COMPARATIVE STUDY OF SEISMIC LATERAL FORCES AS PER IS 1893:1984 & IS 1893:2002

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ABSTRACT

For a long time earthquake risk was considered unavoidable. It was accepted that buildings would be damaged as a result of an earthquake's ground shaking. Preventive measures for earthquakes were therefore mostly limited to disaster management preparedness. Although measures related to construction methods had already been proposed at the beginning of the 20th century. It is only during the last decades, improved and intensified research has revealed how to effectively reduce the vulnerability of structures to earthquakes.

The present study involves the comparative study of lateral forces calculated as per the provisions of IS 1893 1984 & IS 1893 -2002. Two case studies have been presented and base shear is calculated for both the buildings. The results are tabulated and compared as per both versions of IS 1893.

Key Words: Seismic Coefficient Method, Response Spectrum Method, Base Shear

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INTRODUCTION

In India, the first seismic code IS 1893 (Criteria for earthquake resistant design of structures) was published in 1962. A significant advancement have been made over the years in earthquake resistant design of structures, and seismic design requirements to building codes have improved steadily. These advancements necessitate the revision of codes from time to time.

IS 1893 was revised subsequently in the years 1970, 1975, 1984. The latest revision of IS 1893 is revised in the year 2002, after the gap of 18 years.

The buildings designed as per the earlier version of the code may be required to be checked to establish whether the existing buildings designed by earlier versions are safe for revised recommendations as well. In case, if any deficiency is found, these buildings to be retrofitted to withstand the expected design earthquake as per the latest version of the codes.

SEISMICITY OF INDIA

Earthquakes have been occurring in the Indian subcontinent from the times immemorial but reliable historical records are available for the last 200 years. From the beginning of 20th century, more than 700 earthquakes of magnitude 5 or more have been recorded and felt in India, as given in the catalogues prepared by US National Oceanographic and Atmospheric Administration, India Meteorological Department, National Geophysical Research Institute **[Fig 1].**

