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Seismic behavior of cold-formed steel high-strength foamed concrete shear walls with straw boards

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ABSTRACT

To satisfy the requirements of thermal insulation property and load-bearing capacity of cold-formed steel (CFS) shear walls in mid-high buildings, a new type of CFS shear wall referred to as cold-formed steel high-strength foamed concrete (CSHFC) shear wall with straw boards on both sides is proposed in this study. Straw board is an one-way slab consisting of horizontally distributed natural straw fibers and has excellent thermal property. High-strength foamed concrete (HFC) is a new type of lightweight foamed concrete with high compressive strength. Seven full-scale specimens with different configurations were conducted under reversed cyclic loading to assess the failure mode, load-bearing capacity, ductility, lateral stiffness and energy dissipation. The test parameters include HFC strength grade, aspect ratio, stud section type and opening of the specimens. Compressive bearing capacity of the HFC and restrictive effect of the HFC on the studs and screw connections significantly improved the wall's shear strength and lateral stiffness. Together with bond-slip behavior between the HFC and the studs, HFC cracking and straw boards cracking, these makes the walls exhibit better ductility and energy absorption. The failure mode typically includes local buckling of the studs, inclined cracking of the HFC and straw boards and relative slippage between the stud webs and the HFC. Enhancing HFC strength grade and increasing studs' section area could effectively improve the seismic behavior, whereas increasing walls' length could improve shear capacity and lateral stiffness. Comparison of the results between CSHFC shear walls and traditional CFS shear walls shown that the seismic performance of the CSHFC shear walls was much higher than those of traditional CFS shear walls.

1. Introduction

Cold-formed steel (CFS) structures, consisting of CFS members and lightweight sheathing, have been widely used in low-rise residential and commercial buildings in North America, Europe, Australia, Japan, and China due to their remarkable advantages, such as light weight, cost effectiveness, easy installation and recyclability. As the main force-resisting members of such structural systems, CFS shear walls typically consist of CFS-frames and lightweight sheathing attached to the CFS-frames by screw connections. The CFS shear walls are used to resist the horizontal loads such as wind and earthquake load, and support the vertical loads transferred from the floor and roof. Its design method has been proposed in applicable standards, such as American Iron and Steel Institute, AISI-S213 [1] and AISI-S240 [2] and AISI-S400 [3]. This type of CFS shear wall is still in the primary development phase.

To determine shear behavior of the CFS shear walls sheathed with various types of traditional sheathing materials, numerous experimental and analytical studies have been conducted on the oriented-strand board (OSB) [4–7], gypsum wallboard (GWB)[4–10], bolivian magnesium board (BMG) [8–11], calcium silicate board (CSB) [5,6,10–12], fiber-cement board (FCB) [9,13], sandwich panel [14], steel sheets [9,15–21]. The results showed that the fastener connection failure between the sheathing and the CFS frame and the local buckling of the studs were two main failure modes for CFS shear walls. The failure of the fastener connections between the CFS framing members and the sheathings was seen as a bearing failure of the wallboards, which decreased both the strength and initial stiffness of the walls. The shear capacity and energy dissipation capacity of the walls began to decrease after the appearance of the local buckling of the studs. Consequently, it is important to avoid fastener connection failure and

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premature local buckling of the studs, in order to improve the shear behavior of CFS shear walls.

In recent years, some researchers have proposed different techniques to improve the shear capacity of the CFS shear walls by avoiding fastener connection failure and restraining premature local buckling of the studs. Liu [22] conducted a series of reversed cyclic loading tests on cold-formed-steel-framed shear walls sprayed with lightweight mortar (SLM). The test results showed that the load-bearing capacity and lateral stiffness of the walls with SLM sheathing on both sides were quite high, because of the strong interaction between the steel frame and the SLM layers. CFS shear walls with SLM sheathing were found to exhibit good ductility and energy absorption due to a certain amount of slippage between the steel frame and the SLM layer, compared to the CFS shear wall with the traditional sheathing, such as gypsum board, CSB board and OSB board.

Wang and Ye [8] investigated the shear behavior of CFS-framed shear walls with reinforced end studs under cyclic loading. The results showed that the use of concrete-filled rectangular steel tube (CFRST) columns as end studs was observed to increase obviously shear strength of the walls by restraining early compression buckling of the end studs. The shear strength of the fastener connections was improved because the screws will be less able to tilt due to the concrete core of the reinforced end studs.

