भारतीय मानक
Indian Standard

IS 3370 (Part 2) : 2021

जलीय तरल पदार्थों को प्रतिधारित करने के लिए कंक्रीट संरचनाएं — रीति संहिता

भाग 2 सामान्य एवं प्रबलित कंक्रीट

(दूसरा पुनरीक्षण)

Concrete Structures for Retaining Aqueous Liquids — Code of Practice

Part 2 Plain and Reinforced Concrete

(Second Revision)

ICS 23.020.10; 91.010.30; 91.080.40

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Cement and Concrete Sectional Committee, CED 02

FOREWORD

This Indian Standard (Part 2) (Second Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Cement and Concrete Sectional Committee had been approved by the Civil Engineering Division Council.

The design and construction methods in reinforced concrete and pre-stressed concrete structures for retaining aqueous liquids are influenced by the prevailing construction practices, the physical properties of the materials and the climatic condition. To lay down uniform requirements of structures for the retaining liquids giving due consideration to the above mentioned factors, this standard has been published in four parts. The other parts in the series are:

Part 1 General requirements

Part 3 Prestressed concrete

Part 4 Design tables

This standard was first published in 1965 and subsequently revised in 2009. The second revision has been brought out with a view to keeping abreast with the rapid development in the field of construction technology and concrete design and also to bring further modifications in the light of experience gained while applying the earlier version of this standard. In this revision, the title of the standard has been modified from 'Concrete structures for storage of liquids — Code of practice: Part 2 Reinforced concrete structures' to 'Concrete structures for retaining aqueous liquids — Code of practice: Part 2 Plain and reinforced concrete' for better representation of the contents of the revised standard.

While, the common methods of design and construction have been covered in this standard, for design of structures of special forms or in unusual circumstances, special literature may be referred to or special systems of design and construction may be permitted on production of satisfactory evidence regarding their adequacy and safety by analysis or test or by both.

In this standard it has been assumed that the design of liquid retaining structures, whether of plain, reinforced or pre-stressed concrete is entrusted to a qualified engineer and that the execution of the work is carried out under the direction of a qualified and experienced engineer.

The concrete used in liquid retaining structures should have low permeability. This is important not only for its direct effect on leakage but also because it is one of the main factors influencing durability, resistance to leaching, chemical attack, erosion, abrasion, frost damage; and the protection from corrosion of embedded steel. The standard, therefore, incorporates provisions in design and construction to take care of this aspect.

The requirements of IS 456 : 2000 'Plain and reinforced concrete — Code of practice (*fourth revision*)' and IS 1343 : 2012 'Prestressed concrete — Code of practice (*second revision*)', in so far as they apply, shall be deemed to form part of this standard except where otherwise laid down in this standard. For long term performance of the structure, use of dense, nearly impermeable and durable concrete, adequate concrete cover without macro defects in cover concrete, proper detailing practices, control of cracking, effective quality assurance measures in line with IS 456 and good construction practices particularly in relation to construction joints should be ensured. Designer should take appropriate measures to the need for chemical resistance while dealing with liquids or sewage/effluents.

Following are the significant modifications incorporated in this revision:

a) Scope and provisions of the standard have been updated to reflect the applicability of the standard to concrete structures retaining all aqueous liquids.
b) Design recommendations are generally applicable to the retaining of aqueous liquids having temperature not exceeding 50 °C, and the same has been indicated.
c) Working stress method of design has been removed.
d) All the design provisions, as per limit state method, have been updated and made comprehensive.

(*Continued to third cover*)

Indian Standard

CONCRETE STRUCTURES FOR RETAINING AQUEOUS LIQUIDS — CODE OF PRACTICE

PART 2 PLAIN AND REINFORCED CONCRETE

(Second Revision)

1 SCOPE

1.1 This standard (Part 2) lays down requirements applicable specifically to design of plain and reinforced concrete structures, intended for storage or retaining of aqueous liquids. A concrete structure or member can function as liquid retaining, when the amount of liquid permeating through its thickness, under hydraulic gradient, is practically negligible.

The recommendations are generally applicable to the storage/retaining of aqueous liquids having temperature not exceeding 50 °C and no detrimental action on concrete and steel or where sufficient precautions have been taken to ensure protection of concrete and steel from damage due to action of such liquids.

1.2 This standard does not cover the requirements for concrete structures for storage/retaining of hot liquids, hazardous materials and liquids of low viscosity and high penetrating power, such as petrol, diesel and oil. This standard also does not cover dams, pipes, pipelines, tunnels and damp proofing of basements.

This standard does not cover all the requirements of pressurised tanks, floating structures and tanks having the additional requirement of gas tightness. The selection and design of coatings and linings are not covered in this standard.

2 REFERENCES

The following standards 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 this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below:

IS No.	*Title*
456 : 2000	Plain and reinforced concrete — Code of practice (*fourth revision*)
875	Code of practice for design loads (other than earthquake) for buildings and structures
(Part 1) : 1987	Dead loads — Unit weights of building materials and stored materials (*second revision*)
(Part 2) : 1987	Imposed loads (*second revision*)
(Part 3) : 2015	Wind loads (*third revision*)
(Part 4) : 1987	Snow loads (*second revision*)
(Part 5) : 1987	Special loads and combinations (*second revision*)
1343 : 2012	Prestressed concrete — Code of practice (*second revision*)
1893 (Part 2) : 2014	Criteria for earthquake resistant design of structures: Part 2 Liquid retaining tanks (*fifth revision*)
3370	Concrete structures for retaining aqueous liquids — Code of practice
(Part 1) : 2021	General requirements (*second revision*)
(Part 4) : 2021	Design tables (*first revision*)

3 GENERAL REQUIREMENTS

Design and construction of reinforced concrete liquid retaining structures shall comply with the requirement of IS 3370 (Part 1) and IS 456 unless otherwise laid down in this standard.

4 DESIGN

4.1 General

Provisions shall be made for conditions of stresses that may occur in accordance with principles of mechanics, recognized methods of design and sound engineering practice. In particular, adequate consideration shall be given to the effects of monolithic construction in the assessment of axial force, bending moment and shear.

4.2 Loads

4.2.1 All structures required to retain liquids should be designed for both the full and empty conditions, and the assumptions regarding the arrangements of all types of loading should be, such as to cause the most critical effects.

