BUREAU OF INDIAN STANDARDS

DRAFT FOR COMMENTS ONLY

भारतीय मानक मसौदा

जलशक्ति अन्तर्ग्रहण के जलीय डिज़ाइन के मापदंड – दिशानिर्देश

(IS 9761 का दूसरा पुनरीक्षण)

Draft Indian Standard

CRITERIA FOR HYDRAULIC DESIGN OF HYDROPOWER INTAKES — GUIDELINES

(Second Revision of IS 9761*)*

Water Conductor Systems Sectional Committee, WRD 14

Last Date for Comments: 11/12/2024

FOREWORD

(*Formal clauses of the foreword will be added later*)

An intake is provided in a hydroelectric development to let water into the water conductor system. The intake design should be such as to:

a) Give minimum hydraulic losses;
b) Prevent formation of air entraining vortices;
c) Minimize sediment entry, especially in the case of run-of-the-river schemes; and
d) Prevent ice and floating material from entering the conduit or penstock.

This standard was first published in 1981 and subsequently revised on 1995 to incorporate certain changes necessitated in view of comments received from user organizations based on their experience in the use of the standard. The salient changes that were incorporated in first revision are listed below:

a) Additional information has been laid down for run-of-the-river type intakes.
b) Intakes in concrete and masonry dam has been divided in two parts and figures depicting semi-circular as well as penstock re-entrant type intake have been incorporated.
c) Intakes in reservoir independent of dam have been illustrated.
d) Layout of intake structures have been elaborated to include anti-vortex devices such as perforated breast-walls.
e) Details of side flaring entry have been incorporated as an illustration.

This revision (second revision) has been brought out to bring the standard in latest style and format of the Indian Standards. In addition, the following changes have been made:

a) Intakes have been classified and types of intake have been revised incorporating intake for PSP scheme.
b) Clause 6.3 Dimensioning of Anti-vortex devices has been incorporated.
c) Fig. 15 and Fig. 17 have been modified.

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 : 2022 'Rules for rounding off numerical values (second revision). The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

The composition of the Committee responsible for formulation of this standard is given at Annex A.

Draft Indian Standard

CRITERIA FOR HYDRAULIC DESIGN OF HYDROPOWER INTAKES — GUIDELINES

(Second Revision of IS 9761*)*

Water Conductor Systems Sectional Committee, WRD 14

Last Date for Comments: 03/01/2023

1 SCOPE

This standard describes the criteria for hydraulic design of hydropower intake structures.

2 REFERENCES

The Indian Standards listed below contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision and parties to agreements based on these standards are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below:

IS No.	*Title*
11570 : 1985	Criteria for hydraulic design of irrigation intake structures

3 CLASSIFICATION OF INTAKES

3.1 Depending on the head above the centre line of intake, intakes are categorized as under:

a) Low head (up to 15 m),
b) Medium head (15 to 30 m), and
c) High head (above 30 m).

3.2 Based on the type of development intakes may be broadly classified as under:

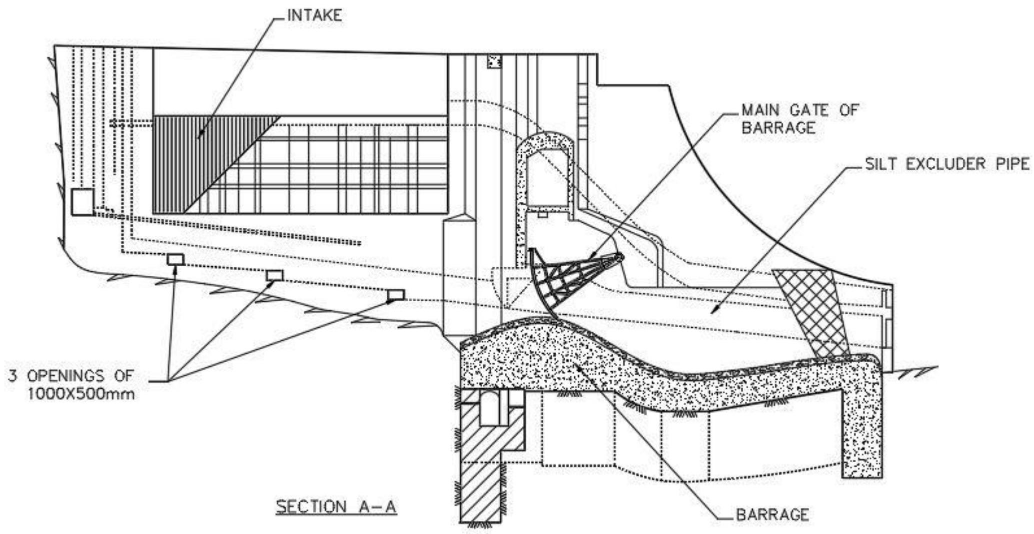
a) Run-of-the-river type intakes - Intakes drawing water from the fresh continuous river inflows with or without any appreciable pondage upstream of the diversion structure.
b) Reservoir type intakes – Intakes provided where discharges for power generation are drawn from storage built up for this purpose.

NOTE — In addition to the above classification, the location/type of intake will also depend on the geological and topographical features of the location, the location of powerhouse vis-à-vis the diverting structure. In cases where there is a considerable movement of boulders, stones and sand in the downstream direction, the intake should be arranged so that the effect of such movement will not lead to a partial restriction or blockage of the intake. In respect of storage reservoir, the sill level of the intake should be aimed to be kept above the sedimentation level at or near the dam face.

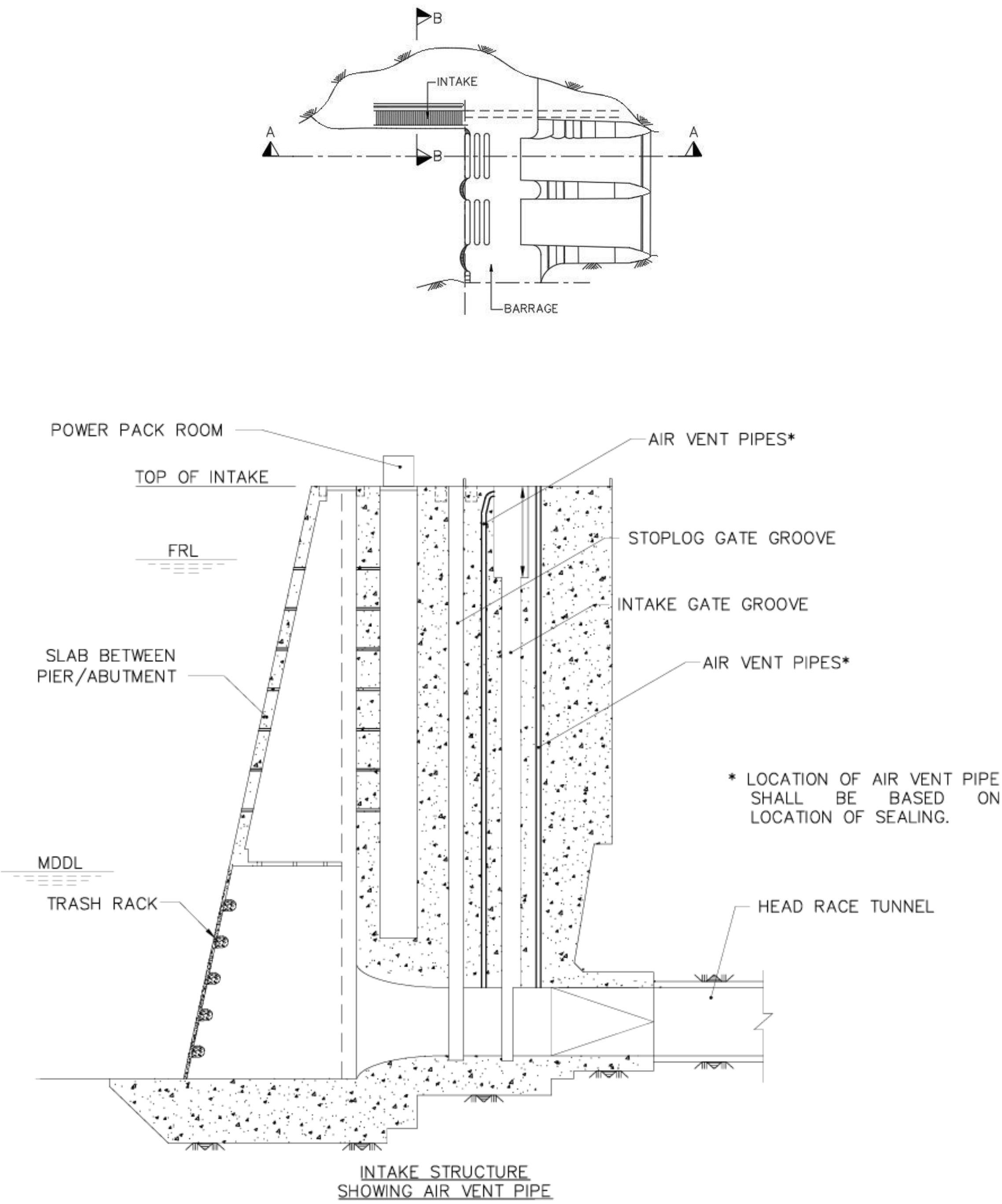
4. TYPES OF INTAKE

4.1 *Intake Adjacent to Diversion structure*

In a Run-of-the-river type development, an intake for tunnel is placed upstream of diversion structure. A typical detail of such intake for a barrage is shown in Fig. 1.



