The design assisted by testing:
a research project of a cold formed steel building system

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Abstract: The adoption of cold-formed steel (CFS) profiles for residential buildings started in USA. Positive experiences in this field took place in other countries such as Australia, Canada and Japan. In Italy, where traditional steel structural system for residential purposes is quite limited, CFS structural systems are not widespread, but the use of CFS profiles in housing systems has grown in recent years. The economic crisis of recent years and the increased competitiveness of the market provided the fertile environment for a new interest by companies in the process of innovation and diversification of their product. An Italian company recently decided to expand its production with the development of a CFS industrialized building system. The advantages of CFS profiles such as the light weight, durability, high efficiency, simplicity and rapidity of installation result in competitive structural systems. However, the design of this structural typology is fairly complex, so in the framework of the activities associated with the development of the building system, the University of Trento was involved in the experimental studies aiming at the structural characterization of the building system. The paper summarized the experimental research program and presents the outcomes of the experimental investigation focusing on the shear walls.

Keywords: Cold-formed steel, Thin-walled, Light weight, Building system.

Introduction

The actual demand of the building market is focused on the concept of safe, efficient and comfortable house, in one word ‘technological’. The last natural events have been increased the attention on the issue of the structural safety. For this reason, the behavior of the building structures, especially under horizontal loads and in particular under the earthquake loads, is a research topic both for industry and academic field. The synergy between these two sectors allows the development of new technologies. Following this point are offered innovative building solutions as the structural use of cold-formed steel (CFS) profiles.

The use of CFS profiles for residential buildings started in USA. Positive experiences in this field took place in other countries such as Australia, Canada and Japan. In Italy, where traditional steel structural system for residential purposes is quite limited, CFS structural systems are not widespread, but the use of CFS profiles in housing systems has grown in recent years. The advantages of CFS profile such as lightweight, high structural efficiency, durability, rapidity and simplicity of installation of the building equipment gave rise to the development of new building systems which have shown to be competitive with respect to the more traditional constructional systems. Moreover, the economic crisis and the increased competitiveness of market provided the fertile environment for new interest by companies in the process of innovating and diversifying their production.

An Italian company recently decided to expand its production with the development of a CFS industrialized building system. In the framework of the activities associated with the development of the building system, the University of Trento was involved in both the experimental and the numerical studies aiming at the structural characterization of the structural components.

This paper describes the research program followed with the purpose of defining the structural behavior of the system’s components. In particular, the paper summarizes the outcomes of a limited series of experimental tests focused on the response under monotonic and cyclic loading of shear walls made up of light gauge members. The key features of experimental study and the main results are presented and discussed. The consequence of different bracing systems (trussed frame bracing, diagonal straps), the presence of openings and the influence of the sheathing are investigated. The performances of the different configuration of shear walls are compared in terms of resistance and stiffness.

The structural system

The structural system is composed with shear walls and flooring systems. The shear walls, which transfer to the foundations the vertical loads of the flooring system and the horizontal load due to wind and earthquake, are built-up with studs located at regular intervals and bottom and top chords. An additional chord located at mid-height reducing slenderness of the studs. All the steel framing elements (stud and chord) were built up using the same C-like cold-formed section with a height of 100 mm, a width of 57 mm and a thickness of 1,2 mm. The task to transfer the horizontal forces is entrusted to bracing systems. Two solutions are adopted: steel strap diagonal cross bracings and trussed bracings. Walls are hence completed with sheathings which can be realized with different materials like cement board or gypsum board.

The research program

In order to develop an industrial prefabricated system, building components require studies at different level of complicity from the individual member to the 2D and 3D subassemblies.

The first phase of the research was focused on the characterization of the C-section. In order to study the behavior of the profiles under compression and under bending has been performed an experimental program. The compression tests (figure 1) and the bending tests, performed in agreement with the UNI EN 1993-1-3 (2007), allowed for determining loads and modes of failure, generally governed by buckling phenomena (figure 1b).

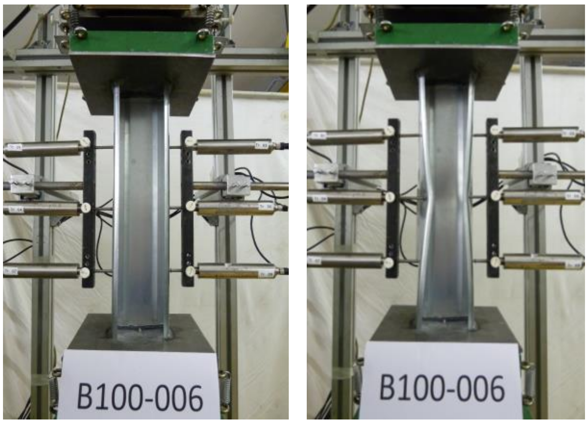
a) b)

Figure 1. Test set-up

The second phase of the research was focused on the characterization of the 3D component such as walls. Tests on several configurations of walls (figure 2), with vertical stud and strap bracing (figure 2a), with vertical stud and vertical trusses at each end (figure 2b), with a trussed frame bracing in presence of a window opening (figure 2c) and, finally with vertical stud only (figure 2d), were performed for evaluate the response under vertical and lateral loads. The possible influence of the sheathing to the wall's response was also considered. The experimental study comprise 21 shear wall specimens with dimension 2400 mm x 3018 mm.

