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SHEAR RESISTANCE DETERMINATION OF CONCRETE DOWEL IN SHALLOW CONCRETE-STEEL COMPOSITE FLOOR-BEAM BASED ON PUSH-OUT TESTS

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Abstract

Unlike conventional composite beam which use headed-shear studs, in shallow concrete-steel composite floor-beam system, the web opening of steel beam infilled with in-situ concrete is considered as shear connector. In this paper, empirical formula for the shear resistance determination of trapezoid concrete dowel in shallow concrete-steel composite floor-beam is formed. This established process is based on the failure mechanism and the ultimate loading of push-out tests. The push-out test results were retrieved from our previous experimental investigations which showed that the shear resistance of the shear connector is mainly contributed by confined compressive strength and splitting tensile strength of concrete. By performing a combined mechanical-analytical analysis, an empirical formulation originating from the shear transferring mechanism of concrete dowel has been proposed. The formula was then verified against existing data and other equations in the published literature. The comparison demonstrates that the proposed formulation is the most suitable for the trapezoid concrete shear connector.

Keywords: shear resistance; concrete dowel; shallow concrete-steel composite floor; push-out tests; empirical formulation.

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1. Introduction

The longitudinal shear resistance of concrete dowels in shallow steel floor-beam with concrete slab cast in place is different from welded-headed shear studs in conventional composite beams. The differences between them are dependent on many factors such as the location of in situ concrete slab; steel beam-type; shape, dimensions, and the number of openings in the steel beam web; reinforcing bar arrangement through the opening, friction forces at the steel-concrete surface... In 1987, the first push-out test of cylinder concrete dowels are implemented by Andrä and Leonhardt [1]; the model and the dimensions of the specimen are illustrated in Fig. 1. The formula to identify the longitudinal shear resistance of a single dowel, which depends on the diameter of the dowel and the compressive strength of concrete is recommended. Since then, much research to improve the shear connection level to apply in bridge construction are studied. The studies of concrete dowel's behavior are not only connected with testing but also on numerical analysis methods. Based on the research results, in general, the longitudinal shear resistance consists of the following components: concrete bearing of

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end steel plate, concrete bearing at the contact of opening, bending or shear of rebar, and friction. For cylinder concrete dowels, numerous formulas have been published to calculate the longitudinal shear resistance [2–11].

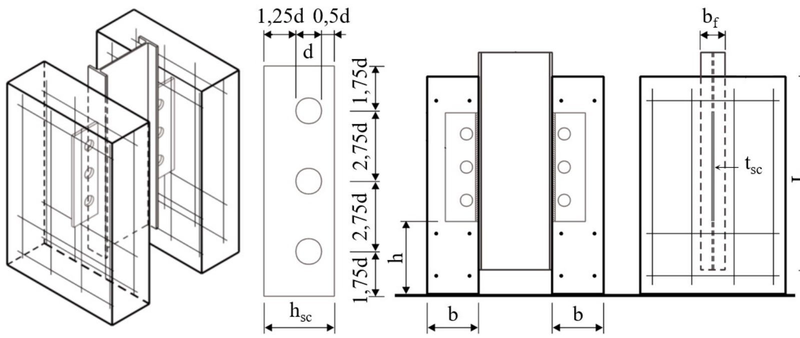
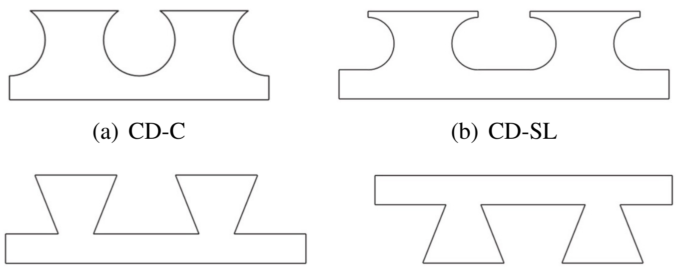


Figure 1. Model and the dimensions of the specimen [1]

The opening shape along the web of steel beam, which is most suitable with precast hollow-core slab normally is a circle. In building construction, various openings such as C-shape (CD-C), long-slotted shape (CD-SL) [10], and trapezoidal shape (CD-Z, CD-iZ) [12–14] are suggested (Fig. 2) to be able to combine with metal deck in composite slim floor structures. Recently, the CD-iZ is firstly applied in the floor beam system of a three-story building in HUCE campus [15], however, the composite action level is not yet well estimated.



