IS 11527 (1985): Criteria for structural design of energy dissipators for spillways [WRD 9: Dams and Spillways]

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# *Indian Standard*

# CRITERIA FOR STRUCTURAL DESIGN OF ENERGY DISSIPATORS FOR SPILLWAYS

UDC 627·838·04



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

Gr 7 November 1986

# *Indian Standard*

# CRITERIA FOR STRUCTURAL DESIGN OF ENERGY DISSIPATORS FOR SPILLWAYS



( *Continued on page* 2 )

( *Continued from page* 1 )

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| --- | --- |
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| SHRI V. N. PENDSE | Irrigation Department, Government of Maharashtra, Bombay |

# AMENDMENT NO. 1 SEPTEMBER 1988
# TO
# IS : 11527-1985 CRITERIA FOR STRUCTURAL DESIGN OF ENERGY DISSIPATORS FOR SPILLWAYS

( *Page* 8, *clause* **4.3.4**, *line* 3 ) — Substitute
'$[0.5 (D_2 \times W + tb \times w) - (D_1 \times w + Wc \times t_b)]$' *for*
'$0.5 [(D_2 \times W') + (t_b \times W') - (D_1 \times W + W_c t_b)]$'.

( BDC 54 )

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# *Indian Standard*

# CRITERIA FOR STRUCTURAL DESIGN OF ENERGY DISSIPATORS FOR SPILLWAYS

## 0. FOREWORD

**0.1** This Indian Standard was adopted by the Indian Standards Institution on 20 November 1985, after the draft finalized by the Spillways Including Energy Dissipators Sectional Committee had been approved by the Civil Engineering Division Council.

**0.2** The design of downstream protection works or energy dissipators below hydraulic structures occupies a vital place in the design and construction dams, weirs and barrages. The problem of designing energy dissipators is essentially of reducing high velocity flow to a velocity low enough to minimize erosion of natural river bed. This reduction in velocity may be accomplished by any, or a combination of the following, depending upon the head, discharge intensity, tail water conditions and the type of bed rock or the bed material:

a) Hydraulic jump type stilling basins:
   1) Horizontal apron type; and
   2) Sloping apron type;

b) Jet diffusion and free jet stilling basins:
   1) Jet diffusion basins;
   2) Free jet stilling basins;
   3) Hump stilling basins; and
   4) Impact stilling basins;

c) Bucket type dissipators:
   1) Solid and slotted roller buckets; and
   2) Trajectory buckets ( ski jump, flip, etc );

d) Interacting jets and other special type of stilling basins.

**0.3** In India, hydraulic jump type stilling basins and bucket type energy dissipators are generally used for dissipation of energy depending on condition of downstream tail water. Indian Standards have already been issued for criteria for hydraulic design of these two types of energy dissipators as under:

| | |
|---|---|
| IS : 4997-1968 | Criteria for design of hydraulic jump type stilling basins with horizontal and sloping apron |
| IS : 7365-1974 | Criteria for hydraulic design of bucket type energy dissipators |

## 1. SCOPE

**1.1** This standard lays down criteria for structural design of various components of hydraulic jump type stilling basins and bucket type energy dissipators below spillways and outlet works founded on rock.

## 2. NOTATIONS

**2.1** For the purpose of this standard, the following notations shall have the meaning indicated against each and as shown in Fig. 1 :

$A_L$ = Anchor depth

$A_{st}$ = Area of steel

$a$ = Area of bar

$b$ = Width of tooth

$D_1$ = Depth of flow at the beginning of the jump measured perpendicular to the floor

$D_2$ = Depth conjugate (sequent) to $D_1$ for horizontal apron

$D_3$ = $D_2$ + floor slab thickness

$d$ = Effective depth

$d_a$ = Diameter of anchor hole

$d_b$ = Diameter of bar

$d_t$ = Depth of bucket at invert elevation

$F_t$ = Tensile yield strength of steel with factor of safety 1·2

$F_{b1}$ = Permissible bond stress between steel and grout

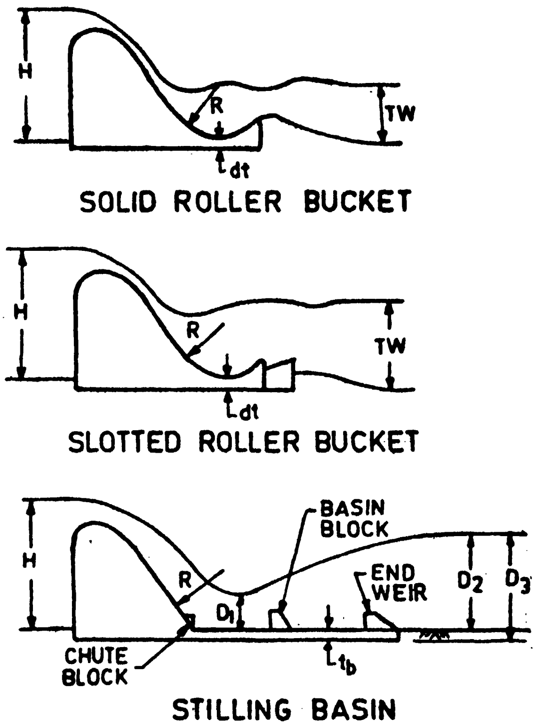


FIG. 1 DEFINITION SKETCH

$F_{b_2}$ = Permissible bond stress between ground and rock

$g$ = Acceleration due to gravity

$H$ = Head of water

$h_b$ = Height of basin block

$L$ = Length of anchor

$n$ = Number of anchors per m²

$q$ = Discharge intensity

$R$ = Radius of bucket

$S_b$ = Spacing between basin blocks

$T_w$ = Tail water depth

$t_b$ = Thickness of stilling basin floor

$t_w$ = Width of bucket lip

$U_h$ = Uplift head = $T_w + d_t$

$V$ = Velocity of flow

$W$ = Density of water

$W_c$ = Density of concrete

$W_r$ = Density of rock

$W_3$ = Width of basin block

$\alpha$ = Ratio of bucket thickness at invert elevation to radius of bucket = $\frac{d_t}{R}$

$\beta$ = Ratio of uplift head $U_h$ to radius of bucket

$\phi$ = Angle between vertical and any radial line within exit angle for bucket

$\theta_e$ = Exit angle of the bucket

$\theta_i$ = Inlet angle of the bucket

$\sigma_{st}$ = Permissible tensile stress of steel

## 3. TERMINOLOGY

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

**3.1 Hydraulic Jump Type Stilling Basin** — A stilling basin in which energy is dissipated by hydraulic jump principle.

**3.2 Length of Stilling Basin** — Dimension of the basin in the direction of flow.

**3.3 Width of Stilling Basin** — Dimension of the basin perpendicular to the direction of main flow.

**3.4 Chute Blocks** — Blocks provided at the entrance of the stilling basin to stabilize the formation of hydraulic jump, to increased effective depth, to break up flow into a number of water jets, to create turbulence and to lift the jets off the floor to reduce basin length.