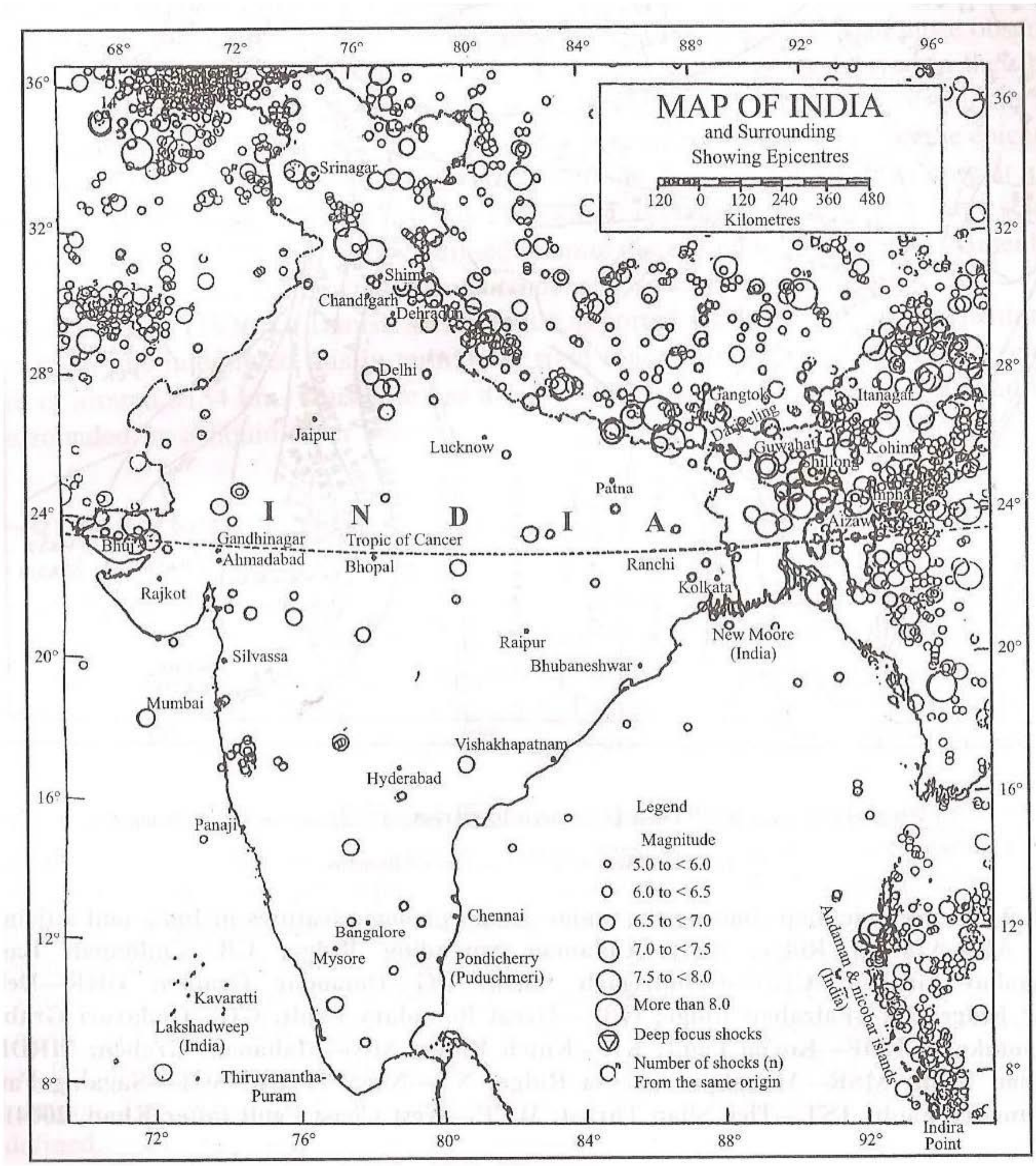

Fig 1 Seismicity Map of India (after, IS 1893 (Pt. 1): 2002

SEISMIC ZONING OF INDIA

The goal of seismic zoning is to delineate regions of similar probable intensity of ground motion in a country, for providing a guideline for provision of an adequate earthquake resistance in constructed facilities, as a step to disaster mitigation.

The minimum standard in a code to withstand earthquake is prescribed such that complete collapse of structure is prevented which ensures that no human life is lost. This requires a forecast of the strongest intensity of likely ground motion at a particular site during the service life of structure. Thus estimate of acceleration, velocity, displacement, frequency content and duration of expected maximum strong motion is required for a site.

Seismic Zoning map of a country segregates country in various areas of similar probable maximum intensity of ground motion. The maximum intensity is fixed in such a way that the lifeline/critical structure will remain functional and there is low possibility of collapse for structures designed with the provision provided in the code even for the occurrence of earthquake with higher intensity. Thus a structure designed with a provision of code can suffer damage of both structural and non-structural type. The damage is repairable but its economic viability is not warranted.

SEISMIC PROVISION IN BUILDING CODES

In the earlier 20^{th} Century the first seismic provisions in building code were introduced in a few countries with high seismicity. These early codes have been periodically updated with increasing knowledge in earthquake engineering. In the 1960's and 1970's countries with moderate seismicity began to adopt seismic requirements in their building codes. In the same period, the better understanding of dynamic soil behavior as well as inelastic structural behavior led to the development of more advanced seismic codes

PROVISIONS OF IS 1893 – 1984

The following are the some of the modifications in IS 1893 – 1984 from the previous version

i). A new concept of performance factor depending on structural framing system and on the ductility of construction was incorporated.

ii). Average acceleration spectra (Fig 2) was also modified and a curve for zero percent damping incorporated.

iii) Seismic zoning map was included in IS 1893 -1984. The purpose of this map is to classify the area of the country in to a number of zones in which one may reasonably expect earth quake shock of more or less same intensity in future.

iv) Seismic Coefficient Method can be used for all the buildings less than 40.0m in height in all the zones.

v) Further modal analysis using response spectrum method, seismic coefficient method was permitted even for buildings greater than 40m and up to 90.0m in height in zones III, II & I.

vi) Modal analysis using response spectrum method is to be carried out for buildings greater than 90m in height in zone I & II

vii) Detailed dynamic analysis (either modal analysis or time history analysis based on expected ground motion for which special studies are required). For preliminary design, modal analysis using response spectrum method may be employed.