(a) CD-C (b) CD-SL (c) CD-Z (d) CD-iZ

Figure 2. Various openings for the concrete dowel

To understand the behavior and verify the longitudinal shear resistance of trapezoid dowel (CD-iz), a series of push-out tests were conducted in LAS-XD 125. Based on the tested results as failure behavior, load transferring mechanism, and load-bearing capacity which are published in [12–14, 16], the empirical formulation to determine the longitudinal shear resistance of the CD-iZ dowel is developed.

2. Push-out tests and shear-transferring mechanism of shear connector

2.1. Push-out tests campaign

In order to investigate the behavior of concrete dowels, a series of push-out tests were performed on three tests group with a total of nine specimens. The design of specimen, materials, and testing procedure is followed Annex B of EN 1994-1-1 [17]. The specimen is composed of concrete and steel T-section shape. The load is applied to the T-section through a 25 mm thickness steel plate to ensure the uniform distribution of force to the T-section of the specimen. Load-controlled push-out with static loading is applied. The displacements of steel and concrete parts are measured by linear variable differential transformers which are attached to the specimen.

Only one web opening is considered in the steel T-section. In these configurations, we vary mainly on two types of variables: the dimension of the trapezoid web opening and the web thickness of the T-section. The geometrical dimensions of trapezoid shape ($d_1 \times d_2 \times h$) respectively are 120×190×88 mm and 180×250×88 mm. The web thickness (t_w) is taken as 6 mm and 10 mm; two types of CD-iz dowel are investigated. These variations enabled us to understand the contribution of the compressive part of the concrete dowel as well as evaluate the effect of the web opening size on the global longitudinal shear resistance of the shear connector. Details of specimen configurations are given in Fig. 4. In this series of push-out tests, the specimens are fabricated from steel grade S235 (yield strength of 235 MPa) and concrete with an average compressive strength of cubic sample f_{cu} is 38.65 MPa.

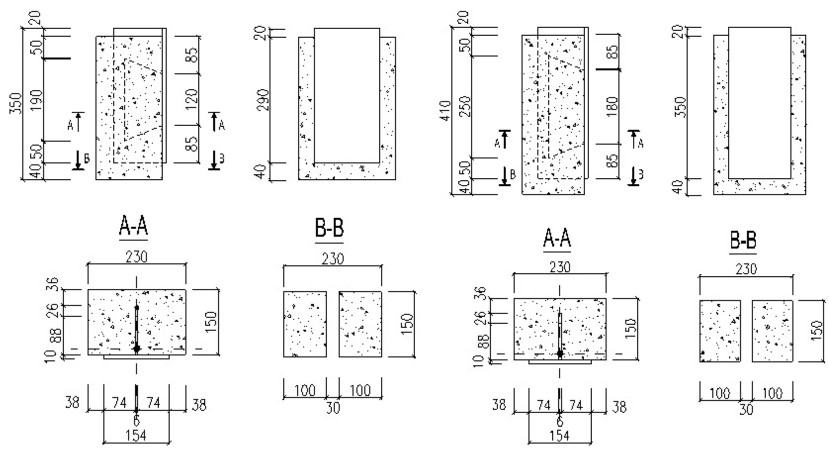


Figure 3. Specimen configurations

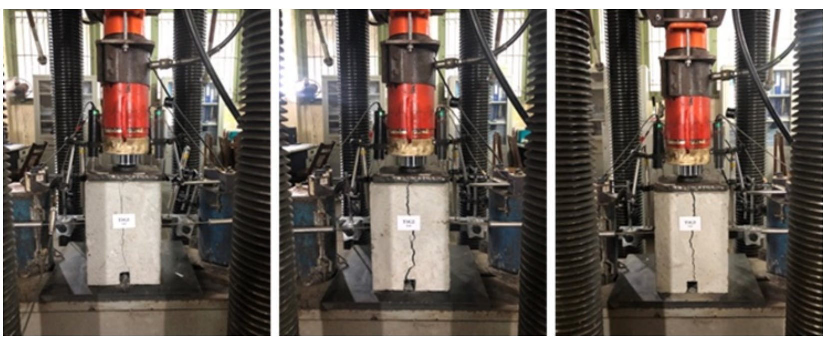


Figure 4. Test set-up and failure mode

2.2. *Shear transferring mechanism*

The experimental results and shear transferring mechanism has been reported in [12, 13]. Analytical readers are invited to the above-mentioned works for more details. In this paper, we only recall the principal results and observations of the shear transferring mechanism of the concrete shear connector. Fig. 5 shows the typical failure observed from push-out test. Several observations can be made:

- A compression zone was observed at the upper part of the concrete dowel. In particular, as indicated by zone number ① in the steel T-section, the concrete was smoothly crushed.

