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BEHAVIOUR AND PUSH-OUT TEST OF CONCRETE DOWEL CONNECTORS FOR LONGITUDINAL SHEAR IN SHALLOW-HOLLOW COMPOSITE BEAMS

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Abstract

The shear transferring mechanisms of shallow-hollow composite beams with concrete slab cast in place are different with conventional headed shear studs and have not been investigated previously. In this study, the behavior and push-out test of concrete dowel connectors for longitudinal shear in shallow-hollow composite beams are described. The theory prediction for concrete dowel connectors without tie-bars adopted in this study was based on EN 1992-1-1 and EN 1994-1-1. Push-out tests of three specimens were conducted and the results were compared with theory prediction and published formula to identify longitudinal shear resistance. The failure of specimens and the ultimate failure load values of push-out test were proved that the behavior of concrete dowel in shallow-hollow composite beams was not under pure shear stress.

Keywords: steel-concrete composite beam; shallow-hollow composite beam; concrete dowel connectors; longitudinal shear resistance; shallow floor structure.

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1. Introduction

In recent years, the increasing demands on composite floor-beams systems in steel building have led to the development of steel and concrete structures. Although steel and concrete composite beams have outstanding advantages in comparison with concrete or steel beam such as bigger moment resistance strength, higher stiffness, shorter and more effective in construction manner [1], it still has some weaknesses such as low fire resistance, large beam-floor structure height, more cost for headed-shear stud connectors. Hence, many types of shallow floor as Slimflor, Slimdek Asymmetric Slimflor Beam [2], Delta beam [3] and Ultra Shallow Floor Beam with precast concrete slab [4] are developed to overcome such problems. Typically, these steel sections of innovative composite beams are partial embedded in concrete slab to increase the fire resistance, the structure height will be reduced and concrete dowel connectors play a role as headed-shear studs in conventional composite beams.

In Vietnam, the shallow-hollow floors composite structures are new type of composite beam in building construction. The steel section of the composite shallow-hollow beam is fabricated by welding trapezoidal-hollow section with flat or U-shaped steel plate together. Along the web of

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trapezoidal-hollow section, the circular openings are perforated. The profiled steel decking is supported by the flat flange plate, creating a shallow-hollow floor construction system, as illustrated in Fig. 1. The overall floor depth will be reduced by steel section embedded in slab. The moment resistance of the composite beams could be optimized by sizes and shape of the steel parts. The circular web openings provide passage for the concrete and reinforcing tie-bars to create the concrete dowel shear connectors. By resisting longitudinal shear at the steel and concrete interface, the composite section act as single unit. The hollow steel section is exposed to direct heat in fire while not only concrete part inside the hollow section but also the slab behaves as "heat sink", so the fire resistance can be archived [1].