SECTION A - A



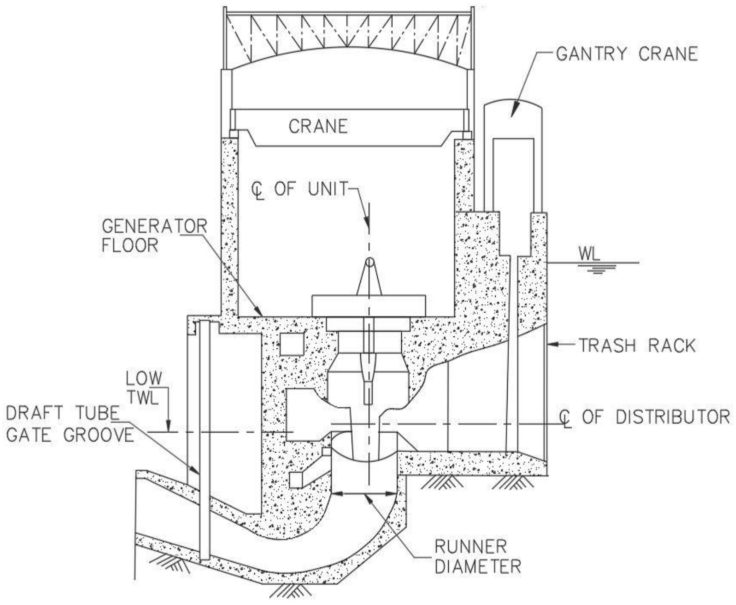
SECTION B-B

FIG. 1 INTAKE AT BARRAGE

4.2 *Canal/River Powerhouses Intakes*

A powerhouse with short intakes as a part of powerhouse structure is located across large canals or rivers to utilize head across a fall in canal or river. In such powerhouses, Kaplan turbines with concrete spiral casing or tubular turbines are used for power generation. In the former case, the intake forms a part of the passage to spiral casing and this is suitably streamlined to minimize hydraulic losses.

Typical layouts are shown in Fig. 2 and Fig. 3.



SECTION THROUGH CL OF UNIT

FIG. 2 CANAL/RIVER POWER HOUSE INTAKES (KALPAN TURBINES)

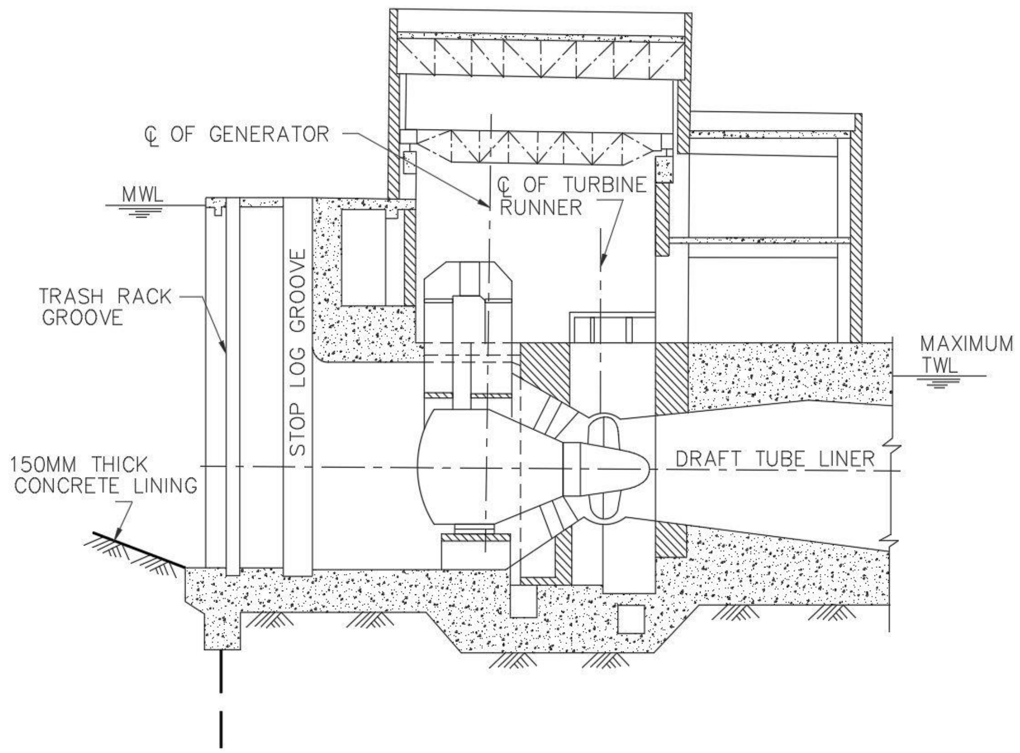
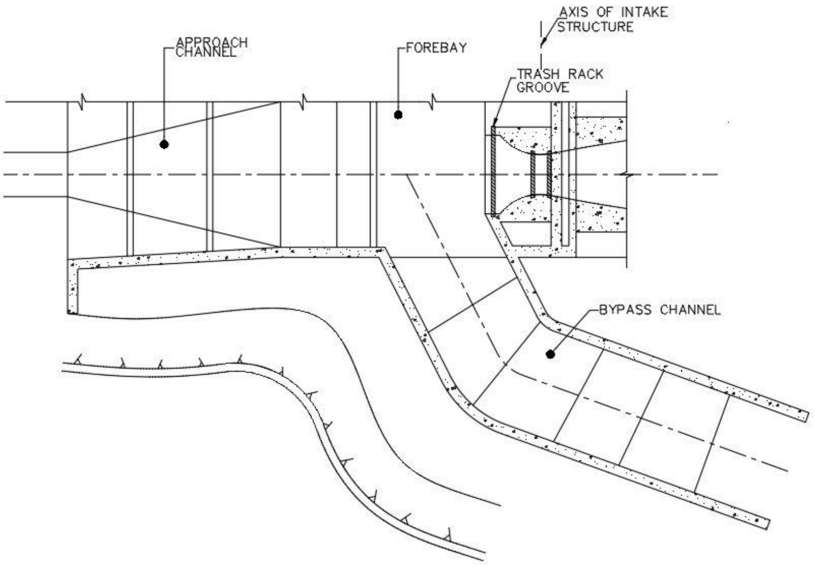


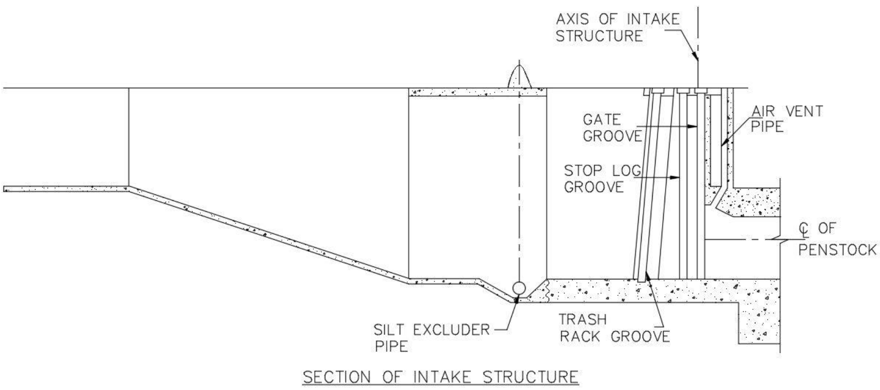
FIG. 3 CANAL/RIVER POWER HOUSE INTAKES (TUBULAR TURBINE)

4.3 *Forebay Intakes*

In an open canal development, the open canal or free flow conduits terminate in a basin known as forebay and intake for penstocks is provided in this forebay. A typical layout of forebay intake is shown in Fig. 4.



