A MODEL STUDY OF COMBINING FLOW IN AN OPEN RECTANGULAR CHANNEL

by

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B. S., NATIONAL TAIWAN UNIVERSITY, 1964

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

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Manhattan, Kansas

1969

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INTRODUCTION

Need For Study

The problem of flow through a channel junction is encountered very often in drainage systems and natural rivers. This phenomenon involves numerous variables, such as the number of the adjoining channels, the angles of intersection, the slope and shape of the channels, the directions and magnitude of flow, the rounding of the corners at the junction, etc. The problem is so complicated that only a few simple and specific cases have been studied. The conclusions of such studies indicate that generalization of the problem is not possible or even desirable. When the application of hydraulic theory to the problem encounters limitations, a model study will give the best solution for the flow characteristics involved.

Scope Of Study

In the present work, the performance of a horizontal combining channel was studied in detail. A branch was set at a right angle to a straight channel. The same rectangular shape was used in all three channel sections. The channels were 6 inches wide and had a maximum depth of 6 inches. Flow was varied from 0.01 to 0.2 c.f.s. during the runs. It was assumed that the flow was parallel to the channel walls immediately above and below the junction, and that ordinary wall friction was negligible.

Purpose Of Study

The purpose of this model study was to predict the depth in each tributary channel just upstream from the junction and to determine the necessary wall heights in the vicinity of the junction. Tests were also conducted to investigate the condition of the reverse flow region and whether or not a hydraulic jump would occur.

REVIEW OF PREVIOUS INVESTIGATION

Combining flow has been studied by only a few people. The first comprehensive study of a combining flow on an open channel was given by Taylor (1) in 1944. In his work, a small, horizontal, rectangular channel was used. Taylor assumed that: (1) the flow was parallel to the channel walls immediately above and below the junction; (2) ordinary wall friction was negligible in comparison with other forces involved; and (3) the depth in the inlet main channel and branch were equal immediately above the junction. Momentum balances were then set up relating the inflow and outflow. It was found that the agreement between theory and experiment was quite good for cases in which the intersecting angle of the channel was 45° and was rather poor for cases with an intersecting angle of 135°. In the former case, an abrupt reversal in the inflow direction did not occur. Consequently, the flow in the junction for an intersecting angle of 45° was less complicated than that for an intersecting angle of 135°, making possible a better estimate of the force developed at the junction.

In 1950, an analysis of the junction of two channels based on pressure-momentum relationships was attempted by Bowers (2) in an effort to explain and assist in the prediction of the flow condition in the vicinity of the junction. He concluded that dependent upon the junction design, the discharge, velocities, and related phenomena of the flow in the vicinity of the junction, a hydraulic jump could form in one or both of the inlet channels. This could necessitate a large increase in the height of the side wall in the vicinity of the junction. When the principle of momentum is applied to such a problem, it is necessary that the position of the jump or the depth of flow at the upstream edge of the junction be known in order to compute the momentum contributed by the inlet flows.

In 1966, Sridharan and Rao (3) suggested that the problem of combination of flow could be solved based on backwater computations or momentum consideration. In natural rivers when the flow profile computation is carried upstream through the confluence of a river and its tributary, it is necessary to determine the water surface elevation immediately upstream of the confluence. This could be done by field measurement and backwater computation based on the discharge between the river and the tributary.

APPARATUS AND EXPERIMENTAL PROCEDURE

Experimental Apparatus

The general test set up used in the model studies is illustrated in Figure 1. It consists of a horizontal, rectangular channel section approximately 12 feet long representing the main channel, and a 6 feet rectangular section representing the lateral channel fitted at the midpoint of main channel vertically; the cross section of both channels was 6 inches wide and 6 inches high. Water was supplied from the laboratory supply pump. The quantity of water used in the experiments varied from 0.01 to 0.2 c.f.s.. Two calibrated orifices were used for measuring the discharges flowing into the channels. Water surface elevations were measured with point gages. Two gates and head boxes were used at the entrance of the main and lateral channel to control the discharge into the test channels.

Experimental Procedure

The preliminary experimental work included orifice calibration tests. The orifices were calibrated over the range of flows. Quantity of flow was determined by timing a certain amount of water into the weighing tank. The calibration curves are shown in Figure 2 and Figure 3.

The experiments were performed in several stages. Initially, a series of preliminary tests were run. From these the general behavior of the flow was determined. Conditions were noted under which reverse flow or hydraulic jumps could be observed, and the ranges of discharges both in main and lateral channel were determined. The principal part of the experiment was executed in a systematic manner to allow permutations of discharge ratios and depth. The discharges were controlled by valves, and the gate positions in the head boxes were varied to control the flow depths. The mean depth of flow in each channel was taken at a station 36 inches upstream of the center of the junction. For the condition of supercritical flow due to the horizontal bottom, water surface were affected by backwater from the combining flow. No stable supercritical flow could be produced. Therefore, no further information could be obtained for this condition.

