Seismic Demand of Reinforced Concrete Structural Systems

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ABSTRACT

This paper deals with evaluation of response reduction factor of various reinforced concrete structural systems. The response reduction factor (R) also known by the name response modification factor depending on the perceived seismic damage performance of the structure, characterized by ductile or brittle deformation. The concept of R factor is to de-amplify the seismic force and accounts nonlinearity with the help of over-strength, redundancy and ductility. Pushover analysis was performed for building systems such as OMRF, OMRF with shearwall and OMRF with cross bracing for 10, 15, 20 stories using ETABS v15.1.0. Various seismic demand parameters such as overstrength factor, ductility factor, response reduction factor are obtained for different structural systems are calculated for various systems.

Keywords: Response Reduction factor, Overstrength factor, Ductility factor, Pushover analysis.

1. INTRODUCTION

Reinforced concrete structures are able to dissipate a large amount of energy that are occurring during earthquake. Structures designed to resist earthquakes must have sufficient stiffness and strength to control deflection and prevent any possible collapse. In order to resist damage to the structural elements, it has to be designed & detailed as per Indian code standards. In this paper the reinforced concrete structural frames of different stories with different types of lateral load resisting systems are taken for pushover analysis. During pushover analysis damage will be occurred in the joints in the structure. Hence the lateral load resisting systems such as bracing and shearwall is place in the frame so that it can perform well under seismic load.

Mohamed S. Issa et al (2015) conducted study on application of pushover analysis for the calculation of behavior factor for reinforced concrete moment-resisting frames. It was concluded that the smallest value obtained for the behavior factor is 2.3 and this is on the conservative side when compared with the value of 1.5 suggested by the Eurocode 8- Part 1 for non-dissipative structures. Kruti J. Tamboli et al (2015) performed an assessment of response reduction factor for asymmetric RC frame building. According to their outcomes, Provision of bracing/shear wall in alternate bays increases the values of responses reduction factor nearly 2.81 to 2.94 times respectively as compared to the bare RC frame respectively. Sanmi Deshpande et al (2015) suggested the formulation of the seismic response reduction factor for earthquake resistant design. It was found that the percentage variation in the value of R in the X-direction is 72.6% and in the Y-direction is 41.6%.

Abhijit P. Ghadi et al (2015) performed an evaluation of response reduction factor for reinforced concrete frame. Based on their results, it was concluded that the response reduction factor for present structural system considered is on higher side as compared to IS code value. Santoshkumar B. Naik et al (2015) conducted seismic performance evaluation of reinforced concrete frames with irregular elevations using nonlinear static pushover analysis. Based on the obtained results, it was concluded that as the percentage of irregularity in elevation increases the base shear decreases, thus reducing the lateral load carrying capacity of the structure. Branci Taïeb et al (2014) investigated the accounting for ductility and overstrength in seismic design of reinforced concrete structures. The results showed that the overstrength factor increases when the ductility of the frame increases. From the literature it was concluded that behaviour of square column is better than rectangular column, in terms of storey drift, base shear & roof displacement. X bracing showing good performance in both the directions than other types of bracing hence it can be recommended. Provision of shear wall in X direction gives a better performance of structure.

2. RESPONSE REDUCTION FACTOR

Response Reduction factor (R) is the ratio of the strength required to maintain the elastic to the inelastic design strength of the structure. Higher R factor leads to lower design base shear for the design purpose of the structure. Response reduction factor is the function of various parameters of the structural system, such as strength, ductility, damping and redundancy:

\[ R = R_\mu R_s R_\xi R_R \]  \hspace{1cm} (1)

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Where,  
\( R_S \) is the strength factor, 
\( R_R \) is the redundancy factor, 
\( R_\mu \) is the ductility factor, 
\( R_\xi \) is the damping factor.

The strength factor \( (R_S) \) is a measure of the built-in overstrength in the structural system and is obtained by dividing the yield base shear \( (V_y) \) by the design base shear \( (V_d) \).

\[
R_S = \frac{V_y}{V_d} 
\]  
(2)

The ductility factor is a measure of the global nonlinear response of a structural system in terms of its plastic deformation capacity.

\[
R_\mu = 1 + \frac{(\mu - 1)}{\phi} 
\]  
(3)

And \( \Phi = 1 + \frac{1}{(12T - \mu T)} - \frac{2}{5T} e^{-(2/5T)(\ln(T) - 0.2)^2} \)  
(4)

Where,  
\( \Phi \) is the constant factor,  
\( \mu \) is the ductility capacity which is the ratio of the ultimate displacement to the yield displacement and,  
\( T \) is the fundamental time period of the structure.

