IS : 4995 (Part II) - 1974
(Reaffirmed 1998)

Indian Standard

CRITERIA FOR DESIGN OF REINFORCED CONCRETE BINS FOR STORAGE OF GRANULAR AND POWDERY MATERIALS

PART II DESIGN CRITERIA

(First Revision)

Fifth Reprint JUNE 1996

UDC 624.953.012.45

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

Gr 6 *September* 1975

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CRITERIA FOR DESIGN OF REINFORCED CONCRETE BINS FOR STORAGE OF GRANULAR AND POWDERY MATERIALS

PART II DESIGN CRITERIA

(First Revision)

0. FOREWORD

0.1 This Indian Standard (Part II) (First Revision) was adopted by the Indian Standards Institution on 9 December 1974, after the draft finalized by the Criteria for Design of Structures Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 Storage structures like bins (silos and bunkers) for storing different materials are one among the important structures coming up in any industrial or organized storage complex. The necessity to store and contain materials like coke, coal, ores, etc, in the various steel plants and other industrial establishments cannot be over emphasized. In cement factories as well as in construction projects, cement is stored in large silos. On the agricultural front the foodgrain storage structures and silos play a vital role in ensuring the supply of foodgrains at all times of the year. Bulk storage of materials in bins has certain advantages over other forms of storage. Therefore, the necessity to formulate criteria for design of such structures has been felt and this standard is aimed at giving the necessary guidelines to arrive at the structural design of reinforced concrete bins for the storage of various materials of different properties and characteristics.

0.3 IS: 4995-1968* covered the requirements of the structural design for foodgrain storage bins (silos). It has been felt that instead of bringing out one separate standard to cover the requirements of all materials other than foodgrains it would be useful to cover the subject under one standard in which the requirements of different materials could be dealt with adequately. Therefore, the revision of IS : 4995-1968* was taken up to cover the requirements of storage bins for all materials including foodgrains.

*Criteria for design of reinforced concrete bins (silos) for bulk foodgrain storage.

0.4 The different stored materials, such as coke, coal, ores, foodgrains, fertilizers, cement, flour etc, can be classified either as granular or powdery materials. Extensive research work all over the world has indicated that assessment of bin loads caused due to a stored material would require different treatment depending upon whether it is a granular or powdery material. Taking this into consideration this standard is being revised and is published in two parts namely, Part I General principles and assessment of bin loads and Part II Design criteria. This standard is a necessary adjunct to Part I.

0.5 In the formulation of this standard due weightage has been given to the findings of recent research and international coordination amongst the standards and practices prevailing in different countries. This has been met with by referring to the following standards and publications:

DIN 1055 : 1964 (Sheet 6) Design loads for buildings — Bin loads. Deutscher Normenausschluss.

BOHM (F). The calculation of circular silo cells for the storage of cement. C & CA Library Translation; No. 101. Cement and Concrete Association, London.

GRAY (W S) and MANNING (C A). Concrete water towers, bunkers, silos and other elevated structures.

PIEPER (K) and WENZEL (F). Pressure distribution in bins. 1964. Verlag von Wilhelm Ernst & Sohn, Berlin, Munchen.

REISNER (W) and ROTHE (M E). Bins and bunkers for handling bulk materials. M. E. Trans Tech Publications, Ohio.

SAFARIAN (S S) and HARRIS (E C). Determination of minimum wall thickness and temperature steel in conventionally reinforced circular concrete silos. *Journal of the American Concrete Institute*, July 1970; 539-547.

Bin wall design and construction. Report of ACI Committee 313. *Journal of the American Concrete Institute*, July 1968; 499-506.

0.5.1 In view of the continuing research done on flow characteristics of materials, the emphasis in the code is on structural adequacy of bins. However, as regards flow characteristics of the materials, the designers would be well advised to consult the relevant literature. This code is based on the latest available data and is amenable to review as and when more reliable information on this subject becomes available.

0.6 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*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

1. SCOPE

1.1 This standard (Part II) deals with the general design criteria for the design of reinforced concrete bins used for bulk storage of granular and powdery materials.

1.2 This standard covers circular, polygonal and interstice bins of a battery of bins.

2. TERMINOLOGY

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

2.1 Aeration — A process in which air is moved through the stored material for ventilation.

2.2 Arching — A phenomenon in the bin during the emptying of a stored material giving rise to formation of arches of the material across the bin walls.

2.3 Bin — A storage structure circular or polygonal in plan and meant for storing bulk materials in vertical direction. Silo is a bin circular for polygonal in plan. Bunker is a bin whose cross section in plan would be square or rectangular.

