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WATER RISE UPSTREAM BRIDGE CROSSINGS

ارتفاع الماء أمام تقاطعات الكبارى

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خلاصة

يتناول هذا البحث دراسة معملية لارتفاع الماء المرتد أمام القطاعات المائية المختنقة (contracted) و المعترضة (obstructed) فى نفس الوقت نتيجة تشييد كل من الركائز الجانبية و الوسطى لمنشأت الكباري في القطاع المائي. و قد أجريت الدراسة على أنواع مختلفة من الركائز الجانبية للكبارى (abutments) و الوسطى (piers) و لقيم مختلفة من نسبة الاختناق تحت تأثير قيم مختلفة للتدفق. كما تناول البحث بالدراسة تأثير طول الركائز على ارتفاع الماء المرتد أمام الكباري. و قد استخدمت البيانات الناتجة من الدراسة المعملية في استنتاج معادلة تقريبية لحساب ارتفاع الماء المرتد فى المجارى المائية المعترضة المختنقة (obstructed and contracted) بالركائز الجانبية و الوسطى للكباري بمعلومية كل من خواص التدفق العادي بعيدا عن منطقة تأثير الكوبرى و الخصائص الهندسية لقطاع الكوبري و الركائز. و بتحليل العوامل المختلفة المؤثرة على ارتفاع الماء المرتد أمام الكباري (dh) وجد أنه يتأثر بصفة أساسية بكل من نسبة عرض المجرى قبل إنشاء الكوبري إلى عرض الفتحات (B/b) و خواص التدفق فى المجرى المائي العادى بعيدا عن منطقة تأثير الكوبرى (Fr_o)، في حين انه أقل تأثرا بالشكل الهندسي لمقدمة الركائز و طول الركائز (L). كما اتضح من النتائج المعملية أن قيمة ارتفاع الماء المرتد أمام الكباري اكثر حساسية لقيمة نسبة عرض المجرى قبل إنشاء الكوبري إلى عرض الفتحات (B/b) مقارنة بالعوامل الأخرى التي تم دراستها فى هذا البحث. و قد تمت المقارنة بين قيم ارتفاع الماء المرتد باستخدام العلاقة المقترحة من هذه الدراسة و تلك الناتجة من معادلة جوتى [3].

ABSTRACT

The present study deals with the backwater rise upstream contracted and obstructed cross-sections due to construction of abutments and piers of bridges through the stream from the experimental point of view. The study was carried out for three different shapes of abutments and piers under different flow conditions. Also, the effect of abutment and pier length on upstream backwater rise was studied. The collected data from the different series of experiments were used to formulate a general relationship for computing the maximum backwater rise as a function of normal flow condition, geometrical boundaries of the bridge cross-section, and geometrical shape of bridge supports. Analysis of experimental results of different factors affecting backwater rise upstream bridges showed that it depended mainly on the ratio of stream width to vents width (B/b) and normal flow conditions away from the bridge zone effect (Fr_o). While both the shape and the length of abutments and piers had a small effect on backwater rise compared with the aforementioned parameters. Also, the experimental results showed that the value of backwater rise was more sensitive to the value of B/b compared with the other parameters under study. The comparison between the values of backwater rise from the proposed formula and those resulted from Gauthy formula [3] was carried out.

KEY WORDS: Backwater- Contracted cross-section- Obstructed - Abutment.

INTRODUCTION

This study characterizes the backwater behavior due to setting of piers and abutments of the bridge through the stream, which called obstructed and contracted stream as shown in Fig. 1.

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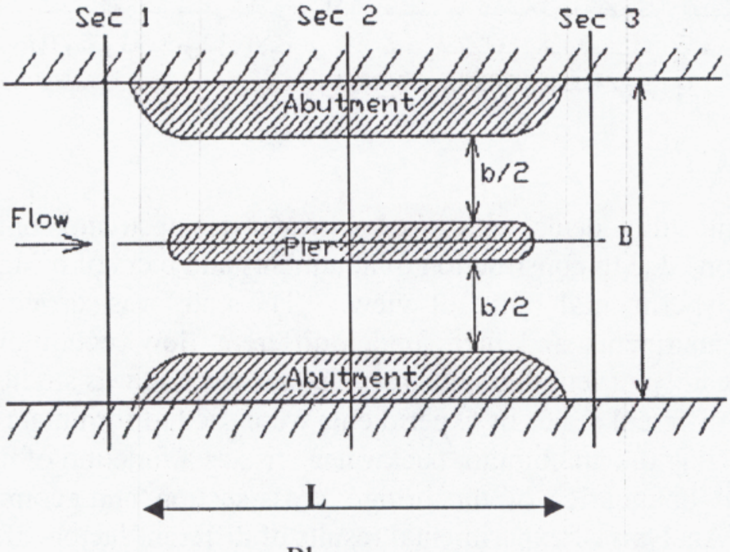
Theoretical and experimental analyses were presented to determine the values of backwater rise and the factors affecting these values. The energy principle is employed to estimate the backwater due to constructing the piers and the abutments through the stream. In 1998 U.S. Army Crops of Engineering [5] studied numerically the contraction and expansion reach lengths using two-dimensional numerical method. They concluded that the contraction length upstream the bridge ranged between 1-2 the bridge length, while the expansion reach equals to 1-2.5 bridge length for reasonable heading-up. Sturm, Terry W. [4], Bradley, J. N. developed an energy method of bridge backwater analysis published in Hydraulic Design Series. The energy equation is applied between sec.1 upstream the bridge and sec.3 downstream the bridge, Fig. 1, as follows:

