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Cyclic tests on corrugated steel plate shear walls with openings in modularized-constructions

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ABSTRACT

Thanks to the superiority in rapid and economic construction and the cooperativity with realization of building function, modular construction provides an excellent scheme for conventional on-site buildings with repetitive units. Corrugated steel plate is a widely adopted and efficient lateral force resisting component in modular construction. The extensive use is motivated by the large initial stiffness, high level of energy dissipation capacity and the ability to accommodate openings. However, it is lack of information regarding the detailed seismic behavior of corrugated steel plate shear walls (CSPSWs), particularly walls with openings. In this paper, five full-scale quasi-static tests on CSPSWs, with and without opening, were carried out to evaluate their seismic performance. The results reveal that although initial stiffness of CSPSWs is significantly reduced due to the opening, the ultimate strength and energy dissipation ratio are averagely 14.4% and 28.7% higher than the CSPSW without opening. Two different lateral-force resistance mechanisms are observed and discussed in details. Meanwhile, several design recommendations are also given for CSPSWs, which will provide useful references for the application of CSPSWs in seismic region.

1. Introduction

Pre-fabricated modular units permit rapid and economic construction and are increasingly used for apartments, schools, hotels, dormitories and other similar buildings where repetitive units are required [1–3]. Fig. 1 presents typical examples of modular construction composed of shipping containers and the common connection. The modular units are manufactured in fabrication yards, transported to construction site with a ready foundation and connected to each other in the corner region on-site. The connection devices lock the module units together by attaching through the top or bottom openings on the corner fitting by twist locks and bolts [4]. Improved accuracy and quality, fast on-site installation and reduced environmental pollution (e.g. noise, dust) are the main motivations for investors to prefer the modular method of construction. Further, detailed characteristics and applications can be found in the case study conducted by Lawson et al. [5–7], and it is proved that the arrangement of the lateral force resistance systems and the connections between the modules are crucial for modular steel constructions (MSCs). This paper mainly focuses on the lateral force resistance systems of MSCs.

Steel plate shear walls (SPSWs) have been widely utilized in the building constructions in high seismic hazard area due to their significant strength and ductility. Numerous studies have been conducted to investigate the lateral force bearing capacity, initial stiffness, energy dissipation, and buckling behavior of SPSWs under cyclic loading [8–9]. Structural and economic considerations may result in the design of SPSWs with unstiffened or stiffened infill plates. Shear buckling behavior of SPSWs is the main concern of the thin unstiffened SPSWs [11]. The buckling behavior of the thin infill plate can transform from global to local or interactive buckling by adding stiffeners [10]. Furthermore, stiffening the panel can obviously increase the amount of energy dissipated under cyclic loading. However, in the stiffened SPSWs, the construction cost is considerably higher due to its time-consuming welding of stiffeners. Corrugated shear panel is proposed in the latest research and adopted in this study as lateral force resistance system. CSPSWs have been verified to offer preferable seismic performance over flat plate including higher initial stiffness, improved buckling stability, out-of-plane stiffness and higher energy dissipation capacity [11–12].

CSPSWs, as evaluated in the present study, consist of rigidly connected frame beams and two frame columns to form a moment resisting frame with an infill corrugated steel plate (Fig. 2(a)) [13]. Due to the significant differences from traditional on-site buildings in terms of construction approach, CSPSWs in modular construction are quite distinguished from traditional shear walls in the followings aspects: i) Openings for

