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Seismic behaviour of double skin composite shear walls with overlapped headed studs

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HIGHLIGHTS

- A novel DSC shear wall with overlapped headed studs was developed.
- Seismic behaviours of DSC shear wall were studied through quasi-static tests.
- Effects of parameters on seismic behaviour of DSC shear wall were evaluated.
- Theoretical models were developed for flexural resistance of DSC shear wall.

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ABSTRACT

This paper proposes a type of double skin composite (DSC) shear walls with boundary columns to make solutions to improve ductility of high-rise buildings. In this DSC shear wall system, overlapped headed studs were used to achieve composite action between the steel face plate and concrete core. Seven DSC shear walls were tested under combined axial compressive force and horizontal cyclic loads to evaluate the seismic behaviours of this DSC shear wall. Key parameters in this test program include height of overlapped headed studs, axial force ratio, introducing steel tubes in boundary columns, and aspect ratio of the DSC shear wall. The test results exhibited that the tested seven specimens failed in flexure mode characterized by local buckling of steel face plate, tensile fracture of steel boundary column, and concrete crushing. Test results also show that using higher headed studs in DSC shear walls improved their deformation capacity and energy dissipation capacity. Increasing axial force on the DSC shear walls did not compromise their energy dissipation capacities but slightly reduced their ductility. Introducing steel tube in the DSC shear walls significantly improved the ultimate resistance, ductility, and energy dissipation of the DSC shear walls. Decreasing the aspect ratio from 2.0 to 1.0 nearly doubles the ultimate resistance and energy dissipation capacity of the DSC shear walls. Theoretical models were also developed to predict the ultimate load carrying capacity of the DSC shear walls under horizontal loads. The validations of the predictions by the developed analytical models against 14 test results confirm the accuracy of the developed theoretical models.

1. Introduction

Reinforced concrete (RC) shear walls have been used in high-rise buildings for many years to resist horizontal forces that were mainly produced by wind and earthquakes. As the height of high-rise buildings keeps increasing, the increased base shear force, bending moment, and self-weight of the top structures acting on lower stories lead to the increased cross-sectional size of RC core shear walls since the compression ratio of these shear walls was limited to avoid severe damage during earthquakes [1,2]. This enlarged cross-sectional size of RC shear walls would minimize the leasable space of buildings and increase the mass of shear walls that amplifies the horizontal base shear force under earthquake loads. In addition, the increased requirement of ductility of RC shear walls resulted in increased amount of consumed reinforcements that usually brings in increased details of reinforcements. Double skin composite (DSC) shear walls could overcome these disadvantages of RC shear walls and offer effective solutions on increased ductility, reduced structural self-weight, and

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increased deformation ability. Thus, in recent 20 years, DSC shear walls have been used in nuclear facilities and high-rise buildings [1–3]. These developed DSC shear walls typically consists of two external steel face plates, a sandwiched concrete core, steel reinforcement mesh, and bonding headed studs or tying rods (bars). In order to simplify the construction procedure, Yan et al. [3,4] have proposed the DSC shear walls with overlapped headed studs that avoids using steel reinforcement mesh and tying bars as shown in Fig. 1. This type of shear walls combines the advantages of both steel and concrete materials, reduces the construction complexity, increases the construction efficiency, prevents the reductions of strength and stiffness due to spalling of concrete in the tensile and compressive zones, maintains structural integrity, and offers relative large strength as well as stiffness [5].

