"RE-AFFIRMED 1996"
IS 6966 (Part 1) : 1989
(Reaffirmed 2001)

Indian Standard

HYDRAULIC DESIGN OF BARRAGES AND WEIRS — GUIDELINES

PART 1 ALLUVIAL REACHES

(First Revision)

UDC 627·82 + 627·43 : 624·04 (026)

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December 1989 **Price Group 5**

Barrages and Weirs Sectional Committee, BDC 65

FOREWORD

This Indian Standard (Part 1) (First Revision) was adopted by the Bureau of Indian Standards on 24 January 1989, after the draft finalized by the Barrages and Weirs Sectional Committee had been approved by the Civil Engineering Division Council.

Agriculture plays an important role in the economy of our country. For proper development of agriculture, we need to ensure irrigation facilities by tapping the river water and taking it to fields through canals. Diversion of water from rivers is achieved by construction of barrages and weirs across them. With increased emphasis on agriculture in our planning, these diversion structures are also becoming important in terms of their use and money spent on them. A need has thus been felt to lay down the guidelines for hydraulic design of barrages and weirs. For detailed design, CBIP Publication (No. 12, 179, Volumes I and II) may be referred.

Foundations on which barrages and weirs have to be constructed may be permeable or impermeable. The criteria for hydraulic design will be different for different reaches. This standard has been formulated for alluvial reaches which is a permeable foundation. For other types of reaches, namely, clayee reaches, bouldery reaches and rocky reaches, separate parts of this standard are under preparation.

This standard was first published in 1973. The committee in view of the suggestions received from users during the course of these years decided to revise this standard into parts based on the type of reaches on which barrages and weirs are constructed. The contents of the standards have been updated and provisions applicable to alluvial reaches have only been specified. This revision also incorporates a curve for determining the coefficient of discharge. Provisions for model studies have also been incorporated.

Attention is drawn to IS : 10751-1983 'Criteria for design of guide banks for alluvial rivers' which is very relevant while referring to this standard.

Salient design parameters of some important barrages in India are given in Annex A for guidance.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated 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 BARRAGES AND WEIRS — GUIDELINES

PART 1 ALLUVIAL REACHES

(First Revision)

1 SCOPE

This standard lays down guidelines for hydraulic design of barrages and weirs in alluvial foundations.

2 REFERENCES

The Indian Standards listed in Annex B are necessary adjuncts to this standard.

3 TERMINOLOGY

For the purpose of this standard, the following definitions and those given in IS 1191 : 1971, IS 4410 (Part 3) : 1967 and IS 4410 (Part 5) : 1982 shall apply.

3.1 Afflux

The difference in water level at any point upstream of barrage before and after the construction of a barrage/weir, maximum afflux occurs just upstream of the barrage/weir.

3.2 Barrage

A barrier with low crest provided with a series of gates across the river to regulate water surface level and pattern of flow upstream and other purposes, distinguished from a weir in that it is gated over its entire length and may or may not have a raised sill.

3.3 Concentration Factor

It is the slope (or gradient) of the hydraulic grade line for subsoil seepage flow, at the exit end of the structure where the seepage water comes out from subsoil.

3.4 Exit Gradient

It is the slope (or gradient) of hydraulic grade line for subsoil seepage flow, at the exit end of the structure where the seepage water comes out from subsoil.

3.4.1 *Critical Exit Gradient (GEC)*

It is the exit gradient at the critical stage when the upward seepage force acting on soil at the exit end of the structure is exactly balanced by the submerged weight of the soil. It may be expressed mathematically as

GEC = $(S - 1) (1 - n)$ where S is the specific gravity of the soil and n is its porosity.

3.4.2 *Safe Exit Gradient (GES)*

Critical exit gradient divided by factor of safety (*see* **17.3**) gives the safe exit gradient. For example, for ordinary alluvial type soil, $S = 2{\cdot}6$ and $n = 0{\cdot}4$,

then GEC $= (2{\cdot}6 - 1) (1 - 0{\cdot}4) \approx 1{\cdot}0$ with a factor of safety of 4,

GES $= 1/4 = 0{\cdot}25$.

3.4.3 *Piping/Sand Boil*

When the actual exit gradient (GE) exceeds the critical gradient (GEC), boiling of sand starts from the exit end. Uncontrolled seepage and sand boiling leads to formation of hollow 'pipe' like structure leading to undermining of the structure.

3.5 Looseness Factor

The ratio of overall length of the weir/barrage proposed or provided to the theoretically computed minimum stable width of river at the design flood obtained by using Lacey's equation.

3.6 Pond Level

The level of water, immediately upstream of the barrage/weir, required to facilitate withdrawal into the canal or for any other purpose.

