BUREAU OF INDIAN STANDARDS

9, Bahadur Shah Zafar Marg, New Delhi 110 002

व्यापक परिचालन मसौदा

हमारा संदर्भ : सीईडी 39/टी-27 **16 जून 2020**

तकनीकी समिति : <u>भूकंपीय इंजीनियरिंग विषय समिति, सीईडी 39 के सभी सदस्य</u>

प्राप्तकर्ता :

1 सिविल इंजीनियरी विभाग परिषद् के रूचि रखने वाले सदस्य

2 सीईडी 39 के सभी सदस्य

3 रूचि रखने वाले अन्य निकाय

महोदय(यों),

निम्नलिखित मानक का मसौदा संलग्न है :

प्रलेख संख्या	शीर्षक
सीईडी 39 (15280)	संरचनाओं के भूकंपरोधी डिज़ाइन के लिए मानदंड भाग 6 : आधार पृथक भवन [आई एस 1893 (भाग 6)] **का भारतीय मानक मसौदा ICS No. 91.120.25**

कृपया इस प्रलेख का अवलोकन करें और अपनी सम्मतियाँ यह बताते हुए भेजे कि यदि ये मानक के रूप में प्रकाशित हो तो इस पर अमल करने में आपके व्यवसाय अथवा कारोबार में क्या कठिनाइयाँ आ सकती हैं।

सम्मतियाँ भेजने की अंतिम तिथि: **<u>15 अगस्त 2020</u>**

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यह प्रलेख भारतीय मानक ब्यूरो की वैबसाइट www.bis.gov.inपर भीउपलब्ध है।

धन्यवाद ।

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(संजय पंत)

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सलंग्न: उपरिलिखित

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DRAFT IN WIDE CIRCULATION

DOCUMENT DESPATCH ADVICE

Reference	Date
CED 39/T-27	**16 June 2020**

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 (& all its Subcommittees, Panel & Working Groups)
3. All others interests

Dear Sirs,

Please find enclosed the following document:

Doc. No.	Title
CED 39 (15280)WC	Draft Indian Standard Criteria for Earthquake Resistant Design of Structures : Part 6 Base Isolated Buildings [IS 1893 (Part 6)] ICS No. 91.120.25

Kindly examine the 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 Standards.

Last date for comments: **15 August 2020**.

Comments, if any, may please be made in the enclosed format and mailed to the undersigned at the above address. We will appreciate receiving your comments through e-mail at **ced39@bis.gov.in**.

In case no comments are received or comments received are of editorial nature, you may kindly permit us to presume your approval for circulating the same in wide circulation for a period of two months. However, in case comments of technical nature are received, then it may be referred to the concerned Group/Sectional Committee for further necessary action if so desired by the Chairman, Sectional Committee.

Thanking you,

Yours faithfully,

Sd/-

(Sanjay Pant)
Scientist 'F' & Head (Civil Engg)

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 in MS WORD format to ced39@bis.org.in shall be appreciated**.]

Doc. No.:CED 39 (15280)WC **BIS Letter Ref**: CED 39/T-27 **Dated**: 16 Jun 2020

Title: Criteria for Earthquake Resistant Design of Structures: Part 6 Base Isolated Buildings *[IS 1893 (Part 6)]*

Name of the Commentator *or* **Organization**: ______________________________

Clause No. with **Para No.** or **Table No.** or **Figure No.** commented *(as applicable)*	**Abbreviation of the commentator**	**Type of comment Gen / Te** (general OR technical)	**Comments/Modified Wordings**	**Justification for the Proposed Change**

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DRAFT Indian Standard
CRITERIA FOR EARTHQUAKE RESISTANT DESIGN OF STRUCTURES
PART 6 BASE ISOLATED BUILDINGS

Earthquake Engineering Sectional Committee, CED 39

FOREWORD

(Formal clauses will be added later)

Large part of land area of India is prone to moderate to severe earthquake shaking, and there are many critical structures built in these areas. Hence, earthquake resistant design is essential. In contrast to conventional approach of earthquake resistant design, wherein damage is expected in select structural members, this Standard attempts to reduce the extent of damage through base-isolation of buildings.

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 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 was split into five parts. The other parts in the series are:

Part 1 General provisions and buildings
Part 2 Liquid retaining tanks – Elevated and ground supported
Part 3 Bridges and retaining walls
Part 4 Industrial structures, including stack-like structures
Part 5 Dams and embankments *(under preparation)*

Unless stated otherwise, provisions of this standard are to be read necessarily in conjunction with the general provisions as laid down in IS 1893 (Part 1).

This standard (Part 6) covers the requirements of base-isolation of buildings, or portions thereof, to be designed and constructed to mitigate the effects of earthquake induced displacements and forces. The provisions of this standard are applicable only to monolithic RC buildings and conventional steel frame buildings, and not to buildings with flat slabs or with precast structural elements. Also, the provisions of this standard are applicable to existing buildings that are base-isolated. The standard provides guidelines for estimation of design lateral force and displacement to be considered in the design of buildings with base-isolation system, method of structural analysis to be adopted in the analysis of such buildings, and guidelines for testing of the seismic isolation devices that are used in such buildings.

The underlying philosophy of this standard is that a base-isolated building will perform better than a conventional building (with fixed-base) when subjected to moderate to severe earthquake shaking. It is not the intent of this standard to reduce the construction cost, but it attempts to minimize damage to base-isolated buildings and their contents.

For buildings that are not explicitly covered by this standard, reference to specialist literature may be made. Such base-isolated buildings shall require full dynamic analysis to be carried out to ascertain the targeted performance level. For identifying and ascertaining the proximity of the site of the base-isolated building to an active or potentially active fault, reference may be made to *Bhukosh* gateway for geoscientific data of Geological Survey of India.

This standard (Part 6) may also be used for the design of base-isolation system for existing buildings, for the purpose of seismic retrofitting; for all such cases full dynamic analysis is to be carried out to ascertain the targeted performance level.

