compared with "y," $\tanh\frac{2\pi y}{\lambda}$ approaches $\frac{2\pi y}{\lambda}$

$$c = \sqrt{gy} \qquad (29)$$

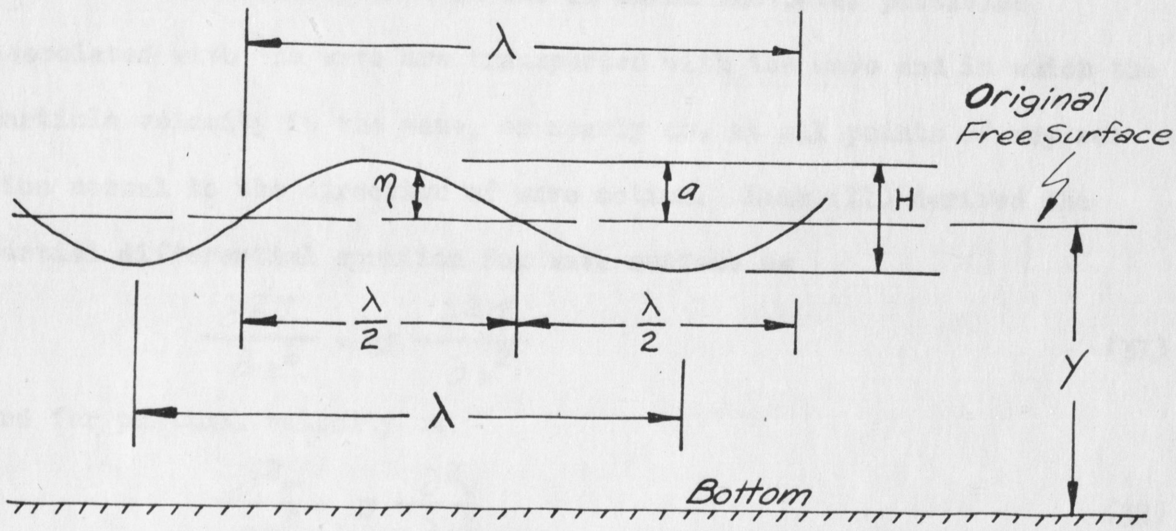
This is the well known equation for celerity of long waves of small amplitude, also known as shallow water waves. It can be seen that the celerity depends on water depth only. Open channel waves belong to this category. In uniform channels of any section

$$c = \sqrt{gD_m} \qquad (30)$$

$D_m = A/T =$ mean depth

Shallow Water Waves

From the previous discussion, it is realized that the shallow-water wave equation, $c = \sqrt{gy}$, applies strictly to waves of small amplitude. However, it is sufficiently accurate for nearly all cases, except when the wave is almost large and steep enough to form a breaker. The following are those waves occurring, generally, in shallow water.



a = Amplitude

H = Wave Height

η = Local Height of Wave above Original Free Surface

y = Original Water Depth

λ = Wave Length

T = Wave Period

$c = \lambda/T$ = Celerity or Wave Velocity

Fig. 11. Wave Profile.

Translatory Wave

The translatory wave is one in which the water particles associated with the wave are transported with the wave and in which the particle velocity is the same, or nearly so, at all points of any section normal to the direction of wave motion. Lamb (11) derived the partial differential equation for wave surface as

$$\frac{\partial^2 \eta}{\partial t^2} = gy \frac{\partial^2 \eta}{\partial x^2} \tag{31}$$

and for partical velocity as

$$\frac{\partial^2 v}{\partial t^2} = gy \frac{\partial^2 v}{\partial x^2} \tag{32}$$

he solved $v = c \dfrac{\eta}{y}$ (33)

From equation (33), the particle is at rest until it is reached by the wave; it then moves forward with a velocity $v = c\ (\eta/y)$ which is less than wave celerity. If the wave is of finite amplitude "a" (not very small), the wave celerity is approximately

$$c = \sqrt{gy}\ (1 + \frac{3}{4}\frac{a}{y}) \tag{34}$$

and the particle velocity is solved (approx.)

$$v = \sqrt{gy}\ \frac{\eta}{y}\ (1 - \frac{\eta}{4y}) \tag{35}$$

Solitary Wave

A solitary wave is a single disturbance propagated, essentially unaltered in form, over long distances at a constant velocity. From the derivation by McCowan (5) the surface profile of a solitary wave is (Figure 12)

$$\eta = a \operatorname{sech}^2\left(\frac{mx}{2}\right) \tag{36}$$

where

$$m = \sqrt{\frac{3a}{y^3}} \qquad \text{Boussinesq}$$

$$m = \sqrt{\frac{3a}{y^2(y + a)}} \qquad \text{Rayleigh}$$

$$m = \sqrt{\frac{3a}{y^2(y + \frac{19}{12} a)}} \qquad \text{McCowan}$$

Daily and Stephan concluded that Boussinesq's "m" appeared to agree best with their experimentation (5).

The celerity of the solitary wave is given, approximately, as

$$c = \sqrt{gy\ (1 + \frac{a}{y})} \tag{37}$$

The solitary wave, when reaching its limiting height, will break at a value of $a/y = \frac{3}{4}$. A theoretical analysis found by McCowan for this value is $a/y = 0.78$.

The Possible Causes of Surface Waves and Wavy Surfaces in Open Channels

1. Resistance is unbalanced by gravity forces--this is the case which occurs in upstream and downstream reaches of a long channel of uniform flow. When water enters the channel slowly, the velocity and hence the resistance are small, and the resistance is outbalanced by the gravity forces, resulting in an accelerating flow in the upstream reach. The velocity and resistance will gradually increase until a

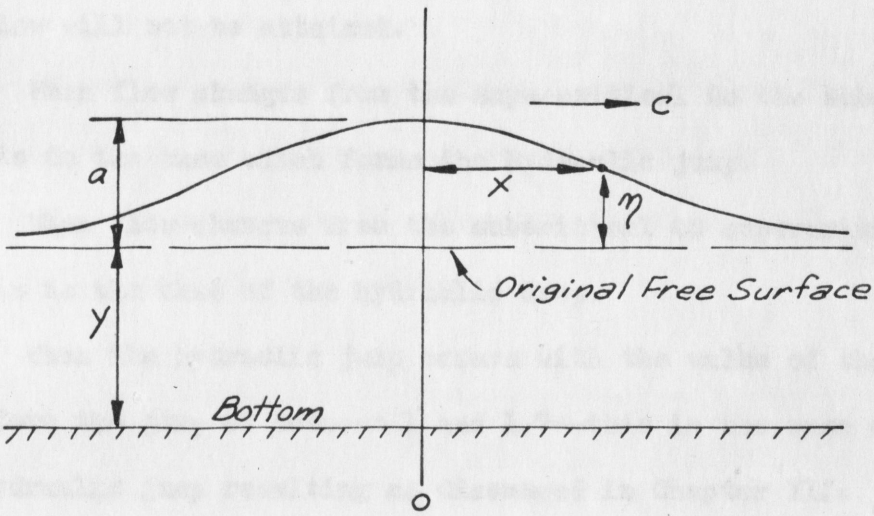


Fig. 12. Solitary Wave.

balance between resistance and gravity forces is reached. At this moment and afterward the flow becomes uniform. Toward the downstream end of the channel, the resistance may again be exceeded by gravity forces, and the flow may become varied again. If the channel is short, uniform flow will not be attained.

2. When flow changes from the supercritical to the subcritical state--this is the case which forms the hydraulic jump.

3. When flow changes from the subcritical to supercritical state--this is the case of the hydraulic drop.

4. When the hydraulic jump occurs with the value of the Froude number before the jump of between 1 and 1.7--this is the case of the undular hydraulic jump resulting as discussed in Chapter III.

5. When curvature of the flow is present--this is the case of the wavy surface as discussed in Chapter III.

6. When a sudden transition is introduced--this is the case of the resulting standing wave or cross waves in the channel as discussed in Chapter III.

7. When flow is unstable--this is the case causing unstable surface waves.

(a) When channel slope is greater than $4g/C^2$ and the Froude number is greater than "2." (C is Chezy's roughness) (18).

(b) When the Vedernikov number is greater than "1" as discussed in Chapter III.

(c) When the channel slope and Reynolds number are such that (15)

$S_o > 0.03$ and $R_N < 420$, roll waves occur.

$0.02 < S_o < 0.03$ and $1200 < R_N < 4000$, slug flow occurs.

$F > 2$, always being the case.

8. There are many other causes of waves such as channels of nonlinear alignment, obstructions within channels, varied discharge, local disturbances, and so forth. They are not discussed because they are not the case in this research.

CHAPTER V

EXPERIMENT AND ANALYSIS

General Description

This experimental work was conducted in the hydraulic laboratory of the Department of Agricultural Engineering of South Dakota State College. The arrangements are shown in Figure 13. The experimental triangular conduit 17 feet 10 inches in length was headed by a 15-inch transition (Detailed dimensions will be described later). They were placed in the 11.75 inch wide rectangular laboratory flume, the slope of which is adjustable. The discharge was controlled by a regulating valve. The discharge was determined from the reading of the manometer across the orifice plate (The calibration chart of discharges vs. manometer readings for the adopted orifice). In this research, 2 and 3-inch circular orifices were used and the flume slopes were varied from 0.001 to 0.0422. A total of 266 observations were made with the combinations of different discharges and slopes.

The Triangular Conduit

The triangular conduit was made of lucite plate 0.25 inch in thickness. Its cross-section was an isosceles triangle with a 30-degree vertex angle and two equal base angles of 75 degrees. The net base width was 3.65 inches or 0.3042 feet and net height of 6.75 inches

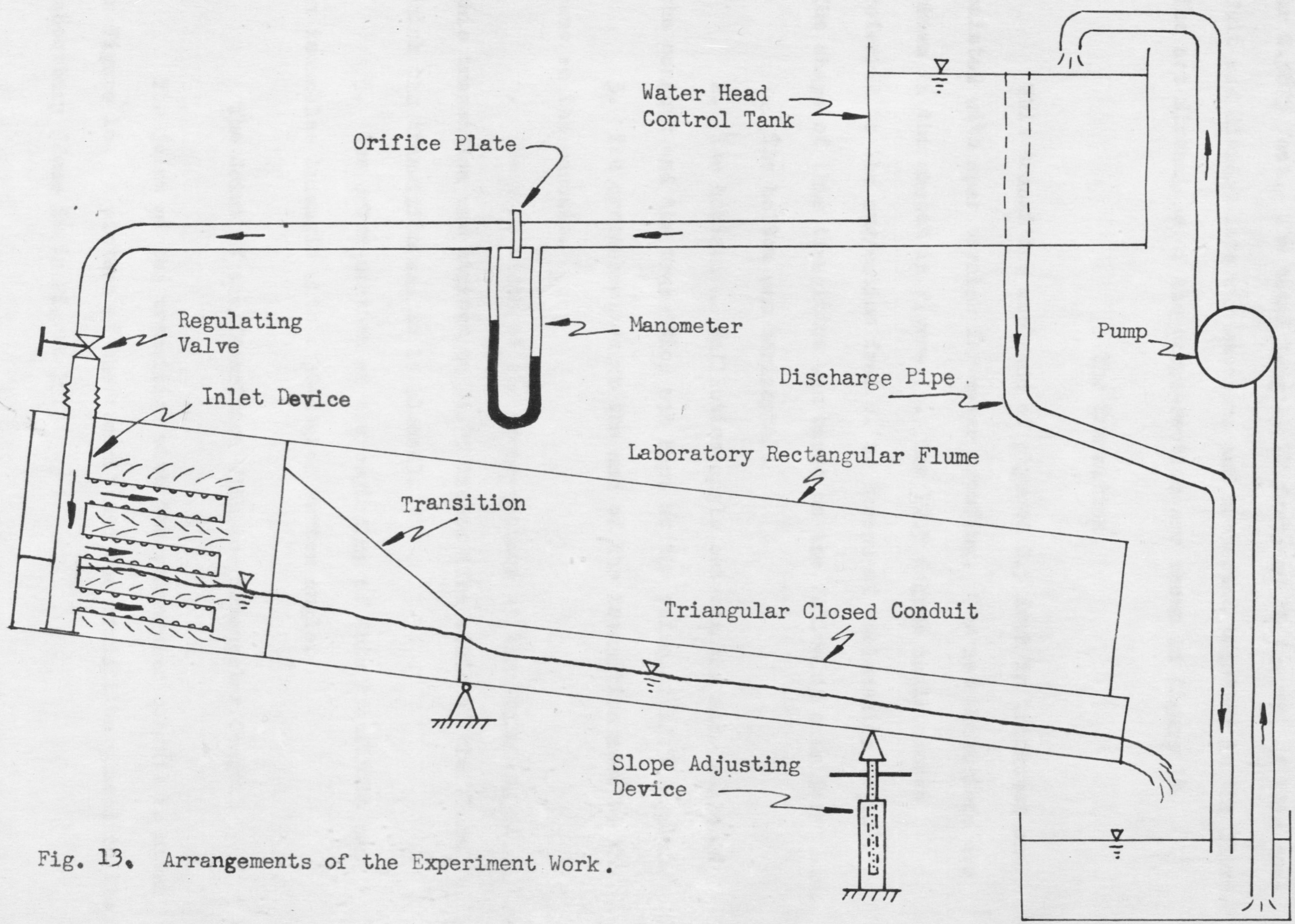


Fig. 13. Arrangements of the Experiment Work.

or 0.5625 feet. The total length, 17 feet and 10 inches, of this conduit was divided into six sections and connected together in the flume. The net dimensions of the cross-section are shown in Figure 14.

The Transition

This transition was made of plywood 0.5 inch in thickness and painted with spar varnish for water proofing. The net dimensions are shown in the sketch in Figure 15. The 12.5 degree angle chosen referred to the suggestion from U. S. Bureau of Reclamation (4,10). The shape of this transition was based on the following considerations:

1. The bottom was horizontal.

2. The horizontal deflection angle between the side walls of the conduit and the transition was kept at the value of 12.5 degrees.

3. The cross-section at the end of the transition must be the same as the conduit.

4. The base width of the cross-section at the beginning of this transition was limited to 11.75 inches (The width of the flume in which the transition was to be placed).

5. The cross-section at the beginning of this transition was an isosceles triangle with a 30-degree vertex angle.

The Joint of the Transition With the Triangular Conduit

The joint of the transition with the triangular conduit is shown in Figure 16. A picture of the conduit and the transition placed in the laboratory flume is in Figure 17.

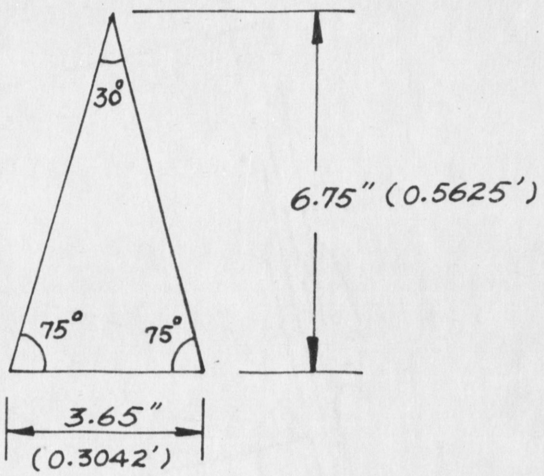


Fig. 14. Net Dimensions of the Triangular Conduit.

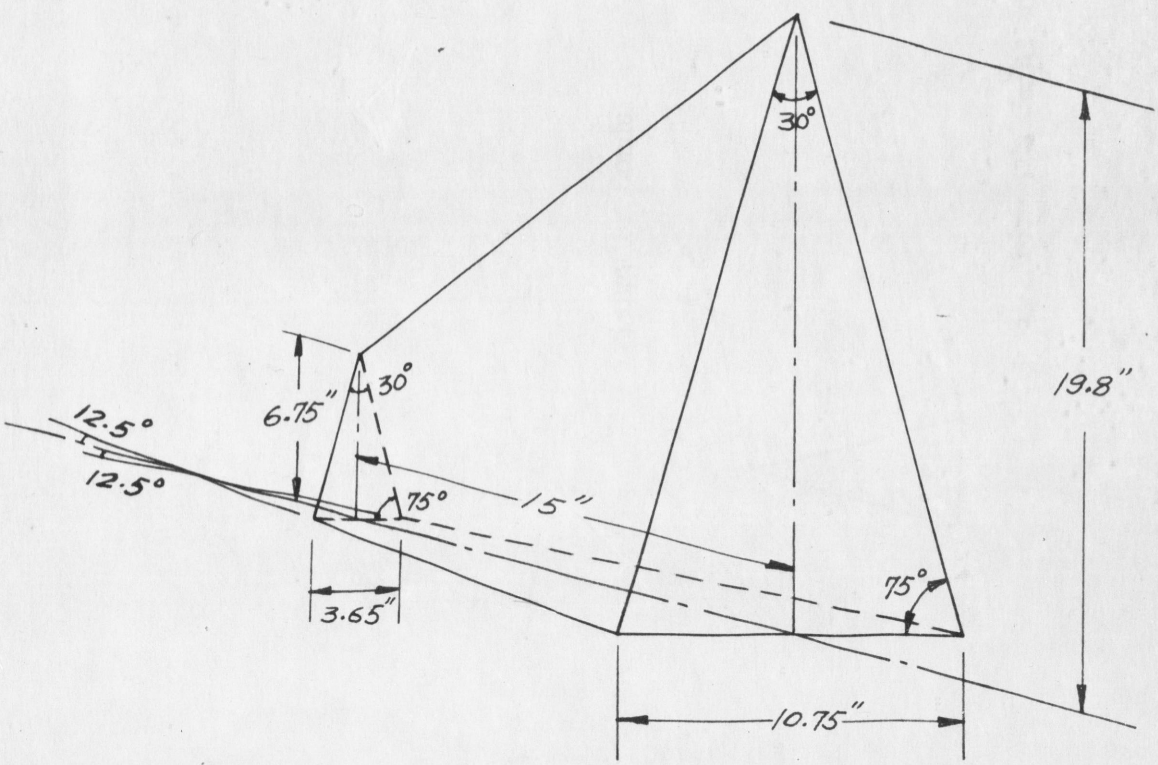


Fig. 15. Net Dimensions of the Transition.

