COMPARATIVE STUDY ON SEISMIC PERFORMANCE OF HIGH-RISE BUILDING WITH ENERGY DISSIPATION AND OUTRIGGER BELT TRUSS SYSTEM

Bishal Sapkota
PG Scholar, Department of Civil Engineering
SRM University, Tamilnadu, India

Surumi R.S
Assistant Professor, Department of Civil Engineering
SRM University, Tamilnadu, India

Jeyashree T.M
Assistant Professor, Department of Civil Engineering
SRM University, Tamilnadu, India

ABSTRACT
This research paper is about the investigation on the seismic performance of a high-rise building with outrigger belt truss system and damper as energy dissipation system. Control of the lateral deflection and inter storey drifts is the major challenge to overcome in the execution of high-rise buildings while subjected to lateral loads. Utilization of outrigger and belt truss framework is a possible method to improve the structural behavior of the high rise building under lateral loads. The performances of a 40 storey RC building with different numbers and locations of outrigger belt truss systems and dampers are compared with that of the conventional building. Non-linear time-history analysis was employed using the program SAP2000 to study the behavior of the building under three different seismic waves.

Key Words: Damper, Drift control, Energy dissipation, Outrigger belt truss, Time-history analysis

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1. INTRODUCTION

As the most vital images of today's urban communities, tall structures have turned into a wellspring of confidence in innovation and national pride, and have changed the idea of the cutting edge city alongside its scale and appearance. Because of the improvement of present day auxiliary frameworks and materials, the stature of a kilometer or more can be achieved. So it demonstrates that sky has no restriction for structural engineers. However, height of the building makes it more vulnerable to wind and earthquake induced lateral loads. To meet the serviceability requirements under the lateral loads, various structural systems are utilized and one of them is outrigger belt truss framework.

Outrigger framework has been adopted as a part of the structural system in the world’s tallest building till date the Burj Khalifa (828m) Dubai. A new concept for the structural design of super high-rise buildings with ‘energy dissipation storey system’ has been proposed by Zhou et al. (2012) [1]. The efficiency of the energy dissipation story system in effectively increasing the model additional damping ratios of building was proven and the optimum position of the same was identified as to be the min height of the building. Time history analysis of a 40 storey building model with multi-outrigger structural system for the ground motion data of Bhuj earthquake was carried out by Biradar and Mallikarjun (2015) [2]. The effect of viscoelastic dampers on the overall increase in damping ratio of RCC structures was investigated by Vijay and et al. (2015) [3]. The effectiveness of the Visco-Elastic dampers in reducing the seismic response of RCC building was substantiated in the study. Comparative study on various types of belt truss has been carried out in various seismic zones by Kumari and Manohar (2015) [4]. Comparative analysis of a G+44 RCC structure with and without viscoelastic dampers was carried out by Kazi et al. (2015) [5] and has concluded that the response of structure can be dramatically reduced by using viscoelastic damper without increasing the stiffness of the structure. Deflection control by the effective utilization of belt truss and outrigger system on a 60-storey composite building when subjected to wind loads was figured out by Fawzia and Fatima in 2010 [6]. A three dimensional Finite Element Analysis is performed with one, two and three levels of outrigger truss systems.

Viscoelastic dampers were used as energy-absorbing devices in buildings by Semih et.al. (2003) [7]. The investigation concluded that the viscoelastic dampers were quite linear in their response and were able to dissipate energy under low levels of shaking. They were able to reduce vibrations due to wind traffic and moderate as well as extreme earthquake loading. Eight 40-storey two dimensional models and five 60-storey three dimensional models were analyzed and compared by Kian and Siahaan (2001)[8] to find the lateral displacement reduction related to the outrigger and belt truss system. The study has indicated that the utilization of outrigger and belt truss framework in high-rise building helps to increase the stiffness and makes the structural form efficient under lateral load.