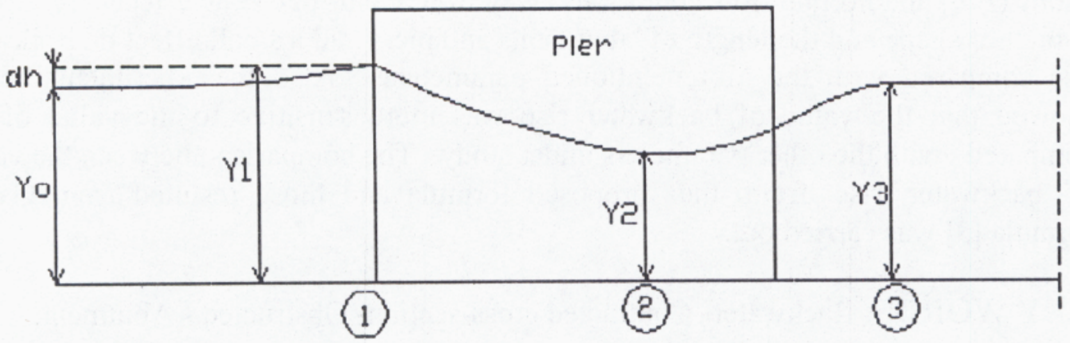
$$S_o L_{1-3} + Y_1 + \frac{\alpha_1 V_1^2}{2g} = Y_3 + \frac{\alpha_3 V_3^2}{2g} + h_T \quad (1)$$

in which

S_o	bed slope;
L_{1-3}	distance between secs. 1 and 3;
Y_1	flow depth upstream the bridge,
V_1	flow velocity upstream the bridge,



Plan



Elevation

Fig. 1 Obstructed and contracted stream.

Y_3	flow depth downstream the bridge = Y_o,
Y_o	normal flow depth before bridge construction,
V_o .	normal flow velocity before bridge construction,
V_3	flow velocity downstream the bridge,
h_T	total energy loss between sec.1 and sec.3 = $h_L + h_b$ (friction loss and minor losses), and
α_1, α_3	energy coefficients at sections 1 and 3, respectively.

Sturm, Terry W. [4] stated that with respect to the normal water surface, the uniform-flow resistance portion of h_T is just balanced by the vertical fall in the channel bottom so that Eq. 1 could be in the following form

$$Y_1 - Y_3 = \frac{\alpha_3 V_3^2}{2g} - \frac{\alpha_1 V_1^2}{2g} + h_b \qquad (2)$$

h_b is the additional head loss due to stream constriction, which is referred as a minor losses coefficient.

$$h_b = k\frac{\alpha_2 V_2^2}{2g}$$

in which V_2 is the velocity under normal flow depth inclusive the area occupied by bridge piers.
then ;

$$dh = Y_1 - Y_3 = k\frac{\alpha_2 V_2^2}{2g} + \alpha_1\left[\left(\frac{A_2}{A_3}\right)^2 - \left(\frac{A_2}{A_1}\right)^2\right]\frac{V_2^2}{2g} \qquad (3)$$

in which A_2 is the gross flow area in the contracted section measured at normal stage.

To calculate backwater, Bradley [1] assumed that $\alpha_2 = 1$ and $\alpha_1 = \alpha_3$. He determined the minor head loss from laboratory and field as follows:-

$$K = k_b + \Delta k_p + \Delta k_e + \Delta k_s$$

in which:

k_b	contraction coefficient,
Δk_p	pier coefficient,
Δk_e	eccentricity coeficient, and
Δk_s	skewness coefficient.

Also, He stated that Δk_e and Δk_s can be neglected then;

$$K = k_b + \Delta k_p$$

The value of k_b can be calculated from Fig. 2 according to the value of M_o [4].

in which

M_o	a_{vents}/A_{stream} ,
b	net width of vents = B-t,
B	approach channel width, and
t	sum of thickness of abutments projection in stream and piers thickness.

The value of Δk_p is calculated from Figs. 3-a and 3-b [4] as follows:

1- determine J= t/b
2- from type of pier get Δk
3- from M_o get σ
4- $\Delta k_p = \Delta k * \sigma$

then $K = k_b + \Delta k_p$, and

$dh = k\frac{\alpha_2 V_2^2}{2g}$, while the second term in Eq. 3 is very small, which could be neglected.

As stated by El-Gawhary et al. [2] the following formula which is known as Gauthy [3] formula could be successfully used in computing the maximum backwater rise upstream contracted and obstructed cross-sections. Also, they stated that the backwater rise calculated from this formula was more than they were calculated.

$$dh = \frac{V_1^2}{2g}\left[\left(\frac{A}{C\,a}\right)^2 - 1\right] \qquad (4)$$

in which :

A area of the approach cross-section,

a total area of vents,

C a factor depends on the front shape of pier and abutment,

$C = 0.85 + 0.014 \sqrt{S}$ for tapered front

$C = 0.78 + 0.021 \sqrt{S}$ for semicircular front,

$C = 0.70 + 0.029 \sqrt{S}$ for square front, and

S span of vents.

