DISCHARGE CHARACTERISTICS OF THROATLESS FLUMES UNDER SUBMERGED CONDITIONS

Ngoc Diep Vo

A Thesis
in
The Department
of
Engineering

Presented in Partial Fulfillment of the Requirements
for the Degree of Master of Engineering at
Concordia University
Montréal, Québec, Canada

August 1986

ISBN 0-315-32227-6

ABSTRACT

DISCHARGE CHARACTERISTICS OF THROATLESS FLUMES UNDER SUBMERGED CONDITIONS

Ngoc Diep Vo

The submerged flow characteristics of the throatless flumes are derived on the basis of a semi-empirical analysis. A pressure correction factor is determined experimentally to account for the non-hydrostatic pressure distribution at the throat section of the flume which acts as a control. This factor is incorporated in the governing equation which is developed on the basis of the momentum principles. Both the present and previously published experimental data are used to validate the expressions developed.

ACKNOWLEDGEMENTS

I would like to thank to Dr. A. S. Ramamurthy for suggesting the research topic. I also wish to express my thanks to Dr. M. V. J. Rao and Mr. R. Balachandar for assisting me in the development of the test flumes.

I gratefully acknowledge the assistance of Mr. Louis Stankevicius, Technical Officer, Civil Engineering Laboratories and the staff of the university machine shop during the course of the present studies.

Lastly, I would like to dedicate this work to my wife, Duyen, for her best understanding and supports.

August, 1986
Montréal, Québec

Ngoc Diep Vo

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

b) Variations of T_s in terms of y_2/y'_1 with y_1/B and of Modular limit in terms of y_2/y'_1 with y_1/B_1.

Fig. 8 - Comparison of free flow discharge relations.

NOTATIONS

The following symbols are used:

b, b_1, b_2, b_3	=	coefficient (Eqs 9,13,14 and 18)
B	=	width at flow section considered
C	=	correction factor for force at diverging wall
f	=	reduction factor, Q/Q_f
g	=	acceleration due to gravity
h	=	piezometric head
k	=	coefficient for free flow discharge (Eq. 1)
K	=	pressure distribution coefficient
l	=	length of diverging wall of the flume
m, m_1, m_2, m_3	=	coefficient (Eqs. 9,13 and 14)
M	=	momentum term
n	=	exponent for free flow discharge (Eq. 1)
P	=	pressure force, pressure
Q	=	discharge, discharge under submerged conditions
r	=	throat depth to approach depth ratio, y_t/y'_1
V	=	mean velocity
x	=	throat width to approach or exit width ratio, B_t/B_1.
y	=	flow depth
y'_1	=	flow depth at section 1 under submerged conditions
Z	=	elevation with respect to floor level
β	=	momentum coefficient
γ	=	specific weight of water
ρ	=	density of water

σ	=	submerged ratio, y_2/y'_1
θ	=	diverging angle

Subscripts:

1	=	approach section
2	=	section 2
a	=	location at 1/3 of flume contraction
b	=	location at 5/6 of flume expansion
f	=	free flow conditions
m	=	measured
N	=	normal to the wall
t	=	throat section
w	=	along wall
WT	=	sum along wall

CHAPTER 1

INTRODUCTION

1.- INTRODUCTION

1.1 - General remarks:

An essential aspect of water resources management is the determination of the flow rate in open channels. In irrigation channels, water treatment plants and water reclamation works, critical flumes can be used to measure the flow rates. In these flumes, the depth y_t at the constricted section is assume to be critical. The most common critical depth flume is the Parshall flume (1,3). One of the recent developments related to the measuring structures (6 to 10) is the throatless flume (Fig.1a). The advantages claimed for this flume are the following:

(i) It operates well under both free flow and submerged flow conditions;

(ii) it has low head-loss because of its level floor;

(iii) it is very easy to design and very simple to construct.

1.2 - Previous studies:

Skogerboe (8) proposed and tested rectangular throatless flumes having identical lengths of converging and diverging sections under free flow conditions. Later, Bennet (2) and Skogerboe (9) conducted additional tests on groups of geometrically similar flumes and proposed the following equation for the discharge Q_f under free flow conditions:

$$Q_f = kB_t^{1.025} h_a^n \qquad (1)$$

In Eq.(1), k and n are coefficients which depend on the flume geometry; h_a= piezometric head at location 'a' (Fig.1a) and B_t=throat width. Keller (6) rightly points out that the effect of non-similar entrance conditions contributed to the scale effects in the works of Bennet (2) and Skogerboe (9). He also reported the absence of scale effects in geometrically similar flumes. Later, Keller (7) conducted systematic tests on throatless flumes under submerged conditions in which a drowned hydraulic jump occurs in the expanding section TBEF (Fig.1a). His data indicate that scale effects occur at higher submergences in very narrow flumes. However, he successfully explained these effects in terms of dissimilar boundary growth.

1.3 - Present study:

In the present study, the modular limit for the flume is determined as function of the ratio y_1/B_1 where y_1 is the upstream depth and B_1 is the width at the entrance and exit sections of the flume. For given value of y'_1/B_1, the discharge Q passing through the flume is determined in terms of the submergence ratio $\sigma = y_2/y'_1$. Here, y_2 is the depth at section 2 (Fig.1). Based on semi-empirical approach, relationship linking Q, σ and y'_1/B_1 is also developed on the basis of the momentum equation. Experiments were conducted on three geometrically similar flumes (Table 1) to verify the equation developed. The test results appear to agree reasonably well with the predicted discharge relationship.

CHAPTER 2

THEORETICAL CONSIDERATIONS

2.- THEORETICAL CONSIDERATIONS

2.1 - The governing equation:

Assumptions: The following assumptions are made in developing the governing relations for the flow discharge rate through throatless flume of width B, for which Q, y, V and β denote the discharge, depth, mean velocity and momentum coefficient respectively. Subscripts 1, t and 2 refer to the upstream, throat and downstream sections (Fig.1a), and θ is the diverging angle of the expansion section TBEF:

(i) The cross section of the flume is rectangular and the floor is horizontal;

(ii) The boundary shear force is negligible in the section TBEF and BCDE of the flume (Fig.1a);

(iii) The momentum coefficient β_t at the throat section is unity and the momentum coefficient β_2 at section 2 (Fig.1a) varies only slightly with the submergence ratio σ.

Applying the momentum equation for the control volume TCDF in Fig.1, one gets:

$$P_t + P_w + \rho Q V_t = P_2 + \rho \beta_2 Q V_2 \qquad (2)$$

where, ρ = density of water and

$$P_t = \frac{\gamma}{2} K_t y_t^2 B_t \qquad (3)$$

Here, γ = specific weight of water, K_t = average pressure correction factor.

Further,

$$P_w = 2\,[\text{Normal force } P_N \text{ on the expanding wall}] \sin\theta$$
$$= 2P_N \sin\theta$$

where, θ = diverging angle

Assuming that the surface profile is linear from the throat to the exit section, for situation in which the pressure distribution is hydrostatic:

$$P'_w = 2\int_0^l \frac{\gamma}{2} y^2 dx \ \sin\theta$$
$$= \frac{\gamma}{6} (B_1 - B_t)(y_t^2 + y_1 y_2 + y_2^2) \qquad (4)$$

In general, the surface profile in the expansion of the flume is not linear from the throat to the exit section (fig.2e). Further, the wall pressure is not hydrostatic, especially near the throat section (Fig.2d). To account for these two factors, coefficient 'C' is used in Eq.(4) to express the actual pressure force component P_w in terms of the linear profile. Thus,

$$P_w = C\,\frac{\gamma}{6}\,(B_1 - B_t)\,(y_t^2 + y_2 y_t + y_2^2) \tag{5}$$

Further, the pressure force at section 2 is

$$P_2 = \frac{\gamma}{2}\,y_2^2\,B_1 \tag{6}$$

Lastly, substituting Eq. (3), (5) and (6) in Eq. (2), and simplifying:

$$\frac{Q^2}{gB_1^{\,5}} = \frac{1}{6}\left(\frac{y_1'}{B_1}\right)^3\left(\frac{x}{\beta_2 x r - \sigma}\right)\left[\sigma^3 r(C - Cx - 3) + \sigma^2 r^2 (C - Cx) + \sigma r^3 (3K_t x + C - Cx)\right] \tag{7}$$

where,

$$r = \frac{y_t}{y_1'},\quad x = \frac{B_t}{B_1}\quad \text{and}\quad \sigma = \frac{y_2}{y_1'} \tag{8}$$

One notes that x = constant for geometrically similar flumes.

2.2 - Variation of K_t with y'_1/B_1 and σ:

To obtain the static pressure correction coefficient K_t at the throat section, actual pressure distributions were determined in the scale model of the throatless flume (Fig.1a). The procedure consisted of several steps. At first, the pressure distribution at the throat section was plotted where the depth was y_t and a line was fitted through the free surface to yield an equivalent area for the pressure diagram (Figs. 2a, and 2b). The procedure was repeated at 5 vertical locations of the throat section including the two wall sections to account for the slight lateral variation of the pressure correction coefficient K. The average value of the pressure correction factor denoted as K_t was determined using these 5 values (Fig. 2c). The values of K_t were plotted against y'_1/B_1 and σ (Fig. 3.1). The detailed procedure to obtain Fig. 3a from the test data is given in Appendix II. This yielded the following approximate linear relation for the coefficient K_t (Fig. 3a):

$$K_t = m_1\left(\frac{y'_1}{B_1}\right) + b_1 \qquad (9)$$

for $x = 0.52$, and the experimental ranges:

$$0.30 \leq y'_1/B_1 \leq 1.50 \text{ and } 0.805 \leq \sigma \leq 0.960.$$

$$m_1 = 0.64\sigma - 0.71 \qquad \text{for } \sigma \leq 0.89$$

$$m_1 = 1.20\sigma - 1.20 \qquad \text{for } \sigma > 0.89$$

and

$$b_1 = 0.55\sigma + 0.42 \qquad \text{for the entire range of } \sigma.$$

2.3 - Variation of C with y'_1/B_1 and σ:

The values of the pressure correction factor K along the vertical section of the expansion walls was determined using the static wall pressure data and step one of the procedure described earlier. Using the values of K along the wall (Fig. 2d) and the water surface profile (Fig. 2e), the variation of the normal wall pressure force per unit width along each of the expansion walls was determined (Fig. 2f). The total areas of these diagrams denote the total normal pressure force P_N over the walls. Knowing the force P_N, the axial component P_w can be determined. Thus,

$$P_w = 2P_N \sin\theta = \frac{2P_N}{\sqrt{37}} \qquad (10)$$

For a radial expanding channel, one obtains the following expression for the ideal axial force component P'_w (12) for a situation in which the pressure distribution is hydrostatic and the water surface is linear:

$$P'_w = \frac{\gamma}{6}(B_1 - B_t)(y_t^2 + y_2 y_t + y_2^2) \qquad (11)$$

As mentioned earlier, the surface profile in the section TBEF (Fig.1a) is not linear from the throat to the exit section BE (Fig. 2e). Further, the wall pressure is not hydrostatic especially near the throat section TF (Fig. 2d). To relate the test data related to the axial force P_w with the axial force P'_w for the linear profile, the factor C is used. Thus,

$$P_w = CP'_w \qquad (12)$$

The values of C were plotted against corresponding values of y'_1/B_1 and σ (Fig. 3.1). This yielded the following approximate linear relation for C (Fig. 3b):

$$C = m_2\left(\frac{y'_1}{B_1}\right) + b_2 \qquad (13)$$

for the above cited experimental ranges of variables:

$m_2 = 0.61\sigma + 0.34$ for $\sigma \leq 0.89$

$b_2 = 3.89\,\sigma - 2.55$ for $\sigma \leq 0.89$

and,

$m_2 = 1.71\sigma - 1.73$ for $\sigma > 0.89$

$b_2 = 1.43\sigma - 0.36$ for $\sigma > 0.89$

2.4 - Variation of $r = y_t/y'_1$ with y'_1/B_1 and σ:

Owing to the difficulty of the depth measurement at the throat at low submergences and free flow conditions, a relationship in terms of the upstream depth y'_1 is desired. The experimental values of $r = y_t/y'_1$ have been plotted against the corresponding values of y'_1/B_1 and σ (Fig. 3.1). This yielded the following approximate linear fit for r (Fig. 3c):

$$r = m_3 \left(\frac{y_1'}{B_1}\right) + b_3 \tag{14}$$

For the above cited experimental ranges of variables:

$m_3 = -0.31\sigma + 0.36$ for $\sigma \leq 0.89$

$b_3 = 0.35\sigma + 0.51$ for $\sigma \leq 0.89$

and,

$m_3 = -1.21\sigma + 1.17$ for $\sigma > 0.89$

$b_3 = 1.64\sigma - 0.64$ for $\sigma > 0.89$

2.5 - Variation of β_2 with σ :

The velocity distribution at section 2 (Fig. 2g) is found to be affected partially by the control of the downstream depth. As result, the momentum coefficient β_2 varies slightly from unity. Experiments yielded the following approximate linear relation for β_2 in terms of σ (Fig. 3d):

$$\beta_2 = 0.19\,\sigma + 0.86 \qquad (15)$$

Table 2 summarizes the values of β_2 and the various empirical coefficients of Eqs. (9,13,14 and 15). The ranges of variables covered by the test program were restricted by the equipment limitation.

Using Eq. (7) and the empirical relations which link K_t, C, r and β_2, with y'_1/B_1 and σ (Table 2), the dependence of f (= Q/Q_t) on σ and y'_1/B_1 can be established. This dependence is shown in the insert of Fig. 4a. The dashed line in Fig4a and its insert denote the mean trend followed by the predicted variation of f with σ when y'_1/B_1 is disregarded. A third degree polynomial fit yielded the following expression of f vs σ:

$$f = 34.8 - 121\,\sigma + 145\,\sigma^2 - 58.8\,\sigma^3 \qquad (16)$$

Using Eq. 7 and the empirical coefficients K_t, C, r and β_2, design charts such as Fig. 4c can be developed to relate Q_2/qB_1^5 with y'_1/B_1 and $\sigma = y_2/y'_1$. The solid line in Fig. 4c denotes this predicted relation for free flow conditions ($\sigma \leq$ 0.805). A fourth degree polynomial fit yielded the following expression for Q_2/gB_1^5 vs y'_1/B_1 when $\sigma \leq 0.805$ and $0.3 \leq y_1/B_1 \leq 1.5$,:

$$\frac{Q^2}{gB_1^5} = -0.027\left(\frac{y_1}{B_1}\right) + 0.125\left(\frac{y_1}{B_1}\right)^2 - 0.109\left(\frac{y_1}{B_1}\right)^3 + 0.133\left(\frac{y_1}{B_1}\right)^4 \qquad (17)$$

Eq.(18)

An alternate expression such as relating Q^2/gB_1^5 with y'_1/B_1 in free flow conditions can also be developed (Fig. 5b):

$$\frac{8\,Q^2}{gB_1^5} = \left(\frac{y_1}{B_1}\right)^b \qquad (18)$$

where, $b = 3.22 + 0.266\left(\frac{y_1}{B_1}\right)$

For submerged flow conditions ($\sigma > 0.805$), the mean variation of f ($=Q/Q_f$) with σ ($= y_2/y'_1$) shown in Fig.4a was used in conjunction with the free flow discharge characteristic curve to obtain the dashed lines denoting the variation of

Q^2/gB_1^5 with y'_1/B_1 for selected values of σ (Fig. 4c).

Also, experimental values of h_a/B_t were plotted against the corresponding y_1/B_1 (Fig.5a). This yielded the following linear relation to relate h_a/B_t with y_1/B_1:

$$\frac{y_1}{B_1} = 0.56\left(\frac{h_a}{B_t}\right). \tag{19}$$

Keller's data were transferred and expressed in terms y_1/B_1 (Figs. 4c, 6b).

CHAPTER 3

EXPERIMENTAL SET-UP AND PROCEDURE

3 - EXPERIMENTAL SET-UP AND PROCEDURE

The experimental set-up used is shown in Fig. 1b. Three geometrically similar rectangular throatless flumes (Table 1) were built using 12mm thick plexiglass sheets. These flumes were located in horizontal glass-walled channel which was 47cm deep. The approach and exit sections had widths matching width of the test flume (Fig. 1b). Sufficient number of pressure taps of diameter 1.5mm spaced in square grid network at 50mm intervals were provided in the floor and in the diverging walls. A static pressure probe of diameter 3mm with a flattened limb (5) was used to record the static pressure distribution at section 2 and the flume throat.

The pressure distribution at the throat section was studied for wide range of discharges at various degrees of submergence. The depth y_1 or y'_1 was measured at section 1 which was at $1B_1$ upstream of the entrance section. The depth y_2 was measured at section which was 3.5 B_1 from the exit section where the velocity distribution is not highly distorted (Fig.1b). A standard pitot tube of diameter 3mm was used to obtain the velocity profiles. All pressure heads were measured to the nearest 0.5mm of water column.

Flow depths and surface profiles were measured by means of point gages which recorded depth to the nearest 0.1mm. A standard 60° V-notch was used to measure the discharge. The maximum error in the discharge measurement was estimated to be 3%.

CHAPTER 4

ANALYSIS OF RESULTS

4 - ANALYSIS OF RESULTS

4.1 - General remarks:

Both the transition submergence T_s and the modular limit for the throatless flume are determined on the basis of test data. The former is defined as the limit of the point at which the flow in the up-stream section stays unaffected by submergence (Fig. 6a). Modular limit denotes the limit of submergence at which flow reduction of 1% is registered for the same up-stream depth (y'_1).

Keller (7) obtained the transition submergence T_s for the throatless flumes and observed that scale effects exist in very narrow flumes at very high values of h_a/B_t and h_b/h_a. The value of the transition submergence T_s can be also found by plotting $Q/\sqrt{g}B_1 y'^{1.5}_1$ against y'_1/B_1 and y_2/y'_1. In graph such as Fig. 6a the value of T_s corresponds to point at which the factor $Q/\sqrt{g}B_1 y'^{1.5}_1$ begins to decrease due to submergence effects associated with higher values of σ. For instance, $T_s = y_2/y'_1 = 0.805$ in Fig. 6a (test #4). For all the tests, sketches similar to 6a were developed using the basic data (Tables 4 and 5). Only representative sketches are shown in Figs. 6a-i to 6a-xii.

To find the existence of scale effects in submerged flows, sketches such as Fig. 6a were drawn (7). These in turn were used to plot y'_1/B_1 as function of $Q/\sqrt{g}B_1y'_1{}^{1.5}$ for various values of $\sigma = y'_2/y'_1$ (Figs. 6b to 6e). For instance, to sketch Fig. 6d, σ is selected to be 0.90 and the corresponding paired values of $Q/\sqrt{g}B_1y'_1{}^{1.5} = 0.298$ and $y'_1/B_1 = 0.48$ are obtained from Fig. 6a. To complete Fig. 6d, the process was repeated for other values of y'_1/B_1. Fig. 6c to 6e were developed in a similar fashion using sketches such as Fig. 6a for other values of the test variables. Fig. 6b is sketched for free flow conditions ($\sigma \leq 0.805$). Figs. 6b to 6e show that scale effects are small and are confined to larger submergence. A plot of h_a/B_t vs $Q/\sqrt{g}B_th_a{}^{1.5}$ is also included in Fig. 6b to compare the present results with Keller's results (7).

In Fig. 7a, the transition submergence is shown in terms of the variable h_b/h_a using the results of the present tests and those of Keller (7). Figs. 7a and 7b show the transmission submergence and modular limit diagrams for submerged flow conditions in which y_2/y'_1 is the main variable. The change in the shape of the two graphs denoting the transition submergence in term of h_b/h_a and y_2/y'_1 in Fig. 7a can be attributed in part to the effects of curvilinear flow which renders the pressure distribution to be non-hydrostatic at section "a" where h_a is registered. In

Fig. 7b, the modular limit based on experimental data appears to vary from 0.83 to 0.815 in the range of y_1/B_1 covered in the test. This compares favorably with the value of $\sigma = 0.815$ for the predicted modular limit (insert, Fig. 4a).

4.2 - Momentum relationship:

The left hand side and right hand side of Eq. (2) denote the momentum at the terms M_t and M_2 corresponding to section t and section 2 (Fig. 1). Using the empirical coefficients K_t, C, r and β_2 of Table 2, the correlation between M_t and M_2 is shown in Fig. 4b. The ratio $(M_t - M_2)/M_t$ is a measure of the agreement between the values of the momentum terms at sections t and 2. For the test series reported, maximum deviation of 2.5% was noted for the ratio $(M_t - M_2)/M_t$. In general, the momentum balance was close for the two sections considered and this validates the use of approximate linear relationships developed for the various empirical coefficients and the general approach adopted.

4.3 - Submerged flow discharge relationships:

For submerged flow conditions, Eq. (7) was used to determine the predicted discharge Q (insert, Fig. 4c). The values of Q correlate reasonably well with the measured values of the discharge Q_m in the range of y'_1/B_1 and σ covered in the tests. The ranges of y'_1/B_1 and σ covered in the test series do fall within the practical limits encountered in the field. For instance, at very low values of $y'_1/B_1 < 0.3$; boundary friction terms can be significant. For values of $y'_1/B_1 >$ 1.5, the curvature of the flow is high and the linear correlation coefficients for K_f, C and r may not be valid. Accuracy of discharge measurement was also a key factor in the choosing the range of variables during the tests.

