IS 1893-4 (2005): Criteria for earthquake resistant design of structure, Part 4: Industrial structures including stack-like structures) [CED 39: Earthquake Engineering]

BLANK PAGE

भारतीय मानक

संरचनाओं के भूकम्परोधी डिजाइन के मानदंड

भाग 4 औद्योगिक संरचनाएँ, चट्टा टाइप संरचनाएँ

Indian Standard

CRITERIA FOR EARTHQUAKE RESISTANT DESIGN OF STRUCTURES

PART 4 INDUSTRIAL STRUCTURES INCLUDING STACK-LIKE STRUCTURES

ICS 91.120.25

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

August 2005 **Price Group 9**

Earthquake Engineering Sectional Committee, CED 39

FOREWORD

This Indian Standard (Part 4) was adopted by the Bureau of Indian Standards, after the draft finalized by the Earthquake Engineering Sectional Committee had been approved by the Civil Engineering Division Council.

Himalayan-Naga Lushai region, Indo-Gangetic Plain, Western India, Kutch and Kathiawar regions are geologically unstable parts of the country where some devastating earthquakes of the world have occurred. A major part of the peninsular India has also been visited by strong earthquakes, but these were relatively few in number occurring at much larger time intervals at any site, and had considerably lesser intensity. The earthquake resistant design of structures, taking into account seismic data from studies of these Indian earthquakes, has become very essential, particularly in view of heavy construction programme at present all over the country. It is to serve this purpose that IS 1893 : 1962 'Recommendations for earthquake resistant design of structures' was published and subsequently revised in 1966, 1970, 1975 and 1984.

In view of the present state of knowledge and in order to update this standard, the committee has decided to cover the provisions for different types of structures in separate parts. This standard has been split into five parts. Other parts in this series are :

Part 1 General provisions and buildings

Part 2 Liquid retaining tanks-elevated and ground supported

Part 3 Bridges and retaining walls

Part 5 Dams and embankments

Part 1 contains provisions that are general in nature and applicable to all types of structures. Also, it contains provisions that are specific to buildings only. Unless stated otherwise, the provisions in Part 2 to Part 5 shall be read necessarily in conjunction with Part 1.

This standard contains provisions on earthquake resistant design of industrial structures including stack-like structures. Industrial structures are covered in Section 1 and Stack-like structures are covered in Section 2.

All sub-clauses under the main clause **0.0** of IS 1893 (Part 1) are also applicable to this part except the **0.4.1**.

In the preparation of this standard considerable assistance has been provided by BHEL, IIT Roorkee, IIT Bombay, IIT Kanpur, NTPC, EIL, TCE, DCE, NPC and various other organizations.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

CRITERIA FOR EARTHQUAKE RESISTANT DESIGN OF STRUCTURES

PART 4 INDUSTRIAL STRUCTURES INCLUDING STACK-LIKE STRUCTURES

1 SCOPE

1.1 The industrial structures shall be designed and constructed to resist the earthquake effects in accordance with the requirements and provisions of this standard. This standard describes the procedures for earthquake resistant design of industrial structures. It provides the estimates of earthquake loading for design of such structures.

1.2 All sub-clauses under **1** of IS 1893 (Part 1) are also applicable to this part except **1.1**.

1.3 This standard deals with earthquake resistant design of the industrial structures (plant and auxiliary structures) including stack-like structures associated with the following industries:

a) Process industries;
b) Power plants;
c) Petroleum, fertilizers and petro-chemical industries;
d) Steel, copper, zinc and aluminum plants;
e) Pharmaceutical plants;
f) Cement industries;
g) Automobile industries;
h) Sugar and alcohol industries;
j) Glass and ceramic industries;
k) Textile industries;
m) Foundries;
n) Electrical and electronic industries;
p) Consumer product industries;
q) Structures for sewage and water treatment plants and pump houses;
r) Leather industries;
s) Off-shore structures and marine/port/harbour structures;
t) Mill structures;
u) Telephone exchanges;
v) Water and waste water treatment facilities; and
w) Paper plants.

This standard shall also be considered applicable to the other industries not mentioned above.

In addition to the above, the following structures are classified as stack-like structures and are covered by this standard:

a) Cooling towers and drilling towers;
b) Transmission and communication towers;
c) Chimneys and stack-like structures;
d) Silos (including parabolic silos used for urea storage);
e) Support structures for refinery columns, boilers, crushers, etc; and
f) Pressure vessels and chemical reactor columns.

2 REFERENCES

The following standards contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication the editions indicated were valid. All standards are subject to revision and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below:

IS No.	*Title*
456 : 2000	Code of practice for plain and reinforced concrete (*fourth revision*)
800 : 1984	Code of practice for general construction in steel (*second revision*)
875	Code of practice for design loads (other than earthquake) for building structures:
(Part 1) : 1987	Dead loads — Unit weights of building material and stored materials (*second revision*)
(Part 2) : 1987	Imposed loads (*second revision*)
(Part 3) : 1987	Wind loads (*second revision*)
(Part 4) : 1987	Snow loads (*second revision*)
(Part 5) : 1987	Special loads and load combinations (*second revision*)
1343 : 1980	Code of practice for prestressed concrete (*second revision*)
1888 : 1982	Method of load test on soils (*second revision*)

IS No.	*Title*
1893 (Part 1) : 2002	Criteria for earthquake resistant design of structures: Part 1 General provisions and buildings
4326 : 1993	Earthquake resistant design and construction of buildings — Code of practice (*second revision*)
4998 (Part 1) : 1992	Criteria for design of reinforced concrete chimneys: Part 1 Assessment of loads (*second revision*)
6403 : 1981	Code of practice for determination of bearing capacity of shallow foundations (*first revision*)
6533 (Part 2) : 1989	Code of practice for design and construction of steel chimney: Part 2 Structural aspects (*first revision*)
13920 : 1993	Ductile detailing of reinforced concrete structures subjected to seismic forces
SP 6 (6) : 1972	Handbook for structural engineers — Application of plastic theory in design of steel structures

3 GENERAL TERMINOLOGY FOR EARTHQUAKE ENGINEERING

All sub-clauses under **3** of IS 1893 (Part 1) are also applicable to this standard.

4 TERMINOLOGY FOR INDUSTRIAL STRUCTURES

The following definition and the others given in IS 1893 (Part 1) except **4.10** and **4.16** are applicable.

4.1 Combined Structures

A structure with lateral load resisting elements constructed from a combination of reinforced/prestressed concrete and structural steel.

5 SYMBOLS

5.1 Symbols and notations applicable to Section 1 are given as under:

A_h — Design horizontal seismic coefficient

b_i — Floor plan dimension of floor i, perpendicular to direction of force

c — Index for closely spaced modes

CQC — Complete quadratic combination method

DL — Response quantity due to dead load

e_{di} — Design eccentricity at floor, i

EL — Response quantity due to earthquake load

EL_x — Response quantity due to earthquake loads in X-direction

EL_y — Response quantity due to earthquake loads in Y-direction

EL_z — Response quantity due to earthquake loads in Z-direction

e_{si} — Static eccentricity at floor, i

g — Acceleration due to gravity

I — Importance factor

IL — Response quantity due to imposed loads

M — Mass matrix of the structural system

M_p — Mass matrix of the primary system

MCE — Maximum considered earthquake

M_F — Total mass of all the equipment that are flexible mounted at different locations in the structure

M_k — Modal mass of mode, k

M_R — Total mass of all the equipment that are rigidly mounted at different locations in the structure

M_s — Total mass of structural system, which supports secondary system

R — Response reduction factor

r — Number of modes being considered

S_a — Spectral acceleration

S_a/g — Spectral acceleration coefficient

SIDL — Super imposed dead loads

N — Standard penetration test value (SPT value) of the soil

SRSS — Square root of sum of squares

T — Undamped natural period of vibration of the structure

W_i — Seismic weight of floor, i

Z — Zone factor

ϕ_j — jth normalized mode shape

U_b — Influence vector-displacement vector of the structural system

ϕ_{ik} — Mode shape coefficient at floor, i, in mode, k

ϕ_{ci} — Mode vector value from the primary system's modal displacement at the location where the secondary system is connected

λ — Peak response quantity due to closely spaced modes

ρ_{ij} — Cross-modal correlation co-efficient

ζ — Modal damping ratio

β — Frequency ratio $= \frac{\omega_j}{\omega_i}$

λ_k — Absolute value of quantity in mode k

λ — Peak response due to all modes considered

δ — Maximum value of deflection

ω_i — Circular frequency, in rad/sec, in ith mode

$\lambda_i, \lambda_j, \lambda_k$ — Response quantity in mode i, j, k respectively

