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On the Strength Headed Shear Studs in Solid Slabs

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Summary

A series of 24 solid slab push-out specimens were tested. Twelve of the tests were performed to investigate the effect on the shear stud strength of the flange thickness to which the stud was welded. In six tests, the steel/concrete interface was changed to investigate the influence of friction at the interface. In sic tests the normal load applied to the specimens was varied to establish the influence on the shear stud strength. The test results show that flange thickness does not affect shear stud strength and that significant friction is developed at the interface.

1. Introduction

The results of 24 solid slab, shear stud push-off tests that were recently conducted at Virginia Polytechnic Institute and State University (VPI&SU) are reported in this paper. The purposes of the tests were (1) to further examine the effect of beam flange thickness on shear stud strength and (2) to examine the contribution of friction at the slab/beam interface to stud strength. The test program to date consisted of eight series of tests with three identical tests in each series. Series 1-4 (Tests 1-12) are used to examine the effect of beam flange thickness on shear stud strength, while Series 5-8 (Tests 13-24) are used to evaluate the contribution of friction to the slab/beam interface.

2. Description of Tests

All test specimens were constructed with the same stud diameter, stud length, stud tensile strength, number of stud connectors per slab, and steel reinforcement. Each series consisted of three tests. For series 1-4 (tests 1-12), the flange thickness to which the stud was welded was varied by using different steel sections. For series 5 and 6 (tests 13-18), only the slab/beam interface was varied. For series 7 and 8 (tests 19-24), only the amount of normal load applied to the specimen was changed. The purpose of these tests is described below.

2.1 Flange Thickness Influence

The first parameter evaluated was the influence on shear stud strength of the thickness of the flange to which the stud is welded. The majority of the push-out tests performed at VPI&SU have used WT155x26 sections, with a nominal flange thickness of 13.2 mm. The writers wished to verify that thinner or thicker flanges would cause no change in stud strength. A stud diameter of 19 mm was used for all tests, and the concrete strength was kept the same. A total of 12 push-out specimens were tested. The desired mode of failure was stud shearing; thus, the diameter-to-flange thickness ratio was kept below 2.7, as recommended by Goble (1968).

Goble (1968) first investigated the behavior of thin flange push-out specimens. From 41 specimens with 13 mm, 16 mm or 19 mm shear studs, he determined a relationship, based on the beam flange thickness, that indicates the point at which the failure mode changes from stud shear to flange pull out. Beam flange thicknesses between 3 mm and 11 mm were used. Concrete strengths varied among the tests. Goble concluded that flange pull out occurs when the ratio of stud diameter to flange thickness is above 2.7.

2.2 Slab/Beam Interface Influence

The second parameter investigated was the effect of friction at the slab/beam interface. The writers wanted to determine if the *apparent* stud strength was reduced by reducing the interaction between the concrete and beam flange. The apparent stud strength is that determined from the push-out test, which includes any effect contributing to the load resistance. Six push-out tests were conducted with a piece of flat sheet steel placed at the interface. Three of the specimens had a layer of lithium grease placed between the sheet steel and beam flange. These two series, along with Series 7, which had no sheet steel at the interface, permit an examination of the interface influence.

An upper limit for the shear stud strength of $A_{sc}F_u$ is used in the American Institute of Steel Construction (AISC) specification (*Load* 1993). The limit appears inconsistent given that it represents the tensile strength of the shear stud, when in fact the behavior of the stud is generally described in terms of shear. If the strength was controlled by a shear limit state, using a failure theory such as von Mises', the upper limit would be expected to be $0.6A_{sc}F_u$. However, the argument for the higher limit appears justified when the test data that were used to formulate the AISC specification provisions are considered (Ollgaard, et al 1971).

Lyons, et al (1994) postulated that the inconsistency between the AISC specification equation and described behavior was due to friction at the slab/beam interface. The friction at the interface, which is present in typical solid slab push-out specimens results in an apparent stud strength that is greater than that predicted using a shear limit state in the stud. The presence of steel deck reduces the friction at the interface, thus reduces the apparent strength of the shear studs.

