IS 6934 (1998): Recommendations for hydraulic design of high ogee overflow spillways [WRD 9: Dams and Spillways]

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IS 6934 : 1998
(Reaffirmed 2003)

भारतीय मानक

उच्च ओगी अधिप्रवाह अधिप्लव का द्रवचालन नियंत्रण के लिए डिजाइन–सिफारिशें

(पहला पुनरीक्षण)

Indian Standard

HYDRAULIC DESIGN OF HIGH OGEE OVERFLOW SPILLWAYS — RECOMMENDATIONS

(First Revision)

ICS 27.140

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

December 1998 **Price Group 5**

Spillways Including Energy Dissipators Sectional Committee, RVD 10

FOREWORD

This Indian Standard (First Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Spillways Including Energy Dissipators Sectional Committee had been approved by the River Valley Division Council.

Spillways are devices provided in conjunction with dams to pass surplus water for reservoir regulation and safety. Various types of spillways include overflow, shaft or morning glory, siphon, chute, side channel, tunnel spillway, etc. The overflow type is by far the most common one. The usual form of overflow spillway has a rounded crest with an ogee profile.

This standard was first published in 1973. In this revision principle of hydraulic design of high ogee spillway have been modified based on the latest technology and practice being followed in this field.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

HYDRAULIC DESIGN OF HIGH OGEE OVERFLOW SPILLWAYS — RECOMMENDATIONS

(First Revision)

1 SCOPE

This standard recommends criteria to be adopted for hydraulic design of high ogee overflow spillway, applicable to spillways without gates, with gates and with breast walls.

2 LETTER SYMBOLS

For the purpose of this standard, the following letter notations shall have the meaning indicated against each (*see also* Fig. 1).

A_1, A_2, etc = Horizontal dimension defining upstream quadrant of the crest,

B_1, B_2, etc = Vertical dimension defining upstream quadrant of the crest,

C = Non-dimensional discharge coefficient,

C_a = Discharge coefficient as affected by downstream apron,

C_b = Discharge coefficient for spillways with breast wall,

C_d = Discharge coefficient for design head,

= $2/3 \sqrt{2g}\ C$,

C_g = Discharge coefficient for flow under the gate,

C_h = Discharge coefficient for head H (other than design head),

C_s = Discharge coefficient as affected by submergence of the crest,

D = Net opening for the spillway with breast wall,

G_O = Gate opening

g = Acceleration due to gravity,

H = Head of overflow,

H_a = Head due to velocity of approach,

H_c = Head from reservoir level up to the centreline of the opening of the gate,

H_d = Design head,

K_1, K_2, etc = Variable parameters,

K_a = Abutment contraction co-efficient,

K_p = Pier contraction co-efficient,

L = Effective length of overflow crest,

L' = Net length of overflow crest (excluding thickness of pier),

M = Riser of the crest,

N = Number of piers,

n_1, n_2, etc = variable parameters,

P = Height of the spillway crest measured from the river bed,

Q = Discharge,

q = Discharge per unit length of the spillway,

R = Radius of abutment,

R_g = Radius of crest gate,

V_a = Approach velocity,

X, X_1, X_2, Y, Y_1, Y_2, etc = Co-ordinates of the profile.

β = Angle formed by the tangent to the gate lip and the tangent to the crest curve at the nearest point of the crest curve.

3 TERMINOLOGY

3.1 For the purpose of this standard, the following definitions shall apply.

3.1.1 *Ogee Spillway*

Spillway which has its overflow profile conforming, as nearly as possible, to the profile of the lower nappe of a ventilated jet of water issuing over a sharp crested weir (free overflow) or through an orifice (spillway with breast wall).

3.1.2 *High Overflow Spillway*

Overflow spillways are classified as high and low depending on whether the ratio of the height of the spillway crest measured from the river bed to the design head is greater than and equal to or less than 1.33 respectively. In the case of high overflow spillways the velocity of approach head may be considered negligible.

3.1.3 *Head*

The head is the distance measured vertically from the water surface (upstream of the commencement of drawdown) to the crest elevation. It also includes head due to velocity of approach.

3.1.4 *Design Head*

The design head is that value of head for which the ogee profile is designed.

3.1.5 *Breast Wall*

A suspended wall on top of the spillway, spanning between the piers, so as to create a rectangular opening above the crest level to pass the flow of water stored behind the wall.

4 OGEE PROFILE FOR FREE OVERFLOW

4.1 Shape of The Profile

4.1.1 The ogee profile consists of two quadrants, the upstream quadrant and the downstream quadrant. Once the design head H_d of the spillway is fixed, the crest geometry may easily be evaluated. The recommended shape is based on detailed observations of the lower nappe profile of a fully ventilated thin-plate weir. Such a profile would generally result in atmospheric pressure along the entire spillway surface at design head H_d. For head lower than H_d, the pressure would be higher than atmospheric and for higher heads, sub-atmospheric pressure would result.

4.1.2 The ogee profile is divided into three groups as follows:

a) Spillways with vertical upstream face,
b) Spillways with sloping upstream face, and
c) Spillways with crest offsets and risers.

However, the same general equation for the upstream and downstream quadrants are applicable to all the three cases as described in **4.1.3** to **4.1.5**.

