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-33 **15 अक्टूबर 2024**

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(26741)WC	**संरचनाओं का भूकंप सुरक्षा मूल्यांकन और पुनःसंयोजन** **भाग 1 सामान्य प्रावधान** (IS 13935 का दूसरा 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: 30 नवंबर 2024

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।

भवदीय
ह-/
द्वैपायन भद्र
वैज्ञानिक ई एवं प्रमुख
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-33 **15 October 2024**

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(26741)WC	Draft Indian Standard Earthquake Safety Assessment and Retrofitting of Structures **Part 1 General Provisions** (Second Revision of IS 13935) 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: 30 November 2024

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(26741)WC

BIS Letter Ref: CED 39/T-33

Title: Draft Indian Standard Earthquake Safety Assessment and Retrofitting of Structures Part 1 General Provisions [Second Revision of IS 13935 (Part 1)] ICS No. 91.120.25

Last date of comments: 30 November 2024

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

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Draft Indian Standard

Earthquake Safety Assessment and Retrofitting of Structures
Part 1 General Provisions

(*Second Revision* of IS 13935)

Earthquake Engineering	**Last Date for Comments:**
Sectional Committee, CED 39	**30 November 2024**

FOREWORD

[*Formal clause will be added later*]

The stock of housing in India alone is over 32 crores, and the stock of the other structures is of a comparable number. A significant share of this stock is in landmass that is likely to sustain moderate to severe earthquake ground shaking. Much of this existing stock of structures in India is unregulated construction, owing to absence of necessary techno-legal process to examine the structural safety of the built environment at the municipal offices across the country. Past earthquakes in India show that large losses of life is attributed primarily due to the collapse of structures. To prevent this, it is essential to assess and retrofit structures before the impending earthquakes. When doing so, efforts should be made to reduce the carbon footprint (say by 70 percent) as a step towards sustainable development.

This standard was first published in 1993 with the title *Seismic Evaluation, repair and strengthening of masonry buildings — Guidelines*, and revised in 2009. In 2022, to keep abreast with rapid developments and extensive research carried out worldwide in earthquake engineering, the Committee decided to comprehensively revise the standard and present the provisions for different types of structures in 11 separate parts, namely:

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

These 11 parts are created for each of the following standards with revised titles as:

a) IS 1893 Design earthquake hazard and criteria for earthquake resistant design of structures;
b) IS 13920 Earthquake resistant design & detailing of structures; and
c) IS 13935 Earthquake safety assessment and retrofitting of structures.

This standard contains general principles on earthquake safety assessment applicable to all structures covered in Parts 2 to 11. Unless stated otherwise, the provisions in Parts 2 to 11 of IS 13935 shall be read necessarily in conjunction with the provisions as laid down in this standard.

In this revision, the following changes have been made:

a) Earthquake hazard levels are specified for design of retrofit depending on the age of the structure;
b) Levels of assessment of a structure are specified;
c) Load combinations to be used are specified when performing structural analysis of the structure for assessment or retrofit;
d) Virtues are identified which need be improved by global and local retrofit of the structure; and
e) Requirements are specified related to configuration, stiffness, strength and deformability of the structure to qualify retrofit options.

In India, on one side, the stock of structures is large, typologies are many, and variations within each typology are significant. And, on the other side, the professional services are of varying competence. Hence, there are many nuances in assessment of structures to resist earthquake. This was recognized in the development of this standard and the evaluation of structures to examine their sufficiency to resist the earthquake shaking effects is recommended to be performed at five levels, namely:

a) Level 0 Basic prioritization,
b) Level 1 Field assessment,
c) Level 2 Preliminary quantitative (hand-calculation) evaluation,
d) Level 3 Basic quantitative (code compliance) evaluation, and
e) Level 4 Detailed quantitative (nonlinear) evaluation.

The assessment at Levels 0 and 1 are qualitative assessment, while the evaluations at Levels 2 to 4 are quantitative. This telescopic method provides a way of prioritizing the structures for earthquake assessment and retrofit. The standard is expected to be used by competent engineers, who have sufficient experience of having designed sufficient number of structures and have a reasonably good understanding of loads, structural behavior and structural design to sustain and resist the effects of loading.

The cost of retrofit should be estimated as a percentage of the reconstruction project cost (excluding the cost of land), namely the structure and finishes, if it were to be built today. These will be provided in respective parts of IS 13935. Considering that the costs involved in retrofitting of existing deficient structures could be large, the statutory authorities shall prioritize the retrofitting work of government owned structures in a

phased manner starting from: (a) the structures in earthquake zone VI and eventually structures in earthquake zone II, and (b) the special and critical structures and eventually important and normal structures. This guidance shall be adopted in the retrofitting of privately owned structures also, even though the costs are to be borne by the owner.

In the preparation 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) NDMA, (2014), National Disaster Management Guidelines on Seismic Retrofitting of Deficient Buildings and Structures, National Disaster Management Authority, Government of India, June 2014.

The units used with the items covered by the symbols shall be consistent throughout this standard, unless specifically noted otherwise.

This standard contributes to the United Nations Sustainable Development Goal 9: ‘Industry, innovation and infrastructure’, particularly its target to develop quality, reliable, sustainable and resilient infrastructure, and also promote inclusive and sustainable industrialization.

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.

BUREAU OF INDIAN STANDARDS
DRAFT STANDARD FOR COMMENTS ONLY
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Draft Indian Standard

Earthquake Safety Assessment and Retrofitting of Structures
Part 1 General Provisions

(*Second Revision* of IS 13935)

Earthquake Engineering	**Last Date for Comments:**
Sectional Committee, CED 39	**30 November 2024**

1 SCOPE

1.1 The provisions of this standard are applicable for:

a) Assessing the earthquake behaviour of existing structures that are not damaged during earthquake and new structures that are being designed as per the relevant national standards.
b) Retrofitting of structures that are found to be deficient against design earthquake effects.

1.2 The provisions of this standard are meant for pre-earthquake assessment and retrofit of structures, and not for post-earthquake damage assessment or repair of earthquake damaged structures.

