Evaluation Of Seismic Design Forces Of Indian Building Code

S. Farrukh Anwar+, A. K. Asthana++

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.

METHODS OF SEISMIC ANALYSIS OF BUILDINGS


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

$$ V_B = K C \alpha_h w $$  \hspace{1cm} (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

$$ T = 0.1 n = n / 10 $$  \hspace{1cm} (2)

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

$$ T = 0.09 H / \sqrt{d} $$  \hspace{1cm} (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. $\alpha_h$ is the design value of horizontal seismic coefficient computed using

$$ \alpha_h = \beta \ I \ \alpha_o $$  \hspace{1cm} (4)
where $\alpha_o$ is the basic horizontal seismic coefficient, $\beta$ 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

$$Q_i = V_B \frac{W_i \ h_i^2}{\sum W_j h_j^2} \quad (j = 1 \ to \ n)$$

(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 lateral seismic force $Q_i$ (at floor $i$) is given by

$$Q_i = \sum Q_i \quad (i = j \ to \ n)$$

(6)

**Response Spectrum Method**

The lateral seismic load $Q_i$, acting at any floor level $i$, due to $r^{th}$ mode of vibration is given by

$$Q_{ir} = W_i \phi_{ir} \zeta_{hr}$$

(7)

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

$$\zeta_{hr} = \beta I F_0 \left( \frac{S_a}{g} \right)$$

(8)

where $F_0$ is the seismic zone factor and $\left( \frac{S_a}{g} \right)$ 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 $i = 1 \ to \ n$)

$$C_r = \frac{\sum W_i \ \phi_{ir}}{\sum W_i \ \phi_{ir}^2}$$

(9)

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

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

(10)

where $V_{ir}$ is the absolute value of maximum seismic shear in the $r^{th}$ storey in $r^{th}$ mode, $\gamma$ 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

$$Q_n = V_n$$

$$Q_i = V_i - V_{i+1}$$

(11)


**Seismic Coefficient Method**

The design seismic base shear $V_B$ (or total design lateral force) along any principal direction is computed using

$$V_B = A_h W_i$$

(12)

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

$$A_h = \left( \frac{Z}{2} \right) \left( \frac{I}{R} \right) \left( \frac{S_a}{g} \right)$$

(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 $\left( \frac{S_a}{g} \right)$ is the average spectral acceleration coefficient for the approximate fundamental natural period of vibration ($T_a$) in seconds, given by

$$T_a = 0.075H^{0.74}$$

(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 ($V_B^*/V_B$).

The peak response $\lambda$ is obtained by “combining the modal responses” using “complete Quadratic Combination” (CQC) method

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

where $\lambda_i, \lambda_j$ are the responses in modes $i$ and $j; \rho_{ij}$ 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

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

The “Modal mass” ($M_k$) of mode $k$ is given by

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

where $\phi_{ik}$ 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

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

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

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

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

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

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) $F_{\text{roof}}$ and $F_i$ at roof and at floor $i$ are given by

$$F_{\text{roof}} = V_{\text{roof}}$$

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

**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 around 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 $Q_i$ and the seismic shears $V_i$ 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 $V_B$ 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