3.7 Weir

Barrier across a water course to raise the water level in the course with or without low shutters.

3.8 Silt Factor

Silt factor may be calculated by knowing the average particle size m_r in mm of the soil from relationship ($f = 1{\cdot}76\sqrt{m_r}$) [f may be checked from Lacey's relationship $f = 290 (R^{\frac{1}{2}} S^{\frac{1}{3}})^{\frac{2}{3}}$]

4 DATA REQUIRED

The following data is essential for hydraulic design of a barrage or weir:

a) An index map showing catchment of the entire river valley upstream of the proposed site of work with position of important irrigation works and power projects, road and railway network and gauge and discharge observation sites on the river, if any.

b) A contour plan of the area around the proposed site of the weir or barrage with contour intervals of not more than 0 5 m, up to an elevation of at least 2·5 m above the high flood level. The contour plan shall extend up to 5 km on the upstream and downstream on the proposed site and up to an adequate distance on both flanks up to which the effect of back-water is likely to extend under all exigencies.

c) Cross-sections of the river at the proposed site and at intervals of 200 m both on upstream and downstream up to at least 1 km from the proposed site. Besides these, cross-sections of the river at 2 km intervals shall be taken up to the distance, the backwater effect of ponding is likely to extend on the upstream of the site. At the detailed design stage, if the topography indicates appreciable fall in the river slope, cross-sections may be taken at closer intervals depending on site conditions.

d) Longitudinal section of the river with observed water levels along the deep current for a distance from 5 km downstream of the site up to 15 km or the distance up to which the backwater effect is likely to extend upstream of the site, whichever is more.

e) Log charts of initial bore holes normally drilled 100 m apart along the axis of the weir or barrage and along divide walls and under abutments to a depth of 20 m or in accordance with design requirements below the deepest river bed level. For barrages on rivers with more than 3 000 cumecs discharge, the spacing and depth of bore holes may be decided based on the requirements of individual cases and site requirements. Such log charts of holes along the upstream and downstream cutoff lines may be taken to decide the bottom level of cutoff and drainage arrangements in case impermeable strata are met with. Permeability tests may be conducted in these bore holes for assessing seepage flow below the structure.

f) Soil samples shall be obtained at suitable intervals of depth and the property of soils determined by sieve analysis and other laboratory tests.

g) Standard penetration values at intervals of about 30 m and up to a depth of at least 10 m below the proposed foundation level under the piers and abutments should also be collected at the initial stage itself.

h) Daily rainfall data of all rainfall gauging stations in and around the catchment, for as many years as possible, shall be collected. Where no discharge data is available rainfall data may be collected for calculation of discharge in river.

j) Information regarding maximum flood discharge and high flood level from flood marks and local enquiry at the site of the work.

k) Daily river stage and discharge data at the river at or near the site of the proposed work, with stages and observed discharges during floods, for as many years as possible shall be collected. A gauging station at or near the proposed site of work should be established as soon as the proposal for the work is first initiated and the stage discharge data should be collected (*see* IS 2914 : 1964) for computing design floods. Two gauges should be established upstream of the axis of the proposed work, one at the axis and two downstream of the axis. More gauges may be installed when necessary. All the gauges should be connected to the common GTS bench mark.

m) If discharge data is available at a distant downstream or upstream established gauging site over a number of years, the flows at the proposed site may be estimated by developing a statistical test fit for correlation between a few years' data at site and the data available at the distant site or by correlating the flows.

n) Observations in regard to suspended silt shall be made at periodic intervals. The frequency should be increased during monsoon months to prepare sediment rating curve for finding the average annual sediment load incoming into the pond.

p) Navigability of the river before and after the construction of barrage/weir. Expected numbers of vessels to be crossed per hour through locks.

q) Fishiculture and existing fisheries. Types of irrigating fish for which fishways to be provided.

r) Other materials, such as logs, bamboos, etc, which are transported by the river for which longways to be provided.

s) Electrical load including seasonal load due to crushing of fruits, jute washing, etc, for determining required capacity of hydel units to be provided in the head regulators (for firm power) and the barrage (for seasonal/secondary power).

t) Aerial map of the flood plain indicating dominant river course for the past years for deciding the location of barrage, guide bundhs, approach embankments and off-take points, etc.

u) Existing structure upstream may be studied for their effects.

5 DESIGN FLOOD DISCHARGE

For purposes of design of items other than free board, a design flood of 50 year frequency may normally suffice. In such cases where risks and hazards are involved, a review of this criteria based on site conditions may be necessary. For designing the free board, a minimum of 500 year frequency flood or the standard project flood [*see* IS 5477 (Part 4) : 1971] may be desirable.

