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

Dr. G. P. Chandradhara
Professor, Dept. of Civil Engineering
S. J. College of Engineering, Mysore
Email: chandu_gpc@yahoo.com
INDIAN STANDARDS FOR EARTHQUAKE DESIGN

- **IS : 1893 –part -4 – 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
Response of structures during earthquake depends on,

1. Natural frequencies of the structure (which is dependent on Mass (M) and Stiffness (K))
2. Frequency content of earthquake
3. Amplitude of earthquake
4. Duration of earthquake
5. Ductility
6. Damping characteristics (energy dissipation capacity)
7. Structural integrity
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
Earthquake Resistant Design Concept

Level 1 Maximum Credible Earthquake (MCE)
The most severe earthquake effects considered by this standard

500 Years Return Period
2 % Possibility of occurrence in 50 Yrs

Level 2 Design Basis Earthquake (DBE)
It is the earthquake which can reasonably be expected to occur at least once during the design life of the structure

250 Years Return Period
10 % Possibility of occurrence in 50 Yrs
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 Buildings

- Buildings resist the effects of ground shaking. Although they may get damaged severely they should not collapse during a strong earthquake.

- Realistic

Earthquake Proof Buildings

- Buildings suffer no damage at all even during strong but rare earthquakes.

- Unrealistic
Earthquake Resistant Design Philosophy

DBE – Max. EQ that can be expected to experience at the site once during life time of the structure. (DBE generally half of MCE)

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 * a

a = Z * g

Z = Zone Factor
The varying geology at different locations in the country implies that the likelihood of damaging earthquakes taking place at different locations is different. Thus a seismic zoning map is essential so that the structures located in different regions can be designed to withstand different level of ground shaking. The seismic zoning map is revised time to time based on the experience gained over the past occurrences of earthquakes.
CONCEPT OF RESPONSE SPECTRUM-1

Find $A_{\text{max}}$

Response of the Structure

Earthquake Accelerogram

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

Earthquake Accelerogram

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

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

- Rock or Hard Soil
- Medium Soil
- Soft Soil

![Graph showing response spectrum for different soil types](image-url)
1. Resonance will not occur during earthquake as the force is random & impulsive, not steady state.
2. Earthquake does not occur simultaneously with maximum wind, flood or sea wave.
3. Static properties (modulii, strength etc.) represent material behavior during earthquake.
METHODS OF FINDING THE EARTHQUAKE FORCES

1. Equivalent Lateral Force (Static Force) Procedure

2. Dynamic Analysis
   - Response Spectrum Method
   - Time History Analysis
Equivalent static load procedure

The equivalent lateral force for an earthquake is a unique concept used in earthquake engineering. The concept is attractive because it converts a dynamic analysis into partly dynamic and partly static analyses for finding the maximum displacement (or stresses) induced in the structure due to earthquake excitation.

For seismic resistant design of structures, only these maximum stresses are of interest, not the time history of stresses.

The equivalent lateral force for an earthquake is defined as a set of lateral static forces which will produce the same peak response of the structure as that obtained by the dynamic analysis of the structure under the same earthquake.

This equivalence is restricted only to a single mode of vibration of the structure.
Basis of Equivalent Lateral Force (Static Force) Procedure

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

\( A_h = \) 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

\[ V_B = W \cdot A_h \]
During an earthquake, structure does not remain rigid, it deflects, thus base shear is disturbed along the height.

\[ V_B = W A_h \]

\( A_h \) 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

\[ V_B = A_h W \]

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

- \( Z \) = 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 (Part I) - 2002

IS:1893 - 1984
Zone Factor & Multiplying Factor for Different Damping

Table 2 Zone Factor, Z
(Clause 6.4.2)

<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>

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

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

Table 3 Multiplying Factors for Obtaining Values for Other Damping
(Clause 6.4.2)

<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>
VALUES OF IMPORTANCE FACTOR - I

I- Importance factor, depending upon functional use of the structures, characterized by hazardous consequences of its failure, post-earthquake functional needs, historical value, or economic importance (Table 6)

### Table 6 Importance Factors, I

(Clause 6.4.2)

<table>
<thead>
<tr>
<th>SI No.</th>
<th>Structure</th>
<th>Importance Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) i)</td>
<td>Important service and community buildings, such as hospitals; schools; monumental structures; emergency buildings like telephone exchange, television stations, radio stations, railway stations, fire station buildings, large community halls like cinemas, assembly halls and subway stations, power stations</td>
<td>1.5</td>
</tr>
<tr>
<td>(2) 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 SI No. (i) and (ii) above may be designed for 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 Buildings(^5)</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</td>
<td></td>
</tr>
<tr>
<td></td>
<td>At corners of rooms and jambs of openings</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Ordinary Reinforced Concrete Shear Walls(^6)</td>
<td>3.0</td>
</tr>
<tr>
<td>7</td>
<td>Ductile shear Walls(^7)</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td><strong>Buildings with Dual Systems</strong>(^8)</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, characterized by ductile or brittle deformation. However, the ratio (I/R) shall not be greater than 1.0 (Table 7). The values of R for buildings are given in Table 7.
EMPIRICAL FORMULA FOR CALCULATION OF NATURAL PERIOD

\[ T_a = 0.075h^{0.75} \]

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

\[ V_B = A_h W \]

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

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

- \( Q_i \) – 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
DAMPING RATIO FOR DIFFERENT TYPES OF STRUCTURES

- STEEL STRUCTURE - 2-5%
- CONCRETE STRUCTURE - 5-10%
- BRICK STRUCTURE - 5-10%
- TIMBER STRUCTURE - 2-5%
- EARTHEN STRUCTURE - 10-30%
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

\[
V_B = A_h W
\]

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

• Here Period and mode shapes of the structure are obtained using free vibration analysis not from Empirical formula
• \((S_a / g)\) is obtained from the same response chart for all the modes separately
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
Dynamic analysis may be performed either by the time history method or by the response spectrum method.

If base shear

\[ V_B < V_B^1 \]

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
    - $Height > 40 \, m$ in seismic zones IV and V
    - $Height > 90 \, m$ in seismic zones II and III
  - Irregular Buildings
    - $Height > 12 \, m$ in seismic zones IV and V
    - $Height > 40 \, m$ in seismic zones II and III
  - Industrial and frame building with
    - Large spans
    - Large heights

Note:
Also recommended (though not mandatory) when $Height < 40 \, m$ 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
Thank you