# BENCHMARKING OF INDIAN SEISMIC CODE IS1893:2016

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***ABSTRACT***-The Bureau of Indian Standards came up with the 6th revision of seismic code IS1893 as draft in 2016 and finally as code in 2017. In this paper, an attempt has been made to understand and document the changes that have been incorporated in the latest revision of the code. An exhaustive comparison is done between all the clauses including deletion and addition of several clauses. Theoretical explanations and numerical calculations are done to understand the clauses better. Also, numerical experimentation is done using readymade Software to benchmark the impact of these changes in clauses to real life design of structures.

***KEYWORDS*** **-Seismic, Code, Earthquake, IS1893, Indian Seismic Code, Indian Earthquake Code**

## INTRODUCTION

There are several clauses in IS1893:2016 for which engineers, academicians and practitioners have reservations. This is partly due to the empiricism inherent in those clauses and partly due to the lack of proper knowledge and illustrations for those clauses. In order to study the apparent ambiguity underlying these clauses a number of case studies are required. They involve linear, non-linear and pushover analysis of real life structures. The clauses for example may be related to computation of base shear, permissible gap between two buildings, ductility and reduction factors, evaluation of torsion, the effect of soil conditions etc. The aim of the present study is to look into some such clauses and provide justification and/or validation of these clauses through numerical experimentation. An extensive literature review has been carried out in order to compare the clauses of IS1893:2016 with IS1893:2002 including other state of the art literature available in the form of journals, books and other international codes of practice on the relevant topics. Numerical experimentation have been carried out for response spectrum and time history analysis of real life structures using state of the art software. Numerical experimentation have also been carried out for non-linear and pushover analysis of real life structures using ETABS 2016. For statistical justification of the experiments, simple regression analysis have been carried out using Microsoft Excel 2016.

The basic problem with the seismic codes lies in our approach towards the earthquake problem. We as a nation have an attitude of dodging the problem until it becomes unavoidable. We are rarely prepared for any natural disaster in advance. We just look out for solutions when the problem already strikes. Our seismic codes follow the same pattern. If we look at the revision history of IS1893, we realize, whenever a major earthquake hits us, we start thinking about updating our code. The latest addition being the Sixth Revision in 2016 after the 2015Nepal earthquake. During the last couple of decades, earthquake engineering has undergone significant development, especially in the last decade with the advancement in the computing world. Complex, lengthy and rigorous calculations to determine the structure's behaviour are possible today with the click of few buttons. We are now at a position to understand the earthquake dynamics better, its propagation and its impact on structures. Each earthquake presents us with experience and understanding about building behaviour during the event. Past earthquakes have demonstrated that buildings designed by seismic design codes are not always safe against earthquake. Therefore, it is necessary that codes should be updated time to time.

It was realized that, the basic issue with our code still remains in its empirical formula approach. However large be the sample size, there would always be buildings that are not part of that sample size. In fact, every other buildings may behave differently under dynamic loads. Thus a more rational approach would be to drop the empirical formula and analyse every building rigorously. A more rigorous dynamic analysis, pushover analysis or performance based analysis would be more suited for the purpose.

In many aspects, our seismic code is not in tune with the current advancements that are taking place the world over. We are still relying upon principles, techniques and methods of analysis that are obsolete. A fresh approach must be taken to deal with the ever growing demand of safe, sustainable and economic development of infrastructure of the country.

## COMPARISON OF IS1893:2002 WITH IS1893:2016

### Scope

Scope of the new code now includes a lot more structures than earlier. The new code is also applicable even to the critical and special structures like Nuclear power plant,Petroleum refinery plant. However, for such structure additional requirements may be imposed based on special studies like site-specific hazards. In such cases, the earthquake effect specified by this code shall be taken as at least minimum.

**Earthquake-generated vertical inertia forces**

IS1893 2016(clause 6.1.1), states that 'the effect of earthquake induced vertical shaking for overall stability analysis of structure especially in structures with large spans and those in which stability is a criterion for design. Reduction in gravity force due to vertical component of ground motions can be particularly detrimental in cases of pre stressed horizontal members and of cantilevered members. Hence, special attention should be paid to the effect of vertical component of the ground motion on pre stressed or cantilevered beams, girders and slab.'

However, a similar clause was also present in the earlier code, but the code was silent on the implementation and applicability aspect of the clause. The latest code specifically mentions the applicability and the method of implementation of the same in detail.