$\delta_x, \delta_y, \delta_z$ — Maximum value of deflection in X, Y, Z direction respectively

5.2 Symbols and notations applicable to Section 2 are defined as under:

A — Area of cross-section at the base of the structural shell

A_h — Design horizontal seismic coefficient

C_T — Coefficient depending upon the slenderness ratio of the structure

C_v — Coefficient of shear force depending on slenderness ratio, k

d — Thickness of pile cap or raft

D_{Max} — Maximum lateral deflection

D_v, D_m — Distribution factors for shear and moment respectively at a distance X from the top

E — Modulus of elasticity of pile material

E_S — Modulus of elasticity of material of the structural shell

g — Acceleration due to gravity

G — Shear modulus of soil = ρV_s^2

V_s — Shear wave velocity of the medium

h — Height of structure above the base

$\bar{h}$ — Height of centre of gravity of structure above base

I — Importance factor

I_m — Moment of inertia of pile section

n — Number of piles

N — Number of locations of lumped weight

r_o — Radius of circular raft foundation

R — Response reduction factor

$\frac{S_a}{g}$ — Spectral acceleration coefficient for rock and soil sites

T_l — Characteristic length of pile

W_i — Weight lumped at ith location with the weights applied simultaneously with the force applied horizontally

W_t — Total weight of the structure including weight of lining and contents above the base

Z — Zone factor

δ_i — Lateral static deflection under its own lumped weight at ith location (chimney weight lumped at 10 or more locations)

υ — Poisson's ratio of soil

η_h — Modulus of sub grade reaction of soil in horizontal direction

6 GENERAL PRINCIPLES

6.1 Ground Motion

6.1.1 The characteristics (intensity, duration, etc) of seismic ground vibrations expected at any location depends upon the magnitude of earthquake, its depth of focus, distance from the epicentre, characteristics of the path through which the seismic waves travel, and the soil strata on which the structure stands. The random earthquake ground motions, which cause the structures to vibrate, can be resolved in any three mutually perpendicular directions. The predominant direction of ground vibration is horizontal.

Earthquake generated vertical inertia forces are to be considered in design unless checked and proven to be not significant. Vertical acceleration should be considered in structures with large spans, those in which stability is a criterion for design, or for overall stability analysis of structures. Reduction in gravity force due to vertical component of ground motions can be particularly detrimental in cases of prestressed horizontal members and of cantilevered members. Hence, special attention should be paid to the effect of vertical component of the ground motion on prestressed or cantilevered beams, girders and slabs.

6.1.2 The response of a structure to ground vibrations is a function of the nature of foundations, soil, materials, form, size and mode of construction of structures; and the duration and characteristics of ground motion. This standard specifies design forces for structures standing on rocks or soils, which do not settle, liquify or slide due to loss of strength during vibrations.

6.1.3 The design approach adopted in this standard is to ensure that structures possess minimum strength to withstand minor earthquakes (< DBE) which occur frequently, without damage; resist moderate earthquakes (DBE) without significant structural damage though some non-structural damage may occur; and withstand a major earthquake (MCE) without collapse. Actual forces that appear on structures during earthquakes are much greater than the design forces specified in this standard. However, ductility, arising from inelastic material behaviour and detailing, and overstrength, arising from the additional reserve strength in structures over and above the design strength, are relied upon to account for this difference in actual and design lateral loads.

Reinforced and prestressed concrete members shall be suitably designed to ensure that premature failure due to shear or bond does not occur, subject to the provisions of IS 456 and IS 1343. Provisions for appropriate ductile detailing of reinforced concrete members are given in IS 13920.

In steel structures, members and their connections should be so proportioned that high ductility is obtained, as specified in SP 6 (6), avoiding premature failure due to elastic or inelastic buckling of any type.

6.1.4 The design force specified in this standard shall be considered in each of the two principal horizontal directions of the structure and in vertical direction.

6.1.5 Equipment and other systems, which are supported at various floor levels of the structure, shall be subjected to motions corresponding to vibration at their support points. In important cases, it may be necessary to obtain floor response spectra for analysis and design of equipment.

6.2 Assumptions

The following assumptions shall be made in the earthquake resistant design of structures:

a) Earthquake causes impulsive ground motions, which are complex and irregular in character, changing in period and amplitude each lasting for a small duration. Therefore, resonance of the type as visualized under steady-state sinusoidal excitations, will not occur, as it would need time to build up such amplitudes.

NOTE — Exceptional, resonance-like conditions have been seen to occur between long distance waves and tall structures founded on deep soft soils.

b) Earthquake is not likely to occur simultaneously with maximum wind or maximum flood or maximum sea waves.

c) The value of elastic modulus of materials, wherever required, may be taken as for static analysis unless a more definite value is available for use in such condition (*see* IS 456, IS 800 and IS 1343).

SECTION 1 INDUSTRIAL STRUCTURES

7 DESIGN CRITERIA

7.1 Categorization of Structures

To perform well in an earthquake, the industrial structure should possess adequate strength, stiffness, and ductility. Generally structures have large capacities of energy absorption in its inelastic region. Structures which are detailed as per IS 13920 or SP 6 (6) and equipment which are made of ductile materials can withstand earthquakes many fold higher than the design spectra without collapse; and damage in such cases is restricted to cracking only.

Structures are classified into the following four categories:

a) Category 1 : Structures whose failure can cause conditions that can lead directly or indirectly to extensive loss of life/property to population at large in the areas adjacent to the plant complex.

b) Category 2 : Structures whose failure can cause conditions that can lead directly or indirectly to serious fire hazard/extensive damage within the plant complex. Structures, which are required to handle emergencies immediately after an earthquake, are also included.

c) Category 3 : Structures whose failure, although expensive, does not lead to serious hazard within the plant complex.

d) Category 4 : All other structures.

Typical categorization of industrial structures is given in Table 5 .

NOTE — The term failure used in the definition of categories implies loss of function and not complete collapse. Pressurized equipment where cracking can lead to rupture may be categorized by the consequences of rupture.

7.2 Design Loads

7.2.1 *Dead Load (DL)*

These shall be taken as per IS 875 (Part 1).

7.2.2 *Super Imposed Dead Loads (SIDL)*

Industrial structures contain several equipment and associated auxiliaries and accessories that are permanently mounted on the structures. These loads shall be taken as per equipment specifications.

7.2.3 *Imposed Loads (IL)*

These shall be taken as per IS 875 (Part 2).

7.2.4 *Earthquake Loads (EL)*

The earthquake load on the different members of a structure shall be determined by carrying out analysis following the procedure described in **10** using the design spectra specified in **8**. Earthquake loads in x and y (horizontal) directions are denoted by EL_x and EL_y and earthquake loads in vertical direction are denoted by EL_z.

7.3 Load Combinations

When earthquake forces are considered on a structure, the response quantities due to dead load (*DL*), imposed load (*IL*), super imposed dead loads (*SIDL*) and design earthquake load (*EL*) shall be combined as per **7.3.1** and **7.3.2**. The factors defined in **7.3.1** and **7.3.2** are applicable for Category 1 to 4 structures only under DBE (*see* **7.5**).

7.3.1 *Load Factors for Plastic Design of Steel Structures*

In the plastic design of steel structures, the following load combinations shall be accounted for:

a) 1.7 (*DL* + *SIDL* + *IL*),

b) 1.7 (*DL* + *SIDL*) ± *EL*, and

c) 1.3 (*DL* + *SIDL* + *IL* ± *EL*).

NOTE — Imposed load (*IL*) in load combination shall not include erection loads and crane payload.

7.3.2 *Partial Safety Factors for Limit State Design of Reinforced Concrete and Prestressed Concrete Structures*

In the limit state design of reinforced and prestressed concrete structures, the following load combinations shall be accounted for:

a) 1.5 (*DL* + *SIDL* + *IL*),

b) 1.2 (*DL* + *SIDL* + *IL* ± *EL*),

c) 1.5 (*DL* + *SIDL* ± *EL*), and

d) 0.9 (*DL* + *SIDL*) ± 1.5 *EL*.

NOTE — Imposed load (*IL*) in load combination shall not include erection load and crane payload.

