Push-out test of headed stud in composite girder using steel deck -An effect of stud length of projecting part from steel deck on shear strength-

Y.Horita& Y Tagawa
Yokohama National University, Japan

H.Asada
Kobe University,Japan

SUMMARY:
In recent year, to meet the demand of high shear resistance on stud connection, the large-diameter stud (25mm) has been developed and added to Japanese Industrial Standard (JIS) in 2011. However, the applicability of current design specifications to the large-diameter stud has not been verified adequately. The purpose of this test is to investigate the current design specifications are available to the large-diameter studs and the effect of stud length of projecting part from steel deck on shear strength and failure mode. In this test, 38 push-out tests were performed. From the results of these tests, it is clarified that the current design specifications aren't sure to apply to the large-diameter studs, so that the stud length of projecting part is bigger, the calculation value is more overvaluing. It is also found the failure mode tend to be the cone-type failure with decrease of stud length of projecting part from steel deck.

Keywords: headed stud connector, composite girder, push-out test, large-diameter (25mm) studs

1. INTRODUCTION

1.1 Background and Objective

The composite girder consisting of concrete deck slab and steel H-shaped beam is widely used in steel building structures. In recent year, to meet the demand of high shear resistance on stud connection, the large-diameter stud (25mm) has been developed and added to Japanese Industrial Standard (JIS) in 2011. The headed stud connectors should transfer the horizontal shear force so that concrete slab and steel girder demonstrate a synthetic effect. However, the applicability of current design specification which has been developed by using studs with diameter of 16mm to 22mm, to the large-diameter stud has not been verified adequately. Furthermore, current design specifications require stud length of projecting part from steel deck more than 30mm. however, There is no reasonable understanding based on mechanical theory. In this test, to investigate shear behavior of the large-diameter stud and effect of stud length of projecting part from steel deck, and length/ diameter ratio, 38 push-out tests were reported.

1.2 Current Design Specifications in Japan and the U.S.

In composite girder design in Japan and the US, the shear connector between composite slab with steel deck and steel girder such as headed stud is designed to transfer the large lateral shear force sufficiently. These design recommendation require sufficient strength of shear connectors. The shear strength of headed shear connectors is evaluated by using equations based on results of push-out tests. In Japan, current design equations have been developed based on test results of push-out specimens with steel deck of less than 75mm height. These tests were conducted without lateral restrainers. The equations are as follows;

$$q_{s1} = 0.5 A_{sc} \sqrt{F_c E_c} \leq 450 A_{sc} \tag{1.1}$$

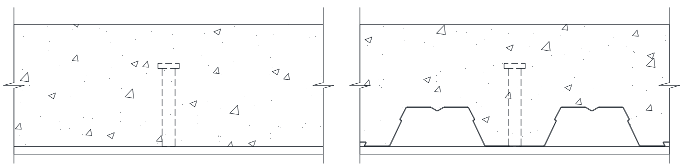
$$q_{s2} = \left(\frac{0.85}{\sqrt{n_d}} \right) \left(\frac{b_d}{H_d} \right) \left(\frac{L}{H_d} - 1 \right) q_{s1} \leq q_{s1} \tag{1.2}$$

Where, A_{SC}: Sectional area of axis [mm^2], F_C: Compress strength of concrete [N/mm^2], E_C: Young's modulus of concrete [N/mm^2], n_d: Number of studs in one ditch, b_d: Width of average of deck ditch [mm] H_d: Height of deck [mm], L : Length of stud [mm]

On the other hand, current the U.S. design recommendation, AISC (American Institute of Steel Construction, 2005) recommends design equation (Eq.1.3) which is based on results of push-out test that is used steel deck of less than 50mm. These tests were conducted with lateral restrainers. The shear strength calculated by using Eq.1.3 is limited by considering the group and position effects. Specifically, Upper limit of shear strength is reduced by Reduction factors R_p and R_g summarized in Table 1.