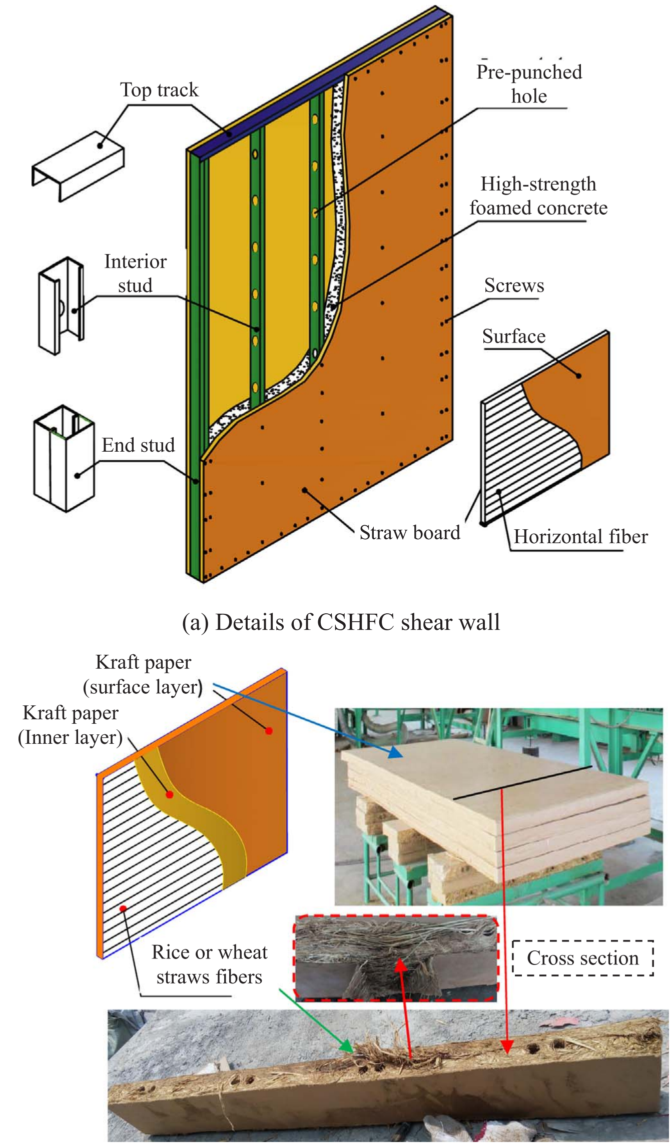
Yu and Pan [23] conducted the seismic behavior of CFS-frame shear walls filled with glazed hollow bead mortar. The results showed that glazed hollow bead mortar as infill material significantly improved the shear strength, lateral stiffness by restraining compression buckling of the surrounding steel elements. Because of the interaction between the steel elements and the glazed hollow bead mortar, the energy dissipation capacity of the shear walls was very high, compared to that of the wall without the glazed hollow bead mortar.

Prabha et al. [24], Md et al. [25] and Hegyi [26] studied the structural performance of lightweight steel-foamed concrete-steel composite walling system under compression and concluded that lightweight foamed concrete (LFC) or polystyrene aggregate concrete (PAC) as infill material was considered effective in restraining early local buckling of the steel sheets in the walls because of the interaction between the steel sheets and LFC. The walls was observed to exhibit higher load-bearing capacity and good ductility.

In engineering practice, the CFS-framed shear walls are required to meet thermal, acoustic, and fire resistance requirements. The thermal insulator in the form of lightweight foamed concrete (LFC) is located inside the cavities of the steel frames. The LFC is a lightweight cellular concrete consisting of Portland cement paste or mortar with a homogeneous pore structure, produced by introducing air in the form of minute bubbles [24–28]. Due to its porous internal structure, LFC has very low thermal conductivity, which improve thermal and acoustic performance of the shear wall buildings and fire resistance performance of the studs in the walls. To improve the thermal, acoustic and fire resistance performance of the structure, and satisfy the requirements of stability and load-bearing capacity of the CFS shear wall in mid-high CFS buildings, a new type of the CFS shear wall referred to as cold-formed steel high-strength foamed concrete (CSHFC) shear wall with straw boards on both sides is introduced in this paper.

As shown in Fig. 1(a), the CSHFC shear wall develops from the traditional CFS shear wall mainly consists of three components, including CFS frames (including studs and tracks), high-strength foamed concrete (HFC) and straw boards attached to the CFS frames by self-drilling screw connections:

(a) CFS frame is similar to that of the traditional CFS shear walls to mainly resist the vertical load, which is similar to vertical reinforcement of reinforced concrete shear walls by function.
(b) The straw board as a sheathing material is a kind of rectangular slab consisting mainly of horizontally distributed natural crop straws, and specific kraft papers pasted on the straw board's surfaces by colloid exuded from straw stalks (Fig. 1a). This wallboards can support the horizontal loads similar to horizontal reinforcement of reinforced concrete shear walls, but also are used as formwork for casting HFC into the walls. Compared to traditional sheathings mentioned above, the straw board as a sheathing material for CSHFC shear walls gives a significantly better thermal insulation property (thermal conductivity is 0.102 W/(m k)), higher cost-effectiveness and other unique advantages, waste utilization and eco-friendly. Moreover, the kraft paper (including surface layer and inner layer) on the straw board surface has good water-proof and moisture-proof properties, and thus HFC moisture has no effect on the straw boards, as shown in Fig. 1b. The straw board can be used as formwork for pouring HFC during CSHFC shear wall construction.
(c) The HFC develops from traditional LFC by optimizing the mixture ratio and appropriately construction technology, and the compressive strength of the HFC with the same density grade is approximately twice that of the traditional LFC. The HFC as infill material can resist vertical and horizontal loads similar to normal concrete of reinforced concrete shear walls, but also improve the load-bearing capacity of the studs and the connection behavior between the straw boards and the studs.



(a) Details of CSHFC shear wall

(b) Details of straw board

Fig. 1. CSHFC shear wall.