**3.5 Basin Blocks or Baffle Blocks** — Obstructions set in the path of high velocity water, such as piers, on the apron of an overflow dam, weir or drop and to dissipate energy thereby preventing scour downstream to control the position of hydraulic jump.

**3.6 End Sill** — A vertical, stepped sloped or dentated wall constructed at the downstream end of a stilling basin. It may be rectangular, trapezoidal, Hornsby, Schoklits, Smetana or Rehbock type.

**3.7 End Weir** — Sharp or broad crested weir constructed at the end of stilling basin floor to maintain adequate tail water level for all discharge.

**3.8 Key Wall** — Small solid wall downstream of end weir penetrating in foundation to prevent retrogression.

**3.9 Solid Roller Bucket Dissipator** — A bucket type energy dissipator which consists or a bucket like apron with a concave profile of considerable radius and a lip which deflects the high velocity flow away from the stream bed and upward forming elliptical hydraulic rollers, namely submerged rollers in the bucket, and ground rollers downstream of the bucket. Energy dissipation is accomplished by the interaction of the submerged roller in the bucket and the high turbulence created on the water surface above and below the bucket. Suitable when the tail water depth is moderately in excess of that required for the formation of a hydraulic jump.

**3.10 Slotted Roller Bucket** — A bucket type energy dissipator in which the lip wall is made up of alternate teeth and slots and below which a sloping apron is provided. This construction of the bucket materially reduces the intensity of surface boil and ground rollers.

**3.11 Trajectory Bucket** — A type of energy dissipator, employed in cases where the tail water depth is less than that required for the formation of hydraulic jump, by throwing water away from the toe of the dam in the form of projectile into the air.

## 4. STRUCTURAL DESIGN OF STILLING BASIN FLOOR

**4.1 General** — The basin floor elevation is generally decided on basis of foundation conditions and the length of the basin is decided on basis of hydraulic considerations in accordance with IS : 4997-1968* and breadth depends on number of openings and piers on spillway crest.

**4.2 Design Forces** — The basin floor slab is subjected to hydrostatic uplift, pounding and vibrations from hydrodynamic forces in the hydraulic jump. On a yielding foundation, it may suffer differential settlement, therefore the

*Criteria for design of hydraulic jump type stilling basins with horizontal and sloping apron.

basin floor slab shall be designed for the stresses induced due to above forces.

**4.3 Floor Slab Anchorages** — Following two extreme conditions may prevail and critical of the two conditions shall be considered for design.

**4.3.1** *Case* I — Stilling basin operating during spillway design flood as shown in Fig. 2. Water surface over slab at hydraulic jump profile for design discharge, that is spillway operating at MWL.

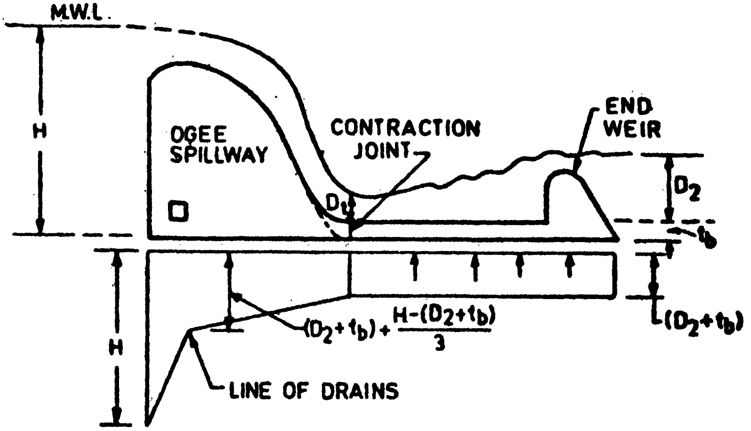


FIG. 2 CASE I SHOWING UPLIFT FORCES

**4.3.2** *Case* II — Reservoir at FRL with gates closed when basin is empty ( *see* Fig. 3 ).

NOTE — Case I is normally critical and same is considered for basin floor design. The design of anchors may also be checked for Case II.

**4.3.3** In view of drainage arrangements provided below the basin floor, it may be adequate to design floor slab with uplift force equal to $0·5 ( D_2 + t_b ) \times W$. Depth of water in stilling basin will fluctuate from $D_1$ to $D_2$ as per jump profile. Provision of effective drainage system below stilling basin floor is necessary.

**4.3.4** The number of anchors required in the upstream portion of apron shall be designed for unbalanced uplift equal to

$$0·5 [ ( D_2 \times W ) + ( t_b \times W ) - ( D_1 \times W + W_c t_b ) ].$$

$$\text{No. of anchors } (n) \text{ required per m}^2 = \frac{[0·5 ( D_2 \times W + t_b \times W ) - ( D_1 \times W + W_c t_b )]}{a \times F_t}$$

