# 第 I 部門　Investigation on pull-out and shear strengths of φ 6 mm studs


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**1.Introductiion**

In recent years, composite and mixed structures are getting more applications as rational structural systems due to saving in material and maintenance cost. However, so far a few experiments were done on beam-column composite rigid connections. Therefore, a study is being carried out now in order to clarify behaviors and roles of studs in those connections. In the study; however, reduced models with small diameter studs(6mm) were used. There was; however, no useful data on 6 mm studs in order to evaluate the composite connection strength. Therefore, a study on 6 mm diameter studs was required to provide basic understandings of mechanical behaviors of 6 mm diameter studs such as the shear and pull out strengths.

**2. The Experiment**

Shear and tensile (pull out) tests were carried out on 6 mm diameter studs. A total of 78 specimens were tested for shear and tension. Three types of stud of 35, 45 and 60 mm long were tested. The parameters of this experiment are the height of the studs, the concrete strength, and existence of the reinforcement in the concrete slab. Figs 1 and 2 show the tests specimens. New testing methods of one stud for shear and pull out were developed using a center hole jack as shown in Fig 3 and 4. Also extensive shear and pull out tests were carried on 6,9,13 mm diameter studs with different heights. The location of studs in the concrete slab was considered to investigate the effect of the distance of stud from the concrete edge.

**3.The experimental results and discussions**

**(a) Shear test**

The shear test results were listed in Tables 1 and 2 with four calculated values by existing evaluation equations. The four equations that were used in the calculation and a modified one as follows:

$$Q_u=100 \cdot As\sqrt{(hs/ds)fcu}+1000 \text{ (by Hiragi)} \quad (1)$$

$$Q_u=0.4 \cdot ds^2\sqrt{fcu \cdot Ec} \text{ (by Fisher)} \quad (2)$$

$$Q_u=58.3 \cdot ds \cdot hs\sqrt{fcu} \text{ (by Slutter)} \quad (3)$$

$$Q_u=86.3 \cdot ds\sqrt{(hs/ds)fcu} \text{ (by Hiragi)} \quad (4)$$

$$Q_u=100 \cdot As\sqrt{(hs/ds)fcu}+200ds^2 \quad (5)$$

(Modified equation )

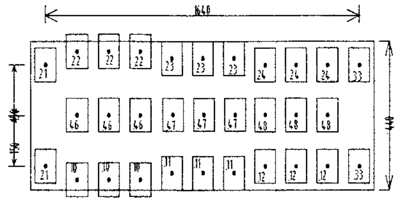


Fig. 1 Shear test specimen.

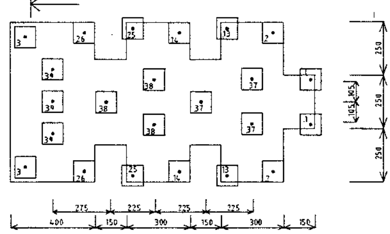

Fig. 2 Pull out test specimen.

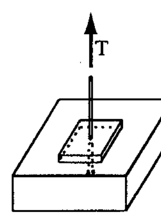


Fig. 3 Studs tension test.

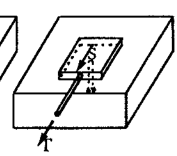

Fig4 Studs shear test.

Table 1 Shear test(concrete $\sigma$=19.6 N/mm$^2$) Qu(kN)

| hs(mm) | No. | Exp. | Eq. 1 | Eq. 2 | Eq. 3 | Eq. 4 | Modified Eq. |
|---|---|---|---|---|---|---|---|
| 35 | 1 | 10.5 | 19.17 | 8.57 | 16.71 | 17.16 | 10.08 |
| | 2 | 10.64 | 19.17 | 8.57 | 16.71 | 17.16 | 10.08 |
| | 3 | 9.07 | 19.17 | 8.57 | 16.71 | 17.16 | 10.08 |
| | 4 | 10.76 | 19.17 | 8.57 | 16.71 | 17.16 | 10.08 |
| | 5 | 10.88 | 19.17 | 8.57 | 16.71 | 17.16 | 10.08 |
| 45 | 1 | 11.26 | 20.42 | 8.57 | 21.48 | 19.45 | 11.33 |
| | 2 | 12.18 | 20.42 | 8.57 | 21.48 | 19.45 | 11.33 |
| | 3 | 11 | 20.42 | 8.57 | 21.48 | 19.45 | 11.33 |
| | 4 | 12.12 | 20.42 | 8.57 | 21.48 | 19.45 | 11.33 |
| | 5 | 9.66 | 20.42 | 8.57 | 21.48 | 19.45 | 11.33 |
| 60 | 1 | 12.5 | 22.06 | 8.57 | 28.65 | 22.46 | 12.97 |
| | 2 | 12.89 | 22.06 | 8.57 | 28.65 | 22.46 | 12.97 |
| | 3 | 10.95 | 22.06 | 8.57 | 28.65 | 22.46 | 12.97 |
| | 4 | 10.28 | 22.06 | 8.57 | 28.65 | 22.46 | 12.97 |
| | 5 | 9.4 | 22.06 | 8.57 | 28.65 | 22.46 | 12.97 |