In most literatures, the backwater rise was studied separately due to either flow contraction by abutments only or flow obstruction by piers only for some limited control parameters without considering mutual interaction between two cases. Also, the effect of abutment and pier length on backwater rise was not considered in most literatures. In the present study, the backwater rise was studied for the contracted and obstructed flow for different values of contraction at bridges under a wide range of flow properties. Also, a general equation was proposed to compute the maximum backwater rise upstream bridges in terms of flow properties and geometrical characteristics of bridge site and supports.

EXPERIMENTAL WORK

The experimental work was carried out in a re-circulating flume in the Hydraulics laboratory of Al-Tahady University, Libya, photo 1. The models of piers and abutments were manufactured from timber sealing with a non permeable material to have a smooth surface. The experiments were carried out for normal Froude number (Fr_o) ranged from 0.53 to 0.83. In the present study, six models of abutments with different thickness were used with constant pier thickness at the centerline of the bridge to have six values of opening ratio (b/B) at bridge site (0.32, 0.42, 0.42, 0.52, 0.62, 0.71), for the first and second ratios, there were no pier at the centerline of the bridge, while for the other four ratios a pier was installed at the centerline of the bridge. For each value of b/B, five values of discharge (15, 18, 24, 36, and 45 liter/min) were used. The effect of pier and abutment length on backwater rise was studied through six different lengths of rectangular abutments and pier (L = 5, 4, 3.5, 3, 2.5, 2 cm). Also, the effect of endnoses shape of both abutment and pier on backwater rise was studied through three shapes (rectangular, triangular, and semicircular). The downstream flow depth accompanied each discharge at normal flow without bridge was constant through the experiments. The discharge was measured by using flowmeter fitted behind the pump of the flume and a calibrated V-notch fixed at the end of the flume. Water depths were measured by using a point gauge supplied with verniers allowing measurements accuracy of ±0.1 mm. The flow velocity was measured by using pitot-tube. The study was carried out through 360 runs through the following steps:

1-The pump speed was adjusted according to the required flow discharge.

2-Both the normal flow depth (Y_o) and the velocity (V_o) were measured.

3- The pump was turned off.

4-The required models of rectangular abutments and pier were installing in the flume.

5-The pump was turned on with the discharge value in step 1.

6-The upstream flow depth (Y_1), flow velocity (V_1), flow depth in downstream (Y_3), velocity in downstream (V_3) and flow depth through vents (Y_2) were measured.

7- Steps 2 to 6 were repeated for the other four values of the discharge.

8- steps 4 to 7 were repeated for both triangular and semicircular endnoses piers and abutments.

A sample of the experimental runs is shown in photo 2.

ANALYSIS AND DISCUSSION OF THE RESULTS

Effect of normal Froude number (Fr_o)

Figures 4-A, 4-B, and 4-C illustrate the relationship between the dimensionless backwater rise (dh/Y_o) and the normal Froude number (Fr_o) for rectangular, triangular endnoses, and semicircular endnoses abutments and pier, respectively. The figures show that the values of the backwater rise were directly proportional to the values of normal Froude number for all types of abutments and pier at different values of b/B. This could be explained due to the increase of normal Froude number was resulted from the increase of flow discharge. The increase of flow discharge at a constant value of blockage resulted an increase of backwater rise (dh). Also, the figures show that at small values of blockage (b/B=0.62, 0.71), the rate of increase of backwater rise due to increase in Fr_o was less that in big values of blockage (b/B=0.32, 0.42, 0.52).

Effect of stream width /vents width (B/b)

Figure 5 shows the effect of the ratio of stream bed width to total vents width (B/b) on the backwater rise (dh) for rectangular, triangular, and semicircular endnoses abutments and pier. From Fig. 5, it was found that the values of dh/Y_o were directly proportional to the values of B/b for three shapes of abutments and pier. This could be explained due to the increase of the ratio B/b resulted from the decrease of vents width (b), in which approach channel width (B) was constant. The decrease of vents width with respect to stream width (B/b) increased the blockage effect, which increased the backwater rise. It was found that the increase of B/b form 1.7 to 2.7 (i.e. 59%) for rectangular abutment resulted an increase of the dimensionless backwater rise from 0.65 to 1.55 (i.e. 138%), which reflects the significance effect of the value of B/b on backwater rise upstream bridges. Also, Fig. 6 shows that the installing of pier with the abutments for the same ratio of b/B increased the backwater rise by 8%. This could be explained due to the fact that the backwater rise in case of abutments only was occurred due to flow contraction, while at existence of pier and abutments it was occurred due to both flow contraction and flow obstruction by pier, which increased the backwater rise.

Effect of abutment and pier length (L/b)

Figure 7 illustrates the effect of dimensionless length of abutments and piers on the dimensionless backwater rise. Fig. 7 shows that the dimensionless backwater rise was directly proportional to the dimensionless length of the abutment and pier. The effect of abutment and pier length on backwater rise could be referred to the increase of friction losses due to the increase in length, which increased the backwater rise. Also, as the length was increased the blockage effect increased, which increased the backwater rise upstream the bridge.