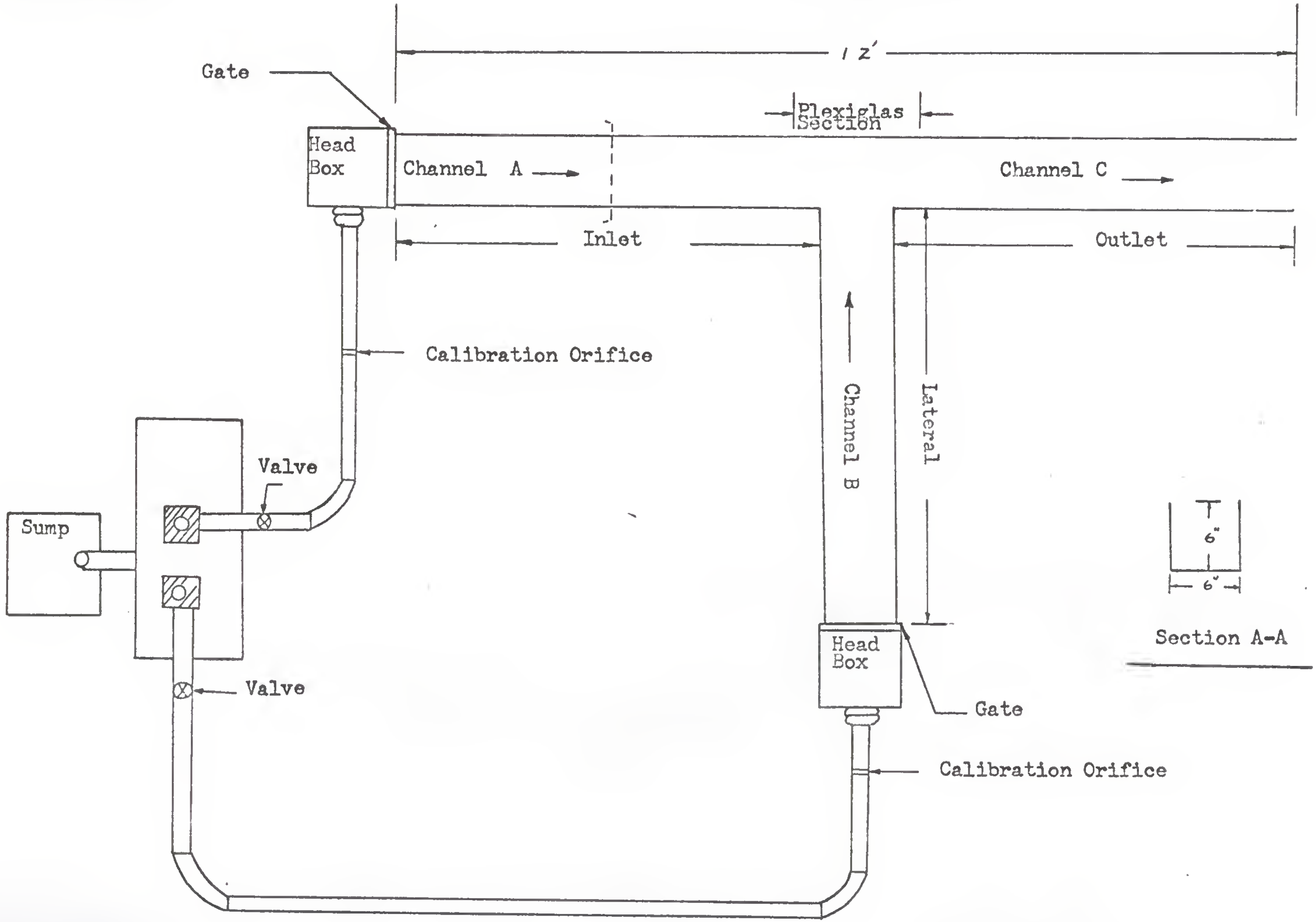

Fig. 1. Schematic of Experimental Apparatus

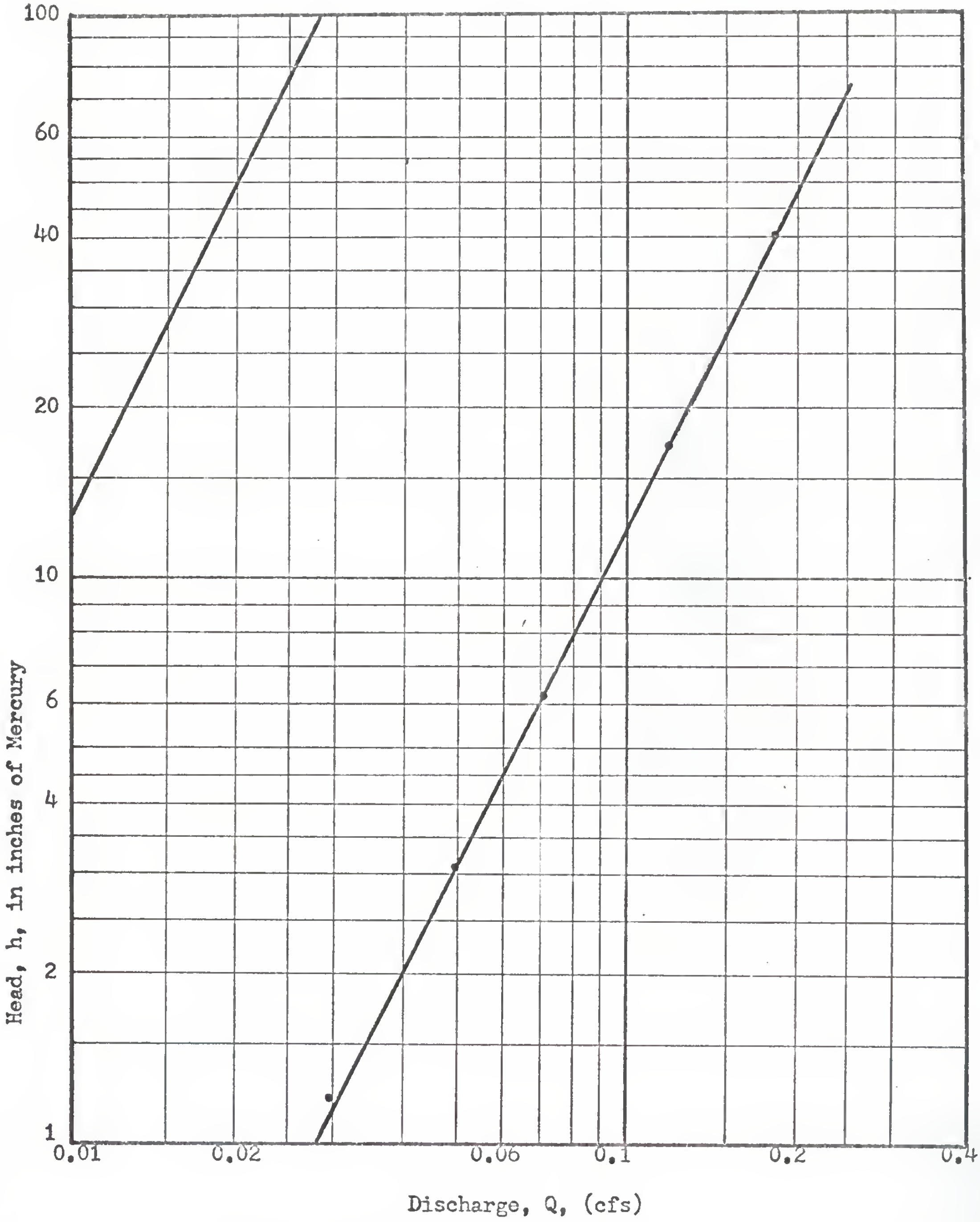

Fig. 2. Orifice Calibration Curve

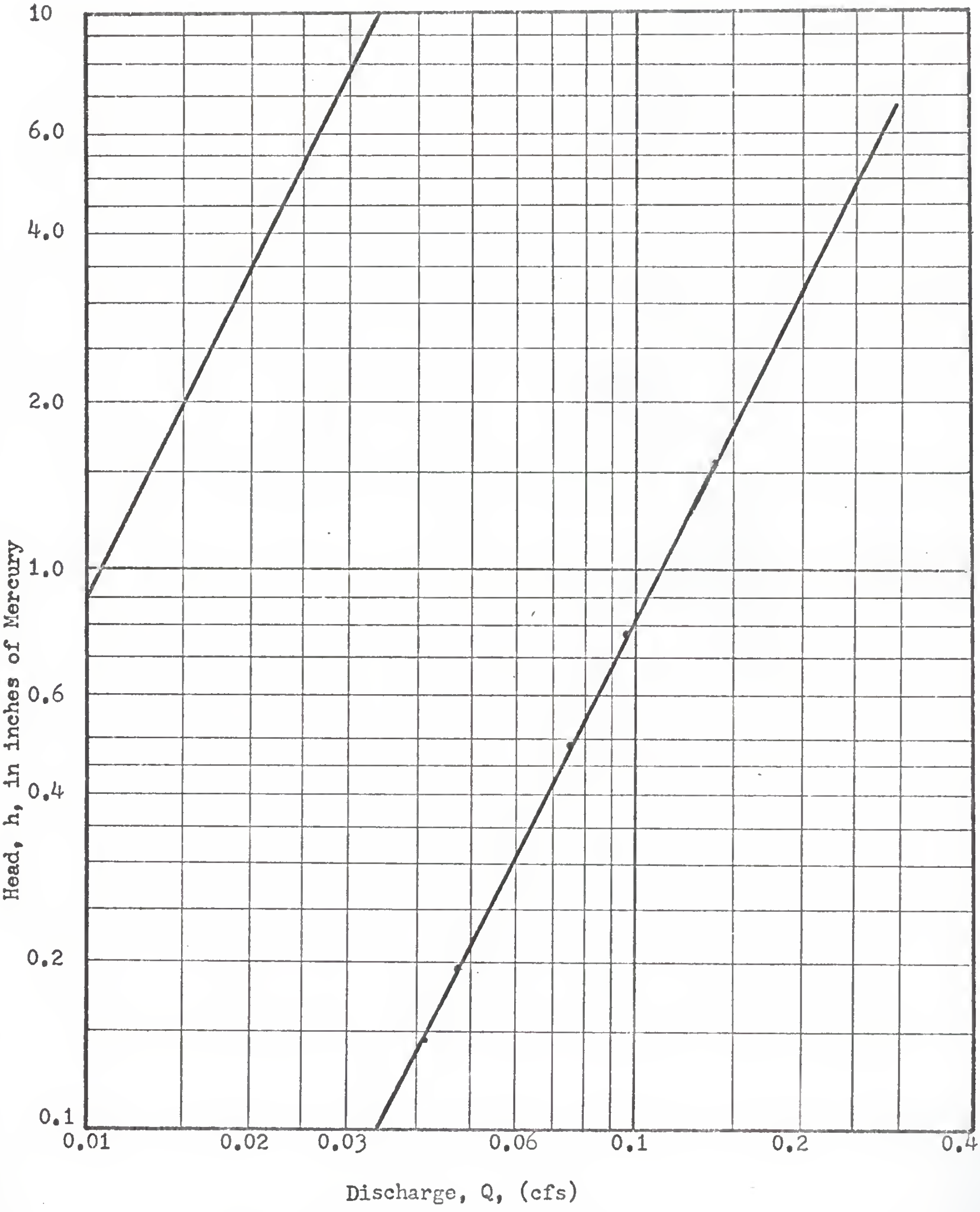

Fig. 3. Orifice Calibration Curve

THEORETICAL ANALYSIS

Momentum Consideration For Main Channel

When two streams combine in a single channel, the depth just below the junction will be fixed by the backwater characteristics of that channel and the magnitudes of the combined rates of flow. There is a variation in the depth of the flow in the junction. However, this variation has been observed to be small. In applying the momentum theory to the combined flow, the sums of the pressure plus momentum of the inlet and lateral channels are equated vectorially to the pressure plus momentum of the outlet channel. In this model, the momentum contributed by the lateral channel would be multiplied by the cosine of 90°, giving no value to be added to the momentum in the inlet channel. Therefore, the momentum equation in the direction of the main channel can be written as

$$P_a Y_a + \frac{Q_a W V_a}{g} = P_c Y_c + \frac{Q_c W V_c}{g} \quad \text{---------------------(1)}$$

in which P_a, P_c = the total hydrostatic pressure in the channel A and channel C, respectively, Q_a, Q_c = the discharge in channel A and C, V_a, V_c = the average velocity across the section in channel A and channel C, Y_a, Y_c = the depth in channel A and channel C, and W = the unit weight of fluid.

Simplifying the above relation yields

$$\frac{Y_a^2}{2} + \frac{V_a^2 Y_a}{g} = \frac{Y_c^2}{2} + \frac{V_c^2 Y_c}{g} \quad \text{---------------------------(2)}$$

The continuity equation is

$$V_a Y_a b = V_c Y_c \left(\frac{Q_a}{Q_c}\right) b \quad \text{---------------------------------(3)}$$