7.3.2.1 When responses from the three earthquake components are to be considered, the response due to each component may be combined using the assumption that when the maximum response from one component occurs, the responses from the other two components are 30 percent of the corresponding maximum. All possible combinations of the three components (EL_x, EL_y and EL_z) including variations in sign (plus or minus) shall be considered. Thus, the response due to earthquake force (*EL*) is the maximum of the following cases:

$$EL = \begin{cases} \pm EL_x \pm 0.3\ EL_y \pm 0.3\ EL_z \\ \pm EL_y \pm 0.3\ EL_x \pm 0.3\ EL_z \\ \pm EL_z \pm 0.3\ EL_x \pm 0.3\ EL_y \end{cases}$$

where x and y are two orthogonal directions and z is the vertical direction.

7.3.2.2 As an alternative to the procedure in **7.3.2.1**, the response (*EL*) due to the combined effect of the three components can be obtained on the square root of the sum of the squares (*SRSS*) basis, that is

$$EL = \sqrt{(EL_x)^2 + (EL_y)^2 + (EL_z)^2}$$

NOTE — The combination procedures of **7.3.2.1** and **7.3.2.2** apply to the same response quantity (say, moment in a column about its major axis, or storey shear in a frame) due to different components of the ground motion. These combinations are to be made at the member force/stress levels.

7.3.3 For structures under Category 1, which are designed under MCE (*see* **7.5.1**) and checked under DBE, all load factors in combination with MCE shall be taken as unity.

7.4 Increase in Permissible Stresses

7.4.1 *Increase in Permissible Stresses in Materials*

When earthquake forces are considered along with other normal design forces, the permissible stresses in material, in the elastic method of design, may be increased by one-third. However, for steels having a definite yield stress, the stress be limited to the yield stress, for steels without a definite yield point, the stress will be limited to 80 percent of the ultimate strength or 0.2 percent proof stress, whichever is smaller; and that in pre-stressed concrete members, the tensile stress in the extreme fibers of the concrete may be permitted so as not to exceed two-thirds of the modulus of rupture of concrete.

7.4.2 *Increase in Allowable Pressures in Soils*

When earthquake forces are included, the allowable bearing pressure in soils shall be increased as per Table 1, depending upon type of foundation of the structure and the type of soil.

In soil deposits consisting of submerged loose sands and soils falling under classification SP with standard penetration *N* values less than 15 in seismic zones III, IV, V and less than 10 in seismic zone II, the vibration caused by earthquake may cause liquefaction or excessive total and differential settlements. Such sites should preferably be avoided while locating new settlements or important projects. Otherwise, this aspect of the problem needs to be investigated and appropriate methods of compaction or stabilization adopted to achieve suitable N values as indicated in Note 3 under Table 1. Alternatively, deep pile foundation may be provided and taken to depths well into the layer, which is not likely to liquify. Marine clays and other sensitive clays are also known to liquefy due to collapse of soil structure and will need special treatment according to site condition.

7.5 Design Basis Earthquake (DBE)

Design basis earthquake (DBE) for a specific site is to be determined based on either : (a) site specific studies, or (b) in accordance with provisions of IS 1893 (Part 1).

7.5.1 Structures in Category 1 shall be designed for maximum considered earthquake (MCE) (which is twice of DBE).

7.5.2 Structures in Category 2, 3 and 4 shall be designed for DBE for the project site.

8 DESIGN SPECTRUM

8.1 For all important projects, and all industries dealing with highly hazardous chemicals, evaluation of site-specific spectra for earthquake with probability of exceedence of 2 percent in 50 years (MCE) and 10 percent in 50 years (DBE) is recommended. All Category 1 industrial structures shall be analyzed using site-specific spectra. However, if site-specific studies are not carried out, the code specified spectra may be used with modifications as per **8.3.2**. If time-history analysis is to be carried out, spectra-compliant time-history shall be determined based on the site-specific spectra.

8.2 For all other structures not covered in **8.1**, the spectra and seismic zone as given in Annex A and Annex B is recommended [these are in accordance with IS 1893 (Part 1)].

8.3 Horizontal Seismic Force

The horizontal seismic coefficient A_h, shall be obtained using the period T, described as under.

8.3.1 When using site specific spectra, the seismic coefficient shall be calculated from the expression :

$$A_h = \frac{\left[S_a / g \right]}{(R/I)}$$

where S_a/g = spectral acceleration coefficient corresponding to site specific spectra.

8.3.2 When using code specific spectra, the seismic co-efficient shall be calculated from the expression:

$$A_h = \frac{\left[Z/2 \right] \left[S_a/g \right]}{(R/I)}$$

NOTE — Structures in Category 1 shall be designed for seismic force twice that found using the provisions of this clause.

where

Z = zone factor, given in Annex A [This is in accordance with Table 2 of IS 1893 (Part 1)].

S_a/g = spectral acceleration coefficient for rock and soil sites given in Annex B [This is in accordance with Fig. 1 of IS 1893 (Part 1)].

I = importance factor given in Table 2 is relative importance assigned to the structure to take into account consequences of its damage.

R = response reduction factor to take into account the margins of safety, redundancy and ductility of the structure given in Table 3.

Categorization of some individual structure and components of typical industries are given in Table 5.

8.4 Vertical acceleration values are to be taken as 2/3 of the corresponding horizontal acceleration values.

9 MATHEMATICAL MODELLING

9.1 Modelling Requirements

The mathematical model of the physical structure shall include all elements of the lateral force-resisting system. The model shall also include the stiffness and strength of elements, which are significant to the distribution of forces. The model shall properly represent the spatial distribution of the mass and stiffness of the structures, as well as mass of equipment, cable trays and piping system along with associated accessories, 25 percent of the live load shall also be included as suitably distributed mass on the structure.

9.1.1 *Soil-Structure Interaction*

The soil-structure interaction refers to the effects of the supporting foundation medium on the motion of structure. The soil-structure interaction may not be considered in the seismic analysis for structures supported on rock or rock-like material.

9.2 Interaction Effects Between Structure and Equipment

Interaction effects between structure and equipment shall be considered as under:

a) For Category 2, 3 and 4, simplified considerations as per **9.2.1** may be used.

b) For Category 1, detailed considerations as per **9.2.2** shall be adopted.

9.2.1 For the purpose of **9.2**, the following notations shall be used:

M_s = total mass of the structural system on which the secondary system is supported,

Table 1 Percentage of Permissible Increase in Allowable Bearing Pressure, Resistance of Soils

(*Clause* 7.4.2)

Sl No.	Foundation	Type of Soil Mainly Constituting the Foundation		
		Type I Rock or Hard Soils: Well graded gravel and sand gravel mixtures with or without clay binder, and clayey sands poorly graded or sand clay mixtures (GB, CW, SB, SW and SC) having N above 30, where N is the standard penetration value	Type II Medium Soils: All soils with N between 10 and 30, and poorly graded sands or gravelly sands with little or no fines (SP) with $N > 15$	Type III Soft Soils: All soils other than SP with $N < 10$
(1)	(2)	(3)	(4)	(5)
i)	Piles passing through any soil but resting on soil Type I	50	50	50
ii)	Piles not covered under Sl No. (i)	–	25	25
iii)	Raft foundations	50	50	50
iv)	Combined / Isolated RCC footings with tie beams	50	25	25
v)	Well foundations	50	25	25

NOTES

1 The allowable bearing pressure shall be determined in accordance with IS 6403 or IS 1888.

2 If any increase in bearing pressure has already been permitted for forces other than seismic forces, the total increase in allowable bearing pressure when seismic force is also included shall not exceed the limits specified above.

3 Desirable minimum field values of N are as follows:

Sl No.	*Seismic Zone*	*Depth Below Ground Level* (m)	*N Values*	*Remarks*
i)	III, IV and V	≤ 5 ≥ 10	15 25	For values of depths between 5 m and 10 m, linear interpolation is recommended.
ii)	II	≤ 5 ≥ 10	15 20	

If soils of smaller N values are met, compaction may be adopted to achieve these values or deep pile foundations going to stronger strata should be used.

4 The piles should be designed for lateral loads neglecting lateral resistance of soil layers liable to liquify.

5 Following Indian Standards may also be referred:

a) IS 1498 Classification and identification of soils for general engineering purposes.

b) IS 2131 Method of standard penetration test for soils.

c) IS 6403 Code of practice for determination of bearing capacity of shallow foundations.

d) IS 1888 Method of load tests on soils.

6 Isolated RCC footing without tie beams or unreinforced strip foundation shall not be permitted in soft soils with $N < 10$.