2.4 Bin Loads — Loads exerted by a stored material on the walls of a bin.

2.5 Foodgrain — All cereals, pulses, millets, except oil seeds.

2.6 Granular Materials — All materials having mean particle size more than 0·2 mm. No cohesion between the particles is assumed.

2.7 Interstice Bin — Bin that is formed out of the space enclosed by a battery of interconnected bins.

2.8 Powdery Materials — All materials having mean particle size less than 0·06 mm.

3. NOTATIONS

3.1 For the purpose of this standard the following notations shall have the meaning indicated against each:

A = Horizontal cross-sectional area of the stored material

A_c = Area of columns, cm^2

*Rules for rounding off numerical values (*revised*).

A_{ct} = Concrete area in tension per unit height of bin wall, cm^2/m

A_s = Area of reinforcement in bin wall at the height under consideration, cm^2/m

A_{sc} = Area of reinforcement in column, cm^2

C_a = Surface conductance of concrete to air, kcal/m^2h°C

C_c = Thermal conductivity of reinforced concrete, kcal/mh°C

C_s = Surface conductance of concrete to storage material, kcal/m^2h°C

D = Internal diameter of a circular bin

E_c = Modulus of elasticity of concrete

E_s = Modulus of elasticity of reinforcing steel

h = Height of bin wall

I = Moment of inertia of bin wall section

K = Coefficient of heat transmission

K_1 = Coefficient of maximum negative bending moment in ring girder at the column support

K_2 = Coefficient of maximum positive bending moment in ring girder at midway between column supports

K_3 = Coefficient of maximum torsional moment in ring girder

K_s = Safety factor for concrete cracking

l = Span of bin wall between supports

$M_{\triangle T}$ = Moment due to temperature difference $\triangle T$ across the bin wall

m = Modular ratio

n = Concrete shrinkage coefficient

p = Calculated percentage of reinforcement in columns

p_0 = $\frac{A_s}{A_{ct}}$ = Geometric percentage of tensile reinforcement with respect to concrete area in tension in bin wall

P_d = Dead load on columns

P_h = Horizontal pressure on the wall due to stored material

P_v = Vertical pressure on the horizontal cross-section of the stored material

P_w = Vertical load transferred to the unit wall area due to friction between material and bin wall

P_n = Pressure normal to the longitudinal slope of hopper bottom

P_t = Pressure along the longitudinal slope of hopper bottom

R = A/U

r = Mean radius of ring girder

r_h = Radius of hopper at the plane under consideration

T_i = Temperature of stored material inside the bin (°C)

T_o = Atmospheric temperature outside the bin (°C)

t = Thickness of bin wall

w_{cr} = Crack width in bin wall

W_r = Total load on the ring girder

w_s = Self weight of unit surface area of hopper bottom

α = Angle the hopper bottom makes with the horizontal

σ_{ct} = Permissible tensile strength in concrete

σ_{cu} = Compressive strength of concrete at the age of 28 days

σ_{sa} = Actual stress in reinforcing steel

σ_t' = Tensile strength of concrete

θ = Angular distance from column support to point of maximum torsional moment in the ring girder

ϕ' = Diameter of column reinforcement, cm

μ_e = Coefficient of wall friction during emptying

δ = Angle of wall friction

λ_f = Pressure ratio during filling

λ_e = Pressure ratio during emptying

μ = Coefficient of wall friction (= tan δ)

μ_f = Coefficient of wall friction during filling

Δ_T = Temperature difference across the bin wall

ε_t = Coefficient of thermal expansion of concrete

4. GENERAL DESIGN REQUIREMENTS

4.1 General — Dimensions, shape and layout of reinforced concrete bins shall conform to the provisions given under **4** of Part I of this standard.

4.2 Materials

4.2.1 *Cement* — Cement used for reinforced concrete bins shall be either ordinary or rapid hardening Portland cement conforming to IS : 269-1967* or blastfurnace slag cement conforming to IS : 455-1967†.

*Specification for ordinary, rapid-hardening and low-heat Portland cement (*second revision*).

†Specification for Portland blastfurnace slag cement (*revised*).

4.2.2 *Steel* — Steel reinforcement shall be either mild steel or medium tensile steel bars conforming to IS : 432 (Part I)-1966* or hard drawn steel wire conforming to IS : 432 (Part II)-1966† or deformed bars conforming to IS : 1139-1966‡ or cold twisted bars conforming to IS : 1786-1966§.

4.2.2.1 For side walls and bin bottom deformed or cold twisted bars shall be preferred due to their better bond characteristics and thus avoiding large cracks and ensuring more uniform distribution of cracks.

