Journal of Constructional Steel Research 143 (2018) 148–161

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Seismic performance of high-strength lightweight foamed concrete-filled cold-formed steel shear walls

Zhifeng Xu [a,b,*], Zhongfan Chen [a,b,*], Bashir H. Osman [c], Suhang Yang [d]

[a] Southeast University, Key Laboratory of Concrete and Pre-stressed Concrete Structures of the Ministry of Education, Southeast University, 02, Sipailou, Nanjing 210096, PR China
[b] School of Civil Engineering, Southeast University, 02, Sipailou, Nanjing 210096, PR China
[c] Civil Engineering Department, Faculty of Engineering, Sinnar University, Sinnar, Sudan
[d] School of Civil Engineering, Changzhou Institute of Technology, 666, Liaohelu, Changzhou 213032, PR China

ARTICLE INFO

Article history:
Received 30 October 2017
Received in revised form 19 December 2017
Accepted 25 December 2017
Available online xxxx

Keywords:
Cold-formed steel
Lightweight foamed concrete
Shear wall
Straw board
Cyclic loading
Strut-and-tie model

ABSTRACT

To improve the seismic behavior of cold-formed steel (CFS) shear walls, cold-formed steel high-strength lightweight foamed concrete (CSHLFC) shear walls with straw boards are proposed. This study conducted tests of six full-scale shear wall specimens to investigate the failure mode, load-bearing capacity, ductility, stiffness characteristic and energy dissipation capacity. The test parameters included HLFC density grade, stud section area, wall thickness and vertical load. Test results indicated that HLFC has greater effect on seismic performance and failure mode of the shear walls. The failure modes were cracking and crushing of HLFC, cracking of straw boards, local buckling of studs, and relative slippage between HLFC and studs, which made the wall exhibit good ductility and energy dissipation capacity. Compressive bearing capacity of HLFC and restrictive effect of HLFC on steel frame increased the shear strength and stiffness. The most effective way of improving seismic performance was to increase wall thickness, followed by increasing HLFC density grade and stud section area, but increasing vertical load had an adverse effect on seismic performance. Based on experimental results and mechanism analysis of shear walls, a simplified design formula for predicting the shear strength was proposed base on strut-and-tie model. The calculated results obtained by the proposed formula showed better agreement with the experiment results compared with the results from ACI 318-14, EC8 and CNS 383-16 standards.

1. Introduction

Cold-formed steel (CFS) shear walls have been extensively employed in low-rise residential and commercial buildings to support vertical and horizontal loads such as earthquakes and winds [1–2]. The CFS shear walls typically consisted of CFS-frame and lightweight sheathing attached to the CFS-frame by self-drilling screw connections. Their benefits such as lightweight, low cost, easy installation, environmental characteristics and recyclability made them an attractive alternative in the construction of low-rise buildings in the USA, Japan, Australia, Europe and China. However, due to hollow structure of these traditional CFS shear walls, the walls exhibited poor thermal insulation and sound insulation property as well as low lateral stiffness and shear strength. With the promotion of green buildings and the rising demand of mid-rise buildings, these disadvantages limited the popularization and application of these traditional CFS shear walls in green residence buildings, especially in mid-rise buildings. One of the main problems restricting their practical application in mid-rise buildings was relatively low seismic performance. Therefore, the traditional CFS shear wall did not satisfy the requirements of seismic performance the mid-rise CFS structures.

To improve the seismic performance of CFS shear wall, many researchers have conducted to investigate the influence of various structural measures, mainly including the use of new type sheathing material (e.g. steel sheet [3–7] and double panel [8]), and the use of strengthening approaches for CFS frame (e.g. joint-strengthened knee element or X-shaped steel-strap bracing [2,9]). Experiment results proved that these structural measures improved the seismic performance of CFS shear wall to some extent, whereas the failure mechanisms of the walls were dominated by the local buckling of studs and the failure of screw connections between sheathing and steel frame. This indicated that the mechanical capacity of the new type sheathing and strengthening approaches has not been fully utilized. Therefore, to improve fastener connection performance and avoid premature local buckling of the studs, various filling materials were utilized in CFS shear wall. The filling materials mainly included ordinary concrete [1,10], lightweight mortar [2], glazed hollow bead mortar [11], lightweight concrete [12], lightweight foamed concrete (LFC) [13–14]. These investigations indicated that due to restrictive effect of filling material on the studs and fastener connections, the mechanical properties of the sheathing and the stud have been fully

* Corresponding authors.
E-mail addresses: zhf-xu@seu.edu.cn (Z. Xu), 101003944@seu.edu.cn (Z. Chen).

https://doi.org/10.1016/j.jcsr.2017.12.027
0143-974X/

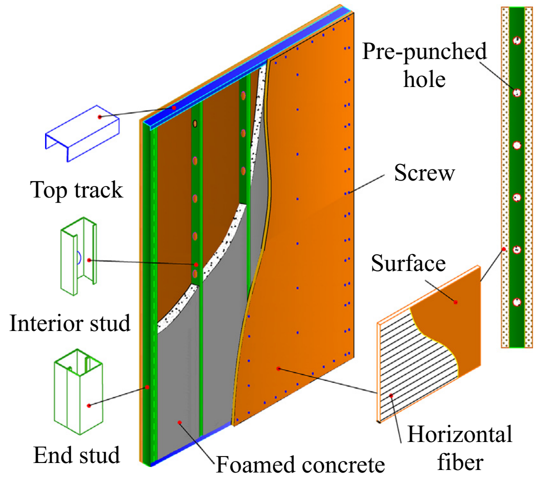

Fig. 1. Detail of CSHLFC shear wall.

utilized. The shear wall was observed to exhibit higher load-bearing capacity and stiffness than the traditional CFS shear wall.