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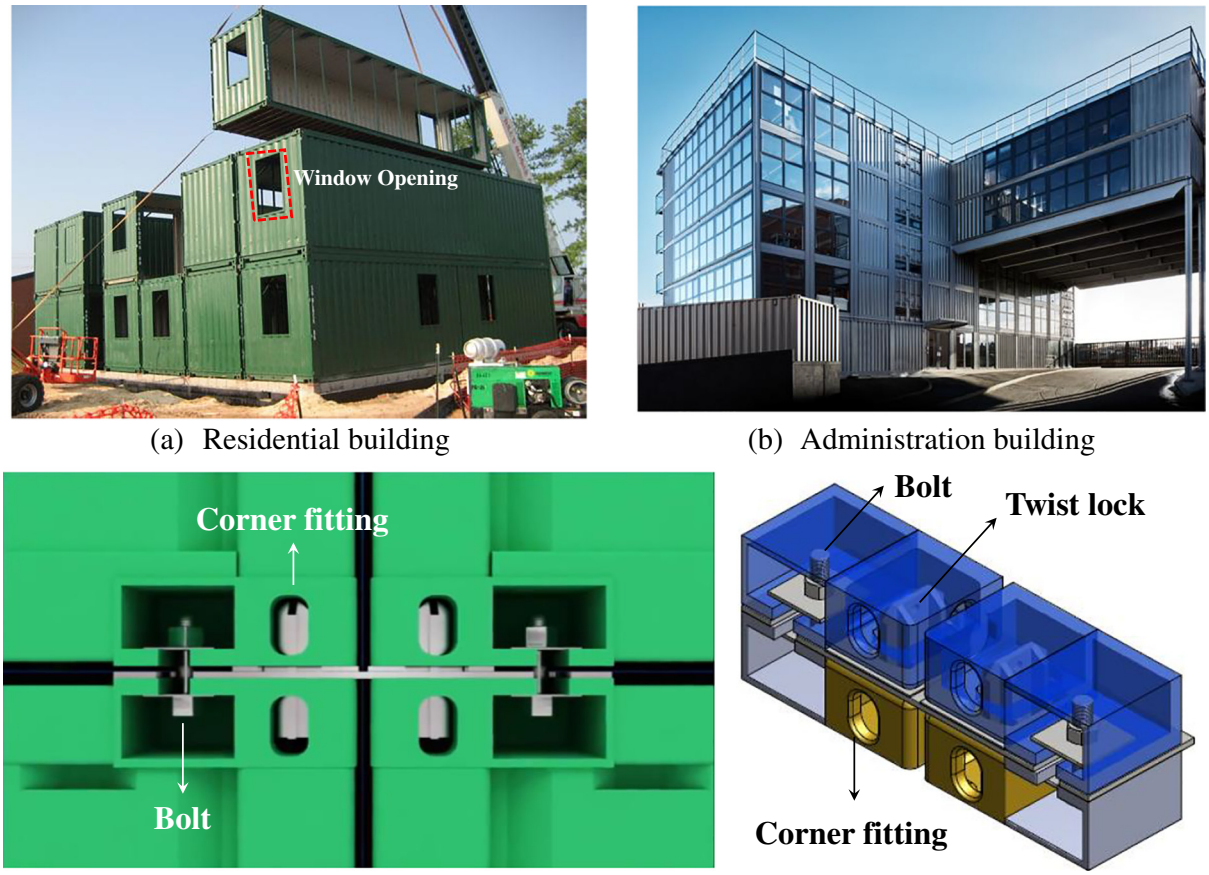

Fig. 1. Instances of modular construction.

building function: openings served as windows or doors are commonplace in the CSPSWs in MSCs for the realization of the building function. Fig. 2(b) shows a typical CSPSW with a window opening. Constructional columns around the opening are introduced into the shear wall to limit the shear buckling and preserve the shear capacity of the plate [14].

ii) Boundary condition: as shown in Fig. 1(a), CSPSWs in modular construction is connected merely in the corner region by connection between modular units, the frame beam of the upper module and lower module is separated. In spite of the extensive studies of CSPSWs in the literature [15–18], the seismic performance of CSPSWs in MSCs with

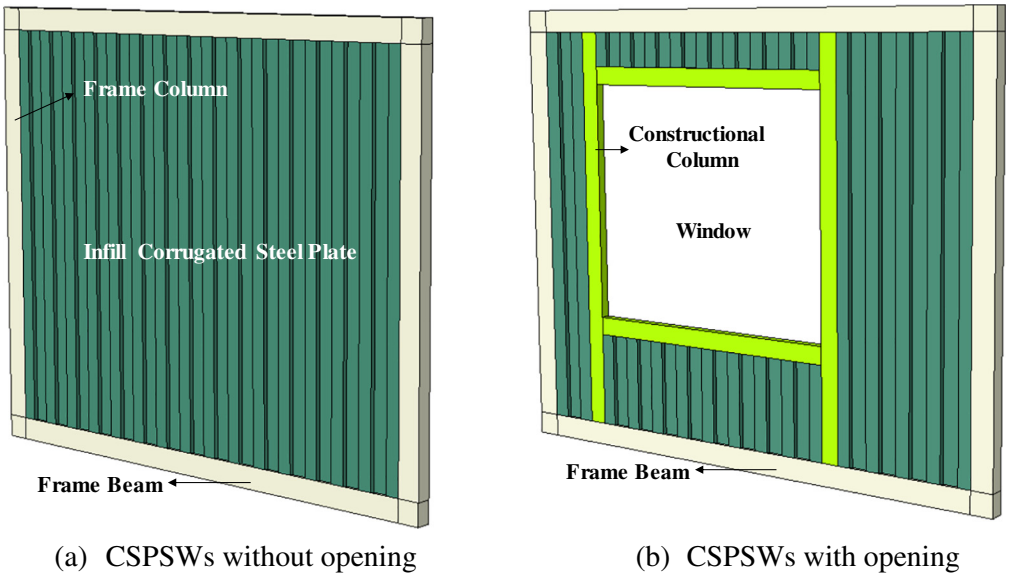

Fig. 2. Corrugated steel plate shear walls.