Numerical study on Built-up Steel Columns Behavior

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Abstract. This study investigates the behavior of Built-up steel columns. The effect of shape, distribution, and angle of inclination of the lacing have been studied. Finite element simulations are performed with ANSYS. A brick element with eight nodes and a shell element with eight nodes were adopted. After completing the study of the convergence between the laboratory analysis and the numerical analysis, the parametric study can begin by changing the dimensions of the lacing and the method of distributing the lacing in the structure of the manufactured steel column to make a comparison between the numerical analysis and the Experimental analysis for modeled models and determine the positive and negative points for each type of lacing used.

Keywords: Experimental analysis, Lacing, built-up columns, Numerical analysis, ANSYS 2020 R1 program, Euler buckling, slenderness ratio.

1. Introduction:

Built-up columns are often used in steel buildings and bridges to provide economical solutions in cases of large spans and heavy loads. Depending on the way that the flanges are connected to each other, they can be grouped into laced and battened built-up columns. Laced columns are investigated in the present work, where the flanges are connected by diagonal bars, thus establishing truss-like action, the built-up steel column is a steel structure consisting of two or more parallel main sections, and most of these main sections are connected with each other by steel ties from the corner sections or plates in a horizontal or inclined angle and are fixed tightly to the sides of the main sections. These fastenings provide support for columns built to resist shear and to ensure the column behaves as an integrated unit capable of achieving maximum compression capacity. The strut system helps reduce the effective lengths of the main sections, thus increasing the bending capacity and torsion resistance of the column.

Bonab and Hashemi (2012) investigated both numerically and experimentally the cyclic behavior of fabricated columns with lacing under lateral concentrated load and different level of axial load. One of their conclusions was that a high level of axial load leads to poor ductility and that fabricated columns with lacing are acceptable for use in exposed areas. In addition, they examined the elastic critical torsion and compressive capacity of columns of centrally loaded laced, and the study was conducted by Pours mad Bonab et al. (2012), focusing on the lattice-shaped behavior of the built-up column due to cyclic load. The
study evaluated the effects of geometric deformations. of the column and the different levels of axial loads on the periodic behavior of the laced columns. From this study the type of load was determined which is an axial load. In the study by Behrokh Hosseini et al. (2013), the behavior of the built-up steel column under the static axial load and the periodic lateral load of eight component columns was examined from two IPE100 as main sections with laced in the experiment, to evaluate the effects of the axial load, different loads were applied to the samples. The use of two different lengths of laced was also used to show the contrast in the effect’s column. The test results showed that the axial load significantly affected the ductility, strength and rigidity of the columns. The difference in distances between the major strings had little effects on strength but had a large change in ductility. Thus, it can be concluded that the distance between the main sections needs to be repaired because it affects the capacity and strength of the built-up steel column, based on the study by Vaidotas Sapalas et al. (2013), the modeling of built-up steel column using FEM Ansys is limited to the assumptions of the Lithuanian national law STR and Eurocode 3. The study also states that FEM modeling of built-up steel column with applied end conditions is safe enough in accordance with STR and EC3. Built-up column models are examined and tested to meet EC3 requirements, based on the experimental investigation by Behrokh Hosseini (2013), when a built-up steel column is subjected to a side load in an earthquake, it may not behave in an acceptable manner. In its investigation, to assess seismic behavior, eight samples of ligature columns were tested. These shafts were subjected to a constant axial load while a gradually increasing lateral cyclic load was applied. The experimental results showed that many of the seismic properties of the tethered column decreased with increasing the axial load. Comparison of the results showed that there is a good correlation in the load displacement, failure patterns and elastic behavior between the experimental and analytical procedure in general gives a conservative prediction of the elasticity of the built-up steel columns, according to Mahmood Hosseini et al (2013), the composite bending is also a factor affecting the critical elastic loads of the columns. This effect was studied by Duan (2002). And others are in built-up steel columns, due to the lower values of thinness in the main sections between the strapping panels compared to the overall thinness of the built-up steel columns, a composite buckling cannot occur. With regard to the complications involved in calculating the flexible micro-load of built-up steel columns by analytical methods, all proposed theoretical methods contain simple assumptions, so, it is necessary to evaluate the accuracy of the different methods of experimental studies according to Konstantininos et al. (2014). The types of steel sections used play a major role in the capacity of the column. In pilot tests, two types of clips were used, IPE80 and UNP60. IPE80 had more cross-sectional area compared to UNP60. From experience, the obtained breakdown load for IPE80 was 309Kn while breakdown loads were for UNP60 197.8 Kn. Hence, this proved that the cross-sectional area had the greatest influence on the capacity of the built-up steel columns from his study of the constructed column, the properties of the main section of the column were determined for the study of finite element modeling. The choice of stem sections (C) in the main column section provides various advantages. Sections (I) are more structurally efficient and therefore less deep than (C) segment. For built-up steel columns with large axial force of compression, (I) or (H) sections will be more suitable. The length of the ties also affects the width of the column. This demonstrates that the fastening system is one of the factors affecting the ability of the built-up steel columns to withstand external stresses. The points of the current investigation are to reproduce the conduct of built-up steel column using Finite element, the efficiency of the models has been compared with the experimental work. A parametric study in terms of lacing configuration were investigated.
2. **Experimental samples**