2.3 Normal Load Influence

The third parameter investigated, which is directly related to the friction at the interface, was the influence on stud strength of normal load applied to the test specimen. Previous solid slab specimens tested at VPI&SU did not have normal load applied. Tests performed with formed steel deck, however, did have normal load applied. To further investigate the effect of friction at the slab/beam interface, six identical push-out specimens were tested. A normal load of 10% of the axial load was applied to three of these specimens. The 10% normal load is used in push-out tests to simulate gravity load on a composite beam (Sublett, et al, 1992). No normal load was applied to the other three specimens. If the amount of normal load applied causes a difference in strength, this is evidence that either friction is being developed or that the state of stresses in the stud is being changed.

3. Specimen Construction and Loading Procedure

All push-out specimens were constructed using wooden forms. Specimens were 915 mm by 915 mm, and consisted of a 146 mm thick normal weight concrete slab on a WT section. Tests 1-3 and 13-24 used WT155x26; the studs were welded over the web of the steel section. Tests 4-6 used WT155x26, tests 7-9 used WT155x19.5, and tests 10-12 used WT205x42.5; studs were welded off-center for these tests. The stud size used for all tests was 19 mm x 105 mm. Material tests conducted by the shear stud manufacturer indicated a tensile strength, F_u, of 448 MPa. Two studs were used in each specimen half, spaced at 460 mm along the length of the flange. Steel reinforcement was the same for all tests: two layers of four 10 mm reinforcing bars placed on the bottom of the slab, and two layers placed on the top. When sheet metal was used, holes were precut in the metal so that the studs were welded directly to the steel beam. All specimens were cast horizontally.

Series 1-4 were cast using the same batch of concrete, Series 5 and 6 were cast together, and Series 7 and 8 were cast together. The specimens were covered and moist-cured for seven days, at which time the forms were removed. Concrete test cylinders were cast along with the specimens and cured similarly. The halves were then bolted through the webs to form a push-out specimen.

Axial load was applied and measured with a hydraulic ram and load cell. In some tests, a load was applied normal to the slab surface using a yoke device placed around the specimen. The normal load was applied using a hydraulic ram and measured with a load cell. Axial load was applied in increments of 22 kN until a load of approximately 80% of the expected capacity was reached. After that, displacement control was used. For the tests with normal load, each axial load increment was preceded by a normal load increment of approximately 10% of the axial load.

4. Test Results

Test results, as well as stud strength calculations using the AISC specification (*Load* 1993), are summarized in Table 1. The failure mode was stud shearing for all tests reported. Series 1, where the studs were welded over the web of a WT155x26 (t_f = 13.20 mm), had an average experimental load per stud of 118.9 kN. The studs were not welded over the web in Series 2-4. Series 2, where the studs were welded on a WT155x26 (t_f = 13.20 mm), had an average experimental load per stud of 117.8 kN. Series 3, which used a WT155x19.5 (t_f = 9.10 mm), had an average experimental load per stud of 114.2 kN. Series 4, which used a WT205x42.5 (t_f = 18.20 mm), had an average experimental load per stud of 112.5 kN. As seen from Fig. 1, flange thickness does not significantly affect stud strength. Also, the experimental stud strengths were underestimated by the AISC equation. The average load at stud failure for Series 1-4 was 1.13 times the AISC predicted value.

Series 5-6, which had sheet metal placed between the concrete and steel, show that there is no significant change in stud strength when the steel/sheet metal interface is greased. The average stud strength when the interface was greased was 105.8 kN, and the average stud strength when the interface was not greased was 110.3 kN. It does seem that by eliminating the steel/concrete interface by using sheet metal, the stud strength is significantly reduced. This conclusion can be made by comparing Series 5 and 6 with Series 7. These series have approximately the same concrete properties. The only difference between the tests was the use of sheet metal in Series 5 and 6, and none in Series 7. Series 7 had an average shear stud strength of 130.6 kN, which is 23% greater than series 5 and 18% greater than series 6. This demonstrates that when steel deck is used, even without a profile rolled in the deck as in series 5 and 6, the stud strength is less than for a solid slab.

