Experimental Investigation on Axial Response of Composite Wood-Cold-Formed-Steel Fixed Ended Studs

Hiba Meddah[1*)], Nouredine Bourahla[2)], Hakim Bechtoula[3)], Hassan Aknouche[4)]

[1*)] National Center of Applied Research in Earthquake Engineering (CGS), Algeirs, Algeria, h.meddah@cgs-dz.org; https://orcid.org/0000-0002-3130-9655
[2)] LGSDS Laboratory,Civil Engineering Departement,National Polytechnic School, Algeria, nedbourahla@gmail.com;
[3)] National Center of Applied Research on Earthquake Engineering (CGS), Algeria, bechhakim@gmail.com
[4)] National Center of Applied Research on Earthquake Engineering (CGS), Algeria, haknouche_70@yahoo.fr

https://doi.org/10.29227/IM-2025-02-02-050

Submission date: *2025-04-04* | Review date: *2025-05-14*

Abstract

Compared to hot-rolled steel sections, cold-formed steel sections are more susceptible to instabilities. Under compressive loading, several global, distortional, and local buckling instability modes are expected to manifest. This paper summarizes results of an experimental program carried out at the National Center of Applied Research on Earthquake Engineering Laboratory (CGS) in ALGERIA to investigate the behavior up to failure of composite wood cold formed steel stud under cyclic axial loading, in which a wood core is incorporated inside the cold formed steel C stud subjected to axial cyclic loading which was compared with simple cold formed steel C stud. Six full scale columns with both ends fixed were tested, three cold formed steel C stud (600s200-68) and three with the same C sections reinforced with wood. Two monotonic axial concentric loading tests (one compression and one tension) and one cyclic axial loading test with different loading rate were performed on both cold-formed steel (CFS) columns and Wood CFS columns. The cyclic loading protocol was adapted from FEMA 461 with initial displacement obtained from the monotonic tests. The results showed that the local deformations (local buckling) were less noticeable for the wood CFS columns. It was also observed that, the degradation of resistance, rigidity and the total hysteretic energy dissipated were more important for composite columns.

Keywords: *Composite wood-cold formed steel column, axial loading, Hysteretic load-deformation behavior, Buckling*

1. Introduction

Elements at the ends of shear wall panels (SWP) of cold-formed steel (CFS) structures under earthquake ground motions sustain high cyclic axial forces. Under these conditions high axial capacity in tension and compression is necessary, yet CFS elements are extremely susceptible to instability phenomena [1]. Research efforts to remedy the shortcomings addressed several influential aspects in order to enhance the compressive capacity of the studs and mitigate early modes of buckling. Experimental tests were performed on cold formed steel elements of various configurations [2-15]. The factors that affect bearing capacity and the primary failure modes have been brought to light by these investigations. The most common failure modes are distortional buckling, local buckling, and global buckling [11, 16]. The strength and stiffness of the element are affected by the slenderness, the geometric properties and the mechanical properties of the material [17-20]. In order to avoid local instabilities, reinforcement techniques have been proposed, such as built-up CFS (box and back-to-back) sections, [11,12,15], as well as CFS-concrete composite elements. [17,21,22], and wood-CFS composite elements [23],

In order to assess the performance of CFS frames under axial loading till failure, this study will identify the mechanisms of elastic and post-elastic instabilities and suggest reinforcement techniques to prevent these issues and improve the resistance and the ductility. Composite elements wood-CFS sections were therefore investigated, and their response under axial loading was analysed.

2. Experimental program

The experimental program contained six specimens divided into two groups, three specimens have CFS section and three specimens have a composite section wood-CFS. Table 1 summarizes the specimen nomenclature. Each group included one monotonic test in compression, one monotonic test in tension and one quasi-static cyclic test with different loading rates. Monotonic tests were carried out to estimate the ultimate displacement and the load-deformation envelope. Cyclic tests were done to determine the axial hysteretic response and hysteretic energy dissipation.

