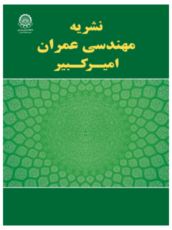

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Experimental Investigation of Composite (Steel-Concrete) Walls under Pure Out-of-plane Load

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ABSTRACT: This paper presents a new structural system for retaining walls. In civil works, in general, there is a trend to use the traditional reinforced concrete (RC) retaining walls to resist soil pressure. Despite their good resistance, RC retaining walls have some disadvantages such as the need for huge temporary formworks, high dense reinforcing, low construction speed, etc. In the present work, a composite wall with only one steel plate (steel-concrete) was proposed to cover the disadvantages of the RC walls. In this system, a steel plate was utilized not only as tensile reinforcement but also as permanent formwork for the concrete. To evaluate the efficiency of the proposed SC composite system, an experimental program that included six specimens was performed. In this experimental campaign, effects of different parameters such as length of shear connectors, use of compressive steel plate, concrete ultimate strength, the distance between shear connectors, and compressive steel reinforcement were investigated. The results showed that with proper design, the composite walls have very good and ductile behavior under out-of-plane loads. Furthermore, it was observed that even with a large distance between the shear connectors, a short length of the shear connectors, etc., this system is capable to keep the flexural performance and shows semi-ductile behavior. Furthermore, the design equations based on the ACI code for calculating out-of-plate flexural and shear strength of SC composite walls were presented and compared to the experimental database.

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1. INTRODUCTION

Nowadays, retaining walls are considered an integral part of high-rise structures. Reinforced concrete retaining walls are both resistant and ductile. Nevertheless, the need for huge temporary formworks, high dense reinforcing, low construction speed, engaging a large number of workers, etc. is some of the disadvantages of this system [1]. In the present work, to overcome the disadvantages of the reinforced concrete walls mentioned above, a composite (steel-concrete) wall is proposed. This SC composite system contains one steel plate, concrete, shear connectors, and reinforcement network. The steel plate is placed on the interior side of the structure. The concrete cover is attached to the steel plate using shear connectors. The concrete cover is in the vicinity of soil and steel plate. The steel plate acts not only as a component of the composite wall but is also utilized as permanent formwork. Fig. 1 shows the details of the proposed SC composite wall.

The idea of using sandwich composite walls was first presented in Japan. In 1998, Sasaki *et al.* [2] and Fujita *et al.* [3] carried out numerous shear and flexural tests on sandwich composite specimens. In 1976, Solomon *et al.* [4] carried out various tests on composite beams and slabs and determined the modes of failure in different conditions. Wright and Oduyemi [5] presented a closed-form solution to analyze the composite beams. Dogan and Roberts [6] compared the results of experimental works of composite beams with the results of partial and full interaction theory. Sabedi and Coyle [7] enhanced the behavior of sandwich composite beams by changing the roughness of the steel plate.

In the present work, to address the disadvantages of the concrete reinforcement walls, the SC composite system is presented to use as retaining walls. To investigate the resistance, ductility, and flexural stiffness of composite walls, six specimens were built in the laboratory and tested under out-of-plane loadings. The effect of different parameters on the behavior of SC composite walls was studied. Unlike previous works, where sandwich systems (steel–concrete–steel) were used, in the proposed system, only one steel plate is used (steel-concrete). Furthermore, the support conditions of the tested specimens are similar to the real situation. The steel faceplate is welded to an upper and a lower beam.

2. METHODOLOGY

An experimental program including six specimens was designed to identify the behavior of SC composite walls under out-of-plane loads. W1 specimen was considered as a reference of SC composite wall to compare with other specimens (i.e., W2 to W6). In the W2 to W6 specimens, only one parameter was changed in comparison to the W1