As stated earlier, the predicted relationship between the flow reduction factor $f = Q/Q_f$ and submergence ratio σ almost collapse into a single curve indicating the small influence of y'_1/B_1 (insert, Fig. 4a). Experimental data related to the smallest flume contribute to some scatter in the relationship between f and σ based on test data (Fig. 4a). However the experimental mean curve and the predicted mean curve relating f and σ in Fig. 4a display a close resemblance to each other.

The dotted lines in Fig. 4c is a design chart which can be used for determining the flume discharge under submerged flow conditions. Under submerged conditions, the measurement of two depths contribute to lower accuracies in the determination of discharge. However, under free flow conditions, the geometrical configuration of the throatless flume leads to considerable head losses in the expansion section of the flume. Consequently, if conservation of head is an important criteria, one could use the throatless flume under submerged conditions to reduce the head loss, although the prediction of Q is slightly less accurate.

4.4 - Comparison with previous studies:

Keller (7) used the following non-dimensional parameters in plotting experimental data: $Q/\sqrt{g}B_t h_a^{1.5}$, h_a/B_t and h_b/h_a. The transition submergence in terms of h_b/h_a varies deeply with h_a/B_t (Fig. 7a). In the range of y_1/B_1 covered, it was found that the transition submergence $T_s = 0.805$ and the modular limit is almost constant at 0.815 (Figs. 7 and 7b).

Under free flow conditions, the present relation Q^2/gB_1^5 vs y_1/B_1 predicted from the momentum principles Eq. (7) agrees quite well with the relations developed from the energy principle (10). The comparison between the trends suggested by the Eq. (7), Eq. (17), Eq. (18) and Eq. (14) of Ref. 10 are shown in Fig. 8 of Appendix VII.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5 - CONCLUSIONS AND RECOMMENDATIONS

5.1 - Conclusions:

The following conclusions can be drawn for the performance of the throatless flumes under submerged conditions:

(i) Scale effects appear to be small and are confined to very high values of submergence.

(ii) Test data indicate that the momentum equation can be used to relate the dimensionless discharge Q^2/gB_1^5 with y'_1/B_1 and σ in the practical ranges of $0.3 \leq y'_1/B_1 \leq 1.5$ and $0.805 \leq \sigma \leq 0.960$. To obtain discharge characteristics of throatless flumes, one should obtain the pressure correction coefficient K_t to account for the curvilinear nature of the flow.

(iii) For field use, a design chart such as Fig. 4c can be used to determine the discharge rate through a throatless flume under free or submerged conditions.

(vi) Under free flow conditions, considerable head losses occur in the expansion section of the flume. Consequently, if conservation of head is an important criteria, the use of the throatless flume under submerged conditions is recommended.

5.2 - Scope for further study:

(i) While the experimental ranges of variables may be satisfactory for most field applications, the study can be extended to cover a range of y'_1/B_1 larger than 1.5.

(ii) It would be desirable to extend studies on models having (a) varying entrance width to throat width ratios, (b) varying converging length to diverging length ratios. These parameters may be incorporated in the discharge relationship to obtain more generalized equations applicable to any geometry of throatless flumes.

(iii) To obtain greater accuracies, one can avoid the depth measurement at the throat section and apply the momentum equation between section 1 and section 2 (Fig. 1a) as explained in appendix III. Tests may be conducted to verify the predictions of this model.

REFERENCES

APPENDIX I

REFERENCES

1. Ackers, P., White, W.R., Perkins, J.A. and Harrison, A.J.M., Weirs and Flumes for Flow Measurement, John Wiley and Sons Ltd., New York, N.Y., 1978.

2. Bennett, R.S., "Cutthroat Flume Discharge Relations", thesis presented to Colorado State Univ., at Fort Collins, Colo., in 1972, in partial fulfillment of the requirements for the degree of Master of Science.

3. Boss, M.G., Discharge Measurement Structures, International Inst. for Land Reclamation and Improvement/ILRI, Wageningen, The Netherlands, 1976.

4. Bradshaw, P., Experimental Fluid Mechanics, Pergamon Press, New York, N.Y., 1959.

5. Chow, V.T., Open-Channel Hydraulics, McGraw-Hill Book Co., New York, N.Y., 1970.

6. Keller, R.J., "Scale Effect in Model Studies of Cut-Throat Flumes", Paper No. 5, XIX IAHR Congress, New Delhi, India, 1981.

7. Keller, R.J., Cut-throat flume characteristics, J. Hyd. Div., (110, 9), Sept. 1984, pp. 1248-1263.

8. Skogerboe, G.V. and Hyatt, M.L., Rectangular cut-throat flumes, J. Irrig. and Drain. Div., ASCE, (98, 4), 1967, pp. 569-583.

9. Skogerboe G.V., Bennett, R.S., and Walker, W.R., Generalised discharge relations for cut-throat flumes, J. Irrig, and Drain. Div., ASCE, (98, 4), 1972, pp. 569-583.

10. Ramamurthy, A.S., Rao, M.V.J., and Dev. Auckle, Free Flow Discharge characteristics of Throatless flumes - J. Irrig. and Drain. Div. ASCE, (III, 1), March 1985, pp. 65-75.

11. Mc. Corquodale, J.A., and Khalifa, A.M., Submerged radial hydraulic jump, J. Hyd. Div., ASCE, HY3, March 198;0, pp. 355-367.

12. France, P.W., Analysis of the Hydraulic Jump within diverging rectangular channel, Proc. Instn. Civil Engrs., Part 2, 1981, 71, June, pp. 369-378.

13. Mazumder, S.K., Limit of submergence in Critical Flow-meters, The Institution of Engineers (India), U.D.C. 681.121.8.

14. Rajaratnam, N., Hydraulic Jump, Advances in Hydro-Sciences, Vol.4, 1967, Academi- Press, N.Y. and London.

15. Fluid Meters - Their Theory and Application - Report of ASME Research Committee on Fluid Meters, 6 th. Edition, 1971.

16. Henderson, F.M., Open Channel Flow, MacMillan Publishing Co., N.Y., 1966.

17. Jaeger, C., Engineering Fluid Mechahics, Blackic and Son Limited, London - Glasgow, 1956.

APPENDIX II

DETERMINATION OF EMPIRICAL COEFFICIENTS

APPENDIX II

DETERMINATION OF EMPIRICAL COEFFICIENTS K_t, C and r

Sketches such as Fig. 3.1a were drawn using the test data to obtain the relation between K_t and y'_1/B_1. For instance, selecting $\sigma = 0.805$, the paired values $K_t = 0.70$ and $y'_1/B_1 = 0.85$ were obtained from Fig. 3.1a. This is plotted as the dark point (•) in Fig. 3a. The process was repeated to obtain other paired values of K_t and y'_1/B_1 at fixed values of σ to complete Fig. 3a. Similar procedure was used to generate Fig. 3b for which Fig. 3.1c and Fig. 3.1b were used as the basis. Fig. 3c was generated from Fig. 3.1d and Fig. 3.1b. Only typical sketches are shown in Figs. 2a to 2g illustrate the procedure. The data in Table 4, and 5 were used to generate other sketches such as 2a to 2g to obtain data for plotting Figs. 3a to 3d.

APPENDIX III

ALTERNATE EQUATION FOR SUBMERGED FLOW DISCHARGE

APPENDIX III

ALTERNATE EQUATION FOR SUBMERGED FLOW DISCHARGE

Using assumptions made in Chapter 2 and applying the momentum equation between the section 1 and 2, one gets:

$$\frac{\gamma}{2} y_1'^2 B_1 + P_D + \rho Q V_1 = \frac{\gamma}{2} y_2^2 B_1 + P_U + \rho \beta_2 Q V_2 \qquad (20)$$

where

P_D = axial wall force on the downstream expanding walls

and

P_U = axial wall force on the upstream contracting walls

For the downstream wall force P_D or previously P_W (Eq. 12), the factor C was determined (Eq. 13).

For the contracting section, one can use the energy equation and the continuity equation to predict the water surface profile. This in turn yields the force P'_U where the pressure is hydrostatic. A correction factor C_1 similar to C used in Eq. (13) can be obtained to account for the variation of P_U with σ and y'_1/B_1 due to the non-hydrostatic distribution of the pressure in the contracting region of the flume. Using the test data related to C_1, σ and y'_1/B_1, curves similar to Fig. 3b can be developed for processing the test data.

$$P_U = C_1 P'_U \tag{21}$$

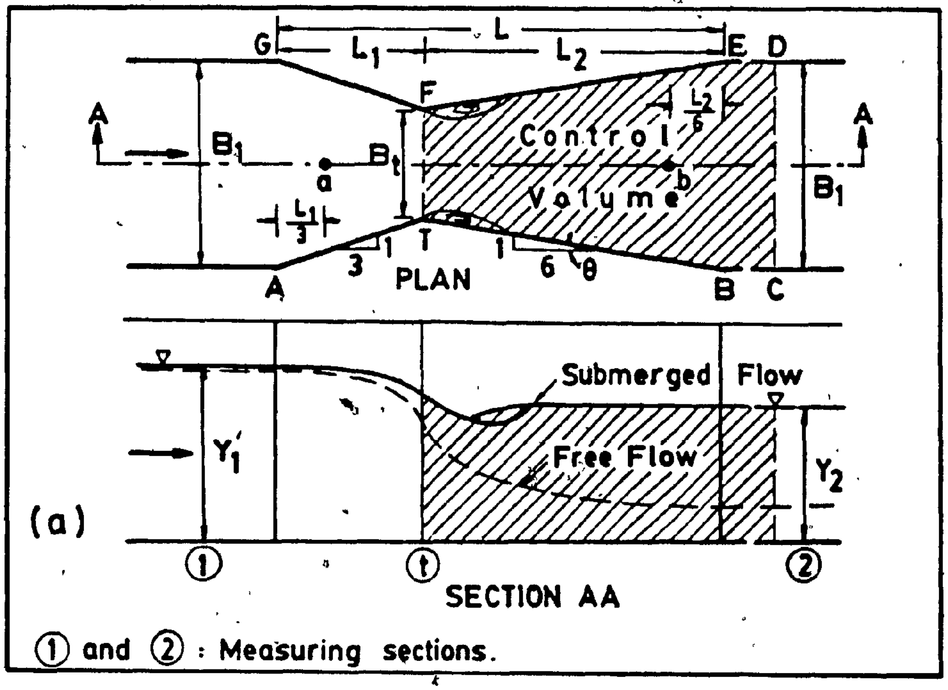
Also, one could combine P_U and P_D and use the total wall force value

$$P_{WT} = P_D - P_U \tag{22}$$

Thus, only one factor C' has to be determined. Substituting Eqs. (12) and (21) or Eq. (22) into Eq. (2) one could obtain a relationship for the discharge Q in which the throat depth y_t and the pressure contraction factor K_t is omitted.

APPENDIX IV

FIGURES



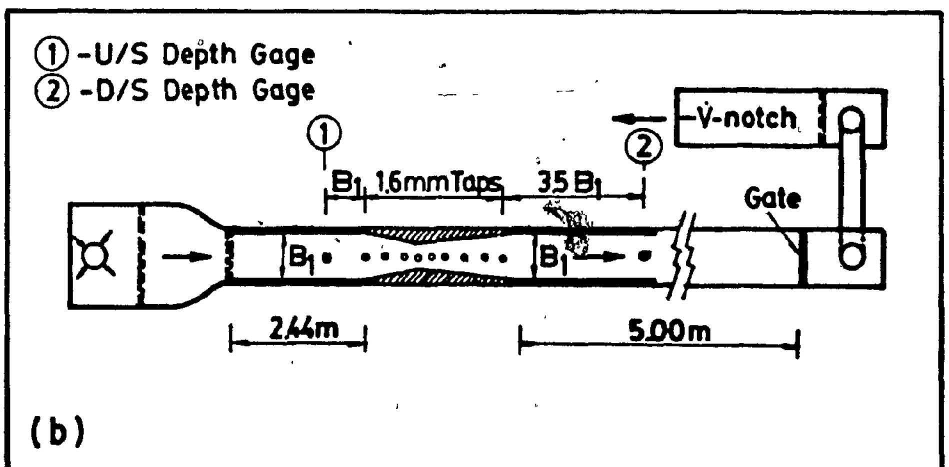


Fig. 1 - a) Test flume geometry, b) Experimental set-up

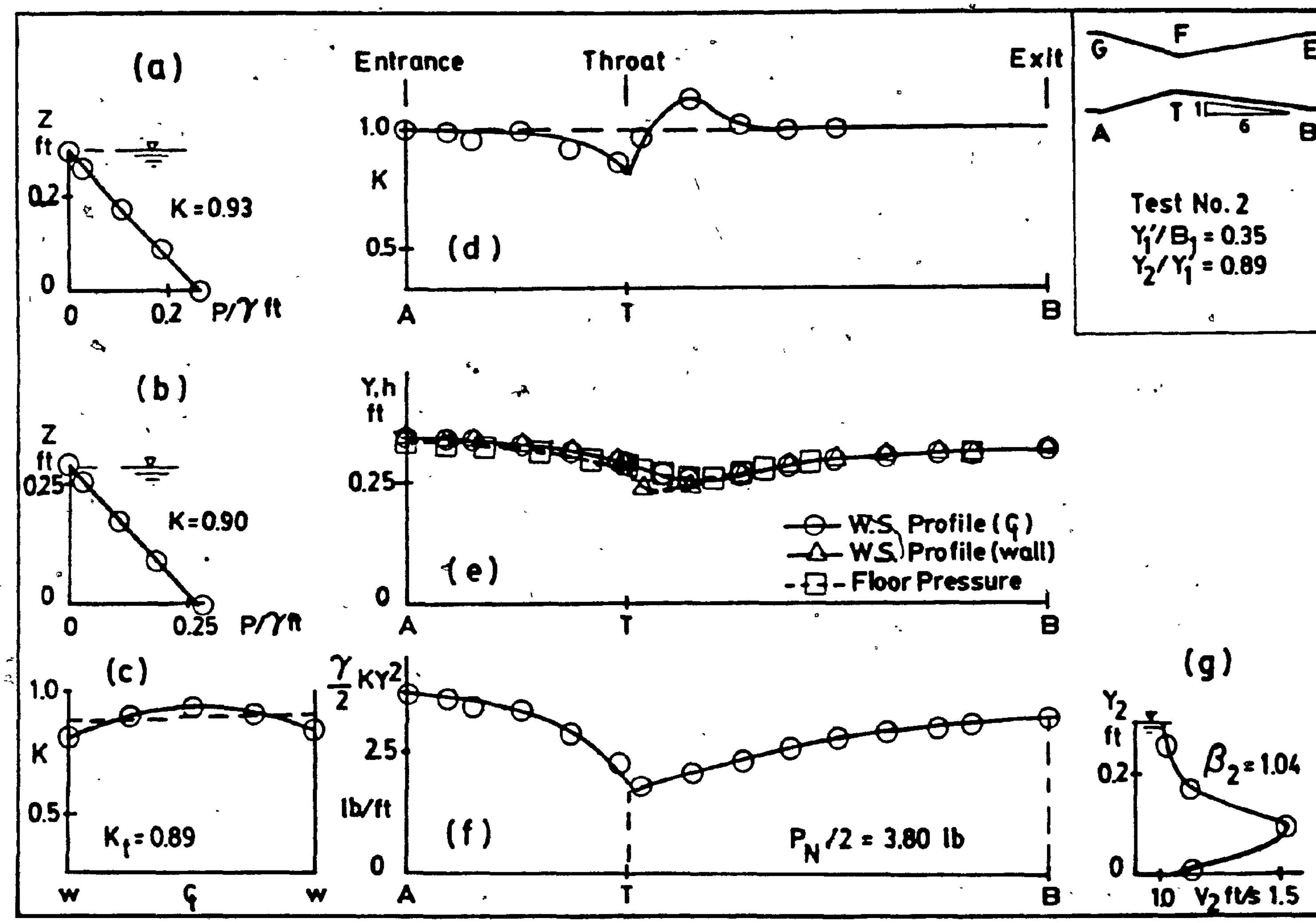


Fig. 2 - a) K at center of throat, b) K at quarter point of throat, c) Determination of K_t, d) Profile of K along the wall ATB, e) Center line profiles of water surface and floor pressure, f) Profile of $\gamma K y^2/2$, g) Velocity distribution at section 2

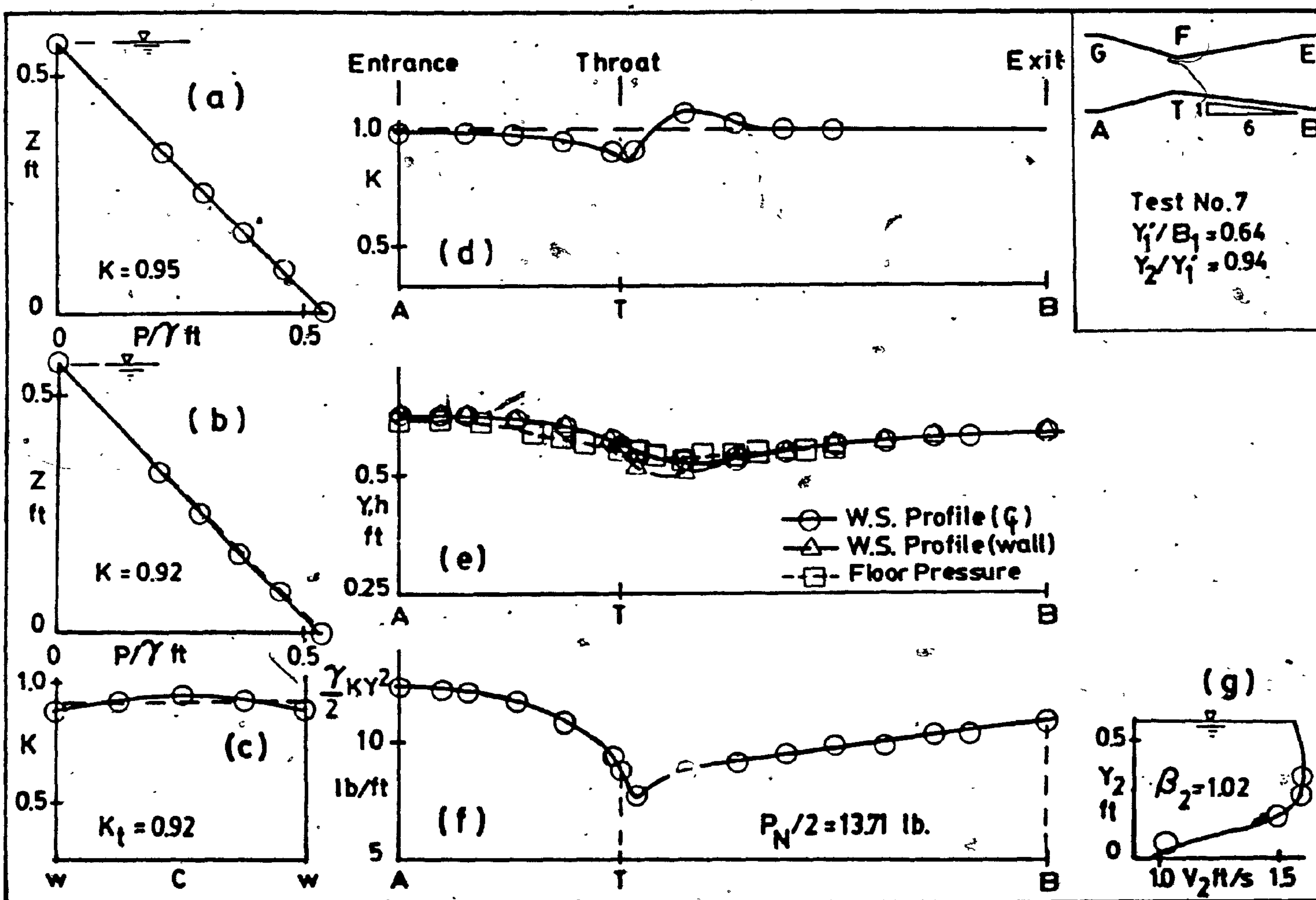


Fig. 2 - a) K at center of throat, b) K at quarter point of throat, c) Determination of K_t,
(Cont'd) d) Profile of K along the wall ATB, e) Center line profiles of water surface and floor pressure,
f) Profile of $\gamma K y^2/2$, g) Velocity distribution at section 2

