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A proposed draft for IS : 1893 provisions on seismic design of buildings – Part I^{+} : Code

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Based on an extensive review of the provisions of the Indian seismic code (IS: 1893-1984) on building systems, a draft on the additions/modifications in the codal provisions is proposed in this paper. Many of the short-comings in the present code have been addressed. Areas requiring further work, for future improvement, are also indicated.

The existing provisions of the Indian seismic code[1] on building systems, have been reviewed[2] in detail elsewhere. A draft proposal, which incorporates most of the suggestions made in the review[2] is presented here. In view of the recent earthquake on 30 September 1993, in Marathwada region which was considered an aseismic zone (zone I), significant revisions in the map are required. This will, however, take time. Hence, in this proposal, the earlier zone map is retained with the understanding that by the time the proposed draft provisions are discussed, a revised zone map will be available. It is assumed that the revised zone map will continue to classify the country into five seismic zones corresponding to expected intensity of shaking as V (or less), VI, VII, VIII and IX (or more) on the Modified Mercalli scale.

In arriving at this proposal, reference has been made to the seismic codes[3-6] of several countries.

Some of the major modifications proposed are inclusion of response reduction factors in place of the performance factor, a lower bound, based on empirical estimation of natural period, on the design seismic force obtained by the dynamic analysis, new expressions for estimating the fundamental period, relative magnitudes of design forces in different zones. Further, the clauses have been completely redrafted for more effective implementation.

In this paper, clause numbers of the present code[1] are maintained wherever possible and clause numbers of the proposal are given in brackets along with titles for easy reference.

DEFINITIONS AND SYMBOLS (2.0)

Definitions (2.1): Definitions in the present code[1] require additions and clarity. They are not covered in this proposal.

Symbols (2.2): The symbols and notations given at the end apply to the provisions of this standard. The units used for the items covered by these symbols shall be consistent throughout, unless specifically noted otherwise.

GENERAL PRINCIPLES AND DESIGN CRITERIA (3.0)

General Principles (3.1)

Ground Motion (3.1.1): The characteristics (intensity, duration, etc.,) of seismic ground vibrations expected at any location depend upon the magnitude of earthquake, the depth of focus, distance from the epicenter, characteristics

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+ Part II of this paper will be published in the next issue of the Journal

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of the path through which the seismic waves travel, and the soil strata on which the structure stands. The random earthquake ground motions, which cause the structures to vibrate, can be resolved in any three mutually perpendicular directions. All structures are expected to withstand the vertical ground motions safely, as the factors of safety in the gravity load design already provide the required additional strength. Hence, in general, separate design provisions are required for structures to withstand horizontal (lateral) ground motions only.

However, the earthquake-generated vertical inertia forces shall be specifically considered in the case of structures having large spans, those in which stability is a criterion for design, or for overall stability analysis of structures, except as otherwise stated elsewhere in this standard.

Reduction in gravity force due to vertical component of ground motions can be particularly detrimental in cases of prestressed horizontal and cantilevered members. Hence, special attention should be paid to the effect of vertical component of the ground motion on prestressed or cantilevered beams, girders and slabs.

Clause 3.1.2 : Same as in the present code[1].

3.1.3: The intention of this standard is to ensure that structures possess adequate lateral strength to withstand earthquakes. The intention is not to prevent damage to structures due to the most severe shaking that a structure may be subjected to during its lifetime. Actual forces that may act on structures during earthquakes are much greater than the design lateral forces specified in this standard. However, ductility, arising from material behaviour and detailing, and overstrength, arising from the reserve strength in structures over and above the design forces, are relied upon to account for this difference in actual and design lateral loads.

Reinforced and prestressed concrete members shall be under-reinforced so as to cause a tensile failure. Further, they should be suitably designed to ensure that premature failure due to shear or bond does not occur, subject to the provisions of IS: 456-1978[9] and IS: 1343-1980[10]. Provisions for appropriate ductile detailing of reinforced concrete members are given in IS: 4326-1993[7].