They should be designed to withstand the loads that they would be subjected to during their service life. Loads, such as dead load, imposed load, earthquake load, wind load, earth pressure, snow load (where applicable) and liquid load should be considered in the design. Additionally, the loads during constructions should also be considered during the design.

4.2.2 *Dead Load (DL)*

Dead loads shall be calculated in accordance with IS 875 (Part 1). Earth covering and plants on the roof may be taken as dead load. Due consideration should be given in the design to the construction loads from plant and heaped earth which may exceed the intended design load.

Sometimes, a provision is made to erect a masonry wall on the liquid retaining structure. Such dead loads, which may or may not be present, are called provisional dead loads (DL_p) and need separate considerations.

4.2.3 *Imposed Load (IL)*

Imposed loads (live loads), such as weights of fixed equipment (installation, operation, and maintenance), material stored and normal live loads due to personnel and other transient loadings shall be assumed in accordance with IS 875 (Part 2). With equipment, its allowance for impact or its action under dynamic conditions shall also be considered.

For example, heavy equipment, such as pump sets may be temporarily placed near the centre span of a floor during installation or maintenance, even though its final location may be elsewhere. Weights of concrete bases for equipment may be included in the loads, and consideration should be given to weights of piping, valves, and other equipment accessories that may be supported by the floor slab and beams. Alternately, conservative value of uniform imposed loads may be used in the design.

4.2.4 *Earthquake Load (EL)*

Earthquake loads may induce large horizontal and overturning forces in the structures and shall be calculated in accordance with IS 1893 (Part 2). *See also* Table 1.

4.2.5 *Wind Load (WL)*

Wind loads shall be assumed in accordance with IS 875 (Part 3).

4.2.6 *Earth Pressure (EP)*

Allowance should be made for the effects of any adverse earth pressures on the walls, according to the compaction and/or surcharge of the soil and the condition of the structure during construction and in service.

For pressure on wall, the appropriate active earth pressure coefficient should be chosen considering the fact that in most cases the displacement (or deflection) possible are much smaller than that require to achieve active pressure state. Earth pressure coefficient should be in between the values at rest and at active state, but shall not be less than 0.5 in any case.

No relief should be given for beneficial soil pressure effects on the walls of liquid retaining structures in the full condition. Relief in bending moments in wall due to simultaneous action of water pressure inside and that due to earth pressure (only up to half the active pressure of soil) from outside the wall may be made, provided that,

a) there is no risk of slip in the embankment or fear of a reduction in the earth pressure arising from shrinkage or future excavations or any other cause; and
b) the earth pressure allowed by way of relief in is the minimum which can be relied upon under the most unfavourable conditions possible, including those under which the reservoir is to be tested for water tightness.

4.2.7 *Snow Load*

Snow loads, where applicable, shall be assumed in accordance with IS 875 (Part 4).

4.2.8 *Liquid Load (FL)*

It is the effect of mass or pressure of the liquid to be considered in the design. It includes the dead storage, liquid pressure as well as the static and dynamic effect of liquid mass, wherever applicable.

Liquid load should account for the actual density of the liquid retained. Aqueous solutions or suspensions may have higher densities and the weight due to deposited silt, grit, accumulated sludge, lime, etc, should be taken into account.

In any combination, liquid load should be calculated at zero, partial and full condition so as to achieve the most critical load combination. Each tank shall be designed and also checked for tank empty condition. Free board of 150 to 300 mm may be considered. However, higher freeboard may be required for large horizontal tanks and the same shall be decided from hydraulic considerations.

The maximum level of liquid considered in tank for its basic operations is called full supply level (*FSL*) or working top level (*WTL*) of liquid.

The quantity of liquid shall be assumed up to the following levels, in the calculation of liquid load:

a) *Full Supply Level (FSL) Including Dead Storage* — FSL shall be considered for limit state of serviceability. However, in load combinations having wind and/or earthquake loads, liquid load shall be considered up to FSL only, in case of limit state of collapse as well.
b) *Level Under Maximum Overflow Rate or Maximum Top Level (MTL)* — MTL shall be considered for limit state of collapse.

4.2.8.1 The internal pressure of liquid shall be assumed to act at the centre of thickness of the retaining circular wall in contact with the liquid, unless impermeable lining is applied. The external pressure of liquid shall be assumed to act at outer surface of structure.

4.2.9 Loading effects due to temperature occurs when thermal expansion of a roof forces the walls of an empty structure into the surrounding backfill causing passive soil pressure. This effect may be reduced by providing a sliding joint between the top of the wall and under side of the roof which may be either a temporary free sliding joint that is not cast into a fixed or pinned connection, or a permanently sliding joint of assessed limiting friction. Movement of a roof may occur also where there is substantial variation in the temperature of the contained liquid. Where a roof rigidly connected to a wall this may lead to additional loading in the wall that should be considered in the design. Structures above the ground are more vulnerable to stresses resulting from temperature variations than those below ground.

4.2.10 A structure subject to groundwater (or uplift) pressures should be designed to resist floatation, especially when it is empty. Design of each member shall also account the pressure due to groundwater in suitable critical load combinations [*see* **8.2** (c) of IS 3370 (Part 1)].

4.2.11 The concrete, on drying loses moisture and contracts in size. This contraction (drying shrinkage), if restrained, produces tensile stresses that may exceed the tensile strength of concrete and cause cracking.

4.2.12 The junctions between various members (between wall and floor) intended to be constructed as rigid should be designed accordingly and effect of continuity should be accounted in design and detailing of each member.

4.3 Method of Design

4.3.1 General basis of design shall be in line with the requirements of IS 456, except where stated otherwise in this standard. Structural elements that are not exposed to retained liquid shall be designed in accordance with the requirements of IS 456 and IS 1343, as applicable.

4.3.2 While designing the liquid retaining concrete structure, plastic redistribution of moments as per IS 456 shall not apply. For design of flat slab, estimate of bending moments as per direct design method of IS 456 shall not apply. Bending moments and stresses shall be worked out based on the coefficients given in IS 3370 (Part 4).

4.3.3 Additional provisions for design of floors, walls and roof shall be as given in **5**, **6** and **7**, respectively.

4.4 Limit State Design

4.4.1 *Limit State Requirements*

All relevant limit states shall be considered in the design to ensure an adequate degree of safety and serviceability.

