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Indian Standard

CRITERIA FOR HYDRAULIC DESIGN OF IRRIGATION INTAKE STRUCTURES

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Indian Standard

CRITERIA FOR HYDRAULIC DESIGN OF IRRIGATION INTAKE STRUCTURES

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Indian Standard
CRITERIA FOR HYDRAULIC DESIGN OF IRRIGATION INTAKE STRUCTURES

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 6 December 1985, after the draft finalized by the Intake Structures Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 An intake is provided in an irrigation development to allow water into a channel or tunnel under controlled conditions. The intake design shall be such as to:

a) give minimum hydraulic losses,

b) provide smooth entry into the water conductor system, and

c) prevent/minimize ice, floating trash and coarse sediment entering the tunnel or channel.

0.3 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 the IS : 2-1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

1. SCOPE

1.1 This standard lays down the criteria for hydraulic design of irrigation intake structures. Typical layouts of intake structures are also covered in this standard.

2. TYPES AND CHOICE OF INTAKES

2.1 The position and location of an intake generally depend upon the type of intake and may be broadly classified as under:

a) Run-of the river type intakes, and

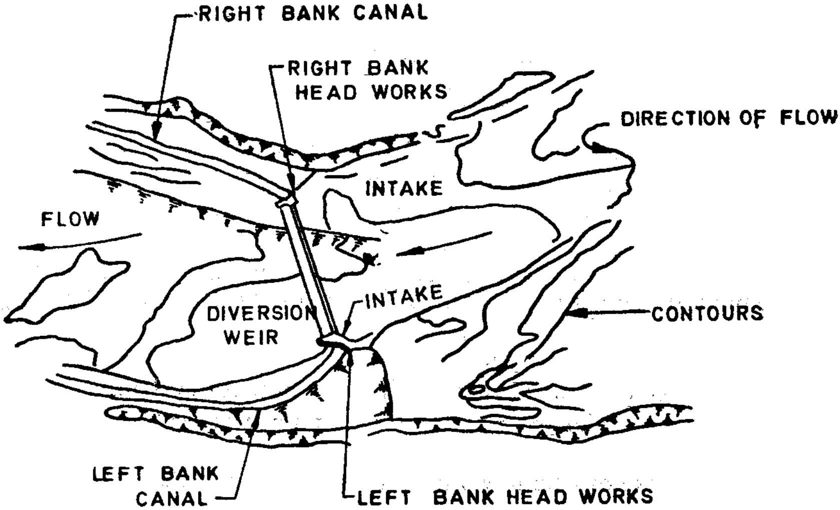
b) Reservoir type intakes.

2.2 Run-of the River Type Intake

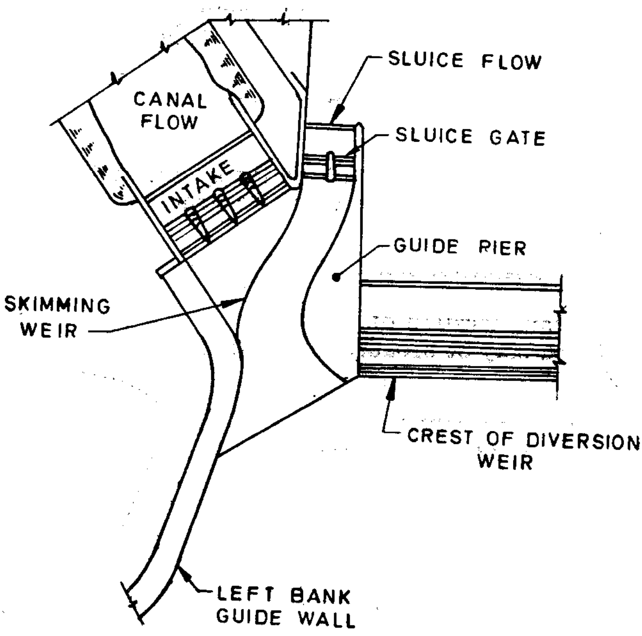
2.2.1 Run-of the river type intakes are those which draw water from the fresh continuous river inflows without any appreciable storage upstream of the diversion structure. A typical sketch of intake to meet

*Rules for rounding off numerical values (*revised*).

special characteristics, such as steep slopes, high peaks and short duration flood flows and high sediment loads, is shown in Fig. 1.



1A Typical Location Plan



1B Modified Design of Head Works

FIG. 1 RUN-OF RIVER TYPE INTAKE

2.2.1.1 *Intakes adjacent to diversion weir/barrage* — In a run of the river type development without any diurnal pondage, an intake of irrigation water conductor system is placed upstream of diversion dam or barrage. A typical layout is shown in Fig. 2.

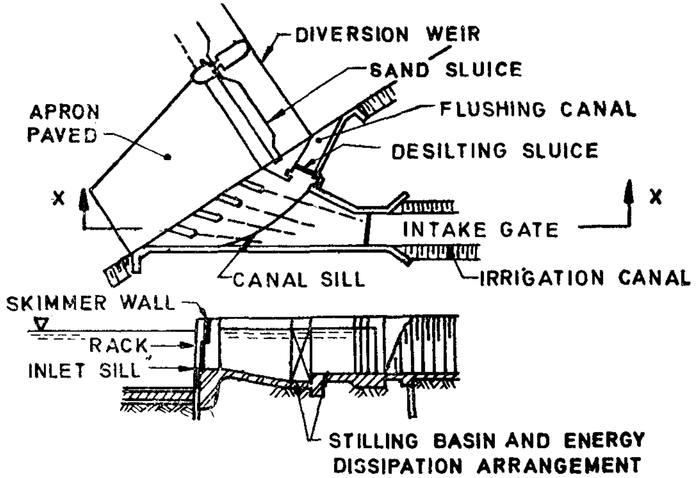


FIG. 2 TYPICAL CANAL INTAKE

2.2.1.2 *Drop type intake* — A diversion structure, consisting of a trench weir and trashrack structure over it, is constructed across mountain streams to entrap the entire minimum discharges of the river. The trench may be either in the river bed or in the weir (raised above the river bed) as per typical layout shown in Fig. 3 and Fig. 4.

