Evaluation Of Seismic Design Forces Of Indian Building Code

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Abstract

To keep abreast with the rapid development and extensive research carried out in the field of earthquake engineering, the recent fifth revision of Indian Seismic Code, IS:1893 has been split into five separate parts for different types of structures. The new code, IS:1893 (Part-1) – 2002 contains provisions specific to buildings only, along with general provisions applicable to all structures. This paper deals with the comparison of seismic design forces for multi-storeyed buildings, obtained by using the new code, with those obtained by the previous 1984 version. From the results of seismic analysis of buildings it is concluded that the new code is more conservative for buildings resting on soft and medium soils.

INTRODUCTION

India was hit by many great earthquakes having magnitudes exceeding 8 on Richter Scale. Some of the greatest earthquakes of the world have occurred in the North-Eastern region of India, Himalayan belt, Indo-Gangetic plains, Western India, Kutch and Kathiawar regions. A major part of Peninsular India have also witnessed strong earthquakes, relatively few in number and having lesser intensity. Even moderate earthquakes (M = 6 - 7) have caused considerable damage and loss of life in India. Over 50% area in the country is considered prone to earthquakes (Jain, 1998).

In view of the heavy construction programme launched all over the country after independence, IS:1893-1962 was published and subsequently revised five times. A number of important modifications have been made in the new 2002 version of the code. The objective of this paper is to compare the seismic design forces obtained by the latest 2002 version with those obtained by the previous 1984 version in different cases of buildings.

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METHODS OF SEISMIC ANALYSIS OF BUILDINGS

Provisions of Previous Code (IS: 1893 –1984)

Two methods are prescribed by the code.

Seismic Coefficient Method This is a "Pseudo static" or "equivalent" lateral force procedure. For the entire building, the design base-shear, V_B , is worked out by the codal formula

$$V_B = K\,C\,\alpha_h\,w \qquad (1)$$

where K is the performance factor , W is the total dead load + appropriate amount of live-load, C is the flexibility coefficient of the structure, depending upon the fundamental time period T, estimated for moment resisting frames without bracing or shear walls using

$$T = 0.1\,n = n / 10 \qquad (2)$$

where n is the number of storeys including basement storeys. For all other buildings

$$T = 0.09\,H / \sqrt{d} \qquad (3)$$

where H is the total height of the building in metres and d is the maximum base dimension in metres in the direction parallel to the applied seismic force. α_h is the design value of horizontal seismic coefficient computed using

$$\alpha_h = \beta\ I\ \alpha_o \qquad (4)$$

where α_o is the basic horizontal seismic coefficient , β is the soil foundation coefficient and I is the Importance factor .The code suggests a parabolic distribution of forces such that the Seismic shears are higher near top storeys for the same base-shear. The lateral seismic force Q_i (at floor i) is given by

$$Q_i = V_B \; Wi \; hi^2 / \sum Wj \; hj^2 \qquad (j = 1 \text{ to } n) \qquad (5)$$

where h_i is the height of floor i above the base of the building; W_i is the lumped weight at floor i , V_B is the base shear and n is the number of storeys.
The shear in j th storey V_j , is obtained by summing up the lateral forces above that level

$$V_j = \sum Q_i \qquad (i = j \text{ to } n) \qquad (6)$$

<u>Response Spectrum Method</u> The lateral seismic load Q_{ir} acting at any floor level i , due to r th mode of vibration is given by

$$Q_{ir} = K \, W_i \, \phi_{ir} \, C_r \, \propto_{hr} \qquad (7)$$

where ϕ_{ir} is the mode shape coefficient at floor i in the r^{th} mode of vibration, obtained from free vibration analysis; $\propto_{hr}$ is the design horizontal seismic coefficient corresponding to appropriate period and damping in r^{th} mode of vibration, computed using

$$\propto_{hr} = \beta \, I \, F_0 \; (S_a / g) \qquad (8)$$

in which F_0 is the seismic zone factor and (S_a / g) is the average spectral acceleration coefficient for appropriate natural period and damaging of the structure.
The mode participation factor C_r is found using Eq.(9) (for i = 1 to n)

$$C_r = \sum W_i \, \phi_{ir} / \sum W_i \, \phi_{ir}^2 \qquad (9)$$

The maximum seismic shear V_i, acting in r^{th} storey may be obtained by the superposition of first 3 modes using

$$V_i = (1 - \gamma) \sum | V_{ir} | + \gamma \sqrt{\sum [V_{ir}]^2} \quad (r = 1 \text{ to } 3) \qquad (10)$$

where V_{ir} is the absolute value of maximum seismic shear in the r^{th} storey in r^{th} mode, γ value depends upon the height (All coefficients values are given in code).
The total earthquake lateral load acting at roof level n and floor level i may be computed using

$$Q_n = V_n$$

$$Q_i = V_i - V_{i+1} \qquad (11)$$

Provisions of New Code (IS : 1893 - 2002)