By substituting the mean Froude numbers in inlet and outlet channel, respectively, equation (3) becomes

$$\left(\frac{Y_a}{Y_c}\right)^3 = \left(\frac{F_c}{F_a}\right)^2 \left(\frac{Q_a}{Q_c}\right)^2 \quad \text{-----------------------------------} \quad (4)$$

where $F_c = \frac{V_c}{\sqrt{gY_c}}$ and $F_a = \frac{V_a}{\sqrt{gY_a}}$ are Froude numbers.

Combining equations (1) and (4) yields

$$\left(\frac{Q_a}{Q_c}\right)^2 \left(\frac{F_c}{F_a}\right)^2 = \left(\frac{F_c^2 + 0.5}{F_a^2 + 0.5}\right)^{3/2} \quad \text{-----------------------------} \quad (5)$$

For small F_a and F_c, the above equation can be expressed by

$$F_c \simeq \left(\frac{Q_c}{Q_a}\right) F_a \quad \text{---} \quad (6)$$

For large F_a and F_c, taking logarithm and simplifying, one obtains

$$\frac{4}{3}\log F_c - \log(F_c^2 + 0.5) = \frac{4}{3}\log F_a - \log(F_a^2 + 0.5) - \frac{4}{3}\log\left(\frac{Q_a}{Q_c}\right) \quad \text{--- -------------------------} \quad (7)$$

A plot of F_a against F_c for a particular value of Q_a/Q_c exhibits a linear relationship for $F_c \leq 0.1$ as shown in Figure 4. The experimental data is seen to be in good agreement with the theory. This illustrates that Taylor's assumptions are justified in this case of combining flow.

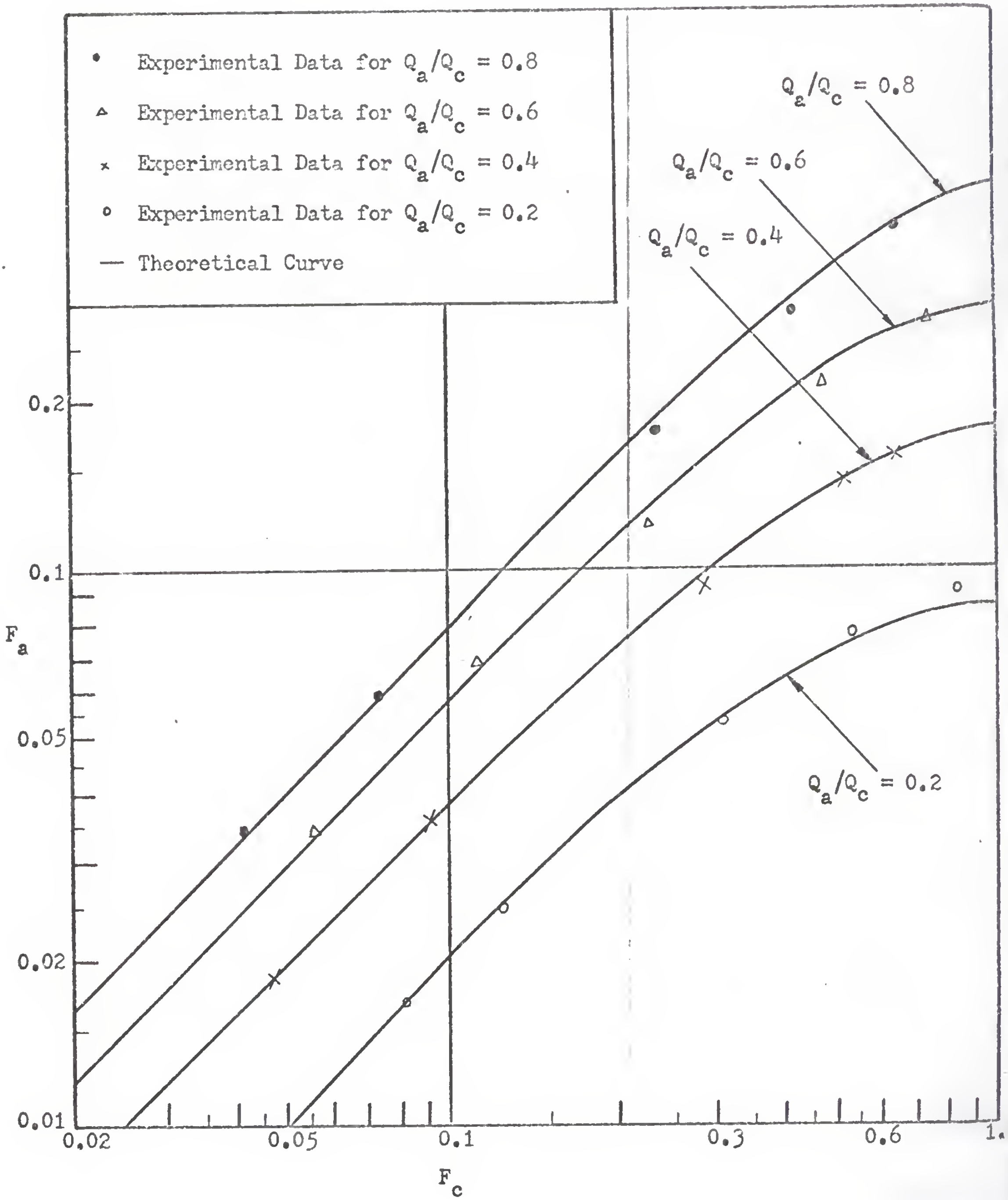

Fig. 4. Values of F_c Versus F_a With Isolines of Q_a/Q_c

Energy Consideration For Main Channel

In this section, the principle of the conservation of energy is applied in the analysis of the flow in the inlet and outlet channel. Thus, the energy loss due to the formation of a hydraulic jump, friction and the turbulence in the junction is disregarded and will be discussed subsequently.