- In zone number ②, where the steel web is close to contact with the concrete dowel, the cutting section is almost flat and smooth. It is possible to conclude that this area is damaged by compressive failure.

- Different from the upper section, the lower part of the concrete dowel after failure is convex (zone number ③). This observation indicates that in the lower section, the failure of concrete dowel is due to the tensile splitting.

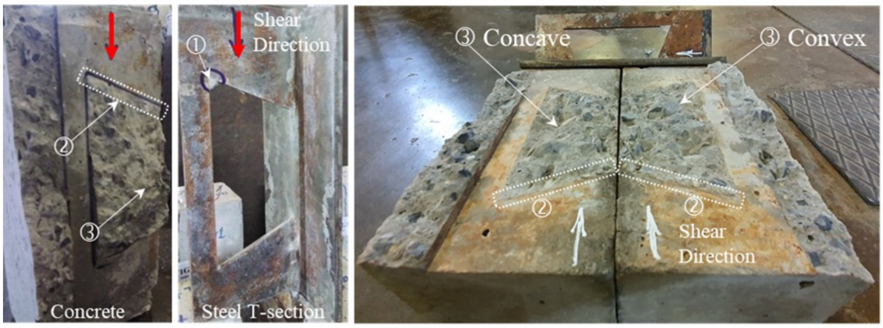


Figure 5. Shear-induced failure of the specimen

Based on these observations, the failure mechanism is contributed by two principal components: confined compressive strength and tensile splitting strength. An illustration Failure mode of a single CD-iz dowel is illustrated in Fig. 6. In the compression zone, the failure behavior is not homogenous inducing that the behavior of sections 2-2 and 3-3 is different. By performing the push-out tests (shear force applied), the failure of the CD-iz was firstly triggered by the splitting of concrete which was initially in the triaxial stress state. This splitting of the concrete is described by zone number ③, which is in tension.

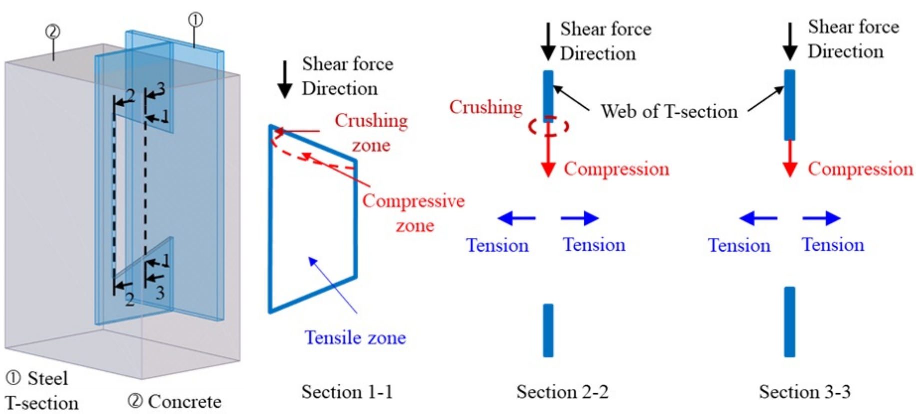


Figure 6. Illustration of shear transferring mechanism [12]

3. Development of empirical formula

3.1. Formula

Based on analysis of experimental results, it was found that the failure mechanism of CD-iz dowels is quite similar to results for circular concrete dowels. The concrete dowel's bearing capacity consists of the compressive capacity of the concrete part of the CD-iz and the tensile capacity of the lower part of CD-iz (Fig. 6). Moreover, unlike the results presented in [11], this obtained experimental results show that the compressive capacity of the concrete part not only varies according to the contact surface area between steel and concrete, but also depends on the proportional relationship between steel plate thickness and trapezoidal opening height [12, 13]. Besides that, the tensile splitting strength of a CD-iz dowel in the transverse direction depends on the height and the edges of the trapezoid as well as the shape of the opening.