In the preparation of this standard, assistance has been derived from the following publications:

BS EN 15129:2018 Anti-seismic devices, British Standards Institution

2018 International Building Code, International Code Council

ASCE-SEI 7-16 Minimum Design Loads and Associated Criteria for Buildings and Other Structures, American Society of Civil Engineering

ISO 22762-1:2018 Elastomeric seismic-protection isolators — Part 1: Test methods, International Standards Organisation

2009 NEHRP Recommended Seismic Provisions: Design Examples FEMA P-751 / September 2012, Federal Emergency Management Agency

Notification 2009 — Structural calculation procedure for buildings with seismic isolation, Ministry of Construction, Japan

Notification 1446 of year 2000 — Standard for specifications and test methods for seismic isolation devices, Ministry of Construction, Japan

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

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DRAFT INDIAN STANDARD
CRITERIA FOR EARTHQUAKE RESISTANT DESIGN OF STRUCTURES
PART 6 BASE ISOLATED BUILDINGS

1 SCOPE

1.1 This standard provides requirements for base-isolation of buildings, their design and construction to resist earthquake induced effects (namely displacements and forces) as specified herein. The provisions of this standard are applicable only to:

a) Conventional monolithic RC buildings and steel frame buildings; and
b) Buildings with base-isolation devices, all of which are located at the same level, along the height of the building (and not at multiple levels).

It does not apply to buildings with flat slabs or precast structural elements.

1.2 This standard suggests the estimation of design earthquake lateral forces and displacements to be considered and the method of structural analysis to be adopted, in the design of buildings with base-isolation systems, and the specifications and method of testing of the base isolators that are proposed to be used in such buildings.

1.3 The underlying philosophy of the provisions of this standard is that seismically isolated buildings designed using this Standard shall perform better than the corresponding fixed-base buildings when subjected to ground motions expected in the applicable seismic zone, especially in terms of damage in the structural and non-structural elements in the superstructure above the level of isolation devices.

1.4 Buildings that do not follow the requirements of this standard, evaluation and design of existing building for incorporating base-isolation system, and those buildings that are not covered by this standard shall require full dynamic analysis to ascertain the targeted performance level.

2 REFERENCES

The Standards listed below contain provisions which, through reference in this Standard, 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 listed below.

IS Number	Title
456 : 2000	Code of practice for plain and reinforced concrete (*fourth revision*)

800 : 2007	Code of practice for general construction in steel (*third revision*)
875 (Part 1) : 1987	Code of practice for design loads (other than earthquake) for buildings and structures: Part 1 Dead loads (second revision) − Unit weights of building material and stored materials (*second revision*)
(Part 2) : 1987	Part 2 Imposed loads (*second revision*)
(Part 3) : 2015	Part 3 Wind loads (*third revision*)
1893 (Part 1) : 2016	Criteria for Earthquake Resistant Design of Structures Part 1: General Provisions and Buildings *(Sixth revision)*

3 TERMINOLOGY

For the purpose of this standard, the following terms and the corresponding definition shall apply.

3.1 Base Level – It is the top level of the base isolators placed in the building.

3.2 Base-Isolation System – The collection of special elements, including all individual isolators and their connections to the adjoining structural elements, which transfer forces due to gravity and forces induced during earthquake shaking, between the structural elements of the building above and below the base-isolation system.

3.3 Base Isolator – The horizontally flexible and vertically stiff structural element of the base-isolation system provided in the building, which is designed to permit a specified value of lateral displacement at the base of the building during earthquake shaking, and to dissipate energy under cyclic loading.

3.4 Design Displacement – The lateral displacement, excluding additional displacement due to actual and accidental torsion, to be considered in the design of the base-isolation system (or one of its isolators thereof) of a building to resist earthquake shaking.

3.5 Effective Damping – The equivalent viscous damping (as percentage of critical damping) of the base-isolator, obtained from its experimental characteristic cyclic loop at the amplitude of interest, which is considered in design of the base-isolator.

3.6 Effective Stiffness – The secant stiffness of the characteristic cyclic loop of the base-isolator at the amplitude of interest, which is considered in design of the base-isolator.

3.7 Load Transfer System – The collection of all structural elements through which the loads (namely axial forces, shear forces, bending moments and torsional moments) flow, which are generated by gravity, earthquake shaking or other load effects on the building. Such system includes segments of columns and connecting beams above the base-isolation system.

3.8 Total Design Displacement – The lateral displacement, plus additional displacement due to actual and accidental torsion, to be considered in the design of the Base-Isolation System (or one of its isolators thereof) of a building to resist earthquake shaking.

4 SYMBOLS

For the purpose of this standard, the following letter symbols shall have the meaning indicated against each:

B	Plan dimension of the building, above the base level, perpendicular to the considered direction of earthquake shaking
D	Plan dimension of the building, above the base level, along the considered direction of earthquake shaking
DL	Dead load on the building as per IS 875 (part 1)
EQ	Design earthquake load as per IS 1893 (part 1), unless otherwise specified in this standard
E	Actual eccentricity measured in plan between the centre of mass of the building above the base level and the centre of resistance of the base-isolation system, plus accidental eccentricity (5 percent of the maximum building dimension perpendicular to the considered direction of earthquake shaking)
$F^{+}_{\max}$	Force in a base-isolator unit in the forward direction along the considered direction of earthquake shaking, during a single cycle of prototype testing, at a displacement amplitude of $\Delta^{+}_{\max}$
$F^{-}_{\max}$	Force in a base-isolator unit in the backward direction along the considered direction of earthquake shaking, during a single cycle of prototype testing, at a displacement amplitude of $\Delta^{-}_{\max}$
h_i	Height of floor i from the base level
I	Importance factor to be used in the estimation of design earthquake lateral force of the building, as given in table 3 of is 1893 (Part 1)
$K_{eff,\max}$	Maximum effective stiffness of the base-isolation system at the design displacement along the considered direction of earthquake shaking
$K_{eff,\min}$	Minimum effective stiffness of the base-isolation system at the design displacement along the considered direction of earthquake shaking
$k_{initial}$	Initial stiffness of the base-isolator along the considered direction of earthquake shaking
$k_{eff,\max}$	Maximum effective stiffness of the base-isolator estimated along the considered direction of earthquake shaking, in a single cycle during prototype testing of the base-isolator out of the first three repeated cycles of loading in the design displacement range $[-\Delta_{\text{ID}}, +\Delta_{\text{ID}}]$ of the base isolator
$k_{eff,\min}$	Minimum effective stiffness of the base-isolator estimated along the considered direction of earthquake shaking, in a single cycle during prototype testing of the base-isolator out of the first three repeated cycles of