2 REFERENCES

The standards given 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 the purpose of this standard, definitions given below shall apply to all structures, in general. Also, reference may be made to the following standards for definition of terms pertaining to:

a) IS 1893 and IS 13920 for effects due to earthquakes; and
b) IS 875 (Parts 1 to 5) for loads other than earthquake.

3.1 Acceptance Criteria — Limiting values of structural characteristics (such as lateral drift, lateral strength and lateral inelastic deformation) used to determine the acceptability of a structure from the standpoint of earthquake safety.

3.2 Action Internal stress resultants (axial load, shear force, bending moment and torsional moment) and deformations (strains, deflections and rotations) developed in a member due to externally applied load or displacement on the structure.

3.3 Architectural Elements and Utilities — The contents, appendages, and services & utilities of structures, which are installed in the structure or are permanently an integral part of a structure, supported by the structural elements, generate inertia forces (but do not themselves carry them down to foundations), and whose inertia forces are carried to foundations by structural elements.

3.4 Capacity — Capability or limit of strength and/or deformation of a structural member or structure considered appropriate for the task at hand, namely design or assessment.

3.5 Deformation — Relative movement (displacement or rotation) of a component or a node of the structure.

3.6 Demand — Amount of force or deformation imposed on a component under the action of loads and/or load effects imposed on the structure.

3.7 Displacement — Total movement (displacement or rotation) of a component or a node of the structure.

3.8 Earthquake Demand — Level of earthquake hazard, commonly expressed in the form of a ground shaking response spectrum, which is used to estimate the structural actions on members of the structure.

3.9 Earthquake Evaluation — An approved process or method of evaluating deficiencies in a structure, which prevent the structure from achieving life safety objective.

3.10 Knowledge Factor — Factor assumed to account for the uncertainty and lack of reliability of the information available about the structural configuration, present condition of materials and details of construction (like reinforcement details) of the existing structures.

3.11 Lateral Force Resisting System — Collection of frames, shear walls, bearing walls, braced frames and interconnecting horizontal diaphragms that provide earthquake resistance to a structure.

3.12 Load Path — Path taken by earthquake-induced inertia forces in the structure, to reach the foundation and to soil underneath.

3.13 Masonry — Assembly of masonry units, mortar, and possibly grout and/or reinforcement to form a structural member.

3.14 Redundancy — Availability of alternative load paths in a structure by which the lateral forces are resisted, allowing the structure to remain stable following the failure of any single element.

3.15 Safety Assessment — Process of measuring qualitatively or quantitatively the extent of departures which the structure has compared to the intended behaviour and/or compliance with the relevant design standard.

3.15.1 *Level 0: Basic Prioritization* — The qualitative basic assessment of the structure based on:

a) Health of the structure,
b) Revision of standards, and/or
c) Requirements of owners and/or compliance to assess.

3.15.2 *Level 1: Field Assessment* — The simplified qualitative assessment performed based on a rapid visual survey of critical aspects of structure, involving limited aspects of: (a) the structural elements (SEs) along the five facets, namely site conditions, architectural form, structural system, material condition, and construction details; and (b) the architectural elements and utilities (AEUs) of the two types, namely rocking, sliding and toppling of acceleration-sensitive AEUs, and stretching, compressing and rupturing of displacement-sensitive AEUs.

3.15.3 *Level 2: Preliminary Quantitative (Hand-Calculation) Evaluation* — The simplified quantitative assessment based on a simplified estimation of lateral safety of structures, involving the examining the sufficiency of: (a) vertical load carrying capacity of members, (b) the horizontal shear capacity of structure and members along two principal plan directions, and (c) the relative strengths of vertical and horizontal members, which requires only hand calculations without the need for structural analysis of the whole structure.

3.15.4 *Level 3: Basic Quantitative (Code Compliance) Evaluation* — The detailed quantitative assessment based on conventional design office procedure of performing linear structural analysis of the whole structure to estimate the demands on the structure and its members, wherein the safety checks are related to the configuration, stiffness and strength of the structure and its members, as per provisions of the standards, namely:

a) CED 39(22343), CED 39(22345), CED 39 (26742) (Part 1), and corresponding parts of IS 1893, IS 13920 and IS 13935 relevant to the structure being examined; and
b) IS 456, IS 800 and IS 1905 relevant to the structure being examined.

3.15.5 *Level 4: Detailed Quantitative (Nonlinear) Evaluation* — The detailed quantitative assessment based on nonlinear structural analysis of the whole structure to estimate the demands on the structure and its members, wherein safety checks are related to the configuration, stiffness, strength and deformability of the structure and its members, as per **5.1.5.1** and **5.1.5.2.**

3.16 Strength — Maximum axial force, shear force, bending moment and torsional moment, which can be resisted by a member/component, either individually or in combination with others.

3.17 Strengthening — Modification to existing members, components, or installation of new members and components, which corrects deficiencies identified in an earthquake safety assessment as part of a strengthening scheme.

3.18 Structural Elements — Physical entities that constitute a structure, including beams, columns, slabs, braces, walls, foundations, joints and connections, and carry all loads imposed on it.

3.19 Vertical Irregularity — Discontinuity of strength, stiffness, geometry or mass along the elevation of the structure.

4 SYMBOLS

For the purpose of this standard, symbols and notations given below shall apply to all structures, in general. For symbols and notations pertaining to:

Symbol	*Description*
DL	Dead load on member/structure.
LL	Imposed load on member/structure.
EE_{DX}	Design earthquake effect on member owing to ground motion along X-direction.
EE_{DY}	Design earthquake effect on member owing to ground motion along Y-direction.
EE_{DZ}	Design earthquake effect on member owing to ground motion along Z-direction.
T_A	Age of the structure form the date of start of construction.
T_{RP}	Return period to be considered to choose the earthquake hazard level.
V_B	Design base shear to be used for the earthquake design of a new structure as specified in respective part of IS 1893 using design earthquake zone factor Z corresponding to a return period T_{RP}.
$V_{B,AR}$	Design lateral base shear for assessment and retrofit of structures
$V_{B,LRP}$	Design base shear to be used after 25 years of the start of its construction, for the earthquake assessment and retrofit design of an existing of structure estimated using a design earthquake zone factor Z for a return period T_{RP} one level lower (as per Table 1) than that specified in **6.2.2.3** of CED 39(22343) for a new structure of the same type as that being assessed.

