Resilient Structures and Sustainable Construction
Edited by Pellicer, E., Adam, J. M., Yepes, V., Singh, A., and Yazdani, S.

ISBN: 978-0-9960437-4-8

EXPERIMENTAL STUDY ON SHEAR PERFORMANCE OF COMPOSITE CONNECTOR FOR PRECAST CONCRETE SANDWICH PANELS

XIMEI ZHAI, WENJIAN YING, and WANG XUEMING

School of Civil Engineering, Harbin Institute of Technology, Harbin, China

In order to ensure desirable overall performance between interior panel and exterior panel for precast concrete sandwich panels, the shear performance of a new composite connector is investigated in this paper through the experiment of shear specimens, including 4 groups of bilateral shear test specimens and 8 groups of unilateral shear test specimens. The connector's shear capability and shear failure process phenomenon of destruction of all specimens are obtained. Then the effect rule on shear performance of connector from positional relation of connector and distribution reinforcement and concrete strength are gained. The experimental results and analysis show that the shear failure model is bending shear failure of connector's reinforcing steel bar, which is brittle failure; the measured value of shear force of experiment compared to the measures values for the actual project, the new composite connector provides an enough safety reserve; The relative position of connector and distribution reinforcement and concrete strength have no influence on the ultimate bearing shear capability; The shear performance of the new composite connector could satisfy the use requirement of sandwich wall panels based on the text results. Furthermore, the connectors perform superb anchoring bond and deformation capability. According to the results and analysis, the new composite connector could be popularly used in engineering practice.

Keywords: Overall performance, Shear specimens, Unilateral shear test, Bilateral shear test, Shear failure, Engineering practice.

1 INTRODUCTION

Compared with conventional cast-in-place structure in construction process, prefabricated assembled concrete structure has a wide range of application prospects in the residential market relate to its unique advantages. As the most vulnerable part of the assembly, precast concrete sandwich panels typically consist of two concrete panels separated by a layer of insulation. The concrete panels are connected through the insulation layer by all kinds of connectors, which are used to ensure desirable overall performance between the two concrete panels. Examples for traditional connector types are ordinary steel connector, metallic connector, Fiber-Reinforced Polymer (FRP) connector and composite connector. Bush and Stine (1994) had an experimental study on truss connectors, and found that it could provide ample resistance to bending; Salmon *et al*. (1997) made an experimental study on the ordinary steel connector and found that it was easy to be corroded with the low thermal efficiency; in addition, scholars also developed numerous researches about FRP connector and regraded that FRP connector owned superb mechanical performance, of which concerned about shear capability researches include: Wade *et al*. (1988)

developed the FRP connector firstly at 1988; Porter and Barnes (1991) studied on the shear performance of FRP connector at 1991; Yang *et al*. (2013) examined the shear performance of FRP connector, etc.

Previous literatures show that: ordinary steel connector stands out for its low cost, but it is easy to be corroded and form thermal bridges in walls; metallic connector usually is used to solve the problem of corrosion resistance but limiting its use for higher cost and more complex construction; FRP connector has seen recent use for its high shear resistance and seismic performance, failure mode is ductile damage. This paper introduces a new kind of composite connector which consists of steel bar and wrapped nylon composition in detail, this new composite connector allows a sandwich panel to develop composite action without compromising cost, durability and bonding with concrete.

2 SHEAR TEST SPECIMEN DESIGN

2.1 Composite Connector

Structural design and size design of composite connector are illustrated in Figure 1, according to the different locations in the sandwich panels, connectors can be divided into three parts: 70 mm long with nylon recessed part inserted the interior panel; 80 mm long outer wrapped nylon of the steel bar inserted the insulation layer; 30 mm long A10 steel bar (A represents HPB300 grade steel bar, B represents HRB335 grade steel bar) inserted the exterior panel, and two orthogonal 250 mm long A6 steel bar were imbedded at the end of the steel bar. All three parts were connected with the center A10 light round steel bar, the outer nylon surface which located in the interior panel and A10 steel bar surface were respectively provided with groove and thread, so as to increase the bond strength and the friction force among the concrete, nylon and reinforcing steel bar, which used to ensure the collaborative work among three parts.

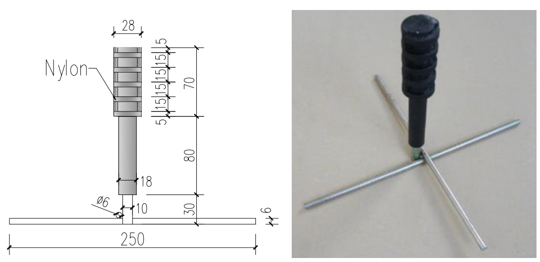


Figure 1. Connector.

