Indian Standard

CODE OF PRACTICE FOR DESIGN AND CONSTRUCTION OF STEEL CHIMNEY

PART 2 STRUCTURAL ASPECT

(First Revision)

1 SCOPE

1.1 This standard (Part 2) covers terminology, loading, materials, structural design, construction, inspection, maintenance and painting of both self-supporting and guyed steel chimneys (with or without lining) and their supporting structures.

1.2 The design of chimneys of cross section other than circular is not included in this standard.

1.3 Chimneys in pairs, rows or groups, and those near other structures of comparable height may be subjected to exceptional wind force and particularly wind induced oscillations greater than that allowed for in this standard. Appropriate expert advice should, therefore, be obtained in these cases.

1.4 The purpose for which the chimney is required will determine whether lining, insulation or cladding is necessary.

2 REFERENCES

2.1 The Indian Standards listed in Annex B are necessary adjuncts to this standard.

3 STATUTORY PROVISIONS

3.1 Compliance with this code does not relieve any one from the responsibility of observing provisions as may have been promulgated by any statutory body and/or observing provincial building byelaws and the civil aviation requirements pertaining to such structures.

4 TERMINOLOGY

4.0 For the purpose of this standard, definitions given in **4.1** to **4.40** shall apply.

4.1 Access Door

A door for the entry of personnel.

4.2 Access Hooks

Fittings welded to a chimney to permit the attachment of steeplejack's equipment.

4.3 Access Ladder

A steel ladder provided along the height of the chimney fixed with chimney shell for providing access for personnel to reach different heights for inspection/maintenance, etc.

4.4 Aerodynamic Stabilizer

A device fitted to the structural shell to reduce wind excited oscillations by modifying vertex sheddings.

4.5 Anchor for Guy

The foundation for the fixing of guy.

4.6 Base Gussets

A triangular or trapezoidal steel plate fixed to the chimney shell and to the base plate.

4.7 Base Plate

A horizontal steel plate fixed to the base of a chimney.

4.8 Base Stool

A construction comprising two vertical plates (base gussets) welded to the chimney shell and to the base plate, supporting a horizontal plate through which the holding down bolts pass and against which the bolts can be tightened.

4.9 Bracket

A construction providing resistance to lateral displacement of the chimney, and/or supporting part or all of the weight of the chimney.

4.10 Bracketed Chimney

A chimney in which not all external applied loads (namely, wind) are carried exclusively by the structural shell and for which brackets are provided to ensure stability.

4.11 Clean Out Door

A door, normally at the base of the chimney, to permit the removal of flue dust and/or provide access.

4.12 Cope Band

A steel flat or angle attached to the top of the chimney around its perimeter to give added strength and corrosion resistance at this level.

4.13 Cope-Hood

A hood fitted externally to the top of a liner, covering the upstand of the cap plate to prevent the ingress of rain water.

4.14 Corrosion Test Piece

A fixed or removable steel plate insert, generally of lesser thickness than the shell of the chimney, in contact with the waste gases and fitted at strategic points where maximum corrosion is expected to occur.

4.15 Cowl

A conical or dished cap fitted to the top of the chimney to prevent or minimize entry of rain water.

4.16 Cowl Stays

Steel stays which connect the cowl to the top of the chimney.

4.17 Cravat

An upstand fixed to the roof of a building or roof plate to prevent the entry of rain water into the building.

4.18 Double Skin Chimney

A chimney consisting of an outer load-bearing steel shell and all inner steel liner which carries the flue gases.

4.19 Doubling Plate

A plate fixed to the shell to reinforce it where increased stresses occur.

4.20 Flare

The bottom portion of the chimney in the form of a truncated cone.

4.21 Gallery

The platform around the shaft for observation and maintenance.

4.22 Guy

A wire rope attached at one end of the chimney and anchored at the other end so as to provide resistance to the lateral displacement of the top of the chimney.

4.23 Guy Band

A steel band/section fitted around the outside of a chimney with provision for the attachment of guys.