The damping factor \( R_\xi \) accounts for the effect of added viscous damping and is primarily applicable for structures provided with supplemental energy dissipating devices. Without such devices, the damping factor is usually assigned a value equal to 1.0.

The redundancy factor, \( (R_R) \) is measure of redundancy in a lateral load resisting system. The redundancy factor \( R_d \) for redundant structures is taken as 1.0.

![Figure 1: Typical Pushover response curve for evaluation of response reduction factor](image)

3. PUSHEROVER ANALYSIS

Pushover analysis is defined as an analysis wherein a mathematical model directly incorporating the nonlinear load-deformation characteristics of individual components and elements of the building shall be subjected to monotonically increasing lateral loads representing inertia forces in an earthquake until a target displacement is exceeded. Target displacement is the maximum displacement (elastic plus inelastic) of the building at roof expected under selected earthquake ground motion.

The structural Pushover analysis assesses performance by estimating the force and deformation capacity and seismic demand using a nonlinear static analysis algorithm. The seismic demand parameters are storey drifts, global displacement, storey forces, and component deformation and component forces. The analysis accounts for material inelasticity, geometrical nonlinearity and the redistribution of internal forces.

4. PROCEDURE FOR PUSHEROVER ANALYSIS

Pushover analysis can be performed by either force controlled or displacement controlled depending on the physical nature of the load and the behavior expected from the structure. Force-controlled option is useful when the load is known (such as gravity loading) and the structure is expected to be able to support the load. Displacement controlled procedure should be used when specified drifts are sought, where the magnitude of the applied load is not known in advance, or where the structure can be expected to lose strength or become unstable.

The following procedure is carried out for the displacement controlled pushover analysis:

1. Define the materials and section properties that are required.
2. Create the 3D view of the structure by drawing beams, columns etc.
3. Apply the live load and floor finish load on the respective slabs.
4. Assign the proper support conditions that are taken into consideration.
5. Define the mass source by taking 1Dead Load + 1Finish Load + 0.25 Live Load.
6. Define the load patterns that are required for the design purpose.
7. Define the load conditions for which the frame is to be designed.
8. Now, the frame is designed for the load combinations 1.2 (DL+FL+LL).
9. Next, the pushover load cases are defined by considering the pushdown load case as 1DL+ 1FL+ 0.25 LL and pushover load case as acceleration in negative X- direction the known displacement is defined so that the structural elements gets yielded.
10. Hinges are assigned for the structural elements such as P-M2-M3 hinges are assigned for columns. While M3 & Fibre P-M2 hinges are assigned for beams, braces and shearwall respectively.
11. Now, the load cases are set so that pushover analysis is carried out.
12. Then the base shear vs displacement curve is taken so as to calculate the required properties.

5. MODEL DESCRIPTION
The buildings are assumed to be symmetric in plan, and regular in elevation. Typical bay width is 5m and column height is selected as 4.2m for ground floor and for other stories 3m. A configuration of 10, 15, and 20 stories with different structural systems and 3 bays in both X and Y direction is considered in this study.

The building frame considered in this study is assumed to be located in Indian seismic zone III with medium soil conditions. Dead and live loads are as per IS 875 (1987) and lateral loads (Earthquake load) are calculated as per IS 1893(2002). OMRF frames are designed as per IS 456 with a response reduction factor of 3.

Model 1-1: G+9 RC frame OMRF
Model 1-2: G+ 9 RC frames with shear wall
Model 1-3: G+ 9 RC frames with cross bracing

Model 2-1: G+14 RC frame OMRF
Model 2-2: G+14 RC frame with shear wall
Model 2-3: G+ 14 RC frames with cross bracing

Model 3-1: OMRF G+19 RC Bare frame
Model 3-2: G+19 RC frame with shear wall
Model 3-3: G+19 RC frame with cross bracing

The dimensions that have been chosen for the models are as follows:
Size of columns: 500x500mm
Size of beams: 300x300mm
Thickness of slab: 125mm
Thickness of shearwall: 230mm
Size of bracing: 300x300mm
Live load on slab: 3 kN/m²
Floor finish on slab: 1kN/m²
Materials: M25 concrete & HYSD415 reinforcement
Importance factor: 1
Soil type: Medium (type II)
Seismic zone: zone 3
Zone factor: 0.16
Support condition: Fixed.
Plan and elevation of model 1-1, model 1-2, model 1-3, model 2-1, model 2-2, model 2-3, model 3-1, model 3-2 & model 3-3 was shown in fig 2-fig 11
6. RESULTS & DISCUSSIONS

Base shear vs Displacement pushover curve, Storey vs Displacement & Storey vs Interstorey drift was plotted for G+9 storey building with different system are shown in fig 12-14

