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EARTHQUAKE RESISTANT DESIGN OF BUILDINGS 2020: A COMPARATIVE STUDY OF OLD AND REVISED PROVISIONS IN INDIAN SEISMIC CODES

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Abstract: *Several devastating earthquakes have taken place world over causing severe damage to structures, loss of life and property. Earthquake resistant design of structures is continuously evolving taking cognizance of behaviour of structures during past earthquakes to achieve an acceptable behaviour of structure during earthquake. Bureau of Indian Standards have also revised the criteria for earthquake resistant design of structures included in code IS:1893. The 'General Provisions and Buildings', which were covered in IS 1893 (Part 1):2002 are revised in IS 1893 (Part 1):2016. Similarly, 'Industrial Structures', which were covered in IS 1893 (Part 4):2005 are revised in IS 1893 (Part 4):2015. The clauses presented in these codes provides guidance to the structural designers and architects to plan and design realistic earthquake resistant structures. Knowledge of the revised provisions vis-à-vis earlier provisions is not only essential for proper design of structures but also mandated by the codes. This paper covers a comparative study of important provisions of the earlier codes and the revised codes in the context of IS 1893. Some very important revised provisions of the IS:13920 pertaining to ductile design and detailing are also included in the study. This study aims to highlight the changes in approach that are needed to be incorporated in the most basic earthquake resistant design of general and industrial buildings.*

***Index Terms* – IS 1893 (Part-1) 2016, IS 1893 (Part-1) 2002, IS 1893 (Part-4) 2005, IS 1893 (Part-4) 2015, IS 13920 2016, Earthquake Resistant Design of Structures, Industrial Buildings, Comparison between Old and Revised Codes.**

1. INTRODUCTION

Earthquakes are taking place world over as a natural phenomenon. They have caused tremendous damage in the past causing largescale loss of life and property. India is no exception. The earthquake of 2001 at Bhuj (Gujarat) is so far the most severe earthquake of the century in India. Earthquake resistant design of structures is necessary to safeguard against the damage caused due to earthquake. Earthquakes are unpredictable in nature and behaviour to a large extent. Every earthquake gives mankind some new insight requiring updating of design criteria. The design codes need to be revised accordingly.

The Earthquake resistant design codes are prepared according to different factors such as seismology of country, safe accepted level of seismic risk, properties of material which are used in construction, methods of construction and types of structures. The provisions given in Earthquake Resistant Design codes are based on the experiments, observations, and analytical case studies made during past earthquake in different regions. In India, IS-1893 (Part-1) "Criteria for Earthquake Resistant Design of Structures: General Provisions and Buildings" is used as the main code of practice for analysis and design of earthquake resistant buildings in India. Earthquake Engineering Sectional Committee of Bureau of Indian Standard has taken cognizance of the detailed & advanced research and damage survey in previous decades and collected data regarding behaviour of various types of structures during seismic action. According to this collective data, a need was felt there is need to revision of existing code i.e. IS 1893 (Part-1)-2002. Hence the sixth revision of IS 1893 (Part-1)-2016 was published in 2016. Similarly, IS-1893 (Part-4) "Criteria for Earthquake Resistant Design of Structures: Industrial Buildings including Stack like Structures" which was published in 2005, was revised in 2015. Both the codes were revised after a long gap of more than 10 years. Meanwhile, the earthquake phenomenon and behaviour of structures is better understood, requiring updating of the codes.

To implementing the latest code into practice, it is necessary to understand the revised provisions in IS 1893 (Part-1): 2016 with respect to IS 1893 (Part-1): 2002 for general buildings. Similarly, it is necessary to understand the revised provisions in IS 1893 (Part-4): 2015 with respect to IS 1893 (Part 4): 2005. This paper makes an attempt to bring forth and analyse the most important points of comparison between the old and the revised codes to highlight the changes required to be incorporated in the planning, analysis and design of general and industrial buildings to make them earthquake resistant as mandated by the latest codes. Provisions pertaining to most generally encountered buildings are covered to understand the basic changes which need attention of almost all structural designers. The study also includes some inescapable revised provisions of IS 13920 i.e. code of practice for "Ductile Design and detailing of Reinforced Concrete Structures Subjected to Seismic forces" which was last published in 1993 prior to revision in 2016.

Earlier limited studies have been made to compare the provisions of old and revised codes. Rethalia *et al* [1] and Urunkar S.S *et al* [2] conducted a comparative study of various clauses of new IS 1893 (part-I)-2016 and old IS 1893 (part-I)-2002 on some important aspects. Islam N. and Baig M. A. [3] have highlighted revised provisions of IS 1893 (Part 1): 2016 in narrative form in their study. These studies basically confined to general buildings. Pisal A. Y. and Pisal Y. [4] conducted a review on critical design provisions of IS 1893 (Part 4): 2015. Their study highlighted some critical points on the analysis and design of industrial structures.

The aim of the present study is to bring forth the important points of comparison between the earlier and revised codes which are of utmost importance for structural designers and architects involved in planning and design of earthquake resistant buildings and industrial structures. The comparison is not exhaustive but covers the important points which are encountered in majority of the designs.

2. COMPARISON OF THE CODES:

2.1 Comparison between IS 1893 (Part-1)-2002 and IS 1893 (Part-1)-2016: A comparative study of various clauses of IS 1893 (Part-1)-2002 and IS 1893 (Part-1)-2016 is carried out in tabular form as follows-

Sr. No.	IS 1893 (Part-1) :2002	IS 1893 (Part-1) :2016	Remarks
	A. SCOPE		
1	As per clause **1.2** Temporary elements such as scaffolding, temporary excavations need not be designed for earthquake forces.	As per clause **1.2** & **1.3**, structures like parking structures, security cabin, ancillary structures, and temporary elements such as scaffolding and temporary excavation need to be designed for appropriate earthquake effects as per the code.	The revised code 2016 brings temporary elements and minor structures in the purview of seismic design as per the code.
2	Importance Factor (I): Clause **6.4.2** Importance factor was 1.5 and 1.0 for important buildings and other buildings respectively which are shown in Table 6 of the code.	Important Factor (I): Clause **7.2.3** Besides the earlier importance factors of 1.5 and 1.0, an intermediate importance factor of 1.2 is introduced for residential or commercial buildings with occupancy more than 200 persons as shown in Table 8 of the code.	Buildings with occupancy of more than 200 persons will now have greater value 1.2 of importance factor in place of 1.0. This will provide greater protection to such buildings at enhanced cost due to enhanced design lateral forces.

B. DESIGN SEISMIC FORCE
(Methods of Analysis & Factors)

Earthquake produces ground motion due to which the structure is subjected to lateral seismic forces in horizontal directions and vertical seismic forces. The buildings are designed for these seismic forces. For seismic design of buildings, the lateral seismic forces are critical. The lateral seismic forces are determined at each floor level and their cumulative value from top to any floor level provides the storey shear at that floor level. Cumulative value of lateral forces from top floor to base gives the base shear. Revised provisions in the code have affected the factors to be considered for determining the design lateral forces and base shear which are discussed below. The seismic forces are determined either by static method or by dynamic method depending upon location, type, and configuration of structure. The revised provisions of the code affecting calculation of design seismic forces are discussed below for both these methods.

I. Static Analysis

It is known as Equivalent Static Seismic Force Method. This method is used for simple buildings of low height in less severe seismic zones as per the criteria given in the codes. The revised codes have made this criterion more stringent. Now only regular buildings with height < 15M in seismic Zone II can be designed using static analysis. For all other buildings, dynamic analysis is made mandatory.

In this method, primarily design base shear V_B is calculated for the building. Then, this design base shear value is distributed to the various floor level at the corresponding centre of mass. And finally, this design seismic force at each floor shall be distributed to individual lateral load resisting elements by structural analysis considering the floor diaphragm action.