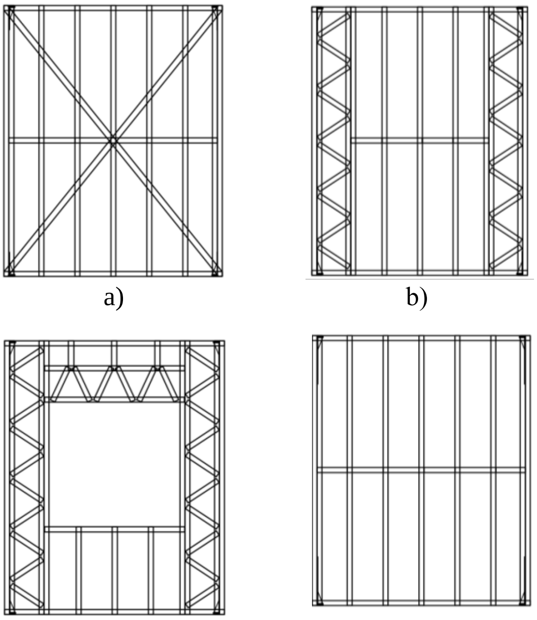
a) b) c) d)

Figure 2. Wall configuration investigated

The third phase of the research was focused on the characterization under shear of the sheathing and of the sheathing to framing connections. At this aim, ancillary tests were performed. Specimens with nominal dimensions of 90 x 250 mm (figure 3) were taken from the sheathing panels considered in the study and loaded in edgewise shear test results were analyses to evaluate the shear modulus G and the shear stress τ.


a) b)

Figure 3. Test set-up for edwise shear test

Test on the stud-sheathing connections (figure 4) were performed for the evaluation of the mechanical proprieties of fasteners: the stiffness and the ultimate resistance. The specimens were tested under pure tension and displacement control.

a) b)

Figure 4. Test set-up for connections

Shear wall test program

The performance of the shear walls to lateral loads was investigated by means of a testing set-up 'ad hoc' (figure 5-6) designed for light framed structures. The testing system (figure 5-6) allows applying both vertical and lateral loads and to perform tests both in monotonic and cyclic regime.

Several configurations of walls were tested, comprising walls with vertical studs and strap bracing, with and without sheathing, walls with vertical studs and vertical trusses at each end, with and without sheathing, walls with a trussed frame bracing in presence of a window opening, with and without sheathing and, finally, walls with vertical studs only with sheathing.

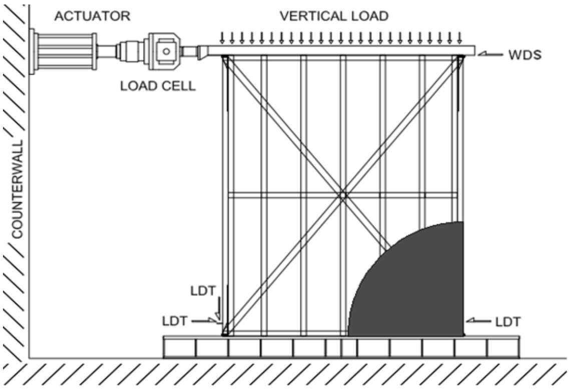

Figure 5. Test set-up for walls

In order to investigate the walls' response in conditions close to the operational ones, the tests were performed by applying a vertical load of 17,07 kN/m, which represents the factored load on the lower wall of a two storey building. At this aim a lever system was adopted and a cantilevered frame installed above the test walls distributed the load along the length of the wall. At the base, the specimens were connected to a rigid counter-beam by means of M12 bolts at 320mm.

Figure 6. Test set-up for walls

During the tests the out of plane displacements of the specimen were prevented. An MTS ± 250 mm actuator with a maximum capacity of 1MN in compression and 0,6 MN in tension was used to apply the lateral displacements. A load cell in line with the actuator's head enabled measurement of the lateral force applied to the wall. The vertical and horizontal displacements of the wall were measured using linear transducers (LDT) and a wire transducer (WDS). A data acquisition system HBM Spider 8 allowed the data logging at 3 Hz sampling frequency.