4.24 Guyed Chimney

A chimney in which not all externally applied loads (namely, wind) are carried exclusively by the structural shell and for which guys are provided to ensure stability.

4.25 Height of Steel Shaft

Length between underside of base plate and the top of the chimney.

4.26 Holding Down Bolts

Bolts built into a concrete foundation or supporting framework to provide anchorage at the base of the chimney.

4.27 Inlet

An opening in the side of a chimney to permit the entry of exhaust gases from connecting flue duct.

4.28 Joint Flange

A steel section fitted to the end of a chimney section to enable section to be connected together.

4.29 Lateral Supports

Supports positioned at appropriate levels within the structural shell to locate the liners and to allow for their independent expansion.

4.30 Liners

Flue ducts contained within a structural shell.

4.31 Multiflue Chimney

A group of two or more chimneys within a structural framework or a group of two or more liners within a structural shell.

4.32 Nominal Chimney Diameter

Internal diameter at the top of the steel shell.

4.33 Roof Plate

A plate which follows the contour of the roof round the chimneys where it passes through the roof. It is also known as flashing around the chimney.

4.34 Self-Supporting Chimney

A chimney in which externally applied loads (namely, wind) are carried exclusively by the structural shell and which together with the foundation, will remain stable under all design conditions without additional support.

4.35 Stack

Normally the straight portion of the chimney.

4.36 Stay

A rigid member providing both tensile and compressive resistance to the lateral displacement of the chimney.

4.37 Stayed Chimney

A chimney in which not all externally applied loads (namely, wind) are carried exclusively by the structural shell and for which stays are provided to ensure stability.

4.38 Strake Vane

An aerodynamic stabilizer fitted to reduce wind excited oscillations.

4.39 Structural Shell

The main external steel plate of the chimney excluding any flanges.

4.40 Weather Hood

A hood designed to shed rain water clear of the cravat and prevent its entry into the building.

5 MATERIALS

5.1 Plates and Sections

Steel plates and sections used in the constructions of chimneys shall conform to IS 226 : 1975, IS 961 : 1975, IS 2062 : 1984 or IS 8500 : 1977, whichever is appropriate. Suitable stainless or alloy steels may be used in special circumstances, such as, when the gases are of an extremely aggressive nature or are at a temperature higher than 480°C but the thickness shall otherwise comply with the requirements of this specification.

5.2 Rivets

Rivets used in the constructions of chimneys shall comply with IS 1929 : 1982 and IS 2155 : 1982, as appropriate. Rivets made of high tensile steel, if used, shall conform to IS 1149 : 1982.

5.3 Welding Consumables

5.3.1 Covered electrodes shall conform to IS 814 (Part 1) : 1974, IS 814 (Part 2) : 1974 or IS 1395 : 1982, as appropriate.

5.3.2 The bare wire electrodes for submerged arc welding shall conform to IS 7280 : 1974. The combination of wire and flux shall satisfy the requirements of IS 3613 : 1974.

5.3.3 Filler rods and bare electrodes for gas sheilded metal arc welding shall conform to IS 6419 : 1971 and IS 6500 : 1972, as appropriate.

5.4 Bolts and Nuts

Bolts and nuts shall conform to IS 1363 : 1984, 1364 : 1983, IS 3640 : 1982, IS 3757 : 1972, IS 6623 : 1972, IS 6639 : 1972, and IS 7002 : 1972 as appropriate. Foundation bolts shall conform to IS 5624 : 1970.

5.4.1 Supply conditions of threaded fasteners shall conform to IS 1367 (Part 1) : 1980, IS 1367 (Part 3) : 1979 and IS 1367 (Part 6) : 1980, as appropriate.

5.5 Washers

Washers shall conform to IS 5369 : 1975, IS 5370: 1969, IS 6610 : 1972 and IS 6649 : 1972, as appropriate.

5.6 Steel Castings

Steel castings shall conform to Grade 23-45 of IS 1030 : 1982.

