IOP Conference Series: Materials Science and Engineering

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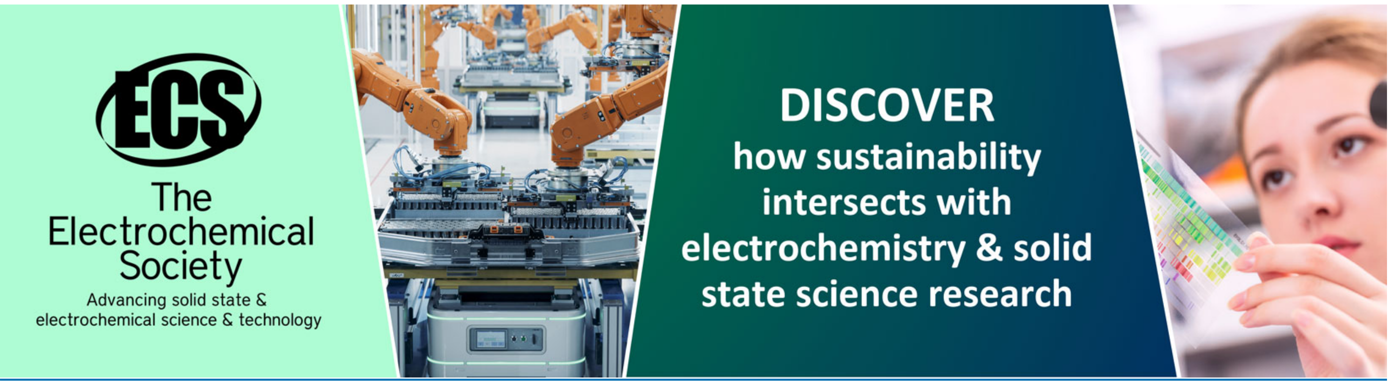
To cite this article: Xie Qun *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **317** 012063



IOP Conf. Series: Materials Science and Engineering **317** (2018) 012063 doi:10.1088/1757-899X/317/1/012063

Axial Compression Behavior of a New Type of Prefabricated Concrete Sandwich Wall Panel

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Abstract. A novel type of prefabricated concrete sandwich wall panel which could be used as a load-bearing structural element in buildings has been presented in this paper. Compared with the traditional sandwich panels, there are several typical characteristics for this wall system, including core columns confined by spiral stirrup along the cross-section of panel with 600mm spacing, precast foamed concrete block between two structural layers as internal insulation part, and a three-dimensional (3D) steel wire skeleton in each layer which is composed of two vertical steel wire meshes connected by horizontally short steel bar. All steel segments in the panel are automatically prefabricated in factory and then are assembled to form steel system in site. In order to investigate the structural behavior of this wall panel, two full-scale panels have been experimentally studied under axial compressive load. The test results show that the wall panel presents good load-bearing capacity and integral stiffness without out-of-plane flexural failure. Compared to the panel with planar steel wire mesh in concrete layer, the panel with 3D steel wire skeleton presents higher strength and better rigidity even in the condition of same steel ratio in panels which verifies that the 3D steel skeleton could greatly enhance the structural behavior of sandwich panel.

1. Introduction

Concrete sandwich panel is a widely used prefabricated wall element in residential and office buildings which is usually composed of two concrete layers separated by an insulation layer. Within each concrete layer there is a steel wire mesh and a serial of continuous rebar trusses as transverse connectors running along the full height of panel are adopted to attach concrete layers together which could provide resistance to horizontal shear. Sandwich panel has several advantages such as light self-weight, heat insulation and fast erection [1]. The sandwich wall panel system was initially developed and manufactured as non-load-bearing cladding or compartment elements in office building in U.S in the 1990s. Since the sandwich panels exhibit fully comparable performance to those of precast concrete solid panels, an interest in sandwich panels using as load-bearing structural elements in low-story buildings has been observed in the past decade years. A. Benayoune [2] has investigated the behavior of precast concrete panels subjected to eccentric compressive load and the results show that the load-bearing capacity of panels will nonlinearly raise with the increase of height-to-thickness ratio. Finally a semi-empirical formula has been proposed for strength prediction. Junsuk Kang [3] has adopted FEM method to study the structural performance of concrete sandwich panel with foam insulation under axial compression. Fabrizio Gara [4] has illustrated experimentally and numerically both the flexural and compressive behavior of fabricated sandwich panels without shear connectors. The aim is to determine the behavior of panel with different slender ratios under the axial and eccentric load. The result indicate that the strength of panels will decrease with the increase of slender ratios. With the development of housing industrialization and prefabricated building construction in