Design Seismic Base Shear, $V_B = A_h W$

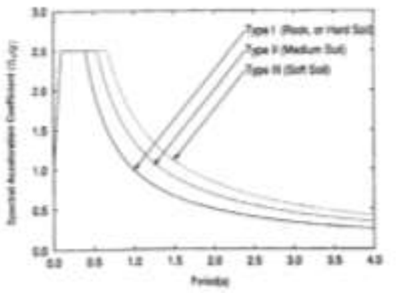
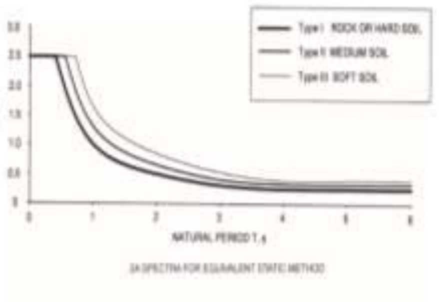
Where, W= Seismic Weight of the building
A_h = Design Horizontal Seismic Coefficient = (Z /2)(I/R)(Sa/g)
Z= Zone Factor, I = Importance Factor, R= Response Reduction Factor, Sa/g = Design Acceleration coefficient of different soil

The design lateral force at any floor i is calculated using following formula

$$\mathbf{Q_i = [\{W_i \times h_i^2\} / \{ \sum_{j=1}^{n} W_j h_j^2\}] V_B}$$

Where,
Q_i = Design lateral force at floor *i*
W_j = seismic weight of floor *i*
h_i = height of floor *i* measured from base
n = number of story in building that is number of levels at which masses are located.
The revised provisions dealing the factors influencing the value of Design Seismic Force V_B are discussed below :-

Sr. No.	IS 1893 (Part-1) :2002	IS 1893 (Part-1) :2016	Remarks
1	Importance Factor (I): Clause **6.4.2** Importance factor was 1.5 and 1.0 for important buildings and other buildings respectively which are shown in Table 6 of the code.	Important Factor (I): Clause **7.2.3** Besides the earlier importance factors of 1.5 and 1.0, an intermediate importance factor of 1.2 is introduced for residential or commercial buildings with occupancy more than 200 persons as shown in Table 8 of the code.	Buildings with occupancy of more than 200 persons will now have greater value 1.2 of importance factor in place of 1.0. This will provide greater protection to such buildings at enhanced cost due to enhanced design lateral forces.
2	Zone Factor (Z): Clause 6.4.2 Table 2 Value of Z is 0.1, 0.16, 0.24 & 0.36 for seismic zones II, III, IV & V respectively	Zone Factor (Z): Clause 6.4.2 Table 3 Value of Z is 0.1, 0.16, 0.24 & 0.36 for seismic zones II, III, IV & V respectively	No change in the value of zone factor in the revised code.
3	Response Reduction Factor (R): Values of 'R' are given for various types of buildings in Table 7 (clause 6.4.2)	Response Reduction Factor (R): Values of 'R' are given for various types of buildings in Table 9 (clause 7.2.6) Steel buildings, braced buildings and load bearing masonry buildings are classified into more categories. Value of 'R' is added for flat slab-structural wall system. More restrictions are added to adopt the type of building in higher seismic zones	Additional building categories are defined in the revised code and flat slab-structural wall system added. Revised provision affects selection of type of buildings in higher seismic zones and the value of 'R' for some categories of buildings. No major change in RC buildings.
4	Time Period, Ta: clauses 7.6.1 and 7.6.2 Formulas for calculation of Time Period Ta, are given in clauses 7.6.1 and 7.6.2 for different types of buildings as follows: For RC Frame Building Ta = $0.075\ h^{0.75}$ For Steel Frame Building Ta = $0.085\ h^{0.75}$ For all Other Building Ta = $\frac{0.09\,h}{\sqrt{d}}$ Where, h = Height of Building in m; d = Base dimension of building at plinth level in m, along the considered direction of lateral force.	Time Period, Ta: clauses 7.6.2 (a), (b) & (c) Formulas for calculation of Time Period Ta, are given in clauses 7.6.2 (a), (b) & (c) for different types of buildings as follows: (a)Bare MRF Building (Without any masonry infills) For RC MRF Building, Ta = $0.075\ h^{0.75}$ For RC-Steel composite MRF Building Ta = $0.080\ h^{0.75}$ For Steel MRF Building, Ta = $0.085\ h^{0.75}$ (b) Building with RC structural Walls Ta = $\frac{0.075\,h^{0.75}}{\sqrt{Aw}} \geq \frac{0.09\,h}{\sqrt{d}}$ (c) For all Other Building, Ta = $\frac{0.09\,h}{\sqrt{d}}$ Where, h = height of the building in m; d = base dimension of the building at the plinth level along the considered direction of earthquake shaking, in m; A_w = Total effective area m^2 of walls in first story of building given by $A_w = \sum_{i=1}^{Nw}[Aw\,\{0.2 + \left(\frac{Lwi}{h}\right)^2\}]$ A_{wi} = effective cross-sectional area of wall *i* in first story of building, in m^2; L_{wi} = Length of structural wall *i* in first story in the considered direction of lateral force, in m; N_w = number of walls in the considered direction of earthquake shaking. The value of L_{wi} / h to be used in this equation shall not exceed 0.9	Formula for buildings with RC structural walls introduced in the revised code. It is felt that T_a for buildings with RC structural walls should have some upper bound also. In absence of the same, it may exceed T_a for bare frame which is not justified.
5	Design Seismic Acceleration Spectrum: Clause **6.4.2** and Fig.1 The response spectra for different soil types for 5% damping are given for period range up to 4 seconds in Fig.2 of the code. The figure is as follows:	Design Seismic Acceleration Spectrum: Clause **6.4.2** and Fig.2A The response spectra for different soil types for 5% damping are given for period range up to 6 seconds in Fig.2A of the code. The figure is as follows:	Provision has been made in the revised code for buildings having time period greater than 4s. Moreover, the values of Sa/g are made constant as 2.5 in the period range of 0<T<0.4s.