All structures experience a constant vertical acceleration (downward) equal to gravity all the time. Hence, the vertical acceleration during ground shaking can simply be added or subtracted to the gravity, depending on the direction of ground motion at that instant. For example, consider a roof accelerating up and down with 0.2g. It implies that it is experiencing acceleration in the range of 1.2g to 0.8g in place of 1g that it would experience without an earthquake. The factor of safety for gravity loads e.g. dead and live loads is usually sufficient to cover the earthquake induced vertical accelerations. Thus, safety during horizontal acceleration is the main concern in seismic design of normal structures. However, in case of very large span structures, pre-stressed structures, structures having floating columns or structures having large cantilevered portions, vertical inertia forces generated due to earthquake can be detrimental to design.

**Classification of Soil**

The classification of soil has now been dealt in more detail and logical order. Now the code categorically specifies that the classification serve two-purpose viz. determining the Percentage increase in Net Bearing pressure and Skin Friction and determining the Spectral to be used to Estimate Design Earthquake Force.In soil type II (medium or stiff soil); it has clearly mentioned that it does not include all soils with N value between 10 and 30. Also poorly graded sand with little or no fines will have N > 30 instead of N > 15. A new type of soil i.e. Type D has been introduced to include unstable, collapsible, liquefiable soils. The same was not mentioned in the earlier code.

**Design Vertical Seismic Coefficient $A_v$**

Design of Vertical Earthquake Load ($A_v$), according to IS1893:2002 is given as two third of Design Horizontal Earthquake Load ($A_h$), i.e.

$A_v = 2/3\ A_h$

In IS1893 2016, effect due to design vertical load is considered when following conditions exists when, structure is located in seismic zone IV and V, structure is having a vertical or plan irregularity, structure is rested on soft soil, structure has long span, structure has long horizontal members of structural members or sub systems.

When design seismic acceleration spectral value, Av for vertical motions shall be taken as:

i. For Buildings, governed by IS1893 (part 1):

$$A_v = \frac{2.5*Z*I}{3R}$$

ii. For Liquid Retaining tanks, governed by IS1893 (part 2):

$$A_v = \frac{2.5*Z*I}{3R}$$

iii. For Bridges, governed by IS1893 (part 3):

$$A_v = \frac{Sa*Z*I}{3Rg}$$

iv. For Industrial Structures, governed by IS1893 (part 4):

$$A_v = \frac{Sa*Z*I}{3Rg}$$

Where;

Z = Zone Factor.

R = Response Reduction Factor

$S_a/g$ = Average response acceleration coefficient.

It is worth noting that, since it is mandatory for all structures in Zone IV and V to consider vertical acceleration in design. This will help in design of transfer beams supporting floating columns properly.

**Design Horizontal Seismic Coefficient $A_h$**

IS1893:2016 has given different curves for spectral acceleration coefficient ($S_a/g$) for both static and dynamic methods separately shown in Figure 1 and Figure 2 respectively. The curve now is for structures up to natural time-period of 6 seconds as against 4 seconds in the previous code. Roughly speaking, the code now includes taller structures having longer natural time-

period. For short-period structures, the curve now has minimum acceleration coefficient of 2.5 as against linearly varying in the earlier code. This will ensure that, all single or two storeybuildings will bedesigned for some minimum base shear.