China recently, some studies have been carried out on the structural behavior of concrete sandwich panel currently. Mohamad N [5, 6] has used foamed concrete as an alternative material to produce a new type of precast sandwich panel and a double symmetrical truss-shaped connectors are employed in this panel. The experimental and theoretical results of axial and eccentric compression show that the slender ratio H/t has significant effect on the axial behavior of panel. Compared with the panel with single connectors the panel with double connectors presents better compressive strength and ductility. Olsen M D [7] has investigated the structural performance of concrete sandwich panels with carbon fiber connectors and the results show that the carbon fiber connector can effectively minimize the influence of thermal bridge due to its excellent property of heat isolation. Woltman G D [8] has adopted glass fiber reinforced polymer (GFRP) connectors as an alternative to metallic connectors and the load-slip behavior of sandwich panel has been established through a serial of shear tests. Hopkins P [9] has developed an innovative fiber reinforced polymer (FRP) shear plate connector and studied its effects on the flexural behavior of insulated concrete sandwich panels in terms of stiffness, strength, and applicability for constructions. Liew J Y R [10] has proposed a new concept for designing composite structures comprising a lightweight concrete core sandwiched between two steel plates which are interconnected by J-hook connectors. Tests confirms that the shear transfer capability of J-hook connector is superior to the conventional headed stud connector.

Based on the existing research results, as a structural system traditional sandwich panels are only employed in buildings with three stories below due to the limitation of load-bearing capacity, stiffness and connection type. In order to the possible application for multi-story buildings even high-rise buildings, a new prefabricated sandwich panel has been presented in this work, compared with the common sandwich panels, there are several typical characteristics for this new panel which includes core columns confined by spiral stirrup along the panel cross-section with 600mm spacing, foamed concrete block between external structural layers as internal insulation layer, and self-compact fine aggregate concrete applied in external layers with high flow performance. To improve the strength and stiffness of panels, a 3D steel wire skeleton in each layer which is composed of two vertical steel mesh connected with horizontal steel bar has been employed. A detailed configuration of panel is shown in figure 1. All steel elements of this panel are mechanically and automatically manufactured in factory, then transported to construction site for the overall steel skeleton assembly. Concrete in layers and core columns is needed to be casted in site. The thickness of concrete layer is adjustable according to the strength requirement of structural system and the existence of 3D steel wire skeleton and core columns is expected to contribute to greatly enhance the structural performance of panel. A test of full-scale specimens subjected to axial compressive load has been carried out in order to understand the actual behavior of this new sandwich panel.

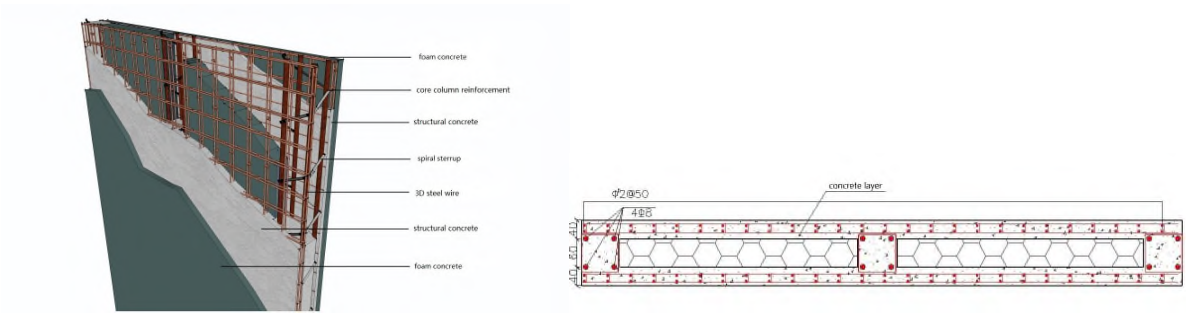

Figure 1. Section of the new fabricated sandwich panel.