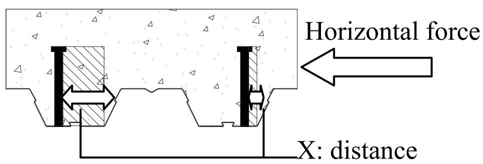
$$q_{s3} = 0.5 A_{sc} \sqrt{F_c E_c} \leq R_p R_g A_{sc} F_u \tag{1.3}$$

Where, R_p: Positioning coefficient, R_g: Group influence coefficient, F_u: Tensile strength of stud [N/mm^2]



(a) Solid slab (b) Slab with steel deck

Figure 1. Type of the slab



Strong position (S) : X≧ 51mm
Weak position (W) : X≦ 51mm

Figure 2. Strong/Weak position

Table 1. Reduction Factors Rg and Rp

Type	Rg	Rp
Flat slab	1.0	1.0
When the ditch of the deck parallels the steel beam	1.0	0.75
When the ditch of the deck crosses the steel beam and the number of the stud is		
one stud	1.0	0.6
two studs	0.85	0.6
three studs	0.7	0.6

2. TEST PROGRAM

2.1 Test Specimen

Table 2 summarizes test specimens. In order to investigate the effects of steel deck and stud geometries on shear strength of stud connecters embedded in concrete slab and on shear strength and failure modes, push-out tests were conducted. The main parameters of tests were stud geometries such as stud length and diameter, steel deck geometries such as steel deck height. In case of multiple studs, the number of stud, stud position as shown in Fig. 2, and Normal position (N) is shown in Fig. 3, and stud spacing were also varied to discuss group effects. With combination of these parameter, totally 38 test specimens were fabricated.

Test specimens consist of H-shaped steel beam and two concrete slabs connected by one or two or three headed studs as shown in Fig. 3. In case of composite slab with steel deck, the test specimens were fabricated by using two different decks profiled with steel deck height (H_d) of 75mm and 120mm shown in Fig. 4, and two different headed studs with diameter φ19mm and 25mm. Steel deck was oriented in perpendicular to loading direction. Studs were welded to the steel flange through the hole of deck opened in advance. Test specimens with solid slab were also prepared to discuss the effects of configuration of concrete slab.

Standard material tests were also conducted on studs and concretes. Material properties which play important role on estimation of shear strength in the push-out tests were summarized in Table 3 respectively.

Table 2. Summary of test specimens

No.	Steel deck height (H_d) [mm]	Stud diameter (d) [mm]	Stud length (l) [mm]	Number of the stud	Stud position	Spacing of studs [mm]
1	75	19	80	2	N	5*d*
2			100			
3			130			
4			150			
5			170			
6			190			
7			100			10*d*
8			130			
9			150			
10-A,B	Solid slab	25	120	2	N	5*d*
11	75		120	1	S	-
12			150			
13-A,B			120	2	N	5*d*
14-A,B					S	
15-A,B					W	
16-A,B			150		N	
17-A,B					S	
18-A,B					W	
19-A,B			170		N	
20-A,B			190			
21-A,B			120		N	10*d*
22-A,B			150			
23			120	3	S	5*d*
24			150			
25	120		120	2	N	5*d*
26			150			
27			190			

Table 3. Material tests

(a) Stud

Stud diameter (*d*) [mm]	Stud length (*l*) [mm]	Tensile strength [N/mm^2]	Stud elongation [%]
19	80	481	14.5 ↑
	100	456	15.2 ↑
	130	459	11.2 ↑
	150	465	9.00 ↑
	170	462	15.3 ↑
	190	466	15.3 ↑
25	120	503	13.1 ↑
	150	499	11.8 ↑
	170	507	10.9 ↑
	190	502	11.1 ↑

(b) Concrete

Design strength F_C[N/mm^2]	Tensile Strength [N/mm^2]	Compressive Strength [N/mm^2]
21.0	2.85	30.2