5.7 Guy Ropes and Fittings

Guy ropes shall conform to IS 2141 : 1979 and IS 2266 : 1970 and shall be galvanized or protected from corrosion by other suitable means.

5.8 Other materials used in association with steel works shall, where appropriate Indian Standard Specification for the material exist, conform to such specification.

6 LOADING AND LOAD COMBINATIONS

6.1 Dead Loads

Where the unit weight of materials are not known, the dead load shall be calculated according to IS 875 (Part 1) : 1987.

6.1.1 In calculating dead loads, the weight of chimney shell, permanent fixtures such as, ladders, platforms, baffles, and guys (if any) shall be included. The weight of flue lining shall be treated as a separate load for the purpose of load combinations. The flue lining shall not be assumed to increase section modulus of the shell nor resist overturning due to its lateral bending stiffness or strutting action.

6.2 Imposed Loads

Imposed loads on platforms shall be taken at the rate of 300 kg/m^2.

6.3 Wind Loads

The wind loads shall be calculated in accordance with the provisions contained in IS 875 (Part 3): 1987.

6.3.1 Wind force on ladders and other fixtures fixed to a chimney shall be determined and added to the force on the chimney.

6.4 Earthquake Loads

Unless otherwise specified, the provision contained in IS 1893 : 1975 shall apply.

6.5 Load Combination

For the design of chimney and its foundation, any of the following load combinations which produce maximum forces and effects and consequently maximum stresses shall be chosen:

a) Dead load + wind load,

b) Dead load + earthquake load,

c) Dead load + load due to lining + imposed load on service platforms + wind load, or

d) Dead load + load due to lining + imposed load on service platforms + earthquake loads.

7 DESIGN

7.1 General

For the design of chimney shell and other components of chimney in steel, the relevant provisions contained in IS 800 : 1984 shall be applicable in conjunction with the provision of this standard.

7.1.1 The provisions covered in IS 800 : 1984 regarding the following shall, however, be superseded by the requirements of this standard:

a) Minimum thickness,
b) Allowable deflection,
c) Allowance for corrosion,
d) Allowance for temperature,
e) Allowable compressive stress in circular shells due to direct force and bending moment, and
f) Stresses due to earthquake.

7.2 Basic Dimensions

7.2.1 The basic dimensions of the chimney, namely, clear diameter, height, etc, are decided on considerations of temperature, composition of flue gases, adjacent structures, pollution control, draft requirements, etc, with Part 1 in accordance with this standard. Nevertheless, certain recommended proportions should be maintained for the strength and stability of the chimney.

7.2.2 The clear diameter of the chimney is the nominal diameter of the shell if the chimney is unlined or partially lined. For fully lined chimney the clear diameter shall be the clear diameter of the lining at the top. The fully lined chimney shall have a minimum clear diameter of 500 mm. If, for technological reasons, it is necessary to have a smaller diameter, the top opening shall be reduced by constricting the passage locally.

7.2.3 A self-supporting chimney of height 40 m and above shall be provided with a flare at the base to achieve better stability.

7.2.4 Proportions of the basic dimensions of a self-supporting chimney shall conform to the following:

a) Minimum height of flare be equal to one-third the height of the chimney.
b) Minimum outside diameter of unlined chimney shell at top be equal to one-twentieth of the height of cylindrical portion of chimney and for lined chimney it shall be one-twentyfifth of the height of the cylindrical portion.
c) Minimum outside diameter of flared chimney shell at base be equal to 1·6 times the outside diameter of chimney shell at top.

7.3 Minimum Thickness of Steel

7.3.1 *Chimney Shell*

The minimum thickness of the structural chimney shell in single or multiple shell constructions, shall be the calculated thickness obtained from stress and deflection considerations plus the corrosion allowance (*see* **7.5**), but shall not be less than 6·0 mm nor less than 1/500 of the outside diameter of the chimney at the considered height.

7.3.2 *Chimney Liner*

The minimum thickness of the steel liner in a double skin or multiple construction shall be the calculated thickness obtained from stress considerations plus the corrosion allowance, but shall be not less than 6·0 mm.