6 RATING CURVE

6.1 In the absence of detailed data, preliminary rating curve may be prepared by computing the discharges at different water levels using the following formula:

$$Q = \frac{1}{n} \cdot A\, R^{\frac{2}{3}}\, S_f^{\frac{1}{2}}$$

where

Q = rate of flow,

n = rugosity co-efficient (*see* IS 2912 : 1964)

A = area of cross-section of flow,

R = hydraulic mean radius in m, and

S_f = friction slope.

6.2 The rating curve obtained from **6.1** is for the existing unretrograded condition of the river. This rating curve will have to be modified to account for possible retrogression in the river after the construction of a weir or a barrage. This may be done by suitable reduction of the stages at high and low discharges as in **9.3** and **9.4** with proportionate reduction of stages at intermediate discharges and by redrawing the curve through these points.

7 POND LEVEL

Pond level, in the under-sluice pocket, upstream of the canal head regulator shall generally be obtained by adding the working head to the designed full supply level in the canal. The working head shall include the head required for passing the design discharge into the canal and the head losses in the regulator. If under certain situations, there is a limitation of pond level, the full supply level shall be fixed by subtracting the working head from the pond level. While determining pond level, losses through trash-rack (if provided), shall also be taken into account in addition to losses through head regulator.

8 AFFLUX

8.1 The width of the barrage/weir is governed by the value of afflux (at the design flood) to be permitted and the proposed crest levels. It is also important for the design of downstream cistern, flood protection and river training works, upstream and downstream loose protections and upstream and downstream cutoffs. The maximum permissible value of afflux has to be carefully evaluated depending upon the river conditions upstream and after considering the extent of backwater effect, the area being submerged and its importance.

8.2 In the case of barrages or weirs, an afflux of 1 m is found satisfactory in the upper and middle reaches of the river. In lower reaches with flat gradients, the afflux may have to be limited to about 0·3 m.

9 RETROGRESSION

9.1 Progressive retrogression or degradation of the downstream river and levels as a result of construction of a weir or barrage causes lowering of the downstream river stages which has to be suitably provided for in the design of downstream cisterns. The lowering of river water level due to retrogression on the downstream causes increased exit gradients.

9.2 Retrogression of water levels is more pronounced in alluvial rivers carrying more silt having finer bed material and having steep slope. A value of 1·25 to 2·25 m may be adopted as retrogression for alluvial rivers at lower river stages depending upon the amount of silt in the river, type of bed material and slope. Whenever a proposed barrage/weir is situated downstream of a dam, the possibility of heavier retrogression than normal shall be considered for the design of downstream floor level and downstream protection works.

9.3 As a result of retrogression, low stages of the river are generally affected more compared to the maximum flood levels. Reduction of river gauge at low stage which governs the design, should be carefully evaluated.

9.4 At the design flood, the reduction of gauges due to retrogression may be considered to vary from 0·3 to 0·5 m depending upon whether the river is shallow or confined during floods. For intermediate discharges, the effect of retrogression may be obtained by plotting the retrogressed high flood levels on log - log graph.

10 WATERWAY

10.1 In deep and confined rivers with stable banks, the overall waterway (between abutments including thickness of piers) should be approximately equal to the actual width of the river at the design flood.

10.2 For meandering alluvial rivers for minimizing shoal formations, the following looseness factor shall be applied to Lacey's waterway for determining the primary value of the waterway.

Silt Factor	*Looseness Factor*
Less than 1	1·2 to 1
1 to 1·5	1 to 0·6

Lacey's waterway is given by the following formula:

$$P = 4{\cdot}83\ Q^{\frac{1}{2}}$$

where

Q = design flood discharge in cumecs for 50 year frequency flood.

10.2.1 For deciding the final waterway, the following additional considerations may also be taken into account:

a) Cost of protection works and cutoffs,
b) Repairable damages for floods of higher magnitudes, and
c) Afflux constraints as determined by model studies.

11 DISCHARGE

11.1 The discharge shall be obtained from the following formula:

$$Q = CLH^{\frac{3}{2}}$$

where

Q = discharge in cumecs,
C = coefficient of discharge (in free flow condition),
L = clear waterway of the barrage or weir in m, and
H = total head causing the flow in m.

11.1.1 In the formula given in **11.1**, the exact value of C depends on many factors including the head over the sill, shape and width of the sill, its height over the upstream floor, and roughness of its surface. It is, therefore, recommended that the value of C be determined by model studies where values based on prototype observations on similar structures are not available. In the past, some studies were made for the value of C by the Punjab Irrigation Research Institute (Malikpur). Based on these studies, a curve indicating coefficient of discharge (C) *vs* drowning ratio has been developed and shown in Fig. 1. This curve may be used for determining the value of C subject to modifications by model studies.