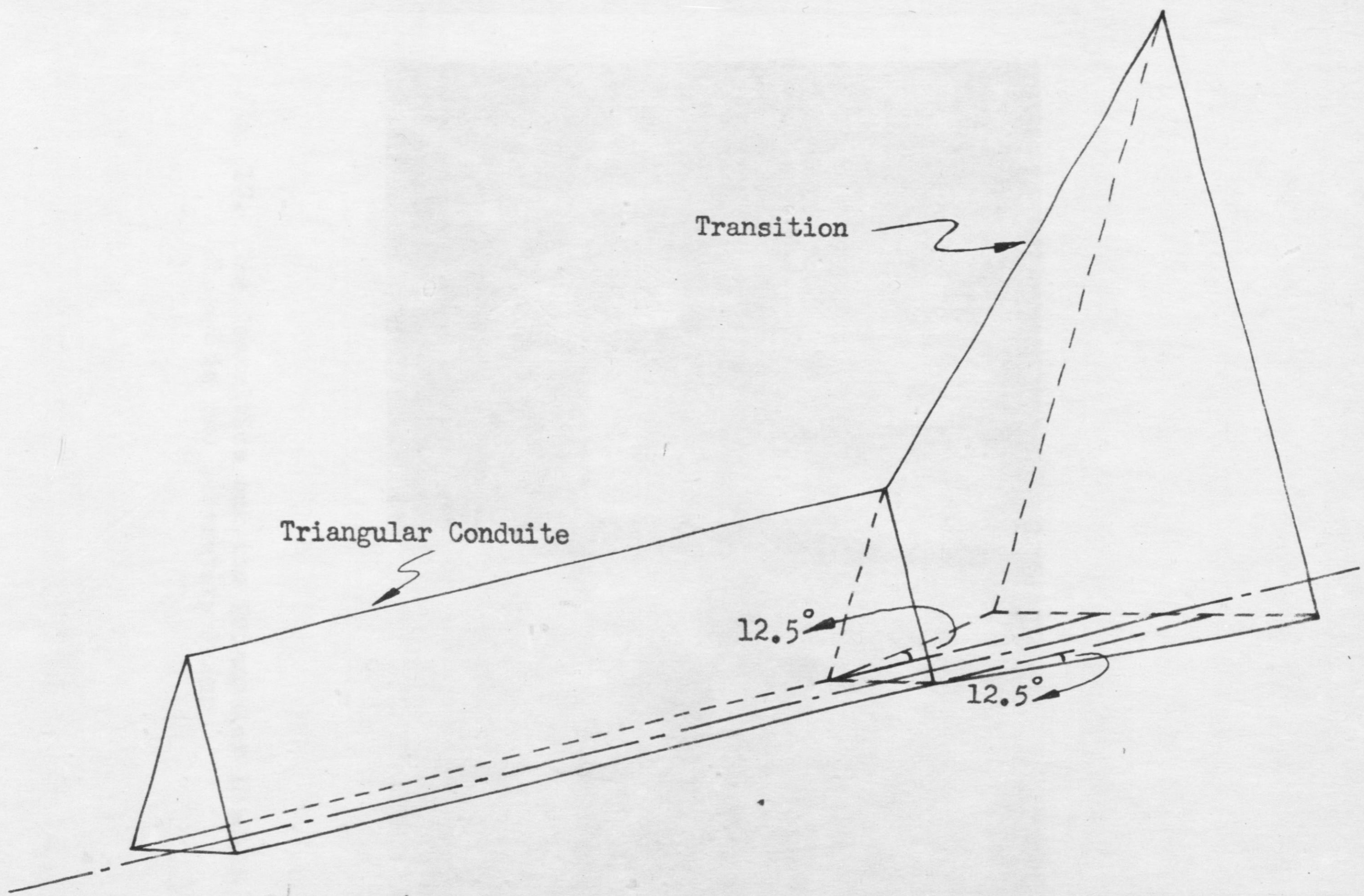


Fig. 16. The Joint of the Transition with the Triangular Conduit.

Fig. 17. The Transition and the Triangular Conduit Placed in the Laboratory Flume

Runs and Observations

In this research, the laboratory equipment was simple. After the triangular conduit and transition were placed in the laboratory flume, the equipment used was the orifice plate to measure the discharge and the survey level to measure the slope. The observations were divided into two groups:

(1) Group A

The conduit was set in various slopes from mild to steep. For each one of these slopes, the various discharges from low to high were run. The water surface profiles for each of the combinations between discharge and slope were observed. These profiles are plotted as shown in Figures 18, 19, 20, 21, 22, 23, 24, 25 and 26 respectively. Although there are only six different discharges shown in each of these figures, the actual runs were more. If all the runs would have been plotted, the surface profiles would blend with each other. The following generalizations were observed.

(a) In all the cases when waves occurred, they were stationary or standing waves in nature. The highest wave was the one nearest the end of the transition. The water surface was concaved between the end of transition and the beginning of the first wave in the conduit.

The fact that stationary waves were observed is quite different from ordinary cases. Sometimes slug flow waves are observed in circular conduits (13,17,14,6). In

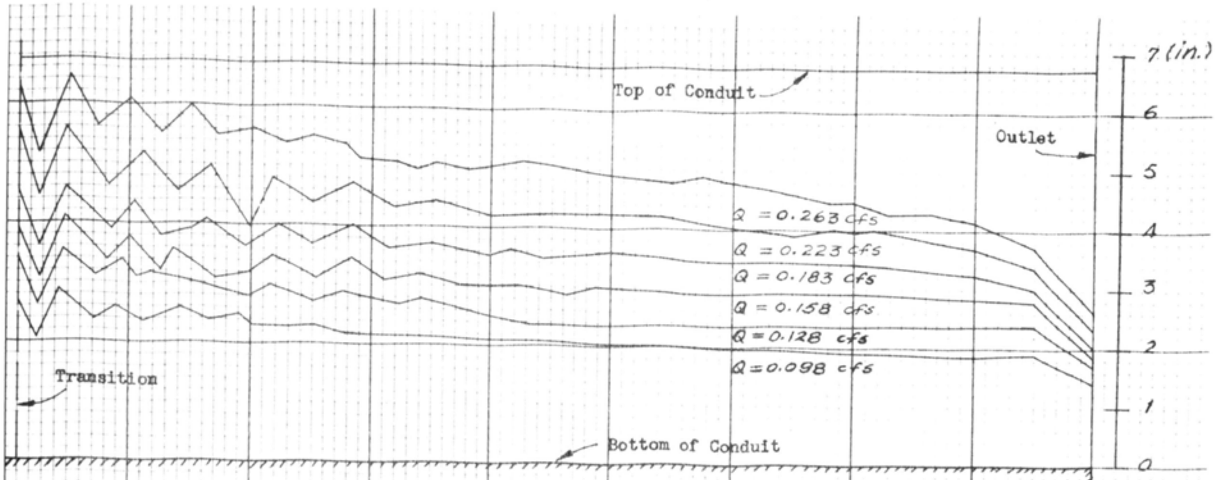


Fig. 18. The Surface Profiles for Different Discharges at S_o = 0.007

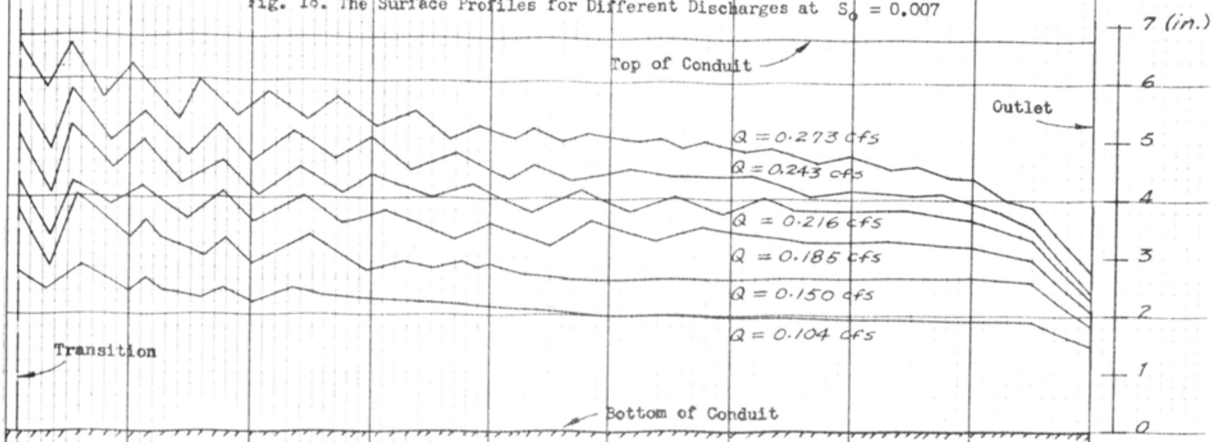


Fig. 19. The Surface Profiles for Different Discharges at S_o = 0.008

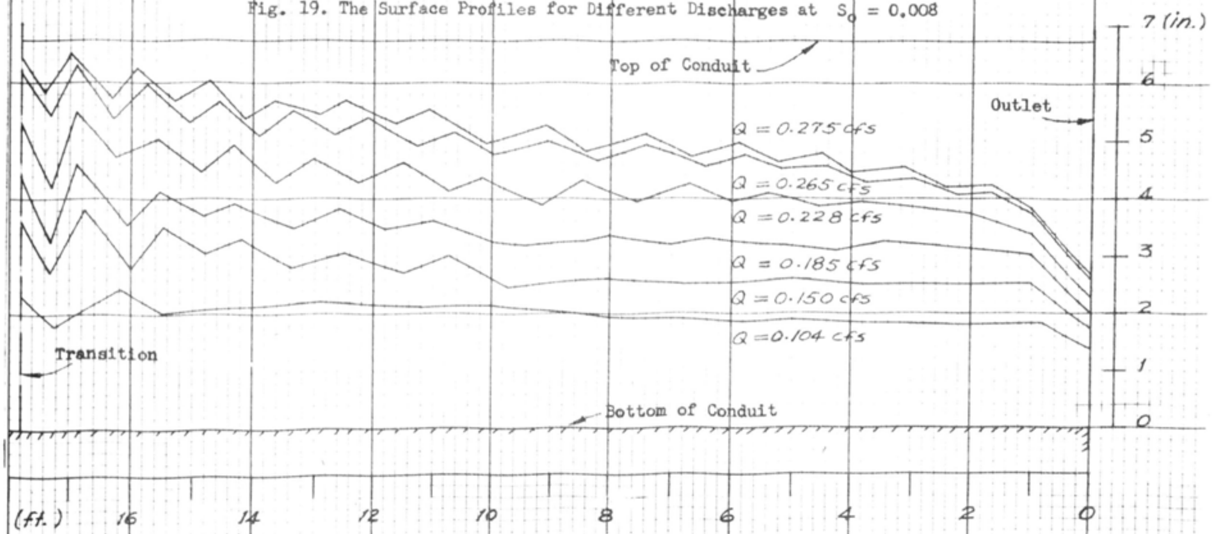


Fig. 20. The Surface Profiles for Different Discharges at S_o = 0.009

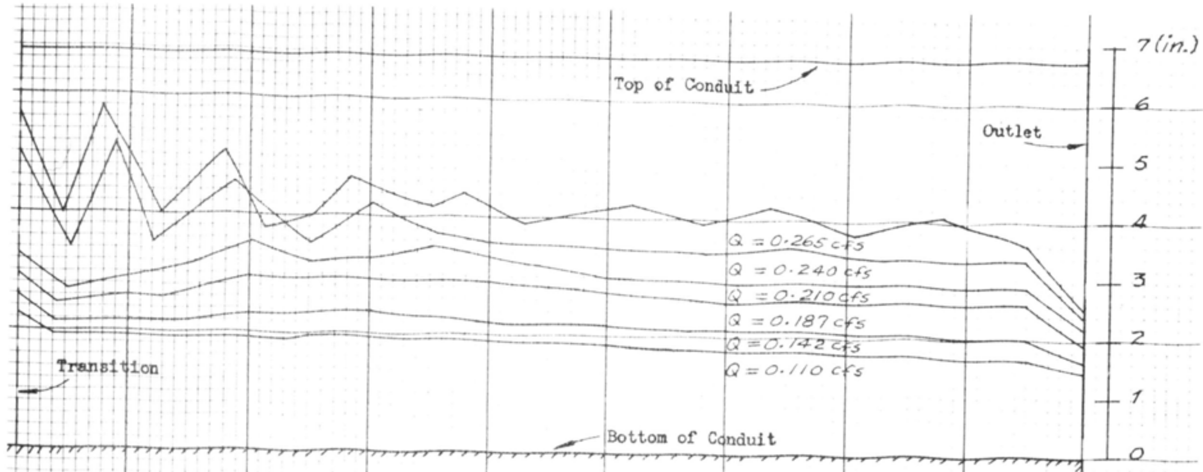


Fig. 21. The Surface Profiles for Different Discharges at $S_o = 0.013$

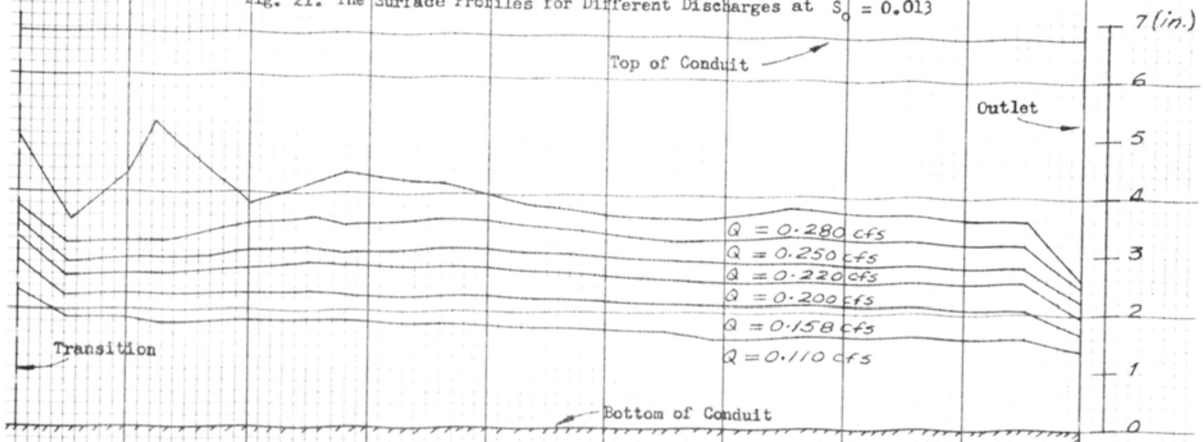


Fig. 22. The Surface Profiles for Different Discharges at $S_o = 0.0163$

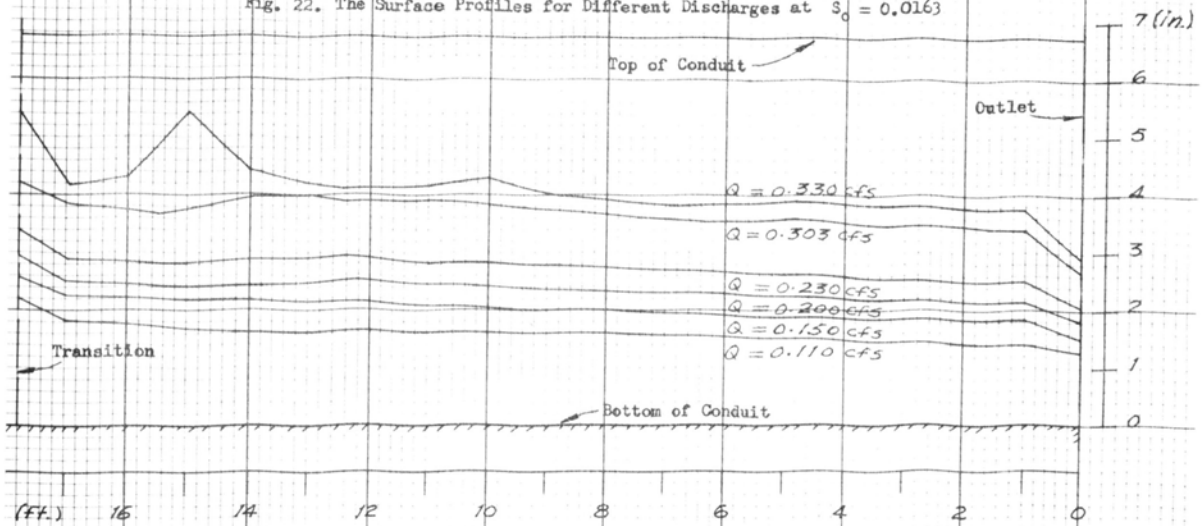


Fig. 23. The Surface Profiles for Different Discharges at $S_o = 0.021$

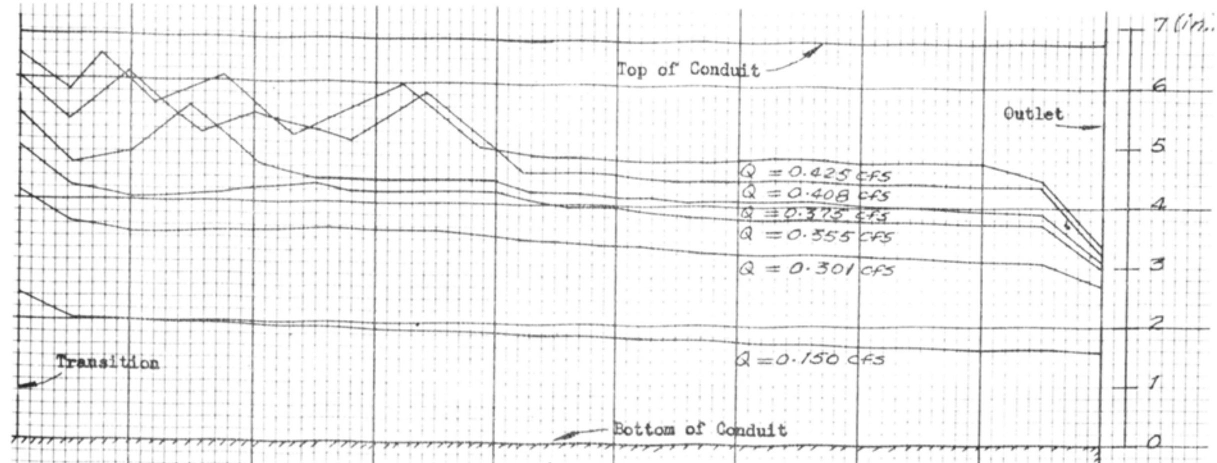


Fig. 24. The Surface Profiles for Different Discharges at $S_o = 0.0257$

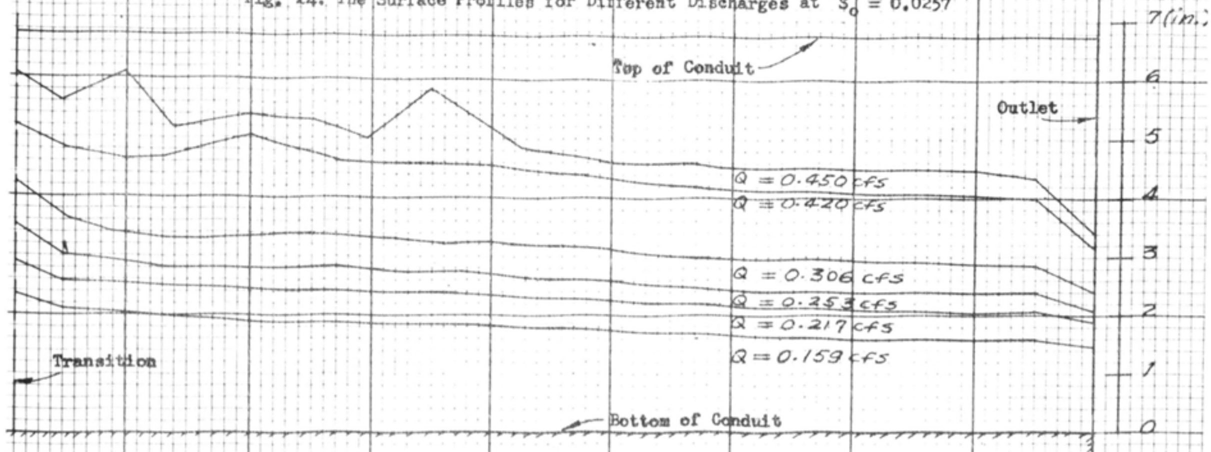


Fig. 25. The Surface Profiles for Different Discharges at $S_o = 0.030$

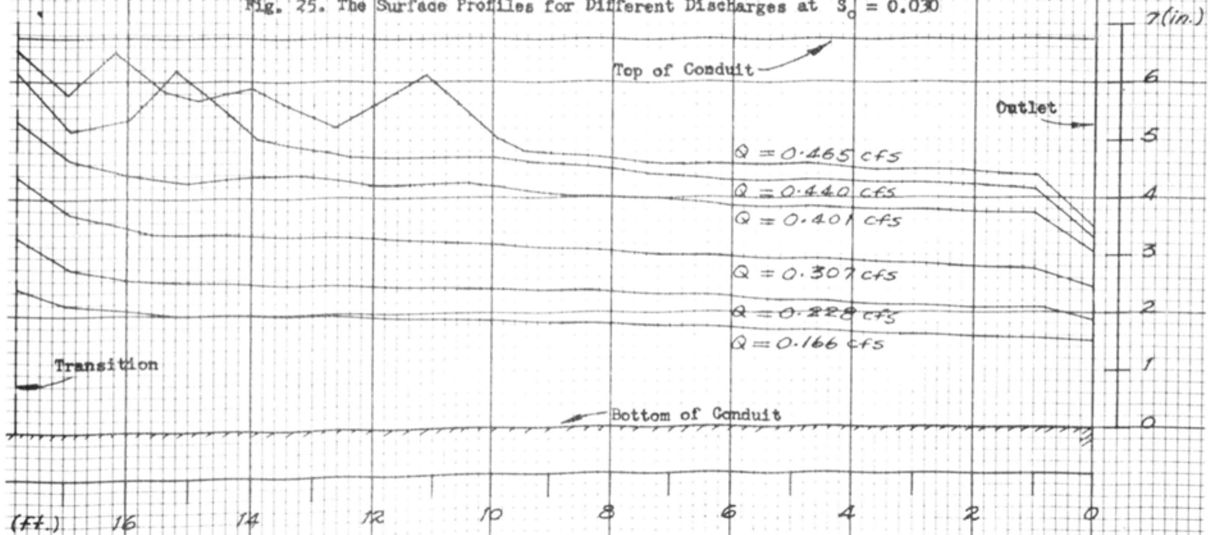


Fig. 26. The Surface Profiles for Different Discharges at $S_o = 0.032$

ordinary open-channel flow, there is no case where the surface profile of flow has the form of a stationary wave. It can be said that the occurrence of the stationary waves in this research was a special case.