7.3.3 *Supporting Steelwork*

The minimum thickness for hot rolled sections used for external construction exposed to the weather shall be 8·0 mm, and for constructions not so exposed and ancillary steelwork, 6·0 mm. These provisions do not apply to the webs of Indian Standard rolled steel sections or to packings. The minimum thickness of hollow sections sealed at the ends, used for external constructions exposed to the weather or other corrosive influences shall be 4 mm, and for constructions not so exposed shall be 3 mm.

7.3.4 *Angle Flanges*

The minimum thickness of jointing flanges to chimney shall be 6·0 mm.

7.4 Allowable Deflection

The maximum deflection at the top of the steel chimney produced by the wind load without taking into account the dynamic factors, calculated as acting on the circular cross section shall not be greater than $h/200$. Where 'h' is the unsupported height of the chimney.

7.5 Allowance for Corrosion

The total allowance for corrosion shall be the sum of the external (T_{ce}) and internal (T_{ci}) allowances given in Table 1. This total allowance shall be added to the thickness of shell obtained from the calculations of the stresses and deflection. Internal flanges shall have corrosion allowance T_{ci}, and external flanges corrosion allowance T_{ce} except if they are encased.

NOTE — However, a lower corrosion allowance than specified in Table 1 may be adopted at the discretion of the designer/owner, if it can be ensured that the properties of flue gas and its effect on the chimney shell will not adversely affect the safety requirements.

7.6 Effective Height of Chimney Shell

Effective height of chimney shall be as specified in Table 2.

Table 1 Corrosion Allowance T_{ce} and T_{ci}

(*Clause* 7.5)

Degree of Corrosion Expected	Corrosion Allowance, in mm			
	Copper Bearing Steel		Non-copper Bearing Steel	
	Design Life		Design Life	
	10 yrs	20 yrs	10 yrs	20 yrs
a) *External*, T_{ce}				
1) None (that is, paint, insulation, cladding or similar protection available always)	Nil	Nil	Nil	Nil
2) Above average (that is, unprotected)	1	2	1·5	3
b) *Internal*, T_{ci}				
1) None (such as, non-corrosive flue gases or the structural shells of multiflue chimney)	Nil	Nil	Nil	Nil
2) Average (such as, lined, insulated or natural gas fired)	1	2	1·5	3
3) Above average (such as, unprotected coal fired)	2	3	3	5

NOTES

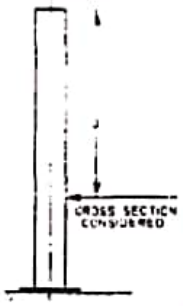
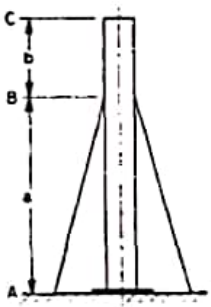
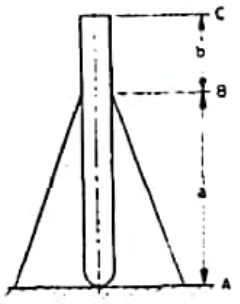
1 The internal corrosion allowance for the exceptional degree of corrosion shall be as mutually agreed between the purchaser and the designer, based on the desired life of the chimney.

2 No corrosion allowance need be provided if the chimney shell is made of stainless steel.

3 Partly lining the inside chimney with stainless steel does not eliminate the possibility of corrosion because of the condensed effluent passing down to chimney. The same is not recommended.

Table 2 Effective Height of Chimney Shell

(*Clauses* 7.6 *and* C-1)

Description	Effective Height, h_e
Self-supporting chimney 	
Supported chimney, fixed base 	For stresses in *BC* $h_e = b$ For stresses in *AB* $h_e = 0{\cdot}85\ a$
Supported chimney, pinned based 	For stresses in *BC* $h_e = b$ For stresses in *AB* $h_e = a$

7.7 Maximum Permissible Stress in the Shell

To control buckling, the compressive stress caused by the combination of extreme fibre stresses due to bending and direct load for the load combination given in **6.5**, shall not exceed values specified in Table 3 for steels conforming to IS 226 : 1975 and IS 2062 : 1984. The values shall be reduced further if necessary for temperature and calculated with the corrosion allowance deduced from the thickness t.