4.2.3 *Concrete Mix* — Only controlled concrete of grade not leaner than M-150 as specified in IS : 456-1964|| and satisfying the relevant provisions shall be used for the construction of reinforced concrete bins.

4.3 Doors and Openings — Openings required for manual access to the bin or for spout inlets, aeration, temperature detection, etc, shall be left during the process of concreting. Breaking the previously laid concrete for this purpose shall strictly be avoided. These openings shall be provided with airtight covers.

4.3.1 Openings shall preferably be avoided in the zones of critical stresses. Small openings of size less than or equal to five times the wall thickness shall be treated in the same manner as in other conventional reinforced concrete structures. Detailed analysis shall be made when large openings, of size greater than five times the wall thickness, are required.

4.4 Supports — The arrangements for supporting the walls of a bin shall depend upon the layout, the outlet openings, positions of draw off conveyors and type of bin bottom, etc. For polygonal bins, columns shall normally be placed at the junctions of side walls. For circular bins the wall may be either extended up to the foundation level or stopped on a ring beam supported on a group of columns.

4.5 Foundations

4.5.1 The type of foundation for the storage bin shall be decided taking into account the layout, site conditions, nature of soil and the load transferred.

4.5.2 The bin structure shall rest on reinforced concrete raft foundation, pile foundations or isolated footings depending upon the soil conditions.

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*Specification for mild steel and medium tensile steel bars and hard-drawn steel wire for concrete reinforcement: Part I Mild steel and medium tensile steel bars (*second revision*).

†Specification for mild steel and medium tensile steel bars and hard-drawn steel wire for concrete reinforcement : Part II Hard-drawn steel wire (*second revision*).

‡Specification for hot rolled mild steel and medium tensile steel deformed bars for concrete reinforcement (*revised*).

§Specification for cold twisted steel bars for concrete reinforcement (*revised*).

||Code of practice for plain and reinforced concrete (*second revision*).

Site investigations for foundation shall be carried out in accordance with IS : 1892-1962*.

4.5.3 In case, the reinforced concrete raft is to be laid over the piles, the top of the mat shall be at the plinth level.

4.5.4 Design of foundation shall be carried out according to the provisions of IS : 456-1964†, IS : 1080-1962‡, IS : 2911 (Part I)-1964§, IS : 2911 (Part III)-1967|| and IS : 2950-1965¶.

5. DESIGN CRITERIA

5.1 General Requirements of Working Stress Method — Provision shall be made for conditions of stresses that may occur in accordance with the 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 bending moments and shear forces.

5.2 Basis of Design — The general basis of design of all components of a storage bin excepting the walls and bin bottom which are in contact with the stored material shall be in accordance with the recommendations of IS : 456-1964†.

5.3 Design Loads and Effects

5.3.0 The following loading conditions and effects shall be considered while designing the various components of a storage bin namely, roof, bin walls, ring girder, hopper bottom, supporting columns and foundation:

a) Dead load of the structure;

b) Superimposed loads due to material handling and transportation machinery, if any;

c) Bin loads as specified under Part I of this standard;

d) Live load (for roof only) recommended in IS : 875-1964**;

e) Wind load recommended in IS : 875-1964**;

f) Seismic loads recommended in IS : 1893-1975††;

g) Effect due to temperature variation;

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*Code of practice for site investigations for foundations.

†Code of practice for plain and reinforced concrete (*second revision*).

‡Code of practice for design and construction of simple spread foundations.

§Code of practice for design and construction of pile foundations — Part I Load-bearing concrete piles.

||Code of practice for design and construction of pile foundations — Part III Under reamed pile foundations.

¶Code of practice for design and construction of raft foundations.

**Code of practice for structural safety of buildings—loading standards (*revised*).

††Criteria for earthquake resistant design of structures (*third revision*).

h) Effect due to shrinkage of concrete; and

j) Effect of fixity of the bin at the top and bottom edges and with adjoining structures.

5.3.1 While designing a bin structure, worst combinations of the loads and effects named under **5.3.0** shall be considered.

5.3.2 Wind and seismic loads need not be considered as acting simultaneously.

5.4 Permissible Stresses

5.4.1 *Stresses in Concrete* — The permissible stresses in tension (direct and due to bending) and shear shall conform to the values specified in Table 1. The permissible tensile stress due to bending apply to the outside face of the bin. In members less than 225 mm thick and in contact with material on one side, the permissible stresses in bending are also applicable to side in contact with the stored material.