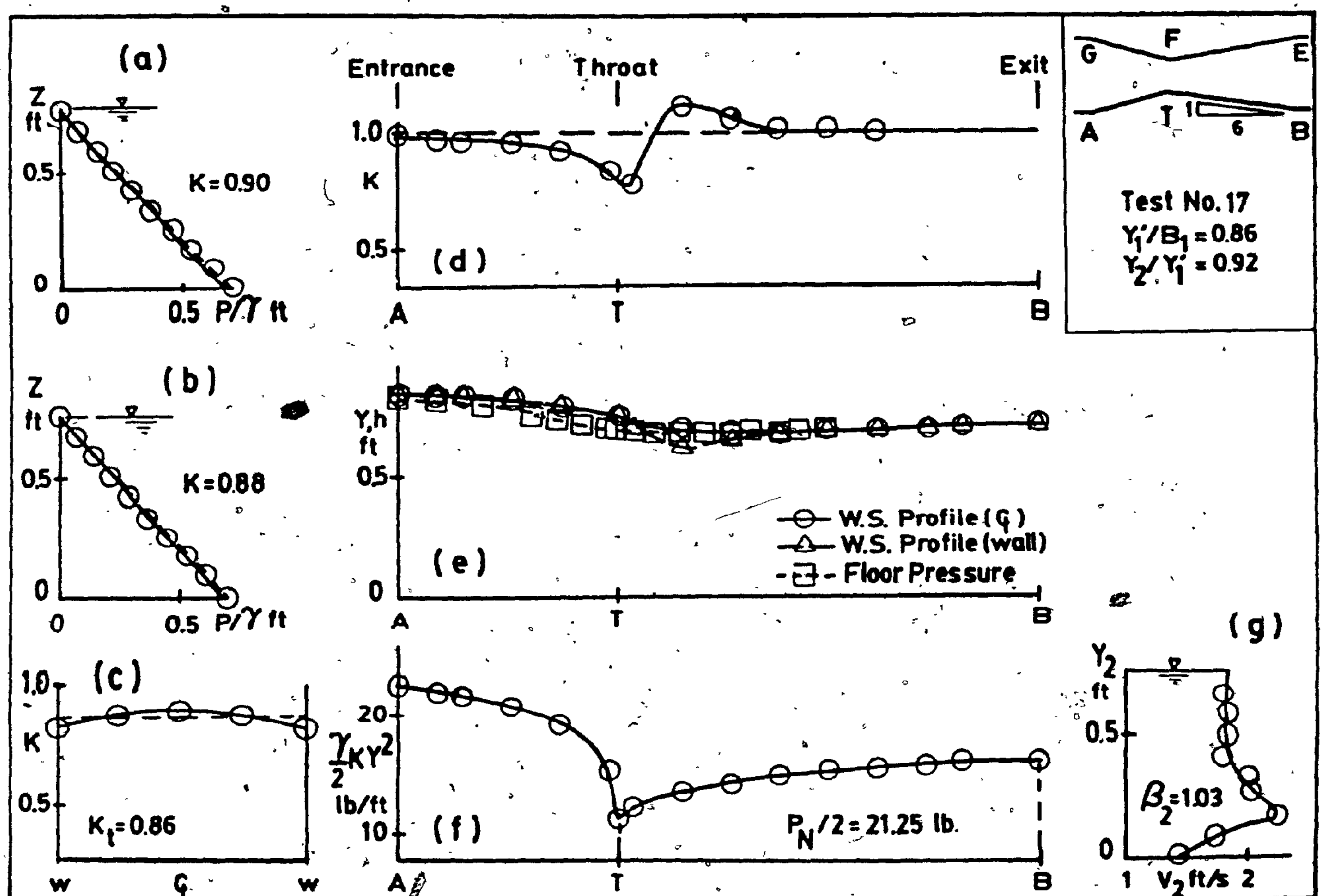


Fig. 2 - (Cont'd) a) K at center of throat, b) K at quarter point of throat, c) Determination of K_t, d) Profile of K along the wall ATB, e) Center line profiles of water surface and floor pressure, f) Profile of $\gamma K y^2/2$, g) Velocity distribution at section 2

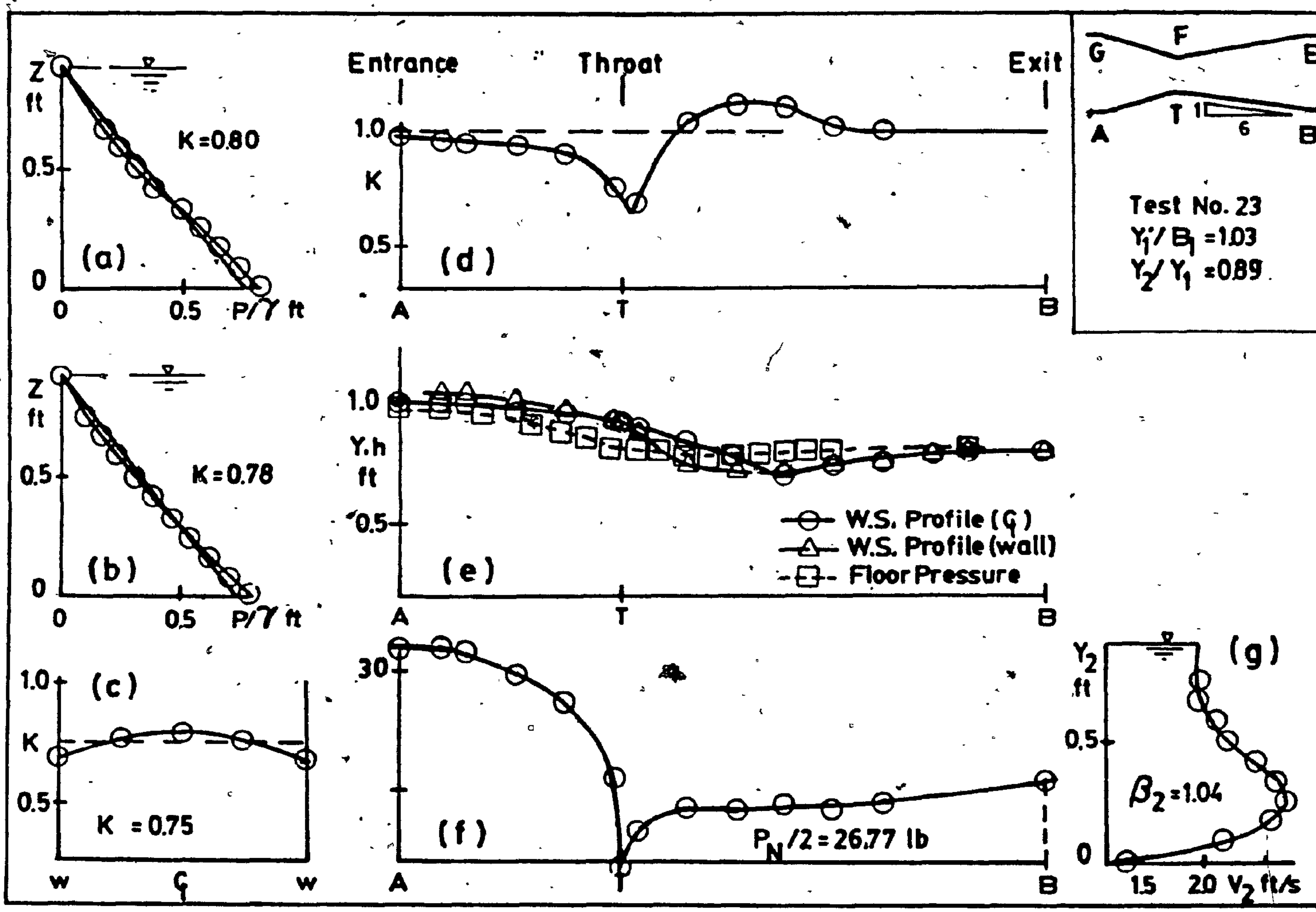


Fig. 2 - (Cont'd) a) K at center of throat, b) K at quarter point of throat, c) Determination of K_1 d) Profile of K along the wall ATB, e) Center line profiles of water surface and floor pressure, f) Profile of $\gamma K y^2/2$, g) Velocity distribution at section 2

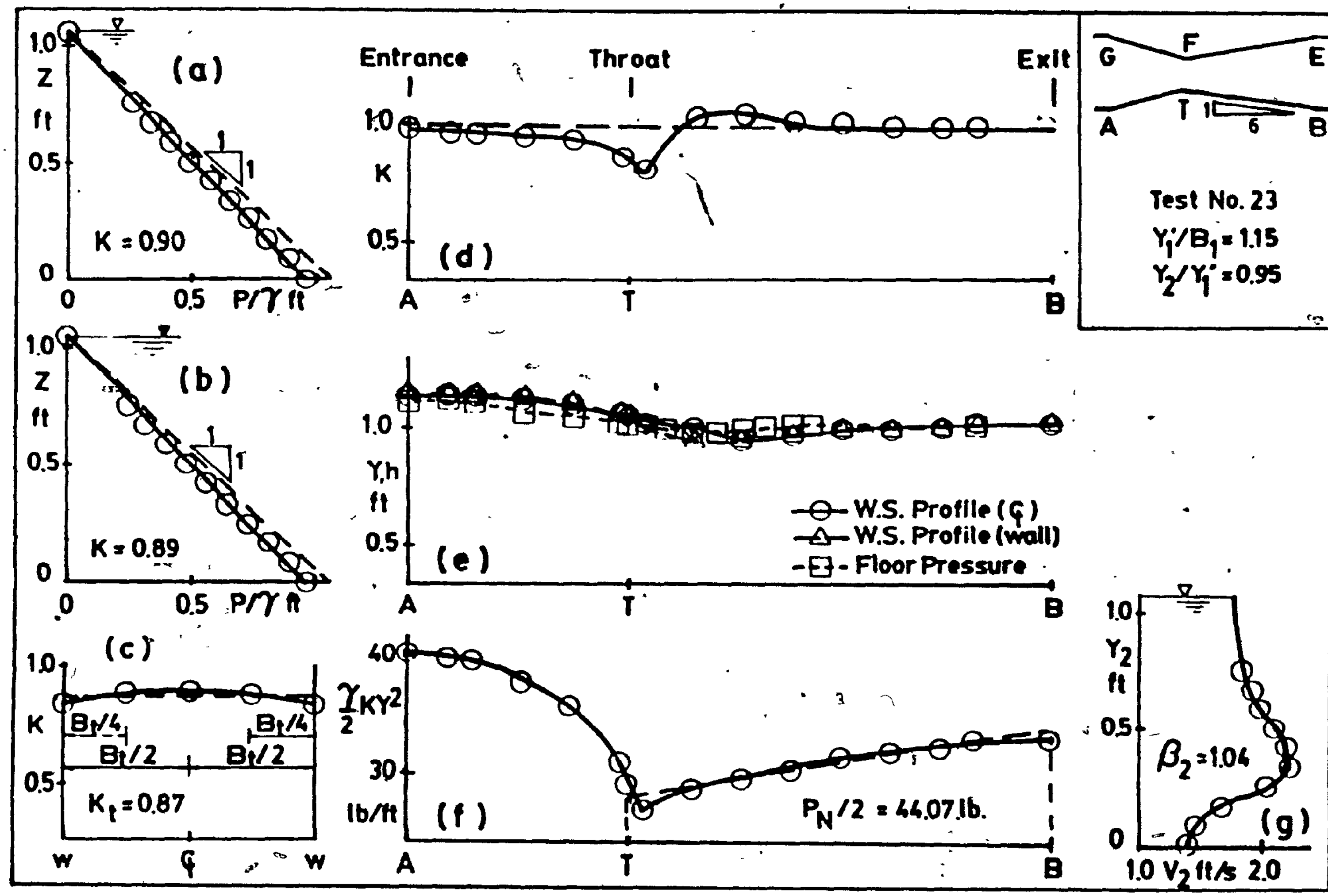


Fig. 2 - a) K at center of throat, b) K at quarter point of throat, c) Determination of K_t,
(Cont'd) d) Profile of K along the wall ATB, e) Center line profiles of water surface and floor pressure,
f) Profile of $\gamma K y^2/2$, g) Velocity distribution at section 2

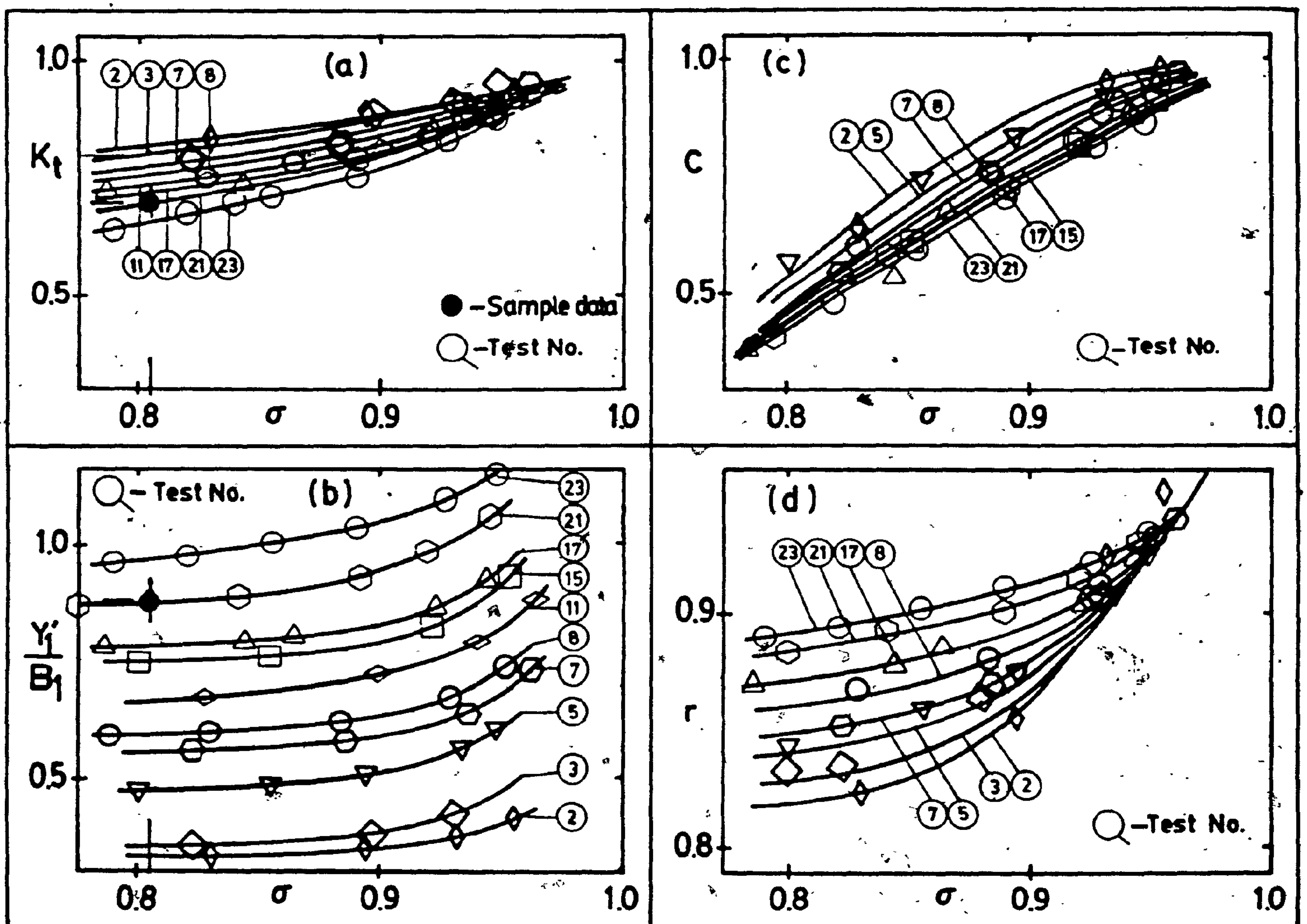


Fig. 3.1 - Variations of K_t, C, r with y'_1/B_1 and σ

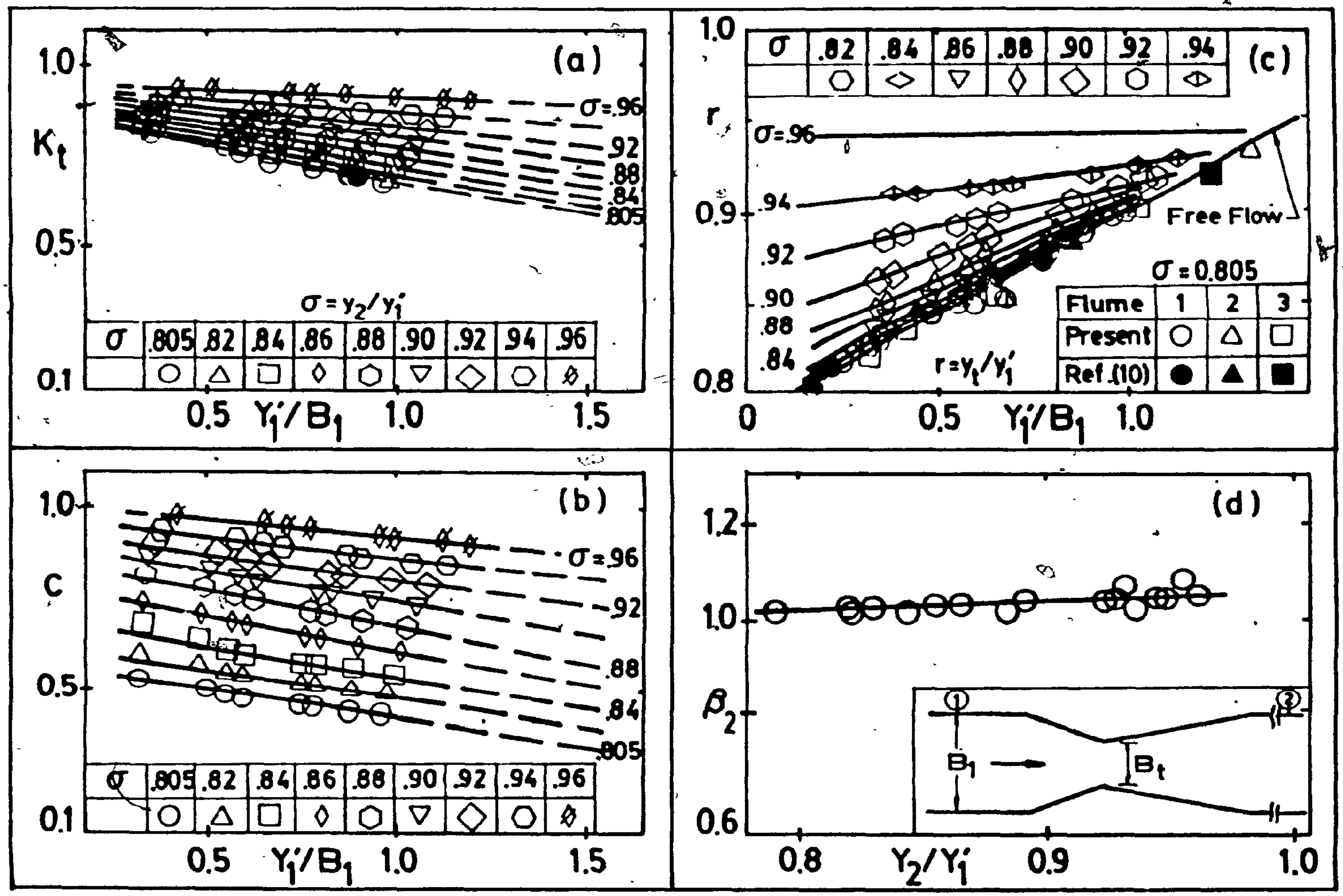


Fig. 3 - a) Variations of K_t with y'_1/B_1 and σ, b) Variations of C with y'_1/B_1 and σ, c) Variations of r with y'_1/B_1 and σ, d) Variation of β_2 with σ

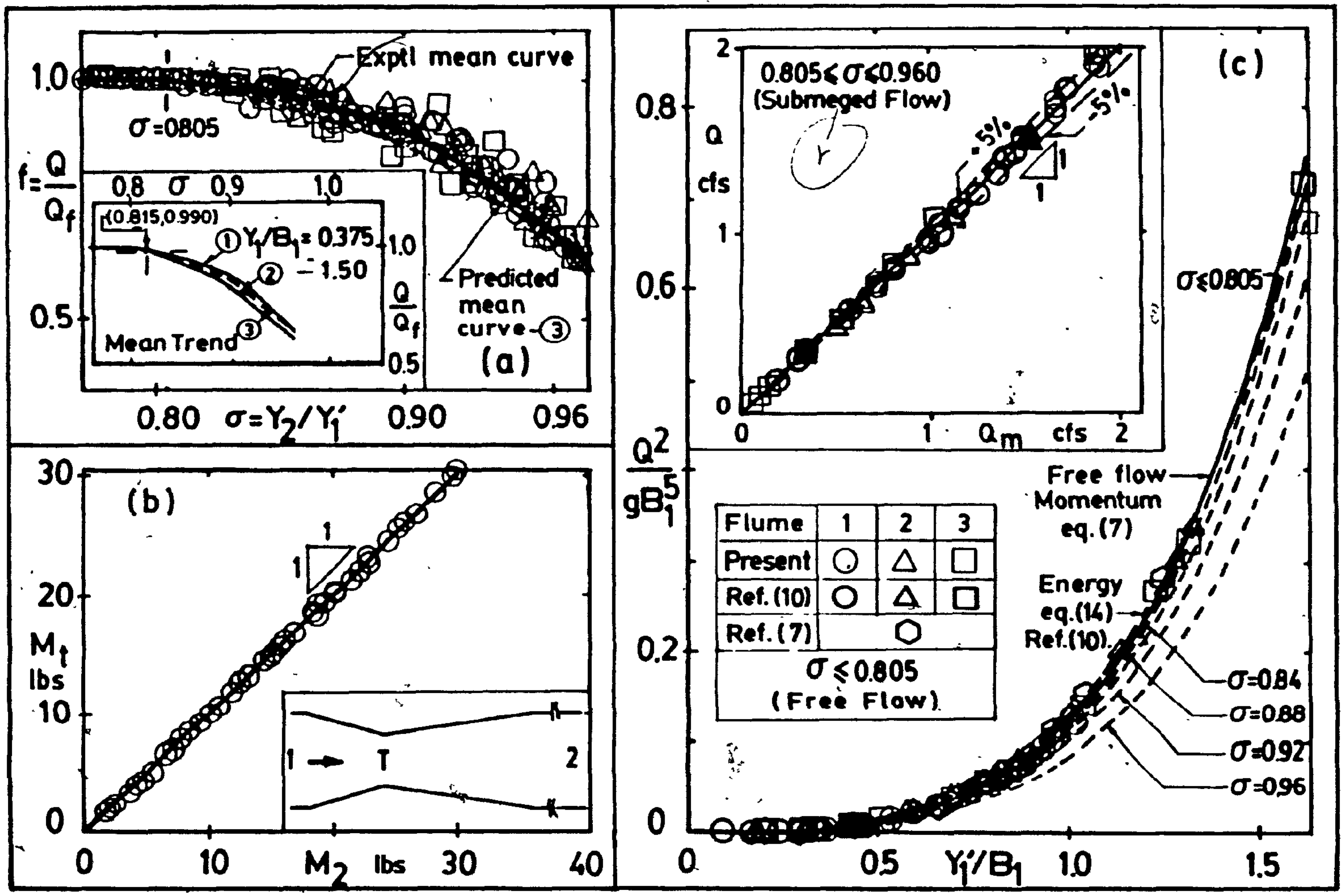


Fig. 4 - a) Variation of $f(=Q/Q_f)$ with σ; Insert - predicted variation of Q/Q_f with σ

b) Momentum balance, c) Variations of Q^2/gB_1^5 with y'_1/B_1 and σ; Insert - Q against Q_m.