(b) For a smaller slope, waves would occur with a low discharge as well as high discharge. For a steeper slope, waves would occur but only with a high discharge.

(c) The downstream water surface was unstable. When discharge was higher the unstable surface was stronger.

(d) There were cross-waves on the surface, except for very small slope with very low discharge the cross-waves were not seen. The phenomena of the cross-waves were due to the transition as discussed in Chapter III.

(e) During high discharges, the flume vibrated slightly and the upstream water surface was unstable. The trembling of the flume body might be caused by the following.

1. The impact of the supplying water directly hit at the walls of the flume in the region of the entrance. The impact force is proportional to the mass, when the head is constant. The higher the discharge the greater is the impact.

2. The supply line connects the inlet device which was directly set on the bottom of the flume. When the discharge was getting higher, the turbulence of the

flow would be stronger. Then the supply line would be shaking and this action transferred to the flume.

3. The framework of the flume was not rigid enough.

(2) Group B

The water was discharged at various slopes where the highest wave was about to touch the top of the conduit. There were 95 observations. Fifty-two observations were made using the 2-inch orifice and 43 observations by using the 3-inch orifice. The observed values of slope and discharge are shown under column 2 and 5 in Table II and Table III respectively.

Normal Depth and Critical Depth

When water is run in a conduit or channel, the normal and critical depths of the flow are some of the more important items needed in analysis. From Manning's formula

$$Q = VA = \frac{1.486}{n} AR^{2/3}S^{1/2}$$

it may be written

$$Q/\sqrt{S} = \frac{1.486}{n} AR^{2/3} \qquad (38)$$

From the right side of equation (38), if the coefficient of roughness "n" is a constant and the section of the conduit is prismatic and uniform, the flow rate will be a function of the depth "y." Then

$$\frac{Q}{\sqrt{S}} = \frac{1.486}{n} AR^{2/3} = f\ (y) \qquad (39)$$

Table II. **The Observed Discharges and Slopes for Maximum Open Channel Flow in the Triangular Conduit for a 2-Inch Orifice Plate**

Run	S_o	$\sqrt{S_o}$	Mano. (in.)	Q (cfs)	y_c (in.)	y_c/y_o ($y_c/6.75$)
1	0.00100	0.03163	4.20	0.211	3.23	0.479
2	0.00200	0.04472	4.50	0.227	3.28	0.486
3	0.00300	0.05478	4.90	0.238	3.39	0.502
4	0.00390	0.06245	5.20	0.242	3.43	0.508
5	0.00480	0.06929	5.40	0.250	3.50	0.519
6	0.00600	0.07746	5.80	0.260	3.59	0.532
7	0.00650	0.08063	6.10	0.267	3.66	0.542
8	0.00680	0.08247	5.80	0.260	3.60	0.533
9	0.00700	0.08367	6.05	0.265	3.64	0.539
10	0.00727	0.08526	6.10	0.267	3.64	0.539
11	0.00760	0.08718	6.20	0.268	3.67	0.544
12	0.00780	0.08832	6.30	0.270	3.69	0.547
13	0.00800	0.08946	6.40	0.273	3.71	0.550
14	0.00813	0.09017	6.45	0.275	3.73	0.553
15	0.00853	0.09236	6.60	0.278	3.75	0.556
16	0.00880	0.09381	6.75	0.280	3.77	0.559
17	0.00887	0.09418	6.80	0.282	3.79	0.561
18	0.00900	0.09487	6.80	0.282	3.79	0.561
19	0.00947	0.09731	7.10	0.288	3.84	0.569
20	0.00950	0.09747	7.10	0.288	3.84	0.569
21	0.01000	0.10000	7.30	0.293	3.88	0.575
22	0.01037	0.10183	7.40	0.295	3.90	0.578
23	0.01067	0.10330	7.65	0.298	3.92	0.581
24	0.01133	0.10644	7.80	0.303	3.79	0.588
25	0.01181	0.10868	8.00	0.308	4.01	0.594
26	0.01233	0.11104	8.30	0.314	4.06	0.610
27	0.01300	0.11402	8.50	0.318	4.09	0.606
28	0.01373	0.11705	8.80	0.324	4.14	0.613
29	0.01447	0.12124	9.10	0.330	4.20	0.622
30	0.01527	0.12357	9.60	0.340	4.26	0.631
31	0.01607	0.12677	10.10	0.350	4.33	0.641
32	0.01633	0.12779	10.30	0.353	4.35	0.644
33	0.01700	0.13039	10.40	0.355	4.37	0.647
34	0.01790	0.13379	10.80	0.363	4.43	0.656
35	0.01880	0.13711	11.20	0.372	4.49	0.665
36	0.01977	0.14061	11.75	0.382	4.56	0.676
37	0.02093	0.14467	12.15	0.388	4.60	0.681
38	0.02100	0.14491	12.20	0.389	4.61	0.683

Table II. (Continued)

Run	S_o	$\sqrt{S_o}$	Mano. (in.)	Q (cfs)	y_c (in.)	y_c/y_o (y_c/6.75)
39	0.02230	0.14933	12.90	0.401	4.68	0.693
40	0.02333	0.15275	13.14	0.405	4.71	0.698
41	0.02467	0.15707	14.00	0.420	4.80	0.711
42	0.02567	0.16022	14.50	0.427	4.84	0.717
43	0.02600	0.16125	14.55	0.428	4.86	0.720
44	0.02760	0.16613	14.90	0.434	4.88	0.723
45	0.02850	0.16882	15.50	0.443	4.93	0.730
46	0.02927	0.17109	15.90	0.449	4.96	0.735
47	0.03000	0.17322	16.00	0.450	4.97	0.736
48	0.03133	0.17701	16.85	0.462	5.03	0.745
49	0.03200	0.17889	17.20	0.467	5.06	0.750
50	0.03280	0.18111	17.55	0.473	5.09	0.754
51	0.03320	0.18221	17.75	0.475	5.10	0.756
52	0.03350	0.18303	17.95	0.477	5.11	0.757

Remarks: The first trough is about 5.85 inches deep in all the cases (or the first lowest water depth before the standing waves)

Table III. The Observed Discharges and Slopes for Maximum Open Channel Flow in the Triangular Conduit for a 3-Inch Orifice Plate

Run	S_o	$\sqrt{S_o}$	Mano. (in.)	Q (cfs)	y_c (in.)	y_c/y_o ($y_c/6.75$)
1	0.00100	0.03163	0.80	0.223	3.24	0.480
2	0.00150	0.03874	0.82	0.225	3.26	0.483
3	0.00200	0.04472	0.84	0.230	3.31	0.490
4	0.00300	0.05478	0.92	0.240	3.40	0.504
5	0.00400	0.06324	1.00	0.252	3.52	0.521
6	0.00500	0.07071	1.05	0.260	3.60	0.533
7	0.00600	0.07748	1.10	0.265	3.64	0.539
8	0.00700	0.08367	1.20	0.275	3.73	0.553
9	0.00800	0.08944	1.25	0.280	3.77	0.559
10	0.00900	0.09487	1.35	0.295	3.90	0.578
11	0.01000	0.10000	1.40	0.300	3.94	0.584
12	0.01100	0.10488	1.45	0.305	3.98	0.590
13	0.01200	0.10954	1.50	0.310	4.02	0.596
14	0.01300	0.11402	1.55	0.315	4.06	0.601
15	0.01400	0.11832	1.65	0.330	4.18	0.619
16	0.01500	0.12248	1.75	0.335	4.22	0.625
17	0.01600	0.12649	1.85	0.345	4.29	0.636
18	0.01700	0.13039	1.95	0.355	4.37	0.647
19	0.01800	0.13417	2.05	0.365	4.44	0.658
20	0.01900	0.13784	2.15	0.370	4.47	0.662
21	0.02000	0.14142	2.25	0.380	4.54	0.673
22	0.02100	0.14492	2.35	0.390	4.61	0.683
23	0.02200	0.14832	2.45	0.400	4.67	0.692
24	0.02300	0.15166	2.55	0.410	4.74	0.702
25	0.02400	0.15492	2.65	0.415	4.77	0.707
26	0.02500	0.15811	2.75	0.425	4.83	0.716
27	0.02600	0.16125	2.85	0.430	4.86	0.720
28	0.02700	0.16432	2.95	0.435	4.89	0.724
29	0.02800	0.16733	3.05	0.440	4.92	0.729
30	0.02900	0.17029	3.15	0.455	5.00	0.741
31	0.03000	0.17321	3.20	0.457	5.01	0.742
32	0.03100	0.17607	3.25	0.458	5.01	0.742
33	0.03200	0.17889	3.35	0.465	5.05	0.748
34	0.03300	0.18166	3.45	0.475	5.10	0.756
35	0.03400	0.18439	3.55	0.480	5.12	0.759
36	0.03500	0.18708	3.60	0.490	5.17	0.766
37	0.03600	0.18974	3.70	0.495	5.20	0.770
38	0.03700	0.19235	3.80	0.500	5.22	0.773

Table III. (Continued)

Run	S_o	$\sqrt{S_o}$	Mano. (in.)	Q (cfs)	y_c (in.)	y_c/y_o ($y_c/6.75$)
39	0.03800	0.19494	3.90	0.505	5.25	0.778
40	0.03900	0.19748	4.00	0.510	5.26	0.779
41	0.04000	0.20000	4.10	0.515	5.29	0.784
42	0.04150	0.20372	4.23	0.525	5.33	0.790
43	0.04220	0.20543	4.30	0.530	5.35	0.793

Remarks: The first trough is about 5.85 inches deep in all the cases (or the first lowest water depth before the standing waves) or $$\frac{Q}{\sqrt{S}} = K = f\,(y) \tag{40}$$

$$K = \frac{1.486}{n} AR^{2/3} = \text{conveyance}$$

Equation (40) reveals that for a given depth "y," there is a value of the conveyance "K." When the value of "$Q/\sqrt{S}$" is equal to this "K" value, the corresponding "y" value will be its normal depth for the discharge "Q" running in the conduit with the slope "S."

Again from the condition of critical flow it is defined that

$$Q^2T = gA^3$$

or $$Q = \sqrt{gA^3/T} = A\sqrt{A/T}\cdot\sqrt{g}$$

$$Q = Z\sqrt{g} \tag{41}$$

where $Z = A\sqrt{A/T}$ is called section factor.

Since "Z" is the function of the flow depth "y" and "g" is a constant, from the right side of equation (41), there is a given value of "y," there will be a value of "$Z\sqrt{g}$." When the value of the discharge "Q" is equal to this "$Z\sqrt{g}$" value, the corresponding "y" value will be its critical depth.

By the above discussion, if a table can be constructed for the values of "K" and "$Z\sqrt{g}$" with respect to the various values of "y," it will have the advantages.

(1) When the discharge "Q" and the slope "S" are known, the value of "$Q/\sqrt{S}$" may be easily computed. When this "$Q/\sqrt{S}$" value is found under the column "K" in this table, the corresponding value of "y" will be its normal depth.

(2) When the value of discharge "Q" is found under the column "Z $\sqrt{g}$" in this table, the corresponding value of "y" will be its critical depth.

For this research, the triangular conduit was made of lucite plate with the dimensions as described before. The coefficient of roughness n = 0.009 was used (4). By the geometry of the section of the conduit as shown in Figure 14, a table was worked out using an IBM 1620 computer as shown in Table IV in the Appendix B. In this table, the depth "y" is in inches and

$$T = \frac{1}{12} \left(\frac{B}{y_o}\right) (y_o - y) = \frac{1}{12} \left(\frac{3.65}{6.75}\right) (6.75 - y) \qquad \text{ft}$$

$$A = \frac{1}{12} \left(\frac{1}{2}\right)\left(\frac{3.65}{12} + T\right) \qquad \text{ft}^2$$

$$p_w = \frac{1}{12} \left(3.65 + \frac{2y}{\sin 75°}\right) \qquad \text{ft}$$

$$R = A/p_w \qquad \text{ft}$$

$$Z = A \sqrt{A/T} \qquad \text{ft}^{5/2}$$

$$Q = Z \sqrt{g} = A \sqrt{A/T} \sqrt{g} \qquad \text{cfs}$$

$$Q/\sqrt{S} = K = \frac{1.486}{0.009} AR^{2/3} \qquad \text{cfs}$$

Limitations of This Research

Since it was observed that there were cross waves which were caused by the transition as discussed in Chapter III, the longitudinal standing waves might be influenced by the cross-waves. There was also no case of parallel flow observed. This was caused by the short length of the triangular conduit. When uniform flow had not yet been developed, the water was drained out by free fall at the end of the conduit.

The Causes for the Wave

Since there were standing waves observed through this research, it can be verified that the flow was steady and non-uniform. The following analysis compares with that in Chapter IV.

(1) Hydraulic jump and undular hydraulic jump or hydraulic drop.

In fulfilling the condition of hydraulic jump, the depth of the incoming flow must be less than the critical depth, the Froude number of the incoming flow must be greater than unity and between 1 and 1.7 for undular hydraulic jump formation. However, from Table II and Table III, there was no case where the depth of the incoming flow was less than the critical depth. Also the Froude numbers of the incoming flow were less than unity in all cases. There was no case of a hydraulic drop.

(2) Flow is unstable, if the following conditions are to be satisfied.

(a) The conditions of $S_o > 4g/C^2$ and $F > 2$.

Since from Table II and Table III, the Froude numbers are less than unity in all the cases, and the waves occurred with various slopes (S_o from 0.001 to 0.0422), so the waves did not belong to this case.

(b) The Vedernikov number is greater than unity.

From Chapter III, Vedernikov number $V_N = \frac{2}{3} F \left(1 - R \frac{dp_w}{dA}\right)$ where $\frac{dp_w}{dA}$ may be changed to

$$\frac{dp_w}{dy} \cdot \frac{dy}{dA} = \frac{dp_w}{dy} \cdot \frac{1}{\frac{dA}{dy}}$$

From the geometry of the section of the triangular conduit as shown in Figure 14.

$$p_w = \frac{3.65}{12} + \frac{2y}{\sin 75°} = 0.3042 + \frac{2y}{0.96593}$$

$$= 0.3042 + 2.0705\ y$$

$$\frac{dp_w}{dy} = 2.0705$$

$$A = \frac{1}{2}\left(\frac{6.75}{12}\right)\left(\frac{3.65}{12}\right) - \frac{1}{2}\left(\frac{6.75}{12} - y\right)\left[2\left(\frac{6.75}{12} - y\right)/\tan 75°\right]$$

$$= 0.0856 - \frac{1}{3.7321}(0.5625 - y)^2$$

$$= 0.0856 - 0.2679\,(0.5625 - y)^2$$

$$\frac{dA}{dy} = +\,2\,(0.2679)(0.5625 - y)$$

$$= 0.3014 - 0.5358\ y$$

Then $$\frac{dp_w}{dA} = \frac{2.0705}{0.3014 - 0.5358\ y}$$

At the point of the first trough,

y = 5.85 inches = 0.4875 ft.

R = 0.0640 ft. (from Table IV)

$$F = \frac{V}{\sqrt{gD_m}} = \frac{Q}{A\sqrt{gD_m}} = \frac{Q}{A\sqrt{A/T}\ \sqrt{g}}$$

$$= \frac{Q}{Z\sqrt{g}} = \frac{Q}{0.686} \qquad \text{(from Table IV)}$$

When $Q = 0.53$ cfs is used (Max. value from Table II and III)

$$F = \frac{0.53}{0.686} = 0.7726$$

$$\frac{dp_w}{dA} = \frac{2.0705}{0.3014 - 0.5358\ (0.4875)}$$

$$= \frac{2.0705}{0.3014 - 0.2612} = 51.5050$$

Therefore the Vedernikov number

$$V_N = \frac{2}{3} F \left(1 - R \frac{dp_w}{dA}\right)$$

$$V_N = \frac{2}{3} (0.7726) \left[1 - (0.064)(51.505) \right]$$

$$V_N = \frac{2}{3} (0.7726)(1 - 3.2963) < 1$$

This tells us that the Vedernikov number is less than unity even if the max. Froude number is taken, so the waves were not of this kind of unstable flow.

(c) When $S_o > 0.03$, $R_N < 420$; $F > 2$ for roll waves occurring, and

$$0.02 < S_o < 0.03, \quad 1200 < R_N < 4000; \quad F > 2$$

for slug flow occurring.