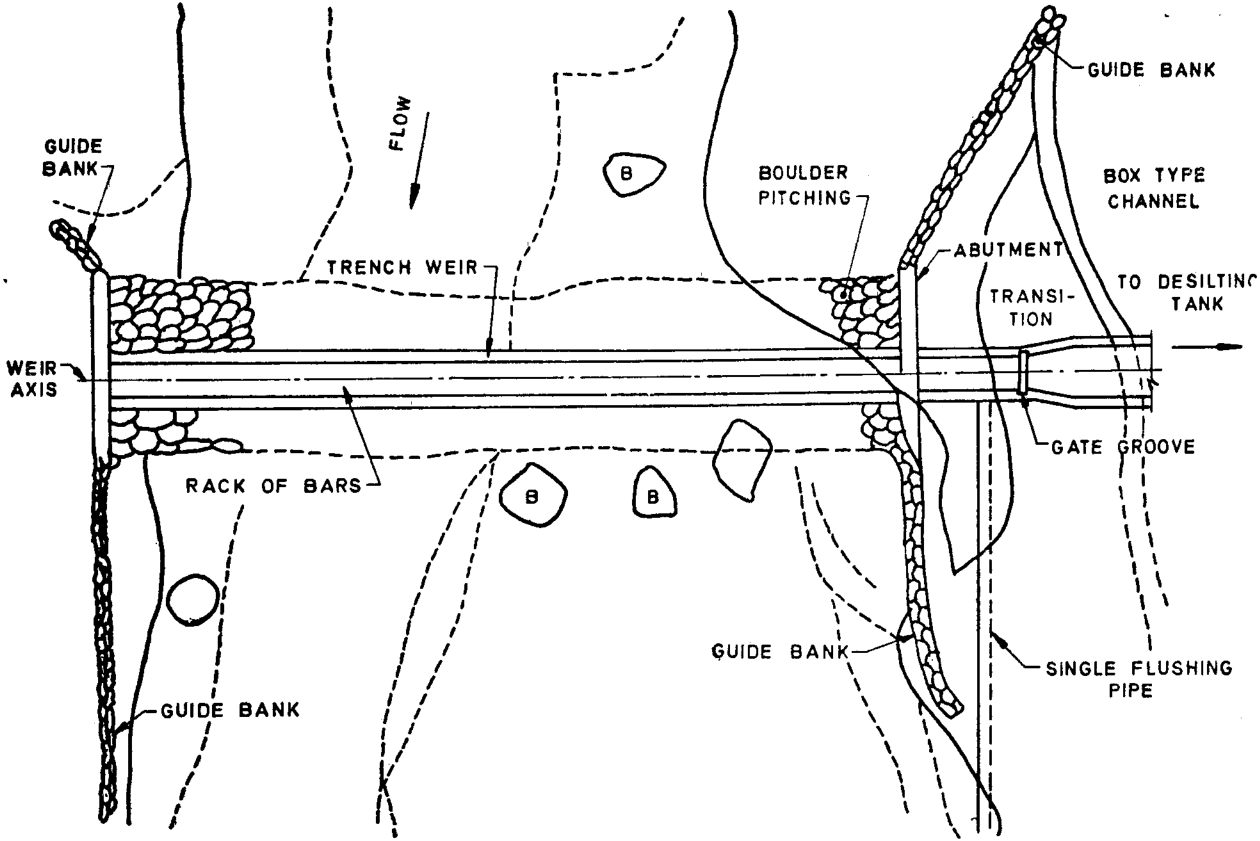
2.3 Reservoir Type Intake

2.3.1 Reservoir type intake is provided where discharges for irrigation are drawn from storage built up for this purpose. Depending on the head, this is further categorized as under:

a) Low head (up to 15 m),

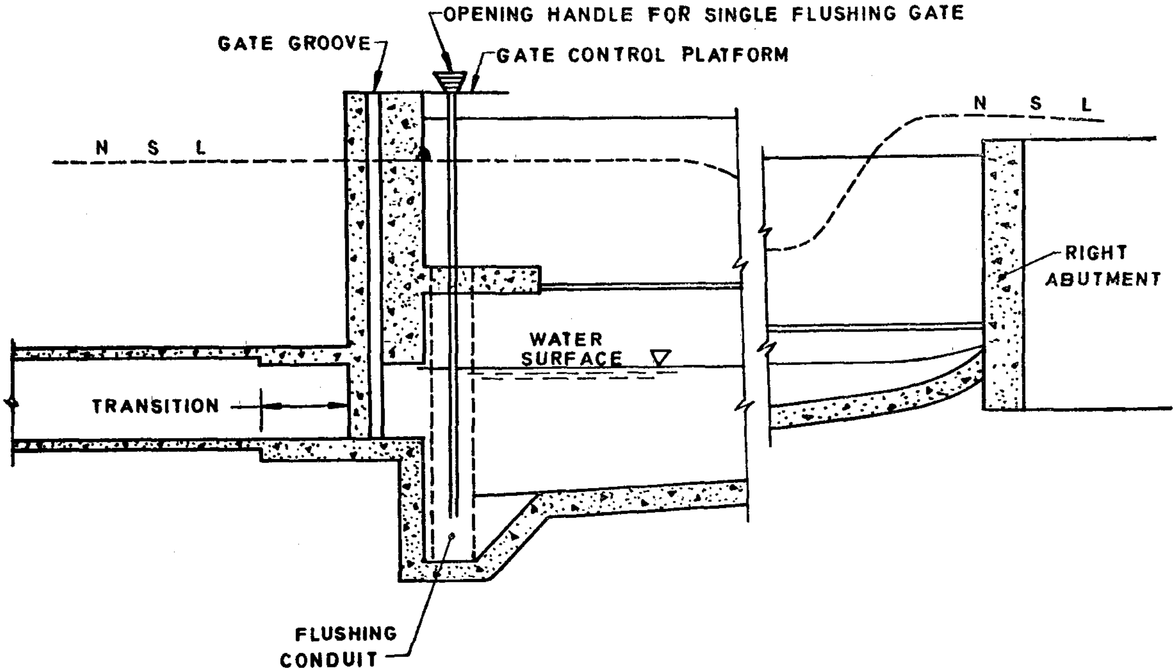
b) Medium head (15 to 30 m), and

c) High head (above 30 m).