	loading in the design displacement range $[-\Delta_{ID}, +\Delta_{ID}]$ of the base isolator
LL	Imposed load on the building as per IS 875 (Part 2)
Q_i	Design floor lateral forces to be applied at floor level i of the building above the base level
R	Response reduction factor of a fixed base building
R_I	Response reduction factor of a base-isolated building
$\left(\frac{S_a}{g}\right)_{T_{eff}}$	Design horizontal spectral acceleration coefficient (corresponding to 5 percent damping) at a natural period of T_{eff} , as obtained from Fig. 2 of IS 1893 (Part 1)
T	Fundamental lateral translational natural period (in seconds) of the fixed-base building (without a base-isolation system)
T_{eff}	Effective natural period (in seconds) estimated of base-isolated building at the design displacement in the considered direction of earthquake shaking
$T_{eff,\max}$	Maximum value of effective natural period (in seconds) T_{eff} obtained from experiments of the base-isolated building at the design displacement in the considered direction of earthquake shaking
$T_{eff,\min}$	Minimum value of effective natural period (in seconds) T_{eff} obtained from experiments of the base-isolated building at the design displacement in the considered direction of earthquake shaking
T_S	Site period is the fundamental natural period of the site for shaking in the horizontal direction.
V_B	Design earthquake lateral force to be used in the design of the structural elements below the base-isolation system in the direction of shaking
V_S	Design earthquake lateral force to be used in the design of the structural elements above the base-isolation system in the direction of shaking
V_S^e	Elastic maximum base shear without using the response reduction factor
W_i	Effective seismic weight of floor i of the building above the base isolator system
W_j	Effective seismic weight of floor j of the building above the base isolator system
W'	Effective seismic weight of the building above the base isolator system
y	Distance between the centre of resistance of the all base-isolators together and location of the base isolator in focus, measured perpendicular to the considered direction of earthquake shaking
Z	Seismic zone factor, as given in table 2 of IS 1893 (Part 1)
β	Multiplier to be applied on 5 percent damping, corresponding to effective damping of the base-isolator in focus
β_{eff}	Effective damping in the base-isolation system at the design displacement
β_{eff}^i	Effective damping in the base-isolator i estimated through prototype testing of the base-isolator
Δ_{ID}	Design displacement of a base-isolator unit, including both translational displacement at the centre of resistance, and the component of torsional displacement in the considered direction of earthquake shaking
$\Delta_{\max}^+$	Maximum displacement in a base-isolator in the forward direction along the considered direction of earthquake shaking, in a single cycle during prototype testing of the base-isolator
$\Delta_{\max}^-$	Maximum displacement in a base-isolator in the backward direction along the considered direction of earthquake shaking, in a single cycle during prototype testing of the base-isolator
Δ_{SD}	Design displacement of the base-isolation system at the centre of

	resistance in the considered direction of earthquake shaking

When other symbols are used, they are explained at the appropriate place. Unless otherwise specified, all dimensions are in millimetres (mm), loads in Newton (N) and stresses in Megapascal (MPa) and period in second (s).

5 GENERAL REQUIREMENTS

5.1 The base-isolation system employed shall:

a) be stable at the total design displacement,
b) offer increased resistance with increase in displacement,
c) not sustain significant degradation of its properties under repeated cyclic loading, and
d) possess well-established and reproducible engineering properties (namely effective stiffness and damping).

Items (c) and (d) above shall be in compliance with requirements given under **7**.

A base-isolated building shall be designed considering seismic zone, site characteristics, vertical acceleration, section properties (for example, gross section properties), occupancy, configuration, structural system and height in accordance with clauses provided for the same in IS 1893 (Part 1). In general, base-isolated buildings shall not be built when the site period T_S is 0.8 s or more.

5.2 Elements of a Base-Isolated Building

The design requirements of this standard distinguish between the four sub-systems of a base-isolated building (see Fig. 1):

a) Superstructure, which includes elements of the structure above the Base Level;
b) Base-Isolation System, which includes all individual base isolators and their connection elements;
c) Substructure, which includes structural elements of the structure below the Base Level and above the Foundation; and
d) Foundation, which includes the foundation structural elements and the soil in contact with the foundation and beyond it up to a depth and width beyond the foundation structural elements as per acceptable principles of soil mechanics and structural dynamics.
e) All base isolator units shall be firmly anchored to the sub-structure and the super-structure. The forces in the connecting elements shall not exceed its design strength as per IS 800 for elements in structural steel, and as per IS 456 for concrete.

