Experimental study of the behavior of prefabricated lightweight concrete shear walls with channel sections framing under axial compression

C Li¹, J Zhang¹, E Wang¹,² and X Zheng¹

¹School of Civil Engineering, Hebei University of Engineering, Handan 056038, China
²Hebei Prefabricated Concrete Structure Technology Research Center, Handan 056038, China
Email: lihao050308@163.com

Abstract: In order to satisfy requirements of fireproof and thermal insulation property of lightweight steel and lightweight concrete structures, an innovative prefabricated lightweight concrete shear wall with channel sections framing is developed. This paper focuses on axial compressive behavior of the wall. Two full-scale specimens are tested under axial compressive loads. The compressive strength of ceramsite-foamed concrete is varied to investigate their impacts on axial bearing capacity and axial compressive stiffness of the specimens. The failure modes, load-displacement curves, and deformability of the specimens are also investigated. Test results show that the failure modes of shear wall are mainly local buckling failure of channel sections framing and local crushing of ceramsite-foamed concrete plate. Compared with the specimen infilled C7-grade ceramsite-foamed concrete, the axial bearing capacity and the axial compressive stiffness of infilled C10-grade ceramsite-foamed concrete specimen are increased by 15.6% and 16.3%, respectively. Therefore, this study can provide a reference for further research on the axial compression performance of the prefabricated lightweight concrete shear walls with channel sections framing.

1. Introduction

The precast concrete structure has the advantages of high degree of industrialization, fast construction speed, less pollution, less material, less wet work on site, cost effectiveness and workability, and it has become an important direction of building industrialization [1]. Structure behaviors of precast concrete shear walls have been investigated by researchers, such as (Soudki et al. [2,3], Dal et al. [4], Aaleti et al. [5], Seifi et al. [6], Smith et al. [7]). However, precast concrete shear walls are mainly used in high-rise buildings, and have poor ductility, deformability, and energy absorption capacity.

In order to improve ductility, deformability, and energy absorption capacity of precast concrete shear walls, some researchers have proposed steel plate shear wall, steel plate-concrete shear wall, and cold-formed steel (CFS) shear wall. Among them, CFS shear wall has been widely used in commercial and residential buildings in Europe, North America, and Australia due to environmentally friendly, lightweight, recyclability, easy installation, and low cost. Among them, CFS shear wall has been widely used in commercial and residential buildings in Europe, North America, and Australia due to environmentally friendly, lightweight, recyclability, easy installation, and low cost. Some researchers performed experimental and theoretical studies on axial compressive behavior of CFS structures. Li et al. [8] conducted a series of experimental tests on the axial compressive behavior of cold-formed thin-
walled columns with built-up box and I section. Vieira et al. [9,10] performed axial compression tests on CFS stud walls sheathed with OSB panels and gypsum board. The results show that OSB panels and gypsum board can improve the stability and load-bearing capacity of the walls.

With this in mind, an innovative prefabricated lightweight concrete shear wall with channel sections framing is presented in this paper (Figure 1). Prefabricated lightweight concrete shear walls with channel sections framing are mainly used as bearing wall in low-rise buildings. The wall is formed of channel sections framing and ceramsite-foamed concrete plate. Ceramsite-foamed concrete plate has a large number of porous internal structures, prefabricated lightweight concrete shear wall with channel sections framing has low thermal conductivity, which improves thermal and acoustic property of the shear wall buildings, and fireproof property of the studs. However, very few experimental and numerical studies are available on prefabricated lightweight concrete shear wall with channel sections framing. In this paper, attention is focused on axial compressive behavior of prefabricated lightweight concrete shear walls with channel sections framing. Two full-scale specimens are tested under axial compressive loads. The compressive strength of ceramsite-foamed concrete is varied to investigate their impacts on axial bearing capacity and axial compressive stiffness of the specimens. This study can provide a reference for further research on the axial compression performance of the prefabricated lightweight concrete shear walls with channel sections framing.