From the literatures, it has been observed that the utilization of outrigger belt truss framework is a productive approach to control the lateral deflection in the structures. The validity and feasibility of the building with dampers as energy-dissipation system in reducing structural vibration responses under wind and earthquake excitations is also approved. In this context, an investigation is carried out to compare the performances of (1) an RC multistoried building with different numbers and locations of outrigger belt truss systems and that of (2) the same RC multistoried building with dampers as energy dissipation systems at two different levels. The performances of the buildings with the two systems are compared with that of the conventional building also to find out the effectiveness of the systems in terms of enhancement of seismic behavior. Thus, the objective of this paper is to study the seismic performance of a building with outrigger belt truss systems and dampers as energy-dissipation systems.
2. DESCRIPTION OF STRUCTURAL MODEL

A 40 storied building model has been considered for this study. Building plan size is 30m×36m. The total height of building is 152m with a typical floor to floor height of 3.8m. Columns are spaced at 9m centre to centre in longitudinal direction and 10m centre to centre in transverse direction. The plan view of the building is represented in Figure. 1. Three different sizes of column are provided throughout the height of building (foundation to 20th storey-1.2m×1.2m, 21st to 30th storey 1m×1m and 31st to 40th-0.8m×0.8m). Size of beam provided is 0.45m×0.85m throughout the building. Core shear wall of thickness 0.3m is provided throughout the height. M40 grade of concrete is used for all shear wall and beams and for column M60 grade of concrete is used.

![Figure 1 Plan view of the building model](image)

2.1. Test Models and Analysis

Frame is modeled as a special moment resisting frame having core shear wall. Beams and columns are modeled as frame elements while shear wall is modeled as shell element. Columns are restrained against rotation and translation at foundation level. The test models includes the (1) conventional building (2) buildings with two different numbers and locations of outrigger belt truss systems and (3) buildings with dampers as energy dissipation systems at two different levels. The designation of the test specimens are as follows:

1. MB0 - Model without outrigger and damper, as represented in Figure 2.
2. MB1 - Model with two outrigger systems. Outrigger belt truss systems are placed at 24th and 40th storey as represented in Figure 3.
3. MB2 - Model with three outrigger systems. Outrigger belt truss systems are placed at 13th, 27th and 40th storey as represented in Figure 4.
4. MB3 - Model with two energy dissipation stories. Energy dissipation systems (Dampers) are placed at 24th and 40th storey, as represented in Figure 5.
5. MB4 - Model with three energy dissipation stories. Energy dissipation system (Dampers) is placed at 13th, 27th and 40th storey, as represented in Figure 6.
Figure 2 View of model MB0 – Conventional Building

For the outrigger and belt truss system, steel truss was used in the structural model for the analysis. Viscoelastic dampers were provided as the energy dissipation device stiffness (k) of 900kN/mm and damping coefficient (c) of 400kN/mm.S^-1.

Figure 3 View of model MB1-Model with two outrigger systems .Figure 4 View of model MB3- Model with two energy dissipation stories
Comparative Study on Seismic Performance of High-Rise Building With Energy Dissipation and Outrigger Belt Truss System

Figure 5 (a) View of MB2 Figure 6 (b) View of MB4 Figure 7(c) Seismic waves

Non-linear time history analyses of three dimensional building models were performed using SAP2000 software program. A series of time history analysis of the building with outrigger systems and with dampers are carried out using three different seismic waves. Time history graph of different seismic waves, viz. Wave1, Wave2 & Wave3 are shown in Figure 7 (a), (b) & (c).

3. RESULTS AND DISCUSSION

The use of both outrigger belt truss system and energy dissipation system has improved the performance of the building under lateral loads. Comparison of the graphs of the lateral displacement of the basic model arrangements (Figure8, Figure9 & Figure10) shows that appreciable reduction in lateral displacement was obtained. The reduction into floor displacement of MB1 while subjected to Wave1 was 2.95% when compared with MB0. Whereas 3.46% reduction was achieved by MB2 with three outrigger systems when compared with MB0. Considering the buildings with energy dissipation system, 8.53% and 10.40% reduction in top floor displacement was observed for MB3 & MB4 respectively when compared with MB0.