7.7.1 For steels other than IS 226 : 1975 and IS 2062 : 1984, maximum permissible stresses shall be obtained by multiplying the values in Table 3 by the factor F_y / f_y, where F_y is the guaranteed yield stress of steel used and f_y is the guaranteed yield stress of steel conforming to IS 226, IS 2062, that is, 270 MPa.

7.7.2 The maximum permissible stresses given in Table 3 have been worked out in accordance with the formulae given in Annex C.

7.8 Allowance for Temperature

7.8.1 Maximum permissible stresses as obtained in **7.7** shall be corrected for the most adverse temperature conditions to which the member or part may reasonably be expected to be exposed by multiplying with the appropriate temperature coefficient K_t given in Table 4. The expected temperature of steel components shall not be allowed to exceed 400°C.

In case of steels other than IS 226 : 1975 and IS 2062 : 1984, maximum permissible stresses as obtained from **7.7.1**, shall shall be reduced based on temperature coefficient factor K_t obtained by dividing yield stress at the operating temperature by the yield stress at 20°C.

7.9 Other Stresses in Steel

Allowable stresses in axial tension, shear and bearing shall be as specified in IS 800 : 1984.

7.10 Increase in Stresses

For load combination involving earthquake, the permissible stresses may be exceeded by 33⅓ percent provided the steel thickness shall neither be less than the minimum thickness specified nor when the earthquake loads are neglected.

7.11 Allowance for Large Openings in Shell

The allowable stresses apply to the shell plates after due allowance for rivets and bolt holes. Where large apertures are cut in the shell plates, as for inlets or inspection panels, a structural analysis of the stresses shall be made and compensating material provided, as required, to ensure that the stresses specified in the standard are not exceeded. Apertures in the shell plates, other than flue inlets, shall have the corners rounded to a minimum radius of 10 t, where t is the thickness of the plate.

Table 3 Maximum Permissible Stress for Circular Chimneys

(*Clauses* 7.7, 7.7.1, 7.7.2 *and* C-1)

Ratio h_e/D	Maximum Permissible Stress in MPa, for D/t													
	140 and less	150	160	170	180	190	200	225	250	300	350	400	450	500
Up to 20	126	124	123	120	118	115	112	105	99	87	78	70	64	58
30	108	107	105	103	101	99	96	90	85	75	67	60	55	50
40	89	88	86	85	83	81	79	74	70	62	55	50	45	41
50	72	71	70	69	68	66	64	60	57	50	45	40	37	34
60	59	58	57	56	55	54	52	49	46	41	36	33	30	27
70	48	48	47	46	45	44	43	40	38	33	30	27	24	22
80	40	40	39	38	37	37	36	33	31	28	25	22	20	19
90	33	33	33	32	31	31	30	28	26	23	21	19	17	16
100	28	28	28	27	26	26	25	24	22	20	18	16	14	13
110	24	24	24	23	23	22	22	20	19	17	15	13	12	11
120	21	21	20	20	19	19	19	17	16	14	13	12	11	10
130	18	18	18	17	17	17	16	15	14	13	11	10	9	8
140	16	16	15	15	15	15	14	13	12	11	10	9	8	7
150	14	14	14	13	13	13	13	12	11	10	9	8	7	7

t = thickness of the plate of the level considered,

D = mean diameter at the level considered (in metres), and

h_e = effective height for consideration of buckling in m.

NOTE — Intermediate values may be linearly interpolated.

Table 4 Temperature Coefficient, K_t
(*Clause* 7.8.1)

	Temperature, °C				
	0-200	250	300	350	400
K_t	1·0	0·75	0·67	0·6	0·5

NOTE — Intermediate values shall be linearly interpolated.

