Seismic Analysis of Steel Braced Reinforced Concrete Frames
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ABSTRACT

Steel braced frame is one of the structural systems used to resist earthquake loads in multistoried buildings. Many existing reinforced concrete buildings need retrofit to overcome deficiencies to resist seismic loads. The use of steel bracing systems for strengthening or retrofitting seismically inadequate reinforced concrete frames is a viable solution for enhancing earthquake resistance. Steel bracing is economical, easy to erect, occupies less space and has flexibility to design for meeting the required strength and stiffness. In the present study, the seismic performance of reinforced concrete (RC) buildings rehabilitated using concentric steel bracing is investigated. The bracing is provided for peripheral columns. A four-storey building is analyzed for seismic zone IV as per IS 1893: 2002 using STAAD Pro software. The effectiveness of various types of steel bracing in rehabilitating a four-storey building is examined. The effect of the distribution of the steel bracing along the height of the RC frame on the seismic performance of the rehabilitated building is studied. The performance of the building is evaluated in terms of global and story drifts. The study is extended to eight storied, twelve storied and sixteen storied building. The percentage reduction in lateral displacement is found out. It is found that the X type of steel bracing significantly contributes to the structural stiffness and reduces the maximum interstorey drift of the frames.

Keywords: Earthquake strengthening, retrofit, seismic performance, analysis, steel braced RC structures

1. Introduction

1.1. Strengthening of RC Structures for Earthquake Resistance

The aftermath of an earthquake manifests great devastation due to unpredicted seismic motion striking extensive damage to innumerable buildings of varying degree, i.e. either full or partial. This damage to structures in turn causes irreparable loss of life with a large number of casualties. Strengthening of structures proves to be a better option catering to the economic considerations and immediate shelter problems rather than replacement of buildings. Moreover it has been often seen that retrofitting of buildings is generally more economical as compared to demolition and reconstruction. Therefore,
1.2. Methods of Strengthening

Seismic strengthening or retrofitting is generally carried out in the following ways:7

- Structure level or global retrofit methods
- Member level or local retrofit methods

a. Structure level or Global Retrofit Methods

In Structure level or global retrofit methods two approaches are used for structure level retrofitting.

i) Conventional methods based on increasing the seismic resistance of existing structure.

ii) Non-conventional methods based on reduction of seismic demands.

Conventional methods of retrofitting or strengthening are used to enhance the seismic resistance of existing structures by eliminating or reducing the adverse effects of design or construction. The methods include the options like adding of shear wall, infill walls or steel braces.

In case of non conventional methods, seismic base isolation and addition of supplemented device techniques are the most popular. These techniques proceed with quite different philosophy in the sense that it is fundamentally conceived to reduce the horizontal seismic forces.

b. Member level or Local Retrofit Methods

The member level retrofit or local retrofit of strengthening approach is to upgrade the strength of the members, which are seismically deficient. This approach is more cost effective as compared to the structure level retrofit. The most common method of enhancing the individual member strength is jacketing. It includes the addition of concrete, steel or fiber reinforced polymer (FRP) jackets for use in confining reinforced concrete columns, beams, joints and foundations.

1.3. Strengthening of RC Structures with Steel Bracing Systems

Steel bracing is a highly efficient and economical method of resisting horizontal forces in a frame structure. Bracing has been used to stabilize laterally the majority of the world’s tallest building structures as well as one of the major retrofit measures. Bracing is efficient because the diagonals work in axial stress and therefore call for minimum member sizes in providing stiffness and strength against horizontal shear. A number of researchers have investigated various techniques such as infilling walls, adding walls to existing columns, encasing columns, and adding steel bracing to improve the strength and/or ductility of existing buildings. A bracing system improves the seismic performance of the frame by increasing its lateral stiffness and capacity. Through the addition of the bracing system, load could be transferred out of the frame and into the
braces, bypassing the weak columns while increasing strength. Steel-braced frames are efficient structural systems for buildings subjected to seismic or wind lateral loadings. Therefore, the use of steel-bracing systems for retrofitting reinforced-concrete frames with inadequate lateral resistance is attractive.

1.4 Types of Bracings

Existing RC framed buildings designed without seismic criteria and ductile detailing can represent a considerable hazard during earthquake ground motions. The non-ductile behaviour of these frames derives from the inadequate transverse reinforcement in columns, beams and joints, from bond slip of beam bottom reinforcement at the joint, from the poor confinement of the columns. In the presence of these deficiencies the upgrading of seismic performance may be realized with two different approaches,

i) The introduction of new structural members such as steel bracing systems or RC shear walls.

ii) The local strengthening of some structural elements with the use of concrete, steel and fiber reinforced plastic.