2. Experimental program

2.1. Specimen details

Prefabricated lightweight concrete shear walls with channel sections framing is a new type of shear wall, thus there is no corresponding standard to follow. However, design and construction of the shear wall can refer to some relevant codes and standards, including Chinese Standard JGJ 227–2011 and JGJ 383–2016. Two full-scale prefabricated lightweight concrete shear walls with channel sections framing were designed, and named SW-C7 and SW-C10 respectively. SW-C7 is infilled with C7 grade ceramsite-foamed concrete, and SW-C10 is infilled with C10 grade ceramsite-foamed concrete. The configuration details of the specimen are shown in Figure 1. The basic size of the prefabricated lightweight concrete shear wall with channel sections framing is 3000 mm (height) × 1150 mm (width) × 126 mm (thickness). The wall is formed of channel sections framing and ceramsite-foamed concrete plate. Different types of channel are cut and combined to form a framing by welding. The Φ3@10 double wire mesh is welded the front and back of inner channel sections framing. The ceramsite-foamed concrete is poured inside the channel sections framing. The white cement is smeared on the outside of the ceramsite-foamed concrete, and the fiberglass mesh is laid on the front and back of the wall.
2.2. Material properties
The material properties of channel steel and reinforcements are measured by tensile coupon in accordance with the Chinese standard GB/T 228.1-2010. The measurement results are shown in Table 1. The material properties of two batch ceramsite-foamed concrete are tested in accordance with the Chinese standard JG/T 266-2011, including cube specimens (100 mm × 100 mm × 100 mm) and prism specimens (100 mm × 100 mm × 300 mm). The measurement results are shown in Table 2.

| Material type | Yield stress (MPa) | Ultimate stress (MPa) | Elastic modulus(MPa) | Elongation(%) |
|---------------|-------------------|-----------------------|----------------------|--------------|
| [12]          | 316.8             | 457.6                 | 2.14×10^5           | 26.76        |
| [8]           | 320.5             | 461.8                 | 2.20×10^5           | 24.57        |
| Φ3            | 278.6             | 314.1                 | 2.13×10^5           | 27.96        |

Table 2. Mechanical properties of ceramsite-foamed concrete.

| Material type | Density (kg/m³) | Cubic compressive strength (f_u) (MPa) | Prism compressive strength (f_u) (MPa) | Elastic modulus (MPa) |
|---------------|-----------------|---------------------------------------|----------------------------------------|-----------------------|
| C7            | 1378            | 7.24                                  | 6.28                                   | 1135                  |
| C10           | 1436            | 10.12                                 | 8.83                                   | 1272                  |

2.3. Test setup and loading protocols
The configuration of the test setup is shown in Figure 2. Axial loads are applied to the test specimens by a 1500-kN hydraulic jack, the loading protocol utilized the force-control mode. When the specimens are installed in place, a mortar layer is placed on the bottom of the bottom tracks to ensure that the bottom surface is flat. The bottom tracks of the specimens are connected to a base reaction beam, which is fixed on the strong floor by 20-mm-diameter high-strength bolts.

Before the test, the preloading is firstly carried out, and the applied load is 10%~20% of the ultimate load. The purpose is to eliminate the gap between the bottom tracks and the mortar layer, and to check whether the test setup is well-connected and the instruments worked functionally. After the preloading was completed, the load is unloaded to zero for formal loading. The formal loading adopts force control and is loaded step by step. The load increment of each stage is 10% of the ultimate load, and the load of each stage lasts for about 5 minutes. After the load is stable, the data are read. The test is terminated when the load decreased to 80% of the peak load.

2.4. Instrumentation
A total of five linear variable displacement transformers (LVDTs) are used in the tests, as is shown in Figure 2. D1 and D2 are used to measure vertical displacements of the test specimens. D3, D4 and D5 are used to measure out-of-plane deformation of the test specimens. Measured results of the LVDTs and the load are recorded by the data collection system.

3. Test results and analysis
3.1. Failure phenomena
For test specimen SW-C7, there is no obvious observed phenomenon in the initial stage of loading. When the load reaches to 20%~30% of the peak load, the inside of the test specimen emits a slight ceramsite-foamed concrete extrusion sound, and a diagonal crack appears in the lower right corner of the test specimen, as is shown in Figure 3a. When the load reaches to about 40% of the peak load, the diagonal crack of the test specimen is extended, and accompany by the sound of a large internal ceramsite-foamed concrete extrusion, as is shown in Figure 3b. When the load reaches to 60%~80% of the peak load, the ceramsite-foamed concrete is crushed and fell off at the diagonal crack of the test specimen, and the local bucking failure of the lower left corner channel, as is shown in Figure 3c. At the
peak load, the local bucking of the lower left corner channel sections framing is severe, and the diagonal crack runs through the whole test specimen. Meanwhile, the inside of the test specimen emits a huge ceramsite-foamed concrete extrusion sound, which is shown in Figure 3d.

Figure 3. Failure modes of SW-C7 specimen. Figure 4. Failure pattern of SW-C10 specimen.

