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A Numerical Study on the Seismic Performance of Built-Up Battened Columns

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Abstract—Built-up columns have been widely employed by practice engineers in the design and construction of buildings and bridges. However, failures have been observed in this type of columns in previous seismic events. This study analyses the performance of built-up columns with different configurations of battens when it is subjected to seismic loads. Four columns with different size of battens were simulated and subjected to three different intensities of axial load along with a lateral cyclic load. Results indicate that the size of battens influences significantly the seismic behavior of columns. Lower shear capacity of battens results in higher ultimate strength and ductility for built-up columns. It is observed that intensity of axial load has a significant effect on the ultimate strength of columns, but it is less influential on the yield strength. For a given drift value, the stress level in the centroid of smaller size battens is significantly more than that of larger size battens signifying damage concentration in battens rather than chords. It is concluded that design of battens for shear demand lower than code specified values only slightly reduces initial stiffness of columns; however, it improves seismic performance of battened columns.

Keywords—Battened column, built-up column, cyclic behavior, seismic design, steel column.

I. Introduction

BUILT-UP columns have been widely used in construction industry worldwide. They are composed of two parallel steel profiles that are connected to each other along their length by lacings or battens. Channels and I-shape sections are the most commonly used steel profiles in built-up columns. Plates, angles, and flat bars are often employed as lacings or battens. The main advantage of built-up columns over other types of framing systems is their lower steel weight and higher moment of inertia. However, compared to solid columns, built-up columns have lower shear stiffness, and their axial resistance is significantly affected by shear deformation and compound buckling (i.e. interaction between global buckling and local buckling of individual chords). Buckling resistance of built-up columns under axial load has been addressed by many researchers, and many analytical equations have been derived for estimating their axial load capacity [1]-[3]. However, only few studies have been carried out on their seismic behavior. Hashemi and Bonab [4], through a series of experimental tests, showed that axial compressive load affected significantly the ductility of laced built-up columns. They also showed that the energy dissipation capacity of tested specimens was not influenced by the distance between chords. They also concluded that the tested built-up laced specimens had a good seismic performance. In another study, Razzaghi et al. [5] examined cyclic performance of concrete-filled built-up battened columns through numerical studies. It was found that the distance between battens at the bottom of examined columns has a great influence on the ultimate load capacity. They concluded that when the applied axial force was distributed between chords and concrete uniformly, the concrete-filling approach was an efficient method for strengthening the built-up columns. Sahoo and Rai [6] showed that when battens are designed for 2-2.5% of axial load, they failed to reach their expected flexural capacity under a constant axial load. By examining five half-scale double-channel battened columns, they indicated that the design of battens should be based on moment-shear interaction of chords. They also found that, when the distance of battens was closer at the plastic hinge location, columns exhibited better cyclic performance.

Despite detailed specifications provided by design codes [7]-[9], built-up battened columns have shown a poor performance when subjected to seismic actions. During past earthquakes, different failure modes have been observed for built-up battened columns among which local buckling of chords has been widely reported. In order to avoid local buckling, design codes often limit the distance between battens based on the slenderness ratio of each individual member. Many codes specify that the slenderness ratio of each member between battens should not exceed three-fourths of the governing slenderness ratio of the built-up column. In addition, the battens are often asked to be designed for a shear force that is equal to 2-2.5% of axial load in the column plus the shear force due to lateral loads.

Herein, a numerical study is performed in order to investigate seismic behavior of built-up columns that their battens have been designed for different ranges of shear capacities. The main intention of this study is to investigate the appropriateness of existing design approach that determines size of battens.

II. Finite Element Study

A series of numerical studies were carried out in order to compare the cyclic performance of the built-up battened

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columns designed for different size of battens. As can be seen from Fig. 1, all studied columns are composed of two channels with a clear distance of 5 cm and are welded to a base plate with the thickness of 2 cm and dimensions of 35x30 cm. The yield and ultimate strength of employed steel was assumed to be 250 MPa and 400 MPa, respectively. All battens are 13 cm in length and 0.8 cm in thickness. The distance between battens is similar in all columns. The considered distance between battens satisfies the requirement of design codes regarding the minimum slenderness ratio. The width of battens was considered as a variable parameter in order to alter their shear and flexural capacities. Three different widths including 10 cm, 5 cm, and 2.5 cm were studied.