	 **Fig. Response Spectra for Rock & Soil Sites For 5 Percent Damping** Multiplying factors for other damping are given in Table 3.	 **Fig. Design Acceleration Coefficient (Sa/g) Corresponding to 5 Percent Damping: Spectra for Equivalent Static Method** Damping ratio of 5% is fixed for all type of buildings as per Clause 7.2.4 of the code for static as well as dynamic analysis.	Spectra are given in the revised code corresponding to damping ratio of 5% only, as this damping ratio is kept fixed for static as well as dynamic analysis in the revised code.
6	Average Response Acceleration Coefficient (Sa/g): Clause 6.4.2 and 6.4.5, Fig. 2, Table 3 Average Response Acceleration Coefficient (Sa/g) for different soil types are given in clauses 6.4.2 & 6.4.5 ad Fig.2 for 5% damping. Multiplying factors for other damping are given in Table 3 For rocky, or hard soil sites Sa/g= {1+15 T 0.00≤T≤0.10} Sa/g= {2.50 0.10≤T≤0.40} Sa/g= {1.0/T 0.40≤T≤4.00} For medium soil sites Sa/g= {1+15 T 0.00≤T≤0.10} Sa/g= {2.50 0.10≤T≤0.55} Sa/g= {1.36/T 0.55≤T≤4.00} For soft soil sites Sa/g= {1+15 T 0.00≤T≤0.10} Sa/g= {2.50 0.10≤T≤0.67} Sa/g= {1.67/T 0.67≤T≤4.00}	Design Acceleration Coefficient (Sa/g): Clause 6.4.2 and Fig.2A Design Acceleration Coefficient (Sa/g) for different soil types for 5% damping are given in clause 6.4.2 and Fig.2A. Damping ratio of 5% is fixed for all type of buildings as per Clause 7.2.4 of the code for static as well as dynamic analysis. For equivalent static method, the values are: For rocky, or hard soil sites Sa/g= {2.5 0.00 < T < 0.40s} Sa/g= {1 / T 0.40s < T<4.0s} Sa/g= {0.25 T > 4.0s} For medium soil sites Sa/g= {2.5 0.00 < T < 0.55s} Sa/g= {1.36 / T 0.55s < T<4.00s} Sa/g= {0.34 T > 4.0s} For soft soil sites Sa/g= {2.5 0.00 < T < 0.67s} Sa/g= {1.67 / T 0.67s < T<4.00s} Sa/g= {0.42 T > 4.0s}	In the revised code, the values of Sa/g are made constant as 2.5 in the period range of 0<T<0.4s. Moreover, values of Sa/g are provided for T>4s. Values are given in the revised code corresponding to damping ratio of 5% only, as this damping ratio is kept fixed for static as well as dynamic analysis in the revised code for all types of buildings.
7	Damping Ratio: Clause **6.4.2** & Table13 Damping of 5% is adopted for all types of buildings for providing the values of Sa/g and for the response spectra. Multiplying factors for other damping (0, 2, 5, 7, 10, 15, 20, 25, and 30% damping) are given in Table 3.	Damping Ratio: Clause 7.2.4 Damping ratio is fixed as 5% of the critical damping for all types of buildings irrespective of the material of construction (steel, reinforced concrete, masonry, or combination of these three materials) for use in static as well as dynamic analysis.	Damping ratio of 5% is fixed for all type of buildings as per Clause 7.2.4 of the code for static as well as dynamic analysis.
8	Minimum Design Lateral Force: No provision exists in the code in this regard.	Minimum Design Lateral Force: Clause7.2.2, Table 7 Buildings and portions thereof, are to be designed for a minimum horizontal force not less than $(V_B)_{min}$ equal to 0.7, 1.1, 1.6 and 2.4 percent of the seismic weight of the building, in seismic zones II, III, IV and V respectively.	This is a new provision in the revised code. If calculated value of V_B comes less than $(V_B)_{min}$ then the building has to be designed based $(V_B)_{min.}$ This makes the EQ resistant design more rational.
9	Design Acceleration Spectra for Vertical Motion: Clause 6.4.5 As per Clause 6.4.5, the design acceleration spectra for vertical motion is taken equal to 2/3 of the design horizontal acceleration spectra. i.e. Av = (2/3) Ah	Design Acceleration Spectra for Vertical Motion: Clauses 6.3.3 and 6.4.6 As per Clause 6.4.6, the design acceleration spectra for vertical motion for buildings is taken as Av = (Z /2) (I/R) (2.5) which is equivalent to 2/3 of the design horizontal acceleration spectra for	The revised code specifies the conditions when the effects due to vertical earthquake shaking are to be considered. This was missing in the earlier code. Thus, all buildings located in seismic zones IV and V, all buildings having plan or vertical irregularities and all

	Clause 6.3.3 mentions that when vertical earthquake loads are to be considered, the design vertical force shall be calculated as per Clause 6.4.5. Conditions under which vertical earthquake loads are to be applied are not specified.	horizontal acceleration calculated with Sa/g=2.5 ………… Ah = (Z /2) (I/R) (Sa/g) Clause 6.3.3.1 specifies that effects due to vertical earthquake shaking shall be considered when any one of the following conditions apply: 1. Structure is located in seismic zone IV or V; 2. Structure has vertical or plan irregularities; 3. Structure is rested on soft soil; 4. Bridges; 5. Structure has long spans; or 6. Structure has large horizontal overhangs of members or sub-system.	buildings resting on soft soil are required to be designed considering the effects due to vertical earthquake shaking.

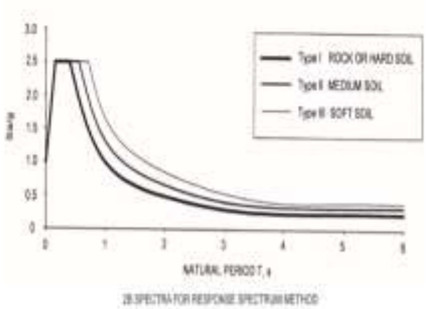
II. Dynamic Analysis

Simplified analysis i.e. static analysis (Equivalent Static Seismic Force Method) is used for simple buildings of low height in less severe seismic zones. Buildings having irregularities of plan and elevation have uneven distribution of mass and they require more rigorous analysis i.e. dynamic analysis. Even regular structures in higher seismic zones or regular high-rise structures in all zones require dynamic analysis. The revised code IS:1893 has made criterion more stringent and brought more buildings under the purview of dynamic analysis. Now only regular buildings with height < 15M in seismic Zone II can be designed using static analysis. For all other buildings, dynamic analysis is made mandatory.

For buildings, linear dynamic analysis is carried out to obtain the design seismic force and its distribution at different floor levels and to different structural elements. Three methods are mentioned in the revised code for dynamic analysis as mentioned below-

1. Response spectrum method, 2. Modal time history method and 3. Time History Method

The IS: 1893 recommends methods 1 and 3 above and provides detailed procedure for the Response Spectrum Method. Design base shear calculated from dynamic analysis is compared with the base shear calculated using fundamental time (static method) period and if it is less than the fundamental base shear value, the lateral force is multiplied by the ratio of fundamental base shear to calculated design base shear in order to obtain the design base shear.

Sr. No.	IS 1893 (Part-1) :2002	IS 1893 (Part-1) :2016	Remarks
1	Dynamic Analysis Condition: Clause **7.8.1** Dynamic analysis is required in following cases: a. For regular type of buildings i. Zone IV, V – Height > 40 m ii. Zone II, III – Height > 90 m b. For irregular type of buildings i. Zone IV, V – Height > 12 m ii. Zone II, III – Height > 40 m	Dynamic Analysis Condition: Clause **7.7.1** Dynamic analysis is required in following cases: a. For regular type of buildings i. Zone II, IV, V – All buildings ii. Zone II – All buildings with eight >= 15 m b. For irregular type of buildings i. Zone II, III, IV, V – All buildings	Dynamic Analysis is made mandatory for all irregular buildings in all zones. Dynamic analysis is also made mandatory for all regular buildings in zone III, IV and V. In zone II regular buildings having height >=15 m are brought under the purview of dynamic analysis.
2	Design Seismic Acceleration Spectrum: Clause **6.4.2** and Fig.1 Same spectra for 5% damping are applicable as provided for static analysis. Multiplying factors for other damping are also same as given in Table 3. However, for dynamic analysis, Clause 7.8.2.1 of the code provides damping values as 2% for use in steel buildings and 5% for use in reinforced concrete buildings.	Design Seismic Acceleration Spectrum: Clause **6.4.2** and Fig.2B For dynamic analysis using response spectrum method, the response spectra for different soil types for 5% damping are given for period range up to 6 seconds in Fig.2B of the code. The figure is as follows:  **Fig. Design Acceleration Coefficient (Sa/g) Corresponding to 5 Percent Damping: Spectra for Response Spectrum Method**	Spectra are same in the revised code as that in the earlier code except that the spectra are extended to include values of Sa/g for T>4.0 s. Spectra are given in the revised code corresponding to damping ratio of 5% only, as this damping ratio is kept fixed for static as well as dynamic analysis in the revised code