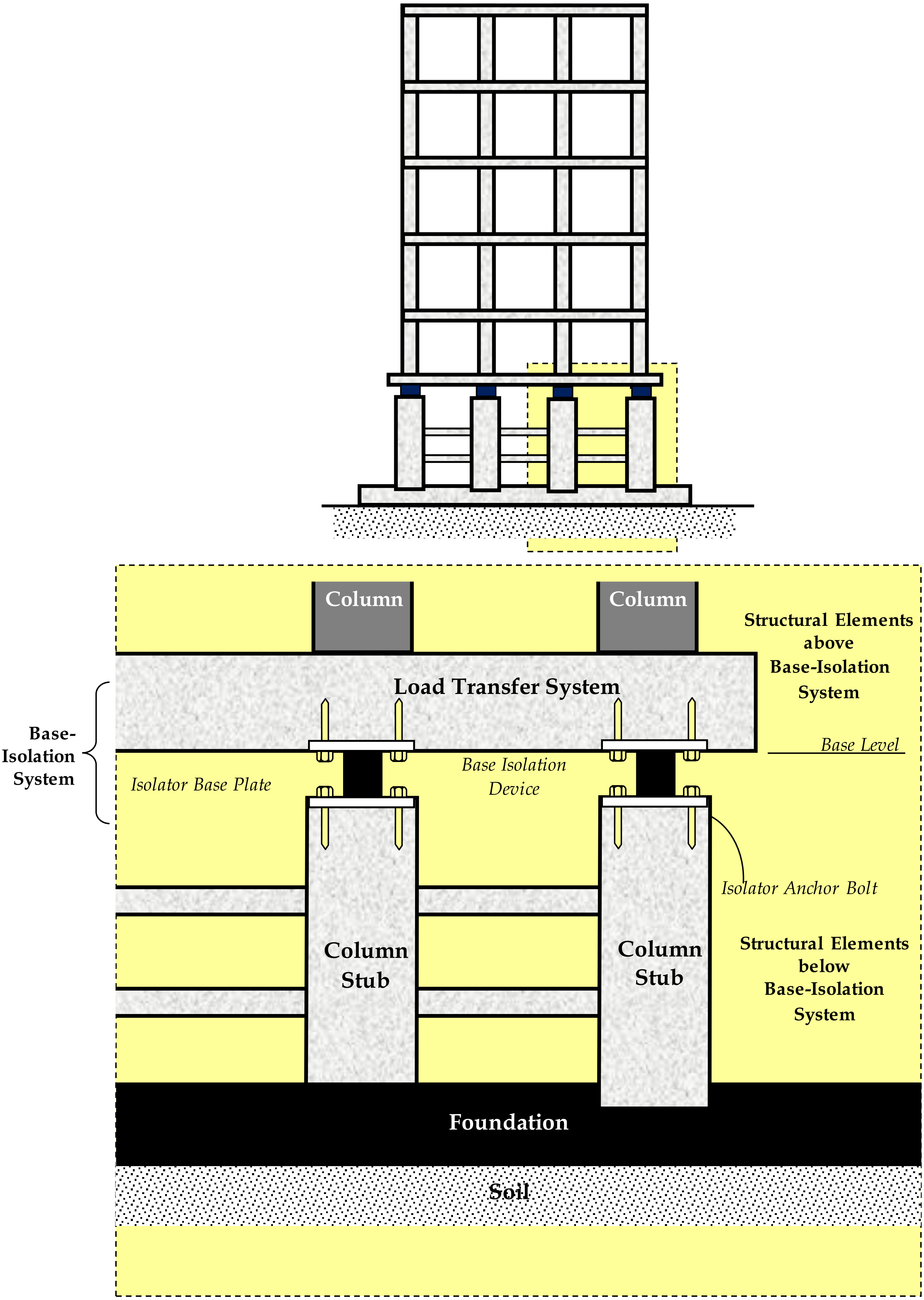

FIG. 1 SECTIONAL ELEVATION OF A BASE ISOLATOR BUILDING

5.3 Stability of the Base-Isolation System

The stability of the Base-Isolators (under the expected vertical loads) shall be verified by both structural analysis and cyclic testing (as per **7.2**), at the total design lateral displacement. A base-isolator is said to be in uplift condition, if it develops tensile force in the axial vertical direction under any load combination. No tensile load shall be permitted in any base-isolation device.

Whether or not uplift is likely to occur in a base-isolated building with any type base isolator system, time history analysis shall be performed (including the effect of vertical earthquake ground shaking).

Under the load combinations that involve earthquake load effects, the factor of safety against overturning shall be at least 1.4 and that against sliding at least 1.2. For the purposes of the estimation of the above factors of safety, the earthquake load effects in the superstructure shall be estimated using elastic maximum base shear $V_S^e = ZI\left(\frac{S_a}{g}\right)_{T_e} W'$, without using the response reduction factor as given by:

$$V_S^{e,\max} = ZI\left(\frac{S_a}{g}\right)_{T_{eff}} W'.$$

5.4 Configuration Requirements

The structural configuration of a base-isolated building shall be assessed to be regular or irregular based on of the portion of the building above the base-isolation system, in accordance with the provisions of IS 1893 (Part 1). The provisions of this standard shall be applicable only for a base-isolated buildings that are regular as per IS 1893 (Part 1). In addition, the in-plan placement of the shall be such that the centre of resistance of all base-isolators in each of the two horizontal plan directions shall coincide with the corresponding centre of resistance of the structural elements below the base-isolation system along that direction.

5.5 Residual Displacement

Base-Isolated Building may sustain residual drift at the level of isolator. Services and utilities that cross the isolation interface shall be designed and detailed to accommodate the residual drift without disruption in their functionality.

5.6 Separation from the Adjacent Building and Location of Moat

The wall of the moat of a base-isolated building shall be placed at a distance equal to the design displacement Δ_{ID} as estimated in **6.2.4**.

A base-isolated building shall be separated from an adjacent building (base-isolated or otherwise) by a distance at least equal to the design displacement Δ_{ID} (as estimated in **6.2.4**) plus the separation distance specified in **7.11.3** of IS 1893 (Part 1).

5.7 Design Acceleration Spectrum

The design acceleration spectral value of the base-isolated building shall be taken as per **6.4** of IS 1893 (Part 1).

5.8 Location of Base Isolators

The base isolator units shall be placed such that there is adequate space for inspection, both during installation and later for inspection. Necessary provisions shall be incorporated in the general design of the building to ensure that there is no possibility of damage to the base isolator units due to exposure to flooding or freezing, as the case may be.

6 METHODS OF ANALYSIS

6.1 Two methods of structural analysis may be employed for structural analysis of base-isolated buildings to arrive at the design lateral displacement and the design lateral force of the components of the isolation system and the superstructure, namely:

a) Linear equivalent static single mode method, and
b) Linear equivalent static multi-mode method (or linear response spectrum method).

Also, non-linear response history analysis (or non-linear time history analysis) shall be used for checking the adequacy of the design of the base-isolated buildings, as specified in IS 1893 (Part 1).