4.1.3 *Spillways with Vertical Upstream Face*

4.1.3.1 *Upstream quadrant*

The upstream quadrant of the crest may conform to the ellipse:

$$\frac{X_1^2}{A_1^2} + \frac{Y_1^2}{B_1^2} = 1$$

The magnitudes of A_1 and B_1 are determined with reference to the parameter P/H_d from the graphs, given in Fig. 2.

4.1.3.2 *Downstream profile*

The downstream profile of the crest may conform to the equation :

$$X_2^{1.85} = K_2 \; H_d^{0.85} \; Y_2$$

The magnitude of K_2 is determined with reference to the parameter P/H_d from the graphs given in Fig. 2.

4.1.4 *Spillway with Sloping Upstream Face*

In the case of sloping upstream face, the desired inclination of the face is fitted tangential to the elliptical profile described in **4.1.3.1**, with the appropriate tangent point worked out from the equation. The profile of the downstream quadrant remains unchanged.

4.1.5 *Spillways with Crest Offsets and Risers*

Whenever structural requirements permit, removal of some mass from the upstream face leading to offsets and risers as shown in Fig. 1, results in economy. The ratio of riser M to the design head H_d that is M/H_d should be at least 0.6 or larger, for the flow conditions to be stable. The crest shapes defined in **4.1.3.1** and **4.1.3.2** are applicable to overhanging crests also, for the ratio $M/H_d > 0.6$.

4.2 Discharge Computations

4.2.1 *Coefficient of Discharge*

The charge over the spillway may be computed from the basic equation:

$$Q = \frac{2}{3} \sqrt{2g} \; C. \; L' \; H^{3/2}$$

4.2.2 The non-dimensional coefficient of discharge has a theoretical minimum value of $\pi/(\pi + 2) = 0.611$ and a practical upper limit of about 0.75. The parameter $\frac{2}{3}\sqrt{2g}\;C$ is often called C_d, which, however, is a dimensional quantity. The value of C_d generally varies from 1.80 to 2.21 (SI units).

4.2.3 The value of the coefficient of discharge depends on the following:

a) shape of the crest,
b) depth of overflow in relation to design head,
c) depth of approach,
d) extent of submergence due to tail water, and
e) inclination of the upstream face.

4.2.4 Figure 3 gives the coefficient of discharge C for the design head as a function of approach depth and inclination of upstream face of the spillway. These curves may be used for preliminary design purpose.

4.2.5 Figure 4 gives the variation of coefficient of discharge as a function of ratio of the actual head to the design head (H / H_d). This curve may be used to estimate C_d for heads other than design head H_d.

4.2.6 The coefficient of discharge is reduced due to submergence by the tail water. The position of the downstream apron relative to the crest level also has an effect on the discharge coefficient. Figures 5A and 5B give the variation of C_d with the above parameters.

4.3 Effective Length of Overflow Crest

4.3.1 The net length of overflow crest is reduced due to contractions caused by the abutments and crest piers. The effective length L of the crest may be calculated as follows:

$$L = L' - 2\ H\ (N.\ K_p + K_a)$$

4.3.2 The pier contraction coefficient, K_p is affected by the shape and location of the pier nose, thickness of the pier, the head in relation to the design head and the approach velocity. Average pier contraction coefficients may be taken as follows:

Type	K_p
For square-nosed piers with rounded corners on a radius of about 0.1 times the pier thickness	0.02
For round-nosed piers	0.01
For pointed-nosed piers	0

4.3.3 The abutment contraction coefficient is affected by the shape of the abutment, the angle between the upstream approach wall and the axis of flow, the head in relation to design head and the approach velocity.

Average abutment contraction coefficient may be taken as follows:

Type	K_a
For square abutments with head wall at 90° to direction of flow	0.20
For rounded abutments with head wall at 90° to direction of flow, when $0.5\ H_d > R > 0.15\ H_d$	0.10
For rounded abutments where $R > 0.5\ H_d$ and head wall is placed not more than 45° to the direction of flow	0

4.4 Determination of Design Head

Designing the crest profile for a particular head H_d results in a profile conforming to the lower nappe of a fully ventilated sharp crested weir and hence the pressures on the profile for the head H_d are atmospheric. Operating the spillway for heads lower than H_d would give pressures higher than atmospheric and for heads higher than H_d, the pressure would be sub-atmospheric. At the same time the coefficient of discharge would be reduced or increased (relative to that for the design head) for the heads lower or higher than the design head. Generally, designing the profile for a head lower than the highest anticipated head results in a steeper profile provided the sub-atmospheric pressures could be kept within acceptable limits so as not to induce cavitation. The ratio of actual head to design head (H/H_d) for ensuring cavitation-free performance of the spillway crest is a function of design head H_d. The extent of sub-atmospheric pressure for an underdesigned spillway profile shall be ascertained from hydraulic model studies for the specific case. Generally design head is kept as 80 to 90 percent of the maximum head.