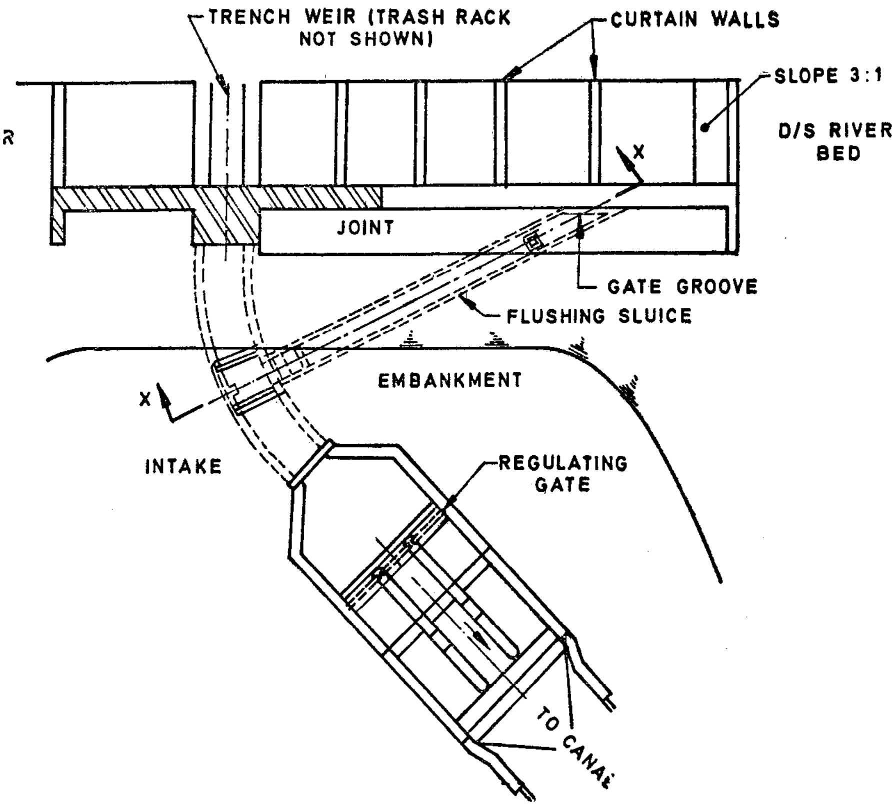
3A General

FIG. 3 DROP TYPE IRRIGATION INTAKE TRENCH IN RIVER BED — *Contd*



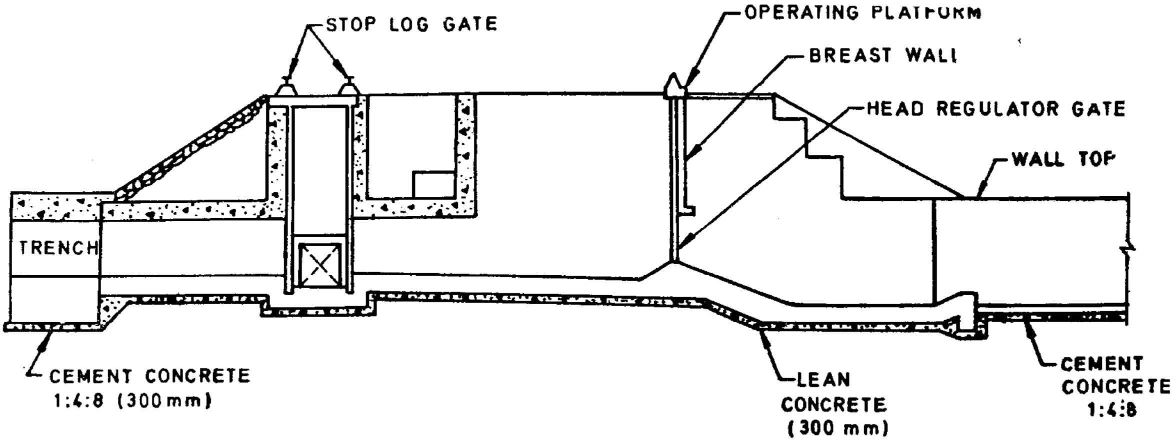
3B Sectional Elevation

FIG. 3 DROP TYPE IRRIGATION INTAKE TRENCH IN RIVER BED

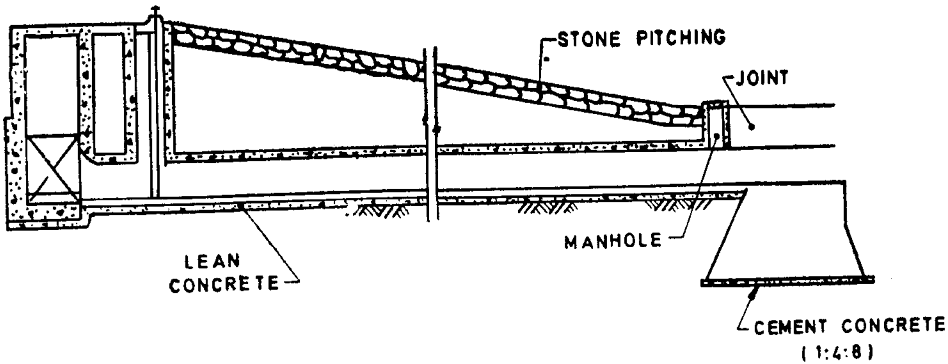


4A General

FIG. 4 DROP TYPE IRRIGATION INTAKE (TRENCH IN THE WEIR) — *Contd*



4B L-Section Through Intake

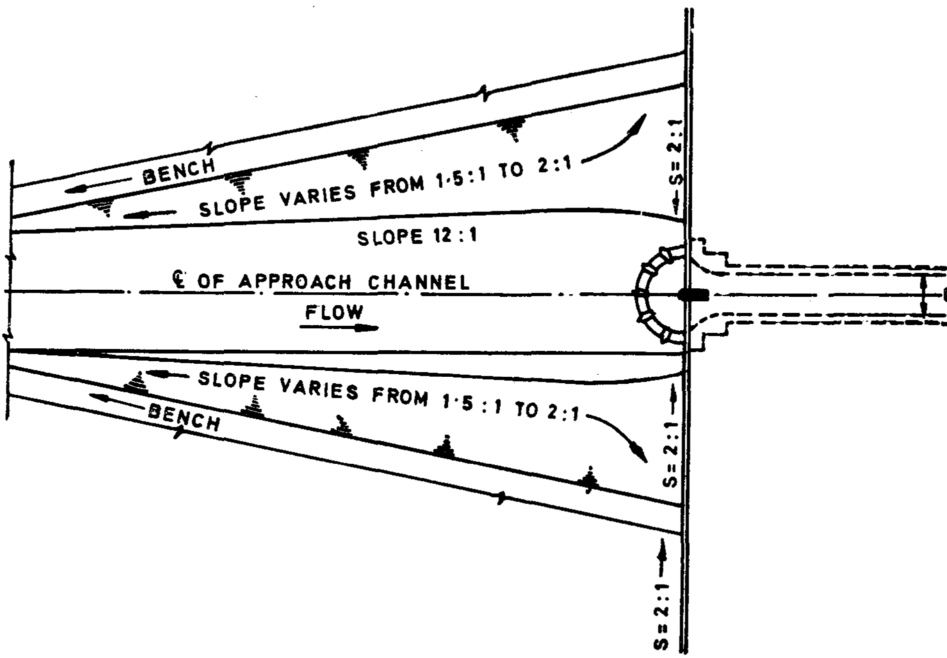


4C L-Section Through Flushing Duct

FIG. 4 DROP TYPE IRRIGATION INTAKE (TRENCH IN THE WEIR)

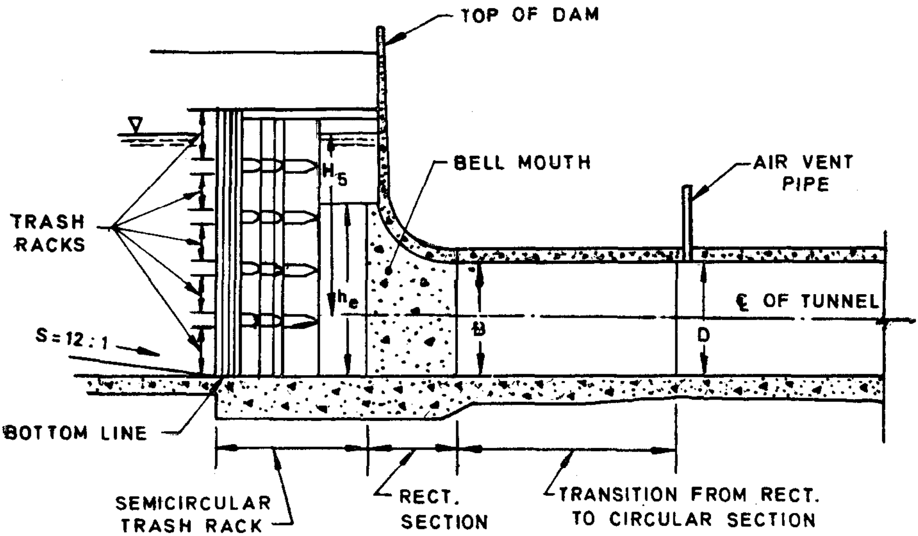
2.3.1.1 *Intake in concrete or masonry dams* — In the case of concrete or masonry dams irrigation intake structure can be located either at the toe when operating head is low or in the body of the dam itself when operating head is medium or high. Typical layouts are shown in Fig. 5A, 5B and 5C.

2.3.1.2 *Intake in earthen dams* — When the reservoir is formed by an earthern dam, the irrigation tunnel is laid below it or in the abutment. The intake structure for such situations will be a sloping intake or tower type of intake. Typical layouts for sloping and tower type intakes are shown in Fig. 6A, 6B and 6C respectively. As far as possible, reinforced cement concrete pressurized system should be avoided in the body of the earth dam. Measures like provision of steel liners and suitable drainage downstream of core, provisions of joints for differential settlements when not founded on rock should be considered in case pressure conduits are provided under earth dams.