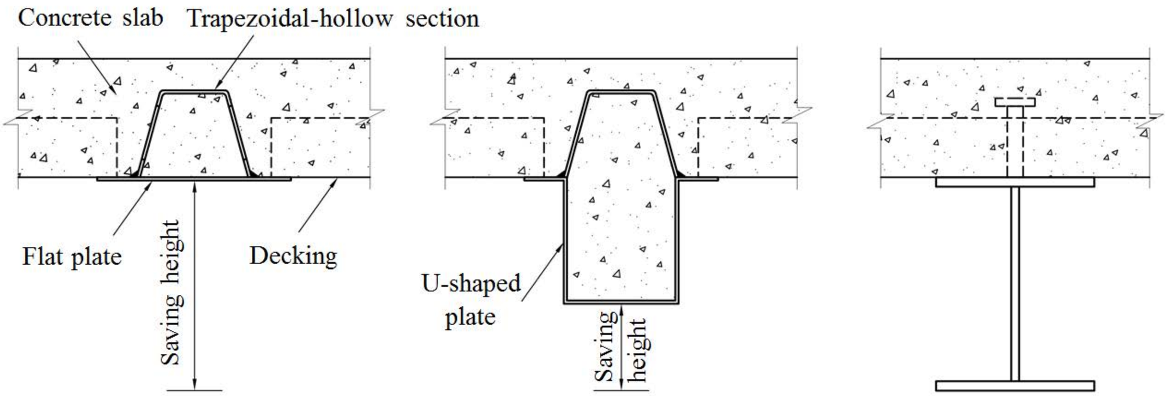

Figure 1. Cross-section of drawing of the shallow-hollow composite beam

The studies based on EN 1992-1-1 [5]; EN 1994-1-1 [6] presented in this paper have provided information on the behavior of concrete dowel connectors in shallow-hollow composite beams. A series of push-out tests consisting of three full-scale test specimens were performed to investigate the shear connection under the direct longitudinal shear force.

2. Longitudinal shear resistance of shallow-hollow composite beams

One of the most important characteristics of shallow floor composite structures is identify the shear connection level. The behavior of longitudinal shear has been mentioned in many articles since 2004. Peltonen S. and Leskelä M. V. pointed out the shear behavior of shallow floor structures with precast concrete slab [7]. Huo. B. Y and D'Mello. C. A implemented the push-out test and published the shear mechanism on composite shallow cellular floor beams in 2013 [8]. The longitudinal force transferring mechanism, load bearing capacity and failure behavior of the shear connections under direct longitudinal shear forces were investigated by numerical simulation in 2017 [9, 10]. However, the behavior of shallow-hollow composite beams with concrete slab cast in place still has not mentioned. The longitudinal shear resistance of shallow-hollow composite beam depends on shear resistance of concrete dowels with or without tie-bars along the beam and friction (bond) force at outer interface of hollow steel section and concrete slab. The tie-bars arrangement in concrete dowel are excluded in this study.

2.1. Shear resistance of concrete members by design code EN 1992-1-1

In EN 1992-1-1 [5], shear resistance of concrete members without reinforcement is mentioned relying on shear failure of reinforced concrete beams. Shear force in a concrete beam causes cracks on incline planes near the support where magnitude of shear force is high. The cracks are formed by principle tensile stress and compressive stresses of the same magnitude as the shear stress and inclined 45° to the neutral axis. An accurate analysis for shear strength is impossible because of complex state of stress and many mechanisms of concrete material. The problem has been solved by testing beams of the type normally used in practice. Simplified equation to determine the shear strength of concrete members was provided in design code [5] as:

$$V_{Rd,c} = \max\left(k_1\sigma_{cp}b_w d; (v_{\min} + k_1\sigma_{cp})b_w d\right) \tag{1}$$

$$\sigma_{cp} = N_{Ed}/A_c < 0.2f_{cd}\,(\text{MPa}) \tag{2}$$

$$\begin{aligned} v_{\min} &= 0.035k^{3/2}{f_{ck}}^{1/2} \\ k &= 1 + \sqrt{200/d} \leq 2.0 \end{aligned} \tag{3}$$

where b_w is the smallest width of the cross section in the tensile area (mm); d is the height of member under shear force (mm); N_{Ed} is the axial force in the cross-section due to loading, the influence of imposed deformation on N_{Ed} may be ignored; A_c is the area of concrete section (mm^2); f_{ck} is the cylinder strength of concrete at 28 days (MPa); The recommended value for k_1 is 0.15.

2.2. *Interface bond resistance between steel and concrete*

The friction resistance between steel and concrete material is normally calculated as contact shear strength τ_{Rd} by area of interface as shown in following formula:

$$V_{Rd,f} = \tau_{Rd}A \tag{4}$$

The shear strength provided in Table 1 [6] for outer surface of steel section contact with the concrete is unpainted and free from oil, grease and loose scale or rust.

