भारतीय मानक ब्यूरो
(उपभोक्ता मामले, खाद्य एवं सार्वजनिक वितरण मंत्रालय, भारत सरकार)
BUREAU OF INDIAN STANDARDS
(Ministry of Consumer Affairs, Food & Public Distribution, Govt. of India)

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व्यापक परिचालन मसौदा

हमारा संदर्भ : सीईडी 39/टी- 13 **20 फरवरी 2025**

तकनीकी समिति : भूकंप इंजीनियरिंग अनुभागीय समिति , सीईडी 39

प्राप्तकर्ता :

1. **सिविल अभियांत्रिकी विभाग परिषद, सीईडीसी के सभी सदस्य**
2. **भूकंप इंजीनियरिंग अनुभागीय समिति, सीईडी 39**
3. **सीईडी 39 की उपसमितियों और अन्य कार्यदल के सभी सदस्य**
4. **रुचि रखने वाले अन्य निकाय।**

महोदय/महोदया,

निम्नलिखित मानक का मसौदा संलग्न है:

प्रलेख संख्या	शीर्षक
सीईडी 39(27624)WC	**संरचनाओं के भूकंपरोधी डिज़ाइन के लिए मानदंड** **भाग 4 औद्योगिक संरचनाएँ** [IS 1893 (*भाग 4*) *का तीसरा पुनरीक्षण*] का भारतीय मानक मसौदा आई सी एस संख्या : 91.120.25

कृपया इस मसौदे का अवलोकन करें और अपनी सम्मतियाँ यह बताते हुए भेजे कि यह मसौदा प्रकाशित हो तो इन पर अमल करने में आपको व्यवसाय अथवा कारोबार में क्या कठिनाइयां आ सकती हैं।

सम्मतियाँ भेजने की अंतिम तिथि: 06 अप्रैल 2025

सम्मति यदि कोई हो तो कृपया अधोहस्ताक्षरी को ई-मेल द्वारा **ced39@bis.gov.in** पर या उपरलिखित पते पर, संलग्न फोर्मेट में भेजें। सम्मतियाँ बीआईएस ई-गवर्नेंस पोर्टल, **www.manakonline.in** के माध्यम से ऑनलाइन भी भेजी जा सकती हैं।

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यह प्रालेख भारतीय मानक ब्यूरो की वेबसाइट www.bis.gov.in पर भी उपलब्ध हैं।
धन्यवाद।

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सिविल अभियांत्रिकी विभाग

संलग्न: उपरलिखित

भारतीय मानक ब्यूरो
(उपभोक्ता मामले, खाद्य एवं सार्वजनिक वितरण मंत्रालय, भारत सरकार)
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WIDE CIRCULATION DRAFT

Our Reference: CED 39/T- 13 **20 February 2025**

TECHNICAL COMMITTEE: EARTHQUAKE ENGINEERING SECTIONAL COMMITTEE, CED 39

ADDRESSED TO:

1. All Members of Civil Engineering Division Council, CEDC
2. All Members of Earthquake Engineering Sectional Committee, CED 39
3. All Members of Subcommittees, Panels and Working Groups under CED 39
4. All others interested.

Dear Sir/Madam,

Please find enclosed the following draft:

Doc No.	**Title**
CED 39(27624)WC	**Draft Indian Standard Criteria for Earthquake Resistant Design of Structures** **Part 4 Industrial Structures** [*Third Revision* of IS 1893 (Part 4)] ICS No. 91.120.25

Kindly examine the attached draft and forward your views stating any difficulties which you are likely to experience in your business or profession, if this is finally adopted as National Standard.

Last Date for comments: 06 April 2025

Comments if any, may please be made in the enclosed format and emailed at ced39@bis.gov.in or sent at the above address. Additionally, comments may be sent online through the BIS e-governance portal, www.manakonline.in.

In case no comments are received or comments received are of editorial nature, kindly permit us to presume your approval for the above document as finalized. However, in case comments, technical in nature are received, then it may be finalized either in consultation with the Chairman, Sectional Committee or referred to the Sectional Committee for further necessary action if so desired by the Chairman, Sectional Committee.

The document is also hosted on BIS website www.bis.gov.in.

Thanking you,

Yours faithfully,
Sd/-
Dwaipayan Bhadra
Scientist ‘E’ & Head
Civil Engineering Department

Encl: As above

FORMAT FOR SENDING COMMENTS ON THE DOCUMENT

[Please use A4 size sheet of paper only and type within fields indicated. Comments on each clause/sub-clause/ table/figure, etc, be stated on a fresh row. Information/comments should include reasons for comments, technical references and suggestions for modified wordings of the clause. Comments through e-mail to ced39@bis.gov.in shall be appreciated.]

Doc. No.: CED 39(27624)WC

BIS Letter Ref: CED 39/T- 13

Title: Draft Indian Standard Criteria for Earthquake Resistant Design of Structures Part 4 Industrial Structures and Stack-like Structures [*Third Revision* of IS 1893 (Part 4)] ICS No. 91.120.25

Last date of comments: 06 April 2025

Name of the Commentator/ Organization:

____

Sl No.	Clause/ Para/ Table/ Figure No. commented	Type of Comment (General/ Technical/ Editorial)	Comments/ Modified Wordings	Justification of Proposed Change

NOTE- *Kindly insert more rows as necessary for each clause/table, etc*

BUREAU OF INDIAN STANDARDS

DRAFT STANDARD FOR COMMENTS ONLY

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Draft Indian Standard

Criteria for Earthquake Resistant Design of Structures

Part 4 Industrial Structures

[*Third Revision* of IS 1893 (Part 4)]

ICS No. 91.120.25

Earthquake Engineering
Sectional Committee, CED 39

Last Date for Comments:
06 April 2025

FOREWORD

[*Formal clause will be added later*]

About 64 percent of India's land area is prone to moderate to strong earthquake shaking intensities (see Annex E of IS 1893 (Part 1) for 1964 MSK Intensity Scale for earthquake ground shaking). Hence, earthquake resistant design is essential.

The standard IS 1893: 1962 'Recommendations for earthquake resistant design of structures' was first published in 1962, and revised in 1966, 1970, 1975 and 1984. Further, in 2002, the Committee decided to present the provisions for different type of structures in separate parts, to keep abreast with rapid developments and extensive research carried out in earthquake-resistant design of various structures.

Considering the state of knowledge available then and in order to update this standard, the Committee had decided to cover the provisions for different types of structures in separate parts. This standard was therefore split into parts. The other parts of IS 1893 which have been published are:

Part 1 General provisions and buildings
Part 2 Liquid retaining tanks
Part 3 Bridges and retaining walls
Part 6 Base isolated buildings

Part 4 of the standard was first published as a separate one in 2005 in which provisions on earthquake resistant design for industrial structures including stack-like structures were covered respectively in sections 1 and 2. Thereafter, the Part 4 was revised in 2015 and revised again in 2024. The significant changes in 2024 version were: definition of design spectrum updated and defined up to natural period of 10 s; importance factor for Category 3 structures modified; maintenance specific imposed load introduced; detailed categorization of industrial structures expanded in three tables separately for industrial structures, stack-like structures and equipment/piping;

inclusion of effect of masonry infill walls in analysis for RCC structures; considerations for temporary facilities and specific provisions for ground supported vertical cylindrical tanks, anchorages, structure supporting cranes, structural considerations during maintenance, bunkers and silos and pre-engineered steel structures provided.

In this revision, the Committee decided to present the provisions for different types of structures in separate parts, to keep abreast with rapid developments and extensive research carried out in earthquake-resistant design of various structures. Thus, IS 1893 is split into 11 Parts, namely:

Part 1	General Provisions
Part 2	Liquid Retaining Tanks
Part 3	Bridges and Retaining Walls
Part 4	Industrial Structures
Part 5	Buildings
Part 6	Base-Isolated Buildings
Part 7	Pipelines
Part 8	Dams and Embankments
Part 9	Coastal Structures
Part 10	Steel Towers
Part 11	Tunnels

This standard contains provisions specific to earthquake-resistant design of industrial structures. Unless stated otherwise, the provisions in this part of IS 1893 shall be read necessarily in conjunction with the general provisions as laid down in IS 1893 (Part 1) and provisions of buildings in IS 1893 (Part 5) as applicable to industrial structures depending on the category of industrial structures.

In this third revision, the following significant changes have been incorporated:

a) Categorisation of industrial structures have been aligned with the categorisation of structures provided in IS 1893 (Part 1);
b) Importance factors have been adjusted in view of the revised earthquake hazard;
c) Response reduction factor has been renamed as Elastic Force Reduction Factor and values have been revised for some structural systems;
d) Provisions on interaction effects between primary and secondary systems have been improved;
e) Generation of In-structure Response Spectra (ISRS) for use in design of secondary systems brought under the purview of this standard;
f) Operational and Functional Components (OFCs) defined and procedures for design of OFCs included;
g) Estimation of natural period for stack-like structure included up to first three modes and clarity on the limitation of simplified method is provided; and
h) Provisions on chimneys and stacks have been improved.

In the formulation of this standard, effort has been made to coordinate with standards and practices prevailing in different countries in addition to relating it to the practices in the field in this country. Assistance has particularly been derived from the following publications:

a) ASCE/SEC 7-22, Minimum Design Loads for Buildings and Other Structures, American Society of Civil Engineers, USA, 2022;
b) ASCE/SEI 4-16, Seismic Analysis of Safety-Related Nuclear Structures, American Society of Civil Engineers, USA, 2016;
c) NEHRP 2020, NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures, Volume I: Part 1 Provisions, Part 2 Commentary; and
d) BS EN 1998-4, Design of Structures for Earthquake Resistance, Part 4: Silos, Tanks and Pipelines, Eurocode 8, 2006.

This standard contributes to the following Sustainable Development Goals:
Goal 9 Industry, Innovation and Infrastructure towards building resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation; and
Goal 11 Sustainable Cities and Communities towards making cities and human settlements inclusive, safe, resilient and sustainable.

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

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: 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

CONTENTS

Draft Indian Standard

Criteria for Earthquake Resistant Design of Structures

Part 4 Industrial Structures and Stack-like Structures

[*Third Revision* of IS 1893 (Part 4)]

ICS No. 91.120.25

Earthquake Engineering Sectional Committee, CED 39

Last Date for Comments: 06 April 2025

1 SCOPE

1.1 All industrial structures and stack-like structures other than nuclear installations 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 and provides the procedure of estimating the earthquake forces for design of such structures.

1.2 This standard shall also be referred for provisions related to earthquake resistant design of equipment and piping (including the seismic qualification of equipment).

1.3 In Seismic Zones II and III, temporary structures such as scaffolding, temporary excavations, structures or equipment needed during a scheduled shutdown or maintenance period, structures erected to temporarily support heavy equipment and other facilities of industrial structures during construction and are meant for a limited time use not exceeding one year need not be designed for earthquake forces.

1.4 In Seismic Zones IV, V and VI, these temporary structures (as in **1.3**) shall be designed as Category 4 structures. The drift limitation provisions of Category 4 structures need not be applied to design of temporary structures.

1.5 Temporary facilities or structures that may be in service for longer than one year shall be designed as permanent structures as per the provisions of this standard in all seismic zones.

1.6 This standard does not deal with the construction features relating to earthquake resistant design in non-industrial buildings and structures. For guidance on earthquake resistant construction of these structures, reference may be made to the respective parts of IS 1893, IS 13920 and IS 13935.

1.7 This standard shall be considered applicable to structures of all industries, including those listed below, unless exclusively noted otherwise:

a) Process industries;
b) Power plants;
c) Petroleum, fertilizers, chemical 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, electronic and semi-conductor industries;
p) Consumer product industries;
q) Water treatment plants, effluent treatment plants and sewage treatment plants;
r) Leather industries;
s) Off-shore structures, marine/ port and harbour structures;
t) Mills of various plants;
u) Information technology, data processing centers and communication industries;
v) Pulp and paper industries; and
w) Food processing and packaging plants.

1.8 In addition to the above, the standard is applicable to the following structures, which are classified as stack-like structures:

a) Natural draught cooling towers and prilling towers;
b) Transmission and communication towers and masts, including those mounted on buildings;
c) Chimneys and stack-like structures;
d) Steel tubular support structures for onshore wind turbine generator systems;
e) Silos (including parabolic silos);
f) Support structures for refinery columns including distillation columns; and
g) Pressure vessels and chemical reactor columns.

1.9 For nuclear installations, reference shall be made to the applicable safety standards.

2 REFERENCES

The standards listed in Annex A 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 in Annex A.

3 TERMINOLOGY FOR INDUSTRIAL STRUCTURES

Terminology given under **3** of IS 1893 (Part 1) and under **3** of Section 1 of IS 1893 (Part 5) shall apply to this standard as well. In addition, the following terms related to industrial structures shall also apply to this standard. For definition of terms pertaining to soil mechanics and soil dynamics, reference may be made to IS 2809 and IS 2810, and for definition of terms pertaining to 'loads', reference may be made to IS 875 (Part 1 to Part 5).

3.1 Combined Structures — A structure with lateral load resisting elements constructed from a combination of reinforced or prestressed concrete and structural steel.

3.2 Equipment/Component — An equipment is a mechanical or electrical component that is part of a mechanical and/or electrical system attached to the industrial structure or independent of it. A component is an item of architectural, mechanical or electrical system.

3.3 Height of Structure ($\boldsymbol{h}$) — The difference in levels between its base and its highest level. For pitched or sloped roofs, the height of structure is from the base to the average height of the roof.

3.4 In-Structure Response Spectra (ISRS) — The response spectra generated from the dynamic response of the structure at selected locations in a structure. In-structure response spectra are used for design of systems and components supported within a structure.

3.5 Main Load-Resisting System — Part of the primary system that has been considered in the design to provide the required resistance to both gravity and seismic forces used for design.