TABLE 1 PERMISSIBLE CONCRETE STRESSES

(All values in kg/cm^2)

Grade of Concrete	Permissible Stress in Compression		Permissible Stress in Shear Measured as Inclined Tension	Permissible Stress in Bond		Permissible Bearing Pressure on Full Area (Plain Concrete Only)
	Bending	Direct		Average	Local	
(1)	(2)	(3)	(4)	(5)	(6)	(7)
M 150	50	40	5·0	6·0	10·0	30
M 200	70	50	7·0	8·0	13·0	40
M 250	85	60	8·0	9·0	15·0	50
M 300	100	80	9·0	10·0	17·0	60
M 350	115	90	10·0	11·0	18·0	70
M 400	130	100	11·0	12·0	19·0	80

Note — Permissible stress in tension in bending may be taken to be the same as permissible stress in shear (measured as inclined tension).

5.4.2 *Stress in Concrete for Resistance to Buckling* — The maximum compressive stress on the net wall section deducting all openings, recesses, etc, shall not exceed 0·25 σ_{cu}, where σ_{cu} is the compressive strength of concrete at the age of 28 days.

5.4.3 *Stresses in Steel Reinforcement* — The permissible stresses in steel reinforcement shall conform to the values specified in Table 2.

TABLE 2 PERMISSIBLE STRESSES IN STEEL REINFORCEMENT

Sl No.	Type of Stresses in Steel Reinforcement	Permissible Stresses in kg/cm²			
		Mild Steel Bars, Grade I or Deformed Mild Steel Bars	Medium Tensile Steel or Deformed Medium Tensile Steel Bars or Plain Round Cold Twisted Bars	High Yield Strength (Hot Rolled and Cold Twisted) Deformed Bars	Welded Wire Fabric
(1)	(2)	(3)	(4)	(5)	(6)
i)	Tension (σ_{st}) other than in helical reinforcement in a column, and in shear reinforcement:				
	Up to and including 40 mm	1 400	Half the guaranteed yield stress subject to a maximum of 1900	—	—
	Over 40 mm	1 300		—	—
	Up to and including 20 mm	—	—	2 300	—
	Over 20 mm	—	—	2 100	—
	Welded wire fabric, all sizes	—	—	—	2 300
ii)	Tension in helical reinforcement in a compression member (σ_{sh})	1 000	1 300	1 600	—
iii)	Tension in shear reinforcement (σ_{ss})	1 400	1 400	1 750	—
iv)	Compression in column bars (σ_{sc})	1 300	1 300	1 750	—
v)	Compression in bars in a beam or slab when the compressive resistance of the concrete is taken into account	The calculated compressive stress in the surrounding concrete multiplied by 1·5 times the modular ratio or σ_{sc} whichever is lower			
vi)	Compression in bars in a beam or slab when the compressive resistance of the concrete is not taken into account:				
	Up to and including 40 mm	1 400	Half the guaranteed yield stress subject to a maximum of 1 900	1 900	—
	Over 40 mm	1 300		1 900	—

Note 1 — When mild steel conforming to Grade II of IS : 432 (Part I)-1966 'Specification for mild steel and medium tensile steel bars and hard-drawn steel wire for concrete reinforcement: Part I Mild steel and medium tensile steel bars (*second revision*)' is used, the permissible stresses shall be 90 percent of the permissible stress in col 3 or if the design details already been worked out on the basis of mild steel conforming to Grade I of IS : 432 (Part I)-1966 the area of reinforcement shall be increased by 10 percent of that required for Grade I steel.

Note 2 — For the purpose of this standard, the yield stress of steels for which there is no clearly defined yield point should be taken to be the 0·2 percent proof stress.

5.4.4 *Increase in Permissible Stresses* — Where stresses due to wind or earthquake are combined with those due to dead, live and impact loads and temperature and shrinkage effects the permissible stress specified under **5.4.1**, **5.4.2** and **5.4.3** may be exceeded up to a limit of 33·33 percent.

5.5 Design of Bin Walls

5.5.1 *Walls of Circular Bins* — Walls of circular bins shall be designed essentially for hoop stresses due to bin loads. The walls shall be checked for all loading cases and effects as specified under **5.3**.

5.5.2 *Walls of Polygonal Bins* — The wall shall be considered as slabs spanning vertically or horizontally or as two-way slabs for horizontal loads and as beams for vertical loads with due consideration to combined co-existing bending and axial forces. They shall be checked for all loading cases and effects as specified under **5.3**. Due provisions shall be made for bending moment caused due to temperature variation, restraint at top and bottom edges and wind or seismic loads.

NOTE — If the bins are to be designed as deep beams refer to curves given in the article 'Design of Deep Girders' — Portland Cement Association, Concrete Information Structural Paper ST-66, 1951.