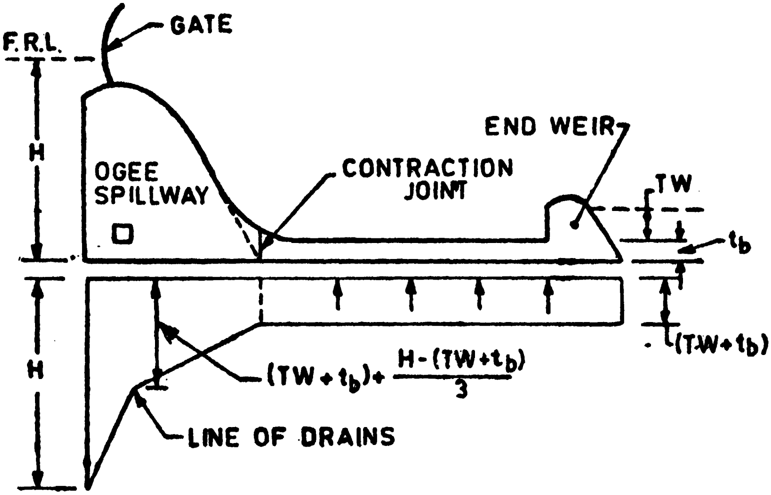


FIG. 3 CASE II SHOWING UPLIFT FORCES

The number of bars will be rounded to next higher integer.

$$\text{Spacing of anchors} = \sqrt{\frac{1}{n}}$$

$$\text{Actual force in each anchor} = \frac{\text{Net upward force}}{\text{No. of bars}}$$

$$= \frac{[\,0{\cdot}5\,(D_2 \times W + t_b\,W) - (D_1 \times W + W_c\,t_b)\,]}{n}$$

$$\text{Required bond length} = \frac{\text{Actual force in each anchor}}{\pi \times d_b \times F_{b1}}$$

or

$$\text{Required bond length} = \frac{\text{Actual stress in each anchor}}{\pi \times d_a \times F_{b2}}$$

The greater of the two should be adopted as anchor depth. The value for permissible bond stress will vary for different site conditions and proportion of grout. In absence of data assume following values for 1 : 2 grout proportion.

where

$F_{b1}$ = permissible bond stress between steel and grout

= 6 kg/cm²

$F_{b2}$ = permissible bond stress between grout and rock

= 4 kg/cm²

( Bond length shall be checked for bond between steel and grout and also for bond between rock and grout ).

$d_b$ = diameter of bar.

$d_a$ = diameter of anchor hole.

**4.3.5** Notwithstanding results of above calculations, minimum 3·0 m long anchors shall be provided and dia of bar shall not be less than 25 mm. The diameter of hole into which anchors are placed and grouted shall be not less than 1·5 times diameter of anchor bar designed. The maximum spacing of anchor bars shall be 3 m centre to centre staggered in plan.

**4.3.6** *Check for Dislodging of Rock Mass Anchored Against Uplift Pressure* — Length of anchors shall be sufficient to engage a conical mass of rock with a vortex angle of 45° the submerged weight of which will withstand the net upward force ( *see* Fig. 4 ).

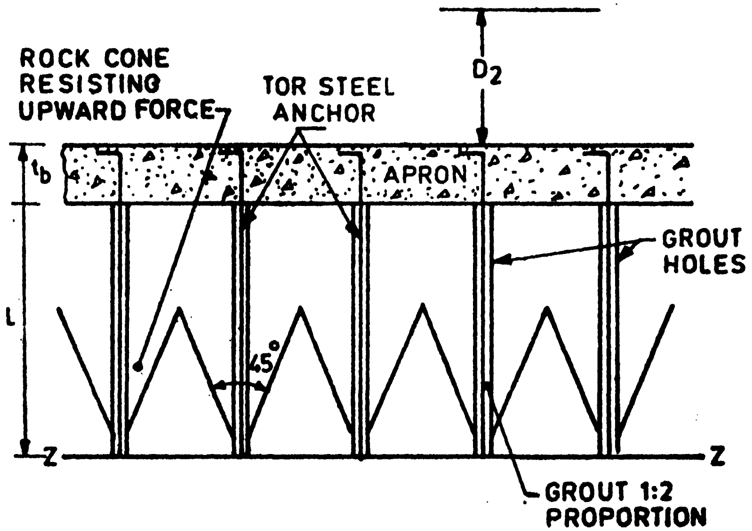


FIG. 4 DETAILS OF ANCHOR AND GROUT HOLE

Total uplift pressure on plane '*ZZ*' per unit areas shown in Fig. 4

$$= W\left(\frac{D_2 + t_b}{2} + L\right)$$

Total uplift pressure per unit area = Weight of slab + weight of rock

$$W\left(\frac{D_2 + t_b}{2} + L\right) = W_c \times t_b + W_r\ L$$

$$\text{Therefore } L = \frac{0.5\ W\ (D_2 + t_b) - W_c \times t_b}{(W_r - W)}$$

**4.4 Basin Floor Slab Thickness** — The thickness of floor slab depends on the foundation conditions and magnitude of uplift forces. A slab of about 600 mm thickness is the minimum recommended. Actual slab thickness needed shall be determined by analysing hydrostatic uplift and differential foundation movement.

**4.4.1** *Floor Slab Reinforcement* — In thick slabs on rock foundations normally covered with tail water, structural reinforcement is not necessary except possibly in the baffles. Uplift on a slab should be taken care of by adequate anchors. The slab is divided into independent approximately square panels by contraction joints parallel and perpendicular to channel or basin centre line to avoid serious shrinkage and temperature cracking with the use of nominal reinforcement which does not extend across the joints. Size of panel should be large enough to resist destorting hydrodynamic forces, at the same time the quantity of concrete in a panel may be manageable to be completed by available machinery in one single stretch. Panels should be cast in alternate bays with construction joints.

**4.4.2** The independent panels of slab are reinforced with small amount of steel to prevent harmful cracking resulting from shrinkage and temperature stresses not relieved by contraction joints and on yielding foundations to avoid possible cracking from differential settlement. Usually, a slab on unyielding foundation is reinforced in the top face only because bond between the concrete and rock at the bottom is relied on to distribute shrinkage cracks and to minimize bending stresses in the anchored slab for the assumed uplift head. The minimum amount of reinforcement for independent panels on unyielding rocks is 20 mm $\phi$ bars at 300 mm centre-to-centre both ways. Additional reinforcement shall be provided for unfavourable foundation condition or for high hydrostatic uplift pressure.