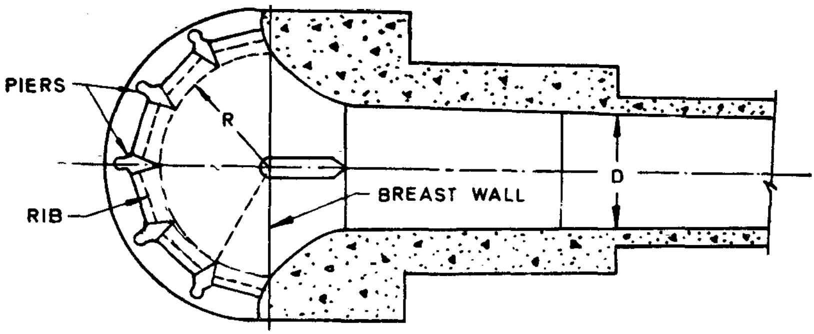


i) APPROACH GEOMETRY

5A Semicircular Type Intake Structure — *Contd*



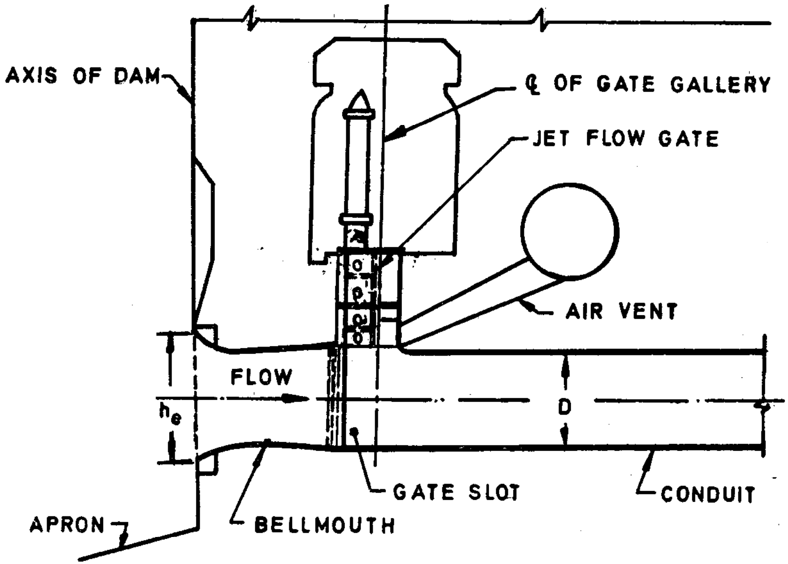
ii) ELEVATION



iii) PLAN

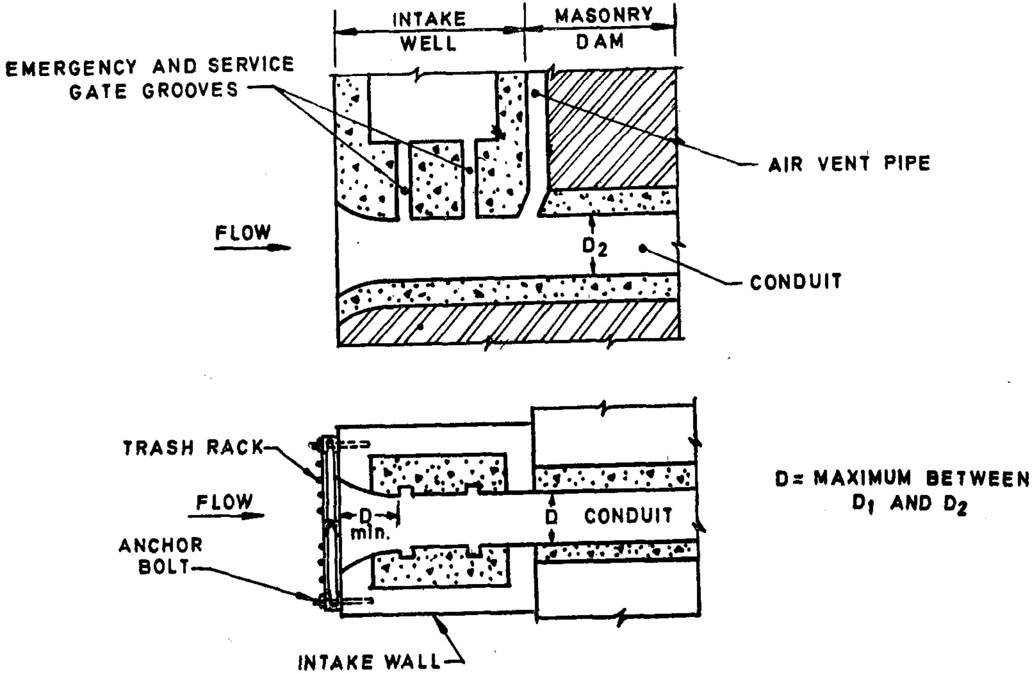
5A Semicircular Type Intake Structure

FIG. 5 RESERVOIR TYPE IRRIGATION INTAKE STRUCTURES IN CONCRETE/MASONRY DAMS — *Contd*



5B Typical Installation in a Concrete/Masonry Dams — *Contd*

FIG. 5 RESERVOIR TYPE IRRIGATION INTAKE STRUCTURES IN CONCRETE/MASONRY DAMS



5C Typical Installation in a Concrete/Masonry Dams

FIG. 5 RESERVOIR TYPE IRRIGATION INTAKE STRUCTURES IN CONCRETE/MASONRY DAMS

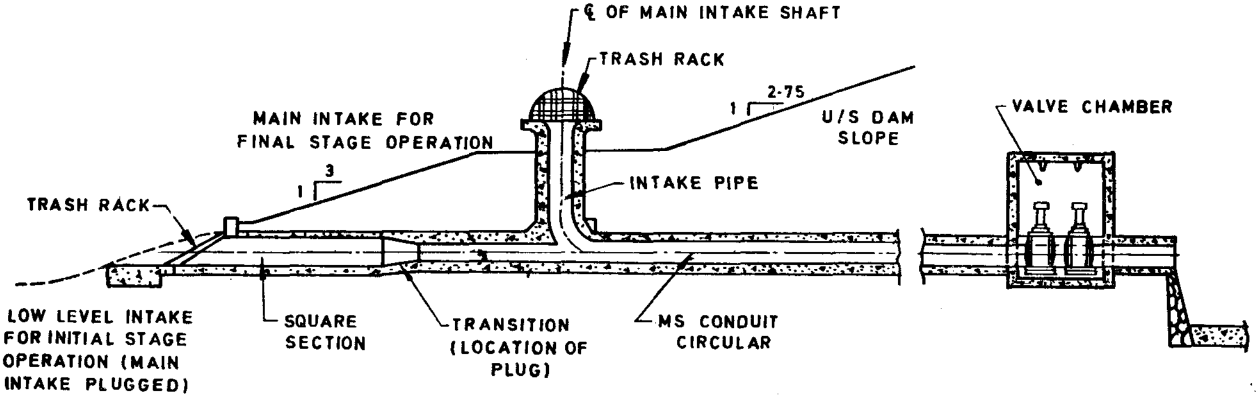


FIG. 6A TYPICAL INSTALLATION IN AN EARTH DAM — SLOPING INTAKE

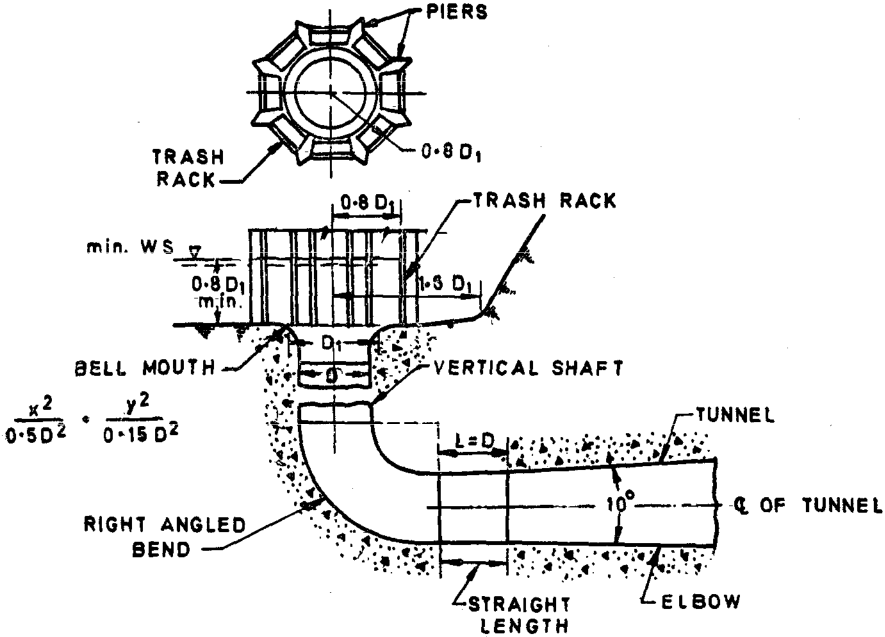
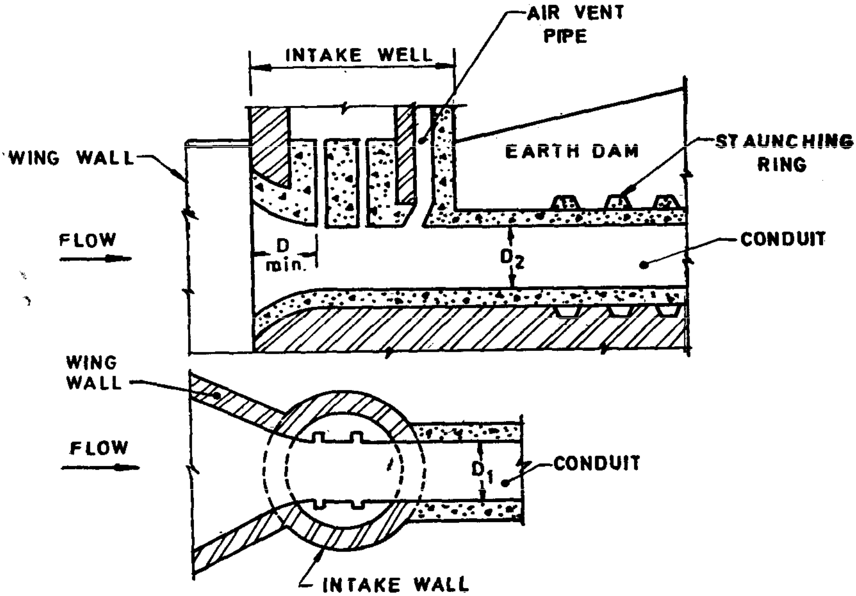


FIG. 6B TYPICAL INSTALLATION IN AN EARTH DAM TOWER TYPE INTAKE (TYPE I)



D = Maximum Between D_1 and D_2

FIG. 6C TYPICAL INSTALLATION IN AN EARTH DAM TOWER TYPE INTAKE (TYPE II)

2.3.1.3 *Intake in reservoir independent of dam* — In case of a high-head installation; irrigation tunnel taking off from a storage reservoir, the intake is located at a distance from the dam. The intake structure of such a layout will be either tower type semicircular, circular, rectangular or inclined.

3. LAYOUT OF INTAKE STRUCTURE

3.1 Main components of an irrigation intake structure are listed below:

a) Trashrack and supporting structures;

b) Anti-vortex devices;

c) Bell-mouth entrance with transition and rectangular to circular opening; and

d) Gate slot enclosures with air vents.

3.1.1 The efficient and economic design of an intake to serve the functions set out in **0.2** will depend upon the conditions prevailing in each development. In **5.3.3** and **5.3.5** few formulae have been suggested which may be modified to suit any special condition. Hydraulic model studies may be necessary under special conditions.

3.2 The main types of layouts are given below.

3.2.1 *Canal Intake* — In low-head development, the intake admits water into diversion/irrigation canal. Sediment excluder or trap is an essential component of this type of intake. The invert at inlet is generally raised to form a sill to prevent the entry of coarse fraction of bedload into the canal. A skimmer wall to prevent the floating material and trashrack to check entry of submerged heavy bodies, such as tree trunks, are provided at the entrance. Stilling basin