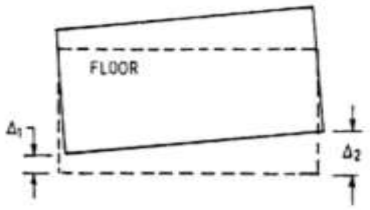
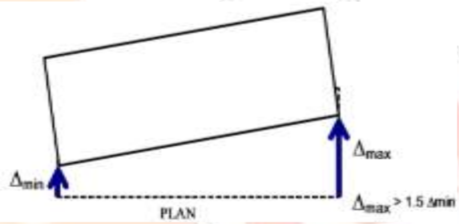
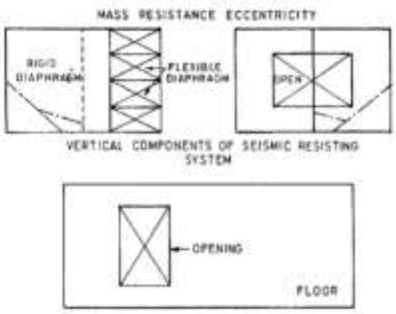
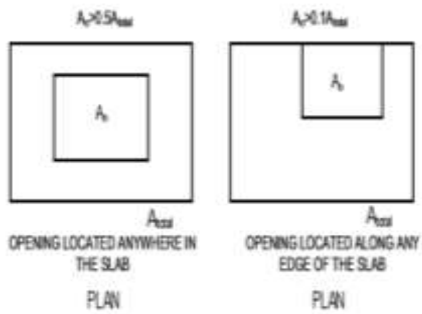
		Damping ratio of 5% is fixed for all type of buildings as per Clause 7.2.4 of the code for static as well as dynamic analysis.	
3	Average Response Acceleration Coefficient (Sa/g): Clause 6.4.2 and 6.4.5, Fig. 2, Table 3 Same values of Sa/g for 5% damping are applicable as provided for static analysis. Multiplying factors for other damping are given in Table 3. However, for dynamic analysis, Clause 7.8.2.1 of the code provides damping values as 2% for use in steel buildings and 5% for use in reinforced concrete buildings.	Design Acceleration Coefficient (Sa/g): Clause 6.4.2 and Fig.2B Design Acceleration Coefficient (Sa/g) for different soil types for 5% damping are given in clause 6.4.2 and Fig.2(b) for dynamic analysis using response spectrum method. Damping ratio of 5% is fixed for all type of buildings as per Clause 7.2.4 of the code for static as well as dynamic analysis. Sa/g for response spectrum method: For rocky, or hard soil sites Sa/g= {1+15T T < 0.10s} Sa/g= {2.5 0.10s < T < 0.40s} Sa/g= {1 / T 0.40s < T<4.0s} Sa/g= {0.25 T > 4.0s} For medium soil sites Sa/g= {1+15T T < 0.10s} Sa/g= {2.5 0.10s < T < 0.55s} Sa/g= {1.36 / T 0.55s < T<4.0s} Sa/g= {0.34 T > 4.0s} For soft soil sites Sa/g= {1+15T T < 0.10s} Sa/g= {2.5 0.10s < T < 0.67s} Sa/g= {1.67 / T 0.67s < T<4.00s} Sa/g= {0.42 T > 4.0s}	Values of Sa/g for 5% damping are same in the revised code as that in the earlier code except that the values are introduced for the extended range of period i.e. for T>4.0 s. Values are given in the revised code corresponding to damping ratio of 5% only, as this damping ratio is kept fixed for static as well as dynamic analysis in the revised code.
4	Damping Ratio: Clause **6.4.2** & Table13 Damping of 5% is adopted for all types of buildings for providing the values of Sa/g and for the figure of response spectra. Multiplying factors for other damping (0, 2, 5, 7, 10, 15, 20, 25, and 30%) are given in Table 3. For dynamic analysis, Clause 7.8.2.1 of the code provides damping values as 2% for use in steel buildings and 5% for use in reinforced concrete buildings.	Damping Ratio: Clause 7.2.4 Damping ratio is fixed as 5% of the critical damping for all types of buildings irrespective of the material of construction (steel, reinforced concrete, masonry, or combination of these three materials) for use in static as well as dynamic analysis.	Damping ratio of 5% is fixed for all type of buildings as per Clause 7.2.4 of the code for static as well as dynamic analysis. Thus, for steel buildings also 5% damping is applicable unlike 2% provided in the earlier code. This will result in lesser value of S_a/g, so lesser design lateral seismic force and consequently more economical design of steel buildings.
5	Treatment of buildings with re-entrant corners: Table 4 Buildings with re-entrant corners (as defined in the code) are included in Table 4, which shows buildings having plan irregularities. No specific mention of dynamic analysis requirement	Treatment of buildings with re-entrant corners: Table 5 Buildings with re-entrant corners (as defined in the code) are included in Table 5, which shows buildings having plan irregularities. Here code specifically mentions that for such buildings, three-dimensional dynamic analysis method shall be adopted	Revised code makes three-dimensional dynamic analysis mandatory for buildings with re-entrant corners (as defined in the code).
6	Treatment of buildings with Torsional Irregularities: Table 4 No specific mention of dynamic analysis requirement	Treatment of buildings with Torsional Irregularities: Table 5 When Δ_{max}. = (1.5-2.0) Δ_{min}. (ref. Fig.3A), the code requires not only revision of the building configuration but also 3D dynamic analysis.	Revised code makes three-dimensional dynamic analysis mandatory for buildings with torsional irregularities beyond certain limit of relative drift.

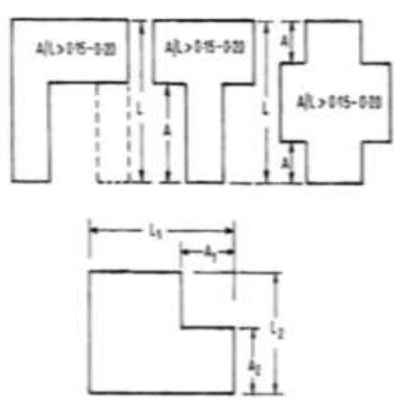
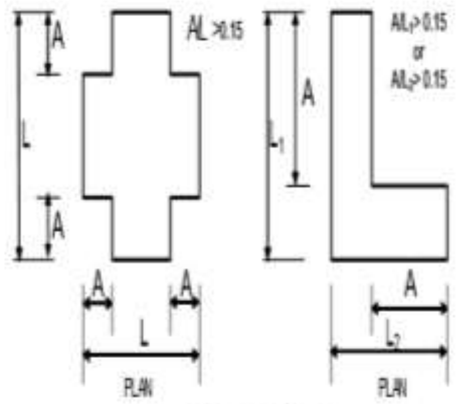
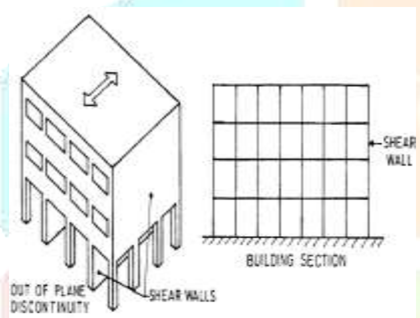
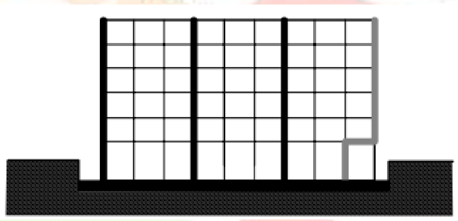
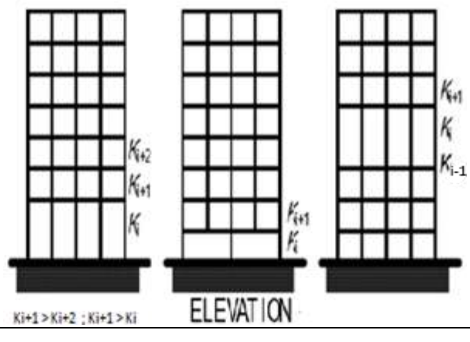
C. IRREGULAR BUILDINGS