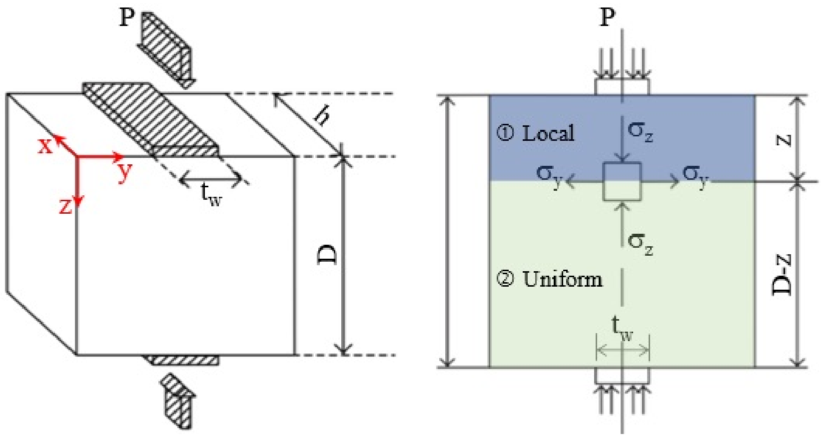


Figure 7. Splitting tensile strength test model and stress distribution

The zone at the acute angle of CD-iz dowel is under local compression effect. The area is extremely small compared to the overall area of the trapezoidal section (Fig. 5), the contribution of the local compression effect (zone ① in Fig. 7) in the shear resistance determination will be ignored in this article. Thus, determining the overall longitudinal shear resistance of CD-iz dowels is proposed as the following formula:

$$P_{Rd} = \alpha \left(k_1 f_{cu} A_c + k_2 f_{ct} A_t\right) \tag{1}$$

where: α is an empirical coefficient that is drawn from the analysis of experimental results; f_{cu} is the compressive strength of concrete cubic sample; f_{ct} is the tensile splitting strength of the concrete, $f_{ct} = 0.53 f_{ck}^{0.5}$ [18]; f_{ck} is the compressive strength of concrete cylinder sample; k_1 is the correction factor, taking into account the compressive failure of the concrete area at the steel-concrete contact area; k_2 is the correction factor, considering cross-section shape of the CD-iz concrete dowel; A_c is cross-sectional area of web plate in contact with CD-iz concrete dowel in compression;

$$A_c = h t_w \tag{2}$$

while h and t_w are the height of the trapezoidal opening and the thickness of the steel web, respectively; A_t is trapezoidal opening area;

$$A_t = \left(d_1 + d_2\right) h/2 \tag{3}$$

with d_1, d_2 are the long and short bases of the trapezoidal opening, respectively; Specific data on CD-iz dowel dimension, concrete strength, and the result of failure load are shown in Table 1.

Table 1. Geometrical and material characteristics, failure loads of the specimen

No.	Specimen name	Push-out failure load (kN)	d_1 (mm)	d_2 (mm)	h (mm)	t_w (mm)	A_c (mm^2)	A_t (mm^2)	f_{cu} (MPa)	f_{ct} (MPa)
1	T1G*1	112								
2	T1G*2	107	190	120	88	6	528	13640	38.65	3.356
3	T1G*3	120								
4	T1GW*1	126								
5	T1GW*2	128	250	180	88	6	528	18920	38.65	3.356
6	T1GW*3	121								
7	T1GT*1	142								
8	T1GT*2	124	190	120	88	10	880	13640	38.65	3.356
9	T1GT*3	134								

3.2. Coefficients

a. Proposed correction factors k_1 and k_2

The uniformly distributed compressive stress (zone ② in Fig. 7) under the force P in the area of $(h \cdot t_w)$ at location z for the CD-iZ concrete dowel can be determined in [19] as:

$$\frac{2P}{\pi h D}\left(\frac{D^2}{z(D-z)} - 1\right) = \frac{P}{h t_w} \tag{4}$$

The expression (4) could be re-write as a quadratic equation with variable z as follows:

$$z^2 - zD + \frac{D^2}{\pi D/2t_w + 1} = 0 \tag{5}$$

The suitable root of the quadratic equation (5) is:

$$z = \frac{D}{2}\left(1 - \sqrt{\frac{\pi D - 6t_w}{2t_w + \pi D}}\right) \tag{6}$$

The expression (6) is examined with values of t_w equal to 6, 8, 10, and 12 mm; D equal to 100, 150, and 200 mm, the result shows that the z/t_w ratio does not much fluctuate.

The value of the ratio is recommended to:

$$\frac{z}{t_w} = 0.65 \tag{7}$$

The correction factor k_1 represents the contribution of confined compressive strength of concrete dowel which is proposed as:

$$k_1 = \sqrt{A_1/A} = \sqrt{1.3t_w/h} \tag{8}$$

where: A_1 is the local compressive area of the CD-iz dowel, corresponding to the position $z = 0.65t_w; A_1 = 2\cdot(0.65t_w)\,h$; A is the compressive area of the concrete dowel corresponds to the position where the local compressive stress is uniformly distributed over the entire concrete dowel without the local compression effect; $A = 2 \cdot (0.5h)h$.

