IS 12966 (Part 2) : 1990
(Reaffirmed 1997)

भारतीय मानक

बांधों में दीर्घा और अन्य दिवारों की रीति संहिता

भाग 2 संरचना डिजाइन

Indian Standard

CODE OF PRACTICE FOR GALLERIES AND OTHER OPENINGS IN DAMS

PART 2 STRUCTURAL DESIGN

UDC 627·8·068 : 624·04

BUREAU OF INDIAN STANDARDS
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February 1991 Price Group 4

Dams (Overflow and Non-overflow) Sectional Committee, RVD 9

FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards on 22 February 1990, after the draft finalized by the Dams (Overflow and Non-overflow) Sectional Committee had been approved by the River Valley Division Council.

A large number of galleries and other openings are provided in practically all modern high dams. The galleries are required for access, grouting, inspection, drainage and for the operation of gates. Other major openings include sluices, temporary diversion conduits, river outlets and penstock openings. In addition there are openings for stairwells, shafts, air vents; drainage holes etc.

To enable the designing of gallery it is necessary to determine the general stress field to which the opening is subjected and subsequently to analyse the local alteration in it due to the particular shape of the opening.

In this standard only small openings such as foundation gallery, inspection gallery, adit to gallery etc have been considered. The openings such as sluices, penstocks and other similar openings have been excluded from this standard.

For the purpose of deciding whether a particular requirement of this standard is complied with the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding of 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

CODE OF PRACTICE FOR GALLERIES AND OTHER OPENINGS IN DAMS

PART 2 STRUCTURAL DESIGN

1 SCOPE

1.1 This standard lays down method of determining reinforcement around openings in solid gravity dams constructed either in concrete or in masonry, and are applicable to openings which can be analysed as two dimensional problems.

1.2 The design of openings which are large in comparison with the size of the dam is not considered in this standard. If *d* is the maximum cross-sectional dimension of the gallery of the opening, it is considered large when either of the following is complied with :

a) $d \geq 6$ m, or

b) concrete or masonry cover any where around it is less than *d*.

2 REFERENCES

2.1 The following Indian Standards are necessary adjunct to this standard:

IS No.	*Title*
456 : 1978	Code of practice for plain and reinforced concrete (*third revision*)
457 : 1957	Code of practice for general construction of plain and reinforced concrete for dams and other massive structures
4410 (Part 8): 1968	Glossary of terms relating to river valley projects: Part 8 Dams and dam sections
6512 : 1984	Criteria for design of solid gravity dams (*first revision*)
8605 : 1977	Code of practice for construction of masonry in dams

3 TERMINOLOGY

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

3.1 Air Vent

An opening provided for the entry/escape of air.

3.2 Boundary Stress

The normal stress on a plane perpendicular to a free boundary.

3.3 Critical Load

A loading condition which will produce maximum or the most significant stresses in the structure under consideration.

3.4 Diversion Conduit

A conduit used for the temporary diversion of water from the reservoir.

3.5 Drainage Hole

Openings for ensuring proper drainage of the structure.

3.6 Gate Gallery

Gallery, made in a dam, to provide access to and room for, the mechanical equipment required for the operation of gates in outlet conduits or power penstocks, etc.

3.7 Penstock Opening

Openings for pipes which convey water from intake to turbine in hydroelectric schemes.

3.8 Plumbline Shaft

A shaft located in a dam in order to make observations of the deflection of the dam with respect to the base.

3.9 Reservoir Empty Condition

The condition in which no water load is assumed to be present on upstream side of the dam.

3.10 Reservoir Full Condition

The condition in which the water level is at F.R.L. on upstream side of the dam.

3.11 Stair Well

A vertical opening provided in the body of the dam to accommodate staircase.

3.12 Total Tension

Integral of the tensile stress normal to the section from the boundary, of zero tensile stress.

3.13 Transverse Gallery

A gallery in the direction perpendicular to that of longitudinal axis of the dam.

3.14 Uniaxial Stress Field

If a thin plate is loaded by forces applied at the boundary only in one direction a state of uniaxial stress field is said to exist.

