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Push-Out Test on Shear Connectors Embedded in UHPC

Kim, Jee Sang[1, a], Park, Sang Hyeok[1,b], Joh, Changbin[2,c]
Kwark, Jong D.K.[2,d], and Choi, Eun Suk[2,e]

[1] Department of Civil Engineering, Seokyeong University, Republic of Korea

[2] Korea Institute of Construction Technology, Republic of Korea

[a]zskim@skuniv.ac.kr, [b]psh870623@naver.com, [c]cjoh@kict.re.kr

[d]origilon@kict.re.kr, [e]eschoi@kict.re.kr

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Abstract. The various push-out tests have been performed to investigate the load carrying capacity and ultimate behavior of headed studs in UHPC (Ultra High Performance Concrete), which has high compressive and tensile strength as well as high durability compared to ordinary concrete. The test program included the studs with a diameter of 16mm and 22mm for various aspect ratios (height to depth ratio of a stud) and cover depths. This paper presents the main results of the experimental investigations.

Introduction

Ultra High Performance Concrete (UHPC) has many advantages such as high compressive and tensile strength, excellent durability, and ductility compared to ordinary concrete, which have resulted in many researches to utilize them in structural applications. One of them tried in Korea is the development of precast UHPC deck for a composite girder bridge to reduce self-weight, increase durability and save construction time and so on. The confirmation of the sound and robust connections between a deck and a girder is vital in composite members. There are two typical test methods to estimate the composite behavior of concrete decks and steel girders, which are the Composite Beam method and the Push-Out method. The Push-Out test is more widely used because of more conservative test results and easier and more economic experimental procedure [1].

Valente et al. [2] investigated the composite actions of decks made of high strength light-weight concrete of more than 50MPa compressive strength with headed studs of 19mm, 22mm, and 25mm diameters. In the experiment, the shear resistance increased as the concrete strength and diameters of studs increase and the specimens failed as the fracture of studs. Hegger et al. [3] have given the relations between the load and the deflection by an experiment with the specimens made of 22mm-diamater studs and high strength concrete of higher than 100MPa compressive strength[3]. Hegger et al. [4] also used headed studs which were covered by UHPC of 150MPa embedded in normal and high strength concrete to find out that the UHPC-treatment on welding parts of studs can give more ductility to the shear connections. Yoo et al. [5] evaluated the static behavior of shear connections between the 260mm thick UHPC deck of 180MPa compressive strength and studs with 19mm, 22mm, and 25mm diameters and 150mm height to conclude the increase in shear strength of connections both with increasing compressive strength of concrete and stud diameters.

This paper presents the experimental results of push-out tests of shear connections made of 180MPa compressive strength UHPC decks and studs with various diameters and aspect ratios. The experiment followed the standard test procedures in Annex B of EuroCode-4 [6].

Testing Arrangements

Preparation of Specimens. The specimens were made to have smaller thickness than the normal concrete decks to utilize high strength of UHPC. The aspect ratios of studs are varied to find the effects of them in composite actions. The three specimens were made for each case to reduce the errors in tests. The dimensions of specimens are summarized in Table 1 And Fig.1. The specimens are

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named according the thickness of the deck and aspect ratios of the headed studs. The name S150-22/100 means the specimen is made of 200MPa compressive strength UHPC decks with 150mm thickness and 22mm diameter stud with 100mm height. The suds are arranged in 2 rows to minimize the load eccentricity and the spacings in both directions were determined to according to the standard procedure in Eurocode-4 as shown in Fig. 1 and Fig.2. The additional reinforcements are not included in the concrete deck because steel fibers in UHPC can enough give reinforcing effects [7]. The placement of UHPC was performed without compaction as shown in Fig.3 and completed specimens are shown in Fig. 4.