PROVISIONS OF IS 1893 – 2002

The following are some of the major and important modifications in IS 1893 – 2002 from the previous version of the code.

i) The seismic zone map is revised with only four zones, instead of five. The earlier zone I has been merged to Zone II.

ii) The values of seismic zone factors are changed.

iii) Response spectra are now specified for three types of founding strata, viz., rock & hard soil, medium soil & soft soil.

iv) Empirical expression for estimating the fundamental period T_a of multistoried buildings with regular moment resisting frames has been revised.

v) The actual force that may be experienced by the structure during the probable earthquake, if it the structure were to remain elastic is to be calculated first. The response reduction factor is introduced in place of performance factor.

vi) A lower bound is specified for the design base shear of the buildings, based on empirical estimate of the fundamental natural period $T_{a.}$

vii) Modal combination rule in dynamic analysis of buildings have been revised.

The present code has given clear definitions of irregularities in the vertical (Elevation) and Horizontal (Plan) directions in the configuration of buildings.

- Plan irregularities causing torsion are re-entrant corners, diaphragm discontinuity, out of plane offsets and non-parallel systems

- Vertical irregularities are caused by variations in lateral stiffness, mass, vertical geometry, in-plane discontinuity in vertical elements resisting lateral forces and discontinuity in capacity like weak storey

This paper aims to determine and compare the earthquake forces on buildings calculated as provisions of IS 1893 – 1984 & IS 1893 -2002. The buildings are analyzed using seismic coefficient method & response spectrum method respectively as recommended by the codes.

DETAILS OF THE BUILDINGS

A) CASE STUDY 1 [Fig 2]

Stilt Floor + 11 Floors situated in Zone I upgraded to Zone II

B) CASE STUDY 2 [Fig 3]

Stilt + 10 Floors situated in Zone II.

CASE STUDY 1

The building consists of Stilt Floor + 11 floors (Total 12 Floors). The building is 40.50m height with large base area resting on the hard soil stratum. The soil bearing capacity as per the soil report is 400 KN/sqm at a depth of 2.0 m from N.G.L. The structure is situated in Zone I

The entire sub-structure supporting the frame work is in R.C.C. All the walls above Ground Level will be supported by superstructure.

The building structure will be analyzed using latest version of STAAD PRO. This software has been thoroughly tested, validated and recognized internationally by several organizations and is well suited for the analysis of building systems.

Geometrical dimensions, member properties and member –node connectivity including eccentricities are modeled in the analysis problem

The seismic load for the structure would be calculated in accordance with the code IS: 1893 and applied in the analysis.

The permissible values of load factors and stresses will be utilized within the purview of the above mentioned standards.