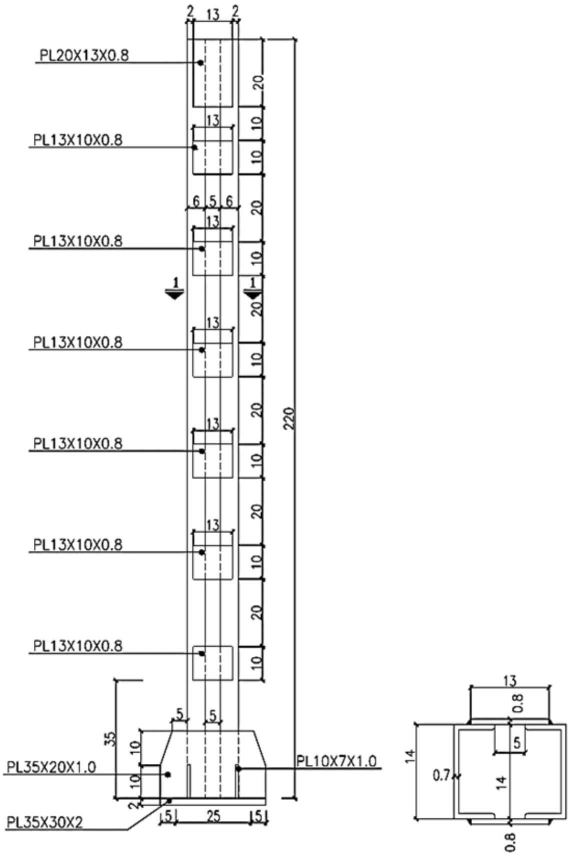


Fig. 1 Details of analyzed built-up battened columns.

Considering the lateral load applied to the columns (see Fig. 2) and the 0.8 cm thickness of battens, the employed widths do not satisfy codes requirement for shear design of battens. Therefore, in order to investigate seismic behavior of a battened column that comply with the shear design requirement of building codes, battens with the thickness of 1.6cm and width of 10cm were also studied. The moment capacity of battens with 0.8 cm thickness and 10 cm, 5 cm, and 2.5 cm widths are 8.5%, 2.1%, and 0.53% of employed columns, respectively. However, compared to moment capacity of a single channel, they are 87%, 21.7%, and 5.5%, respectively. The moment capacity of the batten with the thickness of 1.6 cm is 1.7 times more than that of the single channel in direction of loading. The applied axial load to the columns varied from 10 kN to 20 kN with the increment of 5 kN.

All columns were subjected to the constant axial loads along with a cyclic lateral load that followed the recommended load protocol by FEMA 461 [10]. The finite element models of columns were established in ABAQUS software. Nonlinear behavior of materials together with the effect of large displacements was included in the models.

III. Results and Discussions

Fig. 2 displays the backbone curves derived from cyclic loading of columns for different axial loads and sizes of battens. It can be seen that the larger is the size of battens the higher is the initial stiffness of columns.