4.4.1.1 *Limit state of collapse (ultimate limit state, ULS)*

The recommendations given in IS 456 shall be followed.

4.4.1.2 *Limit states of serviceability (SLS)*

a) *Deflection* — The limits of deflection shall be as per IS 456.
b) *Cracking* — The maximum calculated crack width due to direct tension, flexure, restrained temperature and moisture effects shall not exceed 0.2 mm with specified cover. For aesthetics, aggressive conditions, or more severe exposures, owner may specify or designer may choose limiting crack width lower than 0.2 mm (*see* **4.4.3**).

4.4.1.3 *Partial safety factors*

a) *For loads* (γ_f) — The values given in Table 1 should be used.
b) *For materials* (γ_m) — The values should be taken as 1.5 for concrete and 1.15 for steel.

4.4.1.4 *Load combinations*

The various load combinations given in Table 1 shall be used. Any additional load combination, if required, may be chosen by the designer.

Table 1 Load Combinations and Partial Safety Factors, γ_f for Loads

[*Clauses* 4.2.4, 4.4.1.3 (a) *and* 4.4.1.4]

Load Case	Limit State of Collapse					Limit State of Serviceability				
	DL	*IL*	*EP*	*FL*	*WL/EL (see Note 1)*	*DL*	*IL*	*EP*	*FL*	*WL/EL (see Note 1)*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1	1.5	1.5	1.5	1.5	–	1.0	1.0	1.0	1.0	–
2	1.2	–	1.0	1.2	1.4	1.0	–	0.7	1.0	0.3
3	0.9	–	1.0	1.0	1.4					
4	1.4	–	1.0	–	1.4					
5	1.2	1.2	1.2	1.2	1.2					

NOTES

1 Wind and earthquake loads should be considered one at a time and not simultaneously.

2 For any load combination, the partial safety factor for liquid load (*FL*) may be further reduced if it is expected to give more critical design action at a section of a member. Liquid load may vary from zero (tank empty) to 1.5 in a combination. Same holds true for earth pressure in load combinations.

3 Earthquake base shear shall be worked out for a load combination 1 DL + 1 FL + 1 IL_s + 0.7 IL_p, where IL_s is the imposed load due to storage and IL_p is the provisional imposed load such as equipment load. The earthquake base shear (or force action), as determined, shall be multiplied by the load factor as given in Table 1, for further combination with other loads.

4.4.2 *Basis of Design*

Design and detailing of reinforced concrete shall be as specified in IS 456 except where stated otherwise. Additionally, the following shall apply:

a) Shear strength of a member subjected to design direct tension in combination with bending moment — The design shear strength of concrete given in Table 19 of IS 456 shall be multiplied by the following factor:

$$\delta = 1 - 8 \times \frac{P_u}{(A_g\ f_{ck})}$$

where

P_u = design direct tension, N; and

A_g = gross cross-sectional area of concrete, mm²

For member subject to direct tension, the critical section for shear force should be taken at face of support and not at a distance *d* from face of support (**22.6.2.1** and **40.5** of IS 456 shall not apply). If shear force exceeds the shear resistance of concrete, stirrups shall be designed to take shear and spacing of such stirrups shall not be more than half the effective depth of member, but not less than 75 mm.

b) Shear strength of a member at the construction joint reduces in comparison to that at any section on the monolithic concrete and depends largely on interface roughness and cleanliness of the surface at the time of placing second phase concrete.

c) Where there is need for higher shear resistance, combination of shear key, dowels and diagonal reinforcement may be adopted and accordingly designed to meet the shear requirement.

4.4.3 *Crack Widths*

Crack widths due to the temperature and moisture effects shall be calculated as given in Annex A for immature concrete and Annex B for mature concrete.

4.4.3.1 A reinforced concrete member subjected to direct tension and flexural tension may be deemed to be satisfactory in the absence of crack width calculations, if stresses in steel reinforcement under limit state of serviceability does not exceed the values given in Table 2.

For walls and slabs, the crack width requirement of 0.2 mm may be deemed to be satisfactory, in the absence of crack-width calculations, if for given reinforcement bar, the diameter, bar spacing and stress in high strength deformed steel reinforcement under limit state of serviceability does not exceed the values given in Table 3.

Table 2 Maximum Tensile Stresses in Steel Reinforcement (*SLS*)

(*Clause* 4.4.3.1)

Sl. No.	Limiting Crack Width (mm)	Maximum Stresses (N/mm²)	
		Plain Round Mild Steel Bars	High Strength Deformed Bars
(1)	(2)	(3)	(4)
i)	0.1	85	100
ii)	0.2	115	130

Table 3 Maximum Tensile Stress in Steel Reinforcement for Crack Control in Walls and Slabs (SLS)

(*Clause* 4.4.3.1)

Sl. No	Diameter of Steel Reinforcement (mm)	Centre-to-centre Spacing of Reinforcement, *Max* (mm)	Maximum Stress, *Max* (N/mm^2)
(1)	(2)	(3)	(4)
i)	10 or 12	75	155
ii)	12 or 16	100	150
iii)	16 or 20	125	148
iv)	20 or 25	150	145
v)	20 or 25	175	142
vi)	25 or 28	200	140
vii)	32	200	135

4.4.3.2 The liquid retaining structures may be classified in relation to the degree of protection against leakage required as given in Table 4. It should be noted that all concrete will permit the passage of small quantities of liquids and gasses by diffusion.

Table 4 Classification of Tightness

(*Clause* 4.4.3.2)

Sl. No.	Tightness Class	Requirements for Leakage
(1)	(2)	(3)
i)	1	Leakage to be limited to a small amount. Some surface staining or damp patches acceptable
ii)	2	Leakage to be minimal. Appearance not to be impaired by staining
iii)	3	No leakage permitted. Special measures such as Prestressing or liner required.

4.4.3.3 Limiting crack width should be chosen depending on the classification of the particular element under consideration and the required function of the whole structure. The following guidelines may be adopted, in absence of more specific requirements:

a) *Tightness Class 1* — Limiting crack width for cracks expected to pass through the full thickness of the section (that is, no compression block) be limited to 0.2 mm.

b) *Tightness Class 2* — Limiting crack width shall be 0.2 mm and cracks expected to pass through the full thickness of the section are avoided unless appropriate measures such as liners or water bars have been incorporated. Alternatively, limiting crack width shall be 0.1 mm.

c) *Tightness Class 3* — Limiting crack width shall be 0.1 mm. Cracks should not pass through the full thickness of the section and a compression zone of at least 50 mm should be available. Generally, special measures like application of liners or prestress will be required to ensure this class of water-tightness.

