論文 Investigation on Pull-out and Shear Strength of ϕ 6mm Studs

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ABSTRACT The objective of this paper is to investigate the basic behaviors of ϕ6mm studs. Three groups of studs by changing the length were tested for shear and tensile strength. The first essential tests were carried out for isolated stud and the second tests were carried out with specimens of tension type having multiple studs. Effect of concrete strength, reinforcements in the concrete, location of studs from the edge of the concrete were surveyed and evaluated. Then some equations for estimating the pull-out strength and shear strength of studs were derived considering their failure mode.
KEY WORDS: stud, pull-out strength, shear strength, composite structure

1. ITRODUCTION

The authors have investigated design methods of rigid frame bridges in which the super structures are steel beam and sub structures are reinforced concrete piers and have carried out experimental tests on beam-column connection parts using reduced scale models [3]. Generally, in such rigid connection parts studs are commonly used. Therefore, in our scale reduced models, small studs of ϕ6mm were used to fit the scale down factors of the models. Because there is few data of the studs, the authors have carried out essential tests to know the strength and behavior of the studs and to apply the data to evaluate the behavior to the beam-column specimens. The essential tests are two kind series of tests on isolated stud and tension type test on group arranged studs. When the test results were compared with existing prediction equations, PCI equation[1] for pull out strength, and Hiragi[2] for shear seem to be reasonable ones. But the present test results because lower the calculated values. Therefore, new equations were proposed for pull-out and shear strengths by modifying the above mentioned equations. From the isolated stud tests, essential strength equations for shear and pull-out strength were carried out including the effects of concrete strength and stud length. Also the effect of the stud location was checked. Then the equations were applied to the results of the group arranged studs. By considering the failure mode, fitness of the equation was verified.

2. EXPERIMENTS OF ISOLATED STUD AND GROUP ARRANGED STUDS

2.1 TESTS FOR ISOLATED STUD

Pull-out and shear tests were carried out on 6mm diameter studs of the total number of 78. Three types of studs of 35, 45 and 60mm long were arranged. The pull-out test was carried out with the apparatus shown in Fig.1. The isolated stud welded on a steel plate was pulled out upward by a center hole jack through reaction box made of steel pipe. The applied load and displacements were measured. The isolated studs were prepared in a concrete slab as shown in Fig.2. The concrete strengths for the pull-out studs were 19.6 and 30.8 N/mm^2. The shear tests were carried out with the stud specimens arranged in the slab as shown in Fig.3. With same instrument, each base steel plate of stud was pulled horizontally to give shear force to the stud. This testing method is called as one face shear test against to two faces shear test of a push-out test. The method was considered to be better than the two faces shear test because the actual structures studs will be welded to thin steel plate and separation of steel plate and concrete will be presume. The concrete strengths for the shear were 21.7 and 28.4 N/mm^2. In the concrete

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mix, only fine aggregate of 5 mm maximum size was used as aggregate. The parameters of this test are shown in Table 1 and 2. As seen in Figs.2 and 3, the locations of stud from the concrete slab edge were changed to investigate the effect of concrete cover thickness.6mm diameter net reinforcement of 50 mm interval was provided in both direction for the reinforced concrete slabs.

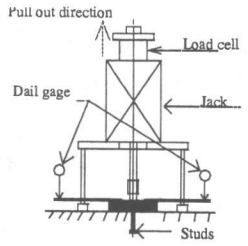

Fig. 1 Apparatus for tension and shear test

2.2 TESTS FOR GROUP ARRANGED STUDS

In actual structures many studs will be arranged and they will be influenced mutually to reduce strength from the one isolated stud. To investigate the effect of group arrangement of studs, Tension type specimens having group studs were planned. The specimens shown in Fig.4 are for pull-out strength of studs. Four studs were welded on the steel plates of the top and bottom. Concrete size surrounding studs were changed to know the effect of location of studs from the concrete