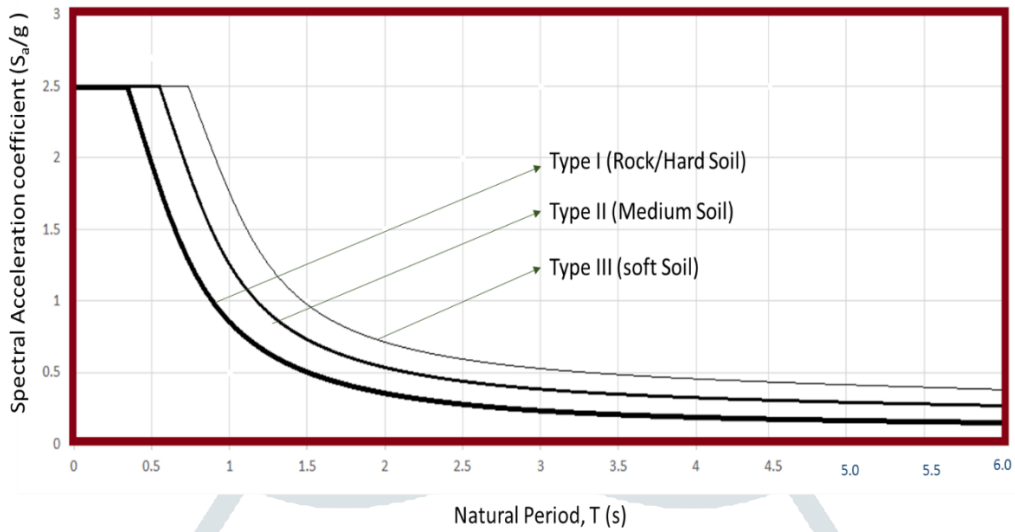


Figure (1): Response spectra for Equivalent Static Method

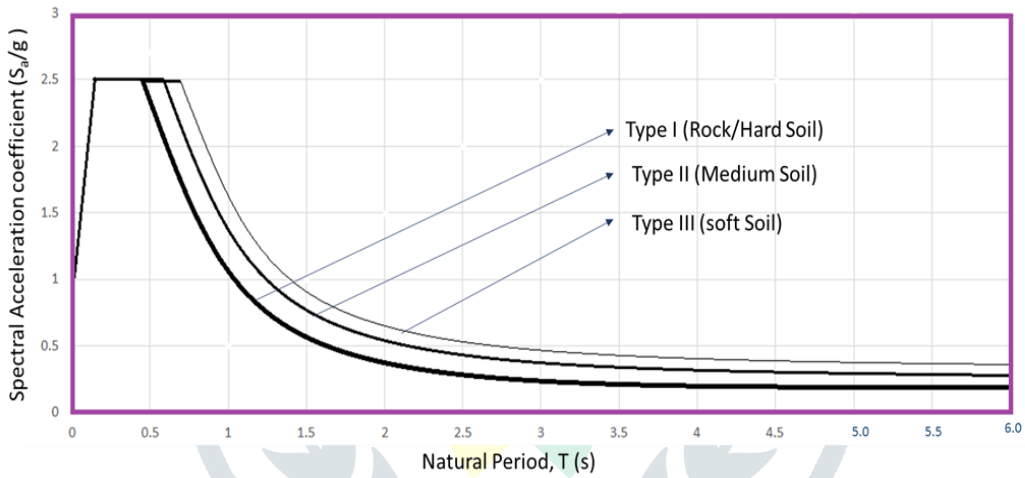


Figure (2) Spectra for Response Spectrum Method

**Structural Irregularity**

Floor Slabs having Excessive Cut-Outs or Openings, out -of-Plane Offsets in Vertical Elements, Non-Parallel Lateral Force System and other forms of structural irregularity have now been more clearly illustrated and explained in the new code.

**Torsional Irregularity**

As per earlier code, the torsional irregularity of a building is when the maximum storey drift, computed with design eccentricity, at one end of the structures transverse to an axis is more than 1.2 times the average of the storey drifts at the two ends of the structure.

The new code has elaborated the Torsional Irregularity in detail and now with more clarity. A building is assumed to have torsional irregularity if, either of the two conditions is met.

i) Maximum horizontal displacement of any floor in the direction of the lateral force at one end of the floor is more than 1.5 times its minimum horizontal displacement.

ii) The natural period corresponding to the fundamental torsional mode of oscillation is more than those of the first two translational mode of oscillation along each principal plan direction.

In addition to above, the new code also suggests remedial measures when the building does have torsional irregularity.

**Soft Storey**

In IS1893 2016 a soft storey is the one in which lateral stiffness is less than the storey above, where as in IS1893:2002 if lateral stiffness is less than 70% of that in the storey above or less than 80% of the average lateral stiffness of the three storeys above. This clause has been made more stringent to avoid Soft Storey altogether as it is an undesirable feature.

**Mass Irregularity**

Mass irregularity is considered to exist in IS1893 2016 only when the seismic weight of any floor in more than 150% of that of its adjacent floor, where as in IS1893:2002 seismic weight of any more than 200% of that of its adjacent floor has been considered to have mass irregularity. (Decrease in the seismic weight).

Mass irregularity is induced by the presence of a heavy mass on a floor. The relaxation in case of roofs is warranted because the seismic weight of roof is usually much smaller than that of the typical floors. This relaxation is not applicable particularly when large masses are added on the roof, for instance by the addition of a swimming pool. The draft version of the code was more conservative on this issue. It considered a building irregular even if a storey is 150 percent heavier than adjacent storeys.

**Vertical Geometric Irregularity**

A vertical geometric irregularity is considered when the horizontal dimension of the lateral force in any storey is more than 150 percent of that its adjacent storey (IS1893:2002), it has been decreased to a lower percentile of 125 in IS1893 2016.

