GUIDELINES FOR EARTHQUAKE RESISTANT DESIGN

Dr. G. P. Chandradhara
Professor of Civil Engineering
S. J. College of Engineering
Mysore- 570 006

E mail: chandu_gpc@yahoo.com
Mobile: 094482 46425
General Guidelines for Planning

Building and its Structure Should Have a Uniform and Continuous Distribution of Mass, Stiffness, Strength and Ductility
## Building Configuration: Problems & Solution

<table>
<thead>
<tr>
<th>Problem in Extreme Direction</th>
<th>Structural Problem</th>
<th>Remedial Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extreme height/depth ratio</td>
<td>High overturning forces, Large drift causing non-structural damage, foundation stability</td>
<td>Revise proportion or special structural system</td>
</tr>
<tr>
<td>Extreme plan area</td>
<td>Built-up large diaphragms forces</td>
<td>Subdivide building by seismic joints</td>
</tr>
<tr>
<td>Extreme length depth ratio</td>
<td>Built up of large lateral forces in perimeter, large differences in resistance of two axes Experience greater variations in ground movement and soil conditions</td>
<td>Subdivide building by seismic joints</td>
</tr>
</tbody>
</table>
## Building Configuration: Problems & Solution

<table>
<thead>
<tr>
<th>Problem of Vertical Layout</th>
<th>Structural Problem</th>
<th>Remedial Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical set back &amp; reverse setbacks</td>
<td>Stress concentration at notch, different periods for different parts of building, high diaphragms forces to transfer at setback</td>
<td>Special structural systems, careful dynamic analysis</td>
</tr>
<tr>
<td>Soft storey frame</td>
<td>Causes abrupt changes of stiffness at point of discontinuity</td>
<td>Add bracing, Add columns, braced</td>
</tr>
<tr>
<td>Variation in column stiffness</td>
<td>Causes abrupt changes of stiffness, much higher forces in stiffer columns</td>
<td>Redesign structural system to balance stiffnesses</td>
</tr>
</tbody>
</table>
Design of Soft storey frame

Special arrangements are necessary to increase the strength and stiffness

1. Dynamic analysis is carried out by considering stiffness and mass distribution and inelastic deformation of the members

OR

1. Columns and Beams of soft storey are to be designed for 2.5 times storey shear and moments calculated under seismic loads.

2. Shear walls are provided in both the parallel direction away from the center of the building and need to be designed for 1.5 times the lateral storey shear.
Guidelines for Planning

Arrangement of Columns

Good arrangement of columns

Poor arrangement of columns
Guidelines for Planning

Rotation about the axis

Building is strong about YY axis and weak about XX axis

Provide columns to make it strong about XX axis
Redundancy in Building

Simple Connection

Rigid Connection

One load path

Two load paths

Walls

Column/Beam
POUNDING

Maintain a good distance Between adjacent tall Buildings to avoid Collision during oscillation.
Whip Effect of Apartment Bhuj 2001
# Building Configuration: Problems & Solution

<table>
<thead>
<tr>
<th>Problems of Adjacency</th>
<th>Structural Problem</th>
<th>Remedial Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building separation (Pounding)</td>
<td>Possibility of pounding dependent on building period, height, drift, distance</td>
<td>Ensure adequate separation, assuming opposite building vibrations</td>
</tr>
</tbody>
</table>

*Figure 4: Pounding can occur between adjoining buildings due to horizontal vibrations of the two buildings.*
Short Column Behavior

Figure 2: Short columns are stiffer and attract larger forces during earthquakes – this must be accounted for in design.

Figure 3: Short columns effect in RC buildings when partial height walls adjoin columns – the effect is implicit here because infill walls are often treated as non-structural elements.

Figure 1: Buildings with short columns – two explicit examples of common occurrences.
Shear Failure in Captive Column

- Brittle shear failure of columns and beams
- Buckling of longitudinal bars in beam - columns due to inadequate spacing or lack of transverse stirrups
- Shear failure of columns which were shortened by the supporting effect of non-structural elements
- Brittle failure in corner columns caused by torsion and biaxial bending effects
The diagonal cracks and shear failures in the short columns of a multi-storey car park almost caused collapse (Northridge, California 1994)
Figure 4: Effective height of column over which it can bend is restricted by adjacent walls – this short-column effect is most severe when opening height is small.