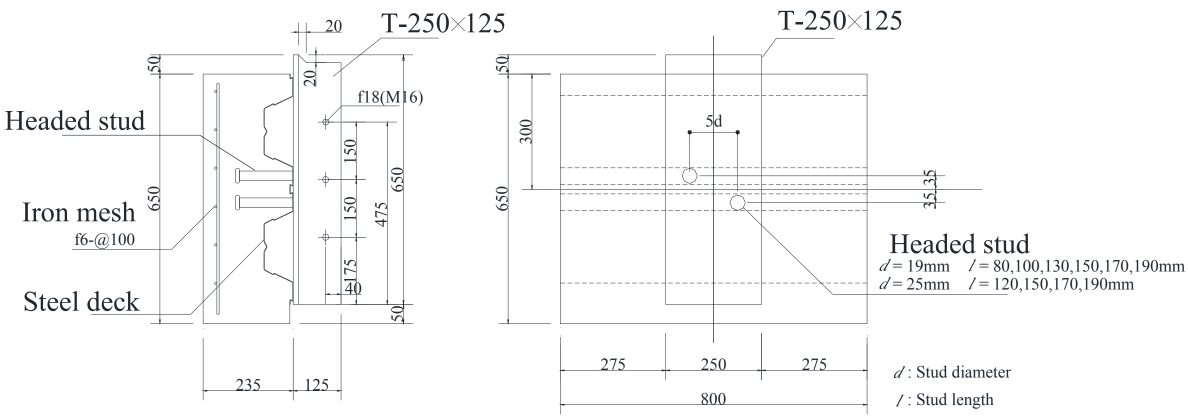


Figure 3. Specimen geometries

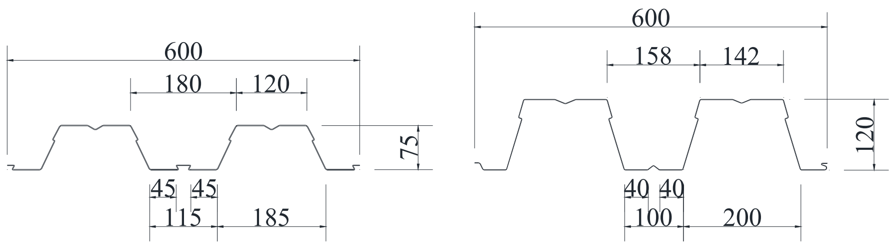


Figure 4. Steel deck properties

2.3 Loading Methodology and Measurement

Fig. 5 shows test set-up. A testing machine with its loading capacity of 2000kN was employed to offer vertical load *P*. The vertical load was applied to test specimen monotonically. In order to avoid rotational deformation of deck, lateral restrainers were set around concrete slab. The applied shear force was recorded by the load cell of the testing machine. Four displacement transducers were set to measure the relative displacement (slip) between concrete slab and steel beam.

