METHODS OF ANALYSIS FOR EARTHQUAKE RESISTANT STRUCTURES
IS – 1893 (part-1) -2002

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INDIAN STANDARDS FOR EARTHQUAKE DESIGN

- IS : 1893 – 2002: Criteria For Earthquake Design Of Structures
- IS : 4326 – 1976: Code Of Practice For Earthquake Resistant Design And Construction Of Buildings
- IS : 13920 – 1993: Code Of Practice For Ductile Detailing Of Reinforced Concrete Structures Subjected To Seismic Forces
- SP: 22 – Explanatory Handbook On Codes For Earthquake Engineering
<table>
<thead>
<tr>
<th>Year</th>
<th>Region</th>
<th>Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>1897</td>
<td>THE ASSAM EARTHQUAKE</td>
<td>M 8.7</td>
</tr>
<tr>
<td>1938</td>
<td>THE BIHAR-NEPAL EARTHQUAKE</td>
<td>M 8.4</td>
</tr>
<tr>
<td>1950</td>
<td>THE ASSAM-TIBET EARTHQUAKE</td>
<td>M 8.7</td>
</tr>
<tr>
<td>1967</td>
<td>THE KOYNA EARTHQUAKE</td>
<td>M 6.5</td>
</tr>
<tr>
<td>1988</td>
<td>THE BIHAR-NEPAL EARTHQUAKE</td>
<td>M 6.6</td>
</tr>
<tr>
<td>1991</td>
<td>THE UTTAR KASHI EARTHQUAKE</td>
<td>M 6.6</td>
</tr>
<tr>
<td>1993</td>
<td>THE LATUR EARTHQUAKE</td>
<td>M 6.4</td>
</tr>
<tr>
<td>1997</td>
<td>THE JABALPUR EARTHQUAKE</td>
<td>M 6.0</td>
</tr>
<tr>
<td>1999</td>
<td>THE CHAMOLI (U.P) EARTHQUAKE</td>
<td>M 6.8</td>
</tr>
<tr>
<td>2001</td>
<td>THE BHUJ (GUJARAT) EARTHQUAKE</td>
<td>M 7.9</td>
</tr>
</tbody>
</table>
STRUCTURAL RESPONSE

Structural Response depends on

Input motion
Structural Properties

Uncertainties in Input motion

- When and where the next earthquake
- On what fault (location)
- On what magnitude
- Effect of travel path on shaking at a distance
- Effect of local geology, topography and soil profile
OBJECTIVES OF EQ RESISTANT DESIGN

- Should the structure be designed to withstand strong shaking without sustaining any damage. Such a construction will be too expensive.

- It may be more logical to accept some damage in case of strong shaking.

- However, loss of life must be protected even in case of strong shaking.
Earthquake Resistant Design Concept

Level 1 Maximum Credible Earthquake (MCE)
500 Years Return Period
2 % Possibility of occurrence in 50 Yrs

Level 2 Design Basis Earthquake (DBE)
250 Years Return Period
10 % Possibility of occurrence in 50 Yrs
Earthquake Resistant Design Philosophy

- Building
  - should resist minor earthquakes (<DBE) with some non-structural damage
  - should resist moderate earthquake (DBE) with some structural damage, but without failure
  - can fail at most severe earthquake (MCE), but with sufficient warning.
F = m \times a

a = Z \times g

Z = Zone Factor
Structures should be able to resist

- **Resist Minor shaking** ( < DBE, Design based EQ)
  - No damage
- **Resist Moderate shaking** ( DBE)
  - No structural damage
  - Some non structural damage
- **Resist Severe shaking** ( MCE, Max. considered EQ)
  - Structural damage without collapse

DBE – Max. EQ that can be expected to experience at the site
Once during life time of the structure. (DBE generally half of MCE)
CONCEPT OF RESPONSE SPECTRUM-1

It is a plot of the peak response (Velocity, Displacement or Acceleration) w.r.t Period of SDOF system for a given Accelerogram.
Earthquake Accelerogram

