Journal of Constructional Steel Research 107 (2015) 1–11

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Seismic performance of cold formed steel walls sheathed by fibre-cement board panels

Mehran Zeynalian [a,*], H.R. Ronagh [b]

[a] Department of Civil Engineering, The University of Isfahan, Iran
[b] School of Civil Engineering, The University of Queensland, Brisbane, Australia

ARTICLE INFO

Article history:
Received 19 July 2014
Accepted 5 January 2015
Available online 22 January 2015

Keywords:
Cold-formed steel
Fibre-cement board
Lateral performance
Seismic response modification factor

ABSTRACT

This paper presents an experimental study of cold formed steel frames sheathed by fibre-cement boards (FCB) under cyclic lateral loading. Four full scale fibre-cement shear walls were tested. Of particular interests are the specimens maximum lateral load capacity and the load–deformation behaviour as well as a rational estimation of the seismic response modification factor, R factor. The study also looks at the failure modes of the systems and investigates the main factors contributing to the ductile response of the CFS shear walls in order to suggest improvements so that the FCB sheathed walls respond plastically with a significant drift and without any risk of brittle failure such as connection failure or fibre-cement board fracture. Both double-sided and single-sided FCB shear panels as well as a new proposed configuration were studied. The study shows that while the overall performance of the currently in-use FCB sheathed lateral resistant system under cyclic loads is not satisfactory with a small average R factor of 2.5, the proposed FCB lateral resistant system can be considered as a reliable system with a much higher value of R factor of 5.

1. Introduction

Nowadays, cold formed steel, CFS, frames are widely used in housing industry especially in low rise residential buildings. They have many considerable advantages such as being cost-effective, light, and easy to work with. Compared to common hot rolled steel structures, the structural behaviour of CFS structures is more complicated as they are thin-walled and suffer from intersection plate instability. Although light-weight cold-formed steel walls are not new and have been used as non-structural components for many years [1], their application as main load-bearing structural frames is relatively new. As a result, appropriate guidelines that address the seismic design of CFS structures have not yet been fully developed and the lateral design of these systems is not covered in detail in the standards of practice as highlighted in the next section. Hence, more research work is required in order to clarify the many different aspects of their seismic performance.

Fibre cement board sheathed panel lateral resistant system is already being used in housing industry though there are very few studies on the structural performance of these systems. Hence, the aim of the current research is to evaluate the lateral seismic performance of currently in-use CFS fibre cement board sheathed shear panels. Moreover, a new configuration for FCB walls is investigated and its performance is compared to the other usual walls. This evaluation is completed by estimation of the seismic response modification factor for all panels, followed by a comparison with the recommended code values of the R factor.

2. Past studies' and standards' review

Pan and Shan [2] conducted a total of 13 full scale cold formed steel shear walls sheathed by calcium silicate boards as well as four unsheathed walls. The ultimate strength, stiffness, energy absorption, ductility ratio, and stiffness degradation of the frames under monotonic shear loads were investigated. They employed three different thicknesses of calcium silicate board for the frame's sheathing. They reported that individual sheathings placed next to each other worked as if they were one single unit when the horizontal displacement of walls was small but as separate units when the lateral deflection was large and screws tore into the sheet. They suggested that the ductility ratio of the tested CFS wall framing system as 2.53.

Fulop and Dubina [3] performed six series of full scale wall tests with various types of cladding arrangements including X-strap braced frames, corrugated sheathed walls, gypsum board sheathed panels, and oriented strand board (OSB) sheathed panels. Each series consisted of identical wall panels tested using both monotonic and cyclic loading regime. They found that in most specimens, strengthening of the walls' corners is fundamental as the failure starts at the bottom track in the anchor bolt region. Thus, the corner detail should be designed so that the uplift force is directly transmitted from the brace or corner stud to the anchoring bolt, so that it does not induce bending in the bottom track. Also they reported that the seam fastener represented the most

* Corresponding author. Tel.: +98 913 3139618; fax: +98 313 7932089.
E-mail address: m.zeynalian@eng.ui.ac.ir (M. Zeynalian).

http://dx.doi.org/10.1016/j.jcsr.2015.01.003
0143-974X/

sensitive part of the corrugated sheet specimens; damage is gradually increased in seam fasteners, until their failure causes the overall failure of the panel.

Al-Kharat and Rogers [4] studied the inelastic performance of 16 X-strap braced 2.4 × 2.4 m CFS wall studs experimentally. For this purpose, they tested three different types of X-strap bracing which were welded to the double stud chord sections under a cyclic loading regime. They concluded that the ductile performance of CFS walls which is reflected in some codes with R factor of 4, is not reliable and, for the medium and heavy walls, one should consider R = 3.

AISI standards [5–7] as one of the pioneer centres working on CFS framing systems prescribe a range of R factors between 2 and 7 for different basic seismic force resisting system though it emphasizes that some additional detailing is essential for R > 3. However, the code does not prescribe any R factor for FCB shear walls, specifically. American NEHRP recommended seismic provisions FEMA 450 [8], FEMA P750 [9] and the Technical Instructions, TI 809-07 [10] specify that the seismic response modification factor of 4 for diagonal strapping system. Also, the Australian cold-formed steel structures standard, AS/NZS 4600-05 [11], requires that when cold-formed steel members are used as the primary earthquake resisting element, the selected response modification factor shall not be greater than 2, unless specified otherwise.