<u>Seismic Coefficient Method</u> The design seismic base shear V_B (or total design lateral force) along any principal direction is computed using

$$V_B = A_h \; W_i \qquad (12)$$

where W_i is the Seismic Weight of the entire building and A is the design horizontal acceleration coefficient for the structure, computed using

$$A_h = (Z / 2)(I / R)(S_a / g) \qquad (13)$$

where Z is the seismic Zone factor for the Maximum Considered Earthquake (MCE); I is the Importance factor; R is the Response reduction factor, and S_a /g is the average spectral acceleration coefficient for the approximate fundamental natural period of vibration (T_a) in seconds, given by

$$T_a = 0.075H^{0.75} \qquad (14)$$

for R-C moment-resisting frame building without brick infil panels. For all other buildings, including moment-resisting R-C frame buildings with brick infil panels, T_a may be estimated using Eq. (3) of old code (1984)
Similarly, the Eq.(5) of old code is used to find the lateral seismic forces Q_i at various floor levels, by distributing the computed design base shear V_B along the height of the building.
Dynamic Analysis This may be performed either by the Time History Method or the Response Spectrum Method. However, in either method, the design base shear (V_B) shall be compared with the base-shear (V_B') calculated using fundamental period T_a . If $V_B < V_B$', then all the response quantities (e.g. member forces, displacements, storey forces, shear and base reactions) shall be increased by multiplying by the ratio (V_B' / V_B).

Response Spectrum Method First the natural frequencies of vibration (or periods T) and mode shapes {ϕ} of the building are obtained by performing the "free-vibration analysis". The "number of modes to be considered" (r) in the analysis should be such that the sum total of modal masses considered is atleast 90% of the total seismic mass (W / g).
The peak response λ is obtained by "combining the modal responses" using "complete Quadratic Combination" (CQC) method

$$\lambda = \sqrt{\Sigma \Sigma \lambda_i \lambda_j \rho_{ij}} \quad (\text{ for } i = j = 1 \text{ to } r) \qquad (15)$$

where λ_i , λ_j are the responses in modes i and j ; ρ_{ij} is the cross modal coefficient and r is the number of modes considered. If the building does not have closely-spaced modes then even "square-root-of-sum-of-squares" (SRSS) method can be used

$$\lambda = \sqrt{\Sigma \lambda_i^2} \quad (i = 1 \text{ to } r) \qquad (16)$$

The "Modal mass" (M_k) of mode k is given by

$$M_k = [\Sigma W_i \phi_{ik}]^2 / g \Sigma W_i \phi_{ik}^2 \quad (i = 1 \text{ to } n) \qquad (17)$$

where ϕ_{ik} is the mode shape coefficient at floor i in mode k and g, the acceleration due to gravity. The "modal participation factor" (P_k) of mode k is given by

$$P_k = \Sigma W_i \phi_{ik} / \Sigma W_i \phi_{ik}^2 \quad (i = 1 \text{ to } n) \qquad (18)$$

The peak lateral force (Q_{ik}) at floor i in mode k is given by

$$Q_{ik} = A_k P_k \phi_{ik} W_i \qquad (19)$$

where A_k is the design horizontal spectral acceleration coefficient for mode k using Eq.(13) for the period of vibration T_k. The peak seismic storey shear (V_{ik}) acting in storey j in mode k is obtained using

$$V_{ik} = \Sigma Q_{ik} \quad (i = j \text{ to } n) \qquad (20)$$

The peak seismic storey shear V_{ik} in storey i due to all modes considered is obtained by combining the modal values. The design lateral forces (due to all modes considered) F_{roof} and F_i at roof and at floor i are given by

$$F_{roof} = V_{roof}$$

$$F_i = V_i - V_{i+1} \qquad (21)$$

EXAMPLE BUILDING

To have a check on the results, the 15 storeyed building (shown in Fig.1) of SP:22-1982 is analysed by the two methods of old and new codes described above. The building is located in Zone V in hard soil. The live load is 2KN/ sqm. The sizes in mm are beams (400x500), columns (600x600), slab (150) and wall alround 120 mm thick, floor height is 3 m. Earthquake force is applied in the Y direction.

DISCUSSION OF RESULTS

Table 1 shows that the first three modes of the building are well separated. The lateral forces Qi and the seismic shears Vi obtained using 'Seismic Coefficient Method' of old and new codes are compared in Table 2. For this R.C. ductile building having Special Moment Resisting Frames (SMRF), located on hard soil in the highest seismic zone V, it is observed that old code gives higher responses. However using Response Spectrum Method , it is observed from Table 3 that for lower storeys old code gives higher responses while the stepped-up responses of new code are more for higher storeys. Table 4 shows the comparison of design base shear V_B (or the total design laterial force) for the 15 storeyed building located in different seismic zones. It is observed that for both ordinary and ductile buildings located on soft and medium soils the new code gives higher responses. However for hard soil, old code gives higher responses for all zones.