2. Test program

With the purpose of performance comparison, two full-scale panels are designed with same height and width but different panel thickness, wire diameter as well as steel wire type, for specimen ZY1 planar steel wire mesh is used in concrete layers while a 3D steel wire skeleton is employed for specimen ZY2. The compressive strength of concrete is 36.8 MPa and the yield strength of rebar is 417 MPa. The detailed information of specimens is shown in table 1.

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Table 1. Specimens information (unit:mm).

No.	Height	Width	Thickness Concrete layer	Insulation thickness	Total	Steel wire mesh	Diameter of steel wire	Slenderness ratio	Reinforcement ratio
ZY1	2400	1300	25	60	110	planar	3	21.8	1.17%
ZY2	2400	1300	40	60	140	three-dimension	2	17.1	0.97%

All the specimens are vertically installed with an unconstrained end on the top and a fixing end on the bottom. Two 2500kN hydraulic jacks are setup at the top beam of specimen whose function was to transmit the centralized load to a uniformly distributed load along the full width of specimen. The axial load has been applied monotonically with a constant increment of 50kN. A lateral support system consisting of a serial of 50mm-diameter solid steel rollers and 20mm-thick steel angles is installed close to the side face of top beam to restrain lateral movement. The test setup is presented in Figure 2.

Figure 2. Test setup.

3. Experimental results

In the early stage of loading, the strains for both steel reinforcement and concrete have a linear increase with the growth of load, and the vertical and horizontal displacements slowly develop within a very small value. For ZY1 the first visual crack occurs in the mid-height of panel under the axial load of 1060 kN. Under load of 1280 kN another inclined crack appears at the corner of panel bottom which develops obliquely upwards following the load increment. With the increase of axial loads, several new cracks vertically occur in the middle of panels and the existing diagonal cracks extend and widen quickly. At the ultimate load of 1420kN a sudden failure occurs with a main vertical crack almost thorough the panel height. The specimen ZY-2 had similar structural performance with ZY-1 in the process of loading. The peak strength was 4280 kN with severely local concrete crush in the top of concrete layer. For two specimens there were no massive cracks found in the surface of panel even in the ultimate state. The main test results were listed in table 2.

Table 2. Experimental results.

Specimen No.	ZY-1	ZY-2
Crack load	1060 kN	4000kN
Ultimate load	1420 kN	4284kN
Maximum lateral displacement	3.2mm	8.9mm
Failure mode	Vertical through crack	Local concrete crush

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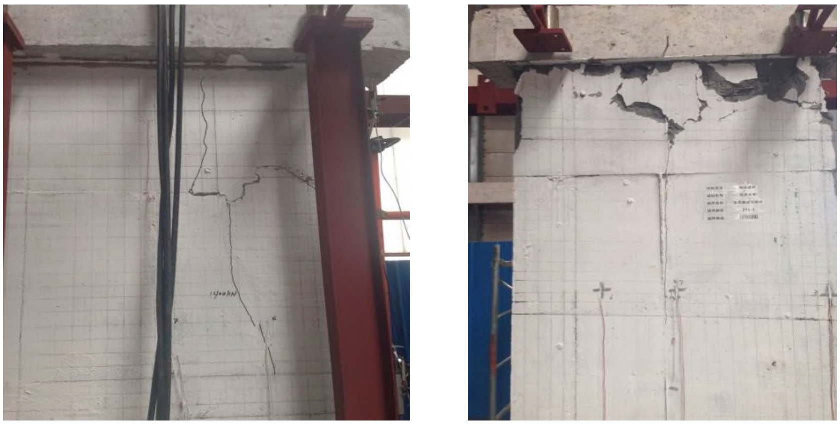


ZY-1 ZY-2

Figure 3. Failure modes.

