Vulnerability assessment methodological elements of reinforced cement concrete structures to earthquake – case study

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ABSTRACT

In this paper, seismic vulnerability of every individual building in Guduvancheri at Chennai is being studied. The areas which have been covered in this study are (Gandhi Nagar, Nackiran Street & V.O.C street). The data’s collected are Plan availability, Age of Buildings, Damages available, Number of Storey, Soil type and Type of construction. Type of construction considered is (RCC Building). For which, building design and analysis is done using Linear static method by STADD pro vi8 package. The Checks of building is done according to FEMA 310. These checks have been carried out before the earthquake occurs to ensure whether the building is in safe conditions. Chennai has been facing mild earthquakes recently. Therefore, this project has been carried out as a real time project.

KEY WORDS: Vulnerability, Elements, Earthquake.

1. INTRODUCTION

Seismic hazards due to ground shaking have varying impacts and are location specific. the geographical conditions and improper construction techniques forms other reasons.

Vulnerability can be stated as the amount by which a building is prone to risk upon a seismic activity. Usually the magnitude varies from 0 to 10.

Importance of seismic design codes: Seismic activity has effects ranging from minimal to catastrophic on structures. Structures may undergo deformation to collapsing based upon the impact and withstanding capacity of the structure. Seismic codes are standards developed in order to impose guidelines which will enable reduced vulnerability and improved strength in buildings. Various countries have developed their own codes based upon the seismic history, topography and soil conditions. These standards if adopted will ensure structural stability and improved life.

- Efficient Structural Configuration: the building should be designed in such way that its dimensional parameters ensure a good flow of inertia to the ground.
- Lateral force resisting capacity: The highest lateral load that can be beard without undergoing failure in the structure.
- Good Stiffness: The resisting nature of the system such that the deformations caused due to a moderate seismic activity doesn’t affect the components of the structure.
- Improved Ductility: the ability of a structure to sustain deformations without collapsing. Ductility prevents from sudden failure of the structure.

Configuration – related checks:

Seismic evaluation

Configuration based checks
- Load path
- Weak storey
- Soft storey
- Geometry
- Effective mass
- Torsion
- Pounding
- Short column

Strength checks
- Global level checks
- Shear stress check
- Axial stress check

Figure 1. Configuration

Methods of seismic design: There are two methods of seismic analysis

- Equivalent static method
- Dynamic analysis

The dynamic analysis is easier than the static analysis method but with the advantage and use of various software, we can get result in fraction of seconds. This method is very useful because it relates directly to the lifetime situation.
The dynamic analysis can be carried out in two ways.
- Time history method
- Response Spectrum method

2. METHODOLOGY

Area of Investigation of Buildings:

Figure 2. Layout map of Guduvancheri

Analysis: All the calculated loads are given as input to STAAD.ProVi8 software. STAAD.ProVi8 will analyze the structure based on the input values of loads. The new interface empowers the user of STAAD.ProVi8 (Structural Analysis and Design for Professionals) to obtain accurate results for interlaced problems but also to maintain the comprehensive nature of solution.

Design and Analysis of RCC Structure Building:

Preliminary Data for RCC Structure:

Location: Chennai city
Type of Construction: C
Zone: III
Plan: As illustrated in Fig.1
Number of Floors: One (G+1) as illustrated in Fig.1
Ground Storey height: 3.05m
Floor to Floor height: 3.048m
External Walls: 250mm thick including wall
Internal Walls: 150mm thick including wall
L.L: 3.5 KN/m² on Floor
Seismic Analysis: Equivalent static method
Design philosophy: Limit State method
Depth of foundation below ground: 1.82m
Type of soil: Type II, Medium
Size of Column: 300 x 230 mm
Size of Beam: 230 x 2300 mm
Total Depth of Slab: 120 mm

DL at level of roof:
Weight of slab = 25 D = 25 x 0.23 = 3.0 KN/m²
Total weight = 5.0 KN/m²

Analysis of dead load:
Total weight on beam B1
Tributary floor area on beam B1 = 2.207 m²
Slab weight on beam B1 = 5 x 2.207 = 11.035 KN
Total Weight on Beam B1 = 3.16 + 2.625 = 5.35 KN/m