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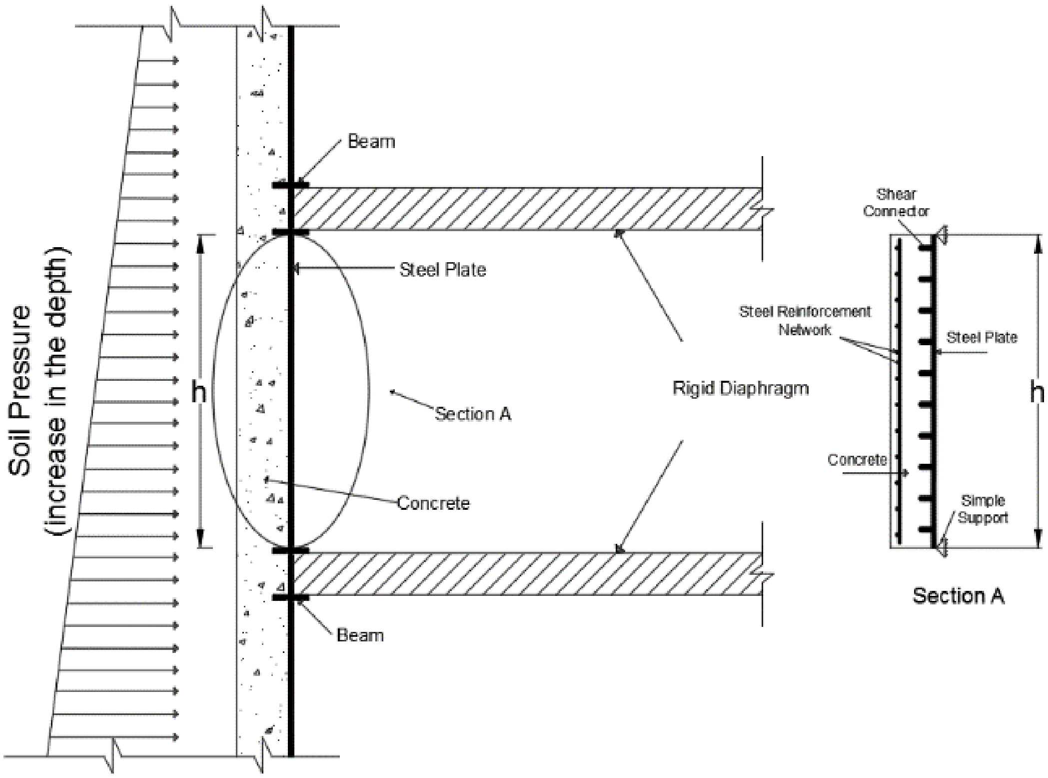


Fig. 1. Details of SC composite wall.

specimen, to study the effect of different parameters on the behavior of SC walls. To evaluate the effect of the shear connector length, the W2 specimen was fabricated with a 40 mm shear connector length. In the W1 specimen, the shear connector length was 85 mm. The effect of the steel plate in the compressive side (steel-concrete-steel) was assessed in the W3 specimen. In the W4 specimen, the influence of concrete compressive strength was investigated on the SC composite wall behavior. The effect of shear connector distance was considered in the W1 and W5 specimens. In the W6 specimen, a reinforcement network was utilized in the compressive side of the wall.

3. RESULTS AND DISCUSSION

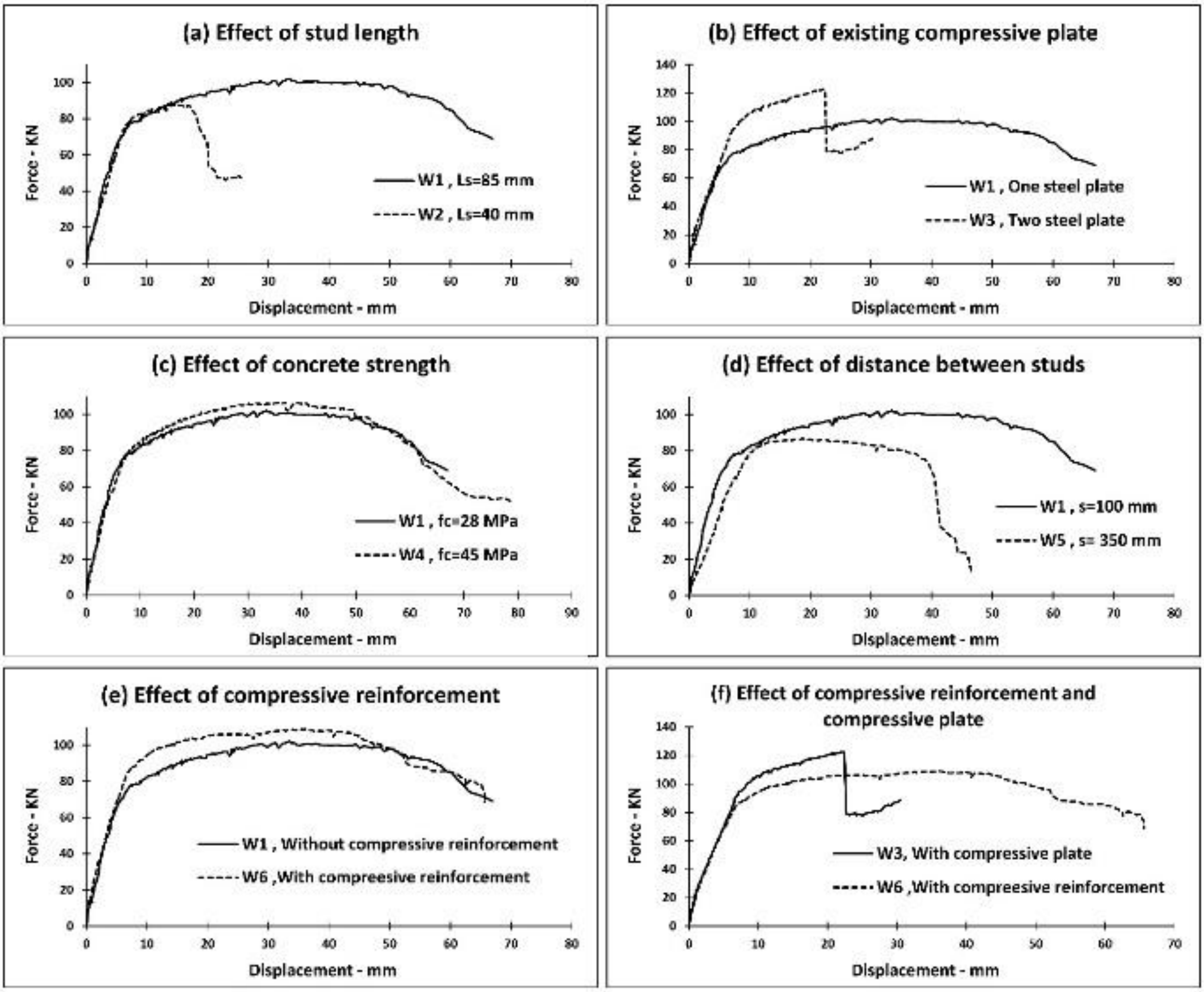
In this section, the effects of different parameters on the behavior of SC composite walls were discussed. These parameters include space between the shear connectors, length of shear connectors, concrete ultimate strength, use of compressive steel reinforcement, and compressive steel plate (sandwich system).