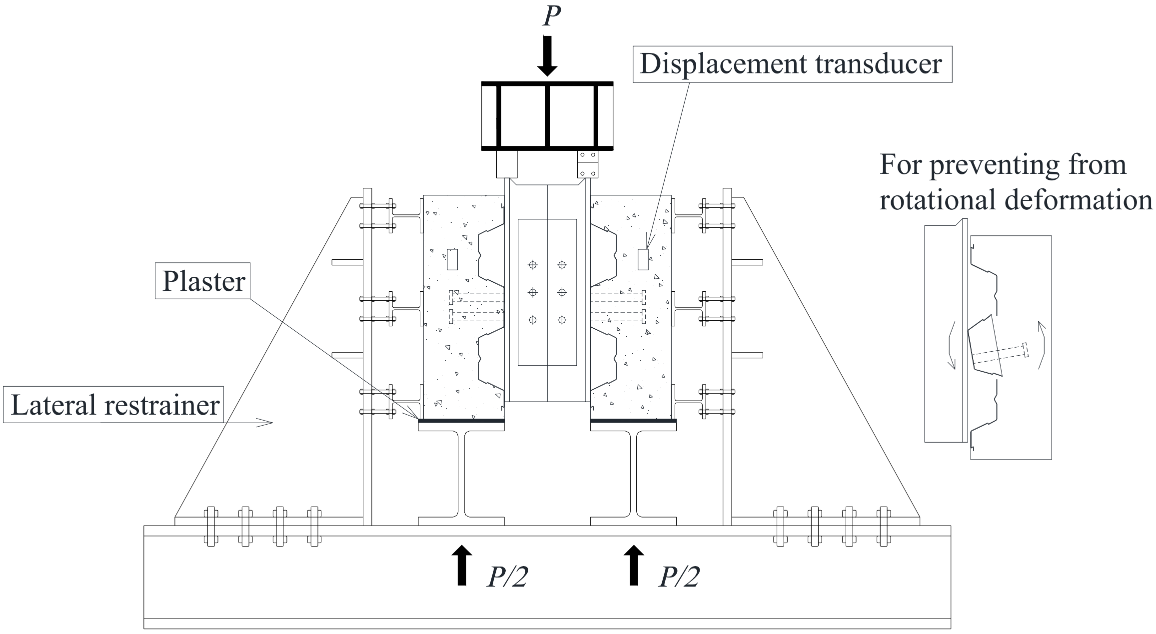
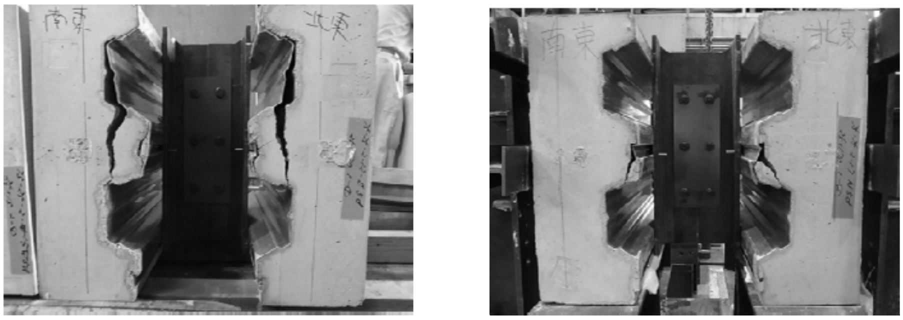


Figure 5. Test set-up

3. TEST RESULTS AND DISCUSSIONS

3.1 Failure Mode

Typical cracking pattern in the concrete slab are shown in Photo 1. In this tests, concrete breakout at boundary between solid slab and steel deck shown in Photo 1(a) (hereinafter collectively called ‘‘Shear failure of concrete slab”) are observed when stud length of projecting part from steel deck (l_p) shown in Fig.6 is short, as well as typical failure pattern such as shear yield of stud and bearing fracture of concrete slab around stud (hereinafter collectively called ‘‘Stud failure”). Fig. 7 shows load-deformation curves of test specimens which reach to different failure modes. Shear strength of test specimens reach to shear failure of concrete slab were relatively higher than that of the specimens reach to stud failure. In case of shear failure of concrete slab, after it reach peak load, strength is reduced drastically. On the other hand, for stud failure, obvious strength degradations were not observed until slip deformation reach 20mm.



(a) Shear failure of concrete slab (b) Stud failure

Photo 1. Typical cracking pattern

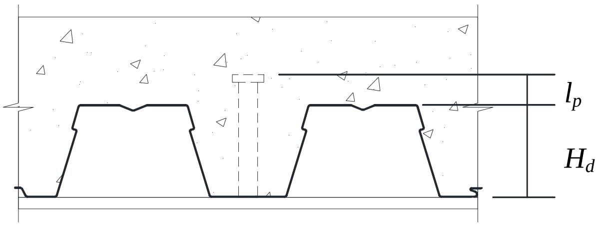
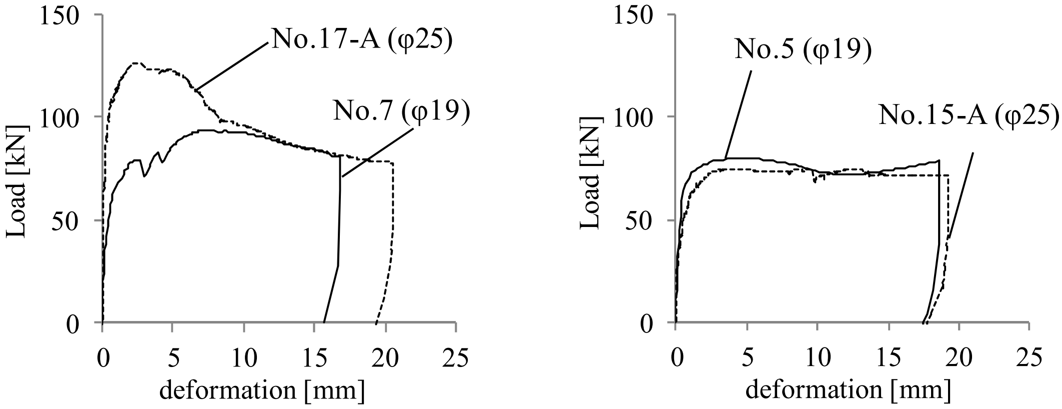