In this research, there were no roll waves observed, even when the slope was as large as 0.0422. There were waves observed, even when the slope was as small as 0.001. The greatest Froude number was $F_g = 0.7726$. The smallest Reynold's number, $(R_N)_S$ for the lowest discharge was

$$(R_N)_S = \frac{VR}{\nu} = \frac{Q}{A}\frac{R}{\nu}$$

Q = 0.211 cfs (lowest discharge from Table II and III)

R = 0.064 ft. (at first trough from Table IV)

A = 0.074 ft^2 (at first trough from Table IV)

ν = 1.05 x 10^{-5} ft^2/sec (at 70°F. temp.)

$$(R_N)_S = \frac{0.211}{0.084}\,\frac{(0.064)(100000)}{1.05}$$

$$= \frac{(2.51)(6400)}{1.05} = 15{,}300$$

As a summary from the above, the comparison between the criteria and the observations are as follows:

(i)

Mayer's research (15)	This research
$S_o > 0.03$	$S_o = 0.0422$
$R_N < 420$	$(R_N)_S = 15{,}300$
$F > 2$	$F_g = 0.7726$
Condition for roll waves occurring	No roll waves observed

(ii)

Mayer's research (15)	This research
$0.02 < S_o < 0.03$	$S_o = 0.001 \rightarrow 0.0422$
$1200 < R_N < 4000$	$(R_N)_S = 15{,}300$
$F > 2$	$F_g = 0.7726$
Condition for slug flow occurring	Stationary waves observed

So it can be stated that it was not of this kind of unstable flow.

(3) Unbalance between the resistance and gravity forces.

This unbalanced condition usually refers to the flow at a free entrance. In this research, the entrance was enforced by the transition within a short distance. The unbalanced condition could occur. However, by the effect of the transition in three dimensions and the inclination of the side walls of the triangular conduit, there might be some additional effects on the flow. It can be said that there existed unbalanced conditions but these were not completely the same as ordinary cases.

(4) The sudden transition introduced.

As was discussed in Chapter III, when supercritical flow is introduced through a contraction with symmetrical converging walls, cross waves will appear. In this research, cross waves and longitudinal waves were observed, even in the cases of subcritical flow state (except for very mild slopes with very low discharges where the cross waves were not seen as mentioned earlier in this chapter). For Ippen's (8) observations, the side walls of the transition and the conduit were vertical. In this research, they were inclined. The transition then became three dimensional. This could be one of the factors causing waves.

(5) The curvature of the flow.

In this research, a concave water surface between the end of the transition and the beginning of the waves was observed in every case. For Boussinesq's derivation for curvature of flow, the rectangular section was used. For this research, it could be that the curvature of flow is one of the factors for longitudinal waves.

The Explanation by the Hypothesis of the Accelerated Flow

From the above discussion, the possible cause for waves found in this research may be found by the effects of

(i) the unbalanced condition between the resistance and gravity forces,

(ii) the transition condition

(iii) the curvature of the flow, and

(iv) some other uncertain factors which have not yet been realized.

As they are combined together, their interactions would make this problem more and more complex. The wave surface is impossible to solve by simple mathematical methods. Furthermore, the one dimensional assumption used in ordinary open channel analysis might not be adequate in covering the phenomena of the flow in this research because the transition was three dimensional. The cross-waves resulted from motion in the Z-direction (perpendicular to the axis of the conduit). The longitudinal vertical waves may be influenced by the inclined side walls of the triangular conduit to affect the motion in the Y-direction (vertical direction). If the influence by the cross-waves was considered being less important and could be neglected, the flow in the conduit was at least two dimensional. The author could not derive equations to explain the reason of the longitudinal standing waves. In explaining the effects of the transition and the concaved curvature of the flow pattern, in this research, it can be said that the flow was definitely accelerated. It looked something like the case where flow passes underneath a part open inclined or tainter gate. Under the gate, the channel section decreases gradually as a transition. After the gate the stream lines of the flow net vary from concave at the surface to horizontal lines at the bottom. From the flow net, this accelerated flow can be realized clearly. It will gradually approach uniform flow after some distance. In other words, the acceleration force is gradually reduced by the resistance of the boundary friction. At last it diminishes to zero and only the gravitational force of the flow body exists. Uniform flow will be expected, as the gravitational force becomes equal to the resistance. If the conduit is not long enough, uniform flow will never be expected. In other words the flow will be accelerated throughout. Because of the fact that the flow was accelerated not only by the gravity but by the additional effects of the transition and the curvature of the flow, the flow rate could be expected to be higher than that of its normal condition. This is the reason, in this research, that each of the observed discharges in Table II and Table III was higher than that of its normal flow condition. As an example of actual flow from Table III.

$$S_o = 0.001, \quad Q = 0.223 \text{ cfs}$$

$$\frac{Q}{\sqrt{S_o}} = \frac{0.223}{0.03163} = 7.05 = \text{conveyance}$$

$$S_o = 0.0422, \qquad Q = 0.530 \text{ cfs}$$

$$\frac{Q}{\sqrt{S_o}} = \frac{0.530}{0.20543} = 2.58 = \text{conveyance}$$

But from Table IV, Appendix B, under the last column it shows that the maximum value of conveyance is 2.22635. It is seen that this conduit could carry a discharge higher than its maximum allowable capacity with uniform flow and at the same time the open-channel flow characteristics can still be kept. This is one support of the hypothesis of accelerated flow for the purpose of explanation. Figure 27 and Figure 28 show that the water depths before the transition were higher than the conduit, but the flow in the conduit was still part-full.

When the water was flowing in the conduit with a greater slope, the gravitational force and the accelerated flow by the transition were so large that the friction resistance was not enough to balance them within the conduit length. The flow accelerated throughout the entire length of the conduit. This is the reason that there were no waves observed for a comparatively high discharge in the conduit with a greater slope. For a small slope the acceleration forces were relatively low. The flow might be easily decelerated. After decelerating, the flow would rise in depth. This is the reason that there were waves observed for a lower discharge under a small slope. From Figure 18, it shows that waves were observed for

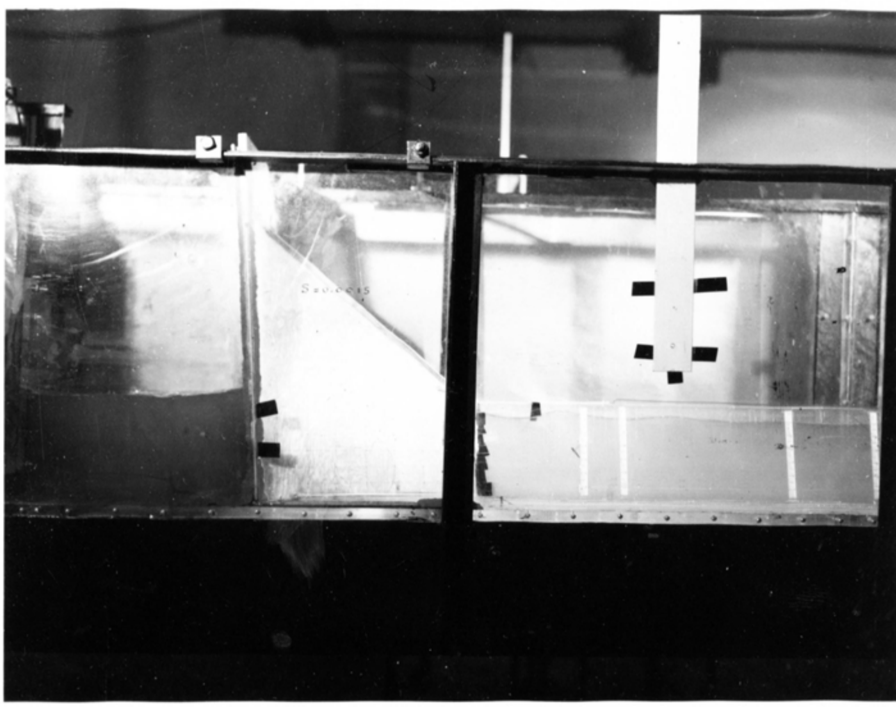


Fig. 27. Water Depth Before and After the Transition at $S_o = 0.0015$

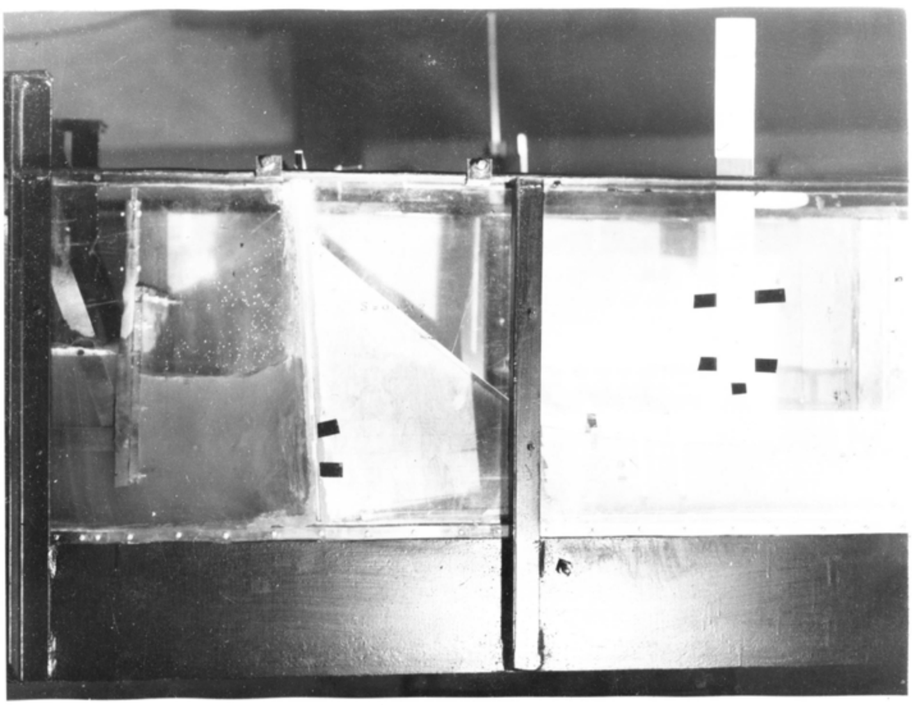


Fig. 28. Water Depth Before and After the Transition at $S_o = 0.042$

$S_o = 0.007, \quad Q = 0.098$ cfs

From Figure 26, it shows that no waves were observed for

$S_o = 0.032, \quad Q = 0.307$ cfs

The occurring of the waves may be explained as follows:

(1) For greater slope

As discussed previously, the acceleration forces were greater than the resistance, the flow was accelerated and no waves occurred. However, when the discharge increased, the conveyance of the section increased, too. As a result, the friction resistance was increased with increasing in wetted perimeter of this section. Moreover, it is known from dynamics that the higher the velocity the greater the resistance will be. Consequently, when the discharge increased up to some amount, the friction resistance would be able to decelerate the flow. At that point, the velocity was reduced to such a degree that the magnitude of velocity before this point was larger. From the energy equation

$$p_1 + \frac{\rho V_1^2}{2} = p_2 + \frac{\rho V_2^2}{2}$$

$$p_2 = p_1 + \frac{\rho}{2}(V_1^2 - V_2^2) \tag{42}$$

In the above equation, because $V_2 < V_1$, so $p_2 > p_1$, the water rose. The rising height could not develop to the maximum amount of p_2/γ because of losses. After the rising, the gravitational force increased, the friction decreased due to the decrease in velocity and another curvature of flow was formed. Therefore, the flow was accelerated again. By this process, a series of waves was formed. The wave heights were lower, one after another, because of frictional losses.

(2) For smaller slope.

Because the gravitational force was comparatively small, even at lower discharges, the first wave could be formed. By the same process as above, a series of waves was formed.

When flow is accelerated, its unstability is commonly accepted.

The Relationships Between the Discharge and the Slope for the Maximum Condition of Open-Channel Flow

When the discharge increased, the waves rose higher. After the first wave rose to touch the top of the conduit, the following waves rose gradually. Finally, the open-channel flow condition changed to pipe flow with air bubbles contained. One object of this research was to find out the relationship between the discharge and the slope at the maximum condition of open-channel flow. From Table II and Table III, a diagram of y_c/y_o vs. S_o is plotted as shown in Figure 29, where y_o = 6.75 inches was the total depth of the triangular conduit. The values of the critical depths "y_c" corresponding to individual discharges are obtained by finding the desired "Q" value from column 8 then reading the corresponding "y" value from the first column of Table IV in Appendix B.

The curve plotted as a dotted line in Figure 29 is the theoretical curve such that the normal depth "y_n" is taken as the same as the full depth "y_o" for the triangular conduit. This is the conditon of full gravitational flow. The ordinates of this curve are as shown in Table V in which the values under the column "Q" are obtained by multiplying 2.12258 (the value of $K = Q/\sqrt{S}$ for water depth equals to 6.75 inches = y_o from Table IV, Appendix B) with the individual corresponding values of "S_o" and the values under the column "y_c" are read from column 1 of Table IV by finding the corresponding desired "Q" value from column 8 of Table IV, Appendix B.

By studying Figure 29, both the observed and theoretical curves show that in the region where the slope "S_o" is greater than "0.01," the trace of either curve is very close to a straight line. In the region of "$S_o < 0.01$" both are curved lines. The theoretical curve is not shown. The equations of the curves for the portion $S_o > 0.01$ can be determined to be approximately

$$y_r = y_c/y_o = 0.3148 \log_{10} \left(\frac{S_o}{0.01}\right) + 0.5750$$ ....for the observed curve

$$y_r = y_c/y_o = 0.4277 \log_{10} \left(\frac{S_o}{0.01}\right) + 0.4625$$ ....for the theoretical curve

From these two equations, it can be said that the rate of increasing discharge with an increasing slope followed a regular rule. In other words, the acceleration in the flow was a control factor with $S_o > 0.01$. This supports the hypothesis of the accelerated flow in this research as discussed previously in this chapter. The observed and theoretical curves are not parallel to each other. The former was

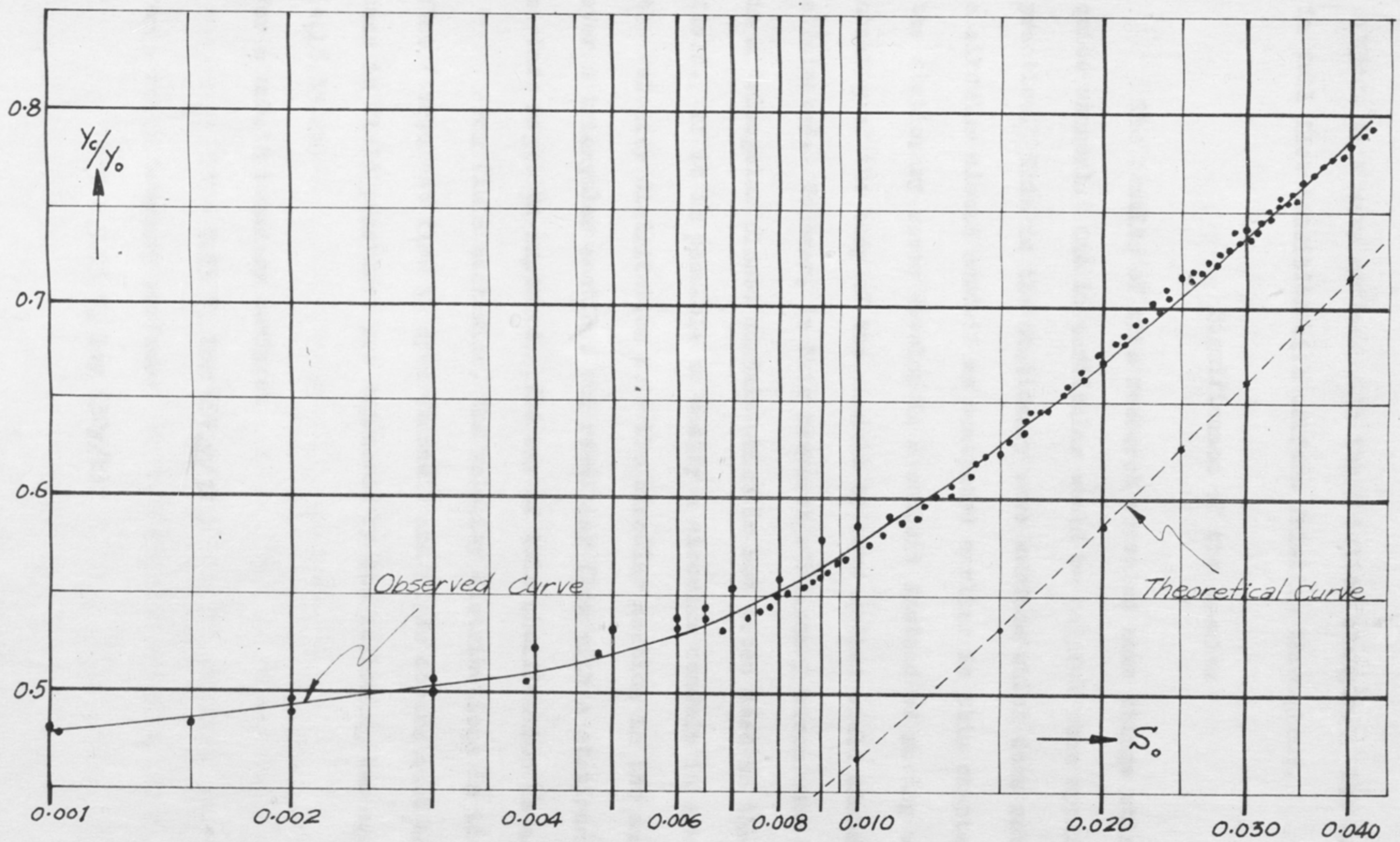


Fig. 29. y_c/y_o vs. S_o Curves for the Maximum Condition of Open-Channel Flow and for the Gravitational Full Flow in the Triangular Conduit

subject to a wave surface with the friction changing. The latter was in full flow condition with uniform friction throughout.

Significance of the Results

The results of this research revealed some things which appeared quite unusual. One in particular would be helpful when applied to field practice. This is the stationary wave surface which does not occur in a circular closed conduit as mentioned earlier in this chapter. When the stationary waves develop in a conduit instead of moving waves, the shaking of the body of the conduit by wave action would almost be eliminated. However, in this research stationary waves were observed in a triangular closed conduit which is not often used in the engineering field. If it is possible to modify a circular conduit in a way so that the velocity distribution over the circular section is the same as that over a triangular section, the resulting flow with a stationary wave surface might be expected. The way of this modification is as follows:

From fluid mechanics, the velocity distributions in turbulent flow (turbulent flow in open channels and pipes occurs most commonly case in field practice) are expressed by the following two equations: (4,18,19,21)

For a smooth boundary surface:

$$V = 5.75\, V_* \log (9V_* y/\nu) \qquad (43)$$

For a rough boundary surface:

$$V = 5.75\, V_* \log (30y/k) \qquad (44)$$

Where y = distance from the boundary at which the velocity is to be evaluated

V = velocity distribution in turbulent flow

$V_* = \sqrt{\tau_o/\rho}$ = shear velocity

ν = kinematic viscosity

k = roughness height

τ_o = shear force along boundary surface or boundary friction

ρ = density

In field practice, usually the boundary surface is rough and equation (44) is applied. By examining equation (44), we find that the velocity distribution over a section depends on the distance, "y," from the boundary and the roughness of the boundary ("k" and "τ_o" are the function of the boundary roughness). If two different shapes of cross-section, say circular and triangular, have the same value of boundary roughness, the velocity distributions between them will differ with distances from the boundary. The farther this distance the higher the velocity is. Because the triangular section has its two sides converging much faster than the circular section, the maximum point velocity occurring in a triangular section will usually be lower than in a circular one when full depth is taken as a reference.