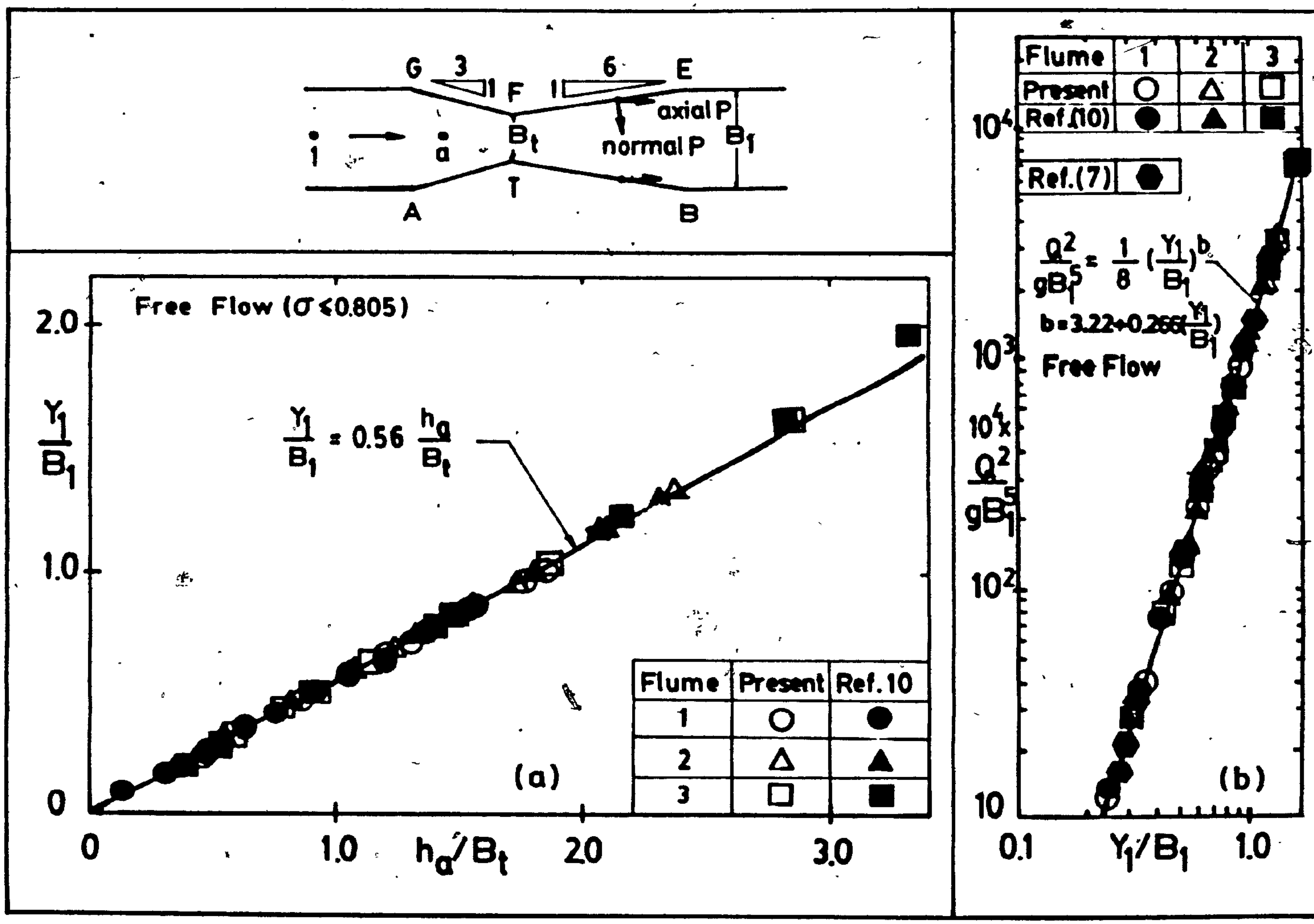


Fig. 5 - a) Variation of y_1/B_1 with h_a/B_t, b) Variation of Q^2/gB_1^5 with y_1/B_1

b) - - - - - -

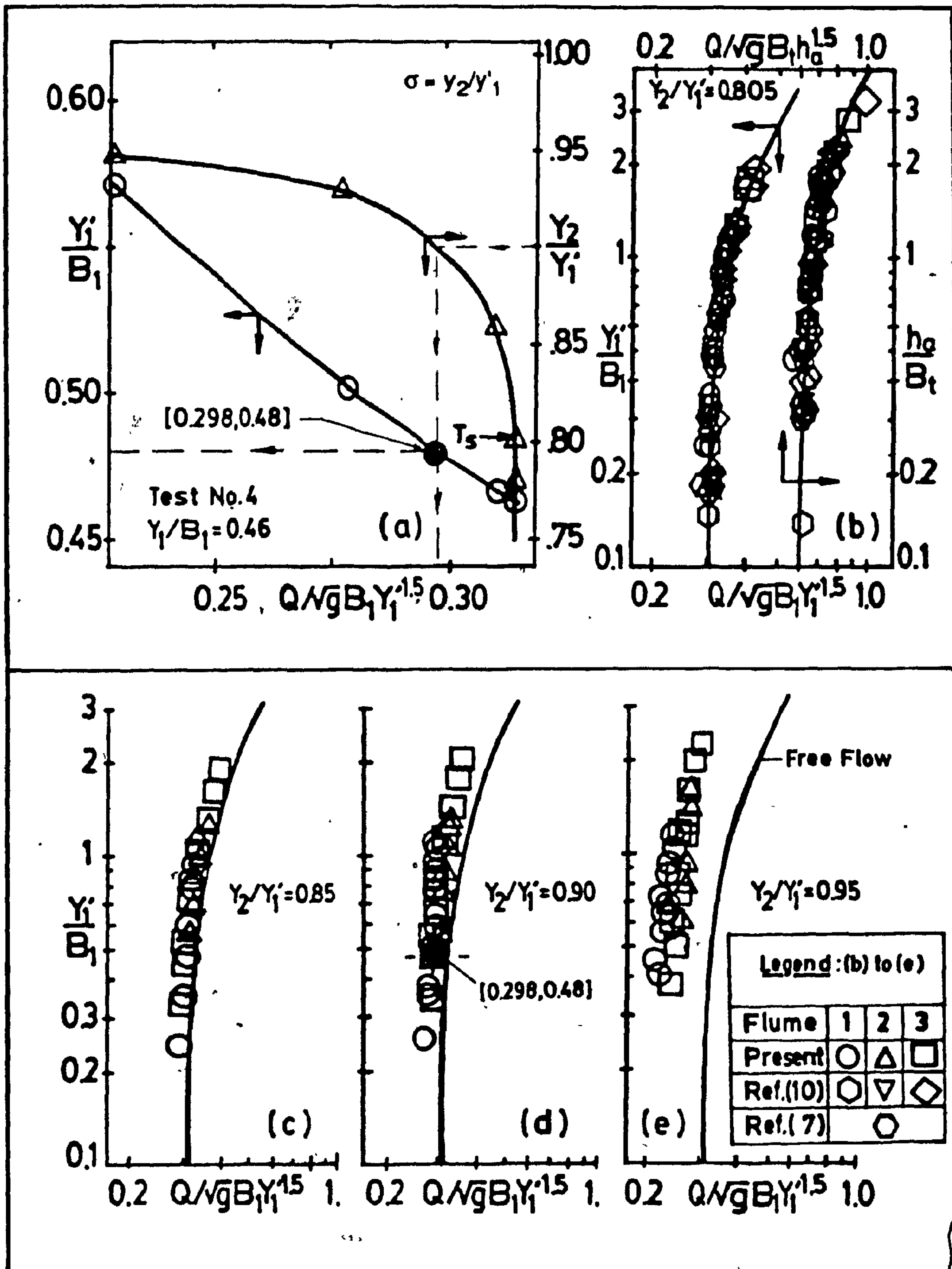


Fig. 6 - a) Variations of $Q/\sqrt{g}B_1y'_1{}^{1.5}$ with y'_1/B_1 and σ,
b) Variation of y'_1/B_1 with $Q/\sqrt{g}B_1y'_1{}^{1.5}$: ($\sigma \leq 0.805$),
c), d), e) Variation of y'_1/B_1 with $Q/\sqrt{g}B_1y'_1{}^{1.5}$: (σ = 0.85, 0.90 and 0.95)

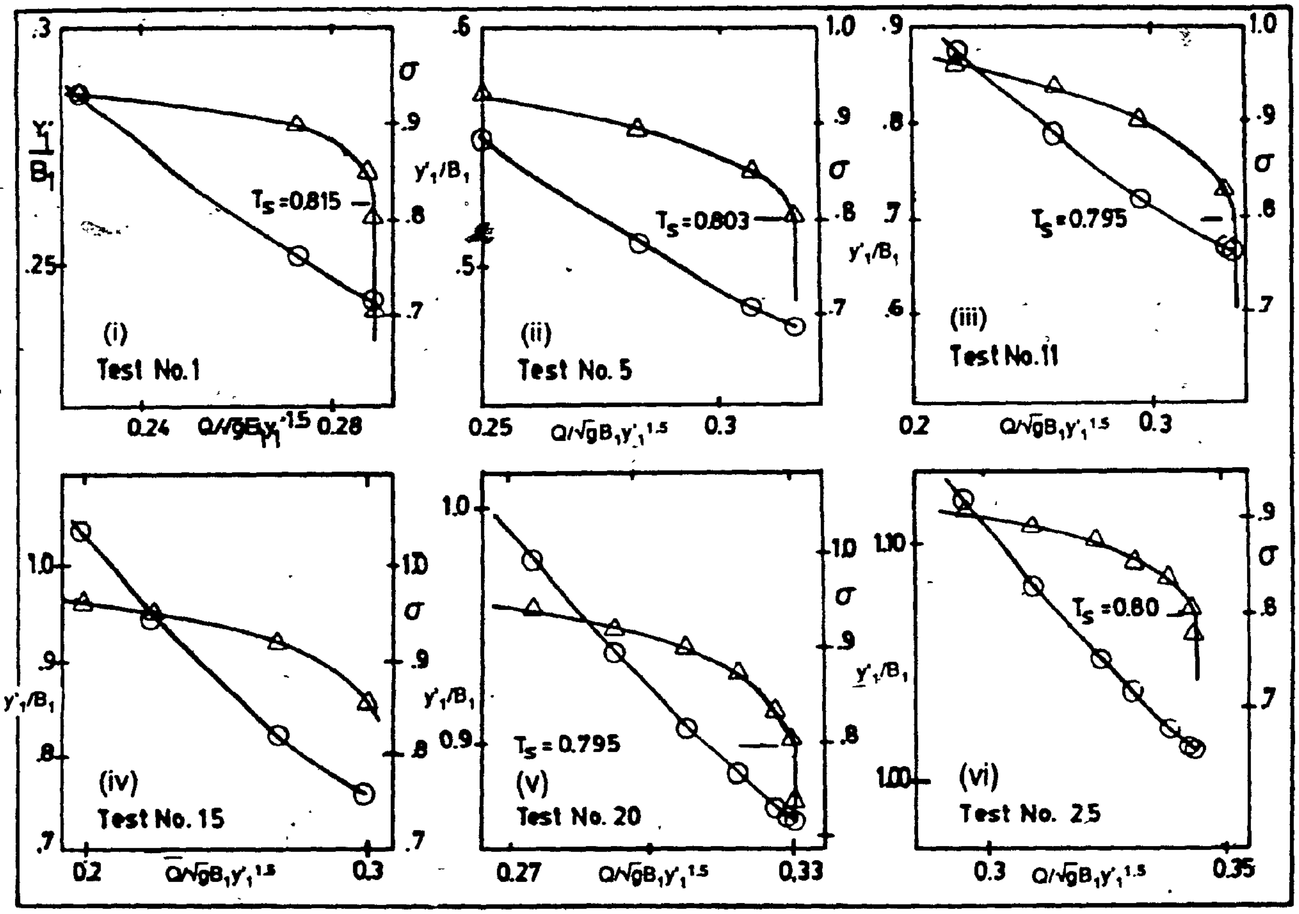


Fig. 6 - a) Variations of $Q/\sqrt{g}B_1y_1'^{1.5}$ with y'_1/B_1 and σ. (Cont'd)

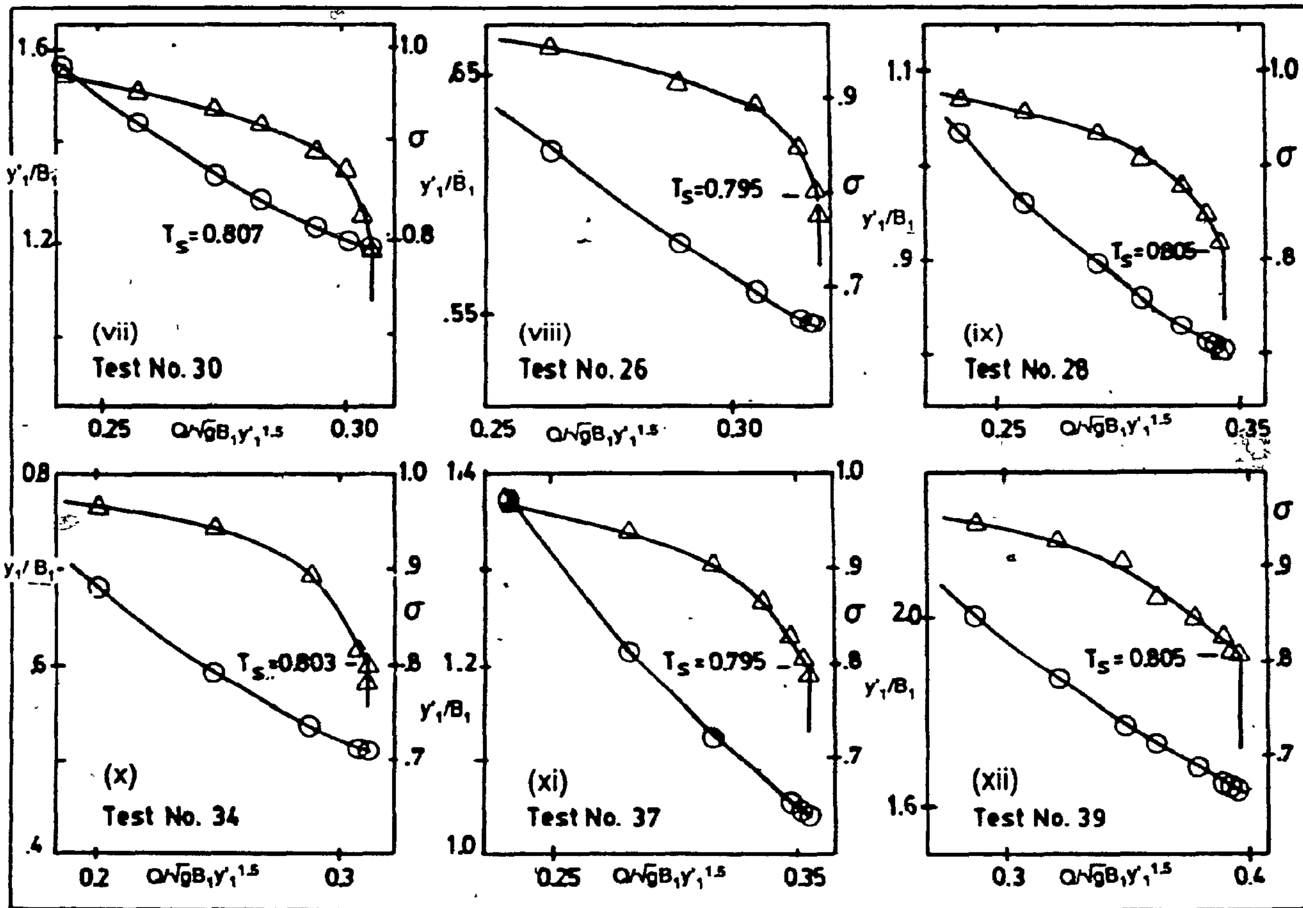


Fig. 6 - a) Variations of $Q/\sqrt{g}B_1y'^{1.5}_1$ with y'_1/B_1 and σ. (Cont'd)

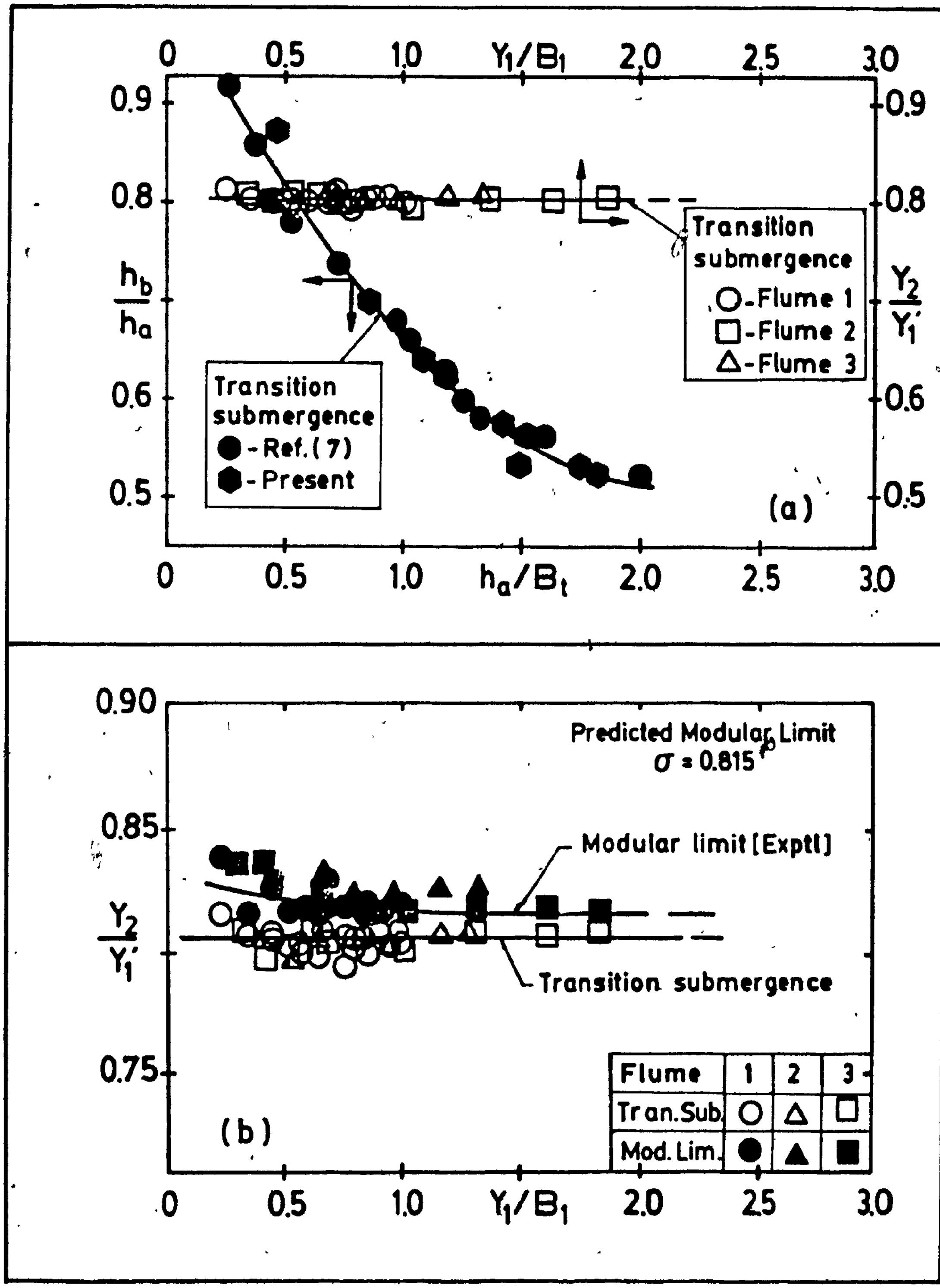


Fig. 7 - a) Variations of T_s with y_1/B_1 and of T_s with h_a/B_t

b) Variations of T_s with y_1/B and of Modular limit with y_1/B_1.