Base shear vs Displacement pushover curve, Storey vs Displacement & Storey vs Interstorey drift was plotted for G+14 storey building with different system are shown in fig 15- fig17
Base shear vs Displacement pushover curve, Storey vs Displacement & Storey vs Interstorey drift was plotted for G+19 storey building with different system are shown in fig 18- fig 20

![Figure.18](image)

![Figure.19](image)

![Figure.20](image)

Table 1: Pushover results for different system at ultimate base shear

<table>
<thead>
<tr>
<th>System</th>
<th>Max base shear</th>
<th>Max displacement</th>
<th>Max interstorey drift</th>
<th>Max storey force</th>
<th>Max overturning moment</th>
<th>W</th>
<th>Sa, g</th>
<th>T_e</th>
<th>K_e</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1-1</td>
<td>2576.34</td>
<td>214.362</td>
<td>0.01125</td>
<td>1629.594</td>
<td>122617.4</td>
<td>16136.3</td>
<td>0.329</td>
<td>1.698</td>
<td>15022.54</td>
</tr>
<tr>
<td>Model 1-2</td>
<td>6665.87</td>
<td>243.836</td>
<td>0.00874</td>
<td>1063.034</td>
<td>166379.3</td>
<td>17484.4</td>
<td>0.872</td>
<td>0.641</td>
<td>82926.34</td>
</tr>
<tr>
<td>Model 1-3</td>
<td>2469.48</td>
<td>41.272</td>
<td>0.00149</td>
<td>2391.715</td>
<td>126599.3</td>
<td>16136.3</td>
<td>1.071</td>
<td>1.62</td>
<td>78253.28</td>
</tr>
<tr>
<td>Model 2-1</td>
<td>2423.07</td>
<td>286.448</td>
<td>0.01058</td>
<td>1400.671</td>
<td>184109</td>
<td>24333.9</td>
<td>0.206</td>
<td>2.716</td>
<td>8637.722</td>
</tr>
<tr>
<td>Model 2-2</td>
<td>5434.51</td>
<td>298.726</td>
<td>0.00726</td>
<td>995.342</td>
<td>200256.2</td>
<td>26379.8</td>
<td>0.476</td>
<td>1.172</td>
<td>37614.83</td>
</tr>
<tr>
<td>Model 2-3</td>
<td>2494.93</td>
<td>75.942</td>
<td>0.001977</td>
<td>2439.63</td>
<td>180826.3</td>
<td>24845.6</td>
<td>0.452</td>
<td>1.235</td>
<td>35470.03</td>
</tr>
<tr>
<td>Model 3-1</td>
<td>2340.43</td>
<td>371.013</td>
<td>0.01036</td>
<td>1412.906</td>
<td>245600.7</td>
<td>35274</td>
<td>0.305</td>
<td>1.829</td>
<td>20354.85</td>
</tr>
<tr>
<td>Model 3-2</td>
<td>5206.74</td>
<td>414.402</td>
<td>0.00777</td>
<td>972.197</td>
<td>266975</td>
<td>35274</td>
<td>0.305</td>
<td>1.829</td>
<td>20354.85</td>
</tr>
<tr>
<td>Model 3-3</td>
<td>2627.81</td>
<td>124.519</td>
<td>0.00254</td>
<td>2472.589</td>
<td>253517.3</td>
<td>33726.3</td>
<td>0.311</td>
<td>1.795</td>
<td>22270.27</td>
</tr>
</tbody>
</table>

Table 2: Response reduction factor for the systems was tabulated in the following table