4A Plan

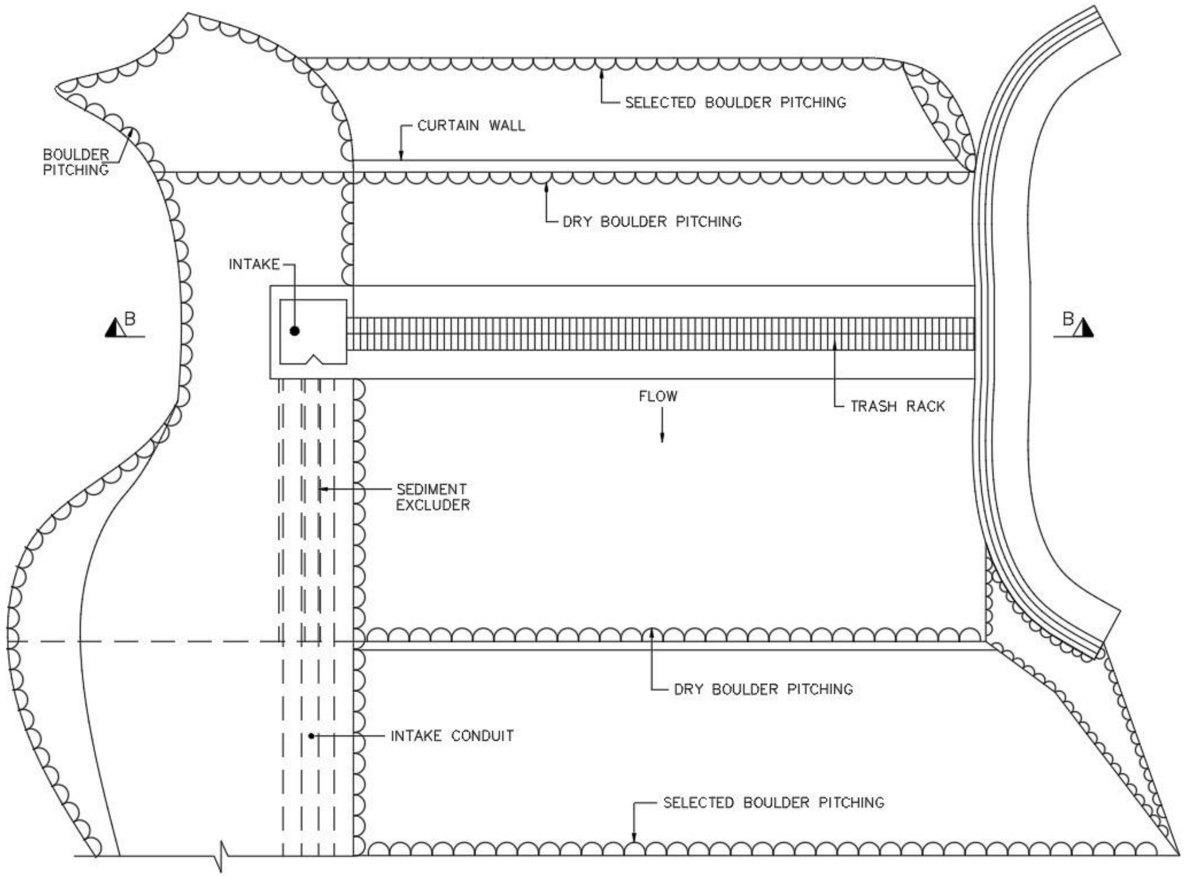


4B Section of Intake Structure

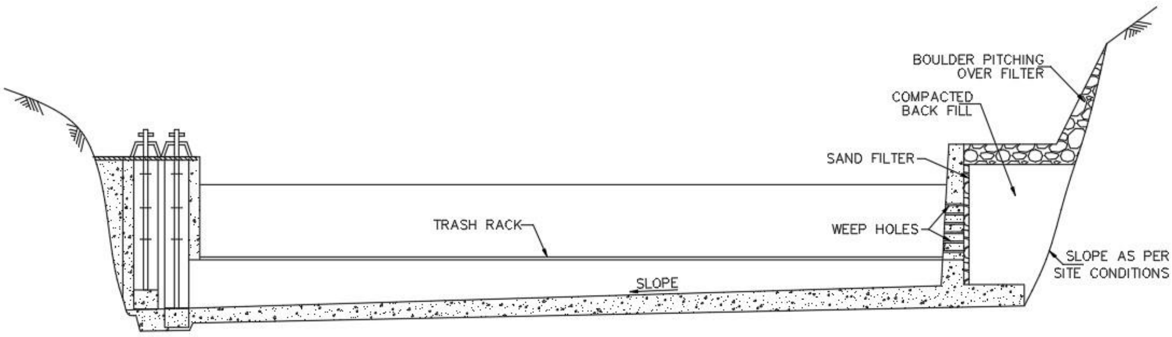
FIG. 4 LAYOUT OF FOREBAY INTAKE

4.4 *Drop Type Intake*

A diversion structure, consisting of a trough trench and trash rack structure over it, is constructed across hilly streams to entrap the entire minimum discharge of the hilly stream. It is also called a trench type weir. Typical layouts are shown in Fig. 5.



5A Plan



SECTION B-B

FIG. 5 DROP TYPE INTAKE

4.5 *Dam Body Type Intake*

These intakes are provided in the dam body.

4.5.1 *Intake in Concrete or Masonry Dams*
When power house is located at the toe of concrete or masonry dam and the water passage to turbine is embedded penstock through the body of dam, the intake structure for such penstocks is of semi circular type. A typical layout is shown in Fig. 6 and Fig. 7.

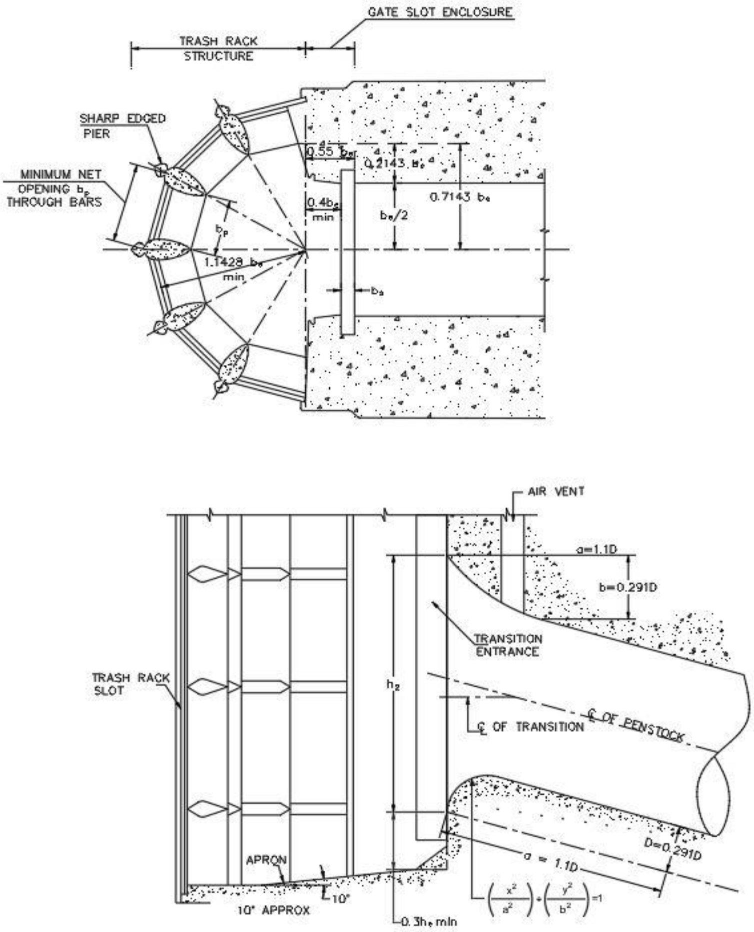
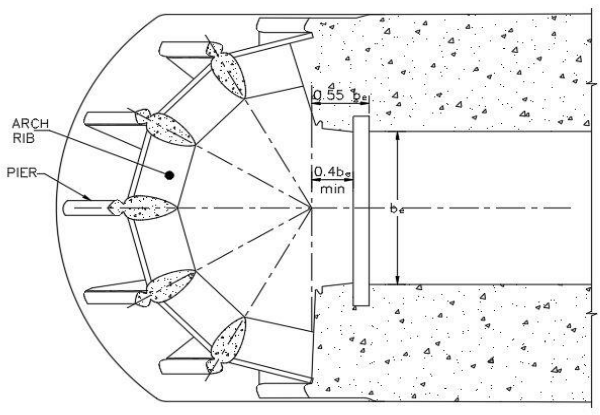


FIG. 6 SEMI CIRCULAR TYPE INTAKE STRUCTURE



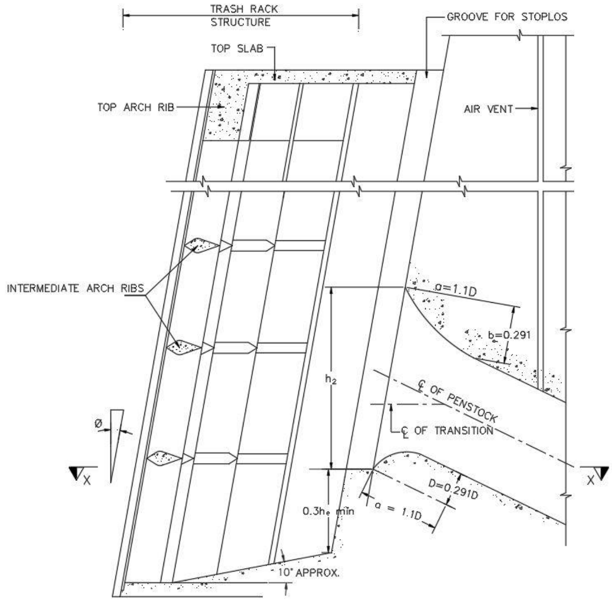


FIG. 7 SEMI CIRCULAR TYPE INTAKE

4.5.2 *Intake in Earthen Dam*

When the reservoir is formed by an earthen dam and a conduit is laid below it, the intake structure for such layout will be a sloping intake or tower type of intake. A typical layout for sloping type intake is shown in Fig. 8 and for tower type intake in Fig. 9.

