Shear Strength of Thin Flange Composite Specimens

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LIGHT GAGE STEEL is finding increasing use in load-carrying elements of structural systems. If very thin steel sections are to be used extensively in composite construction, experimental data on the behavior of the shear connector system are necessary. The purpose of this study was to explore the behavior of stud shear connector composite pushout specimens. Previous experimental studies of this composite system have been concerned with determining the behavior of the specimen when failure occurs either by pulling-out of the shear connector from the concrete or by shearing of the connector. If very thin steel flanges are used, it must be expected that failure could be controlled by pull-out of the connector from the steel flange. The tests reported here examined the behavior of thin flange push-out specimens with ½, ⅝, and ¾-in. diameter welded stud shear connectors. The line defining the shift in failure mode from stud shear to flange pull-out is located.

SPECIMENS AND TEST PROCEDURE

A total of 41 specimens were tested in three groups. In the first series of ten tests all specimens contained ½-in. diameter studs. The second series of 19 tests contained some specimens with ½-in. studs to more accurately locate the point of transition in failure mode, some with ⅝-in. studs and a few with ¾-in. studs. The third series of 12 specimens all contained ¾-in. studs. The procedure used in selecting specimen dimensions was to cover the region where a transition in failure mode could be expected with single specimens for each of three flange thicknesses. Subsequently, additional specimens were tested to provide duplication and to examine the region at closer intervals of flange thickness. In most cases, three specimens for each nominal flange thickness were tested. The important specimen characteristics are given in Table 1. Specimens were identified by letters in the first series, by roman numerals in the second series, and by arabic numerals in the third series.

The specimens were constructed with two studs on each flange of a section prepared by welding three plates together in a wide-flange shape. The concrete slabs were cast in the horizontal position on consecutive days. Slabs I and II refer, respectively, to the first and second slabs cast. Three test cylinders were cast from each batch and cured in a manner similar to the specimen concrete. Average cylinder strengths are given in Table 1. Specimen details are shown in Fig. 1.

The specimens were tested using an incremental testing procedure and slip measurements were taken. For the ½-in. and ⅝-in. stud specimens, 4-kip load increments were used and for the ¾-in. series, 5-kip increments. After completion of testing, tensile test specimens were taken from the flange of each specimen. Yield and ultimate strengths were determined and are given in Table 1.

RESULTS

The results of all of the tests are given in Table 1. These results include a record of the failure mode. The partial pull-out mode indicates that a mixture of flange pull-out and stud shear failure occurred in a single specimen. Load-slip data, taken for each test, was plotted and examined. Representative load-slip curves for ½-in. stud specimens are shown in Fig. 2. It is noted that the thinner flange specimens are somewhat more flexible in the lower load ranges, although the differences are not great. There was no difference in specimen ductility for the two failure modes.

Figure 3 shows the typical appearance of the connector after failure in the shear mode. The flange-pull-out mode is shown in Fig. 4.

The nominal stud shear stress at failure is plotted against the stud diameter, flange thickness ratio in Fig. 5. The shift in failure mode occurs at a d_s/t_f ratio of about 2.7, where d_s is the nominal stud diameter and t_f is the flange thickness. Furthermore, it is very important to note that the specimen strength does not drop in this region and only appears to be reduced for d_s/t_f values greater than 3. It should be noted that Specimen X, having a d_s/t_f of 3.03, contained a flange steel having a surprisingly low ultimate strength. In Fig. 6 the failure load for each stud size is shown. Each point represents the average of the specimens tested at a particular flange thickness. It is shown clearly that no reduction of strength occurs in the neighborhood of the shift in failure mode. In fact, a consistent, although very small, increase in