4 SYMBOLS

4.1 For the purpose of this code and unless otherwise defined in the text, the following letter symbols shall have the meaning indicated against each:

A_t	=	Cross-sectional area of steel in tension
a	=	Semi-major axis of elliptic openings
b	=	Semi-minor axis of elliptic opening
F	=	Total tensile force across the section
A	=	Height of rectangular opening
B	=	Width of rectangular opening
r	=	Radius of circle
r, θ	=	Polar co-ordinates
σ_r, σ_θ	=	Radial and tangential normal stresses in polar co-ordinates
$\tau_{r\theta}$	=	Shear stress in polar co-ordinates
σ_x	=	Normal stress on vertical plane
σ_y	=	Normal stress on horizontal plane
σ_{yu}, σ_{yd}	=	Normal stress on horizontal plane at the upstream/downstream face of the dam (calculated by stability analysis at the level of consideration)
τ_{xyu}	=	Shear stress on xy plane at the upstream face of dam
τ_{xyd}	=	Shear stress on xy plane at the downstream face of dam
p_u	=	Pressure (water + silt, if any) at the u/s face of dam at the level of consideration
p_d	=	Pressure (water + silt, if any) at the d/s face of dam at the level of consideration
T	=	Total base width of the dam at the level of consideration
x	=	Distance of centre of gallery from toe
ΣP	=	Total horizontal force at the level of consideration
ΣW	=	Total vertical force at the level of consideration
ΣM	=	Total moment about c.g. of the Section of the base of dam i.e. middle of the Section assuming the dam base as 1 m wide strip.

5 MATERIALS

5.1 Concrete

Plain and reinforced concrete shall conform to IS 456 : 1978. Mass concrete shall conform to IS 457 : 1957.

5.2 Masonry

Stone masonry shall conform to IS 8605 : 1977.

6 BASIS OF DESIGN

6.1 Openings in structure develop a discontinuity in the stress field and may develop zones of tensile stress and high compressive stress and in general weaken the structure. Reinforcement, has, therefore, to be provided in many cases.

6.2 The analysis has to be conducted in two stages:

a) Determination of overall stress field in the centre of openings, and

b) Detailed determination of the stress distribution around openings and determination of total tension therefrom.

6.3 Overall Stress Field

The stress field at the center line of the opening is determined by one of the following methods.

6.3.1 *Approximate Analytical Method*

"Gravity Method of Analysis", which assumes linear distribution of vertical stresses on horizontal planes, is generally used. The method provides a two-dimensional solution and idealizes the dam as composed of a number of vertical elements, each of which carries its load to the foundation without any transfer of the load to adjacent vertical elements. The shear stress distribution is parabolic and horizontal stress distribution is cubic. This method is used to determine, for each loading combination (*see* IS 6512 : 1984), the normal stresses on horizontal and vertical planes. The details of the method are given in Annex A.

6.4 Stress Distribution Around Openings

Distribution of stress field due to opening is generally determined by one of the following methods.

6.4.1 *Theory of Elasticity*

Where a closed form analytical solution is available it may be used for analysis.

6.4.1.1 *Circular openings*

For a circular hole of radius 'r_0' in an infinite plate subjected to uniform uniaxial stress (p) in the vertical direction, using polar co-ordinates (r, θ), the stress coefficients are given by :

$$\frac{\sigma_r}{p} = \frac{1}{2}\left(1 - \frac{r_0^2}{r^2}\right) + \frac{1}{2}\left(1 + \frac{3r_0^4}{r^4} - \frac{4r_0^2}{r^2}\right)\cos 2\theta$$

$$\frac{\sigma_\theta}{p} = \frac{1}{2}\left(1 - \frac{r_0^2}{r^2}\right) - \frac{1}{2}\left(1 + \frac{3r_0^4}{r^4}\right)\cos 2\theta$$

$$\frac{\tau_{r\theta}}{p} = \frac{1}{2}\left(1 - \frac{3r_0^4}{r^4} + \frac{2r_0^2}{r^2}\right)\sin 2\theta$$

where θ = angle from the crown as shown in Fig. 2. At a distance of ($\sqrt{3} - 1$) r_0 from the crown the tensile stress reduces to zero and then charges to compressive. If the distance is approximately assumed as 0·5 r_0 and stress distribution taken as linear, total tension at top and bottom works out to approximately 0·25 pr_0 for which reinforcement shall be provided in the absence of more detailed analysis.