11.2 Uplift Pressure

The uplift pressure at any point shall be calculated by any accepted practice taking into account the depth of permeable strata below floor, the effect of the upstream and downstream cutoffs, intermediate cutoffs (if any), interference of cutoffs, thickness of floor and slope of the glacis. In general, the uplift pressure at any point of floor of barrage/weir is computed on the basis of Khosla's theory for permeable foundation of infinite depth. The uplift pressure for a limited depth of previous strata below barrage floor may be computed either by mathematical or electrical models or by the method given in CBIP technical report No. 17.

12 LEVELS OF CREST AND UPSTREAM FLOOR

12.1 It would be desirable to keep the crest and upstream floor level in the pocket upstream of undersluices at the normal low bed level of the deep current of the rivers, as far as practicable. The provision of such a low level for the crest and the upstream floor may not be necessary where a high pond level has to be maintained. The limits imposed by the consideration of cost of foundations and gates and hoists and their operation, the difficulty of dewatering during construction, the permissible afflux upstream of the work and the silt charge of river should be kept in view.

12.2 Sill levels of the canal head regulator shall be decided according to IS 6531 : 1972.

12.3 In the river bays portion, the upstream floor level should be fixed at the general river bed level at or below the level of the crest. The crest levels should be fixed according to **12.3.1** to **12.3.3**.

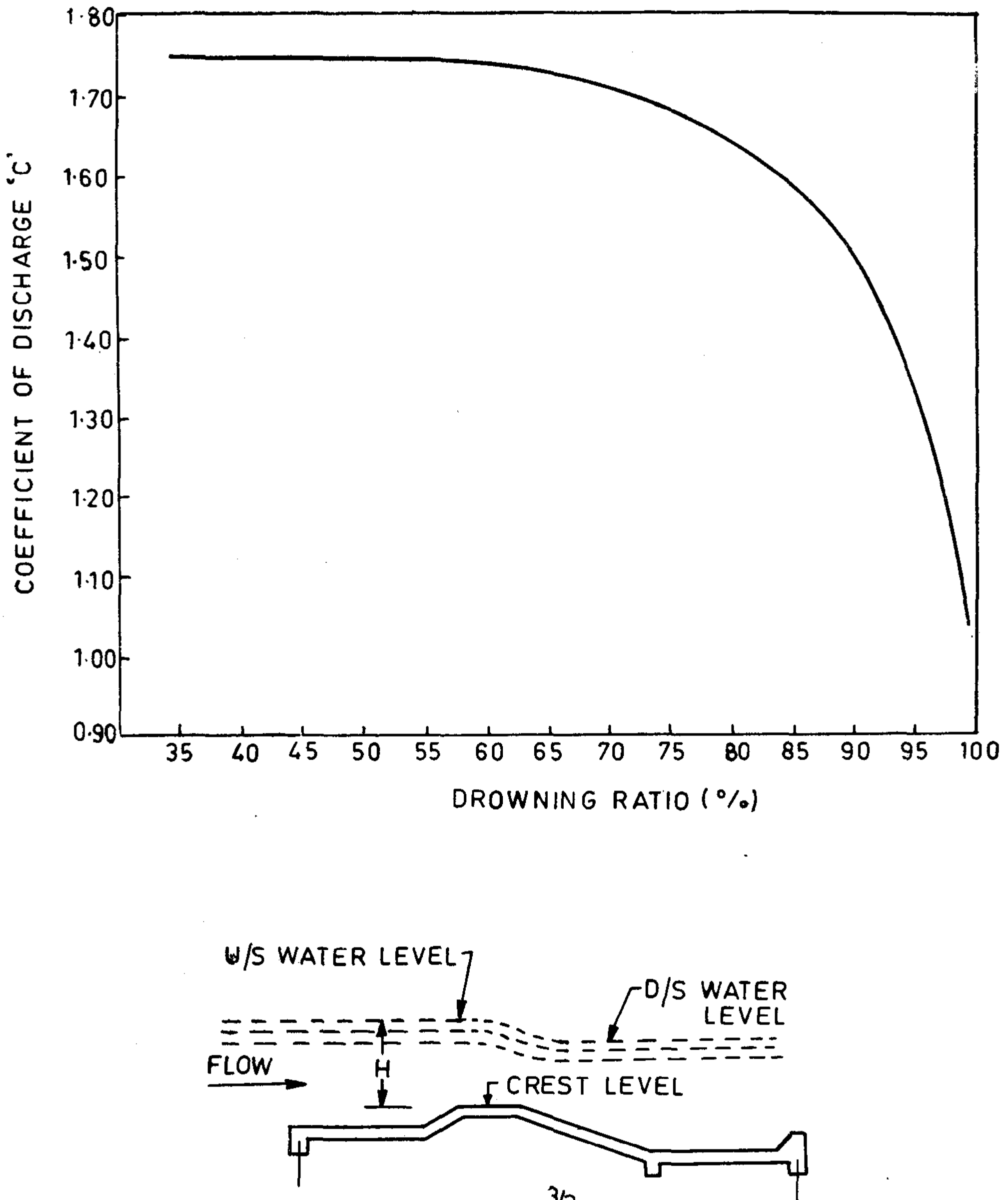
12.3.1 For weirs without shutters, the crest level shall be at the required pond level.