3.6 Maintenance Specific Imposed Load (MSIL) — Load imposed on a specified floor area for maintenance and repair operations. MSIL shall include but not limited to the load due to maintenance equipment, staging, increased imposed load due to personnel and their equipment, etc. MSIL shall also duly account for the effect of non-uniform distribution of the load and influence of factors such as impact, if applicable.

3.7 Operational and Functional Components (OFCs) — OFCs are those components housed inside or attached to the industrial structure which are not part of the main load-resisting system and that are required for the function and operation of the industrial structure.

3.8 Primary System — Part of the structural system that includes the main load-resisting system that carry the inertia forces to the base, and which are not part of the secondary structural system.

3.9 Secondary System — Structures, systems and equipment or components that are not part of the primary system. Examples of secondary system include but not limited to OFCs.

4 SYMBOLS

The symbols and notations applicable to both Sections 1 and 2 are given as under:

A	Area of cross section at the base of the structural shell, in mm^2
$A_{\mathrm{H}}(T)$	Elastic maximum horizontal PSA corresponding to the fundamental natural period T of the structure in horizontal mode
$A_{\mathrm{HD}}(T)$	Design horizontal PSA corresponding to the natural period T of the structure
$A_{\mathrm{V}}(T)$	Elastic maximum vertical PSA corresponding to the fundamental natural period T of the structure in the vertical mode
$A_{\mathrm{VD}}(T)$	Design vertical PSA corresponding to the natural period T of the structure
C_{T}	Coefficient depending upon the slenderness ratio k of the structure for the first four modes
C_{di}	Coefficient for displacement for the i^{th} mode
C_{dm}	Crane dead load for multiple cranes with crane bridges and crane trolleys positioned to produce the maximum load effect for the element in consideration
C_{ds}	Crane dead load for a single crane with crane trolley positioned to produce the maximum load effect for the element in consideration
C_{mi}	Coefficient for bending moment for the i^{th} mode
C_{vi}	Coefficient for shear force for the i^{th} mode
DL	Dead load
$D_{\max}$	Maximum seismic lateral displacement
EE_{D}	Effect of design earthquake forces
EL_{DX}	Response quantity due to design earthquake load for horizontal shaking along X-direction
EL_{DY}	Response quantity due to design earthquake load for horizontal shaking along Y-direction
EL_{DZ}	Response quantity due to design earthquake load for vertical shaking along Z-direction
E_{s}	Modulus of elasticity of material of the structural shell
e_{di}	Design eccentricity to be used at floor i
F_{i}	Lateral force at level i
f_{c}	Central frequency for the frequencies that exceed 80 percent of the peak amplitude
f_{pi}	Frequency of primary system mode i
f_{s}	Frequency of secondary system
g	Acceleration of gravity
h	Height of structure above the base
I	Importance factor

I_b	Moment of inertia at the base
IL	Imposed loads
k	Slenderness ratio
k_{p}	Stiffness of primary system
k_{s}	Stiffness of secondary system
$\{M\}$	Mass matrix of the structural system
$M_{\mathrm{D,x,i}}$	Design bending moment of stack-like structure for the i^{th} mode
$[M_{\mathrm{p}}]$	Mass matrix of the primary system
M_{FS}	Total mass of all the equipment that are flexibly mounted (using isolators) at different locations in the structure
M_{P}	Total modal mass of the primary system
$M_{\mathrm{p}i}$	Modal mass of primary structure for mode i
M_{S}	Total mass of secondary system
$MSIL$	Maintenance specific imposed load
n	Number of levels of lumped weight or floors of the structure
n_{m}	Number of modes
R	Elastic force reduction factor
R_1	Elastic force reduction factor of structure 1 or unit 1 of the same structure
R_2	Elastic force reduction factor of structure 2 or unit 2 of the same structure
r	Mean radius of structural shell
r_{e}	Radius of gyration of the structural shell at the base section
S_{E}	In-structure response spectrum considering every evaluated mode of the structure
$S_{\mathrm{E}i}$	The absolute maximum value of acceleration response of the secondary system under ith mode acceleration of the primary structure
$SIDL$	Super imposed dead loads
$S(T_{\mathrm{p}i}\xi_{\mathrm{p}i})$	The design ground spectral value corresponding to $T_{\mathrm{p}i}, \xi_{\mathrm{p}i}$ of the primary structure
$S(T_{\mathrm{s}}\xi_{\mathrm{s}})$	The design ground spectral value corresponding to $T_{\mathrm{s}}, \xi_{\mathrm{s}}$ of the secondary system
T	Undamped natural period of oscillation of the structure
$T_{\mathrm{p}i}$	Natural period of the primary structure
T_{s}	Natural period of the secondary system
t	Thickness of structural shell
$\{U_{\mathrm{b}}\}$	Influence vector (displacement vector) of the structural system

$V_{\mathrm{BD,B}}$	Design seismic base shear for bare frame model
$V_{\mathrm{BD,H}}$	Design horizontal base shear force along any principal horizontal direction of a structure
$V_{\mathrm{BD,I}}$	Design seismic base shear for infilled frame model
$V_{\mathrm{BD,V}}$	Design vertical base shear force along vertical direction of a structure
$V_{\mathrm{BD,x,i}}$	Design horizontal base shear force of stack-like structure for the i^{th} mode
W	Seismic weight of the structure
W_{i}	Seismic weight of floor i; Weight at level i
W_{t}	Total weight of the structure including weight of lining and contents above the base
Z	Earthquake zone factor, which reflects the mean horizontal peak ground acceleration (PGA) corresponding to a return period T_{RP}(years) and the earthquake zone in which the structure lies
Γ_{j}	Participation factor for the jth mode
$\Delta f_{0.8}$	Total frequency range over spectral amplitudes that exceeds 80 percent of the peak spectral amplitude
Δ_{sep}	Separation between adjoining structures or adjoining units of the same structure
Δ_1	Storey lateral displacement of structure 1 or unit 1 of the same structure
Δ_2	Storey lateral displacement of structure 2 or unit 2 of the same structure
Λ_i	Modal mass ratio
Ω	Overstrength factor, reflecting the ratio of maximum lateral resistance offered by the structure and the design lateral force
βU_i	The ith mode excitation value of the floor on which the secondary system is installed
δ	Maximum value of deflection
δ_{i}	Lateral displacement at level i
δ_{x}, δ_{y}, δ_{z}	Maximum value of deflection in X, Y, Z direction respectively
$\eta_{max,\xi}$	Multiplying factor for estimating design horizontal and vertical PSA for other damping ratios
ξ	Damping ratio
$\xi_{\mathrm{p}i}$	Damping ratio of the primary structure
ξ_{s}	Damping ratio of the secondary system
φ_{ci}	Mode vector value from the primary system's modal displacement at the location where the secondary system is connected
φ_{j}	Shape of mode j

5 GENERAL PRINCIPLES AND OBJECTIVES

5.1 General Principles

The general principles covered under **5** of IS 1893 (Part 1) are applicable even to industrial structures. In addition, the following shall be applicable for industrial structures.

5.1.1 The design philosophy articulated in this standard calls for maintaining the structural integrity of all structures and components in the industrial facility, that is, forces and deformations in the structures and components shall remain within the limits specified in the relevant design standards. In addition, all structures, systems and components that are needed after an earthquake, such as electrical supply systems, communication towers, firefighting systems or other emergency systems shall be designed by limiting the forces and deformations specified in the relevant design standards.

5.1.2 For fulfilling the above objectives, structures, systems and components shall be designed based on **5.1.1**.

5.1.3 Equipment and other mechanical systems and machinery, which are supported at various floor levels of the industrial structure, will be subjected to different motions at their support points. In such cases, it may be necessary to obtain in-structure response spectra for analysis and design of equipment. For example, containers and vessels of hazardous or toxic materials with solids, liquids, or gases, shall be analyzed using applicable in-structure response spectra **9.7** shall be referred for generation of in-structure response spectra.

5.1.4 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.

5.2 Assumptions and Considerations

Assumptions under **5.9** of IS 1893 (Part 1) are applicable even to industrial structures. In addition, maintenance specific imposed loads ($MSIL$) as defined in **3.6** shall be considered only when the duration of maintenance loads is longer than 10 days. When the duration of maintenance loads is less than 10 days, $MSIL$ need not be combined with earthquake forces but shall be separately considered as a super imposed load in the structural design.

5.3 Categorization of Structures

For the purposes of seismic design, structures and components at an industrial facility are divided into four categories.

a) *Special Structures* (*Category* 1)

   i) Structures, whose failure (including failure due to hazard of fire, explosion or air and water poisoning) can cause conditions that can lead directly or indirectly to loss of life to population at large in the areas adjacent to the industrial facility, or

- ii) Structures that support components and equipment whose failure can cause conditions that can lead directly or indirectly to loss of life to population at large in the areas adjacent to the industrial facility, or

- iii) Structures housing contents such toxic materials, combustible materials or materials of explosive nature whose release may cause loss of life to occupants of the plant and/or population in areas adjacent to the industrial facility.

b) *Critical Structures* (*Category* 2)

- i) Structures not falling in Category 1, whose failure can cause conditions that can lead directly or indirectly to extensive damage (including due to consequent fire hazards) within the industrial facility, or

- ii) Structures in industrial facilities, which are required to handle emergencies immediately after an earthquake, such as hospitals, communication facilities, fire stations and designated emergency response centers etc. are also included under this category, or

- iii) Structures that support components and equipment that do not fall in Category 1 and whose failure can cause conditions that can lead directly or indirectly to extensive damage (including due to consequent fire hazards) within the industrial facility, or

- iv) Structures housing contents such toxic materials, combustible materials or materials of explosive nature whose release may cause extensive damage to the plant and/or areas adjacent to the industrial facility.

c) *Important Structures* (*Category* 3)

- i) High monetary value structures or structures housing expensive plant, machinery or equipment, and not falling in Categories 1 and 2, or

- ii) Structures that support high monetary value components and equipment that do not fall in Categories 1 and 2.

d) *Normal Structures* (*Category* 4)

All other structures, components and equipment not included in Categories 1, 2 and 3.

5.3.1 The term failure used in the definition of categories implies loss of function and these structures, components and equipment may not experience complete collapse.

5.3.2 Pressurized equipment where cracking can lead to rupture may be categorized based on the severity of consequences of rupture.

5.3.3 Mixed use of structures where components of more than one category are present, the entire structure shall comply with the requirement of the most stringent category.

6 EARTHQUAKE HAZARD

6.1 The earthquake ground shaking expected at a site and to be used in the design of industrial structures is described in terms of the design response spectra specified in **6.2** of IS 1893 (Part 1).

6.2 The earthquake zone factor (Z) to be used for the four categories of industrial structures (identified in **5.3**), shall be based on the corresponding return period T_{RP} (years) specified in Table 1 of IS 1893 (Part 1).

6.3 The earthquake zone factor (Z), which reflects the horizontal peak ground acceleration (PGA) and which is normalized with acceleration due to gravity corresponding to different return period T_{RP} (years) in each earthquake zone shall be as per Table 2 of IS 1893 (Part 1).

6.4 The site class used to characterize the type and properties of soils at a given site shall be as per **6.2.4.1** of IS 1893 (Part 1).

6.5 The elastic maximum horizontal PSA and the elastic maximum vertical PSA corresponding to the chosen damping ratio shall be estimated as per **6.2.4.4** of IS 1893 (Part 1).

6.6 Site-specific probabilistic seismic hazard assessment shall be carried out based on the requirements specified in **6.3** of IS 1893 (Part 1).

6.7 The importance factor (I) to be used in the estimation of design acceleration coefficient of different categories of industrial structures shall be taken as specified in Table 2.

7 DESIGN ACCELERATION COEFFICIENT

7.1 The design horizontal acceleration coefficient $A_{\text{HD}}(T)$ along any principal plan direction of an industrial structure and the design vertical acceleration coefficient $A_{\text{VD}}(T)$ shall be estimated as:

$$A_{\text{HD}}(T) = \frac{A_{\text{H}}(T)}{R}, \text{ and}$$

$$A_{\text{VD}}(T)=A_{\text{V}}(T)$$

where

$A_{\text{H}}(T)$ = Elastic maximum horizontal PSA corresponding to the fundamental natural period T in the horizontal translational mode [as per **6.2.4.4** or **6.3.1** of IS 1893 (Part 1)];

$A_{\mathrm{V}}(T)$ = Elastic maximum vertical PSA corresponding to the fundamental natural period T in the vertical mode [as per **6.2.4.4** or **6.3.1** of IS 1893 (Part 1)];

R = Elastic force reduction factor as per Table 3; and

T = Natural period of the industrial structure (*see* **11.1** and **14**).

SECTION 1 INDUSTRIAL STRUCTURES

8 DESIGN APPROACH

8.1 General

8.1.1 To perform well in an earthquake, industrial structures shall possess adequate strength, stiffness, redundancy and ductility.

8.1.2 For appropriate application of this standard, industrial structures and equipment are classified into the four categories as identified in **5.3**. For facilities not covered in **5.3**, the owner, statutory authority and project process engineers shall be consulted as applicable to determine the assignment of risk categories for industrial structures for the purpose of applying seismic provisions as per this standard.

8.1.3 Typical categorization of industrial structures is given in Table 6, Table 7 and Table 8. These are applicable for design of equipment, as well as its supporting structure and their foundation.

8.1.4 For structures and equipment not included in Table 6, Table 7 and Table 8, the category shall be selected by the designer based on the risk categories defined in **5.3**.

8.1.5 For design of supporting structures and foundations which are not covered in Table 6, Table 7 and Table 8, the category shall be selected same as that of the supported equipment or vessel or piping.

8.1.6 For structures identified in Table 6, Table 7 and Table 8 housing contents such as toxic materials, combustible materials or materials of explosive nature whose release may cause extensive loss of life to occupants of the plant and/or population in areas adjacent to the industrial facility shall be assigned as Category 1.

8.1.7 For structures identified in Table 6, Table 7 and Table 8 housing contents such as toxic materials, combustible materials or materials of explosive nature whose release may cause extensive damage to the plant and/or areas adjacent to the industrial facility shall be assigned as Category 2.