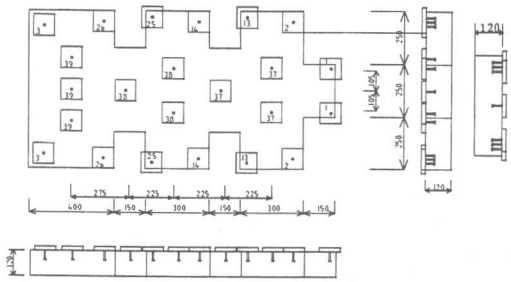

Fig. 2 Pull out test studs specimen concrete slab

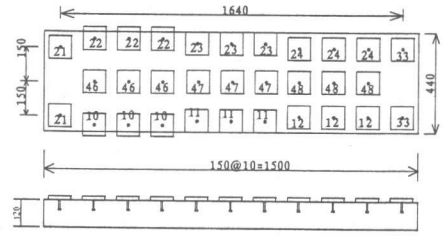

Fig. 3 Shear test studs specimen concrete slab

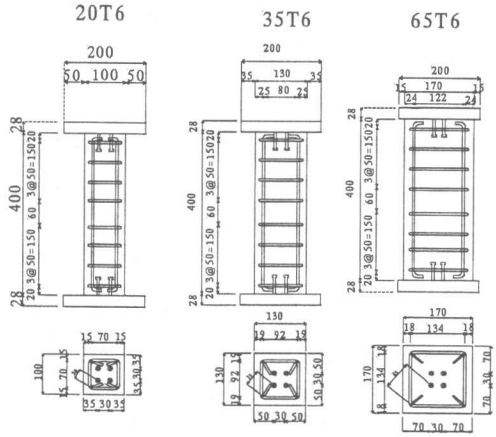

Fig. 4 Group studs under pull out force

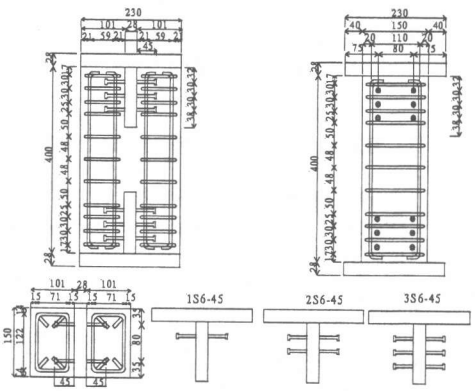

Fig. 5 Group studs under shear force

Table 1 Pull out test I for isolated studs

hs (mm)	Reinforcement	Pu	Failure
35	provided	8.91	Cone
	not provided	7.11	Cone
45	provided	14.23	Stud
	not provided	13.46	Cone
60	provided	13.70	Stud
	not provided	14.53	Stud

σ_c = 21.7 N/mm2, Pu (kN)

Table 2 Pull out test II for isolated studs

hs (mm)	Reinforcement	Pu	Failure
35	provided	10.41	Cone
	not provided	7.87	Cone
45	provided	14.52	Stud
	not provided	12.25	Cone
60	provided	14.57	Stud
	not provided	13.05	Stud

σ_c =28.4 N/mm2,Pu (kN)

Table 3. Group studs under shear, σc=28.6 N/mm^2

Specimen	Diameter	hs (mm)	Axial reinf.	Stud level	Ultimate load(kN)
1S6-45R	ϕ 6 mm	45	hook	1	18.91
2S6-45R				2	40.92
3S6-45R	shear			3	59.17
1S13-80R	ϕ 13 mm	80		1	57.61
2S13-80R				2	159.60
3S13-80R1	shear			3	215.69

Table 4. Group studs under pull out, σc=28.6 N/mm^2

Specimen	Diameter	hs (mm)	Axial reinf.	Location from reinf.	Ultimate load(kN)
20T6-45S	ϕ 6 mm tension	45	straight	20	10.97
20T6-45R			hook		13.79
20T6-60S		60	straight		19.96
20T6-60R			hook		20.24
35T6-45R		45	hook	35	12.38
65T6-45R				65	14.40
35T6-60R		60		35	20.73
65T6-60R				65	20.78
40T13-80R	ϕ 13 mm tension	80		40	45.05
80T13-80R				80	46.47

edges. Also, reinforcement positions were changed to investigate the effect of the pull-out strength. The concrete strength for this test was 28.6 N/mm^2. The specimens of Fig.5 are for shear strength of studs. Studs were welded on the web plate to subject studs to shear force. The stories of studs were changed from one to three. Eight reinforcing bars were arranged in the concrete. Tension load was applied to the top plate with fixing the bottom plate. The parameters of this test are shown in Table 3 and 4.