<table>
<thead>
<tr>
<th>Mode (r)</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period in Seconds</td>
<td>1.042</td>
<td>0.348</td>
<td>0.210</td>
</tr>
<tr>
<td>Floor No.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.037</td>
<td>0.108</td>
<td>0.175</td>
</tr>
<tr>
<td>2</td>
<td>0.073</td>
<td>0.206</td>
<td>0.305</td>
</tr>
<tr>
<td>3</td>
<td>0.108</td>
<td>0.285</td>
<td>0.356</td>
</tr>
<tr>
<td>4</td>
<td>0.143</td>
<td>0.336</td>
<td>0.315</td>
</tr>
<tr>
<td>5</td>
<td>0.175</td>
<td>0.356</td>
<td>0.192</td>
</tr>
<tr>
<td>6</td>
<td>0.206</td>
<td>0.342</td>
<td>0.019</td>
</tr>
<tr>
<td>7</td>
<td>0.235</td>
<td>0.296</td>
<td>-0.158</td>
</tr>
<tr>
<td>8</td>
<td>0.261</td>
<td>0.222</td>
<td>-0.296</td>
</tr>
<tr>
<td>9</td>
<td>0.285</td>
<td>0.127</td>
<td>-0.355</td>
</tr>
<tr>
<td>10</td>
<td>0.305</td>
<td>0.019</td>
<td>-0.324</td>
</tr>
<tr>
<td>11</td>
<td>0.323</td>
<td>-0.089</td>
<td>-0.208</td>
</tr>
<tr>
<td>12</td>
<td>0.336</td>
<td>-0.190</td>
<td>-0.039</td>
</tr>
<tr>
<td>13</td>
<td>0.347</td>
<td>-0.273</td>
<td>0.140</td>
</tr>
<tr>
<td>14</td>
<td>0.353</td>
<td>-0.330</td>
<td>0.283</td>
</tr>
<tr>
<td>15</td>
<td>0.356</td>
<td>-0.355</td>
<td>0.353</td>
</tr>
</tbody>
</table>
### Table 2  Comparison of Lateral Forces and Seismic Shears using Seismic Coefficient Method

<table>
<thead>
<tr>
<th>Floor No.</th>
<th>( W_i ) (KN)</th>
<th>( h_i ) (m)</th>
<th>Old Code IS:1893–1984</th>
<th>New Code IS:1893–2002</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>( Q_i ) (KN)</td>
<td>( V_i ) (KN)</td>
</tr>
<tr>
<td>1</td>
<td>5143</td>
<td>3</td>
<td>2.9</td>
<td>3463</td>
</tr>
<tr>
<td>2</td>
<td>5143</td>
<td>6</td>
<td>11.7</td>
<td>3460</td>
</tr>
<tr>
<td>3</td>
<td>5143</td>
<td>9</td>
<td>26.3</td>
<td>3448</td>
</tr>
<tr>
<td>4</td>
<td>5143</td>
<td>12</td>
<td>46.7</td>
<td>3422</td>
</tr>
<tr>
<td>5</td>
<td>5143</td>
<td>15</td>
<td>73</td>
<td>3375</td>
</tr>
<tr>
<td>6</td>
<td>5143</td>
<td>18</td>
<td>105</td>
<td>3302</td>
</tr>
<tr>
<td>7</td>
<td>5143</td>
<td>21</td>
<td>143</td>
<td>3197</td>
</tr>
<tr>
<td>8</td>
<td>5143</td>
<td>24</td>
<td>187</td>
<td>3054</td>
</tr>
<tr>
<td>9</td>
<td>5143</td>
<td>27</td>
<td>236.3</td>
<td>2867</td>
</tr>
<tr>
<td>10</td>
<td>5143</td>
<td>30</td>
<td>291.8</td>
<td>2631</td>
</tr>
<tr>
<td>11</td>
<td>5143</td>
<td>33</td>
<td>353.1</td>
<td>2339</td>
</tr>
<tr>
<td>12</td>
<td>5143</td>
<td>36</td>
<td>420.2</td>
<td>1986</td>
</tr>
<tr>
<td>13</td>
<td>5143</td>
<td>39</td>
<td>493.1</td>
<td>1566</td>
</tr>
<tr>
<td>14</td>
<td>5143</td>
<td>42</td>
<td>571.9</td>
<td>1073</td>
</tr>
<tr>
<td>15</td>
<td>3924</td>
<td>45</td>
<td>500.9</td>
<td>501</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Floor No.</th>
<th>( W_i ) (KN)</th>
<th>( h_i ) (m)</th>
<th>Old Code IS:1893–1984</th>
<th>New Code IS:1893–2002</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>( V_i ) (KN)</td>
<td>( Q_i ) (KN)</td>
</tr>
<tr>
<td>1</td>
<td>5143</td>
<td>3</td>
<td>3913</td>
<td>84.4</td>
</tr>
<tr>
<td>2</td>
<td>5143</td>
<td>6</td>
<td>3829</td>
<td>157.4</td>
</tr>
<tr>
<td>3</td>
<td>5143</td>
<td>9</td>
<td>3671</td>
<td>210.9</td>
</tr>
<tr>
<td>4</td>
<td>5143</td>
<td>12</td>
<td>3461</td>
<td>241.5</td>
</tr>
<tr>
<td>5</td>
<td>5143</td>
<td>15</td>
<td>3219</td>
<td>250.0</td>
</tr>
<tr>
<td>6</td>
<td>5143</td>
<td>18</td>
<td>2970</td>
<td>241.4</td>
</tr>
<tr>
<td>7</td>
<td>5143</td>
<td>21</td>
<td>2728</td>
<td>268.5</td>
</tr>
<tr>
<td>8</td>
<td>5143</td>
<td>24</td>
<td>2460</td>
<td>288.2</td>
</tr>
<tr>
<td>9</td>
<td>5143</td>
<td>27</td>
<td>2171</td>
<td>289.7</td>
</tr>
<tr>
<td>10</td>
<td>5143</td>
<td>30</td>
<td>1882</td>
<td>270.9</td>
</tr>
<tr>
<td>11</td>
<td>5143</td>
<td>33</td>
<td>1611</td>
<td>283.7</td>
</tr>
<tr>
<td>12</td>
<td>5143</td>
<td>36</td>
<td>1327</td>
<td>296.8</td>
</tr>
<tr>
<td>13</td>
<td>5143</td>
<td>39</td>
<td>1030</td>
<td>340.5</td>
</tr>
<tr>
<td>14</td>
<td>5143</td>
<td>42</td>
<td>690</td>
<td>382.5</td>
</tr>
<tr>
<td>15</td>
<td>3924</td>
<td>45</td>
<td>307</td>
<td>307.3</td>
</tr>
</tbody>
</table>
### Table 4: Comparison of Base Shears for the same Building located in different Seismic Zones