The first approach is realized with the introduction of steel braces in steel structures and of RC shear walls in RC structures. However, the use of steel bracing systems for RC buildings may have both practical and economical advantages. In particular, this system offers advantages such as the ability to accommodate openings and the minimal added weight of the structure. Furthermore, if it is realized with external steel systems (External Bracing) the minimum disruption to the full operability of the building is obtained. There are two types of bracing systems, Concentric Bracing System figure 1 and Eccentric Bracing System figure 2.

![Figure 1 Concentric Bracings](image1)

![Figure 2 Eccentric Bracings](image2)

The steel braces are usually placed in vertically aligned spans. This system allows to obtain a great increase of stiffness with a minimal added weight, and so it is very effective for existing structure for which the poor lateral stiffness is the main problem.

The concentric bracings increase the lateral stiffness of the frame, thus increasing the natural frequency and also usually decreasing the lateral drift. However, increase in
the stiffness may attract a larger inertia force due to earthquake. Further, while the bracings decrease the bending moments and shear forces in columns, they increase the axial compression in the columns to which they are connected. Since reinforced concrete columns are strong in compression, it may not pose a problem to retrofit in RC frame using concentric steel bracings.

Eccentric Bracings reduce the lateral stiffness of the system and improve the energy dissipation capacity. Due to eccentric connection of the braces to beams, the lateral stiffness of the system depends upon the flexural stiffness of the beams and columns, thus reducing the lateral stiffness of the frame. The vertical component of the bracing forces due to earthquake cause lateral concentrated load on the beams at the point of connection of the eccentric bracings.

2. Modeling

The STAAD Pro V8i software is utilized to create 3D model and carry out the analysis. The buildings are modeled as a series of load resisting elements. The lateral loads to be applied on the buildings are based on the Indian standards. The study is performed for seismic zone IV as per IS 1893:2002. The buildings adopted consist of reinforced concrete and brick masonry elements. The frames are assumed to be firmly fixed at the bottom and the soil–structure interaction is neglected.

- Four storied building analysed only for gravity loads.
- Four storied building analysed for seismic forces.
- Four storied building analysed with different types of bracing systems.

The eight, twelve and sixteen storied buildings are analyzed for zone IV and with X type bracings for peripheral columns only.

The data of modeled buildings is given below in table 1

<table>
<thead>
<tr>
<th>Table 1: Model data of the buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure</td>
</tr>
<tr>
<td>No. of stories</td>
</tr>
<tr>
<td>Storey height</td>
</tr>
<tr>
<td>Type of building use</td>
</tr>
<tr>
<td>Foundation type</td>
</tr>
<tr>
<td>Seismic zone</td>
</tr>
<tr>
<td><strong>Material Properties</strong></td>
</tr>
<tr>
<td>Young’s modulus of M20 concrete, E</td>
</tr>
<tr>
<td>Grade of concrete</td>
</tr>
<tr>
<td>Grade of steel</td>
</tr>
<tr>
<td>Density of reinforced concrete</td>
</tr>
<tr>
<td>Modulus of elasticity of brick masonry</td>
</tr>
<tr>
<td>Density of brick masonry</td>
</tr>
<tr>
<td><strong>Member Properties</strong></td>
</tr>
<tr>
<td>Thickness of slab</td>
</tr>
</tbody>
</table>
Beam size | 0.23 x 0.30 m.  
Column size | 0.23 x 0.60 m.  
Thickness of wall | 0.23 m.

**Dead Load Intensities**

| Floor finishes | 1.0 kN/m² |

**Live Load Intensities**

| Roof and Floor | 3.0 kN/m² |

**Earthquake LL on slab as per Cl. 7.3.1 and 7.3.2 of IS 1893(part 1)-2002**

| Roof | 0 kN/m² |
| Floor | 0.25 x 3.0 = 0.75kN/m² |

Seismic Zone - IV  
Zone factor, Z - 0.24  
Importance factor, I - 1.00  
Response reduction factor, R - 3.00  
The load cases considered in the seismic analysis are as per IS 1893 – 2002.