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

3.1.4: The design lateral force specified in this standard shall be considered in each of the two principal directions of the structure. For buildings which have lateral force resisting elements in the two principal directions only, the design lateral force shall be considered along one direction at a time, and not in both directions simultaneously. However, in case of buildings, which have lateral force resisting elements (e.g., frames, shear walls) in directions other than the two principal directions, the forces shall be considered in accordance with 4.9.2.

Where both horizontal and vertical seismic forces are taken into account, horizontal force along the direction as above shall be considered simultaneously with the vertical force as specified in 3.4.5.

3.1.5: Equipment and other systems, which are supported at various floor levels of the structure, will be subjected to motions corresponding to vibration at their support points. Hence, their supports must be designed for the actual forces that may be envisaged, and not for the reduced design lateral forces specified in this standard. For important cases, it may be necessary to obtain floor response spectra for design of equipment supports.

Assumptions (3.2): Same as clause 3.2 of the present code[1].

Load Combinations and Increase in Permissible Stresses (3.3)

Load Combinations (3.3.1): When earthquake forces are considered on a structure whose lateral force resisting elements are oriented along principal axes, say x and y, the dead load (*DL*), live load (*LL*), design earthquake load in x-direction (EL_x) and design earthquake load in y-direction (EL_y) shall be combined as per 3.3.1.1 and 3.3.1.2.

However, if the lateral force resisting elements are not oriented along the principal axes, EL_x and EL_y shall be replaced by ($EL_x \pm 0.4\ EL_y$) and ($EL_y \pm 0.4\ EL_x$), respectively.

Load Factors for Plastic Design of Steel Structures (3.3.1.1): In the plastic design of steel structures, the following load combinations shall be accounted for:

1. $1.7\ (DL)$
2. $1.7\ (DL + LL)$
3. $1.7\ (DL + EL_x)$
4. $1.7\ (DL - EL_x)$
5. $1.7\ (DL + EL_y)$
6. $1.7\ (DL - EL_y)$
7. $1.3.\ (DL + LL + EL_x)$
8. $1.3\ (DL + LL - EL_x)$
9. $1.3\ (DL + LL + EL_y)$
10. $1.3\ (DL + LL - EL_y)$

Partial Safety Factors for Limit State Design of Reinforced Concrete and Prestressed Concrete Structures (3.3.1.2): In the limit state design of reinforced and prestressed concrete structures, the following load combinations shall be accounted for:

1. $1.5\ (DL + LL)$
2. $1.2\ (DL + LL + EL_x)$
3. $1.2\ (DL + LL - EL_x)$
4. $1.2\ (DL + LL + EL_y)$
5. $1.2\ (DL + LL - EL_y)$
6. $1.5\ (DL + EL_x)$
7 $1.5\ (DL - EL_x)$
8. $1.5\ (DL + EL_y)$
9. $1.5\ (DL - EL_y)$
10. $0.9\ DL + 1.5\ EL_x$
11. $0.9\ DL - 1.5\ EL_x$
12. $0.9\ DL + 1.5\ EL_y$
13. $0.9\ DL - 1.5\ EL_y$

Increase in permissible stresses (3.3.2): Clauses 3.3.2.1 and 3.3.2.2 (including Table 1*) are same as in the present code[1].

Design Spectrum (3.4)

3.4.1: For the purpose of determining seismic forces the country is classified into five seismic zones as shown in Fig.1**.

3.4.2: The design horizontal acceleration spectrum for a structure shall be determined by the following expression:

$$A = \frac{ZICS}{R} \tag{1}$$

Where I is obtained from Table 3***, and Z, R and S are from Tables 2, 4 and 5 respectively.

