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Experimental and analytical studies on different configurations of cold-formed steel structures

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ABSTRACT

Popularity of Cold-Formed Steel (CFS) structures has recently increased considerably in the last years as a consequence of discovered advantages such as lightness of the material, significant energy absorption capacity providing seismic performance against lateral loading, time efficiency and cost effectiveness. CFS structures are composed of shear panels which involve cold-formed steel bare frames coated with different kind of sheathings such as gypsum wallboard (GWB), oriented strand board (OSB), plywood or some infill materials which are connected to the frame. Combination of CFS bare frames and sheathing boards provides the shear panels with lateral load resistance against seismic actions. There are several factors which have a direct influence on the behavior of CFS shear panels such as type of sheathing board, thickness of cold-formed steel, spacing of the screws binding the sheathing board to the bare frame and magnitude of the axial loads. On behalf of observing the impact of these outlined factors upon the behavior of CFS shear panels as well as to attain some experimental data to be utilized in the new Turkish Earthquake Code 2016, a considerable amount of laboratory tests was conducted in Structures Laboratory of Bogazici University on different configurations of CFS shear panels. Posterior to the acquisition of these experimental data, studies upon developing analytical models representing the actual experimental behavior of one of the shear panels have been conducted, thus providing possibilities for 3-D seismic performance assessment of a representative one-story cold-formed steel structure for the final part of this paper.

1. Introduction

Cold-formed steel (CFS) structures have been considered as an efficient solution for rapidly growing construction demand particularly for low-rise and mid-rise buildings. Especially with the publication of various editions of "Specifications for the Design of Cold-Formed Steel Structural Members" by American Steel and Iron Institute (AISI) [1], the popularity of CFS structures has started to spread all over the world including North and South America, Great Britain, Germany and so forth. However, some downsides such as vulnerability to instability problems arising from large width-to-thickness ratio always kept the researchers erring on the side of caution and conduct further experimental and analytical studies.

Regarding the experimental and analytical studies conducted by researchers, Miller and Pekoz [2–3] proposed studies which include tests of CFS shear walls under axial loading and they conducted experiments of CFS frames sheathed with gypsum wallboard (GWB), Serette and Ogunfunmi [4] proposed a research including test results of CFS specimens coated with GWB, flat strap X-bracing and combination of these two systems, Serette et al. [5] conducted a research in order to investigate the impact of board type and screw spacing on the behavior of shear panels, Fülöp and Dubina [6–7] have conducted an interactive study observing performance of wall-stud cold-formed steel shear panels under monotonic and cyclic loading, Rogers et al. [8] implemented an experimental study to investigate the effect of the dimensions of the CFS shear panels on the behavior, Corte et al. [9] have conducted a study in order to investigate seismic behavior of sheathed cold-formed steel structures, Landolfo et al. [10] have conducted an experimental study to investigate the seismic behavior of CFS stud shear walls sheathed with GWB and OSB, Xu and Martinez [11] presented a research involving an interactive study between experiments under monotonic loading and development of an analytical model representing the experimental behavior, Fiorino et al. [12] observed the lateral response of sheathed cold-formed steel shear walls with an analytical approach, Fiorino et al. [13] have conducted tests on typical screw connections for CFS housing, Yu et al. [14,18] conducted two-phase full-scale tests of steel sheet coated shear walls to provide a wide range of data referring to the nominal strength of different wall configurations, Simsir and Jain [15] proposed a study about nonlinear analysis of wood-frame shear walls using SAP2000 software, Dubina [16] conducted a research on behavior and performance of cold-formed steel-framed houses under seismic action, Fiorino et al. [17] and