**Figure 3** Plan of the building  
**Figure 4** Elevation of the building
Figure 5  Building with X bracings

Figure 6  Building with diagonal bracings
3. Results

3.1. Lateral Displacements

The lateral displacements of un-braced building for the cases of dead and live load for seismic analysis in all the three directions are presented in Table 1. The results are compared with that of buildings with various types of bracings. It is observed that the maximum lateral displacements are reduced due to the presence of bracings. It is observed that the lateral displacements are reduced to the largest extent for X type of bracing systems.

<table>
<thead>
<tr>
<th>Floor level</th>
<th>DL+LL</th>
<th>Without bracing</th>
<th>Diagonal bracing</th>
<th>X intersected bracing</th>
<th>K bracing</th>
<th>X bracing</th>
</tr>
</thead>
<tbody>
<tr>
<td>4th floor</td>
<td>0.06</td>
<td>70.10</td>
<td>23.71</td>
<td>18.01</td>
<td>20.45</td>
<td>18.02</td>
</tr>
<tr>
<td>3rd floor</td>
<td>0.00</td>
<td>64.04</td>
<td>21.87</td>
<td>16.64</td>
<td>19.00</td>
<td>16.64</td>
</tr>
<tr>
<td>2nd floor</td>
<td>0.00</td>
<td>50.90</td>
<td>16.98</td>
<td>12.65</td>
<td>14.66</td>
<td>12.65</td>
</tr>
<tr>
<td>1st floor</td>
<td>0.00</td>
<td>33.13</td>
<td>10.71</td>
<td>7.71</td>
<td>9.12</td>
<td>7.71</td>
</tr>
<tr>
<td>Ground floor</td>
<td>0.02</td>
<td>13.82</td>
<td>4.37</td>
<td>3.10</td>
<td>3.69</td>
<td>3.10</td>
</tr>
</tbody>
</table>

3.2 Maximum Forces and Bending Moments in Columns

The maximum axial, shear forces and bending moments in columns of the building frame without bracing, for dead and live load analysis and for seismic analysis is presented in Table 2 to Table 4. The results are compared with that of building frames with various types of bracings. The results in all the three directions are obtained. It is seen that the maximum axial forces are increased for buildings with bracings compared to that of the building without bracings. Further, while bracings decrease the bending moments and shear forces in columns they increase the axial compression in the columns to which they are connected. Since reinforced concrete columns are strong in compression, it may not pose a problem to retrofit in reinforced concrete frame using concentric steel bracings. It seen that the bending moment values are smaller for the buildings with X types of bracing systems.
Table 2 Maximum axial forces in column in kN for zone IV

<table>
<thead>
<tr>
<th>Floor level</th>
<th>DL+LL</th>
<th>Seismic load</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Without bracing</td>
<td>Diagonal</td>
<td>X intersected</td>
<td>K bracing</td>
<td>X bracing</td>
</tr>
<tr>
<td>4th floor</td>
<td>71.62</td>
<td>91.58</td>
<td>92.50</td>
<td>82.37</td>
<td>78.55</td>
<td>82.38</td>
</tr>
<tr>
<td>3rd floor</td>
<td>223.89</td>
<td>243.60</td>
<td>233.76</td>
<td>235.12</td>
<td>204.93</td>
<td>235.24</td>
</tr>
<tr>
<td>2nd floor</td>
<td>376.10</td>
<td>418.78</td>
<td>399.78</td>
<td>447.64</td>
<td>375.92</td>
<td>447.80</td>
</tr>
<tr>
<td>1st floor</td>
<td>528.13</td>
<td>606.89</td>
<td>631.38</td>
<td>695.75</td>
<td>603.10</td>
<td>696.10</td>
</tr>
<tr>
<td>Ground floor</td>
<td>679.57</td>
<td>793.89</td>
<td>886.45</td>
<td>949.19</td>
<td>856.79</td>
<td>949.24</td>
</tr>
</tbody>
</table>