DL at the level of roof:
Weight of slab = 25 D = 25 x 0.23 = 3.0 KN/m²
Weight of finishes (F.F) = 0.5 KN/m²
Final weight = 3.5 KN/m²
Live Load Analysis
Final weight on beam B1
Tributary floor area on beam B1 = 2.207 m²
Slab weight on beam B1 = 1.5 x 2.207 = 3.310 KN
Weight on beam B1 per meter = 3.310/3.5 = 0.945 KN/m
Self-weight of beam = 2.207 KN/m
Total Weight on Beam B1 = 2.207 + 0.945 = 3.15 KN/m

**Design Seismic Base Shear:**

\[ V_B = A_h W \]
\[ A_h = Z I S / 2 R_g \]
\[ T = 0.09 h / \sqrt{d} \]
\[ T = 0.09 \times 6.096 / \sqrt{13} = 0.15 \text{ sec.} \]

**Calculation of seismic weight:**

- Average roof dead load = 5.0 KN/m²
- Average floor dead load = 3.5 KN/m²
- Live load intensity = 3.5 KN/m² referring to clause 7.3.1 in IS 1893: 2002,
- For seismic weight imposed load to be considered is 50% of the actual imposed load = 1.75 KN/m²
- Total live load on each floor except roof = 1.75 x 13 x 5.4 = 123 KN
- Dead load on roof = 5 x 13 x 5.4 = 351 x 10³ KN
- Dead load on other floors = 3.5 x 13 x 5.4 = 245 x 10³ KN
- Seismic weight on roof = 351 x 10³ KN
- Seismic weight on other floors = 245 x 10³ + 123 = 368 x 10³ KN
- Total seismic weight of the building = (351 + (1 x 368)) x 10³ = 7190 x 10³ KN
- Hence, modified seismic base shear = \( A_h W = 0.04 \times 7190 \times 10^3 = 288 \times 10^3 \text{ KN} \)
- Base Shear in each frame = 288/13 = 22.15 KN

**Table 1. Arrival of design lateral loads with respect to individual floors**

<table>
<thead>
<tr>
<th>Floor</th>
<th>( W_i ) (MN)</th>
<th>( h_i ) (M)</th>
<th>( W_i h_i^2 )</th>
<th>( W_i h_i^2 / \sum W_i h_i^2 )</th>
<th>( Q_i ) (KN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof (Level 3)</td>
<td>3.51</td>
<td>6.096</td>
<td>130.43</td>
<td>0.792</td>
<td>17.55</td>
</tr>
<tr>
<td>First Floor (Level 2)</td>
<td>3.68</td>
<td>3.048</td>
<td>34.18</td>
<td>0.207</td>
<td>4.59</td>
</tr>
<tr>
<td>Ground Floor (Level 1)</td>
<td>-</td>
<td>0.00</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>( \sum = 164.61 )</strong></td>
<td><strong>( \sum = 1.0 )</strong></td>
<td><strong>( \sum = 22.125 )</strong></td>
</tr>
</tbody>
</table>

**Figure 3. G+1 residential building 3D frame**

**Figure 4. 3D Frame structure**

**Figure 5. Bending moment diagram**
Table 2. Load combination

<table>
<thead>
<tr>
<th>Load Cases</th>
<th>Details of Load cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.5(DL+LL)</td>
</tr>
<tr>
<td>2</td>
<td>1.2(DL+LL+EQ)</td>
</tr>
<tr>
<td>3</td>
<td>1.2(DL+LL-EQ)</td>
</tr>
<tr>
<td>4</td>
<td>1.5(DL-EQ)</td>
</tr>
<tr>
<td>5</td>
<td>1.5(DL-EQ)</td>
</tr>
</tbody>
</table>

Damages on RCC buildings:

![Figure 6. Floor bent with the beam but shear failure occurs. Fine crack on floor](image)

![Figure 7. Beam and slabs were of in-situ concrete. Shear failure on floor at cement mortar](image)

![Figure 8. Short column effect. Unreinforced masonry infills placed up to partial height in frame panels adjoining the columns reduced column height. Such columns draw shear forces larger than designed](image)