2.2 Test Piece Design

Two different cases were considered to obtain the influence of location between connector and distribution steel bar to connector’s shear performance in this paper, which included connector respectively located in the middle parts and crossing parts of the distribution steel bar, so in this paper shear test can be divided into two types, which means ends of connector were respectively buried in: 1) inner panel grid central +outer panel grid central, 2) inner panel connecting parts + outer panel grid central. In addition, study on the effect of concrete strength grade also was conducted which respectively were C30 and C40 (C represents concrete strength grade).

Specimens design details are illustrated in Figure 2 and Figure 3, specimens’ identifications are showed in Table 1 and Table 2. Descriptions of specimens’ identifications exhibited as followings: S represented shear; I stood interior panel, E represented the exterior panel; A on behalf of connector located in the distribution grid reinforced central, B on behalf of connector arranged on the cross point of distribution steel bar; Digital 30 (40) on behalf of the design grade of concrete strength. Researchers selected HPB300 A4@200 steel wire mesh for steel mesh in the exterior panel, and the steel bar in the interior panel selected HRB335 B12@200 steel bar.

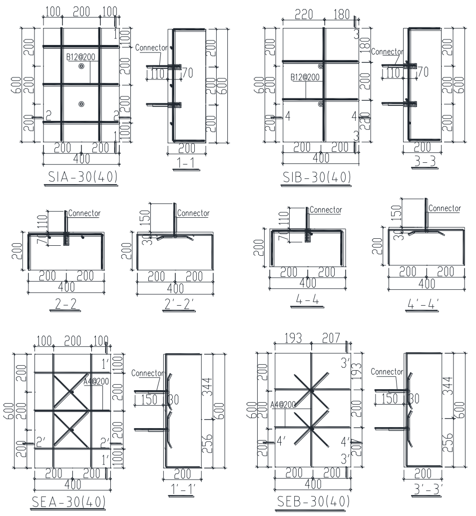


Figure 2. Unilateral shear test specimens.

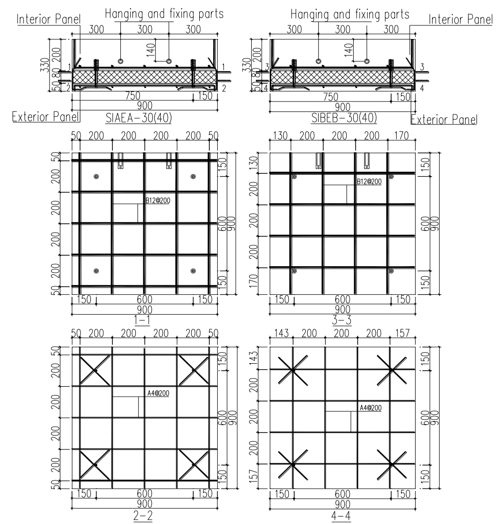


Figure 3. Shear test specimens design details.

In general, a 200-mm-thick exterior panel and 50-mm-thick interior panel commercially available in the actual engineering, in this paper, researchers selected the same thickness of exterior panel which was 200 mm for convenience of construction, but the size of the connector which inserted exterior panel was 30 mm as the same as the actual engineering situation.

3 TEST MEASUREMENT SYSTEM AND LOADING DEVICE

In the unilateral shear test and bilateral shear test, 50 mm range of mechanical dial indicator were set at the loading end to measure the deformation of specimens. For the unilateral and bilateral shear tests, corresponding specific devices were designed and LSS tensile tester was used in loading process. In the unilateral shear test, horizontal load was applied to the connector's reinforcing steel bar with the force transmitting device as shown in Figure 4, whereas bilateral shear test was conducted with vertical load applied at the top of exterior panel (Figure 5).

4 TEST PROCESS, RESULTS AND ANALYSIS

4.1 Unilateral Shear Test

In the unilateral shear test, the loading end displacement of connector increased with the increasing of load and accompanied with gradually root bending of connector, meanwhile, one side concrete was crushed and the other one side performed slightly separate with reinforcing steel bar. When the load reached the ultimate bearing capability of connector, the reinforcing steel bar occurred large root bending deformation and concrete did not happen shear failure yet. The bearing capability of test is showed in Table 1 and the destruction photographs of specimens are showed in Figure 6. The test results indicated that the specimens' failure of unilateral shear test performed as root bending deformation of connectors' reinforcing steel bar.

Figure 4. Unilateral shear test loading device.