12.3.2 For weirs with falling shutters, the crest level shall not be lower than 2 m below the elevation of the pond as the maximum height of the falling shutters is normally limited to 2 m. It may be suitably raised if possible, from consideration of passing the design flood discharge at the desired afflux and with the waterway provided. If the lowest crest level fixed in the above manner causes too much of afflux, the waterway of weir may be suitably increased.

12.3.3 For barrages, the head required to pass the design flood at the desired afflux directly determines the crest level. The level of crest in this portion should be fixed by adjustment of the waterway. It should, in any case, be kept higher than the undersluice crest level.

13 SHAPE OF BARRAGE/WEIR PROFILE

13.1 Where the upstream floor level and the crest level are not the same, the crest may be provided flat at the top with a width of about 2 m. An upstream slope of 2 : 1 to 3 : 1 shall be given depending on site conditions. The downstream slope shall be as required for the glacis of stilling basin (*see* **14.3**). For major projects, it is advisable to undertake model studies for obtaining the best shape for the crest.



$$Q = CLH^{3/2}$$

WHERE

Q = DISCHARGE IN CUMECS

C = COEFFICIENT OF DISCHARGE IN FREE CONDITIONS

L = CLEAR WATER WAY IN METRE

H = HEAD OF WATER OVER CREST IN METRE

$$\text{DROWNING RATIO} = \frac{\text{D/S WATER LEVEL} - \text{CREST LEVEL}}{\text{U/S WATER LEVEL} - \text{CREST LEVEL}}$$

FIG. 1 DROWNING RATIO VS COEFFICIENT OF DISCHARGE CURVE (IN MKS UNITS) (BASED ON MALIKPUR CURVE) APPLICABLE IN BROAD CRESTED BARRAGES

13.2 For weirs with falling shutters, top width of the crest shall be limited to that required for accommodating the shutter in fallen position.

14 ENERGY DISSIPATION

14.1 For barrages/weirs on alluvial foundations, hydraulic jump type stilling basins designed in accordance with IS 4997 : 1968 would normally be required for dissipation of energy.

14.2 The concentration of flow will depend on upstream and downstream river conditions including formation of islands, obliquity of flow and river stage. Normally provision for 20 percent concentration for the governing conditions may be found adequate.

14.3 Downstream Glacis — A slope of 3 : 1 is recommended for the downstream glacis.

14.4 Downstream Floor — The hydraulic design of the downstream floor shall conform to IS 4997 : 1968.

15 UNDERSLUICES

15.1 A weir or barrage normally requires deep pockets of undersluices portions in front of the head regulator of offtaking canal and long divide walls to separate the remaining river bays portion from the undersluices portion. The arrangement is aimed at keeping the approach channel to the canal head regulator comparatively clear of the silt and to minimize the effect of main river current on the flow conditions in the regulator. Provision of intermediate divide wall to produce favourable flow condition may be decided on the basis of model studies and proposed operation of gates.

15.1.1 A layout of a typical barrage showing the various components is given in Fig. 2.

15.2 The width of the undersluice portion shall be determined on the basis of the following considerations:

a) It should be capable of passing at least double the canal discharge to ensure good scouring capacity.
b) It should be capable of passing about 10 to 20 percent of the maximum flood discharge at high floods.
c) It should be wide enough to keep the approach velocities sufficiently lower than critical velocities to ensure maximum settling of suspended silt load.
d) In case of weirs, it should be capable of passing fair weather freshets and low monsoon floods for obviating overtopping and/or operation of crest gates.
e) Where silt excluders are provided, the width of the pocket should be determined by the velocity required in the pocket to induce siltation. Where the width of barrage is appreciable, river sluices adjoining the pockets can be provided to take care of low floods and freshets thereby economizing on the cost.

15.2.1 The section of the river sluice bay, wherever provided, will be similar to that of undersluice bay without silt excluder.

16 DIVIDE WALLS

16.1 On all important works, the width of undersluice portion and the length of divide walls shall be fixed on the basis of model experiments.