Bernoulli's equation gives

$$\frac{V_a^2}{2g} + Y_a = \frac{V_c^2}{2g} + Y_c \quad \text{------------------------------}(8)$$

Combining equation (8) with continuity equation (4) yields

$$\left(\frac{F_c}{F_a}\right)^2\left(\frac{Q_a}{Q_c}\right)^2 = \left(\frac{F_c^2 + 2}{F_a^2 + 2}\right)^3 \quad \text{------------------------------}(9)$$

When F_a and F_c are both small, clearly, the right side of equation (9) can be equal to unity. Therefore, equation (9) can be expressed once again by

$$F_c \simeq \left(\frac{Q_c}{Q_a}\right) F_a \quad \text{------------------------------------}(10)$$

This equation is the same as equation (6). This indicates that for the condition of small F_a and F_c, both the momentum and energy principles can be applied to solve the combining flow. Taking the logarithm of both sides of equation (9), we have

$$\frac{2}{3} \log F_c - \log(F_c^2 + 2) = \frac{2}{3} \log F_a - \log(F_a^2 + 2) - \frac{2}{3} \log \frac{Q_a}{Q_c} \quad \text{---}$$

$$\text{-----------------------------------}(11)$$

Equation (11) is shown graphically in Figure 5 for various ratios of Q_a/Q_c. The lack of agreement between theory and experiment, especially for high Froude

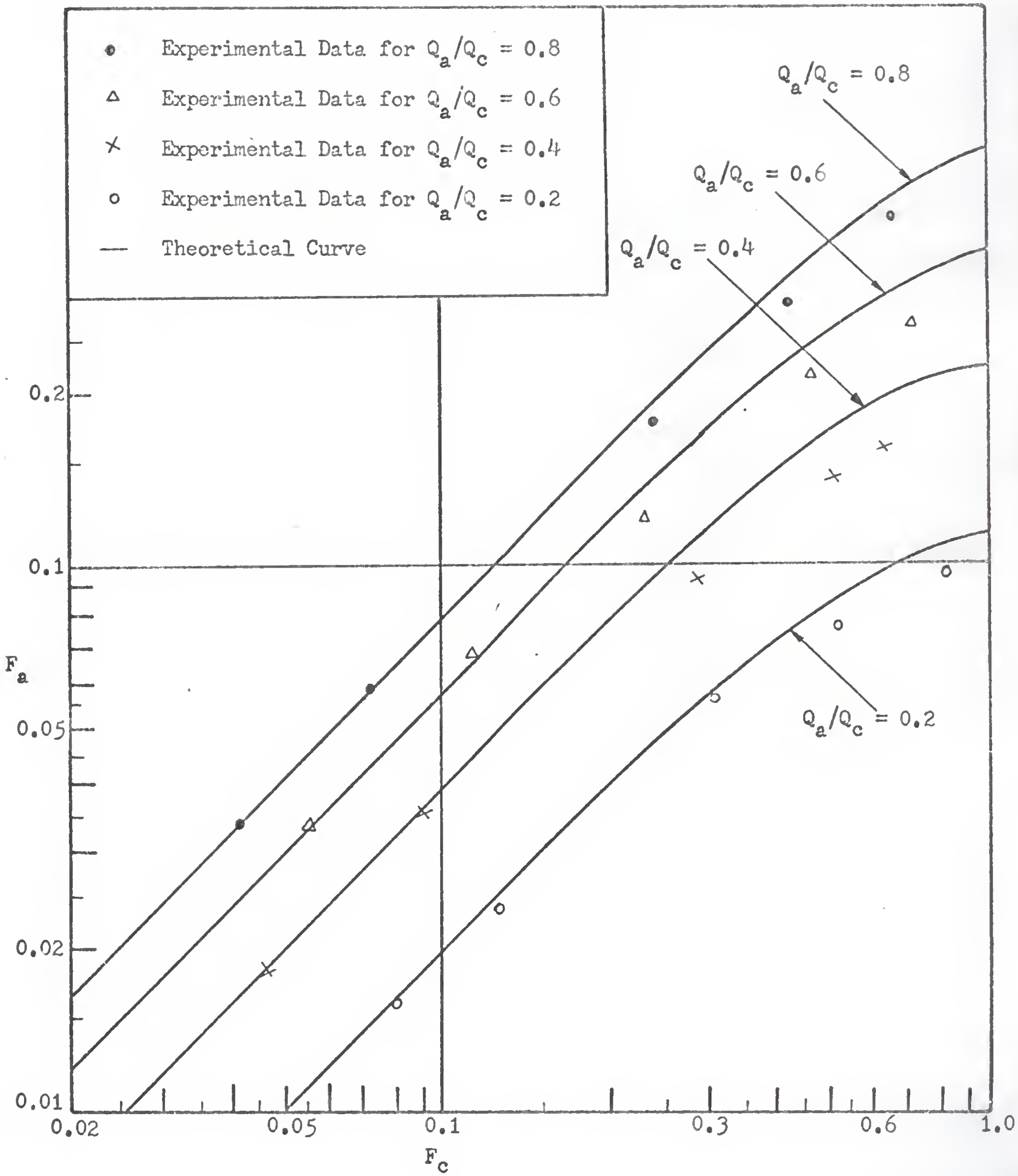

Fig. 5. Values of F_c Versus F_a With Isolines of Q_a/Q_c

numbers, is due to the neglect of energy loss at the junction. Therefore, in analysing the combining flow for higher Froude number, the energy theory can not be used unless the energy loss in the junction can be determined.

Energy Loss In Main Channel

(a) Energy Loss Due To Hydraulic Jump

A hydraulic jump may form in one or both of the inlet channels, depending upon the junction design, the discharge, velocities, and related flow condition in the adjoining channels. It is assumed that a hydraulic jump forms at the outlet section just after the flow passes through the junction. Equation (9) is then applied to relate the flow upstream of the junction and the flow in the junction by changing F_c to F_j, where the subscript j refers to the flow in the junction immediately before the jump.

On taking sections before the jump in the junction and after the jump in the outlet channel, the momentum equation and continuity equation combine to yield

$$F_j^2 = \frac{Y_c}{2\,Y_j}\left(1 + \frac{Y_c}{Y_j}\right) \qquad \text{------------------------------------} \quad (12)$$

The energy loss, E, across the jump in a horizontal, rectangular channel was determined by Bresse early in 1860, and can be written as

$$\frac{\Delta E}{Y_j} = -\frac{1}{4}\,\frac{Y_j}{Y_c}\left(1 - \frac{Y_c}{Y_j}\right)^3 \qquad \text{----------------------------} \quad (13)$$

This equation could be helpful to evaluate energy loss due to the hydraulic jump in the horizontal, rectangular channel for the combining flow.

