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Testing and design of cold-formed steel clip angles in tension: Pull-over and serviceability

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ABSTRACT

A cold-formed steel (CFS) clip angle is a common connector used in CFS building structures. This research project was conducted to investigate the behavior of the CFS clip angles in tension and to develop the corresponding design methods. The test program included two phases of testing: Phase I of program focused on the pull-over strength of screw connections on the anchored leg of the clip angles, and Phase II of program concentrated on the tensile strength of the anchored leg of the clip angles within the service deflection limit. Design methods for determining the nominal pull-over strength as well as the nominal tension strength of the clip angles with consideration of the serviceability were developed based on the test results. The Allowable Strength Design safety factors and the Load and Resistance Factor Design, Limit State Design resistance factors were also produced to support the proposed design methods.

1. Introduction

A cold-formed steel (CFS) clip angle is an L-shaped piece of steel member (normally with a 90-degree bend) which is typically used as connectors in CFS buildings. Fig. 1 shows an application of a clip angle in steel framing. As illustrated, the cantilevered leg of the clip angle may be subject to shear, axial (compression or tension), bending, or a combination of those three forces. A comprehensive test program was recently conducted at the University of North Texas to investigate the clip angles' behavior under shear, tension, and compression. Shear and compression test results and the recommended design methods have previously been reported by Yu et al. [1,2]. This paper focuses on the tensile capacities of the anchored leg of clip angle connectors in two limit states: screw pull-over failure and the deflection limit due to serviceability.

Ellifritt and Burnette [3] conducted a test program to simulate the pull-over strength in real building roof systems. The test program included the standard pull-over tests, the static suction pull-over tests and the dynamic pull-over tests. The static suction test results indicated that a reduction factor of about 0.4 of the standard tests gave a good estimate of the pull-over strength of a fastener in real building applications for the tested materia1 and configurations. Ellifritt and Burnette pointed out that the reduction was due to actual building practices in which the roof sheet is perpendicular to the screw axis and in a state of biaxial membrane tension when pulled in a direction parallel to the axis of the screw. This causes a completely different state of stress in the panel than that of the standard pull-over test performed on a small sample of the panel material.

The results of over 3500 tests were summarized by Pekoz [4] to formulate design provisions for CFS screw connections. Equations for determining pull-out strength and pull-over strength were proposed with a modification of the European recommendation provisions. The reliability index of 3.5 was adopted when determining the resistance factors and safety factors.

In order to provide a better understanding of pull-over connection failures, Kreiner and Ellifritt [5] performed standard tests in addition to simulated building tests. Rather than testing single components alone, the test apparatus included system testing which involves a vacuum box testing. A reduction factor of 0.235 was recommended by Kreiner and Ellifritt to the AISI equations for predicting the nominal pull-over strength according to the wider range of testing variables as well as the simulated building tests.

The research findings from Pekoz [4] form the design basis for screw pull-over strength in North American Specification for the Design of Cold-formed Steel Structural Members AISI S100 [6].

The objective of this research is to investigate the tensile capacity of

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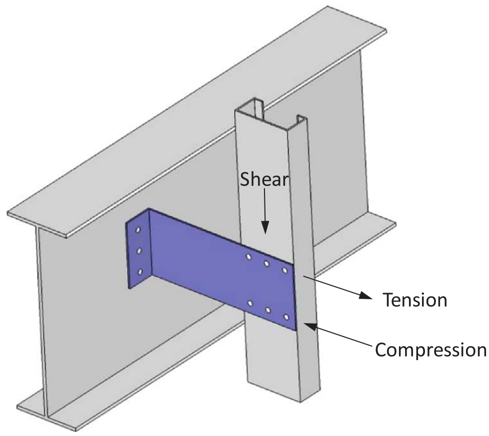

Fig. 1. Simple application of CFS clip angles.

the anchored leg of CFS clip angles when a tension force is applied perpendicularly to the bend line of the clip angle. The test program included two phases of testing: Phase I of program encompassed pull-over tests of screw connections on the anchored leg of the clip angles, and Phase II of program included tension tests of the anchored leg of the clip angles within the service deflection limit, which is 3.2 mm (1/8 in.) according to the Acceptance Criteria For Connectors Used With Cold-Formed Steel Structural Members ICC-ES AC261 [7]. Design methods for determining the nominal pull-over strength as well as the nominal tension strength of the clip angles with consideration of the serviceability were developed based on the test results. The Allowable Strength Design (ASD) safety factors, Load and Resistance Factor Design (LRFD), and the Limit State Design (LSD) resistance factors were also produced to support the proposed design methods.