Table 3. Maximum shear forces in column in kN for zone IV

<table>
<thead>
<tr>
<th>Floor level</th>
<th>DL+LL</th>
<th>Seismic load</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Without bracing</td>
<td>Diagonal</td>
<td>X intersected</td>
<td>K bracing</td>
<td>X bracing</td>
</tr>
<tr>
<td>4th floor</td>
<td>1.78</td>
<td>23.15</td>
<td>11.50</td>
<td>11.45</td>
<td>14.32</td>
<td>11.49</td>
</tr>
<tr>
<td>3rd floor</td>
<td>1.10</td>
<td>39.80</td>
<td>15.92</td>
<td>11.88</td>
<td>18.76</td>
<td>11.88</td>
</tr>
<tr>
<td>2nd floor</td>
<td>0.97</td>
<td>51.87</td>
<td>18.71</td>
<td>12.84</td>
<td>21.17</td>
<td>12.85</td>
</tr>
<tr>
<td>1st floor</td>
<td>0.46</td>
<td>56.15</td>
<td>17.97</td>
<td>10.65</td>
<td>21.61</td>
<td>10.62</td>
</tr>
<tr>
<td>Ground floor</td>
<td>0.26</td>
<td>51.90</td>
<td>35.83</td>
<td>21.19</td>
<td>29.02</td>
<td>21.18</td>
</tr>
</tbody>
</table>

Table 4 Maximum bending moments in column in kN-m for zone IV

<table>
<thead>
<tr>
<th>Floor level</th>
<th>DL+LL</th>
<th>Seismic load</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Without bracing</td>
<td>Diagonal</td>
<td>X intersected</td>
<td>K bracing</td>
<td>X bracing</td>
</tr>
<tr>
<td>4th floor</td>
<td>3.30</td>
<td>58.45</td>
<td>26.35</td>
<td>23.20</td>
<td>29.33</td>
<td>23.40</td>
</tr>
<tr>
<td>3rd floor</td>
<td>1.58</td>
<td>81.29</td>
<td>29.65</td>
<td>20.25</td>
<td>33.32</td>
<td>20.25</td>
</tr>
<tr>
<td>2nd floor</td>
<td>1.52</td>
<td>86.10</td>
<td>30.46</td>
<td>19.62</td>
<td>33.03</td>
<td>19.66</td>
</tr>
<tr>
<td>1st floor</td>
<td>0.85</td>
<td>103.00</td>
<td>28.54</td>
<td>18.45</td>
<td>35.66</td>
<td>18.30</td>
</tr>
<tr>
<td>Ground floor</td>
<td>0.47</td>
<td>151.15</td>
<td>87.50</td>
<td>52.14</td>
<td>70.27</td>
<td>32.15</td>
</tr>
</tbody>
</table>

4. Analysis of Eight, Twelve and Sixteen Storied Buildings

From the results obtained for four storied building frame, it is observed that the X type of bracing system is the most effective type of bracing system which can reduce the lateral displacements and moments in the structures. Therefore, the X type of bracing system can be used for strengthening of multi storied buildings. For the analysis of eight, twelve and sixteen
storied building frames; X type of bracing system is considered. These buildings are analyzed for earthquake zone IV. The lateral displacement is obtained for these structures, for the seismic load case only. The percentage reduction in lateral displacements is found out for increase in the number of stories. It is observed that the X bracing system reduce the displacements considerably.

4.1 Comparison of results for displacements

Comparing the results obtained for maximum lateral displacement in X and Z direction for G+4, G+8, G+12 and G+16 storied buildings, it can be found that the X type bracing system reduce the lateral displacement considerably. The displacements in X direction for G+4, G+8, G+12 and G+16 storied buildings are presented in Table 5 for the various categories of models for zone IV. The variation of displacements and the percentage reduction in displacement for the braced frame in comparison to that of unbraced frame is presented.

Table 5 Maximum displacements in X direction (mm)

<table>
<thead>
<tr>
<th>No. of stories</th>
<th>Seismic loads</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without bracing</td>
<td>X bracing</td>
</tr>
<tr>
<td>4 stories</td>
<td>70.10</td>
<td>18.01</td>
</tr>
<tr>
<td>8 stories</td>
<td>126.32</td>
<td>33.04</td>
</tr>
<tr>
<td>12 stories</td>
<td>188.44</td>
<td>63.39</td>
</tr>
<tr>
<td>16 stories</td>
<td>279.13</td>
<td>105.72</td>
</tr>
</tbody>
</table>

5. Conclusions

The following conclusions are drawn based on present study.

a) The concept of using steel bracing is one of the advantageous concepts which can be used to strengthen or retrofit the existing structures.

b) Steel bracings can be used as an alternative to the other strengthening or retrofitting techniques available as the total weight on the existing building will not change significantly.

c) Steel bracings reduce flexure and shear demands on beams and columns and transfer the lateral loads through axial load mechanism.

d) The lateral displacements of the building studied are reduced by the use of X type of bracing systems.

e) The building frames with X bracing system will have minimum possible bending moments in comparison to other types of bracing systems.

6. References


