Characteristics of Flow Over Normal and Oblique Weirs With Semicircular Crests

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ABSTRACT

In this investigation, the characteristics of free flow over normal and oblique weirs with semicircular crests are studied experimentally. For this purpose, forty eight weir models were constructed and tested. The first twelve models were normal weirs in which the crest radius was varied three times; 5cm, 7.5cm and 10cm. For each crest radius, the weir height was varied four times; 35cm, 30cm, 25cm and 20cm. The remaining models were oblique weirs. The oblique angle was varied three times; 60°, 45° and 30°. In weirs of the same oblique angle, the crest radius and weir height were varied similarly to those of normal weirs.The experimental results showed that for normal weirs, the discharge coefficient (C_{dw}) increases with the increase of head to crest height ratio (h/P) for the same height of weir. In case of oblique weirs, it was found that (C_{dw}) decreases with the increase of (h/P) values and weirs of small oblique angle (α) give high values of (C_{dw}).For normal weirs, the discharge magnification factor (Q_{NC} /Q_{NS}) and performance increase as values of (h/P) increase. Normal weirs of semicircular crests perform better than those of sharp crested weirs for all values of weir height and crest radius tested in this study. While, for oblique weirs the discharge magnification factor (Q_{OB}/Q_{NS}) and performance increased with the decrease of (h/P) values. As (h/P) value approaches zero, the discharge magnification factor approaches the length magnification of the weir. Weirs of small oblique angles give high discharge magnification factor and high performance.A simple procedure was applied for the hydraulic design of oblique weirs. The design method yields the final dimensions of a weir and predicts its head-discharge curve for the whole range of operation.

[illegible]

[illegible]

[illegible] (h/P) [illegible] (C_{dw}) [illegible] (h/P) [illegible] (C_{dw}) [illegible] (C_{dw}). [illegible] (h/P) [illegible] (Q_{NC}/Q_{NS}) [illegible] (Q_{OB}/Q_{NC}) [illegible] (h/P) [illegible] (h/P) [illegible]

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NOTATION

The following symbols are used in this paper :

C_d = dimensionless discharge coefficient,

$C_{dw} = \sqrt{g}.C_d$,

g = acceleration due to gravity,

h = upstream head above weir crest,

L = crest length of oblique weir,

P = height of weir above channel bed,

Q_{OB} = discharge passing over oblique weir of semicircular crest,

Q_{NC} = discharge passing over normal weir of semicircular crest,

Q_{NS} = discharge passing over normal sharp-crested weir,

q = discharge per unit width of the channel,

R = radius of weir crest,

W = channel width,

α = angle which the weir makes with channel axis (oblique angle),and

φ_1 to φ_4 = signify function of .

INTRODUCTION

The increasing need for stored water requires intensive efforts from hydraulic engineers to develop rapid methods for weir design and construction. A weir structure is an essential feature of many hydraulic structures such as dams, barrages, canal drops or falls, regulators, etc. An oblique weir usually passes greater discharge at given operating head than a corresponding normal weir (weir perpendicular to the channel occupying the same lateral width). The advantage of oblique weir over normal weir appears clearly when the lateral width of the channel is limited.The performance of oblique sharp-crested weir was studied by Aichel[1] and Ibraheem et al. [2] . While, laybrinth sharp-crested weirs of different shapes were studied extensively by many investigators, to name few, Hay and Taylor[3,4] , Darvas[5], Al-Hasson[6] and Ibraheem[7].Characteristics of flow over normal weirs having round crests were studied by Al-Tabatabie et al. [8] and Abid Ali[9]. From the available literature, no work has been published on the hydraulic characteristics of flow over oblique weirs of semicircular crests. The present investigation attempts to do that under free flow conditions for the purpose of obtaining a general equation for the discharge coefficient and design criteria for these types of weirs.

DIMENSIONAL ANALYSIS

A functional relationship for the characteristics of flow over oblique weirs with semicircular crests can be expressed as follows:

$$q = \phi_1(h, P, R, g, \alpha) \quad \text{.......} \quad (1)$$

where,

q = discharge passing over the weir per unit width of the channel,

h = upstream head over weir crest,

P = height of weir crest above channel bed,

R = radius of weir crest,

g = acceleration due to gravity, and

α = angle which the weir makes with channel axis (oblique angle).

