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Structural performance of profiled composite wall under in-plane cyclic loading

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ABSTRACT

This paper presents the behaviour of a composite walling system consisting of two skins of profiled steel sheeting and an infill of concrete under in-plane cyclic shear loading. Double skin composite wall (DSCW) specimens with overall wall dimensions of 1626 mm high by 720 mm wide were tested. Steel sheet–concrete connections were provided by intermediate fasteners along the height and width of the wall to generate composite action. Two types of concrete namely self-consolidating concrete (SCC) and highly ductile engineered cementitious composite (ECC) as well as cold formed profiled steel sheet having same geometry but with two different yield strengths were incorporated to investigate their influence on the composite wall behaviour. The benefit of using mild over high strength steel was demonstrated through more ductile failure. Overall, ECC wall showed better performance showing lower stiffness degradation and higher displacement ductility as well as higher energy ductility (based on hysteretic loop) compared to its SCC counterpart.

1. Introduction

Reinforced concrete (RC) shear walls have been traditionally used as lateral load resisting systems in many structures [1–3]. Steel plate shear walls have been also used as lateral load resisting system in mid-rise and tall buildings [4]. A steel–concrete composite shear wall can have the benefits of both steel and RC shear walls and yield the best traits of concrete and steel. In recent years, researchers have paid attention to composite walls made of flat steel plate and concrete [5–12].

Zhao and Astaneh-Asl [5] carried out experimental studies on one bay – three-storey composite shear wall specimens consisted of a reinforced concrete panel bolted to one side of a steel plate wall by applying cyclic displacements according to the AISC specifications [13] for seismic provisions for structural steel buildings. Composite shear walls had shown high ductility and good lateral load resisting properties. The maximum inter-storey drift was more than 5% and the system withstood up to 4% inter-storey drift without any reduction in the shear strength. Qian et al. [7] proposed an innovative composite shear wall with enhanced seismic performance, named the steel tube-reinforced concrete composite wall, with steel tubes embedded at the wall boundary elements and fully anchored within the foundation. A series of quasi-static tests were conducted to study the behaviour of these walls subjected to high axial forces and lateral cyclic loads. The test results showed that the composite walls had larger load-carrying, deformation and energy dissipation capacities relative to the traditional reinforced concrete wall counterpart.

Hu et al. [8] studied seismic resistance of concrete-filled steel plate composite shear walls by analysing deformation capacity and interaction of geometric and material properties. The developed simplified formulas based on geometric and material inputs for calculating the ultimate curvature associated with a 15% loss in moment capacity that can be used to calculate the drift capacities and ductility of composite shear walls. Nie et al. [9] carried out experimental and theoretical investigation on composite shear walls made of two steel plates with studs inside, side columns made of steel tubing, and an infill of concrete. A model for calculating the effective shear stiffness of the composite shear wall is derived and its predictions correlate well with the test results. Nie et al. [10] also investigated a high-strength concrete filled double-steel-plate composite walling system to improve the ductility of the core wall in super high-rise buildings. Twelve wall specimens were tested under large axial compressive force and reversed cyclic lateral load. All the specimens exhibited good energy dissipation ability and deformation capacity with full

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Nomenclature

σ_{p1} and σ_{p2}	maximum and minimum principal stresses, respectively
ε_{p1} and ε_{p2}	maximum and minimum principal strains, respectively
E_s and E_c	modulus of elasticity of steel plate and concrete, respectively
v_s	Poisson's ratio of steel sheet
γ_{max}, τ_{max}	maximum shear strain and maximum shear stress, respectively
F_y	yield strength of profiled steel sheet
f'_c	cylinder compressive strength of concrete
d_v; h	width of the steel sheet or wall or effective shear depth/width and height of the wall, respectively
DSCW	double skin composite wall
SCC	self-consolidating concrete
ECC	engineered cementitious composite
HSS	high strength steel
MSS	mild strength steel (MSS)
V	applied cyclic lateral load at the top of the wall
V_y	lateral load at approx. $0.85V_{peak}$
V_{peak}	peak load derived from monotonic test
Δ	horizontal displacement at the top of the wall
Δ_y	horizontal displacement at V_y
μ_Δ	displacement ductility ratio

hysteretic curves and large ultimate drift ratios, thereby good potential for the system in seismic-resistant structures.