Tab. 1. Specimen's nomenclature

Type	Specimen	Test	Loading rate (mm/s)
Wood-CFS (with wood)	WWM	Monotonic compression	0.02
	WWMT	Monotonic tension	0.02
	WWC	Cyclic	0.5
CFS (without wood)	WOWM	Monotonic compression	0.02
	WOWMT	Monotonic tension	0.02
	WOWC	Cyclic	0.5

2.1 Specimen's dimensions and materials properties

All specimens had the same length L=1500mm. The CFS cross section was the same for all specimens considered 600s200-68, was chosen from standard sizes as listed in the Structural Stud Manufacturers Association (SSMA) catalogue [24]. The composite specimens were filled with wood as shown in Fig.1. The steel yielding stress was 281 Mpa and that of wood was 50 Mpa for compression and 100 Mpa for tension. Boundary conditions were adapted to be fixed-fixed as executed in the real field.

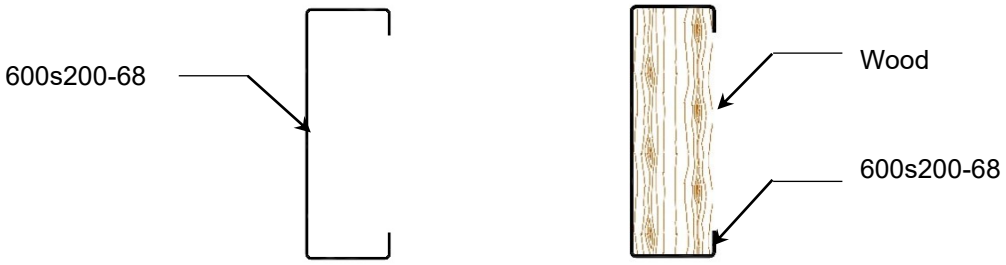

Fig. 1. Cross-section geometry (right) 600-S200-68 (left) composite Wood-CFS section.

2.2 Test setup and instrumentation

As shown in Fig. 2 (a), the studs were tested vertically using a loading frame at the National Center of Applied Research in Earthquake Engineering Laboratory (CGS)-Algeria. In order to transfer axial load, end plates were attached to both ends of the specimens. Lateral braces were used to prohibit all displacements out of plane.

For monotonic tests, a loading rate of 0.02 mm/s was used and 0.5 mm/s was used as the loading rate for cyclic displacement history loading.

Eight Linear Variable Displacement Transducers (LVDTs) were used to measure the deformations : six for lateral deflexion east-west and north-south (three in each direction), one for axial deformations, and one for relative displacement between the base and the end plate (Fig. 2(b)).

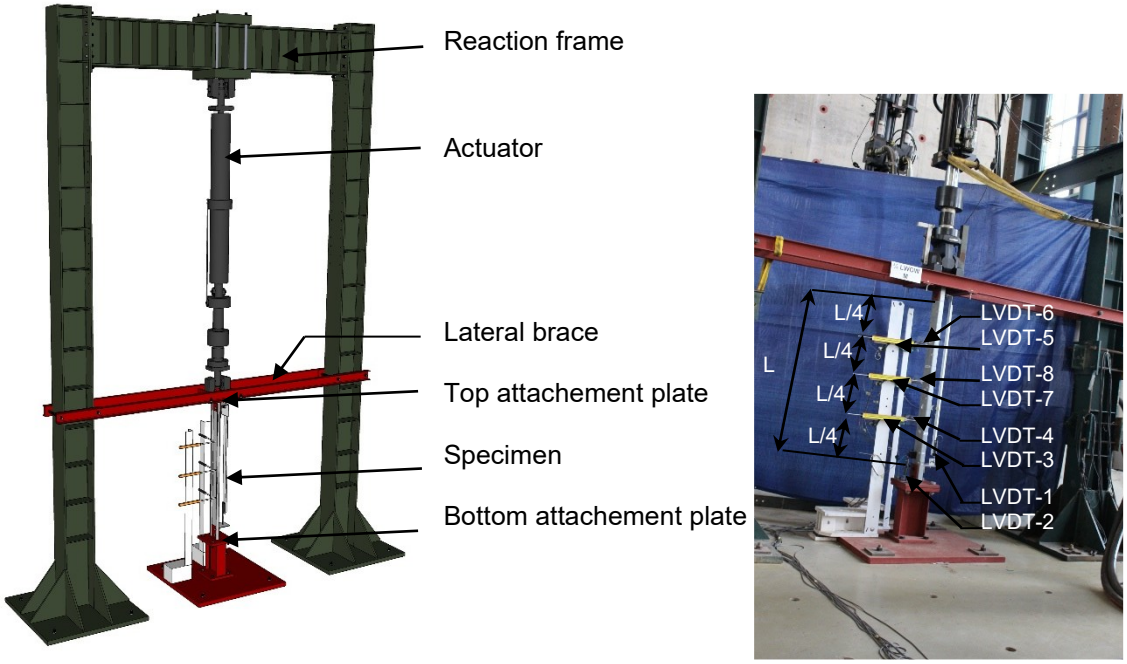

Fig. 2. (a)Test setup, (b) LVDTs positions.