Figure 6. Stud length of projecting part from steel deck (l_p)



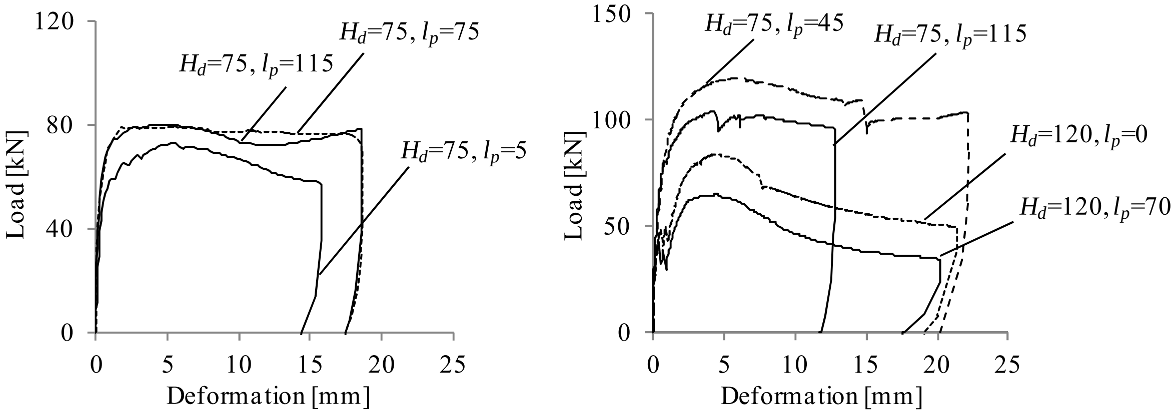
(a) Shear failure of concrete slab (b) Stud failure

Figure 7. Load-deformation curve of specimens reach different failure modes

3.2 Effect of Stud Length of Projecting Part from Steel Deck on Shear Strength

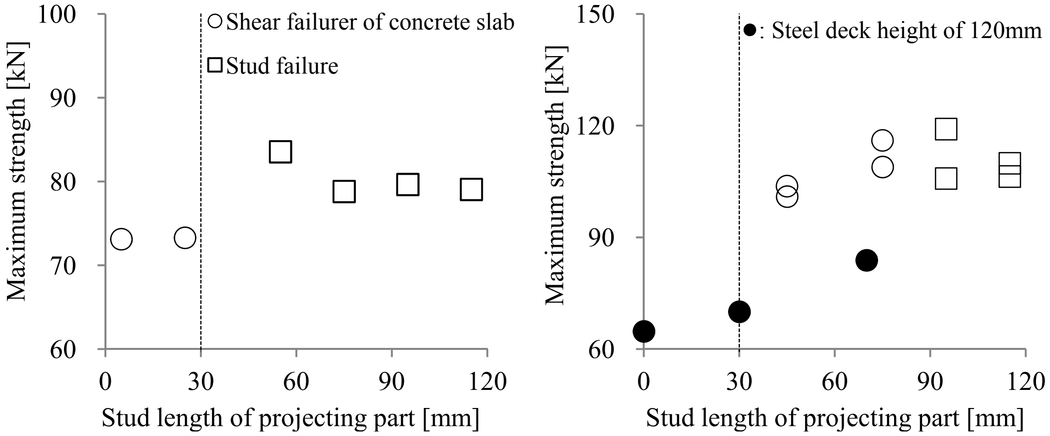
Fig. 8 shows load-deformation curves of specimens with different length projecting part from steel deck. As stud length of projecting part from steel deck is shorter, strength degradations after the peak load become more severe. Maximum strengths of test specimens with deck height of 120mm were relatively lower than those of specimens with deck height of 75mm when specimen is failed by shear failure of concrete slab. Moreover, strength degradations of specimens with deck height of 120mm after the peak load were more severe than that of 75mm.