Again lets go back to equation (44); if we carefully adjust the roughness for the circular section so that the computed maximum velocity is at the same level as that for a triangular section, there would be a stationary wave surface of flow expected in this modified circular section.

The above discussion may be applicable, but a very precise laboratory investigation, using a modified circular conduit, is necessary.

CHAPTER VI

SUMMARY AND CONCLUSIONS

(A) In this research, the phenomena of flow were complicated by the effects of the cross waves, longitudinal waves, curvature of flow, transition, triangular section of the conduit, the short length of the conduit, and undoubtedly others.

(B) The interactions between these performances would be uncertain. The flow condition would result in three dimensions.

(C) As the stationary longitudinal waves were observed, it was quite unusual. It can be said that the occurrence of the stationary waves in this research was a special case.

(D) So far as the stationary wave surface of flow is concerned, it might be said that it was some special kind of surface profile of the flow. However, owing to the complication of this flow phenomena, this special surface profile could not be explained by simple mathematical methods.

(E) The fact that the flow was accelerated by the effects of the transition and the curvature of flow in this research, it can be concluded this was the main cause of the stationary wave surface formation.

(F) The curve of y_c/y_o vs. S_o for the maximum condition of open channel flow kept in this triangular conduit shows that the discharge is higher than its maximum gravity flow capacity for the same slope.

(G) The curves of y_c/y_o vs. S_o in Figure 29 show that when S_o 0.01, they follow the equations

$$y_r = y_c/y_o = 0.3148 \log_{10} \left(\frac{S_o}{0.01}\right) + 0.5750 \text{ .... for the observed curve}$$

$$y_r = y_c/y_o = 0.4277 \log_{10} \left(\frac{S_o}{0.01}\right) + 0.4625 \text{ .... for the theoretical curve}$$

(H) The observed curve in Figure 29 gives support to the hypothesis of accelerated flow for this research.

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APPENDICES

APPENDIX A

NOTATIONS

A	Flow area
A_o	Full section area of closed conduit
B	Bottom width of channel
C	Coefficient of Chezy's formula
c	Celerity
D_m	Hydraulic depth or mean depth
F	Froude number
g	Gravitational acceleration
K	Conveyance
n	Manning's roughness coefficient
P	Total pressure
p	Pressure intensity
P_w	Wetted perimeter
Q	Total discharge
q	Unit discharge
R	Hydraulic radius
R_N	Reynold's number
S	Slope
S_o	Bottom slope = $\tan\theta$, θ is the angle of the bottom making with the horizontal plane
S_f	Friction slope
T	Water surface width in conduit or in channel

T	Wave period
V	Average velocity
V_w	Wave absolute velocity
V_N	Vedernikov number
y	Depth
y_o	Total depth of closed conduit
y_c	Critical depth
y_n	Normal depth
Z	Section factor
ρ	Density
γ	Specific weight
ν	Kinematic viscosity
μ	Dynamic viscosity
λ	Wave length
η	Wave local height above original free surface

APPENDIX B.

TABLE IV. THE HYDRAULIC ELEMENTS FOR THE ISOSCELES TRIANGULAR SECTION OF 30 DEGREES VERTEX ANGLE AND 6.75 INCHES IN HEIGHT.

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	($FT.^2$)	($FT.^{5/2}$)	(FT.)	(FT.)	($FT.^{2/3}$)	(CFS)	(CFS)
.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
.01000	.30370	.00025	.00000	.30592	.00082	.00881	.00004	.00037
.02000	.30325	.00050	.00002	.30765	.00164	.01393	.00011	.00116
.03000	.30280	.00075	.00003	.30937	.00245	.01818	.00021	.00227
.04000	.30235	.00101	.00005	.31110	.00324	.02193	.00033	.00366
.05000	.30190	.00126	.00008	.31282	.00403	.02535	.00046	.00528
.06000	.30145	.00151	.00010	.31455	.00481	.02850	.00060	.00712
.07000	.30100	.00176	.00013	.31627	.00558	.03146	.00076	.00917
.08000	.30055	.00201	.00016	.31800	.00633	.03425	.00093	.01140
.09000	.30009	.00226	.00019	.31972	.00708	.03689	.00111	.01380
.10000	.29964	.00251	.00023	.32145	.00782	.03942	.00130	.01637
.11000	.29919	.00276	.00026	.32318	.00855	.04183	.00150	.01910
.12000	.29874	.00301	.00030	.32490	.00927	.04415	.00171	.02197
.13000	.29829	.00326	.00034	.32663	.00999	.04638	.00193	.02499
.14000	.29784	.00351	.00038	.32835	.01069	.04854	.00216	.02814
.15000	.29739	.00375	.00042	.33008	.01139	.05062	.00239	.03142
.16000	.29694	.00400	.00046	.33180	.01207	.05264	.00264	.03483
.17000	.29649	.00425	.00050	.33353	.01275	.05459	.00289	.03835
.18000	.29604	.00450	.00055	.33525	.01342	.05649	.00314	.04199
.19000	.29559	.00474	.00060	.33698	.01409	.05833	.00341	.04573

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	($FT.^2$)	($FT.^{5/2}$)	(FT.)	(FT.)	($FT.^{2/3}$)	(CFS)	(CFS)
.20000	.29514	.00499	.00064	.33871	.01474	.06013	.00368	.04958
.21000	.29469	.00524	.00069	.34043	.01539	.06187	.00396	.05354
.22000	.29424	.00548	.00074	.34216	.01603	.06358	.00424	.05758
.23000	.29379	.00573	.00080	.34388	.01666	.06524	.00453	.06173
.24000	.29334	.00597	.00085	.34561	.01728	.06686	.00483	.06596
.25000	.29289	.00621	.00090	.34733	.01790	.06844	.00513	.07028
.26000	.29243	.00646	.00096	.34906	.01851	.06999	.00544	.07469
.27000	.29198	.00670	.00101	.35078	.01912	.07150	.00576	.07918
.28000	.29153	.00695	.00107	.35251	.01971	.07298	.00608	.08375
.29000	.29108	.00719	.00113	.35423	.02030	.07442	.00641	.08839
.30000	.29063	.00743	.00118	.35596	.02088	.07584	.00674	.09311
.31000	.29018	.00767	.00124	.35769	.02146	.07723	.00708	.09790
.32000	.28973	.00791	.00130	.35941	.02203	.07859	.00742	.10276
.33000	.28928	.00816	.00137	.36114	.02259	.07992	.00777	.10769
.34000	.28883	.00840	.00143	.36286	.02315	.08123	.00812	.11268
.35000	.28838	.00864	.00149	.36459	.02370	.08251	.00848	.11773
.36000	.28793	.00888	.00155	.36631	.02424	.08377	.00884	.12285
.37000	.28748	.00912	.00162	.36804	.02478	.08500	.00921	.12802
.38000	.28703	.00936	.00169	.36976	.02531	.08621	.00958	.13326
.39000	.28658	.00960	.00175	.37149	.02584	.08740	.00996	.13855

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_W	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	(FT.^{2})	(FT.$^{5/2}$)	(FT.)	(FT.)	(FT.$^{2/3}$)	(CFS)	(CFS)
.40000	.28613	.00983	.00182	.37322	.02636	.08857	.01034	.14389
.41000	.28568	.01007	.00189	.37494	.02687	.08972	.01073	.14928
.42000	.28522	.01031	.00196	.37667	.02738	.09085	.01112	.15473
.43000	.28477	.01055	.00203	.37839	.02788	.09196	.01151	.16022
.44000	.28432	.01078	.00210	.38012	.02838	.09305	.01191	.16577
.45000	.28387	.01102	.00217	.38184	.02887	.09412	.01232	.17136
.46000	.28342	.01126	.00224	.38357	.02936	.09517	.01273	.17699
.47000	.28297	.01149	.00231	.38529	.02984	.09621	.01314	.18267
.48000	.28252	.01173	.00239	.38702	.03031	.09723	.01356	.18839
.49000	.28207	.01196	.00246	.38874	.03079	.09823	.01398	.19415
.50000	.28162	.01220	.00254	.39047	.03125	.09922	.01440	.19995
.51000	.28117	.01243	.00261	.39220	.03171	.10019	.01483	.20579
.52000	.28072	.01267	.00269	.39392	.03217	.10115	.01527	.21166
.53000	.28027	.01290	.00276	.39565	.03262	.10209	.01570	.21757
.54000	.27982	.01314	.00284	.39737	.03306	.10302	.01614	.22352
.55000	.27937	.01337	.00292	.39910	.03350	.10393	.01659	.22950
.56000	.27892	.01360	.00300	.40082	.03394	.10483	.01704	.23552
.57000	.27847	.01383	.00308	.40255	.03437	.10572	.01749	.24156
.58000	.27802	.01407	.00316	.40427	.03480	.10659	.01795	.24764
.59000	.27756	.01430	.00324	.40600	.03522	.10745	.01841	.25375

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	(FT.^{2})	(FT.$^{5/2}$)	(FT.)	(FT.)	(FT.$^{2/3}$)	(CFS)	(CFS)
.60000	.27711	.01453	.00332	.40773	.03564	.10830	.01887	.25988
.61000	.27666	.01476	.00341	.40945	.03605	.10914	.01934	.26605
.62000	.27621	.01499	.00349	.41118	.03646	.10996	.01981	.27224
.63000	.27576	.01522	.00357	.41290	.03687	.11077	.02028	.27846
.64000	.27531	.01545	.00366	.41463	.03727	.11157	.02076	.28470
.65000	.27486	.01568	.00374	.41635	.03766	.11236	.02124	.29097
.66000	.27441	.01591	.00383	.41808	.03805	.11314	.02172	.29726
.67000	.27396	.01614	.00391	.41980	.03844	.11391	.02221	.30357
.68000	.27351	.01636	.00400	.42153	.03883	.11467	.02270	.30991
.69000	.27306	.01659	.00409	.42325	.03921	.11541	.02320	.31627
.70000	.27261	.01682	.00417	.42498	.03958	.11615	.02370	.32264
.71000	.27216	.01705	.00426	.42671	.03995	.11687	.02420	.32904
.72000	.27171	.01727	.00435	.42843	.04032	.11759	.02470	.33546
.73000	.27126	.01750	.00444	.43016	.04069	.11830	.02521	.34190
.74000	.27081	.01772	.00453	.43188	.04105	.11900	.02572	.34835
.75000	.27036	.01795	.00462	.43361	.04140	.11968	.02624	.35482
.76000	.26990	.01818	.00471	.43533	.04176	.12036	.02675	.36131
.77000	.26945	.01840	.00481	.43706	.04211	.12103	.02727	.36781
.78000	.26900	.01862	.00490	.43878	.04245	.12170	.02780	.37433
.79000	.26855	.01885	.00499	.44051	.04279	.12235	.02832	.38087

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_W	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	(FT.^{2})	(FT.$^{5/2}$)	(FT.)	(FT.)	(FT.$^{2/3}$)	(CFS)	(CFS)
.80000	.26810	.01907	.00508	.44224	.04313	.12299	.02885	.38742
.81000	.26765	.01930	.00518	.44396	.04347	.12363	.02939	.39398
.82000	.26720	.01952	.00527	.44569	.04380	.12426	.02992	.40055
.83000	.26675	.01974	.00537	.44741	.04413	.12488	.03046	.40714
.84000	.26630	.01996	.00546	.44914	.04445	.12549	.03100	.41374
.85000	.26585	.02018	.00556	.45086	.04477	.12610	.03155	.42035
.86000	.26540	.02041	.00566	.45259	.04509	.12669	.03209	.42697
.87000	.26495	.02063	.00575	.45431	.04541	.12728	.03264	.43360
.88000	.26450	.02085	.00585	.45604	.04572	.12786	.03320	.44024
.89000	.26405	.02107	.00595	.45777	.04603	.12844	.03375	.44690
.90000	.26360	.02129	.00605	.45949	.04633	.12901	.03431	.45355
.91000	.26315	.02151	.00615	.46122	.04664	.12957	.03488	.46022
.92000	.26269	.02173	.00625	.46294	.04694	.13012	.03544	.46690
.93000	.26224	.02194	.00635	.46467	.04723	.13067	.03601	.47358
.94000	.26179	.02216	.00645	.46639	.04753	.13121	.03658	.48027
.95000	.26134	.02238	.00655	.46812	.04782	.13174	.03715	.48697
.96000	.26089	.02260	.00665	.46984	.04810	.13227	.03773	.49367
.97000	.26044	.02282	.00675	.47157	.04839	.13279	.03830	.50038
.98000	.25999	.02303	.00685	.47329	.04867	.13331	.03889	.50710
.99000	.25954	.02325	.00696	.47502	.04895	.13382	.03947	.51381

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	($FT.^2$)	($FT.^{5/2}$)	(FT.)	(FT.)	($FT.^{2/3}$)	(CFS)	(CFS)
1.00000	.25909	.02347	.00706	.47675	.04923	.13432	.04006	.52054
1.01000	.25864	.02368	.00716	.47847	.04950	.13482	.04064	.52727
1.02000	.25819	.02390	.00727	.48020	.04977	.13531	.04124	.53400
1.03000	.25774	.02411	.00737	.48192	.05004	.13579	.04183	.54073
1.04000	.25729	.02433	.00748	.48365	.05030	.13627	.04243	.54747
1.05000	.25684	.02454	.00758	.48537	.05057	.13675	.04303	.55421
1.06000	.25639	.02475	.00769	.48710	.05082	.13721	.04363	.56095
1.07000	.25594	.02497	.00780	.48882	.05108	.13768	.04423	.56770
1.08000	.25549	.02518	.00790	.49055	.05134	.13813	.04484	.57444
1.09000	.25503	.02539	.00801	.49228	.05159	.13859	.04545	.58119
1.10000	.25458	.02561	.00812	.49400	.05184	.13903	.04606	.58794
1.11000	.25413	.02582	.00823	.49573	.05209	.13947	.04668	.59469
1.12000	.25368	.02603	.00834	.49745	.05233	.13991	.04729	.60144
1.13000	.25323	.02624	.00844	.49918	.05257	.14034	.04791	.60819
1.14000	.25278	.02645	.00855	.50090	.05281	.14077	.04853	.61494
1.15000	.25233	.02666	.00866	.50263	.05305	.14119	.04916	.62169
1.16000	.25188	.02687	.00877	.50435	.05329	.14161	.04978	.62843
1.17000	.25143	.02708	.00889	.50608	.05352	.14202	.05041	.63518
1.18000	.25098	.02729	.00900	.50780	.05375	.14243	.05105	.64193
1.19000	.25053	.02750	.00911	.50953	.05398	.14283	.05168	.64867

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	($FT.^2$)	($FT.^{5/2}$)	(FT.)	(FT.)	($FT.^{2/3}$)	(CFS)	(CFS)
1.20000	.25008	.02771	.00922	.51126	.05420	.14323	.05232	.65541
1.21000	.24963	.02792	.00933	.51298	.05443	.14362	.05295	.66215
1.22000	.24918	.02813	.00945	.51471	.05465	.14401	.05359	.66889
1.23000	.24873	.02833	.00956	.51643	.05487	.14439	.05424	.67562
1.24000	.24828	.02854	.00967	.51816	.05508	.14477	.05488	.68235
1.25000	.24783	.02875	.00979	.51988	.05530	.14515	.05553	.68908
1.26000	.24737	.02895	.00990	.52161	.05551	.14552	.05618	.69580
1.27000	.24692	.02916	.01002	.52333	.05572	.14589	.05683	.70252
1.28000	.24647	.02936	.01013	.52506	.05593	.14625	.05749	.70924
1.29000	.24602	.02957	.01025	.52679	.05614	.14661	.05814	.71595
1.30000	.24557	.02977	.01037	.52851	.05634	.14697	.05880	.72266
1.31000	.24512	.02998	.01048	.53024	.05654	.14732	.05947	.72936
1.32000	.24467	.03018	.01060	.53196	.05674	.14767	.06013	.73606
1.33000	.24422	.03039	.01072	.53369	.05694	.14801	.06079	.74275
1.34000	.24377	.03059	.01083	.53541	.05714	.14835	.06146	.74944
1.35000	.24332	.03079	.01095	.53714	.05733	.14869	.06213	.75612
1.36000	.24287	.03100	.01107	.53886	.05752	.14902	.06280	.76279
1.37000	.24242	.03120	.01119	.54059	.05771	.14935	.06348	.76946
1.38000	.24197	.03140	.01131	.54231	.05790	.14967	.06416	.77613
1.39000	.24152	.03160	.01143	.54404	.05809	.15000	.06483	.78278

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	($FT.^2$)	($FT.^{5/2}$)	(FT.)	(FT.)	($FT.^{2/3}$)	(CFS)	(CFS)
1.40000	.24107	.03180	.01155	.54577	.05827	.15031	.06552	.78943
1.41000	.24062	.03200	.01167	.54749	.05846	.15063	.06620	.79608
1.42000	.24016	.03220	.01179	.54922	.05864	.15094	.06688	.80271
1.43000	.23971	.03240	.01191	.55094	.05882	.15125	.06757	.80934
1.44000	.23926	.03260	.01203	.55267	.05900	.15155	.06826	.81596
1.45000	.23881	.03280	.01215	.55439	.05917	.15185	.06895	.82258
1.46000	.23836	.03300	.01228	.55612	.05935	.15215	.06965	.82919
1.47000	.23791	.03320	.01240	.55784	.05952	.15244	.07034	.83578
1.48000	.23746	.03340	.01252	.55957	.05969	.15273	.07104	.84237
1.49000	.23701	.03360	.01265	.56130	.05986	.15302	.07174	.84896
1.50000	.23656	.03379	.01277	.56302	.06002	.15331	.07244	.85553
1.51000	.23611	.03399	.01289	.56475	.06019	.15359	.07315	.86210
1.52000	.23566	.03419	.01302	.56647	.06035	.15387	.07385	.86865
1.53000	.23521	.03438	.01314	.56820	.06051	.15414	.07456	.87520
1.54000	.23476	.03458	.01327	.56992	.06068	.15441	.07527	.88174
1.55000	.23431	.03477	.01339	.57165	.06083	.15468	.07598	.88827
1.56000	.23386	.03497	.01352	.57337	.06099	.15495	.07670	.89479
1.57000	.23341	.03516	.01365	.57510	.06115	.15521	.07741	.90130
1.58000	.23296	.03536	.01377	.57683	.06130	.15547	.07813	.90780
1.59000	.23250	.03555	.01390	.57855	.06145	.15573	.07885	.91429