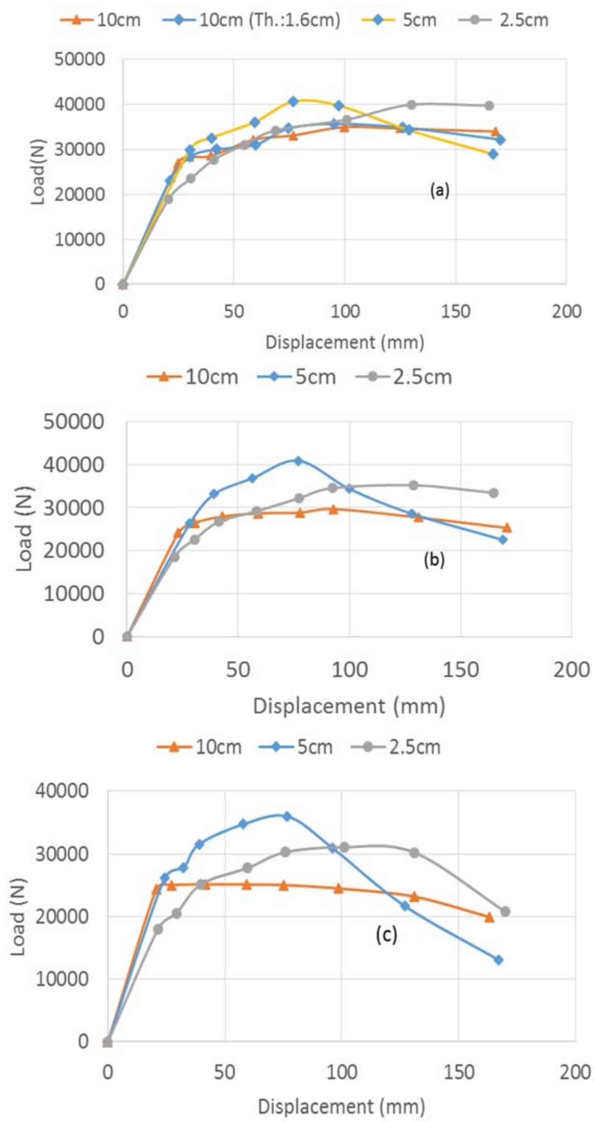


Fig. 2 Backbone curves obtained from cyclic loading; (a) 10 kN axial load (b) 15 kN axial load (c) 20 kN axial load

The initial stiffness of the column having 10 cm width, 1.6 cm thickness battens is 17% more than that of column having battens with thickness of 0.8 cm and width of 2.5 cm. This indicates that initial stiffness of the studied columns has not been significantly influenced by the size of battens.

Fig. 2 (a) shows that increase in the thickness of battens from 0.8 cm to 1.6 cm has negligible change in the initial stiffness. Similarly, such increase in the thickness of battens has slightly altered the yield and ultimate strength of the column. A positive post-yield stiffness can be observed for columns having smaller size of battens (i.e. 5 cm and 2.5 cm widths). This matter is more pronounced when larger axial force is imposed to columns. In general, increase in the axial load has slightly reduced the yield strength of columns. However, it has significantly reduced the ultimate strength of columns. Regardless of imposed axial force, the column having battens with 2.5 cm width shows higher ductility compared to other columns. In addition, regardless of the intensity of axial load, the highest ultimate strength is obtained for the column having battens with 5 cm width. Moreover, the column having the largest size of battens shows the lowest ultimate strength compared to other columns.

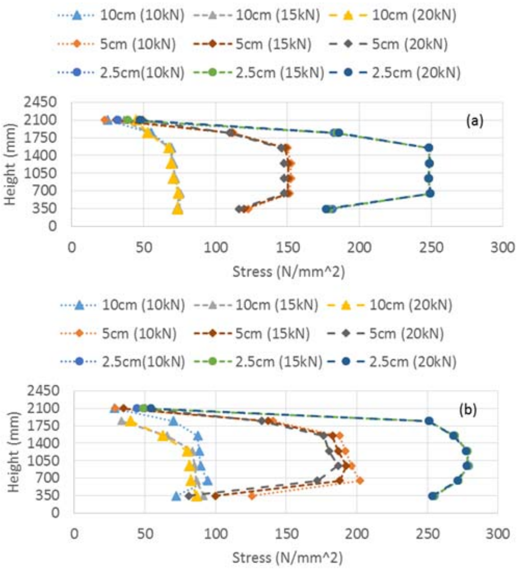
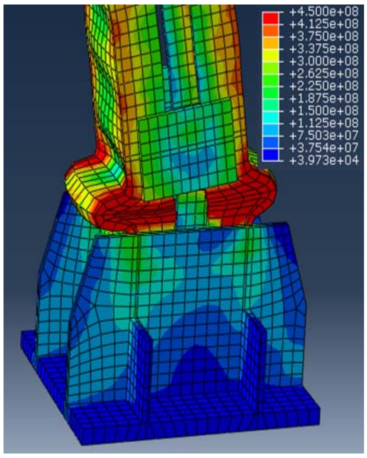
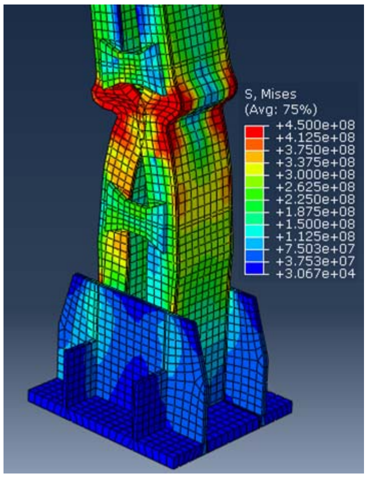