8.2 Design Loads

Industrial facilities typically have design loads that are unique to the structure or the type of equipment. In addition to the loads specified in this section, other applicable loads including, but not limited to, hydrostatic, dynamic, earth pressure, vehicle, buoyancy and erection shall be considered as appropriate. Any other loads anticipated in future and specified by the owner shall also be considered. The design of industrial structures and components shall account for the effects of all loads, including those defined below:

8.2.1 *Dead Load* (*DL*)

The dead loads shall be taken as per IS 875 (Part 1).

8.2.2 *Super Imposed Dead Loads* (*SIDL*)

Industrial structures contain equipment and associated fluids, bulk materials, auxiliaries and accessories, which are mounted permanently on the structures. These loads shall be taken in accordance with equipment specifications.

8.2.2.1 $SIDL$ may be provisional, that is, during service, some of $SIDL$ (or at some locations) may be smaller or negligible. Such variations shall be accounted in the design of individual members.

8.2.2.2 Equipment supported on a structure can have multiple operational scenarios such as empty, partially full and full. These operational scenarios may result in mass irregularities that shall be duly accounted for. In case of multiple equipment supported on a structure, various possible combinations of operational conditions shall be considered.

8.2.3 *Imposed Loads* (*IL*)

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

8.2.4 *Maintenance Specific Imposed Loads* (*MSIL*)

Areas specified for maintenance shall be designed to support the imposed loads taken as per **3.6**.

8.2.5 *Earthquake Loads* (EE_{D})

Earthquake force estimation, analysis, and design for various categories of structures shall comply with Table 1.

8.2.5.1 For Category 1 structures, specialist literature shall be referred for nonlinear response history analysis for verification of mechanism, wherever required. Refer **7.6.2.2**(b) of IS 1893 (Part 1) for additional details related to response history method.

8.2.6 *Other Loads*

Loads and load effects due to temperature changes, soil and hydrostatic pressures, accidental loads, differential settlement, etc. shall also be considered appropriately in the design of industrial structures.

In addition, any operating loads specified from process requirements shall also be considered as appropriate.

Table 1 Earthquake Force Estimation, Method of Analysis and Design for Various Categories of Structures
(*Clause* 8.2.5)

Sl No.	**Structure Category** (see 5.3)	**Earthquake Force Estimation**			**Method of**		**Minimum Lateral Force (Percent of Seismic Weight W) for different Zones**				
		Seismic Hazard Assessment Method	Damping Ratio	Method of Calculating Natural Period	Structural Analysis Method	Structural Design	II	III	IV	V	VI
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
i)	1	Site specific assessment as per **6.6** or assessment as specified in **6.1**.	5 percent for RC structures and 2 percent for steel structures (*See* **9.4, 15** and Table 4)	(*See* **11.1**, **14.1** and **14.2**) Modal analysis with all stiffnesses of the lateral as well as vertical load resisting members and masses of the structures modeled (For preliminary natural period estimation, *See* **11.1**)	a) Linear for design, and b) Nonlinear Response History Analysis for verification of mechanism (*see* **8.2.5.1**)	Limit state design as per IS 456 & IS 13920 (Part 2/Section 3) for RC structures and as per IS 800 and IS 13920 (Part 2/Section 4) for steel structures	2.5	4.5	5.5	8.0	12.0
ii)	2				Linear for Design		2.0	3.5	4.5	6.5	10.0
iii)	3						1. 5	2.5	3.5	5.0	7.5
iv)	4						1.5	2.0	3.0	4.5	6.5

8.3 Load Combinations

When earthquake loads are considered on a structure, the response quantities (namely member forces, displacements, storey forces, shears and base reactions) due to dead load (DL), imposed load (IL), super imposed dead loads ($SIDL$), maintenance specific imposed loads ($MSIL$), and design earthquake load (EE_{D}) shall be combined as per **8.3.1**. In addition, operating loads provided from process requirements shall also be considered appropriately in the earthquake load combinations.

8.3.1 *Basic Combinations*

8.3.1.1 In the Limit State Design of structural elements, the following combinations shall be considered to estimate the earthquake effects:

a) $1.2(DL + SIDL + IL + MSIL) \pm EE_{\mathrm{D}}$,
b) $1.5(DL + SIDL) \pm EE_{\mathrm{D}}$,
c) $0.9(DL + SIDL) \pm EE_{\mathrm{D}}$, and
d) $1.0(DL + SIDL + IL) \pm \Omega EE_{\mathrm{D}}$ (only for shear design of vertical members and design of connections),

where,

DL = Dead load as specified in **8.2.1**,
$SIDL$ = Super imposed dead load as specified in **8.2.2**,
IL = Imposed load as specified in **8.2.3** and IL shall not include erection loads and crane payload,
$MSIL$ = Maintenance specific imposed load as specified in **5.2**,
EE_{D} = Effect of design earthquake forces to be considered for strength design [as specified in **7.4.2 (1)** of IS 1893 (Part 1)] applied on the structure, and
Ω = Overstrength factor as specified in **7.1.7** and **8.1.6** of IS 1893 (Part 5).

Also, all connections in the structure shall be ensured to have the capacity to transfer forces induced under load combination (d) above.

8.3.1.2 In checking the shear stress, bearing pressure demands on soil and pile capacities (using Working Stress Method), the following load combinations shall be considered to estimate the earthquake effects on soils and piles:

a) $1.1(DL + SIDL + IL + MSIL) \pm EE_{\mathrm{D}}$,
b) $1.1(DL + SIDL) \pm EE_{\mathrm{D}}$, and
c) $0.7(DL + SIDL) \pm EE_{\mathrm{D}}$.

Increase in the net allowable bearing pressure on soils and pile capacities for the above load combinations is not permitted.

8.3.2 In industrial structures, the plan-wise distribution of mass and stiffness of the structural system may or may not be symmetrical along two mutually orthogonal horizontal directions in plan (that is, X and Y directions). When earthquake ground shaking is considered to act simultaneously along multiple directions, the same response quantity (say, bending moment in a column about its major axis, or storey shear in a frame) due to different components of the ground motion shall be combined as per **8.3.2.1** and **8.3.2.2**.

8.3.2.1 Where the plan-wise distribution of mass and stiffness of the industrial structural system is not symmetrical along two mutually orthogonal horizontal directions in plan (that is, X and Y directions), effects of earthquake ground shaking along three mutually orthogonal directions (that is, two plan directions and vertical direction) shall be considered in the design of industrial structures. In such cases, the responses due to each component shall be combined using the assumption that when the maximum response from one component occurs, the responses from the other two components are 30 percent each of their maximum.

All possible combinations of the three components (EL_{DX}, EL_{DY}, EL_{DZ}) including variations in sign (plus or minus) shall be considered. Thus, the load combinations specified in **8.3.1** shall be replaced with:

8.3.2.1.1 *For strength design of structural elements*:

a) $1.2(DL + SIDL + IL + MSIL) \pm (EL_{\mathrm{DX}} \pm 0.3\, EL_{\mathrm{DY}} \pm 0.3\, EL_{\mathrm{DZ}})$,
b) $1.2(DL + SIDL + IL + MSIL) \pm (0.3\, EL_{\mathrm{DX}} \pm EL_{\mathrm{DY}} \pm 0.3\, EL_{\mathrm{DZ}})$,
c) $1.2(DL + SIDL + IL + MSIL) \pm (0.3\, EL_{\mathrm{DX}} \pm 0.3\, EL_{\mathrm{DY}} \pm EL_{\mathrm{DZ}})$,
d) $1.5(DL + SIDL) \pm (EL_{\mathrm{DX}} \pm 0.3\, EL_{\mathrm{DY}} \pm 0.3\, EL_{\mathrm{DZ}})$,
e) $1.5(DL + SIDL) \pm (0.3\, EL_{\mathrm{DX}} \pm EL_{\mathrm{DY}} \pm 0.3\, EL_{\mathrm{DZ}})$,
f) $1.5(DL + SIDL) \pm (0.3\, EL_{\mathrm{DX}} \pm 0.3\, EL_{\mathrm{DY}} \pm EL_{\mathrm{DZ}})$,
g) $0.9(DL + SIDL) \pm (EL_{\mathrm{DX}} \pm 0.3\, EL_{\mathrm{DY}} \pm 0.3\, EL_{\mathrm{DZ}})$,
h) $0.9(DL + SIDL) \pm (0.3\, EL_{\mathrm{DX}} \pm EL_{\mathrm{DY}} \pm 0.3\, EL_{\mathrm{DZ}})$,
j) $0.9(DL + SIDL) \pm (0.3\, EL_{\mathrm{DX}} \pm 0.3\, EL_{\mathrm{DY}} \pm EL_{\mathrm{DZ}})$,
k) $1.0(DL + SIDL + IL) \pm \Omega(EL_{\mathrm{DX}} \pm 0.3\, EL_{\mathrm{DY}} \pm 0.3\, EL_{\mathrm{DZ}})$
(only for shear design of vertical members and design of connections),
m) $1.0(DL + SIDL + IL) \pm \Omega(0.3\, EL_{\mathrm{DX}} \pm EL_{\mathrm{DY}} \pm 0.3\, EL_{\mathrm{DZ}})$
(only for shear design of vertical members and design of connections), and
p) $1.0(DL + SIDL + IL) \pm \Omega(0.3\, EL_{\mathrm{DX}} \pm 0.3\, EL_{\mathrm{DY}} \pm EL_{\mathrm{DZ}})$
(only for shear design of vertical members and design of connections).

8.3.2.1.2 *For soil-bearing pressure and pile capacity check*:

a) $1.1(DL + SIDL + IL + MSIL) \pm (EL_{\mathrm{DX}} \pm 0.3\, EL_{\mathrm{DY}} \pm 0.3\, EL_{\mathrm{DZ}})$,
b) $1.1(DL + SIDL + IL + MSIL) \pm (0.3\, EL_{\mathrm{DX}} \pm EL_{\mathrm{DY}} \pm 0.3\, EL_{\mathrm{DZ}})$,
c) $1.1(DL + SIDL + IL + MSIL) \pm (0.3\, EL_{\mathrm{DX}} \pm 0.3\, EL_{\mathrm{DY}} \pm EL_{\mathrm{DZ}})$,
d) $1.1(DL + SIDL) \pm (EL_{\mathrm{DX}} \pm 0.3\, EL_{\mathrm{DY}} \pm 0.3\, EL_{\mathrm{DZ}})$,
e) $1.1(DL + SIDL) \pm (0.3\, EL_{\mathrm{DX}} \pm EL_{\mathrm{DY}} \pm 0.3\, EL_{\mathrm{DZ}})$,
f) $1.1(DL + SIDL) \pm (0.3\, EL_{\mathrm{DX}} \pm 0.3\, EL_{\mathrm{DY}} \pm EL_{\mathrm{DZ}})$,
g) $0.7(DL + SIDL) \pm (EL_{\mathrm{DX}} \pm 0.3\, EL_{\mathrm{DY}} \pm 0.3\, EL_{\mathrm{DZ}})$,
h) $0.7(DL + SIDL) \pm (0.3\, EL_{\mathrm{DX}} \pm EL_{\mathrm{DY}} \pm 0.3\, EL_{\mathrm{DZ}})$, and
j) $0.7(DL + SIDL) \pm (0.3\, EL_{\mathrm{DX}} \pm 0.3\, EL_{\mathrm{DY}} \pm EL_{\mathrm{DZ}})$,

8.3.2.2 Where the plan-wise distribution of mass and stiffness of the industrial structural system is symmetrical along two mutually orthogonal horizontal directions in plan (that is, X and Y directions), effects of two-dimensional earthquake ground shaking [that is, one plan direction and vertical direction (Z)] shall be considered in the design of industrial structures. In such cases, responses due to each component shall be combined using the assumption that when the maximum response from one component occurs, the response from the other component is 30 percent.

All possible combinations including variations in sign (plus or minus) shall be considered. Thus, the load combinations specified in **8.3.1** shall be replaced with:

8.3.2.2.1 *For strength design of structural elements*:

a) $1.2(DL + SIDL + IL + MSIL) \pm (EL_{\mathrm{DX}} \pm 0.3\ EL_{\mathrm{DZ}})$,
b) $1.2(DL + SIDL + IL + MSIL) \pm (0.3\ EL_{\mathrm{DX}} \pm EL_{\mathrm{DZ}})$,
c) $1.2(DL + SIDL + IL + MSIL) \pm (EL_{\mathrm{DY}} \pm 0.3\ EL_{\mathrm{DZ}})$,
d) $1.2(DL + SIDL + IL + MSIL) \pm (0.3\ EL_{\mathrm{DY}} \pm EL_{\mathrm{DZ}})$,
e) $1.5(DL + SIDL) \pm (EL_{\mathrm{DX}} \pm 0.3\ EL_{\mathrm{DZ}})$,
f) $1.5(DL + SIDL) \pm (0.3\ EL_{\mathrm{DX}} \pm EL_{\mathrm{DZ}})$,
g) $1.5(DL + SIDL) \pm (EL_{\mathrm{DY}} \pm 0.3\ EL_{\mathrm{DZ}})$,
h) $1.5(DL + SIDL) \pm (0.3\ EL_{\mathrm{DY}} \pm EL_{\mathrm{DZ}})$,
j) $0.9(DL + SIDL) \pm (EL_{\mathrm{DX}} \pm 0.3\ EL_{\mathrm{DZ}})$,
k) $0.9(DL + SIDL) \pm (0.3\ EL_{\mathrm{DX}} \pm EL_{\mathrm{DZ}})$,
m) $0.9(DL + SIDL) \pm (EL_{\mathrm{DY}} \pm 0.3\ EL_{\mathrm{DZ}})$,
n) $0.9(DL + SIDL) \pm (0.3\ EL_{\mathrm{DY}} \pm EL_{\mathrm{DZ}})$,
p) $1.0(DL + SIDL + IL) \pm \Omega(EL_{\mathrm{DX}} \pm 0.3\ EL_{\mathrm{DZ}})$
(only for shear design of vertical members and design of connections),
q) $1.0(DL + SIDL + IL) \pm \Omega(0.3\ EL_{\mathrm{DX}} \pm EL_{\mathrm{DZ}})$
(only for shear design of vertical members and design of connections),
r) $1.0(DL + SIDL + IL) \pm \Omega(EL_{\mathrm{DY}} \pm 0.3\ EL_{\mathrm{DZ}})$
(only for shear design of vertical members and design of connections), and
s) $1.0(DL + SIDL + IL) \pm \Omega(0.3\ EL_{\mathrm{DY}} \pm EL_{\mathrm{DZ}})$
(only for shear design of vertical members and design of connections).

