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Testing and analysis of different hold down devices for CFS construction

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ABSTRACT

This paper summarizes the findings of a two-phase study on hold down devices used in cold formed steel (CFS) structural systems. The first phase consisted of component testing and numerical analysis of hold down devices while the second phase was based on testing of CFS framed sheathed wall panels under cyclic lateral loading. Eleven monotonic and three cyclic tensile load tests were performed on seven different types of hold down devices to assess the performance of readily available hold downs and propose new hold down geometries that employ hot rolled angle sections. Tests revealed that some of the hold down devices that have been used in CFS construction exhibited very poor behavior with significant deformation under loading. The experimentally observed deformation mode of all hold down device types was correctly captured by the finite element models. Experimental and numerical findings proved that a superior performance in terms of strength and stiffness can be obtained from a simple hold down device that is manufactured from a steel angle section. In the second group of tests, the proposed angle section geometry was further studied as part of oriented strand board (OSB) sheathed CFS framed wall panels that were subjected to cyclic lateral loading. Close agreement was observed between the wall panel test results and those obtained from the hold down assembly tests. Wall panel test results indicated that the angle type hold down device has adequate mechanical performance to develop the expected strength of OSB sheathed CFS framed wall panel.

1. Introduction

Hold-down devices are used in conventional cold formed steel (CFS) structural systems as part of the lateral force resisting system for the purpose of transferring the CFS wall panel chord stud forces between adjacent floors and to the foundation system at the wall base. In order to provide a proper load transfer, these devices need to have adequate strength and stiffness characteristics [1]. Failure of the hold down devices to meet the strength and stiffness requirements may prevent the lateral force resisting system to utilize its entire capacity and will negatively affect the performance of the structure against seismic and wind forces.

The capacity-based design approach adopted in the current AISI Standard for Seismic Design of CFS Structural Systems [2] does not consider the hold downs as energy-dissipating elements in seismic force resisting systems of CFS structures. Accordingly, the hold downs are required to be designed based on increased seismic forces considering seismic overstrength or the expected strength of the designated energy-dissipating elements. Even though the AISI Standard requires the strength and stiffness of hold-downs to be considered in design of seismic force resisting system, no method is provided explicitly for calculation of these properties. Therefore, laboratory testing is usually required in order to establish the mechanical response of such devices.

Another motivation for load testing of hold down devices, other than to obtain the design strength and stiffness, is to determine their mechanical response to use in numerical modeling of wall panels or the structure as a whole. Accurate numerical modeling of the restraint against uplift of wall panels requires a full characterization of the mechanical response of hold down devices.

Despite their importance on seismic response of CFS structural systems, the literature on behavior of hold down devices under tensile loading is very scarce. Besides the scientific literature, a few patented hold down devices are also available in the market [3–5]. The main reason for limited amount of research work on the subject is considered to be the fact that the manufacturer of hold down devices usually perform laboratory testing and tabulate the design load capacities under various circumstances. Nevertheless, damage on hold down, anchor rod, or the connection between hold down and CFS stud member has been observed by several researchers during load testing of sheathed or braced wall panels [6–9].

Baran and Alica investigated CFS framed sheathed wall panels under monotonic horizontal loading and observed extensive damage on hold down devices, which had a detrimental effect on the overall performance of wall panels [6]. It is also reported that due to hold down devices being the weakest link in the wall panel system, walls sheathed with double-sided OSB showed almost no appreciable increase in load capacity when compared with single-sided sheathed walls, while theoretically the load capacity is expected to double. Study of Wang and Ye [7] focused on the cyclic performance of two and three story

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CFS shear walls with reinforced end studs and they reported that sudden failure of the wall specimen was observed during one of the load tests because of damaged hold downs. Research work of Al-Kharat and Rogers [8] on strap braced CFS walls also revealed that hold down details directly affect the performance of wall panels. Due to damage occurred on flexible flat plate hold down, the measured initial elastic stiffness was reported to be in the range of 20%–26% of the expected nominal stiffness value. Work of Accorti et al. [9] showed that premature failure of walls with sheathing can happen due to tension failure of hold down anchor rods. Moreover, hold downs and hold down anchor rods might undergo severe stress conditions leading to reductions in the ultimate deformation capacity. Since contribution of hold downs to the overall structural behavior of CFS systems has great importance, there have been efforts to investigate this contribution by means of its effect on global response as well as to design hold down devices satisfying the required strength requirements and come up with more efficient hold down types [10–12]. Research work of Ozaki et al. [10] resulted in the development of a new hold down which is equipped with a fuse function and contributes to reducing damage in CFS framed buildings. Study of Iuorio et al. [11] focused on the lateral response of sheathed cold formed steel shear walls and investigated the behavior of force resisting system both in local and global scale. Work on local scale included the design of a hold down device and verification of the design by means of loading tests. Study of Fiorino et al. [12] investigated the influence of structural components on the overall behavior of CFS strap-braced stud walls by means of testing these components along with tests on shear walls. As part of structural components, hold down devices were subjected to loading tests, which showed the load capacity and different failure mechanisms for hold down devices.

