Fracture Mechanics of Concrete and Concrete Structures -
Assessment, Durability, Monitoring and Retrofitting of Concrete Structures- B. H. Oh, et al. (eds)
 ISBN 978-89-5708-181-5

Push-out tests on shear studs in high strength concrete

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ABSTRACT: A lot of push-out tests of shear studs embedded in normal strength concrete were conducted. So current design code methods of the shear studs are based on the test results of studs embedded in normal strength concrete. It also appeared that the strength of connector and the concrete strength are the main factors affecting the behavior of shear connections. But push-out test data of studs embedded in high strength concrete is insufficient until currently. So it is necessary to evaluate the load-slip behavior and the shear capacity of studs embedded in high strength concrete for the appropriate design code. In this paper, it was performed push-out tests of shear studs embedded in high strength concrete and fiber reinforced concrete used widely in high-rise building. Experimental push-out tests were used to evaluate both the shear stud capacity and the load-slip curve of the connector. And the results of the finite element model are compared with push-out tests and the values given in current codes of practice.

1 INTRODUCTION

Steel-concrete composite members have seen widespread use in high-rise building. Shear Studs are commonly used to transfer longitudinal shear forces across steel-concrete interface in composite member design. But current design code methods of the shear studs are based on the test results of studs embedded in normal strength concrete.[1)] It also appeared that the strength of connector and the concrete strength are the main factors affecting the behavior of shear connections.[2)] As the use of high strength concrete increase in high rise building, it is also necessary to evaluate the load-slip behavior and the shear capacity of studs embedded in high strength concrete for the appropriate design code. In this paper, it was performed push-out tests of shear studs embedded in high strength concrete and fiber reinforced concrete used widely in high-rise building. Experimental push-out tests were used to evaluate both the shear stud capacity and the load-slip curve of the connector.[3)] And the results of the finite element model are compared with push-out tests and the values given in current codes of practice.

2 DESCRIPTION OF TESTS

2.1 *Test specimens*

The specimens used in the push-out tests consisted of 300mm thick concrete slabs, shear studs of 16mm, 19mm, 22mm diameter and H-beam of 350x350x12x19 size. The slabs were connected to the steel beam by means of four shear studs welded on each side of the beam. The height of the welded stud was 135mm. Concrete strength design was 60MPa and 80MPa. concrete passed 510m pumping pipe (Fig. 2). As pumping pipe was used mostly in construction of high rise building, the pumping pipe was used for this experimental test. And one specimen used fiber reinforced concrete of 80MPa strength (1% fiber content). As fiber reinforced concrete was used to fire resisting construction of tall building, the same material was applied to this experimental test. Strain gauges was also placed on the surface of the each stud to observe the strain behavior of the studs qualitatively. In this study, the test was conducted by employing four specimens, which differ in material properties of the concrete and stud as shown in Figure 1.

2.2 *Test setup and loading procedure*

Specimens were tested in UTM machine with a capacity of 300 tons. The experiment was controlled by displacement result of LVDT. Displacement control was used for the monotonic tests. The monotonic tests were conducted at a displacement rate of 0.005mm/s. The test setup used in the experiments is shown in Figure 1.

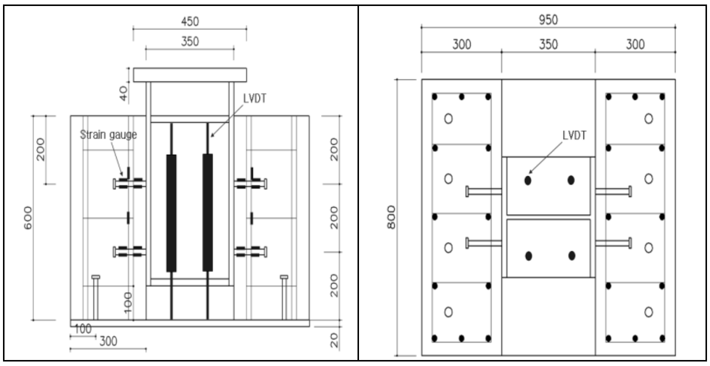


Figure 1. Details of push out test specimen.

Figure 2. Concrete pumping pipe arrangement.

3 PROPERTY OF MATERIAL

Concrete mix ingredient is shown in Table 1. Mechanical properties of concrete is shown in Table 2. Mechanical properties of Stud is shown in Table 3. And stud welding technique and dimension parameter is shown in Table 4.

Table 1. Concrete mix ingredient.