Three samples simply-supported eccentrically loaded columns as shown in Fig. (1) from one of the previous studies carried out by Konstantinos E. Kalochairetis were selected to perform a comparison of the numerical analyzes that we will carry out using the ANSYS 2020 R1 program to complete the study of the convergence between experimental results and numerical analyzes.

The length of the experimental columns was \(L= 2020, \: L_e= 2345\) mm and the width was \(h0=200\) mm. Opposite UNP60 sections were used in the first and second models, and the IPE80 clips were used in the third model. The laced sections used in all models were angle cross-section \(L25 \times 25 \times 3\) linked. By welding well on the edges of the main sections, it is inclined at an angle of 60 degrees from the perpendicular to the column with respect to the first and third models and is tilted at an angle of 45 degrees with respect to the second model, as shown in Table (1).

| sample | Panel's (a) length (mm) | Flanges' cross-section | Yield stress (MPa) | \(e\) top mm | \(e\) bot mm | E MPa |
|--------|-------------------------|------------------------|-------------------|--------------|-------------|-------|
| 1      | 400                     | UNP60                  | 338               | 10           | 10          | 210000 |
| 2      | 400                     | UNP60                  | 338               | 10           | 10          | 210000 |
| 3      | 200                     | IPE80                  | 395               | 10           | 10          | 210000 |

![Table (1). Characteristics of the three specimens](image)

**Fig (1)** Three samples simply-supported eccentrically loaded columns

3. **Modeling using ANSYS software and results**

To conduct a study of the convergence between the experimental analysis results and the numerical analysis results using ANSYS program, we will represent the experimental models according to the groups
mentioned in Table 1 by simulating the experimental model using the Workbench program and then converting the model to APDL program to lead the mathematical examination utilizing the finite element technique. Which requires determining the type of element, such as if the solid brick element 185 or the shell element 181, after determining the type of element, the mesh density is chosen to convert the model into small elements interconnected by nodes, and after completing this stage of model programming the model is ready to apply the loads to it. After determining the supports according to the conditions that the experimental model was exposed to, and by determining the type of analysis the program analyzes the numerical model and gives the necessary results for the purpose of comparing them with the results of the experimental analysis.

The following are the results of the numerical analysis by ANSYS program for the three experimental models shown in Table (1):

3.1. The first model

Fig (2a) shows the model numerically representing the model using ANSYS program, which determines the deformation locations in the column and the amount of horizontal displacement caused by the loads being subjected to the same loading conditions for the experimental model shown in Fig (2b) noting that the model was analyzed numerically using two types of elements and was compared the results of the two analyzes with the results of the experimental analysis shown in Fig (2c).
3.2. The second model Figure (3a) shows the model is numerically representing the model using ANSYS program, which determines the deformation locations in the column and the amount of horizontal displacement caused by the loads being subjected to the same loading conditions of the experimental model shown in Figure (3b) noting that the model was analyzed numerically using two types of elements and a comparison was made. The results of the two analyzes with the results of the experimental analysis shown in Figure (3c)
Fig (3c)

fig (3) Comparison between experimental analysis and numerical analysis for sample (2)