**4.4.3** On relatively yielding rock foundations, the independent floor panels are subject to possible differential movement of adjacent blocks and a key at each transverse contraction joint ( extending into foundation under the joint attached to the slab downstream and supporting the slab upstream from the joint ) may be required to prevent the downstream side of a joint from being raised above the upstream side as water at high velocity striking such a projection would increase the hydrostatic pressure in the joint and hence the uplift under the slab. The higher the velocity the more serious will be the condition resulting from such relative movement. The keys also increase resistance to possible movement and serve as seepage cutoffs downstream from transverse drains. For details of key **7.2.3** of IS : 5186-1969* may be referred.

**4.4.4** *Concrete and Reinforcement Cover* — The concrete of M-15 grade up to 40 m ( crest-apron level ) and concrete of M-20 grade above 40 m fall shall be provided. Chute floor and stilling basin slab shall have minimum 100 mm cover for reinforcement.

**4.5 Basin Blocks or Baffle Blocks ( Structural Provisions )**

**4.5.1** *General* — Location and optimum shape of baffle blocks shall be decided on the basis of IS : 4997-1968†. The dimensions of the basin blocks are shown in Fig. 5. The purpose of the block is to dissipate energy and thereby to reduce the length of basin.

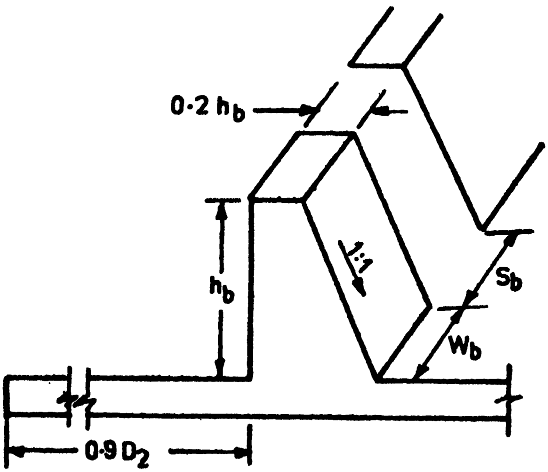


FIG. 5 BASIN BLOCK

*Criteria for design of chute and side channel spillways.
†Criteria for design of hydraulic jump type stilling basins with horizontal and sloping apron.

$h_b$ = height of basin block,

$S_b$ = spacing between the blocks,

$W_b$ = width of block, and

$D_2$ = conjugate depth.

**4.5.2** *Forces on Basin Blocks* — Dynamic force against the upstream face of the baffle blocks is approximately that of a jet impinging upon a plane normal to the direction of flow.

Force $P$ acting at $h_b/2 = 2WA\,(D_1 + h_{v1})$

where

$W$ = unit weight of water,

$A$ = area of upstream face of block, and

$(D_1 + h_{v1})$ = specific energy of the flow entering the basin.

**4.5.2.1** Negative pressure on the back face of the blocks will further increase the total load. However, this may be neglected if above equation is used. Baffle block is to be designed as cantilever as shown in Fig. 6.

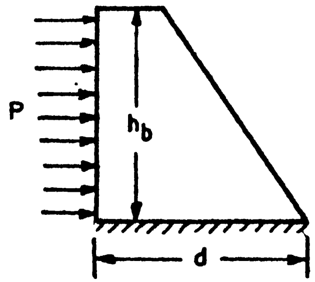


FIG. 6 FORCES ON BASIN BLOCK

**4.5.3** *Reinforcement* — The reinforcement shall be calculated by the following formula and placement of the reinforcement is shown in Fig. 7 and 8.

Area of steel $A_{st} = \dfrac{M}{\sigma_{st} \cdot j \cdot d}$

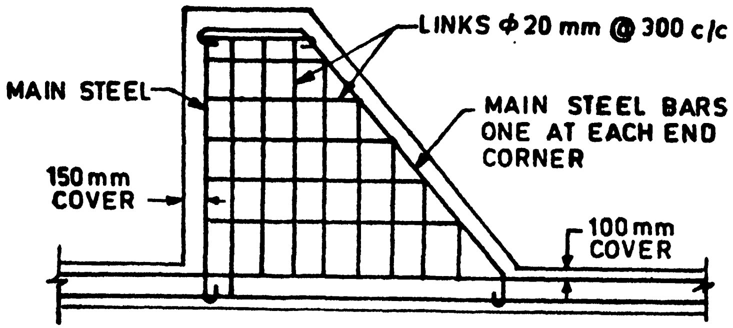


FIG. 7 VERTICAL SECTION SHOWING GENERAL ARRANGEMENT OF REINFORCEMENT

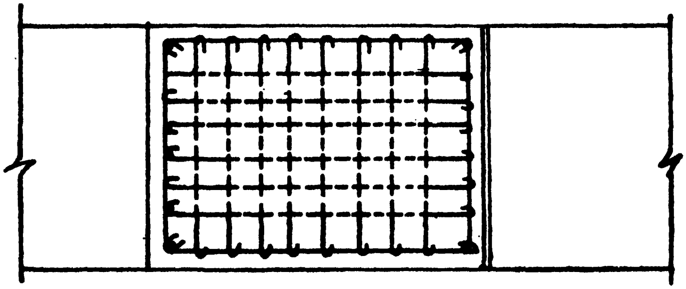

FIG. 8 PLAN AT BOTTOM OF BLOCK

where

$M$ = moment due to force $P$ ( defined in **4.5.2** ),

$= P \times \frac{h_b}{2}$,

$\sigma_{st}$ = permissible tensile stress of steel, and

$d$ = depth of block.

NOTE 1 — The baffle block is tied into the floor slab by reinforcing steel in it.

NOTE 2 — All reinforcing steel in a baffle block is placed minimum 150 mm from the exposed surface because of the possible erosive and cavitation action of the high velocity currents.

**4.6 Chute Blocks** — Nominal reinforcement of about 20 mm $\phi$ at 300 c/c both ways may be provided on all exposed faces duly anchored in apron concrete.