8.3.2.2.2 *For soil-bearing pressure and pile capacity check*:

a) $1.1(DL + SIDL + IL + MSIL) \pm (EL_{\mathrm{DX}} \pm 0.3\ EL_{\mathrm{DZ}})$,
b) $1.1(DL + SIDL + IL + MSIL) \pm (0.3\ EL_{\mathrm{DX}} \pm EL_{\mathrm{DZ}})$,
c) $1.1(DL + SIDL + IL + MSIL) \pm (EL_{\mathrm{DY}} \pm 0.3\ EL_{\mathrm{DZ}})$,
d) $1.1(DL + SIDL + IL + MSIL) \pm (0.3\ EL_{\mathrm{DY}} \pm EL_{\mathrm{DZ}})$,
e) $1.1(DL + SIDL) \pm (EL_{\mathrm{DX}} \pm 0.3\ EL_{\mathrm{DZ}})$,
f) $1.1(DL + SIDL) \pm (0.3\ EL_{\mathrm{DX}} \pm EL_{\mathrm{DZ}})$,
g) $1.1(DL + SIDL) \pm (EL_{\mathrm{DY}} \pm 0.3\ EL_{\mathrm{DZ}})$,
h) $1.1(DL + SIDL) \pm (0.3\ EL_{\mathrm{DY}} \pm EL_{\mathrm{DZ}})$,
j) $0.7(DL + SIDL) \pm (EL_{\mathrm{DX}} \pm 0.3\ EL_{\mathrm{DZ}})$,
k) $0.7(DL + SIDL) \pm (0.3\ EL_{\mathrm{DX}} \pm EL_{\mathrm{DZ}})$,
m) $0.7(DL + SIDL) \pm (EL_{\mathrm{DY}} \pm 0.3\ EL_{\mathrm{DZ}})$, and
n) $0.7(DL + SIDL) \pm (0.3\ EL_{\mathrm{DY}} \pm EL_{\mathrm{DZ}})$.

8.3.3 Other loads in accordance with **8.2.6** shall be combined as per IS 875 (Part 5).

8.4 Seismic Weight

8.4.1 *Seismic Weight of Floor*

Seismic weight of each floor shall be taken as the sum of its full dead load (DL), superimposed dead load ($SIDL$), appropriate amount of imposed load (IL) as specified in Table 6 of IS 1893 (Part 5) and applicable maintenance specific imposed loads ($MSIL$) as per **5.2**. Weight of piping, electrical cable trays, any other such utility that runs across the floors shall be included in the seismic weight of upper and lower supporting floors using law of statics. The seismic weight shall be converted into seismic mass and used in the analysis of the structure.

Further,

a) While computing the seismic weight of each floor, the weight of elements in any storey shall be appropriately apportioned to the floors above and below the storey. Any other weight supported in between storeys shall be distributed to floors above and below in inverse proportion to its distance from the floors.

b) In calculating the design earthquake forces of industrial structures, imposed load need not be considered on roofs.

c) In the estimation of seismic weight, the reduction allowed in imposed load as per Table 6 of IS 1893 (Part 5) alone shall be admissible, and not that allowed by IS 875 (Part 2).

8.4.2 *Seismic Weight of Structure*

Seismic weight of structure is the sum of seismic weight of each floor.

8.5 Importance Factor (I)

In estimating design horizontal and vertical elastic PSA of industrial structures as per **6.2.4.4** or **6.3.1** of IS 1893 (Part 1), the importance factor I of industrial structures shall be taken as per Table 2. Further, higher importance factor may be assigned to different structures at the discretion of the owner and/or project authorities.

Table 2 Importance Factor *I* for Various Categories of Industrial Structures and Stack-Like Structures

(*Clauses* 6.7, 8.5, 12.2.1 *and* 12.2.2)

Sl No.	*Categories of Structures	Importance Factor I
(1)	(2)	(3)
i)	*Special Structures* (Category 1)	1.0
ii)	*Critical Structures* (Category 2)	1.0
iii)	*Important Structures* (Category 3)	1.0
iv)	*Normal Structures* (Category 4)	1.0

*Categorization of individual structure and components applicable to typical industries are given in Tables 6, 7 and 8.

8.6 Elastic Force Reduction Factor (R)

Elastic force reduction factor (R) reflects ductile inelastic actions in desirable and predetermined locations in structural systems and accounts for inherent system ductility, redundancy and overstrength available in structures. For industrial structures including stack-like structures, elastic force reduction factors are given in Table 3. These factors shall be used only for steel and RCC structures/ support structures and not for design of equipment.

8.6.1 For capacity checks of equipment, R value of 1 shall be used.

8.6.2 Structures or equipment not defined in Table 3, shall have the R value based on the strength, safety, redundancy and ductility requirement keeping its usage/earthquake damage level in consideration.

8.6.3 For the purpose of deciding the elastic force reduction factor (R), silos are classified as follows:

Slender silo : Height/Inner Diameter ≥ 1.0
Squat silo : 0.4 < Height/Inner Diameter < 1.0
Thick-walled silo : Inner Diameter/Wall Thickness ≤ 200
Thin-walled silo : Inner Diameter/Wall Thickness > 200

For silos supported on moment resisting frames or on frames with bracings, and for cast-in-place concrete silos supported on concrete walls continuous to the foundation, R values defined for the corresponding structural system times a factor equal to 0.7 shall be considered.

Table 3 Elastic Force Reduction Factor, R for Industrial Structures and Stack Like Structures

(*Clauses* 7 *and* 8.6)

Sl No. (1)	**Lateral Force Resisting System** (2)	***R*** (3)
i)	For buildings with different structural systems: R shall be as per Table 4 of IS 1893 (Part 2)	
ii)	Structures designed to remain elastic	1.0
iii)	Elevated frame foundations supporting equipment	3.0
iv)	Stack like Structures	
	a) Reinforced concrete ventilation stacks	2.0
	b) Reinforced concrete chimneys	2.0
	c) Reinforced brick masonry chimney	1.25
	d) Unreinforced brick masonry chimney	1.0
	e) Reinforced concrete TV towers	2.0
	f) Reinforced electric and traffic poles	2.0
	g) Steel chimneys and HRSG steel stack	2.0
	h) Slender and thin-walled silos	2.0
	j) Squat and thin-walled silos	2.0
	k) Squat and thick-walled silos	3.0
	m) Steel refinery vessels	2.0
	n) Steel tubular support structures for onshore wind turbine generator systems	1.5
	o) Natural draught cooling tower	1.5

9 MODELLING OF STRUCTURES

9.1 General Requirements

The mathematical model of the physical structure shall include all elements of the lateral force-resisting system. Also, the model shall include the stiffness and strength of elements, which are required for the distribution of forces and deformations in the structure. The model shall represent properly the spatial distribution of mass and stiffness throughout the structure, especially the mass of equipment, cable trays and piping systems and the associated accessories. Further, fifty percent (50 percent) of the imposed load shall also be included, besides $SIDL$ and $MSIL$, as suitably distributed mass on the structure.

The mathematical model shall be capable of adequately resolving the frequency range of interest and calculating the significant features of its dynamic response. The frequency range of interest shall be identified, where frequencies of interest are those that contribute to the response of the primary and/or secondary systems.

9.2 Modelling of Stiffness

The deformation of structures under the design load combinations specified in **8.3.1** and **8.3.2** shall be obtained by structural analysis using a structural model with section properties given in Table 2 of IS 1893 (Part 5).

9.3 Modelling of Mass

The mass included in the model used for dynamic analysis shall include all mass expected to be present at the time of the earthquake and shall not include added conservatism. The inertial mass properties of a structure may be modelled by assuming that the structural mass and associated rotational inertia are discretized and lumped at node points of the model. Alternatively, the consistent mass formulation may also be used.

9.4 Modelling of Damping

Damping ratios listed in Table 4 shall be used for structures composed of the same material. The value of damping ratio ξ for the purposes of estimating design horizontal and vertical PSA of industrial structures for damping other than 5 percent of critical shall be obtained by using the multiplying factor as given below.

$$\eta_{max,\xi} = \begin{cases} 3.2 & \xi = 0 \\ 3.2 - 2.68(\xi) & 0 < \xi < 0.5\% \\ \left(\dfrac{7}{2+\xi}\right)^{0.6} & 0.5\% < \xi < 5\% \\ \left(\dfrac{10}{5+\xi}\right)^{0.5} & 5\% < \xi < 30\% \end{cases}$$

For natural period $T \leq 0.01$, the multiplying factor shall be 1. For $0.01 < T \leq 0.1$, the factor shall be linearly interpolated between 1 and the factor given in the Table 5. For $T > 0.1$, the factor shall be same as specified in the Table 5. For values of $\eta_{max,\xi}$ corresponding to values of damping between 0 and 0.5 percent, linear interpolation may be adopted.

The entire frequency range of interest that contribute to the response of the primary and/or secondary systems shall be considered when selecting the damping ratio.

9.4.1 For combined structures with more than one material, damping ratio shall be determined based on well established procedures.

9.4.2 If such a composite damping ratio is not evaluated, it shall be taken as that corresponding to material having lower damping.

9.4.3 When soil-structure interaction effects are considered, the composite modal damping values shall be estimated. The estimated composite modal damping values shall be limited to 20 percent of critical damping.

9.4.4 The damping ratio of water and other liquids contained in tanks shall be considered as 0.5 percent unless otherwise determined. For other liquids in sloshing mode, specialist literature shall be referred for damping ratio.

9.4.5 The damping ratio of granular materials contained in tanks and silos shall be considered as 10 percent.

9.4.6 For equipment, storage tanks, onshore wind turbine generator system and piping system, reference may be made to specialist literature for damping ratio.

Table 4 Damping Ratio for Different Construction Materials
(*Clauses* 9.4 *and* 15)

Sl No. (1)	**Material** (2)	**Damping Ratio** (3)
i)	Aluminum	0.02
ii)	Steel	0.02
iii)	Reinforced concrete	0.05
iv)	Brick masonry and plain concrete	0.07
v)	Pre-stressed concrete	0.03

$$\eta_{max,\xi} = \begin{cases} 3.2 & \xi = 0 \\ 3.2 - 2.68(\xi) & 0 < \xi < 0.5\% \\ \left(\dfrac{7}{2+\xi}\right)^{0.6} & 0.5\% < \xi < 5\% \\ \left(\dfrac{10}{5+\xi}\right)^{0.5} & 5\% < \xi < 30\% \end{cases}$$

9.5 Soil-Structure Interaction (SSI)

The soil-structure interaction refers to two effects of the supporting soil-foundation system on the response of superstructure, namely flexibility of the soil strata underneath and inertia forces of the mass of the soil-foundation system. Methodologies for considering SSI effects are presented in **7.7** of IS 1893 (Part 1).

Specialist literature may also be referred to include SSI and pile-soil-structure interaction effects. However, maximum reduction in the base shear on account of soil-structure interaction as well as pile-soil-structure interaction shall not be more than 20 percent of base shear obtained from a fixed-base analysis.

The soil-structure interaction shall not be considered in the seismic analysis of structures founded on competent material (stiff soil or rock) having soil site Class A or Class B as per Table 5 of IS 1893 (Part 1).

9.6 Interaction Effects between Primary and Secondary Systems

The design seismic forces on the structure (primary system) and equipment (secondary system) falling under Categories 2, 3 and 4 shall be considered as per **9.6.1** and **9.6.2**. For primary and secondary systems falling under Category 1, the design seismic forces shall be estimated as per **9.6.3**.

9.6.1 For estimation of design seismic forces in primary systems, interaction effects between structure and equipment shall be considered as given below:

9.6.1.1 Wherever secondary system is rigidly supported or fastened to the floor of the primary system, the secondary system mass M_{S}, shall be considered as lumped mass at its support location appropriately. No interaction between the primary and secondary systems need to be considered.

9.6.1.2 For flexibly mounted secondary system with mass, M_{FS}, that is, equipment mounted on *isolators*, one of the following two procedures shall be adopted:

a) If $\frac{M_{\mathrm{FS}}}{M_{\mathrm{P}}+M_{\mathrm{S}}} < 0.20$, no interaction needs to be considered between the primary and secondary systems. In such a case, M_F shall be considered as lumped mass at appropriate locations.

b) If $\frac{M_{\mathrm{FS}}}{M_{\mathrm{P}}+M_{\mathrm{S}}} \geq 0.20$, the interaction between the primary and secondary systems shall be considered by suitably modelling the flexibly mounted support system while considering the equipment as lumped mass (coupled analysis).

9.6.2 For estimation of design seismic forces in secondary systems falling under Categories 2, 3 and 4, one of the following two procedures shall be adopted:

a) Decoupling criteria as given in **9.6.4** shall be used for the interaction effects.

b) Specialist literature on design on secondary system shall be referred.

9.6.3 For Category 1 structures**,** the design seismic forces shall be estimated considering the decoupling criteria as given in **9.6.4** for the interaction effects between primary system (structure) and secondary system (equipment).

9.6.4 *Decoupling Criteria*

9.6.4.1 Decoupling criteria given below shall be used for the interaction effects between primary system (structure) and secondary system (equipment).