APPENDIX V

TABLES AND EXPERIMENTAL DATA

APPENDIX V

TABLES

TABLE 1 - Test Flumes

[All dimensions in centimeters]

Flume (1)	B_t (2)	L_1 (3)	L_2 (4)	L (5)	B_1 (6)
1	15.6	21.6	43.2	64.8	30.0
2	11.7	16.2	32.4	48.6	22.5
3	7.8	10.8	21.6	32.4	15.0

TABLE 2 - Values of β_2 and various empirical coefficients.

		$0.805 \leq \sigma \leq 0.890$	$0.890 < \sigma \leq 0.960$
K_t	m_1	$0.64\ \sigma - 0.71$	$1.20\ \sigma - 1.20$
	b_1	$0.55\ \sigma + 0.42$	$0.55\ \sigma + 0.42$
C	m_2	$0.61\ \sigma + 0.34$	$1.71\ \sigma - 1.73$
	b_2	$3.89\ \sigma - 2.55$	$1.43\ \sigma - 0.36$
r	m_3	$-0.31\ \sigma + 0.36$	$-1.21\ \sigma + 1.17$
	b_3	$0.35\ \sigma + 0.51$	$1.64\ \sigma - 0.64$
Momentum Coefficient		$\beta_2 = 0.19\ \sigma + 0.86$	

TABLE 3 - Accuracy of Measurements

Number (1)	Variable (2)	Accuracy (3)
1	Length	± 1.0 mm
2	Pressure Head	± 0.5 mm
3	Discharge	± 3.0 %

TABLE 4

```
      PROGRAM FLUME(INPUT,OUTPUT,TAPE14,TAPE15)
      INTEGER TN(25),JD(25)
      REAL MT(25,10),M2(25,10),K(25,10)
      DIMENSION Y2(25,10),SIG(25,10),C(25,10),
     • P(25,10),PT(25,10),PD(25,10),P2(25,10),DVM(25,10),
     • YB1(25,10),Y1(25,10),Q(25),QC(25,10),ERQ(25,10),
     • X(25,10),U(25,10),V(25,10),W(25,10),Q2(25,10),QT(25,10),
     • RQT(25,10),XX(25,10),SUM(25,10),BET(25,10),
     • UM(25,10),DM(25,10)
C
      DO 5 I=1,25
         READ(14,*)TN(I),Q(I)
 5    CONTINUE
      DO 6 I=1,25
         READ(15,*) JD(I)
         DO 6 J=1,JD(I)
            READ(15,*) Y1(I,J),Y2(I,J)
 6    CONTINUE
      PRINT 100
      DO 20 I=1,25
         DO 20 J=1,JD(I)
            SIG(I,J)=Y2(I,J)/Y1(I,J)
            YB1(I,J)=Y1(I,J)/.984
            IF ((SIG(I,J).LT.0.8).OR.(SIG(I,J).GT.0.960)) GO TO 20
            IF (SIG(I,J).GT.0.89) GO TO 1
            AM1=.644*SIG(I,J)-.709
            GO TO 2
 1          AM1=1.2*SIG(I,J)-1.203
 2          BM=0.55*SIG(I,J)+0.420
            K(I,J)=AM1*YB1(I,J)+BM
            IF (SIG(I,J).GT.0.89)GO TO 3
            CM=-0.611*SIG(I,J)+0.344
            CA=3.889*SIG(I,J)-2.551
            GO TO 4
 3          CM=1.714*SIG(I,J)-1.726
            CA=1.429*SIG(I,J)-0.361
 4          C(I,J)=CM*YB1(I,J)+CA
            PF=.112*YB1(I,J)+.79
            IF (SIG(I,J).GT.0.96) GO TO 12
            IF (SIG(I,J).GT.0.89) GO TO 11
            AA=-.306*SIG(I,J)+.357
            GO TO 13
 11         AA=-1.214*SIG(I,J)+1.166
            GO TO 13
 12         AA=0.
 13         IF (SIG(I,J).GT.0.89) GO TO 23
            BB=.353*SIG(I,J)+.506
            GO TO 15
 23         BB=1.636*SIG(I,J)-.636
 15         PP=AA*YB1(I,J)+BB
            IF (PP.LT.PF) GO TO 16
            P(I,J)=PP
            GO TO 17
 16         P(I,J)=PF
 17         BET(I,J)=0.194*SIG(I,J)+0.864
```

(Table 4 cont'd)

```
                PT(I,J)=31.2*0.512*K(I,J)*((P(I,J)*Y1(I,J))**2.0)
                P2(I,J)=31.2*0.984*(Y2(I,J)**2.0)
                MT(I,J)=(62.4/32.2)*(Q(I)**2.0)/(0.512*(P(I,J)*Y1(I,J)))
                M2(I,J)=((62.4/32.2)*(Q(I)**2.0)/(.984*Y2(I,J)))*
     •                  BET(I,J)
                PD(I,J)=(62.4/6.0)*(0.984-.512)*((P(I,J)*Y1(I,J))**2.0+
     •                  Y2(I,J)**2.0+(P(I,J)*Y1(I,J))*Y2(I,J))*C(I,J)
                SUM1=PT(I,J)+PD(I,J)+MT(I,J)
                SUM2=P2(I,J)+M2(I,J)
                DVM(I,J)=100.0*(SUM1-SUM2)/SUM1
                UM(I,J)=SUM1
                DM(I,J)=SUM2
                A=(0.48*C(I,J)-3.0)*P(I,J)*SIG(I,J)**3.0
                B=0.48*C(I,J)*(P(I,J)*SIG(I,J))**2.0
                E=(1.56*K(I,J)+0.48*C(I,J))*SIG(I,J)*P(I,J)**3.0
                D=0.52*32.2*(.984**5.0)*(VB1(I,J)**3.0)/(6.0*(.52*P(I,J)*
     •            BET(I,J)-SIG(I,J)))
                QQ=D*(A+B+E)
                QC(I,J)=QQ**0.5
                ERQ(I,J)=100.0*(QC(I,J)-Q(I))/Q(I)
 20     CONTINUE
        DO 30 I=1,25
            PRINT 35,TN(I),Q(I)
            DO 30 J=1,JD(I)
                IF (SIG(I,J).LT.0.8) THEN
                    PRINT 39,Y1(I,J),Y2(I,J),VB1(I,J),SIG(I,J)
                ELSEIF (SIG(I,J).GT.0.960) THEN
                    PRINT 41,Y1(I,J),Y2(I,J),VB1(I,J),SIG(I,J)
                ELSE
                    PRINT 40,Y1(I,J),Y2(I,J),VB1(I,J),SIG(I,J),
     •                      PT(I,J),MT(I,J),PD(I,J),P2(I,J),M2(I,J),
     •                      DVM(I,J),UM(I,J),DM(I,J)
                ENDIF
 30     CONTINUE
        PRINT 300
        DO 60 I=1,25
            PRINT 35,TN(I),Q(I)
            DO 60 J=1,JD(I)
                IF ((SIG(I,J).LT.0.8).OR.(SIG(I,J).GT.0.960)) GO TO 60
                PRINT 50,VB1(I,J),SIG(I,J),K(I,J),C(I,J),
     •          P(I,J),QC(I,J),ERQ(I,J)
 60     CONTINUE
        DO 70 I=1,25
            DO 70 J=1,JD(I)
                IF ((SIG(I,J).LT.0.8).OR.(SIG(I,J).GT.0.960)) GO TO 70
                X(I,J)=0.52*(P(I,J)*Y1(I,J))*Y2(I,J)/
     •                  (0.52*BET(I,J)*(P(I,J)*Y1(I,J))-Y2(I,J))
                XX(I,J)=X(I,J)*(32.2/6.)*(.984**2.)
                U(I,J)=3.*K(I,J)*0.52*((P(I,J)*Y1(I,J))**2.)
                V(I,J)=0.48*C(I,J)*(((P(I,J)*Y1(I,J))**2.)+
     •                  (Y2(I,J)**2.)+(P(I,J)*Y1(I,J))*Y2(I,J))
                W(I,J)=3.*(Y2(I,J)**2.)
                SUM(I,J)=U(I,J)+V(I,J)-W(I,J)
                Q2(I,J)=ABS(SUM(I,J))*ABS(XX(I,J))
                QT(I,J)=Q2(I,J)**0.5
                RQT(I,J)=100.*(QT(I,J)-Q(I))/Q(I)
 70     CONTINUE
```

(Table 4 cont'd)

```
              PRINT 200
              DO 80 I=1,25
                  PRINT 35,TN(I),Q(I)
                  DO 80 J=1,JD(I)
                      IF ((SIG(I,J).LT.0.8).OR.(SIG(I,J).GT.0.960)) GO TO 80
                      PRINT 250,YB1(I,J),SIG(I,J),
             •        X(I,J),XX(I,J),U(I,J),V(I,J),W(I,J),
             •        SUM(I,J),Q2(I,J),QT(I,J),RQT(I,J)
        80    CONTINUE
        35    FORMAT(/5X,'TEST#',I2,2X,'QACT=',F5.3,2X,'CFS')
        39    FORMAT(4X,2F7.3,2F6.2,10X,'FREE FLOW')
        40    FORMAT(4X,2F7.3,7F6.2,F5.1,2F6.2)
        41    FORMAT(4X,2F7.3,2F6.2,10X,'SIGMA >> 0.96')
        50    FORMAT(4X,6F7.2,F6.1)
       100    FORMAT(/ 8X,'Y1',5X,'Y2',3X,'Y1/B1',1X,'Y2/Y1',
             •2X,'PT',4X,'MT',4X,'PW',4X,'P2',4X,
             •'M2',2X,'%DEVM',2X,'UM',4X,'DM')
       200    FORMAT(/6X,'Y1/B1',1X,'Y2/Y1',
             •3X,'X',5X,'XX',5X,'U',6X,
             •'V',6X,'W',4X,'U+V-W',4X,'Q2',5X,'QT',2X,'RQT')
       250    FORMAT(4X,2F6.2,F7.3,F6.2,6F7.3,F5.1)
       300    FORMAT(/7X,'Y1/B1',2X,'Y2/Y1',4X,'K',6X,'C',6X,
             •'R',6X,'QC',3X,'%ERQ')
              STOP
              END
```

(Table 4 cont'd)

Y1	Y2	Y1/B1	V2/Y1	PT	MT	PW	P2	M2	%DEVM	UM	DM
TEST# 1	QACT=	.189	CFS								
.239	.169	.24	.71		FREE FLOW						
.239	.178	.24	.74		FREE FLOW						
.239	.186	.24	.78		FREE FLOW						
.239	.192	.24	.80	.50	.69	.30	1.13	.37	-1.3	1.49	1.51
.240	.204	.24	.85	.54	.68	.43	1.28	.35	.8	1.65	1.63
.248	.223	.25	.90	.63	.64	.61	1.53	.33	1.5	1.88	1.85
.281	.262	.29	.93	.93	.54	.91	2.11	.28	-.6	2.37	2.39
TEST# 2	QACT=	.306	CFS								
.324	.269	.33	.83	.95	1.31	.67	2.22	.70	.3	2.93	2.92
.339	.303	.34	.89	1.16	1.22	1.10	2.82	.63	.9	3.48	3.45
.365	.340	.37	.93	1.56	1.08	1.52	3.55	.57	.9	4.15	4.12
.403	.385	.41	.96	2.07	.95	2.06	4.55	.50	.3	5.07	5.05
TEST# 3	QACT=	.348	CFS								
.346	.246	.35	.71		FREE FLOW						
.348	.286	.35	.82	1.09	1.58	.72	2.51	.85	.6	3.39	3.36
.368	.330	.37	.90	1.39	1.45	1.31	3.34	.75	1.2	4.14	4.09
.412	.383	.42	.93	1.97	1.24	1.91	4.50	.65	-.8	5.11	5.15
.457	.438	.46	.96	2.68	1.07	2.67	5.89	.57	-.6	6.42	6.46
TEST# 4	QACT=	.541	CFS								
.456	.137	.46	.30		FREE FLOW						
.456	.335	.46	.73		FREE FLOW						
456	.355	.46	.78		FREE FLOW						
.456	.365	.46	.80	1.81	2.89	1.02	4.09	1.61	.4	5.72	5.70
.460	.395	.47	.86	2.02	2.82	1.61	4.79	1.50	2.4	6.45	6.29
.563	.534	.57	.95	3.91	2.13	3.83	8.75	1.13	-.1	9.87	9.89
.563	.534	.57	.95	3.91	2.13	3.83	8.75	1.13	-.1	9.87	9.89
TEST# 5	QACT=	.561	CFS								
.466	.374	.47	.80	1.90	3.03	1.08	4.29	1.69	.5	6.02	5.98
.475	.406	.48	.85	2.14	2.94	1.67	5.06	1.57	1.6	6.74	6.63
.501	.448	.51	.89	2.55	2.74	2.35	6.16	1.44	.6	7.64	7.60
.544	.508	.55	.93	3.47	2.41	3.35	7.92	1.28	.3	9.23	9.20
.593	.562	.60	.95	4.32	2.17	4.23	9.70	1.16	-1.2	10.72	10.85
TEST# 6	QACT=	.673	CFS								
.519	.164	.53	.32		FREE FLOW						
.538	.448	.54	.84	2.64	3.75	1.89	6.16	2.04	.8	8.28	8.21
.554	.494	.56	.89	3.10	3.36	2.81	7.49	1.87	1.1	9.47	9.36
.623	.584	.63	.94	4.60	3.01	4.43	10.47	1.60	-.2	12.04	12.07
.695	.670	.71	.96		SIGMA >> 0.96						
TEST# 7	QACT=	.713	CFS								
.544	.447	.55	.82	2.67	4.14	1.71	6.13	2.29	1.0	8.51	8.43
.562	.497	.57	.88	3.14	3.95	2.77	7.58	2.09	1.9	9.86	9.67
.626	.586	.64	.94	4.63	3.36	4.44	10.54	1.79	.8	12.43	12.33
.712	.684	.72	.96		SIGMA >> 0.96						

(Table 4 cont'd)

Y1	Y2	Y1/B1	Y2/Y1	PT	MT	PW	P2	M2	%DEVM	UM	DM
TEST# 8	QACT=	.782	CFS								
.579	.456	.59	.79		FREE FLOW						
.586	.486	.60	.83	3.13	4.59	2.08	7.25	2.54	.2	9.81	9.79
.608	.537	.62	.88	3.67	4.37	3.20	8.85	2.32	.6	11.24	11.18
.660	.614	.67	.93	5.04	3.85	4.78	11.57	2.05	.4	13.67	13.62
.724	.689	.74	.95	6.49	3.44	6.34	14.57	1.83	-.8	16.27	16.41
TEST# 9	QACT=	.822	CFS								
.585	.196	.59	.34		FREE FLOW						
.585	.438	.59	.75		FREE FLOW						
.585	.451	.59	.77		FREE FLOW						
.586	.473	.60	.81	3.02	5.09	1.75	6.87	2.87	1.3	9.87	9.74
.591	.487	.60	.82	3.16	5.03	2.03	7.28	2.80	1.5	10.23	10.08
.623	.555	.63	.89	3.92	4.69	3.50	9.46	2.49	1.4	12.11	11.94
.701	.658	.71	.94	5.84	3.97	5.60	13.29	2.12	1.0	15.41	15.41
TEST#10	QACT=	.924	CFS								
.641	.210	.65	.33		FREE FLOW						
.641	.496	.65	.77		FREE FLOW						
.641	.503	.65	.78		FREE FLOW						
.642	.525	.65	.82	3.69	5.82	2.27	8.46	3.28	.4	11.78	11.74
.669	.560	.68	.84	4.14	5.55	2.84	9.63	3.08	-1.5	12.53	12.71
.691	.623	.70	.90	5.01	5.26	4.51	11.92	2.80	.4	14.78	14.72
.775	.735	.79	.95	7.34	4.50	7.12	16.59	2.40	-.1	18.96	18.98
TEST#11	QACT=	.984	CFS								
.652	.240	.66	.37		FREE FLOW						
.657	.544	.67	.83	3.93	6.43	2.56	9.09	3.59	1.9	12.93	12.68
.709	.638	.72	.90	5.25	5.81	4.69	12.50	3.10	1.0	15.75	15.60
.775	.729	.79	.94	7.17	5.13	6.85	16.32	2.74	.5	19.35	19.05
.865	.834	.88	.96		SIGMA >> 0.96						
TEST#12	QACT=	.994	CFS								
670	.271	.68	.40		FREE FLOW						
.672	.559	.68	.83	4.14	6.40	2.75	9.59	3.57	1.0	13.29	13.16
.704	.620	.72	.88	4.92	6.04	4.16	11.80	3.25	.4	15.11	15.05
.757	.713	.77	.94	6.87	5.36	6.59	15.61	2.86	1.9	18.82	18.46
.834	.797	.85	.96	8.67	4.81	8.49	19.50	2.56	-.4	21.97	22.06
TEST#13	QACT=1.027		CFS								
.667	.281	.68	.42		FREE FLOW						
.677	.519	.69	.77		FREE FLOW						
.679	.551	.69	.81	4.09	6.78	2.39	9.32	3.85	.7	13.26	13.17
.698	.604	.71	.87	4.72	6.52	3.72	11.20	3.55	1.4	14.96	14.75
.757	.691	.77	.91	6.25	5.85	5.69	14.66	3.13	.0	17.79	17.79
841	.795	.85	.95	8.54	5.12	8.20	19.40	2.74	-1.2	21.87	22.14
TEST#14	QACT=1.062		CFS								
.697	.231	.71	.33		FREE FLOW						
.697	.563	.71	.81	4.28	7.05	2.44	9.73	4.03	.1	13.77	13.76
.697	.573	.71	.82	4.38	7.03	2.74	10.08	3.97	.8	14.16	14.05
.697	.590	.71	.85	4.56	7.01	3.27	10.69	3.87	1.9	14.84	14.56
.700	.605	.71	.86	4.74	6.95	3.72	11.24	3.79	2.5	15.41	15.02
.713	.637	.72	.89	5.19	6.77	4.58	12.46	3.62	2.8	16.54	16.07
.736	.671	.75	.91	5.88	6.45	5.36	13.82	3.45	2.4	17.69	17.27
760	.707	.77	.93	6.67	6.14	6.27	15.35	3.28	2.4	19.08	18.63
.805	.770	.82	.96	8.11	5.69	7.96	18.20	3.03	2.5	21.76	21.23
TEST#15	QACT=1.149		CFS								
.746	.637	.76	.85	5.29	7.61	3.91	12.46	4.20	.9	16.82	16.66
.811	.747	.82	.92	7.37	6.77	6.77	17.13	3.63	.7	20.91	20.76
.928	.884	.94	.95	10.59	5.78	10.27	23.99	3.08	-1.6	26.64	27.08
1.022	.983	1.04	.96		SIGMA >> 0.96						

(Table 4 cont'd)