Table 2 Importance Factor for Various Industrial Structures

(*Clause* 8.3.2)

Sl No.	Categories of Structures (*see* 7.1)	Importance Factor
(1)	(2)	(3)
i)	Structures in Category 1	2.00
ii)	Structures in Category 2	1.75
iii)	Structures in Category 3	1.50
iv)	Structures in Category 4	1.00

NOTE — Higher importance factor may be assigned to different structures at the discretion of the project authorities.

M_R = total mass of all the equipment that are rigidly mounted at different locations in the structure, and

M_F = total mass of all the equipment that are flexible mounted at different locations in the structure.

9.2.1.1 Wherever equipment are rigidly fastened to the floor, the equipment mass (M_R) shall be taken as lumped mass at appropriate locations. No interaction between the structures and equipment shall be considered.

9.2.1.2

$$\text{If} \quad \frac{M_F}{M_S + M_R} < 0.25$$

No interaction between the structures and equipment shall be considered. In such case M_F should be considered as lumped mass at appropriate locations.

9.2.1.3 If $M_F/(M_R + M_S) \geq 0.25$, interaction between the flexibly mounted equipment and the structure shall be considered by suitably modelling the flexible equipment support system while considering the equipment as lumped mass.

9.2.2 Decoupling criteria as given below shall be used for all Category 1 systems.

9.2.2.1 For the purpose of this clause, the following notations shall be used.

$$\sqrt{j} = \frac{.\,\text{Ø}_j^{\,T}\ M\ .U_b}{\text{Ø}_j^{\,T}\ M\ \ \text{Ø}_j} = \text{Participation}$$

where

M = mass matrix of the structural system,

Ø_j = jth normalized mode shape, $\text{Ø}_j^{\,T}\ M\text{Ø}_j = 1$, and

U_b = influence vector, displacement vector of the structural system when the base is displaced by unity in the direction of earthquake motion.

9.2.2.2 All combinations of the dominant secondary system modes and the dominant primary modes must be considered and the most restrictive combination shall be used.

9.2.2.3 Coupled analysis of a primary structure and secondary system shall be performed when the effects of interaction are significant based on **9.2.2.9** and **9.2.2.11**.

9.2.2.4 Coupling is not required, if the total mass of the equipment or secondary system is 1 percent or less of the mass of the supporting primary structure. If a coupled analysis will not increase the response of the primary system over that of a decoupled analysis by more than 10 percent, then a coupled analysis is not required. However, the requirements of section **9.2.2.11** regarding the multiple supports should be considered.

9.2.2.5 In applying sections **9.2.2.9** and **9.2.2.11**, one sub-system at a time may be considered, unless the sub-systems are identical and located together, in which case the sub-system masses shall be lumped together.

9.2.2.6 When coupling is required, a detailed model of the equipment or secondary system is not required, provided that the simple model adequately represents the major effects of interaction between the two parts. When a simple model is used, the secondary system shall be re-analyzed in appropriate detail using the output motions from the first analysis as input at the points of connectivity.

9.2.2.7 For applying the criteria of this section to have a modal mass greater than 20 percent of the total system mass, the total system mass is defined by

$$M = \sum_{j=1}^{m} (\Gamma_j)^2$$

9.2.2.8 When carrying out simplified analysis (as per **9.3**), equipment or secondary system shall be considered as per **9.2.2.4**, **9.2.2.5** and **9.2.2.6**.

9.2.2.9 When detailed analysis is to be carried out for structures with equipment attached at a single point,

Table 3 Response Reduction Factor [1], *R* for Industrial Structures

(*Clause* 8.3.2)

Sl No.	Lateral Load Resisting System	*R*
(1)	(2)	(3)
	Building Frame Systems	
i)	Ordinary RC Moment—Resisting Frame (OMRF) [2]	3.0
ii)	Special RC Moment—Resisting Frame (SMRF) [3]	5.0
iii)	Steel Frame with :	
	a) Concentric brace	4.0
	b) Eccentric braces	5.0
iv)	Steel moment resisting frame designed as per SP 6(6)	5.0
	Building with Shear Walls [4]	
v)	Load bearing masonry wall buildings [5]	
	a) Unreinforced	1.5
	b) Reinforced with horizontal RC bands	2.5
	c) Reinforced with horizontal RC bands and vertical bars at corners of rooms and jambs of openings	3.0
vi)	Ordinary reinforced concrete shear walls [6]	3.0
vii)	Ductile shear walls [7]	4.0
	Buildings with Dual Systems [8]	
viii)	Ordinary shear wall with OMRF	3.0
ix)	Ordinary shear wall with SMRF	4.0
x)	Ductile shear wall with OMRF	4.5
xi)	Ductile shear wall with SMRF	5.0

[1] The values of response reduction factors are to be used for buildings with lateral load resisting elements, and not just for the lateral load resisting elements built in isolation.

[2] OMRF are those designed and detailed as per IS 456 or IS 800. However, OMRF shall not be used in situations explained in IS 13920.

[3] SMRF has been defined in **4.15.2** of IS 1893 (Part 1).

[4] Buildings with shear walls also include buildings having walls and frames, but where:

a) frames are not designed to carry lateral loads, or

b) frames are designed to carry lateral loads but do not fulfil the requirements of dual systems.

[5] Reinforcement should be as per IS 4326.

[6] Prohibited in zones IV and V.

[7] Ductile shear walls are those designed and detailed as per IS 13920.

[8] Buildings with dual systems consist of shear walls (or braced frames) and moment resisting frames such that:

a) the two systems are designed to resist the total design force in proportion to their lateral stiffness considering the interaction of the dual system at all floor levels, and

b) the moment resisting frames are designed to independently resist at least 25 percent of the design seismic base shear.

NOTE — For steel buildings not covered in Table 3, value of *R* shall be 2.

the coupling criteria shown in Fig. 1 shall be used. The mass ratio in Fig. 1 is the modal mass ratio computed as per **9.2.2.10** and the frequency ratio is the ratio of uncoupled modal frequencies of the secondary and primary systems.

9.2.2.10 For a secondary system dominant mode and the primary system mode *i*, the modal mass ratio can be estimated by:

$$A_i = \frac{M_s}{M_{pi}}$$

where

M_{pi} = $(1/ø_{ci})^2$;

$ø_{ci}$ = the mode vector value from the primary system's modal displacement at the location where the secondary system is connected, from the *i*th normalised modal vector , $(ø_{ci})$, $ø^T_{ci}\ M_p\, ø_{ci} = 1$;

M_p = mass matrix of the primary system; and

M_s = total mass of the secondary system.

9.2.2.11 Multisupport secondary system shall be reviewed for the possibility of interaction of structure and equipment stiffness between the support points, and for the effect of equipment mass distribution between support points. When these effects can significantly influence the structure response, reference shall be made to specialized literature.

9.3 Time Period Estimation

The time period of different industrial structures would vary considerably depending on the type of soil, span and height of the structure, distribution of load in the structure and the type of structure (concrete, steel and aluminium). It would be difficult to give one or two generalized formulae to cover all such structures. Accordingly, no simple guidelines can be given for estimation of time periods of industrial structures.

9.3.1 The time period shall be estimated based on Eigen value analysis of the structural mathematical model developed in accordance with **9.1** and **9.2**.

9.3.2 For preliminary design, the time period can be established based on its static deflection under mass proportional loading in each of the three principal directions. This load is applied by applying a force equal to the weight of the structure or equipment at each mode in X, Y or Z direction. Where the founding soil is soft soil, the effect of the same shall be considered in the estimates for static deflection.