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	($FT.^2$)	($FT.^{5/2}$)	(FT.)	(FT.)	($FT.^{2/3}$)	(CFS)	(CFS)
1.60000	.23205	.03575	.01403	.58028	.06160	.15598	.07957	.92078
1.61000	.23160	.03594	.01415	.58200	.06175	.15624	.08030	.92725
1.62000	.23115	.03613	.01428	.58373	.06190	.15649	.08102	.93371
1.63000	.23070	.03632	.01441	.58545	.06205	.15673	.08175	.94016
1.64000	.23025	.03652	.01454	.58718	.06219	.15698	.08248	.94660
1.65000	.22980	.03671	.01467	.58890	.06234	.15722	.08321	.95303
1.66000	.22935	.03690	.01480	.59063	.06248	.15746	.08394	.95945
1.67000	.22890	.03709	.01493	.59235	.06262	.15769	.08468	.96586
1.68000	.22845	.03728	.01506	.59408	.06276	.15792	.08542	.97226
1.69000	.22800	.03747	.01519	.59581	.06289	.15816	.08616	.97864
1.70000	.22755	.03766	.01532	.59753	.06303	.15838	.08690	.98502
1.71000	.22710	.03785	.01545	.59926	.06316	.15861	.08764	.99138
1.72000	.22665	.03804	.01558	.60098	.06330	.15883	.08839	.99773
1.73000	.22620	.03823	.01571	.60271	.06343	.15905	.08913	1.00408
1.74000	.22575	.03842	.01585	.60443	.06356	.15927	.08988	1.01040
1.75000	.22530	.03860	.01598	.60616	.06369	.15949	.09063	1.01672
1.76000	.22484	.03879	.01611	.60788	.06382	.15970	.09139	1.02303
1.77000	.22439	.03898	.01624	.60961	.06394	.15991	.09214	1.02932
1.78000	.22394	.03917	.01638	.61134	.06407	.16012	.09290	1.03560
1.79000	.22349	.03935	.01651	.61306	.06419	.16032	.09366	1.04187

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	(FT.^{2})	(FT.$^{5/2}$)	(FT.)	(FT.)	(FT.$^{2/3}$)	(CFS)	(CFS)
1.80000	.22304	.03954	.01665	.61479	.06432	.16053	.09442	1.04813
1.81000	.22259	.03972	.01678	.61651	.06444	.16073	.09518	1.05437
1.82000	.22214	.03991	.01691	.61824	.06456	.16093	.09594	1.06061
1.83000	.22169	.04009	.01705	.61996	.06468	.16113	.09671	1.06683
1.84000	.22124	.04028	.01718	.62169	.06479	.16132	.09748	1.07303
1.85000	.22079	.04046	.01732	.62341	.06491	.16151	.09825	1.07923
1.86000	.22034	.04065	.01746	.62514	.06502	.16170	.09902	1.08541
1.87000	.21989	.04083	.01759	.62686	.06514	.16189	.09979	1.09158
1.88000	.21944	.04101	.01773	.62859	.06525	.16208	.10057	1.09773
1.89000	.21899	.04120	.01787	.63032	.06536	.16226	.10134	1.10387
1.90000	.21854	.04138	.01800	.63204	.06547	.16245	.10212	1.11000
1.91000	.21809	.04156	.01814	.63377	.06558	.16263	.10290	1.11612
1.92000	.21763	.04174	.01828	.63549	.06569	.16280	.10368	1.12222
1.93000	.21718	.04192	.01842	.63722	.06579	.16298	.10447	1.12831
1.94000	.21673	.04210	.01856	.63894	.06590	.16315	.10525	1.13438
1.95000	.21628	.04228	.01869	.64067	.06600	.16332	.10604	1.14044
1.96000	.21583	.04246	.01883	.64239	.06611	.16349	.10683	1.14649
1.97000	.21538	.04264	.01897	.64412	.06621	.16366	.10762	1.15252
1.98000	.21493	.04282	.01911	.64585	.06631	.16383	.10841	1.15854
1.99000	.21448	.04300	.01925	.64757	.06641	.16399	.10921	1.16455

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	(FT.^{2})	(FT.$^{5/2}$)	(FT.)	(FT.)	(FT.$^{2/3}$)	(CFS)	(CFS)
2.00000	.21403	.04318	.01939	.64930	.06651	.16415	.11001	1.17054
2.01000	.21358	.04336	.01953	.65102	.06660	.16431	.11080	1.17652
2.02000	.21313	.04354	.01968	.65275	.06670	.16447	.11160	1.18248
2.03000	.21268	.04371	.01982	.65447	.06680	.16463	.11241	1.18843
2.04000	.21223	.04389	.01996	.65620	.06689	.16478	.11321	1.19436
2.05000	.21178	.04407	.02010	.65792	.06698	.16494	.11401	1.20028
2.06000	.21133	.04424	.02024	.65965	.06708	.16509	.11482	1.20619
2.07000	.21088	.04442	.02039	.66137	.06717	.16524	.11563	1.21208
2.08000	.21043	.04460	.02053	.66310	.06726	.16539	.11644	1.21796
2.09000	.20997	.04477	.02067	.66483	.06735	.16553	.11725	1.22382
2.10000	.20952	.04495	.02082	.66655	.06743	.16568	.11807	1.22967
2.11000	.20907	.04512	.02096	.66828	.06752	.16582	.11888	1.23550
2.12000	.20862	.04529	.02110	.67000	.06761	.16596	.11970	1.24131
2.13000	.20817	.04547	.02125	.67173	.06769	.16610	.12052	1.24712
2.14000	.20772	.04564	.02139	.67345	.06777	.16623	.12134	1.25290
2.15000	.20727	.04581	.02154	.67518	.06786	.16637	.12216	1.25868
2.16000	.20682	.04599	.02168	.67690	.06794	.16650	.12299	1.26443
2.17000	.20637	.04616	.02183	.67863	.06802	.16664	.12382	1.27018
2.18000	.20592	.04633	.02198	.68036	.06810	.16677	.12464	1.27590
2.19000	.20547	.04650	.02212	.68208	.06818	.16690	.12547	1.28161

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	($FT.^2$)	($FT.^{5/2}$)	(FT.)	(FT.)	($FT.^{2/3}$)	(CFS)	(CFS)
2.20000	.20502	.04667	.02227	.68381	.06826	.16702	.12630	1.28731
2.21000	.20457	.04684	.02241	.68553	.06833	.16715	.12714	1.29299
2.22000	.20412	.04701	.02256	.68726	.06841	.16727	.12797	1.29866
2.23000	.20367	.04718	.02271	.68898	.06849	.16740	.12881	1.30430
2.24000	.20322	.04735	.02286	.69071	.06856	.16752	.12965	1.30994
2.25000	.20277	.04752	.02301	.69243	.06863	.16764	.13049	1.31556
2.26000	.20231	.04769	.02315	.69416	.06871	.16775	.13133	1.32116
2.27000	.20186	.04786	.02330	.69588	.06878	.16787	.13217	1.32675
2.28000	.20141	.04803	.02345	.69761	.06885	.16799	.13302	1.33232
2.29000	.20096	.04820	.02360	.69934	.06892	.16810	.13387	1.33787
2.30000	.20051	.04836	.02375	.70106	.06899	.16821	.13471	1.34341
2.31000	.20006	.04853	.02390	.70279	.06906	.16832	.13556	1.34894
2.32000	.19961	.04870	.02405	.70451	.06912	.16843	.13642	1.35444
2.33000	.19916	.04886	.02420	.70624	.06919	.16854	.13727	1.35994
2.34000	.19871	.04903	.02435	.70796	.06926	.16865	.13813	1.36541
2.35000	.19826	.04919	.02450	.70969	.06932	.16875	.13898	1.37087
2.36000	.19781	.04936	.02466	.71141	.06938	.16886	.13984	1.37631
2.37000	.19736	.04952	.02481	.71314	.06945	.16896	.14070	1.38174
2.38000	.19691	.04969	.02496	.71487	.06951	.16906	.14157	1.38715
2.39000	.19646	.04985	.02511	.71659	.06957	.16916	.14243	1.39255

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	(FT.^{2})	(FT.$^{5/2}$)	(FT.)	(FT.)	(FT.$^{2/3}$)	(CFS)	(CFS)
2.40000	.19601	.05002	.02526	.71832	.06963	.16926	.14330	1.39793
2.41000	.19556	.05018	.02542	.72004	.06969	.16935	.14416	1.40329
2.42000	.19510	.05034	.02557	.72177	.06975	.16945	.14503	1.40863
2.43000	.19465	.05050	.02572	.72349	.06981	.16954	.14590	1.41396
2.44000	.19420	.05067	.02588	.72522	.06987	.16963	.14678	1.41928
2.45000	.19375	.05083	.02603	.72694	.06992	.16973	.14765	1.42457
2.46000	.19330	.05099	.02619	.72867	.06998	.16982	.14853	1.42985
2.47000	.19285	.05115	.02634	.73040	.07003	.16991	.14940	1.43512
2.48000	.19240	.05131	.02650	.73212	.07009	.16999	.15028	1.44036
2.49000	.19195	.05147	.02665	.73385	.07014	.17008	.15117	1.44559
2.50000	.19150	.05163	.02681	.73557	.07019	.17016	.15205	1.45081
2.51000	.19105	.05179	.02696	.73730	.07024	.17025	.15293	1.45600
2.52000	.19060	.05195	.02712	.73902	.07030	.17033	.15382	1.46118
2.53000	.19015	.05211	.02728	.74075	.07035	.17041	.15471	1.46635
2.54000	.18970	.05227	.02743	.74247	.07040	.17049	.15560	1.47149
2.55000	.18925	.05242	.02759	.74420	.07045	.17057	.15649	1.47662
2.56000	.18880	.05258	.02775	.74592	.07049	.17065	.15738	1.48174
2.57000	.18835	.05274	.02791	.74765	.07054	.17073	.15828	1.48683
2.58000	.18790	.05290	.02806	.74938	.07059	.17080	.15917	1.49191
2.59000	.18744	.05305	.02822	.75110	.07063	.17088	.16007	1.49697

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g} = Q$	$K = Q/\sqrt{S}$
(IN.)	(FT.)	(FT.^{2})	(FT.$^{5/2}$)	(FT.)	(FT.)	(FT.$^{2/3}$)	(CFS)	(CFS)
2.60000	.18699	.05321	.02838	.75283	.07068	.17095	.16097	1.50202
2.61000	.18654	.05336	.02854	.75455	.07072	.17102	.16188	1.50705
2.62000	.18609	.05352	.02870	.75628	.07077	.17109	.16278	1.51206
2.63000	.18564	.05367	.02886	.75800	.07081	.17116	.16368	1.51705
2.64000	.18519	.05383	.02902	.75973	.07085	.17123	.16459	1.52203
2.65000	.18474	.05398	.02918	.76145	.07090	.17130	.16550	1.52699
2.66000	.18429	.05414	.02934	.76318	.07094	.17136	.16641	1.53193
2.67000	.18384	.05429	.02950	.76491	.07098	.17143	.16732	1.53686
2.68000	.18339	.05444	.02966	.76663	.07102	.17149	.16824	1.54177
2.69000	.18294	.05460	.02982	.76836	.07106	.17156	.16915	1.54666
2.70000	.18249	.05475	.02999	.77008	.07109	.17162	.17007	1.55153
2.71000	.18204	.05490	.03015	.77181	.07113	.17168	.17099	1.55639
2.72000	.18159	.05505	.03031	.77353	.07117	.17174	.17191	1.56123
2.73000	.18114	.05520	.03047	.77526	.07121	.17180	.17284	1.56605
2.74000	.18069	.05535	.03064	.77698	.07124	.17186	.17376	1.57086
2.75000	.18024	.05550	.03080	.77871	.07128	.17191	.17469	1.57565
2.76000	.17978	.05565	.03096	.78043	.07131	.17197	.17562	1.58042
2.77000	.17933	.05580	.03113	.78216	.07135	.17202	.17655	1.58517
2.78000	.17888	.05595	.03129	.78389	.07138	.17208	.17748	1.58991
2.79000	.17843	.05610	.03146	.78561	.07141	.17213	.17841	1.59462

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	(FT.^{2})	(FT.$^{5/2}$)	(FT.)	(FT.)	(FT.$^{2/3}$)	(CFS)	(CFS)
2.80000	.17798	.05625	.03162	.78734	.07144	.17218	.17935	1.59933
2.81000	.17753	.05640	.03179	.78906	.07148	.17223	.18028	1.60401
2.82000	.17708	.05655	.03195	.79079	.07151	.17228	.18122	1.60867
2.83000	.17663	.05669	.03212	.79251	.07154	.17233	.18216	1.61332
2.84000	.17618	.05684	.03228	.79424	.07157	.17238	.18311	1.61795
2.85000	.17573	.05699	.03245	.79596	.07160	.17242	.18405	1.62257
2.86000	.17528	.05713	.03262	.79769	.07162	.17247	.18500	1.62716
2.87000	.17483	.05728	.03279	.79942	.07165	.17252	.18595	1.63174
2.88000	.17438	.05742	.03295	.80114	.07168	.17256	.18690	1.63630
2.89000	.17393	.05757	.03312	.80287	.07171	.17260	.18785	1.64085
2.90000	.17348	.05771	.03329	.80459	.07173	.17264	.18880	1.64537
2.91000	.17303	.05786	.03346	.80632	.07176	.17269	.18976	1.64988
2.92000	.17257	.05800	.03363	.80804	.07178	.17273	.19072	1.65437
2.93000	.17212	.05815	.03380	.80977	.07181	.17276	.19167	1.65884
2.94000	.17167	.05829	.03396	.81149	.07183	.17280	.19264	1.66330
2.95000	.17122	.05843	.03413	.81322	.07185	.17284	.19360	1.66774
2.96000	.17077	.05858	.03430	.81494	.07188	.17288	.19456	1.67216
2.97000	.17032	.05872	.03448	.81667	.07190	.17291	.19553	1.67656
2.98000	.16987	.05886	.03465	.81840	.07192	.17295	.19650	1.68094
2.99000	.16942	.05900	.03482	.82012	.07194	.17298	.19747	1.68531

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	($FT.^2$)	($FT.^{5/2}$)	(FT.)	(FT.)	($FT.^{2/3}$)	(CFS)	(CFS)
3.00000	.16897	.05914	.03499	.82185	.07196	.17301	.19844	1.68966
3.01000	.16852	.05928	.03516	.82357	.07198	.17305	.19942	1.69399
3.02000	.16807	.05942	.03533	.82530	.07200	.17308	.20039	1.69830
3.03000	.16762	.05956	.03550	.82702	.07202	.17311	.20137	1.70260
3.04000	.16717	.05970	.03568	.82875	.07204	.17314	.20235	1.70688
3.05000	.16672	.05984	.03585	.83047	.07206	.17316	.20333	1.71114
3.06000	.16627	.05998	.03602	.83220	.07207	.17319	.20432	1.71538
3.07000	.16582	.06012	.03620	.83393	.07209	.17322	.20530	1.71961
3.08000	.16537	.06026	.03637	.83565	.07211	.17325	.20629	1.72381
3.09000	.16491	.06039	.03655	.83738	.07212	.17327	.20728	1.72800
3.10000	.16446	.06053	.03672	.83910	.07214	.17330	.20827	1.73217
3.11000	.16401	.06067	.03690	.84083	.07215	.17332	.20927	1.73633
3.12000	.16356	.06080	.03707	.84255	.07217	.17334	.21026	1.74046
3.13000	.16311	.06094	.03725	.84428	.07218	.17336	.21126	1.74458
3.14000	.16266	.06108	.03742	.84600	.07219	.17339	.21226	1.74868
3.15000	.16221	.06121	.03760	.84773	.07221	.17341	.21326	1.75276
3.16000	.16176	.06135	.03778	.84946	.07222	.17343	.21426	1.75683
3.17000	.16131	.06148	.03796	.85118	.07223	.17344	.21527	1.76087
3.18000	.16086	.06162	.03813	.85291	.07224	.17346	.21628	1.76490
3.19000	.16041	.06175	.03831	.85463	.07225	.17348	.21729	1.76891

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	($FT.^2$)	($FT.^{5/2}$)	(FT.)	(FT.)	($FT.^{2/3}$)	(CFS)	(CFS)
3.20000	.15996	.06188	.03849	.85636	.07226	.17350	.21830	1.77291
3.21000	.15951	.06202	.03867	.85808	.07227	.17351	.21931	1.77688
3.22000	.15906	.06215	.03885	.85981	.07228	.17353	.22033	1.78084
3.23000	.15861	.06228	.03903	.86153	.07229	.17354	.22135	1.78478
3.24000	.15816	.06241	.03921	.86326	.07230	.17355	.22237	1.78870
3.25000	.15771	.06255	.03939	.86498	.07231	.17357	.22339	1.79260
3.26000	.15725	.06268	.03957	.86671	.07232	.17358	.22441	1.79649
3.27000	.15680	.06281	.03975	.86844	.07232	.17359	.22544	1.80035
3.28000	.15635	.06294	.03993	.87016	.07233	.17360	.22647	1.80420
3.29000	.15590	.06307	.04011	.87189	.07234	.17361	.22750	1.80804
3.30000	.15545	.06320	.04029	.87361	.07234	.17362	.22853	1.81185
3.31000	.15500	.06333	.04048	.87534	.07235	.17363	.22957	1.81564
3.32000	.15455	.06346	.04066	.87706	.07235	.17364	.23060	1.81942
3.33000	.15410	.06358	.04084	.87879	.07236	.17364	.23164	1.82318
3.34000	.15365	.06371	.04103	.88051	.07236	.17365	.23269	1.82692
3.35000	.15320	.06384	.04121	.88224	.07236	.17365	.23373	1.83065
3.36000	.15275	.06397	.04140	.88397	.07237	.17366	.23478	1.83436
3.37000	.15230	.06410	.04158	.88569	.07237	.17366	.23582	1.83804
3.38000	.15185	.06422	.04177	.88742	.07237	.17367	.23687	1.84171
3.39000	.15140	.06435	.04195	.88914	.07237	.17367	.23793	1.84537

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	(FT.^{2})	(FT.$^{5/2}$)	(FT.)	(FT.)	(FT.$^{2/3}$)	(CFS)	(CFS)
3.40000	.15095	.06447	.04214	.89087	.07237	.17367	.23898	1.84900
3.41000	.15050	.06460	.04232	.89259	.07237	.17367	.24004	1.85262
3.42000	.15004	.06473	.04251	.89432	.07237	.17367	.24110	1.85621
3.43000	.14959	.06485	.04270	.89604	.07237	.17367	.24216	1.85980
3.44000	.14914	.06497	.04289	.89777	.07237	.17367	.24323	1.86336
3.45000	.14869	.06510	.04307	.89949	.07237	.17367	.24429	1.86690
3.46000	.14824	.06522	.04326	.90122	.07237	.17367	.24536	1.87043
3.47000	.14779	.06535	.04345	.90295	.07237	.17367	.24643	1.87394
3.48000	.14734	.06547	.04364	.90467	.07237	.17366	.24751	1.87743
3.49000	.14689	.06559	.04383	.90640	.07237	.17366	.24858	1.88090
3.50000	.14644	.06571	.04402	.90812	.07236	.17365	.24966	1.88436
3.51000	.14599	.06584	.04421	.90985	.07236	.17365	.25074	1.88779
3.52000	.14554	.06596	.04440	.91157	.07236	.17364	.25182	1.89121
3.53000	.14509	.06608	.04459	.91330	.07235	.17364	.25291	1.89461
3.54000	.14464	.06620	.04478	.91502	.07235	.17363	.25400	1.89800
3.55000	.14419	.06632	.04498	.91675	.07234	.17362	.25509	1.90136
3.56000	.14374	.06644	.04517	.91848	.07234	.17361	.25618	1.90471
3.57000	.14329	.06656	.04536	.92020	.07233	.17360	.25728	1.90804
3.58000	.14284	.06668	.04556	.92193	.07233	.17359	.25838	1.91135
3.59000	.14238	.06680	.04575	.92365	.07232	.17358	.25948	1.91464

