IS 9178-1 (1979): Criteria for Design of Steel Bins for Storage of Bulk Materials, Part 1: General Requirements and Assessment of Loads [CED 7: Structural Engineering and structural sections]

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Indian Standard

CRITERIA FOR DESIGN OF STEEL BINS FOR STORAGE OF BULK MATERIALS

PART 1 GENERAL REQUIREMENTS AND ASSESSMENT OF LOADS

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Gr 7 *April* 1980

Indian Standard

CRITERIA FOR DESIGN OF STEEL BINS FOR STORAGE OF BULK MATERIALS

PART I GENERAL REQUIREMENTS AND ASSESSMENT OF LOADS

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AMENDMENT NO. 1 FEBRUARY 1985

TO

IS : 9178 (Part I)-1979 CRITERIA FOR DESIGN OF STEEL BINS FOR STORAGE OF BULK MATERIALS

PART I GENERAL REQUIREMENTS AND ASSESSMENT OF LOADS

(*Page* 14, *clause* **6.2.1.2**) — Substitute the following for the existing formula:

$$\sum_{0}^{Z} P_w = \pi DWR \left[Z - Z_{oe} \left(1 - e^{-\frac{Z}{Z_{oe}}} \right) \right]$$

(SMBDC 7)

Printed at New India Printing Press, Khurja, India

AMENDMENT NO. 2 AUGUST 1992
TO
IS 9178 (Part 1) : 1979 CRITERIA FOR DESIGN OF STEEL BINS FOR STORAGE OF BULK MATERIALS
PART 1 GENERAL REQUIREMENTS AND ASSESSMENT OF LOADS

(*Page* 18, *Fig.* 5) — Interchange angle 'A' with angle 'C' in the hopper sketch.

(CED 7)

Printed at New India Printing Press, Khurja

Indian Standard

CRITERIA FOR DESIGN OF STEEL BINS FOR STORAGE OF BULK MATERIALS

PART I GENERAL REQUIREMENTS AND ASSESSMENT OF LOADS

0. FOREWORD

0.1 This Indian Standard (Part I) was adopted by the Indian Standards Institution on 15 May 1979, after the draft finalized by the Structural Engineering Sectional Committee had been approved by the Structural and Metals Division Council and the Civil Engineering Division Council.

0.2 Bins are known as silos if they have circular or polygonal shape in plan. When square or rectangular in plan they are known as bunkers. In this standard a bin shall mean both silo and bunker unless otherwise stated

0.3 The functions of bins as storage structures are very important in power stations, fertilizer complexes, steel plants, cement plants and similar industries for efficient storage and use of bulk material both in granular and powdery form. On the agricultural front bins are used to store food grains for ensuring their supply all through the year Bulk storage of materials in bins has certain advantages over other forms of storage. Therefore an Indian Standard on this subject has been a long felt need and this standard is aimed at giving the necessary guidance in the analysis and design of steel bins for storing various materials of different characteristics and flow properties.

0.4 Bins have been designed on the basis of Janssen's Theory (with modifications to the original). From experimental investigations and a study of the performance of the existing bins it has been noticed that the pressure distribution is influenced by the size and shape of the material to be stored (that is granular or powdery), moisture and temperature, bulk density, which in turn is affected by storage and flow characteristics. Besides there is an increase in the imposed loads during filling and emptying, the latter being more predominant.

0.5 For reasons mentioned above in the bins designed by conventional *methods, materials do not easily flow due to arching and piping.* This required frequent poking — manually, pneumatically, with steams or by other mechanical means. With research data available, this problem has been successfully solved by adopting mass flow or funnel flow bins where the shape of the bin hopper and size of the openings are based on the flow properties of the stored material.

0.6 In order to deal with the subject in an effective manner this standard has been prepared in three parts namely:

Part I General requirements and assessment of loads

Part II Design criteria

Part III Bins designed for mass flow and funnel flow

0.7 This standard keeps in view the practices being followed in the country and elsewhere in this field Assistance has also been derived from the following publications:

DIN 1055 (Sheet 6) Design loads for building — Loads in silos/bins. Deutscher Normenausschuss.

PIEPER (K) and WENZEL (F) Pressure Distribution in Bins (in German) Verlag Wilhelm Ernst & Sohn, Berlin, Munchen. 1964.

LAMBERT (F E) The Theory and Practical Design of Bunkers The British Constructional Steelwork Associations Ltd, London.

REISNER (W) and ROUTHE (M. E.) Bins and Bunkers for Handling Bulk Materials. Trans-Tech Publication, Ohio, USA

JENIKE (A. W) Storage and Flow of Solids *Bul* 123. 1964 Utah Engineering Experiment Station, University of Utah, Utah, USA.

JOHAN (J R.) and COLIJN (H) New Design Criteria for Hopper and bins *Iron and Steel Engineer, October* 1964.

0.8 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*

1. SCOPE

1.1 This standard (Part I) deals with the general requirements and assessment of bin loads for granular and powdery materials in different bin shapes.

2. TERMINOLOGY

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

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

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

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

2.3 Bin — A structure meant for storing bulk material in vertical direction with outlets for withdrawal either by gravity alone or by gravity assisted by flow promoting devices

2.3.1 *Silo* — A bin, circular or polygonal in plan.

2.3.2 *Bunker* — A bin whose cross section in plan is square or rectangular.

2.4 Bin, Asymmetrical — A bin in which the outlets are asymmetrically placed to axes of the bin.

2.5 Bin, Interstice — Bin formed out of the space enclosed by a battery of interconnected bins.

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

2.7 Bulk Solid — Bulk of granular and powdery material.

2.7.1 *Granular Material* — Material having mean particle size more than 0 2 mm. No cohesion between particles is assumed.

2.7.2 *Powdery Material* — Material having mean particle size less than 0·06 mm

2.8 Bunker Closure or Gate — The closing arrangement for the outlet at the bottom of the hopper for discharging the stored material.

2.9 Consolidated Pressure — The normal pressure acting on the bulk solid causing the particles to move closer together, thereby changing the bulk density and flow properties of the material.

2.10 Food Grain — All cereals, pulses and millets, except oilseeds.

2.11 Funnel or Plug Flow — The flow pattern in which the material flows primarily in the central region of the bin or hopper.

2.12 Hopper — The bottom converging portion of the bin.

2.13 Mass Flow — Flow in which the entire mass of material flows without stagnation.

2.14 Poking Hole — Hole provided at suitable location on the sides for poking the stored material either manually, mechanically, pneumatically or with steam.