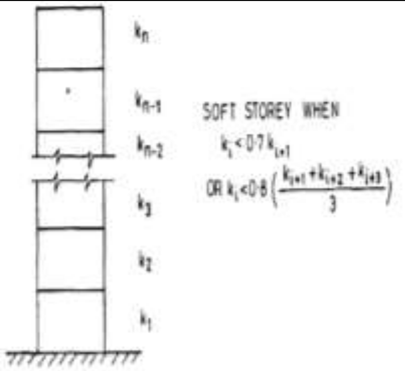
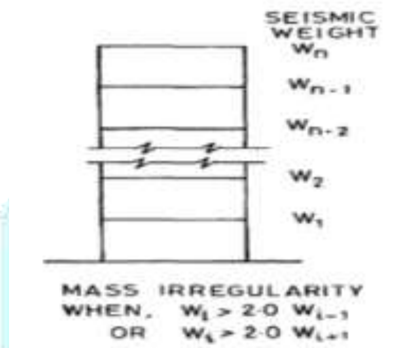
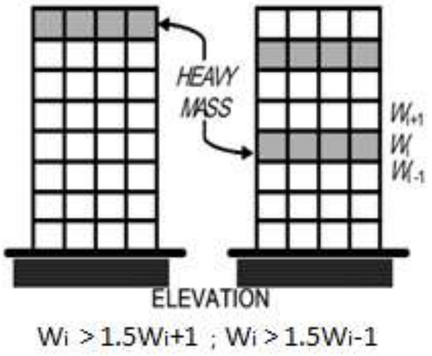
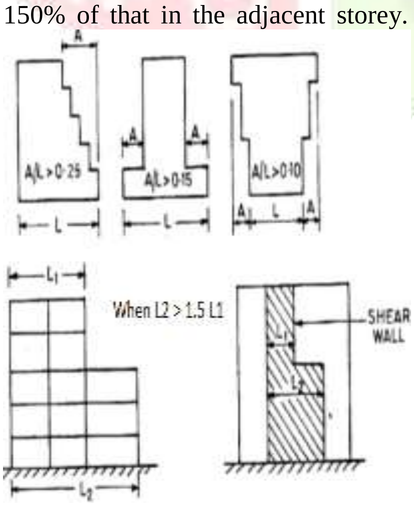
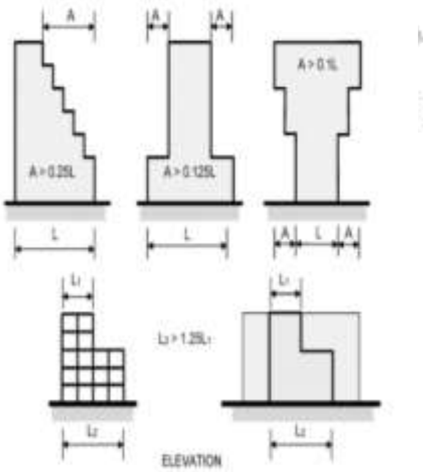
Buildings with simple regular geometry and uniformly distributed mass and stiffness in plan and in elevation, suffer much less damage, than buildings with regular configuration. Keeping this in view, all efforts should be made to eliminate irregularities by proper architectural planning any structural design. More rigorous analysis is required for irregular buildings. The revised code has made it mandatory to carry out dynamic analysis for all irregular buildings in all seismic zones.

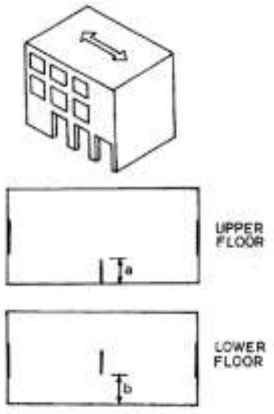
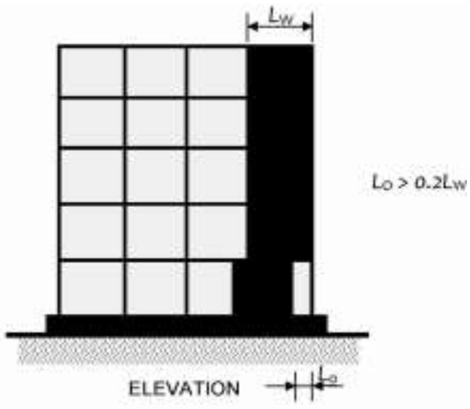
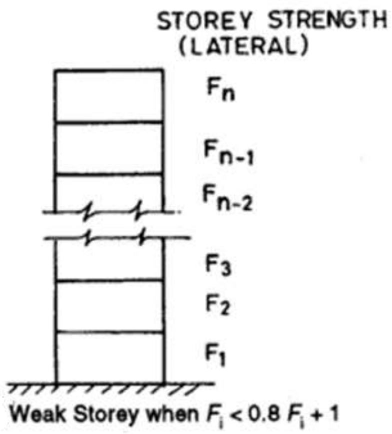
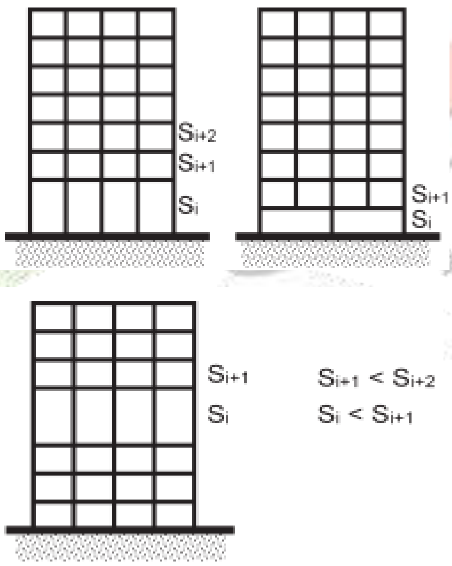
IS:1893 Part 1 has defined various irregularities of plan and elevation in its different tables. A building is considered to be irregular for the purposes of the code, even if any one of these conditions is applicable. Limits on irregularities for seismic zones III, IV and V and special requirements are also laid out in these tables. Comparison between some of the provisions which are revised significantly are discussed below:

I. Plan Irregularities

Sr. No.	IS 1893 (Part-1) :2002	IS 1893 (Part-1) :2016	Remarks
1	Torsion irregularity: Clause **7.1**, Table 4, Fig.3A. Torsional irregularity to be considered to exist when, Max storey drift, $\Delta 2 > 1.2(\Delta 1 + \Delta 2)/2$, as shown in the figure  **Fig. Torsional Irregularities**	Torsion irregularity: Clause **7.1**, Table 4, Fig.3A. A building is said to have torsional irregularity, when, 1) $\Delta_{max}. > 1.5\ \Delta_{min}$. as shown in the following figure.; and 2) The natural period corresponding to the fundamental torsional mode of oscillation is more than those of the first two translational modes of oscillation along each principal plan directions  **Fig. Torsional Irregularities** If $\Delta_{max}. = (1.5\text{-}2.0)\ \Delta_{min}.$, the building configuration is to be revised to ensure that the condition 2) above is not encountered, and 3D dynamic analysis is performed If $\Delta_{max}. > 2.0\ \Delta_{min}.$, then it is not acceptable, and the building configuration has to be revised altogether.	Definition of torsional irregularity expanded and made stricter in the revised code. If $\Delta_{max}. = (1.5\text{-}2.0)\ \Delta_{min}.$, the building configuration is to be revised, to ensure that the condition restricting torsional and translational modes of oscillations is not encountered. This may require revision in structural or architectural planning. Further, 3D dynamic analysis is made mandatory in such cases. Torsional irregularities beyond a threshold ($\Delta_{max}. > 2.0\ \Delta_{min}$) are not at all permitted now and building configuration has to be revised altogether. This may completely change the architectural as well as structural planning of the building. It is felt that the check for maximum and minimum drift may be applied only when Δ_{min} crosses some minimum value, else negligible drifts may create torsional irregularities as per the definition.
2	Diaphragm Discontinuity: (excessive cut-outs) Clause **7.1,** Table-4, Fig.3C In this code flexible/rigid diaphragm are not specified. When $Ao > 0.5\ A_{total}$, this condition is shows discontinuous diaphragm Where, Ao = area of opening  **Diaphragm Irregularity**	Diaphragm Discontinuity:(excessive cutout) Clause **7.1,** Table- 5, Fig.3C As per this code – When $Ao > 0.5\ A_{total}$ = flexible diaphragm When $Ao < 0.5\ A_{total}$ = Rigid or flexible diaphragm depending on location and size of openings  **Diaphragm Irregularity**	Openings in slabs result in flexible diaphragm behaviour, and hence the lateral shear force is not shared by the frames and or vertical members in proportion to their lateral translational stiffnesses. The revised code has introduced a more stringent criteria by treating diaphragms with less than 50% openings also as flexible depending on location and size of openings.
3	Re-entrant corners: Clause 7.1, Table-4	Re-entrant corners: Clause 7.1, Table – 5	In the revised code, the definition of buildings having re-entrant corners is made