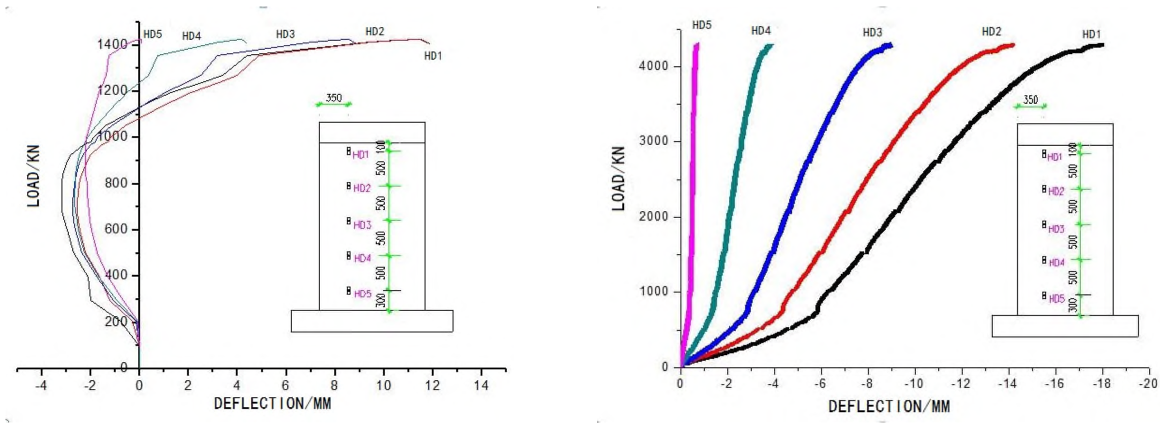
4. Results analysis

4.1. Load-deformation analysis

The lateral deflections obtained from the data of five LVDTs along the specimen height under axial load have been presented in figure 4. For ZY-1 the lateral deflections approximately kept a linear growth in the initial loading stage. While the load exceeds 800kN lateral deformation began to develop towards inverted direction since the excessive displacement of panel top triggered the restriction function of lateral bracing system. After then with the load increased, the lateral displacement at HD5 which is near the bottom end of panel gradually decreased back to zero in the final failure, while the displacement at HD1 which is near the loaded end of panel developed much faster than other measured points. The farther distance away from the panel top, the less lateral displacement was expected which could be attribute to the second-order effect. Similar to the deformation characteristic of ZY-1, the load-lateral deflection curves of ZY-2 developed almost elastically in the early stage of loading. Compared with ZY-1, the curves of ZY-2 measured at different positions show a monotonic development towards one direction mainly due to the smaller slenderness ratio.

