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Numerical Study of Cold-Formed Steel Built-Up Battened Columns Under Axial Compression

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Abstract : The Cold-formed steel members such as Beams and columns are recently used in nowadays in large scale in order to achieve light weight, cost economical, durable & speedy construction process. This section has the property of Post-buckling behavior which can't be there in Hot rolled steel section. However, there is no specific method of design for predicting the Cold-formed steel sections behavior under axial compression. This paper presents the numerical investigation results of the pin ended cold-formed steel built-up battened lipped channel columns under axial compression. The finite element model was developed using the finite element software ABAQUS 6.10. Comparison of finite element analysis results with the test results available in the literature shows that the analysis model can simulate the buckling behaviour and ultimate capacity of cold-formed steel built-up columns. Two types of sections were selected based on the limitations provided in AISI -2007 for prequalified sections for single lipped channel. Spacing between the chords was chosen such that moment of inertia about major axis equals the moment of inertia about minor axis. The parametric study has been carried out by varying the slenderness ratio and number of battens. The ultimate loads were obtained from FEA. At the end design condition is recommended by FEA to evaluate ultimate strength of the lipped channel built-up battened columns.

Keywords : Cold-formed Steel, Battened column, Built-up column, lipped channel, Direct Strength Method, etc.

1.0 Introduction

The use of cold-formed steel members has increased in recent years, especially in light-weight steel construction, such as steel-framed housing, low-rise office buildings, factories, and warehouses due to its high strength to weight ratio. Cold formed steel built-up sections are commonly used as compression members to carry heavier loads and over longer spans when a single individual section is insufficient. The singly symmetric sections are having relatively small torsional rigidity that is weak in twisting compared to doubly symmetric sections[1,6]. In this study, the cold-formed steel built-up closed sections with web stiffeners are investigated, as shown in Fig. 3. The direct strength method is based on open sections, such as the simple lipped channel, lipped channel with web stiffeners, Z-section, hat section, and rack upright section. a need to investigate the appropriateness of the direct strength method on the type of cold-formed steel built-up battened sections.

The purpose of this paper is to study the behaviour and strength of the cold-formed steel built-up battened columns by Numerical and theoretical analysis. A non-linear finite element model was developed for cold formed steel built up columns. The models account for steel plasticity, geometric non-linearities, and geometrical imperfections. The models were verified using experimental results in the literature [10-15,] and used in a parametric study. In the parametric study the slenderness ratio was varied from 30 to 120 for the selected three sections. The strength obtained from the numerical analysis were compared with the design strengths obtained using the direct strength method in the North American Specification(NAS 2007) and Australian/New Zealand Standard (AS/NZS 2005) for cold-formed steel structures. In the calculation of the direct strength method, local buckling stress and distortional buckling stress are required. In this study, two different methods were used to obtain these stresses. The appropriateness of the direct strength method on the cold-formed steel built-up battened columns was investigated. A design recommendation is proposed for DSM to evaluate ultimate strength of the lipped channel built-up battened columns. Furthermore, the advantages and limitations of the proposed design rules are also discussed.

2.0 Literature Review

The research performed on hot-rolled built-up members is the foundation of cold-formed steel built-up member re-searches. Previous researches made by Rondal and Niazzi[7,8] based on the formulas given by Johnston[1] for spaced hot rolled columns in which the battens are attached to the chords by hinged connections, are the only dedicated recommendations to calculate the resistance of such cold-formed built-up members. Aslani and Goel[3] verified the modified slenderness ratio analytically and experimentally for hot-rolled members, thereby verifying the AISC built-up member design method. Temple and Elmahdy[4] , carried out an experimental and theoretical study to investigate the behaviour of battened columns made of standard channel hot rolled steel sections. A combination of an equivalent slenderness ratio and limitations to the slenderness ratio of the main members between batten plates (interconnectors) are provided.