(a) SIAEA-30-1

(b) SIBEB-30-3

(c) SIAEA-40-2

(d) SIBEB-40-2

Figure 5. Loading device and destruction diagrams of bilateral-shear test.

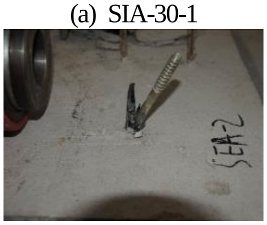
Table 1. Bearing capability and destruction phenomenon of unilateral shear test.

Identification	**Shear Capability （kN）**	**Average Capability （kN）**	**Standard Deviation**	**Destruction Phenomenon**
SIA-30-1,2,3	5.3, 4.7, 4.9	4.97	0.306	Root bending
SIB-30-1,2,3	4.7, 4.9, 5.2	4.93	0.252	Root bending
SEA-30-1,2,3	3.8, 2.5, 4.3	3.53	0.929	Root bending
SEB-30-1,2,3	4.7, 4.2, 4.0	4.30	0.361	Root bending
SIA-40-1,2,3	5.2, 5.8, 5.6	5.5	0.306	Root bending
SIB-40-1,2,3	5.3, 5.5, 5.6	5.5	0.153	Root bending
SEA-40-1,2,3	7.2, 5.4, 5.2	5.9	0.102	Root bending
SEB-40-1,2,3	5.4, 4.9, 5.0	5.1	0.265	Root bending

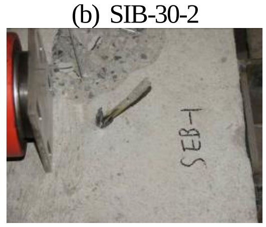
(a) SIA-30-1

(b) SIB-30-2

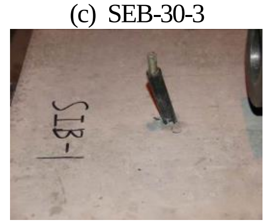
(c) SEB-30-3



(d) SEA-40-2



(e) SEB-40-1



(f) SIB-40-1

Figure 6. Destruction diagrams of unilateral-shear test.

4.2 Bilateral Shear Test

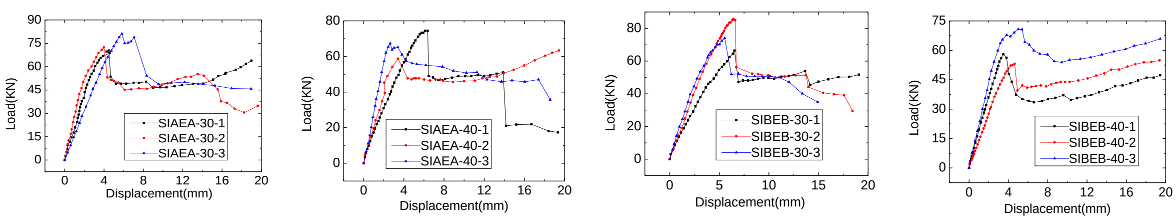
In the bilateral shear test, each connector was loaded to failure under a monotonically force demand under a uniform pressure load which was increasing at a rate of 5 kN, when it came to the ultimate bearing capability, immediately decreased it to 2.5 kN each level. Then, the experiment was conducted under displacement control, which was increasing at a rate of 2mm until test finished. The result of bearing capability from test is illustrated in the Table 2. Figure 5 shows final destruction photographs of some specimens. The average shear force of a single connector vary from a low of 15.5 kN to a high 18.8 kN which are summarized in Table 2, it also shows that the increasing of concrete strength had no effect on the ultimate bearing capability.

Table 2. Bearing capability and destruction phenomenon of bilateral shear test.

Identification	Shearing Capability			Destruction Phenomenon
	Total Bearing Capability(kN)	Single Bearing Capability (kN)	Average (kN)	
SIAEA-30-1	70.4	17.6		Mode B
SIAEA-30-2	72.4	18.1	18.7	Mode B
SIAEA-30-3	81.1	20.3		Mode A
SIBEB-30-1	66.4	16.6		Mode A
SIBEB-30-2	85.7	21.4	18.8	Mode A
SIBEB-30-3	74.0	18.5		Mode A
SIAEA-40-1	74.4	18.6		Mode B
SIAEA-40-2	70.0	17.5	17.6	Mode A
SIAEA-40-3	67.3	16.8		Mode A
SIBEB-40-1	58.0	14.5		Mode A
SIBEB-40-2	56.7	14.2	15.5	Mode B
SIBEB-40-3	70.7	17.7		Mode A

Note: Mode-A: diastrophism of the concrete panels; Mode-B: separate of the concrete panels

During the test, the displacement of loading end were tracked consistently and used to replicate the load–displacement curve of the whole process as shown in Figure 7. The curve exhibited a liner response at the early loading period and the slope decreases rapidly with load descended to 70%-80% of maximum load when it came to the maximum bearing capability, past test inspection revealed that these specimens still had moderate bearing capability, which was owing to that the destruction of connectors didn't occurred at the same time, thus, the shear force in this test was an average level of four connectors in the shear specimens.