Concept of Response Spectrum - 2

Find Response $A_{\text{max}}$ in each case

For various values of Period of SDOF structures, Find Peak acceleration for the given input earthquake acceleration and plot Response (acc) v/s Period

$$f_i = \frac{1}{(2\pi)^2} \sqrt{\frac{k_i}{m}}$$

$$T_i = \frac{1}{f_1}$$
Response Spectrum IS : 1893 :2002

![Graph showing response spectrum for different soil types.](image)
METHODS OF FINDING THE EARTHQUAKE FORCES

1. Seismic Coefficient Method

2. Dynamic Analysis
   - Response Spectrum Method
   - Time History Analysis
BASIS OF SEISMIC COEFFICIENT METHOD

\[ V_B = m \ a \]
\[ V_B = (W/g) \ a \]
\[ V_B = W \ (a/g) \]
\[ V_B = W \ A_h \]

\( A_h \) = Basic horizontal seismic coefficient
\( V_B \) = Base shear
\( W \) = Total weight of the structure
\( a \) = Acceleration induced at the base during earthquake
\( g \) = Acceleration due to gravity
Assumptions

• Assume that structure is rigid.
• Assume perfect fixity between structure and foundation.
• During ground motion every point on the structure experience same accelerations
• Dominant effect of earthquake is equivalent to horizontal force of varying magnitude over the height.
• Crudely determines the total horizontal force (Base shear) on the structure

\[ V_B = W \ A_h \]
\[ V_B = W A_h \]

During an earthquake, structure does not remain rigid, it deflects, thus base shear is disturbed along the height.

\( A_h \) is modified to consider the following effects.

- Natural period
- Damping
- Modal shapes
- Types of structure and place (zone)
- Subsoil conditions
- Importance of the structure
CALCULATION OF SEISMIC FORCE-1

\[ V_B = A_h W \]

\[ A_h = \frac{Z}{2} \cdot \frac{S_a}{g} \cdot \frac{I}{R} \]

- **Z**= Zone Factor
- **S_s/g** = Spectral Acceleration taken from Response Spectrum
- **I**= Importance Factor
- **R**= Ductility / Over-Strength Reduction Factor
Seismic Zone Map

IS:1893-1984

IS:1893 (Part I) - 2002
Zone Factor & Multiplying Factor for Different Damping

\[ V_B = A_h W \]
\[ A_h = \frac{Z}{2} \cdot \frac{S_a}{g} \cdot \frac{I}{R} \]

Zone factor Z is for MCE
For DBE, it is Z/2

Table 2  Zone Factor, Z

<table>
<thead>
<tr>
<th>Seismic Zone</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seismic Intensity</td>
<td>Low</td>
<td>Moderate</td>
<td>Severe</td>
<td>Very Severe</td>
</tr>
<tr>
<td>Z</td>
<td>0.10</td>
<td>0.16</td>
<td>0.24</td>
<td>0.36</td>
</tr>
</tbody>
</table>

Table 3  Multiplying Factors for Obtaining Values for Other Damping

<table>
<thead>
<tr>
<th>Damping, percent</th>
<th>0</th>
<th>2</th>
<th>5</th>
<th>7</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factors</td>
<td>3.20</td>
<td>1.40</td>
<td>1.00</td>
<td>0.90</td>
<td>0.80</td>
<td>0.70</td>
<td>0.60</td>
<td>0.55</td>
<td>0.50</td>
</tr>
</tbody>
</table>
### Table 6 Importance Factors, \( I \)

*Clause 6.4.2*

<table>
<thead>
<tr>
<th>Sl No.</th>
<th>Structure</th>
<th>Importance Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>i) Important service and community buildings, such as hospitals; schools;</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>monumental structures; emergency buildings like telephone exchange,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>television stations, radio stations, railway stations, fire station</td>
<td></td>
</tr>
<tr>
<td></td>
<td>buildings; large community halls like cinemas, assembly halls and</td>
<td></td>
</tr>
<tr>
<td></td>
<td>subway stations, power stations</td>
<td></td>
</tr>
<tr>
<td>ii)</td>
<td>All other buildings</td>
<td>1.0</td>
</tr>
</tbody>
</table>