2.1 Finite Element Modelling

Finite element software package ABAQUS version 6.10 was used for the numerical study. Prior to analyzing the post-buckling behaviour of the structure, a linear buckling analysis is performed on the specimens to obtain its buckling load and mode shape[9]. Following this nonlinear post-buckling analysis is carried out to obtain the load versus end-shortening characteristics and to predict the ultimate load capacity. Thin shell element with four nodes and six degrees of freedom at each node, S4R5 shell element, were used to model the battened columns. Convergence studies have been carried out on the column in order to determine a suitable finite element mesh for the analysis. The element aspect ratio (length to width) nearly equal to 1.0 for the flange and web elements was used. The size of the element was 10 x 10 mm^2. The end conditions of column elastic lines are treated as pinned condition. The loaded end was prevented from both rotation about z-axis and translations in both x and y directions. But the unloaded end was prevented from translation in three directions x, y and z directions and from rotations about z -axis. These boundary conditions were applied to the independent node of the rigid fixed MPC (Multi Point Constraint) located at the geometric centroid of the section at upper and lower end of the model. Dependent nodes are connected to the independent node using rigid beams and all six structural degrees of freedoms are rigidly attached to each other. This MPC acted as a rigid surface that was rigidly connected to the upper and lower end of the columns as shown in Fig.1.

The specimens were loaded axially through the CG of the specimens. The connection between the battens and sections were modeled by using mesh independent fastener option available in ABAQUS. The displacement control load was applied in increments to the master node using the modified RIKS method. The model includes the geometric and material non linearity. Young's modulus of elasticity, E and the yield stress, f_y, of the steel material were considered as $2 X 10^5$Mpa and 250Mpa respectively. Elastic perfect plastic stress-strain curve obeying vonmises yield criterion was adopted for material modeling in the parametric study. From the detailed considerations from the literature, the local and distortional imperfection was taken equal to the 0.006*w*t and 1.0t respectively as recommended by Schafer and Pekoz[5], in addition the global imperfection magnitude was taken as 1/1000 of the full length of the column at the mid -height section for lipped channels were used in the parametric study models to initiate the nonlinear analyses.

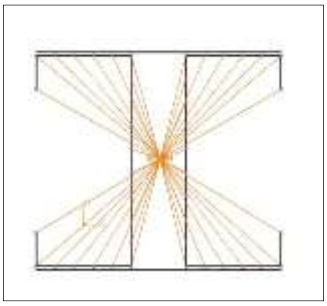

Fig. 1.Parametric model-Rigid Region

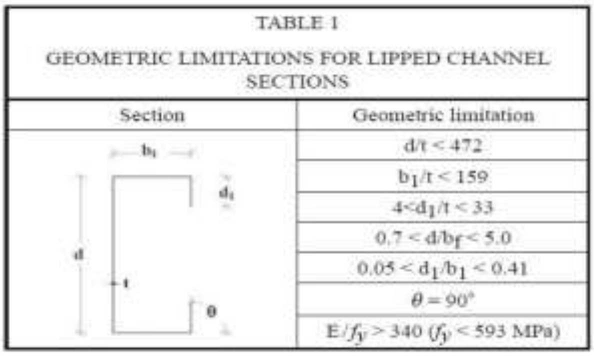

TABLE 1

GEOMETRIC LIMITATIONS FOR LIPPED CHANNEL SECTIONS

Section	Geometric limitation
	$d/t < 472$
	$b_1/t < 159$
	$4 < d_1/t < 33$
	$0.7 < d/b_f < 5.0$
	$0.05 < d_1/b_1 < 0.41$
	$\theta = 90°$
	$E/f_y > 340$ ($f_y < 593$ MPa)

Table1-Geometric Limitations of Lipped Channel Sections

2.2 Section Design

The battened columns were made from cold-formed steel lipped channel sections. The lipped channel built-up battened column cross-section dimensions were suitably chosen. The cross-sectional dimension satisfies the limitations given for pre-qualified sections of columns in Direct Strength method (Table1). The geometric properties for the three selected specimens are presented in Table 2.Spacing between the chords was chosen such that moment of inertia about major axis equals the moment of inertia about minor axis. To ensure that the built-up member acts as a unit, AISC E6.2 requires that individual components of built-up compression member connector spacing be such that the effective slenderness ratio of each component does not exceed three-fourths of the slenderness ratio of the built-up member. In this study, spacing between the battens was chosen to satisfy this requirement

Table 2 Section properties and Geometry

SI No	1	2
Column designation	BC 1	BC2
Thickness-t (mm)	2	1.6
Web-d (mm)	50	60
Flange-bi (mm)	90	150
Lip-d1 (mm)	15	15
Spacing-s (mm)	26	74.7
Batten Width(mm)	62.12	110.5