Effect of abutment and pier shape

Figure 8 shows a comparison between the effect of three shapes of abutments and pier endnoses (rectangular, triangular, and semicircular) on backwater rise upstream bridge. Fig. 8 shows that the values of backwater rise for the triangular endnoses abutments were less than those for rectangular abutments by almost 12.5%. While the backwater rise due to semicircular endnoses abutments was smaller than that occurred for both rectangular and triangular endnoses abutments by 19.5% and 7.1%, respectively. The decrease of backwater rise for both triangular and semicircular endnoses abutments could be referred to their effect in redirecting flow velocities and decreasing blockage effect, which resulted a decrease of backwater rise. Also, the semicircular endnoses of the abutments and pier improved the streamlines characteristics than that in both rectangular and triangular endnoses abutments, which resulted in decreasing the blockage effect of the flow upstream the bridge, hence the backwater rise was decreased.

Development of a general formula

By using the regression analysis of the experimental data (360 run), the following equation was proposed with the correlation coefficient equal to 0.92.

$$\frac{dh}{Y_o} = 0.236\, C_1\, F_{ro}^{1.79} \left(\frac{B}{b}\right)^{1.37} \left(\frac{L}{b}\right)^{0.167} \tag{5}$$

in which C_1 is a constant depending on abutments and piers endnoses shape = 1.0 for rectangular, 0.88 for triangular, and 0.81 for semicircular endnoses abutments and piers. It is worth to mention that the proposed formula could be safely applied for predicting backwater rise upstream contracted and obstructed cross-sections by bridge abutments and piers at Fr_o=0.53-0.83, B/b=3.12 to 1.41, and L/b=0.5 to 3.0.

Fig. 9 illustrates a comparison between the calculated values of the dimensionless backwater rise by Gauthy formula and the corresponding values computed from the proposed formula in this study. The figure shows that the calculated values of backwater rise from the proposed formula were less than the corresponding ones from Gauthy formula, which may be referred to the difference in conditions of derivation of two formulas and to the elimination of the effect of abutment length in Gauthy formula.

CONCLUSION

From the present experimental study the following points could be concluded:

1-For the different values of both opening ratio and endnoses shapes of abutments and piers of the bridge, the backwater rise was directly proportional to the value of the normal Froude number.

2-The value of backwater rise was very sensitive to the ratio of stream width to vents width (B/b), which reflects the significance of the value of B/b on backwater rise upstream bridges.

3-The obstruction of flow by pier for the same opening ratio at bridge increased the backwater rise by a small amount.

4-The backwater rise upstream triangular endnoses abutment was smaller than that for rectangular one and the backwater rise upstream semicircular endnoses abutments was smaller than the corresponding values for both rectangular and triangular endnoses abutments at the same flow conditions.

5-Both the abutment length and endnoses shape had a small effect on the value of backwater rise compared with the effect of the ratio B/b and the value of normal Froude number (Fr_o).

6-It was found that the calculated values by the proposed formula were smaller than those calculated by Gauthy formula.

7-By using the regression analysis of the experimental results the following formula was proposed with correlation coefficient 0.92.

$$\frac{dh}{Y_o}=0.236\,C_1\,F_{ro}^{1.79}\,(\frac{B}{b})^{1.37}\,(\frac{L}{b})^{0.167}$$

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3-Gauthy, "Traite de la construction des ponts", Paris, 1809 [source 2].

4-Sturm, Terry W "Open channel hydraulics", Mc Graw Hill Inc., New York 2001.

5-U. S. Army Crops of Engineering, HEC-RAS Hydraulic Reference Manual, Version 2.2. Davis, CA: U.S. Army Crops of Engineering, Hydrologic Engineering Center, 1998.

NOTATION

The following symbols were used in the this study

a	total area of vents,
A	area of the approach cross-section,
b	net width of vents,
B	approach channel width,
C	a factor depends on the front shape of pier and abutment,
C_1	shape factor in proposed formula,
dh	backwater rise calculated upstream bridge site,
F_{r1}	upstream Froude number,
F_{r3}	downstream Froude number,
Fr_o	normal Froude number away from bridge zone effect,
h_b	additional head loss due to stream constriction,
h_f	friction loss,
h_T	total energy loss between Sec1 and sec3 = $h_f + h_b$,
k_b	contraction coefficient,
L	abutment and pier length,
M_o	a ratio of $a/A = bY_2/BY_1$,
S	span of vents,
S_o	bed slope,
t	total thickness of abutments and piers,
Y_1	flow depth upstream bridge,
Y_2	flow depth through vents,
Y_3	flow depth downstream bridge,
Y_O	normal flow depth before bridge construction,
V_1	flow velocity upstream bridge,

V_2	flow velocity through vents, and
V_3	flow velocity downstream bridge.

Greek symbols

α_1, α_3	energy coefficients at sections 1 and 3, respectively,
Δh	backwater rise calculated by El-Gawhary et al. [2],
Δk_p	pier coefficient,
Δk_e	eccentricity coefficient, and
Δk_s	skewness coefficient.