3.3. The third model Figure (4a) shows the model numerically is representing the model using ANSYS program, which determines the deformation locations in the column and the amount of horizontal displacement caused by the loads being subjected to the same loading conditions of the experimental model shown in Figure (4b) noting that the model was analyzed numerically using two types of elements and had made comparison was made. The results of the two analyzes with the results of the experimental analysis shown in Figure (4c)
We conclude from the results that appeared to us through the ANSYS program and shown in the previous figures (c2, c3 and c4) when using two types of elements (solid element 185) and (shell element 181) there is a variation in the ability of the built-up steel column to withstand the loads as well as the ductility of the column. We attribute the reason for this to the number of elements generated by the program for each element when fixing the side edge length of element when creating the element grid, as the program generated approximately 3800 epochs when using the shell element 181 and generated approximately 8,700 elements when using a solid element 185 when choosing the edge length of the element’s. The one is 20 mm for both types of elements, and this indicates that the number of elements used in the numerical analysis has a direct effect on the accuracy of the results compared to the results of the experimental analysis and this indicates an increase in the number of elements increases the convergence of the results of the numerical analysis with the experimental analysis.

After completing the study of the approach between experimental analyzes and numerical analyzes using the ANSYS program, and the results of the program proved to be close to the experimental results, now it is possible to complete the parametric numerical study regarding the effect of the ligaments in terms of their angle and shape of their distribution.

4. Parametric study

The aim of the parametric study was to obtain the highest resistance of the built-up steel columns and the lowest cost. Therefore, this study focused on designing the lacing used in the manufacture of the steel column to identify the best resistance and lowest cost of the built-up steel columns. These design effects of the ligatures can be summarized as follows as each effect will be studied separately:

(A) Lacing thickness.
(B) Lacing geometry.
(C) The angle of inclination of the lacing.
4.1 Lacing thickness

To make a comparison of the slenderness ratio of the lacing used in the built-up steel column, several models of the columns were built-up using steel lacing plates of variable thicknesses (6, 8, 10, 12, 17, 23 mm) were tested, and these models were tested and compared with the experimental model that was used in the straps made of the steel angle measuring (25 × 25 × 3) mm and the results are shown in Table (2).

The following figures show the relationship of the slenderness ratio with each of the maximum central vertical load for built-up steel columns and the relationship of the maximum non-central vertical load of the built-up steel columns as well as the relationship of the stress generated on the lacing in both cases of the load shown in the fig (5), (6), (7), and (8).

Table (2) Comparison of the slenderness factor of the straps used in the built-up steel column

| Axial and bending load kN | von mises stress MPa | axial load kN | von mises stress MPa | L/r     | r     | t     |
|--------------------------|---------------------|--------------|---------------------|---------|-------|-------|
| 218.8                    | 251.6               | 438.98       | 58.53               | 230.94  | 1.732 | 6     |
| 220.3                    | 249.7               | 452.23       | 45.223              | 173.16  | 2.31  | 8     |
| 221.54                   | 230.8               | 477.65       | 38.212              | 138.55  | 2.887 | 10    |
| 221.7                    | 228.8               | 511.15       | 37.17               | 125.95  | 3.176 | 11    |
| 222.32                   | 221.7               | 525.95       | 35.016              | 115.46  | 3.464 | 12    |
| 224.05                   | 170.96              | 535.25       | 25.188              | 81.466  | 4.91  | 17    |
| 226.07                   | 149.97              | 533.45       | 18.55               | 60.24   | 6.64  | 23    |

fig (5) The relationship of the slenderness ratio with the maximum central vertical load of the built-up steel column

fig (6) The relationship of the slenderness ratio with the stress generated on the lacing
The relationship of the slenderness ratio with the relationship of the maximum eccentric vertical load of the built-up steel column

We note that the slenderness ratio of the laced has an effect on the resistance of the built-up steel column to the loads, and through the results obtained by used the numerical analysis of the seven models, we note that the best percentage of the slenderness ratio should not exceed 130 to obtain the best resistance of the built-up steel column.