Figure 8 (a) Displacement and (b) inter-storey drift of models subjected to Wave1
The reduction in top floor displacement of MB1 while subjected to Wave2 was 12.87% when compared with MB0. Whereas 21.01% reduction was achieved by MB2 with three outrigger systems when compared with MB0. Considering the buildings with energy dissipation system, 35.84% and 50.65% reduction in top floor displacement was observed for MB3 & MB4 respectively when compared with MB0. While energy dissipation system was compared with outrigger system, a maximum of 21.44% reduction in lateral displacement was achieved when the outriggers were replaced by dampers at same storey levels.

![Figure 9](image9.jpg) (a) Displacement and (b) inter-storey drift of models subjected to Wave 2.

The reduction in top floor displacement of MB1 while subjected to Wave3 was 20.13% when compared with MB0. Whereas 47.17% reduction was achieved by MB2 with three outrigger systems when compared with MB0. Considering the buildings with energy dissipation system, 42.92% and 46.43% reduction in top floor displacement was observed for MB3 & MB4 respectively when compared with MB0.

![Figure 10](image10.jpg) (a) Displacement and (b) inter-storey drift of models subjected to Wave 3.
Table 1 Top floor displacement and percentage reduction of basic models with different seismic waves

<table>
<thead>
<tr>
<th>Wave</th>
<th>Displacements</th>
<th>MB0</th>
<th>MB1</th>
<th>MB2</th>
<th>MB3</th>
<th>MB4</th>
</tr>
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<tbody>
<tr>
<td>Wave 1</td>
<td>Displacement(mm)</td>
<td>706.56</td>
<td>685.67</td>
<td>682.83</td>
<td>648.27</td>
<td>639.14</td>
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<td></td>
<td>Reduction (%)</td>
<td>*</td>
<td>2.95</td>
<td>3.46</td>
<td>8.53</td>
<td>10.40</td>
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<tr>
<td>Wave 2</td>
<td>Displacement(mm)</td>
<td>188.513</td>
<td>164.24</td>
<td>154.007</td>
<td>133.31</td>
<td>120.98</td>
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<tr>
<td></td>
<td>Reduction (%)</td>
<td>*</td>
<td>12.87</td>
<td>21.01</td>
<td>35.84</td>
<td>50.65</td>
</tr>
<tr>
<td>Wave 3</td>
<td>Displacement(mm)</td>
<td>348.165</td>
<td>278.08</td>
<td>216.97</td>
<td>255.03</td>
<td>229.75</td>
</tr>
<tr>
<td></td>
<td>Reduction (%)</td>
<td>*</td>
<td>20.13</td>
<td>47.17</td>
<td>42.92</td>
<td>46.43</td>
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</tbody>
</table>

Despite the fact that there is a sudden vacillation and change in the slope of the curve with the introduction of dampers, the inter-storey drift of the building with dampers is a bit less than the building with outrigger belt truss systems. In view of the scopes of values that show up in Table 1, high-rise structure with dampers has shown preferable seismic performance over a similar building with outrigger belt truss system.

4. CONCLUSION

The utilization of outriggers and dampers in tall structures increases the stiffness and makes the auxiliary frame productive under lateral loads. To enhance the execution of the structural perspective, the maximum drift at the top floor end up noticeably the most important components influencing the tenant's solace. Based on the analysis results of the five building models following conclusions were drawn:

- Both structural systems i.e. outrigger belt truss and dampers can increase the performance of the building while subjected to earthquake ground motion by reducing the lateral deflection of the building.
- Seismic performance of the building with dampers as energy dissipation system is superior to the building with outrigger belt truss frameworks.
- The inter-storey drift of the building with dampers as energy dissipation system is more uniform than the building with outrigger belt truss frameworks.

REFERENCES