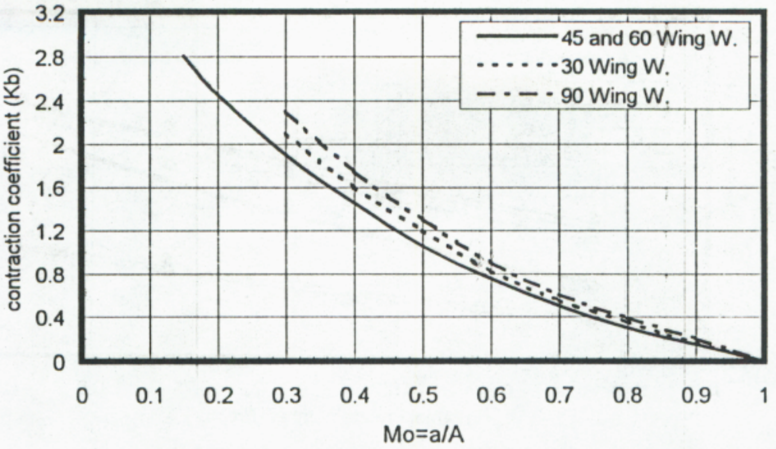

Fig.2 Backwater coefficient base curve - subcritical flow (after Bradley 1978).

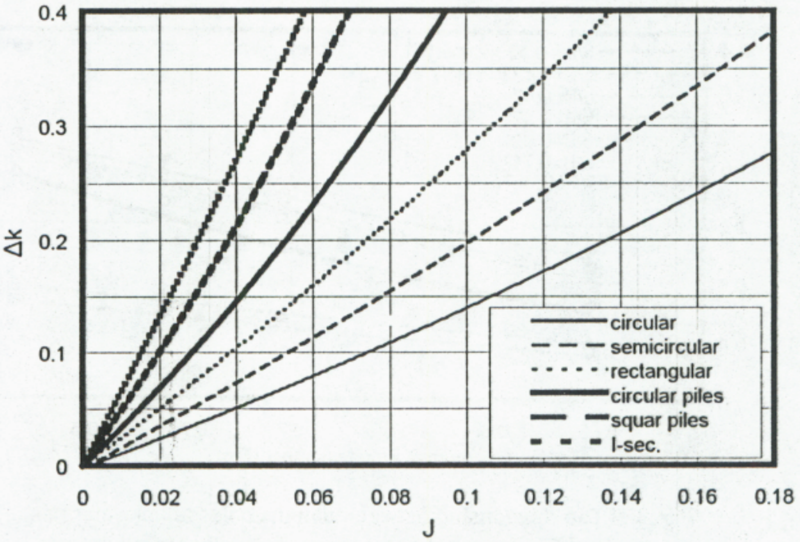

Fig. 3-a Incremental backwater coefficient for piers (after Bradley 1978).

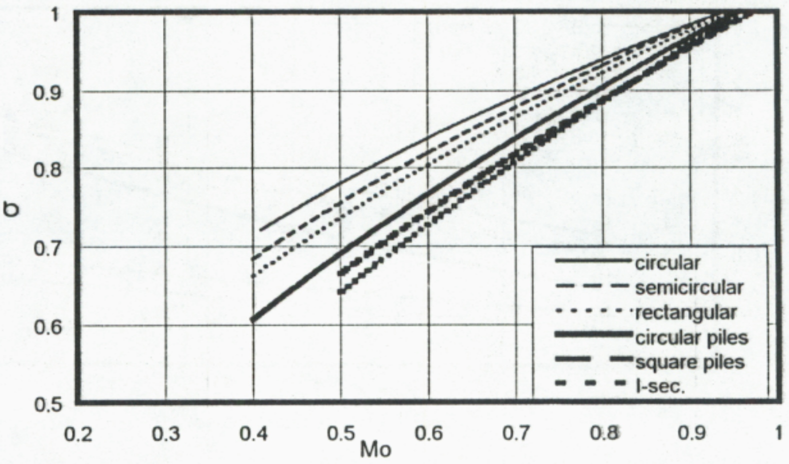

Fig. 3-b Incremental backwater coefficient for piers (after Bradley 1978).

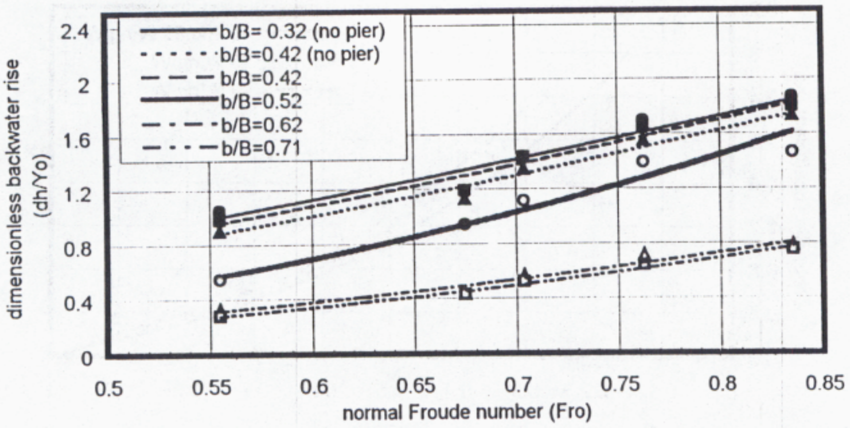

Fig. 4-A The relaticnship between dimensionless backwater rise and normal Froude number for rectangular abutments and pier.