Relationships between maximum strength and stud length of projecting part from steel deck are shown in Fig. 9. In this figure, lower limit (30mm) of stud length of projecting part from steel deck according to current design specification is also shown. In this test specimens with φ19, when stud length of projecting part from steel deck is smaller than 30mm, failure mode became shear failure of concrete slab and shear strength is lower than which is more than 30mm. On the other hand, In test specimens with φ25, failure mode became shear failure of concrete slab even though stud length of projecting part is more than 30mm. moreover , in this test, when stud length of projecting part from steel deck is less than 75mm, stud length of projecting part is smaller, the shear strength tend to be lower.



(a) φ19 (b) φ25

Figure 8. Lord-deformation curve of each of length projecting part from steel deck (l_p) differs.



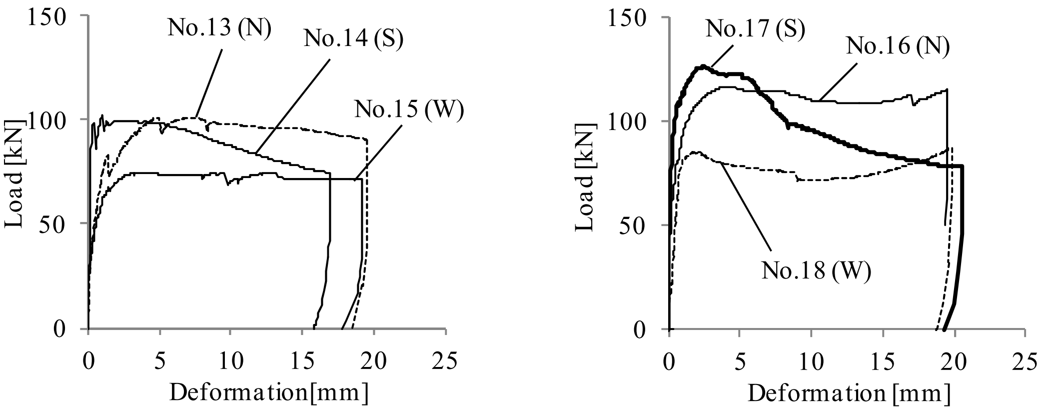
(a) φ19 (b) φ25

Figure 9. Relationships between maximum strength and stud length of projecting part

3.3 Effect of Stud Position on stud behavior in large-diameter studs

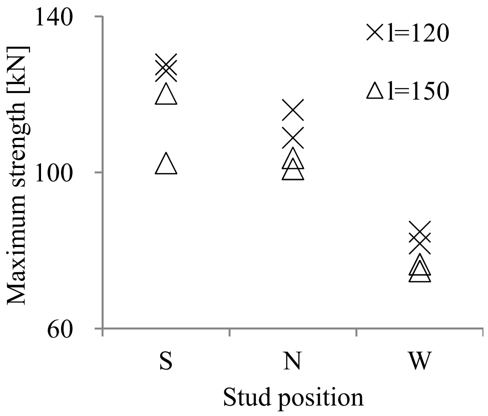
Typical load-deformation curves of test specimens with different stud position are shown in Fig. 10. For the aspects of load- deformation curve, shear resistance behavior of the studs in weak position (W) was more ductile than that of the studs in strong position (S). It seems that these results are due to the differences of resisting mechanism and failure modes.

Relationships between maximum strength and stud positions and between deformations at the maximum strength and stud positions are shown in Fig. 11 and Fig. 12 respectively. Deformations at maximum strength of studs in strong position were smaller than that of studs in weak position.