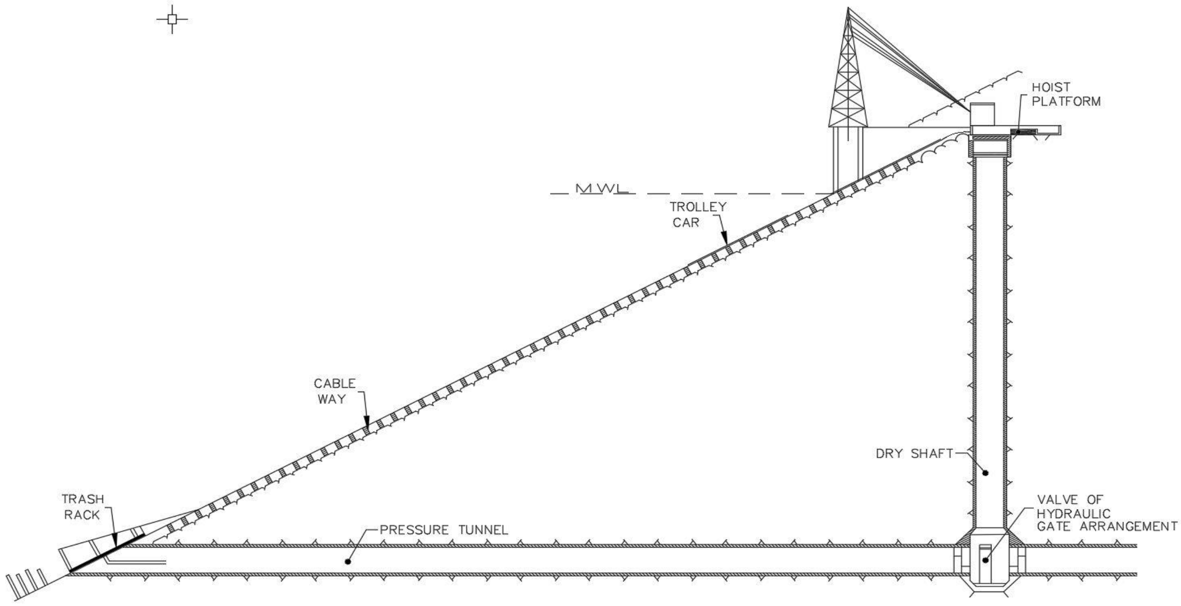


FIG. 8 SLOPING INTAKE FOR AN EARTH DAM

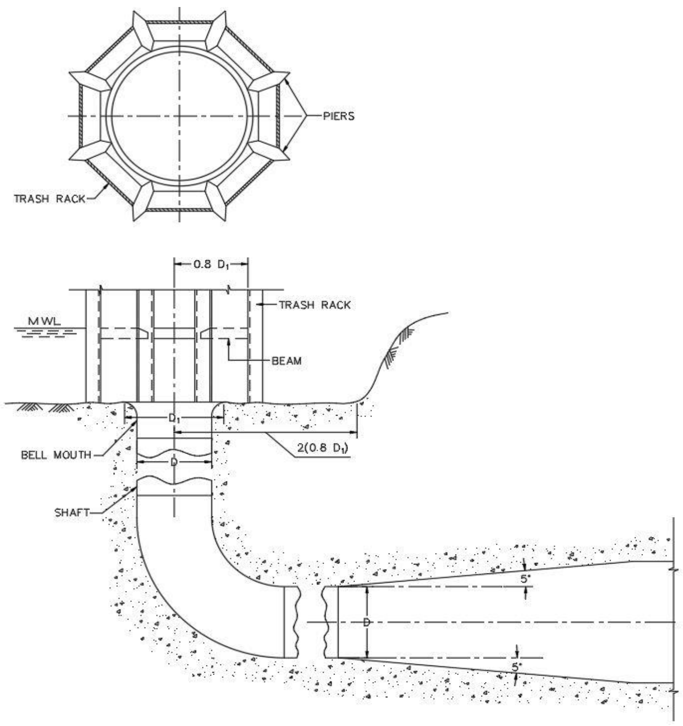


FIG. 9 TOWER TYPE INTAKE

4.6 *Intakes in Reservoir Independent of Dams*

In the case of pressure tunnel taking off from a storage reservoir where the intake is located at a distance from the dam, the intake structure of such layout will be either tower type straight or inclined. Typical layouts are shown in Fig 9 and Fig. 10.

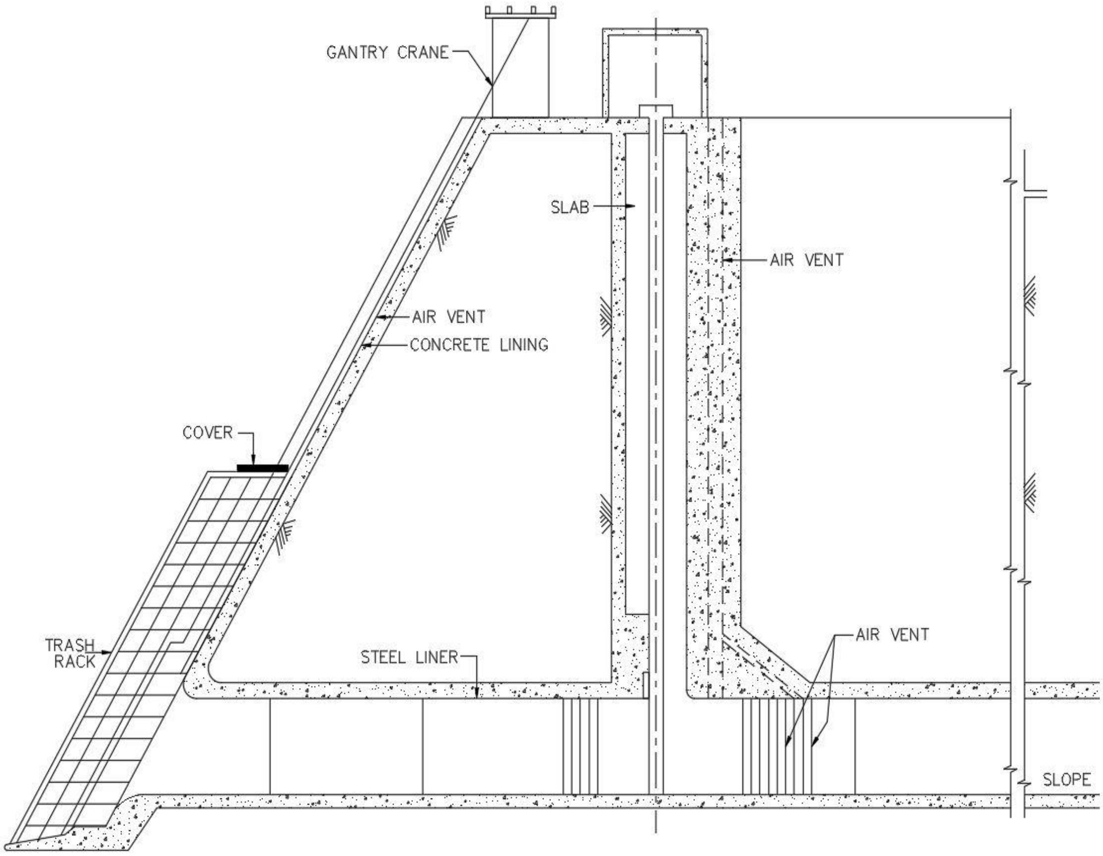


FIG. 10 INTAKE IN RESERVOIR INDEPENDENT OF DAMS

5 LAYOUT OF INTAKE STRUCTURE

5.1 The economic design of intake to serve its function will depend upon the conditions in each project. In **7.1.3** and **7.1.5** some formulae have been indicated which may be modified to suit special conditions. Hydraulic model studies may be necessary under special conditions.