V1	V2	V1/B1	V2/V1	PT	MT	PW	P2	M2	%DEVM	UM	DM
TEST#16	QACT=1.256		CFS								
.762	.257	.77	.34		FREE FLOW						
.776	.629	.79	.81	5.33	8.76	3.05	12.15	5.04	-.3	17.14	17.19
.811	.715	.82	.88	6.55	8.28	5.45	15.70	4.50	.4	20.27	20.19
.871	.814	.89	.93	8.86	7.45	8.31	20.34	3.99	1.1	24.61	24.33
.945	.901	.96	.95	11.00	6.78	10.67	24.92	3.62	-.3	28.46	28.54
1.040	1.008	1.06	.97		SIGMA >> 0.96						
TEST#17	QACT=1.261		CFS								
.767	.602	.78	.78		FREE FLOW						
.774	.653	.79	.84	5.61	8.82	3.91	13.09	4.93	1.7	18.33	18.02
.796	.688	.81	.86	6.13	8.53	4.73	14.53	4.70	.9	19.40	19.23
.846	.781	.86	.92	8.07	7.79	7.42	18.73	4.18	1.6	23.27	22.91
.906	.855	.92	.94	9.84	7.17	9.38	22.44	3.84	.4	26.39	26.28
TEST#18	QACT=1.350		CFS								
.804	.243	.82	.30		FREE FLOW						
.804	.627	.82	.78		FREE FLOW						
.812	.660	.83	.81	5.86	9.63	3.38	13.37	5.56	-.4	18.86	18.93
.815	.688	.83	.84	6.22	9.56	4.32	14.53	5.36	1.0	20.09	19.89
.851	.749	.86	.88	7.20	9.08	5.90	17.22	4.96	.0	22.18	22.18
TEST#19	QACT=1.404		CFS								
.828	.244	.84	.29		FREE FLOW						
.828	.598	.84	.72		FREE FLOW						
.828	.667	.84	.81	6.02	10.19	3.30	13.66	5.94	-.5	19.51	19.60
.834	.684	.85	.82	6.25	10.10	3.77	14.36	5.81	-.2	20.12	20.17
.858	.733	.87	.85	7.01	9.76	5.09	16.50	5.45	-.4	21.86	21.95
.906	.814	.92	.90	8.55	9.12	7.37	20.34	4.95	-1.0	25.04	25.29
.983	.929	1.00	.95	11.60	8.17	11.04	26.50	4.38	-.2	30.81	30.87
1.084	1.037	1.10	.96	14.51	7.37	14.09	33.01	3.93	-2.7	35.96	36.94
TEST#20	QACT=1.448		CFS								
.852	.627	.87	.74		FREE FLOW						
.853	.682	.87	.80		FREE FLOW						
.858	.715	.87	.83	6.77	10.40	4.39	15.70	5.92	-.3	21.56	21.62
.872	.762	.89	.87	7.48	10.18	5.94	17.83	5.60	.8	23.61	23.43
.893	.804	.91	.90	8.35	9.84	7.25	19.85	5.33	1.1	25.45	25.18
.923	.850	.94	.92	9.52	9.39	8.64	22.18	5.07	1.1	27.55	27.25
.961	.907	.98	.94	11.05	8.90	10.50	25.26	4.77	1.4	30.46	30.02
1.010	.967	1.03	.96	12.67	8.41	12.36	28.71	4.48	.8	33.44	33.19
TEST#21	QACT=1.485		CFS								
.857	.681	.87	.79		FREE FLOW						
.874	.735	.89	.84	7.11	10.71	4.80	16.59	6.07	-.1	22.63	22.65
.914	.814	.93	.89	8.48	10.15	7.16	20.34	5.53	-.3	25.79	25.87
.968	.890	.98	.92	10.42	9.40	9.37	24.32	5.09	-.7	29.19	29.40
1.041	.984	1.06	.95	12.98	8.62	12.31	29.73	4.62	-1.3	33.92	34.35
TEST#22	QACT=1.664		CFS								
.918	.271	.93	.30		FREE FLOW						
.918	.742	.93	.81	7.42	12.76	4.07	16.90	7.50	-.6	24.26	24.40
.973	.869	.99	.89	9.70	11.89	8.15	23.18	6.51	.1	29.74	29.69
1.066	.989	1.08	.93	12.93	10.63	11.74	30.03	5.76	-1.4	35.31	35.79
1.153	1.113	1.17	.97		SIGMA >> 0.96						
1.243	1.203	1.26	.97		SIGMA >> 0.96						

(Table 4 cont'd)

Y'1	Y2	Y'1/B1	V2/Y'1	PT	MT	PW	P2	M2	%DEVM	UM	DM
TEST#23	QACT=1.730		CFS								
.944	.746	.96	.79		FREE FLOW						
.956	.784	.97	.82	8.20	13.18	4.83	18.87	7.69	-1.3	28.22	26.56
.986	.843	1.00	.85	9.27	12.72	6.59	21.82	7.20	-1.5	28.58	29.02
1.017	.905	1.03	.89	10.47	12.27	8.65	25.14	6.75	-1.6	31.39	31.90
1.078	.999	1.10	.93	13.18	11.36	11.92	30.64	6.16	-.9	36.46	36.80
1.132	1.073	1.15	.95	15.41	10.73	14.63	35.35	5.76	-.8	40.77	41.10
TEST#24	QACT=1.877		CFS								
.998	.292	1.01	.29		FREE FLOW						
.998	.747	1.01	.75		FREE FLOW						
.998	.798	1.01	.80		FREE FLOW						
1.003	.826	1.02	.82	9.08	14.70	5.42	20.95	8.60	-1.2	29.20	29.55
1.025	.879	1.04	.86	10.06	14.34	7.19	23.72	8.13	-.8	31.59	31.85
1.059	.931	1.08	.88	11.15	13.82	8.73	26.61	7.71	-1.8	33.70	34.32
1.146	1.062	1.16	.93	14.88	12.54	13.35	34.63	6.82	-1.7	40.77	41.45
TEST#25	QACT=1.905		CFS								
.995	.777	1.01	.78		FREE FLOW						
.996	.802	1.01	.81	8.67	15.27	4.60	19.75	9.09	-1.1	28.53	28.84
1.004	.844	1.02	.84	9.37	15.12	6.16	21.87	8.70	.3	30.66	30.57
1.020	.867	1.04	.85	9.83	14.86	6.77	23.08	8.48	-.3	31.46	31.56
1.034	.907	1.05	.88	10.59	14.62	8.27	25.26	8.15	.2	33.48	33.41
1.065	.947	1.08	.89	11.47	14.15	9.36	27.53	7.82	-1.1	34.98	35.36
1.100	1.002	1.12	.91	13.10	13.55	11.32	30.82	7.42	-.7	37.97	38.25

(Table 4 cont'd)

V1/B1	V2/V1	K_f	C	π	QC	%ERQ
TEST# 1	QACT=	.189	CFS			
.24	.80	.82	.54	.82	.19	3.0
.24	.85	.85	.72	.83	.19	-2.1
.25	.90	.88	.88	.85	.18	-4.6
.29	.93	.91	.93	.90	.19	2.7
TEST# 2	QACT=	.306	CFS			
.33	.83	.82	.62	.83	.30	-.8
.34	.89	.87	.85	.85	.30	-2.9
.37	.93	.90	.92	.90	.29	-3.8
.41	.96	.92	.97	.93	.30	-1.9
TEST# 3	QACT=	.348	CFS			
.35	.82	.81	.59	.83	.34	-1.6
.37	.90	.87	.85	.86	.34	-3.5
.42	.93	.89	.91	.90	.36	3.5
.46	.96	.92	.97	.93	.36	3.6
TEST# 4	QACT=	.541	CFS			
.46	.80	.77	.49	.84	.54	-.9
.47	.86	.82	.70	.85	.51	-6.0
.57	.95	.90	.94	.92	.54	.5
.57	.95	.90	.94	.92	.54	.5
TEST# 5	QACT=	.561	CFS			
.47	.80	.77	.50	.84	.55	-1.3
.48	.85	.81	.69	.85	.54	-4.1
.51	.89	.85	.82	.87	.55	-1.8
.55	.93	.89	.90	.91	.55	-1.4
.60	.95	.90	.93	.92	.59	6.1
TEST# 6	QACT=	.673	CFS			
.54	.84	.79	.63	.86	.66	-2.1
.56	.89	.84	.80	.87	.65	-3.2
.63	.94	.89	.90	.92	.68	1.0
TEST# 7	QACT=	.713	CFS			
.55	.82	.77	.56	.85	.70	-2.4
.57	.88	.83	.78	.87	.68	-5.2
.64	.94	.88	.90	.91	.69	-3.4
TEST# 8	QACT=	.782	CFS			
.60	.83	.77	.58	.86	.78	-.5
.62	.88	.82	.76	.87	.77	-1.6
.67	.93	.87	.88	.91	.77	-1.5
.74	.95	.90	.93	.93	.81	4.0
TEST# 9	QACT=	.822	CFS			
.60	.81	.75	.50	.86	.80	-2.9
.60	.82	.77	.56	.86	.79	-3.4
.63	.89	.83	.79	.87	.79	-3.9
.71	.94	.88	.90	.92	.82	-.1
TEST#10	QACT=	.924	CFS			
.65	.82	.75	.53	.86	.92	-1.0
.68	.84	.76	.59	.87	.96	3.6
.70	.90	.83	.80	.89	.91	-1.4
.79	.95	.89	.92	.93	.93	.5
TEST#11	QACT=	.984	CFS			
.67	.83	.76	.56	.87	.94	-4.6
.72	.90	.83	.79	.89	.96	-2.9
.79	.94	.88	.89	.92	.96	-2.1
TEST#12	QACT=	.994	CFS			
.68	.83	.76	.57	.87	.97	-2.4
.72	.88	.80	.74	.88	.98	-1.2
.77	.94	.88	.90	.92	.92	-7.4
.85	.96	.90	.93	.93	1.01	1.9
TEST#13	QACT=1.027		CFS			
.69	.81	.74	.50	.87	1.01	-1.6
.71	.87	.79	.68	.88	.99	-3.7
.77	.91	.84	.82	.90	1.03	.0
.85	.95	.88	.90	.93	1.08	5.4

(Table 4 cont'd)

V1/B1	V2/V1	K_1	C	R	QC	%ERQ
TEST#14	QACT=1.062 CFS					
.71	.81	.73	.48	.87	1.06	-.2
.71	.82	.74	.53	.87	1.04	-1.8
.71	.85	.77	.62	.87	1.01	-4.7
.71	.86	.79	.68	.88	1.00	-6.3
.72	.89	.82	.77	.88	.98	-7.7
.75	.91	.84	.82	.90	.98	-7.4
.77	.93	.86	.87	.91	.97	-8.4
.82	.96	.90	.94	.93	.95	-10.7
TEST#15	QACT=1.149 CFS					
.76	.85	.77	.64	.88	1.12	-2.4
.82	.92	.85	.83	.91	1.12	-2.4
.94	.95	.89	.91	.93	1.24	7.7
TEST#16	QACT=1.256 CFS					
.79	.81	.72	.48	.88	1.26	.6
.82	.88	.79	.72	.89	1.24	-1.2
.89	.93	.86	.86	.92	1.20	-4.2
.96	.95	.89	.91	.93	1.27	1.2
TEST#17	QACT=1.261 CFS					
.79	.84	.75	.60	.88	1.21	-4.2
.81	.86	.77	.66	.89	1.23	-2.3
.86	.92	.85	.83	.91	1.19	-5.2
.92	.94	.87	.89	.93	1.24	-1.8
TEST#18	QACT=1.350 CFS					
.83	.81	.71	.48	.88	1.36	.8
.83	.84	.75	.59	.89	1.32	-2.5
.86	.88	.78	.70	.89	1.35	-.1
TEST#19	QACT=1.404 CFS					
.84	.81	.70	.46	.88	1.42	1.0
.85	.82	.72	.51	.89	1.41	.5
.87	.85	.75	.62	.89	1.42	.9
.92	.90	.80	.75	.90	1.45	3.0
1.00	.95	.87	.88	.93	1.42	.8
1.10	.96	.89	.91	.93	1.59	13.3
TEST#20	QACT=1.448 CFS					
.87	.83	.73	.55	.89	1.46	.6
.89	.87	.77	.68	.89	1.42	-2.0
.91	.90	.80	.76	.90	1.40	-3.1
.94	.92	.83	.82	.92	1.39	-3.7
.98	.94	.87	.88	.93	1.37	-5.5
1.03	.96	.89	.92	.93	1.40	-3.4
TEST#21	QACT=1.485 CFS					
.89	.84	.73	.57	.89	1.49	.2
.93	.89	.79	.73	.90	1.50	.8
.98	.92	.83	.81	.92	1.52	2.4
1.06	.95	.87	.88	.93	1.56	5.2
TEST#22	QACT=1.664 CFS					
.93	.81	.69	.45	.89	1.69	1.3
.99	.89	.78	.72	.91	1.66	-.5
1.08	.93	.83	.82	.92	1.74	4.7
TEST#23	QACT=1.730 CFS					
.97	.82	.70	.49	.90	1.78	3.0
1.00	.85	.73	.60	.90	1.80	3.9
1.03	.89	.77	.70	.91	1.81	4.4
1.10	.93	.83	.81	.92	1.78	3.1
1.15	.95	.87	.88	.93	1.79	3.3
TEST#24	QACT=1.877 CFS					
1.02	.82	.69	.49	.90	1.93	2.8
1.04	.86	.73	.60	.91	1.92	2.0
1.08	.88	.75	.66	.91	1.97	4.8
1.16	.93	.82	.80	.93	1.98	5.7
TEST#25	QACT=1.905 CFS					
1.01	.81	.67	.43	.90	1.95	2.4
1.02	.84	.71	.55	.90	1.89	-.8
1.04	.85	.72	.57	.91	1.92	.7
1.05	.88	.75	.66	.91	1.89	-.6
1.08	.89	.76	.69	.91	1.96	2.9
1.12	.91	.80	.76	.92	1.95	2.2

(Table 4 cont'd)

Y1/B1	Y2/Y1	X	XX	U	V	W	U+V-W	Q2	QT	RQT
TEST# 1	QACT= .189 CFS									
.24	.80	-.221	-1.15	.049	.029	.111	-.033	.038	.195	3.0
.24	.85	-.216	-1.12	.052	.042	.125	-.030	.034	.185	-2.1
.25	.90	-.226	-1.17	.062	.060	.149	-.028	.033	.180	-4.6
.29	.93	-.276	-1.43	.090	.089	.206	-.026	.038	.194	2.7
TEST# 2	QACT= .306 CFS									
.33	.83	-.302	-1.57	.093	.065	.217	-.059	.092	.303	-.8
.34	.89	-.311	-1.61	.113	.107	.275	-.055	.088	.297	-2.9
.37	.93	-.360	-1.87	.152	.149	.347	-.046	.087	.294	-3.8
.41	.96	-.415	-2.16	.202	.201	.445	-.042	.090	.300	-1.9
TEST# 3	QACT= .348 CFS									
.35	.82	-.328	-1.70	.106	.070	.245	-.069	.117	.343	-1.6
.37	.90	-.341	-1.77	.135	.128	.327	-.064	.113	.336	-3.5
.42	93	-.407	-2.12	.192	.187	.440	-.061	.130	.360	3.5
.46	.96	-.473	-2.46	.262	.261	.576	-.053	.130	.361	3.6
TEST# 4	QACT= .541 CFS									
46	.80	- 451	-2.34	.177	.100	.400	- 123	.287	.536	-.9
47	.86	-.436	-2.27	.197	.157	.468	-.114	.259	.509	-6 0
.57	.95	- 577	-3.00	.382	.375	.855	- 099	.296	.544	.5
.57	.95	-.577	-3.00	.382	.375	.855	-.099	.296	.544	.5
TEST# 5	QACT= .561 CFS									
.47	.80	-.461	-2.40	.185	.106	.420	-.128	.307	.554	-1.3
.48	.85	-.453	-2.36	.209	.163	.495	-.123	.289	.538	-4.1
.51	.89	-.475	-2.47	.249	.230	.602	-.123	.304	.551	-1.8
.55	.93	-.547	-2.84	.338	.327	.774	-.108	.306	.553	-1.4
.60	.95	-.608	-3.16	.422	.413	.948	-.112	.354	.595	6.1
TEST# 6	QACT= .673 CFS									
.54	.84	-.521	-2.71	.257	.184	.602	-.160	.434	.659	-2.1
.56	.89	-.529	-2.75	.303	.275	.732	-.154	.424	.651	-3.2
.63	.94	-.632	-3.29	.449	.433	1.023	-.141	.462	680	1.0
TEST# 7	QACT= .713 CFS									
.55	.82	-.541	-2.81	.260	.167	.599	-.172	.484	.696	-2.4
.57	.88	-.537	-2.79	.307	.271	.741	-.164	.457	.676	-5.2
.64	.94	-.635	-3.30	.452	.434	1.030	-.144	.475	.689	-3.4
TEST# 8	QACT= .782 CFS									
60	.83	-.586	-3.05	.306	.204	.709	- 199	.605	.778	-.5
.62	.88	-.588	-3.05	.359	.313	.865	-.194	.592	.769	-1.6
.67	93	-.667	-3.47	.492	.468	1.131	-.171	.593	770	-1 5
.74	.95	-.747	-3.88	.634	.620	1.424	-.170	.662	.813	4.0
TEST# 9	QACT= 822 CFS									
.60	.81	-.598	-3.11	.295	.171	.671	-.205	.636	.798	-2.9
.60	.82	-.595	-3.09	.309	.199	.712	-.204	.630	.794	-3.4
.63	.89	-.602	-3.13	.382	.342	.924	-.199	.624	.790	-3.9
.71	.94	-.716	-3.72	.570	.547	1.299	-.181	.675	.821	-.1
TEST#10	QACT= .924 CFS									
.65	.82	-.659	-3.42	.361	.222	.827	-.245	.838	.915	-1.0
.68	.84	-.680	-3.53	.404	.277	.941	-.259	.916	.957	3.6
.70	.90	-.684	-3.55	.489	.441	1.164	-.234	.831	.911	-1.4
.79	.95	-.800	-4.15	.717	.696	1.621	-.207	.862	.928	.5
TEST#11	QACT= .984 CFS									
.67	.83	-.671	-3.49	.384	.251	.888	-.253	.882	.939	-4.6
.72	.90	-.703	-3.65	.512	.459	1.221	-.250	.913	.955	-2.9
.79	.94	-.796	-4.14	.700	.670	1.594	-.224	.928	.963	-2.1
TEST#12	QACT= .994 CFS									
.68	.83	-.687	-3.57	.404	.269	.937	-.264	.941	.970	-2.4
.72	.88	-.696	-3.62	.480	.406	1.153	-.267	.964	.982	-1.2
.77	.94	-.777	-4.04	.671	.645	1.525	-.210	.848	.921	-7.4
.85	.96	-.865	-4.49	.847	.830	1.906	-.228	1.027	1.013	1.9
TEST#13	QACT=1.027 CFS									
.69	.81	-.709	-3 68	.399	.234	.911	-.277	1.022	1.011	-1.6
.71	.87	-.698	-3.62	.461	.364	1.094	-.270	.979	.989	-3.7
.77	.91	-.763	-3.97	.610	.557	1.432	-.266	1.054	1.026	.0
.85	.95	-.869	-4.51	.834	.802	1.896	-.260	1.172	1.083	5.4

(Table 4 cont'd)