7.12 Deflection Stresses

If the chimney carries a vertical load other than its own weight, due for example, to the reaction of guys, lining or an imposed vertical load so that an appreciable compressive stress results, deflection due to wind may cause the axial load to become eccentric, the bending moment so produced shall be determined, added to that from the windload and any other live or dead load and used to calculate the combind stress which shall not exceed those specified in **7.8**. This procedure is necessary only if the total axial load produces stresses greater than one-third of the bending stress due to wind.

7.13 Factor of Safety for Guy Ropes and Fittings

A minimum factor of safety of 3 shall be adopted in the design of guy ropes and other fittings.

7.13.1 For guyed chimney, it is necessary to establish the safety of the chimney shell and guys for the forces induced due to temperature effect.

7.14 Foundation

The foundation shall be designed for the worst combination of loads specified in **6**, such that the resulting pressure on the subsoil by considering the dead weight, movements and horizontal forces, is limited to safe bearing capacity of the soil. Necessary care should be taken on the effects of the temperature and seasonal changes.

8 DESIGN CALCULATION

8.1 General

Design of chimney shall be such that the stresses in any part of the chimney do not exceed the values specified in **7** for the loads and load combinationsgiven in **6**.

8.2 Calculation of Static Wind Load

8.2.1 Static wind pressure, q, acting normal to the surface of chimney shall be taken as specified in IS 875 (Part 3) : 1987 for the appropriate wind zone, terrain and topography.

8.2.2 To determine the wind force acting at different heights of chimney, the latter shall be divided into a number of convenient zones such that the number of zones shall not be less than three and the zone height shall not exceed 10 m.

8.2.3 Static wind force acting at the midpoint of K^{th} zone (K varying from 1 to r) shall be calculated from the formula,

$$P_{st,k} = C\, q_k\, h_k\, d_k$$

where $P_{st,k}$ = static wind load acting at the midpoint of K^{th} zone, in N;

q_k = static wind pressure at the midpoint of K^{th} zone, in Pa;

h_k = height of K^{th} zone strip, in metres;

d_k = external diameter of chimney of K^{th} zone, in metres taking into account strakes, if fitted. For chimney with strakes, this shall be 1·2 times the external diameter of the chimney shell; and

C = shape factor for chimney which may be taken as 0·7 for the portion with circular cross section, without strakes.

NOTE — For other shapes, surface conditions, attachments, line platform, hand rails and for groups of chimneys on suitable shape factors shall be taken.

8.3 Calculation of Dynamic Wind Loads

8.3.1 In case of self-supported chimneys, if the period of natural oscillation for the chimney computed as given below exceeds 0·25 seconds, the design wind loads shall take into consideration the dynamic effect due to pulsation of thrust caused by wind velocity in addition to the static wind load calculated under **8.2.3**.

The natural frequency, first mode, for a chimney of varying diameter or thickness, shall be calculated by dividing the chimney into a number of convenient zones as given in **8.2.2**.

The frequency $f = \frac{1}{2\pi}\left[\frac{g\,\Sigma\,(mx)}{\Sigma\,(mx^2)}\right]^{\frac{1}{2}}$

where

m = mass of the zone including the lining or covering, in kg;

x = deflection of the same zone due to the force equal to gravity acting on its mass normally at the mass centre with the base fixed and top free, in metres; and

g = rate of gravitational acceleration = 9·8 m/s^2.

8.3.2 Dynamic effect of wind is influenced by a number of factors, such as, mass and its disposition along chimney height, period and mode of natural oscillation, logarithmic decrement of dampening, pulsation of velocity thrust, etc. Values of dynamic components of wind load should be determined for each mode of oscillation of the chimney as a system of inertia forces acting at the centre of the zone being considered.