(b) Energy Loss In The Junction

The flow in the junction itself is complicated and may include hydraulic jumps, recirculation regions, and both subcritical and supercritical flows which will produce much energy loss. This total energy loss may be determined by the principle of the conservation of energy. Two sections are taken as shown in Figure 6.

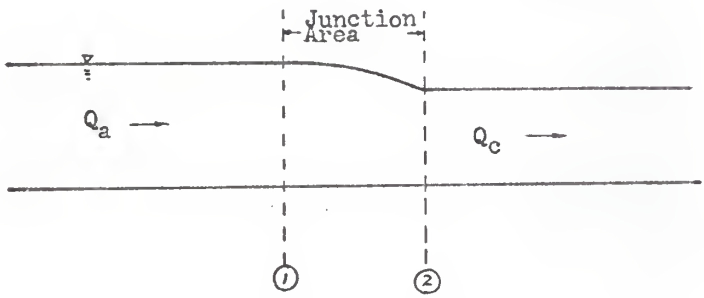

Figure 6. Flow Profile in Main Channel

Section (1) is just upstream of the junction and section (2) downstream of the junction. The energy loss, ΔE, can be expressed by

$$\Delta E = (Y_a - Y_c) + \left(\frac{V_a^2}{2\,g} - \frac{V_c^2}{2\,g}\right) \text{------------------------------}(14)$$

Combining equation (14) with continuity equation (4) yields

$$\frac{\Delta E}{Y_c} = \left(\frac{Y_a}{Y_c} - 1\right) + \frac{F_c^2}{2}\left[\left(\frac{Y_c}{Y_a}\right)^2 \left(\frac{Q_a}{Q_c}\right)^2 - 1\right] \text{-----------------}(15)$$

The experimental data for the relationship between $\Delta E/\ Y_c$ and Y_a/Y_c with the discharge ratio Q_a/Q_c are shown in dimensionless plots in Figure 7.

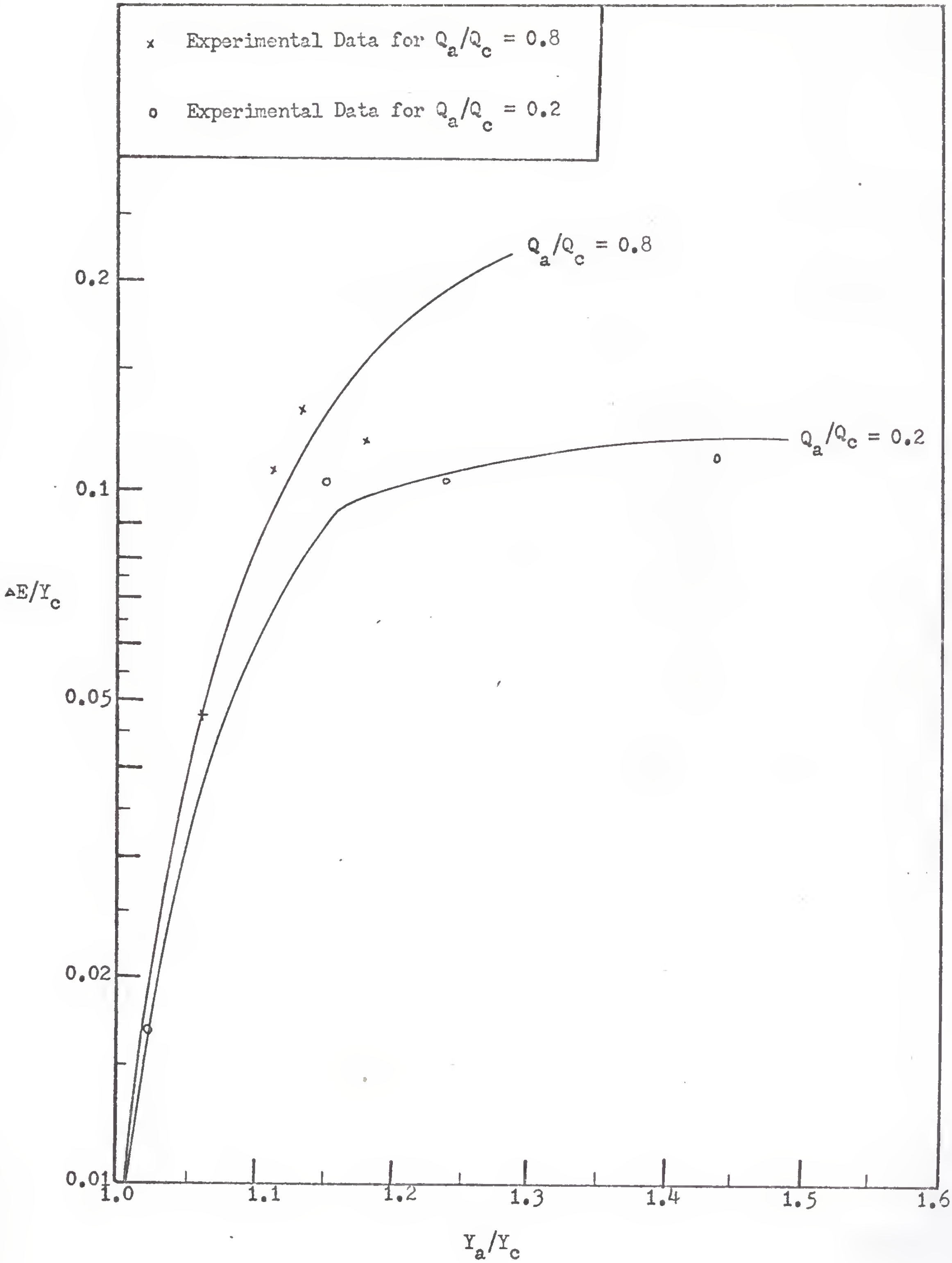

Fig. 7. Energy Loss In The Junction

DISCUSSION OF RESULTS

Comparison Of Momentum Theory And Energy Theory With The Experimental Data

In this section, a detailed comparison of the experimental results and the theoretical results are presented. Experimental data are shown in Figure 4 and Figure 5. The theoretical curves were plotted by evaluating equation (5) and equation (9). For low Froude numbers in main channel, $F<0.1$, both the momentum and the energy principles reveal that there is a linear relationship existing between small values of F_a and F_c with the constant of proportionality being Q_a/Q_c. In this case, the agreement with both the momentum and the energy theory is seen to be quite good. This agreement supports the conclusion that all the aforementioned assumptions are justified. At higher Froude numbers, the disagreement between the energy theory and the experimental data are shown in Figure 5. Figure 4 shows good agreement between the momentum theory curves and the experimental data.

A possible source of error in the energy conservation theory is from the assumption of negligible energy loss.

Energy Loss In The Junction

The energy loss in the junction is due to the friction, turbulence, and deflection. Experimental tests for depth ratio, Y_a/Y_c, from 1.01 to 1.45 with the discharge ratios Q_a/Q_c = 0.2 and 0.8 were run in order to see what happens for the energy loss in the junction. The experimental data are shown in dimensionless plots in Figure 7. It was found that the energy loss in the junction increases with the increasing of discharge ratio Q_a/Q_c at a constant value of Y_a/Y_c. In combining flow, the energy loss in the junction is usually high and can not be neglected, if the energy theory is used.