(a) l=120 (b) l=150

Figure 10. Load-deformation curves of test specimens with different stud position



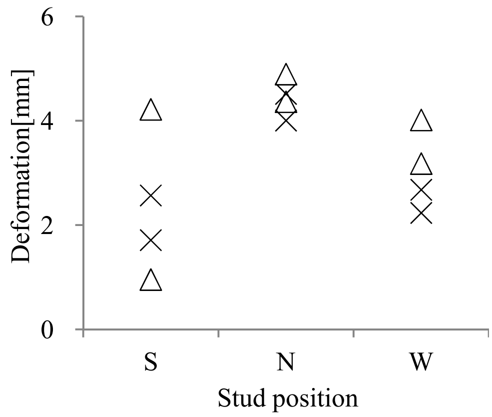
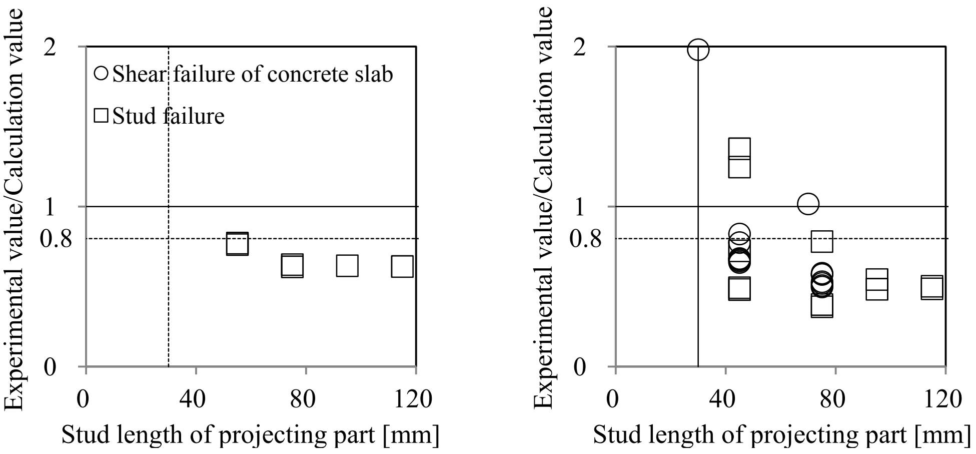


Figure 11. Relationships between maximum strength and stud positions (Left)
Figure 12. Relationships between deformations at the maximum strength and stud positions (Right)

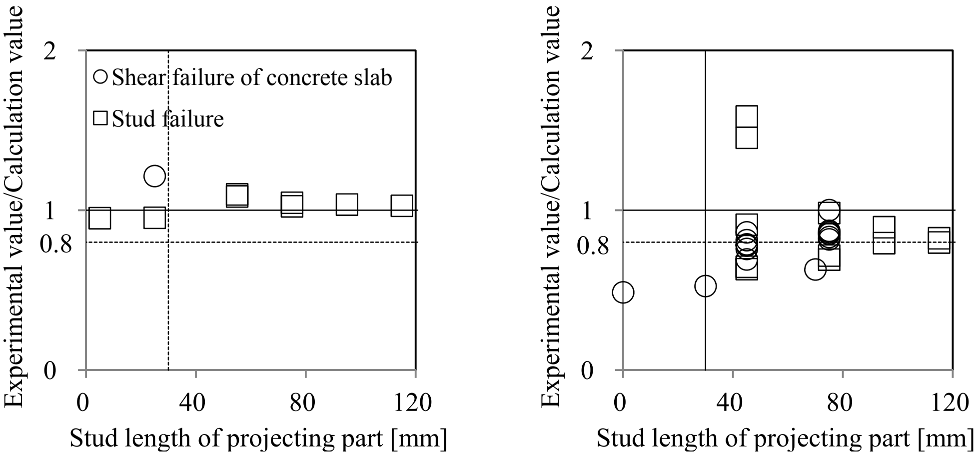
3.4 Comparison of Test results with AIJ design code and AISC (2005)