V1/B1	V2/V1	X	XX	U	V	W	U+V-W	Q2	QT	RQT
TEST#14	QACT=1.062 CFS									
.71	.81	-.735	-3.82	.418	.238	.951	-.294	1.123	1.060	-.2
.71	.82	-.724	-3.76	.428	.268	.985	-.289	1.087	1.043	-1.8
.71	.85	-.708	-3.68	.446	.320	1.044	-.278	1.024	1.012	-4.7
.71	.86	-.700	-3.64	.463	.363	1.098	-.272	.991	.995	-6.3
.72	.89	-.704	-3.66	.507	.448	1.217	-.262	.960	.980	-7.7
.75	.91	-.739	-3.84	.575	.524	1.351	-.252	.966	.983	-7.4
.77	.93	-.775	-4.03	.651	.613	1.500	-.235	.947	.973	-8.4
.82	.96	-.835	-4.34	.792	.779	1.779	-.208	.900	.949	-10.7
TEST#15	QACT=1.149 CFS									
.76	.85	-.762	-3.96	.517	.383	1.217	-.318	1.258	1.121	-2.4
.82	.92	-.827	-4.30	.719	.662	1.674	-.292	1.257	1.121	-2.4
.94	.95	-.963	-5.00	1.034	1.004	2.344	-.306	1.531	1.238	7.7
TEST#16	QACT=1.256 CFS									
.79	.81	-.835	-4.34	.521	.298	1.187	-.368	1.597	1.264	.6
.82	.88	-.820	-4.26	.640	.532	1.534	-.362	1.541	1.241	-1.2
.89	.93	-.898	-4.67	.865	.813	1.988	-.310	1.447	1.203	-4.2
.96	.95	-.981	-5.10	1.074	1.044	2.435	-.317	1.617	1.272	1.2
TEST#17	QACT=1.261 CFS									
.79	.84	-.803	-4.17	.547	.382	1.279	-.350	1.460	1.208	-4.2
.81	.86	-.815	-4.23	.599	.462	1.420	-.359	1.519	1.232	-2.3
.86	.92	-.867	-4.50	.788	.725	1.830	-.317	1.428	1.195	-5.2
.92	.94	-.938	-4.87	.961	.918	2.193	-.314	1.533	1.238	-1.8
TEST#18	QACT=1.350 CFS									
.83	.81	-.880	-4.57	.572	.330	1.307	-.405	1.851	1.361	.8
.83	.84	-.855	-4.44	.608	.422	1.420	-.390	1.734	1.317	-2.5
.86	.88	-.869	-4.52	.703	.577	1.683	-.403	1.821	1.349	-.1
TEST#19	QACT=1.404 CFS									
.84	.81	-.912	-4.74	.588	.322	1.335	-.424	2.011	1.418	1.0
.85	.82	-.902	-4.69	.611	.368	1.404	-.425	1.991	1.411	.5
.87	.85	-.900	-4.68	.685	.497	1.612	-.429	2.009	1.417	.9
.92	.90	-.931	-4.84	.835	.721	1.988	-.432	2.089	1.445	3.0
1.00	.95	-1.022	-5.31	1.133	1.079	2.589	-.377	2.003	1.415	.8
1.10	.96	-1.127	-5.86	1.417	1.378	3.226	-.432	2.530	1.590	13.3
TEST#20	QACT=1.448 CFS									
.87	.83	-.920	-4.78	.661	.429	1.534	-.443	2.121	1.456	.6
.89	.87	-.900	-4.68	.731	.581	1.742	-.430	2.013	1.419	-2.0
.91	.90	-.915	-4.76	.816	.709	1.939	-.414	1.969	1.403	-3.1
.94	.92	-.953	-4.95	.930	.845	2.168	-.393	1.946	1.395	-3.7
.98	.94	-.998	-5.18	1.079	1.027	2.468	-.361	1.874	1.369	-5.5
1.03	.96	-1.050	-5.45	1.237	1.209	2.805	-.359	1.958	1.399	-3.4
TEST#21	QACT=1.485 CFS									
.89	.84	-.934	-4.85	.695	.469	1.621	-.456	2.215	1.488	.2
.93	.89	-.939	-4.88	.828	.700	1.988	-.459	2.241	1.497	.8
.98	.92	-1.005	-5.22	1.018	.916	2.376	-.442	2.311	1.520	2.4
1.06	.95	-1.085	-5.64	1.268	1.204	2.905	-.433	2.439	1.562	5.2
TEST#22	QACT=1.664 CFS									
.93	.81	-1.035	-5.38	.724	.398	1.652	-.529	2.844	1.686	1.3
.99	.89	-1.012	-5.26	.947	.797	2.265	-.521	2.743	1.656	-.5
1.08	.93	-1.117	-5.81	1.263	1.148	2.934	-.523	3.037	1.743	4.7
TEST#23	QACT=1.730 CFS									
.97	.82	-1.072	-5.57	.801	.472	1.844	-.571	3.178	1.783	3.0
1.00	.85	-1.067	-5.54	.905	.644	2.132	-.582	3.228	1.797	3.9
1.03	.89	-1.066	-5.54	1.022	.846	2.457	-.589	3.262	1.806	4.4
1.10	.93	-1.132	-5.88	1.287	1.166	2.994	-.541	3.181	1.783	3.1
1.15	.95	-1.183	-6.15	1.505	1.430	3.454	-.519	3.191	1.786	3.3
TEST#24	QACT=1.877 CFS									
1.02	.82	-1.135	-5.90	.886	.529	2.047	-.631	3.721	1.929	2.8
1.04	.86	-1.116	-5.80	.983	.703	2.318	-.632	3.668	1.915	2.0
1.08	.88	-1.134	-5.89	1.089	.854	2.600	-.657	3.873	1.968	4.8
1.16	.93	-1.211	-6.29	1.453	1.306	3.384	-.625	3.933	1.983	5.7
TEST#25	QACT=1.905 CFS									
1.01	.81	-1.156	-6.01	.846	.450	1.930	-.634	3.806	1.951	2.4
1.02	.84	-1.110	-5.77	.915	.603	2.137	-.619	3.572	1.890	-.8
1.04	.85	-1.120	-5.82	.960	.662	2.255	-.633	3.681	1.918	.7
1.05	.88	-1.103	-5.73	1.034	.809	2.468	-.625	3.583	1.893	-.6
1.08	.89	-1.129	-5.87	1.120	.916	2.690	-.655	3.839	1.959	2.9
1.12	.91	-1.165	-6.05	1.279	1.107	3.012	-.626	3.790	1.947	2.2

TABLE 5

```
      PROGRAM QCOMP(INPUT,OUTPUT,TAPE16,TAPE17)
      INTEGER TN(15),JD(15)
      DIMENSION QA(15),QC(15,10),YB(15,10),SIG(15,10),
     ● H(15),AK(15,10),C(15,10),P(15,10),Y1(15,10),
     ● G(15,10),ERQ(15,10),Y2(15,10),BET(15,10)
C
      DO 10 I=1,15
         READ(16,*) TN(I),H(I)
   10 CONTINUE
      DO 20 I=1,15
         READ(17,*) JD(I)
         DO 20 J=1,JD(I)
            READ(17,*) Y1(I,J),Y2(I,J)
   20 CONTINUE
      DO 15 I=1,15
         QA(I)=1.4258*((0.0038+(H(I)/12.))**2.5)
   15 CONTINUE
      DO 17 I=1,6
         DO 17 J=1,JD(I)
            YB(I,J)=Y1(I,J)/0.738
   17 CONTINUE
      DO 18 I=7,15
        DO 18 J=1,JD(I)
            YB(I,J)=Y1(I,J)/0.492
   18 CONTINUE
      DO 19 I=1,15
        DO 19 J=1,JD(I)
            SIG(I,J)=Y2(I,J)/Y1(I,J)
   19 CONTINUE
      DO 30 I=1,15
         DO 40 J=1,JD(I)
            IF (SIG(I,J).GT.0.89) GO TO 1
            IF ((SIG(I,J).LT.0.8).OR.(SIG(I,J).GT.0.960)) GO TO 40
            AM1=0.644*SIG(I,J)-.709
            GO TO 2
    1       AM1=+1.2*SIG(I,J)-1.203
    2       BM=0.55*SIG(I,J)+0.420
            AK(I,J)=AM1*YB(I,J)+BM
            IF (SIG(I,J).GT.0.89) GO TO 3
            CM=-0.811*SIG(I,J)+0.344
            CA=3.889*SIG(I,J)-2.551
            GO TO 4
    3       CM=1.714*SIG(I,J)-1.726
            CA=1.429*SIG(I,J)-0.361
    4       C(I,J)=CM*YB(I,J)+CA
            PF=0.112*YB(I,J)+0.79
            IF (SIG(I,J).GT.0.96) GO TO 6
            IF (SIG(I,J).GT.0.89) GO TO 5
            AA=-0.306*SIG(I,J)+0.357
            GO TO 7
    5       AA=-1.214*SIG(I,J)+1.166
            GO TO 7
    6       AA=0.0
    7       IF (SIG(I,J).GT.0.89) GO TO 8
            BB=0.353*SIG(I,J)+0.506
```

(Table 5 cont'd)

```
                GO TO 9
      8         BB=1.636*SIG(I,J)-0.636
      9         PP=AA*YB(I,J)+BB
                IF (PP.LT.PF) GO TO 11
                P(I,J)=PP
                GO TO 12
     11         P(I,J)=PF
     12         BET(I,J)=0.194*SIG(I,J)+0.864
                A=0.52*(YB(I,J)**3.)/(6.*(BET(I,J)*.52*P(I,J)-SIG(I,J)))
                CP=0.48*C(I,J)
                B1=(CP-3.)*P(I,J)*(SIG(I,J)**3.)
                B2=CP*((P(I,J)*SIG(I,J))**2.)
                B3=(1.56*AK(I,J)+CP)*SIG(I,J)*P(I,J)**3.0
                B=B1+B2+B3
                G(I,J)=A*B
     40      CONTINUE
     30   CONTINUE
          DO 51 I=1,6
             DO 52 J=1,JD(I)
                QC(I,J)=(G(I,J)*32.2*0.738**5.)**0.5
                ERQ(I,J)=(QC(I,J)-QA(I))*100.0/QA(I)
     52      CONTINUE
     51   CONTINUE
          DO 53 I=7,15
             DO 54 J=1,JD(I)
                QC(I,J)=(G(I,J)*32.2*0.492**5.)**0.5
                ERQ(I,J)=(QC(I,J)-QA(I))*100.0/QA(I)
     54      CONTINUE
     53   CONTINUE
          PRINT 200
          DO 70 I=1,15
             PRINT 80, TN(I),QA(I)
             DO 90 J=1,JD(I)
                IF (SIG(I,J).LT.0.8) THEN
                   PRINT 149,Y1(I,J),Y2(I,J),YB(I,J),SIG(I,J)
                ELSEIF (SIG(I,J).GT.0.960) THEN
                   PRINT 151,Y1(I,J),Y2(I,J),YB(I,J),SIG(I,J)
                ELSE
                   PRINT 150,Y1(I,J),Y2(I,J),YB(I,J),SIG(I,J),
     *                   AK(I,J),C(I,J),P(I,J),QC(I,J),ERQ(I,J)
                ENDIF
     90      CONTINUE
     70   CONTINUE
     80   FORMAT(/10X,'TEST#',I4,'  QACT= ',F6.3,'  CFS')
    149   FORMAT(2X,2F8.3,F7.2,F8.2,10X,'FREE FLOW')
    150   FORMAT(2X,2F8.3,F7.2,4F8.2,F8.3,F7.1)
    151   FORMAT(2X,2F8.3,F7.2,F8.2,10X,'SIGMA >> 0.96')
    200   FORMAT(//7X,'Y1',6X,'Y2',4X,'Y1/B1',4X,'SIG',
     *          6X,'K',7X,'C',7X,'R',5X,'QCOM',3X,'%ERQ')
          STOP
          END
```

(Table 5 cont'd)

Y1	Y2	Y1/B1	SIG	K	C	[illegible]	QCOM	%ERQ
TEST# 26		QACT=	.338	CFS				
.401	.311	.54	.78		FREE FLOW			
.402	.322	.54	.80	.76	.48	.85	.338	.1
.404	.342	.55	.85	.80	.65	.86	.324	-4.1
.412	.368	.56	.89	.84	.81	.87	.312	-7.7
.427	.391	.58	.92	.86	.86	.89	.311	-8.0
.455	.433	.62	.95	.91	.94	.93	.294	-12.8
.497	.485	.67	.98		SIGMA >> 0.96			
TEST# 27		QACT=	.504	CFS				
.506	.387	.69	.76		FREE FLOW			
.508	.415	.69	.82	.74	.52	.87	.487	-3.3
.515	.448	.70	.87	.79	.70	.88	.466	-7.5
.535	.487	.72	.91	.84	.82	.90	.457	-9.4
.563	.528	.76	.94	.88	.89	.92	.450	-10.6
.615	.591	.83	.96		SIGMA >> 0.96			
.669	.653	.91	.98		SIGMA >> 0.96			
TEST# 28		QACT=	.656	CFS				
.593	.414	.80	.70		FREE FLOW			
.594	.485	.80	.82	.72	.50	.88	.633	-3.5
.600	.510	.81	.85	.76	.61	.88	.617	-5.9
.613	.539	.83	.88	.79	.71	.89	.615	-6.3
.636	.577	.86	.91	.82	.79	.90	.615	-6.3
.662	.617	.90	.93	.86	.86	.92	.605	-7.7
.710	.681	.96	.96	.90	.93	.93	.603	-8.0
.762	.741	1.03	.97		SIGMA >> 0.96			
TEST# 29		QACT=	.889	CFS				
.714	.563	.97	.79		FREE FLOW			
.718	.587	.97	.82	.69	.48	.90	.873	-1.8
.734	.643	.99	.88	.76	.67	.90	.839	-5.6
.760	.683	1.03	.90	.79	.73	.91	.853	-4.1
.788	.724	1.07	.92	.82	.79	.92	.854	-4.0
.832	.787	1.13	.95	.86	.87	.93	.847	-4.7
.907	.878	1.23	.97		SIGMA >> 0.96			
TEST# 30		QACT=	1.226	CFS				
.870	.683	1.18	.79		FREE FLOW			
.874	.721	1.18	.82	.66	.47	.92	1.223	-.2
.884	.773	1.20	.87	.73	.62	.92	1.163	-5.1
.906	.806	1.23	.89	.74	.66	.93	1.187	-3.1
.949	.876	1.29	.92	.81	.77	.93	1.160	-5.3
.988	.928	1.34	.94	.84	.83	.94	1.161	-5.2
1.067	1.021	1.45	.96	.87	.88	.95	1.183	-3.5
1.153	1.123	1.56	.87		SIGMA >> 0.96			
TEST# 31		QACT=	1.528	CFS				
.992	.763	1.34	.77		FREE FLOW			
.994	.831	1.35	.84	.65	.48	.94	1.521	-.4
1.004	.843	1.36	.84	.65	.48	.94	1.541	.9
1.026	.888	1.39	.87	.69	.56	.95	1.540	.8
1.062	.963	1.44	.91	.75	.69	.95	1.482	-3.0
1.112	1.018	1.51	.92	.77	.71	.96	1.547	1.2
1.206	1.143	1.63	.95	.83	.83	.97	1.464	-4.2
1.286	1.248	1.74	.97		SIGMA >> 0.96			

(Table 5 cont'd.)

Y1	Y2	Y1/B1	SIG	K_t	C	M	QCOM	%ERQ
TEST# 32		QACT=	.053	CFS				
.160	.127	.33	.79		FREE FLOW			
.160	.133	.33	.83	.82	.63	.83	.053	-.8
.161	.136	.33	.84	.83	.68	.84	.052	-1.5
.165	.151	.34	.92	.89	.89	.88	.047	-10.6
.189	.177	.38	.94	.90	.93	.91	.054	1.4
.238	.233	.48	.98		SIGMA >> 0.96			
TEST# 33		QACT=	.086	CFS				
.216	.169	.44	.78		FREE FLOW			
.217	.174	.44	.80	.78	.50	.84	.087	2.2
.219	.181	.45	.83	.80	.59	.84	.087	1.1
.230	.210	.47	.91	.87	.87	.88	.081	-5.7
.261	.251	.53	.96		SIGMA >> 0.96			
.328	.320	.67	.98		SIGMA >> 0.96			
TEST# 34		QACT=	.109	CFS				
.250	.195	.51	.78		FREE FLOW			
.250	.200	.51	.80	.76	.49	.85	.110	.5
.252	.206	[illegible]	.82	.78	.55	.85	.109	.0
.263	.235	.53	.89	.84	.81	.87	.105	-3.5
.291	.275	.59	.95	.90	.93	.92	.103	-5.4
.335	.324	.68	.97		SIGMA >> 0.96			
.398	.389	.81	.98		SIGMA >> 0.96			
TEST# 35		QACT=	.157	CFS				
.310	.249	.63	.80	.74	.48	.86	.155	-1.2
.312	.256	.63	.82	.76	.54	.86	.154	-2.0
.318	.272	.65	.86	.79	.66	.87	.152	-3.1
.333	.300	.68	.90	.83	.80	.89	.152	-3.3
.360	.341	.73	.95	.89	.92	.93	.146	-7.2
.391	.378	.79	.97		SIGMA >> 0.96			
.448	.442	.91	.99		SIGMA >> 0.96			
TEST# 36		QACT=	.191	CFS				
.351	.280	.71	.80		FREE FLOW			
.353	.284	.72	.80	.73	.47	.87	.192	.7
.359	.305	.73	.85	.77	.63	.88	.187	-1.8
.375	.334	.76	.89	.81	.76	.89	.190	-.5
.401	.375	.82	.94	.87	.87	.92	.185	-3.2
.443	.426	.90	.96		SIGMA >> 0.96			
TEST# 37		QACT=	.363	CFS				
.512	.403	1.04	.79		FREE FLOW			
.514	.414	1.04	.81	.66	.43	.91	.365	.3
.519	.431	1.05	.83	.69	.51	.91	.359	-1.3
.531	.460	1.08	.87	.73	.62	.91	.356	-2.1
.553	.500	1.12	.90	.78	.73	.92	.355	-2.4
.598	.562	1.22	.94	.85	.84	.93	.360	-1.1
.677	.657	1.38	.97		SIGMA >> 0.96			
TEST# 38		QACT=	.546	CFS				
.650	.518	1.32	.80		FREE FLOW			
.653	.533	1.33	.82	.63	.42	.94	.554	1.3
.661	.560	1.34	.85	.67	.51	.94	.540	-1.1
.678	.585	1.38	.86	.68	.55	.94	.552	1.1
.697	.625	1.42	.90	.73	.65	.95	.543	-.6
.740	.687	1.50	.93	.80	.76	.96	.527	-3.5
.794	.756	1.61	.95	.85	.85	.97	.507	-7.3
.869	.840	1.77	.97		SIGMA >> 0.96			

(Table 5 cont'd)

Y1	Y2	Y1/B1	SIG	K	C	⊓	QCOM	%ERQ
TEST# 39*		QACT= .790 CFS						
.799	.643	1.62	.80	.55	.34	.97	.832	5.3
.804	.650	1.63	.81	.56	.35	.97	.836	5.9
.807	.668	1.64	.83	.59	.40	.97	.814	3.1
.823	.696	1.67	.85	.61	.45	.98	.820	3.8
.849	.736	1.73	.87	.64	.50	.98	.839	6.2
.870	.790	1.77	.91	.72	.64	.99	.769	-2.6
.918	.853	1.87	.93	.77	.72	1.00	.739	-6.5
.990	.940	2.01	.95	.81	.80	1.02	.676	-14.5
1.083	1.048	2.20	.97		SIGMA >> 0.96			
TEST# 40*		QACT= 1.020 CFS						
.913	.731	1.86	.80	.50	.29	1.00	1.100	7.9
.915	.748	1.86	.82	.53	.34	1.00	1.070	4.9
.927	.768	1.88	.83	.55	.37	1.00	1.076	5.5
.949	.808	1.93	.85	.58	.42	1.01	1.080	5.9
.972	.848	1.98	.87	.61	.47	1.01	1.088	6.7
1.004	.898	2.04	.89	.65	.52	1.02	1.093	7.2
1.042	.958	2.12	.92	.71	.63	1.03	.991	-2.9
1.132	1.078	2.30	.95	.81	.78	1.05	.738	-27.7
1.217	1.168	2.47	.96	.82	.81	1.07	.592	-41.9

* Note that y_1'/B_1 is far beyond its range of applicability in Eq.(7).

TABLE 5a

Data for determination of F_t, C, $r=y_t/y'_1$ and $Beta_2$

Test#	Q	y'_1	y_t	y_2	F_t	$1/2F_N$	C	$Beta_2$
2	.306	.324	.267	.269	.82	2.08	.65	1.02
		.339	.289	.303	.89	3.80	.96	1.04
		.365	.338	.340	.91	4.90	.95	1.07
		.403	.384	.385	.93	6.53	.99	1.09
3	.348	.346	.287	.246				
		.348	.291	.286	.80			
		.368	.319	.330	.89			
		.412	.374	.383	.92			
		.457	.426	.438	.96			
5	.561	.466	.398	.374		3.88	.58	
		.475	.409	.406		5.60	.75	
		.501	.439	.448		7.43	.84	
		.544	.493	.508		10.39	.93	
		.593	.548	.562		13.21	.96	
7	.7[illegible]4	.544	.464	.447	.80	5.10	.55	1.01
		.562	.489	.497	.83	8.47	.78	1.01
		.626	.568	.586	.92	13.71	.92	1.02
		.712	.670	.684	.96	20.10	.98	1.05
8	.762	.579	.496	.456		4.24	.42	
		.586	.509	.486	.75	6.82	.62	
		.608	.535	.537	.84	9.76	.76	
		.660	.602	.614	.88	14.71	.89	
		.724	.675	.689	.93	19.45	.93	
11	.984	.652		.240				
		.657		.544	.75			
		.709		.638	.82			
		.775		.729	.91			
		.065		.834	.95			
15	1.149	.746		.637		11.62	.62	
		.811		.747		20.15	.82	
		.928		.884		31.74	.92	
		1.022		.983		40.90	.96	
17	1.261	.767	.667	.602	.73	6.82	.38	
		.774	.678	.653	.74	10.48	.53	1.00
		.796	.706	.688	.79	14.93	.69	1.03
		.846	.764	.781	.86	21.24	.80	1.03
		.906	.834	.855	.87	28.14	.88	1.04
21	1.485	.857	.757	.681		9.47	.41	
		.874	.782	.735	.71	15.22	.59	
		.914	.822	.814	.80	22.18	.74	
		.968	.888	.890	.84	29.57	.84	
		1.041	.971	.984	.88	38.62	.90	

(Table 5a cont'd)

Test#	D	y'_1	y_t	y_2	F_t	$1/2P_N$	C	$Beta_2$
23	1.730	.944	.840	.746	.64	11.63	.41	1.01
		.956	.854	.784	.68	14.57	.49	1.02
		.986	.890	.843	.71	20.24	.60	1.03
		1.017	.927	.905	.75	26.77	.71	1.04
		1.078	.992	.999	.84	36.39	.82	1.04
		1.132	1.057	1.073	.87	44.07	.87	1.04

Notes: D in (cfs), y'_1, y_t, y_2 in (ft), and P_N in (lb).