Speci mens	W/ B	S/a (%)	W (kg/ m3)	Combination ashes(%)				SP (*B %)
				OPC	BS	FA	SF	
60 MPa	27.5	47	160	75	0	20	5	1.65
80 MPa	22.5	43	152	75	0	20	5	1.65

S/a = fine-total aggregate ratio ; OPC = cement ; BS = blast-furnace slag ; FA = fly ash ; SF = silica fume

Age of concrete at testing was 28days. when compared with design strength of concrete, compressive strength of concrete was differ from 10.31MPa to 24.39MPa. Elastic modulus showed results from 36.88GPa to 44.78GPa. Compressive strength of concrete between D19-80MPa and D19-80MPa(fiber) was appeared to difference of 12.4MPa.

Table 2. Mechanical properties of concrete.

Speci-mens	Age of concrete at testing(days)	Concrete strength(design) (MPa)	Compressive strength of concrete (MPa)	Elastic modulus (GPa)
D16-60MPa D22-60MPa	28	60	84.4	36.9
D19-80MPa (Fiber)	28	80 (Fiber)	90.3	43.5
D19-80MPa	28	80	102.7	44.8

D=diameter of stud ; MPa = Concrete strength ; Fiber = Fiber mixed concrete

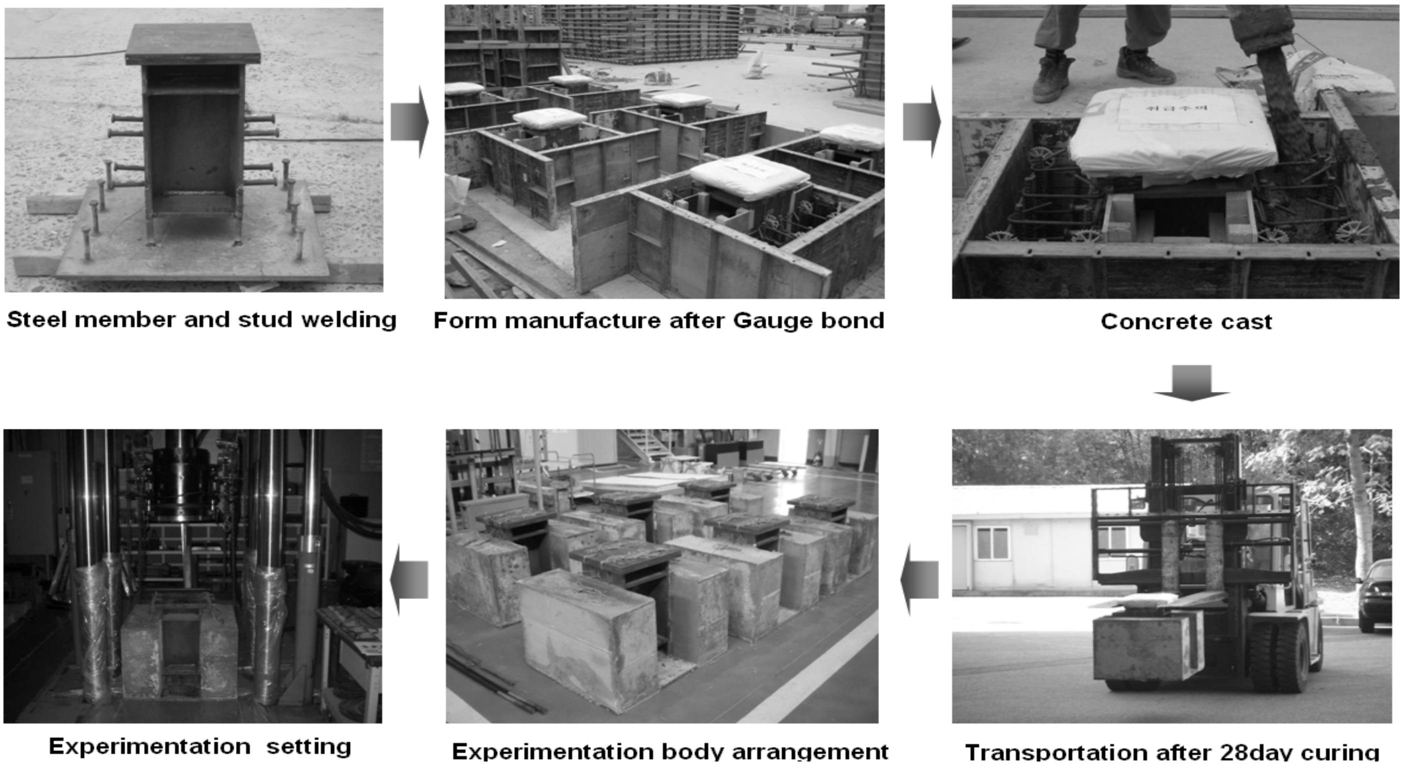


Table 3. Mechanical properties of stud.