## 5. SPILLWAY BUCKET REINFORCEMENT

**5.1 Solid Roller Bucket** — ( *See* Fig. 9 and 10 ).

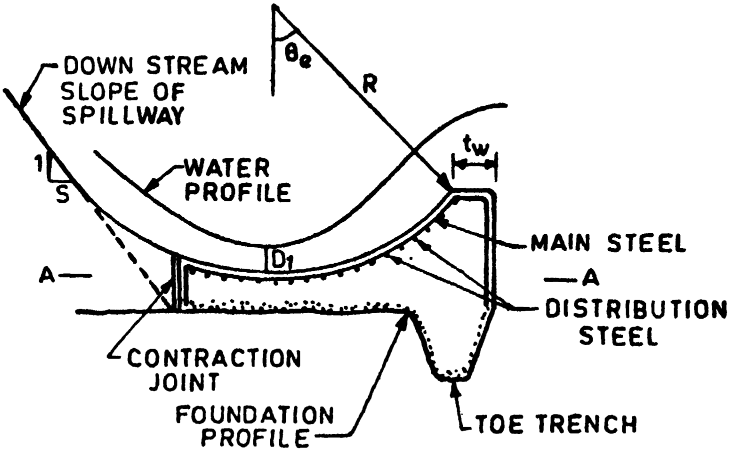


FIG. 9 TYPICAL SECTION OF A BUCKET

**5.1.1** *Forces and Moments* — Horizontal force on the bucket is due to change in momentum and is given by the following formulae:

Total horizontal force on the lip ( $F$ ) = $\frac{WbV}{g}(1 - \cos \theta_e)$

Moment of the horizontal force about plane $A$-$A$, $M = \frac{F \times R(1 - \cos \theta_e)}{2}$

Effective depth $d$ of bucket for resisting moment ( $M$ )

$$d = \sqrt{R^2 + (R \sin \theta_e + t_w)^2} - R - \text{effective cover}$$

**5.2 Reinforcement** — Area of the steel $A_{st}$ to resist moment $M$ is given

by $A_{st} = \frac{M}{\sigma_{st} . j . d.}$

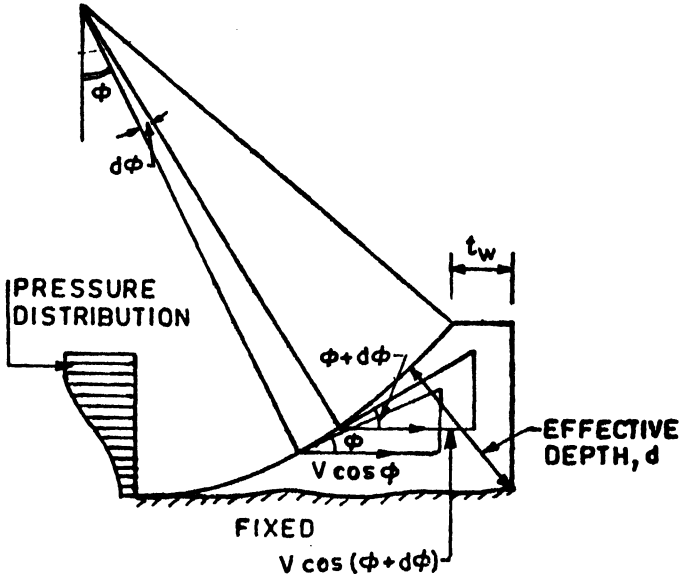


FIG. 10 FORCES ON THE BUCKET DUE TO MOVING WATER

Provide minimum steel ( along flow ) 20 mm $\phi$ at 300 c/c

Provide distribution steel = 20 percent of main steel. Minimum 16 mm $\phi$ at 300 c/c

( Refer Fig. 9 ).

**5.3 Anchorage of Spillway Bucket** — (*See* Fig. 11).

$$\frac{\text{Assuming 50 percent of the uplift force}}{\text{Net upward force/unit area} = F_u}$$ ( Provision of effective drainage system for bucket is essential )

$$F_u = R\left[0{\cdot}5\,\beta W - W_c\,\alpha - W_c\left\{1 - \frac{\frac{1}{4}(\sin 2\theta_e + \sin 2\theta_i) + \frac{1}{2}(\theta_e + \theta_i)}{(\sin\theta_e + \sin\theta_i)}\right\}\right]$$

Anchorage steel/unit area = $F_u/F_t$

$$A_{st} = \frac{R}{F_t}\left[0{\cdot}5\,W\beta - W_c\,\alpha - W_c\left\{1 - \frac{\frac{1}{4}(\sin 2\theta_e + \sin 2\theta_i) + \frac{1}{2}(\theta_e + \theta_i)}{(\sin\theta_e + \sin\theta_i)}\right\}\right]$$

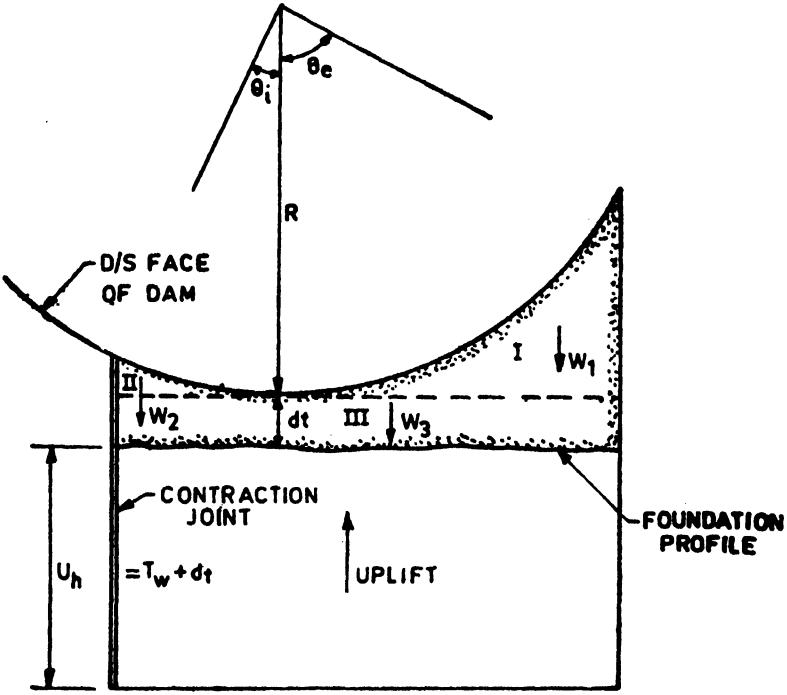


FIG. 11 UPLIFT AND BODY FORCES ON THE BUCKET

Number of anchors per m², $n = \frac{A_{st}}{a}$ and spacing of anchors $= \sqrt{\frac{1}{n}}$.