	According to the Fig.3B in this code, for re-entrant corner, A/L > 0.15-0.20.  **Fig. Re-entrant Corner**	According to the Fig.3B in this code, for re-entrant corner, A/L > 0.15.  **Fig. Re-entrant Corner**	more stringent. Further, 3 - dimensional dynamic analysis made mandatory for buildings having re-entrant corners.
4	Out-of-Plane Offsets: Clause 7.1, Table 4, Fig.3D It is defined as discontinuities in a lateral force resistance path such as out of plane offsets of vertical elements. No restrictions imposed on storey drift.  **Fig. Out-of-Plane Offsets**	Out-of-Plane Offsets in Vertical Plane: Clause 7.1, Table 5, Fig.3D A building is said to have out-of-plane offset in vertical elements, when structural walls or frames are moved out of plane in any storey along the height of the building. For buildings in seismic zone III, IV and V, lateral drift is restricted to 0.2% in the story having the offset and, in the stories, below.  **Fig. Out-of-Plane Offsets in Vertical Plane elements**	In the revised code, the definition of out-of-plane offset is made clearer. Restriction imposed on storey drift in seismic zone II, IV and V.
5	Non-Parallel Lateral Force System: Clause 7.1, **6.3.2.2,** Table 4, Fig.3E The structure is to be designed for the effects due to full design earthquake load in one horizontal direction plus 30% of the design earthquake load in the other direction.	Non-Parallel Lateral Force System: Clause 7.1, **6.3.2.2, 6.3.4.1,** Table 5, Fig.3E In addition to the provision of old code, the building is to be designed for three-directional earthquake loading combinations.	The revised code makes three-directional earthquake analysis mandatory in this case. However, as per Clause 3.3.3.1 the revised code has made it mandatory to include effects due to vertical shaking when structure has any vertical or plan irregularity. In view of same the above requirement is superfluous.
		II. Vertical Irregularities	
Sr. No.	**IS 1893 (Part-1) :2002**	**IS 1893 (Part-1) :2016**	**Remarks**
1	Soft Story (Stiffness irregularity): clauses **7.1,** Table 5, Fig.4A A soft story is defined as the story in which the lateral stiffness is less than 70% of that in the story above or less than 80% of the average lateral stiffness of the three story above.	Soft Story (Stiffness irregularity): clause **7.1,** Table 6, Fig.4A A soft story is defined as the story in which the lateral stiffness is less than that in the story above.  	In the latest code the criteria for soft story is made more stringent as the soft story is a source of weakness in the structure. Now more buildings will come under this irregularity. Provision for dealing frames with URM added in the revised code.

	 **Fig. Stiffness Irregularity (soft-story)**	**Fig. Stiffness Irregularity (soft- story)** Effect of un-reinforced masonry (URM) infills is to be considered if its structural plan density (SPD) exceeds 20 percent by explicitly modelling the same in structural analysis (as per Clause 7.9). Further, the inter-storey drift shall be limited to 0.2 percent in the storey with stiffening and also in all storeys below.	
2	Mass irregularity: Clause **7.1** It is defined in Table-5 and shown in Fig. 4B. Mass irregularity is considered to exist where the seismic weight of any storey is more than 200% of that of its adjacent storeys.  **Fig. Mass Irregularity**	Mass irregularity: Clause **7.1** It is defined in Table-6 and shown in Fig. 4B. Mass irregularity is considered to exist where the seismic weight of any floor is more than 150% of that of the floor below.  **Fig. Mass Irregularity**	The definition of mass irregularity is made more stringent in the revised code. Now more buildings will come under this irregularity.
3	Vertical Geometric Irregularity: Clause **7.1**, Table-5, Fig.4C Vertical geometric irregularity is considered to exist, if the horizontal dimension of the lateral force resisting system in any storey is more than 150% of that in the adjacent storey.  **Fig. Vertical Geometric Irregularity**	Vertical Geometric Irregularity: Clause **7.1**, Table-6, Fig.4C Vertical geometric irregularity is considered to exist, if the horizontal dimension of the lateral force resisting system in any storey is more than 125% of that in the storey below.  **Fig. Vertical Geometric Irregularity**	The definition of vertical geometric irregularity is made more stringent in the revised code. Now more buildings will come under this irregularity.
4	In-Plane Discontinuity in Vertical Elements Resisting Lateral Force: Clause 7.1, Table 5, Fig. 4D It is considered to exist when lateral force resisting elements greater than the length of those elements	In-Plane Discontinuity in Vertical Elements Resisting Lateral Force: Clause 7.1, Table 6, Fig.4D It is considered to exist when in-plane offset of the lateral force resisting elements is greater than 20 percent of the plan length of those elements.	Provision made more stringent in the revised code. Moreover, restriction imposed on lateral drift for buildings in zone II. In zone III, IV and V such irregularities are not permitted. This will have a great impact

	 **Fig. In-Plane Discontinuity in Vertical Elements Resisting Lateral Force when b>a**	 **Fig. In-Plane Discontinuity in Vertical Elements Resisting Lateral Force** For such case in zone II, the lateral drift of the building under the design lateral force is limited to 0.2 percent of the building height Buildings with in-plane discontinuity are not permitted in Zones III, IV and V.	on architectural planning in these zones.
5	Discontinuity in Capacity - Weak Storey: Clauses 7.1, 7.10, Table 5, Fig.4E A weak storey is one in which the storey lateral strength is less than 80 percent of that in the storey above. Strengthening measures as per Clause 7.10 for weak storey only. Column and Beam strengthening permitted shear wall optional.  **Fig. Strength Irregularity (Weak Storey)**	Strength Irregularity (Weak Storey): Clause 7.1, 7.10, Table 6, Fig.4E A weak storey is a storey whose lateral strength is less than that of the storey above. Strengthening measures as per Clause 7.10 for weak storey and the storey below. Column and Beam strengthening alone not permitted, shear wall or braced frames permitted. Ductile detailing made mandatory in zones III, IV and V.  **Fig. Strength Irregularity (Weak Storey)**	Revised code makes this provision stricter. Now more buildings will come under the purview of this provision. Also strengthening now necessary for the storey below also. Column and Beam strengthening alone not permitted, shear wall or braced frames are required. This will ensure greater safety at additional cost.
6	Floating/ Stub Column: No provision exists in the code.	Floating/ Stub Column: Clause 7.1, Table 6 Such columns are likely to cause concentrated damage in the structure, hence prohibited, if it is part of or supporting the primary lateral load resisting system.	It is a new provision in the revised code. Now floating/ stub column (which are part of or supporting the primary lateral load resisting system) are not permitted. This imposes restrictions on the architectural planning.
7	Irregular Modes of Oscillation in Two Principal Plan Directions. No provision exists in the code.	Irregular Modes of Oscillation in Two Principal Plan Directions: Clause 7.1, Table 6	This is a new provision in the revised code. This will affect the structural planning and, if needed, revision in the architectural planning also.

		A building is said to have lateral storey irregularity in a principal plan direction, if a) the first three modes contribute less than 65 percent mass participation factor in each principal plan direction, and b) the fundamental lateral natural periods of the building in the two principal plan directions are closer to each other by 10 percent of the larger value. Removal of both a) and b) is to be ensured in zones IV and V. and IV. In zones II and III removal of a) is to be ensured.	