Although these filling materials can improve the seismic performance of shear walls, several shortcomings cannot be overlooked. The mass of ordinary concrete was much greater than that of LFC, resulting in the increase of dead loads of the shear wall and the consequent increase of seismic base shear of the building during an earthquake. Ordinary concrete also exhibited poor thermal property that lead to reduce the wall's thermal insulation property. While the lightweight mortar, lightweight concrete and LFC showed lower compressive strength (0.8–2.0 MPa) that cannot effectively improve the shear strength of shear walls. Thus, high-strength lightweight foamed concrete (HLFC), as a new type of LFC, which developed from traditional LFC by optimizing the mixture ratio and appropriately construction technology, had been used in this paper.

In this research, based on the above analysis, a new type of CFS shear wall referred to as cold-formed steel high-strength lightweight foamed concrete (CSHLFC) shear wall with straw boards on both sides was proposed on the basis of full consideration of load-bearing capacity, thermal insulation and sound insulation property, as shown in Fig. 1. CSHLFC shear wall consisted of CFS frame, HLFC and straw boards. The straw board was a new type of sheathing consisted mainly of horizontally distributed natural crop straws. This sheathing not only resisted the horizontal loads similar to horizontal reinforcement of RC shear walls, but also was used as non-dismantling formwork for casting HLFC into the walls. According to Chinese Code GB 50176-2016 [15], the thermal conductivity of traditional sheathings, such as gypsum wallboard, calcium silicate board, fiber-cement board and cement particle board, were 0.33, 0.20–0.35, 0.23–0.34 and 0.19–0.34 W/(m·K), respectively. Based on the comparison of thermal conductivity, the straw board had a better thermal insulation property (thermal conductivity of 0.10 W/(m·K)), which improve the thermal insulation property of CFS shear walls.

Owing to the following features of HLFC, CFS shear walls with HLFC had better performances than traditional CFS shear walls: (1) HLFC had excellent physical and mechanical properties, such as light weight (i.e. lower density) and high compressive strength, as listed in Table 3, which reduced the dead load of the structural elements and the seismic base shear of the building. (2) HLFC as infill material not only resisted vertical and horizontal loads, but also restrained premature local buckling of studs and tilting of screws. This is beneficial to improve the bearing capacity of the shear wall. (3) HLFC had good thermal insulation property (thermal conductivity was only 0.12 W/(m·K)) because of its porous internal structure. It indicated that HLFC promoted thermal and acoustic property of the building. (4) HLFC protected the CFS frame against fire by package effect on CFS members, improving the fire-resistance property of CFS frame. Therefore, CSHLFC shear wall sheathed with straw boards has many advantages, such as shear strength, thermal insulation property (thermal resistance of 1.92 (m^2·K)/W) and sound insulation property, compared to the traditional CFS shear wall. These advantages makes the promotion and application of CSHLFC shear wall with straw boards in the field of urban and town mid-rise green buildings to be possible. And it also provides a new idea and a new research direction for the further study of the CFS shear walls, ensuring the sustainable development of CSHLFC shear wall structural system.

The main objective of this study is to investigate the seismic performance of shear walls, promoting them be applied to practice. An experimental program was carried out to test a number of shear wall specimens under reversed cyclic loading. The influence of various parameters, such as HLFC density grade, stud section area, wall thickness and vertical load on the seismic performance of these walls was examined. This included the effects on failure mode, strength, ductility, stiffness and energy-dissipation capacity. Experimental results were compared with the current seismic evaluation standards, such as ACI 318-14, EC8 and CNS 383-16. Then, a simplified formula based on strut-and-tie model was proposed to predict the shear strength of shear walls.

2. Experimental program

2.1. Test specimens

Six full-scale shear wall specimens were prepared according to Chinese Standard [16], including one CFS shear wall as the reference specimen and five CSHLFC shear walls, which represented the part of an existing CSHLFC shear wall building in China. HLFC density grade, stud section area, wall thickness and vertical load were considered as the main parameters. The wall specimens were divided into three types considering above mentioned parameters. All specimens were subjected to in-plane lateral reversed cyclic loading. The failure mode, load-bearing capacity, ductility, lateral stiffness and energy dissipation were investigated.

Table 1 summarizes the configuration details of the wall specimens. Specimen WA-1 without HLFC was considered as the reference

Table 1
Test specimen details.

Group	Specimen number	Wall thickness t_w (mm)	Section type of CFS members (mm)			HLFC density grade	Vertical load (kN)
			Interior studs	End studs[a]	Studs tracks		
Type A	WA-1	190	C90 90 × 50 × 15 × 1.0	□ C90[b]	U93 93 × 50 × 1.0	–	120
Type B	WB-1	190	C90 90 × 50 × 15 × 1.0			A05	
	WB-2	190	C90 90 × 50 × 15 × 1.0			A07	
	WB-3	190	C90 90 × 50 × 15 × 1.5	□ C90[c]	U93 93 × 50 × 1.5	A05	
Type C	WC-1	240	C140 140 × 50 × 15 × 1.2	□ C140	U143 143 × 50 × 1.2		
	WC-2	240	C140 140 × 50 × 15 × 1.2				160

Note: a. Coupled C sections (see Fig. 2). b and c. Section thickness of the studs were 0.9 mm and 1.5 mm, respectively.