The correction factor k_2 is determined based on the variation of the CD-iz dimensions. Through the tested result, the correction factor k_2, which is dependent on the height and edge bases of CD-iz is proposed as:

$$k_2 = \sqrt{2h/\left(d_1 + d_2\right)} \tag{9}$$

Table 2. The examination of t_w and D

t_w	z/t_w		
	D = 100 mm	D = 150 mm	D = 200 mm
6	0.638	0.637	0.637
8	0.638	0.637	0.637
10	0.639	0.638	0.637
12	0.641	0.638	0.638

b. Experimental coefficient α

The coefficient α of each group of specimens could be determined through the formula (1). Table 3 presents these α values, which are dependent on push-out failure load as well as k_1 and k_2 values.

Table 3. Determination of coefficient α

Specimen	Push-out failure load (kN)	k_1	k_2	$k_1 f_{cu} A_c$ (kN)	$k_2 f_{ct} A_t$ (kN)	Coeff. α
T1G*1	112	0.30	0.75	6.08	34.49	2.76
T1G*2	107					2.64
T1G*3	120					2.96
T1GW*1	126	0.30	0.64	6.08	40.62	2.70
T1GW*2	128					2.74
T1GW*3	121					2.59

The average value of α is 2.73. Substituting k_1, k_2 and α into (1), the empirical formula to identify the longitudinal shear resistance of a CD-iz dowel is:

$$P_{Rd} = 2.73\left(\sqrt{\frac{1.3t_w}{h}} f_{cu} A_c + \sqrt{\frac{2h}{d_1 + d_2}} f_{ct} A_t\right) \tag{10}$$

3.3. *Comparison*

a. Comparison with experimental results

The formula (10) is used to calculate the value of push-out load of each group of specimens T1G*, T1GW* and T1GT*. The compared results are shown in Table 4.

The difference between experimental results and values by the proposed formula is less than 2%.

Table 4. Comparison values using (10) with experimental results

Group of specimen	Value of		Difference (%)
	average push-out failure load (kN)	empirical formula (10) (kN)	
T1G*	113.0	110.8	1.9
T1GW*	125.0	127.5	2.0
T1GT*	133.3	129.9	2.3

b. Comparison with other published formulas

Numerous formulas to identify the longitudinal shear resistance of circular concrete dowels have been published [10, 11]. The compared results are presented in Table 5. To evaluate the difference between experimental data and predicted value by various empirical formulas, we compute the relative error as $\delta(\%) = (P^{\text{pre.}} - P^{\text{exp.}})/P^{\text{exp.}}$ where $P^{\text{exp.}}$ and $P^{\text{pre.}}$ are failure loads obtained from experiments (column(2)) and predictions (column (3) to (5) in the following table), respectively. For each group of specimens, the predicted value is presented in the first line while the second shows the corresponding relative error.

Table 5. Comparison values using Eq. (10) with published formulas

Group of specimen	Experimental value of push-out failure load (kN)	Predicted values and differences δ		
		Eq. (10) (kN)	Ref. [10] (kN)	Ref. [11] (kN)
(1)	(2)	(3)	(4)	(5)
T1G*	113.0	110.8 1.9%	102.0 9.7%	122.0 8.0%
T1GW*	125.0	127.5 2.0%	128.0 2.4%	159.0 27.2%
T1GT*	133.0	129.9 2.3%	126.0 5.3%	139.0 4.5%

As shown in Table 5, it is worth noting that for all groups of specimen, the predicted results by refs. [10, 11] show higher relative errors than the proposed formula by Eq. (10). In particular, this relative error reaches up to 27% for T1GW* case. This large disparity could be explained by the influence of the shape, ratio of steel plate thickness, and opening height.

4. Conclusions

This paper presents a combined mechanical-analytical analysis to propose an empirical formulation for trapezoid concrete dowel shear resistance estimation. The shear transferring mechanism of the concrete dowel connector, retrieved from previous push-out tests' series, has been considered as the starting point. By combining both mechanical behavior of tested failure and statistical analysis of the ultimate loading of push-out tests, an empirical formulation has been proposed for shear resistance of the trapezoid shear connector. The shear resistance is mainly contributed by the confined compressive and tensile splitting strength of the concrete dowel. Suitable factors have been also proposed based on the mechanical behavior of concrete dowels and verified against existing results in the literature.

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