CHAPTER 3

PUSH-OUT TEST RESULTS

3.1 Solid Slab Push-Out Test Results

The results for the solid slab tests are shown in Table 3.1. For comparison purposes, the strength calculated per the AISC specifications (*Load* 1993) is also shown in the table. More detailed comparisons to calculated values are described in Chapter 4. The test designation contains information on the relevant test parameters.

The first parameter is the *stud diameter* (i.e., 3/4 in.).

The second group of letters/numbers contains the *concrete strength* to the nearest 0.5 ksi and *concrete weight* (**N** for **N**ormal weight).

The next group of letters/numbers contains "special" parameters unique to that series of tests (the numbers represent the tee flange thickness, "**C**" stands for the stud being welded **C**entrally on the flange, "**F**" stands for the stud being welded midway between the tee web and **F**lange tip, "**FS,G**" stands for **G**reased **F**lat **S**heet, "**FS,N**" stands for **N**on-greased **F**lat **S**heet, "**10NL**" stands for **10**% **N**ormal **L**oad, and "**0NL**" stands for **0**% **N**ormal **L**oad.

Table 3.1 Solid Slab Test Results

Series	Test	Test Designation	f'_c (psi)	w (pcf)	Normal Load (%)	Q_{AISC} (kips)	Q_e (kips)	Q_e/Q_{AISC}	Failure Mode
1	1	3/4-3.5N-0.52,C	3435	139	10	23.03*	25.76	1.12	SS
	2	3/4-3.5N-0.52,C	3435	139	10	23.03*	28.83	1.25	SS
	3	3/4-3.5N-0.52,C	3435	139	10	23.03*	25.56	1.11	SS
2	4	3/4-3.5N-0.52,F	3435	139	10	23.03*	28.42	1.23	SS
	5	3/4-3.5N-0.52,F	3435	139	10	23.03*	25.19	1.09	SS
	6	3/4-3.5N-0.52,F	3435	139	10	23.03*	25.85	1.12	SS
3	7	3/4-3.5N-0.38,F	3435	139	10	23.03*	22.88	0.99	SS
	8	3/4-3.5N-0.38,F	3435	139	10	23.03*	26.66	1.16	SS
	9	3/4-3.5N-0.38,F	3435	139	10	23.03*	27.51	1.19	SS
4	10	3/4-3.5N-0.715,F	3435	139	10	23.03*	26.03	1.13	SS
	11	3/4-3.5N-0.715,F	3435	139	10	23.03*	25.41	1.10	SS
	12	3/4-3.5N-0.715,F	3435	139	10	23.03*	24.40	1.06	SS
5^{+}	13	3/4-4.5N-FS,G	4665	144	10	28.66**	24.03	0.84	SS
	14	3/4-4.5N-FS,G	4665	144	10	28.66**	24.59	0.86	SS
	15	3/4-4.5N-FS,G	4665	144	10	28.66**	22.74	0.79	SS
6^{++}	16	3/4-4.5N-FS,N	4665	144	10	28.66**	24.59	0.86	SS
	17	3/4-4.5N-FS,N	4665	144	10	28.66**	24.03	0.84	SS
	18	3/4-4.5N-FS,N	4665	144	10	28.66**	25.76	0.90	SS
7	19	3/4-4.5N-10NL	4880	144	10	28.66**	29.71	1.04	SS
	20	3/4-4.5N-10NL	4880	144	10	28.66**	28.64	1.00	SS
	21	3/4-4.5N-10NL	4880	144	10	28.66**	29.71	1.04	SS
8	22	3/4-4.5N-0NL	4880	144	0	28.66**	23.59	0.82	SS
	23	3/4-4.5N-0NL	4880	144	0	28.66**	26.67	0.93	SS
	24	3/4-4.5N-0NL	4880	144	0	28.66**	26.79	0.93	SS

NOTES:

Q_{AISC} = AISC predicted load per stud

Q_e = Experimental load per stud

SS = Stud Shearing

F_u = 64.9 ksi (measured stud property provided by manufacturer)

$^{+}$ Used flat sheet metal between the steel beam and concrete; Steel flange greased

$^{++}$ Used flat sheet metal between the steel beam and concrete

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

3.2 Composite Slab Push-Out Test Results

The results for the composite slab tests are shown in Table 3.2. As in Table 3.1, calculated strengths using the AISC specification (*Load* 1993) are included. The test designation contains information on the relevant test parameters.