9.6.4.2 Coupled analysis of a primary system and secondary system shall be performed when the effects of dynamic response interaction are significant based on **9.6.4.7** and **9.6.4.8**.

9.6.4.3 If a coupled analysis will not increase the response of key design parameters 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 **9.6.4.8** regarding the static constraint shall be considered.

9.6.4.4 In applying **9.6.4.7** and **9.6.4.8**, one subsystem at a time may be considered, unless the subsystems are essentially identical (uncoupled dominating frequencies within ± 10 percent) and located together, in which case the subsystem masses shall be lumped together.

9.6.4.5 When coupling is required, a detailed model of the secondary system is not required for global response of the primary system, 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 reanalyzed in appropriate detail using the output motions from the first analysis as input at the points of connectivity.

9.6.4.6 All combinations of the dominant secondary system modes and the dominant primary system modes shall be considered, and the most restrictive combination shall govern. The dominant frequency has a modal mass greater than 20 percent of the total system mass. The total system mass is defined by

$$[M] = \sum_{j=1}^{n_m} (\Gamma_\mathrm{j})^2$$

where

$\{M\}$ = Mass matrix of the structural system,

n_m = Number of modes,

$\{\varphi_\mathrm{j}\}$ = j th mode shape, where $\{\varphi_\mathrm{j}\}^T [M] \{\varphi_\mathrm{j}\}$ = 1,

Γ_j = Participation factor for the jth mode, and

$\{U_\mathrm{b}\}$ = Influence vector, displacement vector of the structural system when the base is displaced by unity in the direction of earthquake motion.

The participation factor Γ_j is

$$\Gamma_{\mathrm{j}} = \frac{\{\varphi_{\mathrm{j}}\}^{T}[M]\{U_{\mathrm{b}}\}}{\{\varphi_{\mathrm{j}}\}^{T}[M]\{\varphi_{\mathrm{j}}\}} = \{\varphi_{\mathrm{j}}\}^{T}[M]\{U_{\mathrm{b}}\}$$

9.6.4.7 To determine if coupled analyses are required owing to dynamic interaction, the criteria shown in Fig. 1 shall be used. These are applicable for secondary systems with a single-point attachment to the primary system. The mass ratio if Fig. 1 is the modal mass ratio computed as given below and the frequency ratio is the ratio of the dominant uncoupled modal frequencies of the secondary and primary systems.

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

$$\Lambda_{\mathrm{i}} \approx \frac{M_{\mathrm{s}}}{M_{\mathrm{pi}}}$$

where

$M_{\mathrm{p}i}$ = $(1/\varphi_{\mathrm{c}i})^2$,
φ_{ci} = Mode vector value from the primary system's modal displacement at the location where the secondary system is connected, from the ith normalized modal vector $\{\varphi_{\mathrm{pi}}\}$, $\{\varphi_{\mathrm{pi}}\}^{\mathrm{T}}[M_{\mathrm{p}}]\{\varphi_{\mathrm{p_i}}\}$ = 1,
$[M_{\mathrm{p}}]$ = Mass matrix of the primary system, and
M_{s} = Total mass of the secondary system.

9.6.4.8 For a subsystem supported to the primary system with multiple attachment points, the following are applicable:

a) The stiffness of a subsystem supported at two or more points may restrict movement of the primary system. In addition to mass and frequency ratio consideration, the relative stiffness of the subsystem to structure shall be investigated to determine when coupling is required. Coupling is required when the values of key design parameters from the coupled model are more than 10 percent higher than those from an uncoupled model.

b) A coupled analysis of the primary-secondary system shall be performed if the static constraints cause significant load redistribution in the primary system.

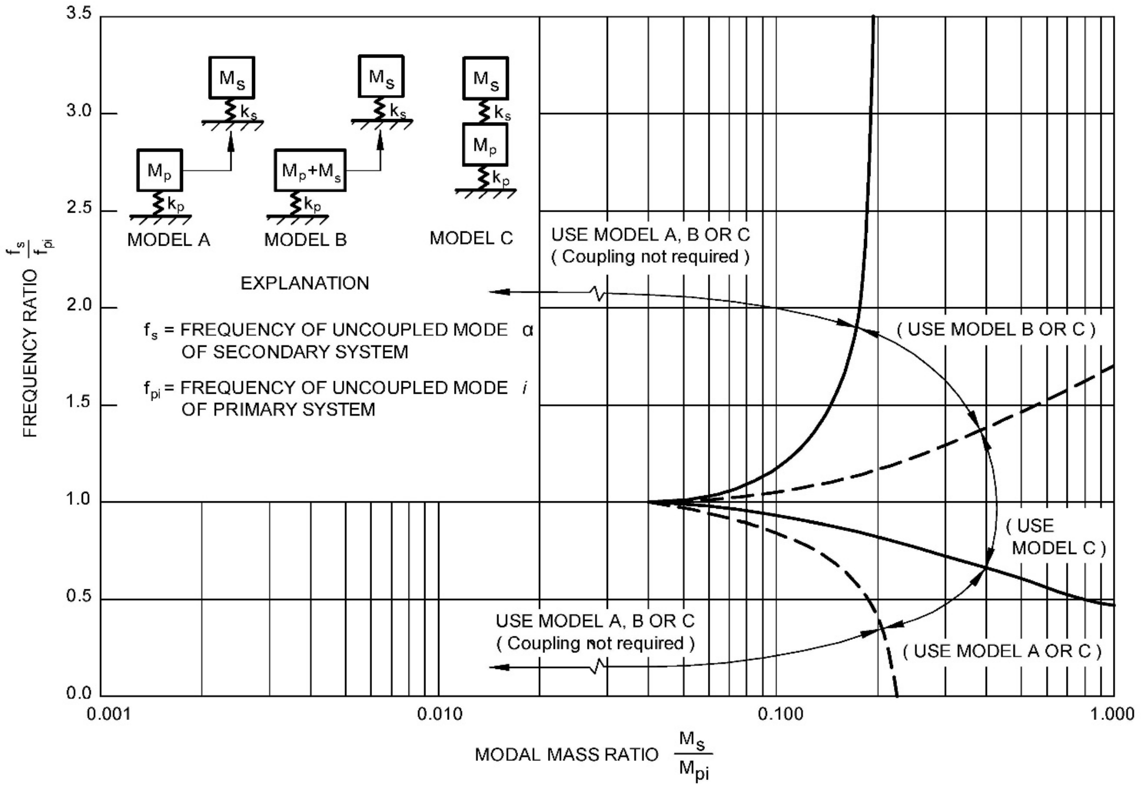

FIG. 1 DECOUPLING CRITERIA FOR SECONDARY SYSTEMS WITH SINGLE-POINT ATTACHMENT TO THE PRIMARY SYSTEM

9.7 In-Structure Response Spectra (ISRS)

ISRS is a decoupled analysis method, in which the primary and secondary systems are analyzed separately. ISRS for use in design of secondary systems (such as piping, HVAC and mechanical and equipment supports) shall be developed using the linear response history method from linear structural analysis or a direct spectra-to-spectra method within their established range of applicability.

9.7.1 *Response History Method*

a) The strong ground motions appropriate for use in response history method shall be representative of the project site and shall be compatible with the design ground acceleration spectrum. This shall be used as input for the primary structure.
b) A dynamic analysis for primary structure shall be conducted by using a step-by-step time integration.
c) The time-histories of responses at the floors (nodes) to which secondary systems are attached shall be obtained and used to generate ISRS at the specified location.
d) When the supporting structure is subjected to the simultaneous action of three statistically independent spatial components of input ground motions, the two horizontal components and one vertical component of the floor acceleration shall be used to compute the corresponding ISRS.

e) When the supporting structure is subjected individually to the action of the three statistically independent spatial components of input ground motion, the floor acceleration for each direction shall be obtained by the algebraic summation of the co-directional accelerations from the three individual analyses. The resulting floor accelerations shall be used to compute the corresponding ISRS.

9.7.2 *Direct Spectra-to-Spectra Method*

a) In this direct approach, ISRS is directly generated from a specified ground response spectrum, or design spectrum.
b) A modal analysis of the primary structure is performed to obtain the basic modal information of the structure, including modal frequencies, damping ratios, mode shapes and modal participation factors.
c) Response spectra of desired floors are obtained in terms of the modal information and the prescribed design ground response spectrum.
d) The ISRS may be obtained directly applying the following equations from the two standard design ground spectra which corresponds to the damping ratio $\xi_{\mathrm{p}i}$ of the primary structure and $\xi_{\mathrm{s}}$of the secondary system, using modal characteristics of the primary structure obtained from the modal analysis.

$$S_{\mathrm{E}} = \sqrt{\sum_{i}^{n} (\beta U_i S_{\mathrm{E}i})^2}$$

$$S_{\mathrm{E}i} = \frac{1}{\sqrt{\left\{1 - \left(T_{\mathrm{p}i}/T_{\mathrm{s}}\right)^2\right\}^2 + 4\left(\xi_{\mathrm{s}} + \xi_{\mathrm{p}i}\right)^2 \left(T_{\mathrm{p}i}/T_{\mathrm{s}}\right)^2}} \text{ x } \sqrt{\left\{\left(T_{\mathrm{p}i}/T_{\mathrm{s}}\right)^2 S\left(T_{\mathrm{p}i}\xi_{\mathrm{p}i}\right)\right\}^2 + S(T_{\mathrm{s}}\xi_{\mathrm{s}})^2}$$

where

S_{E} = In-structure response spectrum considering every evaluated mode of the structure,

βU_{i} = The ith mode excitation value of the floor on which the secondary system is installed,

S_{Ei} = The absolute maximum value of acceleration response of the secondary system under ith mode acceleration of the primary structure,

ξ_{s} = Damping ratio of the secondary system,

T_{s} = Natural period of the secondary system,

ξ_{pi} = Damping ratio of the primary structure,

T_{pi} = Natural period of the primary structure,

$S\left(T_{\mathrm{pi}}\xi_{\mathrm{pi}}\right)$ = The design ground spectral value corresponding to $T_{\mathrm{pi}}, \xi_{\mathrm{pi}}$ of the primary structure, and

$S(T_{\mathrm{s}}\xi_{\mathrm{s}})$ = The design ground spectral value corresponding to $T_{\mathrm{s}}, \xi_{\mathrm{s}}$ of the secondary system.

9.7.2.1 While applying the provisions of **9.7.2**, the mass M_s of the secondary system needs to be sufficiently smaller than the mass M_{pi} of the primary structure and the response of the primary structure will not be affected by the response of the secondary.

9.7.2.2 The ISRS obtained from the above method need to be broadened by at least ± 15 percent to account for the uncertainty in the modal analysis.

9.7.3 *Frequency Interval for Generation of ISRS*

a) When generating ISRS, the spectrum ordinates shall be computed at sufficiently small frequency intervals to produce response spectra to a maximum frequency of 50 Hz, including the fundamental frequencies of the supporting structure and predominant frequencies of input ground motions.
b) Additionally, a set of frequencies be selected such that each frequency is within 5 percent or less of the previous one.
c) The frequency interval may be increased in the frequency range above twice the dominant SSI frequency, or the cutoff frequency.

9.7.4 *Smoothing ISRS and Broadening Peaks*

9.7.4.1 To account for uncertainties in the structural frequencies, the computed ISRS shall be smoothed, and peaks associated with each of the structural frequencies be broadened as described below:
The minimum broadening shall be

a) ±15 percent at each frequency in the amplified response region for the best-estimate soil shear modulus case,
b) -15 percent at each frequency in the amplified frequency range for the lower bound soil case, and
c) +15 percent at each frequency in the amplified frequency range for the lower bound soil case.

The final ISRS shall envelop the peak broadened best-estimate, upper and lower bound soil cases.

9.7.4.2 In conjunction with the peak broadening, a 15 percent reduction in the narrow frequency peak amplitude is permissible if the subsystem damping is less than 10 percent. Narrow frequency peaks of the unbroadened response spectrum shall have a bandwidth-to-central frequency ratio less than 0.30:

$$\frac{\Delta f_{0.8}}{f_{\mathrm{c}}} < 0.30$$

where

$\Delta f_{0.8}$ = Total frequency range over spectral amplitude that exceed 80 percent of the peak spectral amplitude, and
f_{c} = Central frequency for the frequencies that exceed 80 percent of the peak amplitude.

10 SEISMIC ANALYSIS OF INDUSTRIAL STRUCTURES

10.1 General

Industrial structures shall be analyzed for estimating the effects of design earthquake shaking (namely the stress resultants and deformations) and combined with those of the other loads as specified in **8.3**.

10.2 Selection of Analysis Procedures

When performing seismic analysis of new industrial structures, effects of design earthquake loads applied on them can be assessed by the following methods of linear structural analysis:

a) *Simplified Linear Dynamic Analysis Method*, and
b) *Dynamic Analysis Method.*

The selection of analysis method shall be based as per Table 5.

Table 5 Methods of Linear Structural Analysis
(*Clause* 10.2)

Sl No. (1)	**Method** (2)	**Earthquake Zone** (3)	**Category of Structure** (4)
i)	Simplified Linear Dynamic Analysis	Zone II	Category 2
		Zones II and III	Category 3
		All zones	Category 4
ii)	Dynamic Analysis	All zones	Category 1
		Zones III, IV, V and VI	Category 2
		Zones IV, V and VI	Category 3

10.2.1 *Simplified Linear Dynamic Analysis Method*

This method of analysis of industrial structure shall be selected in accordance with Table 6 using the procedure laid out in **5.3.1.2** of IS 1893 (Part 5). The stress resultants in the members shall be estimated by static analysis. The peak response quantities shall be combined as per complete quadratic combination (CQC) method.

10.2.2 *Dynamic Analysis Method*

Dynamic analysis may be performed either by the response spectrum method or the response history method. This method of analysis may be used in all categories of structures in any seismic zone. Response spectrum method shall be carried out as per **7.6.2.2** (a) of IS 1893 (Part 1) and the peak response quantities shall be combined as per complete quadratic combination (CQC) method. Response history method shall be as per **7.6.2.2** (b) of IS 1893 (Part 1).