5 OGEE PROFILE FOR GATES SPILLWAY

5.1 Shape of the Profile

5.1.1 When spillways are equipped with gates (the most common type of gate is radial gate), discharges for partial gate openings will occur as orifice flow. With full head on the gate and with the gate partially opened the jet emerging from the gate will be in the form of a trajectory conforming to a parabola

$$X^2 = 4HY$$

If sub-atmospheric pressures are to be avoided along the crest, the shape of ogee downstream from the gate sill should conform to the trajectory profile. The adoption of a trajectory profile rather than a nappe profile will result in a flatter profile and reduced discharge efficiency under full gate opening. Where the discharge efficiency is not important and a flatter profile is needed from consideration of structural stability, the trajectory profile may be adopted to avoid sub-atmospheric pressures along the crest. When the ogee is shaped to the ideal nappe profile for the maximum head (*see* **4.1.3.1** and **4.1.3.2**), sub-atmospheric pressures would occur in the region immediately downstream of the gate for small gate openings. The magnitude and area of sub-atmospheric pressures may be minimized by placing the gate sill 0.3 m to 0.5 m below the crest level, downstream of the crest axis. Experiments have shown that under such a condition the minimum crest pressures may range from about 0.1 H_d for upstream water level at design head to about 0.2 H_d for heads about 1.3 H_d. The ogee profile may thus be designed considering the magnitude of the minimum pressures.

5.2 Discharge Computation

5.2.1 The discharge for a gates ogee crest at partial gate opening is similar to flow through a low-head orifice and may be computed by the equation:

$$Q = C_g\ G_o\ L \sqrt{2g}\ H_e$$

The coefficient C_g differs with different gate and crest arrangements and is influenced by the approach and downstream conditions. Figure 6 shows coefficient of discharge for flow under the gate for various ratios of gate opening to total head. The curve presents average determined for various approach and downstream conditions and may be used for preliminary design purpose.

6 OGEE PROFILE FOR SPILLWAYS WITH BREAST WALL

6.1 Spillways are sometimes provided with breast wall from various considerations such as increasing the regulating storage of flood discharge, reducing the height of gate, minimizing the cost of gate operating mechanism, etc.

For the spillways with breast wall, the following parameters are required to be determined:

a) Profile of the spillway crest including the upstream and downstream quadrants,

b) Profile of the bottom surface of the breast wall, and

c) Estimation of discharge efficiency of the spillway.

6.2 The flow through a spillway with breast wall has been idealised as two-dimensional flow through a sharp edged orifice in a large tank. The following guidelines for determining the parameters mentioned above may be used for preparing preliminary designs and studies on hydraulic model may be conducted for confirming or improving on the preliminary design. Figure 7 shows pertinent details of various profiles of the spillway with a breast wall.

6.3 Ogee Profile

6.3.1 *Upstream Quadrant*

The upstream quadrant may conform to an ellipse with the equation:

$$\frac{X_3^2}{A_3^2} + \frac{Y_3^2}{B_3^2} = 1$$

where

$A_3 = 0.541\ D\ (H_d/D)^{0.32}$, and

$B_3 = 0.369\ 3\ D\ (H_d/D)^{0.04}$

6.3.2 *Downstream Profile*

6.3.2.1 The downstream profile may conform to the equation:

$$X_4^{n_4} = K_4 \cdot H_d^{n_4-1} \cdot Y_4$$

where

$$K_4 = 0.44 - 0.025\ \frac{H_d}{D}, \text{ and}$$

$$n_4 = 1.782 - 0.009\ 9 \left(\frac{H_d}{D} - 1\right)$$

6.4 Bottom Profile of the Breast Wall

6.4.1 The bottom profile of the breast wall may conform to the equation:

$$X_5 = \frac{K_5}{n_5^{2.4}} \cdot Y_5^{2.4}$$

where

$K_5 = 0.541\ D\ (H_d/D)^{0.32}$, and

$n_5 = 0.4\ D$

6.4.2 The upstream edge of the breast wall is in line with the upstream edge of the spillway and the downstream edge is in line with the spillway crest axis, as shown in Fig. 7.

6.5 Discharge Computation

6.5.1 The discharge through the breast wall spillway may be estimated by the equation:

$$Q = C_b \cdot L \cdot D\ [\ 2g\ (H_e + V_a^2/2g)\ ]^{0.5}$$

The following equation relates C_b with the para meter (H/H_d) in the range of H/H_d = 0.8 to 1.33.

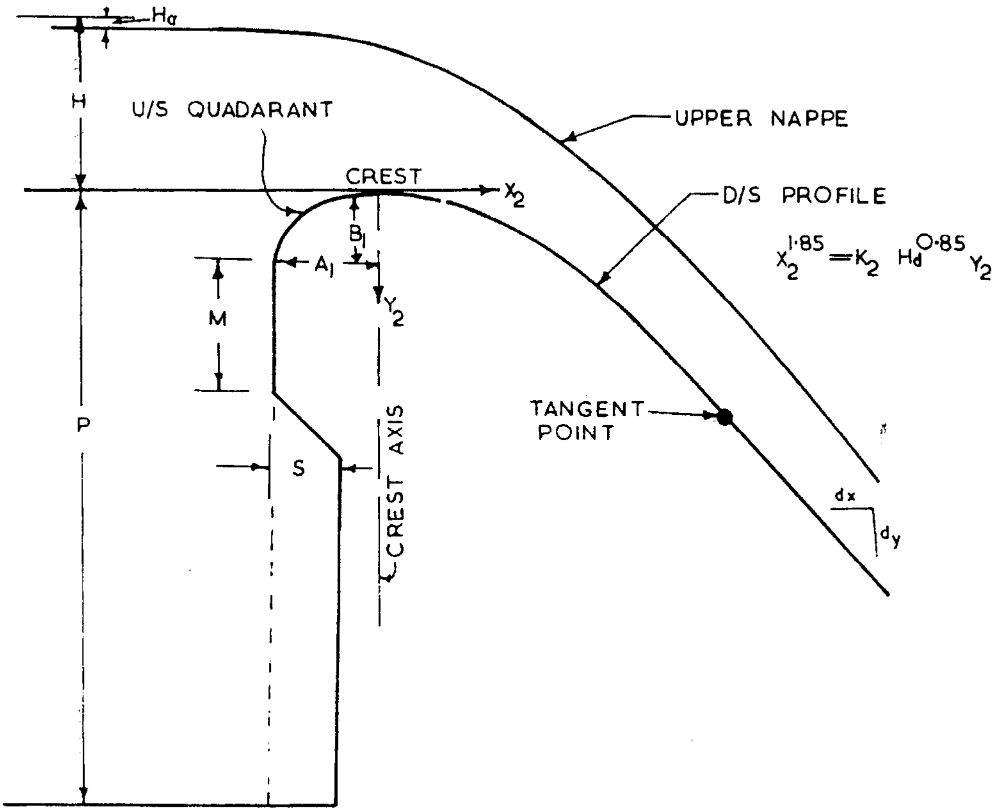
$$C_b = 0.148\ 631 + 0.945\ 305\ (H/H_d) - 0.326\ 238\ (H/H_d)^2$$