APPENDIX - VI

DEVELOPMENT OF DESIGN CHART

TABLE 6

```
      PROGRAM FSIG(INPUT,OUTPUT)
      COMMON A1,A2,A3,A4
      EXTERNAL FF
      DIMENSION VB(12),SIG(9),QF(12),AK(12,9),C(12,9),
     *P(12,9),VB1(12),QC(12,9),F(12,9),SSIG(9),FM(9),
     *BET(9),ERQ(12),GD(12),GS(12),GDS(12),SF(9),QFS(12)
     *,GGS(12,9)
      VB(1)=0.25
      DO 10 I=2,12
   10 VB(I)=VB(I-1)+0.125
      SSIG(1)=0.805
      SSIG(2)=0.82
      DO 30 J=3,9
   30 SSIG(J)=SSIG(J-1)+0.02
      DO 40 I=1,12
      AQ=1.58*(VB(I)*0.984)**1.5
      FRK=1.0-0.29*VB(I)
      AG=AQ**2.0/(32.2*0.984**5.0)
      R3=(2.1632*FRK)/((1.0+2.0*FRK)**3.0)
      A1=0.125/VB(I)**6.0
      A2=0.75/VB(I)**3.0
      A3=1.5-(1.0/R3)
      A4=VB(I)**3.0
      E=AG
      D=AG*3.0
      K=20
      CALL BISEC(FF,E,D,K,Z)
      GF=Z
      GD(I)=GF*10.0**5.0
      QF(I)=(GF*32.2*0.984**5.0)**0.5
   40 CONTINUE
      PRINT 100
  100 FORMAT(//8X,'SIG',6X, 'K',6X,'C',7X,'R',
     *6X,'QC',7X,'F',6X,'SIG')
      DO 50 I=1,12
      VB1(I)=VB(I)
      PRINT 51,VB1(I)
   51 FORMAT(/10X,'Y1/B1=',F6.3)
      DO 60 J=1,9
      SIG(J)=SSIG(J)
      IF(SIG(J).GT.0.89) GO TO 1
      AM=0.644*SIG(J)-0.709
      GO TO 2
    1 AM=1.2*SIG(J)-1.203
    2 BM=0.55*SIG(J)+0.420
      AK(I,J)=AM*VB1(I)+BM
      IF(SIG(J).GT.0.89) GO TO 3
      CM=-0.611*SIG(J)+0.344
      CA=3.889*SIG(J)-2.551
      GO TO 4
```

(Table 6 cont'd)

```
3     CM=1.714*SIG(J)-1.726
      CA=1.429*SIG(J)-0.361
4     C(I,J)=CM*YB1(I)+CA
      PF=0.112*YB1(I)+0.79
      IF(SIG(J).GT.0.96) GO TO 6
      IF(SIG(J).GT.0.89) GO TO 5
      AA=-.306*SIG(J)+.357
      GO TO 7
5     AA=-1.214*SIG(J)+1.166
      GO TO 7
6     AA=0.
7     IF(SIG(J).GT.0.89) GO TO 8
      BB=.353*SIG(J)+.506
      GO TO 9
8     BB=1.636*SIG(J)-.636
9     PP=AA*YB1(I)+BB
      IF(PP.LT.PF) GO TO 11
      P(I,J)=PP
      GO TO 12
11    P(I,J)=PF
12    BET(J)=0.194*SIG(J)+0.864
      A=0.52*YB1(I)**3.0/(6.*(BET(J)*.52*P(I,J)-SIG(J)))
      CP=0.48*C(I,J)
      B1=(CP-3.)*P(I,J)*(SIG(J)**3.)
      B2=CP*((R(I,J)*SIG(J))**2.0)
      B3=(1.56*AK(I,J)+CP)*SIG(J)*(P(I,J)**3.)
      B=B1+B2+B3
      ST=32.2*(0.984**5.)
      QQ=A*B*ST
      QC(I,J)=QQ**0.5
      F(I,J)=QC(I,J)/QC(I,1)
      PRINT 200,SIG(J),AK(I,J),C(I,J),P(I,J),QC(I,J),
     *F(I,J),SIG(J)
200   FORMAT(3X,7F8.3)
60    CONTINUE
      ERQ(I)=(QC(I,1)-QF(I))*100.0/QF(I)
      GS(I)=((QC(I,1)**2.)/(32.2*0.984**5.))*10.**5.
      AQ1=1.58*(YB1(I)*0.984)**1.5
      AG1=AQ1**2.0/(32.2*0.984**5.0)
      A1=0.125/YB1(I)**6.0
      A2=0.75/YB1(I)**3.0
      R3=(2.1632*AK(I,1))/((1.0+2.0*AK(I,1))**3.0)
      A3=1.5-(1.0/R3)
      A4=YB1(I)**3.0
      E=AG1
      D=AG1*3.0
      K=20
      CALL BISEC(FF,E,D,K,Z)
      GFS=Z
      QFS(I)=(GFS*32.2*0.984**5.)**0.5
      GDS(I)=GFS*10.0**5.0
      PRINT 250,YB1(I),QF(I),QC(I,1),QFS(I),ERQ(I),
     *GD(I),GS(I),GDS(I)
```

(Table 6 cont'd)

```
 250   FORMAT(/3X,4F8.3,F7.1,3F12.1)
 50    CONTINUE
       PRINT 300
 300   FORMAT(/6X,'Y1/B1',5X,'QF',6X,'QC',5X,'QFS',4X,
      *'%ERQ',4X,'QF2/GB15',4X,'QC2/GB15',4X,'QFS2/GB15')
       PRINT 350
 350   FORMAT(//11X,'SIG',6X,'FM')
       SF(J)=0.0
       DO 70 J=1,9
       DO 80 I=2,12
       SF(J)=SF(J)+F(I,J)
 80    CONTINUE
       FM(J)=SF(J)/11.0
       PRINT 400,SIG(J),FM(J)
 400   FORMAT(7X,2F8.3)
 70    CONTINUE
       PRINT 450
       DO 90 I=1,12
       DO 90 J=1,9
       GGS(I,J)=GS(I)*FM(J)
 90    CONTINUE
       DO 95 I=1,12
       PRINT 455,YB1(I),(GGS(I,J),J=1,9)
 455   FORMAT(5X,F5.3,9F10.1)
 95    CONTINUE
 450   FORMAT(//5X,'Y1/B1',5X,'GS805',5X,'GS82',6X,
      *'GS84',6X,'GS86',6X,'GS88',6X,'GS90',6X,
      *'GS92',6X,'GS94',6X,'GS96')
       STOP
       END
```

```
       SUBROUTINE BISEC(FF,E,D,K,Z)
       DO 500 I=1,K
       Z=(E+D)/2.0
       PF=FF(E)*FF(Z)
       IF(PF.LE.0) THEN
       D=Z
       ELSE
       E=Z
       END IF
 500   CONTINUE
       END
```

```
       FUNCTION FF(X)
       COMMON A1,A2,A3,A4
       FF=A1*X**3.0+A2*X**2.0+A3*X+A4
       RETURN
       END
```

(Table 6 continued)

SIG	K_r	ς	π	QC	f	SIG	
Y1/B1= .250							
.805	.815	.543	.818	.203	1.000	.805	
.820	.826	.599	.822	.200	.985	.820	
.840	.840	.673	.828	.196	.963	.840	
.860	.854	.748	.833	.191	.938	.860	
.880	.868	.823	.839	.185	.911	.880	
.900	.884	.879	.855	.178	.874	.900	
.920	.901	.916	.881	.167	.820	.920	
.940	.918	.954	.908	.151	.744	.940	
.960	.935	.991	.935	.130	.638	.960	
.250	.215	.203	.231	-5.6	155.9	139.0	178.9
Y1/B1= .375							
.805	.791	.524	.832	.382	1.000	.805	
.820	.803	.579	.835	.376	.985	.820	
.840	.819	.652	.840	.368	.962	.840	
.860	.835	.725	.845	.358	.938	.860	
.880	.851	.799	.850	.348	.911	.880	
.900	.869	.856	.864	.334	.875	.900	
.920	.889	.898	.888	.314	.822	.920	
.940	.909	.939	.911	.287	.751	.940	
.960	.929	.981	.935	.250	.655	.960	
.375	.404	.382	.430	-5.4	549.6	491.5	622.4
Y1/B1= .500							
.805	.767	.506	.846	.603	1.000	.805	
.820	.781	.559	.849	.593	.984	.820	
.840	.798	.631	.853	.580	.962	.840	
.860	.815	.703	.857	.565	.937	.860	
.880	.833	.774	.861	.549	.911	.880	
.900	.854	.833	.873	.528	.875	.900	
.920	.877	.879	.894	.497	.824	.920	
.940	.900	.925	.914	.456	.757	.940	
.960	.923	.971	.935	.403	.668	.960	
.500	.636	.603	.672	-5.2	1362.0	1223.8	1521.0
Y1/B1= .625							
.805	.744	.487	.860	.865	1.000	.805	
.820	.758	.540	.862	.851	.984	.820	
.840	.777	.610	.865	.831	.961	.840	
.860	.796	.680	.868	.810	.936	.860	
.880	.815	.750	.871	.788	.911	.880	
.900	.838	.810	.882	.756	.874	.900	
.920	.864	.860	.900	.713	.824	.920	
.940	.890	.910	.917	.657	.760	.940	
.960	.916	.960	.935	.586	.678	.960	
.625	.909	.865	.954	-4.9	2783.1	2518.4	3063.4
Y1/B1	QF	QC	QFS	%ERQ	QF2/GB15	QC2/GB15	QFS2/GB15

(Table 6 cont'd)

SIG	K_f	C	R	QC	Γ	SIG	
V1/B1= .750							
.805	.720	.469	.874	1.169	1.000	.805	
.820	.735	.520	.875	1.149	.983	.820	
.840	.756	.589	.877	1.121	.959	.840	
.860	.777	.657	.880	1.093	.935	.860	
.880	.797	.726	.882	1.063	.909	.880	
.900	.823	.788	.891	1.020	.873	.900	
.920	.852	.842	.906	.962	.823	.920	
.940	.881	.896	.920	.890	.761	.940	
.960	.910	.950	.935	.801	.685	.960	
.750	1.223	1.169	1.274	-4.4	5035.3	4599.4	5460.5
V1/B1= .875							
.805	.696	.450	.888	1.517	1.000	.805	
.820	.713	.501	.888	1.490	.982	.820	
.840	.735	.568	.890	1.453	.958	.840	
.860	.757	.635	.892	1.415	.933	.860	
.880	.780	.702	.893	1.377	.908	.880	
.900	.807	.765	.901	1.321	.871	.900	
.920	.839	.823	.912	1.244	.820	.920	
.940	.871	.882	.924	1.154	.761	.940	
.960	.903	.940	.935	1.045	.689	.960	
.875	1.578	1.517	1.630	-3.9	8377.6	7742.4	8946.8
V1/B1= 1.000							
.805	.672	.432	.902	1.910	1.000	.805	
.820	.690	.481	.902	1.874	.981	.820	
.840	.714	.547	.902	1.826	.956	.840	
.860	.738	.612	.903	1.778	.931	.860	
.880	.762	.678	.904	1.730	.905	.880	
.900	.792	.742	.910	1.658	.868	.900	
.920	.827	.805	.918	1.560	.817	.920	
.940	.862	.867	.927	1.449	.758	.940	
.960	.897	.930	.935	1.319	.690	.960	
1.000	1.973	1.910	2.023	-3.2	13111.0	12287.4	13783.0
V1/B1= 1.125							
.805	.648	.413	.916	2.354	1.000	.805	
.820	.667	.461	.916	2.306	.980	.820	
.840	.693	.525	.916	2.244	.953	.840	
.860	.718	.589	.916	2.183	.927	.860	
.880	.744	.653	.916	2.123	.902	.880	
.900	.777	.719	.919	2.034	.864	.900	
.920	.815	.786	.924	1.911	.812	.920	
.940	.853	.853	.930	1.776	.754	.940	
.960	.891	.920	.935	1.623	.690	.960	
1.125	2.412	2.354	2.453	-2.4	19583.4	18654.1	20257.6
V1/B1= 1.250							
.805	.625	.395	.930	2.851	1.000	.805	
.820	.645	.442	.930	2.788	.978	.820	
.840	.672	.504	.930	2.708	.950	.840	

V1/B1 QF QC QFS %ERQ QF2/GB15 QC2/GB15 QFS2/GB15

(Table 6 cont'd)

SIG	K_f	C	R	QC	F	SIG	
.860	.699	.567	.930	2.630	.922	.860	
.880	.726	.629	.930	2.553	.895	.880	
.900	.761	.696	.930	2.443	.857	.900	
.920	.802	.767	.931	2.298	.806	.920	
.940	.843	.839	.933	2.135	.749	.940	
.960	.884	.910	.935	1.957	.687	.960	
1.250	2.894	2.851	2.919	-1.5	28194.4	27359.4	28689.2
Y'1/B1= 1.375							
.805	.601	.376	.944	3.405	1.000	.805	
.820	.622	.422	.944	3.326	.977	.820	
.840	.651	.483	.944	3.224	.947	.840	
.860	.680	.544	.944	3.125	.918	.860	
.880	.708	.605	.944	3.028	.889	.880	
.900	.746	.673	.944	2.880	.846	.900	
.920	.790	.749	.944	2.680	.787	.920	
.940	.834	.824	.944	2.471	.725	.940	
.960	.878	.900	.944	2.246	.660	.960	
1.375	3.421	3.405	3.422	-.5	39398.5	39039.0	39427.5
Y'1/B1= 1.500							
.805	.577	.358	.958	4.023	1.000	.805	
.820	.600	.402	.958	3.923	.975	.820	
.840	.630	.462	.958	3.795	.944	.840	
.860	.660	.521	.958	3.672	.913	.860	
.880	.691	.581	.958	3.551	.883	.880	
.900	.731	.650	.958	3.358	.835	.900	
.920	.778	.730	.958	3.088	.768	.920	
.940	.825	.810	.958	2.801	.696	.940	
.960	.872	.890	.958	2.488	.619	.960	
1.500	3.994	4.023	3.962	.7	53706.5	54473.2	52855.2
Y'1/B1= 1.625							
.805	.553	.339	.972	4.708	1.000	.805	
.820	.577	.383	.972	4.585	.974	.820	
.840	.609	.441	.972	4.427	.940	.840	
.860	.641	.499	.972	4.275	.908	.860	
.880	.673	.557	.972	4.128	.877	.880	
.900	.715	.627	.972	3.88[illegible]	.824	.900	
.920	.765	.711	.972	3.525	.749	.920	
.940	.815	.796	.972	3.142	.667	.940	
.960	.865	.880	.972	2.717	.577	.960	
1.625	4.614	4.708	4.540	2.0	71680.9	74616.6	69387.2
Y'1/B1	QF	QC	QFS	%ERQ	QF2/GB15	QC2/GB15	QFS2/GB15

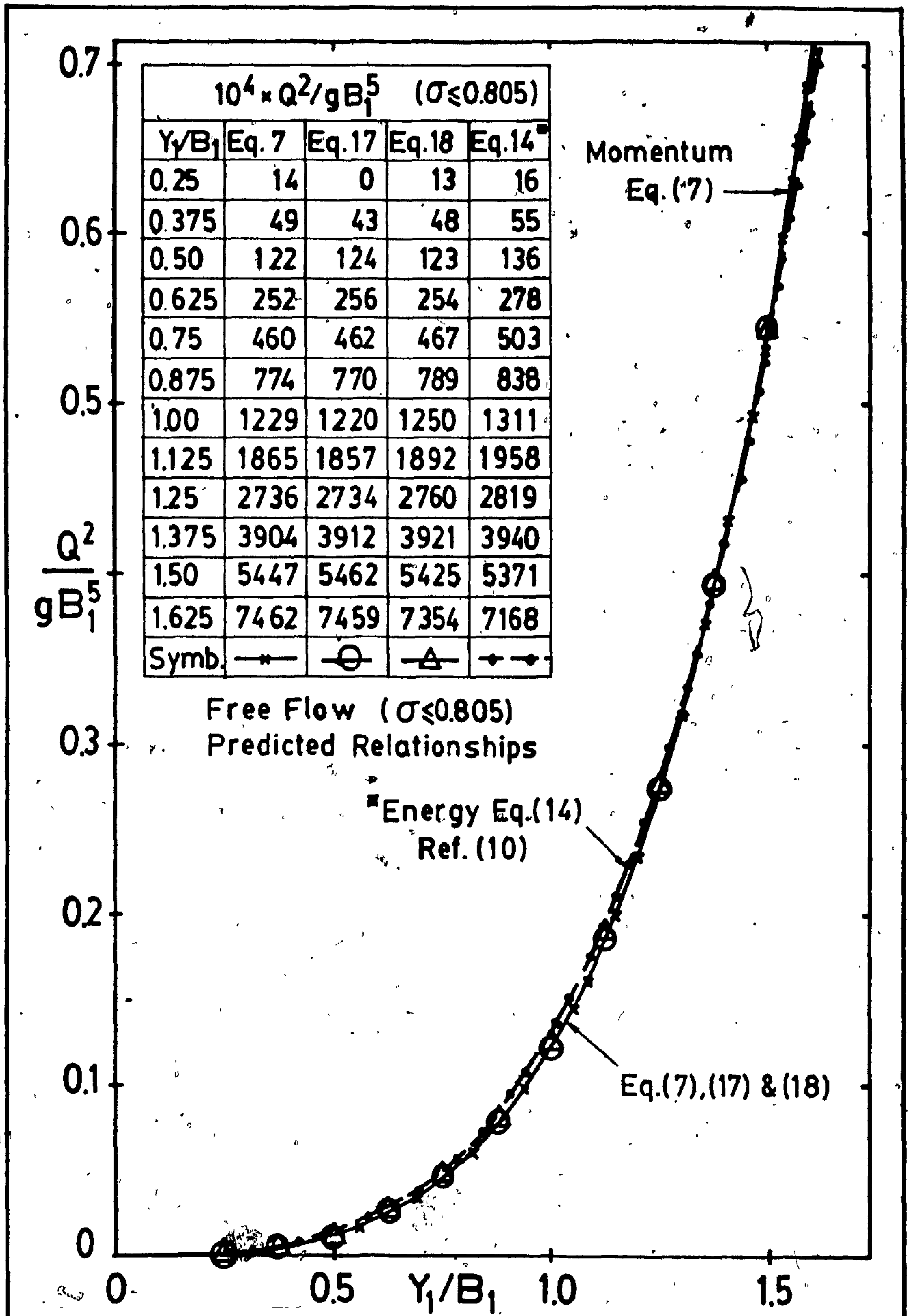
SIG	FM
.805	1.000
.820	.980
.840	.954
.860	.927
.880	.900
.900	.860
.920	.805
.940	.740
.960	.663

(Table 6 cont'd)

Y1/B1	GS805	GS82	GS84	GS86	GS88	GS90	GS92	GS94	GS96
.250	139.0	136.3	132.6	128.9	125.2	119.6	111.9	102.9	-92.2
.375	491.5	481.8	468.7	455.7	442.4	422.7	395.5	363.7	326.0
.500	1223.8	1199.6	1167.2	1134.6	1101.6	1052.6	984.7	905.7	811.8
.625	2518.4	2468.7	2402.0	2335.0	2267.0	2166.3	2026.5	1863.8	1670.6
.750	4599.4	4508.6	4386.7	4264.3	4140.2	3956.2	3701.0	3403.9	3051.0
.875	7742.4	7589.5	7384.4	7178.3	6969.3	6659.7	6230.0	5729.9	5136.0
1.000	12287.4	12044.8	11719.3	11392.3	11060.6	10569.2	9887.2	9093.5	8151.0
1.125	18654.1	18285.8	17791.6	17295.1	16791.6	16045.6	15010.3	13805.3	12374.3
1.250	27359.4	26819.2	26094.4	25366.2	24627.7	23533.5	22015.1	20247.8	18149.1
1.375	39039.0	38268.3	37234.0	36194.9	35141.2	33579.9	31413.2	28891.5	25896.8
1.500	54473.2	53397.7	51954.5	50504.6	49034.4	46855.8	43832.5	40313.7	36135.2
1.625	74616.6	73143.4	71166.6	69180.6	67166.6	64182.4	60041.2	55221.2	49497.5

APPENDIX - VII

COMPARISON OF FREE FLOW DISCHARGE RELATIONS



$10^4 \times Q^2/gB_1^5$ ($\sigma \leq 0.805$)				
Y_1/B_1	Eq. 7	Eq. 17	Eq. 18	Eq. 14*
0.25	14	0	13	16
0.375	49	43	48	55
0.50	122	124	123	136
0.625	252	256	254	278
0.75	460	462	467	503
0.875	774	770	789	838
1.00	1229	1220	1250	1311
1.125	1865	1857	1892	1958
1.25	2736	2734	2760	2819
1.375	3904	3912	3921	3940
1.50	5447	5462	5425	5371
1.625	7462	7459	7354	7168
Symb.	—×—	—O—	—△—	—•—•—

Fig. 8 - Comparison of Free Flow Discharge Relations.