The general relationship among all variables is :

$$\phi_2(q,h,P,R,g,\alpha)=0 \qquad (2)$$

From dimensional analysis Eq. (2) can be written as :

$$\frac{q}{\sqrt{gh^{1.5}}}=C_d=\phi_3\left(\frac{h}{P},\frac{R}{P},\sin\alpha\right) \qquad (3)$$

In which C_d = discharge coefficient. It should be noted that the left-hand side of Eq.(3) is in the form of Froude number which is the reason behind the disappearance of Froude number on the right-hand side. A more direct presentation of data for design purposes can be achieved by the introduction of another discharge coefficient C_{dw} = $\sqrt{g}$ C_d. Therefore Eq.(3) becomes:

$$C_{dw}=\frac{Q_{OB}}{Wh^{1.5}}=\phi_4\left(\frac{h}{P},\frac{R}{P},\sin\alpha\right) \qquad (4)$$

Where,
Q_{OB} =total discharge in the channel, and
W =channel width.

Eq. (4) indicates that the coefficient of discharge is a function of head to crest height ratio,crest radius to crest height ratio and oblique angle. A definition sketch is shown in Fig. (1).

EXPERIMENTAL SETUP

The experiments were conducted in a flume having a working length of 10m with a cross section 30cm wide and 45cm deep. The side walls of the flume were of toughened glass with a number of perspex panels and steel bed. A pair of adjustable rails were fitted along it's working length. Two movable carriages equipped with point gauges were mounted on the rails for vertical elevations measurements. An arrangement was used to provide two directional movement of point gauges along and across the flume. Water was circulated through the flume by an electrically driven centrifugal pump providing a total flow of 16 l/sec. The flume was leveled both longitudinally and transversely.

Forty eight models were manufactured and tested in which the crest radius, crest height and oblique angle were varied. The models were classified into four groups based on the value of the oblique angle (α).Each group was tested for three values of crest radius (R) and four weir heights (P), respectively. Details of the testing program are shown in Table (1). All models were manufactured from wood and well varnished to give smooth surfaces. Every model was placed in the flume at a distance 2.5m downstream from the flume inlet and the desired oblique angle. Then the model was glued to the sides and bed of the flume. After wards, the testing programme was started by allowing different discharges to overtop the weir model. For each discharge, upstream and downstream water surface profiles were found by measuring the heads over a number of grid points covering the two regions. Discharges were measured by a thin-plate sharp crested rectangular weir designed and manufactured according to the British Standard Specifications[10] . It was manufactured from a 6mm thick perspex sheet having crest height of 0.1m. The standard weir was installed at the downstream end of the flume. Point guages with vernier scales reading to 0.1mm were used for the measurements of water heads.

Table(1): Details of the weir models

Model No.	Group No.	Oblique Angle(α)	Series No.	Crest Radius R(cm)	Crest Length L(cm)	Crest Height P(cm)
1-4 5-8 9-12	1	90° (normal weir)	A B C	5.0 7.5 10.0	30.0 30.0 30.0	35,30,25,20 = =
13-16 17-20 21-24	2	60°	A B C	5.0 7.5 10.0	34.6 34.6 34.6	35,30,25,20 = =
25-28 29-32 33-36	3	45°	A B C	5.0 7.5 10.0	42.4 42.4 42.4	35,30,25,20 = =
37-40 41-44 45-48	4	30°	A B C	5.0 7.5 10.0	60.0 60.0 60.0	35,30,25,20 = =

ANALYSIS OF RESULTS

The results obtained from teasing programme concerning the hydraulic characteristics of free flow over oblique weirs of semicircular crests are analyzed considering two main aspects, discharge coefficient and weir performance.

Discharge Coefficient

For normal weirs α=90°, the variation of (C_{dw}) with (h/P) is plotted in Figs. (2),(3) and (4) for crest radius (R)=5cm, 7.5cm and 10cm, respectively. From these figures, one may observe that for the same height of weir an increase in (h/P) causes an increase in (C_{dw}) value. This behavior is similar to that of normal sharp-crested weirs (British Standard Institution[10]).

Figures (5), (6) and (7) show the variation of (C_{dw}) with (h/P) for crest radius (R)=5cm and oblique angles (α)=30°, 45° and 60°, respectively. A similar set of curves were obtained for other values of crest radius (R)=7.5cm and 10cm as shown in Figs. (8) to (13). From these curves the following points are noted : (1) The discharge coefficient (C_{dw}) decreases with the increase of (h/P) values and for small values of (h/P) the weir behaves almost ideally giving high values of (C_{dw}). This behavior is because for small values of (h/P) the discharge is small and the velocity head of flow is negligible. Changes in depth due to contraction also are negligible and the operating head is the same at every point along the crest and is almost equal to the head in the approach channel. Further more, the discharge per unit length of crest is the same. Thus, for small (h/P) values the weir performance tends to be ideal. As (h/P) increases, discharge and velocity heads increase, consequently, a large proportion of the crest operates under a head less than that in the approach channel with a corresponding fall in performance and (C_{dw}) value. (2) Weirs of oblique angle (α)=30° give higher values of (C_{dw}) than those of 45° and 60° because weirs of small oblique angles have longer lengths for the flow to pass over. (3) Weirs of crest height (P) =35cm give higher values of (C_{dw}) than those of smaller heights. (4) weirs of crest radius (R)=5cm give higher vales of (C_{dw}) than those of large crest radius.