**5.3.1** *Length of Anchors* — The length of anchor bars is governed by the bond strength and density of rock, the criteria being that the stresses on horizonal plane passing through the bottom end of anchor bars should not be more than permissible tensile stress in the rock ( this is usually taken as zero except in hard sound rocks ). A cone of rock having vertex angle of 45° is assumed to be bonded to anchor bar. As the anchors are usually provided at close spacing (0·75 m to 2·5 m c/c ), the cones of bonded rock will be overlapping ( *see* Fig. 12 ). It is, therefore, possible to consider the entire rock mass up to bottom end of anchors as countering the uplift forces on the plane $Z - Z$ without introducing significant errors.

**5.3.1.1** Considering the equilibrium of vertical forces on plane $Z - Z$, we have net upward force at the base of bucket/unit area + additional uplift head ( for depth $L$ ) bounded by planes $AA$ and $ZZ$.

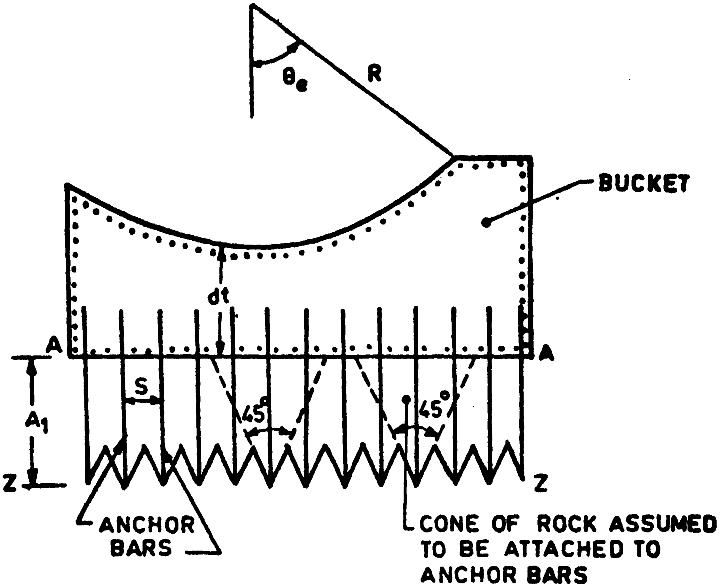


FIG. 12 ANCHOR BARS FOR COUNTERING UPLIFT

If $L$ is the length of anchors below bucket foundation ( that is, vertical distance between planes $AA$ and $ZZ$ ).

On substitution, we get,

$$R\left[0{\cdot}5\, W\beta - W_c\,\alpha - W_c \times \left\{1 - \frac{\frac{1}{4}(\sin 2\theta_e + \sin 2\theta_i) + \frac{1}{2}(\theta_e + \theta_i)}{(\sin\theta_e + \sin\theta_i)}\right\}\right]$$

$$+\ W.L. \qquad = W_r\, L$$

where density of rock ( $W_r$ ) is taken same as that of concrete ( $W_c$ ). Re-arranging and substituting we have

$$L = \frac{A_{st}\ \ F_t}{W_r\ - W}$$

The above equation has been derived on the basis that no tension is permissible in the foundation rock. However, in sound and hard rocks, some tension can be allowed in rock to reduce anchor length.

If $\sigma_r$ is the permissible tension in rock, then it can be seen that the above equation gets modified as

$$L = \frac{A_{st}\, F_t - \sigma_r}{W_r - W}$$

**5.3.2** *Check for Bond Length* — Length of anchor bars obtained from considerations of the preceding clause should be checked for bond failure as explained in **4.3.4** and **4.3.5**. The anchors are grouted in holes drilled by standard drill bits. In addition to bond between bar and grout, bond between the grout and rock should also be checked which, in most cases, is the weakest link. The usual practice is to assume a bond strength of 4 kg/cm² between the grout and rock contract surface.

## 6. SLOTTED ROLLER BUCKET STRUCTURAL PROVISION

### 6.1 General

**6.1.1** Dimensions of the roller bucket can be worked out on the basis of IS : 7365-1975*. Definition sketch is shown in Fig. 1. For anchor design **5.3** will be applicable. Provision of effective drainage system below the bucket is essential.

**6.1.2** A vertical contraction joint perpendicular to the flow in the bucket is proposed at the invert elevation of the bucket and another vertical joint is given at junction of 8° and 16° aprons as shown in Fig. 20. Generally one panel consists of two teeth, one full slot and two half slots with transverse joints in between panels as shown in Fig. 13. With modifications different panel arrangements can also be adopted.

**6.1.3** Discharge/$m$ = $q$ = $Q/L$ m³/s/m

where

$Q$ = total design discharge at MWL;
$L$ = length of bucket spillway;
$V$ = $\sqrt{2\, g\, H}$ m/s;
$H$ = fall of water ( head ) from MWL to bucket invert.

**6.2 Design of Reinforcement for Bucket Tooth** — ( Figure 14 shows definition sketch of bucket tooth. )

**6.2.1** Horizontal force on tooth above plane '*AB*' is shown in Fig. 14.

$$F_1 = \frac{W.q.V.}{g} \left( \cos\phi - \cos\theta_0 \right) \times b \text{ ( approx )}$$

*Criteria for hydraulic design of bucket type energy dissipators ( *under revision* ).

The tooth has to be designed as a cantilever ( vertical ) fixed at bottom *AB* and $b$ = width of bucket tooth at downstream end.

Bending moment $M = F_1 \times \frac{h}{2}$ where $h$ = height of tooth as shown in Fig. 14.