The first group of letters/numbers contains information about the stud: The first letter stands for the *stud position* ("**S**" is for **S**trong, "**W**" is for **W**eak, and "**2S**" is for a pair of **S**trong studs); the first number stands for the *stud diameter in eighths* of an inch; and the next number represents the *stud length* in inches).

The next group of letters/numbers contains information about the concrete slab: The number represents the *concrete strength* to the nearest 0.5 ksi; the letter represents the *concrete weight* (**N** is for **N**ormal weight); the next number is the overall *slab thickness* in inches.

The last number is the *deck height* to the nearest 0.5 in.

3.3 Discussion of Solid Slab Push-Out Test Results

3.3.1 Effect of Flange Thickness

Test results, as well as stud strength predictions by Eqn. 1.11, are summarized in Table 3.1. The failure mode was stud shearing for all tests reported. Series 1 (Tests 1 – 3), in which each stud was welded over the stem of a WT6x17.5 (t_f = 0.52 in.), had an average stud strength of 26.72 k. Series 2 (Tests 4 – 6), in which each stud was welded

Table 3.2 Composite Slab Test Results

Series	Test	Test Designation	f'c (psi)	w (pcf)	F_u~ (ksi)	Normal Load (%)	Q_{AISC} (kips)	Q_e (kips)	Q_e/ Q_{AISC}	Failure Mode
D1	D1	S44-4.5N6-2	4430	143	74.0	10	12.66*	9.77	0.77	SS/WP
	D2	S44-4.5N6-2	4430	143	74.0	10	12.66*	7.29	0.58	SS
	D3	S44-4.5N6-2	4430	143	74.0	10	12.66*	9.23	0.73	SS
D2	D4	2S44-4.5N6-2	4430	143	74.0	10	12.66*	8.95	0.71	SS/WP
	D5	2S44-4.5N6-2	4430	143	74.0	10	12.66*	8.76	0.69	SS/WP
	D6	2S44-4.5N6-2	4430	143	74.0	10	12.66*	7.16	0.57	SS/WF/WP
D3	D7	W44-4.5N6-2	4430	143	74.0	10	12.66*	6.16	0.49	SS/RP/WP
	D8	W44-4.5N6-2	4430	143	74.0	10	12.66*	8.01	0.63	SS/RP/SR
	D9	W44-4.5N6-2	4430	143	74.0	10	12.66*	7.44	0.59	SS/RP/SR
D4	D10	S54-3N6-2	2915	141	72.6	10	14.30*	12.53	0.88	SS/WP
	D11	S54-3N6-2	2915	141	72.6	10	14.30*	13.54	0.95	SS
	D12	S54-3N6-2	2915	141	72.6	10	14.30*	15.55	1.09	SS
D5	D13	W53.5-3N6-2	2915	141	67.0	10	14.30*	15.08	1.05	SS/RP
	D14	W53.5-3N6-2	2915	141	67.0	10	14.30*	11.65	0.81	SS/RP/SR
	D15	W53.5-3N6-2	2915	141	67.0	10	14.30*	10.90	0.76	SS/RP/SR
D6	D16	2S54-3N6-2	2915	141	72.6	10	14.30*	11.87	0.83	SS
	D17	2S54-3N6-2	2915	141	72.6	10	14.30*	15.42	1.08	SS/TR
	D18	2S54-3N6-2	2915	141	72.6	10	14.30*	--	--	TR
D7	D19	S44-6N6-2	5890	150	74.0	10	14.54***	8.86	0.61	SS
	D20	S44-6N6-2	5890	150	74.0	10	14.54***	9.14	0.63	SS/WF
	D21	S44-6N6-2	5890	150	74.0	10	14.54***	6.63	0.46	SS
D8	D22	2S44-6N6-2	5890	150	74.0	10	14.54***	9.23	0.63	SS/WP
	D23	2S44-6N6-2	5890	150	74.0	10	14.54***	10.30	0.71	SS/WF
	D24	2S44-6N6-2	5890	150	74.0	10	14.54***	11.46	0.79	WF/WP
D9	D25	W44-6N6-2	5890	150	74.0	10	14.54***	9.17	0.63	SS/RP/SR
	D26	W44-6N6-2	5890	150	74.0	10	14.54***	7.32	0.50	SS/RP/SR
	D27	W44-6N6-2	5890	150	74.0	10	14.54***	6.88	0.47	WF/SR
D10	D28	S64-7N6-2	7080	151	65.8	10	29.08***	20.01	0.69	SS
	D29	S64-7N6-2	7080	151	65.8	10	29.08***	18.72	0.64	SS/WF
	D30	S64-7N6-2	7080	151	65.8	10	29.08***	21.80	0.75	SS
D11	D31	2S64-7N6-2	7080	151	65.8	10	29.08***	7.76	0.27	SS/WF
	D32	2S64-7N6-2	7080	151	65.8	10	29.08***	17.49	0.60	SS
	D33	2S64-7N6-2	7080	151	65.8	10	29.08***	20.89	0.72	SS
D12	D34	W64-7N6-2	7080	151	65.8	10	29.08***	15.05	0.52	SS/RP
	D35	W64-7N6-2	7080	151	65.8	10	29.08***	12.03	0.41	SS/RP/WP
	D36	W64-7N6-2	7080	151	65.8	10	29.08***	15.67	0.54	SS/RP
D13	D37	S54-4.5N6-2	4710	144	72.6	10	20.83*	16.18	0.78	SS
	D38	S54-4.5N6-2	4710	144	72.6	10	20.83*	17.07	0.82	SS
	D39	S54-4.5N6-2	4710	144	72.6	10	20.83*	14.53	0.70	SS/WP

