



## Full length article

## Behaviour of laced built-up cold-formed steel columns: Experimental investigation and numerical validation



M. Adil Dar, Dipti Ranjan Sahoo\*, Sunil Pulikkal, Arvind K. Jain

Department of Civil Engineering, Indian Institute of Technology Delhi, New Delhi 110016, India

## ARTICLE INFO

## Keywords:

Built-up column  
Cold-formed steel  
Experiment  
Laced configuration  
Numerical modelling

## ABSTRACT

This study is focussed on the performance evaluation of built-up cold-formed steel (CFS) columns under monotonically increasing axial compression loading. Five test specimens of built-up columns were fabricated using four CFS angle sections connected by single lacing systems. Width-to-thickness ratios and slenderness ratios of chord and lacing elements, and height of columns were varied in the test specimens. Column strengths, axial load vs. displacement response, mode of failure, and deformed configurations were the main parameters evaluated in the experimental investigation. In addition, a numerical study was conducted to predict the behaviour of laced built-up CFS columns using a finite element software ABAQUS. The developed numerical models were validated using the test results. Test results were used to develop the column strength curves for built-up laced CFS columns. Finally, the results of this study were compared with the design strength predictions by North American Standards and European Standards for CFS sections.

## 1. Introduction

The utilization of cold-formed steel (CFS) in the construction industry is rising due to its favourable features, such as, higher strength-to-weight ratio, faster production, ease in fabrication and construction, light-weight, ease in transportation and handling, and optimum design. Buckling instability of these thin-walled members can be delayed/eliminated by suitable modifications in design and detailing, thus significantly improving their strength and stiffness characteristics [1,2]. In the recent years, there have been major developments in the design of CFS members for their suitability in civil engineering applications [3–6]. Despite numerous advantages, the primary compression members in CFS structures are still constructed using hot-rolled steel. The main reason for such a choice is due to the inherent higher resistance of hot-rolled steel sections against the premature buckling. Even in the hot-rolled steel constructions, built-up sections are adopted as compression members when the individual sections do not suffice the strength and stiffness requirements. Further, built-up sections lead to more efficient use of steel [7–10].

Many researchers have carried out extensive studies to investigate the behaviour of CFS columns. Load eccentricity about the weak axis of stocky members has substantial effect on their column strengths [11]. For very slender CFS columns, the eccentricity has no significant influence on their ultimate load capacities [12,13]. Residual stresses have

very limited effect on the ultimate load capacity of columns [14–18]. Both the size and type of stiffeners affect the performance in the CFS stiffened members [19–21]. The presence of slotted openings affects both post-peak response and ductility of columns [22,23]. Modifications to the available design procedures have been suggested for columns failing by interaction of local, distortional and other buckling modes [24–26]. Dimpled CFS columns perform better than the plain ones [27]. Stiffener ties affect the strength and failure mode in open CFS sections under compressive loading [28,29]. For back-to-back gapped built-up CFS columns, with the increase in vertical spacing between the link-channels, the reduction in the load carrying capacity is higher in the intermediate and slender columns as compared to that of in stub and short columns [30]. For built-up CFS columns composed of two channels back-to-back, the interaction of local and flexural buckling is very prominent, mainly in the sections with the deeper and thinner webs [31].

Past studies on CFS built-up columns have predominantly focused on the performance of CFS columns comprising of two channel sections connected either by stitch welding/screws or by batten plates at the intermediate locations under axial loading conditions. Stone and LaBoube [32] carried out tests on built-up CFS columns to assess the design provisions of the North American Specifications (NAS) for the Design of Cold-Formed Steel Structural Members (AISI S-100 [33]). It was concluded that for the thicker CFS sections, the design strengths

\* Corresponding author.

E-mail address: [drsahoo@civil.iitd.ac.in](mailto:drsahoo@civil.iitd.ac.in) (D.R. Sahoo).

**Nomenclature**

$\chi$	Reduction factor	$L + F$	Combined local and flexural buckling
$\alpha$	Imperfection factor	$l_{chord}$	Length of unbraced chord
$\bar{\lambda}$	Overall non-dimensional slenderness	$L_{cr}$	Buckling length
$a$	Intermediate fastener spacing	$l_e$	Length of end plate
$A_e$	Effective cross-sectional area	$L_{eff}$	Effective length of the column
$b$	Width of built-up section	$l_z$	Unbraced length of angle chord
$b_c$	Width of angle leg	$MPC$	Multi-point constraint
$b_e$	Depth of end plate	$N_{cr}$	Elastic critical force
$E$	Modulus of elasticity	$P_{EC3}$	Design strength predicted by EC-1993-3
$F_e$	Least of elastic flexural, torsional and flexural-torsional buckling stress	$P_{FEA}$	Ultimate FEA predicted strength
$F_n$	Critical buckling stress	$P_{NAS}$	Design strength predicted by AISI-S100
$f_n$	Nominal yield strength	$P_{Test}$	Ultimate test strength
$f_u$	Ultimate strength	$r_1$	Minimum radius of gyration of individual shape in the built-up member
$f_u$	Ultimate strength	$r_i$	Radius of gyration of the built-up member
$f_y$	Yield strength	$t_c$	Thickness of chord
$i_z$	Radius of gyration of the angle chord	$t_{lac}$	Thickness of lacing
$K$	Effective length factor	$\delta$	Geometric imperfection
$l$	Height of the column	$\varepsilon$	Strain at fracture
$L$	Local buckling	$\lambda$	Overall column slenderness ratio
		$\lambda_c$	Critical slenderness
		$\lambda_{chord}$	Chord slenderness ratio