Buildings with vertical offsets (e.g., set back buildings) fall in this category. There is also a possibility that a building may have no apparent offset, but its lateral load carrying elements may have irregularity. For instance, shear wall length may suddenly reduce. When building is such that a larger dimension is above the smaller dimension, it acts as an inverted pyramid and is particularly undesirable. Therefore, IS1893 2016 has further decrease the limit of horizontal dimension.

**In-Plane Discontinuity in Vertical Elements Resisting Lateral Force**

In IS1893:2002, in-plane offset of the lateral force resisting elements is greater than the length of those elements where as in-plane discontinuity in vertical elements which are resisting lateral force exists when in- plan offset of the lateral force resisting elements is greater than 20 percent of the plan length of those element in IS1893 2016.

**Imposed Load**

In IS1893:2002 cl. 7.3.3, it is stated that the percentage for imposed load shall also be used for 'Whole Frame Loaded' condition in the load combinations, where gravity loads are combined with the earthquake loads. No reduction in the imposed load will be used.

In IS1893:2016 (clause 7.3), this provision is now dropped and the design will now only be based on 1.2(DL+IL+EL). In other words, even though seismic load is calculated on the basis of seismic weight which includes only 25% of IL, one must consider full design imposed load in different load combinations.

Earlier in IS1893:2002 the code had permitted an engineer to use "reduced imposed load" when considering both live load and seismic load. For example, in buildings with imposed load of 3 kN/m2, the combination 1.2(DL+IL+EL) effectively became 12. DL+0.3IL+1.2EL. (In some cases it still permits reduction in imposed load in view of the large floor area or large number of storeys supported by columns or foundation)

**Minimum Design Earthquake Lateral Force**

The IS1893:2016 (Table 7, clause 7.2.2) states that buildings and portions there of shall be designed and constructed, to resist at least the effects of design lateral force. However, buildings shall have lateral load resisting systems capable of resisting a horizontal force not less than ρ percent of the seismic weight of the building. A similar clause was not present in the earlier code.

Table 1: Minimum Design Earthquake Lateral Force

| **Seismic Zone** | II | III | IV | V |
|---|---|---|---|---|
| **ρ (%)** | 0.7 | 1.1 | 1.6 | 2.4 |

**Fundamental Time-Period**

A new formula is provided for calculation of fundamental time-period of structures with shear walls.

$T_a = 0.075h^{0.75} / A_w^{1/2} \quad \geq \quad 0.09h/\sqrt{d}$

Where,

$A_w$ = total effective area ($m^2$) of walls in the first storey of the building

$$A_w = \sum_{i=1}^{N_w} \left[ A_{wi} \left\{ 0.2 + \left( \frac{L_{wi}}{h} \right) \right\}^2 \right]$$

$A_{wi}$= Effective cross-sectional area (m2) of wall *i* in first storey of building.

$L_{wi}$ = Length (m) of structural wall *i* in first storey.

$N_w$= Number of walls

$L_w/h$ shall not exceed 0.9.

**Diaphragm Action**

If the floor diaphragm 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 it shall than be only than considered as flexible given in IS1893 2016 whereas, in IS1893:2002, the deformed shape at any point was considered to be more than 1.5 times the average displacement.

The IS1893 2016 has also mentioned about those buildings whose floor diaphragms cannot provide rigid horizontal diaphragm action in their own plan.

The minimum measurements on floor and roof and the minimum reinforcement with spacing of bars have been given in IS1893 2016 of Reinforced concrete monolithic slab-beam floors or those consisting of prefabricated or precast elements with reasonable reinforced screed concrete as toppings.

**Damping**

IS1893:2016, specifies same value of damping (5% of critical) for concrete, steel, or masonry buildings. Steel as a material exhibits lower damping than masonry and therefore, different damping should be specified for three types of building material. Using a lower damping for steel buildings than for RC buildings will imply a higher value of seismic coefficient for steel buildings which has not been still justified in view of the relative performance of the RC and steel buildings in the past earthquakes. Moreover, partitions and other non-seismic members in steel building will still contribute the same amount of energy dissipation as in say RC buildings.

## CONCLUSION

Most of the changes incorporated in the latest revision have been documented. However, the list is not exhaustive. This was a much needed update in the seismic code in view of the recent developments in the field. The present code is now more equipped to cater the ever rising skylines of big cities. However, the draft version of the code had some suggested guidelines about performance based design, but, it is dropped in the final revision. This is in line with the current understanding and expertise available for the topic. This is still a developing idea and needs further work to be able to be codified.

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