Z	Design earthquake zone factor.
α	Factor used to estimate effective imposed load participating in transferring earthquake inertia to the structure.

5 ASSESSMENT OF EARTHQUAKE BEHAVIOUR OF STRUCTURES

The assessment of existing structures should be guided by the provisions specified hereunder. The need for assessment of structure may arise from any of the following reasons:

a) Change of use of the structure,
b) Extension and modification of the structure,
c) Revision in the standards related to design earthquake hazard, and design and detailing of structures,
d) Owners and/or compliance requirements to assess and retrofit, if required, and
e) Present health of the structure.

The Earthquake Zone Factor *Z* to be considered in the safety assessment of different structures shall be performed as per CED 39 (26742) (Part 1) for all structures, IS 13935 (Part 2) for buildings and IS 13935 (Part 3 to Part 11) for other structures.

The assessments mentioned below are pre-earthquake assessments, wherein the structure has not yet suffered damage due to earthquake ground shaking.

5.1 Levels of Assessment

Unless stated otherwise elsewhere in this standard or its parts, the structure as a whole and its members individually should be assessed by the 4-level telescopic method provided hereunder (see Fig. 1). This 4-level Telescopic Method will guide designers to:

a) Examine the sufficiency of the earthquake resistance of a structure with respect to the requirements of CED 39(22343), CED 39(22345), and corresponding Parts of IS 1893 and IS 13920 relevant to the structure being examined, and
b) Determine the need (if any) for and the extent of earthquake retrofit required.

5.1.1 *Basic Prioritization*

A qualitative prioritization should be performed at the start of the earthquake safety assessment of the structure. This assessment should examine the reason(s) to assess and retrofit the structure:

a) Original structure designed to resist earthquake effects, but:
   1) Use of the structure changed to carry heavier loading : Yes / No;
   2) Revised provisions of standard are more stringent related to:
      i) Design earthquake hazard, and/or
      ii) Design and detailing of structures : Yes /No;

3) Extension and Modification of the structure : Yes / No;
4) Extent of distress is substantial in the structure : Yes / No;

or

b) Structure originally not designed for earthquake forces : Yes / No.

This information should be used to escalate to the higher level of assessment recommended in Table 1, after completing Level 1 Field Assessment. This flow chart provides the minimum level of assessment to be carried out. But the project authority can opt for higher level of assessment depending the type of functionality of the structure.

Table 1 Prioritization of Structures based on the reason for Retrofit after Level 1 Field Assessment

(*Clause* 5.1.1)

Sl No. (1)	**Reason** (2)	**Priority** (3)	**Level of Assessment recommended** (4)
i)	a(1) only	Low	Level 2
ii)	a(2) only	Medium	Level 3
iii)	a(3) only	Medium	Level 3
iv)	a(4) only	High	Level 4
v)	b	High	Level 4
vi)	Any other reason	Low	Level 2

5.1.2 *Level 1 Field Assessment*

The *qualitative* assessment of the structure should be performed at the site of the structure and documented in two features, namely:

a) *Structural Elements (SEs)*:

Structural Elements shall be assessed under 6 sub-features, namely:

1) Site Issues,
2) Soil and Foundation Conditions,
3) Architectural Features,
4) Structural Aspects,
5) Material Conditions, and
6) Construction Details.