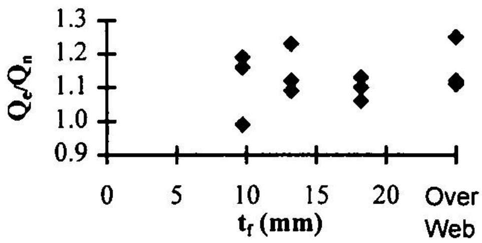

Fig. 1 Effect of flange thickness on stud strength

Series 7 resulted in a higher stud strength than series 8. In series 8, where normal load was not applied, the average stud strength was 114.2 kN. The normal load increases the frictional resistance from the slab and beam.

Series	Test	Stud Loc.	t_f (mm)	Concrete Strength f'_c (MPa)	Concrete Weight w (kN/m^3)	Percent Normal Load	Calculated Load Per Stud Q_n (kN)	Experimental Load Per Stud Q_e (kN)	Ratio Q_e/Q_n	Failure Mode
1	1	C	13.2	23.7	21.8	10	102.4*	114.6	1.12	SS
	2	C	13.2	23.7	21.8	10	102.4*	128.2	1.25	SS
	3	C	13.2	23.7	21.8	10	102.4*	113.7	1.11	SS
2	4	F	13.2	23.7	21.8	10	102.4*	126.4	1.23	SS
	5	F	13.2	23.7	21.8	10	102.4*	112.1	1.09	SS
	6	F	13.2	23.7	21.8	10	102.4*	115.0	1.12	SS
3	7	F	9.7	23.7	21.8	10	102.4*	101.8	0.99	SS
	8	F	9.7	23.7	21.8	10	102.4*	118.6	1.16	SS
	9	F	9.7	23.7	21.8	10	102.4*	122.4	1.19	SS
4	10	F	18.2	23.7	21.8	10	102.4*	115.8	1.13	SS
	11	F	18.2	23.7	21.8	10	102.4*	113.0	1.10	SS
	12	F	18.2	23.7	21.8	10	102.4*	108.5	1.06	SS
5#	13	C	13.2	32.2	22.7	10	127.5**	106.9	0.84	SS
	14	C	13.2	32.2	22.7	10	127.5**	109.4	0.86	SS
	15	C	13.2	32.2	22.7	10	127.5**	101.2	0.79	SS
6#	16	C	13.2	32.2	22.7	10	127.5**	109.4	0.86	SS
	17	C	13.2	32.2	22.7	10	127.5**	106.9	0.84	SS
	18	C	13.2	32.2	22.7	10	127.5**	114.6	0.90	SS
7	19	C	13.2	33.6	22.7	10	127.5**	132.2	1.04	SS
	20	C	13.2	33.6	22.7	10	127.5**	127.4	1.00	SS
	21	C	13.2	33.6	22.7	10	127.5**	132.2	1.04	SS
8	22	C	13.2	33.6	22.7	0	127.5**	104.9	0.82	SS
	23	C	13.2	33.6	22.7	0	127.5**	118.6	0.93	SS
	24	C	13.2	33.6	22.7	0	127.5**	119.2	0.93	SS

SS = Stud Shearing
C = studs welded centrally on beam
F = studs welded off-center on beam
# Series 5 & 6 used flat sheet metal between the steel beam and concrete
Series 5 was greased between the sheet metal and beam

$* = 0.5A_{sc}\sqrt{f'_c E_c}$ $\quad ** = A_{sc}F_u$

Table 1 Test results summary

5. Conclusions

Based on the limited number of tests conducted to date, the following conclusions are made:

1. Experimental stud strengths were between 79% and 125% of the AISC predicted value.
2. Flange thickness, for the stud diameter-to-flange thickness ratios tested in this paper, has little or no influence on the strength of a stud.
3. Adding flat sheet metal between the steel and concrete in a solid slab specimen significantly reduces the stud strength obtained in a push-out test.
4. Applying a normal load to a test specimen measurably increases the stud strength.
5. Based on the tests reported, the lack of friction between the concrete and steel significantly reduces the apparent shear stud strength.

6. Notation

A_{sc} = cross sectional area of a shear stud
f'_c = concrete compressive strength
F_u = tensile strength of shear stud
Q_e = experimental strength of shear stud
Q_n = nominal strength of a shear stud (note that calculations in the paper made with measured material properties)
t_f = flange thickness of steel section

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