TABLE 2 : ZONE FACTOR, *Z*

Seismic Zone	I	II	III	IV	V
Z	0.05	0.075	0.15	0.30	0.50

TABLE 4 : RESPONSE REDUCTION FACTOR, *R*

S.No.	Lateral Load Resisting System	*R*
	Building Systems	
1	Special Moment-Resisting Frame (SMRF)	10
2	Ductile shear walls with SMRF	10
3	Shear Walls	8
4	Braced Frame	8
5	Ordinary Moment-Resisting Frame (OMRF)	6
6	Ordinary shear walls with OMRF	6
7	Masonry Walls	4
	Other Structural Systems	
1	Tanks, vessels or pressurized spheres	3
2	Silos, stacks and chimneys	4
3	Trussed towers, and guyed stacks and chimneys	4
4	Inverted pendulum-type structures	3
5	Cooling towers	5
6	Bins and hoppers on braced and unbraced legs	4
7	Storage racks	5
8	Signs and billboards	5
9	Amusement structures and monuments	3
10	Compound Walls	3
11	All other self-supporting structures not otherwise covered	4

TABLE 5 : SOIL FACTOR, *S*

Soil Type	Description	*S*
I	Rock or Hard Soils	1.0
II	Medium Soils	1.2
III	Soft Soils	1.5

Note: See Table 1* for definition of Soils

The value of *CS* need not exceed 2.0 and may be used for any structure without regard to soil profile type or structure period. Figure 2 shows the variation of *CS* with natural period *T*.

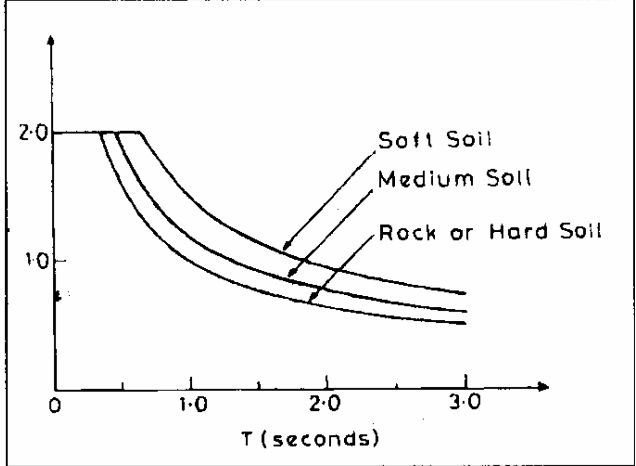

FIG. 2 CS VERSUS NATURAL PERIOD (T)

3.4.3: Where a number of modes are to be considered for seismic analysis, the value of *A* for each mode shall be determined using the natural period of the corresponding mode.

3.4.4: For underground structures and foundations at depths of 30m or below, the value for *A* shall be taken as half the value obtained from 3.4.2. For structures and foundations placed between the ground level and 30m depth, *A* value shall be linearly interpolated between *A* and 0.5*A*, where *A* is as specified in 3.4.2.

3.4.5: The design acceleration spectrum for vertical motions, when required, may be taken as *A* value specified in 3.4.2 multiplied by 0.5.

3.4.6: In case design spectrum is specifically prepared for a structure at a particular site, the same may be used for design. However, the structure shall still comply with the minimum requirements specified in this standard.

BUILDINGS (4.0)

To perform well in an earthquake, a building should possess four main attributes, namely simple and regular configuration, large lateral stiffness, adequate ductility, and adequate lateral strength. Buildings having simple regular geometry, and uniformly distributed mass and stiffness in plan as well as in elevation, suffer much less damage than buildings with irregular configurations.

Design Live Loads for Earthquakes (4.1)

4.1.1: The lateral design force for earthquakes shall be calculated using only a percentage of imposed live loads

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* Table 1 of this paper is same as in the present code

** Fig. 1 of this paper is the seismic zone map of present code, under revision.

*** Table 3 of this paper is the same as Table 4 of present code[1] specified in IS: 875-1987[11] as per Table 6. No further reductions in live load shall be permissible.