16.2 If indicated by model studies, long submerged spurs (longer than the bed protection) shall be provided to keep any parellel flows far away from the protection works.

16.3 The following guidelines shall be adopted in fixing the length of divide walls for barrages of lesser importance and before referring the model experiments:

a) It shall not extend beyond the upstream end of the head regulator.
b) Generally, satisfactory results are obtained if it covers two-thirds the width of the head regulator.
c) Downstream divide wall shall extend up to the end of the downstream apron or as required by model studies.
d) If the pocket is at the outer curvature of the river, the length and alignment of divide walls is to be decided by model studies.

17 CUTOFFS

17.1 The upstream and downstream cutoffs should generally be provided to cater for scours up to 1 R and 1·25 R, respectively where R is the depth of scour as defined in **17.1**. The concentration factor shall be taken into account in fixing depth of cutoffs. These should be suitably extended into the banks on both sides up to at least twice their depth from top of the floors.

17.1.1 In case the substratum continuous layer of clay in the neighbourhood of downstream cutoffs, a judicious adjustment in the depths of upstream and downstream cutoffs shall be made to avoid build up of pressure under the floor.

17.2 The depth of downstream cutoffs along with the total length of impervious floor should also be sufficient to reduce the exit gredient to within safe limits, for the governing design condition.

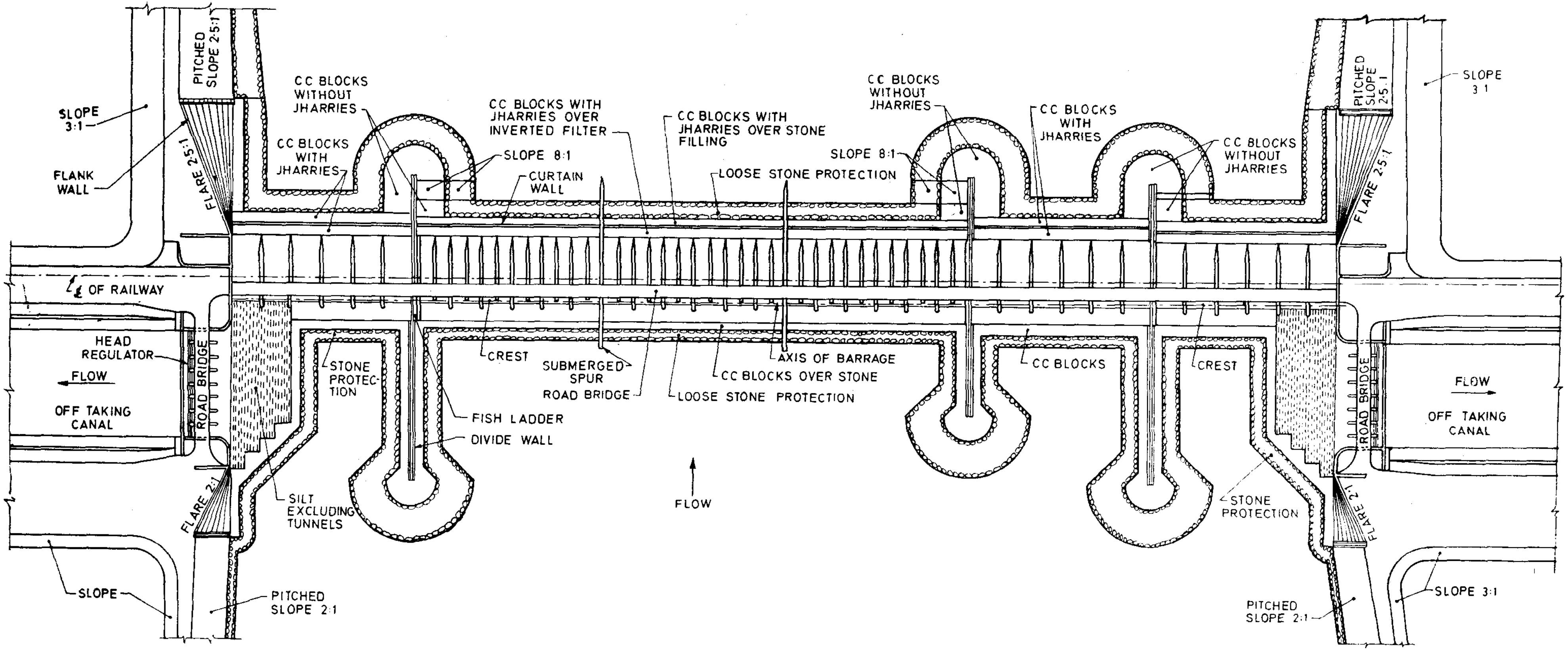


FIG. 2 TYPICAL LAYOUT OF A BARRAGE

17.3 Exit Gradient at the End of Impervious Floor

The exit gradient shall be determined from accepted formulae and curves. The factors of safety for exit gradient for different types of soils shall be as follows:

a) Shingle : 4 to 5,
b) Coarse sand : 5 to 6, and
c) Fine sand : 6 to 7.