4.4.3.4 The limiting crack width values as given in **4.4.3.3** may be exceeded by 0.05 mm, if H/t ratio is 20 or less. However, the limiting crack width shall not exceed 0.2 mm, in any case.

4.4.3.5 The crack width at construction joint may be assumed to be 0.05 mm more than the crack width estimated for monolithic construction.

4.4.3.6 The crack width enhances due to shear in absence of shear reinforcement in slabs and the same shall be checked against additional equivalent moment due to shear, M_{es} given by $SF \times D/3$, where D is overall depth of slab at the section considered.

4.5 Stresses Due to Moisture or Temperature Changes

4.5.1 No separate calculation is required for stresses due to moisture or temperature change in the concrete provided that:

a) The reinforcement provided is not less than that specified in **8**.

b) With regard to the provision of movement joints, the design comply with either of the following:

   1) Option 1 in Table 2 of IS 3370 (Part 1).

   2) Option 2 or option 3 in Table 2 of IS 3370 (Part 1) and a suitable sliding layer beneath the tank given therein.

4.5.2 Where reservoirs are protected with an internal impermeable lining, consideration should be given to the possibility of concrete eventually, drying out. Unless it is established on the basis of tests or experience that the lining has adequate crack bridging properties, allowance for the increased effect of drying shrinkage should be made in the design.

5 FLOORS

5.1 Provisions of Movement Joints

Movement joints shall be provided in accordance with IS 3370 (Part 1).

5.2 Floors of Tanks Resting on Ground

The floors of tanks resting on ground shall be in accordance with IS 3370 (Part 1). When the bottom of the tank is below the water table, the loading on the slab from hydrostatic pressure should be considered in the design. If the upward pressure exceeds the dead load of the tank floor, there may be a danger of heaving unless the floor is designed and constructed as a structural slab with loading directed upward rather than downward.

5.3 Floors of Tanks Resting on Supports

If the tank is supported on walls or other similar supports, the floor slab shall be designed for bending moments due to water load and self-weight. The worst conditions of liquid load may be other than those given in **22.4.1** of IS 456, since, liquid level extends over all spans in normal construction. However, in case of multi-cell tanks, these will have to be determined by the designer for each particular case.

5.3.1 When the floor is rigidly connected to the walls (as is generally the case), the bending moments at the junction between the walls and floor shall be taken into account in the design of floor together with any direct forces transferred to the floor from the walls or from the floor to the wall due to the suspension of the floor from the wall (*see* **8.3**).

6 WALLS

6.1 Provision of Joints

6.1.1 *Sliding Joints at the Base of the Wall*

Where it is desired to allow the walls to expand or contract separately from the floor, or to prevent moments at the base of the wall owing to fixity to the floor, sliding joints may be provided.

6.1.1.1 Constructions affecting the spacing of vertical movement joints are discussed in IS 3370 (Part 1). While the majority of these joints may be of the partial or complete contraction type, sufficient expansion joints should be provided to satisfy the requirements of IS 3370 (Part 1).

6.1.1.2 Structure may be provided as a continuous one without movement or partial movement joints. If movement joints are provided, it is recommended that partial or induced contraction joint should not be placed more than 10 m spacing from a movement joint. Full contraction joint shall not be placed at more than 30 m spacing, and may have partial joints in between.

6.2 Pressure on Walls

6.2.1 In liquid retaining structures with fixed or floating covers, the gas pressure developed above liquid surface shall be added to the liquid pressure.

6.2.2 When the wall of liquid retaining structure is built in ground or has earth embanked against it, the effect of earth pressure shall be taken into account as discussed in IS 3370 (Part 1).

6.3 Walls of Tanks Rectangular or Polygonal in Plan

While designing the walls of rectangular or polygonal concrete tanks, the following points should be taken care of:

a) In plane walls, the liquid pressure is resisted by both vertical and horizontal bending moments. An estimate of the bending moments in the vertical and horizontal planes should be made. The horizontal tension caused by the direct pull due to water pressure on end walls should be added to that resulting from horizontal bending moment.
b) Vertical junctions and all other junctions of wall and any other member shall be analysed and designed for force actions due to continuity, even if the wall panel is designed primarily spanning in direction parallel to the line of junction (that is, wall vertically spanning). At the junction, reinforcement shall be designed for continuity effect.

In the case of rectangular or polygonal tanks, the side walls act as two way panel, whereby the wall is continued or restrained in the horizontal direction, fixed or hinged at the bottom and hinged or free at the top. The walls thus act as thin plates subject to triangular loading and with boundary conditions varying between full restraint and free edge. The analysis of moment and forces may be made on the basis of any recognized method, such as finite element method. The moment coefficients, for some common boundary conditions of wall panels are given in IS 3370 (Part 4) for general guidance.

6.4 Walls of Cylindrical Tanks

While designing walls of cylindrical tanks, the following should be considered:

a) Wall thickness should be designed, such as to keep concrete from cracking and the steel ring carry all the tension.
b) Walls of cylindrical tanks are either cast monolithically with the base or are set in grooves and keyways (movement joints). In either case, deformation of the wall under the influence of liquid pressure is restricted at the base.
c) Unless the extent of fixity at the base is established by analysis with due consideration to the dimensions of the base slab, the type of joint between the wall and slab and the type of soil supporting the base slab, the wall should be assumed to be fully fixed at the base for the purpose of estimating moment at base of wall. For moments at mid span of wall, condition of partial fixity at base should be considered. In the absence of detailed analysis involving stiffness of floor slab and foundation, for partial fixity, average of the two conditions (namely, fixed and hinged) may be taken.

Coefficient for ring (hoop) tension and vertical moments for different conditions of the walls for some common cases are given in IS 3370 (Part 4).

7 ROOFS

7.1 Provision of Movement Joints

To avoid the possibility of sympathetic cracking, it is important to ensure that movement joints in the roof correspond with those in walls, if roof and walls are monolithic. If, however, provision is made by means of a sliding joint for movement between the roof and the wall, correspondence of joints is not necessary.