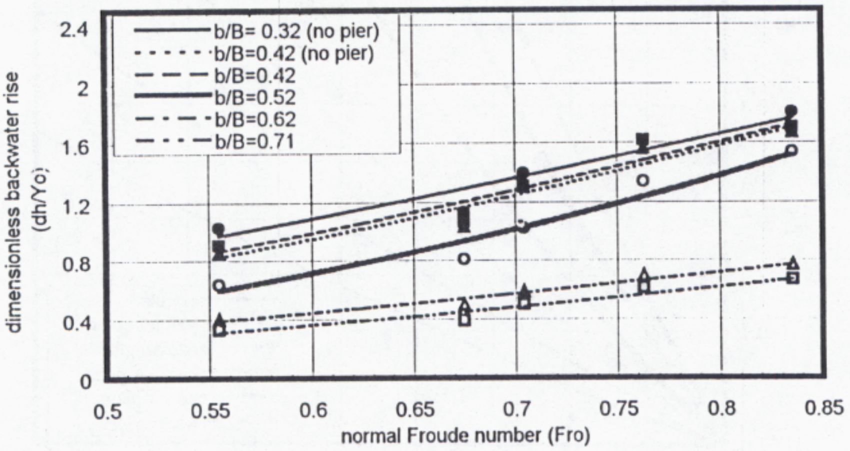

Fig. 4-B The relationship between dimensionless backwater rise and normal Froude number for triangular endnoses abutments and pier.

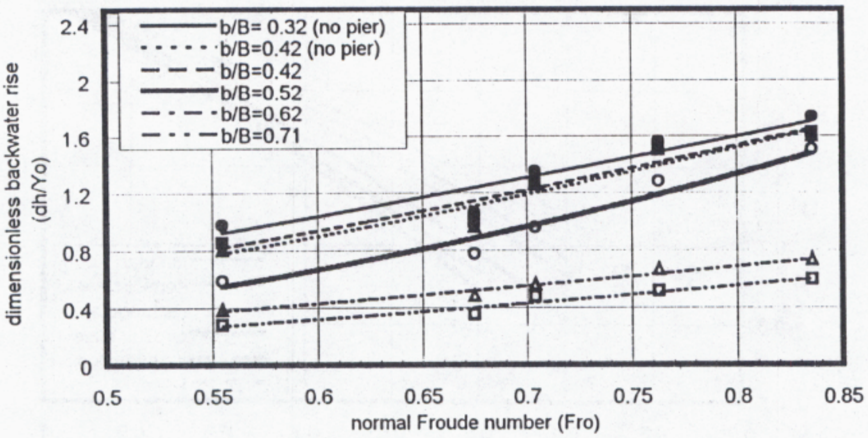

Fig. 4-C The relationship between dimensionless backwater rise and normal Froude number for semicircular endnoses abutments and pier.

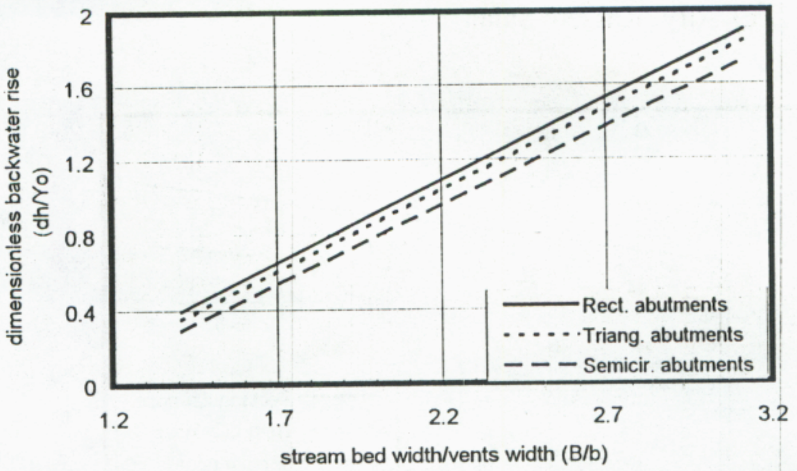

Fig. 5 Effect of stream bed width to vents width (B/b) on dimensionless backwater rise (Fr1 =0.19 and L =5 cm).

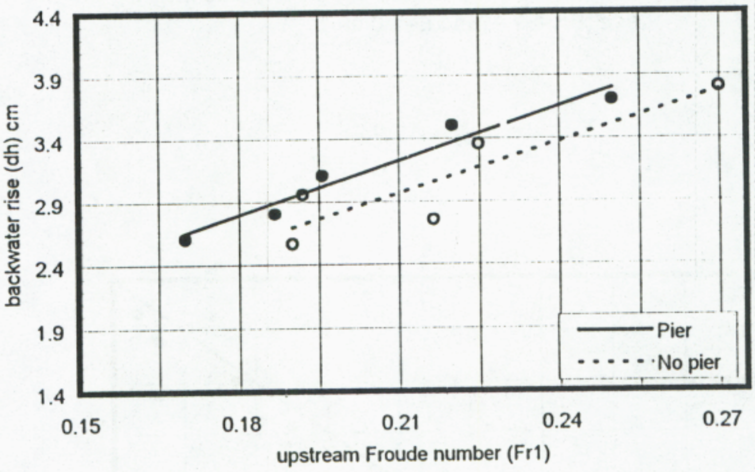

Fig. 6 Effect of flow obstruction by a pier on backwater rise at the same bed width ratio for rectangular abutments (b/B=0.42).