2.3 Loading protocol

An increasing displacement-controlled load was applied at a rate of 0.02 mm/s during the monotonic tests until the specimen failed in either compression or tension.

The quasi-static cyclic loading protocol was taken from FEMA461. This protocol is suitable for racking testing, or hysteretic testing which is used to quantify all damage states for which fragility functions are to be developed [25].

The FEMA reversed cyclic protocol is made up of iterative cycles with progressively larger deformation amplitudes. Every amplitude contain two cycles. δ_i is the amplitude of the cycles, as they increase in magnitude i.e. the first amplitude is δ_0 and the last planned amplitude is δ_m. Where δ_m is estimated from the monotonic test, it is defined as the displacement observed when the post-peak resistance is reduced to 80% of the ultimate resistance. The protocol contains six initiation cycles of small amplitude δ_0=0.018 δ_m. The amplitude δ_{i+1} of the step i+1 (not of each cycle, since each step has two cycles) is given by the equation δ_{i+1}=1.4 δ_i where δ_i is the amplitude of the preceding step. Fig.3. shows the reversed cyclic loading history applied during the tests [25].

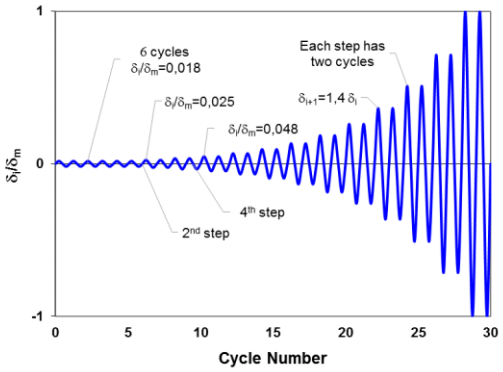

Fig. 3. Loading path [25].

3. Experimental results

3.1 Monotonic and cyclic response

To estimate the ultimate displacement and the load-displacement envelope curve, monotonic compression and monotonic tension tests were combined to produce monotonic load-displacement responses for each group. A global comparison of WOW and WW monotonic behaviour is shown in Fig. 4.