D. DEFINITIONS

Sr. No.	IS 1893 (Part-1) :2002	IS 1893 (Part-1) :2016	Remarks
1	Centre of Mass (CM): clause **4.4** Centre of mass is as the point through which the resultant of the masses of whole system acts. It is the centre of gravity of the mass system.	Centre of Mass (CM): clause **4.4** Centre of mass is defined as a point in a floor of a building through which the resultant of the inertia force of the floor is considered to act during earthquake shaking.	Definition of Centre of Mass is more rationalised in the latest code.
2	Flexible Diaphragm: Clause **7.7.2.2** A floor diaphragm is considered to be flexible if it deforms such that the maximum lateral displacement measured from the chord of the deformed shape at any point of the diaphragm is more than 1.5 times the average displacement of the entire diaphragm.	Flexible Diaphragm: Clause **7.6.4** A floor diaphragm is considered to be flexible if it deforms such that the maximum lateral displacement measured from the chord of the deformed shape at any point of the diaphragm is more than 1.2 times the average displacement of the entire diaphragm.	A more stringent criteria for rigid diaphragm is provided in the revised code by revising the definition of flexible diaphragm.
3	Height and Base Width of Building: For calculation of T_a in Clause 7.6 No explanatory figure is available in the code which shows & explains the definition of height & base width of building.	Height and Base Width of Building: For calculation of T_a in Clause 7.6 Fig.5 shows & explains the definitions of height & base width of building	More clarity is given in the revised code regarding definition of height & base width of building for calculation of time period.

E. DESIGN PARAMETERS

Sr. No.	IS 1893 (Part-1) :2002	IS 1893 (Part-1) :2016	Remarks
1	Increase in Allowable Bearing Pressure on Soil: Clause **6.3.5.2** Under seismic forces, percentage increases in allowable bearing pressure for different soil types & different kind of foundations is given in Table-1.	Increase in Net Bearing Pressure on soil: Cause. **6.3.5.2** Under seismic forces, percentage increases in net bearing pressure for different soil types is given in Table-1. It is made common for all types of foundations. Further, no increase is allowed for soft soils with the reasoning that settlement can not be restricted by increasing bearing pressure. A simplified procedure for evaluation of liquefaction potential is added in the code as Annexure F	The revised code does not allow any increase in bearing pressure in soft soil. This is a big change, which may revise the design of foundations considerably for structures resting on soft soils. Liquefiable soils are undesirable and need further investigation. No procedure for evaluation of liquefaction potential was available earlier, which is now added.
2	Increase in permissible stresses in material: Clause **6.3.5.1** When earthquake forces are considered along with other normal design forces, the code permitted an increase in permissible stresses in material by one third for elastic design method, in general.	Increase in permissible stresses in material: No clause exists in the code The code does not permit any increase in permissible stresses under earthquake forces.	This will require stronger structural members for the design of structures which are based on working stress method.
3	Moment of Inertia for Earthquake Loads: RC and Masonry Structures, no separate clause	Moment of Inertia for Earthquake Loads: RC and Masonry Structures, **Clause 6.4.3.1**	Revised code considered a more realistic approach by considering stiffnesses for cracked sections under

	Full moment of inertia of gross (uncracked) sections of the columns and beams are considered. .	Reduced moment of inertia of cracked section is considered. Reduced moment of inertia of 70% of gross is considered for columns & 35% of gross is considered for beams.	earthquake+ forces. This may result in more deflections and stresses in the structural members.
4	Maximum number of load combinations to be considered for design: 73	Maximum number of load combinations to be considered for design: 73	No change in maximum number of load combinations.
5	Ductile Design Requirement: Clause 6.4.2, Table 7 No restriction on providing OMRF (Ordinary Moment Resisting Frame) system (i.e. frame not meeting ductile detailing requirement) in any seismic zone. Ordinary RC shear walls not allowed in zones IV and V (old zones)	Ductile Design Requirement: Clause 7.2.6, Table 9 OMRF not allowed in seismic zones III, IV and V which means that it is mandatory to follow ductile design and detailing requirements in these zones, as per IS: 13920 for RCC frames and as per SP 6(6) for steel frames. Only ductile RC shear walls are permitted in zones III, IV and V.	The revised code has made it mandatory to follow ductile design and detailing requirements in seismic zones III, IV and V for all Steel and RCC buildings. This will enhance safety of buildings under earthquakes. However, ductile design and detailing require additional cost and skillful construction.
6	RC Framed Buildings with Unreinforced Masonry (URM) Infill Walls: No procedure for modelling URM infill walls and determining its strength and stiffness is available in the code.	RC Framed Buildings with Unreinforced Masonry (URM) Infill Walls: Clause 7.9 Procedure for modelling URM infill walls and determining its strength and stiffness is added in the revised code.	More rational design is now possible for frames with URM infill walls.

2.2 Comparison between IS 1893 (Part-4)-2005 and IS 1893 (Part-4)-2015: The part 4 of IS: 1893 redirects to part 1 for analysis of category 4 buildings so provisions of Part 1 becomes applicable, which now includes latest revised provisions of 2016. Otherwise there are many mismatches/contradictions in Part 4 of 2015 and Part 1 of 2016. For example, temporary structures are continued to be exempted from earthquake resistant design in Part 4 2015 whereas, as per Part 1 2016, these are now included for earthquake resistant design. This calls for review of Part 4 2015 to include the important provisions of Part 1 2016. Some important additional clauses of IS 1893 (Part-4)-2005 and IS 1893 (Part-4)-2015 for industrial buildings are compared in tabular form as follows-

S.No.	IS 1893 (Part-4) – 2005	IS 1893 (Part-4)-2015	Remarks
1	**Load combinations: Clause 7.3.2** 1. 1.5 (DL+SIDL+IL) 2. 1.2 (DL+SIDL+IL ± EL) 3. 1.5 (DL+SIDL ± EL) 4. 0.9 (DL+SIDL) ± 1.5 EL Where, DL= Dead Load IL= Imposed Load SIDL= Super Imposed Dead Load EL= Earthquake Load	**Load combinations: Clause 8.3.2** 1. 1.5 (DL+SIDL+IL) 2. 1.2 (DL+SIDL+IL ± EL) 3. 1.5 (DL+SIDL ± EL) 4. 1.5 (0.6DL ± EL) Where, DL= Dead Load IL= Imposed Load SIDL= Super Imposed Dead Load EL= Earthquake Load	One load combination modified in the revised code. Now Super Imposed Dead Load is not to be considered in 4th load combination.
2	Maximum number of load combinations to be considered for design: 73	Maximum number of load combinations to be considered for design: 73	No change in maximum no. of load combinations.
3	**Importance Factor: Table 2** Category 1 – 2.00 Category 2 – 1.75 Category 3 – 1.50 Category 4 – 1.00	**Importance Factor: Table 3** Category 1 – 2.00 Category 2 – 1.50 Category 3 – 1.25 Category 4 – 1.00	Importance factors are reduced in the revised code for category 2 and category 3 structures. This will reduce lateral load and result in some economy in design.

2.3 Comparison between IS 13920-1993 and IS 13920-2016: Two major changes in IS: 13920-2016 as compared to IS: 13920-1993 are discussed here which have far reaching impact on the architectural and structural planning of earthquake resistant design of buildings.

1. As per IS 13920-2016 (Code of Practice – Ductile Design & Detailing of RCC Structures Subjected to Seismic Forces) Clause 7.1.1 provides that the minimum dimension of a column shall not be less than-
   a) 20 db, where db = diameter of the largest longitudinal reinforcement bar in the beam passing through or anchoring into the column at the joint.
   b) 300mm.
   Additionally, the minimum cross-sectional aspect ratio of column shall not be less than 0.45.

   As per the earlier code, the minimum column dimension was 200 mm with the minimum cross-sectional aspect ratio of column to be not less than 0.4 (preferably). It is a big change requiring special attention of architects while planning the buildings. Also, structural designers shall have to control the diameter of beam bars or column sizes while designing the buildings. Further, for the columns having cross sectional aspect ratio less than 0.4, special design criteria are added under clause 9 in the revised code.

2. A provision of relative strengths of beams and columns at a joint is introduced in the revised code under Clause 7.2. beam-column joint of a moment resisting frame:- The sum of nominal design strength of columns meeting at that joint along each principle plane shall we at least 1.4 times the sum of nominal designs strength of beams meeting at that joint in the same plane.