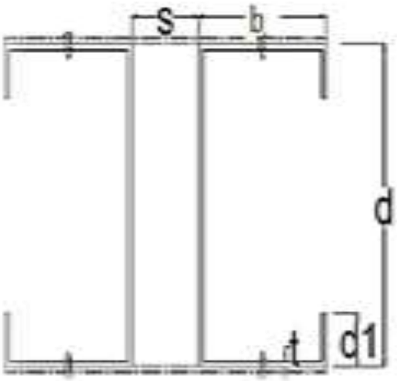

Fig.2. Specimen Details

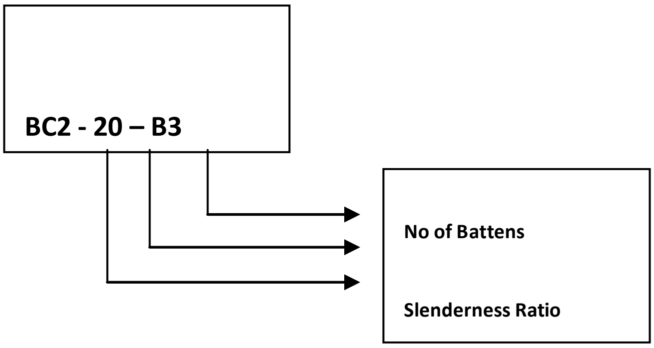

Fig.3. Labeling of specimen

Figure 2 shows the detail drawing of a typical specimen. The specimens were labeled to identify their variable parameters. The connection between the battens and sections is made by using self-drilling screw

2.3 Parametric Study

In the parametric study, numerical analysis was carried out for 2 cross-sections as mentioned in Table 2. For each cross-section different member lengths are chosen to obtain a wide range of member slenderness ratios, varying from 20 to 120. Totally 22 number of analysis were carried out by both the methods. The ultimate strength obtained by finite element analysis is compared with the direct strength method as shown in Table 3.

Table.3.

Specimen ID	**FEM (kN)**	**Failure Mode**
BC 1-20-B3	184.854	L+D+F
BC 1-30-B4	197.325	L+D+F
BC 1-40-B4	176.753	L+D+F
BC 1-50-B5	183.751	L+D+F
BC 1-60-B5	178.102	L+D+F
BC 1-70-B6	165.226	D+F
BC 1-80-B7	154.552	D+F
BC 1-90-B7	142.56	D+F
BC 1-100-B8	134.689	D+F
BC 1-110-B8	133.055	D+F
BC 1-120-B9	99.692	D+F
BC 2-20-B3	159.071	L+D+F
BC 2-30-B4	156.726	L+D+F
BC 2-40-B4	155.637	L+D+F
BC 2-50-B5	153.614	L+D+F
BC 2-60-B5	152.592	L+D+F
BC 2-70-B6	153.712	D+F
BC 2-80-B7	149.116	D+F
BC 2-90-B7	151.445	D+F
BC 2-100-B8	143.821	D+F
BC 2-110-B8	143.451	D+F
BC 2-120-B9	143.851	D+F

As a sample, the deformed shape at failure load from finite element method is shown in Figure4. Figure5 shows the load versus axial shortening curves for BC1 series column

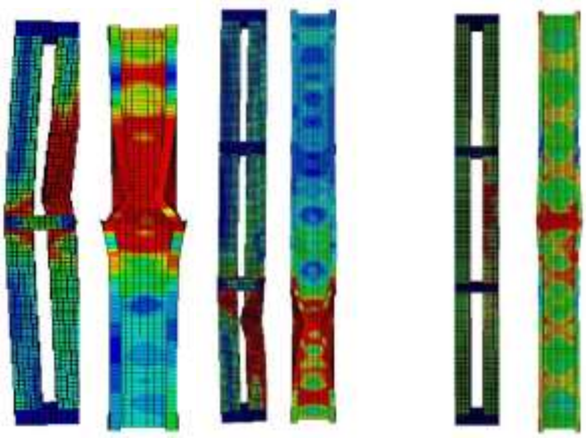

Fig. 4.Deformed shapes at failure loads from FEM ((a) For BC1-20-B3, b) For BC2-20-B3,c) For BC2-30-B3)