4.2 Lacing geometry and the angle of inclination of the lacing

A comparison can now be made for numerical analyzes of the two groups (the angle of inclination of the lacing 45 degrees and 60 degrees) and according to the same load and support conditions to show the difference in the bearing capacity of the built-up steel columns to determine the effectiveness of the angle of inclination of the lacing of the steel column. The following is a comparison of the maximum horizontal displacement towards the X axis with maximum load resistance according to the samples six models shown in Fig (9):

Fig (7) The relationship of the slenderness ratio with the relationship of the maximum eccentric vertical load of the built-up steel column

Fig (8) The relationship of the slenderness ratio with stress generated on the lacing

Fig (9) Different models of built-up steel columns differently according to the distribution of the lacing and their angle of inclination
Simply supported column (pin-pin): support from the top in the two axes (x, z) so that it is free to move down towards the (y) axis and support from the bottom in all three axes (x, z, y) and the force is applied to the column from the top in the center of the column. Figure (10) shows the deformation states and the amount of horizontal displacement in the direction of the X axis and its relationship to the size of the maximum load resistance of the column and according to the shapes of the columns.

Fig (10) The shape of the models shows the deformation and the horizontal displacements that occur due to the central vertical loads on the column.
Figure (11) shows a comparison between the six models in terms of the maximum resistance of the column to the loads and the amount of horizontal displacement caused by the load, and shows the effect of the shape and distribution of the lacing, as Figures (12), (a,b and c) show the effect of the angle of inclination of the lacing on column resistance to loads.

**Figure (11)** The effect of the shape and distribution of the lacing

**Figure (12a)**

**Figure (12b)**
We note from previous results the following:

1. Model No. (1) and (4) give a high load resistance compared to other models by 22% due to the density of the bonds used to connect the main sections, so it is preferable to use it in buildings that need to withstand high loads, as shown in fig. (12a).

2. Model No. (2) and (5) give more ductility than the rest of the models to increase the amount of horizontal displacement of the deformation during loading, and therefore because the distribution of the ligaments is in two directions instead of one, as shown in fig. (12b).

3. Model No. (3) and (6) give the least resistance than the rest of the models as they do not contain horizontal laced as shown fig. (12c).

5. Buckling Load of the Pin-ended Column

Numerical analysis of the experimental model was performed to determine the critical buckling load of a steel built-up column using the finite element method by numerical simulation in ANSYS software as shown as in figures (13a). The program showed the results as shown in figure (13b) that were compared with the results of the AISC design equations for American specifications (Euler load), as shown in table (3).

Fig (12c) The effect of the angle of inclination of the lacing

Fig (13a) numerical simulation in ANSYS software
Where:

$P_{SU}$ = The Maximum value of the load according to the American equations of specifications AISC

$P_{AU}$ = The Maximum value of the load as per numerical analysis using the items determined by ANSYS software

$P_{EB}$ = The Maximum value of Euler Buckling load according to the American equations of specifications AISC

$P_{AB}$ = The Maximum value of Euler Buckling as per numerical analysis using items determined by ANSYS software

We note from the previous results of the buckling load that the first model has a buckling load greater than the fourth model, and therefore due to the effect of the length of the space between the horizontal lacing, since the first model consists of five spaces, the angle of inclination of the laced is 60 degrees with constant width of the column. Ten spaces as the angle of inclination of the laced is 45 degrees for the same width of the column. This means that the greater the angle of inclination of the laced leads to an increase in the resistance of the shaft to the buckling load

6. Conclusions

1. All numerical analyzes were performed using the finite element method by ANSYS software.

2. The type of elements used in the analysis approved (solid element 185).

3. Approval of the length side of one element is 20 mm.

4. The number of elements used in the finite element analysis ranges from 8,500 to 11,000 elements per model.
5. Reducing the tilting angle of the laced increases the load resistance of the built-up steel column due to the increase in the cross-sectional area of the shaft, which is represented in Model No. (4).

6. Increasing the angle of inclination of the laced increases the resistance of the column to the buckling load due to the increase in the distance between the horizontal laced represented in Model No. (1).

7. The increase in the slenderness ratio of the tie used in the built-up steel column increases the failure load resistance of the built-up steel column due to the increase in the cross-sectional area of the column and the slenderness ratio of the tie used in the model is 130.

8. The percentage of increase in the resistance of the column to the axial load, a comparison between the numerical analysis and the design analysis, ranges from (11-33) %

9. The percentage of increase in the resistance of the column to the buckling load, a comparison between the numerical analysis and the design analysis, ranges from (7-19) %

7. References

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