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Landolfo et al. [19] proposed a research based on two successive phases of a study ending up with acquisition of design nomographs to be used for design purposes of cold-formed steel structures, Rogers et al. [20] conducted a research on experiments of typical weld and screw-connected single-story diagonal strap braced cold-formed steel frame configurations, Yu [21] performed monotonic and cyclic tests on CFS shear walls with different thickness of steel sheets measuring their nominal shear strength under wind and seismic loads. He concluded his work with a comparison of reduction factor between code and practice, Rossi et al. [22] conducted full-scale tests on CFS structural sections subjected to concentric compression in order to observe the effect of combined distortional and global flexural-torsional buckling, Schafer et al. [23] proposed a study about computational modeling of cold-formed steel intending to see the effect of choice of element and mesh type during modeling process, Fiorino et al. [24] presented an article about seismic analysis of sheathing-braced cold-formed steel structures, Vieria and Schafer [25] conducted an experimental and analytical study so as to analyze the local stiffness of small-scale stud-fastener-sheathing assemblies. Besides, they developed a simplified conservative analytical model backed up by more detailed finite element modeling providing the local stiffness when experimental work is not possible. They also worked on a simplified analytical model supplying translational stiffness induced by the sheathing diaphragm action. Liu, Peterman and Schafer [26] conducted a series of monotonic and cyclic experiments on wood sheathed CFS shear walls investigating the impact of geometry, type of sheathing, use of ledger and location of sheathing seams on the nonlinear structural response of the shear walls. The ultimate motivation of this study was to assess current design procedures utilizing AISI-S213–07 and to develop nonlinear (hysteretic) models for global performance assessment, Baran and Alica [27] carried out an experimental study on OSB sheathed CFS shear panels representing construction practices in Turkey so as to evaluate the performance of these panels as well as to observe different deformation modes, Yanagi and Yu [28] presented a design model (Effective Strip Model) anticipating the nominal strength of CFS shear walls sheathed with steel sheet. The experimental results were also used to verify the model which yielded a good match with the actual test results, Peterman and Schafer [29] tested CFS stud-fastener-sheathing assemblies under in-plane cyclic loads and they characterized hysteretic behavior of each sheathing-to-frame fastener by using either radially symmetric linear or non-linear spring elements. When it comes to nonlinear analysis, they used Pinching4 model to enlighten the hysteretic behavior accurately, Afshan et al. [30] and Rossi et al. [31] proposed studies backed up with material testing which emphasize increase of strength in CFS structural sections due to manufacturing process (plastic deformations) and development of predictive models anticipating these strength enhancements, Peterman et al. [32] proposed a paper about hysteretic characterization of cold-formed steel stud-to-sheathing connections, Peterman and Schafer [33] conducted a study relevant to sheathed CFS studs under axial and lateral load to characterize the system behavior, Zeynalian and Ronagh [34] worked on seismic performance parameters of currently used fiber-cement board sheathed CFS shear panels aiming to compare the results of a new configuration type and current practices, Buonopane et al. [35] developed a computational model of a CFS shear wall representing the nonlinear behavior of each fastener by a nonlinear, radially-symmetric spring element. The analytical model is composed of a softening backbone curve, pinching, loading and unloading parameters. Physical tests on sheathing-to-stud fasteners have also been performed for backing up the analytical material model. The researchers eventually came up with an efficient overlap between computational approach and actual lateral behavior of the walls.

As a result of the observations on the conducted research relevant to CFS systems, it has been proven that they have satisfactory resistance against lateral loading, thus their use has been expanded to seismic-prone regions taking full benefit from energy absorption capacity (i.e. ductility). The main advantages of CFS systems can be listed as follows:

- Low seismic forces due to lightness of the material
- Practicability in the field (easy erection)
- Dimensional superiority
- High level of ductility and energy absorption capacity
- Environmental issues

In the scope of this research, displacement-controlled cyclic tests have been implemented on dissimilar configuration of CFS shear panels in order to observe the effect of different factors on the performance parameters. In case the experiments were conducted multiple times, namely two or three times for some of the specimens, the average of results has been used to represent the system for more accuracy (as long as the difference between two successive experimental results does not exceed 10%). Shear strength per unit length and strength reduction factors (R) of cold-formed steel shear panels have been obtained and presented in the content of this paper. The main motivation of this study was to perform cyclic loading tests on different configuration of CFS shear panels so as to examine the contribution of effects such as board type, steel thickness, screw spacing and axial loads on the seismic performance of shear panels as well as to obtain analytical models of shear panels to be used for 3-D structural analysis and seismic performance assessment. Ultimately, it was intended to utilize the nonlinear parameters that are obtained from the experimental results of large series of CFS shear panels, and to assess the global performance of a typical one-story structure. It was also aimed to determine the strength and ductility parameters of different configurations of CFS shear panels in order to embed the results in the new Turkish Seismic Code 2016 considering that the strength results may be different in Turkey due to manufacturing process.

2. Load carrying methodology of CFS shear panels

Lateral loading is resisted by CFS shear panels which are composed of CFS bare frame and sheathing board. For the structural level, it is desired to transfer the lateral loads to the shear panels by roof and floor diaphragms. The fundamental aim is to transfer the lateral load eventually to the foundation. In the first stage, lateral load is taken by the top track of the shear panel and then transferred to the sheathing panel via sheathing-to-frame fasteners. Therefore, it can be clearly deduced that board type, steel thickness and screw spacing take up a really significant role in assuring the satisfactory structural performance of a CFS shear panel.

The lateral load is transferred to the bottom track and then to the foundation by hold-down and shear anchors. The forces transferred from panel to studs via screws result in axial load on studs. To sum up the main picture relevant to the load carrying mechanism of a CFS framed structure, overturning moment and shear forces are two main forces acting on a CFS shear wall when a lateral load is applied to the top track (Fig. 1). Overturning moment is compensated with a force couple in the hold-down anchors on the tension side and the chord studs on the compression side whereas in-plane shear forces are resisted by the sheathing, sheathing to frame fasteners and ultimately by shear anchorage at the foundation.

3. Test specimens

In order to observe the effects of board type, steel thickness, screw spacing and axial loads on structural performance of CFS shear panels, different configurations have been selected as shown in Table 1. Properties in common for all of the specimens are summarized in Table 2. There are two sheathing types used on the specimens:

- Board Type 1: White gypsum based sheathing that is used for interior walls, partition walls, drywall linings and suspended ceilings. The core of this type is made from specially calcined high purity natural gypsum that provides lightness, hardness, resistance and workability to plasterboard.