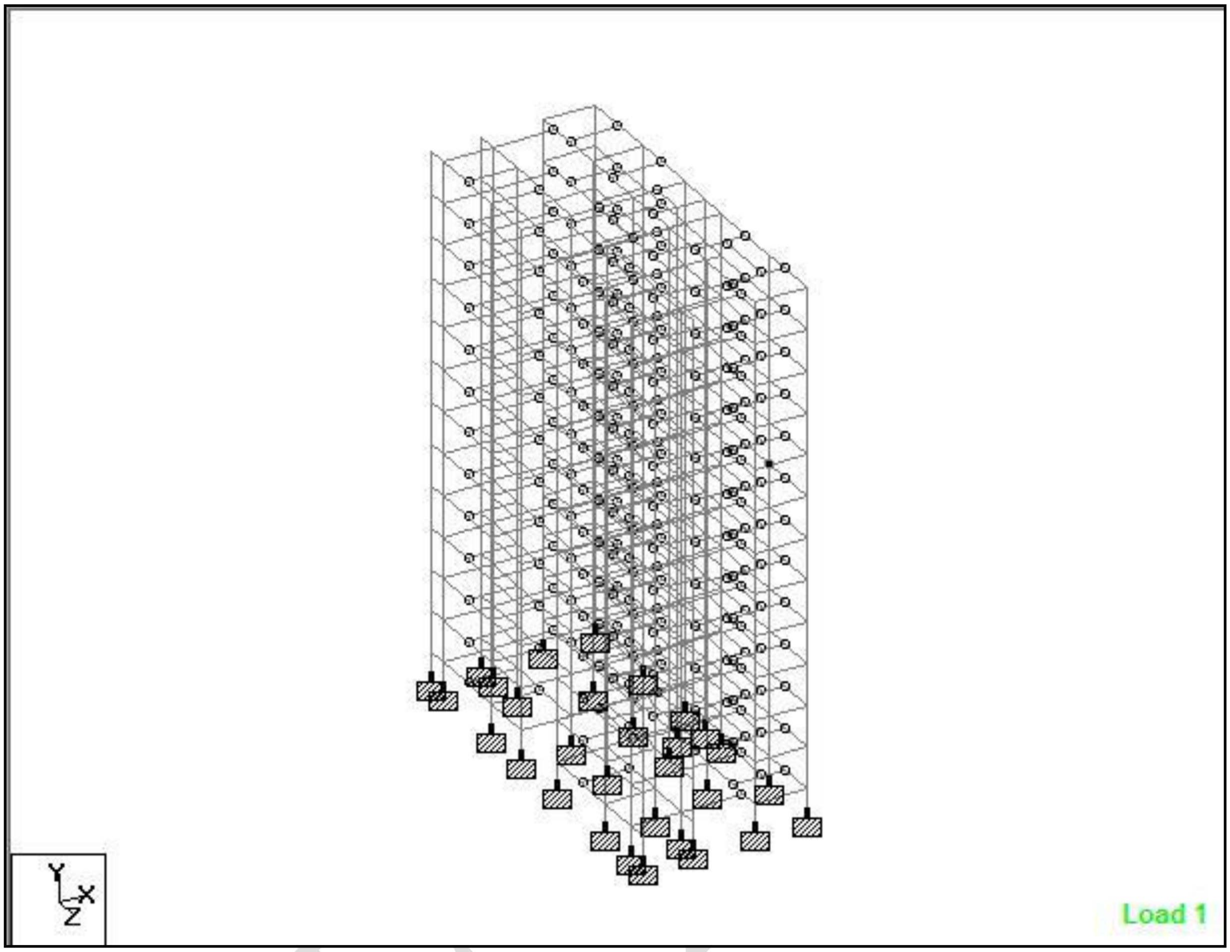

Fig 2: Case Study 1 Building

Table 1: Case Study 1 - Load Calculations as per IS 1893 -1984

Ref IS 1893 - 1984	
Height of the building	40.50
Width of the building	12.99
Zone	I
No. of Stories including Basement storeys	12
Seismic Coefficient Method	
Horizontal Seismic Coefficent Refer 3.4.2.3 a) $\alpha_h = ß I \alpha_0$	0.01
ß = Coefficient depending on soil foundation system - Table 3	1
I = a factor depending upon the importance of the structure - Table 4	1
$\alpha_0 =$ Basic horizontal seismic coefficient as given in Table 2	0.01
Response Spectrum Method	
Horizontal Seismic Coefficent Refer 3.4.2.3 b) $\alpha_h = ß I F_0 Sa/g$	0.005
ß = Coefficient depending on soil foundation system - Table 3	1
I = a factor depending upon the importance of the structure - Table 4	1
$F_0 =$ Seismic zone factor for average acceleration spectra as given in Table 2	0.05
Sa/g = Average acceleration Coefficient as read from Fig 2 for appropriate natural period and damping of the structure	
For natural period 1.2 and damping of 5% , As per Fig. 2, Sa/g=	0.1
Base Shear V_B = K C αh W	
K = Performance factor depending on the structural framing system and brittleness or ductility of construction - Table 5	1.6
C = Coefficient defining the flexibility of structure with the increase in number of storey depending upon fundamental time period T - Figure 3	0.47
W - Total dead load + appropriate amount of live load as defined in 4.1	58021.15
T = fundamental time period of the building in seconds (Note 1)	
T= 0.1 n where n is number of storeys including basement storeys	1.2
For all others T = 0.09H /√ d	0.988
H = total height of the main structure of the building in meters	
d = maximum base dimension of the building in metres in a direction parallel to the applied seismic force	
Base Shear V_B = K C αh W	**KN**
Base Shear - Seismic Coefficient Method	**436.32**
Base Shear - Response Spectrum Method	**218.16**

Table 2: Case Study 1 - Distribution of Base Shear along the Height of the Building as per IS 1983:1984

Base Shear - V_B					**436.32**	KN
Weight of Building					**58021.15**	KN
V_B/W					0.01	
DISTRIBUTION OF BASE SHEAR						
Floor	**Wi**	**Hi**	**Wi*Hi*Hi**	**Qi**		
Plinth	1725.97	1.75	5286	0.07		
1 Floor	4788.39	4.9	114969	1.50		
2 Floor	4788.39	8.05	310299	4.06		
3 Floor	4788.39	11.2	600655	7.86		
4 Floor	4788.39	14.35	986036	12.90		
5 Floor	4788.39	17.5	1466443	19.18		
6 Floor	4788.39	20.65	2041875	26.71		
7 Floor	4788.39	23.8	2712333	35.48		
8 Floor	4788.39	26.95	3477817	45.49		
9 Floor	4788.39	30.1	4338325	56.74		
10 Floor	4788.39	33.25	5293860	69.24		
11 Floor	4788.39	36.4	6344420	82.98		
12 Floor	3622.94	39.55	5667009	74.12		
	58021.15		**33359328**	**436.32**		
Total Base Shear in + Z Direction				**436.32**		

