Structure behavior of a fabricated shotcrete sandwich wall system under axial compression

Shoushuo Zhang¹, and Qun Xie*¹

¹ School of Civil Engineering and Architecture, University of Jinan, Jinan, Shandong, China
*Corresponding author’s e-mail: cee_xie@ujn.edu.cn

Abstract. A new type of fabricated shotcrete sandwich wall system is proposed. The wall system consisted of steel mesh, foamed concrete blocks, reinforced concrete layers, and core column. The shotcrete has been adopts in structural layer. Steel mesh is placed in the concrete layer. Foam concrete blocks are filled between concrete layers with function of insulation. Core columns are arranged along the cross section of wall with spacing 600mm. Prefabricated rebar cage place in core column. The finite element software ABAQUS is used to calculate its compressive strength, and the calculation results are compared with the theoretical method of related code. The results show that the FE simulation results have a good agreement with the formulation recommended by code.

1. Introduction
Sandwich wall has attracted more and more attention and application with the characteristics of light weight, heat preservation and high strength. Hao[1] studied the axial performance of the composite wall with interior insulation. The results showed that the integrity of the new composite wall can be used effectively, which improved the utilization efficiency of concrete and steel. Wang[2] investigated the structural behaviour of a composite panel system consisting of two outer skins of profiled thin-walled steel plates with lightweight foamed concrete core under axial compression. The results showed that the increase in load carrying capacities of the panels with stopping edge and welded edge can be attributed to the increased effective width of the steel sheeting. Huang[3] investigated the structural behaviour of steel-concrete-steel sandwich wall. A series of compression tests have been carried out on the SCS sandwich walls. The test results were compared against the predictions by Eurocode 4. The predictions showed a reasonable correlation with the test results. Zhu[4] investigated the overall instability performance of I-section concrete-infilled double steel corrugated-plate walls under uniform compressions. The results obtained from the experiment showed an agreement with those obtained from FE numerical analyses. Yan[5-6] investigated compressive behaviour of steel-UHPC-steel sandwich composite walls, the results showed that the developed theoretical models offered more accurate predictions on ultimate compression resistance. Wang[7] studied novel steel-concrete-steel sandwich composite walls compressive behaviours through axial compression tests. The results showed that the EC4 theoretical models offer the most accurate predictions on ultimate compressive resistance of sandwich composite walls. Huang[8] used nonlinear finite element (FE) model to simulate the mechanical behaviour of sandwich wall in terms of ultimate strength and load-deflection curves.

A new approach was proposed to evaluate the resistance of sandwich wall. Fabricated shotcrete sandwich wall system has the advantages of light weight, high strength, insulation, fire protection and so on. Nowadays, there are few researches on the axial compressive behaviour of fabricated shotcrete...
sandwich wall system. In this paper, a new type of prefabricated shotcrete sandwich wall system is proposed, and its mechanical behavior under axial compression are researched by using the finite element software ABAQUS. The sandwich wall structure system is shown in Figure 1.

Figure 1. Structure of sandwich wall

2. Test specimens

2.1. Specimen design

The concrete layers are constructed by shotcrete technology, and steel mesh is placed in the concrete layers. The core columns arrange along the cross section of wall are cast in situ before the construction of the concrete layer. The diameter of longitudinal reinforcement and stirrup is 8mm and 4mm respectively and the spacing of core column is 600 mm along the cross-section length of panel. The horizontal direction of the test specimen is placed with long tie bar of 6mm diameter. Steel mesh consisted of wire with 25mmx25mm spacing arranged on two faces of the concrete layer. Concrete cover of 20 mm is maintained on all the wall components. Dimension and reinforcement arrangement of specimen are seen in Figure 2.

Figure 2. Dimension and reinforcement arrangement of specimen
2.2 Material property
The steel of specimen include cold drawn plain round bar of 8mm diameter and hot rolled plain round bar of 6mm diameter. The mechanical properties of concrete and reinforcement are obtained according to the Chinese standard[9-10].

3. Numerical simulation

3.1 Model creation
The specimen FE model is built according to the symmetric geometry and loading pattern of sandwich wall. The displacement loading is applied to the top surface to investigate the compression behavior of the specimen. Three dimensional solid models are adopted for concrete. Wire model is used for reinforcement framework.

3.2 Material properties
A concrete damage plasticity model is adopted in which the compressive and tensile behavior of concrete is modeled. The compressive stress of the concrete, the compressive strain of the concrete, the axial compressive damage parameter, the tensile stress of the concrete, the tensile strain of the concrete and the axial tensile damage parameter are modeled based on the code for design of concrete structures[11]. The constitutive relations of concrete is ideal elastic with the elastic modulus of 2.2×10⁴ MPa.

The constitutive relations of steel is ideal elastic with the elastic modulus of 2.06×10⁵ MPa. The yield strength is 390 MPa. The yield plastic strain is 0. The density is 7800kg/m³.