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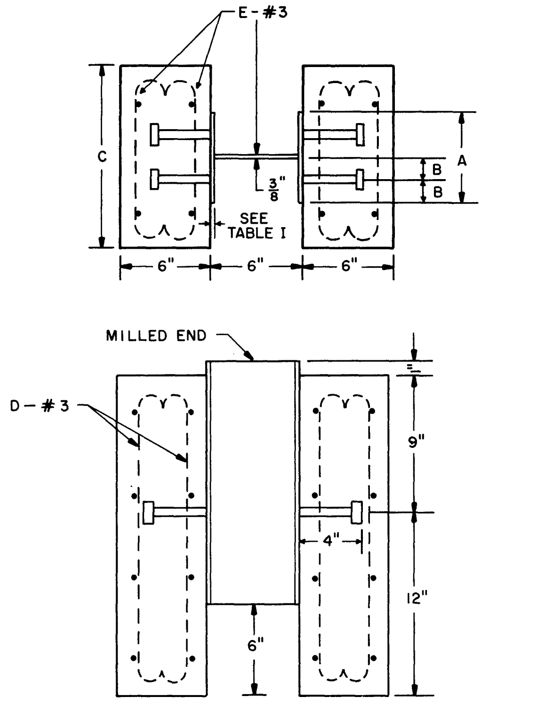
Table 1. **Specimen Details and Test Results**

Specimen No.	Stud Size (in.)	Flange Thickness (in.)	f_c' Side I (ksi)	f_c' Side II (ksi)	f_y (ksi)	f_u (ksi)	Failure Side	Failure Mode[a]	Ultimate Load/Stud (kips)
A	½	0.128	5.61	5.15	59.3	76.6	II	FPO	12.0
A′	½	0.128	5.61	5.46	63.7	77.0	II	FPO	12.0
A″	½	0.128	5.61	5.46	62.7	76.1	II	FPO	12.0
B	½	0.257	5.61	5.15	46.6	67.7	I	SS	14.0
B′	½	0.257	5.90	4.65	47.2	67.2	I	SS	14.4
B″	½	0.257	5.52	4.90	47.2	66.9	II	SS	14.5
C	½	0.380	5.61	5.15	45.5	60.3	I	SS	14.0
D	½	0.192	5.61	5.46	43.4	68.0	II	SS	15.5
D′	½	0.192	5.90	4.65	41.3	64.3	II	SS	15.4
D″	½	0.192	5.90	4.65	42.7	64.8	I	SS	16.0
IV	½	0.154	4.24	4.12	45.7	66.2	Both	FPO	12.1
V	½	0.153	4.24	4.12	43.5	65.2	I	FPO	13.3
VI	½	0.159	4.24	4.12	45.5	66.0	I	FPO	13.1
VII	½	0.170	4.39	4.86	46.7	65.7	II	FPO	13.6
VIII	½	0.171	4.39	4.86	45.5	65.8	Both	FPO	13.4
IX	½	0.170	4.39	4.86	47.3	66.2	I	PPO	13.1
III	⅝	0.193	4.86	4.58	48.8	69.0	Both	PPO	21.0
XIV	⅝	0.187	3.60	3.96	39.0	47.8	I	FPO	18.6
XIX	⅝	0.187	4.10	4.33	37.4	47.0	I	FPO	19.0
XIII	⅝	0.255	3.60	3.96	40.6	61.4	II	FPO	20.6
XVII	⅝	0.256	4.10	4.33	41.5	61.3	II	SS	23.0
XVIII	⅝	0.261	4.10	4.33	45.0	64.0	II	PPO	20.0
II	⅝	0.314	4.86	4.58	45.3	63.8	II	SS	24.5
XV	⅝	0.305	3.60	3.96	50.1	68.8	II	SS	22.0
XVI	⅝	0.308	4.10	4.33	51.8	70.8	I	SS	22.2
I	⅝	0.380	4.26	3.98	41.8	59.4	II	SS	20.9
XI	¾	0.190	4.32	4.75	40.3	50.0	II	FPO	25.4
X	¾	0.248	4.32	4.75	39.5	44.7	II	PPO	22.8
XII	¾	0.370	4.32	4.75	37.4	56.3	I	PPO	31.5
2	¾	0.259	4.39	4.56	42.7	59.9	II	FPO	32.1
10	¾	0.260	5.30	4.52	40.0	59.3	I	PPO	32.9
11	¾	0.260	5.30	4.52	38.7	59.2	Both	FPO	34.6
12	¾	0.441	5.30	4.52	36.3	62.4	II	SS	36.0
6	¾	0.325	3.81	4.03	42.4	61.1	I	SS	35.7
8	¾	0.333	4.32	4.82	43.0	61.6	II	SS	35.1
9	¾	0.324	4.32	4.82	41.4	55.3	I	SS	31.8
1	¾	0.380	4.39	4.56	36.0	56.8	I	SS	32.2
4	¾	0.389	3.81	4.03	36.4	55.6	II	SS	36.2
5	¾	0.374	3.81	4.03	36.9	58.1	I	SS	32.5
3	¾	0.439	4.39	4.56	38.4	63.5	I	SS	33.6
7	¾	0.442	4.32	4.82	36.3	62.3	II	SS	38.6