2.15 Valley Angle — The angle of the corner of pyramidal hopper measured with respect to the horizontal plane.

2.16 Waist or Transition — The junction of the vertical walls and the sides of hopper.

3. NOTATIONS

3.0 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 at depth Z.

a = Side of a square bin or shorter side of a rectangular bin

b = Longer side of a rectangular bin

D = Internal diameter in a circular bin

d = Maximum diameter of the circle that can be inscribed in the bin

h = Height of bin

P_a = Pressure of air injected for pneumatic emptying of a bin

P = Pressure

i = Suffix indicating h, v or w corresponding to horizontal (lateral), vertical or wall friction respectively

P_h = Horizontal (lateral) pressure on the bin wall due to stored material depth Z

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

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

P_{n1} = Pressure obtained on the wall of a bin imagined to be enlarged in plan so as to make the eccentric opening concentric

S = Bottom diameter of insert

R = A/U

U = Perimeter of the cross-section of the stored material at depth Z

W = Bulk density of the stored material

Z = Depth below the levelled surface of the maximum possible fill in the bin (*see* Fig. 1)

δ = Angle of wall friction of the stored material on the walls of the bin

θ = Slope of hopper wall with horizontal
ϕ = Angle of internal friction of the stored material (for non-cohesive materials it is also the angle of repose)
μ = Coefficient of wall friction ($\tan \delta = P_w/P_h$)
μ_f = Coefficient of wall friction during filling
μ_e = *Coefficient of wall friction during emptying*
λ = Pressure ratio (P_h/P_v)
λ_f = Pressure ratio (P_h/P_v) during filling
λ_e = Pressure ratio (P_h/P_v) during emptying.

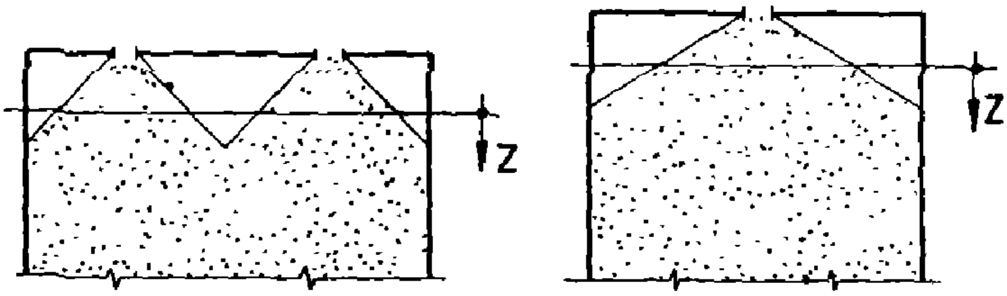


FIG 1 DEPTH BELOW THE LEVELLED SURFACE OF THE MAXIMUM POSSIBLE FILL IN THE BIN

4. GENERAL

4.1 Location — Location of bins and specially those storing foodgrains shall conform to the relevant provisions of IS : 5503 (Part I)-1969*. Depending upon material handling and pressure requirements, bins should be suitably located

4.2 Economic Consideration — Optimum dimensions, shape and lay-out, etc, of bins shall be selected in accordance with clauses **4.2.1** to **4.2.3**. In addition the material handling facilities shall also be considered.

4.2.1 *Dimensions* — Volume of each bin and height to diameter ratio shall be governed by the storage and functional requirement of materials. To achieve reduction in lateral pressure over a longer height, it may be preferable to select a height diameter ratio greater than or equal to two.

4.2.2 *Shape* — A bin may be circular or polygonal in plan and is provided with a roof and a bottom which may be flat, conical or pyramidal. In case of gravity flow bin, the angle made by the hopper with the horizontal shall preferably be determined in accordance with IS : 9178 (Part III)†.

*General requirements for silos for grain storage: Part I Constructional requirements.

†Criteria for the design of steel bins for storage of bulk materials. Part III Bins designed for mass flow and funnel flow (*under preparation*).

4.2.3 *Layout* — Storage bins may be either free standing individual bins or arranged in the form of batteries of free standing bins or bins interconnected in one or both the directions.

5. DESIGN PARAMETERS

5.1 Design parameters of stored materials include bulk density w, angle of internal friction ϕ, angle of wall friction δ and pressure ratio (λ) which are the governing factors for the computation of bin loads Storage and flow characteristics of granular materials differ widely from those of powdery materials.

5.2 Shape of the Bin — The cross-sectional shape of the bin is taken into account by the factor R. In the case of interstice bins, the value of R shall be approximated by the value of R for an equivalent square bin of the same area.

5.3 Bulk Density and Angle of Internal Friction — Tables 1 and 2 give the classification and characteristics of bulk material commonly stored.

TABLE 1 CLASSIFICATION OF BULK MATERIALS

	Material Characteristic	Class
Size	Very fine — 100 mesh and under	A
	Fine 3 mm and under	B
	Granular — 12 mm and under	C
	Lumpy-containing lumps over 12 mm	D
	Irregular — being fibrous, stringy or the like	H
Flowability	Very free flowing	1
	Free flowing	2
	Sluggish	3
Abrasiveness	Non-abrasive	6
	Mildly abrasive	7
	Very abrasive	8
Other Characteristics	Contaminable, affecting use or saleability	K
	Hygroscopic	L
	Highly corrosive	N
	Mildly corrosive	P
	Gives off dust or fumes harmful to life	R
	Contains explosive dust	S
	Degradiable, affecting use of saleability	T
	Very light and fluffy	W
	Interlocks or mats to resist digging	X
	Aerates and fluidized	Y
	Packs under pressure	Z

TABLE 2 CHARACTERISTICS OF BULK MATERIALS

(*Clause* 5.3)

MATERIAL	AVERAGE BULK DENSITY *W*	CLASS	ANGLE OF INTERNAL FRICTION ϕ *Min*
(1)	(2)	(3)	(4)
	kg/m³		Degree
Ammonium chloride, crystalline	830	B26LP	30-45°
Ammonium nitrate	720-1 000	B27NLS	25°
Ammonium sulphate	720-920	B26N	32-45°
Ashes, coal, dry, 12 mm and under	560-640	C37	40°
Ashes, coal, dry, 75 mm and under	560-640	D37	38°
Ashes, coal, wet, 12 mm and under	720-800	C27PZ	52°
Ashes, coal, wet, 75 mm and under	720-800	D37PZ	50°
Asphalt, crushed, 12 mm and under	720	C26	30-45°
Benzine hexachloride	890	A36R	45°
Bicarbonate of soda	650	A26	30°
Calcium carbide	1 120-1 280	D27	30-45°
Carbon black, pelletized	320-400	B16TZ	28°
Carbon black powder	600-900	A17WZ	21°
Cinders, blast furnace	910	D38	35-45°
Cinders, coal	640	D28	35-45°
Coal, anthracite	830-960	C27P	30-45°
Coal, pulverized	510-560	—	—
Coal, powdered	800-960	—	—
Coal, bituminous, mined, run of mine	800	D26P	35°
Coal, bituminous, mined, sized	800-910	D26PT	22-31°
Coal, bituminous, mined, slack 12 mm and under	640-800	C36P	29-45°
Coal, bituminous, stripping, not cleaned	800	D37P	45°
Coal char	380	B27SY	30-45°
Coke loose	360-510	D38TX	27-45°
Coke breeze	400-560	—	≥45°
Cement	1 550	—	25°
Cement clinker	1 650	—	35-37°

