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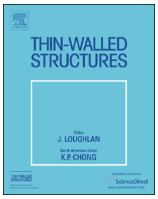

A statistical and experimental investigation into the accuracy of capacity reduction factor for cold-formed steel shear walls with steel sheathing

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ABSTRACT

Buildings constructed of cold-formed steel members are increasingly used in many countries. In recent years, cold-formed steel shear walls with steel sheathing were introduced as lateral force resisting systems. Design provisions of these structures require that the shear strength of shear walls with a height to width aspect ratio (h/w) greater than 2:1 be reduced by the factor $2w/h$ for satisfying allowable story drift limit. In this research, the accuracy of the factor is investigated using the results of previous tests and the tests performed by the researcher. Results show that the reduction factor ($2w/h$) is conservative. Thus, a relation is proposed for the reduction factor.

1. Introduction

Many advantages like rapidity, facility, and high quality in production and installation have made buildings with lightweight cold-formed steel frames more popular in recent years. In high-risk seismic regions, seismic behavior of these buildings is very important. Shear panels, supplying the structures with lateral resistance, are developed in different ways using materials such as structural wood, gypsum or cement boards or using braced frames. In recent years, using thin steel sheets as shear walls have also gained popularity and caught the researchers' attention due to their construction facility, favorable seismic behavior such as high lateral resistance, and high ductility. The above-mentioned system have already been approved as a lateral force resisting system in international codes such as IBC-06 [1] and ASCE7-10 [2], in which their design parameters have also been specified.

Fulop and Dubina [3,4] studied the performance of wall-stud cold-formed shear panels under monotonic and cyclic loading both experimentally and numerically. Pastor and Rodriguez-Ferran [5] presented a differential model of the hysteretic behavior of unsheathed x-braced frames. Xu and Martinez [6] determined lateral strength and stiffness of shear wall panels with cold-formed steel bracing experimentally and presented an analytical method. Lange and Naujoks [7] studied the behavior of cold-formed steel shear walls under horizontal and vertical loads and developed a design procedure based on the results of a large series of tests. Moghimi and Ronagh [8] evaluated the performance of cold-formed steel (CFS) strap-braced walls by experimental tests on full-scale $2.4 \times 2.4\ \text{m}^2$ specimens and presented some techniques to improve their behavior. Fiorino et al. [9] presented a seismic design procedure along with a procedure for the prediction of the whole pushover response curve of sheathed cold-formed steel shear walls. Yu [10] presented a research project aimed to add shear strength values for 0.686, 0.762, and 0.838 mm steel sheathed CFS shear walls with aspect ratios of 2:1 or 4:1. Yu and Chen [11] presented an experimental investigation on 1.83 m wide, 2.44 m high cold-formed steel (CFS) stud framed shear walls using steel sheathing through monotonic and cyclic tests. Pan et al. [12] focused on the experimental study of the structural strength of cold-formed steel wall frames with sheathing under monotonic shear loading. Martinez and Xu [13] presented a simplified approach for analyzing cold-formed steel buildings by using finite element methods.

In recent years, a series of experimental researches has been conducted on shear walls with steel sheathing in cold-formed steel structures in order to achieve such aims as presenting design values for these structures, adding new design parameters to the codes, verifying strength values presented in the codes and

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studying the differences between results of conducted tests. They also examined the effect of different details on the structures. These researches are briefly reviewed in the following.

The first study in which its results have come into the codes was undertaken by Serrette [14] in Santa Clara University, aiming to present design values for shear walls with steel sheathing in cold-formed steel structures. He tested some specimens with 2:1 and 4:1 aspect ratios, a height of 2.44 m, and steel sheathing width of 1.22 and 0.61 m. The thickness of frame members was 0.033 in. (0.84 mm), and the thicknesses of steel sheathing were 0.018 in. (0.46 mm) and 0.027 in. (0.69 mm). For performing cyclic tests, Serrette used Sequential Phased Displacement (SPD) load protocol.