6.2 Linear Equivalent Static Single Mode Method

The linear equivalent static single mode (LESSM) method is a linear static analysis procedure, which uses effective stiffness and effective damping properties in the modelling of base isolators, and first translational mode of the building associated with the base isolator alone deforming without any deformation in the superstructure. This method assumes most of the lateral displacement to occur in the base-isolation system. The method is used for design of both the superstructure and base-isolation system of buildings that meet the conditions given in **6.2.1**. The results of this method of analysis stand as the lower-bound limit to the results of linear equivalent static multi-mode (LESMM) Method as per **6.3**, when used.

6.2.1 *Conditions for Use of this Method*

The method can be used for design of a base-isolated buildings, without performing dynamic analysis to confirm the acceptable behaviour, if the building satisfies all of the following:

a) Not located within 20 km from any known active fault.
b) Resting on Soil Type I or Soil Type II, as per IS 1893 (Part 1).
c) Less than 20 m in height, above the base-isolation interface.
d) Has effective natural period T_{eff} equal to or less than 3.0 s.

e) Has effective natural period T_{eff} along a considered direction of shaking more than three times the fundamental natural period T along a same direction of shaking of the corresponding Fixed-Base Building.
f) The base-isolation system meets all of the following 3 criteria:
   1) Its effective stiffness at the design displacement is more than one-third of its effective stiffness at 20 percent of the design displacement;
   2) It is capable of re-centering after the earthquake; and
   3) It possesses force-displacement characteristic independent of the rate of cyclic loading.
g) Located in seismic zone II only.
h) Confirms to configueration regurity criteria as per IS 1893 (Part 1).

6.2.2 *Design Displacement*

The Base-Isolation System shall be designed and constructed to withstand a minimum lateral earthquake displacement of Δ_{SD} along each of its principal plan direction, and estimated by:

$$\Delta_{SD} = \left[Z \left(\frac{S_a}{g} \right)_{T_{eff,\max}} \beta \right] g \frac{T_{eff,\max}^2}{4\pi^2},$$

where damping multiplier is given by:

$$\beta = \sqrt{\frac{0.10}{0.05 + \beta_{eff}}}.$$

6.2.3 *Effective Natural Period of the Base-Isolated Building*

The maximum effective natural period $T_{eff,\max}$ and minimum effective natural period $T_{eff,\min}$ of the base-isolated building at the design displacement along each of its principal plan direction shall be determined using its effective minimum stiffness $K_{eff,min}$ and effective maximum stiffness $K_{eff,max}$, respectively, of the entire set of the base isolators provided in the building, derived from the hysteretic force-displacement loops of the testing of typical base isolators used, when subjected to cyclic inelastic excursion in the design displacement range $[-\Delta_{ID}, +\Delta_{ID}]$ of the base isolator, shall be estimated as:

$$T_{eff,\max} = 2\pi \sqrt{\frac{W'}{gK_{eff,\min}}}, \text{ and}$$

$$T_{eff,\min} = 2\pi \sqrt{\frac{W'}{gK_{eff,\max}}}.$$

6.2.4 *Total Design Displacement*

A *base-isolator* of the base-isolation system shall be designed to sustain additional displacement owing to actual and accidental torsion arising from the spatial distribution of the lateral stiffness of the base isolators distributed in plan and the most disadvantageous location of mass eccentricity. The base-isolator of a base-isolated building with uniform spatial distribution of lateral stiffness shall be designed to resist a design displacement Δ_{ID} of the base isolator given by:

$$\Delta_{ID} = \Delta_{SD}\left[1+\left(\frac{12e}{B^2+D^2}\right)y\right].$$

Δ_{ID} estimated as above shall not be less than 1.1 times the design displacement Δ_{SD} of the base-isolation system specified in **6.2.2**, provided the base-isolation system is shown by analyses to be capable of resisting torsion accordingly.

6.2.5 *Design Earthquake Lateral Force for the Design of the Components of the Isolation System and of the Structural Elements below the Base-Isolation System*

The components of the base-isolation system and the structural elements below the base-isolation system of a base-isolated building shall be designed to resist along each principal plan direction at least for the design earthquake lateral force V_B estimated by:

$$V_B = K_{eff,\max}\Delta_{SD}$$

6.2.6 *Design Earthquake Base Shear Force of the Superstructure*

The structural elements above the base-isolation system of a base-isolated building shall be designed at least to resist along each principal plan direction the design earthquake base shear force V_S estimated by:

$$V_S = \frac{V_B}{R_I}$$

where

R_I = response reduction factor of a base-isolated building given by:

$$R_I = Min\left[\frac{3}{4}R;\ 2\right],$$

in which R is the response reduction factor specified in table 9 of IS 1893 (Part 1) based on the structural system of the building above the base-isolation system.

The minimum design lateral force V_S along each direction of shaking shall not be less than any of the following:

a) The design earthquake base shear force for a fixed-base structure of effective seismic weight W' and the period equal to $T_{eff,\min}$ of the isolation system, estimated as:

$$V_S = \frac{ZI}{R}\left(\frac{S_a}{g}\right)_{T_{eff,\min}} W'$$

b) The design wind base shear force estimated as per IS 875 (Part 3) corresponding to the design wind load; and

c) 1.5 times the shear force H_A required for activation of the isolation system, estimated as:

$$H_A = \sum_{i=1}^{N_{BI}} \left[\frac{k_{initial,i}\Delta_{y,i}}{1+\left(\dfrac{12e}{B^2+D^2}\right)y_i} \right],$$

where

y_i = Distance between the base isolator i and the centre of resistance at the level of base-isolation, perpendicular to the direction of shaking considered

d) Slip threshold of sliding isolation system.

6.2.7 *Distribution of Design Lateral Force along the Height of the Building above the Base level*

The design floor lateral forces Q_i to be applied at floor level *i* of the building above the base level shall be estimated using the design earthquake base shear force V_S, by:

$$Q_i = V_S \left(\frac{W_i h_i^2}{\sum_{j=1}^{N+1}\left(W_j h_j^2\right)} \right).$$

The summation in the above expression shall include the mass of the base slab also at the top of the beam resting on the isolator system (*see* Fig. 2).