The time period *T*, would then be :

$$T = 2\pi\sqrt{\frac{\delta}{g}}\ \text{sec}$$

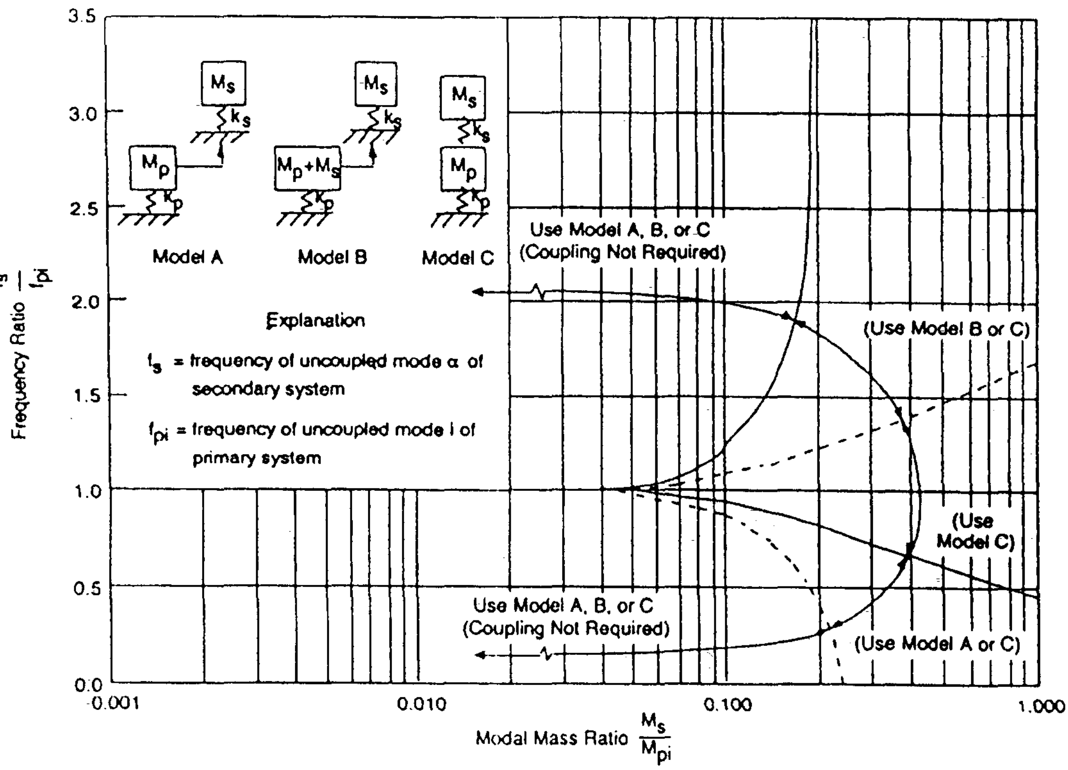

FIG. 1 DECOUPLING CRITERIA FOR EQUIPMENT OR SECONDARY SYSTEM WITH SINGLE POINT ATTACHMENT TO THE PRIMARY SYSTEM

Where δ is the maximum value of deflection at any mode out of δ_x δ_y δ_z and 'g' is acceleration due to gravity in the corresponding unit.

9.4 Damping

The damping factor to be used in determining spectral acceleration coefficient (S_a/g) depends upon the material and type of construction of the structure and the strain level. The recommended damping factors are given in Table 4.

10 ANALYSIS PROCEDURE

10.1 Classification of Analysis Techniques

10.1.1 Detailed analysis shall be carried out for structures of Category 1, in all seismic zones.

10.1.2 Detailed analysis shall be carried out for all structures of Category 2 and 3 in seismic zones III, IV and V.

10.1.3 Simplified analysis may be used for structures of Category 2 and 3 in seismic zone II.

10.1.4 Simplified analysis may be used for structures of Category 4 in all seismic zones. However, those structures of Category 4, which could be identified as buildings, may be analysed as per provisions of IS 1893 (Part 1).

10.2 Detailed Analysis

10.2.1 *Secondary Effect*

The analysis shall also include the influence of $P-\Delta$ effect.

10.2.2 *Torsion*

The effect of accidental eccentricity shall be considered for rigid floors/diaphragms. This shall be applied as an additional torsion force equal to product of the mass at floor level and 5 percent of the structure dimension perpendicular to the earthquake direction at the centre of mass of the floor.

10.2.2.1 The design eccentricity, e_{di} to be used at floor i shall be taken as:

$$e_{di} = \begin{cases} 1.5\, e_{si} + 0.05\, b_i \\ \text{or } e_{si} - 0.05\, b_i \end{cases}$$

whichever of these gives more severe effect.

e_{si} = static eccentricity at floor i, defined as the distance between centre of mass and centre of rigidity; and

b_i = floor plan dimension of floor i, perpendicular to direction of force.

The factor 1.5 represents dynamic amplification factor, while the factor 0.05 represents the extent of accidental eccentricity.

NOTE — For the purposes of this clause, all steel or aluminium flooring system may be considered as flexible unless properly designed floor bracings have been provided. Reinforced concrete flooring system at a level shall be considered rigid only if the total area of all the cut-outs at that level is less than 25 percent of its plan floor area.

10.2.3 Seismic analysis shall be performed for the three orthogonal (two horizontal and one vertical) components of earthquake motion. The earthquake motion in each direction shall be combined as specified in 7.3.

10.2.4 *Time-History Analysis Method*

Time-history analysis of structures subjected to seismic loads shall be performed using linear analysis technique. The analysis shall be based on well-established procedures. Both direct solution of the equations of motion or model superposition method can be used for this purpose.

10.2.4.1 In model superposition method, sufficiently large number of modes shall be used for analysis to include the influence of at least 90 percent of the total seismic mass.

Table 4 Damping Ratio Coefficient for Different Construction Materials for DBE and MCE Conditions

(*Clause* 9.4)

Sl No.	Material	DBE	MCE
(1)	(2)	(3)	(4)
i)	Aluminium	0.02	0.04
ii)	Steel	0.02	0.04
iii)	Reinforced Concrete	0.05	0.07

NOTE — For combined structures, damping ratio coefficient shall be determined based on well established procedures, if a composite damping ratio coefficient is not evaluated, it shall be taken as that corresponding to material having lower damping.

10.2.4.2 *Modal mass*

The modal mass (M_k) of mode k is given by :

$$M_k = \frac{\left[\sum_{i=1}^{N} W_i \phi_{ik}\right]^2}{g \sum_{i=1}^{N} W_i (\phi_{ik})^2}$$

where

g = acceleration due to gravity,

ϕ_{ik} = mode shape coefficient at floor i, in mode k, and

W_i = seismic weight of floor i.

10.2.5 *Response Spectrum Analysis*

Response spectrum method of analysis shall be performed using the design spectrum.

10.2.5.1 Sufficiently large number of modes shall be used for analysis to include the influence of at least 90 percent of the total seismic mass. The model seismic mass shall be calculated as per the provisions of **10.2.4.1**.

10.2.5.2 *Modal combination*

The peak response quantities (for example, member forces, displacements, storey forces, and shears and base reactions) should be combined as per complete quadratic combination (CQC) method as follows :

$$\lambda = \sqrt{\sum_{i=1}^{r} \sum_{j=1}^{r} \lambda_i \rho_{ij} \lambda_j}$$

where

λ = peak response quantity;

λ_i = response quantity, in mode i (including sign);

λ_j = response quantity, in mode j (including sign);

ρ_{ij} = cross-modal correlation co-efficient;

$$\rho_{ij} = \frac{8\zeta^2(1+\beta).\beta^{1.5}}{(1-\beta^2)^2 + 4\zeta^2 \beta\ (1+\beta^2)}$$

r = number of modes being considered;

ζ = modal damping ratio as specified in **9.4**;

β = frequency ratio = $\dfrac{\omega_j}{\omega_i}$

ω_j = circular frequency, in jth mode; and

ω_i = circular frequency, in ith mode.

Alternatively, the peak response quantities may be combined as follows:

a) If the structure does not have closely-spaced modes, then the peak response quantity (λ) due to all modes considered shall be obtained as:

$$\lambda = \sqrt{\sum_{k=1}^{r} (\lambda_k)^2}$$

where

λ_k = absolute value of quantity, in mode k; and

r = number of modes being considered.

b) If the structure has a few closely-spaced modes [*see* **3.2** of IS 1893 (Part 1)], then the peak response quantity λ^* due to these modes shall be obtained as :

$$\lambda^* = \sum_{c} \lambda_c$$

where the summation is for the closely spaced modes only. This peak response quantity due to the closely spaced modes (λ^*) is then combined with those of the remaining well-separated modes by the method described in **10.2.5.2**(a).

10.3 Simplified Analysis

Structures of category 2, 3 and 4 located in seismic zones II and III may be analyzed using the provisions of this clause. For all other industrial structures, the analysis procedure specified in **10.1** shall be used.

10.3.1 Simplified analysis shall be carried out by applying equivalent static lateral loads along each of the three principal directions. The equivalent static lateral loads shall be determined from design acceleration spectrum value (A_h) calculated from **8.3.2** and **9.3.2**. The static load at each node shall equal the product of its mass and the design spectral acceleration value.