Typical value of C_b are:

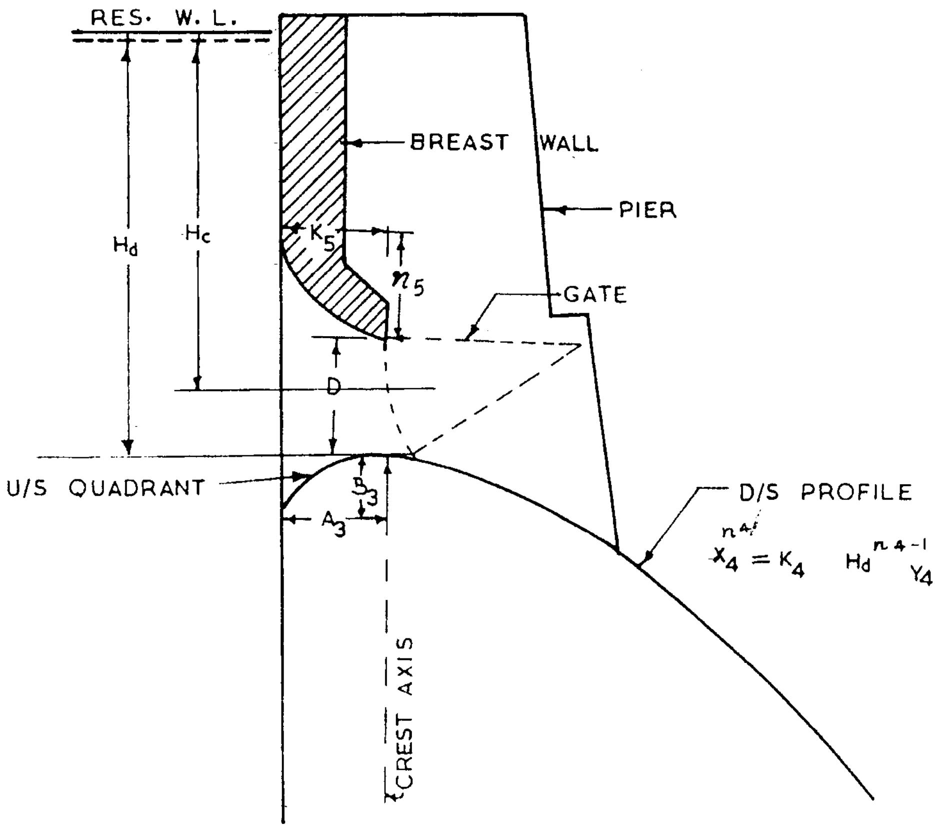
H/H_d	C_b
0.80	0.696
1.00	0.769
1.15	0.797
1.33	0.829

6.6 Provision of Stoplog Groove

6.6.1 The configuration shown in Fig. 7 includes provision of stoplog gate groove upstream of the crest axis through the breast wall. If in a specific case, structural requirement does not permit a stoplog gate groove through the body of the breast wall, a breast wall with a section thinner than A_3 or K_5 permitting location of the stoplog groove in the available space (between the upstream face of the spillway and uptstream face of the breast wall) could be developed. The entire configuration would then need studies on a hydraulic model for discharging capacity, pressures on spillway surface and breast wall, etc.