Along the contour the normal stress coefficient is given by:

$$\frac{\sigma_\theta}{p} = (1 - 2\cos 2\theta)$$

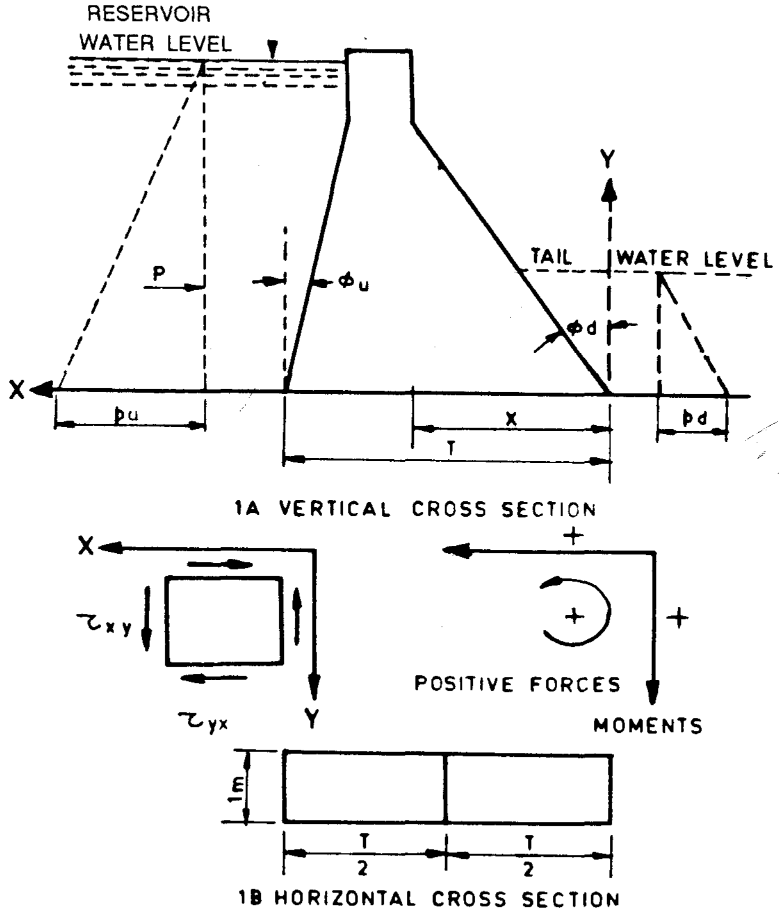


FIG. 1 SIGN CONVENTION FOR THE FORCES ACTING ON THE DAM SECTION

6.4.1.2 *Elliptic openings*

For elliptic opening with major and minor axes 2a and 2b, in a plate, subjected to uniform uniaxial stress field (p) tangential stress coefficient along the contour is given by:

$$\frac{\sigma_\theta}{p} = \frac{\sin^2\theta + 2K\sin^2\theta - K^2\cos^2\theta}{\sin^2\theta + K^2\cos^2\theta} \quad \text{where } K = \frac{a}{b}$$

For $\theta = 0$, $\frac{\sigma\theta}{p} = 1$ and for $\theta = \frac{\pi}{2}$, $\frac{\sigma_\theta}{p}\left(1 + \frac{2a}{b}\right)$

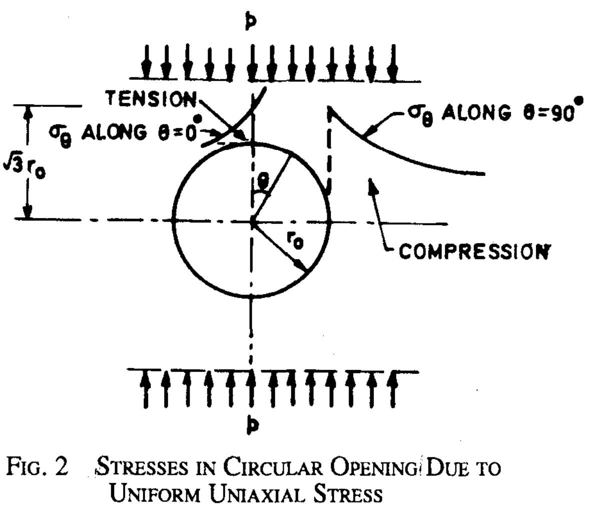


FIG. 2 STRESSES IN CIRCULAR OPENING DUE TO UNIFORM UNIAXIAL STRESS

6.4.2 *Stress Coefficients*

Stress coefficient for rectangular openings of various width and height ratio, for normal stress perpendicular to the centre line of opening, due to uniform stress fields parallel to or perpendicular to the line, can be obtained from the curves given in Fig. 3 and 4.