11 DEFORMATIONS

11.1 Drift Limitations

The drift limitations of horizontal and vertical members shall be taken as those specified in IS 1893 (Part 1).

11.2 Separation Between Adjacent Units

Two adjacent buildings, or adjacent units of the same structure with separation joint in between shall be separated by a distance equal to the amount R times the sum of the calculated storey displacements as per **11.1** of each of them, to avoid damaging contact when the two units deflect towards each other. When floor levels of two adjacent units or structures are at the same elevation levels, factor R in this requirement may be replaced by $R/2$ +25 mm.

12 MISCELLANEOUS

12.1 Foundations

The use of foundations vulnerable to significant differential settlement due to ground shaking shall be avoided for structures in seismic zones III, IV and V. In seismic zones IV and V, individual spread footings or pile caps shall be interconnected with ties (*see* **5.3.4.1** of IS 4326) except when individual spread footings are directly supported on rock. All ties shall be capable of carrying, in tension and in compression, an axial force equal to $A_h/4$ times the larger of the column or pile cap load, in addition to the otherwise computed forces. Here, A_h is as per **8.3.1** or **8.3.2**.

12.2 Cantilever Projections

12.2.1 *Vertical*

Towers, tanks, parapets, smoke stakes (chimneys) and other vertical cantilever projections attached to structures and projecting above the roof, shall be designed for five times the design horizontal acceleration spectrum value specified in **8.3.1** and **8.3.2**.

12.2.2 *Horizontal*

All horizontal projections like cornices and balconies shall be designed for five times the design vertical acceleration spectrum value specified in **8.4**.

12.2.3 The increased design forces specified in **12.2.1** and **12.2.2** are only for designing the projecting parts and their connections with the main structures. For the design of the main structure, such increase need not be considered.

SECTION 2 STACK-LIKE STRUCTURES

13 DESIGN CRITERIA

Stack-like structures are those in which the mass and stiffness is more or less uniformly distributed along the height. Cantilever structures like reinforced or prestressed cement concrete electric poles; reinforced concrete brick and steel chimneys (including multiflue chimneys), ventilation stacks and refinery vessels are examples of such structures. The guyed structures are not covered here.

14 TIME PERIOD OF VIBRATION

Time period of vibration, T of such structures when fixed at base, shall be calculated using either of the following two formulae given (*see* **14.1** and **14.2**). The formulae given at **14.1**, is more accurate. Only one of these two formulae should be used for design. Time period of structure, if available, through vibration measurement on similar structure and foundation soil condition can also be adopted.

Table 5 Categorization of Industrial Structures (Typical)

(*Clause* 7.1)

Sl No. (1)	Structures (2)	Category (3)
1.	Administration building	4
2.	Air washer pump house	2
3.	Air pre-heaters	2
4.	Ash collection silos	2
5.	Ash dyke	2
6.	Ash water pump house	2
7.	Ash water re-circulation building	2
8.	Ash/slurry pump house	2
9.	Auto base	3
10.	Bagging and palletizing building	2
11.	Ball mill and silos	2
12.	Boiler and boiler house	2
13.	Bridges over rivers	2
14.	C&I maintenance stores	3
15.	Canteen building	4
16.	Caustic tanks	2
17.	Chiller plant	2
18.	Chlorine storage handling/ dozing buildings	2
19.	Clarifloculator	2
20.	Coal handling plant	2
21.	Coal slurry settling pond	2
22.	Compressor foundation	2
23.	Compressor house	2
24.	Condenser polishing unit	2
25.	Construction workshop	3
26.	Control and instrumentation building	2
27.	Control building	2
28.	Control building (blast resistant)	1
29.	Converters	2
30.	Conveyor galleries	2
31.	Cooling towers (wet and dry) and control room	2
32.	Corex gas station (for co-generation plant)	2
33.	Crusher house	2
34.	Crushers	2
35.	Cryogenic storage tank (double walled) (ethylene)	1
36.	Cryogenic storage tanks with refrigerated liquefied gasses	2

Table 5 — *Continued*

Sl No. (1)	Structures (2)	Category (3)
37.	CW pump house	2
38.	DG hall	2
39.	Dirty and clean oil building	2
40.	DM plant	2
41.	Effluent treatment plant	3
42.	Electro static precipitator- ESP	2
43.	ESP control room	2
44.	Extrusion building	2
45.	F.O. pump house	2
46.	F.O. storage tank and day tank	2
47.	Fans - PA, FD, GR and ID fans	2
48.	Filter	2
49.	Filtration and chlorination plant	3
50.	Fire station	2
51.	Fire tender	2
52.	Fire water pump house	2
53.	Fire water reservoir	2
54.	Flare stack supporting structure	2
55.	Gate and gate house	4
56.	Generator transformer	3
57.	H_2 plant building	2
58.	Heater /furnace	2
59.	Heaters with steel rack	2
60.	Horizontal vessel/heat exchanger	2
61.	Intake structure	3
62.	Laboratory building	4
63.	LPG storage	2
64.	Main condensate storage tank	2
65.	Main plant building (TG, BFP including bunker bay)	2
66.	Make-up water pump house and fore-bay	2
67.	Microwave towers	2
68.	OD ducts	2
69.	Other non-plant buildings and utility structures	4
70.	Overhead water tank	3
71.	Pipe pedestal and cable trestles	2
72.	Pipe rack	2
73.	Pipe supports including anchors	2

Table 5 — *Concluded*

Sl No. (1)	Structures (2)	Category (3)
74.	Polymerisation building	2
75.	Process building (closed)	2
76.	Process column on elevated structures	1
77.	Process column/vessel/reactors on low RCC pedestal	1
78.	Process water storage tank	2
79.	Product storage sheds/building	2
80.	Rail loading gantry	3
81.	RCC chimney	2
82.	Regeneration building	2
83.	Scrubber	2
84.	Settling tanks (RCC)	2
85.	Sheds (tall and large span, high capacity cranes)	2
86.	Silos	2
87.	Smelters on RCC/steel structures	2
88.	Sphere/bullets	2
89.	Start-up transformer.	3
90.	Storage silos (RCC/steel/aluminum) on elevated structure	2
91.	Storage tank (dome/cone roof)	2
92.	Stores	3
93.	Substation	2
94.	Substation buildings	2
95.	Switch-gear building	2
96.	Switchyard	2
97.	Switchyard structures	2
98.	Tanks for refrigerated liquefied gases	2
99.	Technological structures in RCC/steel or both	2
100.	Track hopper	2
101.	Transformers and radiator bank	2
102.	Truck loading gantry	3
103.	Tunnel/trenches	3
104.	Wagon tippler	4
105.	Warehouse	2
106.	Water treatment plant	2
107.	Workshop	4

14.1 The fundamental time period for stack-like structures, 'T' is given by:

$$T = C_T \sqrt{\frac{W_t . h}{E_s . A . g}}$$

where

C_T = coefficient depending upon the slenderness ratio of the structure given in Table 6,

W_t = total weight of the structure including weight of lining and contents above the base,

h = height of structure above the base,

E_S = modulus of elasticity of material of the structural shell,

A = area of cross-section at the base of the structural shell,

For circular sections, $A = 2\pi rt$, where r is the mean radius of structural shell and t its thickness, and

g = acceleration due to gravity.

NOTE — This formula is only applicable to stack-like structure in which the mass and stiffness are more or less uniformly distributed along the height.

14.2 The fundamental time period, T of a stack-like structure can be determined by Rayleigh's approximation for fundamental mode of vibration as follows :

$$T = 2\pi / \sqrt{g . C_\delta}$$

$$C_\delta = \frac{\sum_{i=1}^{N} W_i \delta_i}{\sum_{i=1}^{N} W_i \delta_i^2}$$

where

W_i = weight lumped at ith location with the weights applied simultaneously with the force applied horizontally,

δ_i = lateral static deflection under its own lumped weight at ith location (chimney weight lumped at 10 or more locations),

N = number of locations of lumped weight, and

g = acceleration due to gravity.

NOTES

1 Any elastic analysis procedure like moment area theorem or column analogy or matrix method may be used for determining the lateral static deflection d value.

2 For determining the time period of vibration of structures resting on frames or skirts like bins, silos, hyperbolic cooling towers, refinery columns, only the formula given at 14.2 should be used. Approximate methods may be adopted to estimate the lateral stiffness of the frame or skirt in order to determine the lateral static deflection. Dynamic response spectrum modal analysis will be necessary in such cases.