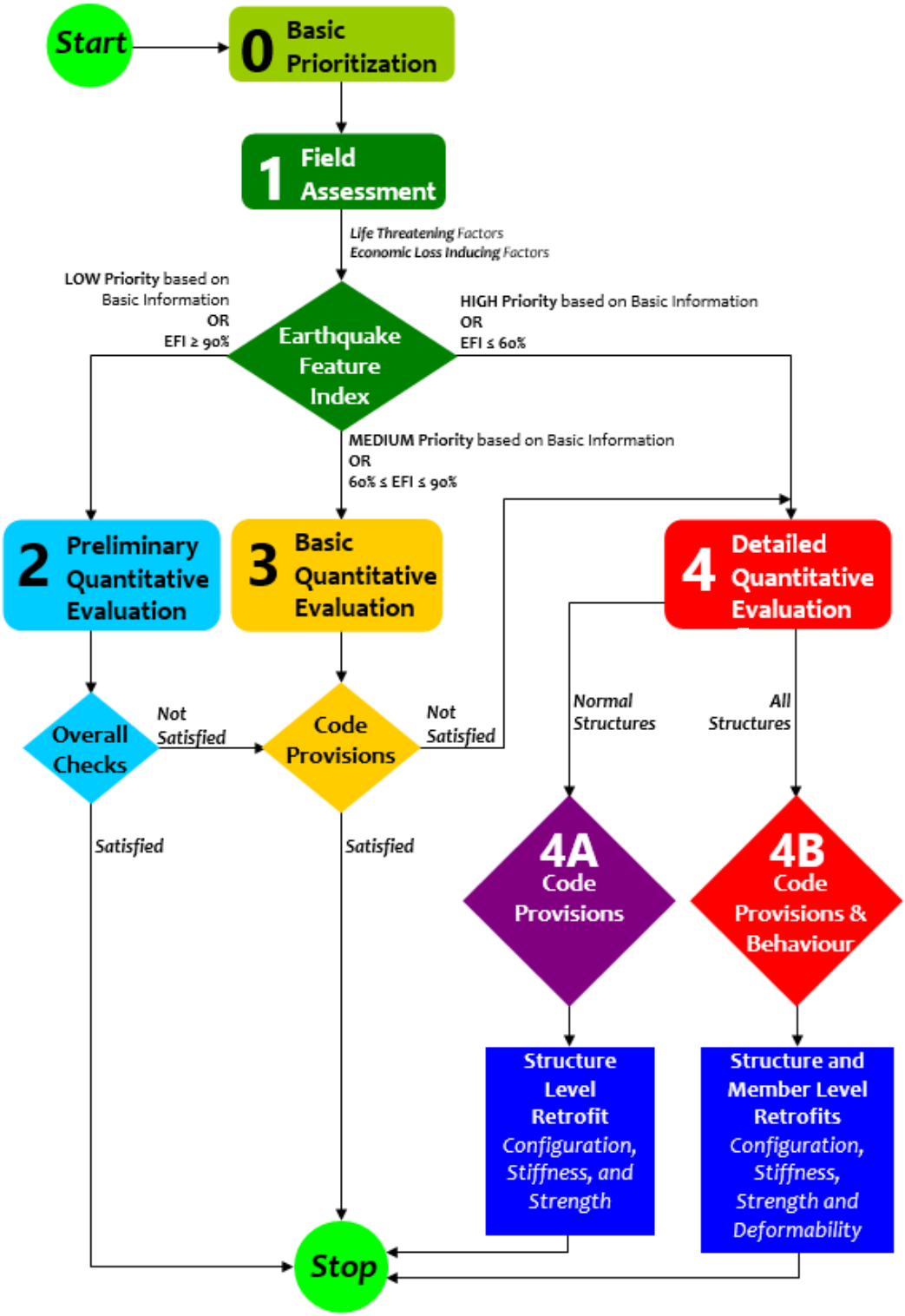

FIG. 1 4-LEVEL TELESCOPIC METHOD FOR ASSESSING SUFFICIENCY OF EARTHQUAKE RESISTANCE OF STRUCTURES TOWARDS DETERMINING THE NEED FOR EARTHQUAKE RETROFIT

b) *Architectural Elements and Utilities (AEUs)*:

Non-Structural Elements shall be assessed under 2 sub-features, namely:
1) Rocking, sliding and toppling of acceleration-sensitive AEUs, and
2) Stretching, compressing and rupturing of displacement-sensitive AEUs.

The details of the assessment of the sub-features of the Structural and Non-Structural Elements depend on the typology of the structure being assessed corresponding to the earthquake zone that it is located in. Also, these sub-features are categorized under:

i) Life-Threatening (L) factors that are known to have caused collapses of structures of similar typology during past earthquakes, and
ii) Economic Loss-inducing (E) factors that have the potential to sustain damage during earthquakes and are known to have caused economic losses in the structures of similar typology during past earthquakes.

The outcome of this method is a value of the earthquake feature index on a scale of 0 percent to 100 percent. Depending on the value of this index, the earthquake safety evaluation of the structure is escalated to one of the next three levels described hereunder (Fig. 1).

A detailed description of the Level 1 Field Assessment (of SEs and AEUs as L factors and E factors) shall be taken as presented in the respective earthquake safety assessment and retrofit standard depending on the type of the structure, namely IS 13935 (Part 2 to Part 11).

With respect to Levels 2, 3 and 4 Assessments (as in **5.1.3**, **5.1.4** and **5.1.5**) the minimum design forces shall be specified by IS 13935 (Part 2 to Part 11) depending on the type of structure for the quantitative assessment and retrofitting. But the statutory body having jurisdiction for undertaking assessment and retrofitting of structures may specify values different from these (even smaller) and the same may govern.

5.1.3 *Level 2 Preliminary Quantitative (Hand-Calculation) Evaluation*

This quantitative evaluation should be performed to examine compliance of the structure with select basic checks stated hereunder.

a) Input

1) *Retrofit Force Demand* — The estimate design lateral force to be used in the assessment and retrofit of the structure shall be as per **5.2**.
2) *Material Properties* — The current in-situ strength of materials used in the structure shall be as per the available structural and limited semi-/non-destructive testing.

b) Method of Analysis

The linear elastic method shall be used for the analysis for estimating the effects of earthquake on the structure.

c) Checks and Acceptance Criteria

1) *Axial stress demand in columns and walls*:

The axial stress in each column and wall (with axial force arising from dead loads, imposed loads estimated considering tributary areas of load distribution, and from earthquake effects) shall not exceed the corresponding permissible stress in the constituent material, that is masonry, reinforced concrete or structural steel;

2) *Shear stress demand in columns and walls*:

The horizontal shear stress in each column and wall under the action of design lateral earthquake storey shear force demand along each principal plan direction (X or Y) estimated considering their relative stiffnesses, shall not exceed the corresponding permissible stress in the constituent material, that is masonry, reinforced concrete or structural steel;

3) *Shear force demand on the whole structure*:

The design horizontal base shear force demand applied along each principal plan direction (X or Y) shall not exceed the overall horizontal shear capacity of the structure at the base along the corresponding principal plan direction (X or Y), that is the sum of design shear force capacities of vertical members resisting the lateral earthquake shear force in the direction considered; and

4) *Relative strength hierarchy*:

The relative flexural strength ratio of vertical and horizontal members at each joint shall satisfy the limit specified in IS 13920 corresponding to the type of the structure.

A detailed description of the Level 2 Preliminary Quantitative Evaluation (of the above factors) shall be taken as specified in the respective earthquake safety assessment and retrofit standard depending on the type of the structure, namely IS 13935 (Parts 2 to 11). And, if the structure complies with the above checks and acceptance criteria, then earthquake safety assessment shall be said to be complete, and no retrofit is recommended. Otherwise, the structure should be subjected to Level 3 Basic Quantitative Evaluation described in **5.1.4**.

5.1.4 *Level 3 Basic Quantitative (Code Compliance) Evaluation*

This quantitative evaluation shall be performed to examine compliance of the structure and its members with the configuration, stiffness and strength provisions of the existing standards given in:

a) CED 39(22343), CED 39(22345) and corresponding parts of IS 1893, IS 13920 and IS 13935 relevant to the structure being examined; and
b) IS 456, IS 800 and IS 1905 relevant to the structure being examined.