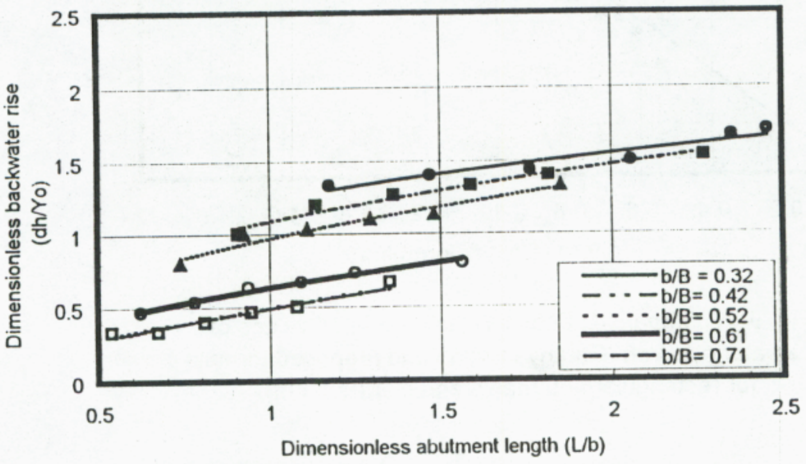

Fig. 7 Effect of abutments and pier length on dimensionless backwater rise for rectangular abutments and pier.

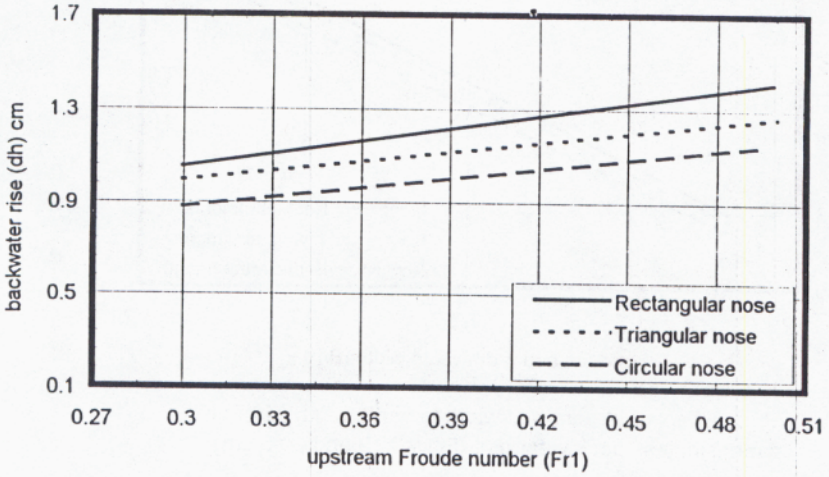

Fig. 8 Effect of abutment and pier endnoses shape on backwater rise (B/b= 1.41and L=5.0 cm).

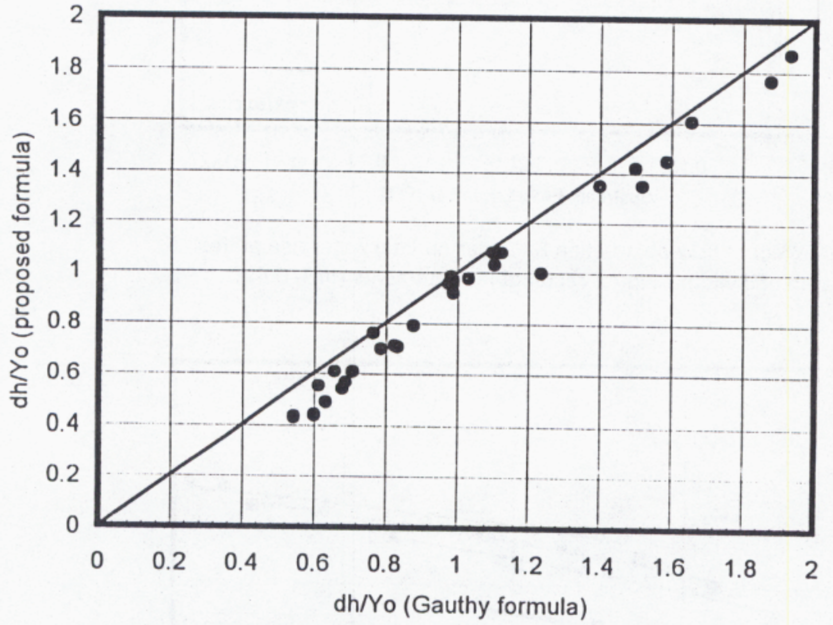

Fig. 9 A comparison between the calculated values of backwater rise from Gauthy formula and proposed formula for rectangular abutments and pier (L=5 cm).