6.2.8 *Drift Limits in the Building above the Base Level*

The maximum inter-storey drift in a base-isolated building above the base level when subjected to design earthquake lateral force V_S specified in **6.2.6** shall not exceed 0.001 times the storey height.

6.3 Linear Equivalent Static Multi-Mode Method or Linear Response Spectrum Method

6.3.1 The linear equivalent static multi-mode method (also called linear response spectrum method) is a linear static analysis procedure, which uses effective stiffness and effective damping properties in the modelling of base isolators, and modes including the first translational mode of the building associated with the base isolator alone deforming and not the superstructure. This method assumes more than one mode of the building to participate (including the mode with most of the lateral displacement to occur in the base-isolation system). The method shall be used for design of both the superstructure and base-isolation system of buildings that do not meet the conditions given in **6.2.1**. When this method of analysis is employed, the design lateral force as per the linear equivalent static multi-mode method given by **6.2** shall stand as a lower bound.

This method of analysis shall be performed using a 3-dimensional model of the complete soil – foundation – base-isolation – superstructure system. Even when a building meets the requirements of **6.2** of this standard, the linear equivalent static multi-mode method may be used for the design of the base-isolated building. Soil shall be modelled when the soil underneath is soft as per IS 1893 (Part 1); the modelling of soil is not necessary when the soil underneath is hard or medium.

Effects of earthquake shaking shall be considered independently along the three principal orthogonal directions of the building, namely:

a) Shaking effect along the plan direction X,
b) Shaking effect along the plan direction Y, and
c) Shaking effect along the vertical direction Z.

The resultant of the earthquake shaking effect along two mutually orthogonal plan directions and along the vertical directions shall be combined to determine the net design earthquake effect, in line with the requirements of **6.4.1, 6.4.2, 6.4.3** and **6.4.4** of IS 1893 (Part 1), and as per acceptable principles of structural dynamics to estimate their combined effects.

6.3.2 *Modelling of Base-Isolated Building*

The structural model of a base-isolated building to be used in structural analysis, when using this method, shall include four sub-systems of the building, namely:

a) the lateral force resisting system of the portion of the building above the base-isolation system,
b) the base-isolation system,
c) the lateral force resisting system of the portion of the building below the base-isolation system, and
d) the soil – foundation sub-system,

each elaborated as per the provisions of this Standard. The said model shall employ linearized force-displacement characteristics of all structural elements of the four sub-systems of the base-isolated building. When employing the linear equivalent static multi-mode method for the purpose of design of the base-isolated building, the maximum displacement of each floor and design forces and displacements in the elements of the earthquake lateral force resisting system can be calculated using a linear elastic model of the base-isolated building, wherein:

1) All elements of the Lateral Force Resisting System of the building above the base-isolation system are elastic; and
2) Stiffness properties of the nonlinear components of the base-isolation System are linearized using the minimum effective stiffness of the Base-Isolation System (as per **7.3** of this standard) and the remaining elements (foundation and column stub portions) are elastic.

Also, the model shall include, incorporate and account for:

i) Linearized load-displacement characteristic of each base isolator along each of the two mutually orthogonal horizontal directions in plan, which are developed and verified based on prototype test, and including effect of vertical load, and/or the rate of loading, if force-displacement characteristics of all base-isolators are dependent on one or more of these attributes. Effective stiffness shall be used corresponding to the minimum lateral stiffness of the base-isolation system;
ii) Spatial distribution of base isolators in plan of the building;
iii) Lateral displacement along each of the two mutually orthogonal horizontal directions in plan, and torsion of the building above base-isolation system considering most disadvantageous location of eccentric mass; and
iv) Overturning and uplift forces arising on individual base isolators.

Further, the analysis shall be performed by the method as per **7.7.5** of IS 1893 (Part 1), using a modal damping for:

(1) The fundamental mode of the base-isolated building in the direction of shaking considered, not greater than the smaller of effective damping of the base-isolation system or 25 percent of critical damping, and
(2) The higher modes shall be selected consistent with those appropriate for linear response spectrum analysis of the part of the building above the base-isolation system, assuming it to be a fixed-base building.

6.3.3 *Lower bound limits on Results of Linear Equivalent Static Multi-Mode Method*

To avoid possible under-design using linear equivalent static multi-mode method (or linear response spectrum analysis method), limits prescribed in table 1 shall be ensured for various design quantities in terms of those obtained from linear equivalent static single mode method. The limits specified in table 1 are mandatory for buildings located in seismic zones III, IV and V, and optional for buildings for buildings located in seismic zone II.

Table 1 Lower Bound of Various Quantities Estimated from Linear Equivalent Static Multi-Mode Method (or Linear Response Spectrum Method) as a Fraction of those Estimated from Linear Equivalent Static Single Mode Method
(Clause 6.3.3)

Design Parameter	*Lower Limit as percentage of value computed using Linear Equivalent Static Single Mode Method*
Design displacement Δ_{SD} of the base-isolation system	90 percent
Total design displacement Δ_{ID} of the individual base isolator	80 percent
Design force of substructure V_B	90 percent
Design force of superstructure V_S	80 percent

6.3.4 *Design Earthquake Lateral Force of the Components of the Isolation System*

The base-isolation components, column stubs and foundation elements below the base-isolation system shall be designed to resist the forces estimated in the superstructure considering the building to be a fixed-base one without any response reduction factor applied in its estimation.

7 TESTING OF BASE-ISOLATORS

7.1 The design displacements and forces on a base-isolated building shall be based on the force- displacement characteristics of the base isolators to be used in the project. The force-displacement characteristics and damping values of the base isolators used in the design and analysis of base-isolated buildings shall be based on full-scale testing of select samples of base isolators. The tests specified herein shall be performed prior to design as prescribed herein; they are meant for establishing and validating the properties used in design of the base-isolation system, and shall not be considered for pre-qualifying the quality of manufacturing (in the factory) of the base isolators.