Table 1. Design contact shear strength

Type of cross section	τ_{Rd} (N/mm^2)
Completely concrete encased steel sections	0.30
Concrete filled circular hollow sections	0.55
Concrete filled rectangular hollow sections	0.40
Flanges of partially encased sections	0.20
Web of partially encased sections	0.00

These values τ_{Rd} given in Table 1 for completely concrete encased steel section apply to section with a minimum concrete cover of 40 mm. For greater concrete cover and adequate reinforcement, higher values of τ_{Rd} may be used. Unless verified by test, for completely encased sections, the increased value of β_c may be used. With β_c given by:

$$\beta_c = 1 + 0.02c_z\,(1 - 40/c_z) \leq 2.5 \tag{5}$$

where c_z is the nominal value of concrete cover in mm.

In this research the given values in Table 1 were used to estimate shear bond strength between steel and concrete of composite specimens.

2.3. Analytical study of previous experimental test

A similar configuration of shear connectors relying on shear strength of perfobond rib shear connections has been investigated by Ahn et al. [11]. A series of push-out test including 24 specimens were conducted to obtain a calculation design method of shear resistance for the shear connection. The proposed design shear resistance of the shear connector is given by:

$$Q = 2.76 h_{sc} t_{sc} f_{ck} + 1.06 A_{tr} f_y + 3.32 n\pi (d/2)^2 \sqrt{f_{ck}}\ (\mathrm{N}) \tag{6}$$

where A_{tr} is the area of the transverse rebars in the rib holes (mm^2); f_y is the yield strength of the transverse rebar (MPa); n is the number of rib holes; h_{sc} is the height of the rib; d is the diameter of the rib (mm) and t_{sc} is the thickness of the rib (mm).

If the reinforcement is omitted, the web thickness is thin then in this study the shear strength of perfobond rib shear connections could be rewritten as:

$$Q = 3.32 n\pi (d/2)^2 \sqrt{f_{ck}}\ (\mathrm{N}) \tag{7}$$

3. Push-out test

3.1. Test specimen

The push-out test aimed to identify the shear resistance of concrete infill only shear connector, so the test specimens consisted of a steel hollow section and concrete slab without any reinforcement. There were three opening holes in each web of the steel beams. Concrete infilled the hollow section of steel beam passed through the web opening to form the shear connection subjected to longitudinal shear force. There were three similar composite beams including two de-bonding specimens with greased and one nature bond specimen. The designed shape with dimensions of steel part and specimen is shown in Fig. 2.