(*Continued*)

TABLE 2 CHARACTERISTICS OF BULK MATERIALS — *Contd*

Material	Average Bulk Density W	Class	Angle of Internal Friction ϕ *Min*
(1)	(2)	(3)	(4)
	kg/m³		Degree
Copper sulphate, ground	1 200	D26P	30°
Dicalcium phosphate	680	A36	45°
Disodium phosphate	400-490	B27PT	30-45°
Ferrous sulphate	800-1 120	C27	30-45°
Flue dust, boiler house, dry	560-720	A18Y	< 30°
Fly ash, pulverized	560-720	—	—
Gypsum, calcined, 12 mm and under	880-960	C27	40°
Gypsum, calcined, powdered	960-1 280	A37	45°
Gypsum, raw, 25 mm and under	1 440-1 600	D27	30-45°
Lime, ground, 3 mm and under	960	B36LZ	> 45°
Lime, hydrated, 3 mm and under	640	B26YZ	30-45°
Lime, hydrated, pulverized	510-640	A26YZ	30-45°
Lime pebble	840 890	D36	> 45°
Limestone, agricultural 3 mm and under	1 080	B27	30-45°
Limestone, crushed	1 360-1 440	D27	30-45°
Limestone dust	880-1 520	A37YL	38-45°
Phosphate, rock, pulverized	960	—	40-52°
Phosphate rock	1 200-1 360	D27	30-45°
Phosphate sand	1 440 1 600	B28	30-45°
Potassium carbonate	810	B27L	30-45°
Potassium chloride, pellets	1 920-2 080	C27P	30 45°
Potassium nitrate	1210	C17PZ	< 30°
Potassium sulphate	670-760	B37Z	45°
Pyrites, pellets	1 920 2 080	C27R	30-45°
Salt, common, dry course	640-1 020	C27PI	30 45°
Salt, common, dry fine	1 120 1 280	B27PL	30 45°
Salt cake, dry, coarse	1 360	D27	30°
Salt cake, dry, pulverized	1 140 1 360	B27	35°
Sand bank, damp	1 760-2 080	B38	45°

(*Continued*)

TABLE 2 CHARACTERISTICS OF BULK MATERIALS — *Contd*

Material	Average Bulk Density W	Class	Angle of Internal Friction ϕ *Min*
(1)	(2)	(3)	(4)
	kg/m³		Degree
Sand, bank, dry	1 440-1 760	B28	30°
Sand, silica, dry	1 440-1 600	B18	30-35°
Silica gel	450	B28	30-45°
Soda ash, heavy	880-1 040	B27	35°
Soda, ash, light	480-610	A27W	37°
Sodium nitrate granular	1 120-1 280	B17NS	24°
Sulphur crushed, 12 mm and under	800-960	C26S	30-45°
Sulphur, 76 mm and under	880-1 360	D26S	32°
Sulphur, powdered	800-960	B26SY	30-45°
Trisodium phosphate	960	B27	30-45°
Triple superphosphate	800-880	B27NRZ	30-45°
Urea, prills	650	C17NXL	23-26°
Ammonium nitrate, prills	750-850	B17LPS	27°
Calcium ammonium nitrate	1 000	—	28°
Diammonium phosphate	800-860	—	29°
Nitrophosphate (suphala)	820	—	30°
Double salt (ammonium sulphate nitrate)	720-950	B26NLS	34°
Single superphosphate (S. S. P.), granulated	780-840	—	37°
Barley	690		27°
Wheat	850		28°
Rice	900		33°
Paddy	575		36°
Maize	800		30°
Corn	800		27°
Sugar	820		35°
Wheat flour	700		30°

NOTE — The values given in this table may not be taken to be applicable universally. The bulk density and angle of internal friction depend on many variable factors, such as moisture content, particle sizes, temperature, consolidating pressure, etc. Detail study and test shall be conducted on actual sample to obtain their values under the actual condition of storage. A reference to IS : 9178 (Part III) 'Criteria for the design of steel bins for storage of bulk materials: Part III Bins designed for mass flow and funnel flow (*under preparation*)' may be made for details.

5.4 Wall Friction — In the absence of reliable experimental data, the angle of wall friction for granular and powdery materials, irrespective of the roughness of bin wall, may be taken as given in Table 3.

TABLE 3 ANGLE OF WALL FRICTION AND PRESSURE RATIO

SL No.	MATERIAL	ANGLE OF WALL FRICTION δ		PRESSURE RATIO λ	
		While filling	While emptying	While filling	While emptying
i)	Granular materials with mean particle diameter $\geqslant$ 0.2 mm	0.75 ϕ	0.6 ϕ	0.5	1.0
ii)	*Powdery materials (except wheat flour) with mean particle diameter less than 0.06 mm*	*1.0 ϕ*	*1.0 ϕ*	*0.5*	*0.7*
iii)	Wheat flour	0.75 ϕ	0.75 ϕ	0.5	0.7

NOTE — For materials having mean particle diameters in between 0.06 mm and 0.2 mm, the necessary values of angle of wall friction may be obtained by linear interpolation.

5.4.1 If there is a possibility that the moisture, pressure increase due to consolidation, etc, may affect the angle of internal friction ϕ and wall friction δ then these values shall preferably be determined experimentally.

6. ASSESSMENT OF BIN LOADS

6.1 General — There are three types of loads caused by a stored material in a bin structure (*see* Fig. 2):

a) Horizontal load due to horizontal pressure (P_h) acting on the side walls.

b) Vertical load due to vertical pressure (P_v) acting on the cross-sectional area of the bin filling.

c) Friction wall load due to frictional wall pressure (P_w) introduced into the side walls due to wall friction.

6.1.1 For the purpose of computing bin loads the pressure ratio of horizontal to vertical pressure may be assumed as given in Table 3.

6.1.2 In this standard, Janssen's theory has been used for the assessment of bin loads and the values of λ, δ and W are assumed to be constant along the bin height. The theory has been suitably modified wherever necessary and with this the structural adequacy and safety are ensured.