All experimental results of normal and oblique weir models were used as input data in a regression analysis computer programme to obtain the following equation for the variation of (C_{dw}) with (h/P), (R/P) and (sinα) :

$$C_{dw} = \frac{0.674}{(h/P)^{0.15}(R/P)^{0.54}(\sin\alpha)^{0.86}} \quad \text{.......................................} \; (5)$$

With a correlation coefficient = (0.85). The relation between calculated values of (C_{dw}) and values predicted by Eq.(5) is shown in Fig.(14).

Weir Performance

For normal weirs, the hydraulic performance may be best represented by the magnification factor defined as the ratio of discharge passing over normal weir of semicircular crest (Q_{NC}) to the discharge passing over an imaginary normal sharp-crested weir of the same height (Q_{NS}). Values of (Q_{NS}) were obtained from the relevant equation recommended by the British Standard Institute[10] :

$$Q_{NS} = \frac{2}{3}\sqrt{2g}\left(0.602 + 0.083\frac{h}{P}\right).W.(h + 0.0012)^{3/2} \quad \text{......................} \; (6)$$

The flow magnification factor (Q_{NC}/Q_{NS}) is plotted against (h/P) in Figs. (15), (16) and (17) for different values of crest radius (R)=5cm, 7.5cm and 10cm, respectively. From these figures, one may observe that (Q_{NC}/Q_{NS}) increases with an increase in (h/P) value and values of magnification factor are always higher than unity for all values of (h/P). This means that weirs of semicircular crests perform better than those of sharp-crests for any value of weir height and crest radius.

For oblique weirs, the magnification factor is defined as the ratio of discharge passing over the oblique weir with semicircular crest (Q_{OB}) to the discharge of normal weir with semicircular crest (Q_{NC}). The magnification factor (Q_{OB}/Q_{NC}) is plotted against (h/P) in Figs. (18), (19) and (20) for crest radius (R)=5cm and oblique angles 30°, 45° and 60° , respectively. A similar set of curves is obtained for weirs of crest radius (R)=7.5cm and 10cm as shown in Fig.(21) to (26). From these results, the following can be stated: (1) Weirs of oblique angle (α)=30° give higher values of magnification factor (better performance) than those of 45° and 60° because weirs of small oblique angle give longer lengths for flow to pass over. (2) Weirs of crest radius (R)=5cm give higher values of magnification factor (better performance) than those of larger crest radius. (3) The magnification factor increases with the decrease of head to crest height ratio (h/P). For small values of (h/P) the weir shows almost ideal performance. As (h/P) approaches zero, the discharge magnification factor approaches the length magnification (weir crest length / channel width). (4) For a constant value of head above crest (h),weirs of large heights give higher magnification factor (better performance) than those of small heights.

Design Procedure

The following design procedure is based on the discussions and results obtained in the pervious sections:

1. From site conditions, determine the crest height (P) and the channel width (W).
2. From the operational requirements of the weir, determine the maximum allowable head over crest (h).
3. From hydrographic surveys, find the maximum discharge (Q_{OB}) to overflow the weir at the maximum operating head.
4. Substitute the known values of (W), (h) and (Q_{OB}) into Eq.(4) to determine the discharge coefficient (C_{dw}) as: $C_{dw}=Q_{OB} / (W\,h^{1.5})$

5. Adopt a suitable value of crest radius to crest height ratio $0.14 \le R/P \le 0.3$.
6. Using Eq.(5) with known values of (C_{dw}), (h/P) and (R/P), determine the oblique angle of the weir (α).
7. Determine weir length (L) as : $L = W / \sin\alpha$.
8. Substituting the known values of (R/P) and (α) into Eq.(5) yields an equation for the estimation of (C_{dw}) interms of (h/P) only. Using this equation and Eq.(4), the head-discharge curve for the designed weir can be predicted.

Numerical design example : It is required to design a weir passing a maximum discharge of $10m^3$/sec. under a maximum head of 0.5m. From site conditions, the maximum channel width is 10m and maximum crest height is 1.5m.
Solution : The given data are: $Q_{OB}= 10m^3$/sec., h= 0.5m, W = 10m and P= 1.5m.