10.3 Torsional Effects

The torsional effect of accidental eccentricity shall be considered for structures of Category 4 in all seismic zones.

This effect shall be considered for structures with rigid floors or diaphragms. This effect shall be accounted assuming the center of mass is shifted in each horizontal direction from its calculated value by a distance equal to 5 percent of the structure dimension perpendicular to the earthquake direction being considered. The design eccentricity e_{di} shall be as per **5.2.3.8** (a) of IS 1893 (Part 5).

10.3.1 For the purpose of applying the torsional effects in seismic analysis, requirements given in **10.3.2**, **10.3.3**, **10.3.4** and **10.3.5** shall also be considered.

10.3.2 Diaphragms with span-to-depth ratios of 3 or less, and where the diaphragm is constructed of reinforced concrete slabs or slabs over metal deck with reasonable reinforced concrete as topping, the diaphragm can be considered as rigid.

10.3.3 All steel or aluminum flooring system shall be considered as flexible unless properly designed floor bracings have been provided.

10.3.4 Reinforced cement concrete flooring systems in steel structures shall be considered flexible, unless formally designed floor bracings are provided.

10.3.5 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 the floor plan area at that level.

11 SEISMIC STRUCTURAL DESIGN CONSIDERATIONS

11.1 Fundamental Natural Period

The fundamental natural period of different industrial structures varies considerably depending upon structural configuration, height of the structure, soil conditions and appropriate percent of $SIDL$, IL and $MSIL$, as per applicable clauses. A single generalized formula for the natural period may not cover all such structures and may lead to erroneous results in certain cases. Hence, no simple guidelines can be given for estimation of natural period of industrial structures.

11.1.1 For preliminary design, the fundamental natural period can be established based on its static deflection under mass proportional loading in each of the three principal directions. The structure is analyzed by applying a force equal to the weight of the structure or equipment at each corresponding node in X, Y or Z direction (one at a time) and corresponding deflection δ is evaluated in X, Y and Z direction.

The fundamental natural period T (in s), would then be:

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

where

δ is the maximum value of deflection of the structure (maxima out of δ_x, δ_y and δ_z), and g is acceleration due to gravity, both of which are taken in consistent units.

Where the founding soil is soft soil, the effect of the same shall also be considered in the model for estimates for static deflection.

11.1.2 Alternatively, the fundamental natural period can be computed from the following equation:

$$T = 2\pi\sqrt{\frac{\sum_{i=1}^{n} W_i \delta_i^2}{g \sum_{i=1}^{n} F_i \delta_i}}$$

where

W_i = Weight at Level i,
F_i = Lateral Force at Level i,
δ_i = Lateral Displacement at Level i,
n = Number of Levels of Lumped Weight, and
g = Acceleration due to gravity.

The formulae given in **5.2.3.5** of IS 1893 (Part 5), for estimation of fundamental natural period of buildings are not applicable for industrial structures.

The natural period of industrial structures shall be estimated by Eigen value (modal) analysis of the structural mathematical model developed in accordance with **9**.

11.2 Design Base Shear

The design horizontal base shear force $V_{\mathrm{BD,H}}$ along any principal direction and design vertical base shear force $V_{\mathrm{BD,V}}$ shall be estimated as:

$$V_{\mathrm{BD,H}} = A_{HD}(T)W, \text{ and}$$
$$V_{\mathrm{BD,V}} = A_{VD}(T)W$$

where

W = Seismic weight of the structure as per **8.4.2**,
$A_{\mathrm{HD}}(T)$ = Design horizontal acceleration coefficient as per **7**, and
$A_{\mathrm{VD}}(T)$ = Design vertical acceleration coefficient as per **7**.

For industrial structures, base shear estimated from dynamic analysis methods need not be increased as recommended for buildings in **5.3.1.4** of IS 1893 (Part 5).

11.2.1 Whenever masonry infill walls contribute to the in-plane stiffness of the structure, two different mathematical models are required to be considered during design.

11.2.1.1 In the first mathematical model, the stiffness of infill wall panel shall be accounted and modeled as diagonal struts. IS 1893 (Part 5) shall be referred for modeling of equivalent diagonal strut and for estimation of in-plane stiffness of the masonry infill walls. This model shall be used for estimation of natural periods and storey drifts. The base shear of the model $V_{\mathrm{BD,I}}$ shall be estimated from this model.

11.2.1.2 The second mathematical model shall be a model of the bare frame structure without considering the stiffness of the infills. The mass of the infill shall be duly considered in the model. The second model shall be used for the estimation of forces in the structural members. The base shear of this model, $V_{\mathrm{BD,B}}$ shall be enhanced by the ratio of $V_{\mathrm{BD,I}}/V_{\mathrm{BD,B}}$ to obtain the design base shear. Similar amplification by this ratio shall be carried out for all member seismic forces. But, this amplification shall not be applied to storey drifts.

11.3 $P - \Delta$ Effects

Structures in all categories and in all seismic zones shall be analyzed to account for the $P - \Delta$ effects.

11.4 Lateral Storey Drift Limit

The lateral storey drifts in industrial structures, under the load combinations specified in **8.3** shall not exceed 0.004 times the storey height. The lateral storey drifts shall be estimated by linear structural analysis.

11.5 Separation between Adjoining Units

Two adjoining structures, or two adjoining units of the same structure shall be separated (with a seismic gap between them) by a distance equal to the square root of sum of squares of inelastic storey displacements, R_1 times Δ_1 and R_2 times Δ_2 given by

$$\Delta_{\mathrm{sep}} = \sqrt{(R_1\Delta_1)^2 + (R_2\Delta_2)^2},$$

where

R_1 = Elastic force reduction factor of structure 1 or unit 1 of the same structure,
Δ_1 = Storey lateral displacement of structure 1 or unit 1 of the same structure,
R_2 = Elastic force reduction factor of structure 2 or unit 2 of the same structure, and
Δ_2 = Storey lateral displacement of structure 2 or unit 2 of the same structure.

Here, Δ_1 and Δ_2 shall be estimated using the load combinations specified in **8.3** and section properties given in Table 2 of IS 1893 (Part 5).

12 ADDITIONAL PROVISIONS

12.1 Structure Supporting Cranes

While evaluating earthquake ground shaking effects on the structure supporting cranes, the seismic mass associated with cranes supporting a suspended load need not include the weight of the suspended load. The dead load of cranes shall be included in the seismic weight (or mass) as well as in the seismic load combinations. In case of more than one crane in a bay or in parallel bays, the design shall consider a load combination with all the cranes unloaded and parked at the most unfavourable position.

For load cases with crane loads, the load combinations listed in **8.3** shall be modified to include the crane loads as given below:

a) $1.2\ [DL + SIDL + IL + C_{\mathrm{dm}}(\text{or } C_{\mathrm{ds}})] \pm EE_{\mathrm{D}}$,
b) $1.5\ [DL + SIDL + C_{\mathrm{dm}}(\text{or } C_{\mathrm{ds}})] \pm EE_{\mathrm{D}}$, and
c) $0.9(DL + SIDL) + C_{\mathrm{dm}}(\text{or } C_{\mathrm{ds}}) \pm EE_{\mathrm{D}}$.

where

C_{ds} = Crane dead load for a single crane with crane trolley positioned to produce the maximum load effect for the element in consideration. Crane dead load includes weight of the crane bridge, end trucks and trolley, and
C_{dm} = Crane dead load for multiple cranes with crane bridges and crane trolleys positioned to produce the maximum load effect for the element in consideration.

Combinations of EE_{D} shall be considered as per **8.3.2.1** and **8.3.2.2**.

12.2 Industrial Tanks and Vessels Storing Liquids

12.2.1 For seismic design of liquid storage tanks in an industrial structure, its category shall be as per Table 7, the importance factor shall be as per Table 2 and the design shall be carried out as per IS 1893 (Part 2).

12.2.2 For the seismic design of ground supported flat bottom liquid storage tanks, that are not covered by IS 1893 (Part 2), specialist literature shall be referred. For such tanks, the category shall be as per Table 7 and the importance factor shall be as per Table 2.

12.2.3 Foundations and footings for mechanically anchored flat-bottom tanks shall be proportioned to resist peak anchor uplift and overturning bearing pressure. Overturning stability shall be evaluated for uplift due to seismic moment. The factor of safety against overturning stability shall be at least 2.0.

12.2.4 Content weight and soil load directly over the ring-wall and footing may be used to resist the maximum anchor uplift on the foundation, provided the ring-wall and footing are designed to carry the eccentric loading.

12.3 Anchorages

Anchorage design shall be based on ductile design philosophy. Anchor strength shall be governed by ductile yielding of a steel element. If the anchor cannot meet these ductility requirements, then either the attachment is designed to yield, or the calculated anchor strength is substantially reduced to minimize the possibility of a brittle failure. Procedure for designing the anchorages for earthquake considerations shall be as per IS 13920 (Part 4).

Post-installed anchors shall be qualified for earthquake-induced forces. These involve the performance of specific tests and application of acceptance criteria for qualification and determination of relevant design parameters.

12.4 Structural Considerations during Maintenance

In industrial structures, key structural elements that are part of seismic-force resisting system may be required to be temporarily removed, as dictated during the erection, replacement and maintenance of large size equipment and machinery. Such removal of structural elements may result in change in centre of stiffness leading to alternate load path for resisting seismic forces than originally designed. For such structures, seismic analysis shall be carried out for both the conditions, that is, with and without removal of these key structural elements. Further, structural stability shall be assessed under both of these conditions.

12.5 Bunkers and Silos

The requirements shall be as given hereunder:

a) Categories indicated in Table 7 and Table 8 for bunkers and silos are applicable to all RCC and steel bunkers and silos as well as RCC Silos supported on RCC frame and RCC shafts.
b) For design of silos and bunkers, seismic forces shall be estimated considering full range of material loading, that is, from empty condition to full condition. The most critical condition shall be adopted for design.
c) The effects of earthquake ground shaking in the supporting structure shall be estimated assuming that the particulate contents move together with the silo shell and modelling them with their effective mass at their centre of gravity.
d) The unit weight of stored material used for computing seismic forces shall be same as that used for all load calculations.

12.6 Pre-Engineered Steel Structures

Pre-engineered steel industrial structures (for example, PEBs) shall be checked for adequacy against earthquake effects as per the provisions of this standard. Steel design and detailing, member sizing, check for deflections and minimum member thickness shall also conform to IS 800 and IS 13920. Loads and load combinations shall be as per IS 800, IS 875 and IS 1893.

12.7 Foundations

Foundations shall be designed for the stress-resultants imposed by the superstructure under the action of loads combined as per combinations given in **8.3**. Geotechnical considerations shall be as per **7.8** of IS 1893 (Part 1). Foundation design shall comply with the requirements specified in **5.4.3** of IS 1893 (Part 5) with the following exception.

In case the interconnection between individual spread footings or pile caps is not feasible due to interference between foundations (such as dynamic equipment foundations, large span equipment foundations etc.), it shall be demonstrated that equivalent restraint is provided by RC beams within slabs on grade or RC slabs on grade or confinement by competent rock, hard cohesive soils, very dense granular soils or other approved means.

12.8 Cantilever Projections

Cantilever projections shall comply with the requirements specified in **5.4.4** of IS 1893 (Part 5).

12.9 Operational and Functional Components (OFCs)

To resist effects of design earthquake ground shaking, OFCs shall be designed as specified in **12.9.1** and **12.9.2**.

12.9.1 Rational methods described in **9.6** and **9.7** shall be used in the following cases, when:

a) The mass of a single OFC is more than 1 percent of that of the primary system on which it rests;
b) The total mass of all OFCs at a certain level together is more than 1 percent of that of the primary system on which they rest; and
c) The mass of a single OFC is more than 1 percent but the total mass of all OFCs at a certain level together is less than 10 percent of that of the primary system, and if the ratio of the natural period of the OFC and that of the primary system is in the range of 0.80 to 1.25.

12.9.2 For OFCs that do not fall under the cases specified in **12.9.1** may be designed for the design earthquake shaking as per the provisions provided in **8** of IS 1893 (Part 1).