5.5.3 *Walls of Battery of Bins*

5.5.3.0 In the case of interconnected polygonal bins without interstice, effect on the junction walls shall be considered for worst combinations of full and empty conditions of the bin under consideration and its adjoining bins.

5.5.3.1 In a battery of interconnected circular or polygonal bins with one interstice, the bin walls shall be designed for the following two loading cases:

a) Interstice bin empty while adjoining main bins full, and

b) Interstice bin full while adjoining main bins empty.

5.5.3.2 In a battery of bins having more than one interstice bin in one or both the directions, due provisions shall be made to strengthen the bin walls. Loading conditions as under **5.5.3.1** and worst combinations of full and empty conditions of the farther bins shall be taken into account for determining additional bending moments and forces developed in the bin walls.

5.5.3.3 Walls of interstice bins shall be designed with due consideration to structural and loading configurations and interactions with appropriate boundary conditions.

5.5.4 *Thickness of Bin Walls* — The minimum thickness shall be calculated from the formula given below:

$$t_{(Min)} = \frac{nE_s + \sigma_{sa} - m\sigma_t'}{100\sigma_{sa}\ \sigma_t'}(T_v)_{st}$$

where

n = concrete shrinkage coefficient assumed as 0·003;

E_s = modular of elasticity of reinforcing steel in kg/cm²;

σ_{sa} = stress in reinforcing steel;

m = modular ratio;

σ_t' = tensile strength of concrete = $1·19\sqrt{\sigma_{cu}}$;

$(T_v)_{st}$ = $P_{hf} \times \frac{D}{2}$ static ring tensile force per unit length of wall at depth Z in kg/cm²);

P_{hf} = static lateral pressure at depth Z in kg/cm²; and

D = inside diameter of bin, m.

Subject to a minimum thickness of 10 cm. Alternatively, the minimum thickness may be calculated by the empirical method given in **5.5.4.1**.

5.5.4.1 The thickness of bin walls shall be governed by the following provisions:

a) The wall thickness for curved walls shall be not less than the larger of the following with a minimum thickness of 10 cm:

  a) $t = 10 + 2·5\ (D - 3)/3$ or
  b) $t = 10 + 2·5\ (h - 6)/12$

where

t is in cm and D and h are in m.

b) The wall thickness of straight walls (in the case of polygonal bins) shall not be less than the smaller of the following with a minimum thickness of 10 cm:

  a) $t = 4\ h$ or
  b) $t = 4\ l$.

where

t is in cm, h and l are in m.

c) However, where slip from work is used in construction, the wall thickness shall not be less than 15 cm.

5.5.4.2 The crack width in walls of bins shall not exceed the following:

Where water tightness is required = 0·1 mm

Otherwise = 0·2 mm

This shall be computed as in **5.10** of this standard.

5.6 Ring Girder

5.6.0 When the conical hopper is supported on a ring girder provided at the junction of the wall and the hopper, the girder shall be designed to resist axial force, bending, torsion and shear.

5.6.1 The axial compressive force induced on the girder shall be equal to that resulting from the horizontal component of the inclined pull of the loaded hopper minus that resulting from the outward lateral thrust exerted by the stored material. The girder shall be designed for the net horizontal component obtained when (a) the bin is assumed to be full, and (b) when the top surface of material is assumed at the ring level, whichever gives the critical value.

5.6.2 The bending and torsional moments in the ring girder simply supported on a number of columns placed equidistant along the circumference of the girder shall be calculated from the following formulae:

a) Maximum negative moment at supports = $K_1 W_r r$

b) Maximum positive moment at midway between supports = $K_2 W_r r$

c) Maximum torsional moment at an angular distance of θ from support = $K_3 W_r r$

where

W_r = total load on the ring girder including its self-weight located along the central line of the beam,

r = mean radius of the ring girder,

K_1, K_2, K_3 = coefficients of bending and torsional moments as specified in Table 3,

θ = angular distance from support to point of maximum torsional moment as specified in Table 3.

5.7 Bin Bottom

5.7.1 The vertical load for the design of bin bottom shall be as indicated in **6.1.1.2** (a) and (b) of Part I of the standard subject to the condition that in the case of **6.1.1.2** (a), the vertical loading shall not be less than that indicated in **6.1.1.2**(b). Reference is also made to the provisions of **6.3.2** of Part I of the standard.