From Eq.(4), $C_{dw} = \dfrac{10}{10 * 0.5^{1.5}} = 2.83$

Adopt a crest radius to crest height (R/P)=0.2, determine (R)=0.2 × 1.5=0.3m. Using Eq.(5) with known values of (C_{dw})=2.83, (h/P)=0.3 and (R/P)=0.2, find the oblique angle (α)=39.7°. For simplicity use (α)=40°. Thickness of the weir = (2R) = 0.6m and length of the weir (L) = (W/ sinα) = 10 /0.64 = 15.6m. Substituting (R/P) = 0.2 and (α)= 40° into Eq.(5) yields an equation for the estimation of (C_{dw}) values interms of (h/P) only as :

$$C_{dw} = \frac{2.36}{(h/P)^{0.15}} \qquad \text{.......................................} (7)$$

To draw the head-discharge curve, choose different values of (h), for the determined value of (P), substitute into Eq.(7) in order to find the corresponding values of (C_{dw}). Substituting (h) and (C_{dw}) values into Eq.(4) yields the corresponding values of discharge (Q_{OB}). The discharge capacity for the designed weir are shown in table (2). The corresponding shape and head-discharge curve are shown in Figs.(27) and (28).

Table (2): Discharge capacity of the oblique weir designed in text.

h (m)	**h/P**	**C_{dw}** From Eq.(7)	**$W h^{1.5}$** $m^{2.5}$	**$Q_{OB}=C_{dw}Wh^{1.5}$** m^3/sec
0.1	0.07	3.52	0.32	1.1
0.2	0.13	3.21	0.89	2.9
0.3	0.20	3.00	1.64	4.9
0.4	0.27	2.87	2.53	7.3
0.5	0.33	2.79	3.54	9.9
0.6	0.40	2.71	4.65	12.6
0.7	0.47	2.64	5.86	15.5

CONCLUSIONS

Within limits of the experimental study of the characteristics of free flow over normal and oblique weirs with semicircular crests, the following conclusions can be stated:

1. For normal weirs (α)=90°, a relation between discharge coefficient (C_{dw}) and head to crest height ratio (h/P) shows that for the same height of weir an increase in (h/P) value causes an increase in (C_{dw}) value.

2. Relations between (C_{dw}) and (h/P) for oblique weirs show that (C_{dw}) decreases with increase of (h/P) values and that for small values of (h/P) the weir behaves almost ideally giving high values of (C_{dw}).
3. A general equation is obtained for the estimation of discharge coefficient (C_{dw}) interms of head to crest height ratio (h/P), crest radius to crest height ratio (R/P) and oblique angle (α), see Eq.(5). This equation is uesful for the design of normal and oblique weirs of semicircular crests and the prediction of the head-discharge curve of the designed weir.
4. For normal weirs, the flow magnification factor (Q_{NC}/Q_{NS}) increases with an increase in (h/P) value and it is always greater than unity for all values of (h/P). This means that normal weirs of semicircular crests perform better than those of sharp crests.
5. Weirs of small oblique angles give high discharge magnification factor and high performance. The discharge magnification factor (Q_{OB}/Q_{NC}) increases with the decrease of head to crest height ratio (h/P). As value of (h/P) approaches zero, the discharge magnification factor approaches the length magnification of the weir (weir crest length / channel width). For constant head above crest (h), weirs of large heights give higher magnification factor (better performance) than those of small heights.
6. A procedure was developed for the hydraulic design of oblique weirs which gives its characteristics and predicts its operating head-discharge curve.

NOTATION

The following symbols are used in this paper :

C_d = dimensionless discharge coefficient,

$C_{dw} = \sqrt{g}.C_d$,

g = acceleration due to gravity,

h = upstream head above weir crest,

L = crest length of oblique weir,

P = height of weir above channel bed,

Q_{OB} = discharge passing over oblique weir of semicircular crest,

Q_{NC} = discharge passing over normal weir of semicircular crest,

Q_{NS} = discharge passing over normal sharp-crested weir,

q = discharge per unit width of the channel,

R = radius of weir crest,

W = channel width,

α = angle which the weir makes with channel axis (oblique angle),and

φ_1 to φ_4 = signify function of .