Inertia force P_{dyn} in N acting at the centre of the jth zone of the chimney in the ith mode of natural oscillation is determined as follows (*see* Fig. 1):

$$P_{dyn,\,ij} = M_j\, \xi_i\, \eta_{ij}\, \nu$$

where

M_j = mass of the jth zone in kg concentrated at its centre,

ξ_i = dynamic coefficient in accordance with **8.3.3**,

η_{ij} = deduced acceleration in m/s² of the centre of the jth zone taken in accordance with **8.3.4**, and

ν = coefficient which takes care of the space correlation of wind pulsation speed according to height and vicinity of building structures and is taken in accordance with **8.3.5**.

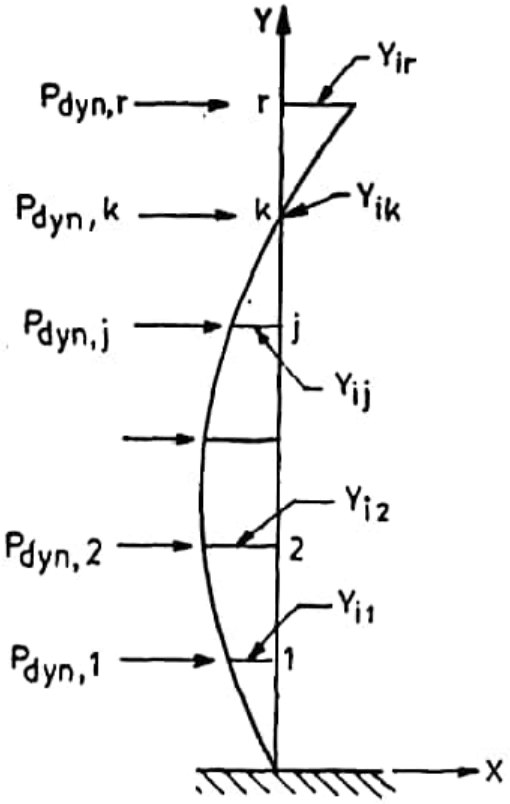


FIG. 1 DESIGN SCHEME OF CHIMNEY IN THE ith MODE OF OSCILLATION

8.3.3 Dynamic coefficient ξ_i (for lined and unlined chimney) is determined from Table 5 depending on the parameter ξ_i :

$$\xi_i = \frac{T_i\, V_b}{1\,200}$$

T_i = period of ith mode of natural oscillation in seconds, and

V_b = basic wind speed in m/s.

Table 5 Coefficient of Dynamic Influence ξ_i for Steel Chimneys

(*Clause* 8.3.3)

ξ_i	Values of ξ_i for	
	Lined Chimney	Unlined Chimney
0	1·20	1·30
0·025	1·70	2·50
0·050	1·90	3·10
0·075	2·10	3·50
0·100	2·30	3·75
0·125	2·45	4·10
0·150	2·60	4·30
0·175	2·70	4·50
0·200	2·75	4·70

NOTE — Intermediate values may be linearly interpolated.

8.3.4 Deduced acceleration η_{ij}, in m/s² is determined according to formula:

$$\eta_{ij} = \frac{Y_{ij} \sum_{k=1}^{r} \gamma_{ik} \cdot P_{st,k} \cdot m_k}{\sum_{k=1}^{r} \gamma^2_{ik} \cdot M_k}$$

where

M_k = mass of the kth zone, in kg;

γ_{ij}, γ_{ik} = relative ordinates of mode shape corresponding to the centres of jth and kth zones in the i^{th} mode of oscillation. In special cases involving the interaction of soil structure affecting the mode shape considerably, the relative ordinates shall be accordingly calculated.;

$P_{st,k}$ = wind load on the kth zone determined according to **8.2.3**;

r = number of zones into which the chimney is divided; and;

m_k = coefficient of pulsation of speed thrust for the centre of the kth zone, taken as in Table 6.

8.3.5 The value of coefficient ν shall be taken from Table 7 depending upon the parameter ξ_i as given in **8.3.4**. For structures of cantilever type, ν shall be taken only for the first mode of natural oscillation. For higher modes, ν shall be taken as 1.