*Note: the shear force* Qu *given by the above Equations in kilogram force using the dimensions in cm.*
Where, Qu: shear strength of a stud in kgf, As: the cross sectional area of the shank of the stud in cm$^2$, hs: height of stud in cm, ds: diameter of the shank of the stud in cm, fcu: compression strength of concrete in kgf/cm$^2$.


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Table 5 Effect of stud location on shear strength($\sigma_c$=27.25 N/mm2)

| Diameter (mm) | Length (mm) | Location from Slab Edge (mm) | Exp. Load (KN) | Failure Mode |
|---|---|---|---|---|
| 6 | 35 | 40 | 4.70 | concrete |
| 6 | 35 | 80 | 13.18 | stud |
| 6 | 35 | > 80 | 13.82 | stud |
| 6 | 60 | 40 | 7.21 | concrete |
| 6 | 60 | 80 | 12.16 | stud |
| 6 | 60 | > 80 | 13.86 | stud |
| 9 | 45 | > 80 | 31.13 | stud |
| 9 | 55 | > 80 | 28.14 | stud |
| 13 | 65 | > 80 | 52.33 | concrete |
| 13 | 80 | > 80 | 60.39 | stud |

The modified equation above estimates the shear strength satisfactorily comparing to the experimental values in the case of low concrete strength. But it gives a little bit higher estimation values for the studs in high strength concrete. A relation between the present test results and existing test results for normal size of studs having the diameter from 13 to 22 mm is shown in Fig. 5. The new data showed the same trend as the existing data.

**(b) Pull out test**

In the case of pull out test, Tables 3 and 4 show the test results with calculated values by 4 existing equations and a derived one. Those equations as follow:

$$Tu = 1.06\sqrt{2} \cdot \pi \cdot le(le + dh)\sqrt{fcu} \quad \text{(by PCI)} \qquad (6)$$

$$Tu = As \cdot \sigma s \qquad (7)$$

$$Tu = 0.15 \cdot \pi \cdot dh \cdot hs \cdot Bw \leq \pi \cdot ds^2 \sigma_y \quad \text{(by Sattler)} \qquad (8)$$

$$Tu = 10.96\sqrt{hs}(hs + d2)\sqrt{Bw} \quad \text{(by Bode \& Roik)} \qquad (9)$$

$$Tu = 1.33Le \cdot \pi \cdot (Le + dh) \cdot \sqrt{Bw} \quad \text{(derived equation)} \qquad (10)$$

Table 3 Pull out test results ( concrete σc =21.7 N/ mm2 )

| Studs | Reinf. | Pu(kN) | Eq.(6) | Eq.(7) | Eq.(8) | Eq.(9) | Derived Eq. |
|---|---|---|---|---|---|---|---|
| 35 | yes | 8.91 | 11.18 | 13.77 | 4.21 | 14.19 | 9.92 |
| | no | 7.11 | 11.18 | 13.77 | 4.21 | 14.19 | 9.92 |
| 45 | yes | 14.23 | 17.43 | 13.77 | 5.41 | 19.52 | 15.47 |
| | no | 13.46 | 17.43 | 13.77 | 5.41 | 19.52 | 15.47 |
| 60 | yes | 13.70 | 29.36 | 13.77 | 7.22 | 28.47 | 26.06 |
| | no | 14.53 | 29.36 | 13.77 | 7.22 | 28.47 | 26.06 |