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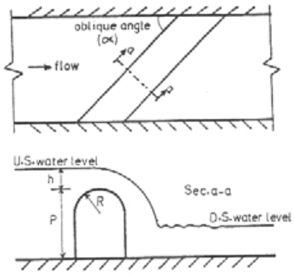


Fig. (1), Definition sketch

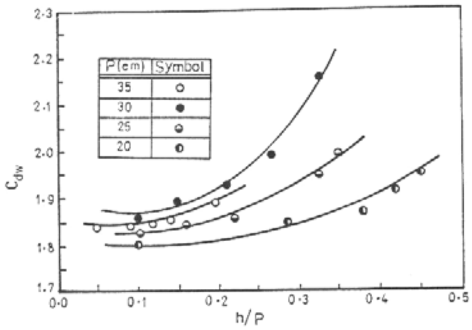


Fig. (2), Variation of (C_{dw}) with (h/P) normal weirs of crest radius (R)=5cm.

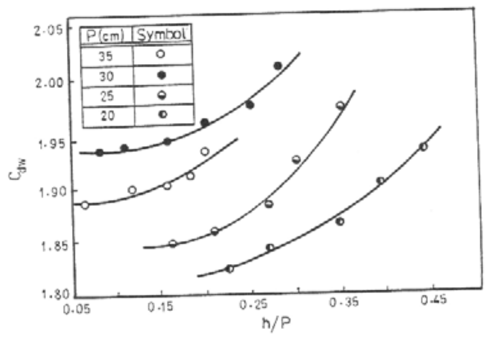


Fig. (3), Variation of (C_{dw}) with (h/P) for normal weirs of crest radius (R)=7.5cm.

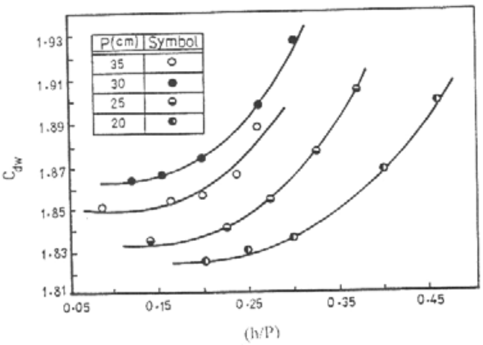


Fig. (4), Variation of (C_{dw}) with (h/P) for normal weirs of crest radius (R)=10cm.

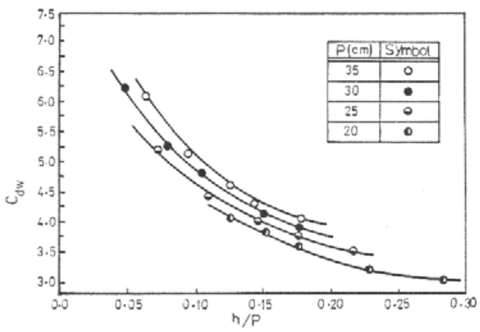


Fig. (5), Variation of (C_{dw}) with (h/P) for oblique weirs of crest radius (R)=5cm and (α)=30°.

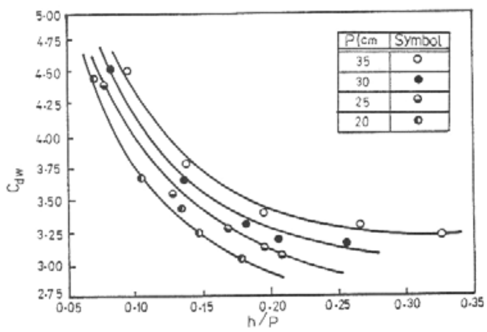


Fig. (6), Variation of (C_{dw}) with (h/P) for oblique weirs of crest radius (R)=5cm and (α)=45°

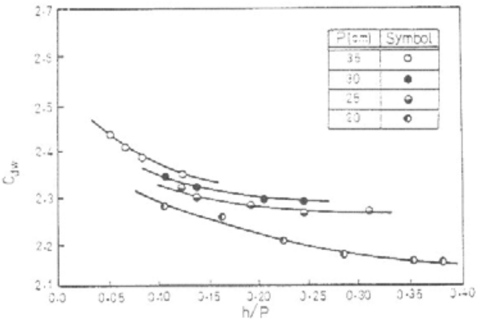


Fig. (7). Variation of (C_{dw}) with (h/P) for oblique weirs of crest radius (R) 5cm and (α)=60°.