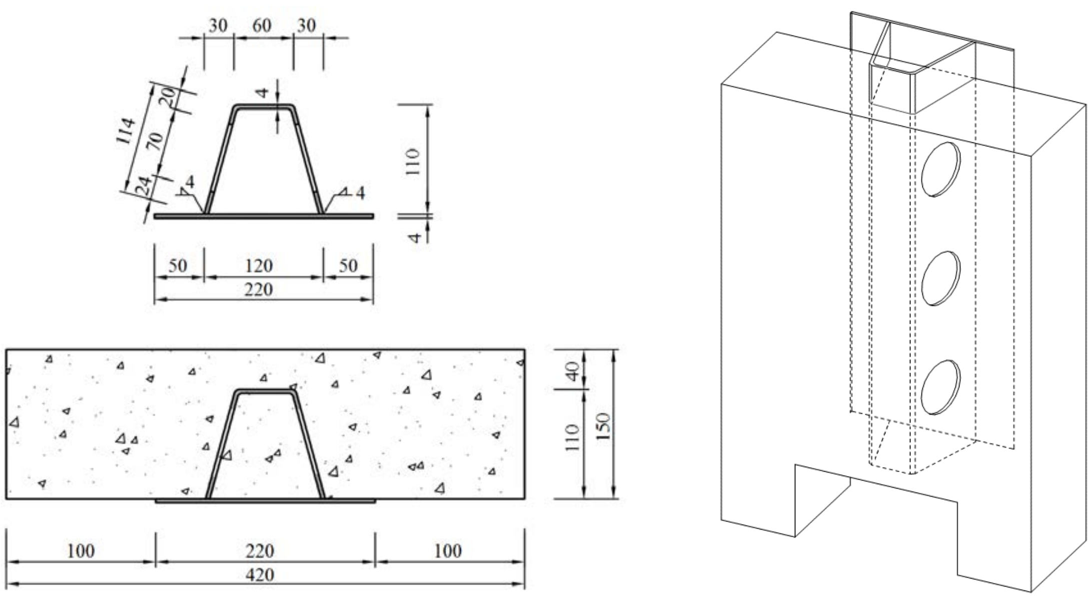

Figure 2. Dimensions and shape of push-out test specimens

The steel section of the test was a short trapezoidal hollow section with 550 mm in length. Three couple of 70 mm circular openings were perforated on the web post. The trapezoidal section was used to investigate shear connections in some innovative composite beams which are embedded in concrete slabs. The steel beams are fabricated by SS400 steel material follow EN 1993-1-1 [12] that have 245 MPa yield strength; 400 MPa ultimate strength. The total depth of the steel beams was 114 mm, and the total width was 220 mm. The concrete slabs in the push-out test used concrete grade C25/30 following [5] specification. The overall width of concrete slabs was 420 mm. The concrete cover of trapezoidal hollow section was 40 mm which is similar to actual working conditions. The concrete batch of each specimen was extracted to do unit test that was conducted to test concrete compressive strength.

Two of three steel beams were applied with greased to prevent the development of the bond between concrete and steel and then, they were put in formwork for concreting. All the push out test specimens were casted in the laboratory LAS-XD 125 of National University of Civil Engineering. Some pictures of construction of composite specimens are shown in Fig. 3. Time for concrete hardening was 28 days. After concrete hardening, three specimens were marked as Table 2.

Figure 3. Formwork and finishing of the specimens

Table 2. Name of specimens and their features

No	Specimens	Hole diameter	Feature
1	TN-C1-G	70 mm	Circular hole, un-bond
2	TN-C2-G	70 mm	Circular hole, un-bond
3	TN-C3-F	70 mm	Circular hole, friction

3.2. Test set up and procedures

Test specimens were put into a rig 200-ton capacity vertically. Based on prediction of failure load, a hydraulic jack 50 ton was used to apply load. There were four linear variable differential transformers (LVDTs) attached in steel part and concrete part to measure slip. These loaded jacks and LVDTs were connected to a data logger which wrote and saved data of load and slip in each second. Some pictures of test set up are shown in Fig. 4.

Figure 4. Push-out test set up

The push-out test was carried out following specification Appendix B [6]. The load were first applied increments up to 40% of the expected failure load. Subsequent load increments then were imposed such that failure does not occur in less than 15 minutes. Longitudinal slip between steel and concrete was measured continuously during loading. After failure of specimens, data of load and displacements were collected automatically and analysis later.

3.3. Test result

After three tests have conducted, some pictures of specimen failure are demonstrated in Table 3; the ultimate failure load and maximum relative slip of three specimens are listed in Table 4.

Table 3. Failure of the specimens

No	Specimens	Steel part	Concrete part
1	TN-C1-G		
2	TN-C2-G		
3	TN-C3-F		

Table 4. Ultimate failure load and maximum slip value of the specimens

No	Specimens	Hole diameter	Ultimate failure load (kN)	Maximum Slip (μm)
1	TN-C1-G	70 mm	176.6	805
2	TN-C2-G	70 mm	141.3	665
3	TN-C3-F	70 mm	160.6	905

A load-slip curve was drawn from the result of data logger. These curves illustrate the characteristic behavior of the shear connection in response to direct longitudinal shear force. Three graphs corresponding to three specimens are shown in Fig. 5.