7.2 Prototype Tests

Tests on prototype base isolators shall be performed to estimate the characteristics of the backbone curve for use in the design of base-isolation system. For the purpose of this standard, quasi-static cyclic tests shall be performed separately on three full-scale specimens of predominant type and of each typical size of a base isolator proposed to be used in the building as part of the base-isolation system. The quantitative outcome of the test shall be the cyclic force-displacement curve of the test specimen in each cycle of test. In the force-displacement curves obtained for the type and size of a base isolator, a difference in the force values at any displacement shall not be more than ± 15 percent.

The vertical load shall be applied to a single isolator unit during the test, that is, back-to-back testing of isolator units shall not be permitted.

7.2.1 *Testing Protocol*

The following sequence of tests shall be performed for the prescribed number of cycles on a Base Isolator of the type and size proposed to be used in the project:

a) Vertical load equal to the average dead load plus one-half of the effect due to live load, along with 20 fully reversed cycles of loading at a lateral displacement corresponding to the effect of design wind force;
b) Vertical load equal to the average dead load plus one-half of the effect due to live load, along with 3 fully reversed cycles of loading successively at each of the following increments of displacement: $0.25\Delta_{SD}$, $0.5\Delta_{SD}$ and $1.0\Delta_{SD}$ corresponding to the earthquake effect;
c) Vertical load equal to the average dead load plus one-half of the effect due to live load, along with 3 fully reversed cycles at the total design displacement $1.0\ \Delta_{ID}$ corresponding to the earthquake effect;
d) Vertical load corresponding to the load combination of (1.2 *DL* + 0.5 *LL* + *EQ*), along with 3 fully reversed cycles of loading successively at each of the following increments of displacement: $0.25\ \Delta_{SD}$, $0.5\ \Delta_{SD}$ and $1.0\ \Delta_{SD}$ corresponding to the earthquake effect; and
e) Vertical load corresponding to load combination of (0.8 *DL* – *EQ*), along with 3 fully reversed cycles of loading successively at each of the following increments of displacement: $0.25\ \Delta_{SD}$, $0.5\ \Delta_{SD}$ and $1.0\ \Delta_{SD}$ corresponding to the earthquake effect. Where (0.8*DL* – *EQ*) results in tensile loading on the base-isolator, the building configuration may be reconsidered to ensure no tensile loading on the base-isolator.

7.2.2 *Maximum and Minimum Vertical Load*

Base isolators that carry vertical load shall be tested statically for the maximum and minimum vertical loads, at the total maximum displacement. In these tests, the combined vertical loads corresponding to the load case of $1.2DL + 1.0LL + |EQ|_{max}$ shall be taken as the maximum vertical load, and the combined vertical load corresponding to the load case of $0.8DL - |EQ|_{min}$ shall be taken as the minimum vertical load, on any base isolator of a common type and size.

7.3 Determination of Force- Displacement Characteristics

The concepts of effective stiffness and effective damping are used to define displacement behaviour of base isolators. The force-displacement characteristics of the base-isolation system shall be based on the cyclic load tests of isolator prototypes specified in the **7.1**.

The effective stiffness k_{eff}^{i} for each cycle of the three cycles of loading of base isolator i shall be estimated using (*see* Fig. 2):

$$k_{eff}^{i} = \frac{\left|F_{\max}^{+}\right|^{i} + \left|F_{\max}^{-}\right|^{i}}{\left|\Delta_{\max}^{+}\right|^{i} + \left|\Delta_{\max}^{-}\right|^{i}},$$

and the effective damping $\beta_{e,cycle}^{i}$ for each cycle of loading (see Fig. 2) of base-isolator *i* using:

$$\beta_{eff,cycle}^{i} = \frac{2}{\pi}\left[\frac{E_{loop}^{i}}{k_{eff}^{i}\left(\left|\Delta_{\max}^{+}\right|^{i} + \left|\Delta_{\max}^{-}\right|^{i}\right)^{2}}\right].$$

The maximum effective stiffness $k_{eff,\max}^{i}$ and minimum effective stiffness $k_{eff,\min}^{i}$ of base isolator *i* shall be the largest and smallest k_{eff}^{i} values, respectively, estimated as given above. And, the effective damping β_{eff}^{i} of each base isolator *i* shall be the smallest of the three damping values $\beta_{eff,cycle}^{i}$ obtained from the three cycles of testing of the base isolator *i*. The value of β_{eff} of the whole base-isolation system shall be the smallest of the β_{eff}^{i} values amongst all base isolators; in no case, the value of β_{eff} shall exceed 0.25.

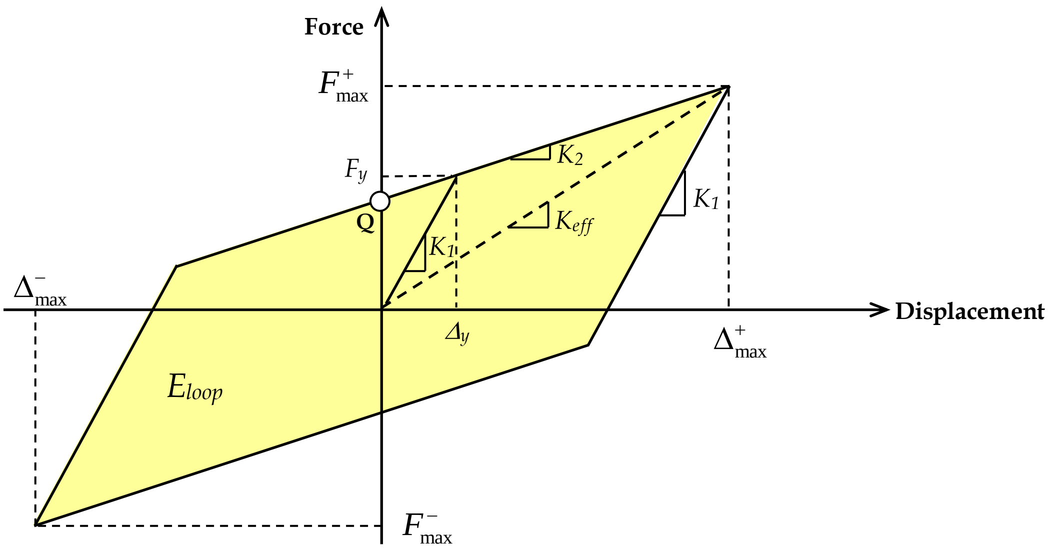

FIG. 2 FORCE-DISPLACEMENT HYSTERETIC CHARACTERISTIC OF A BASE ISOLATOR REPRESENTED BY A BILINEAR IDEALISATION

7.4 Test Specimen Adequacy

The performance obtained from a prototype test shall be considered as adequate, if the following conditions are satisfied:

a) The typical force-displacement curves obtained from all tests (conducted as per **7.1**) have a positive incremental force-carrying capacity within each cycle;
b) For each increment of test displacement specified in **7.2.1**(b), and for each vertical load case specified in **7.2.1**, the difference is ± 15 percent or lesser, between the effective stiffness at each of the three cycles of test and the average value of effective stiffness for each test specimen;
c) For each increment of test displacement specified in **7.2.1**(b), and for each vertical load case specified in **7.2.1**, the difference is ± 15 percent or lesser, between the effective stiffness of the two test specimens of a common type and size of the isolator over the required three cycles of test; and
d) All specimens of vertical load carrying elements of the base-isolation system remain stable at the total design displacement under the static load prescribed in the **7.2.1**.

7.5 Production Testing for Quality Control

Production tests shall be conducted on all base isolators supplied for a project. The test shall be performed under the combined action of maximum compression load expected on the isolator and shear force corresponding to two-thirds of the lateral design displacement of the base isolator. The tests shall be conducted to:

a) verify the as-built properties of the isolation system, and
b) verify and monitor the quality and consistency of the manufacturing process.

7.6 Design Properties of Isolation System

The prototype cyclic test shall be carried under constant compression, and the cyclic shear and the hysteresis loop obtained from the test shall be used to characterize the stiffness and damping of the Base Isolator. The base-isolation system shall have the design properties given in sub-sections below.

7.6.1 *Maximum and Minimum Effective Stiffness of the Base-Isolation System*

At the design displacement Δ_{SD}, the maximum effective stiffness $K_{eff,\max}$ and minimum effective stiffness $K_{eff,\min}$ of the base-isolation system shall be estimated using data from the cyclic tests performed as per **7.1**, and calculated by:

$$K_{eff,\max} = \frac{\sum_{i=1}^{N_{BI}} \left|F_i^+\right|_{\max} + \sum_{j=1}^{N_{BI}} \left|F_j^-\right|_{\max}}{2\Delta_{SD}}$$, and

$$K_{eff,\min} = \frac{\sum_{i=1}^{N_{BI}} \left|F_i^+\right|_{\min} + \sum_{j=1}^{N_{BI}} \left|F_j^-\right|_{\min}}{2\Delta_{SD}},$$

where

$\sum_{i=1}^{N_{BI}} \left|F_i^+\right|_{\max} =$ Sum of absolute values of maximum positive forces of all individual base isolators at a positive displacement Δ_{SD}. For a given base isolator, the maximum positive force at a positive displacement Δ_{SD} shall be determined by examining each of the maximum positive forces that occurred during each cycle of the prototype test sequence associated with displacement Δ_{SD} and selecting the maximum positive value at positive displacement Δ_{SD};

$\sum_{i=1}^{N_{BI}} \left|F_i^+\right|_{\min} =$ Sum of absolute values of minimum positive forces of all individual base isolators at a positive displacement Δ_{SD}. For a given base isolator, the minimum positive force at a positive displacement Δ_{SD} shall be determined by examining each of the minimum positive forces that occurred during each cycle of the prototype test sequence associated with displacement Δ_{SD} and selecting the minimum positive value at positive displacement Δ_{SD};

$\sum_{i=1}^{N_{BI}} \left|F_i^-\right|_{\max} =$ Sum of absolute values of maximum negative forces of all individual base isolators at a positive displacement Δ_{SD}. For a given base isolator, the maximum negative force at a positive displacement Δ_{SD} shall be determined by examining each of the maximum negative forces that occurred during each cycle of the prototype test sequence associated with displacement Δ_{SD} and selecting the maximum negative value at positive displacement Δ_{SD}; and

$\sum_{i=1}^{N_{BI}} \left|F_i^-\right|_{\min} =$ Sum of absolute values of minimum negative forces of all individual base isolators at a positive displacement Δ_{SD}. For a given base isolator, the minimum negative force at a positive displacement Δ_{SD} shall be determined by examining each of the minimum negative forces that occurred during each cycle of the prototype test sequence associated with displacement Δ_{SD} and selecting the minimum negative value at positive displacement Δ_{SD}.

7.6.2 *Effective Damping*

At the design displacement, the effective damping β_{eff} of the base-isolation system shall be based on the cyclic tests specified in **7.2** and estimated by:

$$\beta_{eff} = \frac{\sum_{i=1}^{N_{BI}} E_D^i}{2\pi K_{eff,\max} \Delta_{SD}^2}$$

The energy dissipated E_D^i in base isolator *i* shall be estimated at test displacements $\Delta_{\max}^-$ and $\Delta_{\max}^+$, which are equal in magnitude to the design displacement Δ_{SD} of the Base Isolator.

8 INSPECTION AND MAINTENANCE OF BASE-ISOLATORS

Two additional test isolators of each type and size shall be kept at the site of the base-isolated building subjected to the same environmental condition as the isolator units of the building. These shall be tested periodically to check the impact of aging and deterioration on the mechanical properties as per **7.2**. The first test shall be performed after 15 years of the installation, and then every 3 years thereafter. Should the building experience an earthquake, whose intensity is comparable to that of the design level earthquake, the said test shall be performed after such an event.

If the test indicates that the force values at any displacement in the force-displacement curves of the test isolators differ by more than ± 15 percent of the values considered in the original design of the base-isolated building, the earthquake safety of the building shall be re-certified considering the average force-displacement curves as established by the tests conducted on the two additional test isolators of each type and size shall be kept at the site of the base-isolated building.

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