SIAEA-30 SIAEA-40 SIBEB-30 SIBEB-40

Figure 7. Loading-displacement curve of bilateral shear test.

From the shear test results, it can be found that the connector damage mainly performs as the bending shear failure of steel bars, and the bearing capacity of unilateral shear specimens are significantly lower than the bilateral shear specimens. In addition, it can be seen that the grade of concrete has no effect on the ultimate bearing capacity. Figures 5 and 6 show that the damage of unilateral shear specimen all performed as the obviously bent deformation of root part of connectors, meanwhile, it can be found there exists two different destruction phenomenon in the bilateral shear test and that is because under the action of vertical force, the root position of connector starts to bend, with the increase of the vertical force, the relative displacement of the inner and outer panels is increasing, and the connector is in the state of bending and shearing force.

5 SAFETY EVALUATION OF COMPOSITE CONNECTOR

Zhang *et al*. (2008) from Shenyang Construction University calculated in the literature, the horizontal seismic force of per unit area exterior panel was 1.47 kN under 8 degree area rare earthquake; Yang *et al*. (2013) from Tongji University calculated the connector applied in the prefabricated sandwich insulation walls of a housing project in Shanghai and got the design shear value was 1.39 kN; Liu (2014) from Wuhan University of Technology developed checking calculations of precast concrete sandwich wall under different conditions in Shenyang Huisheng Metro (public housing) project, the research got the conclusion that the most unfavorable shear load design value of a single connector was 1.99 kN. In this paper, the maximum shearing capability of a single connector obtained from unilateral and bilateral shear test was respectively range from 3.53-5.9 kN and 15.5-18.8 kN. Compared to the results of the above scholars, it is obvious that the composite connector could withstand the shear force of the structure and has a large safety reserve, so it can be applied in practical engineering.

6 CONCLUSION

(1) The average shearing capability of a single composite connectors are respectively ranged from 3.53-5.9 kN and 15.5-18.8 kN. Compared with the shear design value of a single connector in the actual engineering, the composite connector performs a large safety reserve in this paper, which can be applied in practical engineering.

(2) The shear failure performs as bending shear failure of the connector's reinforcing steel bar, which belongs to brittle failure; the nylon and the reinforcing steel bar have good bond performance. During the test, the cracking of the concrete mainly causes the displacement of specimen; the elongation of the reinforcing steel bar has little effect on the displacement.

(3) Relative positioning of connector and distribution reinforcement in panels has no effect on the ultimate capability and damage mode of sandwich panels, but the existence of steel mesh and crossing-bar contribute to delaying the connector pulling out from the external layer; Increasing the strength of concrete has no effect on the enhancing of shear capability.

References

Bush, T. D. and Stine, G. L., Flexural behavior of composite precast concrete sandwich panels with continuous truss connectors. *PCI journal*, 39(02), 112–121, 1994.

Liu, R. N., Research on design of connector for precast concrete sandwich wall based on strength theory, Ph.D. thesis, *Wuhan Institute of Technology*, 05, 2014 (in Chinese).

Porter, M. L. and Barnes, B.A., An elemental test series on low-cycle fatigue behavior of ties subjected to cold temperatures and in-plane shear, *Iowa: Iowa State University*,1991.

Salmon, D. C., Einea, A., and Tadros, M. K., Full scale testing of precast concrete sandwich panels, *ACI Structural Journal*, 94, 239–247, 1997.

Wade, T. G., Porter, M. L., and Jacobs, D. R., Glass-fiber composite connectors for insulated concrete sandwich walls, *Engineering Research Institute*, Iowa State University, 118(03), 1988.

Yang, J. L., Xue W. C., and Li, X., Mechanical properties test of FRP connectors in precast sandwich insulation wall panels, *Journal of Jiangsu University(Natural Science Edition)*, 06: 723-729, 2013 (in Chinese).

Zhang, Y. N., Zhang, X., and Liu, M., Experimental study on anchorage performance of ring shaped plastic steel tie for cavity walls, *Journal of Shenyang Jianzhu University(Natural Science)*, 24(04), 543–547, 2008 (in Chinese).