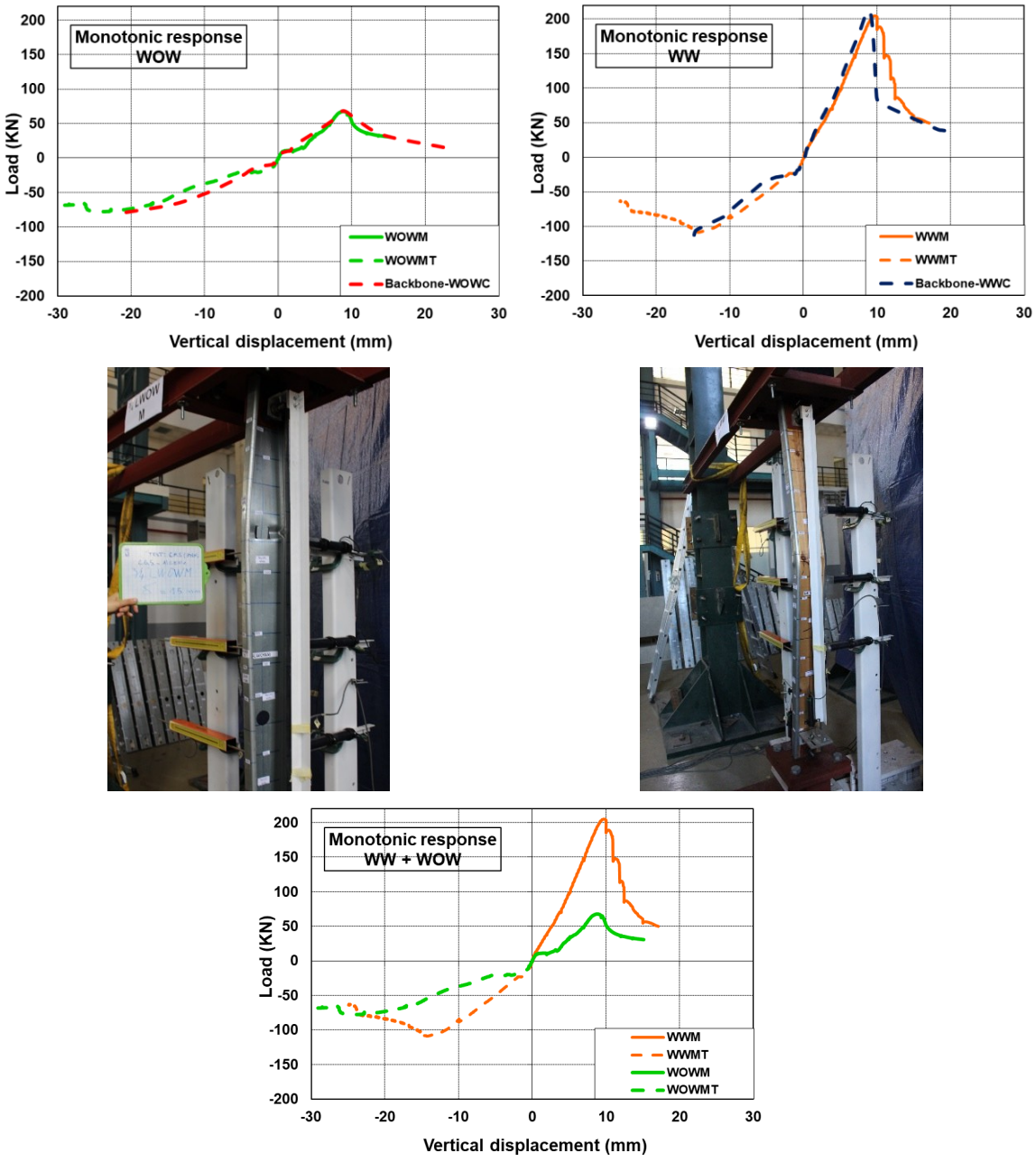

Fig. 4. Comparaison between WW and WOW Cyclic response envelopes and Monotonic Behaviour.

The WOW specimen's monotonic compressive response was characterized by weak axis flexural buckling and some waves of local buckling and accumulation of compression damage at the mid-height.

However, the WW specimen's monotonic compressive response was characterized by global flexural buckling around the weak axis and crushing of the wood core at the mid-height at the test end.

Cyclic tests were done to determine the axial hysteretic response and hysteretic energy dissipation. Fig.5. shows a global comparison between WW and WOW Hysteretic behaviour.