The test specimen SW-C10 is similar to the test specimen SW-C7. No obvious failure phenomenon is observed in the initial stage of loading. When the load reaches to about 20% of the peak load, the lower right corner channel steel and the ceramsite-foamed concrete are slightly separated, and accompany by the sound of a slight internal ceramsite-foamed concrete extrusion, as is shown in Figure 4a. When the load reaches to about 50% of the peak load, a diagonal crack is appeared in the upper left corner of the test specimen, and the local bucking of the upper left corner channel sections framing slightly occurred, as is shown in Figure 4b. When the load reaches to about 80% of the peak load, the lower right corner channel steel and the ceramsite-foamed concrete are obviously separated, and a diagonal crack is appeared in the lower right corner of the test specimen, as is shown in Figure 4c. At the peak load, the ceramsite-foamed concrete is crushed and fell off at the bottom and lower right corner of the test specimen, which is shown in Figure 4d.

3.2. Analysis of test results

Figure 5 shows the load-displacement curves of the SW-C7 and SW-C10 test specimens. These load-displacement curves are generated using the actual displacement and load. The conclusions obtained from the load-vertical displacement curves are as follows:

For the test of specimen SW-C7 and SW-C10, due to the same stud arrangement, the load-displacement curves of these two specimens are nearly coincident. Compared with the specimen infilled C7-grade ceramsite-foamed concrete, the axial bearing capacity and the axial compressive stiffness of infilled C10-grade ceramsite-foamed concrete specimen are increased by 15.6% and 16.3%, respectively. During the initial loading stage, the load-displacement curve develops linearly. The slope of the straight line in the initial stage is less than the slope of the straight line in the later stage. The reason is that there are a large number of closed pores inside the ceramsite-foamed concrete in the initial loading stage. As the load increases, the pores inside the specimen gradually close and the compactness slightly increases. After the peak load, load-displacement curves began to drop due to the local bucking failure of the channel sections framing and the extension of the oblique crack. Continue to load, the curves slowly drop, which shows the prefabricated lightweight concrete shear wall with channel sections framing has good deformation ability.
4. Conclusions

In this paper, an innovative prefabricated lightweight concrete shear wall with channel sections framing is proposed. Experimental study is conducted to analyze the axial compressive behavior of the wall. According to the analytical results in this paper, the following conclusions can be drawn:

(1) The failure modes of the prefabricated lightweight concrete shear walls with channel sections framing are mainly local bucking failure of channel sections framing and local crushing of ceramsite-foamed concrete plate.

(2) Compared with the specimen infilled C7-grade ceramsite-foamed concrete, the axial bearing capacity and the axial compressive stiffness of infilled C10-grade ceramsite-foamed concrete specimen are increased by 15.6% and 16.3%, respectively. The load-displacement curves of the two test specimens slowly drop, which shows the prefabricated lightweight concrete shear wall with channel sections framing has good deformation ability.

Acknowledgements

The research described in this paper was also financially supported by Natural Science Foundation of Hebei Province of China (No. F2017402182). The supports are gratefully acknowledged. Any opinions, findings, conclusions, and recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the sponsors.

References

[1] Yee A A and Eng H D 2001 Structural and Economic Benefits of Precast/Prestressed Concrete Construction *PCI. J.* **46**(4) pp 34-43
[2] Soudki K A, Rizkalla S H and LeBlanc B 1995 Horizontal connections for precast concrete shear walls subjected to cyclic deformations: part 1: mild steel connections *PCI. J.* **40**(4) pp 78-96
[3] Soudki K A, West J S, Rizkalla S H and Blackett B 1996 Horizontal connections for precast concrete shear wall panels under cyclic shear loading *PCI. J.* **41**(3) pp 64-80
[4] Dal Lago B, Muhaxheri M and Ferrara L 2017 Numerical and experimental analysis of an innovative lightweight precast concrete wall *Eng. Struct.* **137** pp 204-222
[5] Aaleti S and Sritharan S 2009 A simplified analysis method for characterizing unbonded post-tensioned precast wall systems *Eng. Struct.* **31**(12) pp 2966-2975
[6] Seifi P, Henry R S and Ingham J M 2019 In-plane cyclic testing of precast concrete wall panels with grouted metal duct base connections *Eng. Struct.* **184** pp 85-98
[7] Smith B J, Kurama Y C and McGinnis M J 2011 Design and measured behavior of a hybrid precast concrete wall specimen for seismic regions *J. Struct. Eng.* **137**(10) pp 1052-1062
[8] Y Li, Y Li, S Wang and Z Shen 2014 Ultimate load-carrying capacity of cold-formed thin-walled columns with built-up box and I section under axial compression *Thin-walled Struct.* **79** pp 202-217.
[9] Vieira L C M, Shifferaw Y and Schafer B W 2011 Experiments on sheathed cold-formed steel studs in compression *J. Constr. Steel Res.* **67**(10) pp 1554-1566
[10] Vieira L C M and Schafer B W 2012 Lateral stiffness and strength of sheathing braced cold-formed steel stud walls Eng. Struct 37 pp 205-213