TABLE 3 COEFFICIENTS OF BENDING AND TORSIONAL MOMENTS OF RING GIRDER IN CIRCULAR BIN

(*Clause* 5.6.2)

No. of Supports	Maximum Shear	K_1	K_2	K_3	θ
(1)	(2)	(3)	(4)	(5)	(6)
3	$W_r/6$	0·062 9	0·033 3	0·013 2	25° — 47·5′
4	$W_r/8$	0·034 2	0·017 6	0·005 3	19° — 12′
5	$W_r/10$	0·021 5	0·010 7	0·002 6	15° — 18·1′
6	$W_r/12$	0·014 8	0·007 5	0·001 5	12° — 44′
7	$W_r/14$	0·010 8	0·005 5	0·000 9	10° — 54·1′
8	$W_r/16$	0·008 2	0·004 2	0·000 6	9° — 32′
9	$W_r/18$	0·006 5	0·003 3	0·000 4	8° — 28·1′
10	$W_r/20$	0·005 3	0·002 6	0·000 3	7° — 37·2′
11	$W_r/22$	0·004 4	0·002 2	0·000 2	6° — 55·5′
12	$W_r/24$	0·003 7	0·001 8	0·000 2	6° — 20·8′

5.7.1.1 *Level Bottom* — The design of a supported bin bottom shall be carried out in the same manner as that of any horizontal structural slab cast monolithically with the supporting structure. The weight of any conveying machinery, including impact, suspended from the slab shall be added to the bin bottom load and to the dead load of the slab to arrive at the total effective load.

5.7.2 *Hopper Bottom*

5.7.2.0 Bin bottoms of special shapes shall be analyzed with care by sophisticated analytical methods, such as finite element technique.

5.7.2.1 *Design pressures on hopper bottom* — Normal pressure P_n and tangential pressure P_t at any point on the hopper bottom for design shall be as follows:

$$P_n = P_v \cos^2\alpha + P_h \sin^2\alpha + w_s \cos\alpha$$

$$P_t = (P_v - P_h) \sin\alpha \cos\alpha + w_s \sin\alpha$$

where

w_s = self weight of hopper per unit area, and

α = angle the hopper bottom makes with the horizontal.

5.7.2.2 *Conical hoppers* — Conical hoppers are subjected essentially to meridional and hoop tensions. Local bending due to effect of continuity at the edges or due to external superimposed loads due to machinery, etc, if any, shall also be taken into account in the design. The total meridional tension at any horizontal plane passing through the hopper shall be such that its vertical component is equal to total vertical pressure on that plane plus the self weight of the hopper and its contents below the plane. The meridional reinforcement shall extend sufficiently into the vertical wall to secure adequate bond. The hoop tension at any level of the conical hopper shall be determined as follows:

$$\text{Hoop tension} = r_h P_n \operatorname{cosec}\alpha$$

where

r_h = radius of hopper at the plane under consideration, and

P_n = normal design pressure at the plane under consideration as in **5.7.2.1**.

5.7.2.3 *Pyramidal hoppers* — Pyramidal hoppers are subjected to bending moments and direct tension besides meridional tension along the slope. The hopper of a polygonal bin shall be analyzed by considering each horizontal strip as a continuous frame subjected to the normal design pressure P_n calculated as in **5.7.2.1**. The meridional tension shall be calculated in the same way as for conical hoppers (*see* **5.7.2.2**).

5.7.2.4 *Bottoms of other shapes* — Bin bottoms of other shapes such as bottoms with one or more sloping sides with the remaining sides vertical, bottoms provided with special emptying arrangements, etc,shall be designed for the loads specified under **5.3.0** and **5.7.2.1** of this standard. The design shall be based on the principles of mechanics and sound engineering practice.

5.7.3 *Special Requirements for Columns* — In the design of columns it shall be necessary to ensure that the percentage of reinforcement should not exceed the percentage calculated by the formula given below, subject to the condition that the numerical value should not exceed 25 percent in the case of mild steel round bars and 4 percent in the case of cold formed bars:

$$p = \frac{\dfrac{P_d}{A_c} + \dfrac{\sigma_{ct}}{K_s}}{\sigma_{shr} + (\sigma_s)_{d+l} + (\sigma_s)_d}$$

where

p = calculated percentage of reinforcement in column,

P_d = dead load on columns,

A_c = area of columns,

K_s = safety factor for concrete cracking assumed as 1·2,

σ_{ct} = permissible tensile stress in concrete,

σ_{shr} = stress in reinforcement due to shrinkage of concrete assumed as 300 kg/cm^2,

$(\sigma_s)_{d+l}$ = stress in reinforcement due to dead and live loads (elastic deformation of concrete)

$$= \frac{P_{(d+l)} \times m}{A_{sc}(m-1) + A_c},$$

A_{sc} = area of reinforcement in column,

m = modular ratio, and

$(\sigma_s)\,d$ = stress in reinforcement due to dead load alone

$$= \frac{P_d \times m}{A_{sc}(m-1) + A_c}.$$

5.8 Effect of Temperature Variation — Bins containing hot materials are subjected to temperature stresses. The thermal stresses and the corresponding additional reinforcement shall be calculated and added to the reinforcement of the bin walls. The following assumptions are made for computing the temperature stresses and the additional reinforcement:

a) The tensile strength of concrete is neglected, and

b) Bin wall temperature vary only radially or on the horizontal plane (temperature difference between shady and sunny side and between points of different elevations and the effect of wind on temperature may be neglected).