6.4.3 *Photoelastic Method*

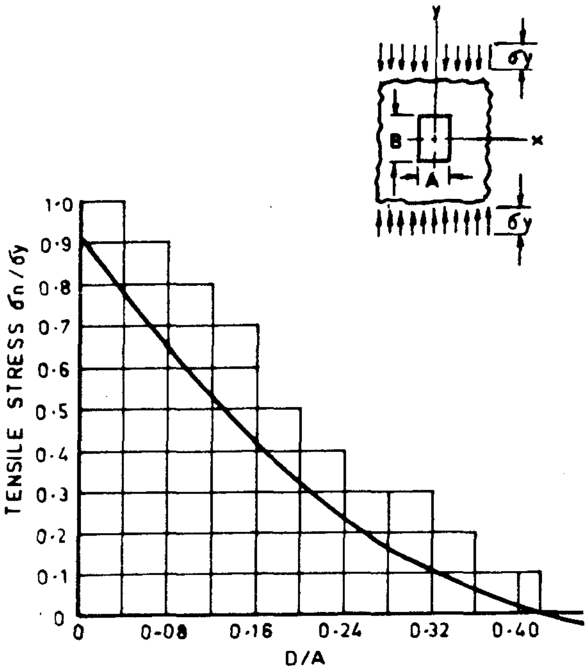
For more complex forms and load conditions photoelastic method is preferred. Numerous applications of photoelastic method have been made in the design of various types of openings required in Civil, Mechanical and Aeronautical structures. Using photoelastic method extensive work has been done to obtain stress distribution around openings of various shapes such as square, rectangular with semi-circular roof and rectangular.

The data is available for the following cases :

1. Openings in uniform uniaxial compressive stress field.
2. Openings in uniform bi-axial stress field.
3. Square openings close to a free boundary.

6.4.4 *Finite Element Method*

Finite element method has been used for obtaining elastic-plastic analysis of openings. This method is particularly useful in investigation of the behaviour of openings in non-linear range and to study the propagation of cracks near the openings.



NOTE — For design purposes the normal stress on the centerline parallel to the stress field direction may be considered to be independent of B. For $\sigma_x = 0$ the tensile area = 0·149 A. σ_n is the normal stress perpendicular to *Y*-axis. *D* is the distance from the boundary of the opening along the *Y*-axis.

FIG. 3 CURVE FOR STRESS COEFFICIENTS FOR RECTANGULAR OPENING DUE TO UNIFORM STRESS FIELD PERPENDICULAR TO THE LINE UNDER CONSIDERATION

7 LOADING CONDITIONS

7.1 Critical Loads

The important loads that are to be considered for the determination of overall stress field are dead load, reservoir and tail-water loads, earthquake forces, uplift pressure, earth and silt pressure, ice-pressure, wind pressure and wave pressure. Designs should be based on the most adverse combination of probable load conditions and include those loads having a reasonable probability of simultaneously occurrence. The gallaries and other openings in gravity dams shall be designed for the load combination listed in IS 6512 : 1984, Load combination *B*, *C*, *E*, *F* and *G*, shall, however, be analysed without uplift.

7.2 Typical planes considered for analysis – For some simplified cases critical loads and sections are indicated in Table 1.

8 ASSUMPTIONS IN DESIGN

8.1 Following assumptions have been made in carrying out the design:

a) The minimum distance of the boundary from the face of opening is two and half the width of the opening;
b) The problem is treated as plane stress problem;
c) Concrete is assumed to behave as a linear and elastic material. Tension upto the values permitted in IS 6512 : 1984 may be allowed. Gallery reinforcement is required if tension exceeds these permissible values; and
d) Total tensile force is taken by steel reinforcement.

9 PERMISSIBLE STRESSES

9.1 The permissible stresses for reinforcement shall be taken in accordance with the relevant standards.

10 DESIGN OF REINFORCEMENT

10.1 The following design procedure will apply to both concrete and masonry dams. In case of masonry dams, a portion around an opening which is reinforced is constructed in concrete. The thickness of concrete around vertical openings like air vents is generally 300 mm. For other opening, the thickness varies from 750 mm to 1 500 mm. The design procedure will be identical with that for a concrete dam; the assumption is that the masonry and concrete behave as one mass.

10.2 The procedure for the design of reinforcement will be as follows:

a) Locate the centre of the opening on a cross-section of the dam;
b) Determine prevalent stress field in the dam section at that location in the absence of the opening (*see* **6.3**)
c) Determine the stress distribution along the plane considered for design subjected to uniform stress field arrived at in (b) above (*see* **6.4**);
d) Compute the total tensile force across the plane considered for design (*see* **10.3**);
e) Compute area of steel reinforcement required (*see* **10.4**);
f) Details of the reinforcement (*see* **10.5**).

