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Numerical study on important parameters of composite steel-concrete shear walls

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ABSTRACT

In recent years, steel-concrete composite shear walls have been widely used in enormous high-rise buildings. This paper demonstrates nonlinear numerical studies on composite steel-concrete shear walls affecting cyclic loading. Five types of three-dimensional finite element model is developed using ABAQUS emphasizing constitutive material modeling and element type to represent the real physical behavior of complex shear wall structures. Modeling details of structural components, contact conditions between steel and concrete, associated boundary conditions, and constitutive relationships for the cyclic loading are explained. Load versus displacement curves, peak load, and hysteretic characteristics are verified with experimental data. Present study investigates important parameters such as concrete failure, hysteresis response, out of plan displacement, frame drift, and dissipated energy. The findings revealed that steel frame with concrete, on one side of shear plate, had better dissipation energy function compared with other types. Comparing the results, it was clearly observed that the lateral stiffness of the system isn't affected by changing the distance between connectors and concrete cover thicknesses. Numerical results show that shear steel plate buckling was reduced by increasing concrete thickness, and energy dissipation increased by reducing connectors' distance.

1. Introduction

Traditionally, reinforced concrete (RC) walls have long been adopted as efficient lateral load resisting systems to enhance the stability and integrity of the buildings against dynamic actions such as wind, earthquakes, etc. Later, steel plate walls were proposed as a promising alternative of concrete walls. Thin steel plate walls contributed to weight reduction of structures with greater stiffness, higher ductility, and enabled rapid constructions.

Composite construction was then used for the structures requiring higher order of safety and reliability. Mo and Chan [1] presented a softened concrete stress-strain relationship for the prediction of overall strength behavior of low- rise reinforced-concrete-framed shear walls with flanged geometry under static loads. The softening parameters were found to be a major factor in overestimating the ultimate strength values for high-strength concrete. Yoshio et al. [2] developed analytical methodology to predict the behavior of RC shear wall structures from elastic to collapse load with multi-axes seismic loading schemes using FEM technology. The methodology was proved significant for evaluating the strength margins of important structures in a nuclear power plant. Singh and Kushwaha [3] determined the ultimate load capacity of reinforced concrete shear walls under static and dynamic loads using a three dimensional finite element.

A number of studies have been reported on the behavior of steel-concrete composite shear walls. Tong et al. [4] experimentally studied the cyclic response of a composite structural system consisting of partially restrained steel frames with reinforced concrete infill walls. The gravity loads and overturning moments were assumed to be resisted by steel components whereas shear was resisted by reinforced concrete infill walls. The system was found to have enough lateral strength for the cyclic loads of seismic nature with good stiffness to control the drift. Hossain and Wright [5] statically tested the small scale models (one sixth scale) to study the flexural performance of the new type of composite wall consisting of concrete filled between two profiled sheets. The load-deflection curves, strength, failure modes, strains, and interaction properties were reported as outcomes. The interaction between steel and concrete was observed to influence the wall behavior. It was concluded that the rigidity of connection between sheeting and concrete core can lead to high shear resistance. The shear strength of composite wall was found to be higher than that of the individual components. Gan et al. [6] carried out studies on the type of shear wall

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formed by inserting the steel plates and steel section into reinforced concrete walls. The investigation was conducted on a series of 1:2 scale specimens, loaded by constant axial compression and cyclic lateral forces.

Such types of walls have shown quite larger shear stiffness compared to traditional reinforced concrete walls. Another type of composite shear walls formed by bolting an RC wall with a steel shear wall on one side was investigated by Zhao and Astaneh-Asl [7–9]. The study emphasized on controlling the damage by providing a gap in the innovative composite shear wall system placed within a moment resisting steel boundary. Due to gap existence, RC wall didn't get involved in resisting lateral loads until the drift had reached the corresponding gap value [8]. Theoretical and experimental studies on composite steel-concrete shear walls with vertical steel encased profiles have been presented by Dan et al. [10]. Five different types of shear walls with steel encased profile and one reinforced concrete wall were proposed and tested. The shear studs for the composite walls were designed to ensure zero slip. The shear walls with steel encased profile showed bending failure mode, with crushing of compressed concrete and tearing of the tensioned steel. The composite walls were found to have higher initial stiffness and energy dissipation with the increasing amount of steel [10]. Rahai and Hatami [11] presented an experimental and numerical investigation on composite shear walls, focusing on the effect of shear studs spacing variations. The results demonstrated reduction in the slope of load-displacement curves with increase in stud spacing. Up to specific studs' spacing, the ductility of the composite unit was improved. The basic design methodology of double skin composite elements subjected to axial and bending loads has been defined by Wright et al. [12]. McKinley and Baswell [13] developed an analytical solution for the elastic-plastic behavior of Bi-Steel panels or double skin composite panels. Due to the continuity of steel, it was observed that such constructions can withstand larger deformations before failure. Wright and Gallocher [14] primarily investigated the ultimate capacity of composite walling and its benefits over traditional concepts. Omer et al. [15] carried out numerical modeling and analysis of double skin composite plates. It was found that concrete core failure can fairly be reduced with increasing effect of side steel plate thickness. Sabouri-Ghomi and Sajjadi [16] by experimental and theoretical studies of steel shear walls with and without stiffness showed that the stiffeners improves the behavior of steel plate shear walls. In addition, they showed that plate-frame interaction theory (PFI) had good capability for predicting the shear load-displacement curve behavior of steel shear walls with and without stiffeners.