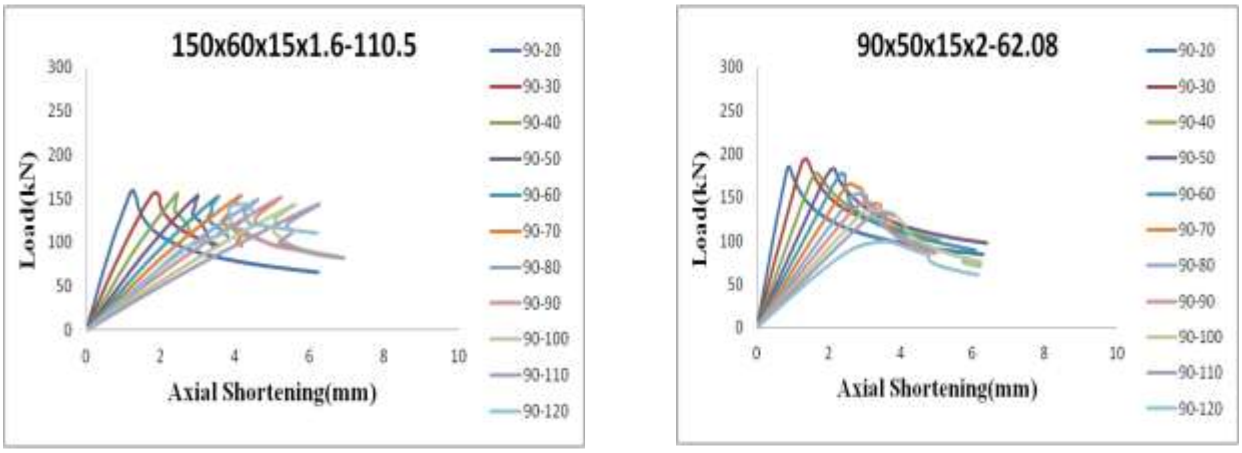

Fig.5. Load versus Axial Shortening

(For section I &Section II)

3.0 Discussion

From the comparison of results it is found that, evaluating the resistance of a built-up battened column member as the sum of resistance of individual chords is not representative of the actual structural response of these members. The conservatively predicts the ultimate capacity of the built-up battened column. The conservatism increases with increasing the member slenderness ratio. For the slenderness ratio less than 70 all the specimens failed by combined local (L), distortional (D) and flexural (F) mode. For slenderness ratio greater than 70, the specimens failed by combined distortional (D) and flexural (F) mode. But the predominant mode is distortional buckling also governs the strength. From the results obtained the following comparisons have be made for BC-1, and BC-2 type columns. The DSM approach unconservative predicts the strength of the built-up battened columns. The unconservatism increases with increasing the member slenderness ratio. From the fig.5 (a) to 5(c) it is found that, the FEM and DSM-2 curve follows same trend. For slenderness ratio greater than 70, the rate of unconservatism is more. From the graphs it is shown that DSM-1underestimates the design strengthwhereDSM-2 overestimates the design strength. From the graph it is observed that the curve follows similar trend. So their behavior will be similar irrespective of the cross section.

4.0 Conclusions

A total of 22 axially loaded built up battened columns were numerically and theoretically studied in this paper. The following conclusions on the axial compressive strength of the built-up battened columns are drawn within the limit of the present investigation.

- The developed finite element models are in reasonable agreement with the test results available in literature, there-fore, ABAQUS program can be used to simulate battened columns.
- Use of the modified slenderness ratio in DSM approach unconservatively predicts the strength of the built-up columns.
- Based on the parametric results, a simple design expression can be proposed to predict the ultimate strength with further study with experiments to validate.
- The ultimate strength of the member decreases with increase of overall slenderness ratio irrespective of section geometry.
- For slenderness ratio between 70 and 120, the predominant failure mode is distortional buckling.

Further study is needed for the recalibration of DSM equations. The authors have planned to conduct experiments in near future to predict the ultimate strength of built-up battened columns. Furthermore, other parameters that effect the ultimate strength of built-up batten columns will be undertaken in future.

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