and energy dissipation devices on the downstream of intake, as shown in Fig. 2, are also required. In the case of trench provided either in the river bed or in the weir, desilting basin is located in the canal and the sediment entrapped is removed either manually or by flushing sluices. In some situations desilting tunnels may also be provided upstream of intake (*see* IS : 6531-1972* and IS : 9761-1981†).

3.2.2 *Semicircular Type of Intake Structure* — In this layout, the structure supporting the rack is formed in a semicircle in plan in front of the tunnel opening so that no parts of rack fall within a radius of 1·143 *B* from face of opening, where *B* is the width of opening of tunnel. The main features of semicircular intake structure are:

a) Semicircular trashrack structure;

b) Bell-mouth entrance to tunnel;

*Criteria for design of canal head regulators.

†Criteria for hydraulic design of hydropower intakes.

c) Gate slot enclosures with air vent (Typical details are shown in Fig. 5A, 5B and 5C); and

d) Transition from rectangular to circular conduit.

3.2.3 *Sloping Intake* — Sloping intake is provided in an earthen dam as shown in Fig. 6A. Trashrack for the intake (made by mild steel rectangular bars) is provided at the entrance. The top and sides at the entrance are provided with bell-mouth.

3.2.4 *Vertical Intake* — Vertical intake is essentially a circular vertical shaft. The structure above it supporting the trashrack is either tower type or hemispherical cage. The main features of this layout are:

a) Hemispherical or tower type rack supporting structure;

b) Circular bell-mouth to shaft;

c) Vertical intake shaft; and

d) Right-angled bend at the base of the shaft or an elbow to join the tunnel.

In case of tower type intake structure, flow is regulated either by a single cylinderical gate or by a number of gates in the tower or by a separate gate in the gate shaft. In case of hemispherical intake structure, the control gate is provided in the tunnel portion only. A typical design of hemispherical vertical intake structure is shown in Fig. 6A.

4. CONDITIONS FOR LOCATION AND LAYOUT OF INTAKE STRUCTURE

4.1 Factors influencing the choice of location and layout of intake structure are:

a) Type of development that is run-of river scheme or storage reservoir;

b) Location and type of dam/weir;

c) Type of water conveyance system that is tunnel or canal; and

d) Topographical features of area.