1A OVERFLOW SPILLWAY



1B SPILLWAY WITH BREAST WALL

FIG. 1 NOTATIONS

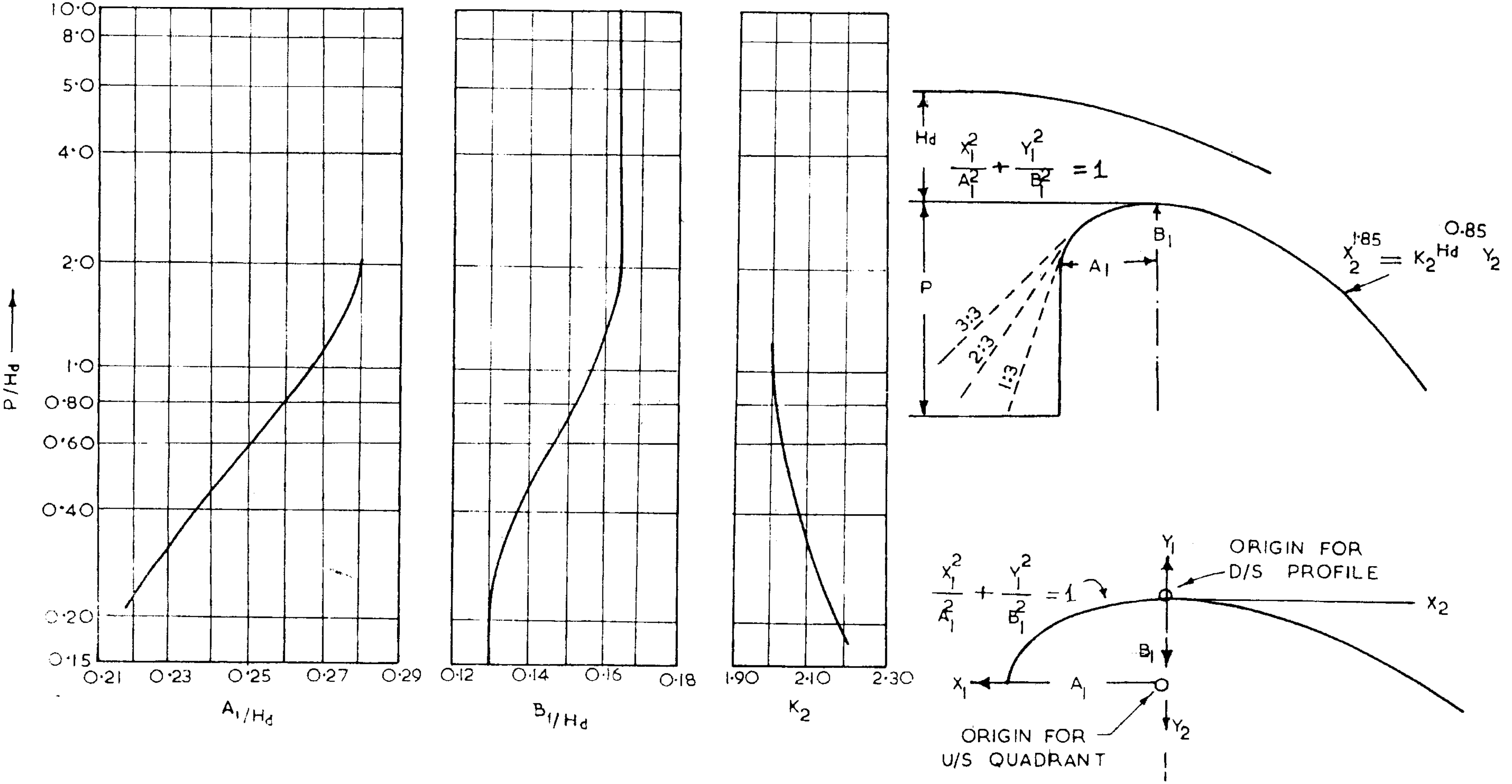


FIG. 2 OVERFLOW SPILLWAY CREST — DESIGN PARAMETERS

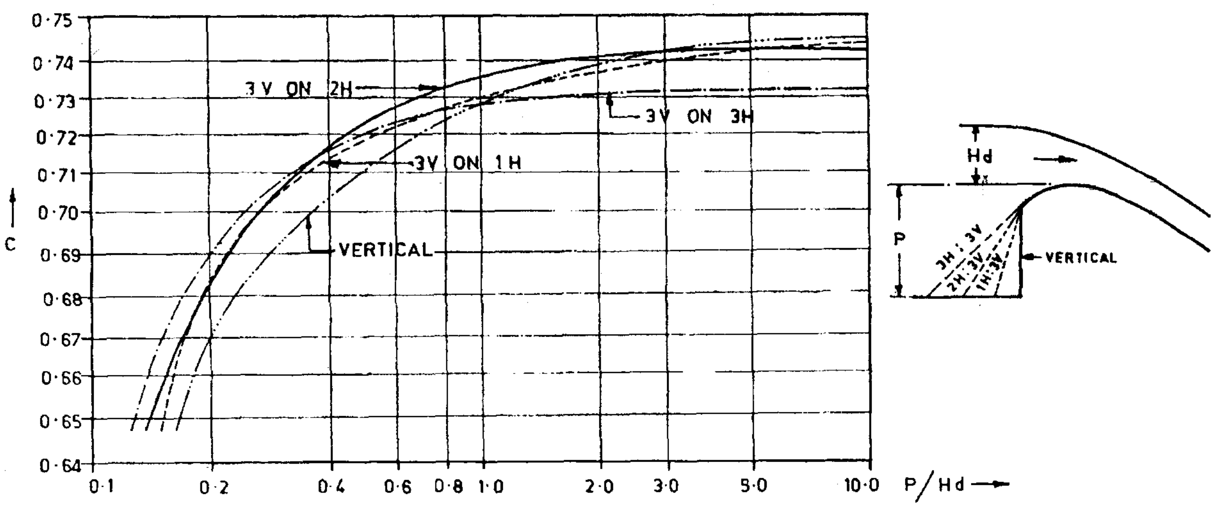


