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Review

A state-of-the-art review on double-skinned composite wall systems

Salam J. Hilo [a,b,*], W.H. Wan Badaruzzaman [a], S.A. Osman [a], Ahmed W. Al-Zand [a], Marwan Samir [a], Q.A. Hasan [a]

[a] Department of Civil and Structural Engineering, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia
[b] Building and Construction Engineering Department, University of Technology, Baghdad, Iraq

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ABSTRACT

The behavior of double-skinned composite walls (DSCWs), with or without infill materials, has been extensively investigated during the past few decades through analytical, experimental, and numerical methods. These investigations have resulted in new design methods for primary design objectives as well as time saving and economical purposes. This paper summarized numerous studies on three types of composite walls (CWs), namely, double-skinned profiled steel sheeting, double-skinned flat steel sheeting, and profiled-flat sheeting with or without infill materials. CWs were classified based on the type of sheeting (profiled, flat, and dry board) and the applied loading (axial, cyclic, lateral, impact, thermal, or a combination of any two). The interaction between sheets and infill material was reviewed in detail through classification. Afterward, the effect of openings on the structural behavior of DSCWs was studied and explained in detail. Finally, all previous studies were remarked on and reported in comprehensive tables, which present the parameters studied and the remarks made on each study.

Contents

* Corresponding author at: Department of Civil and Structural Engineering, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia.
E-mail address: eng.salamjh@gmail.com (S.J. Hilo).

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1. Introduction

Reinforced concrete and steel plate shear walls are traditionally used as axial or cyclic load-resisting systems in structures such as mid-rise and high-rise buildings. Extensive research works have been carried out in the recent past on various steel structural elements acting compositely with reinforced concrete structural components. Such as, composite slabs – with or without steel decks, composite beams, encased or in-filled columns are some of the composite structural elements that have been widely researched. During the development process, a more efficient composite wall (CW) called the double-skinned composite wall (DSCW) was introduced, which consists of two sheets infill with concrete. DSCW was developed from composite flooring, which is popular and commonly used today [1]. It has the benefit of acting as bearing, retaining, and shear walls and can be used in nuclear power plants because of its unique materials [2]. Applications of the DSCW system in buildings are presented in Fig. 1.

The DSCW system has become the preference in many seismic-resistant structures because the presence of the profiled steel sheet (PSS) provides improved shear capacity and ductile resistance to subsequent cycles of overload [3] and reduces concrete cracking [4].

DSCW can be used as earthquake-resistant structures, bearing walls, retaining walls and shear walls to support high-rise buildings. Owing to the increasing use of CWs, extensive theoretical, experimental, and numerical works have been conducted.

This paper presents the state-of-the-art knowledge on DSCWs, including analytical, experimental, and numerical studies. The literature is classified into three types based on DSCW shape, namely, double-skinned profiled steel sheet composite wall (DPSCW), double-skinned flat steel sheet composite wall (DFSCW), and profiled sheet–flat sheet composite wall (PFSCW). Further classifying of the DSCWs based on different types of loading which include axial, cyclic, impact, eccentric, thermal, and a combination of any two loadings, are also been considered. The effect of openings on the structural behavior of the DSCW will be presented in detail and considered based on the classifications which are presented in Fig. 2. Finally, interaction types between sheets and infill materials are presented in detail for each research through this study.

A summary of each section reported in literature is presented in tabular form, including the use of infill material types, interaction technique, study type, parameters, and remarks, and is briefly outlined. A detailed discussion for each type of classification is presented in this study and combined in one section, which includes the main benefit of each DSCW type, best interaction technique, numerous gaps, and various suggestions to provide a clear vision for researchers interested in these unique CW systems.

2. Behavior of double-skinned composite walls

The design of DSCWs comes from the composite flooring system (profiled steel sheet-dry board) developed by Wright et al. [8]. This flooring system has many advantages that allow it to be applied in office buildings, domestic buildings, or during renovation for various structural purposes, such as roofing, flooring, and walling [9].

To achieve the composite action between steel faceplates and concrete, previous studies have suggested numerous interaction types. With the use of steel-headed shear studs, through–through bolts, fastener screws, post-tension anchor bolts, hooks, tie rods, stiffeners, batten plates, and normal studs to tie the sheets and the core concrete, the stability of steel plates was enhanced and loading resistance was increased by degrees of steel sheet buckling, which also worked as reinforcement for the core concrete.

The major parameter in the design of CW structures is the plate sheet type and shape subjected to various loadings. Based on this parameter, DSCWs can be classified according to sheet design and loading type. Interaction types between sheets and infill materials will be explained in detail through the classifications for each research.

2.1. Double-skinned profiled steel sheets infill with concrete composite walls

DPSCW infilled with concrete is a new type of CW that consists of two PSSs infilled with concrete (Fig. 3). It has a potential application as a bearing, retaining, and shear wall to resist axial, lateral, and cyclic loads. The development of DPSCWs came about as an extension of the composite flooring system, which is currently very popular worldwide [10]. This type of CW has the benefits of having both PSSs and infill concrete that can resist axial loads, such as reinforced concrete thin walls, which are now well-known and widely used [11]. Ensuring the load resistance of DPSCW is a key consideration in designing a building's structural system. Given the various types of loadings applied on this type of CW through literature, the current paper suggests classifying it under each type of loading to provide deep understanding and clear presentations. A summary of this section is presented in Table 1.

2.1.1. Under axial loading

Rafiei et al. [5] investigated the behavior of DPSCW under in-plane monotonic loading. Three DPSCW specimens 1626 mm high and 720 mm wide were tested. Two types of infill concrete and two different yield strengths of PSSs were incorporated to investigate their influence on CW behavior. The study connected the PSSs to the core concrete by intermediate fasteners along the height and width of the wall to generate composite action, as presented in Fig. 4. This interaction type provided sufficient steel–concrete composite action to prevent early elastic buckling of the PSSs.

Analytical models for DPSCWs were developed based on experiments. The advantage of using concrete and PSS materials was exhibited through improved ductile wall behavior and energy-absorbing capacity. Experimental and analytical shear resistances of CWs showed very good agreement. In addition, this study found that the analytical models could be used to predict the shear resistance of CWs with reasonable accuracy. The maximum shear strain and stress were derived from Eq. (1), with τ_{max} limited based on the von Mises yield criterion in Eq. (2).

$$\gamma_{max}=\epsilon_{p1}-\epsilon_{p2};\quad \mathcal{T}_{max}=\frac{E_s}{2(1-\nu_s)}\gamma_{max} \tag{1}$$