3. TEST RESULTS AND DISCUSSIONS

3.1 ISOLATED STUD

3.1.1 Pull-out Strength

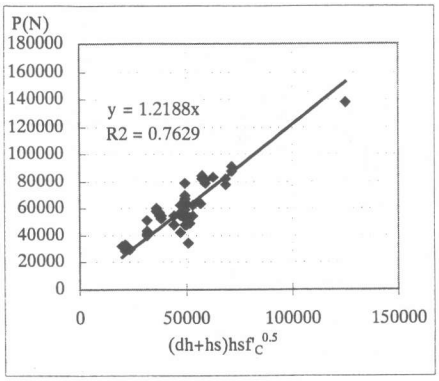

Fig.6 Regression analysis of bigger diameter studs

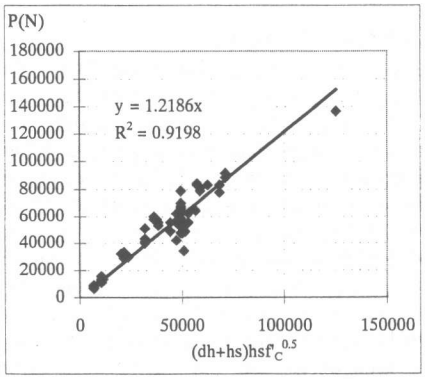

Fig.7 Regression analysis for old data of bigger diameter studs and the present one

All specimens of 20 failed by cone-failure in the pull-out test. The shapes of attached concrete cone were not same and scattered. Then the strengths of cone failure have scattered widely even in same stud length. Eq.(1) is a general equation to evaluate the pull-out strength of studs when the stud fails in cone failure. Eq.(2) is the design formula of PCI [1] with the units of pound and inch.

$$P_U = F \cdot (h_S + d_h) \cdot h_S \cdot \sqrt{f_c'} \qquad (1)$$

$$P_U = 1.22 \cdot (h_S + d_h) \cdot h_S \cdot \sqrt{f_c'} \qquad (2)$$

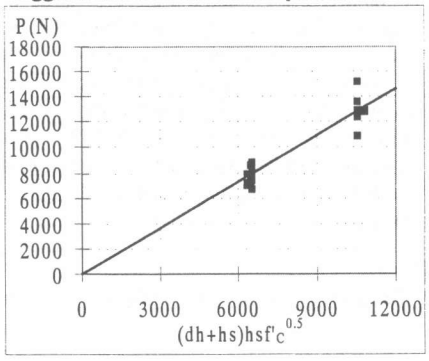

Fig. 8 Regression analysis for only ϕ 6 mm

With Eq.(3) the existing data of pull-out tests can be plotted as shown in Fig.6. For the results, a linear equation can be fitted from regression analysis. Fig.7 is the same figure added with the present data of 6mm stud. Even the data increased the linear equation is not influenced. Fig.8 is the limited figure with only 6mm stud data. For the data, it can be seen that Eq.(3) showed good fitness. From those results, Eq.(3) can be said a favorable equation to estimate the strength of 6mm studs. Eq.(4) is a deformed equation expressed as PCI equation from Eq.(3), which is expressed with the surface area of the concrete cone. To investigate the effect of stud location from the concrete edge the data were plotted on Fig.9. The parameter of the location is the ratio of distance of concrete edge from the stud shank face to stud height When the ratio is less than 2, the pull-out strength decreases from the one of Eq.(3) as seen in the figure. For the range less than 2, Eq.(5) can be used for estimation of the pull-out strength.

$$P_U = 0.388 \cdot \pi (h_S + d_h) h_S \sqrt{f_c'} \qquad \left(2 \le \frac{e - d_S/2}{h_S}\right) \qquad (3)$$

$$P_U = 0.274 \cdot \sqrt{2}\pi (h_S + d_h) h_S \sqrt{f_c'} \qquad \left(2 \le \frac{e - d_S/2}{h_S}\right) \qquad (4)$$

$$P_U = 0.274 \cdot \sqrt{2}\pi (h_S + d_h) h_S \sqrt{f_c'} \cdot \sqrt{\frac{1}{2} \cdot \frac{e - d_S/2}{h_S}} \qquad \left(\frac{e - d_S/2}{h_S} \le 2\right) \qquad (5)$$