[a] SS = stud shear
PPO = partial flange pullout
FPO = full flange pullout



	1/2 and 5/8 Diam. Studs	3/4 Diam. Studs
A	6"	8"
B	1 1/2"	2"
C	12"	16"
D	2"	3"
E	4"	5"

Fig. 1. Specimen details

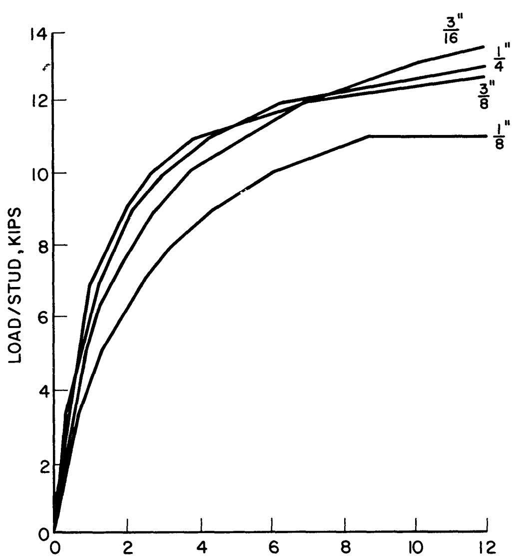


Fig. 2. Load slip curves for ½-in. studs

strength seems to result as flange thickness decreases in the shear failure mode range. Of course, the failure mode shift is related to material properties. If the flange strength were increased it is expected that the failure mode shift would occur at larger values of d_s/t_f.

(*a*)

(*b*)

Fig. 3. Stud shear failure mode

The 21 specimens failing in shear were examined to determine the constant in the stud strength relationship:

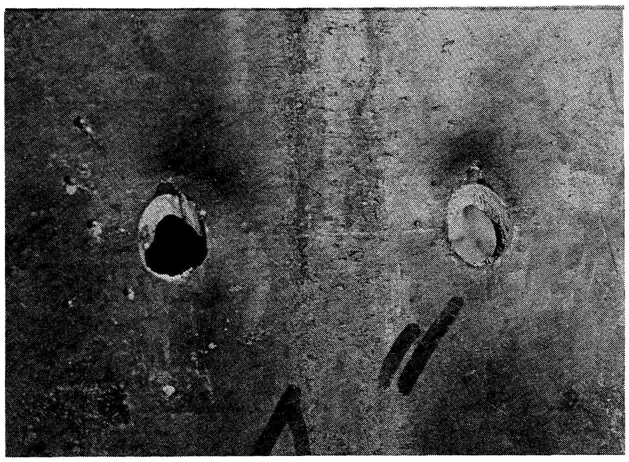
$$q_u = Cd_s^2\sqrt{f_c'}$$

where q_u is the failure load per stud, f_c' is the concrete cylinder strength, and C is the constant. Constant C was found to have an average value of 882 with a coefficient of variation of 8.75%. This compares with 930 reported by Slutter and Driscoll (Ref. 1). However, most of the control cylinders had a strength greater than the 4000 psi limit.