5.2 The main types of layouts of the intake structure are as follows:

5.2.1 *Semicircular Type of Intake Structure*

This type of layout is adopted:

a) When a reservoir is formed by a high concrete or masonry dam and penstock conduit laid in the body of the dam;
b) When the topography and geology permit to have almost vertical face to tunnel inlet portals; and
c) When the minimum depth of water above the centre line is more than 0.8 of the entrance height (h_e).

In this layout, the rack supporting structure is placed in a semicircle plan in front of the conduit opening so that no part of rack falls within a radius of 1.1428 B from the face of the opening (where B is the width of opening of the conduit). The main features of this layout are:

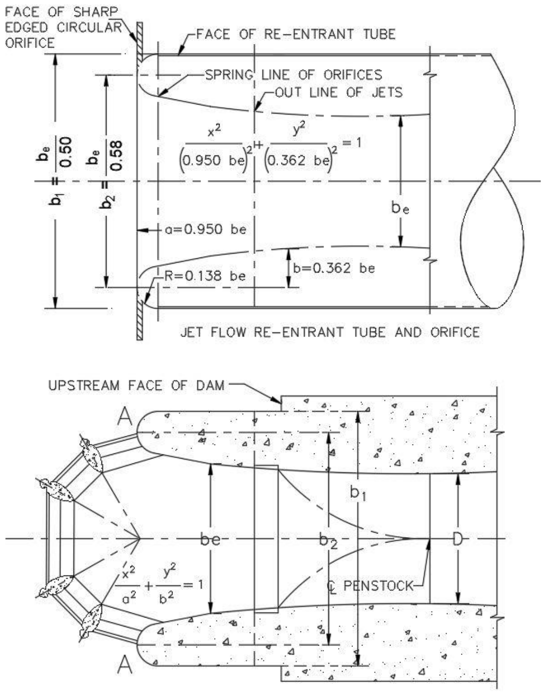
a) Bellmouth entrance and transition;
b) Semicircular trash rack structure;
c) Gate slot enclosure with air vent (typical details are shown in Fig. 6); and
d) Anti-vortex devices such as breast-wall, etc.

5.2.2 *Re-entrant Type Intake*

This type of intake is generally provided either at upstream face of dam or in open channel with flat bottom, the typical layout of which is shown in Fig. 11.

This type of layout is adopted:

a) On upstream face of dam;
b) In open channel with flat bottom; and
c) Where the width of dam is inadequate to accommodate the intake.



Sectional Plan of Intake

FIG. 11 PENSTOCK INTAKE RE-ENTERANT TYPE

5.2.3 *Straight Type of Intake Structure*

This type of layout is adopted:

a) When the reservoir is formed by earthen dam and conduit is laid below it; and
b) When the intake is subjected to low head variations like in run-of-the-river type.

In this layout, the rack supporting structure is straight with a vertical or inclined face. Where mechanical rakes with guides are provided, the trash rack should be kept inclined at an angle of at least 15˚ to the vertical. The main features of this layout are:

a) Bellmouth entrance and transition;
b) Vertical or inclined trash rack structure at the face of transition or away from the face;
c) Gate slot enclosure with air vent (typical details are shown in Fig. 12); and
d) Anti-vortex devices such as breast-wall, etc.

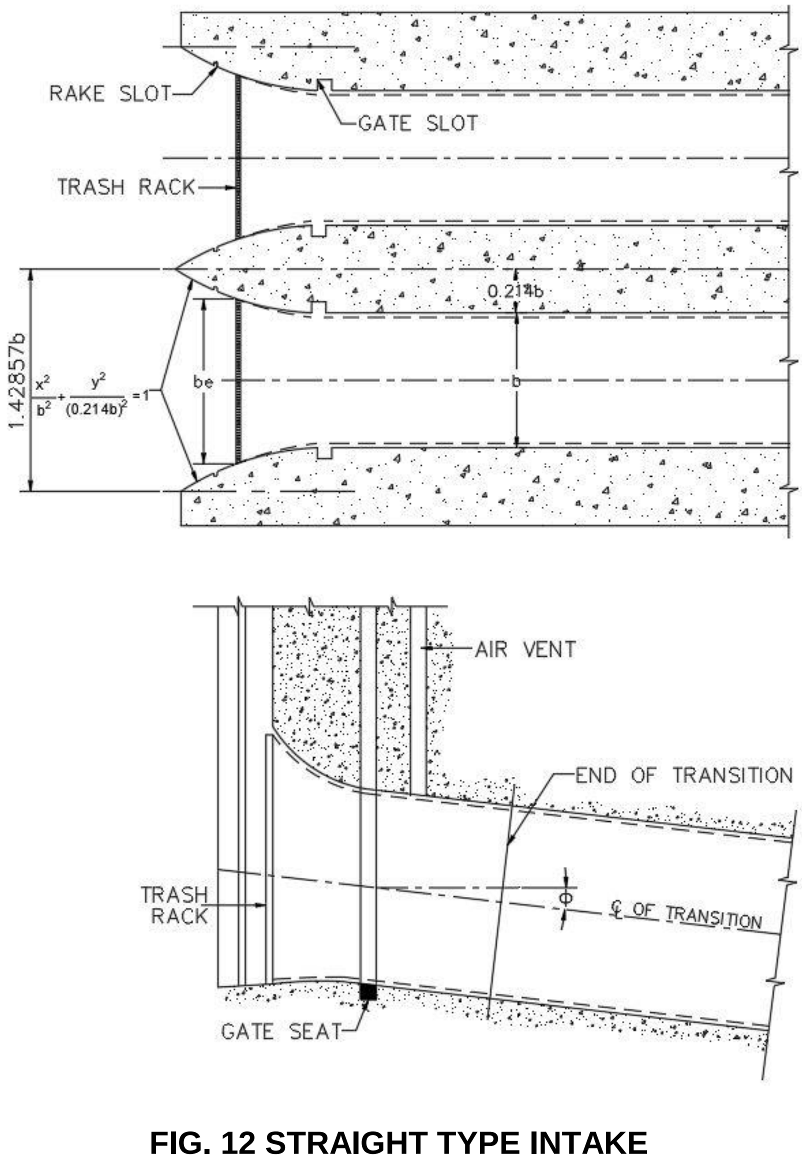


FIG. 12 STRAIGHT TYPE INTAKE

5.2.4 *Tower Type of Intake Structure*

This type of layout is adopted:

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

b) When the reservoir is formed by the earthen dam and penstock tunnel is laid below it; and
c) When the intake is subjected to large head variations, resulting in complete submergence of structure.

Tower type of intake structure is a circular vertical shaft. The main features are:

a) Circular tower type rack supporting structure;
b) Circular bellmouth to shaft;
c) Vertical shaft below tower type rack supporting structure; and
d) Bend from shaft to tunnel with optional accelerating elbow and flare, depending on model studies.

The flow into tower is generally controlled either by a single cylindrical gate or by a number of gates in the tower type intake structure as shown in Fig.10.

5.2.5 *Intake for Pumped Storage scheme*

This type of layout is adopted:

a) When the operation is through both in generation and pumping mode.

Intake for pumped storage hydropower may be designed as a long diffuser. Long diffuser is a long gradually expanding structure whose performance is dependent on approach flow and penstock alignment. To develop a diffuser design, hydraulic model study is recommended. The typical layout such intakes is shown in Fig XX.

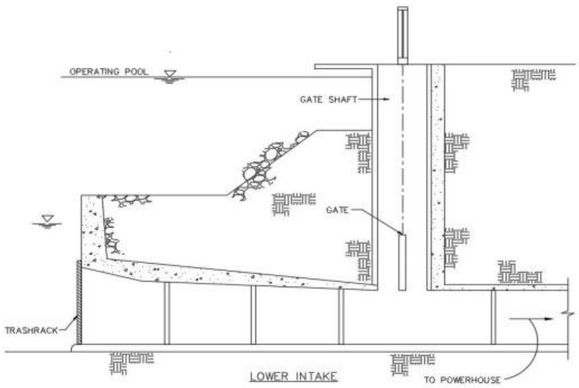


Fig XX

6 HYDRAULIC DESIGN OF COMPONENTS OF INTAKE

The following sections deal with hydraulic design of main components of an intake structure, namely:

a) Bellmouth entrance and transition from rectangular to circular opening,
b) Trash rack supporting structure,
c) Gate slot enclosures with air vents, and
d) Anti-vortex devices such as perforated breast-wall, etc.

6.1 Bellmouth Opening and Transition

6.1.1 *Shape and Size of Opening*

The penstock and conduit entrance should be designed to produce acceleration similar to that found in a jet issuing from a sharp edged orifice. The surface should be formed to natural contraction curve and the penstock or conduit is assumed to be the size of orifice jet at its maximum contraction.