3.1.2 Shear Strength

The authors have proposed Eq.(6) for the shear strength of studs of which diameters are larger than 13mm. But the equation was derived with the data of push-out test. When plotting the present data with the equation, the data gather in lower part as shown in Fig.10. The bold line neglecting the constant of Eq.(6) shows occasionally good fitness with the present data of 6 mm. Because the one face shear test, bending deformation of the base plate seems to be a cause to the drop of strength. So, Eq. (7) can be used as an estimation equation of shear strength of an isolated stud. Push out test for 6mm diameter studs was also carried out and compared with existing data[2] of bigger diameter(19,22mm) studs. Fig.11 is the results to show the effect of location of studs from the concrete edge. In the shear test, the strength of studs will decrease in the range less than 2, but the tendency can be expressed with a linear line as shown in the figure. Eq.(8) can be given to the line.

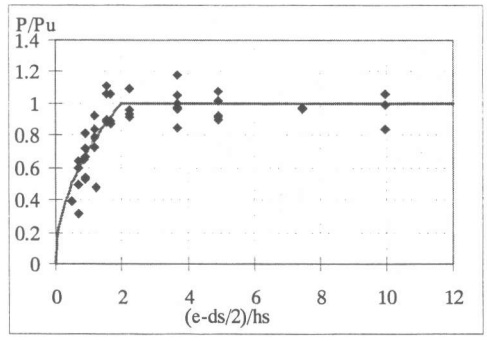

Fig. 9 Effect of stud location on the pull-out strength

$$Qu = 31.3 \cdot As \sqrt{\frac{h}{d_S} f_c'} + 9800 \qquad (6)$$

$$Qu = 31.3 \cdot As \sqrt{\frac{h}{d_S} f_c'} \qquad (7)$$

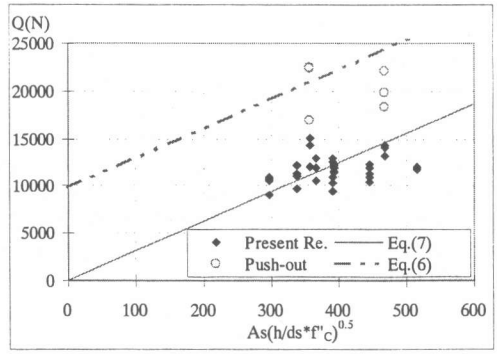

Fig. 10 Shear strength of the present data.

$$Q_U = 31.3 \cdot A_S \sqrt{\frac{h}{d_S} f_c'} \cdot \left(\frac{1}{2} \cdot \frac{e - d_S/2}{h_S} \right) \quad (8)$$

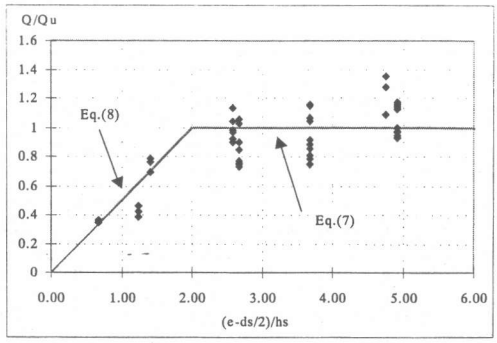

Fig. 11 Effect of stud location on shear strength

3.2 GROUP ARRANGED STUDS

3.2.1 Pull-out tests

In the tension tests of group arranged stud specimens, all specimens failed by cone failure as shown in Photo.1. The failure loads of all specimens were listed in Table 5. The load shows an increasing tendency by increasing stud length and stud diameter. For the experimental loads, the estimated loads with Eq.(5) become a little bit larger. If a reduction factor of 0.7 is applied the mean value shows good agreement with the experimental value. The values in column 11 are ratios to the experimental values and the values of column 12 are the ratios of distances of reinforcements from stud to the stud height. It can be seen that when the ratio of distance of reinforcement to the stud length is less than 0.5, the ratio of strength becomes larger than 1.0. The increase of strength ratio seems to be the effect of reinforcement.