7.2 Loading

Roofs should be designed for the following load conditions:

a) Gravity loads, such as the weight of roof slab, earth cover, live loads and mechanical equipment, if any. Live load should be arranged so as to give the most critical bending moment.
b) Upward pressure, if the tank is subjected to internal pressure or if roof is subjected to upward pressure due to sloshing of liquid.
c) Safety in case of the unequal intensity of loading, which may occur during construction and the placing of the earth cover.
d) Temporary condition of some spans loaded and other spans unloaded, even though in the final state the load may be small and/or evenly distributed.

7.3 Liquid-Tightness

In case of tanks intended for retaining water for drinking/domestic purposes or treated water, the roof should be made liquid-tight. This may be achieved by designing the roof as water retaining member and providing slopes to ensure adequate drainage.

7.4 Protection Against Corrosion

Protective measures shall be taken at the underside of the roof to prevent it from corrosion due to condensation and chlorine attack. It shall also be designed as a liquid retaining member, complying with stipulations regarding minimum cover and crack width.

8 DETAILING

8.1 Minimum Reinforcement

8.1.1 The minimum reinforcement in walls, floors and roofs in each of two directions at right angles, within each surface zone shall not be less than percentage specified in Table 5. The percentage applies to surface zones, as shown in Fig. 1 and Fig. 2.

Table 5 Minimum Percentage of Reinforcement

(*Clause* 8.1.1)

Sl No.	Grade of Reinforcement	Elevated Tank with Length (*see* Note 1)		Ground supported Tank with Length (*see* Note 1)	
		$\leq$ 14 m	$\geq$ 28 m	$\leq$ 14 m	$\geq$ 22 m
(1)	(2)	(3)	(4)	(5)	(6)
i)	Fe 250	0.44 Percent	0.66 Percent	0.40 Percent	0.60 Percent
ii)	Fe 415 or Fe 500	0.28 Percent	0.42 Percent	0.24 Percent	0.36 Percent

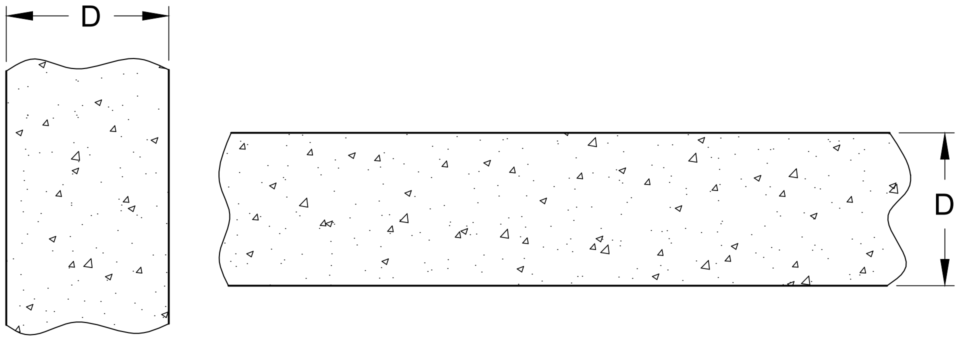
NOTES

1 Length is the horizontal length of continuous reinforced concrete members in between full movement joints (if provided) or end of structure along the direction of main reinforcement. For significantly long lengths (> 30 m) higher percent of steel may be required.

2 For lengths between 14 m and 28 m for elevated tanks, and between 14 m and 22 m for ground supported tanks, minimum percentage of reinforcement required shall be linearly interpolated.

8.1.2 In walls having thickness less than 160 mm or slabs having thickness less than 180 mm, the entire minimum reinforcement may be placed in one face.

For ground slabs having thickness less than 300 mm (*see* Fig. 2), the calculated reinforcement should be placed wholly in top surface with cover not exceeding 50 mm. For ground slabs having thickness more than 300 mm, the reinforcement required shall be calculated separately for top and surface zone as per Annex A and shall be placed accordingly with cover not exceeding 50 mm.



NOTES

1 For $D \leq 500$ mm, assume each reinforcement face controls $D/2$ depth of concrete.

2 For $D > 500$ mm, assume each reinforcement face controls 250 mm depth of concrete, ignoring any central core beyond this surface depth.