8.3.6 While determining the wind load on the chimney, consideration of the first mode of natural oscillation is sufficient. It is recommended to consider higher modes of oscillation only when the chimney is very tall, say, 80 and above and when consideration of mass, stiffness and disposition of various loads acting on the chimney require a more thorough analysis

Table 6 Coefficient of Pulsation of Speed Thruts, m_k

(*Clause* 8.3.4)

Type of Location	Height Above Ground Level, in m						
	Up to 10	20	40	60	100	200	350 and above
A	0·60	0·55	0·48	0·46	0·42	0·38	0·35
B	0·83	0·75	0·65	0·60	0·54	0·46	0·40

NOTES

1 Type *A* relates to open locations (Steppe, desert, sea coast, lake, reservoir, etc).

2 Type *B* relates to outskirts of town, widespread forest and its like, regular obstacles of height more than 10 m.

Table 7 Coefficient ν

(*Clause* 8.3.5)

ξ_1	Height of Chimney, in m					
	Up to 45	60	120	150	300	450 and above
< 0·05	0·70	0·65	0·60	0·55	0·45	—
0·1	—	0·75	0·65	0·60	0·50	0·40
0·2	—	—	0·75	0·70	0·60	0·50

NOTE — Intermediate values may be linearly interpolated.

8.3.7 Total design lateral force (P_k), bending moment (M_k) and deflection (Y_k) due to wind load should be computed from static and dynamic calculations corresponding to the *i*th mode of natural oscillation and summed up according to the following formulae:

$$P_k = P_{st,k} + \sqrt{\sum_{i=1}^{s} (P_{dyn\cdot k})^2}$$

$$M_k = M_{st,k} + \sqrt{\sum_{i=1}^{s} (M_{dyn,k})^2}$$

$$Y_k = Y_{st\,k} + \sqrt{\sum_{i=1}^{s} (Y_{dyn,k})^2}$$

where

$P_{st,k}$ and $P_{dyn,k}$ = the static and dynamic wind load acting at mid point of *k*th zone, respectively;

$M_{st,k}$ and $M_{dyn,k}$ = bending moments due to the static and dynamic wind pressure respectively, acting at *k*th zone;

$Y_{st,k}$ and $Y_{dyn,k}$ = deflections due to static and dynamic wind pressure respectively at the *k*th zone with respect to the original position; and

s = number of modes of oscillation.

8.4 Check for Resonance

8.4.1 In case of self-supporting chimney, checking for resonance shall be carried out if the critical velocity V_{cr} as determined from Annex A is within the range:

a) 0·5 to 0·8 times the design wind velocity for lined chimneys, and

b) 0·33 to 0·8 times the design wind velocity for the unlined chimneys.

8.4.2 For lined chimneys, checking for resonance should be carried out for both the cases, that is, with and without lining.

8.4.3 Design force F, bending moment M and deflection Y at level z during resonance shall be determined by formulae:

$$F = \sqrt{F^2_{res,z} + (F_{st,z} + F_{dyn,z})^2}$$

$$M = \sqrt{M^2_{res,z} + (M_{st,z} + M_{dyn,z})^2}$$

$$Y = \sqrt{Y^2_{res,z} + (Y_{st,z} + Y_{dyn,z})^2}$$

where

$F_{res,z}$, $M_{res,z}$ and $Y_{res,z}$ = transverse force, bending moment and deflection at resonance respectivelyat level z (*see* **A-5**);

$F_{st,z}$, $M_{st,z}$ and $Y_{st,z}$ = static transverse force, bending moment and deflection due to static wind load (*see* **A-6**); and

$F_{dyn,z}$, $M_{dyn,z}$ and $Y_{dyn,z}$ = dynamic transverse force, bending moment and deflection due to dynamic wind load (*see* 8.3.2).

8.5 Holding Down Bolts

The maximum stress in holding down bolts calculated taking into account the worst combination of loading shall not exceed the permissible stresses as specified in IS 800 : 1984.