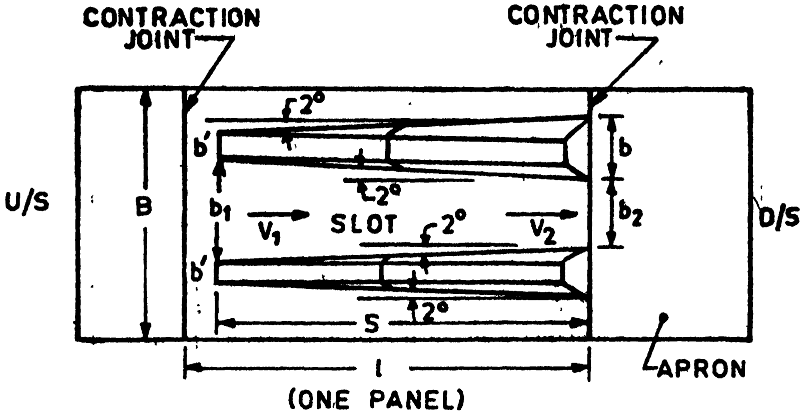


FIG. 13 PLAN SHOWING PANEL WITH TWO TEETH

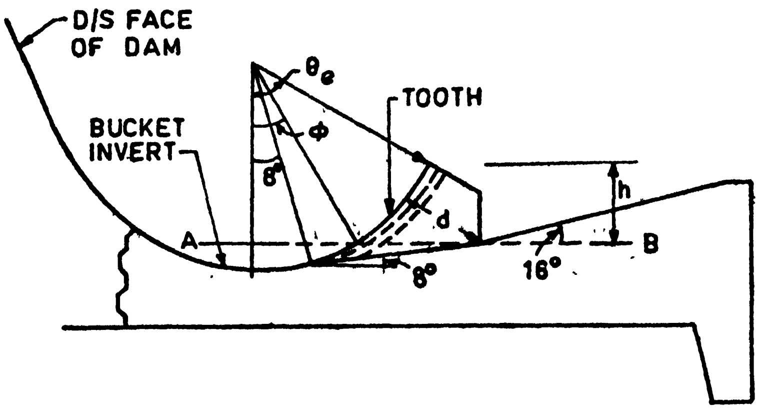


FIG. 14 DEFINITION SKETCH OF BUCKET TOOTH

**6.2.2** Area of steel ( $A_{st}$ ) = $\dfrac{M}{\sigma_{st}\cdot j\cdot d}$

where

$d$ = effective depth $= \sqrt{(R\cos\phi)^2 + (R\sin\theta_o + 0{\cdot}05\,R)^2} - R$ - cover

a) Main steel ( to be provided along curve ), and

b) Distribution steel = 20 percent of main steel ( to be provided in portion below plane *AB* in Fig. 14 ).

NOTE 1 — Check that minimum reinforcement is 20 mm $\phi$, 7 numbers per tooth.

NOTE 2 — Cover in radial direction should be minimum 80 mm.

**6.2.3** *Design of Links for Tooth* — Provide 20 mm $\phi$ link reinforcement at 300 mm c/c around tooth in the direction perpendicular to flow. Distribution steel for links shall be provided on three side faces of tooth and shall be 20 mm $\phi$ at 300 mm c/c.

**6.3 Design of Reinforcement for 8°Apron** — Provide nominal reinforcement as under:

a) Along flow (main steel) = 20 mm $\phi$ at 300 mm c/c, and

b) Perpendicular to flow (distribution steel) = 16 mm $\phi$ at 300 mm c/c.

**6.4 Design of Reinforcement for 16° Apron** — Horizontal force on 16° apron

$$F_2 = \frac{W.q.V_2}{g}\,(\cos 8° - \cos 16°)$$

where

$$V_2 = \frac{b_1\,V}{b_2}$$

$b_1$ = width of slot at entry

$b_2$ = width of slot at exit

The horizontal force on apron is due to change in direction as above and it acts at $\frac{h_2}{2}$ above apron level ( $h_2$ = size of 16° apron ).

$$\text{Bending moment} = F_2 \times \frac{h_2}{2}$$

$$\text{Area of steel} = \frac{B.M.}{\sigma_{st}.j.d_2} = A_{st}$$

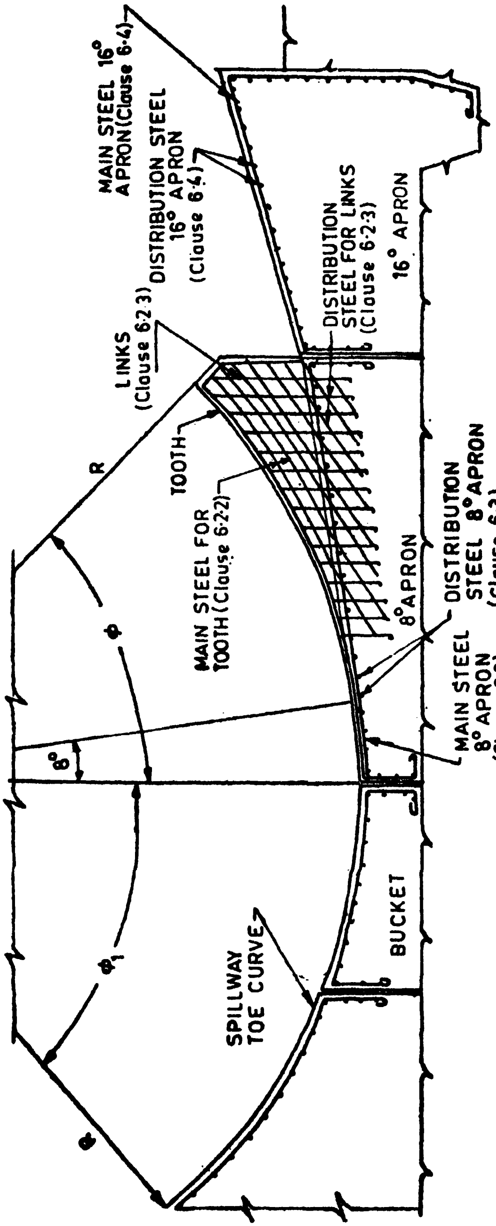


Fig. 15 Reinforcement Details for Bucket, Tooth and Apron

where

$d_2$ = effective depth for 16° apron = $h_2 \cos 16°$ — cover

NOTE — Minimum steel shall be provided as mentioned in **6.3**.