Batch	Yield strength (MPa)	Ultimate tensile strength (MPa)	Elastic modulus (GPa)	Ultimate elongation (%)
Stud	357.4	509.2	218	29.1

Stud welding technique is welded all around. Material of stud and H-beam is SS400. And the size of H-beam is 350x350x12x19 in all specimens

Table 4. Stud welding technique and dimension parameters.

speci-men	Stud diameter (material)	Size of H-beam (material)	Sutd welding tech-nique
D16-60MPa	16 (SS400)	350x350x12x19 (SS400)	Weld all around
D22-60MPa	22 (SS400)	350x350x12x19 (SS400)	Weld all around
D19-80MPa (fiber)	19 (SS400)	350x350x12x19 (SS400)	Weld all around
D19-80MPa	19 (SS400)	350x350x12x19 (SS400)	Weld all around

4 DESIGN CODE CALCULATION METHODS

4.1 *Korea building code*

In the Koea building code (KBC), the stud shear bearing capacity is determined by

$$Pu = 0.5 Ra As \sqrt{f'c Ec} \leq As Fu \tag{1}$$

Ra=1.0 for reinforced concrete flat slab of the fixed thickness (resistance factor of shear stud connectors); As=cross-sectional area of a stud shear connector (mm2) ; f′c = compressive strength of concrete cylinders ; Ec = elastic modulus of concrete

$$f'c \leq 29.4 N/mm^2 : Ec = 4,700 \sqrt{f'c}$$
$$f'c > 29.4 N/mm^2 : : Ec = 3,300 \sqrt{f'c} + 6,900$$

Fu = ultimate tensile strength of stud ($\leq 440 N/mm^2$)

4.2 *Eurocode4*

In the latest proposal of Eurocode 4, the shear resistance of a headed stud is determined by

$$Pu = \frac{0.8 Fu \pi \alpha^2/4}{\gamma_v}, \quad Pu = \frac{0.29 \alpha^2 \sqrt{f'c Ec}}{\gamma_v} \tag{2}$$

Whichever is smaller

Where the units are N, mm; d=diameter of the studs ; Fu = ultimate tensile strength of stud ; f′c = compressive strength of concrete cylinders ; Ec = elastic modulus of concrete ; The partial safety factor γ_v should be taken as 1.25 ; α=0.2(H/d+1)≤1; and H=height of the studs.

4.3 *AASHTO LRFD(2004)*

In AASHTO LRFD(2004), the nominal shear resistance of one stud shear connector embedded in a concrete deck shall be taken as Equation (3)

$$Pu = \o 0.5 As \sqrt{f'c Ec} \leq \o AsFu \tag{3}$$

where Ø = resistance factor for shear connectors (=0.85)

5 TEST RESULTS

Load-slip curve of specimens is shown in Figure 3. And push-out test results is shown in Table 6.

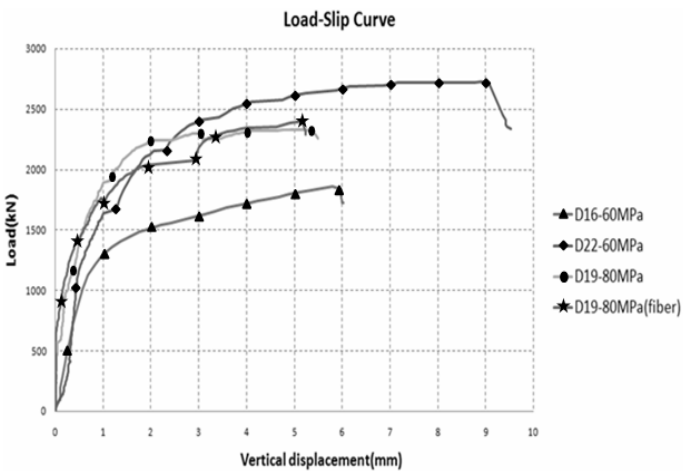


Figure 3. Load-Slip curve of specimens.