15 DAMPING

The damping factor to be used in determining S_a/g depends upon the material and type of construction of the structure and the strain level. The following damping factors are recommended as guidance for different materials for fixed base condition and are given in the Table 7.

16 HORIZONTAL SEISMIC FORCE

Using the period T, as indicated in **14**, the horizontal seismic coefficient A_h shall be obtained from the spectrum given in IS 1893(Part 1). The design horizontal seismic coefficient for A_h design basis earthquake (DBE) shall be determined by the following expression adopted in IS 1893 (Part 1) :

$$A_h = \frac{\left[Z/2 \right] \left[S_a/g \right]}{(R/I)}$$

where

Z = zone factor given in Annex A. This is in accordance with Table 2 of IS 1893 (Part 1),

I = importance factor as given in Table 8,

R = response reduction factor as given in Table 9. The ratio (R/I) shall not be less than 1.0, and

S_a/g = spectral acceleration coefficient for rock and soil sites as given in Annex B. This is in accordance with Fig. 1 of IS 1893 (Part 1).

The horizontal earthquake force shall be assumed to act alone in one lateral direction at a time.

The effects due to vertical component of earthquakes are generally small and can be ignored. The vertical seismic coefficient where applicable may be taken as 2/3 of horizontal seismic coefficient, unless evidence of factor larger than above is available.

The effect of earthquake and maximum wind on the structure shall not be considered simultaneously.

17 DESIGN SHEAR FORCE AND MOMENT

Either simplified method (that is, equivalent static lateral force method) or the dynamic response spectrum modal analysis method is recommended for calculating the seismic forces developed in such structures. Site spectra compatible time history analysis may also be carried out instead of response spectrum analysis.

17.1 Simplified Method (Equivalent Static Lateral Force Method)

The simplified method can be used for ordinary stack-like structures. The design shear force, V, and design

Table 6 Values of C_T and C_V
(*Clauses* 14.1 *and* 17.1)

Sl No. (1)	$k = h/r_e$ (2)	Coefficient, C_T (3)	Coefficient, C_V (4)
i)	5	14.4	1.02
ii)	10	21.2	1.12
ii)	15	29.6	1.19
iv)	20	38.4	1.25
v)	25	47.2	1.30
vi)	30	56.0	1.35
vii)	35	65.0	1.39
viii)	40	73.8	1.43
ix)	45	82.8	1.47
x)	50 or more	1.8 k	1.50

NOTE — k = slenderness ratio, and

r_e = radius of gyration of the structural shell at the base section.

Table 7 Material Damping Factor
(*Clause* 15)

Sl No. (1)	Material (2)	DBE (3)	MCE (4)
i)	Steel	0.02	0.04
ii)	Reinforced Concrete	0.05	0.07
iii)	Brick Masonry and Plain Concrete	0.07	0.10

NOTES

1 For elastic base represented by raft on soft soil or pile foundation, the damping may be worked out as weighted damping based on modal strain energies in superstructure and substructures. As an approximation the values may be assumed as 7 percent of critical damping for reinforced concrete structures.

2 For riveted steel stacks/chimneys, etc, a 5 percent of critical damping may be adopted to account for the frictional losses.

3 The damping values obtained from experimental tests on similar structures can also be used.

4 In case of multi-flue RC chimneys, 3 percent of critical value for DBE and 5 percent for MCE is recommended.

bending moment, M, for such structures at a distance X from the top, shall be calculated by the following formulae:

a) $V = C_v \cdot A_h\ W_t \cdot D_v$

b) $M = A_h W_t \bar{h} D_m$

where

C_v = coefficient of shear force depending on slenderness ratio k given in Table 6,

A_h = design horizontal seismic coefficient determined in accordance with **16**,

W_t = total weight of structure including weight of lining and contents above the base,

$\bar{h}$ = height of centre of gravity of structure above base, and

D_v, D_m = distribution factors for shear and moment respectively at a distance X from the top as given in Table 10. The expressions for these distribution for moment and shear along the height is given in Table 11 for use in computer programme.

The appropriate foundation soil and pile group stiffness are given in Table 12.

Table 8 Importance Factor Applicable to Stack-Like Structures

(*Clause* 16)

Sl No.	Type of Structure	Importance Factor
(1)	(2)	(3)
i)	Reinforced concrete ventilation stacks	1.5
ii)	Reinforced concrete chimneys	1.5
iii)	Reinforced brick masonry chimney for industry	1.5
iv)	Un-reinforced brick masonry chimney for industry	1
v)	Reinforced concrete T.V. towers	1.5
vi)	Electric/traffic light poles	1
vii)	Steel stack	1.5
viii)	Silos	1.5

NOTES

1 In case of important factor given in Table 2 and Table 8 found different, higher values shall be considered.

2 The values of importance factor, *I* given in this table are for guidance. A designer may choose suitable values depending on the importance based on economy, strategy and other considerations.

Table 9 Reduction Factor Applicable to Stack-Like Structures

(*Clause* 16)

Sl No.	Type of Structure	Reduction Factor, *R*
(1)	(2)	(3)
i)	Reinforced concrete, T.V. tower	3.0
ii)	Reinforced concrete ventilation stack	3.0
iii)	Reinforced concrete chimney	3.0
iv)	Reinforced brick masonry	2.0
v)	Steel chimney	2.0
vi)	Steel refinery vessels	2.0
vii)	Un-reinforced brick masonry chimney	1.0
viii)	Reinforced electric/traffic pole	2.0

17.2 Dynamic Response (Spectrum Modal Analysis)

The dynamic analysis using response spectrum method should be carried out for important stack-like structures. The number of mode to be considered in the analysis should be such that about 90 percent of modal mass is excited. The modes could then be combined by modal combination of corresponding response like shear, moment, etc, as suggested in IS 1893 (Part 1). The detailed dynamic analysis using time history shall be required where analysis is based on site-specific response spectrum and compatible time history of ground motion. For combination of three-component motion, *see* **7.3.2.2** of Section 1 'Industrial Structures'.

17.2.1 *Mathematical Model*

The mathematical model of stack-like structures should be able to represent sufficiently the variation in its stiffness (variation in cross-section and thickness of shell), lining mass and foundation modelling (that is foundation stiffness, soil deformations). The number of elements should be such as to capture the variation of stiffness and mass of the system. A minimum of ten beam elements should in general be sufficient. For axi-symmetric structures axi-symmetric finite elements shall be used.

Table 10 Digitized Moment and Shear Distribution Factors D_m and D_v along the Height

(*Clause* 17.1)

Sl No.	X/h[1)]	Moment Distribution (D_m)			Shear Distribution (D_v)		
		Fixed	Soil	Pile Foundation	Fixed	Soil	Pile Foundation
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ii)	0.05	0.09	0.13	0.11	0.28	0.21	0.14
iii)	0.10	0.13	0.19	0.16	0.42	0.27	0.19
iv)	0.20	0.18	0.27	0.22	0.64	0.34	0.26
v)	0.30	0.22	0.33	0.28	0.83	0.38	0.31
vi)	0.40	0.27	0.39	0.33	1.00	0.41	0.35
vii)	0.50	0.32	0.45	0.38	1.00	0.44	0.40
viii)	0.60	0.39	0.52	0.45	1.00	0.49	0.46
ix)	0.70	0.48	0.60	0.54	1.00	0.55	0.54
x)	0.80	0.60	0.70	0.65	1.00	0.65	0.65
xi)	0.90	0.77	0.83	0.80	1.00	0.80	0.80
xii)	0.95	0.88	0.91	0.89	1.00	0.89	0.89
xiii)	1.00	1.00	1.00	1.00	1.00	1.00	1.00

[1)] 'X' is the distance from top and 'h' is the height of chimney above the base.