Table 6 Categorization of Industrial Structures
(*Clauses* 8.1.3, 8.1.4, 8.1.5, 8.1.6 and 8.1.7)

Sl No.	Structure or Component	Category
	A. Main Plants and Process Plants	
	(Power plants, Hydrocarbon Plant, Chemical, Fertilizer and Metallurgy Plants etc.)	
1	Bagging and palletizing building	2
2	Boiler house	2
3	Coke drum structure	2
4	Compressor or expander foundation	2
5	Compressor house	2
6	Control building (Power Plant)	2
7	Control building or Satellite rack room	2
8	Generator building and house	2
9	Main plant building (TG Bay and Electrical Bay)	2
10	Mill and bunker bay structure	2
11	Machine foundations of main plant (Turbo generator, Turbo compressor, Pumps, Fans, Mills, etc)	2
12	Pipe rack with or without Deaerator, Air Fin Coolers, Two Phase Flow Lines	2
13	Polymerization and extrusion building	2
14	Process building closed or open conforming to **8.1.6**	1
15	Process building closed or open conforming to **8.1.7**	2
16	Reactor – regenerator supporting structure conforming to **8.1.6**	1
17	Reactor – regenerator supporting structure conforming to **8.1.7**	2
18	Sheds (tall and large span, high-capacity cranes, like pot room and cast house)	2
19	Substation buildings	2
20	Substation of power plant	2
21	Switch-gear building (Power Plant)	2
22	Switchyard structures	2
23	Technological structures in RCC or Steel supporting process columns and equipment conforming to **8.1.6**	1
24	Technological structures in RCC or Steel supporting process columns and equipment conforming to **8.1.7**	2
	B. Utilities	

Sl No.	Structure or Component	Category
	[Water system (Intake, Conveying, Treatment, Storage and Pumping), ETP/ STP/ Waste water treatment plant, DM water, Condensate polishing, RO plant, Cooling water system, Fire protection/ Extinguishing, Fighting system, Air separation unit, Nitrogen/ Oxygen plant, Fume and Gas treatment plant, Captive power plant, Service buildings]	
1	Air washer pump house	4
2	Air or nitrogen compressor foundation	2
3	Ash dyke	3
4	Ash water pump house	4
5	Ash water re-circulation building	4
6	Ash or slurry pump house	4
7	Boiler house	2
8	Bottom ash hopper and conveying system	2
9	Chiller plant	3
10	Coal handling plant	3
11	Coal slurry settling pond	4
12	Compressor house and turbine house	2
13	Control and instrumentation building	3
14	Conveyor galleries	3
15	Crusher house	3
16	Cryogenic hydrocarbon handling and dozing building	1
17	DCP and desludge building	2
18	Digester	2
19	DG building & DG foundation	2
20	Dirty and clean oil building	2
21	DM plant	2
22	Effluent treatment plant	3
23	Electrostatic precipitator structure	2
24	Fire station	2
25	Fire water pump house	2
26	Fire water reservoir	2
27	Flare stack supporting structure	2
28	Flare trestle	2
29	Fuel oil pump house	2
30	H_2 plant building	1
31	Machine foundations for utilities (Motors, Compressor, Pumps, Fans, etc)	3
32	Mechanical draught cooling tower (Induced or Forced)	2
33	Microwave towers	2
34	Overhead water tank	3
35	Pipe rack (Hydrogen, DM, Power Plant)	2

Sl No.	Structure or Component	Category
36	Pipe rack offsite	3
37	Pump house (Water and effluents, etc)	3
38	Road and rail loading gantry handling non-inflammable, non hazardous material	3
39	Road and rail loading gantry handling LPG or hydrocarbons	2
40	Switchgear building and substations	3
41	Switchyard structures	3
42	Technological structures in RCC or Steel or both	2
43	Water intake structure	3
44	Water treatment plant	3
	C. Storage and handling	
	(Raw material, Intermediate Product, Final Product, Bulk Storage of Chemicals)	
1	Catalyst storage building	2
2	Chemical house	3
3	Hazardous chemical house	1
4	LPG storage shed	1
5	Pipe rack	2
6	Product storage sheds or buildings	3
7	Road and rail loading gantry handling non-inflammable, non hazardous material	3
8	Road and rail loading gantry handling LPG or hydrocarbons	2
	D. Infrastructure	
	(Administrative Block, Laboratory Building, Service Buildings, Road Crossings etc)	
1	Administration building	4
2	Bridges over rivers or canals or drains	2
3	Canteen building	4
4	Communication building or repeater station or telephone exchange	2
5	Gate and gate house	4
6	Hospital	2
7	Laboratory building or MCC Room	3
8	Maintenance stores	4
9	Maintenance workshop	4
10	Medical center or first aid center	2
11	Other non-plant buildings and utility structures	4
12	Service building	4

Sl No.	Structure or Component	Category
13	Warehouse	4

Table 7 Categorization of Industrial Stack-Like Structures and Ground Supported Vertical Cylindrical Structures

(*Clauses* 8.1.3, 8.1.4, 8.1.5, 8.1.6, 8.1.7, 12.2.1, 12.2.2 *and* 12.5)

Sl No.	**Structure or Component**	**Category**
	A. Structure or Component for Main Plant	
1	Coke Drum	2
2	Electric or traffic light poles	4
3	HRSG stack	2
4	Process column or vessel or reactors or any other equipment on low RCC pedestal conforming to **8.1.6**	1
5	Process column or vessel or reactors or any other equipment on low RCC pedestal conforming to **8.1.7**	2
6	Reinforced brick masonry chimney	2
7	Reinforced concrete chimneys	2
8	Reinforced concrete T.V. towers	2
9	Reinforced concrete ventilation stacks	2
10	Settling and digestion tanks	2
11	Silos	2
12	Steel stack	2
13	Steel tubular support structures for onshore wind turbine generator systems	2
14	Storage silos and bunkers	2
15	Unreinforced brick masonry chimney	4
	B. Structure or Component for Utilities	
1	Acid or alkali storage tank	2
2	Cryogenic hydrocarbon storage (Bulk Storage)	1
3	Cryogenic hydrocarbon storage (Day Consumption)	1
4	Cryogenic storage tanks or vessel with hazardous or toxic refrigerated liquefied gases conforming to **8.1.6**	1
5	Cryogenic storage tanks or vessel with refrigerated liquefied gases (Day Tanks) conforming to **8.1.7**	1
6	Fire water storage tank	2
7	Fuel oil storage tank and day tank	2
8	Gas holder conforming to **8.1.6**	1
9	Gas holder conforming to **8.1.7**	2
10	Main condensate storage tank	3
11	Nitrogen storage vessel, air receiver, chemical dosing vessel	2

Sl No.	Structure or Component	Category
12	Water or effluent storage tank (Dome/Cone Roof)	3
	C. Structure or Component for Storage and Handling	
1	Cryogenic bulk storage tank (Double Walled) with refrigerated liquefied gases (for example, Ethylene, LNG, NH_3 etc.)	1
2	Hydrocarbon storage tanks (Cone or Floating Roof)	2
3	Hydrocarbon storage tanks (Dome Roof)	2
4	Process water storage tank	3

Table 8 Categorization of Vessels, Equipment and Piping

(*Clauses* 8.1.3, 8.1.4, 8.1.5, 8.1.6, 8.1.7 *and* 12.5)

Sl No.	Structure or Component	Category
	A. Structure or Component for Main Plant	
1	Bagging and palletizing equipment	2
2	Boiler	2
3	Converters	2
4	Heater or furnace	2
5	Heat recovery steam generator	2
6	Heaters with steel stack	2
7	Horizontal vessel, heat exchanger or filter, coalescer, desalter, air fin cooler or flash drum	2
8	Pharma chemical reactors	2
9	Piping	2
10	Process column on elevated structures conforming to **8.1.6**	1
11	Process column on elevated structures conforming to **8.1.7**	2
12	Scrubber or FGD System	2
13	Smelters on RCC or Steel structures	2
14	Storage silos (RCC, Steel or Aluminium) on elevated structures	2
15	Track hopper	2
16	Transformers and radiator bank	2
17	Turbo generator, Turbo compressor, Boiler feed pump	2
	B. Structure or Component for Utilities	
1	Air Pre-heaters, Tempered water cooler or Drum, Pre or Inter or after condenser, Coalescer	3
2	Boiler	2
3	Chiller Plant	3
4	Centrifuges and nutsche filters	3
5	Coal or Limestone ball mill and bowl mill	2
6	Coal bunker or silo	2
7	Condenser polishing unit	3
8	Corex gas station (for Cogeneration Plant)	2
9	Cooling towers (wet and dry)	3
10	Critical piping and pipelines	2

Sl No.	Structure or Component	Category
11	Crushers	3
12	Digester	2
13	DM Plant	2
14	Dryers: Vacuum tray, Hot air oven and Cone dryers	3
15	Electrostatic precipitator- ESP	2
16	Fans – PA, FD, GR, SA, ID and Booster Fans	2
17	Filtration and chlorination plant	3
18	Flare knock out drum and water seal drum	2
19	Heat exchangers (Pharma Industry)	3
20	Miller	3
21	Piping	3
22	Process gas compressor	2
23	Receivers and storage vessels	3
24	Silos (ash silos, cement silos, any powdery material storage silos, grain storage silos etc.)	3
25	Stability humidity chamber	3
26	Transformers and radiator bank	3
27	Wagon tippler	4
	C. Structure or Component for Storage and Handling	
1	Bagging and palletizing equipment	3
2	Hydrogen bullet	1
3	Mounded LPG bullet	1
4	Sphere or bullets storing hydrocarbon or with liquefied gases	1

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 pre-stressed cement concrete electric poles; reinforced concrete brick and steel chimneys (including multi-flue chimneys), ventilation stacks and refinery vessels are examples of such structures. This standard does not cover seismic analysis of guyed masts.

14 NATURAL PERIOD OF VIBRATION

Natural period of vibration, T, of such structures shall be estimated using either of the following two formulae given below (*see* **14.1** and **14.2**), based on vibration measurement or using detailed dynamic analysis. Measured natural period of structure, if used, shall be obtained through vibration measurement on similar structure and foundation soil condition.

14.1 The natural period T for stack-like structures when fixed at base for the first four modes are given by:

$$T = C_{\mathrm{T}} \sqrt{\frac{W_{\mathrm{t}} h}{E_{\mathrm{s}} A g}}$$

where

C_{T} = Coefficient based on the slenderness ratio of the structure given in Table 9 for the first four modes,
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,
A = Area of cross section at the base,
A_{c} = For circular sections, $2\pi rt$, where r is the mean radius of structural shell and t is thickness, and
g = Acceleration due to gravity

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

14.1.2 For determining the fundamental natural period of vibration of structures resting on frames or skirts like bins, silos, hyperbolic cooling towers, refinery columns, the formula given at **14.1** shall not be used.

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

$$T = 2\pi \sqrt{\frac{\sum_{\mathrm{i}=1}^{\mathrm{n}} W_{\mathrm{i}} \delta_{\mathrm{i}}^{2}}{g \sum_{\mathrm{i}=1}^{\mathrm{n}} F_{\mathrm{i}} \delta_{\mathrm{i}}}}$$

where,

W_{i} = Weight at level i;
F_{i} = Lateral force at level i;
δ_{i} = Lateral displacement at level i;
n = Number of levels of lumped weight; and
g = Acceleration due to gravity.

14.2.1 Any elastic analysis procedure like moment area theorem or matrix method considering the appropriate boundary conditions may be used to determine the lateral static deflection δ value.

14.2.2 For determining the fundamental natural period of vibration of structures resting on frames or skirts like bins, silos, hyperbolic cooling towers, refinery columns, etc., approximate methods shall not be adopted to estimate the lateral stiffness of the frame or skirt in order to determine the lateral static deflection. Dynamic analysis shall be adopted for evaluating the seismic response of such structures.

Table 9 Values of C_{T}
(*Clause* 14.1)

Sl No. (1)	$k = h/r_{\mathrm{e}}$ (2)	C_{T} **(1st Mode)** (3)	C_{T} **(2nd Mode)** (4)	C_{T} **(3rd Mode)** (5)	C_{T} **(4th Mode)** (6)
i)	5	8.935	1.425	0.510	0.260
ii)	10	17.870	2.850	1.020	0.520
iii)	15	26.805	4.275	1.530	0.780
iv)	20	35.740	5.700	2.040	1.040
v)	25	44.675	7.125	2.550	1.300
vi)	30	53.610	8.550	3.060	1.560
vii)	35	62.545	9.975	3.570	1.820
viii)	40	71.480	11.400	4.080	2.080
ix)	45	80.415	12.825	4.590	2.340
x)	50 or more	89.350	14.250	5.100	2.600

where

k = slenderness ratio, and
r_{e}= radius of gyration of the structural shell at the base section.

15 DAMPING

Damping ratios to be used of stack-like structures for different materials shall be as per Table 4. The value of damping ratio ξ for the purposes of estimating design horizontal and vertical PSA of stack-like structures for damping other than 5 percent of critical shall be as per **9.4**.

16 DESIGN EARTHQUAKE BASE SHEAR FORCE

16.1 The design horizontal acceleration coefficient $A_{\mathrm{HD}}(T)$ and the design vertical acceleration coefficient $A_{\mathrm{VD}}(T)$ shall be estimated as per **7**.

16.2 Based on the design horizontal acceleration coefficient $A_{\mathrm{HD}}(T)$, the design horizontal base shear force $V_{\mathrm{BD,H}}$ shall be estimated. For stack-like structures of circular cross section, the horizontal earthquake force shall be considered to act alone in any direction.

16.3 For estimation of earthquake forces on stack-like structures mounted on building or structure, the following provisions shall apply:

16.4 The stack-like structure shall be analyzed based on a model considering the flexibility of the supporting structure and connecting component between the stack and the supporting structure.

16.5 When the decoupled dynamic analysis of the structure mounted stack-like structure is carried out, it shall be performed by either the response history method or the response spectrum method using the floor acceleration time series or the in-structure response spectra as input for subsystem analysis.

17 SEISMIC ANALYSIS OF STACK-LIKE STRUCTURES

Either simplified method (equivalent lateral force procedure) or the dynamic analysis method may be used to estimate the seismic forces developed in stack-like structures.

The expressions given in simplified method for evaluating the shear force and bending moment when fixed at base are to be used when the first mode contributes maximum (about 80 percent) towards base shear. When higher modes influence the response, dynamic analysis shall be performed.

Simplified method shall not be adopted when soil-structure interaction effects are to be considered in the seismic analysis of stack-like structures.

17.1 Simplified Method (Equivalent Static Lateral Force Procedure)

When the first four modes collectively contribute to over 80 percent of the base shear, the design horizontal base shear force $V_{\mathrm{BD,x,i}}$ and design bending moment $M_{\mathrm{D,x,i}}$ for i^{th} mode at a distance x measured from the base, shall be estimated using the following formulae:

$$V_{\mathrm{BD,x,i}} = C_{\mathrm{vi}}\, A_{\mathrm{HD}}(T)\; W_{\mathrm{t}}\ ,$$

and

$$M_{\mathrm{D,x,i}} \ = C_{\mathrm{mi}}\, A_{\mathrm{HD}}(T)\, W_{\mathrm{t}}\, h$$

where

C_{vi} = Coefficient for shear force given in Table 10 for i^{th} mode,
$A_{\mathrm{HD}}(T)$ = Design horizontal acceleration coefficient determined in accordance with **16**,
W_{t} = Total weight of structure including weight of lining and contents above the base,
h = Height of structure above the base, and
C_{mi} = Coefficient for bending moment given in Table 11 for i^{th} mode.