The crack was appeared on the surface slightly. It appeared only a broken piece of concrete. Damage of the concrete was concentrated mainly around the studs. After the experimental test, the crack was the width within 1 mm. And it showed 3mm gap between H-beam and concrete after the experimental test. This crack was shown in Figure 4

6 NUMERICAL VERIFICATION

The finite element model provided for effective analysis of experimental test. The FE results were compared well with results obtained from the experimental push-out tests. In the case of finite element model, maximum shear resistance was 1552kN and maximum slip at failure was 3.2mm in case of D16-60MPa. And the kind of failure was stud failure. In the case of experimental test, maximum shear resistance was 1869kN. Maximum slip at failure was 6.03mm in case of D16-60MPa. And the kind of failure also was stud failure. Test result and numerical verification result were shown in Table 6.

Table 5. ANSYS modeling verification(D16-60MPa).

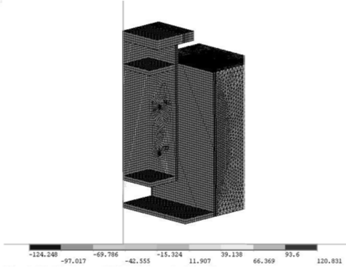
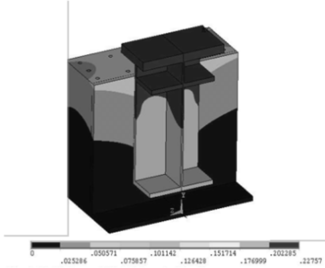
	
Stress (1/4 modeling)	Displacement(1/2 modeling)

Table 6. Test result and numerical verification result.

Speci-men	Maximum shear resis-tance(kN)		Maximum silp at fail-ure(mm)		Con-crete crack width (mm)	Kind of failure
	TR	NR	TR	NR		
D16-60MPa	1869	1552	6.0	3.2	0.1	Stud failure
D22-60MPa	2753	2760	8.2	8.0	0.1	Stud failure
D19-80MPa (fiber)	2404	2528	5.2	6.6	0.1	Stud failure
D19-80MPa	2322	2456	5.1	6.3	0.1	Stud failure

TR : Test result
NR : Numerical verification result

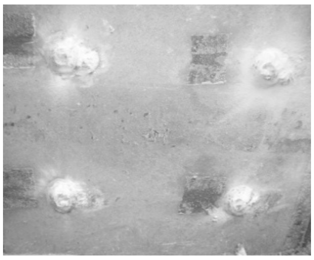
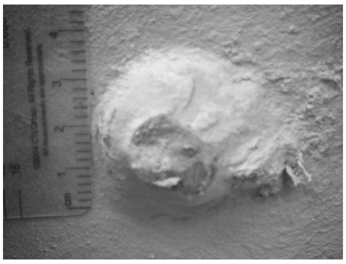
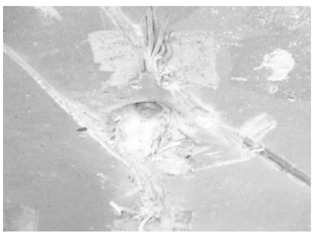
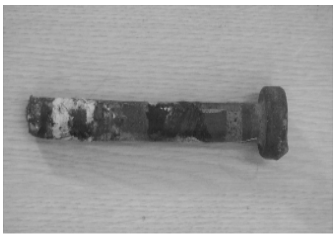
	
H-beam surface	Welding part
	
Concrete surface	Stud shearing

Figure 4. Failure modes.

As compared with the maximum shear resistance result by experimental test and design code, difference is appeared. The reason is that the concrete specimens were strengthened by reinforcements and thick welding part affected in the test result. But the shear resistance of the stud calculated by the design code is determined separately by the concrete or by the stud. The interaction between the two materials has not also been applied in equations.

Table 7. Comparisons of test and design code.

Speci-men	Maximum shear resistance(kN) by experimental test	Maximum shear resistance(kN) by Calculation result		
		KBC	Eurocode4	AASHTO LRFD
D16-60MPa	1869	812	519	690
D22-60MPa	2753	1363	991	1159
D19-80MPa (fiber)	2404	1278	651	1086
D19-80MPa	2322	1278	651	1086

7 CONCLUSION

The FE results were compared with results obtained from push-out tests. experimental result was appeared with a reliability. As compared maximum shear resistance result by experimental test and design code, difference is appeared. The reason is that the concrete specimens were strengthened by reinforcements and thick welding part affected in the test result. But the interaction between the two materials has not been applied in equations. So new design code is proposed for applying to high strength concrete and stud. In the future, it is necessary to analysis shear stress distribution of stud welded all around and high strength concrete from finite element model.

ACKNOWLEDGEMTS

This research supported by a grant from High-Tech Urban Development Program funded by the Ministry of land, transport and maritime affairs.

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