![Figure 9. In some areas, like this part of row constructions are common, with little or no space left between adjoining buildings. At the interface between such buildings, infills are sometimes made only in one of the two buildings. There were no infills in the upper stories of the building on the left. The building on the right suffered a ground storey](image)

3. RESULTS

Table 3. Configuration-Related Checks

<table>
<thead>
<tr>
<th>S. no.</th>
<th>Check</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Load Path</td>
<td>One complete load path exists which transfers the inertial forces from the mass to the foundation.</td>
</tr>
<tr>
<td>2</td>
<td>Geometry</td>
<td>Horizontal dimension is equal at all the stories.</td>
</tr>
<tr>
<td>3</td>
<td>Weak Storey</td>
<td>There are no abrupt changes in the column sizes from one storey to another and no significant geometrical irregularities. Thus, weak or soft storey does not exist.</td>
</tr>
<tr>
<td>4</td>
<td>Soft Storey</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Vertical Discontinuities</td>
<td>Vertical elements in the lateral force resisting system are continuous to the foundation.</td>
</tr>
<tr>
<td>6</td>
<td>Mass</td>
<td>Effective mass at the floors is equal except the roof. The effective mass at the roof varies by 20% (&lt;100%).</td>
</tr>
<tr>
<td>7</td>
<td>Torsion</td>
<td>The building being symmetrical</td>
</tr>
<tr>
<td>8</td>
<td>Adjacent Buildings</td>
<td>Not applicable.</td>
</tr>
<tr>
<td>9</td>
<td>Short Columns</td>
<td>Short columns are applicable</td>
</tr>
</tbody>
</table>
Shear stress in RC frame columns: As per draft code, an estimation of the average shear stress undergone by columns are obtained by

$$\tau_{\text{col}} = \frac{n_c}{n_c - n_f} \left( \frac{v_j}{A_c} \right)$$

For ground level columns.

$\tau_{\text{col}} = \text{For ground level columns.}$

$nc = \text{total number of columns resisting lateral forces in loading direction.}$

$nf = \text{total number of frames in loading direction}$

$Ac = \text{Summation of the c.s.a of all columns in the floor considered}$

$Vj = \text{max} \text{imum shear at floor level ‘j’}$

<table>
<thead>
<tr>
<th>floor</th>
<th>$n_c$</th>
<th>$n_f$</th>
<th>$A_c$ ($m^2$)</th>
<th>$V_j \times 1.5$ KN</th>
<th>$\tau_{\text{col}}$ Mpa</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>6</td>
<td>2</td>
<td>0.414</td>
<td>4575</td>
<td>0.0165</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>2</td>
<td>0.414</td>
<td>26302</td>
<td>0.0952</td>
</tr>
<tr>
<td>1</td>
<td>6</td>
<td>2</td>
<td>0.414</td>
<td>33187</td>
<td>0.1202</td>
</tr>
</tbody>
</table>

$(\tau_{\text{col}})_{\text{all}} < \text{min. of 0.4MPa and } 0.1\sqrt{f_{\text{ck}}} < 0.4\text{MPa}$

But, $\tau_{\text{col}} > (\tau_{\text{col}})_{\text{all}}$

The check is not satisfied.

Axial Stress in Moment Frames: Axial force in moment frames at base at columns

$VB = \text{Base shear} \times \text{Load factor} = 22 \times 125 \times 1.5 = 33.2 \times 10^3 \text{KN}$

$n_l = \text{Number of frames in loading direction} = 2$

$H = \text{total height} = 6.096 \text{m}$

$L = \text{length of the building} = 12.3 \text{m}$

$F_0 = (2/3) \times (V_B/n_l) \times (H/L) = (2/3) \times (33.2 \times 1000/2) \times (6.096/12.3) = 5.49\text{KN}$

$\text{Axial Stress } \sigma = (5.49 \times 10^3)/(0.3 \times 0.23 \times 10^6) = 0.079$

$\sigma_{\text{all}} = 0.25 \sqrt{f_{\text{ck}}} = 5\text{MPa}$

$\sigma < \sigma_{\text{all}} \text{ ok } \text{ Hence, the check is satisfied.}$

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