Performance Of Lateral Channel Flow

The performance of a lateral channel flow was examined experimentally. Results are shown in Figure 8. It was found that when two channels combine in a single channel the depths in the two channels upstream from the junction have nearly the same value for the condition of a horizontal bottom. For the case of supercritical flow in the outlet main channel, the depth of flow above the junction was not affected by backwater from the combining flow, hence, the depth of flow in the two converging channels was not necessarily the same.

Reverse Flow

Reverse flow occurred in the outlet main channel as a result of flow combination at the junction. Figure 4 reveals that the theory predicts the flow extremely well for high discharge ratios. Thus, it is apparent that reverse flows or the recirculation regions have little effect in the combining flow. Experimentally, it was found that the recirculation region ends before the end of the channel. The length of recirculation region, L, was found to be dependent upon the ratio of Q_a/Q_c. The experimental results show that L was 8.6 inches for $Q_a/Q_c = 0.2$, 7.4 inches for $Q_a/Q_c = 0.4$, and 6.8 inches for $Q_a/Q_c = 0.6$ under the same value of $F_c = 0.08$.

Flow In The Junction

The flow in the junction is complicated. A special case for $Q_a/Q_c = 0.6$ was observed. When $F_c = 0.2$, $Q_a/Q_c = 0.6$, the water surface in and around the junction was smooth, no bow waves or hydraulic jumps were formed. For $F_c = 0.6$ and $Q_a/Q_c = 0.6$, the flow in the junction began to become unstable, small waves could be found in the junction. On increasing F_c, the flow became turbulent. the water particles moved in irregular paths which were neither smooth nor fixed but which in the aggregate still represented the forward motion of the entire stream.

Prediction Of The Depth In Each Tributary Channel Just Upstream Of The Junction

If discharges in channels A and B, namely Q_a and Q_b, are known, then

$Q_c = Q_a + Q_b$. Assuming a value of Y_c solve for $F_c = Q_c / bY_c \sqrt{gY_c}$. From momentum theory or Figure 4 (F_c vs F_a chart), F_a can be found. Now Q_a and F_a are known, Y_a can be determined. The experimental data has shown that the depth in channels A and B are equal immediately above the junction, that is $Y_a = Y_b$.

Since Y_a and Y_b are determined, the height of channel wall can be predicted. An example is presented in the appendix.

<u>Wall Heights Necessary In the Vicinity Of The Junction</u>

The height of the side wall in the vicinity of the junction depends upon the junction design, the discharges, velocities, and related flow conditions. In this test, for F_c less than 0.6, the flow in the junction was smooth, and no special side walls are needed. At the higher Froude numbers, small waves developed and side walls higher than those normally provided are required.

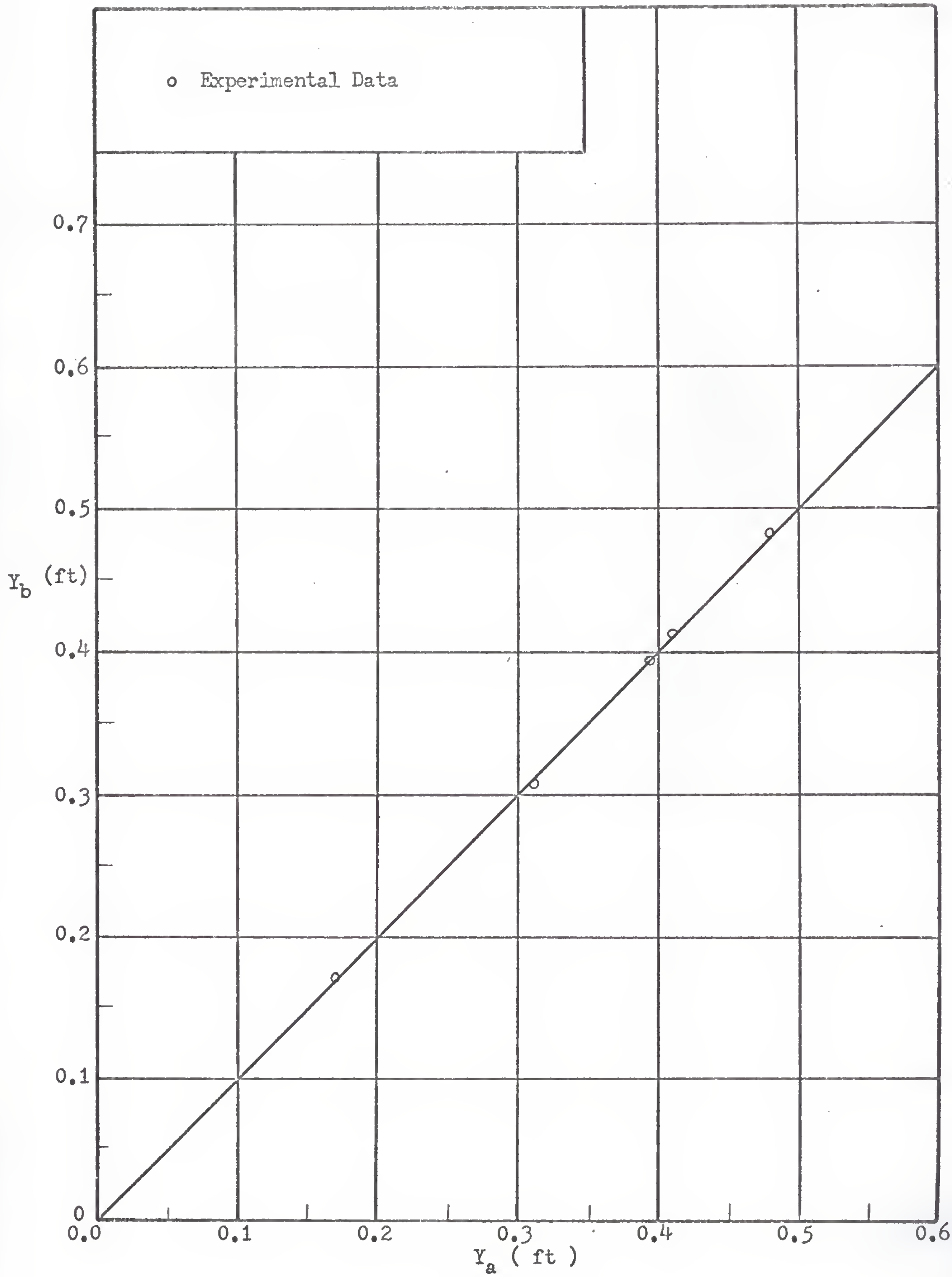

Fig. 8. Relationship between Y_a and Y_b

EXTENSION OF THE THEORY

Momentum Theory For Different Angles Of Intersection

In this section, an attempt is made to extend the theoretical analysis of a combining flow for different angles of intersection.

It has been shown previously that the energy theory could not be applied in combining flow at high Froude number due to the effects resulting from the neglect of energy loss in the junction. Momentum methods worked better. When two channels intersect at an angle θ, as shown in Figure 9, it is necessary to consider the momentum contributed by the lateral channel, $Q_b \, W \, V_b \cos \theta / g$.