10.3 Computation of Total Tension

The total tension is determined by integrating the area under tension along a particular section.

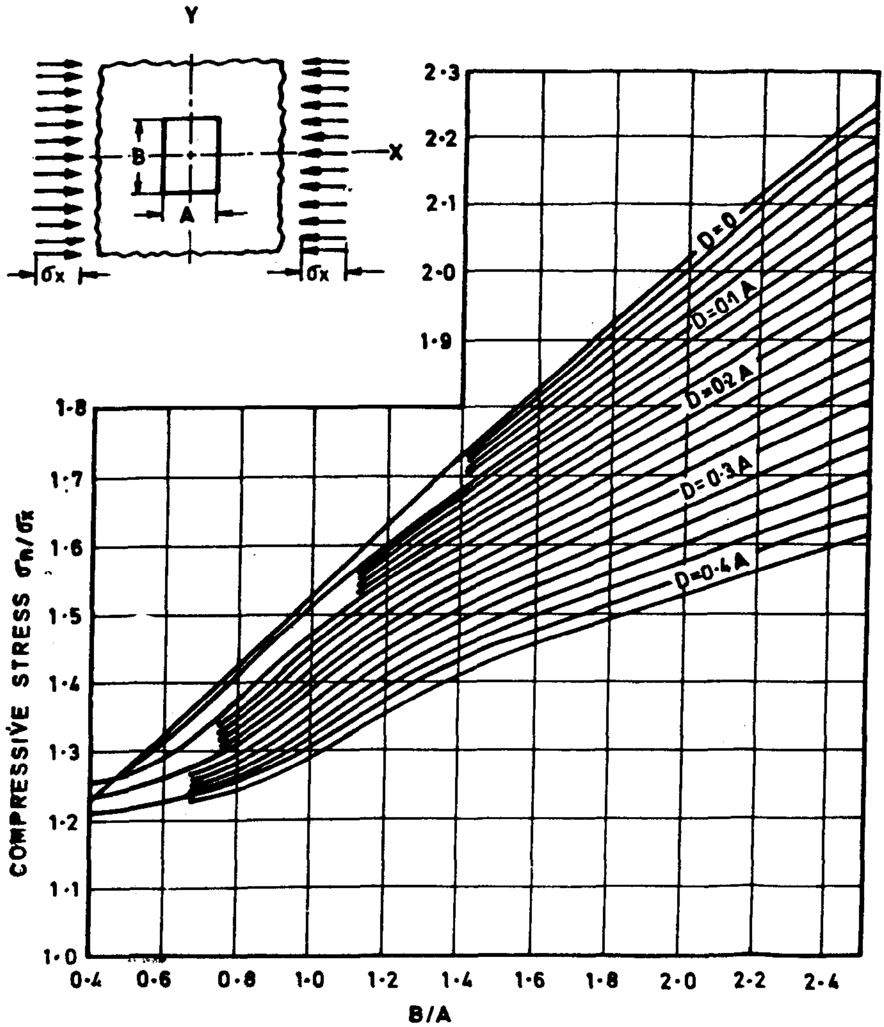
10.4 Computation of Area of Steel Reinforcement

After obtaining the total tension for section under consideration for the opening, for the critical loading condition, the area of steel is calculated by dividing the total tension (*F*) by allowable stress (σ_{st}) that is

$$A_t = \frac{F}{\sigma_{st}}$$

10.5 Detailing of Reinforcement

Typical reinforcement details are shown in Fig. 5. The reinforcement bars must be straight as far as possible and enchored in a zone of compressive stress. The bars will generally be put up horizontally above the roof of the gallery and vertically on the sides. Diagonal bars are necessary at the corners. The spacing of bars



NOTE — σ_n is the normal stress perpendicular to *Y*-axis. *D* is the distance from the boundary of the opening along the *Y*-axis.

FIG. 4 CURVE FOR STRESS COEFFICIENTS FOR RECTANGULAR OPENING DUE TO UNIFORM STRESS FIELD PARALLEL TO THE LINE UNDER CONSIDERATION

Table 1 Critical Loads and Sections

Type of Openings	Critical Loading Condition for Opening Located at			Planes Considered for Analysis
	u/s Third	Middle Third	d/s Third	
(1)	(2)	(3)	(4)	(5)
Longitudinal	Reservoir empty	Reservoir empty or full	Reservoir full	Vertical section perpendicular to the longitudinal axis of dam
Vertical	Reservoir full	Reservoir full	do	Horizontal section through the opening
Transverse	Reservoir empty	Reservoir empty or full	do	Vertical section parallel to longitudinal axis of dam

generally should not be less than 15 cm centre to centre and not greater than 30 cm. The minimum clear cover shall be 15 cm for the reinforcement. The minimum diameter of reinforcement bars shall be 16 mm for main reinforcement and 12 mm for distribution. Other details of reinforcement must follow IS 456 : 1978.