<table>
<thead>
<tr>
<th>System</th>
<th>Yield base shear V_y</th>
<th>Design base shear V_d</th>
<th>Strength factor Rs</th>
<th>Max displacement Δmax</th>
<th>Yield displacement Δy</th>
<th>Ductility ratio µ</th>
<th>Time period T</th>
<th>Ductility based force reduction factor R_p</th>
<th>Response reduction factor R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1-1</td>
<td>1750.31</td>
<td>352.55</td>
<td>4.965</td>
<td>124.8</td>
<td>116.5</td>
<td>1.071</td>
<td>1.62</td>
<td>1.084</td>
<td>5.382</td>
</tr>
<tr>
<td>Model 1-2</td>
<td>2373.89</td>
<td>933.116</td>
<td>2.544</td>
<td>124.8</td>
<td>28.6</td>
<td>4.364</td>
<td>1.69</td>
<td>4.800</td>
<td>12.212</td>
</tr>
<tr>
<td>Model 1-3</td>
<td>1425.69</td>
<td>642.078</td>
<td>2.220</td>
<td>124.8</td>
<td>20.9</td>
<td>5.971</td>
<td>1.47</td>
<td>6.790</td>
<td>15.077</td>
</tr>
<tr>
<td>Model 2-1</td>
<td>1138.72</td>
<td>348.695</td>
<td>3.2657</td>
<td>184.8</td>
<td>131.8</td>
<td>1.402</td>
<td>2.47</td>
<td>1.411</td>
<td>4.608</td>
</tr>
<tr>
<td>Model 2-2</td>
<td>2383.26</td>
<td>708.936</td>
<td>3.3617</td>
<td>184.8</td>
<td>64.9</td>
<td>2.847</td>
<td>2.567</td>
<td>2.864</td>
<td>9.630</td>
</tr>
<tr>
<td>Model 2-3</td>
<td>944.929</td>
<td>603.412</td>
<td>1.5660</td>
<td>184.8</td>
<td>26.6</td>
<td>6.947</td>
<td>2.23</td>
<td>6.934</td>
<td>10.859</td>
</tr>
<tr>
<td>Model 3-1</td>
<td>426.323</td>
<td>343.723</td>
<td>1.240</td>
<td>244.8</td>
<td>68</td>
<td>2.448</td>
<td>3.36</td>
<td>2.426</td>
<td>3.008</td>
</tr>
<tr>
<td>Model 3-2</td>
<td>2510.78</td>
<td>622.922</td>
<td>4.031</td>
<td>244.8</td>
<td>123.4</td>
<td>1.984</td>
<td>3.47</td>
<td>1.969</td>
<td>7.935</td>
</tr>
<tr>
<td>Model 3-3</td>
<td>679.056</td>
<td>548.983</td>
<td>1.237</td>
<td>244.8</td>
<td>30.5</td>
<td>8.026</td>
<td>3.03</td>
<td>7.643</td>
<td>9.454</td>
</tr>
</tbody>
</table>
Table 3: Time period for the various building systems

<table>
<thead>
<tr>
<th>System</th>
<th>Time period</th>
<th>IS CODE Time period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1-1</td>
<td>1.624</td>
<td>0.99</td>
</tr>
<tr>
<td>Model 1-2</td>
<td>1.687</td>
<td>0.725</td>
</tr>
<tr>
<td>Model 1-3</td>
<td>1.469</td>
<td>0.725</td>
</tr>
<tr>
<td>Model 2-1</td>
<td>2.474</td>
<td>1.329</td>
</tr>
<tr>
<td>Model 2-2</td>
<td>2.567</td>
<td>1.0735</td>
</tr>
<tr>
<td>Model 2-3</td>
<td>2.223</td>
<td>1.0735</td>
</tr>
<tr>
<td>Model 3-1</td>
<td>3.355</td>
<td>1.641</td>
</tr>
<tr>
<td>Model 3-2</td>
<td>3.465</td>
<td>1.422</td>
</tr>
<tr>
<td>Model 3-3</td>
<td>3.03</td>
<td>1.422</td>
</tr>
</tbody>
</table>

7. CONCLUSION

From the analytical study, the following conclusions are derived:

1. Irrespective of storey height, buildings with shear wall is having maximum base shear. Base shear of shear wall is 158.734% and 169.93% higher than OMF and Braces for 10 stories, 124.28% & 117.82% for 15 stories and 122.46% & 98.14% for 20 stories respectively.
2. Out of two Lateral Load Resisting System (LLRS), Base shear of Shear wall is 169.93%, 117.82% and 98.14% higher than Braces for 10, 15 and 20 stories respectively.
3. Base shear decreases and displacement increases as the number of stories increases.
4. Out of two LLRS, Max displacement and interstorey drift of system with braces is less when compared to shear wall.
5. For building with braces, interstorey drift (Δ/H) is within codal limits i.e. 0.004. Therefore other Non-structural will not be damaged and structures can be easily put in function after earthquake with less repairs.
6. Overturning moment of Building with shearwall is 8.9% and 5.48% higher than OMF and braces for 10 stories, 8.77% and 5.49% for 15 stories, 8.7% and 5.3% for 20 stories.
7. Time period (T) is found to increase with increase in number of stories.
8. Strength factor decreases and ductility factor increases as the number of stories increases.
9. The ductility factor of OMRF with RC shearwall decreases as the number of stories increases.
10. Response reduction factor, R is directly proportional to strength factor and ductility factor and inversely proportional to natural period irrespective of storey height.
11. Response reduction factor of building with cross bracing is higher when compared to all other systems. R value of Braces are 23.46%, 12.76% and 19.14% higher for 10, 15 and 20 storey when compared to Shear wall.
References


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