FIG. 1 SURFACE ZONES: WALLS AND SUSPENDED SLABS

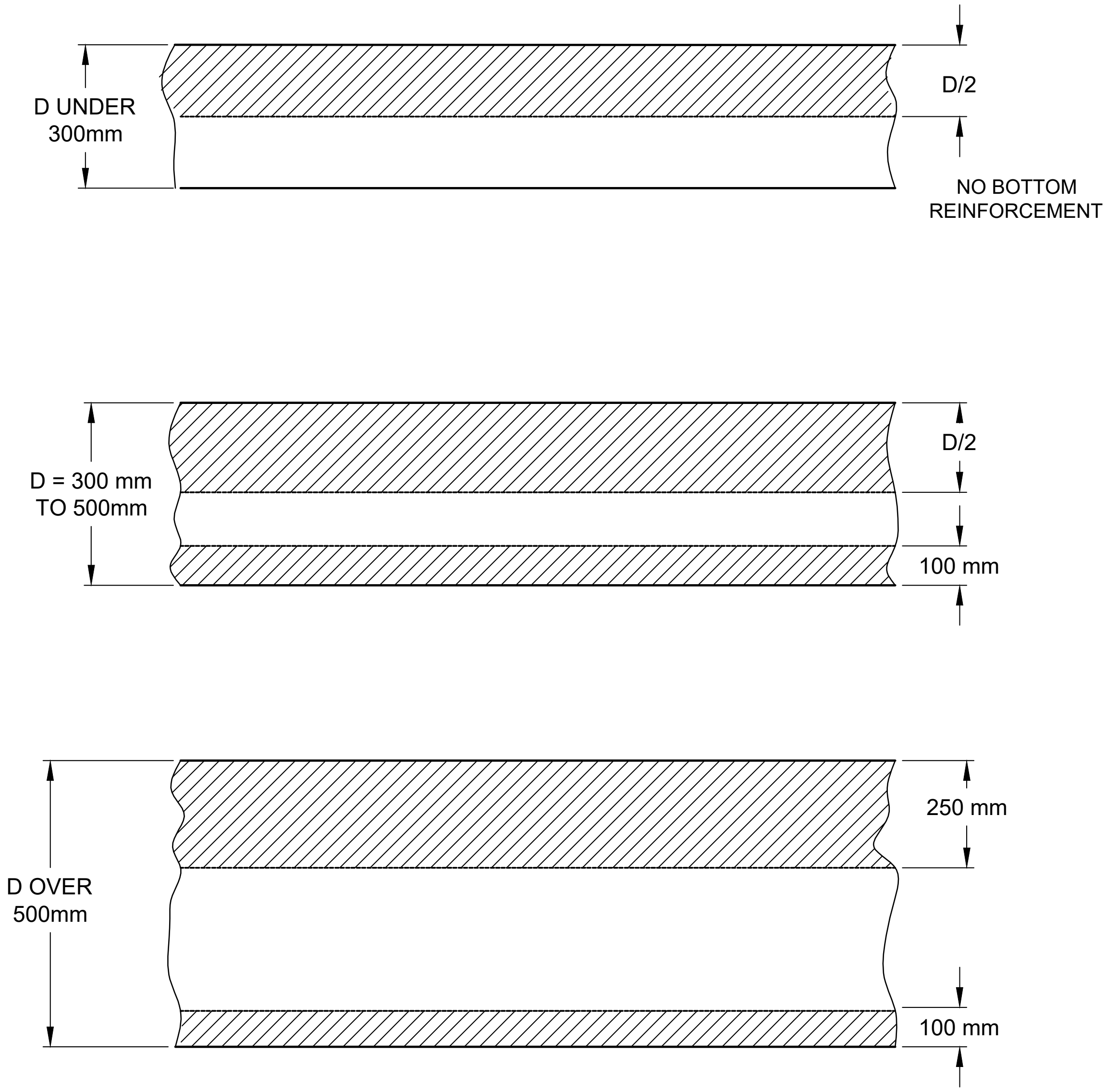


FIG. 2 SURFACE ZONES: GROUND SLABS

8.2 Size of Bars, Distance between Bars, Laps and Bends

8.2.1 Size of bars, distance between bars, laps and bends in bars, and fixing of bars shall be in accordance with IS 456. Spacing of bars should be small as possible, without causing congestion of steel and difficulty in placing and vibrating concrete.

8.2.2 Laps in the horizontal bars of wall or longitudinal bars of beam which can have single concrete pour of 300 mm or more below the bar, shall be provided 1.4 times the calculated lap length. In members subjected to axial tension or hoop, the bars in direct tension shall be provided with lap double that of calculated lap length.

8.2.3 Bar spacing shall not exceed 300 mm or the thickness of the section, whichever is less.

8.3 Junction of Members

Where any two members such as wall and slab, are connected monolithically at a right angled junction and subjected to moments, shears and axial force which tend to open it (that is, the inner faces of the plates are in tension at the corner), proper detailing of the reinforcement shall be ensured to cater for the diagonal tension forces. Detailing should be as shown in Fig. 3 or alternately, the junction may be designed by an appropriate strut and tie model.

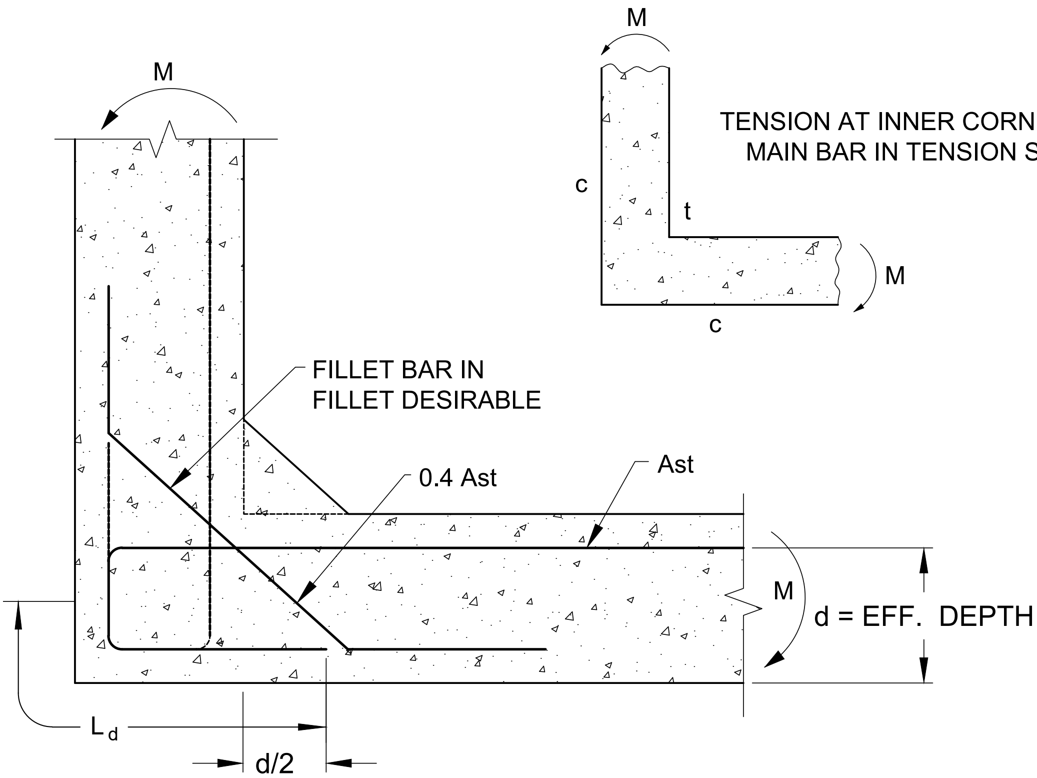


FIG. 3 DETAILING AT THE RIGHT ANGLED JUNCTION

ANNEX A

(*Clauses* 4.4.3 *and* 8.1.2)

CRACK WIDTH DUE TO TEMPERATURE AND MOISTURE IN IMMATURE CONCRETE

A-1 CALCULATION OF MINIMUM REINFORCEMENT CRACK SPACING AND CRACK WIDTHS IN RELATION TO MOISTURE EFFECTS IN THIN SECTIONS

A-1.1 The design procedures given in **A-1.2** to **A-1.3** and **A-2** are appropriate for long continuous wall or floor slabs of thin cross-section. **A-3** considers thick sections.