A detailed description of the Level 3 Basic Quantitative Evaluations shall be taken as presented in the respective earthquake safety assessment and retrofit standard depending on the type of the structure, namely IS 13935 (Parts 2 to 11). And, if the structure complies with the said provisions (related to structural configuration, overall and member lateral stiffnesses, overall and member lateral strengths, and relative and intra-member strengths), then earthquake safety assessment shall be said to be complete, and no retrofit is recommended. Otherwise, the structure should be subjected to Level 4 Detailed Quantitative Evaluation described in **5.1.5**.

5.1.5 *Level 4 Detailed Quantitative (Nonlinear) Evaluation*

This quantitative evaluation should be performed to examine compliance of the structure and its members with the configuration, stiffness, strength and deformability provisions of the existing standards at two levels. These two are described in **5.1.5.1** and **5.1.5.2**.

A detailed description of the Level 4 Detailed Quantitative Evaluation (of the factors mentioned in **5.1.5.1** and **5.1.5.2**) shall be taken as presented in the respective earthquake safety assessment and retrofit standard depending on the type of the structure, namely IS 13935 (Parts 2 to 11).

5.1.5.1 *Level 4A evaluation at structure level only*

This method shall be used only for evaluating normal and important structures. Compliance is examined with code provisions related to overall configuration, stiffness, strength and deformability of the structure. The evaluation shall be performed to examine the deficiencies of an existing structure, and to understand its earthquake behavior.

Nonlinear Pushover Analysis is sufficient. Three basic characteristics of the structure to be evaluated are its overall initial lateral stiffness, overall lateral strength and overall lateral deformability.

5.1.5.2 *Level 4B evaluation at structure and member levels*

This method can be used for evaluating all existing and new structures. But it is necessarily for evaluation of existing critical and special structures identified in Table 4. Compliance is examined with code provisions related to:

a) Configuration, stiffness, and strength of the structure, and
b) Earthquake behaviour through overall deformability of the structure and of members.

The evaluation shall be performed to understand earthquake behavior of the retrofitted structure, and to evaluate sufficiency of the retrofit scheme proposed to be adopted (when required).

Nonlinear response history analysis shall be essential. This method of analysis is known to provide relatively more realistic assessment of the earthquake behaviour of structure being assessed than nonlinear pushover analysis. Four basic characteristics of the structure to be evaluated by the nonlinear response history analysis are overall initial lateral stiffness, overall lateral strength, overall lateral deformability and overall collapse mechanism.

5.2 Earthquake Demand

The design lateral earthquake force to be used in the assessment and retrofit design of existing structures shall be estimated as specified hereunder.

5.2.1 *Assessment Level Earthquake Lateral Force*

The retrofit design earthquake lateral force demand to be used in the earthquake assessment and retrofit of existing structures shall be:

a) For normal structures [as defined in CED 39(22345)], it shall be equal to or smaller than the design earthquake lateral force demand for the earthquake design of a new structure of the same type, dependant on the age of the structure; and
a) For important and critical & lifeline structures [as defined in CED 39(22345)], it shall be equal to the design earthquake lateral force demand for the earthquake design of a new structure of the same type, independent of the age of the structure.

5.2.1.1 *Design lateral and vertical acceleration*

The design horizontal and vertical accelerations $A_H(T)$ and $A_V(T)$, respectively, shall be estimated as per **6.2.4** of CED 39(22343), but using a design earthquake zone factor Z for a return period T_{RP} as specified in CED 39(22343).

The design lateral base shear $V_{B,AR}$ for assessment and retrofit of all structures shall be estimated as:

$$V_{B,AR} = V_B ,$$

where,

V_B = Design base shear to be used for the earthquake design of a new structure as specified in respective Part of IS 1893 using design earthquake zone factor Z corresponding to a return period T_{RP} as specified in Table 1 of CED 39(22343) , and elastic force reduction factor R specified in IS 13935 (Parts 2 to 11) depending on the type of structure (to account for the lack of ductility based on the year of construction).

5.2.1.2 *Design lateral velocity*

The elastic velocity demand shall be estimated as per CED 39(22343) using the design elastic acceleration spectrum specified in **5.2.1.1**.

5.2.1.3 *Design lateral deformation*

The elastic deformation demand shall be estimated as per CED 39(22343) using the design elastic acceleration spectrum specified in **5.2.1.1**.

5.3 Structural Analysis

The method of structural analysis shall be as specified hereunder depending on the use of the results.

5.3.1 Analytical Model

The analytical model of the physical structure shall be such as to represent the spatial distribution of mass and stiffness of the structure to an extent that is adequate for the calculation of significant features of its distribution of lateral forces.

The following shall be considered when modeling of the linear elastic behaviour of the structure:

a) The elastic material properties of the original material to be used in structural analysis shall be taken as per the respective design codes, namely IS 1905 for masonry structures and IS 456 for concrete structures.
b) The geometry and support conditions of the structure shall reflect the conditions of the as-built existing structure.

The following shall be considered when modeling of the inelastic behaviour of the structure:

a) The inelastic material properties of the original material to be used in structural analysis shall be taken as per the test performed on the material coupons collected from the existing structure.

b) The geometry and support conditions of the structure shall reflect the conditions of the as-built existing structure.
c) The following hinge properties shall be considered when modeling members:

1) Plastic ($M-\theta$) hinges at potential locations where moment hinges can form in frame members, especially at the ends of beams framing into columns and at intermediate locations in beams,
2) Shear ($V-v$) hinges at potential locations where shear failure can occur in frame members,
3) Axial ($P-u$) hinges in frame members, and
4) $P-M$ strength interaction in frame members.

In (1), (2) and (3) above, the said load-deformation curves shall be idealized as elasto-plastic curves with strain-hardening along both positive and negative directions of loading.

d) Isotropic hardening rules shall be adopted to describe the hysteretic response of structures.