Table 1. Push-Out Specimens

Specimens	**Stud Connector**		**Aspect ratio (H/D)**	**Thickness of Deck (mm)**	**Cover (mm)**	**Number of specimens**
	Height (mm)	Diameter (mm)				
S150-22/100	100	22	4.5	150	50	3
S100-16/65	65	16	4.1	100	35	3
S100-16/50	50	16	3.1	100	50	3
S75-16/50	50	16	3.1	75	25	3

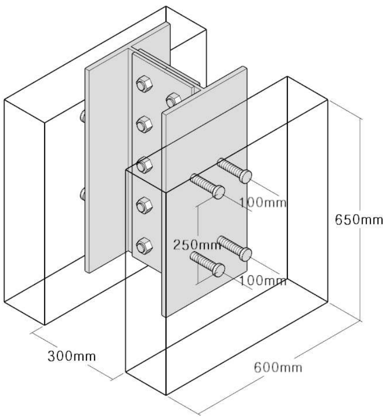

Fig. 1 Stud Arrangement

Fig. 2 Welded Sstuds

Fig. 3 Concrete Placing

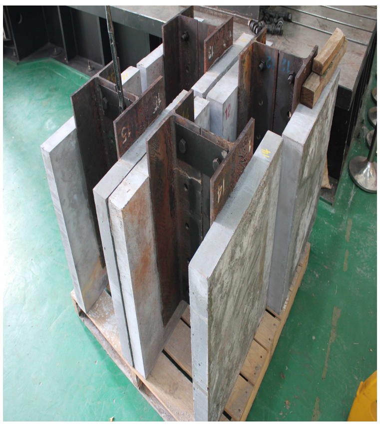

Fig. 4 Specimens Completed

Mix Proportions. The mix proportions of UHPC used are based on basic mix which was recommended by the research results in previous study [7]. Table 2 summarizes the mix proportions.

Table 2. UHPC Basic Mix Proportions (Weight Ratios)

W/B	Cement	Silica fume	Sand	Filler	Super-plasticizer	Steel Fiber (Volume Ratio)
0.2	1	0.25	1.1	0.3	0.018	1.5~2%

Loading and Measurements. The load was first applied in increments up to 40% of the expected failure load and then cycled 5 times between 5% and 40% of the expected failure load. The subsequent load increments were imposed such that failure does not occur in less than 15 minutes. The longitudinal slip between each concrete slab and the steel section was measured continuously during the loading till the load has dropped to 20% below the maximum load. The expected failure loads are obtained according to the equation given by AASHTO LRFD Specifications (2010) as in Eq.1 [8],

$$V_u = 0.5A_{sc}\sqrt{f_c'E_c} \leq A_{sc}F_u \quad (1)$$

in which, V_u = nominal shear resistance of one stud, A_{sc} = cross-sectional area of a stud shear connector, E_c = modulus of elasticity of the deck concrete, and F_u = specified minimum tensile strength of a stud shear connector. The 3,000kN capacity UTM was used to give the 2kN/m of load-control for repeated loading and 0.005mm/sec of displacement control until failure. The relative slips between concrete and steel were measured with LVDT's attached on front and rear sides of the specimens at the locations of 120mm from the bottom as shown in Fig. 5. The test setup is shown in Fig. 6.

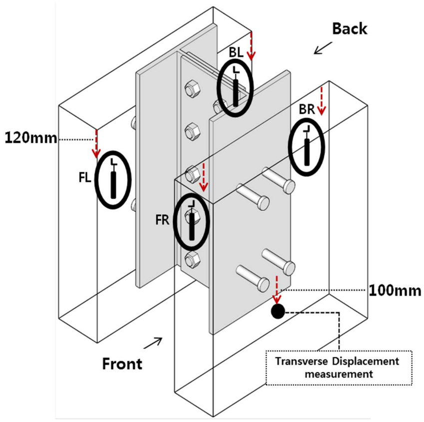

Fig. 5 Locations of Slip Measurement

Fig. 6 Test Setup

Experimental Results.