4.2 The conditions under which the various typical layouts of intake as classified in **3.2.1** to **3.2.4** are adopted, are given below.

4.2.1 *Canal Intake* — This type of layout is adopted when:

a) reservoir is of small capacity formed by a weir or barrage;

b) intake is to function under low heads; and

c) the topography and geology permit straight reaches suitable for such type of intake.

4.2.2 *Semicircular Type of Intake Structure*

This type of layout is adopted when:

a) a reservoir is formed by a concrete or masonry dam and outlet tunnel is laid in the body of the dam;

b) the topography and geology permit to have almost vertical face at tunnel inlet portal; and

c) the minimum water depth above the centre line of intake is more than 0·8 of the entrance height.

4.2.3 *Sloping Type of Intake Structure*

This type of layout is adopted when:

a) the reservoir is formed by an earthen dam and tunnel is laid below it; and

b) the intake is subjected to low-head variations like in run-of the river type.

4.2.4 *Vertical Type of Intake Structure*

This type of layout is adopted when:

a) the intake is located at a distance from upstream face of the dam;

b) the reservoir is formed by an earthern dam and outlet tunnel is laid below it; and

c) the intake is subjected to large head variations, resulting in complete submergence of structure.

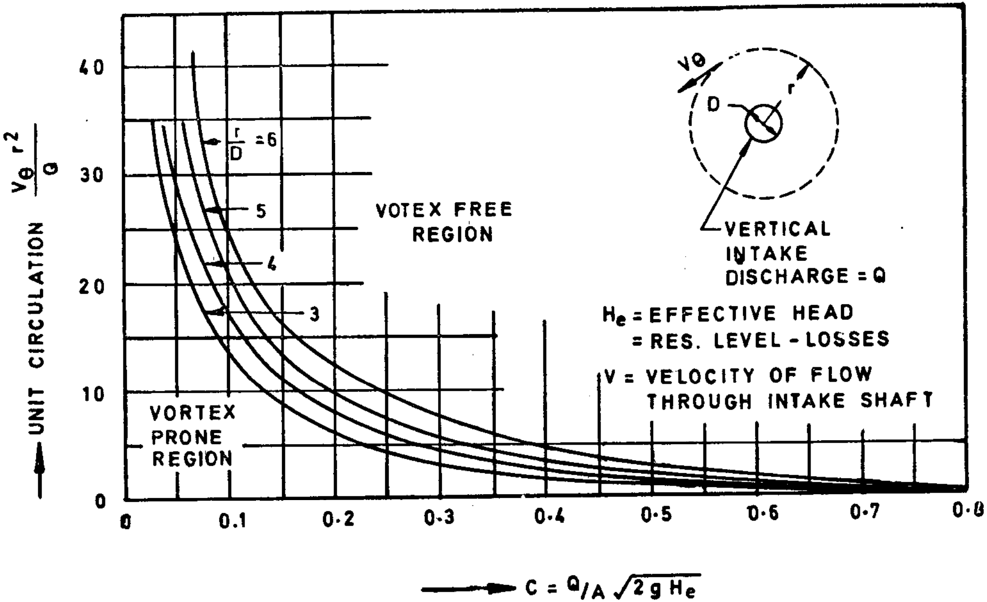
5. HYDRAULIC DESIGN OF COMPONENTS OF INTAKE

5.1 Centre Line of Intake

5.1.1 Centre line of intake shall be located well below the minimum draw down level to prevent formation of vortices. Suitable arrangements, such as cross walls, floating grid may be provided if necessary to prevent/minimize, vortices. Cover of water over the roof of the intake for the prevention of the formation of air entraining vortices both at vertical or horizontal pipe intake may be computed for the purpose of preliminary design from the set of curves given in Fig. 7 A and 7B by trial method (*see* Appendix A). For important works the design may be checked by model studies.

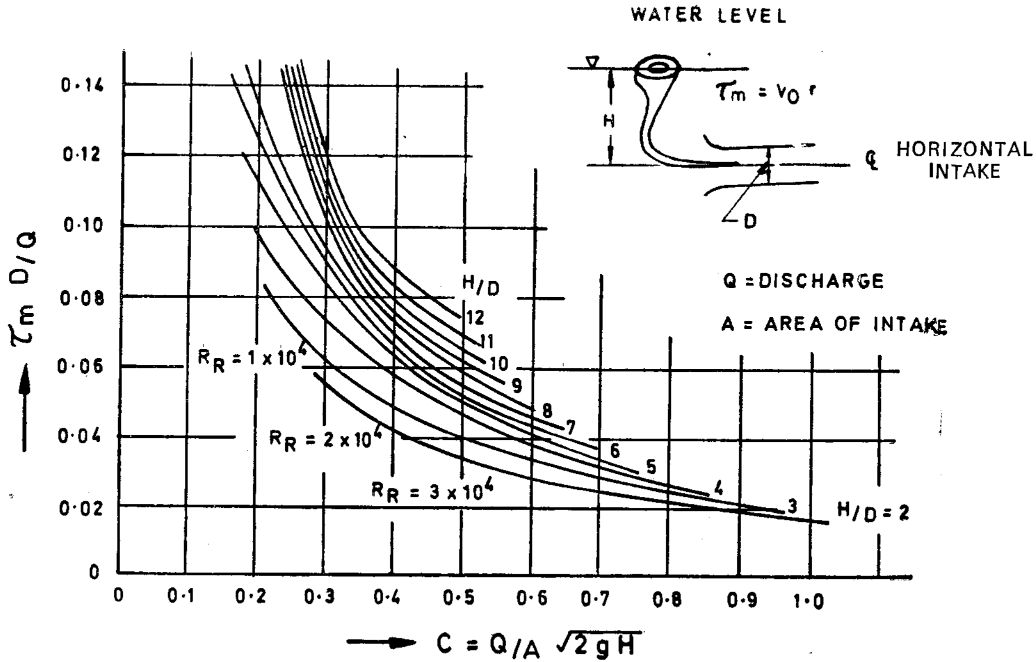
5.2 Trashrack Structure

5.2.1 At entrance to canal or tunnel, where trash may create serious problem in irrigation system, a trashrack structure shall be provided in front of the enterance to the tunnel to prevent the entry of any trash.



7A Co-efficient of Discharge *vs* Unit Circulation

FIG. 7 DIAGRAMS FOR DETERMINING OPTIMUM SUBMERGENCE — *Contd*



7B Co-efficient of Discharge *vs* Circulation Parameter

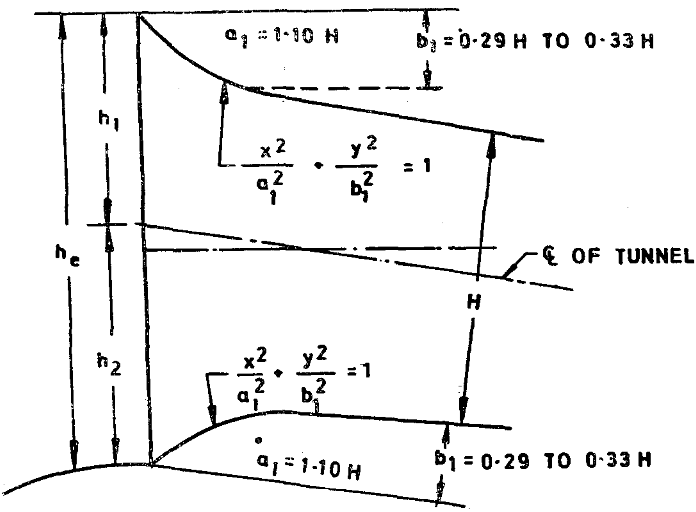
FIG. 7 DIAGRAMS FOR DETERMINING OPTIMUM SUBMERGENCE

5.2.2 The trashrack structure shall be designed in accordance with IS : 11388-1985* and IS : 9761-1981†.

5.3 Bell-Mouth Opening and Transition — A typical sketch is shown in Fig. 8. In non-pressurized system the gate should be provided outside the bell-mouth end.