Table 3: Case Study 1 - Load Calculations as per IS 1893 -2002

Case Study 1	
Ref IS 1893 - 2002	
Height of the building	40.5
Width of the building	12.99
Zone	II
No. of Stories including Basement storeys	12
Horizontal Seismic Coefficent A_h Refer 6.4.2 =	
$A_h = \dfrac{Z\ I\ S_a}{2\ R\ g}$	
Z = Zone Factor in Table 2	0.1
I = Importance Factor, based on the functional use of structures - Table 6	1
R = Response Reduction Factor, Table 7	3
S_a/g = Average response acceleration coefficient - Fig 2 & Table 3	1.17
Soil Type - Medium Soil	Type II
Refer 7.6.1 - Fundamental Natural Period T_a (Without brick infill panels)	
$Ta = 0.075\ h^{0.75}$ (For RC Frame)	1.18
$Ta = 0.085\ h^{0.75}$ (For Steel Frame)	
h is height of building excluding basement storeys	
Refer 7.6.2 Fundamental Natural Period T_a (With brick infill panels)	
$T_a = \dfrac{0.09\ h}{\sqrt{d}}$	0.99
h = height of building excluding basement storeys	
d = base dimension of the building at plinth level in m along direction of lateral force	
Horizontal Seismic Coefficient A_h Refer 6.4.2 =	
A_h=	0.020
A_h= Design Horizontal seismic coefficient as per 6.4.2, using fundamental natural period T_a as per 7.6	0.02
W - Seismic Weight of the building as per 7.4.2	58021.15
Base Shear $V_B = A_h$*W in KN	**1131.41**

Table 4: Case Study 1 - Distribution of Base Shear along the Height of the Building as per IS 1983:2002

Base Shear - V_B					**1131.41**	KN
Weight of Building					**58021.15**	KN
V_B/W					0.02	
DISTRIBUTION OF BASE SHEAR						
Floor	Wi	Hi	Wi*Hi*Hi	Qi		
Plinth	1725.97	1.75	5286	0.18		
1 Floor	4788.39	4.9	114969	3.90		
2 Floor	4788.39	8.05	310299	10.52		
3 Floor	4788.39	11.2	600655	20.37		
4 Floor	4788.39	14.35	986036	33.44		
5 Floor	4788.39	17.5	1466443	49.74		
6 Floor	4788.39	20.65	2041875	69.25		
7 Floor	4788.39	23.8	2712333	91.99		
8 Floor	4788.39	26.95	3477817	117.95		
9 Floor	4788.39	30.1	4338325	147.14		
10 Floor	4788.39	33.25	5293860	179.55		
11 Floor	4788.39	36.4	6344420	215.18		
12 Floor	3622.94	39.55	5667009	192.20		
	58021.15		**33359328**	**1131.41**		
Total Base Shear in + Z Direction				**1131.41**		

CASE STUDY 2

The building consists of Stilt Floor + 10 floors (Total 10 Floors) . The building is 39.55 m height with large base area resting on the hard soil stratum. The soil bearing capacity as per the soil report is 400 KN/sqm at a depth of 2.0 m from N.G.L. The structure is situated in Zone II.