Comparison between experimental shear strength and calculated shear strength according to AIJ and AISC design specification are shown in Fig. 13 and Fig. 14 as function of stud length of projecting part from steel deck. For φ19, AIJ design specification slightly overestimates test results, although calculated value according to AIJ design specification corresponds to test results regardless of stud length of projecting part. However, for φ25, Ratio of experimental to calculated shear strength varies extensively. Especially, when stud length of projecting part from steel deck (l_p) is 30mm, AIJ design specifications underestimate extremely. On the other hand, AISC design specification has good agreement with test results for φ19 compare compared with AIJ design specification. However, for φ25, Even for stud length of projecting part from steel deck is longer than 30mm, AISC design specification overestimate test results. Fig. 15 shows relation of the ratio of experimental to calculated strength and stud position. AIJ design specification overestimate test results of studs in weak position. On the other hand, AISC design specification corresponds to test results regardless of stud position.



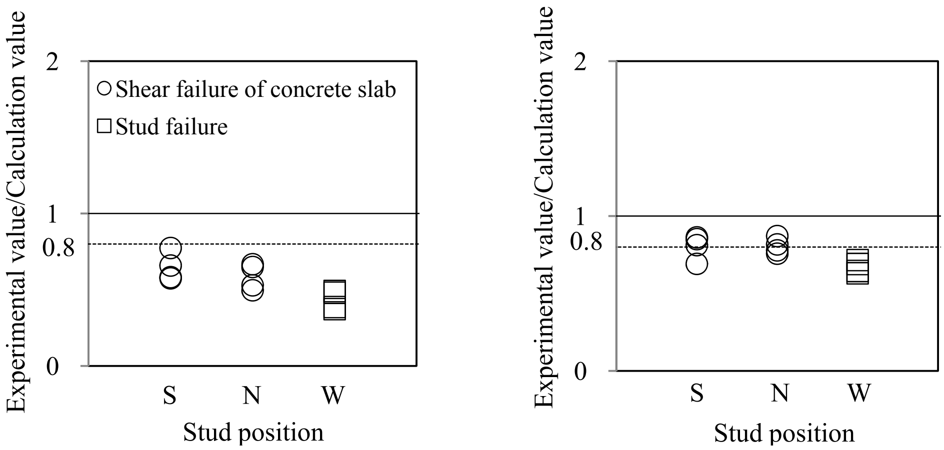
(a) φ19 (b) φ25

Figure 13. Comparison of test results with calculated value according to AIJ as function of stud length projecting part from steel deck



(a) φ19 (b) φ25

Figure 14. Comparison of test results with calculated value according to AISC as function of stud length projecting part from steel deck



(a) AIJ design specification (b) AISC design specification

Figure 15. Relation of the ratio of experimental to calculated strength and stud position

4. CONCLUSION

From Results of 38 push-out tests with various deck and stud geometries, the shear strength of studs with conventional diameter of 16 mm to 22 mm surely could be estimated by using existing design formula based on Fisher's study according when the strength were limited by the shear failure in the shank of stud or bearing failure of concrete. In the case of large-diameter studs such as 25 mm, current design specifications especially tended to overestimate test results when the stud length of projecting part from steel deck is shorter. These results indicated that we need to understand limitation of stud and deck geometries by considering the effect of interaction between studs and steel deck geometries may lead to difference of deformation pattern of studs as shown in Photo 2.

(a) Shear failure of concrete slab

(b) Stud failure

Photo 2. Deformation pattern of studs

REFERENCES

Horita, Y., Tagawa, Y., Nakaso, Y. and Asada, H. (2011). Push-out Test of Headed Stud in Composite Girder Using High-height Steel Deck. Japan Association for Earthquake Engineering. 312-313.

Japan Society of Steel Construction. (1996). Method of Standardized Push-out Test for Headed Stud and Current Research on Stud. Japan Society of Steel Construction Technical Report. No.33.

Architecture Institute of Japan. (2010). Design Recommendations for Composite Connections.

Hawkins, N.M., Mitchell, D. (1984). Seismic Response of Composite Shear Connections. ASCE.

Architecture Institute of Japan. (1999). AIJ Standard for Structural Calculation of Reinforced Concrete Structure.

American Institute of steel Construction. (2005). Specification for Structural Steel Building.