The test results are summarized in Table 3 according to the criteria in EC-4 [6], which shows some differences in strength and ductility according to deck thickness and aspect ratios of the studs. All the specimens have enough shear resistance capacities and initial stiffness but the slip capacities were not assured because of high strength of UHPC. The typical load-deflection relation is shown in Fig. 7 with the slip criterion in EC4, which should be longer than 6.0mm. The limit value of 6.0mm is measured at characteristic load and reduced by 10%. The specimens with 150mm thickness and 22mm diameter studs, S150-22/100, satisfied the criteria in EC4 for both strength and ductility and no cracks were found in deck, which means that it has proper cover depth. The specimens S100-16/65 and S100-16/50 also satisfied the strength limits, but did not meet the ductility limit, which may be the effects of aspect ratio and insufficient cover depths. Comparing two cases , the shear strength of S100-16/65 were higher than that of S100-16/50 by about 100kN, which may come from stronger bond due to the longer shaft of stud. The effects of higher shear capacity and stronger connections were also found in the crackings of concrete decks and slips, since there were no cracks in the concrete deck of S100-16/65. The further reduction of deck thickness to 75mm (S75-16/50) did not give much decrease in both strength and slip capacities, but the width and number of cracks on the concrete deck increased. Though the cover depth of them was only 25mm, the decreases in strength were not so high. If some crack protection mothod were included, the reduction of the deck thickness may be acheived in UHPC composite members.

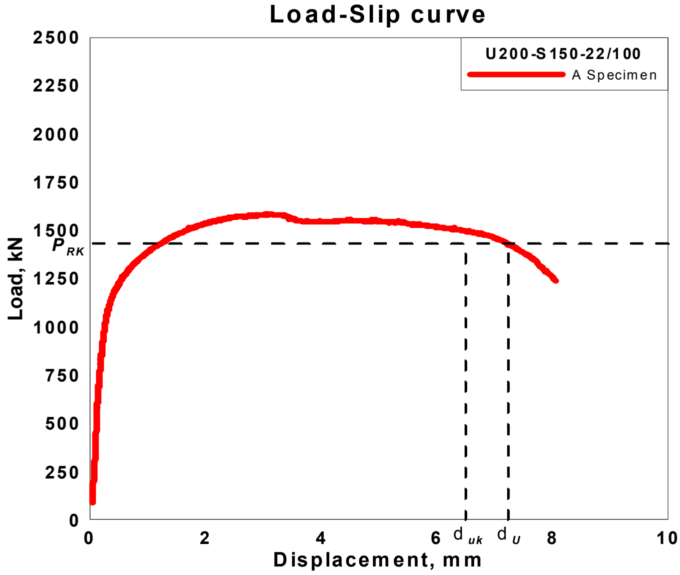

Fig. 7 Determination of δ_u and δ_{uk}

The design shear resistance according to AASHTO LRFD and EC4 were compared to the ultimate failure loads of the experimnets in Table 4. The design shear resistance, P_{Rd} , was determined by application of partial safety factor of 1.25 to the characteristic resistance P_{RK} , which was obtained by 10% reduction of experimental ultimate load P_U. All the specimens have enough safety margin compared to current design codes, but not in ductility limits as mentioned before.

Table 3. Experimental results for push-out tests

Specimens		P_{max}(kN)	P_{RK}(kN)	δ_u(mm)	δ_{uk}(mm)
S150-22/100	A	1587	1429	7.66	6.89
	B	1546	1391	5.73	5.16
	C	1695	1525	7.18	6.46
S100-16/65	A	983	885	4.98	4.48
	B	960	864	4.02	3.62
	C	911	820	4.21	3.79
S100-16/50	A	843	759	4.84	4.36
	B	822	739	5.93	5.34
	C	884	795	5.64	5.08
S75-16/50	A	873	833	5.42	4.88
	B	874	786	5.04	4.54
	C	932	876	5.18	4.66

Conclusions

The Push-Out tests on shear connections made of the UHPC deck and the steel girder were performed to evaluate the shear strength and ductility. All the specimens tested with various deck thickness, cover depth, and stud geometry showed enough resistance in strength side, but not in ductility criteria.

The longer stud shaft and higher cover depth give more ductility and small amounts of cracks in shear connections. Though the brittle failure modes and severe cracks in UHPC-steel composite members should be studied more deeply, the applications of UHPC, to composite members may be profitable in the reduction of the deck thickness and self-weight.

Table 4. Ultimate strength ratio to Codes

Specimens	design resistance, P_{Rd}(kN) (a)	AASHTO LRFD(2010)		Eurocode-4	
		ultimate strength (kN) (b)	ultimate strength (a/b)	ultimate strength (kN) (c)	ratio (a/c)
S150-22/100	1287	1094	1.18	875	1.47
S100-16/65	761	578	1.32	463	1.64
S100-16/50	680	578	1.18	463	1.47
S75-16/50	714	578	1.24	463	1.54

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