Table 11 Values of D_m and D_v

(*Clause* 17.1)

Sl No.	Soil Foundation Condition	D_m	D_v
(1)	(2)	(3)	(4)
i)	Fixed base or raft on hard soil (based on N values)	$0.4\left[\frac{x}{h}\right]^{1/2}+0.6\left[\frac{x}{h}\right]^{4}$	$1.1\left[\frac{x}{h}\right]^{1/2}+0.75\left[\frac{x}{h}\right]+0.9\left[\frac{x}{h}\right]^{4}$ but ≤ 1
ii)	Raft on soil (based on N values)	$0.6\left[\frac{x}{h}\right]^{1/2}+0.4\left[\frac{x}{h}\right]^{4}$	$1.1\left[\frac{x}{h}\right]^{1/2}-0.75\left[\frac{x}{h}\right]+0.65\left[\frac{x}{h}\right]^{4}$
iii)	Pile foundation	$0.5\left[\frac{x}{h}\right]^{1/2}+0.5\left[\frac{x}{h}\right]^{4}$	$0.66\left[\frac{x}{h}\right]^{1/2}-0.20\left[\frac{x}{h}\right]+0.54\left[\frac{x}{h}\right]^{4}$

Table 12 Foundation Soil and Foundation Pile Group Stiffness

(*Clause* 17.1)

Sl No.	Type of Foundation	Stiffness
(1)	(2)	(3)
i)	*Circular raft foundation on soil* :	
	1) Horizontal soil stiffness	$K_h = 32(1-\upsilon)Gr_0/(7-8\upsilon)$
	2) Rocking soil stiffness (full circular raft)	$K_r = 8\ Gr_0^3/3(1-\upsilon)$
ii)	*Annular raft* :	
	1) Friction pile foundation (under reamed piles not covered)	$K_h = \eta EI_m/1.2T_e^3 + \eta_h d^2/2$
	2) Translational stiffness of piles at the base of pile cap	$T_e = (EI_m/\eta_h)^{1/5}$

where

G = shear modulus of soil = $P\,v_s^2$,

V_s = shear wave velocity of the medium,

r_0 = radius of circular raft foundation,

υ = Poisson's ratio of soil,

n = number of piles,

E = modulus of elasticity of pile material,

I_m = moment of inertia of pile section,

T = characteristic length of pile,

d = thickness of pile cap or raft, and

η_h = modulus of sub grade reaction of soil in horizontal direction.

NOTES

1 For rectangular foundation effective radius $r_0 = \sqrt{ab}$ may be taken, where a and b are the dimension of the rectangular foundation.

2 For N values > 50, fixed base condition may be assumed.

3 Classification of soil shall be as per IS 1893 (Part 1).

4 When soil structure interaction effects are to be considered; shear wave velocities are to be determined by suitable methods.

In case of chimneys, no stiffness is considered to be provided by the lining, however, the mass of lining above any corbel is assumed to be lumped at the corbel level.

NOTE — Minimum number of elements should be adequate to ensure that the model represent the frequencies up to 33 Hz.

18 SPECIAL DESIGN CONSIDERATIONS FOR REINFORCED CONCRETE STACKS

18.1 The total vertical reinforcement shall not be less than 25 percent of the concrete area. When two layers of reinforcement are required, the outside vertical reinforcement shall not be less than 50 percent of the reinforcement.

18.2 The total circumferential reinforcement shall not be less than 0.20 percent of the concrete area. When two layers of reinforcement are required, the circumferential reinforcement in each face shall not be less than 0.1 percent of the concrete area at the section.

18.3 The circumferential reinforcement for a distance of 0.2 times diameter of the chimney (from top of the chimney) shall be twice the normal reinforcement.

18.4 Extra reinforcement shall have to be provided in addition to the reinforcement determined by design at the sides, top, bottom and corners of these openings. The extra reinforcement shall be placed on both faces of the chimney shell as close to the opening as proper spacing of bars will permit. Unless otherwise specified, all extra reinforcement shall extend past the opening a sufficient distance to develop the full bond strength.

18.5 At each side of the opening, the additional vertical reinforcement shall have an area at least equal to the established design reinforcement for one-half of the width of the opening.

18.6 At both the top and bottom of each opening, additional reinforcement shall be placed having an area at least equal to one-half of the established design circumferential reinforcement interrupted by the opening.

One half of this extra reinforcement shall extend completely around the circumferential of the chimney, and the other half shall extend beyond the opening to a sufficient distance to develop the bars in bond. The steel shall be placed as close to the opening as practicable, but within a height not to exceed twice the thickness.

18.7 Deflection Criterion

The maximum lateral deflection of the top of a stack-like structure under all service conditions, prior to the application of load factors, shall not exceed the limits set forth by the following equation:

$$D_{Max} = 0.003\, h$$

where

D_{Max} = maximum lateral deflection, and

h = height of structure above the base.

ANNEX A

(*Clauses* 8.2 *and* 16)

ZONE FACTOR

Zone Factor Z for MCE

Seismic[1] Zone	**II**	**III**	**IV**	**V**
Z	0.10	0.16	0.24	0.36

[1] The zoning is as per IS 1893 (Part 1).

ANNEX B

(*Clauses* 8.2)

DESIGN SPECTRUM

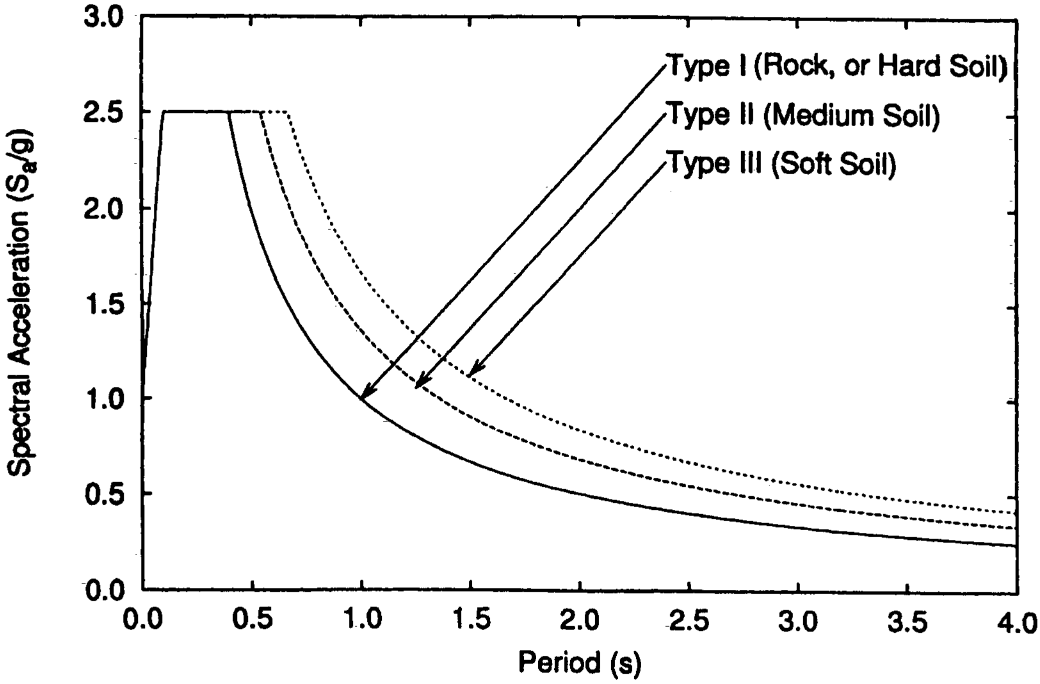

FIG. 2 RESPONSE SPECTRA FOR ROCK AND SOIL SITES FOR 5 PERCENT DAMPING

This Indian Standard has been developed from Doc: No. CED 39 (5743).

Amendments Issued Since Publication

Amend No.	Date of Issue	Text Affected

BUREAU OF INDIAN STANDARDS

Headquarters:

Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002
Telephones: 2323 0131, 2323 3375, 2323 9402 *website* : www.bis.org.in

Regional Offices:		Telephones
Central	: Manak Bhavan, 9 Bahadur Shah Zafar Marg NEW DELHI 110002	2323 7617 2323 3841
Eastern	: 1/14 C.I.T. Scheme VII M, V.I.P. Road, Kankurgachi KOLKATA 700054	2337 8499, 2337 8561 2337 8626, 2337 9120
Northern	: SCO 335-336, Sector 34-A, CHANDIGARH 160022	260 3843 260 9285
Southern	: C.I.T. Campus, IV Cross Road, CHENNAI 600113	2254 1216, 2254 1442 2254 2519, 2254 2315
Western	: Manakalaya, E9 MIDC, Marol, Andheri (East) MUMBAI 400093	2832 9295, 2832 7858 2832 7891, 2832 7892

Branches : AHMEDABAD. BANGALORE. BHOPAL. BHUBANESHWAR. COIMBATORE. FARIDABAD. GHAZIABAD. GUWAHATI. HYDERABAD. JAIPUR. KANPUR. LUCKNOW. NAGPUR. NALAGARH. PATNA. PUNE. RAJKOT. THIRUVANANTHAPURAM. VISAKHAPATNAM.

Printed at Simco Printing Press, Delhi