5.3.2 *Load Combinations*

5.3.2.1 The load combination to be used in the two methods of analysis for assessment and retrofit design shall be as specified in Table 2 depending on whether:

a) The structure is regular or irregular, and
b) The ground motions to be considered along:
   1) Only one horizontal direction at a time,
   2) Along one horizontal direction at a time and vertical direction, or
   3) Along both horizontal directions and vertical direction.

5.3.2.2 In Table 2, α refers to the factor used to estimate effective imposed load participating in transferring earthquake inertia to the structure, and the design forces EE_{DX}, EE_{DY} *and* EE_{DZ} shall be as defined in CED 39(22343).

Table 2 Minimum load combinations to be used in structural analysis when used for Assessment and Retrofit design of structures
(*Clause* 5.3.2)

Sl No.	Linear Analysis	Equivalent Static Nonlinear Analysis (Pushover Analysis)	Nonlinear Dynamic Analysis (Response History Analysis)
(1)	(2)	(3)	(4)
	CONCRETE STRUCTURES AND STEEL STRUCTURES		
1	**Regular Structures**		
	1.1 Horizontal shaking effects		
	Combinations specified in CED 39(22343)	$DL + LL + EE_{DX}$ $DL + LL + EE_{DY}$	$DL + \alpha LL + EE_{DX} + EE_{DY} + EE_{DZ}$
	1.2 Horizontal and vertical shaking effects		
	Combinations specified in CED 39(22343)	$DL + LL + EE_{DX} + EE_{DZ}$ $DL + LL + EE_{DY} + EE_{DZ}$	$DL + \alpha LL + EE_{DX} + EE_{DY} + EE_{DZ}$
2	**Irregular Structures**		
	2.1 Horizontal shaking effects		
	Combinations specified in CED 39(22343)	$DL + LL + EE_{DX} + 0.3EE_{Dy}$ $DL + LL + 0.3EE_{DX} + EE_{Dy}$	$DL + \alpha LL + EE_{DX} + EE_{DY}$
	2.2 Horizontal and vertical shaking effects		
	Combinations specified in CED 39(22343)	$DL + LL + EE_{DX} + 0.3EE_{DY} + 0.3EE_{DZ}$ $DL + LL + 0.3EE_{DX} + EE_{DY} + 0.3EE_{DZ}$ $DL + LL + 0.3EE_{DX} + 0.3EE_{DY} + EE_{DZ}$	$DL + \alpha LL + EE_{DX} + EE_{DY} + EE_{DZ}$
	MASONRY STRUCTURES		
3	**Regular Structures**		
	3.1 Horizontal shaking effects		
	Combinations specified in CED 39(22343)	$DL + 0.67\ LL + EE_{DX}$ $DL + 0.67\ LL + EE_{DY}$	$DL + 0.67\ \alpha\ LL + EE_{DX} + EE_{DY} + EE_{DZ}$
	3.2 Horizontal and vertical shaking effects		

	Combinations specified in CED 39(22343)	$DL + 0.67\ LL + EE_{DX} + EE_{DZ}$ $DL + 0.67\ LL + EE_{DY} + EE_{DZ}$	$DL + 0.67\ \alpha\ LL + EE_{DX} + EE_{DY} + EE_{DZ}$
4	**Irregular Structures**		
	4.1 Horizontal shaking effects		
	Combinations specified in CED 39(22343)	$DL + 0.67\ LL + EE_{DX} + 0.3EE_{Dy}$ $DL + 0.67\ LL + 0.3EE_{DX} + EE_{Dy}$	$DL + 0.67\ \alpha LL + EE_{DX} + EE_{DY}$
	4.2 Horizontal and vertical shaking effects		
	Combinations specified in CED 39(22343)	$DL + 0.67\ LL + EE_{DX} + 0.3EE_{DY} + 0.3EE_{DZ}$ $DL + 0.67\ LL + 0.3EE_{DX} + EE_{DY} + 0.3EE_{DZ}$ $DL + 0.67\ LL + 0.3EE_{DX} + 0.3EE_{DY} + EE_{DZ}$	$DL + 0.67\ \alpha\ LL + EE_{DX} + EE_{DY} + EE_{DZ}$

5.3.3 *Methods of Analysis*

Two methods of structural analysis are admissible, which are described as specified in **5.3.2.1** and **5.3.2.2**, using the analytical model prepared as per **5.3.1**.

5.3.3.1 *Linear analysis*

This method shall be employed in the code compliance evaluation of all structures. The structure shall be considered to behave linearly, and hence no nonlinear hinges are required to be modelled.

5.3.3.2 Nonlinear analysis

This method shall be required in the detailed evaluation of all structures. Two cases of structures are envisaged and shall be considered, namely:

a) Regular structures resting on hard rock stratum, and
b) Rest of them, especially structures resting on soft soil strata, and irregular structures.

The following methods of nonlinear analyses are recommended:

1) Static nonlinear analysis (that is pushover analysis) for both types of structures, and
2) Nonlinear dynamic analysis (that is nonlinear response history analysis) for structures resting on soft soil strata. Incremental nonlinear dynamic analysis method shall not be used for assessing structures as per this standard.

5.3.4 *Recommended Method of Structural Analysis*

Structural analysis shall be performed as per the method specified in Table 3 under the action of the loads specified as per earthquake load combinations specified in **5.3.2** corresponding to the levels of earthquake safety assessment. Also, the output quantities in focus in these assessments are listed in Table 4.