**NOTES**

1. The design engineer may choose values of importance factor \( I \) greater than those mentioned above.
2. Buildings not covered in Sl No. (i) and (ii) above may be designed for a higher value of \( I \), depending on economy, strategy considerations like multi-storey buildings having several residential units.
3. This does not apply to temporary structures like excavations, scaffolding etc of short duration.
<table>
<thead>
<tr>
<th>Sl No</th>
<th>Lateral Load Resisting System</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Building Frame Systems</strong></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Ordinary RC moment Resisting frame (OMRF)²</td>
<td>3.0</td>
</tr>
<tr>
<td>2</td>
<td>Special RC moment Resisting Frame (SMRF)³</td>
<td>5.0</td>
</tr>
<tr>
<td>3</td>
<td>Steel Frames with</td>
<td></td>
</tr>
<tr>
<td></td>
<td>a) Concentric Braces</td>
<td></td>
</tr>
<tr>
<td></td>
<td>b) Eccentric Braces</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Steel Moment Resisting Frame Designed as per SP 6(6)</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td><strong>Buildings with Shear Walls</strong></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Load Bearing Masonry Wall Buildings⁵</td>
<td></td>
</tr>
<tr>
<td></td>
<td>a) Un-reinforced</td>
<td></td>
</tr>
<tr>
<td></td>
<td>b) Reinforced with Horizontal RC Bands</td>
<td></td>
</tr>
<tr>
<td></td>
<td>c) Reinforced with Horizontal RC Bands and Vertical bars At corners of rooms and jambs of openings</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Ordinary Reinforced Concrete Shear Walls⁶</td>
<td>3.0</td>
</tr>
<tr>
<td>7</td>
<td>Ductile shear Walls⁷</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td><strong>Buildings with Dual Systems</strong></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Ordinary Shear wall with OMRF</td>
<td>3.0</td>
</tr>
<tr>
<td>9</td>
<td>Ordinary Shear wall with SMRF</td>
<td>4.0</td>
</tr>
<tr>
<td>10</td>
<td>Ductile Shear wall with OMRF</td>
<td>4.5</td>
</tr>
<tr>
<td>11</td>
<td>Ductile Shear wall with SMRF</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Depends on the perceived seismic damage performance of the structure, characterised by ductile or brittle deformation.
EMPIRICAL FORMULA FOR CALCULATION OF FREQUENCIES

\[ T_a = 0.075h^{0.75} \] for RC frame buildings

\[ T_a = 0.085h^{0.75} \] for Steel frame buildings

\[ T_a = 0.09 \frac{h}{\sqrt{d}} \] for all other buildings, moment resisting frames with Brick In-fill Panels
Response Spectrum IS : 1893 :2002

\[
V_B = A_h W \\
A_h = \frac{Z}{2} \cdot \frac{S_a}{g} \cdot \frac{I}{R}
\]
DISTRIBUTION OF BASE SHEAR

\[ Q_i = V_B \frac{W_i h_i^2}{\sum_{1}^{n} W_i h_i^2} \]

- \( Q_i \) – Design lateral force at floor \( i \)
- \( W_i \) – Seismic Weight of floor \( i \) (DL + LL)
- \( h_i \) – Height of floor \( i \) measured from base
- \( n \) – Number of storey in the building

(LL = 30% of Normal Live Load) < 3 kN/m²)
(LL = 50% of Normal Live Load) > 3 kN/m²)
SEISMIC COEFFICIENT METHOD

Distribution of forces along the storey

\[ Q_i = V_B \frac{W_i h_i^2}{\sum_{i=1}^{n} W_i h_i^2} \]

Frame

Forces on storey level

Shear distribution
<table>
<thead>
<tr>
<th>Structure Type</th>
<th>Damping Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel Structure</td>
<td>2-5%</td>
</tr>
<tr>
<td>Concrete Structure</td>
<td>5-10%</td>
</tr>
<tr>
<td>Brick Structure</td>
<td>5-10%</td>
</tr>
<tr>
<td>Timber Structure</td>
<td>2-5%</td>
</tr>
<tr>
<td>Earthen Structure</td>
<td>10-30%</td>
</tr>
</tbody>
</table>
DYNAMIC ANALYSIS

1. RESPONSE SPECTRUM METHOD

Distribution of forces at various story's is carried out using mode shape, Participation Factors etc.