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_W	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	$(FT.^2)$	$(FT.^{5/2})$	(FT.)	(FT.)	$(FT.^{2/3})$	(CFS)	(CFS)
3.60000	.14193	.06692	.04595	.92538	.07231	.17357	.26058	1.91792
3.61000	.14148	.06703	.04614	.92710	.07230	.17356	.26169	1.92118
3.62000	.14103	.06715	.04634	.92883	.07230	.17355	.26279	1.92442
3.63000	.14058	.06727	.04653	.93055	.07229	.17354	.26391	1.92764
3.64000	.14013	.06739	.04673	.93228	.07228	.17352	.26502	1.93084
3.65000	.13968	.06750	.04693	.93400	.07227	.17351	.26614	1.93403
3.66000	.13923	.06762	.04712	.93573	.07226	.17349	.26725	1.93720
3.67000	.13878	.06773	.04732	.93746	.07225	.17348	.26838	1.94035
3.68000	.13833	.06785	.04752	.93918	.07224	.17346	.26950	1.94348
3.69000	.13788	.06797	.04772	.94091	.07223	.17345	.27063	1.94659
3.70000	.13743	.06808	.04792	.94263	.07222	.17343	.27176	1.94969
3.71000	.13698	.06819	.04812	.94436	.07221	.17341	.27289	1.95277
3.72000	.13653	.06831	.04832	.94608	.07220	.17340	.27403	1.95583
3.73000	.13608	.06842	.04852	.94781	.07219	.17338	.27516	1.95887
3.74000	.13563	.06854	.04872	.94953	.07218	.17336	.27631	1.96190
3.75000	.13518	.06865	.04892	.95126	.07217	.17334	.27745	1.96490
3.76000	.13472	.06876	.04912	.95299	.07215	.17332	.27860	1.96789
3.77000	.13427	.06887	.04933	.95471	.07214	.17330	.27975	1.97087
3.78000	.13382	.06898	.04953	.95644	.07213	.17328	.28090	1.97382
3.79000	.13337	.06910	.04973	.95816	.07211	.17325	.28205	1.97676

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	($FT.^2$)	($FT.^{5/2}$)	(FT.)	(FT.)	($FT.^{2/3}$)	(CFS)	(CFS)
3.80000	.13292	.06921	.04994	.95989	.07210	.17323	.28321	1.97967
3.81000	.13247	.06932	.05014	.96161	.07208	.17321	.28437	1.98257
3.82000	.13202	.06943	.05035	.96334	.07207	.17318	.28554	1.98546
3.83000	.13157	.06954	.05055	.96506	.07205	.17316	.28671	1.98832
3.84000	.13112	.06965	.05076	.96679	.07204	.17314	.28788	1.99117
3.85000	.13067	.06976	.05097	.96851	.07202	.17311	.28905	1.99400
3.86000	.13022	.06986	.05117	.97024	.07201	.17308	.29023	1.99681
3.87000	.12977	.06997	.05138	.97197	.07199	.17306	.29141	1.99960
3.88000	.12932	.07008	.05159	.97369	.07197	.17303	.29259	2.00238
3.89000	.12887	.07019	.05180	.97542	.07196	.17300	.29378	2.00514
3.90000	.12842	.07030	.05201	.97714	.07194	.17298	.29497	2.00788
3.91000	.12797	.07040	.05222	.97887	.07192	.17295	.29616	2.01060
3.92000	.12751	.07051	.05243	.98059	.07190	.17292	.29736	2.01330
3.93000	.12706	.07062	.05264	.98232	.07189	.17289	.29856	2.01599
3.94000	.12661	.07072	.05285	.98404	.07187	.17286	.29976	2.01866
3.95000	.12616	.07083	.05307	.98577	.07185	.17283	.30096	2.02131
3.96000	.12571	.07093	.05328	.98750	.07183	.17280	.30217	2.02394
3.97000	.12526	.07104	.05349	.98922	.07181	.17277	.30339	2.02656
3.98000	.12481	.07114	.05371	.99095	.07179	.17274	.30460	2.02916
3.99000	.12436	.07124	.05392	.99267	.07177	.17270	.30582	2.03174

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	($FT.^2$)	($FT.^{5/2}$)	(FT.)	(FT.)	($FT.^{2/3}$)	(CFS)	(CFS)
4.00000	.12391	.07135	.05414	.99440	.07175	.17267	.30705	2.03430
4.01000	.12346	.07145	.05436	.99612	.07173	.17264	.30827	2.03685
4.02000	.12301	.07155	.05457	.99785	.07171	.17260	.30950	2.03938
4.03000	.12256	.07166	.05479	.99957	.07169	.17257	.31074	2.04189
4.04000	.12211	.07176	.05501	1.00130	.07166	.17253	.31197	2.04438
4.05000	.12166	.07186	.05523	1.00303	.07164	.17250	.31322	2.04686
4.06000	.12121	.07196	.05545	1.00475	.07162	.17246	.31446	2.04931
4.07000	.12076	.07206	.05567	1.00648	.07160	.17243	.31571	2.05175
4.08000	.12031	.07216	.05589	1.00820	.07157	.17239	.31696	2.05417
4.09000	.11985	.07226	.05611	1.00993	.07155	.17235	.31822	2.05658
4.10000	.11940	.07236	.05633	1.01165	.07153	.17232	.31948	2.05897
4.11000	.11895	.07246	.05655	1.01338	.07150	.17228	.32074	2.06134
4.12000	.11850	.07256	.05678	1.01510	.07148	.17224	.32201	2.06369
4.13000	.11805	.07266	.05700	1.01683	.07146	.17220	.32328	2.06602
4.14000	.11760	.07276	.05723	1.01855	.07143	.17216	.32456	2.06834
4.15000	.11715	.07285	.05745	1.02028	.07141	.17212	.32584	2.07064
4.16000	.11670	.07295	.05768	1.02201	.07138	.17208	.32712	2.07292
4.17000	.11625	.07305	.05791	1.02373	.07136	.17204	.32841	2.07519
4.18000	.11580	.07315	.05813	1.02546	.07133	.17200	.32970	2.07743
4.19000	.11535	.07324	.05836	1.02718	.07130	.17195	.33099	2.07966

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	($FT.^2$)	($FT.^{5/2}$)	(FT.)	(FT.)	($FT.^{2/3}$)	(CFS)	(CFS)
4.20000	.11490	.07334	.05859	1.02891	.07128	.17191	.33230	2.08187
4.21000	.11445	.07343	.05882	1.03063	.07125	.17187	.33360	2.08407
4.22000	.11400	.07353	.05905	1.03236	.07122	.17183	.33491	2.08625
4.23000	.11355	.07362	.05928	1.03408	.07120	.17178	.33622	2.08841
4.24000	.11310	.07372	.05952	1.03581	.07117	.17174	.33754	2.09055
4.25000	.11265	.07381	.05975	1.03754	.07114	.17169	.33886	2.09267
4.26000	.11219	.07391	.05998	1.03926	.07111	.17165	.34019	2.09478
4.27000	.11174	.07400	.06022	1.04099	.07109	.17160	.34152	2.09687
4.28000	.11129	.07409	.06045	1.04271	.07106	.17156	.34285	2.09894
4.29000	.11084	.07418	.06069	1.04444	.07103	.17151	.34419	2.10100
4.30000	.11039	.07428	.06093	1.04616	.07100	.17146	.34554	2.10304
4.31000	.10994	.07437	.06117	1.04789	.07097	.17142	.34689	2.10506
4.32000	.10949	.07446	.06140	1.04961	.07094	.17137	.34824	2.10706
4.33000	.10904	.07455	.06164	1.05134	.07091	.17132	.34960	2.10905
4.34000	.10859	.07464	.06188	1.05306	.07088	.17127	.35097	2.11102
4.35000	.10814	.07473	.06213	1.05479	.07085	.17122	.35234	2.11297
4.36000	.10769	.07482	.06237	1.05652	.07082	.17118	.35371	2.11490
4.37000	.10724	.07491	.06261	1.05824	.07079	.17113	.35509	2.11682
4.38000	.10679	.07500	.06286	1.05997	.07076	.17108	.35647	2.11872
4.39000	.10634	.07509	.06310	1.06169	.07073	.17103	.35786	2.12060

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	(FT.^{2})	(FT.$^{5/2}$)	(FT.)	(FT.)	(FT.$^{2/3}$)	(CFS)	(CFS)
4.40000	.10589	.07518	.06335	1.06342	.07069	.17097	.35926	2.12247
4.41000	.10544	.07527	.06359	1.06514	.07066	.17092	.36066	2.12431
4.42000	.10498	.07535	.06384	1.06687	.07063	.17087	.36206	2.12615
4.43000	.10453	.07544	.06409	1.06859	.07060	.17082	.36347	2.12796
4.44000	.10408	.07553	.06434	1.07032	.07057	.17077	.36489	2.12976
4.45000	.10363	.07561	.06459	1.07205	.07053	.17071	.36631	2.13154
4.46000	.10318	.07570	.06484	1.07377	.07050	.17066	.36774	2.13330
4.47000	.10273	.07579	.06509	1.07550	.07047	.17061	.36917	2.13504
4.48000	.10228	.07587	.06535	1.07722	.07043	.17055	.37061	2.13677
4.49000	.10183	.07596	.06560	1.07895	.07040	.17050	.37205	2.13848
4.50000	.10138	.07604	.06586	1.08067	.07036	.17044	.37350	2.14018
4.51000	.10093	.07613	.06611	1.08240	.07033	.17039	.37496	2.14185
4.52000	.10048	.07621	.06637	1.08412	.07030	.17033	.37642	2.14351
4.53000	.10003	.07629	.06663	1.08585	.07026	.17028	.37788	2.14516
4.54000	.09958	.07638	.06689	1.08757	.07023	.17022	.37936	2.14678
4.55000	.09913	.07646	.06715	1.08930	.07019	.17016	.38084	2.14839
4.56000	.09868	.07654	.06741	1.09103	.07016	.17010	.38232	2.14998
4.57000	.09823	.07662	.06768	1.09275	.07012	.17005	.38382	2.15156
4.58000	.09778	.07671	.06794	1.09448	.07008	.16999	.38531	2.15312
4.59000	.09732	.07679	.06821	1.09620	.07005	.16993	.38682	2.15466

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	($FT.^2$)	($FT.^{5/2}$)	(FT.)	(FT.)	($FT.^{2/3}$)	(CFS)	(CFS)
4.60000	.09687	.07687	.06847	1.09793	.07001	.16987	.38833	2.15618
4.61000	.09642	.07695	.06874	1.09965	.06997	.16981	.38985	2.15769
4.62000	.09597	.07703	.06901	1.10138	.06994	.16975	.39137	2.15918
4.63000	.09552	.07711	.06928	1.10310	.06990	.16969	.39291	2.16065
4.64000	.09507	.07719	.06955	1.10483	.06986	.16963	.39445	2.16211
4.65000	.09462	.07727	.06982	1.10656	.06983	.16957	.39599	2.16355
4.66000	.09417	.07735	.07010	1.10828	.06979	.16951	.39754	2.16497
4.67000	.09372	.07742	.07037	1.11001	.06975	.16945	.39910	2.16638
4.68000	.09327	.07750	.07065	1.11173	.06971	.16939	.40067	2.16777
4.69000	.09282	.07758	.07093	1.11346	.06967	.16933	.40224	2.16914
4.70000	.09237	.07766	.07121	1.11518	.06964	.16926	.40383	2.17050
4.71000	.09192	.07773	.07149	1.11691	.06960	.16920	.40542	2.17184
4.72000	.09147	.07781	.07177	1.11863	.06956	.16914	.40701	2.17316
4.73000	.09102	.07789	.07205	1.12036	.06952	.16907	.40862	2.17447
4.74000	.09057	.07796	.07233	1.12209	.06948	.16901	.41023	2.17576
4.75000	.09012	.07804	.07262	1.12381	.06944	.16894	.41185	2.17703
4.76000	.08966	.07811	.07291	1.12554	.06940	.16888	.41348	2.17828
4.77000	.08921	.07819	.07320	1.12726	.06936	.16881	.41511	2.17952
4.78000	.08876	.07826	.07349	1.12899	.06932	.16875	.41676	2.18075
4.79000	.08831	.07833	.07378	1.13071	.06928	.16868	.41841	2.18195

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	($FT.^2$)	($FT.^{5/2}$)	(FT.)	(FT.)	($FT.^{2/3}$)	(CFS)	(CFS)
4.80000	.08786	.07841	.07407	1.13244	.06924	.16862	.42007	2.18314
4.81000	.08741	.07848	.07436	1.13416	.06920	.16855	.42174	2.18431
4.82000	.08696	.07855	.07466	1.13589	.06916	.16848	.42342	2.18547
4.83000	.08651	.07863	.07496	1.13761	.06911	.16842	.42511	2.18661
4.84000	.08606	.07870	.07526	1.13934	.06907	.16835	.42681	2.18773
4.85000	.08561	.07877	.07556	1.14107	.06903	.16828	.42851	2.18884
4.86000	.08516	.07884	.07586	1.14279	.06899	.16821	.43023	2.18993
4.87000	.08471	.07891	.07616	1.14452	.06895	.16815	.43195	2.19100
4.88000	.08426	.07898	.07647	1.14624	.06890	.16808	.43368	2.19206
4.89000	.08381	.07905	.07678	1.14797	.06886	.16801	.43543	2.19310
4.90000	.08336	.07912	.07709	1.14969	.06882	.16794	.43718	2.19412
4.91000	.08291	.07919	.07740	1.15142	.06878	.16787	.43894	2.19513
4.92000	.08245	.07926	.07771	1.15314	.06873	.16780	.44071	2.19612
4.93000	.08200	.07933	.07802	1.15487	.06869	.16773	.44250	2.19710
4.94000	.08155	.07940	.07834	1.15660	.06865	.16766	.44429	2.19806
4.95000	.08110	.07946	.07866	1.15832	.06860	.16758	.44609	2.19900
4.96000	.08065	.07953	.07898	1.16005	.06856	.16751	.44791	2.19992
4.97000	.08020	.07960	.07930	1.16177	.06851	.16744	.44973	2.20083
4.98000	.07975	.07967	.07962	1.16350	.06847	.16737	.45157	2.20173
4.99000	.07930	.07973	.07995	1.16522	.06843	.16730	.45341	2.20260

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	R_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	(FT.^{2})	(FT.$^{5/2}$)	(FT.)	(FT.)	(FT.$^{2/3}$)	(CFS)	(CFS)
5.00000	.07885	.07980	.08028	1.16695	.06838	.16722	.45527	2.20347
5.01000	.07840	.07986	.08061	1.16867	.06834	.16715	.45714	2.20431
5.02000	.07795	.07993	.08094	1.17040	.06829	.16708	.45902	2.20514
5.03000	.07750	.07999	.08127	1.17212	.06825	.16700	.46091	2.20595
5.04000	.07705	.08006	.08161	1.17385	.06820	.16693	.46282	2.20675
5.05000	.07660	.08012	.08195	1.17558	.06815	.16685	.46473	2.20753
5.06000	.07615	.08019	.08229	1.17730	.06811	.16678	.46666	2.20829
5.07000	.07570	.08025	.08263	1.17903	.06806	.16670	.46860	2.20904
5.08000	.07525	.08031	.08297	1.18075	.06802	.16663	.47056	2.20977
5.09000	.07479	.08037	.08332	1.18248	.06797	.16655	.47252	2.21049
5.10000	.07434	.08044	.08367	1.18420	.06792	.16648	.47450	2.21118
5.11000	.07389	.08050	.08402	1.18593	.06788	.16640	.47649	2.21187
5.12000	.07344	.08056	.08437	1.18765	.06783	.16632	.47850	2.21254
5.13000	.07299	.08062	.08473	1.18938	.06778	.16625	.48052	2.21319
5.14000	.07254	.08068	.08509	1.19111	.06774	.16617	.48256	2.21382
5.15000	.07209	.08074	.08545	1.19283	.06769	.16609	.48460	2.21444
5.16000	.07164	.08080	.08581	1.19456	.06764	.16601	.48667	2.21505
5.17000	.07119	.08086	.08618	1.19628	.06759	.16594	.48874	2.21563
5.18000	.07074	.08092	.08655	1.19801	.06754	.16586	.49084	2.21620
5.19000	.07029	.08098	.08692	1.19973	.06750	.16578	.49294	2.21676

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	($FT.^2$)	($FT.^{5/2}$)	(FT.)	(FT.)	($FT.^{2/3}$)	(CFS)	(CFS)
5.20000	.06984	.08104	.08729	1.20146	.06745	.16570	.49507	2.21730
5.21000	.06939	.08110	.08767	1.20318	.06740	.16562	.49720	2.21782
5.22000	.06894	.08115	.08805	1.20491	.06735	.16554	.49936	2.21833
5.23000	.06849	.08121	.08843	1.20663	.06730	.16546	.50153	2.21882
5.24000	.06804	.08127	.08882	1.20836	.06725	.16538	.50372	2.21930
5.25000	.06759	.08132	.08921	1.21009	.06720	.16530	.50592	2.21976
5.26000	.06713	.08138	.08960	1.21181	.06715	.16522	.50814	2.22021
5.27000	.06668	.08144	.08999	1.21354	.06711	.16514	.51038	2.22064
5.28000	.06623	.08149	.09039	1.21526	.06706	.16506	.51263	2.22105
5.29000	.06578	.08155	.09079	1.21699	.06701	.16497	.51491	2.22145
5.30000	.06533	.08160	.09120	1.21871	.06696	.16489	.51720	2.22183
5.31000	.06488	.08166	.09160	1.22044	.06691	.16481	.51951	2.22220
5.32000	.06443	.08171	.09202	1.22216	.06686	.16473	.52184	2.22255
5.33000	.06398	.08176	.09243	1.22389	.06680	.16464	.52419	2.22288
5.34000	.06353	.08182	.09285	1.22562	.06675	.16456	.52656	2.22320
5.35000	.06308	.08187	.09327	1.22734	.06670	.16448	.52895	2.22351
5.36000	.06263	.08192	.09369	1.22907	.06665	.16439	.53135	2.22379
5.37000	.06218	.08197	.09412	1.23079	.06660	.16431	.53378	2.22407
5.38000	.06173	.08202	.09455	1.23252	.06655	.16422	.53624	2.22433
5.39000	.06128	.08208	.09499	1.23424	.06650	.16414	.53871	2.22457