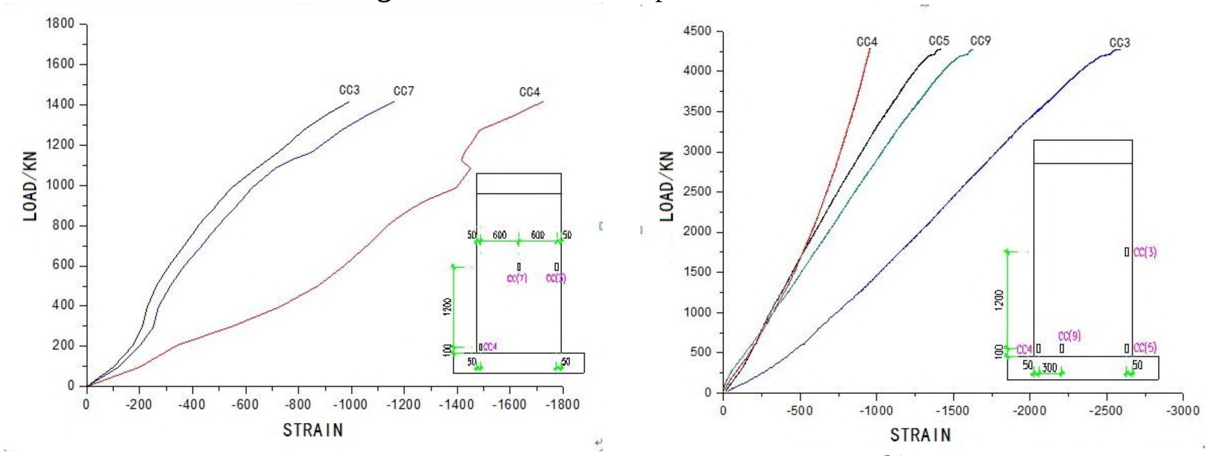
4.2. Load-strain analysis

The load-concrete strain curves of ZY1 were presented in figure 5 (a). There are two measured points in the mid-height of specimen and one at the bottom corner. All the data recorded by concrete strain gauges indicated that the full cross-section of specimen was in compression. However due to the lateral flexure caused by high slenderness ratio even under the axial compression, there actually were a concrete layer of specimen in the combined action of tension and compression and another layer in pure compression. Based on this analysis, the strains of CC3 and CC7 in tensile layer had smaller values than that of CC4 in compressive layer under the same axial load. All concrete strains developed within relatively small values during the loading program and the peak strains is about 1500με which was much lower than the ultimate compressive strain of concrete. In figure 5 (b) there were four load-concrete strain curves for different measure points of ZY2. Compared with ZY1, the growth of concrete strains in ZY2 was almost proportional to the increment of axial load. The strain linearly developed up to 4000με and much exceeded the ultimate concrete strain in uniaxial compression which verified that the excellent confinement of 3D steel skeleton system.



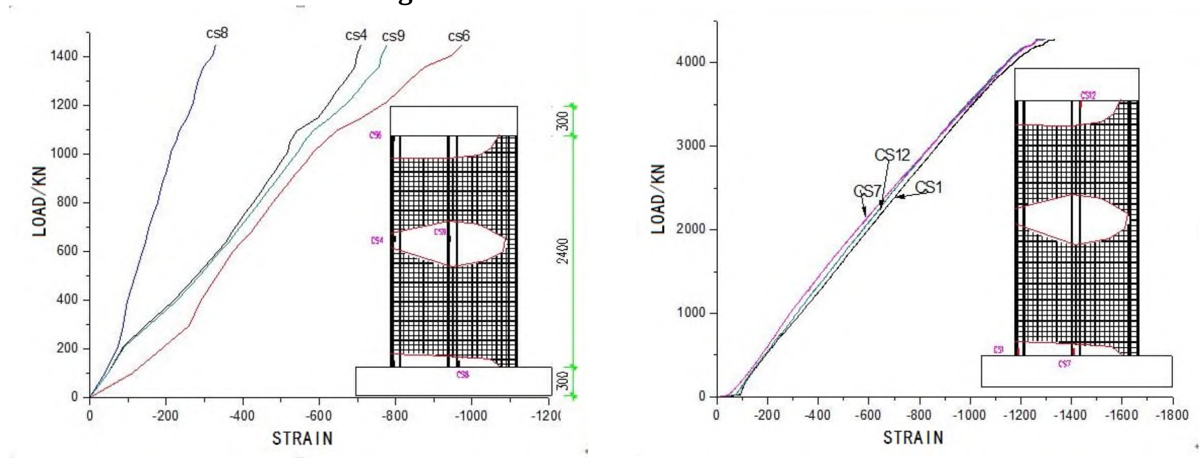
(a) ZY-1 (b) ZY-2

Figure 4. Load-lateral displacement curves.



(a)ZY-1 (b)ZY-2

Figure 5. Load-concrete strains curves.



(a)ZY-1 (b)ZY-2

Figure 6. Load-reinforcement strains curves.

5. Conclusions

The structural behavior of a novel prefabricated sandwich panel under axial load has been experimentally investigated in this work. Some conclusions could be drawn as following:

1) A brittle failure occurred with a main vertical crack almost thorough the full height for specimen ZY-1 and severe local concrete crush in the panel top appeared in the final state for specimen ZY-2. No massive cracks were found in the surface of panels during the whole process of loading.

2) Compared with ZY-1 with planar steel wire mesh, the specimen ZY-2 with 3D steel wire skeleton presented better structural performance with greatly higher strength and robustness due to the smaller value of slenderness ratio even with less reinforcement ratio.

3) The lateral deflections almost kept a linear growth in the initial loading stage and due to the existence of core columns there was no obvious out-of-plane deflection generally seen in traditional sandwich panel subjected to axial compression. The strain curves both for concrete and reinforcement approximately presented a proportional growth with the development of axial load.

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Acknowledgement

This work was supported by the Shandong Provincial Key Research and Development Program of China (Grant no.2017GSF22106) and the Natural Science Foundation in Shandong Province of China (Grant no. ZR2014EL037).