TABLE 6 : PERCENTAGE OF IMPOSED LIVE LOAD TO BE CONSIDERED IN SEISMICWEIGHT CALCULATION

Imposed Floor Loads	Percentage of Live Load
Uniformly Distributed Load (kN/m^2)	
2.0, 2.5 and 3.0	25
4.0, 5.0, 7.5 and 10.0	50
Concentrated Load (kN)	
1.4, 1.8, 2.7	25
3.6, 4.5, 6.7, 7.0 and 9.0	50

4.1.2: For calculating the design seismic forces of the structure, the live load on roof need not be considered.

4.1.3: The percentage of live loads given in 4.1.1 and 4.1.2 shall also be used in the load combinations specified in 3.3.1.1 and 3.3.1.2 where the gravity loads are combined with the earthquake loads (i.e., load combinations (7) to (10) in 3.3.1.1 and (2) to (5) in 3.3.1.2).

4.1.4: The proportion of live load indicated above for calculating the lateral design forces for earthquakes is applicable to average conditions. Where the probable loads at the time of earthquake are more accurately assessed, the designer may alter the proportion indicated or even replace it by the actual assessed load. In such cases, where the live load is not assessed as per 4.1.1 and 4.1.2, only that part of live load, which possesses mass, shall be considered. Lateral design force for earthquakes shall not be calculated on contribution of impact effects towards live loads.

Seismic Weight (4.2)

Seismic Weight of Floors (4.2.1): The seismic weight of each floor is its full dead load plus appropriate amount of live load, as specified in 4.1.1 and 4.1.2. While computing the seismic weight of each floor, the weight of columns and walls in any storey shall be equally distributed to the floors above and below the storey.

Seismic Weight of Building (4.2.2): The seismic weight of the whole building is the sum of the seismic weights of all the floors.

Design Lateral Force (4.3)

4.3.1: Buildings and portions thereof shall be designed and constructed, to resist the effects of design lateral force specified in 4.3.3.

All parts of the building between the separation joints shall be tied together to act as a single unit. All connections between different parts should be capable of transmitting in all possible directions, a force of magnitude equal to Z/3 times the weight of the smaller part (minimum of 5 percent of the weight of the smaller part). Also, beams must be tied to their supports or columns to their footings, for a minimum of 5 percent of the dead and live load reaction. Friction resistance shall not be relied upon for fulfilling these requirements.

4.3.2: The design lateral force shall first be computed for the building as a whole. This design lateral force shall then be distributed to the various floor levels. The overall design seismic force thus obtained at each floor level, shall then be distributed to individual lateral load resisting elements depending on the floor diaphragm action.

Design Base Shear (4.3.3.): The total design lateral force or seismic base shear (V_B) along any principal direction shall be determined by the following expression:

$$V_B = A\,W \qquad (2)$$

Dual Systems (4.3.4): When moment-resisting frames are used in combination with shear walls (or braced frames) to resist the total design lateral force specified in 4.3.3, it shall be ensured that the moment-resisting frame alone will be able to resist at least 25% of this design lateral force. (For instance, if the analysis shows that the shear walls and the frames take 85% and 15% of the total design lateral force, respectively, then the walls and the frames shall be designed for 85% and 25% of the total force, respectively.)

Fundamental Period (4.4)

4.4.1: The approximate fundamental natural period of vibration (T_a), in seconds, of moment-resisting frames without brick infill panels shall be estimated by the expression:

$$T_a = 0.075\,h^{0.75} \qquad (3)$$

4.4.2: T_a of all other buildings, including moment-resisting frames with brick infill panels, shall be estimated by the expression:

$$T_a = \frac{0.09\,h}{\sqrt{d}} \qquad (4)$$

4.4.3: The fundamental period of the building (T) in the considered direction may be established using structural properties and deformational characteristics of the resisting elements in a properly substantiated analysis. The fundamental period so determined shall not exceed $C_a T_a$, where C_a is obtained from Table 7, and T_a determined from 4.4.1 or 4.4.2.