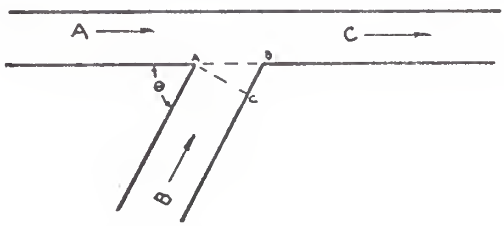

Fig. 9. Combining Flow With An Angle Of Intersection

Therefore, the net force F, acting in the direction A to C is

$$F_{a-b} = \frac{b \, W \, Y_a^2}{2} + \frac{b \, W \, Y_b^2 \cos \theta}{2} - \frac{b \, W \, Y_c^2}{2} + K \quad \text{---------------} \quad (16)$$

where K is an unknown reaction. The rate, M_{a-b}, at which momentum is changed in direction A to C is

$$M_{a-b} = \frac{Q_c \, W \, V_c}{g} - \frac{Q_a \, W \, V_a}{g} - \frac{Q_b \, W \, V_b}{g} \cos \theta \quad \text{----------------} \quad (17)$$

It was assumed that K was the component of the pressure force upon the portion of the wall marked BC in Figure 9. Therefore, equation (16) and equation (17) combine and yield

$$\frac{Q_a W V_a}{g} + \frac{W b Y_a^2}{2} + \frac{Q_b W V_b}{g} \cos \theta = \frac{Q_c W V_c}{g} + \frac{W b Y_c^2}{2} \quad \text{------(18)}$$

In this model case, the depth in channel A is equal to that in channel B above the junction. Substituting equation (4) into equation (18), we have

$$\left(\frac{F_c}{F_a}\right)^4 \left(\frac{Q_a}{Q_c}\right)^4 = \left(\frac{F_c^2 + 0.5}{F_a^2 + F_b^2 \cos \theta + 0.5}\right)^3 \quad \text{-------------------------(19)}$$

The application of equation (19) is limited because of the restrictions placed upon the experimental procedure. It has only been included to indicate the data that would be necessary in order to solve a general problem of this type.

Backwater Method For Combining Flow

The problems of combining flow in channels with some slope and regular channel section and river confluence may be solved by using the concept of continuity of unsteady flow and backwater curve computation.

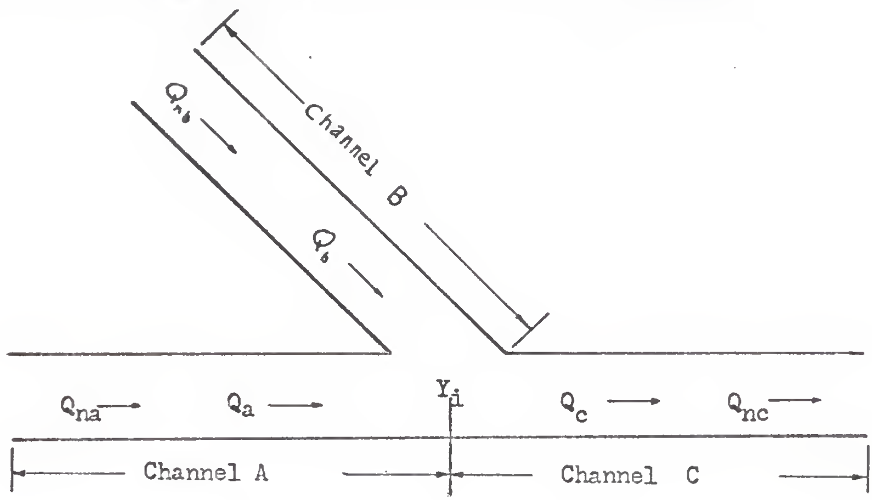

Figure 10. The Condition of Combining Flow

In Figure 10, the initial conditions of the flow in channel A, B and C are respectively, as follows: the normal depth Y_{na}, Y_{nb} and Y_{ci}; the channel slopes, S_{oa}, S_{ob}, and S_{oc}; and the roughness coefficient, n_a, n_b, and n_c. From these data the normal discharge Q_{na} and Q_{nb} can be computed by the Manning Formula. When water moves down channel B to the junction, it creates waves which will travel upstream in channel A. A reflected wave will also travel back up channel B. In this case, an unsteady flow occurs. After a period of time, a steady flow condition will develop. At this time the depth in channel B will change from Y_{nb} to Y_b. It was assumed that the depth in channel A remained Y_{na}. At the final steady flow condition, steady backwater curves will be formed in channel B and ChannelA. Meanwhile, in channel C, the depth will change from Y_{ci} to Y_c. The flow in all channels was assumed to be uniform and subcritical.

At the final steady-flow condition, the following conditions are evident: (1) the discharge in channel A remains the same, or $Q_a = Q_{na}$; (2) the depth of the three channels at the junction are all equal to Y_i; and (3) the sum of the discharge from channel A and channel B is equal to the discharge in channel C, or $Q_a + Q_b = Q_c$. If the depth, Y_i, at the junction could be determined, the backwater method could be applied to determine the depth in channel B and channel A.

The equation of continuity for unsteady flow may be established by considering the conservation of mass in an infinitesimal space between two channel sections, that is

$$B\frac{\partial Y}{\partial t} + \frac{\partial Q}{\partial X} = 0 \qquad \text{------------------------------------} \quad (20)$$

When the channel is to feed laterally with a supplementary discharge of q per unit length, then equation (20) may be written as

$$B \frac{\partial Y}{\partial t} + \frac{\partial Q}{\partial X} - q = 0 \quad \text{------------------------------------(21)}$$

in which B, Y and q are the surface width, the water surface elevation and the lateral flow per unit length, respectively. The distance, X, in the longitudinal direction on a horizontal datum plane and the elapsed time, t , are used as two independent variables.

By the Implicit Method, equation (21) is transformed into the corresponding finite difference equation set, that is

$$Q_h - Q_g + \frac{B_g + B_h}{2} \left(\frac{\Delta X}{\Delta t}\right) \left[\frac{Y_g + Y_h}{2} - \frac{Y_e + Y_f}{2}\right] - q \Delta X = 0 \quad \text{-----} \quad (22)$$

where the subscripts g and h indicate the flow condition at time, t_{i+1} , and the subscripts e and f at time, t_i , as shown in Figure 11.

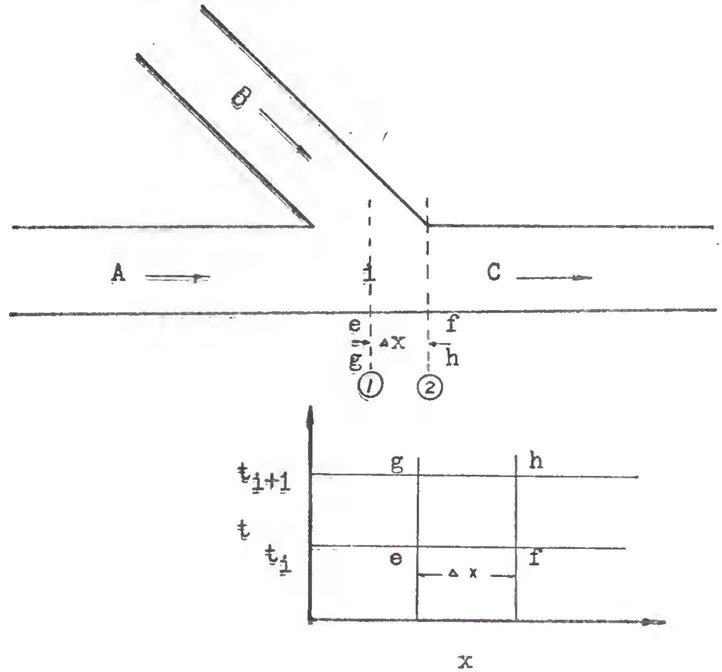

Figure 11, Relationship between Time and Distance

In Figure 11, two cross sections are selected. One is at the junction and the other is just a short distance, ΔX, downstream of the junction. The geometry at sections (1) and (2) is assumed to be simple and almost the same. When no water flows into the junction from channel B, the depths at section (1) and (2) are Y_{na} at time, t_i. As soon as channel B water feeds into junction, equation (22) will become

$$Q_c - Q_c + B_i \left[\frac{\frac{Q_c}{A_i} \Delta t}{\Delta t} \right] \left[Y_i - Y_{na} \right] - Q_b = 0$$

Simplifying, we have

$$Y_i = \frac{Q_b}{Q_c} \frac{A_i}{B_i} + Y_{na} \qquad \text{---(23)}$$

If channel C is a rectangular section, equation (23) becomes

$$Y_i = \frac{Q_c}{Q_a} Y_{na} \qquad \text{---(24)}$$

With Y_i determined, Q_c , Q_a [illegible] Y_{na} are known and the backwater curve can be computed. This approximate me[illegible] could be used to predict the freeboard height necessary to protect the [illegible] from overflowing.