Table 3 Method of structural analysis to be employed in Assessment and Retrofit of structures of masonry and concrete buildings
(*Clause* 5.3.4)

Level of Assessment	Method of Analysis	
	Assessing Earthquake Safety of Existing Structures	Evaluating Earthquake Performance of New Structures compliant with the prevalent standards
(1)	(2)	(3)
1	Not applicable	Not applicable
2	Hand calculations based on principles of mechanics	Not applicable
3	Linear static analysis	
4		
4A	Linear static analysis	Not applicable
4B	(1) Nonlinear static analysis for normal and important structures	(a) Nonlinear static analysis for normal and important structures
	(2) Nonlinear dynamic analysis for critical and special structures	(b) Nonlinear dynamic analysis for critical and special structures

Table 4 Inputs and expected outcomes of structural analysis employed in Assessment and Retrofit of structures
(*Clause* 5.3.4)

Level of Quantitative Assessment	Factors	Method of structural analysis
(1)	(2)	(3)
Level 3 Basic Quantitative (code compliance) Evaluation		
All Structures	Input 1) No Soil-Structure Interaction Output 1) Initial Stiffness 2) Design Strength of Members	Linear Static Analysis
Level 4 Detailed Quantitative (nonlinear) Evaluation		
4A for All Regular Structures resting on	Input 1) No Soil-Structure Interaction, and 2) Equivalent Static Loads Output	Nonlinear Static Analysis Pushover Analysis

hard rock stratum	1) Initial Stiffness of Structure, and 2) Design Strength of Members,	
4B for All Structures, especially those resting on soft soil strata, and Irregular Structures	Input 1) Soil-structure Interaction, 2) Irregularities of structures, and 3) Monotonic loading, or Cyclic shaking Output 1) Envelope backbone curve and hysteresis loops up to ultimate load, 2) Initial stiffness of structure, 3) Ultimate strengths of members, 4) Ultimate deformation demand (plastic rotation demand) on members compared with critical limit states of the inelastic member behaviour, and 5) Collapse mechanism of structure	Nonlinear static analysis Pushover analysis For normal and important structures Nonlinear dynamic analysis Nonlinear Response history analysis For critical and special structures

5.4 Earthquake Capacity

The earthquake capacity of structures and their members shall be estimated as specified hereunder for the different levels of assessment. In the estimation of design strengths of members and of soil systems, the prevalent Limit State Method shall be used for concrete, prestressed concrete, and steel structural members, and Working Stress Method for masonry structural members and soil systems.

5.4.1 *Level 2 Preliminary Quantitative (Hand-Calculation) Evaluation*

In general, the lateral base shear capacity of the structure (estimated as a summation of the lateral shear capacity of its constituent vertical members) shall be estimated using individual member capacities estimated as per the relevant Indian Standard depending on the material type, namely IS 1905 in masonry structures, IS 456 in concrete structures, and IS 800 in steel structures.

5.4.1.1 *Uncertainty*

In the assessment and estimation of the structural capacities, if information of the existing structure is not available regarding:

a) Current strengths of materials if testing is not possible to capture the in-situ strengths of materials in some or all members,
b) Details of reinforcement in masonry and concrete structures, or
c) Details of cross-sections of structural steel in the members.

The strengths given in the standards applicable at the time of construction of the structure and the likely practices may be used, but with the application of the knowledge factors that account for the uncertainty in the required information and

discount the design strengths. The knowledge factors to be used in shall be taken as specified in IS 13935 (Part 2 to Part 11) depending on the structure type.

5.4.2 *Level 3 Basic Quantitative (Code Compliance) Evaluation*

The design strengths of members and structure shall be estimated as per the relevant Indian Standard depending on the material type, namely IS 1905 in masonry structures, IS 456 in concrete structures, and IS 800 in steel structures.

The required information of the existing structure shall be ascertained through in-situ field testing and measurements regarding:

a) Current strengths of materials (masonry, concrete, and reinforcing & structural steel), and
b) Details of geometry and reinforcement in masonry and concrete structures, or details of cross-sections of members in steel structures.

5.4.3 *Level 4 Detailed Quantitative (Nonlinear) Evaluation*

5.4.3.1 The actual strengths of members and structure shall be estimated by basic principles of mechanics, namely:

a) Equilibrium equations (between external loads and internal resistance),
b) Constitutive laws (of constituent materials), and
c) Compatibility conditions (between the nodes of the structure, and between the nodes of the structure and its supports), in case of masonry, concrete and steel structures.

5.4.3.2 The required information of the existing structure shall be ascertained through in-situ field testing and measurements regarding:

a) Current stress-strain curves of materials (masonry, concrete, and reinforcing and structural steel) based on coupons extracted from the structure from structurally less significant members, which does not cause any distress to the structure (a clear method shall be ascertained for reinstating the loss of capacity or cross-sections prior to extracting the testing sample, and the same shall be implemented as soon as the sampling portion of the test is completed),
b) Details of reinforcement in masonry and concrete structures,
c) Details of cross-sections of the members in steel structures, and
d) Stress-strain curves and modulus of subgrade reaction of layers of soil underneath the structure.

5.5 Acceptance Criteria

The earthquake demand on members and the structure estimated as per **5.3** shall be less than the earthquake capacity of members and the structure estimated as per **5.4**.

6 RETROFIT FOR EARTHQUAKE RESISTANCE

Retrofit for improved performance in future earthquakes shall be achieved by one of several options given in this clause. The chosen retrofit measure shall increase the redundancy also of the lateral load resisting system, and thereby improve overall stability of the building and avoid collapse.

Retrofit of structures shall be in accordance with the provisions of **6.1** and **6.2**.

6.1 Principles of Retrofitting

The principles enunciated hereunder shall guide all retrofit effort.

6.1.1 *Sequence of Retrofitting*

When the structure as a whole and its members are found to be deficient, the sequence of adopting retrofit measures should be such that:

a) First the deficiencies of the whole structure are mitigated (if not eliminated), and
b) Then the deficiencies of the members are mitigated (if not eliminated).

6.1.2 *Types of Retrofitting*

The measures of retrofit intervention employed shall be:

a) Minimal to make retrofit economically feasible,
b) Reversible to the extent possible in all structures;
c) Snug with the existing structure.

6.2 Strategies of Retrofitting

Three strategies are available for use in the structure, either individually or in combination, namely:

a) Introduce additional structural elements towards improving the lateral structural configuration, initial lateral stiffness and lateral strength,
b) Reduce earthquake demand, and
c) Enhance earthquake capacities.