3.3 Analysis steps and meshing
The static analysis step is established and the displacement loading is applied. The minimum allowable increment of analysis steps is adjusted to 10⁻⁵, the maximum number of increment steps is adjusted to 100, and other parameters use default values. Eight-node solid elements with reduced integration (C3D8R) are utilized to simulate the concrete. Two-node linear three-dimensional truss elements (T3D2) are used to simulate the steel.

3.4 Boundary Conditions and loading
The reinforcement is embedded in the concrete. Spraying construction method is adopted for concrete layers. The core column and loading beam are cast in situ. In the model, the core column and loading beam are regarded as a whole. Tie algorithm is used in the FE model to simulate the constraint among layers and core column. The bottom surface of the sandwich wall is restrained against the motion in all directions. The reference point RP1 is established at the center of the top surface of the loading beam, the plane coupling constraint is imposed, and the displacement loading method is adopted to obtain better convergence effect.

4 Theoretical analysis

4.1 Strength calculation
The axial compression bearing capacity of shotcrete sandwich wall can be calculated according to the code for design of concrete structures.

\[
N \leq 0.9\varphi (f'_cA_c + f'_tA_t)
\]

\(N\) - Ultimate compression resistance of sandwich wall (N);
\(\varphi\) - Stability coefficient;
\(f'_c\) - Concrete compressive (N/mm²);
\(f'_t\) - Concrete tensile (N/mm²).
$A_c$ - Cross-sectional area of concrete (mm$^2$);
$A_t$ - Cross-sectional area of wall (mm$^2$);
$f_y$ - Yield strength of steel (N/mm$^2$);
$A_s$ - Cross-sectional area of reinforcement (mm$^2$);

### 4.2. Comparison of results

The error between FE simulation result and theoretical result is less than 5%. The finite element software ABAQUS can simulate the mechanical behavior of the sandwich wall well. The stress contour of the specimen is shown in Figure 3.

![Stress contours](image)

(a) Concrete

(b) Reinforcement

Figure 3. Stress contours at the ultimate loading

| Simulation result (kN) | Theoretical result (kN) | Relative deviation |
|------------------------|-------------------------|--------------------|
| 1930.13                | 1872.8                  | 3.06%              |

### 5. Conclusions

A new type of fabricated shotcrete sandwich wall system is proposed. The finite element software ABAQUS is used to calculate its compressive strength.

1. Better convergence effect can be obtained by adopting displacement loading.
2. When the sandwich wall reaches the ultimate bearing capacity, the steel enter the yield stage, and the concrete reach the ultimate stress. The material strength of steel and concrete can be fully utilized.
3. The FE simulation result is in good agreement with the theoretical result. The model can effectively calculate the vertical axial bearing capacity.

### References

[1] Hao Y H, Xu H Z, Li J Q, Wang Y Q, Shi Y. (2015) Experimental study on axial performance of composite wall with interior insulation[J]. Journal of Building Structures, 36(S2):244-249. (in Chinese)
[2] Md Azree Othuman Mydin, Y.C. (2011) Wang. Structural performance of lightweight steel-foamed concrete–steel composite walling system under compression[J]. Thin-Walled Structures, 49: 66-76.

[3] Huang Z Y, J.Y. Richard Liew. (2016) Compressive resistance of steel-concrete-steel sandwich composite walls with J-hook connectors[J]. Journal of Constructional Steel Research, 124: 142-162.

[4] Guo Y L, Zhu J S, Wang M Z, Yang X, Zhou P. (2018) Overall instability performance of concrete-infilled double steel corrugated-plate wall[J]. Thin-Walled Structures, 130: 372-394.

[5] Yan J B, Chen A Z, Wang T. (2020) Compressive behaviours of steel-UHPC-steel sandwich composite walls using novel EC connectors[J]. Journal of Constructional Steel Research, 173:106244.

[6] Wang T, Yan J B. (2020) Developments of steel-concrete-steel sandwich composite structures with novel EC connectors: Members[J]. Journal of Constructional Steel Research, 175: 106335.

[7] Yan J B, Chen A Z, Wang T. (2020) Axial compressive behaviours of steel–concrete-steel sandwich composite walls with novel enhanced C-channels[J]. Structures, 28: 407-423

[8] Huang Z Y, J.Y. Richard Liew. (2016) Structural behaviour of steel–concrete–steel sandwich composite wall subjected to compression and end moment[J]. Thin-Walled Structures, 98: 592-606

[9] (2003) GB/T50081-2002 Standard for test methods of mechanical properties of ordinary concrete[S]. China Construction Industry Press, Beijing. (in China)

[10] (2011) GB/T228.1-2010 Metallic materials-Tensile testing - Part 1: Test Method at room temperature [S]. China Quality Inspection press, Beijing. (in China)

[11] (2011) GB50010-2010 Code for design of concrete structures:[S]. China Construction Industry Press, Beijing. (in China)