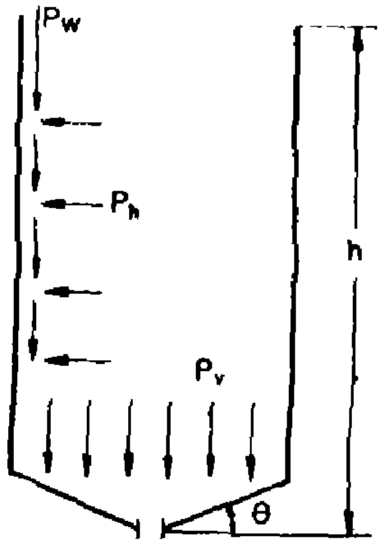


FIG 2 BIN LOADS

6.1.3 *Mass Flow and Funnel Flow Bins* — Bins may be designed on the basis of mass/funnel flow characteristics of the stored material to ensure free flow of material during emptying. Methods of designing mass flow and funnel flow bins are given in IS : 9178 (Part III)*.

6.1.4 *Loading Conditions for Design* — In general the loading cases as indicated in Table 4 will give the governing design pressures for the most adverse loading conditions. However these conditions may be affected by arching, piping and similar load increasing phenomena, and the remedial measures may be adopted to overcome them.

TABLE 4 GOVERNING LOADING CONDITIONS

LOADS	GRANULAR MATERIAL		POWDERY MATERIAL	
	Finite Depth	Infinite Depth	Finite Depth	Infinite Depth
P_v	Filling	Filling	Filling	Filling
P_h	Emptying	Emptying	Emptying	Filling = Emptying
P_w	Emptying	Filling = Emptying	Emptying	Filling = Emptying

6.2 Bin Loads Due to Granular Materials

6.2.1 *Normal Filling and Emptying*

*Criteria for design of steel bins for storage of bulk materials: Part III Bins designed for mass flow and funnel flow (*under preparation*)

6.2.1.1 *Maximum pressures* — The maximum values of the horizontal pressures on the wall (P_h), the vertical pressure on the horizontal cross section of the stored material (P_v) and the vertical load transferred to the wall per unit area due to friction (P_w) shall be calculated as follows (*see also* Fig 2).

Name of Pressure	*During Filling*	*During Emptying*
Maximum P_w	WR	WR
Maximum P_h	$\frac{WR}{\mu_f}$	$\frac{WR}{\mu_e}$
Maximum P_v	$\frac{WR}{\mu_f \lambda_f}$	$\frac{WR}{\mu_e \lambda_e}$

6.2.1.2 P_v and P_w cannot be maximum at the same time Hence for the design of hopper bottom, maximum P_v (during filling) should be considered and this value will be the maximum P_v at the particular depth multiplied by area of cross-section of bin. The maximum P_w (emptying) shall be calculated when the side walls are to be designed at a particular depth as.

$$\sum_{0}^{Z} P_w = \pi DWR \left[(Z - Z_{oe}) \left(1 - e^{\frac{-Z}{Z_{oe}}} \right) \right]$$

If h/D ratio is less than or equal to 2, the values shall be:

a) the total weight of stored material when hopper bottom is to be designed, and

b) the value indicated as P_w when side walls are to be designed.

6.2.1.3 *Variation of pressure along the depth* — The variation of P_w, P_h and P_v along the depth of the bin may be obtained from the expression given below (Fig. 3):

$$P_i (Z) = (P_i)_{max} (1 - e^{-Z/Z_0})$$

where P stands for pressure and suffix i stands for w, h or v corresponding to the pressure P_w, P_h or P_v respectively and Z_0 assumes the values given below:

$$\text{During filling, } Z_{of} = R/\mu_f \lambda_f$$

$$\text{During emptying, } Z_{oe} = R/\mu_e \lambda_e$$

Appendix A gives the values of ($1 - e^{-Z/Z_0}$) for different values of Z/Z_0 Intermediate values may be obtained with sufficient accuracy by linear interpolation.

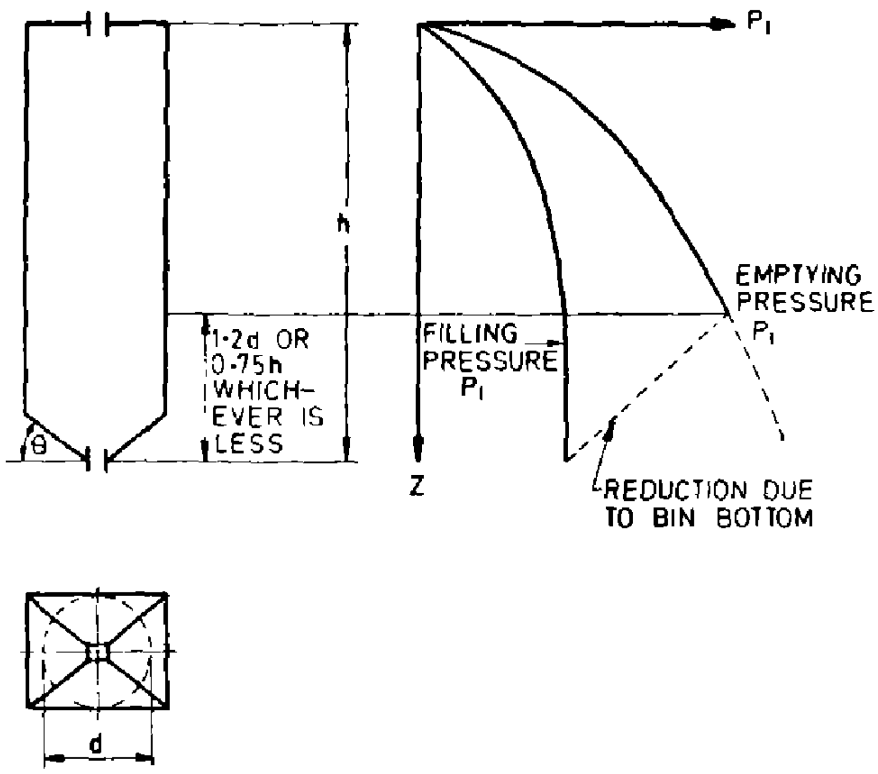


FIG. 3 PRESSURE VARIATION ALONG BIN DEPTH

6.3 Bin Loads Due to Powdery Materials

6.3.1 *Normal Filling and Emptying* — Maximum design pressures under this case shall be computed as specified under **6.2**. Appropriate values of various design parameters shall be taken from Tables 2 and 3.