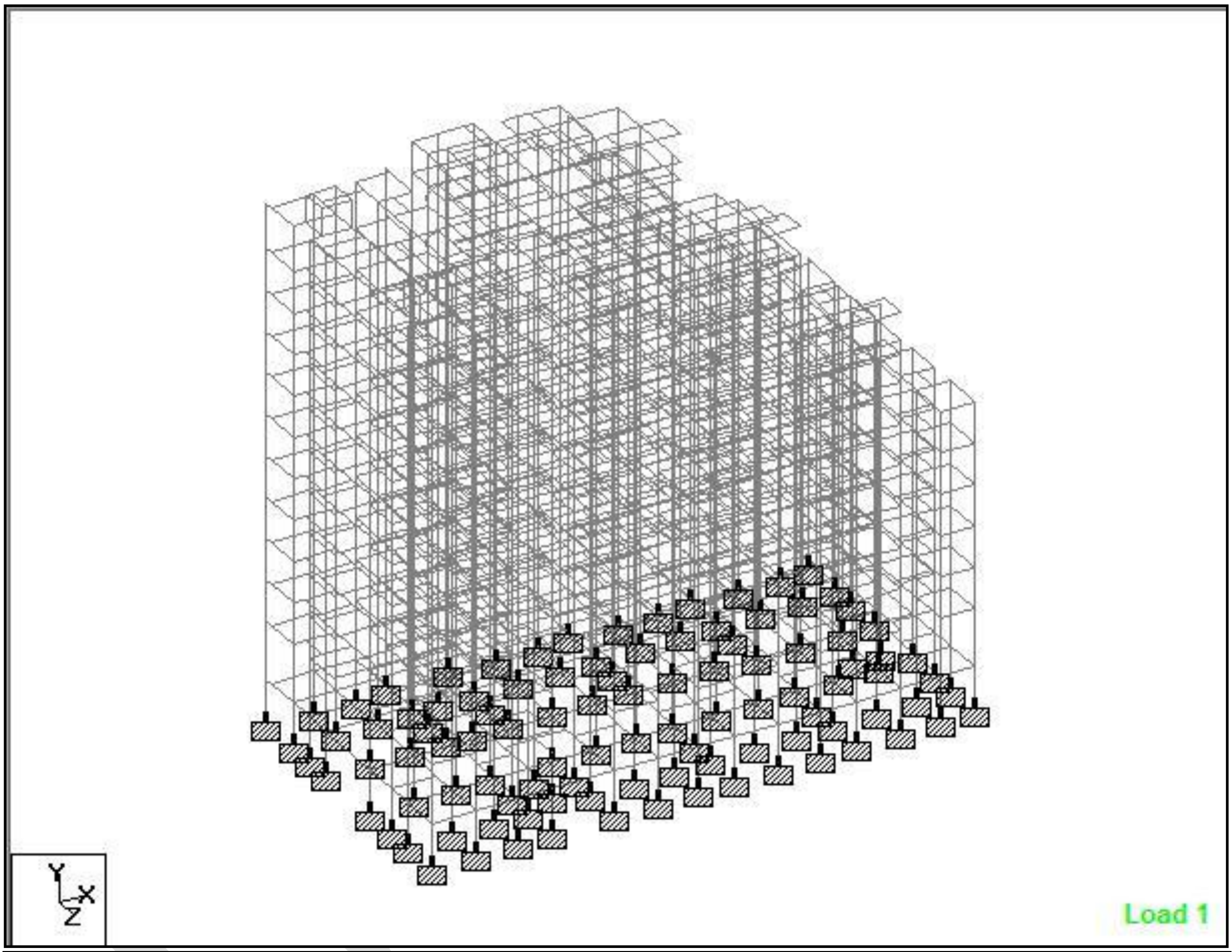

Fig 3: Case Study 2 Building

Table 5: Case Study 2 - Load Calculations as per IS 1893 -1984

Ref IS 1893 - 1984	
Height of the building	39.95
Width of the building	23.46
Zone	II
No. of Stories including Basement storeys	11
Seismic Coefficient Method	
Horizontal Seismic Coefficent Refer 3.4.2.3 a) α_h = ß *I* α_0	0.02
ß = Coefficient depending on soil foundation system - Table 3	1
I = a factor depending upon the importance of the structure - Table 4	1
α_0 = Basic horizontal seismic coefficient as given in Table 2	0.02
Response Spectrum Method	
Horizontal Seismic Coefficent Refer 3.4.2.3 b) α_h = ß $I F_0 Sa/g$	0.01
ß = Coefficient depending on soil foundation system - Table 3	1
I = a factor depending upon the importance of the structure - Table 4	1
F_0 = Seismic zone factor for average acceleration spectra as given in Table 2	0.1
Sa/g = Average acceleration Coefficient as read from Fig 2 for appropriate natural period and damping of the structure	
For natural period 1.1 and damping of 5% , As per Fig. 2, Sa/g=	0.1
Base Shear V_B = K C αh W	
K = Performance factor depending on the structural framing system and brittleness or ductility of construction - Table 5	1.6
C = Coefficient defining the flexibility of structure with the increase in number of storey depending upon fundamental time period T - Figure 3	0.47
W - Total dead load + appropriate amount of live load as defined in 4.1	106500.00
T = fundamental time period of the building in seconds (Note 1)	
T= 0.1 n where n is number of storeys including basement storeys	1.1
For all others T = 0.09H /√ d	0.988
H = total height of the main structure of the building in meters	
d = maximum base dimension of the building in metres in a direction parallel to the applied seismic force	
Base Shear V_B = K C αh W	**KN**
Base Shear - Seismic Coefficient Method	**1601.76**
Base Shear - Response Spectrum Method	**800.88**