5.3.1 *Shape and Size of Opening* — Entrance to the irrigation tunnel shall be designed to produce an acceleration similar to that found in a jet issuing from a sharp edged orifice. The surface shall be formed to natural contraction curve and the tunnel assumed to the size of orifice jet at its maximum contraction.

5.3.2 The normal contraction with coefficient of contraction C_e as 0·6 shall be used in high-head installations and C_e as 0·7 for low-head installations in order to reduce the height of opening. Coefficients of discharge and loss coefficients for typical entrances for conduits are given in Table 1.

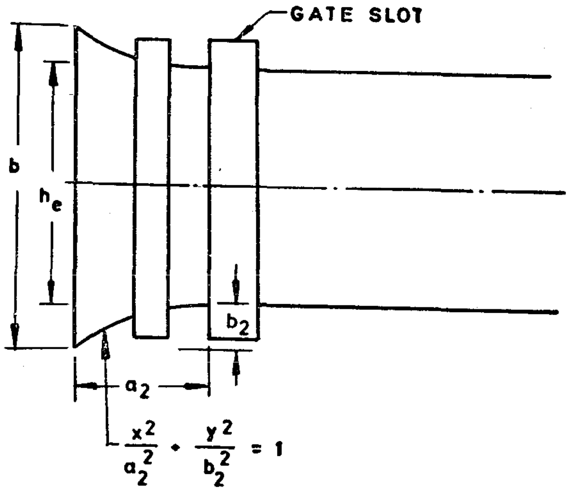


8A Elevation

FIG. 8 BELL-MOUTH DETAILS OF RECTANGULAR OPENING — *Contd*

*Recommendations for design of trashracks for intakes.

†Criteria for hydraulic design of hydropower intakes.



8B Plan

FIG. 8 BELL-MOUTH DETAILS OF RECTANGULAR OPENING

TABLE 1 COEFFICIENT OF DISCHARGE AND LOSS COEFFICIENTS FOR CONDUIT ENTRANCES

	Coefficient			Loss Coefficient		
	Maximum	Minimum	Average	Maximum	Minimum	Average
a) Gate in thin wall unsuppressed contraction	0·70	0·60	0·63	1·80	1·00	1·50
b) Gate in thin wall-bottom and sides suppressed	0·81	0·68	0·70	1·20	0·50	1·00
c) Gate in thin wall-corners rounded	0·95	0·71	0·82	1·00	0·10	0·50
d) Square-cornered entrances	0·85	0·77	0·82	0·70	0·40	0·50
e) Slightly rounded entrances	0·92	0·79	0·90	0·60	0·18	0·23
f) Fully rounded entrances $\frac{r}{D} \geqslant 0{\cdot}15$	0·96	0·88	0·95	0·27	0·08	0·10
g) Circular bell-mouth entrances	0·98	0·95	0·98	0·10	0·04	0·05
h) Square bell-mouth entrances	0·97	0·91	0·93	0·20	0·07	0·16
j) Inward projecting entrances	0·80	0·72	0·75	0·93	0·56	0·80

5.3.3 *Opening Area*

$$\text{Opening area} = \frac{\text{Conduit area}}{C_e \cos \phi}$$

where

ϕ = Angle of inclination of centre line of conduit to horizontal, and

C_e = Coefficient of contraction as defined in **5.3.2**.

5.3.4 *Entrance Curves for Circular Conduits* — For circular conduits, an elliptical entrance curve obtained from the following equation will satisfy the streamlining requirements:

$$\frac{X^2}{(0{\cdot}5\,D)^2} + \frac{Y^2}{(0{\cdot}15\,D)^2} = 1$$

where X and Y are coordinates measured parallel to and prependicular to the conduit centre line respectively, and D is the diameter of the conduit.

5.3.5 *Entrance Curves for Rectangular Conduit*

5.3.5.1 *Height and width of opening*

The height is calculated by the distance above and below the intersection of the tunnel centre line with the face of the entrance (*see* Fig .8).

Centre line to upper edge:

$$h_1 = D\left[\,(1{\cdot}21\tan^2\phi + 0{\cdot}084\,7)^{\frac{1}{2}} + \frac{1}{2\cos\phi} - 1{\cdot}10\tan\phi\,\right]$$

Centre line to lower edge:

$$h_2 = D\left[\left(\frac{0{\cdot}791}{\cos\phi} + 0{\cdot}077\tan\phi\right)\right]$$

$$h_e = h_1 + h_2$$

5.3.5.2 *Shape of the opening* — For a rectangular entrance with the invert at the same elevation as the upstream floor and with curved guide piers at each side of the entrance openings, both the bottom and side contraction will be suppressed and a sharper contraction will take place at the top of the opening. For this condition, the top contraction curve is defined by the equation:

$$\frac{X^2}{H^2} + \frac{Y^2}{(0{\cdot}67\,H)^2} = 1$$

where H is the vertical height of the conduit downstream from the entrance shape.

For rectangular or square openings

$$\frac{X^2}{D^2} + \frac{Y^2}{(0.33\,D)^2} = 1$$

where D is the vertical height of the conduit for defining top and bottom curves and is the horizontal width of the conduit for defining side curves.

The above mentioned formulae for rectangular/square conduit are applicable when the centre line of the transition and centre line of conduit are the same.

For higher heads shape of the opening may be decided by model studies.

5.3.6 *Transitions* — In order to obtain most economical design of intake transitions from a rectangular section to a circular conduit, the vertical walls are flared in the direction of flow. The transition shall be designed in accordance with the following requirements:

a) Transition or turns shall be made about the centre line of mass flow;

b) For contraction, the maximum convergent angle should not exceed that indicated by the relation:

$$\tan \alpha = \frac{1}{U}$$

where

α = Angle of the conduit wall surfaces with respect to its centre line,

U = An arbitrary parameter = $\frac{V}{\sqrt{gH}}$, and

H = Vertical height of the conduit.

The value of V and H are the average of the velocities and dimensions at the beginning and end of the transition.

For expansion $\tan \alpha = \frac{1}{2\,U}$

For usual installations, the flare angle should not normally exceed 10°.

c) The area of any section of the transition shall be proportional to the area of a jet at similar section and modified to provide the acceleration necessary to turn the water through the angle that section makes with the face, and

d) All slots or other necessary departures from the neat outline shall be outside the transition zone.

5.4 Intake Gates and Air Vent

5.4.1 The intake gate slot shall be enclosed in a structure designed to guide the water into the rectangular opening without side contraction.

5.4.2 The upstream edge of the gate slot shall be at least 0·40 b_e from the nose, where b_e is the width of opening.

5.4.3 Where gates are located in a gate shaft, suitable transition from circular to rectangular gate slot shall be provided.