6.1.2 The normal contraction of 40 percent (C_c = 0.6) should be used in high and medium head installations, 30 percent (C_c = 0.7) for low head installations and 50 percent (C_e = 0.5) for re-entrant type intake.

6.1.3 *Opening Area*

$$Opening\ Area = \frac{Penstock\ Area}{C_c\ \cos\emptyset}$$

Where,
$\emptyset$ = angle of inclination of penstock centre line to horizontal; and
C_c = co-efficient of contraction, as defined in **6.1.2**.

6.1.4 *Height and Width of Opening*

The height is calculated from the distance above and below the intersect of the penstock centre line with the face of the entrance (see Fig. 13 for lower and upper nappe and Fig. 14 for details of side-flaring entry in plan).

$$h_1 = D\ \left[(1.21\ tan^2\emptyset + 0.0847)^{\frac{1}{2}} + \frac{1}{2\cos\emptyset} - 1.1\tan\emptyset\right]$$

$$h_2 = D\ \left[\left(\frac{0.791}{\cos\emptyset} + 0.077\tan\emptyset\right)\right]$$

$$h_e = h_1 + h_2$$

$$Width\ of\ opening, b_e = \frac{Area\ of\ opening}{h_e}$$

6.1.5 *Shape of Opening*

The inlet should be streamlined to minimize the losses. The profile of the roof and floor should approximate to that of a jet from the horizontal slot. The profile is generally an ellipse given by the following equation:

$$\frac{X^2}{(1.1D)^2} + \frac{Y^2}{(0.291\ D)^2} = 1$$

NOTE — Hydraulic Model Studies may be conducted for important structures.

6.1.6 The profile of sides should be such that it should generally be followed by equation:

$$\frac{X^2}{(0.55b_e\ )^2} + \frac{Y^2}{(0.2143\ b_e\ )^2} = 1$$

While providing side flarings, it may be ensured that the size of opening at entry does not create any structural problem with the size of dam block or structure. In case the dam block or structure in which the intake is to be accommodated has restrictions, the dimensions of side flaring should be restricted to that extent.

NOTE — Hydraulic Model Studies may be conducted for important structures.

6.1.7 *Transitions*

In order to obtain hydraulically efficient design of intake transitions from rectangular section to a circular section conduit, the transition should be designed in accordance with the following requirements:

a) Transition or turns should be made about the centre line of mass flow and should be gradual,
b) Side walls should not expand at a rate greater than 5˚ from the centre line of mass flow,
c) All slots or other necessary departures from the neat outline should normally be outside the transition zone.

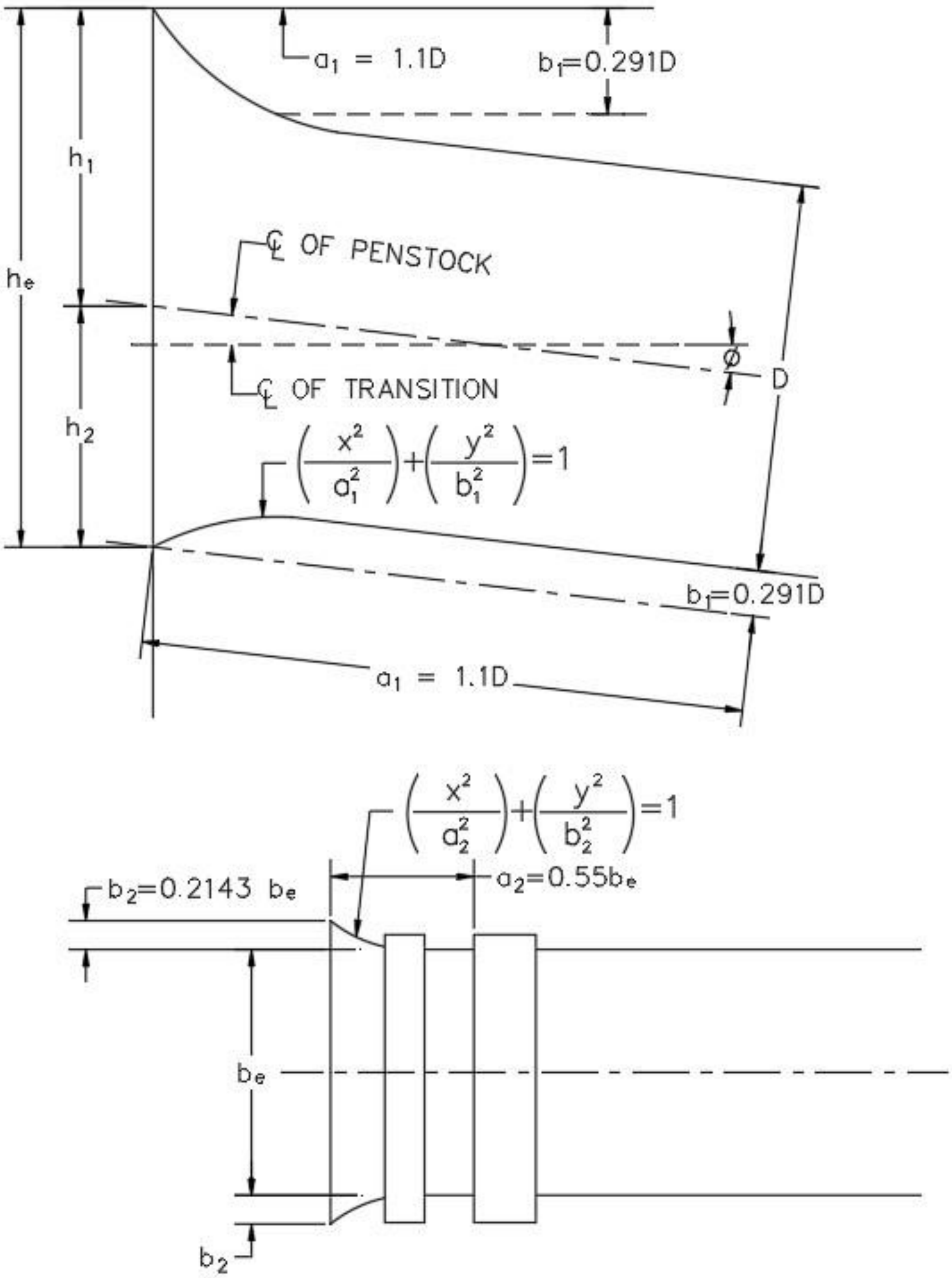


FIG. 13 BELLMOUTH DETAILS FOR LOWER AND UPPER NAPPE

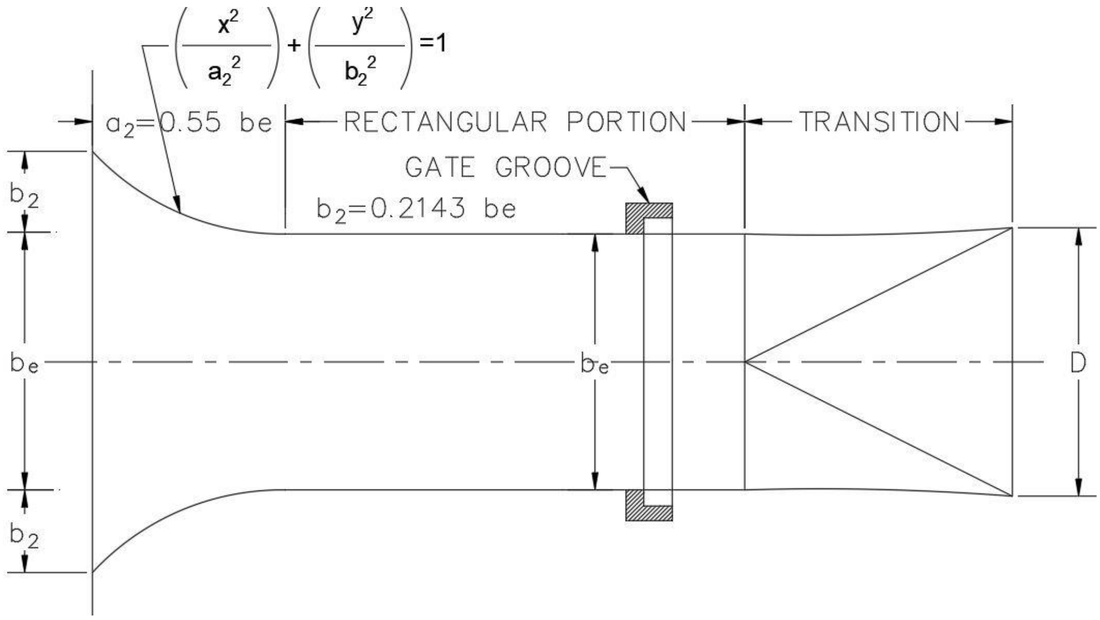


FIG. 14 DETAIL OF (SIDE FLARING) ENTRY IN PLAN

6.2 Centre Line of Intake

6.2.1 Formation of vortices at the intake depends on a number of factors such as approach geometry, flow conditions, velocity at the intake, geometrical features of trash rack structure relative submergence depth and withdrawal Froude number, etc.