TABLE 7 : COEFFICIENT, C_a, FOR UPPER LIMIT ON CALCULATED NATURAL PERIOD

Seismic Zone	I	II	III	IV	V
C_a	1.6	1.6	1.4	1.3	1.2

Distribution of Design Force (4.5)

Vertical Distribution of Base Shear to Different Floor Levels (4.5.1): The design base shear (V_B) computed in 4.3.3 shall be distributed along the height of the building as per the following expression:

$$Q_i = V_B \frac{W_i\, h_i^2}{\sum\limits_{j=1}^{N} W_j\, h_j^2} \qquad (5)$$

The number of storeys in the building N, is the number of levels at which the masses are located. This excludes the basement storeys, where basement walls are connected with the ground floor deck or fitted between the building columns. But, it includes the basement storeys, when they are not so connected.

Horizontal Distribution of Design Lateral Force to Different Lateral Force Resisting Elements (4.5.2)

4.5.2.1: In case of buildings whose floors are capable of providing rigid horizontal diaphragm action, the total shear in any horizontal plane shall be distributed to various vertical elements of lateral force resisting system, assuming the floors to be infinitely rigid in the horizontal plane.

4.5.2.2: In case of buildings whose floor diaphragms cannot be treated as infinitely rigid in their own plane, the lateral shear at each floor shall be distributed to the vertical elements resisting the lateral forces, considering the in-plane flexibility of the diaphragms.

A floor diaphragm shall be considered to be flexible, if it deforms such that the maximum lateral displacement at any point of the diaphragm is more than 1.5 times the average displacement of the entire diaphragm.

Dynamic Analysis (4.6)

4.6.1: Dynamic analysis shall be performed to obtain the design seismic force, and its distribution to different levels along the height of the building and to the various lateral load resisting elements, for the following buildings:

(a) Regular buildings - those greater than 40 metres in height in zones IV and V, and those greater than 90 metres in height in zones I, II and III.

(b) Irregular buildings (as defined in 4.8.1) - all of them irrespective of their heights in zones IV and V, and those greater than 40 metres in height in zones I, II and III. For irregular buildings, less than 40 metres in height in zones I, II and III, dynamic analysis, even though not mandatory, shall be preferred.

The analytical model for dynamic analysis of buildings with unusual configuration should be such that it adequately models the types of irregularities in the building configuration. Buildings with plan irregularities, as defined in Table 8 (as per 4.9.1), cannot be modelled for dynamic analysis by the method given in 4.6.4.6.

(c) Industrial and framed structures of large spans and heights.

TABLE 8 : DEFINITION OF IRREGULAR BUILDINGS - PLAN IRREGULARITIES

S.No.	Irregularity Type and Description
1	**Torsion Irregularity -** Torsional irregularity shall be considered to exist when the maximum storey drift, computed with design eccentricity, at one end of the structure transverse to an axis is more than 1.2 times the average of the storey drifts at the two ends of the structure.
2	**Re-entrant Corners-** Plan configurations of a structure and its lateral force resisting system contain re-entrant corners, where both projections of the structure beyond the re-entrant corner are greater than 15% of its plan dimension in the given direction.
3	**Diaphragm Discontinuity-** Diaphragms with abrupt discontinuities or variations in stiffness, including those having cut-out or open areas greater than 50% of the gross enclosed diaphragm area, or changes in effective diaphragm stiffness of more than 50% from one storey to the next.
4	**Out-of-Plane Offsets-** Discontinuities in a lateral force resistance path, such as out-of-plane, offsets of vertical elements.
5	**Non-parallel Systems-** The vertical elements resisting the lateral force are not parallel to or symmetric about the major orthogonal axes of the lateral force resisting elements.

4.6.2: Dynamic analysis may be performed either by the response spectrum method or by the time history method. However, in either method, the design base shear (V_B) shall be compared with a base shear ($\bar{V}_B$) calculated using a fundamental period $T_1 = C_a T_a$, where C_a and T_a are as per 4.4. Where V_B is less than $\bar{V}_B$, all the response quantities (e.g., member forces, displacements, storey forces, storey shears and base reactions) shall be multiplied by ($\bar{V}_B / V_B$).

Time History Method (4.6.3): Time history method of analysis, when used, shall be based on an appropriate ground motion and shall be performed using accepted principles of dynamics.