Another research was also carried out by Yu [15] in the University of North Texas with the aim of adding new values to codes. He repeated some of the tests done earlier by Serrette. Yu utilized some specimens with the same dimensions as those of Serrette's with CUREE (Consortium of Universities for Research in Earthquake Engineering) loading protocol for conducting the cyclic tests. The thicknesses of frame members were 0.033 in. (0.84 mm) and 0.043 in. (1.09 mm), and the thicknesses of steel sheathing were 0.027 in. (0.69 mm), 0.030 in. (0.76 mm) and 0.033 in. (0.84 mm). The difference that noticed between the results obtained from Yu and Serrette's tests for the 0.027 in. (0.69 mm) thick sheet provided the rationale for another research conducted by Ellis [16]. He studied the effect of using CUREE and SPD loading protocols and of the manner of installing hold-downs by doing some cyclic tests. The specimens were of a 2:1 aspect ratio, a height of 2.44 m, and steel sheathing width of 1.22 m. The thicknesses of studs, tracks and steel sheathing were 0.043 in. (1.09 mm), 0.033 in. (0.84 mm) and 0.027 in. (0.69 mm) respectively. Another research was conducted by Yu [17] in the University of North Texas for verifying the values provided in AISI S213-07 (AISI Lateral Design Standard). This study was done for 0.46 and 0.69 mm thick sheathing and for investigating the behavior of shear walls with 4:3 aspect ratio, height of 2.44, and width of 1.83 m. The thicknesses of frame members were 0.033 in. (0.84 mm), 0.043 in. (1.09 mm) and 0.054 in. (1.37 mm), and the thicknesses of steel sheathing were 0.018 in. (0.46 mm), 0.027 in. (0.69 mm), 0.030 in. (0.76 mm) and 0.033 in. (0.84 mm). NisreenBalh [18] conducted another research in McGill University on the above-mentioned structure with the purpose of developing Canadian seismic design provisions for steel sheathed shear walls. He tested some specimens with 1:1, 2:1, and 4:1 aspect ratios, a height of 2.44 m, and steel sheathing width of 0.61, 1.22 and 2.44 m. The thickness of frame members was 0.033 in (0.84 mm) and 0.043 in (1.09 mm), and the thickness of steel sheathing was 0.018 in (0.46 mm) and 0.030 in (0.76 mm). All of the above-mentioned researchers used CUREE protocol in performing the cyclic tests, except for Serrette [14] who used SPD protocol. The results of these researches along with relevant details and characteristics are presented in Section 4. These results have been used in the present study.

The provisions specified in AISI S213-07 [19] and other similar codes require that the shear strength of shear walls with a height to width aspect ratio (h/w) of greater than 2:1 should be reduced by the factor $2w/h$ in order for satisfying the allowable story drift limitation. For walls with maximum aspect ratio specified as 4:1 in this code and other similar codes, the factor is calculated to be 0.5, which results in a conservative value for shear strength. According to these code provisions for shear walls with steel sheathing having an aspect ratio of lower than or equal to 2:1, no modification factor is used due to a high stiffness-to-shear strength ratio, and the reduction factor value is assumed one.

In this research, the accuracy of the reduction factor is investigated based on the findings of the tests performed by Yu in 2007 [15] and 2009 [17], NisreenBalh [18] and the tests performed in this study on shear walls with cold-formed members and steel sheathing having various aspect ratios, and the relation is suggested according to these results for reduction factor.

2. Problem definition

In case that the drift value corresponding to the shear wall design strength is greater than maximum allowable story drift, shear wall design strength is required to be reduced according to the allowable story drift in order to keep partitions and non-structural elements of the building safe from damage. In this regard, Eq. (1) is used to determine the reduction factor.

$$\text{Reduction factor} = \frac{\text{Allowable shear strength based on drift limit for seismic loads}}{\text{Allowable shear strength based on ultimate load limit for seismic loads}} \tag{1}$$

This factor was first published in the specifications for shear walls with cold-formed members and steel sheathing in AISI S213 [19]. In this publication, the safety factor (Ω) value for designing shear walls under seismic loads was 2.5, and the maximum allowable drift value for keeping non-structural components from damage was 0.5 in. which is the value of allowable story drift limit based on ICBO 1994. Therefore, the relation used for computing the reduction factor is given, for the first time, by Eq. (2).

$$\text{Reduction factor} = \frac{\text{Shear strength at 0.5 in story drift}}{\text{Nominal shear strength}/2.5} \tag{2}$$

According to IBC-06 [1] provisions, the inelastic drift limit of a structure is $\Delta = 0.025\,\text{h}$, which for a story height of 2.44 m (the shear wall height used in this study and previous ones), yields to 61 mm.

In ASCE7-10 [2] and IBC-06 [1], for structures classified in Risk Categories I and II, the allowable story drift is 0.025 times the story height. Assuming this limit for stories of 8-ft height (2.44 m), maximum allowable elastic story drift for SPD and LRFD design methods is determined in the following way.

$$\text{Drift limit for LRFD} = \frac{0.025\,\text{h}}{C_d} = \frac{0.025 \times 8 \times 12}{4} = 0.6\ \text{in.} = 15.24\ \text{mm}$$

$$\text{Drift limit for ASD} = \text{Drift limit for LRFD}/1.4 = 0.43\ \text{in.} = 10.88\ \text{mm}$$

In these codes, the safety factor for seismic loading is assumed 2.5. Therefore, using the foregoing values, the reduction factor for the allowable stress design method is determined using Eq. (3).

$$\text{Reduction factor} = \frac{\text{Shear strength at 10.88 mm story drift}}{\text{Nominal shear strength}/2.5} \tag{3}$$

3. Test program

In this study, four cyclic tests were carried out at Building and Housing Research Center laboratory starting from June 2012.

3.1. Test setup and the instruments

The instruments used for loading, receiving and recording output data, and controlling the events during the tests are listed below.

1. Triangular frames, 4 m long and 2 m wide, for supplying support for lateral loading.
2. Base beam, a 40-cm-high plate girder for attaching the specimen to the rigid steel floor of the laboratory.
3. Load beam connected to the top of the wall for lateral loading (IPB150); Four 1.2-in.-diameter bolts were used to fix the load beam to the top track.