17.4 The cutoffs may be of masonry, concrete or sheet piles depending upon the type of the soil and the depth of the cutoffs to suit construction convenience.

18 TOTAL FLOOR LENGTH

18.1 The total length of impervious floor which consists of upstream floor, upstream glacis, crest, downstream glacis, downstream basin and end sill required from consideration of safety against sliding shall be fixed in conjunction with the depth of downstream cutoff to satisfy the requirements of exit gradient, scours and economy.

19 SCOUR

19.1 River scour is likely to occur in erodible soils, such as clay, silt, sand and shingle. In non-cohesive soils, the depth of scour may be calculated from the Lacey's formula which is as follows:

$R = 0{\cdot}473 \left(\frac{Q}{f}\right)^{\frac{1}{3}}$ when looseness factor is more than 1, or

$R = 1{\cdot}35 \left(\frac{q^2}{f}\right)^{\frac{1}{3}}$ when looseness factor is less than 1

where

R = depth of scour below the highest flood level in m;

Q = high flood discharge in the river in m^3/s;

f = silt factor which may be calculated by knowing the average particle size m_r, in mm, of the soil from the relationship:

$f = 1{\cdot}76 \sqrt{m_r}$ [f may be checked from Lacey's relationship $f = 290 \left(R^{\frac{1}{2}} S \right)^{\frac{2}{3}}$]; and

q = intensity of flood discharge in m^3/s per m width.

19.2 The extent of scour in a river with erodible bed material varies at different places along a weir or barrage. The likely extent of scour at various points are given in Table 1.

Table 1 Likely Extent of Scour at Different Places Along a Barrage/Weir

(*Clause* 19.2)

Sl No.	Location	Range	Mean
(1)	(2)	(3)	(4)
i)	Upstream of impervious floor	1·25 to 1·75 *R*	1·5 *R*
ii)	Downstream of impervious floor	1·75 to 2·25 *R*	2·0 *R*
iii)	Noses of guide banks	2·00 to 2·50 *R*	2·25 *R*
iv)	Noses of divide wall	2·00 to 2·50 *R*	2·25 *R*
v)	Transition from nose to straight	1·25 to 1·75 *R*	1·50 *R*
vi)	Straight reaches of guide banks	1·00 to 1·50 *R*	1·25 *R*

20 PROTECTION WORKS

20.1 Upstream Block Protection

20.1.1 Just beyond the upstream end of the impervious floor, pervious protection comprising of cement concrete blocks of adequate size laid over loose stone shall be provided. The cement concrete blocks shall be of adequate size so as not to get dislodged, and shall generally be of 1 500 × 1 500 × 900 mm size for barrages in alluvium reaches of rivers.

20.1.2 The length of upstream block protection shall be approximately equal to D, the design depth of scour below the floor level.

20.2 Downstream Block Protection

20.2.1 Pervious block protection shall be provided just beyond the downstream end of impervious floor as well. It shall comprise of cement concrete blocks of adequate size laid over a suitably designed inverted filter for the grade of material in the river bed. The cement concrete blocks shall generally be not smaller than 1 500 × 1 500 × 900 mm size to be laid with gaps of 75 mm width, packed with gravel.

20.2.2 The length of downstream block protection shall be approximately equal to $1{\cdot}5\ D$. Where this length is substantial, block protection with inverted filter may be provided in part of the length and block protection only with loose stone spawls in remaining length.

20.2.3 A toe wall of masonry or concrete extending up to about 500 m below the bottom of filter shall be provided at the end of the inverted filter to prevent it from getting disturbed.

20.2.4 The graded inverted filter should roughly conform to the following design criteria:

a) $\frac{D_{15} \text{ of filter}}{D_{15} \text{ of foundation}} \geqslant 4 \geqslant \frac{D_{15} \text{ of filter}}{D_{85} \text{ of foundation}}$

NOTE — D_{15} and D_{85} denote grain sizes. D_{15} is the size such that 15 percent of the soil grains are smaller than that particular size. D_{85} is the size such that 85 percent of the soil grains are smaller than that particular size.

b) The filter may be provided in two or more layers The grain size curves of the filter layers and the base material shall be roughly parallel.