Response Spectrum Method (4.6.4): Response spectrum method of analysis shall be performed using the design spectrum specified by 3.4, or by a site-specific design spectrum.

Free Vibration Analysis (4.6.4.1): Undamped free vibration analysis of the entire building shall be performed as per established methods of analysis using the masses and elastic stiffnesses of the structural system, to obtain natural periods (T) and mode shapes ($\{\phi\}$) of those of its modes of vibration, that need to be considered as per 4.6.4.2.

Modes to be considered (4.6.4.2) : The number of modes to be used in the analysis should be such that at least 90% of the total seismic mass gets excited in each of the principal directions.

Analysis of Building Subjected to Design Forces (4.6.4.3): In the response spectrum method, the building may be analysed in one of the following two ways:

(1) A static analysis of the building is performed for each mode. Then, the peak response quantities (e.g., member forces, displacements, storey forces, storey shears and base reactions) in each of these modes are combined in accordance with 4.6.4.4.

(2) The shear forces in the different storeys in each mode are obtained using the lateral forces at each floor in that mode. Then, these storey shear forces of the different modes are combined in accordance with 4.6.4.4. The peak design lateral forces due to all the modes are then back-calculated from these storey shear forces. Finally, a single static analysis of the building is performed for these design lateral forces to obtain the design response quantities.

Modal Combination (4.6.4.4) : The peak response (e.g. member forces, displacements, storey forces, storey shears and base reactions) shall be combined as follows:

(a) If all the natural periods of the building are separated from each other by more than 15%, then the peak response (λ) due to all modes considered shall be obtained as

$$\lambda = \sqrt{\sum_{k=1}^{r} \left[\lambda_k \right]^2} \tag{6}$$

(b) If some of the natural periods are within 15% of each other, then the peak response (λ_*) due to these modes shall be obtained as

$$\lambda_* = \sum \lambda_c \tag{7}$$

where the summation is for those modes, c, whose natural periods are spaced within 15% of each other. This peak response due to the closely spaced modes (λ_*) is then combined with those of the remaining well-separated modes by the method described in 4.6.4.4(a).

4.6.4.5: For buildings with highly irregular plan configurations, a three-dimensional model shall be used with appropriate modelling of the floor diaphragms.

4.6.4.6: Buildings with regular, or nominally irregular, plan configurations may be modelled as a system of masses lumped at the floor levels with each mass having one degree of freedom, that of lateral displacement in the direction under consideration. The design forces so calculated are to be applied at the centre of mass appropriately displaced so as to cause eccentricity between the displaced centre of mass and centre of stiffness equal to the design eccentricity specified in 4.8. In such a case, the following expressions shall hold in the computation of the various quantities.

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

$$M_k = \frac{\left[\sum_{i=1}^{N} W_i \, \phi_{ik} \right]^2}{g \sum_{i=1}^{N} W_i \left[\phi_{ik} \right]^2} \tag{8}$$

Modal Participation Factors: The modal participation factor (P_k) of mode k is given by:

$$P_k = \frac{\sum_{i=1}^{N} W_i \, \phi_{ik}}{\sum_{i=1}^{N} W_i \left[\phi_{ik} \right]^2} \tag{9}$$

Design Lateral Force at Each Floor in Each Mode: The peak lateral force (Q_{ik}) at floor i in mode k is given by:

$$Q_{ik} = A_k \, \phi_{ik} \, P_k \, W_i \tag{10}$$

Storey Shear Forces in Each Mode: The peak shear force (V_{ik}) acting in storey i in mode k is given by:

$$V_{ik} = \sum_{j=i+1}^{N} Q_{jk} \tag{11}$$

Storey Shear Forces due to All Modes Considered: The peak storey shear force (V_i) in storey i due to all modes considered is obtained by combining those due to each mode in accordance with 4.6.4.4.