6.3.2 *Homogenization* — In the case of homogenizing bin, the filling consists of powdery materials which is circulated by compressed air for mixing purposes. During homogenization of powdery materials the lateral and vertical pressures depend upon the volume of the empty space available in the upper portion of the bin. This may be kept about 40 percent of the total volume of the bin. The lateral and vertical pressures shall be calculated using the following expression and should not be less than pressure evaluated as in **6.2.1**:

$$P_h = P_v = 0.6\,WZ$$

6.3.3 *Rapid Filling* — During rapid filling-material being filled at a rate higher than the minimum filling speed-up to a certain height Z_n from the top layer, the upper stored material flows like a fluid. The following expression may be used for computing the governing lateral pressures during rapid filling of a silo with a filling speed v:

$$\text{Rapid filling } (P_h) = 0{\cdot}8\, W.\, Z_n$$

where

$Z_n = (v - v_0)\, t;$

v = actual filling speed, m/h;

v_0 = the minimum filling speed, *m/h*; and

t = time laps of one hour.

NOTE — The values of v_0 shall be taken as follows:

Material	v_0, m/h
Cement	2 6
Pulverized lime	1 4
Wheat flour	4 8

6.3.3.1 Application of the formula given in **6.3.3** is only for materials filled at a rate more than the minimum filling speed for different materials. For speeds lesser than the minimum filling speed, the pressures in **6.2** shall apply. However, when the filling speed exceeds the minimum filling speed, a check should be made for the maximum pressure due to rapid filling from the greater values arrived at according to the formula given in **6.3.3** and the values given in **6.3.1**, **6.3.2**, **6.3.4** and **6.6**.

6.3.4 *Pneumatic Emptying* — During pneumatic emptying air under pressure is blown inside the bin through a number of small holes located in the bin walls near the bin bottom. This causes fluidization of the material in the lower portion of the bin and gives rise to higher values of P_h and P_v (both being equal). The lateral pressures during pneumatic emptying shall be calculated using the pressure scheme shown in Fig. 4.

6.4 Fermentation Bins — In the fermentation bins the properties of the material differ from the properties of granular and powdery materials. The pressure varies with the content of water in the material and stage of fermentation process. The loads shall be as given in Table 5.

6.4.1 All fermentation bins shall have clearly visible and permanent mark indicating the class if silage is to be stored. In addition, class 1 and 2 bins shall be marked to indicate that the bins may only be filled to halfway mark with silage which is one class wetter. There shall be an outlet to prevent the liquid from standing higher than 1 m.

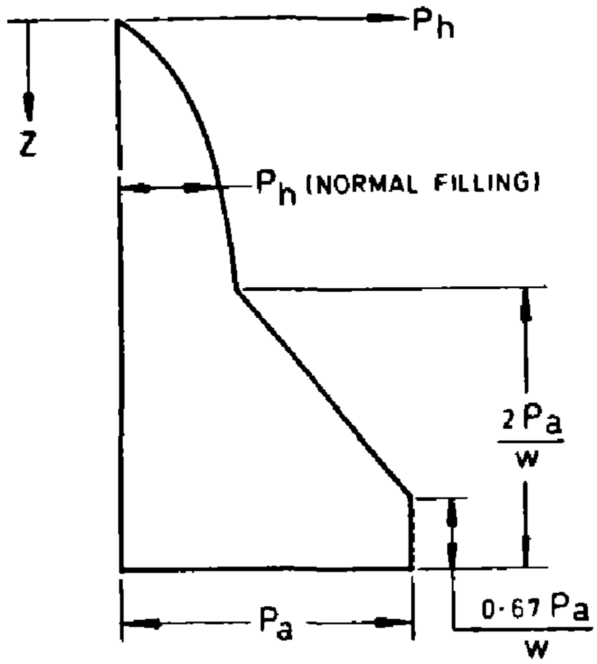


FIG. 4 PRESSURE SCHEME FOR PNEUMATIC EMPTYING

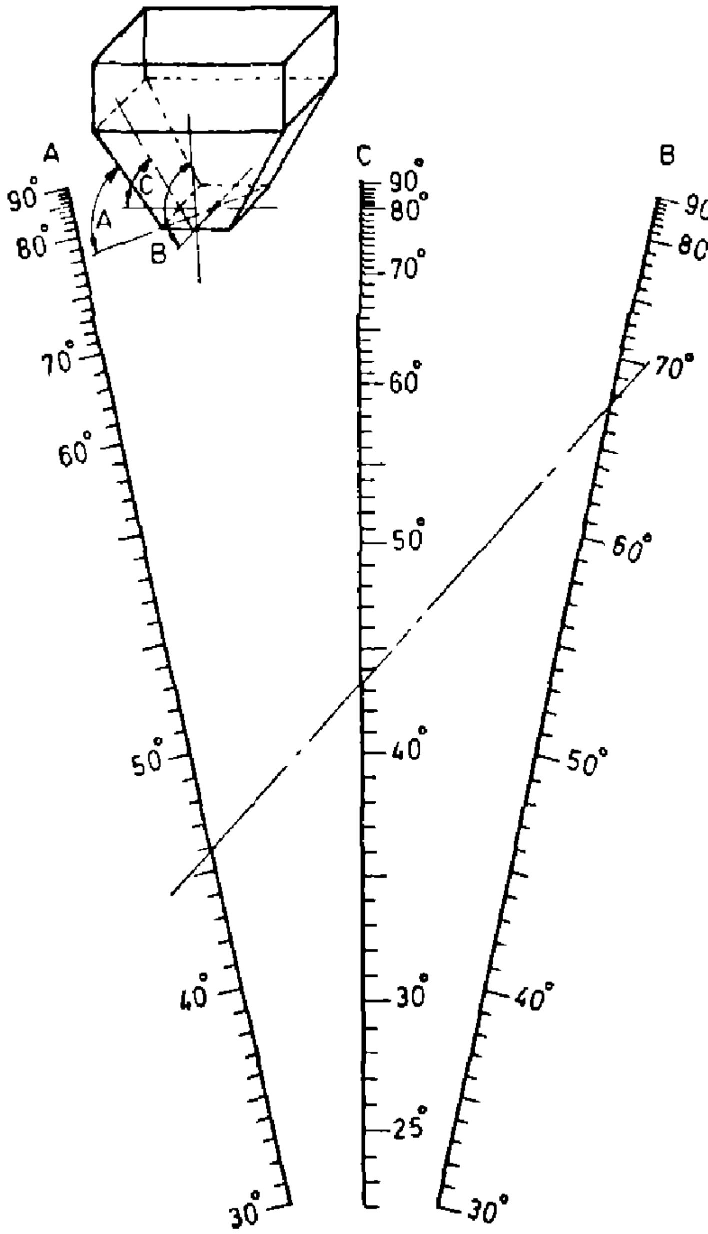
TABLE 5 LOADS IN FERMENTATION BINS

(*Clause* 6.4)