<table>
<thead>
<tr>
<th>Zone No.</th>
<th>Ductile R.C. Building (SMRF) Base Shear (VB) KN</th>
<th>Ordinary R.C. Building (OMRF) Base Shear (VB) KN</th>
</tr>
</thead>
<tbody>
<tr>
<td>II</td>
<td>865.6</td>
<td>1485.2</td>
</tr>
<tr>
<td>III</td>
<td>1731.2</td>
<td>2376.7</td>
</tr>
<tr>
<td>IV</td>
<td>2164.1</td>
<td>3561.2</td>
</tr>
<tr>
<td>V</td>
<td>3462.5</td>
<td>5345.6</td>
</tr>
<tr>
<td>(b) Medium Soil:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>865.6</td>
<td>1207.3</td>
</tr>
<tr>
<td>III</td>
<td>1731.2</td>
<td>1928.7</td>
</tr>
<tr>
<td>IV</td>
<td>2164.1</td>
<td>2900.6</td>
</tr>
<tr>
<td>V</td>
<td>3462.5</td>
<td>4350.9</td>
</tr>
<tr>
<td>(c) Hard Soil:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>865.6</td>
<td>648.5</td>
</tr>
<tr>
<td>III</td>
<td>1731.2</td>
<td>1421.4</td>
</tr>
<tr>
<td>IV</td>
<td>2164.1</td>
<td>2132.2</td>
</tr>
<tr>
<td>V</td>
<td>3462.5</td>
<td>3198.2</td>
</tr>
</tbody>
</table>

---

**Fig. 1 PLAN OF THE BUILDING**