3.1. Effect of shear connector length on the behavior of the SC composite walls

The effect of the shear connector's length was investigated through W1 and W2 specimens. The length of shear connectors was considered 85 mm and 40 mm in W1 and W2 specimens, respectively. Fig. 2(a) shows the force-displacement curves for these two specimens. By reducing the length of shear connectors, semi-ductile behavior was observed and the specimen was failed at small deflection (17.2 mm). In other words, the W1 specimen was failed in flexure with lots of flexural cracks, while the W2 specimen, due to the short length of shear connectors, was failed in flexure-shear mode and diagonal tensile cracks with 45 degrees were observed. In the linear branch, the responses of both specimens were close to each other, but the ductility of the W1 specimen was much better than the W2 specimen.

3.2. Effect of compressive steel plate on the behavior of SC composite walls

In this section, the effect of the existing compressive steel plate was evaluated under out-of-plane loads. The force-displacement curves for W1 and W3 specimens were indicated in Fig. 2(b). As shown in Fig. 2(b), the ultimate capacity of W3 was more than the W1 specimen. The difference in the ultimate strength was about 20 kN. However, the elastic stiffness of both specimens was similar. The high ultimate capacity of the W3 was because of the compressive steel plate. On the other hand, the ultimate deflection of the W1 and W3 specimens were 22.4 and 50 mm, respectively. Therefore, the ductility of the SC composite wall (W1) was much better than the sandwich wall (W3).


(a) Effect of stud length

(b) Effect of existing compressive plate

(c) Effect of concrete strength

(d) Effect of distance between studs

(e) Effect of compressive reinforcement

(f) Effect of compressive reinforcement and compressive plate

Fig. 2. Comparison between the effects of different parameters on the behavior of SC composite wall.

3.3. Effect of shear connector spacing on the behavior of the SC composite walls

In the W5 specimen, the space between the shear connectors was increased significantly and the response was compared to the W1 specimen. In other words, the number of shear connectors was reduced from 30 in the W1 specimen to 6 in the W5 specimen. This comparison was performed to evaluate the effect of the larger spacing between shear connectors. The force-displacement curves for W1 and W5 specimens are shown in Fig. 2(d). As shown in Fig. 2(d), due to large spacing between the shear connectors and less connectivity between the concrete and steel plate, the stiffness of the W5 decreased. In addition, the W5 specimen, unlike the W1 specimen, failed at a smaller deflection of 37.5 mm. The failure mode of the W5 specimen was semi-ductile and caused by weld fracture.

4. CONCLUSION

The main findings of the presented work are as follows:

1. The proposed SC composite showed very good behavior under out-of-plane loads in terms of stiffness, strength, and ductility. Thus, they can be utilized as retaining walls in the deep excavation in tall buildings. However, due to composite action, the exact and accurate design method should be taken into account to increase the efficiency of this system.
2. In the SC composite walls, even with not proper design (e.g. large distance between the shear connectors and short length of shear connectors) the semi ductile behavior was observed under out-of-plane loads.

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