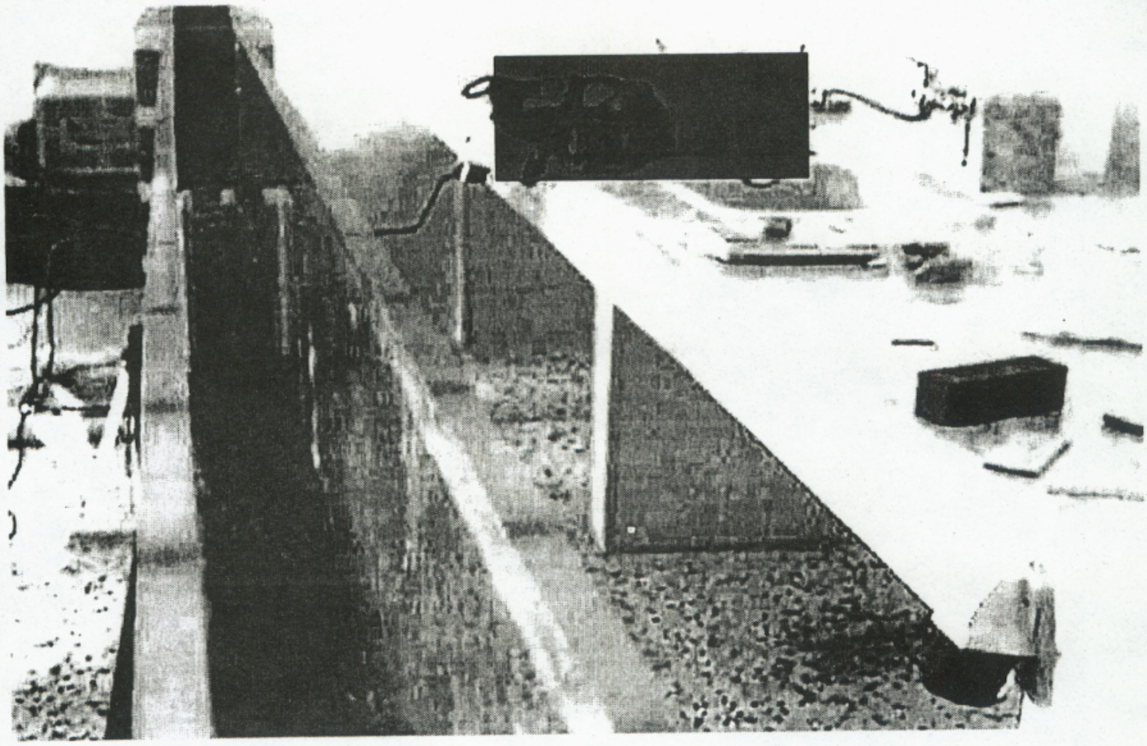

Photo 1 The laboratory flume.

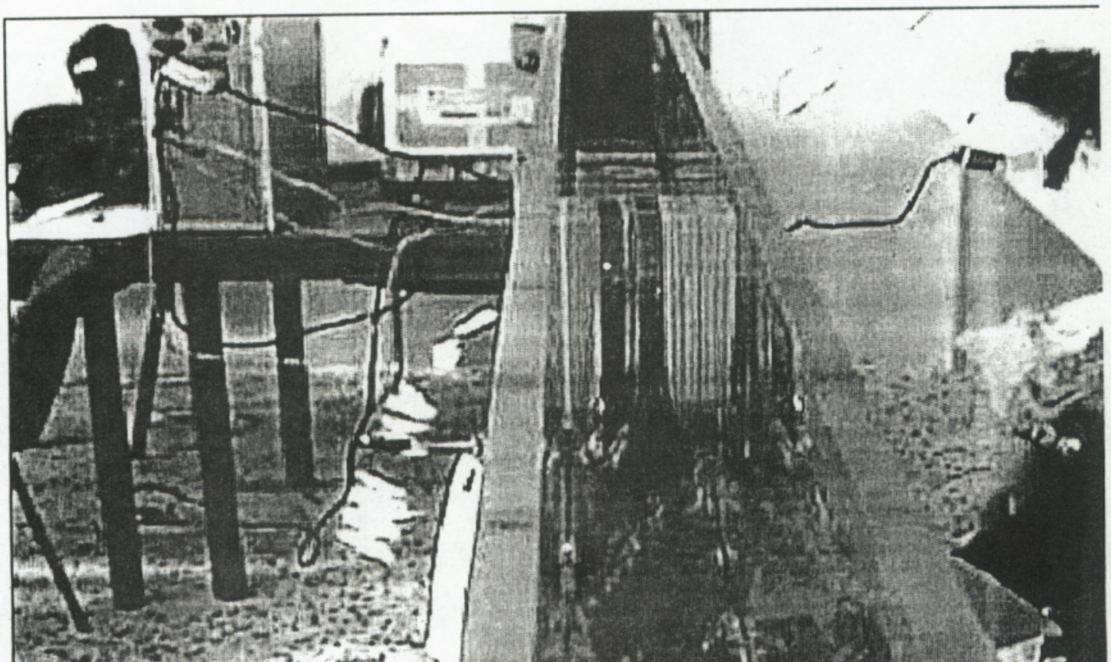

Photo 2 Backwater rise upstream rectangular abutments and pier.