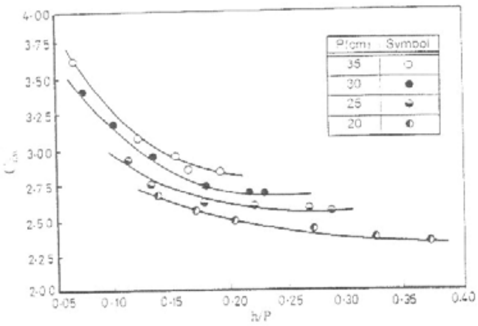


Fig. (8). Variation of (C_{dw}) with (h/P) for oblique weirs of crest radius (R)=7.5cm and (α)=30°

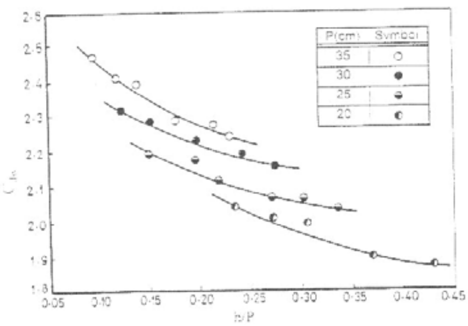


Fig. (9). Variation of (C_{dw}) with (h/P) for oblique weirs of crest radius (R)=7.5cm and (α)=45°.

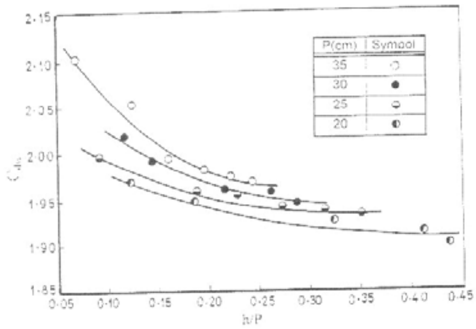


Fig. (10). Variation of (C_{dw}) with (h/P) for oblique weirs of crest radius (R)=7.5cm and (α)=60°.

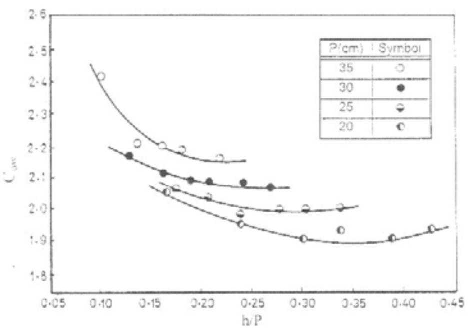


Fig. (11). Variation of (C_{dw}) with (h/P) for oblique weirs of crest radius (R)=10cm and (α)=30°.

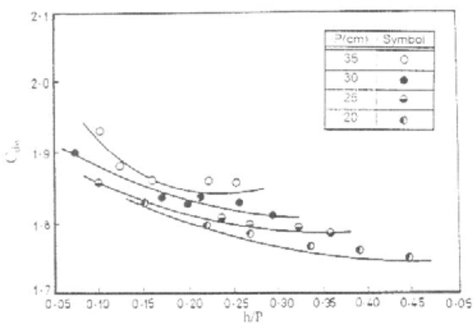


Fig. (12). Variation of (C_{dw}) with (h/P) for oblique weirs of crest radius (R) 10cm and (α)=45°.

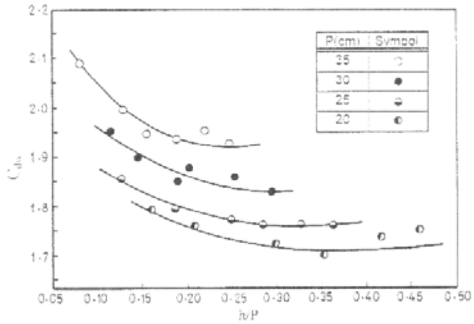


Fig. (13). Variation of (C_{dw}) with (h/P) for oblique weirs of crest radius (R)=10cm and (α)=60°.

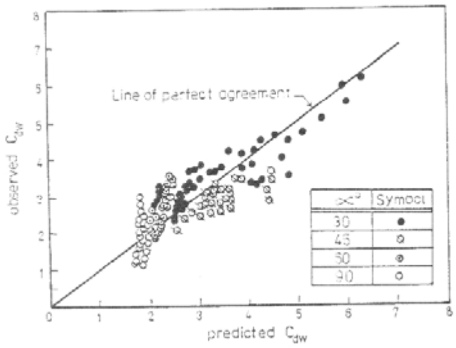


Fig. (14). Relation between observed and predicted (C_{dw}).