	CLASS 1 SILAGE ALREADY VERY DRY	CLASS 2 DRY SILAGE	CLASS 3 WET SILAGE
Dry mass in percentage by weight for fresh silage	> 35	23-35	< 23
Critical weight of stored material in kg/m³	0.50 W	0·75 W	1.0 W
P_h in kgf/m²	0.70 WZ	0.70 WZ	1.0 WZ
P_v in kgf/m²	WZ	WZ	WZ
P_w in kgf/m²	0.16 P_h	0.14 P_h	0.10 P_h

6.5 Hopper Slope — To facilitate easy and continuous flow it is essential that the slope of the hopper is as steep as possible. In the case of gravity flow, it is recommended that the angle made by the hopper wall with the horizontal (valley angle in the case of square and rectangular hopper bottoms), shall preferably be 15° more than the angle of internal friction of the material. However the slope should not be less than 60° to horizontal.

6.5.1 A nomograph to determine the hopper slope (valley angle) in the case of rectangular and square hoppers, when the slope of the side walls are known, is given in Fig. 5.



Example :

To find valley angle when A = 46°, B = 67°, place straight-edge so as to cut 46° on A-Scale and 67° on B-Scale. Read off answer

Valley Angle = 43 4° on C-Scale

NOTE — This chart is based on the formula $\cot^2 C = \cot^2 A + \cot^2 B$

FIG. 5 NOMOGRAPH FOR VALLEY ANGLES OF HOPPERS AND CHUTES

6.6 Effects Causing Increase in Bin Loads

6.6.1 *Arching of Stored Material* — Some stored materials are susceptible to arching action across the bin walls. Frequent collapse of such arches give rise to increased vertical pressures. The vertical pressure on the bottom of the bin storing such materials shall be assumed as twice the pressure, P_v, calculated as per **6.2.1.1** and **6.2.1.2** subject to a maximum of WZ. However, this increased pressure need not be considered when the bin is so designed to eliminate arching.

6.6.2 *Eccentric Emptying* — Eccentric emptying of a bin gives rise to increased horizontal loads, non-uniformly distributed over the periphery and extending over the full height of the bin. Eccentric outlets in bins shall be avoided as far as possible, and, where they have to be provided to meet functional requirements, due consideration shall be given in design to the increased pressure experienced by the walls. Unless determined by investigation the increased pressure may be calculated as given in **6.6.2.1**. This increased pressure shall be considered, for the purpose of design, to be acting both on the wall nearer to the outlet as well as on the wall on the opposite side.

6.6.2.1 The additional pressure P_h' shall be considered to act for the full height of the bin and is obtained from the following formula:

$$P_h' = P_{hl} - P_h$$

where

P_{hl} = Pressure obtained on the wall of the bin imagined to be enlarged in plan so as to make the eccentric opening concentric, and

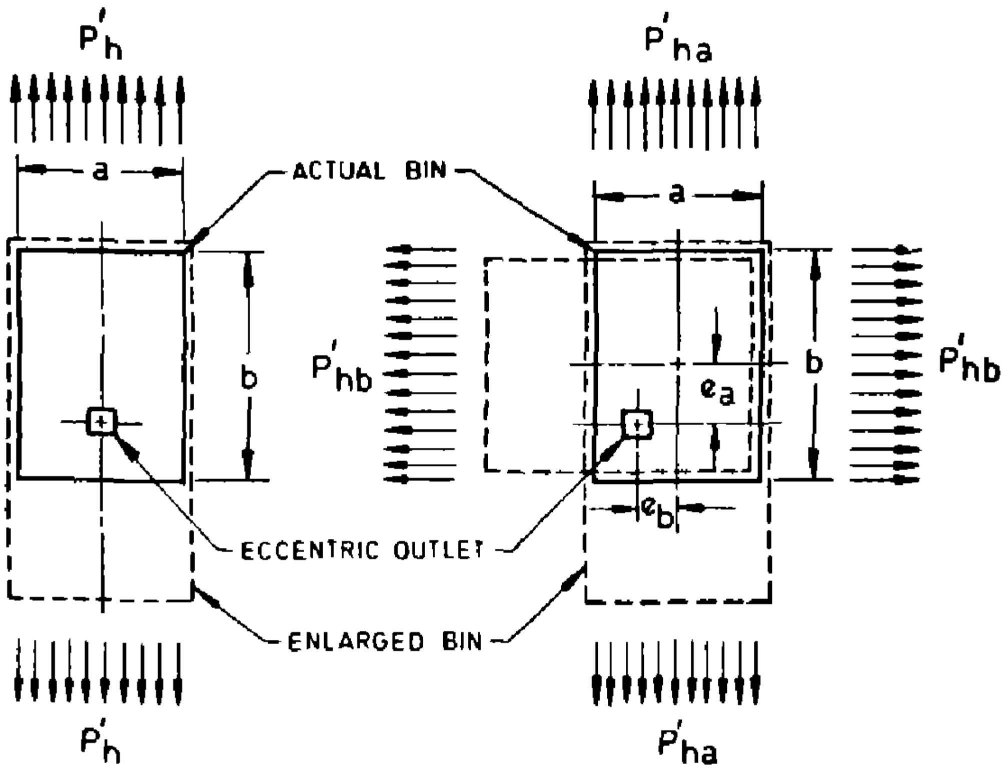
P_h = Horizontal pressure on the wall due to stored material.

P_{hl} and P_h shall be obtained in conformity with **6.2.1**.

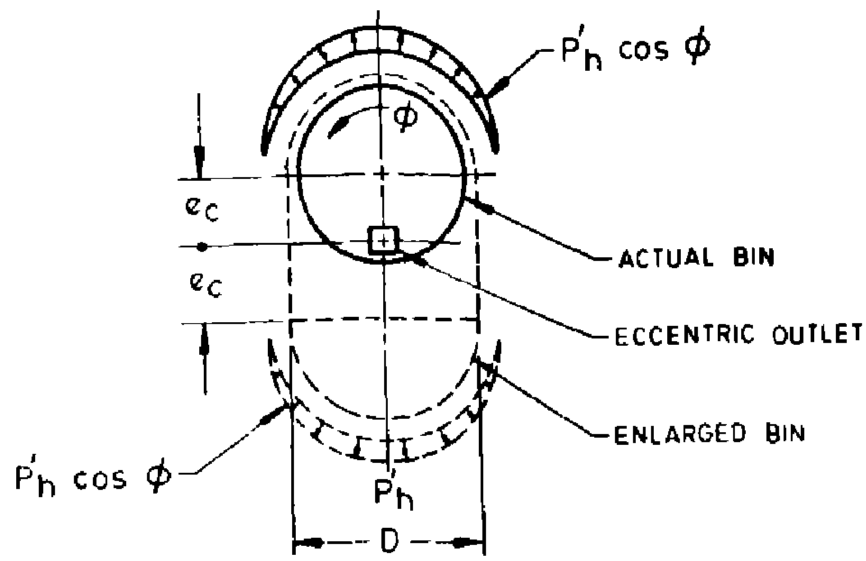
6.6.2.2 The enlarged shape of the bin which is required for the purpose of computation of the pressure P_{hl} shall be obtained as shown in Fig. 6.