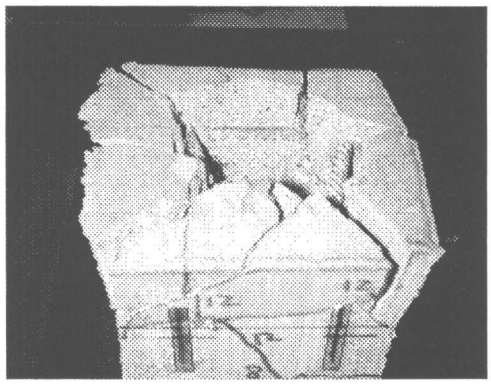

Photo. 1 Concrete cone failure

3.2.2 Shear tests

The failure modes of the specimens of shear test are cracking of concrete at each story of studs by dowel action. The maximum loads at the failure are listed in Table 6 and those increased by the increase of the stud story. In Table 6, calculated values also indicated using Eq.(8). In the calculation, the effect of location of stud from the edge of concrete was considered. For the first story the edge distance was taken as distance of e and for the second and third stories, the stud pitch was taken as e. In the table it can be seen that the final calculated results showed quite good fitness to the experimental values. Here, it should be noted that the shear strength of one story consisting of four studs were given four times of isolated strength for 6mm studs and 3 times for 13mm studs by considering lapping the failure area of concrete.

Table 5 Test results of group studs under pull-out force

Specimen	hs (mm)	ds (mm)	dh (mm)	f'c (Mpa)	e (mm)	hs+dh (mm)	(1)Exp.V. (N)	Cal.V. (N)	(2) Cal.V.*0.7 (N)	(1)/(2)	l/hs
20t6-45	40	6	12	28.6	35	52	13790	14739	10317	1.34	0.50
35t6-45	40	6	12	28.6	50	52	12380	17863	12504	0.99	0.88
65t6-45	40	6	12	28.6	70	52	14400	21327	14929	0.96	1.63
20t6-60	55	6	12	28.6	35	67	20240	20234	14164	1.43	0.36
35t6-60	55	6	12	28.6	50	67	20730	24522	17165	1.21	0.64
65t6-60	55	6	12	28.6	70	67	20780	29278	20495	1.01	1.18
40t13-80	69	13	22	28.6	80	91	45050	58604	41023	1.10	0.58
80t13-80	69	13	22	28.6	110	91	46470	69543	48680	0.95	1.16

Table 6 Test results of group studs under shear force

Specimen	h (mm)	hs (mm)	ds (mm)	dh (mm)	f'c (Mpa)	As (mm2)	Strength of one story (N)	Exp.V. (N)	Cal.V. (N)
1s6-45	45	40	6	12	28.6	28.27	51845	18730	18794
2s6-45	45	40	6	12	28.6	28.27	51845	40920	39532
3s6-45	45	40	6	12	28.6	28.27	51845	59170	60270
1s13-80	80	80	13	22	28.6	132.73	165348	57610	75957
2s13-80	80	80	13	22	28.6	132.73	165348	159600	151913
3s13-80	80	80	13	22	28.6	132.73	165348	215690	227870

4. CONCLUSIONS

Through the two series of specimens, the authors have derived some useful equations for pull-out and shear strengths of 6mm studs. The equation for pull-out strength is similar to PCI equation taking into the cone failure surface and concrete strength. The numerical factor of the equation become less than that of PCI equation which gives a better fitting for the existing data for larger diameter studs. Also the equation is a common equation available to the studs larger than 6mm. The modified equation was derived having a parameter of location of stud for the stud arranged near the concrete edge. The equation for shear strength is a modified equation from the existing one proposed by the authors. Also, The effect of location of studs from the edge of concrete was taken into a factor. Then both the strength equations were verified the applicability for the group arranged studs. By a little change the applicability was proved. In this study, fundamental understandings for shear and pull-out strengths of isolated or in group studs was clarified.

References

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