Moghimi and Ronagh [12,13] investigated nine full-scale CFS walls with four different strap-bracing systems under cyclic loading, in addition to gypsum board sheathed CFS frames. They tried to achieve failure of the frames by yielding of the straps, since this is a desirable ductile failure mode for CFS strap frames. They reported that gypsum board cladding alone is not reliable, especially when compressive vertical loads are present. Moreover, they used brackets at the four corners of the frames where the chords were connected to tracks and showed that this improved the walls' lateral performance characteristics, such as strength, stiffness and ductility, when either single or double studs were used as the chords. They noted that, although using gusset plates provided ample room for straps to be connected to the panels and eliminated the possibility of failure in the strap-to-frame connection, this was not a practical method due to the potential aesthetic problems it may cause, such as the unevenness of the covering plasterboard.

Luiz and Schafer [14] provided stiffness and strength characteristics for walls comprised of cold-formed steel studs stabilized by sheathing. They separated the source of walls lateral stiffness into two parts: local and diaphragm. They conducted an experimental study on small-scale stud–fastener–sheathing assemblies to evaluate the local stiffness considering various sheathing type, stud spacing, fastener spacing, edge distance, environmental conditions, and construction flaws. They developed an analytical model in order to find the local stiffness when testing is unavailable. They also proposed an analytical model for the lateral stiffness supplied by the sheathing diaphragm action. They concluded that it is important to include both local and diaphragm stiffness.

Javaheri et al. [15] conducted an experimental study on 24 full-scale steel sheathed shear walls under cyclic loading regime with different configurations of studs and screws. Of particular interest were the specimens' maximum lateral load capacity and the load–deformation behaviour as well as a rational estimation of the seismic response modification factor, R. They concluded that decreasing the screw spacing enhanced the shear resistance capacity of the single end studs walls by around 17%. However, this enhancement was not seen for panels with double studs at the end. Also they reported that the R value of the panels tested varied in between 6.85 and 8.23 with the majority having been above 7.

Liu et al. [16] performed a series of cyclic tests on full scale oriented strand board sheathed cold-formed steel shear walls. They reported that the first energy dissipation mechanism happens at the fastener-to-sheathing connection behaving a severe pinched hysteretic behaviour. They fitted equivalent energy elastic plastic curves which were obtained from the experimental tests and Pinching4 models; and claimed that they were in a good agreement. They also reported that all tested walls had strength greater than those prescribed by the code AISI-S213-07 [7]; and the use of interior field studs with a lower thickness than the chord studs influenced on the shear wall strength.

Scrutinizing the above review, it is clear that there is no universal agreement on the value of response modification factor in general and there is none available for FCB shear walls. Therefore, more studies are required to clarify on this matter.

3. Seismic response modification factor

The concept of a response modification factor which was first introduced by the Applied Technology Council, ATC, in the ATC-3-06 report

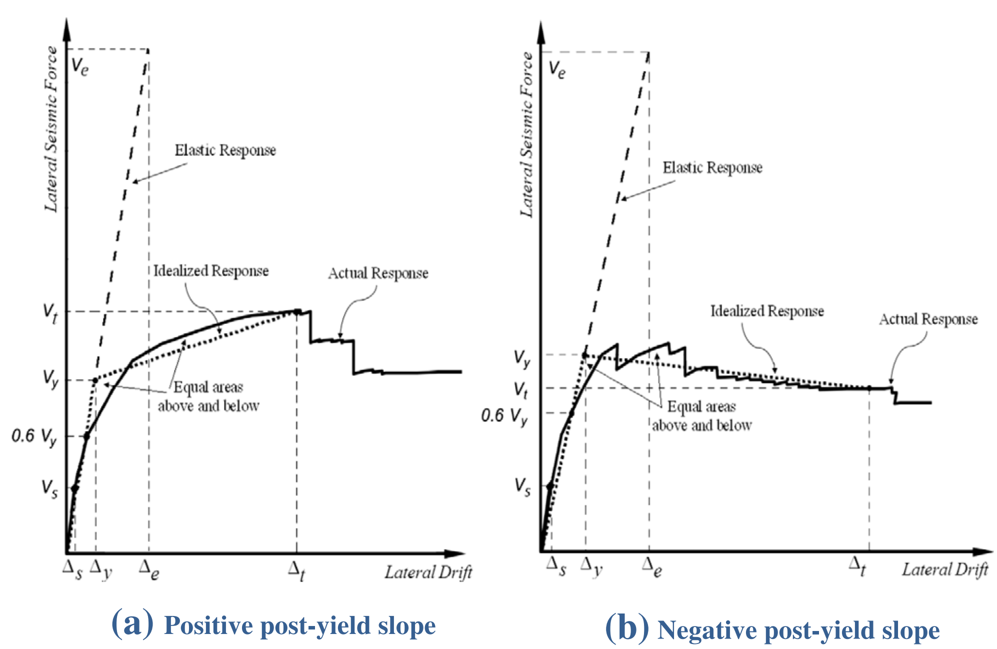

Fig. 1. General structural response, illustrating FEMA's concepts.