Table 4 Effect of location of stud on tension strength(σc=27.25N/mm$^2$)

| Stud Diameter = 6 mm | | | | | Eq.(6) | Eq.(7) | Eq.(8) | Eq.(9) | Derived Eq. |
|---|---|---|---|---|---|---|---|---|---|
| Stud Length = 35 mm | | | | | | | | | |
| Location | Edges | Reinf. | Exp. | F.mode | (kN) | (kN) | (kN) | (kN) | (kN) |
| 30 | 1 | No | 5.34 | Cone | 12.66 | 14.05 | 5.39 | 15.75 | 11.23 |
| 50 | 1 | No | 8.11 | Cone | 12.66 | 14.05 | 5.39 | 15.75 | 11.23 |
| 70 | 1 | No | 8.02 | Cone | 12.66 | 14.05 | 5.39 | 15.75 | 11.23 |
| Q | No | No | 7.69 | Cone | 12.66 | 14.05 | 5.39 | 15.75 | 11.23 |
| 30 | 1 | Yes | 3.97 | Cone | 12.66 | 14.05 | 5.39 | 15.75 | 11.23 |
| 50 | 1 | Yes | 6.47 | Cone | 12.66 | 14.05 | 5.39 | 15.75 | 11.23 |
| 70 | 1 | Yes | 7.3 | Cone | 12.66 | 14.05 | 5.39 | 15.75 | 11.23 |
| 30 | 2 | No | 5.01 | Cone | 12.66 | 14.05 | 5.39 | 15.75 | 11.23 |
| 50 | 2 | No | 7.13 | Cone | 12.66 | 14.05 | 5.39 | 15.75 | 11.23 |
| 70 | 2 | No | 7.52 | Cone | 12.66 | 14.05 | 5.39 | 15.75 | 11.23 |
| 30 | 2 | Yes | 5.41 | Cone | 12.66 | 14.05 | 5.39 | 15.75 | 11.23 |
| 50 | 2 | Yes | 6.18 | Cone | 12.66 | 14.05 | 5.39 | 15.75 | 11.23 |
| 70 | 2 | Yes | 6.96 | Cone | 12.66 | 14.05 | 5.39 | 15.75 | 11.23 |
| Q | No | Yes | 8.56 | Cone | 12.66 | 14.05 | 5.39 | 15.75 | 11.23 |

In case of the tension test (pull out) of the studs, Eqs (6) and (7) have been referred to in the discussion of the test results. Eq.(6) estimates the pull out strength when the stud failed by cone failure of concrete. Eq.(7) gives the failure load when the stud fails by tensile rapture and it predicts the maximum strength of the stud at the pull out test. Where: As is the area of the stud cross section and σs is the tensile stress of the stud. le length of stud, dh diameter of the head of the stud, BW, and fcu is the compressive strength of concrete. By investigating the test results in Table 3 and 4 with the calculated values by Eq. (6), it can be said that the stud of low height in low strength concrete will fail by cone failure of concrete and the strength is lower than the estimated values by Eq.(6). When the stud becomes longer than 35 mm and it is in high strength concrete, the stud would fail by tensile failure of the studs themselves. Therefore, the strength of the studs became constant with no relation to the stud height. In the case of the 45mm long studs, the cone failure strength of the studs and the tension strength were very close. In the case of the 60 mm long studs, all specimens of both type of concrete failed by tensile failure of studs because the cone failure strength becomes larger than the tensile strength of the stud. The slab reinforcement increased the pull out strength in case of the 35 mm long studs ; however, it showed little effect for the 45 mm long studs and showed no effect in case of the 60 mm long studs, because the cone failure strength was much higher than the tensile strength of the studs

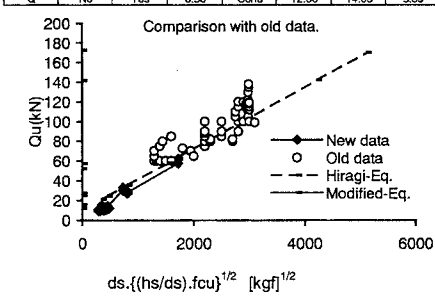


Fig 5 Comparison with old data

**4. Conclusion**

From this experiment, the following points can be pointed out.

The fine stud of 6mm diameter behaves as normal studs in tension and shear. For the shear strength a modified equation proposed. In 35 mm long studs, the reinforcement of the concrete slab increased the concrete bridging and increased the concrete cone failure for the studs . In 45 mm long studs, the reinforcement of the slab did change the failure mode of the studs. Even though, the failure load did not increased much due to the high concrete cone failure. In case of 60 mm long studs the reinforcement of the slab did not seems to effect the failure load of the studs because the concrete cone failure was much bigger than the tensile load failure of the studs.

**References**


(1) Yasuhiro OTANI, Yoshitata MORITO, Yuhshi FUKUMTO, Load-Relative Displacement Relationships of Stud Anchor under Combined Loads, Proceedings of the Third International Conference on Steel-Concrete Composite Structures, September 26-29,1991, pp.629-634.

(2) H.Bode and K. Roik, Headed Studs Embeded In Concrete and Loaded in Tension, ACI annual convention, Los Angels, pp 61-88, 1983.