10.6 Relaxation in Design Criteria

Any change in the reinforcement around galleries as computed by the procedure indicated in **10.2** above can be made if indicated otherwise through the studies carried out by finite element and/or photoelastic methods.

11 SPECIAL CASES

11.1 Opening Close to Surface

In some cases, openings may have to be provided close to the face of the dam or near the face of a block. In such cases, the results obtained for normal openings discussed above are not applicable. Photoelastic method or finite element method should be used to obtain stress fields in such cases.

11.2 Multiple Openings

It is frequently necessary to provide a number of separate outlets through a dam. In a series of such openings in a single horizontal plane, the clear spacing between these openings should be more than two times the width of opening. The average compression on the unbroken portions of a horizontal section containing these openings is equal to the total force on this section, divided by the net area. The distribution of this stress is unknown. A safe design should result if the average compression does not exceed the allowable compressive stress and if reinforcement is provided as for a single opening.

11.2.1 If the clear space between two openings is less than twice the width of openings, the horizontal reinforcement shall be made continuous. Such close spacing should be avoided as far as possible. For high dams, with high working compressive stresses the widest practicable spacing of openings should be adopted.

11.3 Three-Dimensional Openings, Intersections, etc

At the intersection of two or more openings, the state of stress is three-dimensional and the two dimensional procedure described above is not applicable. For a detailed analysis, three-dimensional investigations should be carried out. However, for gallery intersection, it should be generally adequate to double the main reinforcement provided at top and bottom on all the sides of intersection for a distance equal to the width of the gallery. A typical arrangement at gallery intersection is illustrated in Fig. 6.