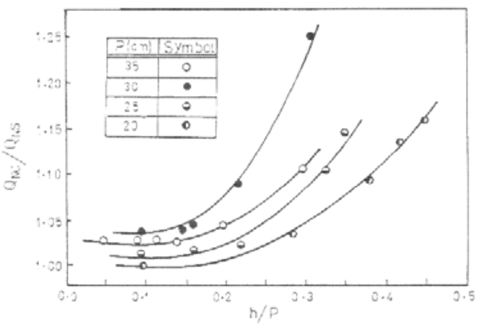


Fig.(15). Variation of (Q_{NC}/Q_{NS}) with (h/P) for normal weirs of crest radius (R)=5cm.

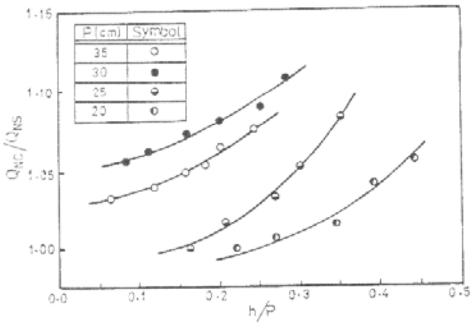


Fig.(16). Variation of (Q_{NC}/Q_{NS}) with (h/P) for normal weirs of crest radius (R)=7.5cm.

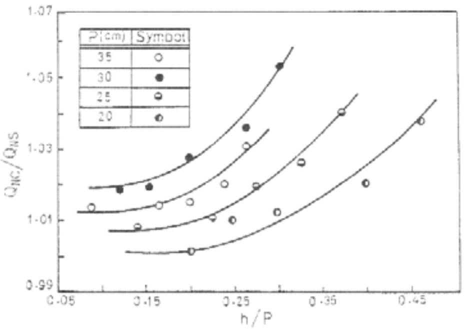


Fig. (17). Variation of (Q_{NC}/Q_{NS}) with (h/P) for normal weirs of crest radius (R)=10cm.

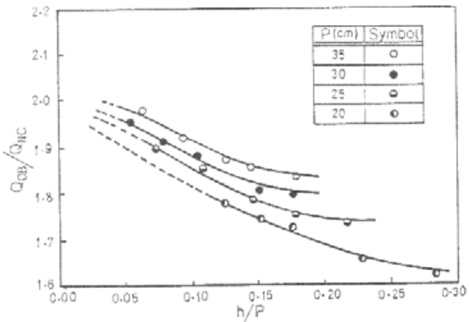


Fig.(18). Variation of (Q_{NC}/Q_{NS}) with (h/P) for oblique weirs of crest radius (R)=5cm and (α)=30°.

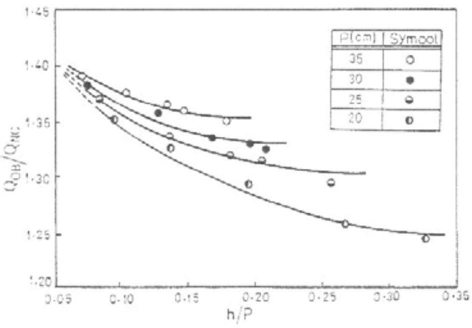
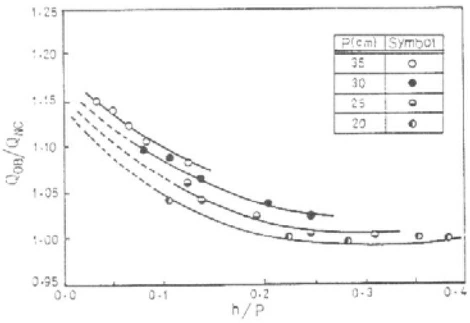


Fig.(19). Variation of (Q_{NC}/Q_{NS}) with (h/P) for oblique weirs of crest radius (R)=5cm and (α)=45°.



Fig(20). Variation of (Q_{NC}/Q_{NS}) with (h/P) for oblique weirs of crest rad (R) 5cm and (α)=60°.

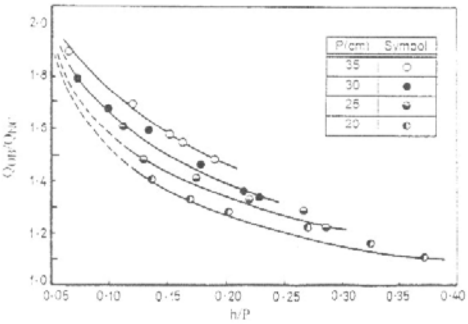


Fig.(21). Variation of (Q_{NC}/Q_{NS}) with (h/P) for oblique weirs of crest radius (R)=7.5cm and (α)=30°.