5.8.1 *Computation of Temperature Change Through Bin Wall* — The temperature difference ΔT (after the steady state sets in) through the bin walls is determined as follows:

$$\Delta T = \frac{t}{C_c} \times \frac{(T_i - T_o)}{1/K}$$

and $$\frac{1}{K} = \frac{1}{C_a} + \frac{t}{C_c} + \frac{1}{C_s}$$

where

t = thickness of bin wall in m,

C_a = surface conductance of concrete to air = 15 in kcal/m^{2}h°C,

C_c = thermal conductivity of reinforced concrete = 1·75 to 2·0 in kcal/mh°C,

C_s = surface conductance of concrete to stored material = 2 kcal/m^{2}h°C for cement and 7·5 kcal/m^{2}h°C for other materials,

K = coefficient of heat transmission in kcal/m²h°C,

T_i = temperature of hot material inside the bin in °C,

T_o = lowest anticipated outside sol-air temperature in °C.

NOTE — Values of C_a, C_c and C_s given above are to be verified from heat transfer characteristics of various materials and should not be adopted without due consideration.

5.8.2 *Stresses due to Change in Temperature* — Bending moment across the bin wall due to change in temperature may be computed according to the following expression:

$$M_{\Delta T} = \varepsilon_t \, \Delta_T \, E_c \, I/_t$$

where

ε_t = coefficient of thermal expansion of concrete
= 11×10^{-6}/per degree per cm,

E_c = modulus of elasticity of concrete ($18000 \sqrt{\sigma_{cu}}$; kg/cm²), and

I = moment of inertia of the bin wall section.

Thermal stresses in concrete and steel due to the bending moment $M_{\Delta T}$ shall be calculated according to the principles of mechanics.

5.9 Effect of Shrinkage — The influence of drying shrinkage in concrete may be considered as being equivalent to a drop in temperature of 15°C (in a structure with more than 0·5 percent reinforcement). The effect of shrinkage may be ignored in all parts of the bin that are not affected by the disturbance due to restraints at the edges. The effect of shrinkage stresses in the region of disturbance due to restraints at the edges shall be considered and additional vertical reinforcement shall be provided to take care of the same.

5.10 Check for Crack-Width

5.10.0 *Permissible Crack-Width* — Crack-width in bin walls shall not exceed a permissible value given in **5.5.4.2.** This shall be computed for circular as well as rectangular bins either as in **5.10.1** or **5.10.2.**

5.10.1 *Determination of Crack-Width* — The maximum crack width in bin walls shall be calculated as follows:

$$w_{cr} = 10^{-6} \left(4 + \rho \frac{\phi'}{p_o} \right) \sigma_{sa} \left\{ 1 - \left(\frac{6}{p_o . \sigma_{sa}} \right)^2 \right\}$$

where

w_{cr} = maximum (95 percent probability) crack-width in cm,

ρ = a factor depending on the bond characteristics of steels (0·09 for plain bars and 0·05 for deformed bars),

ϕ' = diameter of reinforcing bar in cm,

$p_o = \frac{A_s}{A_{ct}}$ = geometric percentage of the tensile reinforcement with respect to the concrete area in tension,

A_s = area of tensile reinforcement per unit height of wall cm^2/m,

A_{ct} = concrete area in tension per unit height of wall cm^2/m [sectional area of unit height of wall for *tension members* (entire section under tension) or half the sectional area below the neutral axis of unit height of wall for *flexural members* (neutral axis within the section)],

σ_{sa} = actual steel stress under permanently acting loads in kg/cm^2.

5.10.2 *Simplified Check for Crack-Width*

5.10.2.1 The crack-width check can be deemed to have been satisfied without any explicit calculation as given in **5.10.1**, if one or both of the following conditions are satisfied:

a) if the geometrical percentage of reinforcement as defined in **5.10.1**

$$p_o \leqslant 0{\cdot}4 \text{ percent}$$

b) if the maximum diameters used for the reinforcement bar are equal to or less than the bar diameters indicated in Table 4.