   This clause is based on strong-column-weak-beam theory. At each joint, the columns should be stronger than the beams meeting at the joint. It is meant to make the beams yield before the columns yield so that the building fail in beam-hinge mechanism. If columns yield before the beams yield, then building fails in the storey mechanism which must be avoided as it causes greater damage. A structural designer has to check all beam column joints to ensure conformance to this provision.

   Both the above provisions were much needed, in line with international standards, to ensure additional safety of the buildings under earthquake.

3. The revised code restricts the factored axial compressive stress in columns to 0.40 f_{ck} for all load combinations relating to seismic loads. This will have a major impact on structural design and stronger columns may have to be provided.

4. Minimum grade of concrete is revised upwards to M25 for buildings which are more than 15 m high in seismic zones III, IV and V. This will change the structural design for these buildings.

3. CONCLUSIONS

The earthquake science is continuously evolving, learning from the past earthquakes world over. Changes are incorporated in relevant codes in pursuit of more rational design and safer buildings. Some major changes are introduced in the relevant Indian Standard codes of practices namely IS:1893 Part 1 and Part 4and IS: 13920 also. The most important changes which every architect and structural designer should know are discussed in this paper. The same are summarized as follows.

1.1 IS: 1893 Part 1 2016: General Provisions and Buildings

1.1.1 Structures like parking structures, security cabin, ancillary structures, and temporary elements such as scaffolding and temporary excavation now comes under the purview of earthquake resistant design as per the revised code of 2016. Provision is now made for buildings with time period greater than 4 s.

1.1.2 Design seismic lateral force will change due to some of the revised provisions. Formula for calculation of time period T_a of buildings with RC structural walls is introduced which will change their design. General residential or commercial buildings with occupancy more than 200 now have now greater importance factor of 1.2 instead of earlier 1.0 which will provide greater protection to such buildings at enhanced cost due to enhanced design lateral forces. Separate spectra are provided for static and dynamic analysis. For static analysis the values of Sa/g are made constant as 2.5 in the period range of 0<T<0.4s. Damping ratio is now fixed for static as well as dynamic analysis at 5%. Concept of minimum design lateral force (in terms of fraction of seismic weight) is also introduced. All these provisions will change the value of design seismic force.

1.1.3 The revised code specifies the conditions under which the effects due to vertical earthquake shaking are to be considered. This was missing in the earlier code making it arbitrary. According to the revised provision, all buildings located in seismic zones IV and V, all buildings having any of the plan or vertical irregularities (as mentioned in the code) and all buildings resting on soft soil are required to be designed considering the effects due to vertical earthquake shaking. This will have a great impact on the earthquake resistant design of the buildings as number of load cases will increase considerably.

1.1.4 Dynamic Analysis is now made mandatory for all buildings having any of the plan or vertical irregularities (as mentioned in the code) in all zones. Definitions of plan and vertical irregularities are also revised and expanded in the revised code. Mostly more stringent criteria are defined bringing more buildings under the definition of irregular buildings. Restriction on drift has now been imposed in certain types of irregularities.

1.1.5 Torsional irregularity when Δ_{max}. = (1.5-2.0) Δ_{min}., the building configuration is to be revised to ensure that the condition restricting torsional and translational modes of oscillations (as mentioned in the code) is not encountered. This may require revision in structural or architectural planning. Torsional irregularity when Δ_{max}. > 2.0 Δ_{min}, is not at all permitted now and building configuration has to be revised altogether. This may completely change the architectural as well as structural planning of the building.

1.1.6 In zone III, IV and V, the irregularities of 'In-Plane Discontinuity in Vertical Elements Resisting Lateral Force', is not permitted now. This will have a great impact on architectural planning in these zones.

1.1.7 For the irregularity of soft storey, strengthening is now necessary for the storey below also. Column and Beam strengthening alone not permitted now, shear wall or braced frames are required. This will ensure greater safety at additional cost.

1.1.8 Two new vertical irregularities are added in the revised code. The first is that of 'Floating/ Stub Column'. Now floating/ stub column (which are part of or supporting the primary lateral load resisting system) are not permitted. This imposes restrictions on the architectural planning. The second one is that for 'Irregular Modes of Oscillation in Two Principal Plan Directions'. This check can only be applied after analysis of the building. If check fails, then structural and architectural planning of the building may have to be revised.

1.1.9 Dynamic analysis is also made mandatory for all regular buildings in zone III, IV and V. In zone II also, regular buildings having height >=15 m are brought under the purview of dynamic analysis. Architects and structural designers have to be extra cautious while planning and designing buildings in such cases.

1.1.10 Revised code makes three-dimensional dynamic analysis mandatory for buildings with re-entrant corners (as defined in the code), for buildings having torsional irregularities when Δ_{max}. = (1.5-2.0) Δ_{min} and for buildings having non-parallel lateral force system.

1.1.11 The revised code does not allow any increase in bearing pressure in soft soils. This is a big change, which may revise the design of foundations considerably for structures resting on soft soils.

1.1.12 Unlike the earlier code, the revised code does not permit any increase in permissible stresses under earthquake forces. This will require stronger structural members for the structures which are designed based on working stress method.

1.1.13 The revised code considers reduced moment of inertia of cracked section for beams (35% of gross) and columns (70% of gross). This is more rational design even though it may require stronger sections.

1.1.14 The revised code has made it mandatory to follow ductile design and detailing requirements in seismic zones III, IV and V for all Steel and RCC buildings (as per IS: 13920 for RCC frames and as per SP 6(6) for steel frames). This will enhance safety of buildings under earthquakes at additional cost.

1.1.15 More rational design of frames with un-reinforced masonry infill walls is now possible as the revised code has introduced the procedure for modelling the same.

1.2 IS: 1893 Part 4 2015: Industrial Buildings

1.2.1 In the revised code of 2015, there is a slight change in one of the load combinations. Now Super Imposed Dead Load (SIDL) is not to be considered in 4th load combination.

1.2.2 Importance factors are reduced in the revised code for category 2 and category 3 structures. This will reduce lateral load and may result in some economy in design.

1.3 IS: 13920 2016: Ductile Design and Detailing

1.3.1 The most important change in the revised code of 2016 is that the minimum size of column to be kept is now 300 mm against 200 mm as per the earlier code. This provision is of special importance to architects as they have to prepare architectural drawings accordingly. Structural designer has also to take care while providing the beam reinforcement as the minimum size of the column should also not to exceed 20 times the largest bar of the beam at the joint. Moreover, the columns having cross sectional aspect ratio less than 0.4, special design criteria have to be followed as per the revised code.

1.3.2 Concept of strong column weak beam is introduced in the revised code to enforce more controlled failure mechanism to reduce the damage. Structural designers need to ensure the same at every beam column junction.

1.3.3 The revised code restricts the factored axial compressive stress in columns to 0.40 f_{ck} for all load combinations relating to seismic loads. This will have a major impact on structural design and stronger columns may have to be provided.

1.3.4 Minimum grade of concrete is revised upwards to M25 for buildings which are more than 15 m high in seismic zones III, IV and V. This will change the structural design for these buildings.

Thus, there are major changes in the revised codes pertaining to earthquake resistant design of buildings. Scope of such design has expanded to a large extent and now includes almost all buildings (including temporary/ ancillary buildings) in zones III, IV and V and majority of the multi-storey buildings in zone II as well. Every architect and structural designer must be aware of these provisions to ensure the safety of the buildings as well as their own safety as these provisions are mandatory.

While doing the comparative study of the old and revised code it is felt that a few provisions of the codes need further review to make the provisions clearer and more specific. The same are as follows.

- It is felt that T_a for buildings with RC structural walls should have some upper bound also. In absence of the same, it may exceed T_a for bare frame which is not justified.
- It is felt that the check for maximum and minimum drift may be applied only when Δ_{min} crosses some minimum value, else negligible drifts may create torsional irregularities as per the definition.
- After publishing of the revised code IS: 1893 Part 1 2016, many of the provisions of the IS: 1893 Part 4 2015 becomes conflicting/ outdated. The same require a fresh review IS: 1893 Part 4 2015 for issuing corrigendum to remove these anomalies.

4. REFERENCES

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