A two-phase study was conducted to investigate the mechanical behavior of different types of hold downs. The first phase of the study consisted of component testing and numerical analysis of hold down devices and the second phase was based on testing of wall panels under lateral loading. In the component-testing phase, monotonic and cyclic tensile load tests were performed on various types of hold down devices, in an attempt to reveal the hold down geometries that can enhance the performance of CFS framed buildings. The hold downs tested as part of the study represent devices that are commercially available as well as a simple hold down geometry that is made of a steel angle section. Some of the hold down geometries were studied with additional test parameters in order to come up with construction details that would result in improved performance. In the second group of tests, the hold down that is made of a steel angle section was further studied as part of oriented strand board (OSB) sheathed CFS framed wall panels. Monotonic and cyclic lateral loading were applied on wall panels, keeping the hold down devices under tensile force effects.

The main objectives of this study are to assess the performance of different hold downs produced by various manufacturers, as well as to demonstrate that simple hold down geometries that are relatively easy and less costly to fabricate can satisfy the necessary strength and stiffness requirements. Scope of the study extends to load testing of CFS framed wall panels incorporating such simple hold down devices in order to qualify the performance of these devices when used in a wall panel.

2. Hold down test procedures and loading protocol based on AISI specifications

AISI S913-13 Specification [13] provides recommendations for load testing of hold downs, which is usually required in order to establish the strength and stiffness characteristics of these devices. In addition to the testing procedures, this specification also explains the procedures for evaluation of test results. Based on AISI S913-13, there are two recommended ways to test hold downs under tensile loads: hold down device test and hold down assembly test. Hold down assembly test simulates the field conditions, where the test setup includes cold-formed steel members connected to hold down devices with fasteners and hold downs connected to test bed with anchor rods. In the current study, hold down test specimens were created in a similar way as the AISI hold down assembly test specimens, except that the CFS sections were sheathed with oriented strand board (OSB) plates on both sides, as shown in Fig. 1. As indicated, the specimen geometry represents the bottom corner of a CFS framed sheathed wall panel.

Based on the experimentally determined load-deformation response obtained from hold down assembly tests, it is possible to determine the design load capacity of hold downs along with the maximum load capacity. In order to calculate the design load capacities, displacement limits are considered as stated in recommendations of AISI S913-13 [13]. These displacement limits are directly related with seismic design limits of CFS framed wall panel structural systems, where hold down devices are used as connectors. Accordingly, Load and Resistance Factor Design (LRFD) load capacity is taken as the smaller of 65% of maximum load attained by the hold down during testing or the load corresponding to 6.35 mm of vertical hold down deformation. Allowable Strength Design (ASD) load capacity, on the other hand, is taken as 70% of LRFD load capacity. Fig. 2 shows a generic load-displacement behavior of a hold down device and the definition of LRFD load capacity.

In the current study, both monotonic and cyclic loading protocols were used for hold down assembly testing phase. In monotonic tests displacement loading was applied on test specimens until failure occurred. Force controlled cyclic loading protocol recommended by CUREE (Consortium of Universities of Research in Earthquake Engineering) [14] was chosen as the cyclic protocol. The CUREE force-controlled cyclic loading protocol involves a reference force value, which is the maximum force the test specimen is expected to experience, and cycles at incrementally increasing force levels are based on this reference force value. Accordingly, reference force values for the cyclic tests were taken as maximum force capacity of hold downs obtained from monotonic testing. Based on the experimentally obtained reference forces, the cyclic loading protocol was created, as shown in Fig. 3.

3. Hold down test program

The geographical location of a CFS construction plays an important role in the selection of the type of hold down device used in a building. In North America patented off-the-shelf products are readily available and can be procured from department stores. These hold downs usually employ a special and sometimes complex geometry to increase the

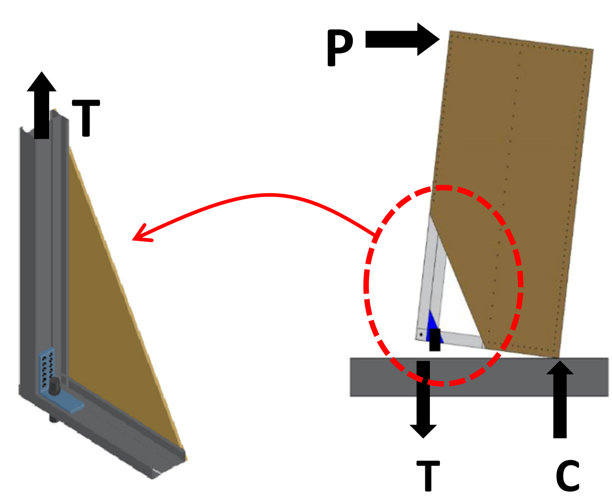

Fig. 1. Representation of specimens on CFS framed wall panel.