20.3 Loose Stone Protection

20.3.1 Beyond the block protection on the upstream and downstream of a weir or a barrage located on permeable foundation, launching apron of loose boulder or stones shall be provided to spread uniformly over scoured slopes. The stone or boulder used shall not be less than 300 mm size and no stone shall weigh less than 40 kg. Where the stone is likely to be swept away due to high velocities or where somewhat smaller stones are to be used due to non-availability of stones of specified size, the loose stone apron shall be provided in the form of cement concrete blocks or wire sausages of suitable size depending on the economics.

20.3.2 The quantity of stone provided at various locations of the barrage shall be adequate to cover the slopes of scour holes corresponding to the factors given in Table 1 for value of *R* calculated from Lacey's formula given in **17.1.** No allowance for concentration shall be made in the discharge per unit length in computing the normal scour *R* for the upstream and downstream protection works.

20.3.3 Slope of Launched Apron

The slopes of the launched apron is primarily dependent on the grade and the size of the material in the river bed. For rivers in alluvium sandy reaches, the slope shall not be assumed steeper than 2 : 1 nor flatter than 3 : 1. The latter figure should be adopted for river with very fine sand or silty bed.

20.3.4 Thickness of Material on Launched Slopes

The requirement of thickness of material on launched slope can be connected to grade of river bed material and river slope. The thickness of loose stone required for covering the launched slope shall be kept 1·25 τ, where τ is the value of thickness obtained from Table 2.

Table 2 Thickness of Pitching (τ for Loose Stone Protection in mm)

Type of River Bed Material	River Slope in m/km				
	0·05	0·15	0·20	0·30	0·40
(1)	(2)	(3)	(4)	(5)	(6)
Very coarse	400	500	550	650	700
Coarse	550	650	700	800	850
Medium	700	800	850	950	1 000
Fine	850	950	1 000	1 100	1 150
Very fine	1 000	1 100	1 150	1 250	1 300

20.3.5 Length and Thickness of Laid Apron

20.3.5.1 The total quantity of loose stone worked out according to **20.3.2, 20.3.3** and **20.3.4** shall be laid in a length of about 1·5 to 2·5 *D*. The higher figure shall be adopted for flatter launched slope.

20.3.5.2 The thickness of stone at the inner edge shall correspond to the quantity required for a thickness τ. The material required for extra thickness of 0·25 τ on launched slope shall be distributed in the length of laid apron in the form of a wedge with increasing thickness towards outer edge.

21 MODEL STUDIES

21.1 For important barrages, model studies should be carried out to get an idea of hydraulic conditions vis-a-vis layout of guide bunds, location and axis to barrage/weir and also to determine distribution of flows.

ANNEX A
(Foreword)

SALIENT DESIGN PARAMETERS OF SOME IMPORTANT BARRAGES IN INDIA

Sl No.	Name of Barrage	Design Discharge Cumecs	Design Flood Frequency Years	Silt Factor, *f*	River Bed Slope, *S*	Overall Waterway m	Alignment of Head Regulator (Angle with the Line Perpendicular to Barrage)
i)	Dakpathar	14 580	—	4·00	—	517	20°
ii)	Durgapur	15 600	1 in 30 000	1·00	—	692	—
iii)	Gandak	24 100	1 in 220	3·00	1 in 833	742	0°
iv)	Godavari	99 100	1 in 200	1·10	1 in 2 450	3 550	—
v)	Harike	18 400	—	1·00	—	635	11·1°
vi)	Kosi	27 000	1 in 600	1·30	1 in 513	1 150	12·5°
vii)	Madhopur	17 700	—	1·00	—	513	0°
viii)	Narora	14 180	—	0·85	—	922	17°
ix)	Ramganga	5 950	—	1·28	—	—	13°
x)	Sone	41 000	1 in 70	1·40	1 in 2 347	1 260	20°
xi)	Yamuna	8 500	—	1·00	1 in 5 000	553	No head regulator

ANNEX B
(*Clause* 2)

LIST OF REFERRED INDIAN STANDARDS

IS No.	*Title*
IS 1191 : 1971	Glossary of terms and symbols used in connection with the measurement of liquid flow with a free surface (*first revision*)
IS 2912 : 1964	Recommendation for liquid flow measurement in open channels by slope-area method (approximate method)
IS 2914 : 1964	Recommendations for estimation of discharges by establishing stage-discharge relation in open channels
IS 4410 (Part 3) : 1967	Glossary of terms relating to river valley projects: Part 3 River and river training
IS 4410 (Part 5) : 1982	Glossary of terms relating to river valley projects: Part 5 Canals (*first revision*)
IS 4497 : 1968	Criteria for design of hydraulic jump type stilling basins with horizontal and sloping apron
IS 5477 (Part 4) : 1971	Methods for fixing the capacities of reservoirs: Part 4 Flood storage
IS 6531 : 1972	Criteria for design of canal head regulators