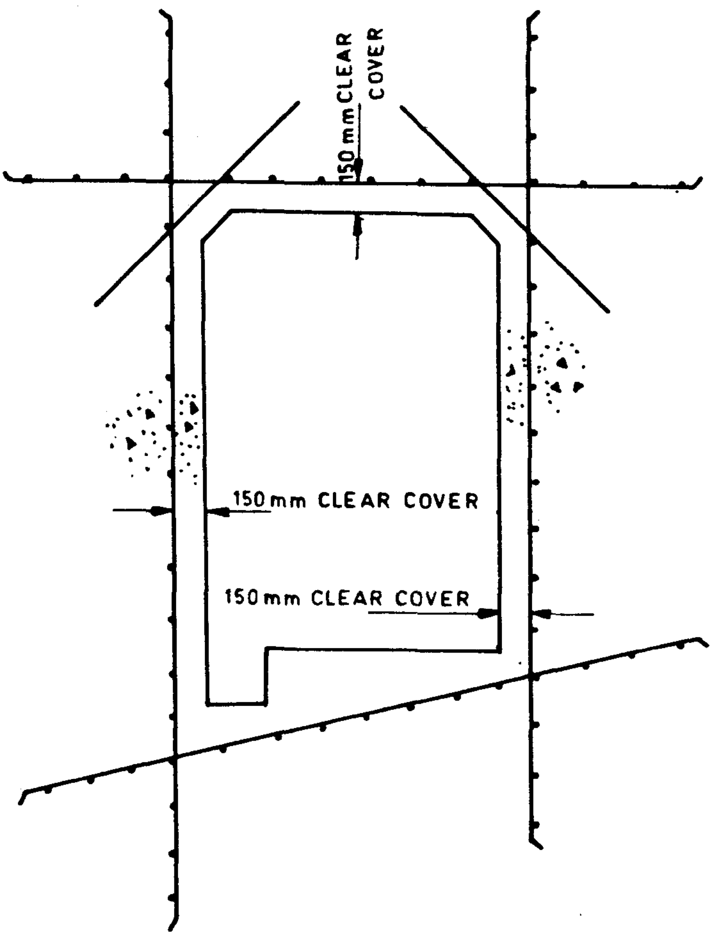
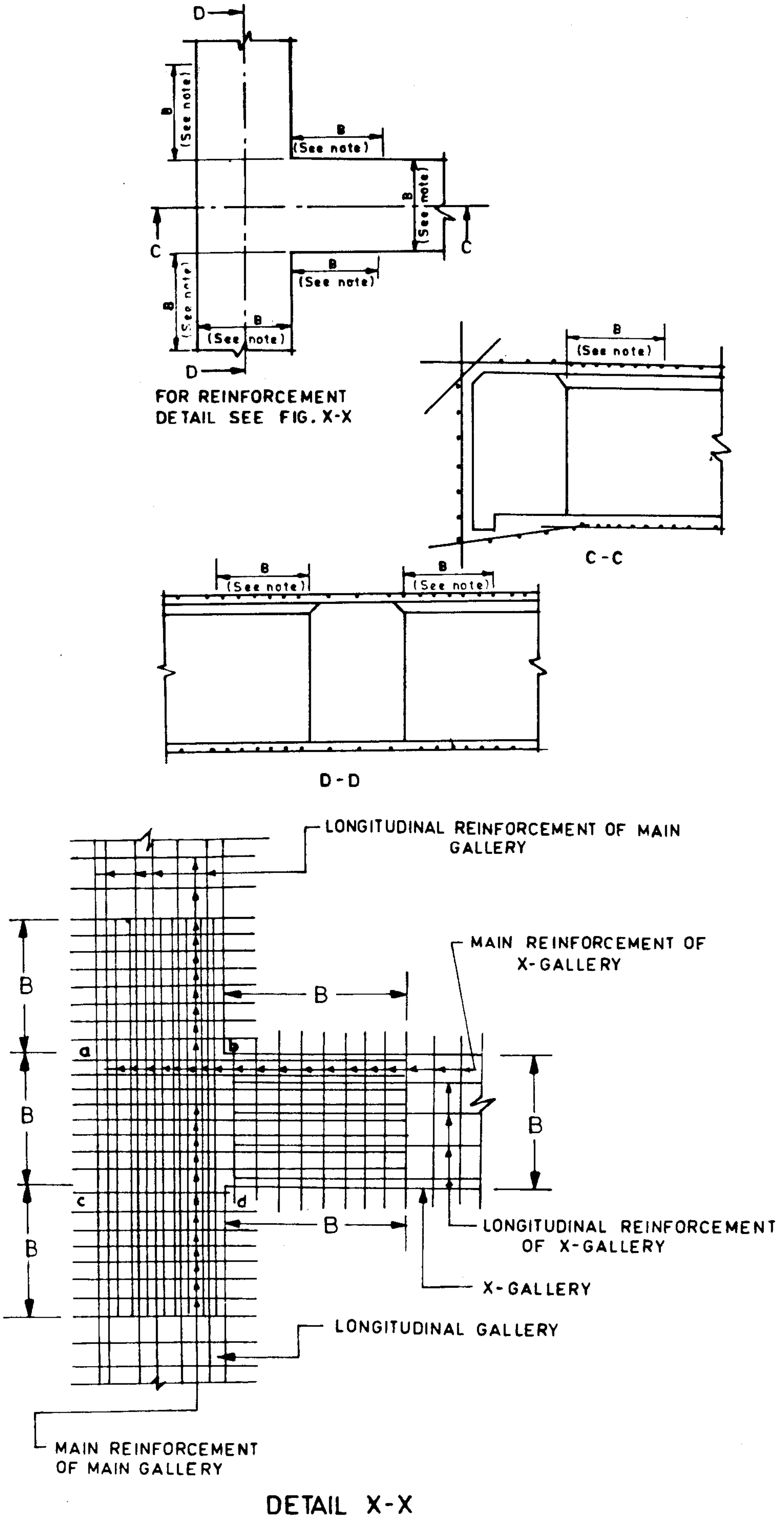


FIG. 5 TYPICAL REINFORCEMENT PLACEMENT POSITION AROUND A RECTANGULAR GALLERY



NOTE — Double the main reinforcement at top and bottom of gallery in the zone abcd, *B* is width of gallery.

