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Cyclic performance of cold-formed steel shear walls sheathed with double-layer wallboards on both sides

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ABSTRACT

To satisfy the requirements of fire resistance and loading capacity of the walls in multi-story cold-formed steel (CFS) structures, shear walls sheathed with double-layer wallboards on both sides were proposed. Sheathing materials in these walls included gypsum wallboard (GWB), bolivian magnesium board (BMG) and calcium silicate board (CSB). Cyclic loading tests on six full-scale walls of this configuration were conducted, from which the shear performance of the walls could be obtained. Factors such as the sheathing material, aspect ratio, stud section and stud spacing were considered. Another experimental study on the shear behavior of the screw connections was also performed to explore the potential relationship between the walls and the screw connections in shear performance. The results showed that the peak strength of the walls sheathed with bolivian magnesium boards as the face layer wallboards significantly exceeded the nominal value of the current standard. However, for the walls sheathed with calcium silicate boards as the face layer wallboards, the tested walls exhibited brittleness damage with poor ductility after the peak strength. The equivalent-bracing model was used to calculate the lateral stiffness of the walls, based on which a series of screw connection deformation limits and shear-wall drift angle limits was suggested.

1. Introduction

Cold-formed steel (CFS) shear walls have been widely used in residential and small commercial buildings in the USA, Japan, Australia, and Europe over the years because of their light weight, easy installation, and other advantages, such as environmental characteristics and recyclability [1–3]. In recent years, a growing number of multi-story buildings have been framed with CFS wall systems as the load-bearing structural components [4].

Because of the complex configuration of CFS shear walls, numerous experimental studies have been conducted to determine their shear performance. Studies on the influence of the sheathing material were performed by Fülöp and Dubina [1], Tarpy and Girard [5], Miller and Peköz [6], and Serrette et al. [7]. Lin et al. [2], Tarpy and Girard [5], and Pan and Shan [8] conducted experimental studies on CFS shear walls concerning the influence of the stud type and stud spacing. These experimental investigations indicated that using thicker and back-to-back end studs can prevent the end studs from distorting before the wallboards reach their full shear strength. However, there was no obvious difference in the shear performance of the CFS shear walls when the stud spacing was decreased. Studies performed by Shakibanasab et al. [3], Tarpy and Girard [5], Landolfo et al. [9], and Yu [10] showed that the influence degree of the aspect ratio depends on the ratio itself. In addition, the effect of the loading mode was also studied by Fülöp and Dubina [1], Lin et al. [2], Landolfo et al. [9], Balh et al. [11], and Nithyadharan and Kalyanaraman [12]. These studies focused on the walls sheathed with single-layer wallboards on one or two sides, which mainly applied to low-rise residential buildings because of their low shear capacity. For multi-story buildings, the loading capacity of the walls and the fire resistance of the sheathings are more important. Experiments performed by Fiorino et al. [13] and Nithyadharan and Kalyanaraman [14] confirmed that the strength and stiffness of the screw connections between the CFS framing members and the sheathings govern the CFS shear-wall behavior, and the failure of the screw connections was finally reflected in the bearing failure of the wallboards. Consequently, it appears notably important to improve the shear capacity of CFS shear walls by using panels with higher strength, such as wallboards, and to consider the fire resistance. Gypsum wallboard is a common anti-fire sheathing for internal wallboards. However, the contribution of gypsum wallboards to the shear capacity of CFS shear walls is small because of its low strength [5–7]. Bolivian magnesium board (BMG) and calcium silicate board (CSB) were adopted in this

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paper because of their good fire resistance performance and high strength [4]. Both types of boards were combined with gypsum wallboards in the form of double-layer wallboards to sheath both sides of the walls.

Specific properties of CFS shear walls, such as the shear capacity and the lateral stiffness, should be determined to provide the basis for the seismic design of such structures. Nominal shear strength for wind and other in-plane loads for the shear walls were provided in AISI-standard tables [15]. The available strength of the material of the same capacity is cumulative for the walls with material of the same type and nominal strength applied to opposite faces of the same wall, and never more than 30% of the total demand on lateral capacity shall be assumed to be provided by gypsum wallboards. The equivalent-bracing model was proposed in the Japanese standard [16], which can be used to evaluate the lateral stiffness of the CFS shear walls. However, these specifications and standards are mainly for walls sheathed with single-layer wallboards on one or two sides. For the walls sheathed with double-layer wallboards on both sides, the applicability of the described methods in these specifications and standards should be further investigated.