The geometry of the approach to the power intake should be such that it can ensure economy, and better hydraulic uniform flow condition. The flow lines should be parallel, having no return flow zone and having no stagnation. Velocity distribution in front of penstock should be uniform.

6.2.2 To prevent vortices, the centre line of intake should be so located as to ensure submergence requirements given in Fig. 18 which has been developed by an evaluation of minimum design submergence at prototypes operating satisfactorily.

For large size intakes at power plants:

$$F_r = \frac{v}{\sqrt{gD}} \leq \frac{1}{3}$$

Especially at pumped storage submergence depth,

h = 1 to 1.5 times the intake height or diameter is recommended.

For medium and small size installations (F_r ≥ I/3), especially at pump sumps, submergence requirements may be calculated using the formula:

$$\frac{h}{D} = 0.5 + 2F_{\mathrm{r}}$$

The recommendations are valid for intakes with proper approach flow conditions. With well controlled approach flow conditions, with a suitable dimensioning and location of the intake relative to its surroundings and with use of anti-vortex devices submergence requirements may be reduced below the limits recommended above.

However, recourse to hydraulic model studies may be taken to determine more accurate value depending on the specific parameters of the particular structure.

6.2.3 The requirement of water cover may be reduced with the provision of anti-vortex devices such as:

a) Parallel vertical fins of R.C.C. on the upstream face of the power dam. Typical layout is shown in Fig. 15.
b) Dinorwic louvered type. Typical layout is shown in Fig. 16.
c) Perforated breast-wall. Typical layout is shown in Fig. 17.

NOTE — Physical model studies are recommended for all important projects as essential part of design. The results of CFD analysis if carried for initial design or for optimization shall also be validated through physical model studies for all important structures.

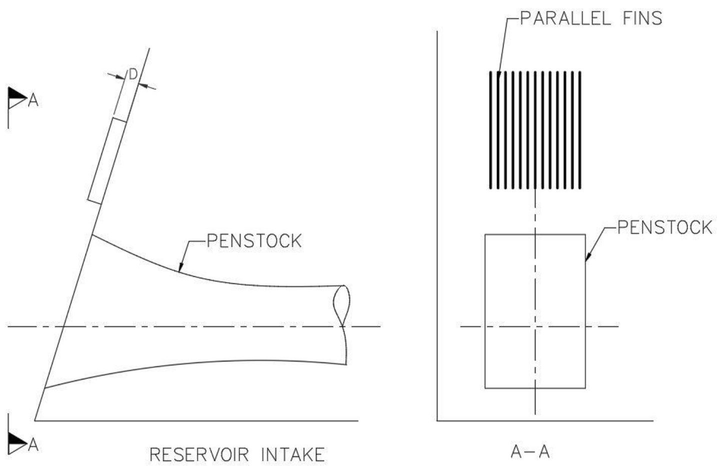


FIG. 15 ANTI VORTEX DEVICE (PARALLEL FINS) AT THE RESERVOIR INTAKE

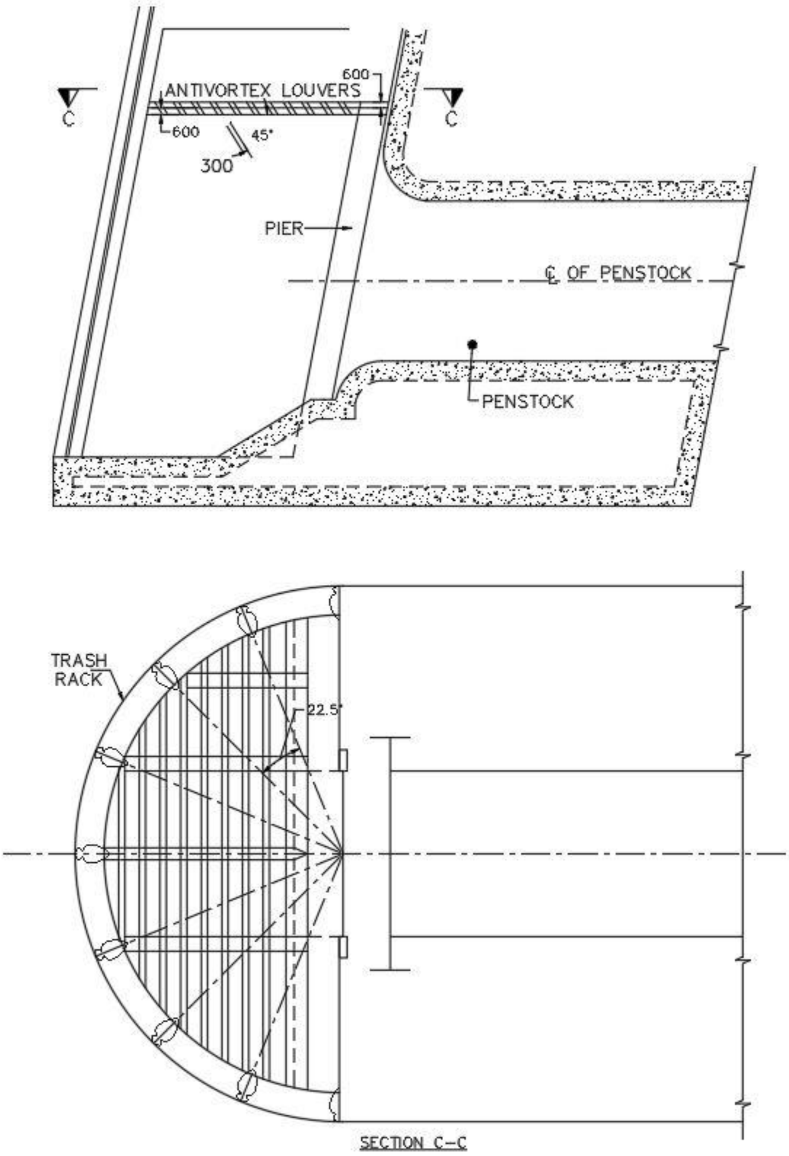


FIG. 16 DINORWIC TYPE ANTI VORTEX DEVICE AT POWER INTAKE

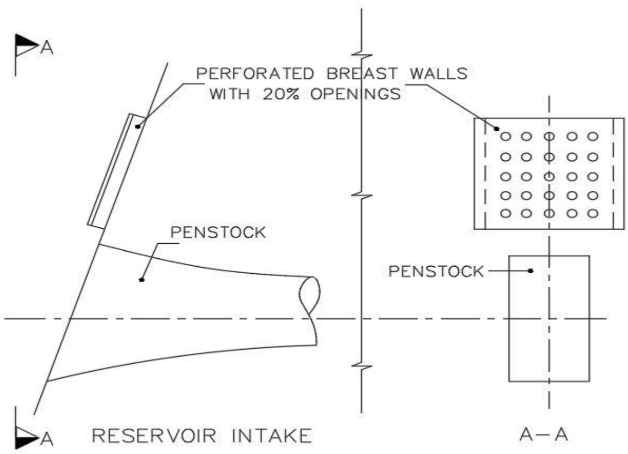


FIG. 17 ANTI VORTEX DEVICE (PERFORATED BREAST - WALL)
AT THE RESERVOIR INTAKE

6.3 Dimensioning of Anti-vortex Devices

6.3.1 Anti-vortex devices such as perforated breast walls, parallel vertical fins, rafts, screens, gratings and cages exert wall shear stresses, produce additional turbulence, suppress non-uniformities of approach flow, modify the velocity profile and cause head losses in the vortex forming region and reduces the secondary flow effects and rotational energy of vortices.

6.3.2 The head loss due to the anti-vortex devices should be minimum possible. The maintenance problem due to the anti-vortex device should be of minimum cost. The developments of anti-vortex devices should result in cost effective construction of intake.

6.3.3 Anti-vortex devices placed in a vertical or in an inclined plane (such as perforated breast walls or vertical parallel fins) are more efficient than the anti-vortex devices placed in a horizontal plane (such as Dinorwic louvered). With variation of reservoir water levels, performances of Dinorwic louvered grid are not as efficient as breast wall type anti vortex device or parallel fins type anti vortex devices.

6.3.4 Based on hydraulic model studies, three broad types of anti-vortex devices for the horizontal intake structures have been developed. The dimensionless configurations of anti-vortex devices are unique to intakes of a project, but configurations of anti-vortex devices thus developed should be applicable to the other intakes because layouts of intakes provided are generally conforming to Indian Standards and velocity through the trash racks for power intakes operate in a very narrow range of 0.75 m/s to 1.5 m/s.