FIG. 3 DISCHARGE COEFFICIENT FOR DESIGN HEAD

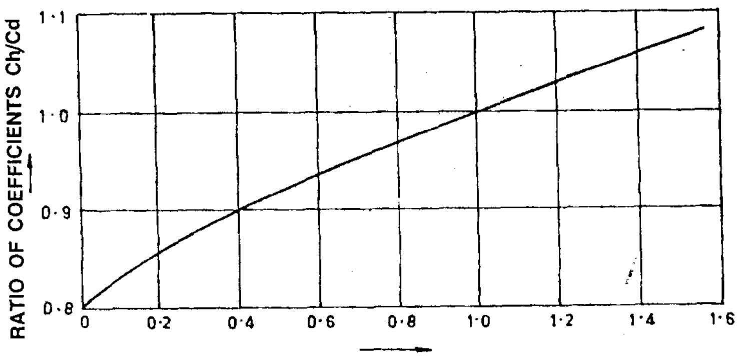
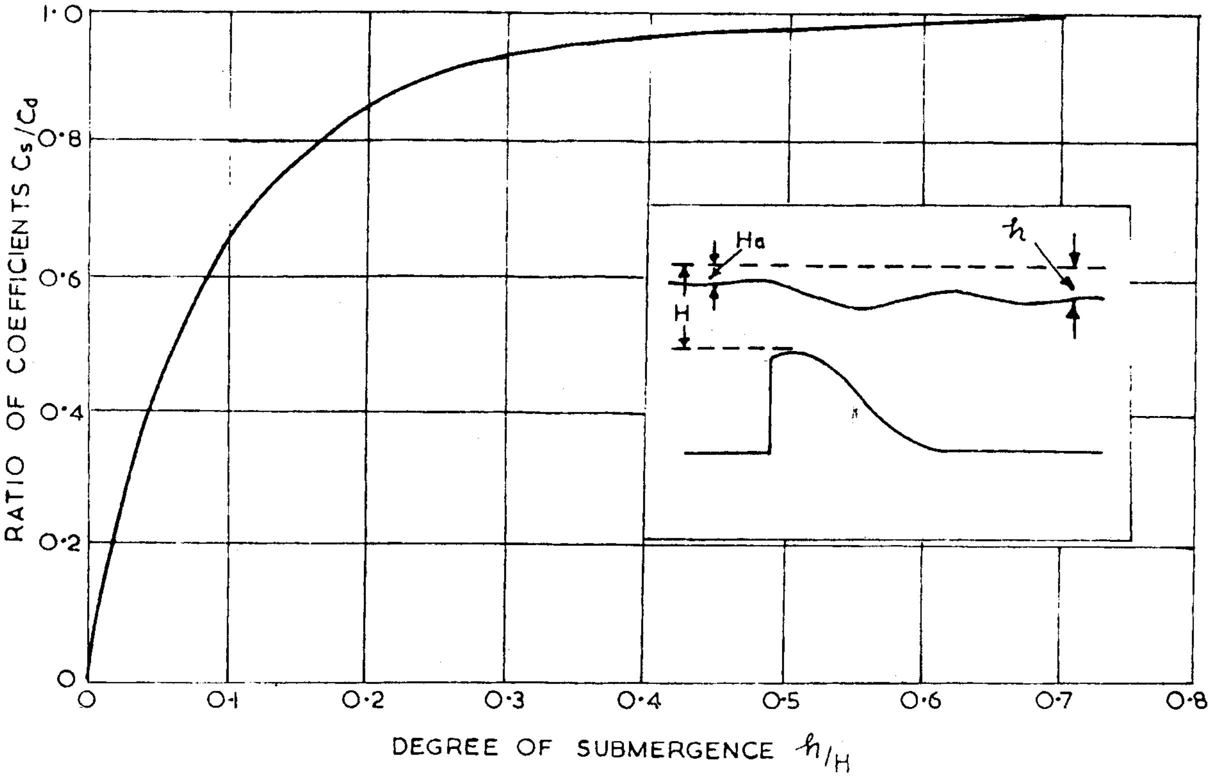
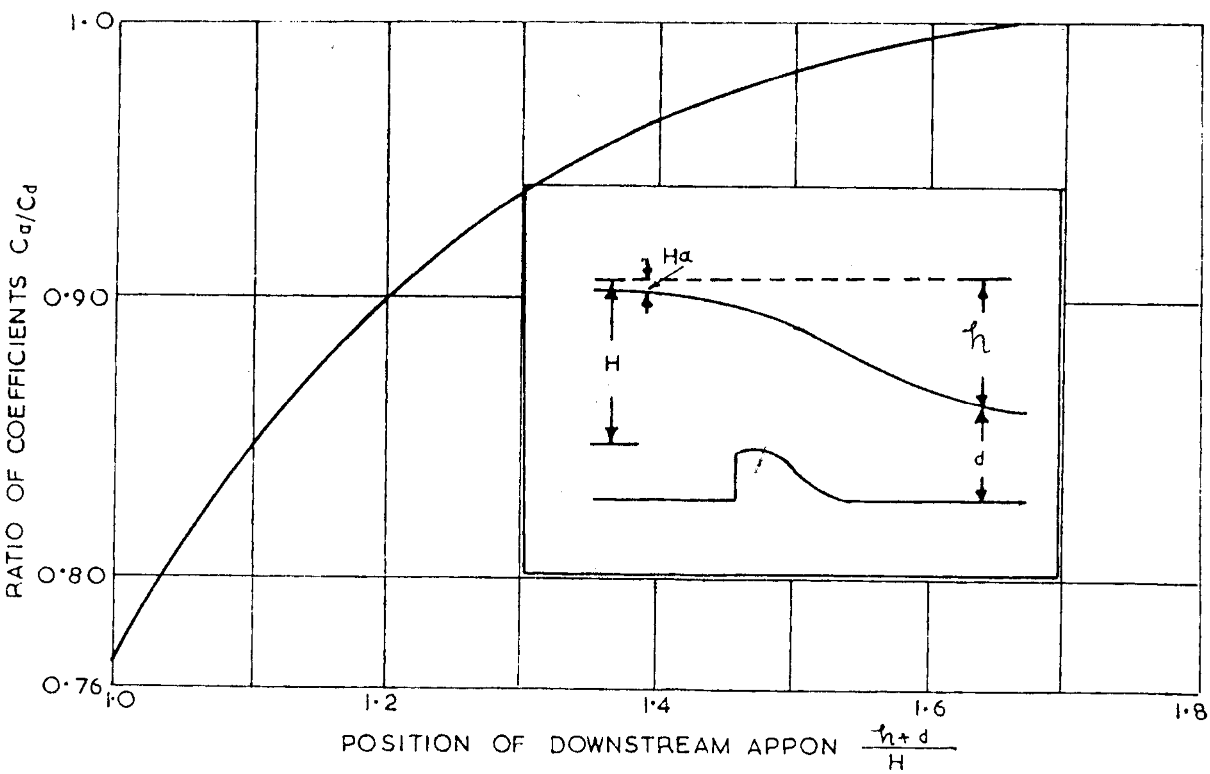