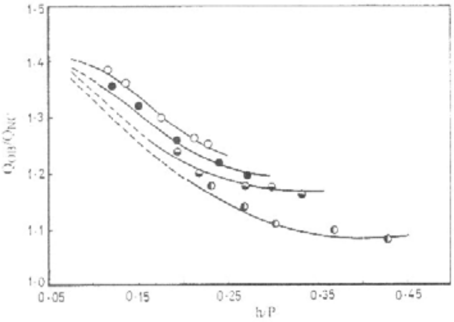


Fig.(22). Variation of (Q_{NC}/Q_{NS}) with (h/P) for oblique weirs of crest radius (R) 7.5cm and (α)=45°.

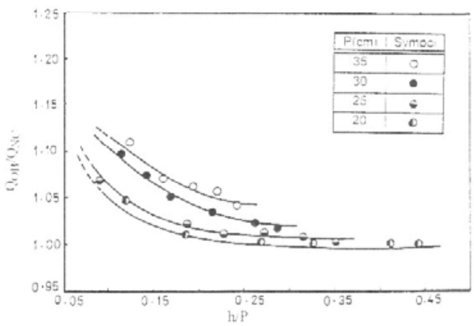


Fig.(23). Variation of (Q_{NC}/Q_{NS}) with (h/P) for oblique weirs of crest radius (R)=7.5cm and (α)=60°.

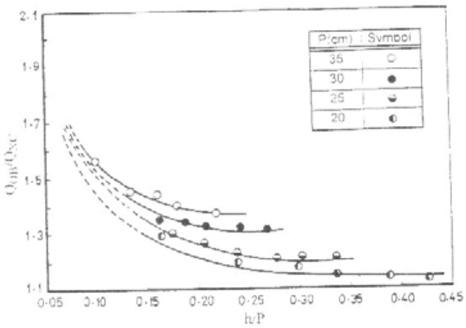


Fig.(24). Variation of (Q_{NC}/Q_{NS}) with (h/P) for oblique weirs of crest radius (R)=10cm and (α)=30°.

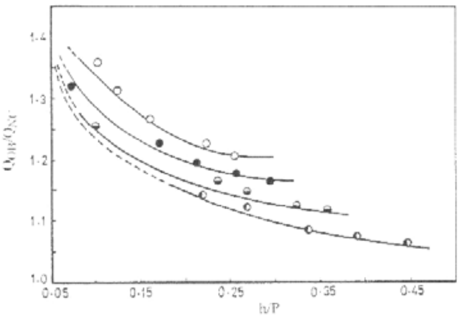


Fig.(25). Variation of (Q_{XC}/Q_{XS}) with (h/P) for oblique weirs of crest radius (R) 10cm and (α)=45°.

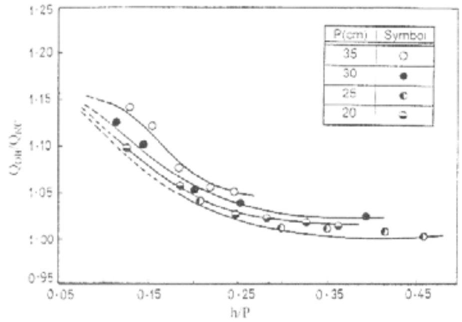


Fig.(26).Variation of (Q_{XC}/Q_{XS}) with (h/P) for oblique weirs of crest radius (R)=10cm and (α) 60°.

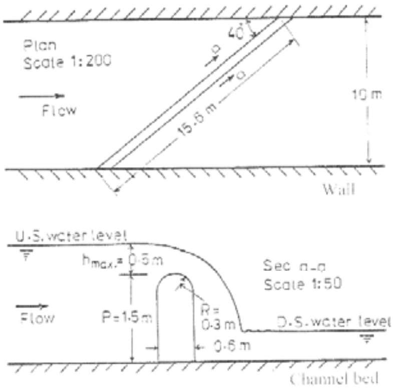


Fig. (27). Variation of (Q_{XC}/Q_{XS}) with (h/P) for oblique weirs of crest radius (R) 7.5cm and (α)=30°.

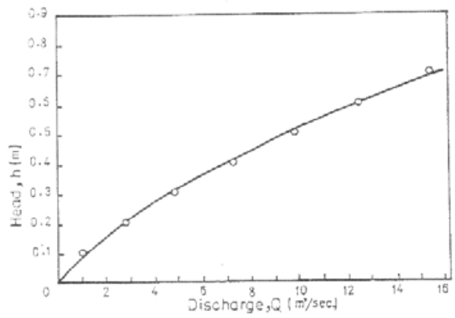


Fig. (28). Variation of (Q_{XC}/Q_{XS}) with (h/P) for oblique weirs of crest radius (R)=7.5cm and (α) 45°.