6.2.1 *Introduce Additional Structural Elements*

The main intent here shall be to:

a) Enhance load paths (using vertical elements with large cross-sectional area, like structural walls) or/and
b) Create additional alternate load paths (using vertical or inclined elements with large cross-sectional area, like buttressing, braces, and structural walls), to

transfer the inertia forces directly (to the extent possible) from the locations where they are generated to the foundation.

6.2.2 *Reduce Earthquake Demand*

Any of the following measures may be employed to reduce earthquake demand:

a) Reduce the mass (if possible) of the structure by changing the use of the structure,
b) Increase damping and filter the input ground motion reaching the structure by employing base isolation devices as per IS 1893 (Part 6).
c) Increase the energy dissipation capacity of the structure by introducing energy dissipation devices.

6.2.3 *Enhance Earthquake Capacity*

Specific measures should be employed to enhance earthquake capacity of the structure (namely the overall lateral stiffness, the overall lateral strength, the overall lateral deformability and thereby overall lateral ductility) and of its members (namely their stiffness, strength, deformability and ductility). It may be relatively easy to enhance the lateral stiffness and lateral strength of the structure but may not be possible to enhance the deformability and ductility of an existing structure with economical retrofit measures.

6.3 Quality Control and Quality Assurance in Retrofitting Projects

Steps shall be taken to put in place systems to ensure quality control and quality assurance in retrofitting projects. In particular:

a) Quality control shall be undertaken by competent persons undertaking planning, designing and executing the retrofit of the existing structure, and
b) Quality assurance shall be undertaken by a group of independent competent persons overseeing planning, designing and executing the retrofit of the existing structure.

The number of persons and size of each team shall depend on the size and category of the structure.

6.3.1 *Compliance with Indian Standards*

All technical proposals (including retrofit interventions) and actions shall comply with the relevant Indian Standard in force, including applicable parts of IS 1893, IS 13920 and IS 13935.

6.3.2 *Selection of Materials, Processes and Services*

Special attention shall be paid to:

a) Determining temporary supports and propping systems for retrofitting,
b) Testing materials as per specifications laid down in the standards, and
c) Selecting competent contractor.

7 ARCHITECTURAL ELEMENTS AND UTILITIES

7.1 Strategy

The following strategy shall be adopted to assess the AEUs, and retrofit the same:

a) Separate the AEUs into three sets as per CED 39(22343), namely:

    1) AEUs that can be protected by the non-engineered method, hereinafter called non-engineered AEUs (NE-AEUs),
    2) AEUs that may be protected by the pre-engineered method or the engineered method, hereinafter called pre-engineered AEUs (PE-AEUs) and
    3) AEUs that need to be protected by the Engineered Method, hereinafter called Engineered AEUs (E-AEUs) and

b) Adopt the following assessment methods:

    1) Qualitative assessment as per **7.2.1** of NE-AEUs, and
    2) Quantitative assessment as per **7.2.2** of PE-AEUs and E-AEUs, and identify the vulnerable AEUs.

c) Reduce liable architectural elements by dismantling as many vulnerable AEUs as possible that can be done away with, and retrofit the remaining by following methods:

    1) *Non-engineered retrofit of NE-*AEUs, and
    2) *Engineered retrofit of PE-*AEUs and *E-AEUs*.

7.2 Assessment

The select AEUs that pass the filter at **7.1(c)** alone shall be subjected to one or both of the assessments specified hereunder.

7.2.1 *Level 1: Qualitative Assessment*

The select AEUs shall be examined as given below:

a) NE-AEUs shall be evaluated based on common sense, and
b) PE-AEUs and E-AEUs shall be evaluated to examine major deficiencies in their safety protection system adopted; and

7.2.2 *Level 2: Quantitative Assessment:*

PE-AEUs and E-AEUs shall be evaluated based on the methods specified in **8.3, 8.4** and **8.5** of CED 39(22343).

7.3 Retrofit

7.3.1 *Non-Engineered Method*

This method shall be adopted for select AEUs that can be protected by the *Non-Engineered Method* as specified in **8** of CED 39(22343).

7.3.2 *Pre-Engineered and Engineered Methods*

When retrofitting, both PE-AEUs and E-AEUs shall be treated the same, and the quantitative method adopted to identify the retrofit measure needed.

ANNEX A
(*Clause* 2)
LIST OF REFERED STANDARDS

IS No.	*Title*
IS 456 : 2000	Plain and reinforced concrete (*fourth revision*)
IS 800 : 2007	General construction in steel (*second revision*)
IS 875	Design loads (other than earthquake) for buildings and structures:
(Part 1 : 1987)	Dead loads (*second revision*)
(Part 2 : 1987)	Imposed loads (*second revision*)
(Part 3 : 2015)	Wind loads (*third revision)*
(Part 4 : 1987)	Snow loads (*second revision)*
(Part 5 : 1987)	Special loads and load combinations (*second revision*)
IS 1343 : 2017	Prestressed concrete (*second revision*)
CED 39(22343)	Design earthquake hazard and criteria for earthquake resistant design of structures (*fifth revision*) Part 1 General provisions [*seventh revision* of IS 1893 (Part 1)]
CED 39(22345)	Design earthquake hazard and criteria for earthquake resistant design of structures (*fifth revision*) Part 2 Buildings [*seventh revision* of IS 1893 (Part 1)]
IS 1905 : 1987	Structural use of unreinforced masonry (*third revision*)
IS 18289 : 2023	Post-earthquake safety assessment of buildings — Guidelines
CED 39(25407)	Specifications for earthquake-resistant design and detailing of structures Part 1 General Provisions (*second revision* of IS 13920)
CED 39(25408)	Specifications for earthquake-resistant design and detailing of structures Part 2 Buildings (*second revision* of IS 13920)
CED 39 (26742)	Earthquake safety assessment and retrofitting of structures (*second revision*) Part 2 Buildings

ANNEX A
(*Foreword*)

(*Composition of the Committee will be added after finalization*)

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