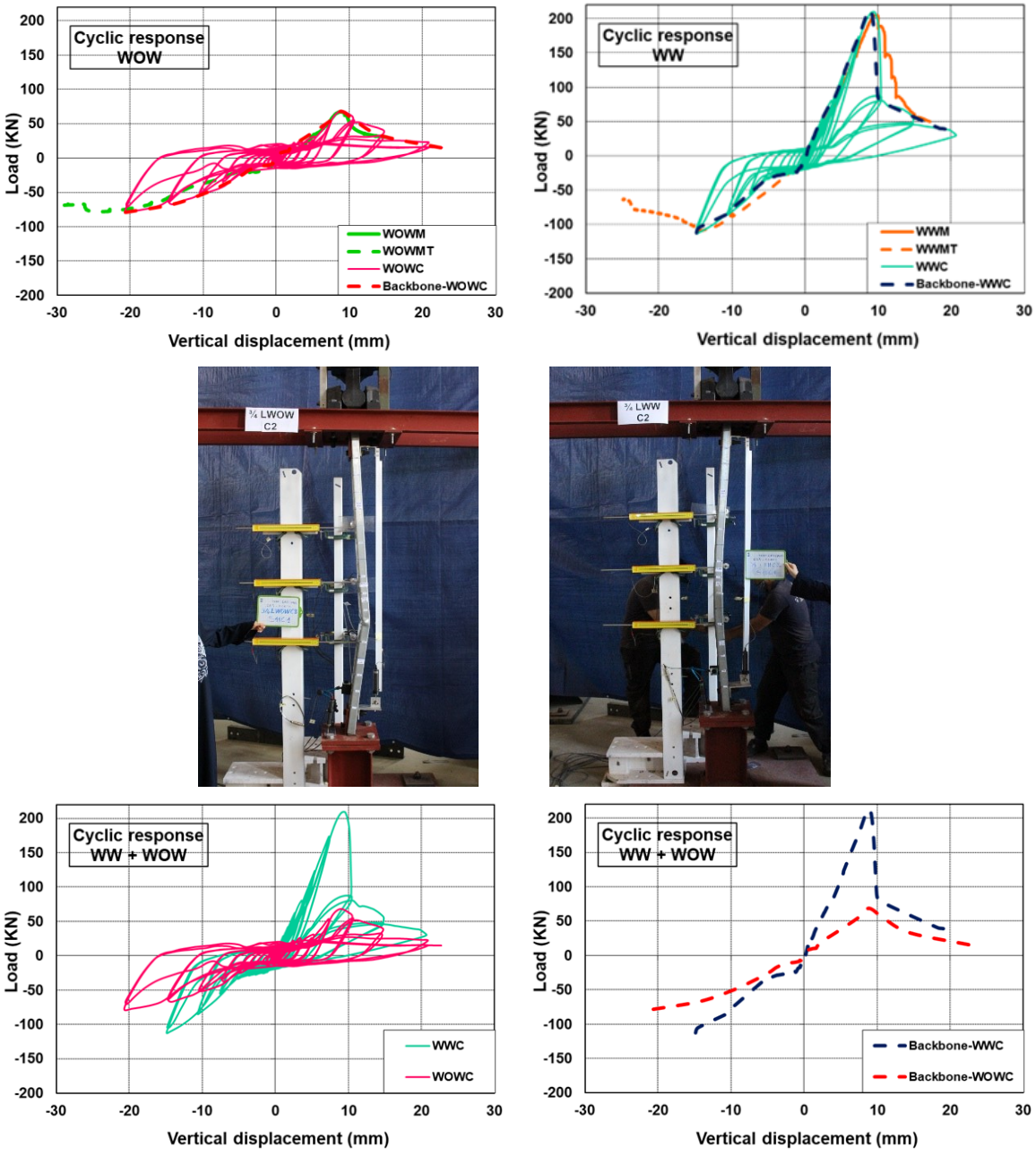

Fig. 5. Comparaison between WW and WOW Cyclic hysteretic Behaviour.

All specimens exhibited weak-axis flexural buckling as a cyclic response, in addition to the opening of the lips- stiffeners, the folding of the flanges and tearing of the cross section at the mid-height for WOW specimens only and the crushing of the wood core at the mid-height for WW specimens as shown in Fig.5.

Because of the damage accumulated at the folded flanges, WOW specimen's compressive strength deteriorated more quickly after reaching peak compressive load. The tension side was characterized by extremely low stiffness for all specimens until the member straightened out.

From the monotonic and the cyclic tests, the average peak load ratio of composite specimens to CFS specimens was 3.00 in compression and 1.50 in tension.

3.2 Hysteretic energy dissipation and rigidity degradation

The hysteretic energy dissipated of the specimen, can be evaluated by calculating the area enclosed by one cycle hysteresis loop.

Fig. 6. show the time history of cumulative energy dissipation. The results made clear that the energy dissipation of WW specimens is more important than those WOW at low cycle number, and for largest number of cycles, it climbed quickly.

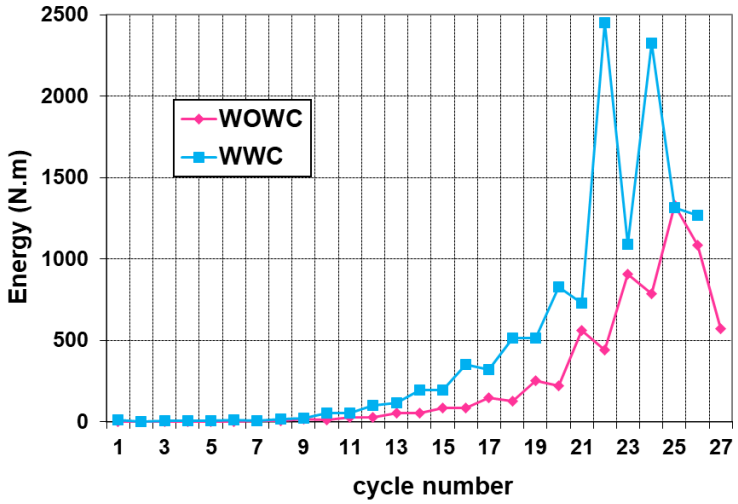

Fig.6. Hysteretic Energy Dissipated.