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	($FT.^2$)	($FT.^{5/2}$)	(FT.)	(FT.)	($FT.^{2/3}$)	(CFS)	(CFS)
5.40000	.06083	.08213	.09543	1.23597	.06645	.16405	.54120	2.22479
5.41000	.06038	.08218	.09587	1.23769	.06639	.16397	.54372	2.22500
5.42000	.05992	.08223	.09632	1.23942	.06634	.16388	.54626	2.22520
5.43000	.05947	.08228	.09677	1.24114	.06629	.16380	.54882	2.22538
5.44000	.05902	.08233	.09723	1.24287	.06624	.16371	.55141	2.22555
5.45000	.05857	.08238	.09769	1.24460	.06619	.16363	.55402	2.22569
5.46000	.05812	.08242	.09815	1.24632	.06613	.16354	.55666	2.22583
5.47000	.05767	.08247	.09862	1.24805	.06608	.16345	.55932	2.22595
5.48000	.05722	.08252	.09910	1.24977	.06603	.16336	.56200	2.22605
5.49000	.05677	.08257	.09958	1.25150	.06597	.16328	.56472	2.22614
5.50000	.05632	.08262	.10006	1.25322	.06592	.16319	.56746	2.22621
5.51000	.05587	.08266	.10055	1.25495	.06587	.16310	.57023	2.22627
5.52000	.05542	.08271	.10104	1.25667	.06581	.16301	.57302	2.22631
5.53000	.05497	.08275	.10154	1.25840	.06576	.16292	.57584	2.22634
5.54000	.05452	.08280	.10204	1.26013	.06571	.16284	.57870	2.22635
5.55000	.05407	.08285	.10255	1.26185	.06565	.16275	.58158	2.22635
5.56000	.05362	.08289	.10306	1.26358	.06560	.16266	.58449	2.22633
5.57000	.05317	.08293	.10358	1.26530	.06554	.16257	.58744	2.22630
5.58000	.05272	.08298	.10411	1.26703	.06549	.16248	.59041	2.22625
5.59000	.05226	.08302	.10464	1.26875	.06544	.16239	.59342	2.22619

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	($FT.^2$)	($FT.^{5/2}$)	(FT.)	(FT.)	($FT.^{2/3}$)	(CFS)	(CFS)
5.60000	.05181	.08307	.10517	1.27048	.06538	.16230	.59646	2.22611
5.61000	.05136	.08311	.10572	1.27220	.06533	.16220	.59954	2.22601
5.62000	.05091	.08315	.10627	1.27393	.06527	.16211	.60265	2.22590
5.63000	.05046	.08319	.10682	1.27566	.06522	.16202	.60580	2.22578
5.64000	.05001	.08324	.10738	1.27738	.06516	.16193	.60898	2.22564
5.65000	.04956	.08328	.10795	1.27911	.06510	.16184	.61220	2.22549
5.66000	.04911	.08332	.10852	1.28083	.06505	.16175	.61546	2.22532
5.67000	.04866	.08336	.10910	1.28256	.06499	.16165	.61875	2.22514
5.68000	.04821	.08340	.10969	1.28428	.06494	.16156	.62209	2.22494
5.69000	.04776	.08344	.11029	1.28601	.06488	.16147	.62547	2.22473
5.70000	.04731	.08348	.11089	1.28773	.06483	.16138	.62889	2.22450
5.71000	.04686	.08352	.11150	1.28946	.06477	.16128	.63235	2.22425
5.72000	.04641	.08356	.11212	1.29118	.06471	.16119	.63585	2.22400
5.73000	.04596	.08360	.11275	1.29291	.06466	.16109	.63940	2.22373
5.74000	.04551	.08363	.11338	1.29464	.06460	.16100	.64300	2.22344
5.75000	.04506	.08367	.11402	1.29636	.06454	.16091	.64665	2.22314
5.76000	.04460	.08371	.11467	1.29809	.06449	.16081	.65034	2.22282
5.77000	.04415	.08375	.11533	1.29981	.06443	.16072	.65408	2.22249
5.78000	.04370	.08378	.11600	1.30154	.06437	.16062	.65788	2.22214
5.79000	.04325	.08382	.11668	1.30326	.06431	.16053	.66172	2.22178

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	$(FT.^2)$	$(FT.^{5/2})$	(FT.)	(FT.)	$(FT.^{2/3})$	(CFS)	(CFS)
5.80000	.04280	.08386	.11737	1.30499	.06426	.16043	.66563	2.22141
5.81000	.04235	.08389	.11807	1.30671	.06420	.16033	.66958	2.22102
5.82000	.04190	.08393	.11878	1.30844	.06414	.16024	.67359	2.22061
5.83000	.04145	.08396	.11949	1.31017	.06408	.16014	.67767	2.22019
5.84000	.04100	.08399	.12022	1.31189	.06402	.16004	.68180	2.21976
5.85000	.04055	.08403	.12096	1.31362	.06397	.15995	.68599	2.21931
5.86000	.04010	.08406	.12171	1.31534	.06391	.15985	.69025	2.21885
5.87000	.03965	.08410	.12247	1.31707	.06385	.15975	.69457	2.21837
5.88000	.03920	.08413	.12325	1.31879	.06379	.15965	.69896	2.21788
5.89000	.03875	.08416	.12403	1.32052	.06373	.15956	.70342	2.21738
5.90000	.03830	.08419	.12483	1.32224	.06367	.15946	.70795	2.21686
5.91000	.03785	.08422	.12565	1.32397	.06361	.15936	.71256	2.21632
5.92000	.03739	.08426	.12647	1.32569	.06355	.15926	.71724	2.21577
5.93000	.03694	.08429	.12731	1.32742	.06350	.15916	.72200	2.21521
5.94000	.03649	.08432	.12816	1.32915	.06344	.15906	.72683	2.21463
5.95000	.03604	.08435	.12903	1.33087	.06338	.15896	.73176	2.21404
5.96000	.03559	.08438	.12991	1.33260	.06332	.15886	.73676	2.21344
5.97000	.03514	.08441	.13081	1.33432	.06326	.15876	.74186	2.21282
5.98000	.03469	.08444	.13173	1.33605	.06320	.15866	.74705	2.21218
5.99000	.03424	.08447	.13266	1.33777	.06314	.15856	.75233	2.21153

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	(FT.^{2})	(FT.$^{5/2}$)	(FT.)	(FT.)	(FT.$^{2/3}$)	(CFS)	(CFS)
6.00000	.03379	.08449	.13361	1.33950	.06308	.15846	.75771	2.21087
6.01000	.03334	.08452	.13457	1.34122	.06302	.15836	.76319	2.21019
6.02000	.03289	.08455	.13556	1.34295	.06296	.15826	.76878	2.20950
6.03000	.03244	.08458	.13656	1.34468	.06290	.15816	.77447	2.20880
6.04000	.03199	.08460	.13759	1.34640	.06284	.15806	.78028	2.20808
6.05000	.03154	.08463	.13863	1.34813	.06277	.15795	.78620	2.20735
6.06000	.03109	.08466	.13970	1.34985	.06271	.15785	.79225	2.20660
6.07000	.03064	.08468	.14079	1.35158	.06265	.15775	.79842	2.20584
6.08000	.03019	.08471	.14190	1.35330	.06259	.15765	.80471	2.20506
6.09000	.02973	.08473	.14303	1.35503	.06253	.15754	.81115	2.20427
6.10000	.02928	.08476	.14419	1.35675	.06247	.15744	.81772	2.20347
6.11000	.02883	.08478	.14537	1.35848	.06241	.15734	.82443	2.20265
6.12000	.02838	.08480	.14658	1.36020	.06235	.15723	.83130	2.20182
6.13000	.02793	.08483	.14782	1.36193	.06228	.15713	.83833	2.20098
6.14000	.02748	.08485	.14909	1.36366	.06222	.15703	.84552	2.20012
6.15000	.02703	.08487	.15039	1.36538	.06216	.15692	.85288	2.19925
6.16000	.02658	.08490	.15172	1.36711	.06210	.15682	.86041	2.19836
6.17000	.02613	.08492	.15308	1.36883	.06204	.15671	.86814	2.19746
6.18000	.02568	.08494	.15448	1.37056	.06197	.15661	.87605	2.19655
6.19000	.02523	.08496	.15591	1.37228	.06191	.15650	.88417	2.19562

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	($FT.^2$)	($FT.^{5/2}$)	(FT.)	(FT.)	($FT.^{2/3}$)	(CFS)	(CFS)
6.20000	.02478	.08498	.15738	1.37401	.06185	.15640	.89250	2.19468
6.21000	.02433	.08500	.15888	1.37573	.06179	.15629	.90105	2.19373
6.22000	.02388	.08502	.16043	1.37746	.06172	.15619	.90984	2.19276
6.23000	.02343	.08504	.16203	1.37919	.06166	.15608	.91886	2.19178
6.24000	.02298	.08506	.16366	1.38091	.06160	.15597	.92815	2.19078
6.25000	.02253	.08508	.16535	1.38264	.06153	.15587	.93770	2.18977
6.26000	.02207	.08510	.16708	1.38436	.06147	.15576	.94753	2.18875
6.27000	.02162	.08512	.16886	1.38609	.06141	.15565	.95765	2.18771
6.28000	.02117	.08514	.17071	1.38781	.06134	.15554	.96809	2.18666
6.29000	.02072	.08515	.17260	1.38954	.06128	.15544	.97886	2.18560
6.30000	.02027	.08517	.17456	1.39126	.06122	.15533	.98997	2.18452
6.31000	.01982	.08519	.17659	1.39299	.06115	.15522	1.00146	2.18343
6.32000	.01937	.08520	.17868	1.39472	.06109	.15511	1.01333	2.18233
6.33000	.01892	.08522	.18085	1.39644	.06102	.15500	1.02561	2.18121
6.34000	.01847	.08523	.18309	1.39817	.06096	.15490	1.03832	2.18008
6.35000	.01802	.08525	.18541	1.39989	.06090	.15479	1.05150	2.17894
6.36000	.01757	.08526	.18783	1.40162	.06083	.15468	1.06518	2.17778
6.37000	.01712	.08528	.19033	1.40334	.06077	.15457	1.07938	2.17661
6.38000	.01667	.08529	.19293	1.40507	.06070	.15446	1.09414	2.17543
6.39000	.01622	.08531	.19564	1.40679	.06064	.15435	1.10950	2.17423

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	(FT.^{2})	(FT.$^{5/2}$)	(FT.)	(FT.)	(FT.$^{2/3}$)	(CFS)	(CFS)
6.40000	.01577	.08532	.19846	1.40852	.06057	.15424	1.12550	2.17303
6.41000	.01532	.08533	.20141	1.41024	.06051	.15413	1.14219	2.17180
6.42000	.01486	.08535	.20448	1.41197	.06044	.15402	1.15963	2.17057
6.43000	.01441	.08536	.20770	1.41370	.06038	.15391	1.17786	2.16932
6.44000	.01396	.08537	.21106	1.41542	.06031	.15380	1.19695	2.16806
6.45000	.01351	.08538	.21459	1.41715	.06025	.15369	1.21699	2.16678
6.46000	.01306	.08539	.21831	1.41887	.06018	.15357	1.23803	2.16549
6.47000	.01261	.08540	.22221	1.42060	.06012	.15346	1.26018	2.16419
6.48000	.01216	.08541	.22633	1.42232	.06005	.15335	1.28354	2.16288
6.49000	.01171	.08542	.23068	1.42405	.05998	.15324	1.30822	2.16155
6.50000	.01126	.08543	.23529	1.42577	.05992	.15313	1.33435	2.16021
6.51000	.01081	.08544	.24018	1.42750	.05985	.15302	1.36209	2.15886
6.52000	.01036	.08545	.24539	1.42923	.05979	.15290	1.39160	2.15749
6.53000	.00991	.08546	.25094	1.43095	.05972	.15279	1.42309	2.15611
6.54000	.00946	.08547	.25688	1.43268	.05965	.15268	1.45678	2.15472
6.55000	.00901	.08548	.26326	1.43440	.05959	.15256	1.49296	2.15332
6.56000	.00856	.08548	.27013	1.43613	.05952	.15245	1.53194	2.15190
6.57000	.00811	.08549	.27757	1.43785	.05946	.15234	1.57412	2.15047
6.58000	.00766	.08550	.28565	1.43958	.05939	.15222	1.61994	2.14903
6.59000	.00720	.08550	.29447	1.44130	.05932	.15211	1.66998	2.14757

TABLE IV. (CONTINUED)

1	2	3	4	5	6	7	8	9
Y	T	A	Z	P_w	R	$R^{2/3}$	$Z\sqrt{g}=Q$	$K=Q/\sqrt{S}$
(IN.)	(FT.)	($FT.^2$)	($FT.^{5/2}$)	(FT.)	(FT.)	($FT.^{2/3}$)	(CFS)	(CFS)
6.60000	.00675	.08551	.30416	1.44303	.05925	.15199	1.72492	2.14610
6.61000	.00630	.08551	.31487	1.44475	.05919	.15188	1.78563	2.14462
6.62000	.00585	.08552	.32678	1.44648	.05912	.15176	1.85321	2.14313
6.63000	.00540	.08552	.34016	1.44821	.05905	.15165	1.92904	2.14162
6.64000	.00495	.08553	.35531	1.44993	.05899	.15153	2.01497	2.14010
6.65000	.00450	.08553	.37268	1.45166	.05892	.15142	2.11346	2.13857
6.66000	.00405	.08554	.39286	1.45338	.05885	.15130	2.22793	2.13703
6.67000	.00360	.08554	.41672	1.45511	.05878	.15119	2.36321	2.13547
6.68000	.00315	.08554	.44551	1.45683	.05872	.15107	2.52650	2.13391
6.69000	.00270	.08554	.48123	1.45856	.05865	.15095	2.72905	2.13232
6.70000	.00225	.08555	.52718	1.46028	.05858	.15084	2.98963	2.13073
6.71000	.00180	.08555	.58942	1.46201	.05851	.15072	3.34261	2.12912
6.72000	.00135	.08555	.68062	1.46374	.05844	.15060	3.85981	2.12751
6.73000	.00090	.08555	.83360	1.46546	.05838	.15049	4.72736	2.12588
6.74000	.00045	.08555	1.17890	1.46719	.05831	.15037	6.68557	2.12423
6.75000	.00000	.08555	∞	1.46891	.05824	.15025	∞	2.12258

Table V. The Theoretical Curve of y_c/y_o vs. S_o for Gravitational Full Flow in the Triangular Conduit

S_o	Q (cfs) ($K\ S_o = 2.12258\ S_o$)	y_c (in.)	y_c/y_o ($y_c/6.75$)
0.00100	0.06714	1.42	0.210
0.00150	0.08222	1.64	0.243
0.00200	0.09492	1.81	0.268
0.00300	0.11627	2.08	0.308
0.00400	0.13423	2.29	0.339
0.00500	0.15009	2.47	0.366
0.00600	0.16446	2.64	0.391
0.00700	0.17760	2.78	0.412
0.00800	0.18984	2.91	0.431
0.00900	0.20137	3.03	0.449
0.01000	0.21226	3.14	0.465
0.01100	0.22262	3.25	0.481
0.01200	0.23251	3.34	0.495
0.01300	0.24202	3.43	0.508
0.01400	0.25114	3.51	0.520
0.01500	0.25997	3.59	0.532
0.01600	0.26849	3.67	0.544
0.01700	0.27676	3.74	0.554
0.01800	0.28479	3.81	0.564
0.01900	0.29258	3.88	0.575
0.02000	0.30018	3.94	0.584
0.02100	0.30760	4.01	0.594
0.02200	0.31482	4.07	0.603
0.02300	0.32191	4.12	0.610
0.02400	0.32883	4.18	0.619
0.02500	0.33560	4.23	0.627
0.02600	0.34227	4.27	0.633
0.02700	0.34878	4.33	0.641
0.02800	0.35517	4.37	0.647
0.02900	0.36145	4.42	0.655
0.03000	0.36765	4.46	0.661
0.03100	0.37372	4.50	0.667
0.03200	0.37971	4.55	0.674
0.03300	0.38559	4.59	0.680
0.03400	0.39138	4.62	0.684
0.03500	0.39709	4.66	0.690
0.03600	0.40274	4.70	0.696
0.03700	0.40828	4.73	0.701
0.03800	0.41378	4.76	0.705
0.03900	0.41917	4.80	0.711
0.04000	0.42452	4.83	0.716
0.04100	0.43604	4.90	0.726

Appendix C

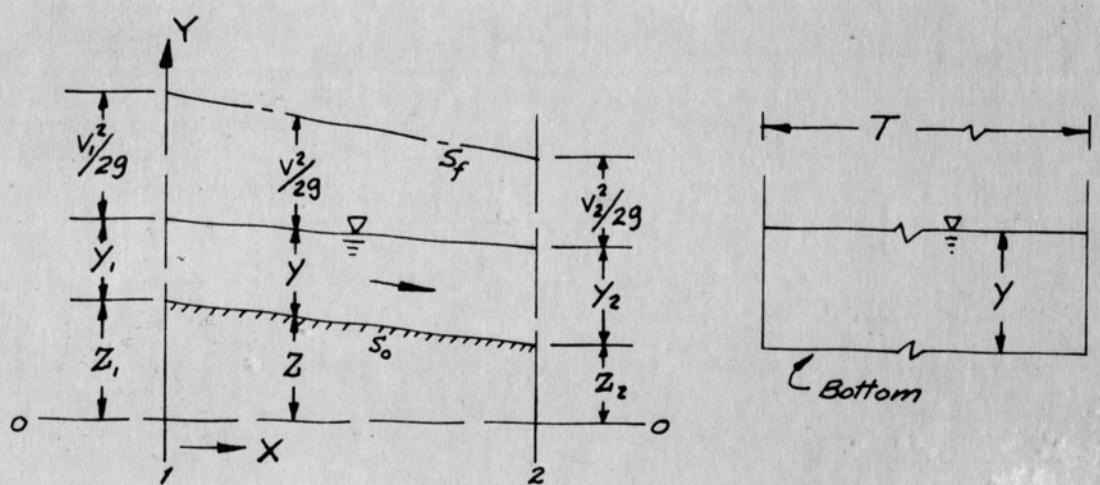

Fig. 30. A Channel Reach for the Analysis of Water Surface Profiles

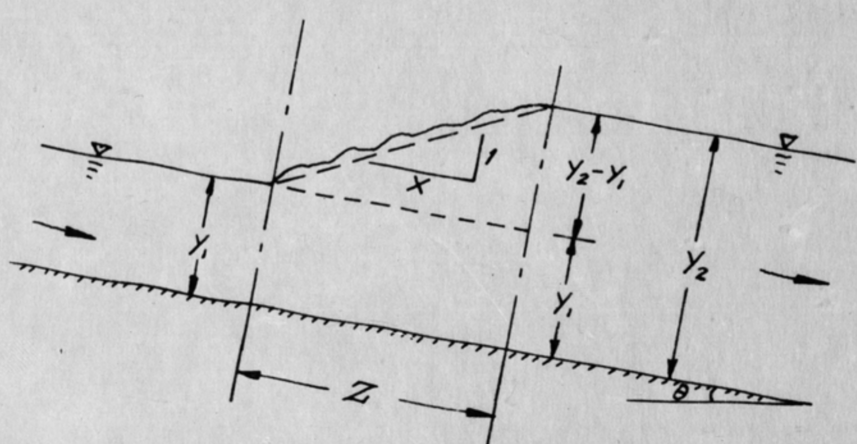

Fig. 31. The General Case of a Hydraulic Jump