A-1.2 Minimum Reinforcement

The minimum reinforcement, required to distribute the cracking in a surface zone for each direction, shall be given by the following formula:

$$\rho_{\text{crit}} = 0.75\,\frac{f_{\text{ct}}}{f_{\text{y}}} \qquad ...(1)$$

where

ρ_{crit} = critical steel ratio, the minimum ratio of area of steel reinforcement to that of the surface zone (bD_{st} or bD_{sb}, as applicable, *see* Table 6 and Fig. 2);

f_{ct} = direct tensile strength of the immature concrete, which may be taken as given in Table 7, in absence of experimental results;

f_y = the characteristic strength of the reinforcement.

Table 6 Top and Bottom Depths of Surface Zone

(*Clause* A-1.2)

Sl No.	Depth of Ground Slab, *D*	Top Depth, D_{st}	Bottom Depth, D_{sb}
(1)	(2)	(3)	(4)
i)	less than 300 mm	D/2	NIL
ii)	300 to 500 mm	D/2	100 mm
iii)	more than 500 mm	250 mm	100 mm

Table 7 Direct Tensile Strength of Immature Concrete

(*Clause* A-1.2)

Concrete Grade	M25	M30	M35	M40	M45	M50	M55
f_{ct}, N/mm²	1.15	1.30	1.45	1.60	1.70	1.80	1.90

A-1.3 Cracks can be controlled by choosing the spacing of movement joint and the amount of reinforcement. The three main options are summarized in Table 2 of IS 3370 (Part 1).

A-1.4 Crack Spacing

When sufficient reinforcement is provided to distribute cracking, the maximum spacing of crack S_{Max} shall be given by the formula:

$$S_{Max} = \frac{f_{\text{ct}}}{f_{\text{b}}} \times \frac{\phi}{2\rho} \qquad ......(2)$$

where

f_{ct}/f_b = ratio of the tensile strength of the concrete (f_{ct}) to average bond strength (f_b) between concrete and steel,

ø = diameter of each reinforcement bar, and

ρ = steel ratio, as defined under **A-1.2** (*see* Fig. 1 and Fig. 2)

For immature concrete, the value of f_{ct}/f_b may be taken as unity for plain round bars and 2/3 for deformed bars. The above formula may be expressed for design purposes as:

$$n_{\text{b}}\,\phi \geq \frac{f_{\text{ct}}}{f_{\text{b}}} \times \frac{2bD'}{\pi\, S_{\text{Max}}} \qquad ...(3)$$

where

n_b = number of bars in width of section,

b = width of section,

D' = D_{st} or D_{sb}, as applicable (*see* Table 5), and

S_{Max} = obtained from W_{Max}.

The width of a fully developed crack due to drying shrinkage and the 'heat of hydration' contraction in lightly-reinforced restrained walls and slabs may be obtained from:

$$W_{\text{Max}} = S_{\text{Max}}\,\varepsilon \qquad ...(4)$$

where

$\varepsilon = [\varepsilon_{cs} + \varepsilon_{te} - (100 \times 10^{-6})]$

W_{Max} = estimated maximum crack width,

S_{Max} = estimated likely maximum crack spacing,

ε_{cs} = estimated shrinkage strain, and temperature due to heat of hydration.

ε_{te} = estimated total thermal contraction after peak, and temperature due to heat of hydration.

A-2 CALCULATION OF MINIMUM REINFORCEMENT CRACK SPACING AND CRACK WIDTHS IN RELATION TO TEMPERATURE EFFECTS IN THIN SECTIONS

A-2.1 For immature concrete, the effective coefficient of thermal contraction may be taken as one half of the value for mature concrete (due to the high creep strain in immature concrete).

A-2.2 For walls exposed to normal climatic conditions, the shrinkage strain less the associated creep strain is generally less than the ultimate concrete tensile strain of about 100×10^{-6} unless high shrinkage aggregates are used. Hence, the value of W_{max} for cooling to ambient from the peak hydration temperature may be assumed to be:

$$W_{Max} = S_{Max} \times \frac{\alpha}{2} \times T_1 \qquad \ldots(5)$$

where

α = coefficient of thermal expansion of mature concrete, and

T_1 = fall in temperature between the hydration peak and ambient.

The value of T_1 depends on the temperature of concreting, cement content, thickness of the member and material for shutters. As guideline, it is recommended to use T_1 = 30 °C for concreting in summer and 20 °C for concreting during winter, when steel shutters are used. For other conditions, the value of T_1 may be appropriately increased.

A-2.3 In addition to the temperature fall T_1, there can be a further fall in temperature, T_2 due to seasonal variations. The consequent thermal contractions occur in the mature concrete for which the factors controlling cracking behaviour are substantially modified. The ratio of the tensile strength of concrete to bond strength, f_{ct}/f_b, is appreciably lower for mature concrete. In addition, the restraint along the base of the member tends to be much more uniform and less susceptible to stress raisers, since a considerable shear resistance can be developed along the entire length of the construction joint.

Although precise data is not available for these effects, a reasonable estimate may be assumed that the combined effect of these factors is to reduce the estimated contraction by half. Hence the value of W_{Max} when taking an additional seasonal temperature fall into account is given by:

$$W_{Max} = S_{Max} \times \frac{\alpha}{2} \times (T_1 + T_2) \qquad \ldots(6)$$

When movement joints are provided at a centre-to-centre spacing of not more than 15 m, the subsequent temperature fall, T_2, need not be considered.

A-3 THICK SECTIONS

For ‘thick’ sections, major causes of cracking are the differences which develop between the surface zones and the core of the section. The thickness of concrete which can be considered to be within the ‘surface zone’ is not exact. However, site observations have indicated that the zone thickness for D > 500 mm in Fig. 1 and Fig. 2 are appropriate for thick sections, and the procedure for calculating thermal crack control reinforcement in thick sections is same as that for thin sections.

The maximum temperature rise due to heat of hydration to be considered should be the average value for the entire width of section. The temperature rise to be considered for the core should be at least 10 °C higher than the value which would be assumed for the entire section.