The PBSD (performance based seismic design) approach is based on the coupling of multiple performance levels and ground motion intensities, which generate performance objectives to be satisfied [17]. Different performance levels were defined in the USA, Europe, Japan, and China: (1) IBC [18] adopted single-level performance criteria, and two ground motion intensities (“design earthquake” and “maximum considered earthquake”) were considered to satisfy the “no collapse” requirement; (2) two-level performance criteria (“no collapse” and “damage limitation”) under different ground motion intensities were adopted in EC8 [19]; (3) BSL [20] adopted two-level performance criteria, which can be concluded as “no damage in moderate earthquake” and “no collapse in severe earthquake”; and (4) three-level performance criteria were proposed in GB 50011-2010 [21], which were concordant with those used in Europe and Japan, and can be concluded as “no damage in minor earthquake”, “repairability in moderate earthquake” and “no collapse in severe earthquake”. Although the application of the performance-based methodology has long been verified for ordinary reinforced concrete and steel structures, its application to CFS steel construction remains largely unexplored [9]. Consequently, it is necessary to divide different damage levels of CFS shear walls under different ground motion intensities to realize the PBSD in CFS structures.

This paper presents the test results of six full-scale shear walls sheathed with double-layer wallboards on both sides. Moreover, another experimental study on the shear behavior of screw connections under monotonic tensile tests was performed to build the relationship between the walls and the screw connections in shear performance. Details of the specimens, test procedures, and test results are presented. Based on the test results and considering the intimate relationship between the walls and the screw connections, methods to evaluate the shear capacity and the lateral stiffness of the walls are presented. Finally, a series of screw connection deformation limits and shear-wall drift angle limits is suggested based on the three-level performance criteria, which designers could reference and benefit from in practice.

2. Experimental program

2.1. Test specimens

The experimental program was based on six full-scale wall tests with different assemblies. The six configurations differed on the sheathing material, aspect ratio, stud section and stud spacing. Fig. 1

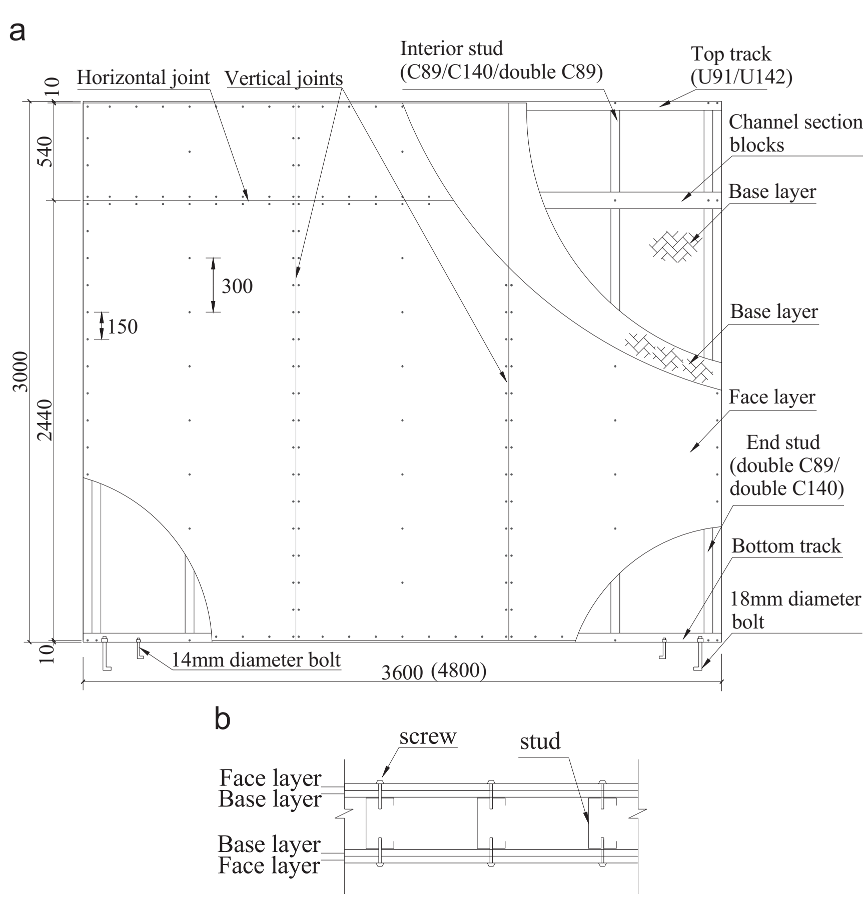

Fig. 1. Details of specimen configurations.