5.4.4 *Size of Air Vent* — An air vent is provided just downstream of the gate to prevent occurrence of excessive subatmospheric pressure. The air vent shall be so designed as to admit air with velocity not exceeding 50 m/s. The area of air vent is given by value of air demand divided by the maximum permissible velocity. Air demand shall be computed on the considerations of type of flow occurring downstream of gates, namely, spray flow, free flow, foamy flow, hydraulic jump formation with free surface flow or hydraulic jump formation with pipe flow.

The air demand for different flow types in the conduit shall be computed with the help of the following formulae:

a) For hydraulic jump formation, $\beta = 0{\cdot}006\,6\,(F_{IC} - 1)^{1{\cdot}4}$ where β is the ratio of volume flow rate of air to that of water, and F_{IC} is the Froude number at vena contracta;

b) For spray flow, $\beta = 0{\cdot}2\,F_{IC}$; and

c) For free flow $\beta = 0{\cdot}09\,F_{IC}$

where

$$\beta = \frac{Q_a}{Q_w}$$

Q_a = air demand,
Q_w = discharge of water, and
F_{IC} = Froude number at vena contracta.

For hydraulic jump formation with channel flow and various types of flows mentioned above, Fig. 9 may be used to compute air demand.

5.4.4.1 *Prevention of air-blows* — The air-blows or return blows characterised by flow of air-water mixture, more or less in the form of a geyser, have been observed at intakes similar to those shown in Fig. 6A and 6B. Sometimes these blows may be very violent and may result in blowing of the trashrack. In some cases the trashrack may be lifted and drawn in the tunnel itself. Return blows may be prevented by the following measures:

a) By providing larger open area of the trashrack;

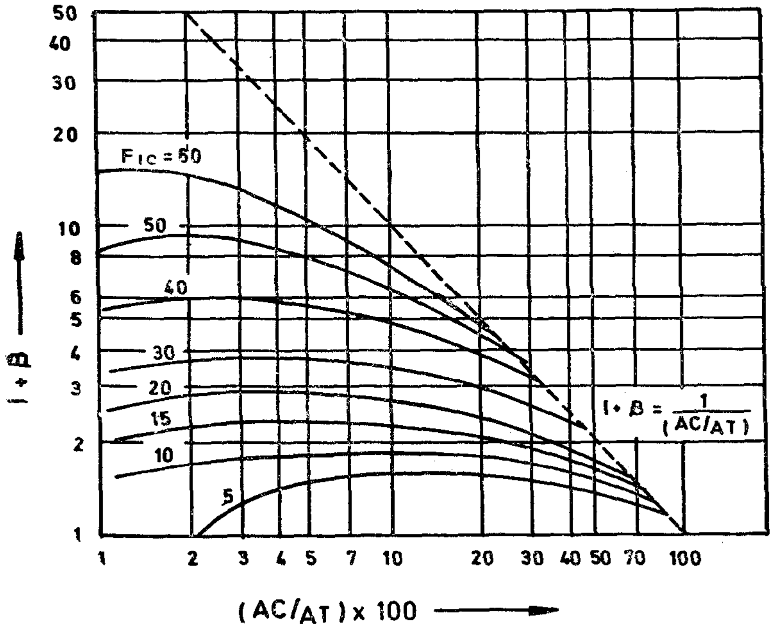
b) By providing another air-vent after the vertical bend in the outlet conduit; and

c) By washing away the air pockets frequently by releasing higher discharge in the tunnel.

5.4.4.2 *Head losses in air vent* — Head loss in the air vent, specially in case of an unusually complicated vent layout containing a number of sharp bends and obstructions, shall be checked to determine whether the pressure drop exceeds 2 m of water in which case the vent size shall be increased suitably.

5.5 Approach Apron

5.5.1 The approach apron shall not be placed closer than 30 percent of the intake height, h_e, from the lower edge of the intake orifice.



A_c = Area of Flow at the Vena Contracta

A_T = Area of the Gutlet Tunnel

F_{IC} = Froude's Number at Vena Contracta

FIG. 9 AIR DEMAND CURVES FOR SPRAY, FREE AND FOAMY FLOW

6. MISCELLANEOUS ARRANGEMENT

6.1 For intakes provided at high altitude above snow line, necessary provision for arresting the formation of ice cover on rack bars and gate shall be made for the free flow. The proposed de-icing arrangements shall conform to IS : 10021-1981*.

6.2 Floating ice shall be arrested by providing ice booms or concrete baffle cast intakes.

6.3 Racking Arrangement — Regular raking arrangement shall be provided for intakes where floating material is expected continuously.

6.4 Sediment Exclusion — In case of run-of-river development sediment exclusion devices such as de-silting basin or flushing ducts shall be provided.

6.5 Bypass and air vent arrangement should be provided in the intake between emergency gate and service gates.

APPENDIX A

(*Clause* 5.1.1)

PROCEDURE FOR DETERMINING OPTIMUM SUBMERGENCE OR LOCATION OF CENTRE LINE OF INTAKE

In order to ascertain whether at submergence 'H_S' of intake pipe of diameter $D = 2r_0$ vortex will form at the intake or not proceed as under:

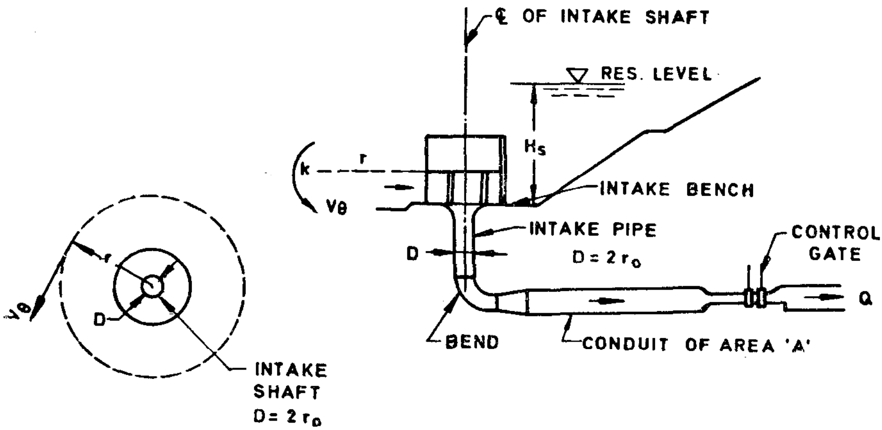
From the design data, the following parameters are known:

a) Effective head — H_E,

b) Discharge corresponding to effective head H_E — Q, and

c) Submergence of the intake — H_S.

*Guidelines for de-icing system for hydraulic installations.



H_E = Effective head = Res. level-head losses up to control gate

Step I Determine coefficient of discharge, C, from

$$C = Q/A\sqrt{2\,gH_E}$$

Step II At any convenient distance r from the centre line of the intake, such that $r/D = 3, 4, 5$ or 6, compute tangential velocity, V_θ from the correlation:

$$H_S = \frac{3{\cdot}45}{2\,g}\left(\frac{V_\theta r}{r_0}\right)^2$$

Step III Evaluate $\dfrac{V_\theta r^2}{Q}$

Step IV Enter Fig. 7A plot of $V_\theta r^2/Q$ *versus* C, and examine; if this point lies above the particular curve corresponding to the adopted value of r/D, no vortex will form. If this point lies below the curve vortex will form.

Step V To determine the optimum water cover or submergence repeat to the above steps till the point corresponding to the computed values of C and $V_\theta r^2/Q$ lies on the particular r/D curve.

For the case of horizontal intake, Fig. 7B may be made use of.