Lateral Forces at Each Storey due to All Modes Considered: The design lateral forces, F_{roof} and F_i, at roof and at floor i, respectively, due to all modes considered is given by:

$$F_{roof} = V_{roof} \tag{12}$$

and

$$F_i = V_i - V_{i+1}. \tag{13}$$

Deformations (4.7)

Storey Drift Limitation (4.7.1): The storey drift in any storey due to the minimum specified design lateral force, with partial load factor of 1.0, shall not exceed 0.004 times the storey height. For the purposes of displacement requirements only (i.e., in 4.7.1, 4.7.2 and 4.7.3 only), it is permissible to use seismic force obtained from the computed fundamental period (*T*) of the building without the upper bound limit on design seismic force specified in 4.6.2.

Deformation Compatibility of Non-Seismic Members (4.7.2): For buildings located in seismic zones IV and V, it shall be ensured that the structural components, that are not a part of the seismic force resisting system in the direction under consideration, do not lose their vertical load-carrying capacity under the induced moments resulting from storey deformations equal to *R* times the storey deformations calculated as per 4.7.1.

Note: For instance, consider a flat-slab building in which lateral load resistance is provided by shear walls. Since the lateral load resistance of the slab-column system is small, these are often designed only for the gravity loads, while all the seismic force is resisted by the shear walls. Even though the slabs and columns are not required to share the lateral forces, these deform with rest of the structure under seismic force. The concern is that under such deformations, the slab-column system should not lose its vertical load capacity.

Separation Between Adjacent Units (4.7.3): Two adjacent buildings, or two adjacent units of the same building with separation joint in between shall be separated by a distance equal to the amount *R* times the sum of the calculated storey displacements as per 4.7.1 of each of them, to avoid damaging contact when the two units deflect towards each other. When floor levels of two adjacent units or buildings are at the same elevation levels, factor *R* in this requirement may be replaced by *R*/2.

Torsion (4.8)

4.8.1: Provision shall be made in all buildings for increase in shear forces on the lateral force resisting elements resulting from the horizontal torsional moment arising due to eccentricity between the centre of mass and centre of stiffness. However, negative torsional shears shall be neglected.

4.8.2: The design eccentricity shall be taken as 1.5 times the calculated eccentricity between centre of mass and centre of stiffness.

4.8.3: The design eccentricity shall not be less than 5% of the plan dimension of the building perpendicular to the direction of force under consideration.

Irregular Buildings (4.9)

4.9.1: A building shall be considered as irregular for the purposes of this standard, if at least one of the conditions given in Tables 8 and 9 is applicable.

TABLE 9 : DEFINITION OF IRREGULAR BUILDINGS – VERTICAL IRREGULARITIES

S.No.	Irregularity Type and Description
1	**Stiffness Irregularity - Soft Storey** A soft storey is one in which the lateral stiffness is less than 50% of that in the storey above or less than 50% of that in the storey below.
2	**Mass Irregularity -** Mass Irregularity shall be considered to exist where the seismic weight of any storey is more than 200% of that of its adjacent stories. The irregularity need not be considered in case of roofs.
3	**Vertical Geometric Irregularity-** Vertical geometric irregularity shall be considered to exist where the horizontal dimension of the lateral force resisting system in any storey is more than 150% of that in its adjacent storey.
4	**In-Plane Discontinuity in Vertical Elements Resisting Lateral Force-** An in-plane offset of the lateral force resisting elements greater than the length of those elements.
5	**Discontinuity in Capacity - Weak Storey** A weak storey is one in which the storey lateral strength is less than 50% of that in the storey above. The storey lateral strength is the total strength of all seismic force resisting elements sharing the storey shear in the considered direction.

Lateral Force Resisting Elements not Oriented along Principal Axes (4.9.2): When the lateral load resisting elements are not oriented along the principal horizontal axes of the building, the building shall be designed for full design lateral force computed for one direction plus 40% of the design lateral force computed for the other direction acting simultaneously, and vice-versa. For instance, if EL_x and EL_y are as defined in 3.3.1, the building should be designed for ($\pm EL_x \pm 0.4\, EL_y$) as well as ($\pm 0.4\, EL_x \pm EL_y$).