Figure 5: Details of reinforcement in a building with short column effect in some columns – additional special requirements are given in IS:13920-1993 for the short columns.
Solution:

1. Add ties at closer spacing. Preferably spiral ties.

2. Provide masonry walls on either side equal to twice the opening sizes by reducing the openings.

3. The best solution is to avoid the opening so that no captive column is created.
CAPTIVE COLUMNS: SOLUTIONS.
Basic principles for the seismic design of buildings

Avoid partially infilled frames!

Severe Shearing Effects on Columns
Short Column behaviour (Kachchh, 2001)
Short column failure due to insufficient transverse reinforcement or?

Krishna Apartments, Airport Road, Bhuj
Failure of Express highway in Kobe
The seismic inertia forces generated at its floor levels are transferred through the various beams and columns to the ground. The correct building components need to be made ductile. The failure of a column can affect the stability of the whole building, but the failure of a beam causes localized effect. Therefore, it is better to make beams to be the ductile weak links than columns.
Strong column and weak beams

Good – Failure in beams

Poor – Failure in Columns
Weak column and strong beams
PLASTIC HINGE
Large Span Cantilevers
Cantilevers and Projections

- Towers, Parapets, Stacks, Balconies (Small)
  - Design of these attachments
  - Design of their connections to main structure
- Design force
  - 5 times vertical seismic coefficient for horizontal projections
  - 5 times horizontal seismic coefficient for vertical projections
No failure – Earthquake Resistant Design
Bhuj 2001
Weak Link

Stair case or Lift well
Weak Link, Bhuj 2001
No lateral load force transfer mechanism to the core
Punjal Apartments, Ahmedabad
Himagiri Apt - weak link

Weak Link, Bhuj 2001
LOSS OF SUPPORT

Simple Supports
Column Beam connection

Movement of supports due to horizontal force
Bad construction practice of casting the ground floor columns up to the bottom of the beam and leaving a gap
Weak joint, Bhuj 2001
Discontinuity of the longitudinal reinforcement
Bombay Dying Market, Station Road, Bhuj
Poor quality materials and workmanship

Neelima Park Apartments, Ahmedabad
L,T, + SHAPE COLUMNS CAN BE USED TO INCREASE THE STIFFNESS OF THE COLUMNS
Behavior of Symmetrical and Asymmetrical Buildings

Figure 2: Identical vertical members placed uniformly in plan of building cause all points on the floor to move by same amount.

Figure 6: Vertical members of buildings that move more horizontally sustain more damage.
Location of Centre of Mass
Location of Centre of Mass

The center of mass wrt A (9.76, 4.10)

\[
X = \frac{(10 \times 4 \times 1200) \times 5 + (10 \times 4 \times 1000) \times 15 + (20 \times 4 \times 1000) \times 10}{(10 \times 4 \times 1200) + (10 \times 4 \times 1000) + (20 \times 4 \times 1000)}
\]

\[
Y = \frac{(10 \times 4 \times 1200) \times 6 + (10 \times 4 \times 1000) \times 6 + (20 \times 4 \times 1000) \times 2}{(10 \times 4 \times 1200) + (10 \times 4 \times 1000) + (20 \times 4 \times 1000)}
\]
Location of Centre of Stiffness

Plan of one Storey Building with size of columns being same
Stiffness of all the columns are same
Location of Centre of Stiffness (COS)

In Y direction the Three frames are symmetrical, COS lies along symmetrical X axis

In X direction there are 4 frames. Let the lateral Stiffness of each frame be ‘k’

\[
X = \frac{k \times 0 + k \times 5 + k \times 10 + k \times 20}{k + k + k + k} = 8.75 \text{ m}
\]

The center of mass w.r.t .A (8.75, 5.0)
Thank You