Test results

The results of shear tests on six different configurations of shear walls are in the following summarized (figures 7-12). The results allow to point out the influence of different type of bracing systems (trussed frame bracing, diagonal straps and sheathed braced), the influence of the sheathing and the presence of opening. In figures 7-12 the dashed curves refer to monotonic tests while the continuous curves are associated to the cyclic tests. The results of the tests on the walls without sheathing (figures 7-9) show that:

- specimen G7 100 400 XX-1 exhibited a stiffer performance than that of specimens G6 100 400 XX, although the wall incorporates a central opening. The horizontal trussed framing, connecting the lateral trussed bracing modules, results in a stiffer mechanism of force transmission which determinate an increase of the stiffness of approximately 50% respect to that of the specimens G6 100 400 XX. No remarkable increase of the resistance was observed: all of these walls were in fact associated with the same collapse mode (e.g., local instability phenomena);

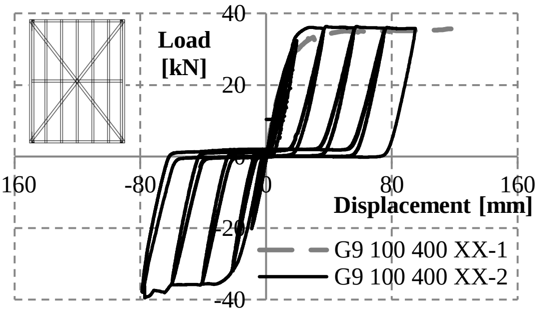

Figure 7. Monotonic and cyclic responses of walls G9 100 400 XX

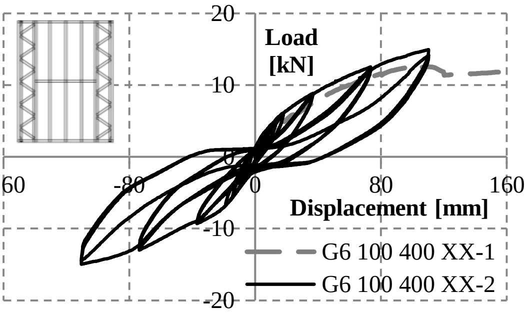

Figure 8. Monotonic and cyclic responses of walls G6 100 400 XX

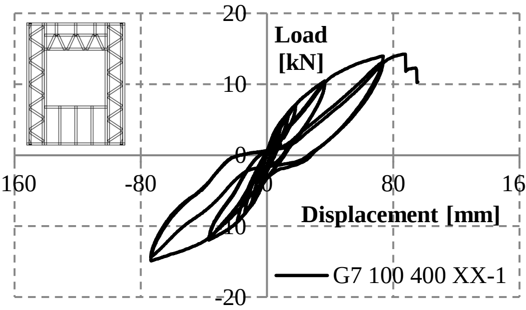

Figure 9. Cyclic response of wall G7 100 400 XX

- the best performance, in terms of both stiffness and resistance, was achieved with the adoption of an X-type bracing system. If the case of the specimens G6 100 400 XX is assumed as reference case, an increase of 805% and 186% in terms of stiffness and resistance, respectively, was achieved in the monotonic tests. In the cyclic test, an increase of 695% and 152%, for the stiffness and resistance, was observed.

As to the tests on the walls with sheathing (figure 10-12), it can be observed that the steel bracing system type did not influence in a substantial way the stiffness or the ultimate load capacity of the walls, which were mainly provided by the cement board sheathing.

In particular:

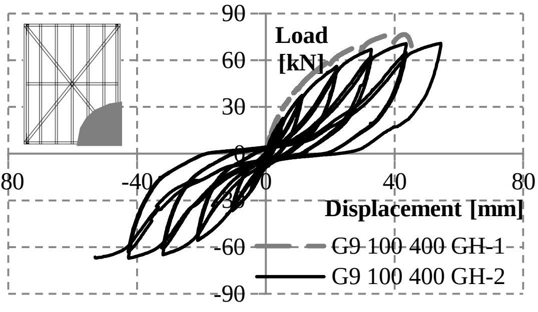

Figure 10. Monotonic and cyclic responses of walls G9 100 400 GH

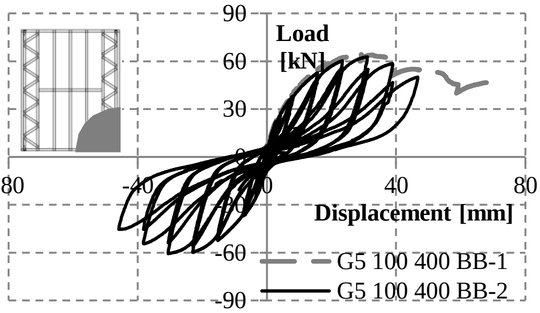

Figure 11. Monotonic and cyclic responses of walls G5 100 400 BB

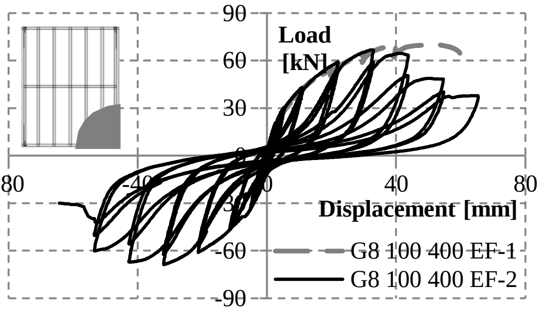

Figure 12. Monotonic and cyclic responses of walls G8 100 400 EF

- the adoption of an X-type bracing system, i.e. the solution with the better performance in wall tests without sheathing, along with the installation of cement board sheathing leads to a quite limited increase of the maximum load capacity but to a premature loss in load carrying ability, which was associated with the tension failure of the hold-down anchor rod;
- the complete absence of a steel bracing system for a sheathed wall seemed to have a negligible effect on the wall's performance: specimen G8 behaved in close agreement with other tested walls.

An appraisal of the sheathing's contribution to the wall performance is achieved by comparing the results of the table 1 with the results of the table 2. The presence of the sheathing leads to a different and

Table 1. Measured response of wall test specimens without sheathing

Specimen	Loading protocol	Positive Load			Negative load		
		Secant Stiffness	Ultimate Resistance	Drift at Ult. Resistance	Secant Stiffness	Ultimate Resistance	Drift at Ult.
		kN/m	kN	mrad	kN/m	kN	mrad
G6 100 400 XX-1	Monotonic	261	12,560	36,4	-	-	-
G6 100 400 XX-2	Cyclic	280	14,920	36,5	317	-14,960	-36,6
G7 100 400 XX-1	Cyclic	429	14,240	28,4	606	-14,880	-24,3
G9 100 400 XX-1	Monotonic	2361	35,920	40,9	-	-	-
G9 100 400 XX-2	Cyclic	2356	35,840	31,5	2388	-39,520	-25,6

Table 2. Measured response sheathed wall test specimens

Specimen	Loading protocol	Positive Load			Negative load		
		Secant Stiffness	Ultimate Resistance	Drift at Ult. Resistance	Secant Stiffness	Ultimate Resistance	Drift at Ult. Resistance
		kN/m	kN	mrad	kN/m	kN	mrad
G5 100 400 BB-1	Monotonic	6760	64,200	9,7	-	-	-
G5 100 400 BB-2	Cyclic	5639	62,720	10,3	5535	-60,600	-10,1
G8 100 400 EF-1	Monotonic	6044	70,040	17,3	-	-	-
G8 100 400 EF-2	Cyclic	5463	66,800	10,8	5254	-68,880	-10,6
G9 100 400 GH-1	Monotonic	5320	76,920	13,3	-	-	-
G9 100 400 GH-2	Cyclic	3824	70,760	18,0	2769	-67,120	-14,1

more efficient mechanism of forces transmission between steel framing elements if compared to one of the sheathed solutions. The sheathing and the connections sheathing-to-steel-framing elements redistribute forces between the steel elements, and prevent or delay the instability phenomena of studs and chords. On the other hand, the screws between studs and hold-downs and of the hold-down anchor rods are more severely stressed. The combination of these factor leads to improved resistance and stiffness but at the 'price' of reducing the ultimate deformation capacity.

Conclusion

The paper presents a limited series of tests part of a study focused on the response under monotonic and cyclic loading of walls made up of light gauge members. This walls are typical of light steel buildings. The goal of the study was to understand the response and compare the effectiveness of different bracing systems. These outcomes are very useful for the design under horizontal loads. Following the concept of 'the design assisted by testing', these results simplify the procedure of the structural project.

As expected, the performance of the walls with diagonal bracing is the best under all aspects. However, solutions using trussed members appear to be adequate for moderate wind and/or seismic loads. The sheathing can provide also an important bracing action. It substantially contributes by itself to the lateral response, as clearly shown by specimens G8, whose steel framing is characterized by absence of any bracing. This importance points out the need of an appraisal of the 'skin' behavior, including its connections to the steel skeleton.

The performance achieved by the tested shear walls allow a competitive building system, which is adequate for use in low rise buildings in low to moderate seismic zones.

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