FIG. 6 TYPICAL REINFORCEMENT PLACEMENT POSITION FOR T JUNCTION FOR RECTANGULAR GALLERIES

ANNEX A

(*Clause* 6.3.1)

APPROXIMATE ANALYTICAL METHOD

The overall stress field σ_x and σ_y in the dam Section along a line passing through the centre of opening for various conditions as stipulated is IS 6512 : 1984 is calculated as under:

i) **Normal Stress σ_y**

$$\sigma_y = a + bx$$

where, $a = \sigma_{yd}$

$$b = \frac{\sigma_{yu} - \sigma_{yd}}{T}$$

ii) **Shear Stress τ_{xy}, τ_{yx}**

$$\tau_{xy} = \tau_{yx} = a_1 + b_1 x + c_1 x^2$$

where,

$$a_1 = \tau_{xyd}$$

$$b_1 = -\frac{2}{T}\left(3\frac{\Sigma p}{T} + \tau_{xyu} + 2\tau_{xyd}\right)$$

$$c_1 = \frac{3}{T^2}\left(2\frac{\Sigma p}{T} + \tau_{xyu} + \tau_{xyd}\right)$$

$$\tau_{xyu} = -(\sigma_{yu} - p_u)\tan\phi_u$$

$$\tau_{xyd} = (\sigma_{yd} - p_d)\tan\phi_d$$

iii) **Normal Stress σ_x**

$$\sigma_x = a_2 + b_2 x + c_2 x^2 + d_2 x^3$$

where,

$$a_2 = a_1 \tan\phi_d + p_d$$

$$b_2 = b_1 \tan\phi_d + \frac{\partial a_1}{\partial y}$$

$$c_2 = c_1 \tan\phi_d + \frac{1}{2}\frac{\partial b_1}{\partial y}$$

$$d_2 = \frac{1}{3}\frac{\partial c_1}{\partial y}$$

The terms $\frac{\partial a_1}{\partial y}, \frac{\partial b_1}{\partial y}, \frac{\partial c_1}{\partial y}$ are calculated as below:

$$\frac{\partial a_1}{\partial y} = \tan\phi_d\left(\frac{\partial \sigma_{yd}}{\partial y} - r_\omega{}^*\right) + \frac{\partial}{\partial y}\tan\phi_d\,(\sigma_{yd} - p_d)$$

$$\frac{\partial b_1}{\partial y} = \frac{\partial T}{\partial y}\left[\frac{12}{T^3}\Sigma P + \frac{2}{T^2}\tau_{xyu} + \frac{4}{T^2}\tau_{xyd}\right] - \frac{6}{T^2}\frac{\partial}{\partial y}\Sigma P - \frac{2}{T}\frac{\partial}{\partial y}\tau_{xyu} - \frac{4}{T}\frac{\partial}{\partial y}\tau_{xyd}$$

$$\frac{\partial c_1}{\partial y} = -\frac{\partial T}{\partial y}\left[\frac{18}{T^4}\Sigma P + \frac{6}{T^3}\tau_{xyu} + \frac{6}{T^3}\tau_{xyd}\right] + \frac{6}{T^3}\frac{\partial}{\partial y}\Sigma P + \frac{3}{T^2}\frac{\partial}{\partial y}\tau_{xyu} + \frac{3}{T^2}\frac{\partial}{\partial y}\tau_{xyd}$$

Where,

$$\frac{\partial T}{\partial y} = \tan\phi_u + \tan\phi_d$$

$$\frac{\partial}{\partial y}\Sigma P = -(p_u - p_d)$$

$$\frac{\partial}{\partial y}\tau_{xyu} = \tan\phi_u\left(r_\omega{}^* - \frac{\partial}{\partial y}\sigma_{yu}\right) + \frac{\partial}{\partial y}\tan\phi_u\,(p_u - \sigma_{yu})$$

$$\frac{\partial}{\partial y}\tau_{xyd} = \tan\phi_d\left(\frac{\partial}{\partial y}\sigma_{yd} - r_\omega{}^*\right) + \frac{\partial}{\partial y}\tan\phi_d\,(\sigma_{yd} - p_d)$$

$$\frac{\partial}{\partial y}\sigma_{yu} = r_c + k_1\tan\phi_u + k_2\tan\phi_d + \frac{6}{T_2}\Sigma P$$

$$\frac{\partial}{\partial y}\sigma_{yd} = r_c + k_3\tan\phi_u + k_4\tan\phi_d - \frac{6}{T_2}\Sigma P$$

$$k_1 = \frac{4}{T}p_u - \frac{4}{T^2}\Sigma W - \frac{12}{T^3}\Sigma M$$

$$k_2 = \frac{2}{T^2}\Sigma W - \frac{2}{T}p_d - \frac{12}{T^3}\Sigma M$$

$$k_3 = \frac{12}{T^3}\Sigma M + \frac{2}{T^2}\Sigma W - \frac{2}{T}p_u$$

$$k_4 = \frac{12}{T^3}\Sigma M - \frac{4}{T^2}\Sigma W + \frac{4}{T}p_d$$

NOTE -- Refer Fig. 1 for reference

* To be omitted if no tail water.

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