CONCLUSIONS

The seismic forces of 15 storeyed building (T=0.85) obtained by the seismic coefficient and Response Spectrum methods of old and new codes are compared. On the basis of this study it is concluded that for buildings resting on soft and medium soils the new code gives higher seismic forces while for those resting on hard soils the old code gives higher forces.

REFERENCES

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Table 1 Periods and Mode Share Coefficients at various levels for first three Modes

Mode (r)	1	2	3
Period in Seconds	1.042	0.348	0.210
Mode share coefficients at various floor levels			
Floor No.			
1	0.037	0.108	0.175
2	0.073	0.206	0.305
3	0.108	0.285	0.356
4	0.143	0.336	0.315
5	0.175	0.356	0.192
6	0.206	0.342	0.019
7	0.235	0.296	-0.158
8	0.261	0.222	-0.296
9	0.285	0.127	-0.355
10	0.305	0.019	-0.324
11	0.323	-0.089	-0.208
12	0.336	-0.190	-0.039
13	0.347	-0.273	0.140
14	0.353	-0.330	0.283
15	0.356	-0.355	0.353

Table 2 Comparison of Lateral Forces and Seismic Shears using Seismic Coefficient Method

Floor No.	Wi (KN)	h_i (m)	Old Code IS:1893–1984		New Code IS:1893-2002	
			Qi (KN)	Vi (KN)	Qi (KN)	Vi (KN)
1	5143	3	2.9	3463	2.7	3198
2	5143	6	11.7	3460	10.8	3196
3	5143	9	26.3	3448	24.3	3185
4	5143	12	46.7	3422	43.1	3160
5	5143	15	73	3375	67.4	3117
6	5143	18	105	3302	97.0	3050
7	5143	21	143	3197	132.1	2953
8	5143	24	187	3054	172.5	2821
9	5143	27	236.3	2867	218.3	2648
10	5143	30	291.8	2631	269.5	2430
11	5143	33	353.1	2339	326.1	2161
12	5143	36	420.2	1986	388.1	1834
13	5143	39	493.1	1566	455.5	1446
14	5143	42	571.9	1073	528.3	991
15	3924	45	500.9	501	462.6	463

Table 3 Comparison of Lateral Forces and Seismic Shears using Response Spectrum

Floor No.	Wi (KN)	h_i (m)	Old Code IS:1893–1984		New Code IS:1893-2002				
			Vi (KN)	Qi (KN)	Vi (KN)	Qi (KN)	Stepped up Vi (KN)	Resulting Qi (KN)	Stepped up Q_i (KN)
1	5143	3	3913	84.4	2258		3198	56.2	
2	5143	6	3829	157.4	2219		3142	98.7	
3	5143	9	3671	210.9	2149		3043	121.5	
4	5143	12	3461	241.5	2063		2922	129.3	
5	5143	15	3219	250.0	1972		2793	130	
6	5143	18	2970	241.4	1880		2663	134.5	
7	5143	21	2728	268.5	1785		2528	144.7	
8	5143	24	2460	288.2	1683		2383	158.9	
9	5143	27	2171	289.7	1571		2224	274.9	
10	5143	30	1882	270.9	1377		1950	221.3	
11	5143	33	1611	283.7	1220		1728	281.9	
12	5143	36	1327	296.8	1035		1446	296.6	
13	5143	39	1030	340.5	811		1150	378.4	
14	5143	42	690	382.5	545		771	426.9	
15	3924	45	307	307.3	243		344	344.5	

Table 4 Comparison of Base Shears for the same Building located in different Seismic Zones

Zone No.	Ductile R.C. Building (SMRF) Base Shear (VB) KN		Ordinary R.C. Building (OMRF) Base Shear (VB) KN	
	Old Code IS:1893-1984	New Code IS:1893-2002	Old Code IS:1893-1984	New Code IS:1893-2002
(a) Soft Soil:				
II	865.6	1485.2	1385	2475.4
III	1731.2	2376.7	2672.8	3960.6
IV	2164.1	3561.2	3462.5	5937.9
V	3462.5	5345.6	5540	8914.4
(b) Medium Soil:				
II	865.6	1207.3	1385	2012.2
III	1731.2	1928.7	2672.8	3227.1
IV	2164.1	2900.6	3462.5	4836.8
V	3462.5	4350.9	5540	7259.1
(c) Hard Soil:				
II	865.6	648.5	1385	1080.5
III	1731.2	1421.4	2672.8	2369.1
IV	2164.1	2132.2	3462.5	3553.6
V	3462.5	3198.2	5540	5330.4

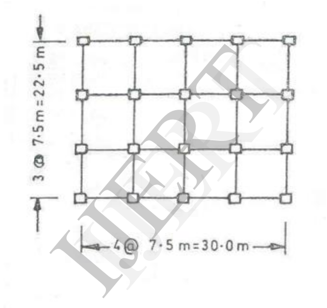

Fig. 1 PLAN OF THE BUILDING