Fig. 3 Von Mises stress at the centroid of battens; (a) 1% drift (b) 2% drift

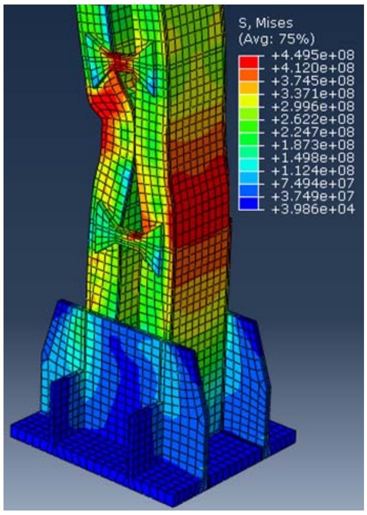
Fig. 3 displays the von Mises stress at the centroid of battens along the height of columns for 1% and 2% drifts. It can be seen that the larger is the size of battens, the smaller is the stress level of battens. Fig. 3 also shows that increase in the axial force has negligible effect on the stress level of battens in all columns. It can be also seen that stress level in battens is not uniformly distributed along the height of columns. In general, battens located closer to the middle of columns have higher level of von Mises stress compared to those located at the bottom or top of columns. Fig. 3 (b) shows that, as the drift increase from 1% to 2%, stress level in battens with smaller size (i.e. 2.5 cm and 5 cm) increases significantly. However, only a small increase in the stress level of 10 cm width battens is observed. This indicates that, smaller size battens have undergone more deformation compared to larger size battens. Therefore, as it was seen in Fig. 1, they have been able to dissipate more energy.



(a)



(b)



(c)

Fig. 4 Failure mode of columns under 15 kN of axial load; (a) 10 cm width (b) 5 cm width (c) 2.5 cm width

Fig. 4 shows the failure mode of columns with different size of battens under axial load of 15 kN. It is evident that size of battens has significantly influenced the failure mode of columns. Damage in the column with 10 cm width battens occurs at base of column where chords connect to the stiffener of the base plat. However, for 2.5 cm and 5 cm width battens, damage concentrates above the first batten located at the bottom of columns. It can be seen that von Mises stresses for 2.5 cm width battens have reached to the ultimate strength of employed steel before local buckling is occurred. These observations indicate that design of battens for a lower shear demand compared to code specified values results in better seismic performance.

IV. Conclusion

Built-up battened columns have been widely used in the construction industry. However, their seismic behavior has not been well researched. Experience from past earthquakes has demonstrated a poor performance for built-up battened columns. In this study, seismic performance of built-up battened columns with different size of battens was investigated. Four built-up battened columns were simulated and were subjected to three different intensities of axial forces along with a cyclic loading. The column having the largest size of battens showed the lowest ultimate strength compared to other columns. The larger was the size of battens the smaller was the stress level in battens. Increase in the axial force had negligible effect on the stress level of battens for all columns. As the drift increased from 1% to 2%, stress level in battens with smaller size (i.e. 2.5 cm and 5 cm) increased significantly. However, only a small increase in the stress level of largest batten was observed. Size of battens influenced significantly the failure mode of columns.

It was concluded that, when battens were designed for lower shear demand compared to requirements of building codes, a better performance in terms of ductility and ultimate strength was observed. Findings of this study showed that more researches need to be conducted in order to develop seismic design specifications for built-up battened columns.

Acknowledgment

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