6.3.5 Range of dimensionless configuration of geometry for parallel fins type of anti-vortex which suppressed vortices is shown in the Figure 15. The range of dimensionless configuration of geometry for anti-vortex device in the form of perforated breast wall with cylindrical perforations is shown in the Figure 17 (a) and configuration of anti – vortex devices in the form of perforated breast wall with rectangular perforations is shown in the Figure 17 (b).

6.3.6 For the design of perforated breast-wall, anti-vortex louvers and vertical fins, a minimum of 1 m differential head may be adopted.

NOTE — Use of anti-vortex devices should be limited to special cases, where other measures are not possible or will not provide sufficient protection against vortex formation.

6.4 Trash Rack Structure

6.4.1 A trash rack structure should be provided in front of a penstock or conduit to prevent the entrance of any trash that would not pass easily through the smallest opening in the turbine runner.

6.4.2 The shape of trash rack structure may be adopted to meet the requirements of the head works layout and head loss. For instance, for high dams with nearly vertical upstream face, semi-circular trash rack structure is usually preferred to provide the required trash rack area economically. For low dams or diversion structures, a straight trash rack is usually preferred. However, model studies required for suitability of shape and size of piers and beams of trash racks should also aim at to prevent dead zones of water and uneven or irregular flow patterns in the tunnel, formation of dimples, dye core and air core vortices, water circulation and other flow irregularities during operation in pumping, turbine or combine modes under symmetrical and asymmetrical operation of unit.

6.4.3 No part of the trash rack structure should fall within 80 percent of the intake height (h_e), from the centre point of intake.

6.4.4 For an upright semicircular intake structure (*see* Fig. 6), the racks should be located on a semicircle in plan with a minimum radius of l.1428 b_e ; where b_e is the width of opening.

For an inclined semicircular intake structure (*see* Fig.7), the racks should be located on a semicircle or a plane perpendicular to the axis of the structure and satisfying the other criteria as for the upright structure. In plane the racks would be laid out on an ellipse, the semi-major axis of which should have a minimum value of

$$\frac{1.1428\, b_{\mathrm{e}}}{\cos\theta}$$

Where θ is the inclination of the trash rack axis to the vertical. The semi minor axis of the structure is parallel to the dam face and would have a value of $1.1428 b_e$. The trash rack screens should be inclined in a three dimensional plane with a bottom corner of the tower screens resting over the base footing.

Suitable fillet should be provided below the lowest screens to plug the gap and effectively support the weight of the trash rack over the entire base.

For shaft intakes (*see* Fig. 10), the racks should be located at 0.8 D_1 from the center of the bellmouth, where D_1 is the inlet diameter of the bellmouth.

6.4.5 The piers and beams of the trash rack supporting structure should be sharp nosed and should be streamlined about the required structural section.

6.4.6 The normal velocity of flow through the rack structure is indicated below:

For units with hand raking,

$$V = 0.75 \text{ m/s}$$

For units with mechanical raking,

$$V = 1.5 \text{ m/s}$$

6.4.7 Trash bars should be so spaced that the net opening between them should be at least 5 mm less than the minimum opening between turbine runner blades.

6.4.8 The trash rack should also be designed to withstand the effect of submerged jets in the case of pumped storage scheme. The spacing of the bars should be adjusted so that the ratio of forcing frequency to natural frequency of bar is less than 0.6.

6.4.9 For the design of trash rack piers, ribs and trash rack screens, a minimum differential head of 3 to 6 m may be adopted depending upon the efficiency of the cleaning of trash racks being adopted.

6.4.10 For the detailed design of trash rack structure the IS 11388 may be referred.

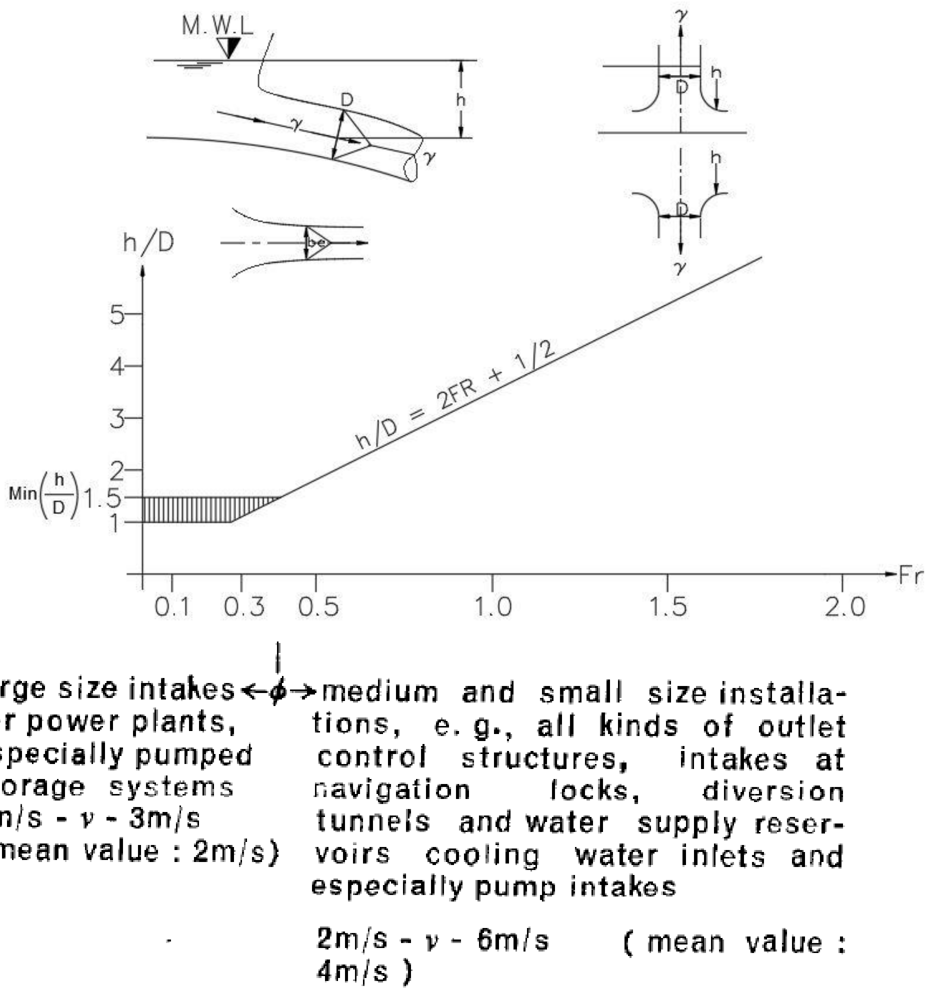


FIG. 18 RECOMMENDED SUBMERGENCE FOR INTAKES WITH PROPER APPROACH FLOW CONDITION BUT WITHOUT USE OF SPECIAL DEVICES FOR VORTEX SUPRESSION

6.5 Intake Gate and Air Vent

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

6.5.2 The upstream edge of the gate slot should be at least 0.40 b_e from the nose, where b_e is the width of opening.

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

6.5.4 An air vent downstream of intake gate should be provided. The air vent should be so designed as to admit air at the rate the turbine is discharging water under full gate conditions.

The area of air vent may be fixed by the following formula:

$$F = \frac{Q\sqrt{S}\,(D/t)^{3/2}}{750\,000_c}$$

Where,
F = Area of air vent pipe in m^2,
Q = Maximum discharge through penstock. Discharge of air through pen-stock is taken as 21 to 22 percent of penstock discharge,
S = factor of safety against collapse of pipe (normally assumed between 3 and 4),
D = diameter of penstock in m,
t = thickness of penstock in m, and
c = co-efficient of discharge through inlet (0.5 for ordinary type of intake valves and 0.7 for short air inlet pipes).

6.6 Approach Apron

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

6.7 Hydraulic Model studies

The economic design of intake to serve its function, will depend upon the condition in each project. Some formulae which have been indicated in the above section may be modified to suit special conditions. Hydraulic model studies may be necessary under special conditions

7 MISCELLANEOUS ARRANGEMENT

7.1 Whenever the intakes are provided at high altitude above snow line, necessary provision for arresting the formation of ice cover on rack bars and gate should be made for the free flow of water. These de-icing arrangements are as under:

a) Bubbler system, and
b) Heating arrangement.

7.2 Floating ice should be arrested by providing ice booms of concrete baffles at intakes.

7.3 Raking Arrangement

Arrangement should be made for removing debris from trash racks at regular intervals or with continuous raking arrangements in the case of intake where floating material is expected to be attracted continuously to the racks due to the abundance of floating material in the flow and the level of water being often near about trash rack levels.

In the case of projects where the requirements of silt exclusion are more stringent, separate arrangements should be made for silt exclusion.