CONCLUSIONS

Flow in open channel intersections was found to involve too many unknowns for a general solution. This model study is admittedly a very special case, as such an ideal set of conditions could hardly be expected to occur in practice. However, this model study appears to be helpful in an attempt to find a solution of the combining flow problem.

For a combining flow at low Froude numbers in a $\theta = 90^\circ$ model, the momentum and energy principles can both be applied to describe the flow in the main channel. At higher Froude numbers, the momentum theory works better. The flow in the branch can be predicted from the conditions of the main channel.

In this model study, the reverse flow region has little effect on the combining flow; no hydraulic jump occurred, but several small waves formed at high Froude number in and around the junction. The energy loss in the junction can not be neglected, especially at high Froude number, if the energy theory is used to solve the combining flow problem.

The flow in the junction itself is complicated, no previous investigation of this phenomenon is known to the writer.

RECOMMENDATIONS FOR FURTHER RESEARCH

The variables affecting combining flow are so numerous that no general solution applicable to all conditions can be found. Only some very special cases can be solved with model studies. This model study is one of a rectangular section and flat grade which will produce low velocities. Stable supercritical flow could not be produced. Further research is needed for the case of supercritical flow to obtain a clear understanding of combining flow. A more extensive experiment with different bottom slopes is recommended in order to set forth a more complete understanding and to provide a solution for practical engineering problems.

It would seem to the writer that if some constants for energy loss factor in the junction could be found that would give an approximate idea of what happens in combining flow in open channel, it would not be necessary to construct a model for every case.

ACKNOWLEDGMENTS

The writer acknowledges the instruction, guidance and critical review given by the major professor of this study, Dr. Richard M. Haynie, Department of Civil Engineering, Kansas State University. His encouragement and efforts made possible the completion of this thesis.

The writer wishes to express his appreciation for review of this thesis and the helpful suggestion contributed by Dr. Jack B. Blackburn, Head of the Civil Engineering Department, Kansas State University.

Acknowledgment is also given to Professor John E. Kipp and Professor Leonard E. Fuller for being on the advisory committee and reviewing the manuscript.

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APPENDICES

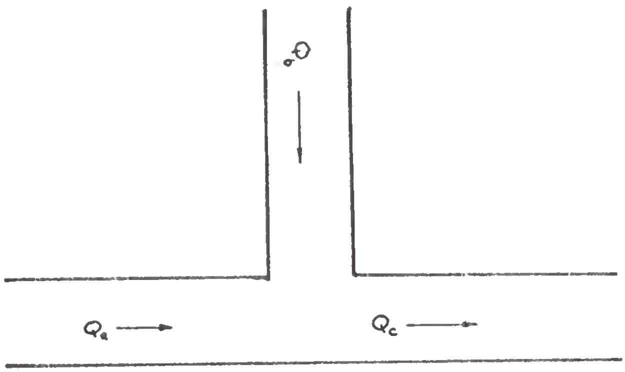
APPENDIX I

Flow Condition		Run Number	Quantity of Flow, Q(cfs)			Depth of Flow, Y(ft)		
			Channel A	Channel B	Channel C	Channel A	Channel B	Channel C
SUBCRITICAL FLOW	I	1	0.038	0.152	0.190	0.314	0.311	0.253
		2	0.035	0.140	0.175	0.258	0.258	0.179
		3	0.040	0.160	0.200	0.424	0.430	0.370
		4	0.015	0.060	0.075	0.370	0.376	0.334
		5	0.012	0.048	0.060	0.410	0.411	0.408
	II	1	0.080	0.120	0.200	0.315	0.313	0.229
		2	0.060	0.090	0.150	0.275	0.275	0.220
		3	0.070	0.105	0.175	0.410	0.410	0.358
		4	0.020	0.030	0.050	0.342	0.344	0.338
		5	0.015	0.023	0.038	0.434	0.433	0.429
	III	1	0.080	0.053	0.133	0.220	0.222	0.162
		2	0.060	0.040	0.100	0.212	0.211	0.177
		3	0.042	0.028	0.070	0.248	0.250	0.226
		4	0.042	0.028	0.070	0.390	0.396	0.364
		5	0.024	0.016	0.040	0.396	0.398	0.390
	IV	1	0.100	0.025	0.125	0.345	0.400	0.324
		2	0.080	0.020	0.100	0.168	0.170	0.142
		3	0.060	0.015	0.075	0.176	0.177	0.159
		4	0.040	0.010	0.050	0.443	0.441	0.390
		5	0.032	0.008	0.040	0.477	0.476	0.465
	V	No stable supercritical flow could be produced.						

APPENDIX II

Example

A branch channel of width 10 feet carrying a discharge of 40 cfs is located at 90° to a main channel having a width of 10 feet. The discharges in the inlet main channel is 60 cfs and the depth in the outlet main channel is 5 feet. Suppose all cross sections are rectangular and horizontal bottom. Predict the depth in the branch channel and inlet main channel after flow combination.



$Q_a = 60$ cfs

$Q_b = 40$ cfs

$\therefore Q_c = 60 + 40 = 100$ cfs. $\because Y_c = 5$ ft. is known,

$$\therefore F_c = \frac{Q_c}{\sqrt{g\, Y_c}\; b\, Y_c} = \frac{100}{\sqrt{32.2 \times 5}\; (10 \times 5)} = 0.1575$$

From Figure 4, $F_a = 0.094$ with $Q_a/Q_c = 60/100 = 0.6$ can be found.

Therefore, $Y_a^3 = Q_a^2 / g\, F_a^2\, b^2$

$$Y_a = 0.314 \left(\frac{60}{0.094 \times 10}\right)^{\frac{2}{3}} = 5.03 \text{ ft.}$$

Since the channel is rectangular in cross section and has a horizontal bottom cross section, $Y_a = Y_b = 5.03$ ft.

A MODEL STUDY OF COMBINING FLOW IN AN OPEN RECTANGULAR CHANNEL

by

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B. S., NATIONAL TAIWAN UNIVERSITY, 1964

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE UNIVERSITY
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1969

THESIS ABSTRACT

The variables affecting combining flow are so numerous that no general solution applicable to all conditions can be found. Only some very special cases can be solved with model studies. This paper is concerned only with the study of the phenomena in the combining flow of water in an open rectangular channel with horizontal bottom.

The principal problem of combining flow in open channel may be stated as; when two streams combine in a single channel, the depth just below the junction will be fixed by the backwater characteristics of that channel and the magnitudes of the combined rates of flow. The problem is to predict the depth in each tributary channel just upstream from the junction. In this $\theta = 90^\circ$ model, the momentum and energy principles can both be applied to describe the flow in the main channel at low Froude numbers. At high Froude numbers, the momentum theory works better. The depth in the branch channel upstream from the junction has nearly the same value as the depth in the main channel upstream from the junction. Energy loss in the junction is usually high, especially at high Froude number.