Miscellaneous (4.10)

Foundations (4.10.1): The use of foundations vulnerable to significant differential settlement shall be avoided for structures in seismic zones III, IV and V.

Cantilever Projections (4.10.2)

Vertical (4.10.2.1): Towers, tanks, parapets, smoke stakes (chimneys) and other vertical cantilever projections attached to buildings and projecting above the roof shall be designed for five times the design horizontal acceleration spectrum value specified in 3.4.2.

Horizontal (4.10.2.2): All horizontal projections like cornices and balconies shall be designed to resist a vertical force equal to five times the design vertical acceleration spectrum value specified in 3.4.5 multiplied by the weight of the projection.

4.10.2.3.: The increased design forces specified in 4.10.2.1 and 4.10.2.2 are only for designing the projecting parts and their connections with the main structures. For the design of the main structure, such increase need not be considered.

Compound Walls (4.10.3): Compound walls shall be designed for the design horizontal acceleration spectrum specified in 3.4.2 using the response reduction factor given in Table 4.

OTHER COMMENTS

Appendices E and F of the present code[1] may be deleted

SUMMARY AND CONCLUSIONS

A draft proposal on provisions for the seismic design of buildings is presented for the next revision of IS:1893.

The following is a brief summary of major and important modifications made in this proposal:

1. Relative values of seismic zone factor have been changed.
2. A single design acceleration spectrum, for use in the equivalent static method and response spectrum method, is introduced.
3. The concept of ductility is brought into the code explicitly, by introducing the response modification factor in place of the performance factor.
4. Empirical expression for estimating the fundamental natural period has been revised.
5. A lower bound is specified for the design base shear, based on empirical estimate of the fundamental natural period. The design force by the dynamic analysis cannot be less than that based on empirical estimate of T.
6. Dynamic analysis is made compulsory for irregular buildings, subject to certain conditions, and certain regular buildings.
7. The soil-foundation system factor is dropped. Instead, a clause is introduced to prohibit the use of foundations vulnerable to differential settlements in severe seismic zones.
8. A soil profile factor depending on the soil profile has been introduced for obtaining the design spectrum.
9. The entire building provisions have been redrafted for better implementation.

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NOTATION

A	Design horizontal acceleration spectrum value
A_k	Design horizontal acceleration spectrum value for mode k of vibration
C	Structure flexibility factor, $1/T^{2/3}$
C_a	Coefficient for upper limit on calculated natural period.
F_{roof}	Peak lateral forces at the roof due to all modes considered
F_i	Peak lateral forces at floor i due to all modes considered
I	Importance factor
N	Number of storeys
P_k	Modal participation factor of mode k
Q_{ik}	Lateral force at floor i in mode k
R	Response reduction factor
S	Soil profile factor
T	Undamped natural period of vibration of the structure (in seconds)
T_a	Approximate fundamental period (in seconds)
T_k	Undamped natural period of mode k of vibration (in seconds)
T_1	Fundamental natural period of vibration (in seconds)
V_B	Design base shear
V_i	Peak storey shear force in storey i in due to all modes considered
V_{ik}	Shear force in storey i in mode k
V_{roof}	Peak storey shear force at the roof due to all modes considered
W	Seismic weight of the structure
W_i	Seismic weight of floor i
Z	Seismic zone factor
c	Index for the closely-spaced modes
d	Base dimension of the building, in metres, in the considered direction of seismic force
g	Acceleration due to gravity
h	Height of structure (in metres)
h_i	Height measured from the base of the building to floor i
r	Number of modes to be considered as per 4.6.4.2
ϕ_{ik}	Mode shape coefficient at floor i in mode k
λ	Peak response (e.g., member forces, displacements, storey forces, storey shears or base reactions) due to all modes considered
λ_k	Absolute value of maximum response in mode k
λ_c	Absolute value of maximum response in mode c, where mode c is a closely-spaced mode
λ_*	Peak response due to the closely-spaced modes only

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