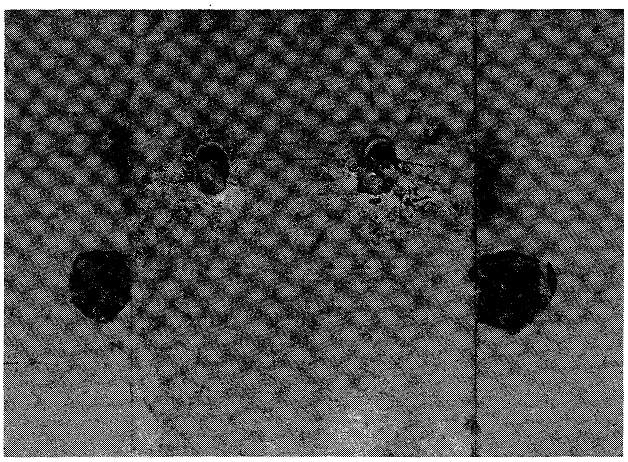
It may be desirable for the engineer to have an estimate of the strength of the system subject to the pull-out failure mode. In most designs this failure would probably be avoided for economic reasons. After an examination of the thirteen specimens which failed by a definite pull-out mode indicates that the expression

$$q_u = C_p\, t_f d_s^2 f_u$$

seems to best fit the data. The term C_p is an empirical constant with units of 1/in. to make the equation dimensionally correct, d_s is the diameter of the stud, and



(*a*)



(*b*)

Fig. 4. Flange pull-out failure mode

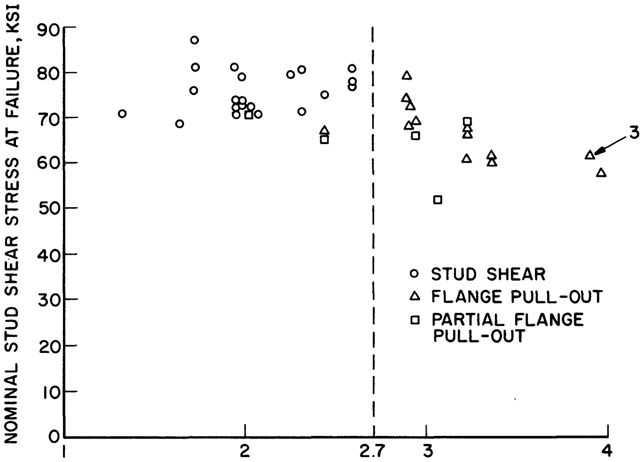


Fig. 5. Nominal stud shear stress versus d_s/t_f

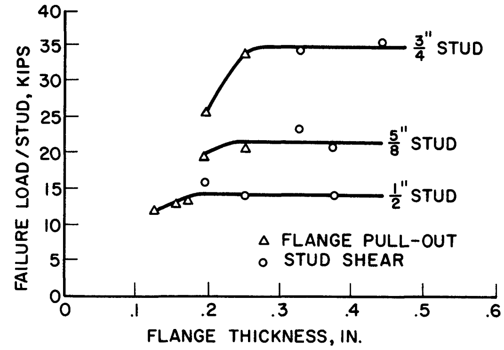


Fig. 6. Failure load versus flange thickness

f_u is the ultimate strength of the flange steel. C_p was found to have an average value of 4.70 with a coefficient of variation of 7.39%. Nine of the thirteen specimens having this failure mode had ½-in. studs.

CONCLUSIONS

Based on the 41 specimens tested, the following conclusions are justified:

1. The shift in failure mode from stud shear to flange pull-out occurs at a d_s/t_f ratio of about 2.7. This limit can be used in design since there is no indication of a decrease in strength near the limit and in fact some specimens tested showed slightly increased strength. The limit is based on the material strengths common in commercially available studs and A36 steel.
2. The flange pull-out failure mode exhibited a satisfactory ductility.
3. Very thin flange specimens showed *slightly* increased flexibility in the low load ranges.
4. The ultimate strength of the 13 specimens failing by flange pull-out seems best described by

$$q_u = 4.70 t_f d_s^2 f_u$$

This expression should be used with care since it is based on 13 tests, many of which were near the region of shift in failure mode.

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REFERENCE

1. *Slutter, R. G. and Driscoll, G. C.* Flexural Strength of Steel-Concrete Composite Beams, *Journal of the Structural Division, ASCE, Vol. 91, No. ST 2, April 1965.*