Table 6: Case Study 2 - Distribution of Base Shear along the Height of the Building as per IS 1983:1984

Base Shear - V_B					**1601.76**	KN
Weight of Building					**106500.00**	KN
V_B/W					0.02	
DISTRIBUTION OF BASE SHEAR						
Floor	Wi	Hi	Wi*Hi*Hi	Qi		
Plinth	3743.00	2.5	23394	0.63		
1 Floor	10766.00	7.1	542714	14.72		
2 Floor	10676.00	10.35	1143640	31.03		
3 Floor	10661.00	13.6	1971859	53.50		
4 Floor	10664.00	16.85	3027750	82.15		
5 Floor	10645.00	20.1	4300686	116.68		
6 Floor	10270.00	23.35	5599435	151.92		
7 Floor	9525.00	26.6	6739509	182.85		
8 Floor	8481.00	29.85	7556762	205.02		
9 Floor	7200.00	33.1	7888392	214.02		
10 Floor	6883.00	36.35	9094663	246.75		
11 Floor	6986.00	39.95	11149673	302.50		
	106500.00					
			59038476	**1601.76**		
Total Base Shear in + Z Direction				**1601.76**		

Table 7: Case Study 2 - Load Calculations as per IS 1893 -2002

Case Study 2	
Ref IS 1893 - 2002	
Height of the building	39.55
Width of the building	23.46
Zone	II
No. of Stories including Basement storeys	11
Horizontal Seismic Coefficent A_h Refer 6.4.2 =	
$A_h = \dfrac{Z\ I\ S_a}{2\ R\ g}$	
Z = Zone Factor in Table 2	0.1
I = Importance Factor, based on the functional use of structures - Table 6	1
R = Response Reduction Factor, Table 7	3
S_a/g = Average response acceleration coefficient - Fig 2 & Table 3	1.17
Soil Type - Medium Soil	Type II
Refer 7.6.1 - Fundamental Natural Period T_a (Without brick infill panels)	
$Ta = 0.075\ h^{0.75}$ (For RC Frame)	1.18
$Ta = 0.085\ h^{0.75}$ (For Steel Frame)	
h is height of building excluding basement storeys	
Refer 7.6.2 Fundamental Natural Period T_a (With brick infill panels)	
$T_a = \dfrac{0.09\ h}{\sqrt{d}}$	0.99
h is height of building excluding basement storeys	
d = base dimension of the building at plinth level in m along direction of lateral force	
Horizontal Seismic Coefficent A_h Refer 6.4.2 =	
A_h=	0.020
A_h= Design Horizontal seismic coefficient as per 6.4.2, using fundamental natural period T_a as per 7.6	
W - Seismic Weight of the building as per 7.4.2	106500.00
Base Shear $V_B = A_h$*W in KN	**2076.75**

Table 8 : Case Study 2 - Distribution of Base Shear along the Height of the Building as per IS 1983:2002

Base Shear - V_B					**2076.75**	KN
Weight of Building					**106500.00**	KN
V_B/W					0.02	
DISTRIBUTION OF BASE SHEAR						
Floor	Wi	Hi	Wi*Hi*Hi	Qi		
Plinth	3743.00	2.5	23394	0.82		
1 Floor	10766.00	7.1	542714	19.09		
2 Floor	10676.00	10.35	1143640	40.23		
3 Floor	10661.00	13.6	1971859	69.36		
4 Floor	10664.00	16.85	3027750	106.50		
5 Floor	10645.00	20.1	4300686	151.28		
6 Floor	10270.00	23.35	5599435	196.97		
7 Floor	9525.00	26.6	6739509	237.07		
8 Floor	8481.00	29.85	7556762	265.82		
9 Floor	7200.00	33.1	7888392	277.48		
10 Floor	6883.00	36.35	9094663	319.92		
11 Floor	6986.00	39.95	11149673	392.20		
	106500.00					
			59038476	**2076.75**		
Total Base Shear in + Z Direction				**2076.75**		

RESULTS & DISCUSSIONS

The effect of changes in the provisions of IS 1893 code from the previous version and assessing the vulnerability of these structures is studied. A preliminary assessment of earthquake loads and distribution of base shear is carried out. Two case studies have been presented.