Ji et al. [11] proposed a composite wall consisting of concrete filled steel tubular boundary elements and a double "skin" composite wall web where two steel plates are connected by tie bolts with space between them filled with concrete. A series of tests involving five slender rectangular wall specimens subjected to axial forces and lateral cyclic loading was conducted. The specimens were failed in a flexural mode showing local buckling of the steel tubes/plates, fracture of the steel tubes, and concrete crushing at the wall base. Simplified formulas developed for the flexure strength of the composite walls were found to be in good agreement with the test results.

Rahai and Hatami [12] conducted tests on the effect of shear connector spacing variation on the composite shear wall behaviour. The experimental tests were performed on small scale, single bay, and one storey composite shear wall specimens consisting of 3.3 mm thick steel plate and 50 mm thick reinforced concrete panel attached to one side of the steel plate by bolts. Cyclic loadings were applied at top of the specimens. It was observed that the decreasing distance between the bolts increases the absorbed energy in the shear wall and reduces the value of the out of plane displacement of steel. Eom et al. [6] tested double skin composite walls composed of two steel plate "skins" connected by tie bars, with the space between them filled with concrete. The cyclic testing was performed to investigate the seismic behaviour of isolated and coupled double skin composite walls. The wall specimens failed mainly by tensile fracture of the welded joints at the wall base and coupling beams, or by local buckling of the steel plates. Because of their large depth, the ductility of the wall specimens was not as good as that of beams having less depth. In particular, the ductility of the walls was significantly affected by the strengthening methods used for the wall base.

The idea of sandwiched double skin composite wall (DSCW) was originated from the floor system using profiled steel deck and concrete [14,15]. A typical DSCW system consisting of two skins profiled steel sheets and a concrete infill is shown in Fig. 1. Such composite walling as shear or core walls in steel frame buildings has many advantages. In building construction stage, profiled steel sheeting can act as a bracing system to the steel frame against lateral loads and also can act as a permanent formwork for infill concrete [16]. During the in-service stage, profiled steel sheets and infill concrete work together to resist lateral loads [16]. Research has been conducted on the axial, flexural and shear load resistance of the DSCW system [17–22]. The interaction between the profiled steel sheet and concrete has an important role in the composite action of the DSCW system. The interface shear bond failure is a limiting criterion for designing this kind of system [17–20]. The bond between the steel sheet and concrete can be improved by embossments or using other forms of shear connector. The mechanical interlock at the sheet–concrete interface may govern the brittle or ductile mode of failure of such composite wall [17–20].

Previous research studies [16–22] conducted on the DSCW system under monotonic and cyclic shear loadings have the following shortcomings: steel sheets and concrete were connected only at the boundary (no sheet–concrete interface connections within the panel) causing premature steel sheet buckling, no variability in concrete types (besides ordinary concrete no new generation of high performance concrete was used), used small-scale tests without using commercially available profiled steel sheets. It is important to prevent the buckling of profiled steel sheets in order to increase the shear resistance of the DSCWs.

Current research addresses the above mentioned shortcomings of previous research studies [23–25]. The buckling of steel sheet is prevented by using adequate intermediate fasteners (acting as

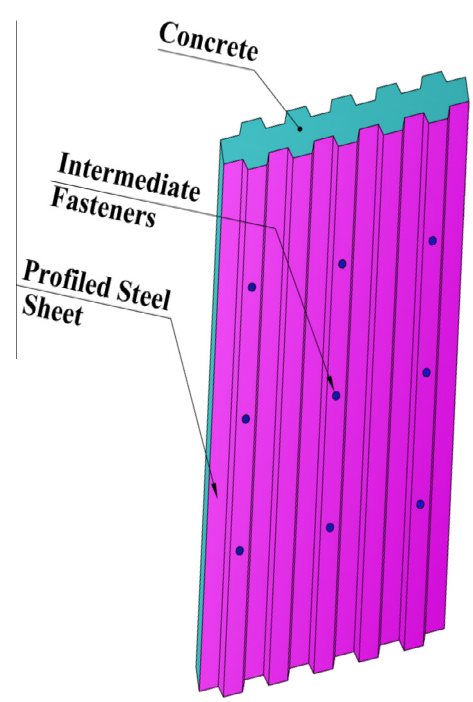

Fig. 1. Application of composite walling system in building.