FIG. 4 RATIO OF HEAD ON CREST TO DESIGN HEAD (H/H_d)



5A EFFECT OF TAIL WATER ON DISCHARGE COEFFICIENTS



5B EFFECT OF APRON ELEVATION ON DISCHARGE COEFFICIENTS

FIG. 5 COEFFICIENT OF DISCHARGE

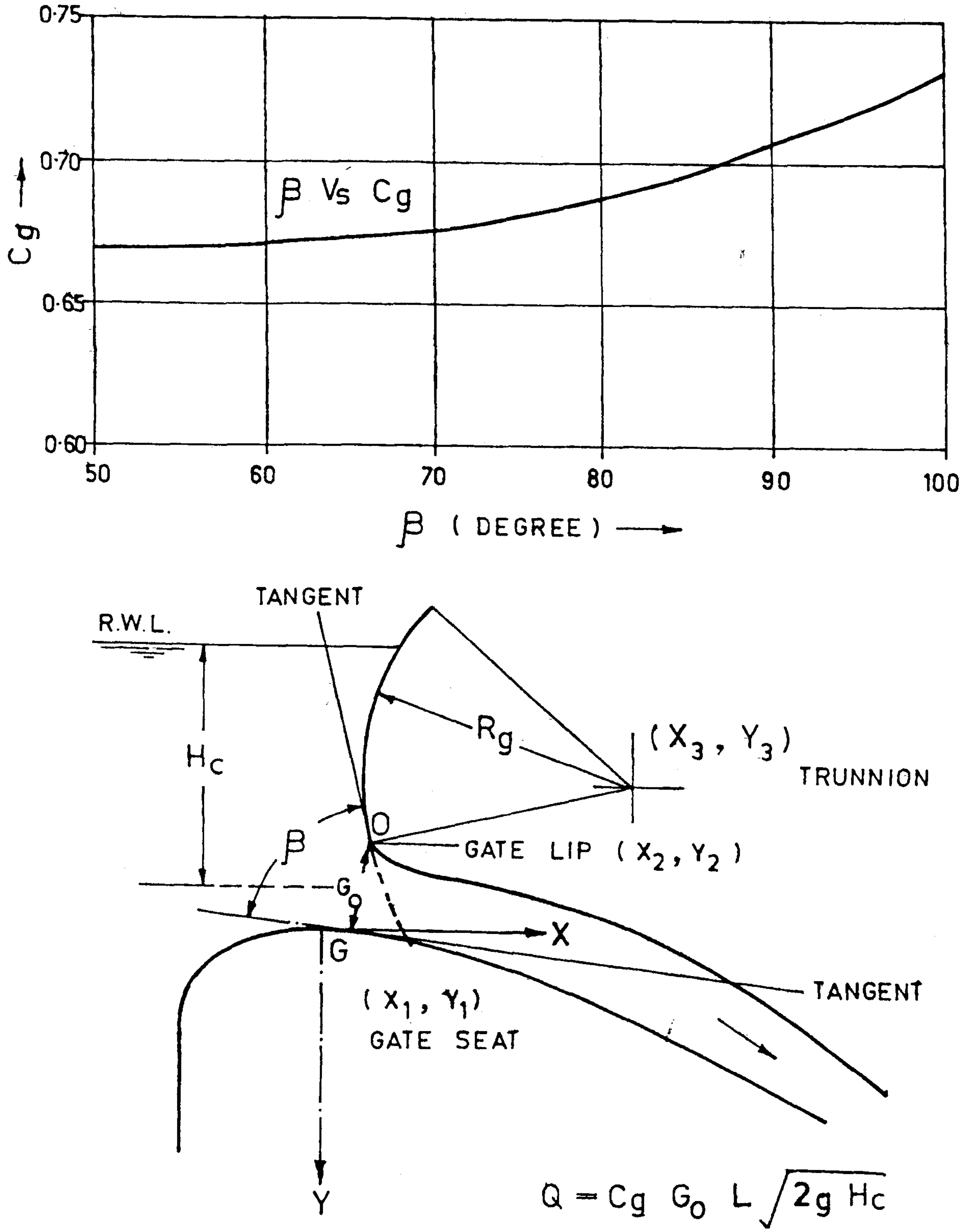
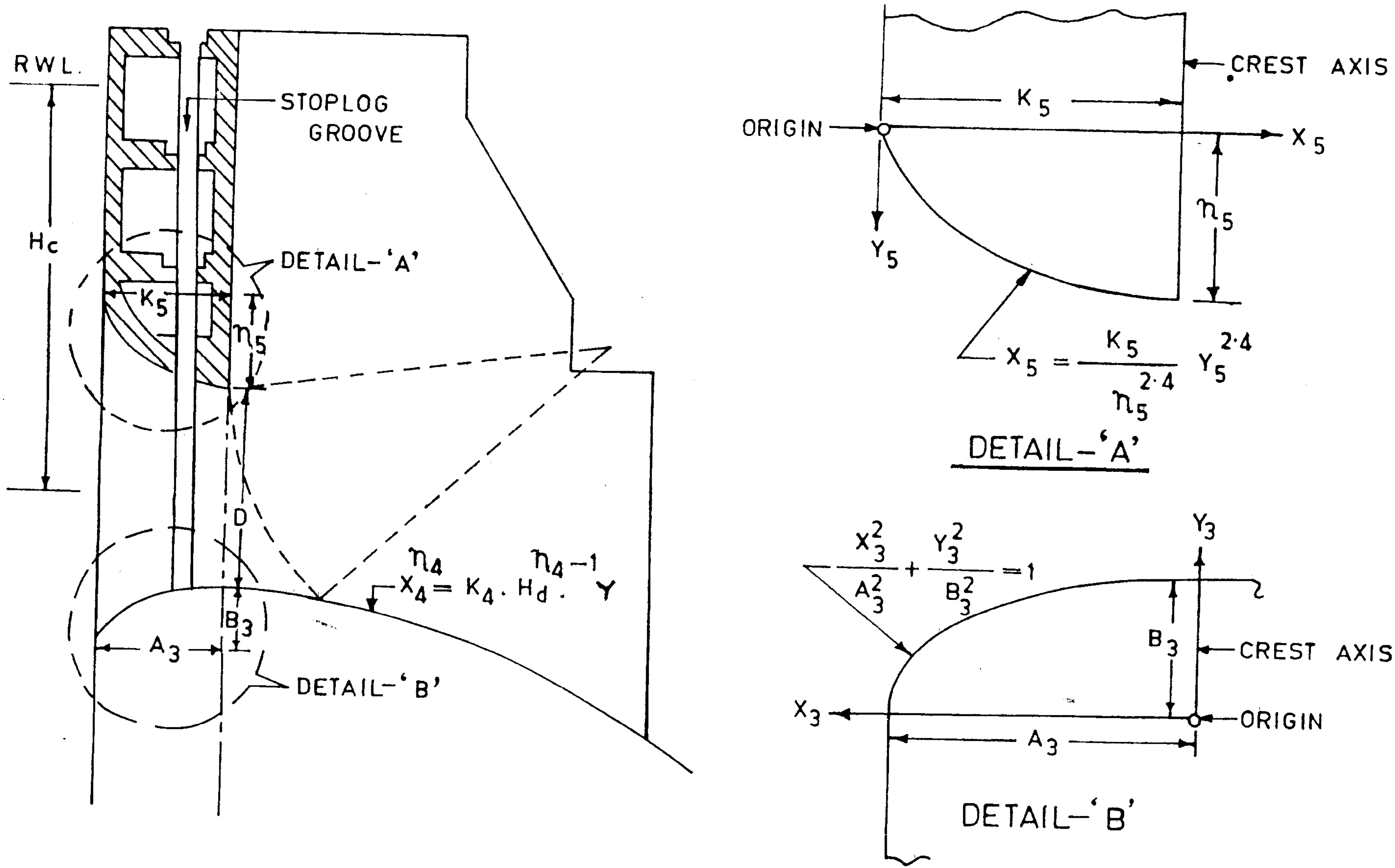


FIG. 6 COEFFICIENT OF DISCHARGE FOR FLOW UNDER GATE



RWL.
STOPLOG GROOVE
H_c
DETAIL-'A'
K_5
η_5
D
$X_4 = K_4 \cdot H_d^{\eta_4 - 1} \cdot Y^{\eta_4}$
B_3
A_3
DETAIL-'B'
CREST AXIS
K_5
ORIGIN
X_5
Y_5
η_5
$X_5 = \frac{K_5}{\eta_5^{2.4}} Y_5^{2.4}$
DETAIL-'A'
Y_3
$\frac{X_3^2}{A_3^2} + \frac{Y_3^2}{B_3^2} = 1$
B_3
CREST AXIS
X_3
ORIGIN
A_3
DETAIL-'B'

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