**6.5** Sample calculations are given in Appendix A.

# APPENDIX A

( *Clause* 6.5 )

## SAMPLE CALCULATIONS FOR SLOTTED ROLLER BUCKET

1) Exit angle $\theta_e = 45°$

2) Length of bucket = 237·0 m

3) Discharge θ at MWL = 14 501 cumecs

4) Width of tooth at *d/s* end = 1·125 m

5) Radius of bucket = 9·0 m

6) Invert level of bucket = R.L. 403·50 m

7) Junction of 8° and 16° apron = R.L. 404·37 m

8) MWL = R. L. 434·800 m

$$\text{Discharge } q = \frac{14\ 501}{237} = 61{\cdot}185 \text{ cumecs}$$

$$\text{Say } q = 62 \text{ cumecs/m}$$

according to **6.1.3**.

$$V = \sqrt{2gH}$$

$$= \sqrt{2 \times 9{\cdot}81 \times 31{\cdot}30} = 24{\cdot}781 \text{ m/s}$$

where $H$ = Fall of water ( head ) from MWL to bucket invert ( 434·800 — 403·50 ) = 31·30 m

## A-1. DESIGN OF REINFORCEMENT FOR BUCKET TOOTH

Horizontal force on tooth above plane *AB*

$$F_1 = \frac{W.q.V}{g} ( \cos \phi - \cos 45° ) \times b$$

according to **6.2.1**

$$\text{where } \cos\phi = \frac{\text{Radius} - (\text{junction of } 8^\circ \text{ and } 16^\circ \text{ apron} - \text{invert level})}{\text{Radius}}$$

$$= \frac{9 - (404{\cdot}37 - 403{\cdot}5)}{9}$$

$$\therefore \phi = 25{\cdot}4^\circ$$

$$\therefore F_1 = \frac{1\,000 \times 62 \times 24{\cdot}78}{9{\cdot}81} \times 0{\cdot}196\,2 \times 1{\cdot}125$$

$F_1 = 34\,568{\cdot}1$ kg

Horizontal ( water ) Force $= F_1$

acting at a distance $\frac{h}{2}$ from bottom.

$h = 1{\cdot}765$ m ( height of tooth )

$$B.M. = F_1 \times \frac{h}{2} \quad (\mathbf{6.2.1})$$

$$= 30\,506{\cdot}35 \text{ kgm}$$

$$\text{Effective depth } d = \sqrt{(R\cos\phi)^2 + (R\sin\theta_e + 0{\cdot}05\,R)^2} - R - \text{cover}$$

$$\therefore d = 152 \text{ cm}$$

$$\text{Area of steel } A_{st} = \frac{B.M.}{\sigma_{st}\cdot j.d.} \quad (\textit{see } \mathbf{6.2.2})$$

$$= \frac{30\,506{\cdot}35 \times 100}{1\,150 \times 0{\cdot}84 \times 152} \text{ cm}^2$$

$$= 20{\cdot}78 \text{ cm}^2$$

Provide 20 mm $\phi$ bars, 7 numbers per tooth.

Distribution steel 20 percent of main steel $= 4{\cdot}4$ cm$^2$

Provide 12 mm $\phi$ bars at the rate of 250 mm c/c below plane $AB$.

*Design of Links* — Provide 20 mm $\phi$ link reinforcement at 300 mm c/c around tooth in the direction perpendicular to flow. Distribution steel for links shall be provided on three side faces of tooth and shall be 20 mm $\phi$ at 300 mm c/c.

**A-2. DESIGN OF REINFORCEMENT FOR 8° APRON**

Provide nominal reinforcement as under:

a) Along flow = 20 mm $\phi$ 300 mm c/c.

b) Perpendicular to flow = 16 mm $\phi$ at 300 mm c/c.

**A-3. DESIGN OF REINFORCEMENT FOR 16° APRON**

Horizontal force on 16° apron

$$F_2 = \frac{W.q.V_2}{g} (\cos 8° - \cos 16°)$$

according to **6.4**.

where

$$V_2 = \frac{b_1 \ V}{b_2} = \frac{0{\cdot}838 \times 24{\cdot}78}{0{\cdot}450} = 46{\cdot}145 \text{ m/s}$$

$\therefore F_2 = 8\,458$ kg

$$B.M. = F_2 \times \frac{h_3}{2}$$

where $h_2$ is rise of 16° apron = 1·3 m

$$\therefore B.M. = 8\,458 \times \frac{1{\cdot}3}{2}$$

$= 5\,498$ kg.m

$$A_{st} = \frac{B.M.}{\sigma_{st}\ j.d_2} \quad (\textit{see } \mathbf{6.4})$$

where $d_2 = (h_2 \cos 16° - \text{cover}) = 1{\cdot}25 - 0{\cdot}1 = 1{\cdot}15$ m

$$\therefore A_{st} = \frac{549\,800}{1\,150 \times 0{\cdot}84 \times 115} = 4{\cdot}95 \text{ cm}^2$$

*Min* Steel provided — a) Along flow = 20 mm $\phi$ at 300 mm c/c

b) Perpendicular to flow = 16 mm $\phi$ at 300 mm c/c.

# INTERNATIONAL SYSTEM OF UNITS ( SI UNITS )

**Base Units**

| Quantity | Unit | Symbol |
|---|---|---|
| Length | metre | m |
| Mass | kilogram | kg |
| Time | second | s |
| Electric current | ampere | A |
| Thermodynamic temperature | kelvin | K |
| Luminous intensity | candela | cd |
| Amount of substance | mole | mol |

**Supplementary Units**

| Quantity | Unit | Symbol |
|---|---|---|
| Plane angle | radian | rad |
| Solid angle | steradian | sr |

**Derived Units**

| Quantity | Unit | Symbol | Definition |
|---|---|---|---|
| Force | newton | N | 1 N = 1 $kg.m/s^2$ |
| Energy | joule | J | 1 J = 1 N.m |
| Power | watt | W | 1 W = 1 J/s |
| Flux | weber | Wb | 1 Wb = 1 V.s |
| Flux density | tesla | T | 1 T = 1 $Wb/m^2$ |
| Frequency | hertz | Hz | 1 Hz = 1 c/s ($s^{-1}$) |
| Electric conductance | siemens | S | 1 S = 1 A/V |
| Electromotive force | volt | V | 1 V = 1 W/A |
| Pressure, stress | pascal | Pa | 1 Pa = 1 $N/m^2$ |

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