obtained using NAS [33] design equations without using the modified slenderness ratio were conservative in the order of about 43%.

Sukumari et al. [34] conducted experimental and numerical studies to investigate the behaviour of CFS open built-up compression members under eccentric axial loading. A design curve was proposed to estimate the ultimate capacity of CFS built-up columns undergoing distortional or mixed local-distortional buckling. Whittle and Ramseyer [35] showed that the average axial strength quantified on the basis of modified slenderness ratio was conservative for the longer and wider built-up columns composed of double channel CFS sections. Furthermore, using the recommended fastener detailing, spacing of chord members, and unmodified slenderness ratio as per NAS [33] provisions, the design strength predictions are very conservative for the immediately welded closed-sections built-up members. El Aghoury et al. [36] investigated the behaviour of battened CFS columns composed of four equal angle sections with pin-ended support conditions under axial loading. This study indicated that the built-up columns comprising of four slender angles were very sensitive to the geometric imperfections. Therefore, the imperfections must be accounted for in the fabrication as well as the design process by adopting the modified slenderness ratio. The design strengths predicted by the AISI S-100 [33] and AISC-LRFD [37] specifications were found to be un-conservative for the battened CFS built-up columns. Reyes and Guzmán [38] conducted tests on CFS box sections to evaluate the role of modified slenderness ratio in predicting the strength of built-up columns. Test results concluded that for predicting the strengths of built-up columns fabricated out of CFS sheets of 1.5 mm and higher thickness, the actual slenderness ratio value can be used provided the seam weld spacing (i.e., distance between the centres of the seam weld lengths) should be less than 600 mm.

Using the moment of inertia of the entire cross-section of built-up CFS box columns, the effective width method may predict the over-estimated column strengths [39]. Overlapping of flanges does not help in improving the local buckling resistance of built-up members. However, it does enhance the distortional buckling resistance to some extent. The fastener arrangement and their spacing affects the failure mode of built-up CFS box columns under compressive loading. Dabaon et al. [40] experimentally investigated the behaviour of pin-ended built-up CFS battened columns composed of two plain channel sections connected back-to-back. Test results indicated that, by increasing the channel spacing, the mode of failure was transformed from the global buckling to the combined local and flexural buckling and from the

combined local and flexural buckling to the local buckling. Test results were also compared with the design strengths predicted by North American Specification [33], Australian/New Zealand Standard [41] and European Code [42] for CFS columns. All these specifications were unconservative for the members failing mainly by local buckling, and conservative for the ones failing by elastic flexural buckling. The focus of the past research on built-up CFS columns has been on the performance evaluation of battened CFS built-up columns. In addition, the design guidelines available in the current design standards are limited to the built-up compression members comprising of two sections in contact. Hence there is a need to explore the behaviour of CFS laced built-up columns and to compare their design strength predictions as per the current design standards with the test results in order to ascertain their applicability in the present form.

## 2. Motivation and objectives of the study

In this study, an attempt has been made to evaluate the behaviour of laced built-up CFS columns under axial compressive loading. Such a study would supply the necessary experimental data pertaining to the behaviour of laced CFS built-up columns, therefore compensate the lack of information on this type of configuration. An experimental investigation was conducted on five column specimens fabricated using four CFS angle sections as the main chord members. The parameters varied in these specimens were width-to-thickness ratio of chords, column slenderness ratio, and slenderness ratio of lacings. The monotonic behaviour of laced CFS specimens were evaluated in terms of axial compressive strengths, axial load vs. axial shortening response, axial load vs. mid-span lateral displacement response, state of strain in chords, and mode of failures. The observed column strengths were compared with the design strengths predicted using North American Standards [33] and Eurocode [42] provisions. In addition, a numerical study was conducted using a finite element software ABAQUS [43] to predict the axial load-resisting capacity, load-displacement response, and mode of failures of the laced CFS columns.

## 3. Experimental investigation

The details of test specimens, material properties, test set-up and procedure, geometric imperfections and test results are discussed in the following sections:

Download English Version:

<https://daneshyari.com/en/article/10132216>

Download Persian Version:

<https://daneshyari.com/article/10132216>

[Daneshyari.com](https://daneshyari.com)