6.6.2.3 The effect of eccentric outlets may be ignored in design if the eccentricity is less than $d/6$ or the height of the bin is not greater than 2 d.

6.6.3 *Aeration of Stored Material* — When bins are provided with equipment for ventilating the bin filling at rest, a distinction shall be made between bins for granular material and bins for powdery material.



6A Rectangular Bin



6B Circular Bin

FIG 6 EFFECT OF EMPTYING THROUGH ECCENTRIC OUTLETS

6.6.3.1 When the material is granular an increase in the horizontal pressure is to be expected. Therefore, the horizontal pressure P_h, as calculated from **6.2.1.1**, for filling is to be increased by the inlet pressure of the air over the portion of the height of the bin in which the air inlets are located. From the level of the highest inlet upwards, this increase in pressure may be tapered off uniformly down to zero at the top of the bin.

6.6.3.2 For powdery materials the investigations made so far do not indicate any significant increases in load when ventilating.

6.6.3.3 Bins for storage of powdery materials are often equipped with devices for pneumatic emptying and these bring about a loosening of the bin filling in the region of the outlet. In this case also, no significant increases in load due to the air supply have so far been detected.

6.7 Effects Causing Decrease in the Bin Loads

6.7.1 *Bin Bottom* — In view of the load reducing effect of the bin bottom, the horizontal pressure during emptying may be reduced up to a height 1·2 d or 0·75 h whichever is smaller from the bin bottom. This may be considered as varying linearly from the emptying pressure at this height to the filling pressure at the bin bottom (*see also* Fig. 3).

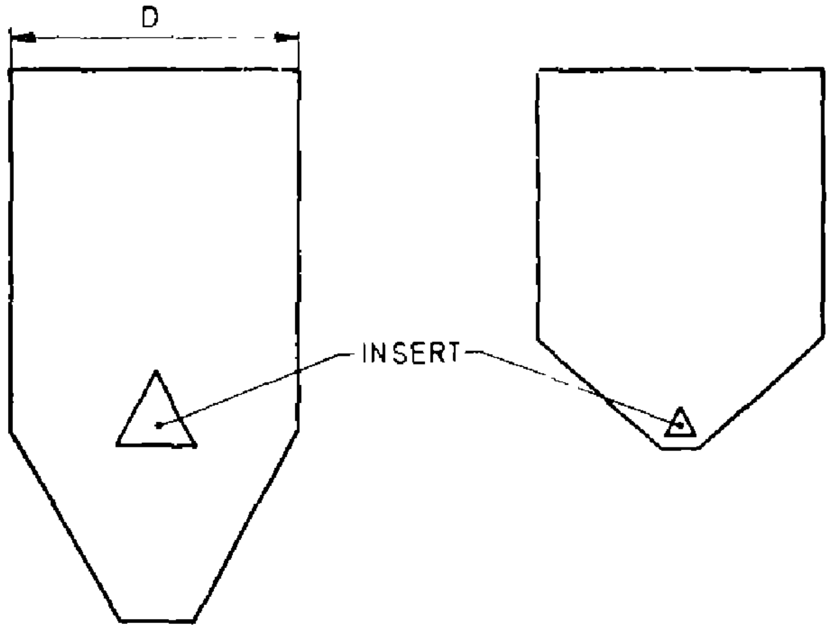
6.7.2 *Special Unloading Devices* — If a bin is fitted with an unloading device which allows only the topmost material at any time to be withdrawn (while the layers below remain at rest) there is no need to take into account the excess pressure during emptying.

7. FLOW CORRECTING DEVICES

7.1 Flow correcting devices are provided to ensure free and continuous flow and to reduce or eliminate the excess pressure during emptying.

7.2 Insert type of flow correcting device is usually used in existing installations with hoppers from which funnel flow takes place and which needs to be converted into a mass flow hopper or to reduce tendency to form stable arches or pipes. Flow-corrective inserts help to increase the live storage capacity and to reduce segregation problems in bins having hoppers with funnel flow.

7.2.1 Insert type of flow correcting device may be used to correct two types of flow problems. A large insert is placed (*see* Fig 7A) near the transition between the bin and hopper to cause mass flow in the vertical bin position. A small insert is placed (*see* Fig 7B) near the hopper outlet to eliminate piping (rat-holing) and arching of bulk solids.



7A 7B

FIG. 7 TYPICAL DETAILS OF INSERTS TO FLOW CORRECTION AND EMPTYING LOAD

7.2.2 The influence of the insert on the flow of materials and on the structural stability of the bin wall should be considered while designing the bins. The performance of the inserts and their influence on the material flow depend on the stored material and the geometry of the bin and hopper and should be experimentally investigated. The support of the insert should not obstruct the flow but at the same time should not fail under the loads that are applied to it. As a guide the diameter S of the insert bottom shall not be less than three times the annular width S' (*see* Fig 8).

7.2.3 The material remaining in the bin for a period of time may result in the formation of arches in the region of insert, and may require to be vibrated to initiate the flow The insert should, therefore, be so designed as to ensure all round flow.

7.3 Poking devices may be incorporated in the bins for ensuring proper flow Poking may be manual, pneumatic with steam or using any suitable mechanical means like vibrators.

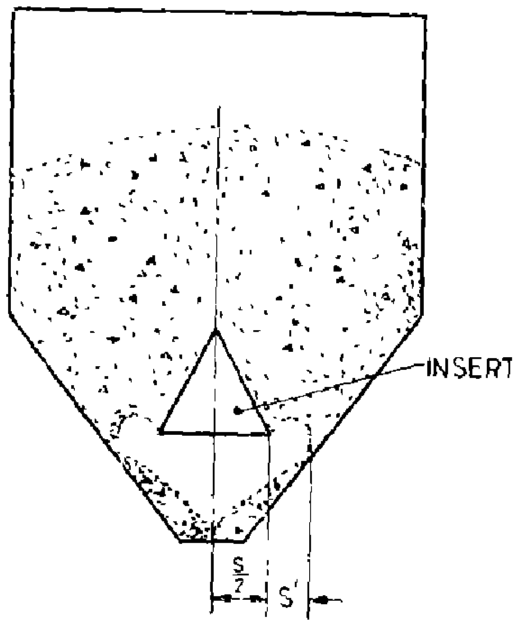


FIG. 8 SKETCH SHOWING INFLUENCE OF INSERT ON THE FLOW OF MATERIAL

8. MATERIAL HANDLING SYSTEM

8.1 Since the material handling system has an effect on the design of bins some details are given for information in Appendix B.