Pilot research on DSC walls may be contributed by Wright et al. [6,7]. In their studies, profiled steel sheeting was used as the external steel skin and no additional mechanical connectors or cohesive materials were taken at steel–concrete interface that would result in local buckling of the steel sheeting and compromise the seismic resistance of the DSC shear walls. DSC walls have also been used as the ice-resistant walls in the Arctic offshore oil platforms for protection purpose [8,9]. These reported DSC walls were in flat or curved shape [10–12]. Link and Elwi [9], Birdy et al. [10], Shukry and Goode [11], Marshall et al. [12], and Yan et al. [13–15] carried out a great amount of tests to investigate their out-of-plane shear or punching shear behaviour that considers the ice-contact pressure acting on the DSC walls. However, these experimental studies only focused on their out-of-plane behaviours that were different from the working state of DSC shear walls in the high-rise buildings. In the past two decades, research on applications of DSC walls in nuclear constructions keeps increasing in Japan, Korea, and USA. Emori [16], Takeda et al. [17], Takeuchi et al. [18], Choi and Han [19], and Varma et al. [20,21] make great efforts on investigating the in-plane structural behaviours of the DSC walls used in the nuclear constructions. Continuous works on this topic were contributed by Zhang et al. [22], Sener and Varma [23], Kurt et al. [24], and Epackachi et al. [25]. However, these researches focused on the structural behaviours of DSC walls used in the nuclear facilities, and the dimensions of these walls were different from those DSC walls used in buildings. In recent ten years, researchers start to apply the DSC shear walls in high-rise and super high-rise buildings (height $\geq$ 300 m) that offer an efficient solution between seismic resistance and deformation capacity [1–2,26–32], e.g., Yancheng TV tower, Beijing Fortune Plaza [33], China Zun Tower [34], and World Trade Center of Beijing [35] in P.R. China. These developed DSC shear walls typically consists of two steel face plates with welded short headed studs, reinforcement mesh, tie bars or through bolts, and boundary columns. The in-plane seismic behaviour of these proposed DSC shear walls working with the boundary columns have been reported by Nie et al. [1], Ji et al. [26,27], Lv et al. [28], Ho et al. [33], Liu et al. [20], and Ge et al. [35]. In their studies, the headed stud connectors were still quite short (their height is usually smaller than half of thickness of the DSC shear wall) and additional tie bars or through bolts were used in the DSC walls. Thus, the in-plane seismic behaviour of DSC shear walls with overlapped headed studs so far has not been fully investigated. And the influence of overlapping length of the headed stud on the seismic behaviour of DSC shear walls has not been fully studied. Thus, it is of interest to carry out experimental studies on the in-plane seismic behaviour of the DSC shear walls with overlapped headed studies to obtain more comprehensive information for the application of such type of DSC shear walls in high-rise buildings.

This paper firstly proposed an innovative DSC shear wall with overlapped headed shear studs. In this developed new type of DSC shear walls, overlapped headed shear studs were used to further reduce construction difficulties that include removals of additional shear reinforcement mesh and tie rods or through bolts in

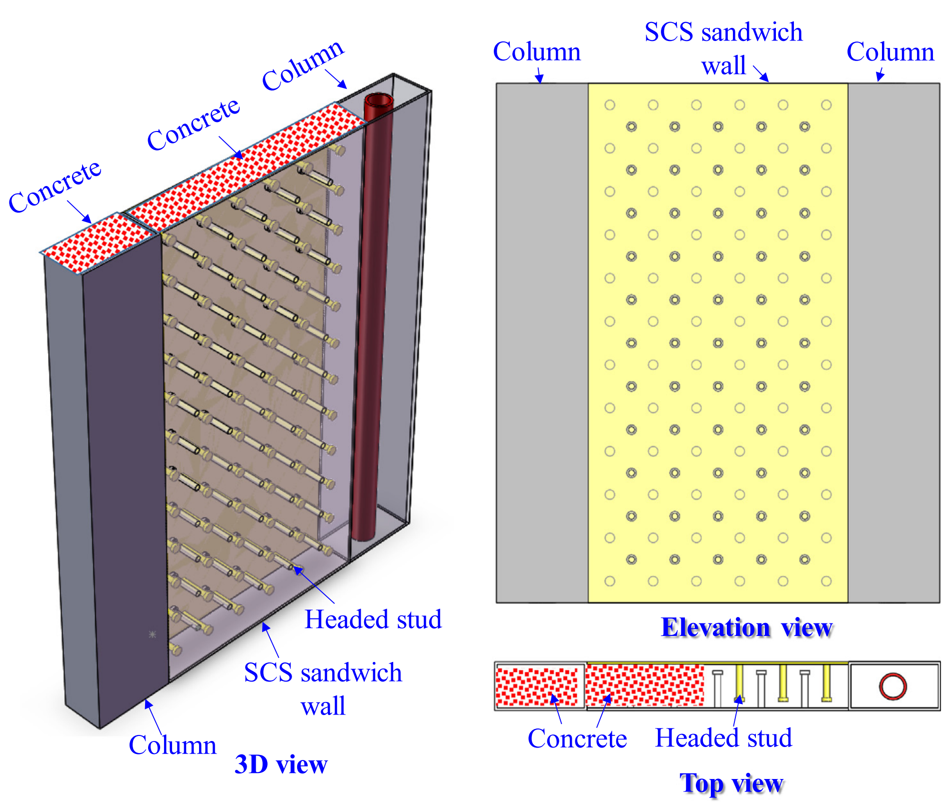

Fig. 1. DSC sandwich shear wall.