ANNEX B

(*Clause* 4.4.3)

CRACK WIDTHS IN MATURE CONCRETE

B-1 ASSESSMENT OF CRACK WIDTHS IN FLEXURE

Provided that the strain in the tension reinforcement is limited to $0.6\, f_y/E_s$ and the stress in the concrete is limited to $0.4 f_{ck}$, the design surface crack width should not exceed the appropriate value given in **4.4.3.2** and may be calculated as follows:

$$w = \frac{3\,a_{cr}\,\varepsilon_m}{1 + \dfrac{2\,(a_{cr} - C_{Min})}{D - x}} \qquad \ldots.(7)$$

where

w = design surface crack width,

a_{cr} = distance from the point considered to the surface of the nearest longitudinal bar,

ε_m = average strain at the level where the cracking is being considered. To be calculated in accordance with **B-2**,

C_{Min} = minimum cover to the tension steel,

D = overall depth of the members, and

x = depth of neutral axis.

B-2 AVERAGE STRAIN IN FLEXURE

The average strain at the level where cracking is being considered, is assessed by calculating the apparent strain using characteristic loads and normal elastic theory. Where flexure is predominant but some tension exists at the section, the depth of the neutral axis should be adjusted. The calculated apparent strain, ε_1 is then adjusted to take into account the stiffening effect of the concrete between cracks ε_2. The value of the stiffening effect may be assessed from **B-3**, and:

$$\varepsilon_m = \varepsilon_1 - \varepsilon_2$$

where

ε_m = average strain at the level where cracking is being considered,

ε_1 = strain at the level considered, and

ε_2 = strain due to stiffening effect of concrete between cracks.

B-3 STIFFENING EFFECT OF CONCRETE IN FLEXURE

The stiffening effect of the concrete may be assessed by deducting from the apparent strain, a value obtained from the following expressions for deformed bars.

For a limiting design surface crack width of 0.2 mm:

$$\varepsilon_2 = \frac{b_t\,(D - x)\,(a' - x)}{3E_s A_s\,(d - x)} \qquad \ldots (8)$$

For a limiting design surface crack width of 0.1 mm:

$$\varepsilon_2 = \frac{1.5\,b_t\,(D - x)\,(a' - x)}{3E_s A_s\,(d - x)} \qquad \ldots (9)$$

where

ε_1 = strain at the level considered,

ε_2 = strain due to the stiffening effect of concrete between cracks,

b_t = width of section at the centroid of the tension steel,

D = overall depth of the member,

x = depth of the neutral axis,

E_s = modulus of elasticity of reinforcement,

A_s = area of tension reinforcement,

d = effective depth, and

a' = distance from the compression face to the point at which the crack width is being calculated.

The stiffening effect factors apply only for the crack widths stated and should not be interpolated or extrapolated. ε_2 calculated from equation (8) or (9) shall be multiplied by 1.0 for uncoated deformed bars; 0.8 for fusion bonded epoxy coated deformed bars; 0.625 for uncoated plain bars, and 0.5 for coated plain bars.

B-4 ASSESSMENT OF CRACK WIDTHS IN DIRECT TENSION

Provided that the strain in the reinforcement is limited to $0.5\, f_y/E_s$, the design crack width should not exceed the appropriate value given in **4.4.3.2** and may be calculated from the following expression:

$$w = 3\,a_{cr}\,\varepsilon_m \qquad \ldots (10)$$

where ε_m is assessed in accordance with **B-5**.

B-5 AVERAGE STRAIN IN DIRECT TENSION

The average strain is assessed by calculating the apparent strain using characteristic loads and normal elastic theory. The calculated apparent strain is then adjusted to take into account the stiffening effect of the concrete between cracks. The value of the stiffening effect may be assessed from **B-6**.

B-6 STIFFENING EFFECT OF CONCRETE IN DIRECT TENSION

The stiffening effect of the concrete may be assessed by deducting from the apparent strain a value obtained from the following expressions:

For a limiting design surface crack width of 0.2 mm:

$$\varepsilon_2 = \frac{2b_t D}{3E_s A_s} \quad \text{... (11)}$$

For a limiting design surface crack width of 0.1 mm:

$$\varepsilon_2 = \frac{b_t D}{E_s A_s} \quad \text{... (12)}$$

where

ε_2 = strain due to stiffening effect,

b_t = width of the section at the centroid of the tension steel,

D = overall depth of the member,

E_s = modulus of elasticity of reinforcement, and

A_s = area of tension reinforcement.

The stiffening effect factors apply only for the crack widths stated and should not be interpolated or extrapolated. ε_2 calculated from equation (11) or (12) shall be multiplied by 1.0 for uncoated deformed bars; 0.8 for fusion bonded epoxy coated deformed bars; 0.625 for uncoated plain bars, and 0.5 for coated plain bars.

ANNEX C

(*Foreword*)

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Panel for Review/Revision of IS 3370, CED 2:2/P1

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(*Continued from second cover*)

e) The sub-clause on loads has been enlarged to include detailed guidance on the various types of loadings; and liquid load has been defined separately.

f) Partial safety factors for loads and various load combinations, applicable to liquid retaining structures, have been provided, duly revised.

g) Provision of classifying liquid retaining structures on the basis of the degree of protection against leakage in three tightness classes has been introduced.

h) The clause on 'Detailing' has been enlarged to include detailed guidance regarding the minimum percentage of reinforcement and lap length. Additionally, detailing at the right angled junction of the members has been included.

j) Title of the standard has, been modified to address the actual coverage.

In the formulation of this standard, assistance has been derived from the following publications:

BS 8007 : 1987 Code of practice for design of concrete structures for retaining aqueous liquids, British Standards Institute

EN 1992-3 : 2006 Design of concrete structures — Part 3: Liquid retaining and containment structures, Committee European Normalization (CEN)

The composition of the Committee responsible for the formulation of this standard is given in Annex C.

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 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.

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Amendments are issued to standards as the need arises on the basis of comments. Standards are also reviewed periodically; a standard along with amendments is reaffirmed when such review indicates that no changes are needed; if the review indicates that changes are needed, it is taken up for revision. Users of Indian Standards should ascertain that they are in possession of the latest amendments or edition by referring to the latest issue of 'BIS Catalogue' and 'Standards: Monthly Additions'.

This Indian Standard has been developed from Doc No.: CED 02 (13639).

Amendments Issued Since Publication

Amend No.	Date of Issue	Text Affected

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