APPENDIX A

(*Clause* 6.2.1.3)

VALUES OF $(1 - e^{-Z/Z_0})$

Z/Z_0	$1-e^{-Z/Z_0}$	Z/Z_0	$1-e^{-Z/Z_0}$	Z/Z_0	$1-e^{-Z/Z_0}$	Z/Z_0	$1-e^{-Z/Z_0}$
0·01	0·010	0·56	0·429	1·11	0·670	1·66	0·811
0·02	0·020	0·57	0·435	1·12	0·674	1·67	0·812
0·03	0·030	0·58	0·440	1·13	0·677	1·68	0·814
0·04	0·040	0·59	0·446	1·14	0·680	1·69	0·815
0·05	0·049	0·60	0·451	1·15	0·683	1·70	0·817

(*Continued*)

Z/Z_0	$1-e^{-Z/Z_0}$	Z/Z_0	$1-e^{-Z/Z_0}$	Z/Z_0	$1-e^{-Z/Z_0}$	Z/Z_0	$1-e^{-Z/Z_0}$
0.06	0.058	0.61	0.457	1.16	0.687	1.71	0.819
0.07	0.068	0.62	0.462	1.17	0.690	1.72	0.821
0.08	0.077	0.63	0.467	1.18	0.693	1.73	0.823
0.09	0.086	0.64	0.473	1.19	0.696	1.74	0.824
0.10	0.095	0.65	0.478	1.20	0.699	1.75	0.826
0.11	0.104	0.66	0.483	1.21	0.702	1.76	0.828
0.12	0.113	0.67	0.488	1.22	0.705	1.77	0.830
0.13	0.122	0.68	0.493	1.23	0.708	1.78	0.831
0.14	0.131	0.69	0.498	1.24	0.711	1.79	0.833
0.15	0.139	0.70	0.503	1.25	0.713	1.80	0.835
0.16	0.148	0.71	0.508	1.26	0.716	1.81	0.836
0.17	0.156	0.72	0.512	1.27	0.720	1.82	0.838
0.18	0.165	0.73	0.518	1.28	0.722	1.83	0.840
0.19	0.173	0.74	0.523	1.29	0.725	1.84	0.841
0.20	0.181	0.75	0.528	1.30	0.727	1.85	0.843
0.21	0.190	0.76	0.532	1.31	0.730	1.86	0.844
0.22	0.198	0.77	0.537	1.32	0.733	1.87	0.846
0.23	0.205	0.78	0.542	1.33	0.735	1.88	0.847
0.24	0.213	0.79	0.546	1.34	0.738	1.89	0.849
0.25	0.221	0.80	0.551	1.35	0.741	1.90	0.850
0.26	0.229	0.81	0.555	1.36	0.743	1.91	0.852
0.27	0.237	0.82	0.560	1.37	0.746	1.92	0.853
0.28	0.244	0.83	0.564	1.38	0.748	1.93	0.855
0.29	0.252	0.84	0.568	1.39	0.751	1.94	0.856
0.30	0.259	0.85	0.573	1.40	0.753	1.95	0.857
0.31	0.267	0.86	0.577	1.41	0.756	1.96	0.859
0.32	0.274	0.87	0.581	1.42	0.758	1.97	0.861
0.33	0.281	0.88	0.585	1.43	0.761	1.98	0.862
0.34	0.288	0.89	0.589	1.44	0.763	1.99	0.863
0.35	0.295	0.90	0.593	1.45	0.765	2.00	0.865
0.36	0.302	0.91	0.597	1.46	0.768	2.05	0.871
0.37	0.309	0.92	0.601	1.47	0.770	2.10	0.873
0.38	0.316	0.93	0.605	1.48	0.772	2.15	0.883
0.39	0.323	0.94	0.609	1.49	0.775	2.20	0.889
0.40	0.330	0.95	0.613	1.50	0.777	2.25	0.895
0.41	0.336	0.96	0.617	1.51	0.779	2.30	0.900
0.42	0.343	0.97	0.621	1.52	0.781	2.35	0.905
0.43	0.349	0.98	0.625	1.53	0.784	2.40	0.909
0.44	0.356	0.99	0.628	1.54	0.786	2.45	0.914
0.45	0.362	1.00	0.632	1.55	0.788	2.50	0.918
0.46	0.369	1.01	0.636	1.56	0.790	2.55	0.922
0.47	0.375	1.02	0.639	1.57	0.792	2.60	0.926
0.48	0.381	1.03	0.643	1.58	0.794	2.65	0.929
0.49	0.387	1.04	0.646	1.59	0.796	2.70	0.933
0.50	0.393	1.05	0.650	1.60	0.798	2.75	0.936
0.51	0.400	1.06	0.653	1.61	0.800	2.80	0.939
0.52	0.405	1.07	0.657	1.62	0.802	2.85	0.941
0.53	0.411	1.08	0.660	1.63	0.804	2.90	0.945
0.54	0.417	1.09	0.664	1.64	0.806	2.95	0.948
0.55	0.423	1.10	0.667	1.65	0.808	3.00	0.950

APPENDIX B

(*Clause* 8.1)

MATERIAL HANDLING SYSTEM

B-1. The purpose of providing material handling facilities in bins is to make the necessary arrangement for filling and emptying the material. This has influence in both layout and design of bunkers in that the loading and unloading arrangements have to be considered in the design.

The main equipments used for filling/emptying the bins are:

a) Belt conveyor
b) Bucket elevator
c) Screw conveyor
d) Pneumatic elevator (pumping)

B-2. Many of the equipment mentioned above require to be supported over the bunker with a suitable opening on the cover of the bunker. The additional load thus transmitted to the bunker or its supporting beams should be considered for design.

B-3. Bins should be provided with bunker columns for proper discharging of the materials. The arrangement may include the simple devices like cast iron box with sliding doors operated by hand, by bell-crank levers or by power or rotary valves or discharge gates or by pneumatic methods. The load of the column and the arrangement of its connection should be considered while designing bunkers and their supporting frame.

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