The design shear and moment values due to all four modes shall be obtained by SRSS rule. However, when some of the modes are closely spaced, the complete quadratic combination (CQC) method shall be used for combining the responses.

17.1.1 The seismic lateral displacement shall be estimated as follows:

$$\Delta_{\mathrm{D,x,i}} = C_{\mathrm{di}}\, A_{\mathrm{HD}}(T)\ \frac{W_{\mathrm{t}} h^3}{E I_{\mathrm{b}}}$$

where

C_{di} = Coefficient for displacement given in Table 12 for i^{th} mode,
$A_{\mathrm{HD}}(T)$ = Design horizontal acceleration coefficient determined in accordance with **16**,

W_{t} = Total weight of structure including weight of lining and contents above
h = Height of structure above the base,
E_{s} = Modulus of elasticity of material, and
I_{b} = Moment of inertia at the base.

Only three modes are sufficient to be considered for estimating the seismic lateral displacements using the simplified method.

Table 10 Values of C_v
(*Clause* 17.1)

Sl No. (1)	x/h (2)	C_v **(1st Mode)** (3)	C_v **(2nd Mode)** (4)	C_v **(3rd Mode)** (5)	C_v **(4th Mode)** (6)
i)	0	0.613 18	0.188 11	0.064 88	0.033 14
ii)	0.05	0.613 07	0.187 74	0.064 29	0.032 35
iii)	0.10	0.612 30	0.185 31	0.060 67	0.027 81
iv)	0.15	0.610 25	0.179 29	0.052 36	0.018 41
v)	0.20	0.606 35	0.168 71	0.039 15	0.005 51
vi)	0.25	0.600 08	0.153 13	0.022 03	0.007 90
vii)	0.30	0.590 96	0.132 64	0.002 95	0.018 34
viii)	0.35	0.578 57	0.107 77	0.015 68	0.023 00
ix)	0.40	0.562 52	0.079 46	0.031 35	0.020 65
x)	0.45	0.542 46	0.048 98	0.041 89	0.012 09
xi)	0.50	0.518 11	0.017 84	0.045 90	0.000 14
xii)	0.55	0.489 22	0.012 32	0.042 92	0.012 40
xii)	0.60	0.455 55	0.039 79	0.033 56	0.021 11
xiv)	0.65	0.416 95	0.062 89	0.019 43	0.023 73
xv)	0.70	0.373 26	0.080 07	0.002 93	0.019 58
xvi)	0.75	0.324 38	0.089 96	0.013 11	0.010 03
xvii)	0.80	0.270 23	0.091 45	0.025 78	0.001 83
xviii)	0.85	0.210 75	0.083 66	0.032 46	0.012 03
xix)	0.90	0.145 92	0.066 02	0.031 13	0.016 77
xx)	0.95	0.075 69	0.038 18	0.020 49	0.013 22
xxi)	1	0.000 09	0.000 02	0.000 02	0.000 00

where

x = distance from bottom of the base, and
h = height of structure above the base.

Table 11 Values of C_{m}
(*Clause* 17.1)

Sl No. (1)	x/h (2)	C_{m} **(1st Mode)** (3)	C_{m} **(2nd Mode)** (4)	C_{m} **(3rd Mode)** (5)	C_{m} **(4th Mode)** (6)
i)	0	0.445 49	0.039 35	0.008 27	0.003 01
ii)	0.05	0.414 83	0.029 95	0.005 03	0.001 37
iii)	0.10	0.384 19	0.020 61	0.001 89	0.000 16
iv)	0.15	0.353 62	0.011 48	0.000 96	0.001 33
v)	0.20	0.323 20	0.002 76	0.003 26	0.001 94
vi)	0.25	0.293 03	0.005 31	0.004 81	0.001 87
vii)	0.30	0.263 24	0.012 47	0.005 43	0.001 20
viii)	0.35	0.233 99	0.018 50	0.005 11	0.000 14
ix)	0.40	0.205 44	0.023 19	0.003 92	0.000 98
x)	0.45	0.177 80	0.026 41	0.002 06	0.001 82
xi)	0.50	0.151 27	0.028 08	0.000 16	0.002 13
xii)	0.55	0.126 07	0.028 21	0.002 41	0.001 81
xii)	0.60	0.102 43	0.026 89	0.004 35	0.000 95
xiv)	0.65	0.080 59	0.024 30	0.005 69	0.000 20
xv)	0.70	0.060 82	0.020 70	0.006 25	0.001 31
xvi)	0.75	0.043 35	0.016 42	0.005 99	0.002 07
xvii)	0.80	0.028 47	0.011 85	0.005 00	0.002 27
xviii)	0.85	0.016 42	0.007 43	0.003 51	0.001 91
xix)	0.90	0.007 48	0.003 65	0.001 88	0.001 16
xx)	0.95	0.001 92	0.001 00	0.000 55	0.000 37
xxi)	1	0.000 00	0.000 00	0.000 00	0.000 00

Where

x = distance from bottom of the base, and
h = height of structure above the base.

Table 12 Values of C_d

(*Clause* 17.1.1)

Sl No. (1)	x/h (2)	C_d **(1st Mode)** (3)	C_d **(2nd Mode)** (4)	C_d **(3rd Mode)** (5)
i)	0	0.000 00	0.000 00	0.000 00
ii)	0.05	0.000 54	0.000 05	0.000 01
iii)	0.10	0.002 13	0.000 17	0.000 03
iv)	0.15	0.004 67	0.000 34	0.000 06
v)	0.20	0.008 09	0.000 54	0.000 08
vi)	0.25	0.012 33	0.000 75	0.000 10
vii)	0.30	0.017 29	0.000 94	0.000 10
viii)	0.35	0.022 92	0.001 10	0.000 09
ix)	0.40	0.029 13	0.001 22	0.000 07
x)	0.45	0.035 85	0.001 28	0.000 04
xi)	0.50	0.043 02	0.001 27	0.000 00
xii)	0.55	0.050 57	0.001 20	0.000 03
xii)	0.60	0.058 43	0.001 05	0.000 06
xiv)	0.65	0.066 55	0.000 84	0.000 08
xv)	0.70	0.074 87	0.000 57	0.000 09
xvi)	0.75	0.083 34	0.000 24	0.000 08
xvii)	0.80	0.091 92	0.000 12	0.000 05
xviii)	0.85	0.100 58	0.000 52	0.000 02
xix)	0.90	0.109 27	0.000 94	0.000 03
xx)	0.95	0.117 99	0.001 36	0.000 08
xxi)	1	0.126 71	0.001 79	0.000 13

where

x = distance from bottom of the base, and
h = height of structure above the base.

17.2 Dynamic Analysis (Response Spectrum Method)

When higher modes contribute significantly to the base shear, dynamic analysis shall be carried out by the response spectrum method. The analysis shall include a sufficient number of modes to obtain a combined modal mass participation of at least 90 percent of the actual mass. The modes shall be combined by modal combination of corresponding response, like base shear and overturning moment.

The soil-structure interaction shall not be considered in the seismic analysis of stack-like structures founded on competent material (stiff soil or rock) having soil site Class A or Class B as per Table 5 of IS 1893 (Part 1).

Methodologies for considering SSI effects are presented in **7.7** of IS 1893 (Part 1). Specialist literature may also be referred to include SSI and pile-soil-structure interaction effects. When soil-structure interaction effects are to be considered, maximum reduction in the base shear on account of soil-structure interaction as well as pile-soil-structure interaction shall not be more than 20 percent of base shear obtained from a fixed-base analysis.

17.2.1 *Mathematical Model*

The mathematical model of stack-like structure used in the analysis shall be sufficiently detailed to represent the variation in its stiffness and mass. The number of elements shall be such as to capture the variation of stiffness and mass of the system.

When a stack is modelled as a stick-model, a minimum of ten elements shall be used for the analysis. It is desirable that the model yields frequencies up to 33 Hz. If this is not achieved, the number of elements shall be increased such that frequencies up to 33 Hz are achieved. The number of elements shall be further increased to include any of above geometrical changes in the model. For stack-like structures with complex geometries and non-uniform mass distribution, finite element analysis shall be conducted.

18 SPECIFIC PROVISIONS FOR CHIMNEYS AND STACKS

18.1 General

Chimneys and stacks either lined or unlined constructed from concrete, steel or masonry shall be designed to resist seismic lateral forces determined as per **Section 2** of this standard. The analytical model shall be sufficiently refined to represent variations in mass and stiffness. Weights from roof structures, platforms and liners shall be included in the analytical model and lumped at the elevation where they occur. No stiffness is considered to be provided by the liners, but the liner weights shall be considered as lumped weights and shall be distributed at discrete elevations to approximate both the vertical and horizontal force transfer at that elevation.

18.2 Seismic Load Effect

For chimneys and stacks of circular cross section, the horizontal earthquake force shall be assumed to act alone in any direction. The vertical seismic load effect shall be ignored. For chimneys and stacks of noncircular cross section, orthogonal effects shall be considered.

Where the loss of horizontal cross-sectional area is greater than 10 percent in the regions of openings/breachings, it shall be designed for the total design shear and moment demands, determined for the affected cross section using an overstrength factor Ω of 1.5. The region where the overstrength applies shall extend above and below openings by a distance equal to half the width of the largest opening in the affected region.

18.3 Seismic Lateral Displacement

The lateral displacement shall be estimated by linear structural analysis. The maximum seismic lateral displacement $D_{\max}$ of the top of a stack-like structure, under the load combinations specified in **8.3** shall not exceed the limits set forth by the following equation:

$$D_{\max} = 0.005h$$

Where

$D_{\max}$ = Maximum lateral deflection, and
h = Height of structure above the base.

The $P - \Delta$ effect between vertical loads and seismic lateral displacement shall be considered. The maximum design displacements shall be used to determine the $P - \Delta$ effect.

The minimum clearance between the chimney shell and liner shall be provided based on inelastic lateral displacements for the chimney and liner. The total design displacement of the liner shall be determined using the elastic force reduction factor (R) appropriate for the lining material and configuration.

ANNEX A

(*Clause* 2)

LIST OF REFERRED INDIAN STANDARDS

IS Number	*Title*
IS 456 : 2000	Plain and reinforced concrete — code of practice (*fourth revision*)
IS 800 : 2007	General construction in steel — code of practice (*second revision*)
IS 875	Design loads (other than earthquake) for building and 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 : 2015	Wind loads (*third revision*)
Part 4 : 2021	Snow loads (*third revision*)
Part 5 : 1987	Special loads and load combinations (*second revision*)
IS 1343 : 2012	Prestressed — Code of Practice (*second revision*)
IS 1498 : 1970	Classification and identification of soils for general engineering purposes (*first revision*)
IS 1888 : 1982	Method of load test on soils (*second revision*)
IS 1893	Design earthquake hazard and criteria for earthquake resistant design of structures
Part 1 : 2025	General provisions (*seventh revision*)
Part 2 : XXXX	Liquid retaining tanks
Part 3 : XXXX	Bridges and retaining walls
Part 5 : 2025	Buildings
Part 6 : XXXX	Base isolated buildings
Part 7 : XXXX	Pipelines
Part 8 : XXXX	Dams and Embankments
Part 9 : XXXX	Coastal Structures
Part 10: XXXX	Steel Towers
Part 11: XXXX	Tunnels
IS 1905 : 1987	Structural use of unreinforced masonry — Code of practice (*third revision*)
IS 2131 : 1981	Method for standard penetration test for soils (*first revision*)

IS 2809 : 1972	Glossary of terms and symbols relating to soil engineering (*first revision*)
IS 2810 : 1979	Glossary of terms relating to soil dynamics (*first revision*)
IS 2974 :	Design and construction of machine foundations – code of practice
Part 1 : 1982	Foundations for reciprocating type machines
Part 2 : 1980	Foundations for impact type machines (hammer foundations)
Part 3 : 1992	Foundations for rotary type machines (medium and high frequency)
Part 4 : 1979	Foundations for rotary type machines of low frequency (*first revision*)
Part 5 : 1987	Foundations for impact machines other than hammer (forging and stamping press, pig breaker, drop crusher and jolter) (*first revision*)
IS 4326 : 2013	Earthquake resistant design and construction of buildings - code of practice (*third revision*)
IS 4998 : 2015	Design of reinforced concrete chimneys - criteria (*third revision*)
IS 6403 : 1981	Code of practice for determination of bearing capacity of shallow foundations (*first revision*)
IS 6533	Code of practice for design and construction of steel chimney:
Part 1 : 1989	Mechanical aspect (*first revision*)
Part 2 : 1989	Structural aspect (*first revision*
IS 8009	Code of practice for calculation of settlement of foundations
Part 1 : 1976	Shallow foundations subjected to symmetrical static vertical loads
Part 2 : 1980	Deep foundations subjected to symmetrical static vertical loading
IS 13920	Earthquake resistant design and detailing of structures
Part 1 : 2025	General provisions (*second revision*)
Part 2 : XXXX	Liquid retaining tanks
Part 3 : XXXX	Bridges and retaining walls
Part 5 : 2025	Buildings
Part 6 : XXXX	Base isolated buildings
Part 7 : XXXX	Pipelines
Part 8 : XXXX	Dams and Embankments

Part 9 : XXXX	Coastal Structures
Part 10: XXXX	Steel Towers
Part 11: XXXX	Tunnels
IS 13935	Earthquake safety assessment, evaluation and retrofit of structures
Part 1 : 2025	General provisions (*second revision*)
Part 2 : XXXX	Liquid retaining tanks
Part 3 : XXXX	Bridges and retaining walls
Part 5 : 2025	Buildings
Part 6 : XXXX	Base isolated buildings
Part 7 : XXXX	Pipelines
Part 8 : XXXX	Dams and Embankments
Part 9 : XXXX	Coastal Structures
Part 10: XXXX	Steel Towers
Part 11: XXXX	Tunnels

ANNEX B

(*Foreword*)

(Committee Composition will be added after finalization)

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