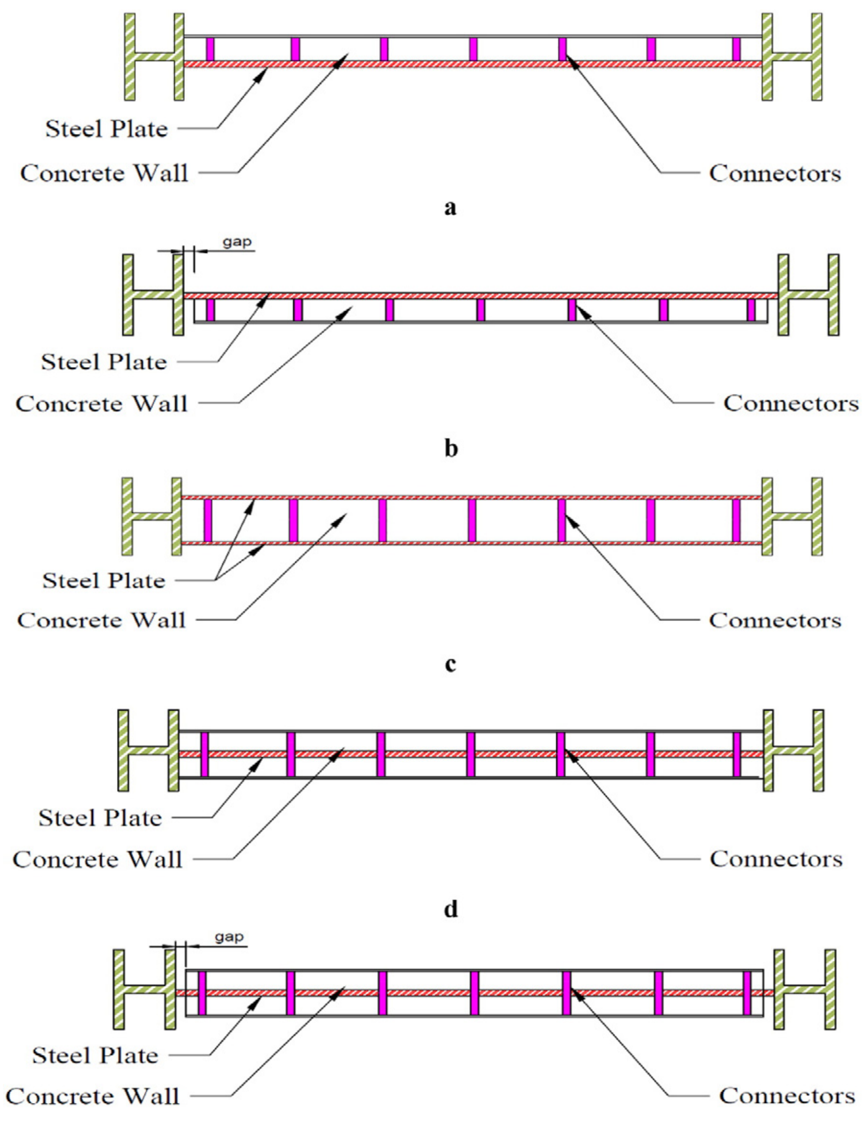

Fig. 1. Composite shear wall systems: a) concrete on one side, b) concrete with gap on one side, c) concrete cast on steel plates, d) concrete on two side, and e) concrete with gap on two side.