Response quantities (BM, SF etc.) are combined using CQC Complete Quadratic combination.

Here Period and mode shapes of the structure are obtained using free vibration analysis not from Empirical formula

(Sa / g) is obtained from the same response chart for all the modes separately

\[ V_B = A_h W \]
\[ A_h = \frac{Z}{2} \cdot \frac{S_a}{g} \cdot \frac{I}{R} \]
MODE SHAPES OF OSCILLATION OF BUILDINGS

Frame

Mode 1

Mode 2

Mode 3

\( \phi_i \)

Lateral forces are found by superimposition of the Forces resulting from each mode
DYNAMIC ANALYSIS
2. TIME HISTORY ANALYSIS

Obtain the design parameters by giving the actual Earthquake excitation
Over-riding of Response Parameters Computed From Analysis

Dynamic analysis may be performed either by the time history method or by the response spectrum method.

If base shear

\[ V_B < \frac{V_B^1}{V_B} \]

R. S. Method  Seismic coefficient method

All response quantities obtained in RSM (for example member forces, displacements, storey forces, storey shears and base reactions) shall be multiplied by \( V_B^1 / V_B \).
COMPARISON OF PSEUDO STATIC ANALYSIS AND DYNAMIC ANALYSIS

Obtain Q1—Q3 using SCM or RSM

• Analyse the frame to obtain design BM & SF in SCM

• Analyse the frame to obtain BM & SF
  Responses are combined as per CQC method in RSM

Directly we get design BM & SF in Dynamic analysis.
CHOICE OF METHOD FOR MULTISTORIED BUILDING

- Dynamic analysis shall be performed for
  - Regular Buildings
    - $\text{Height} > 40 \text{ m}$ in seismic zones IV and V
    - $\text{Height} > 90 \text{ m}$ in seismic zones II and III
  - Irregular Buildings
    - $\text{Height} > 12 \text{ m}$ in seismic zones IV and V
    - $\text{Height} > 40 \text{ m}$ in seismic zones II and III
  - Industrial and frame building with
    - Large spans
    - Large heights

Note:
Also recommended (though not mandatory) when $\text{Height} < 40 \text{ m}$ in seismic zones II and III
PARTIAL SAFETY FACTOR

MATERIALS

• CONCRETE - 1.5
• STEEL - 1.15

LOADS

• 1.5(DL + LL)
• 1.2(DL + LL ±EQ/WL)
• 1.5(DL ± EQ/WL)
• 0.9DL ± 1.5EQ/WL

LL = 25% OF THE NORMAL LIVE LOAD
1. 1.5(DL + LL)
2. 1.2(DL + LL + EQ/WL)
3. 1.2(DL + LL - EQ/WL)
4. 1.5(DL + EQ/WL)
5. 1.5(DL - EQ/WL)
6. 0.9DL + 1.5EQ/WL
7. 0.9DL - 1.5EQ/WL
## DESIGN MOMENTS IN MEMBERS-2 (Ex.)

<table>
<thead>
<tr>
<th>Loading</th>
<th>End A</th>
<th>Cent- C</th>
<th>End-B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loading-1</td>
<td>-60</td>
<td>+40</td>
<td>-70</td>
</tr>
<tr>
<td>Loading-2</td>
<td>+25</td>
<td>+35</td>
<td>-85</td>
</tr>
<tr>
<td>Loading-3</td>
<td>-80</td>
<td>+30</td>
<td>+20</td>
</tr>
<tr>
<td>Loading-4</td>
<td>+10</td>
<td>+35</td>
<td>-80</td>
</tr>
<tr>
<td>Loading-5</td>
<td>-70</td>
<td>+35</td>
<td>-15</td>
</tr>
<tr>
<td>Loading-6</td>
<td>+15</td>
<td>+20</td>
<td>-65</td>
</tr>
<tr>
<td>Loading-7</td>
<td>-60</td>
<td>+20</td>
<td>+10</td>
</tr>
</tbody>
</table>

Design mom.  -80/+25  +40  -85/ +20