TABLE 4 MAXIMUM BAR DIAMETERS (IN mm) FOR WHICH CRACK-WIDTH CALCULATIONS ARE NOT NECESSARY

SL No.	TYPE OF BAR	STEEL STRESS σ_{sa} IN kg/cm^2 FOR MAXIMUM PERMISSIBLE CRACK-WIDTH OF							
		0·1 mm				0·2 mm			
		1 000	1 400	1 800	2 300	1 000	1 400	1 800	2 300
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
i)	For plain bars	14	6	—	—	30	18	—	—
ii)	For deformed bars	—	16	10	6	—	26	16	12

5.10.2.2 In cases which are not covered by **5.10.2.1** the crack-widths will be satisfactory if the diameters of the bars are chosen according to the following formula:

$$\phi' \leqslant \beta{\cdot}p_o$$

where β has the values given in Table 5.

TABLE 5 VALUES OF β

SL No.	TYPE OF BAR	STEEL STRESS σ_{sa} IN kg/cm² FOR MAXIMUM PERMISSIBLE CRACK-WIDTH OF							
		0·1 mm				0·2 mm			
		1 000	1 400	1 800	2 300	1 000	1 400	1 800	2 300
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
i)	For plain bars	65	35	—	—	180	115	—	—
ii)	For deformed bars	—	65	30	10	—	200	140	100

5.11 Check for Stability — The bin walls shall be examined for stability under the following two loading cases:

a) *When Bin is Full* — All possible vertical loads (including the frictional wall load) and lateral loads due to wind or earthquake (whichever is critical) shall be considered in this case.

b) *When Bin is Empty* — In this case all the possible vertical loads except that due to the stored material (that is, the frictional wall load), and the maximum lateral load due to wind or earthquake shall be considered.

6. MINIMUM REQUIREMENTS

6.1 Reinforcement

6.1.1 *Circumferential Reinforcement* — The minimum circumferential reinforcement shall be 0·25 percent of cross-sectional area of the bin wall when deformed bars are used. When mild steel bars are used this shall be 0·3 percent of the cross-sectional area of the bin wall. Splices in bars shall be well staggered. The bars shall be at least 8 mm in diameter. Spacing of circumferential reinforcement shall not exceed 200 mm and bar diameter shall not be less than 8 mm when deformed bars are used and 10 mm when mild steel bars are used.

6.1.2 *Vertical Reinforcement* — Vertical reinforcement shall not be less than 0·2 percent of cross-sectional area of the wall for single bins or exterior walls of battery of bins, when deformed bars are used. For interior walls of battery of bins its minimum value shall be 0·15 percent of the cross-sectional area when deformed bars are used. When mild steel bars are used the vertical reinforcement shall be taken as 0·25 percent and 0·20 percent respectively for the above cases. The minimum bar diameter shall be 10 mm when deformed bars are used and 12 mm when mild steel bars are used. The vertical reinforcement shall preferably be provided in two layers, half near the inside and half near the outside face of the wall. If the reinforcement is provided in one layer, the spacing shall not exceed 225 mm and 300 mm depending upon the two cases of single bins or internal walls of battery of bins and if the reinforcement is provided in two layers, the corresponding spacing shall be 450 and 600 mm.

6.1.3 Deformed bars or cold twisted bars shall preferably be used for the reinforcement in bin walls to facilitate fixing of horizontal bars and operation of sliding form-work.

6.1.4 *Size of Bars, Spacing, etc* — Details regarding reinforcement such as size of bars, spacing laps, etc, shall be in conformity with the provisions of IS: 456-1964* and IS : 2502-1963†. In case of bin walls the minimum requirements regarding the size and spacing of bars shall be as under **6.1.1**, **6.1.2** and **6.1.3**.

6.2 Construction Joints — Vertical construction joint shall not be allowed in the wall. Horizontal construction joints shall be maintained at suitable spacing throughout as far as possible.

6.3 Cover — A minimum clear concrete cover of 30 mm shall be provided for the reinforcement.

*Code of practice for plain and reinforced concrete (*second revision*).
†Code of practice for bending and fixing of bars for concrete reinforcement.

(*Continued from page* 2)

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Printed at Simco Printing Press, Delhi

AMENDMENT NO. 1 JUNE 1976

TO

IS:4995(Part II)-1974 CRITERIA FOR DESIGN OF REINFORCED CONCRETE BINS FOR STORAGE OF GRANULAR AND POWDERY MATERIALS

PART II DESIGN CRITERIA

(First Revision)

Corrigenda

(Page 13, clause 5.5.4, against explanation of n) - Substitute '0.000 3' *for* '0.003'.

(Page 16, clause 5.7.3, line 4) - Substitute '2.5 percent' *for* '25 percent'

(BDC 38)

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