Fig. 7 illustrate the variation of stiffness degradation ratios (K/K_0) where K_0 is the initial stiffness with respect to the axial strain ($\varepsilon=\delta/h_0$).

It can be shown that stiffness degradation of WW specimens is larger to those WOW.

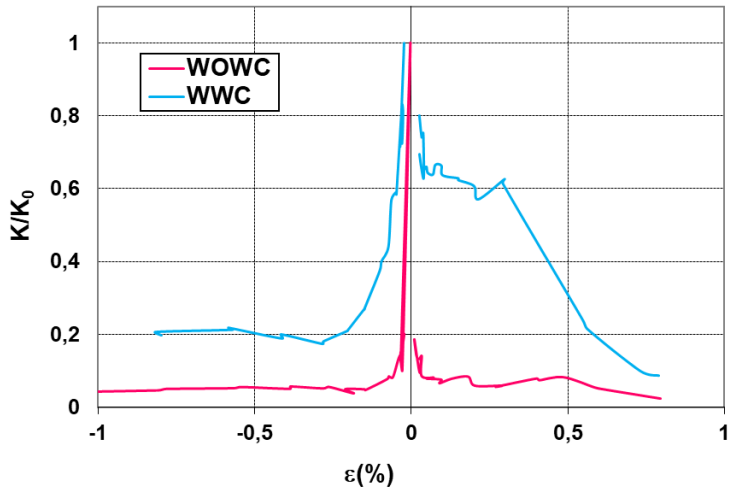

Fig.7. Normalized rigidity

4. Conclusion

Cold-formed-steel components of lateral resisting systems are heavily solicited under seismic action so, they are vulnerable to instability events in compression, which can be harmful. In order to improve the strength and ductility capacity of CFS studs under such conditions, this research suggests a composite section that combines the ductility of wood with the strength and stiffness characteristics of CFS. The objective is to use the composite action to partially compensate the strength loss upon buckling and to prevent early buckling of the CFS section.

An experimental program to investigate the hysteretic behaviour, stability and ultimate capacity of composite wood-cold formed steel stud, and to quantify the effects of the wood was carried out.

Three simple cold formed steel C-stud and three composite wood- cold formed steel C-stud were subjected to axial monotonic and cyclic loading to investigate their hysteretic behaviour.

In this research the advantages of reinforcing the C-studs by a wood core are clear, such us local buckling occurs at higher load level for specimens with wood reinforcement and the displacements corresponding to the maximum axial load is becoming higher.

Furthermore, fat hysteretic curves, ductility and plastic development capacity of specimens with wood are more important than those without wood, in addition the dissipated energy and the stiffness degradation are also more important.

Acknowledgments

The technical support of the National Center of Applied Research on Earthquake Engineering (CGS) for carrying this research is greatly acknowledged. As well as many thanks for the financially support by Frame-metal and Blida University.