2. Test program

2.1. Test setup and procedure

All tests were conducted in the Structural Testing Laboratory at the University of North Texas. Fig. 2 shows the tension test setup. The anchored leg of the clip angle was fixed to the steel base and the cantilevered leg of the clip angle was fastened to a 508 mm (20 in.) long CFS stud column using self-drilling screws. For clip angles with the nominal thickness of 1.37 mm (54 mil) or less, a 1.37 mm (54 mil) thick stud column was used. For clip angles with a nominal thickness of 1.73 mm (68 mil) or greater, a 3.00 mm (118 mil) thick stud member was employed. The CFS stud member was attached to a steel loading plate through two lines of No. 14 screws. Four Simpson Strong-Tie hold-

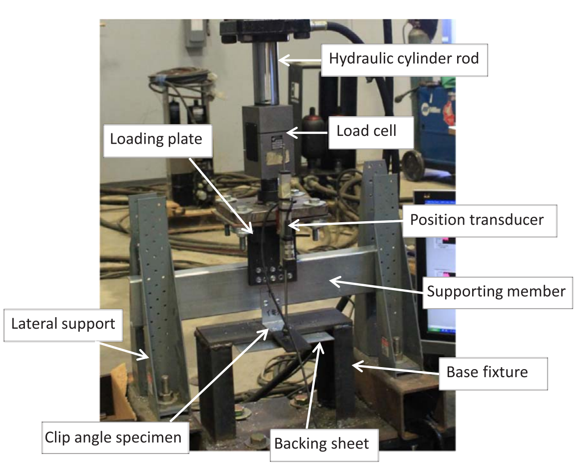

Fig. 2. Test setup for tension tests.

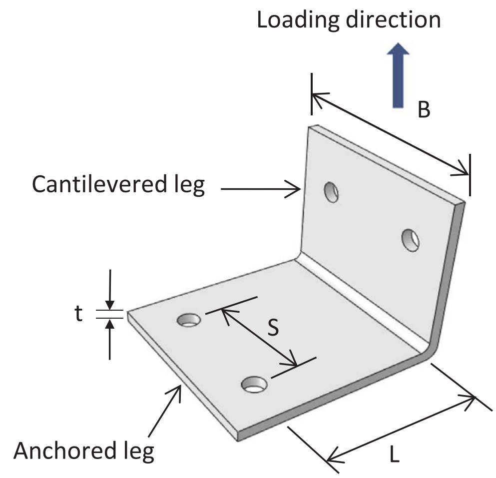

Fig. 3. Loading direction and measured dimensions.

downs, two on each side, were used as lateral supports to prevent out-of-plane movement of the stud member. A 3.00 mm (118 mil) steel backing sheet was used at the bottom side of the structural steel base to hold the screws in place to prevent the occurrence of screw pull-out failure. Fig. 3 illustrates the measured dimensions of the clip angles and the tension load direction.

A 203 mm (8 in.) stroke hydraulic cylinder was used to apply the tension load to the cantilevered leg of the clip angle. The hydraulic system included an electrical servo valve to control the hydraulic flow rate so that the moving speed of the loading plate could be controlled. The applied tension force and the vertical displacement of the clip angle were measured and recorded during the test. The vertical displacement of the loading plate was measured by a position transducer. A universal compression/tension load cell was installed between the end of the hydraulic rod and the loading plate.

All the tension tests were conducted in a displacement control mode. During the test, the loading plate was pulled upward by the hydraulic cylinder at a constant speed of 7.62 mm (0.3 in.) per minute. It was found that the selected loading rate was slow enough to have no apparent influence on the test results.

2.2. Test specimens

In Phase I of pull-over test program, No. 14 screws were used on the cantilevered leg of the clip angles in order to prevent any failures in the cantilevered leg. No. 8 or No. 14 screws were used in the anchored leg and the number of screws varied. A total of 49 tests were conducted in Phase I test program and 38 tests achieved the desired screw pull-over failure. Phase II of project included a total of 26 tension tests. Similar to the Phase 1 specimens, the cantilevered leg was fully screwed and the number of screws on the anchored leg varied. Both cantilevered leg and anchored leg used the same type of screws (No. 8 or No. 12 screws).

The nominal thickness of the test specimens ranged from 0.84 mm (33 mil) to 3.00 mm (118 mil). Table 1 and Table 2 list the measured dimensions, screw configurations, and tested material properties for phase I tests and phase II tests, respectively. As illustrated in Fig. 3, L measures the flat length of the anchored leg between the center of the first line of screws and the bend line; B is the width of the clip angle; and t is the uncoated steel thickness. The d_w' is the measured hex washer head integral washer diameter. The yield stress, Fy, and tensile strength, Fu, were obtained from coupon tests conducted according to ASTM A370 Standard Test Method and Definitions for Mechanical Testing of Steel Products [8]. The clips had pre-punched holes for all screws. The diameter of the pre-punched holes were 5.537 mm (0.218 in.) for "S", "4.5A", "4.5D" clip angles and 4.826 mm (0.19 in.) for "T" clip angles. The edge distance from the hole center to its nearest