Case Study 1. Structure situated in erstwhile Zone I , at presented upgraded to Zone II. [Tables 1-4]

Case Study 2. Structure situated in Zone II. [Tables 5-8]

Case Study 1:

The building is analysed using seismic coefficient method & response spectrum method. The distribution of base shear along the height of the building calculated based on IS 1893 -1984 & IS 1893 -2002 are shown [Table 9].

Table 9 : Case Study 1 - Comparision of Base shear & Lateral Loads distribution by Seismic Coefficient Method & Response Spectrum Method.

Floor Level	Seismic Coefficient Method IS 1893 – 1984	Response Spectrum Method IS 1893 1984	Response Spectrum Method IS 1893 2002
BASE SHEAR	**436.32 KN**	**218.16 KN**	**1131.41 KN**
Lateral Loads Distribution along the Building			
Plinth	0.07	0.03	0.18
1 F	1.50	0.75	3.90
2 F	4.06	2.03	10.52
3 F	7.86	3.93	20.37
4 F	12.90	6.45	33.44
5 F	19.18	9.59	49.74
6 F	26.71	13.35	69.25
7 F	35.48	17.74	91.99
8 F	45.49	22.74	117.95
9 F	56.74	28.37	147.14
10 F	69.24	34.62	179.55
11 F	82.98	41.49	215.18

As per IS 1893 – 1984 , It is observed that base shear calculated by Response Spectrum method is less than the base shear calculated by seismic coefficient method.
However, the base shear calculated by latest revision (IS 1893-2002) is approximately 2.5 times higher than the value by seismic coefficient method. Similarly the base shear calculated by IS 1893: 2002 is approximately five times higher than the value of base shear as calculated by Response Spectrum Method.

Case Study 2:

The building is analysed using seismic coefficient method & response spectrum method. The distribution of base shear along the height of the building calculated based on IS 1893 -1984 & IS 1893 -2002 are shown [Table 10].

Table 10 : Case Study 2 - Comparision of Base shear & Lateral Loads distribution by Seismic Coefficient Method & Response Spectrum Method

Floor Level	Seismic Coefficient Method IS 1893 – 1984	Response Spectrum Method IS 1893 1984	Response Spectrum Method IS 1893 2002
BASE SHEAR	**1601.76**	**800.88**	**2076.75**
Lateral Loads Distribution along the Building			
Plinth	0.63	0.32	0.82
1 F	14.72	7.36	19.09
2 F	31.03	15.51	40.23
3 F	53.50	26.75	69.36
4 F	82.15	41.07	106.50
5 F	116.68	58.34	151.28
6 F	151.92	75.96	196.97
7 F	182.85	91.42	237.07
8 F	205.02	102.51	265.82
9 F	214.02	107.01	277.48
10 F	246.75	123.37	319.92
11 F	302.50	151.25	392.20

Based on IS 1893 – 1984 , the base shear calculated by Response Spectrum method is less than the base shear calculated by seismic coefficient method.
The base shear calculated by latest revision (IS 1893-2002) is approximately 30% higher than the value by seismic coefficient method. Similarly the base shear calculated by IS 1893: 2002 is approximately 2.5 times higher than the value of base shear calculated by Response Spectrum Method IS 1893 2002.

CONCLUSIONS:

1. The forces calculated as per IS 1893-2002 yielded higher values than the previous version for building in Zone I upgraded to Zone II.

2. The base shear calculated as per revised IS 1893 -2002 is higher for structures in Zone II.

3. A study is required to be carried out for calculating the lateral forces by response spectrum method as per IS code 1983 – 2002 clause 7.8.2 to study the effects of higher modes on the base shear calculation even for buildings height up to 40m.

4. Further, detailed evaluation is required to be carried out as per the guidelines – IS 15988: 2013 to assess the vulnerability of the buildings and suggest any strengthening measures if necessary based on the evaluation criteria.

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