References

1. Wei-Wen Y., (2000) "Cold-formed steel design",3rd edition, John Willey & Sons, New York,USA.
2. B.W. Schafer, T. Pekoz, (1998) "Computational modeling of cold-formed steel: characterizing geometric imperfections and residual stresses", Journal of Constructional Steel Research 47,193–210.
3. C. C. Weng and Teoman Pekoz.,(1988) "Compression tests of cold-formed steel columns", Ninth International Specialty Conference on Cold-Formed Steel Structures St. Louis, Missouri, U.S.A., November 8-9.
4. D. Padilla-Llano, C. D. Moen & M. R. Eatherton. (2014), "Cyclic axial response and energy dissipation of cold-formed steel framing members", Journal of Thin-Walled Structures 78,95–107.
5. Hélder D.Craveiro,JoãoPaulo C.Rodrigues , Luis Laím., (2014), "Cold-formed steel columns made with open cross sections subjected to fire", Journal of Thin-Walled Structures 85, 1–14.
6. D.C. Fratamico, S.Torabian, X.Zhao, K.J.R. Rasmussen, B.W. Schafer, (2018), " Experiments on the global buckling and collapse of built-up cold-formed steel columns", Journal of Constructional Steel Research 144, 65–80.
7. D.C. Fratamico, S.Torabian, X.Zhao, K.J.R. Rasmussen, B.W. Schafer, (2018)," Experimental study on the composite action in sheathed and bare built-up cold-formed steel columns", Journal of Thin-Walled Structures 127, 290–305.
8. S.Kechidi, D.C. Fratamico, B.W. Schafer, J.M.Castro,N. Bourahla, (2020)"Simulation of screw connected built-up cold-formed steel back-to-back lipped channels under axial compression"Journal of Engineering Structures 206,
9. F.J. Meza, J.Becque, I.Hajirasouliha,(2020) "Experimental study of cold-formed steel built-up columns" Journal of Thin-Walled Structures 146,
10. Yaochun Zhang , Chungang Wang, Zhuangnan Zhang ,(2007) "Tests and finite element analysis of pin-ended channel columns with inclined simple edge stiffeners", Journal of Constructional Steel Research 63, 383–395.
11. Reza Masoudnia, Soroush Amiri, Mohammad Ali Sadeghian., (2011)"Numerical Investigation of Behavior of RHS Columns Using FE Method", European Journal of Scientific Research 51, 109–114.
12. K.Y. Ning, L. Yang, H.Y. Ban, Y.N. Sun,(2019)" Experimental and numerical studies on hysteretic behaviour of stainless steel welded box-section columns", Journal of Thin-Walled Structures 136, 280–291.
13. NaYang, Ya'nan Zhong, Qing'tong Meng, Hao Zhang,(2014) "Hysteretic behaviors of cold-formed steel beam-columns with hollow rectangular section:Experimental and numerical simulations", Journal of Thin-Walled Structures 80, 217–230.
14. Y. Lu, T. Zhou, W. Li, H. Wu,(2017)" Experimental investigation and a novel direct strength method for cold-formed built-up I-section columns", Journal of Thin-Walled Structures 112 , 125–139.
15. K. Roy, C. Mohammadjani, J.B.P. Lim,(2019)" Experimental and numerical investigation into the behaviour of face-to-face built-up cold-formed steel channel sections under compression", Journal of Thin-Walled Structures 134, 291–309.
16. S. Narayanan, and M. Mahendran,(2003) "Ultimate capacity of innovative cold formed steel columns", Journal of Constructional Steel Research 59, 489–508.
17. K.M.A. Hossain,(2003) "Axial load behaviour of thin walled composite columns", Journal of Composites: Part B 34, 715–725.
18. H.D. Craveiro, J. Paulo, C. Rodrigues, L.Laím,(2016)" Buckling resistance of axially loaded cold-formed steel columns ", Journal of Thin-Walled Structures 106, 358–375 .
19. Shanmuganathan Gunalan, Mahen Mahendran,(2013) "Improved design rules for fixed ended cold-formed steel columns subject to flexural–torsional buckling", Journal of Thin-Walled Structures 73, 1–17.
20. S. Fan, F. Liu, B. Zheng, G. Shu,Y.Tao,(2014) "Experimental study on bearing capacity of stainless steel lipped C sections tub columns", Journal of Thin-Walled Structures 83, 70–84.
21. N. Ferhoune, J. Zeghiche,(2012) "Experimental behaviour of concrete-filled rectangular thin welded steel stubs (compression load case)", Journal of C. R. Mecanique 340, 156–164.
22. N. Ferhoune,(2014) "Experimental behaviour of cold-formed steel welded tube filled with concrete made of crushed crystallized slag subjected to eccentric load", Journal of Thin-Walled Structures 80, 159–166.
23. H.Meddah, N.Bourahla, H.Bechtoula, H.Aknouche, A.Nour, (2022) “Cyclic axial Response of composite wood-cold-formed steel stud: experimental and numerical investigation”, International Journal of steel structures 22, 1126-1146.
24. SSMA Steel Stud Manufacturers Association. Product technical information. ICBO ER-4943P. 〈http://www.ssma.com〉 15.12.11.
25. FEMA, FEMA461-interim protocols for determining seismic performance characteristics of structural and nonstructural components through laboratory testing. Document no.FEMA461. Federal Emergency Management Agency (FEMA); 2007.