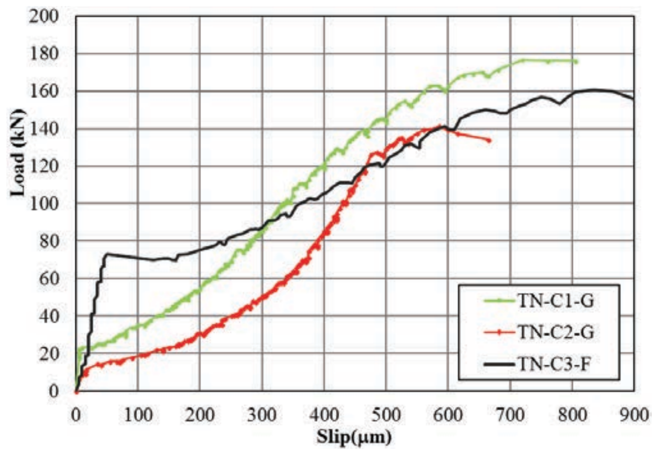

Figure 5. Load-slip curve

It is worth to note that test result shown that the concrete filled in trapezoidal space of the steel beams have not been damaged and still filled in hollow section.

4. Analysis of test result data

During the test, three specimens were ruptured suddenly with no warning or ductile deformation. The failure mode of shear connection could be confirmed that was brittle failure for de-bonding specimen and bonded specimen with maximum displacement were approximate 1 mm which is much smaller than required slip in [6] for ductile connector 6 mm.

After doing unit test, characteristic strength of concrete was obtained to determine ultimate failure load. The mean value of concrete cubic specimen and cylinder specimen were 33.4 and 26.7 MPa, respectively. Based on the detail dimension of test specimens and Eqs. (1) to (7) the ultimate failure load of the specimen has been calculated. Those values were compared to mean value of ultimate failure load obtaining from test result as shown in Table 5.

While calculation of shear resistance by Eq. (1) given much lower value than test result with nearly 2.5 times, Eq. (7) slightly overestimate shear resistance of the concrete dowel with 16%.

Based on the failure of test specimen, the stress state of concrete dowel is illustrated in Fig. 6. The flat surface of concrete could be seen, so the shear connectors have been cut by shear stress along the steel beam length.

Table 5. Comparison of ultimate failure loads

	Prediction of shear strength (kN)	Test result (kN)	Ratio (Test/prediction)
Eq. (1)	60.6	159.5	263%
Eq. (7)	191.0		84%

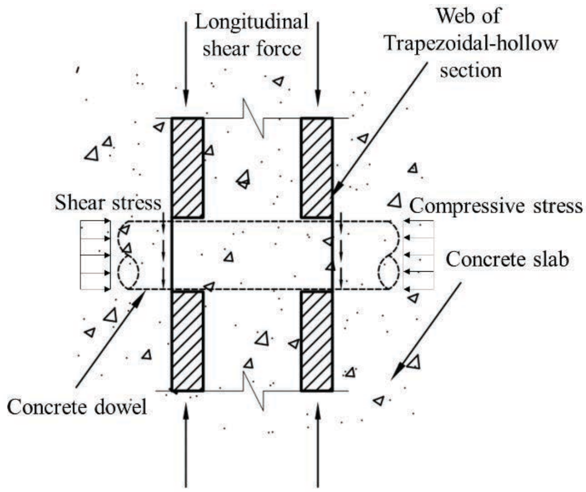

Figure 6. Stress state of concrete dowel

5. Conclusion

In order to investigate behavior of concrete dowel shear connectors for longitudinal shear in shallow-hollow composite beams, the experimental test presented brittle failure mode of the connectors. The failure of specimens and the ultimate failure load values of push-out test are proved that the behavior of concrete dowel in shallow-hollow composite beams is not under pure shear stress. So, the stress in the shear connectors were not only shear stress along the steel beam length but also possible compressive stress of concrete in slab. From this study, future research may be prepared properly to develop calculation method for shear resistance of this type of shear connection.

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