Table 3.2 Composite Slab Test Results (cont'd.)

Series	Test	Test Designation	f'c (psi)	w (pcf)	F_u~ (ksi)	Normal Load (%)	Q_{AISC} (kips)	Q_e (kips)	Q_e/ Q_{AISC}	Failure Mode
D14	D40	2S54-4.5N6-2	4710	144	72.6	10	20.83*	14.70	0.71	SS
	D41	2S54-4.5N6-2	4710	144	72.6	10	20.83*	16.95	0.81	SS
	D42	2S54-4.5N6-2	4710	144	72.6	10	20.83*	17.43	0.84	SS
D15	D43	W54-4.5N6-2	4710	144	72.6	10	20.83*	9.12	0.44	SS/WP
	D44	W54-4.5N6-2	4710	144	72.6	10	20.83*	11.14	0.53	SS/SR/WP
	D45	W54-4.5N6-2	4710	144	72.6	10	20.83*	11.07	0.53	SS/SR
D16	D46	S34-4N6-2	3930	146	79.2	10	6.63*	5.89	0.89	SS/WF
	D47	S34-4N6-2	3930	146	79.2	10	6.63*	5.18	0.78	SS
	D48	S34-4N6-2	3930	146	79.2	10	6.63*	5.36	0.81	SS/WF
D17	D49	S74-4N6-2	3930	146	64.5	10	36.09*	18.92	0.52	WP
	D50	S74-4N6-2	3930	146	64.5	10	36.09*	9.61	0.27	WF
	D51	S74-4N6-2	3930	146	64.5	10	36.09*	13.10	0.36	WF
D18	D52	W34-4N6-2	3930	146	79.2	10	6.63*	4.05	0.49	SS/RP/WF
	D53	W34-4N6-2	3930	146	79.2	10	6.63*	4.54	0.68	SS/WF
	D54	W34-4N6-2	3930	146	79.2	10	6.63*	4.81	0.73	SS/WF
D19	D55	W74-4N6-2	3930	146	64.5	10	36.09*	14.65	0.41	RP
	D56	W74-4N6-2	3930	146	64.5	10	36.09*	11.86	0.33	RP/WP
	D57	W74-4N6-2	3930	146	64.5	10	36.09*	12.78	0.35	RP/WP
D20	D58	S35-5.0N6-3	5240	142	77.2	10	8.03*	6.03	0.75	WF
	D59	S35-5.0N6-3	5240	142	77.2	10	8.03*	8.10	1.01	WF
	D60	S35-5.0N6-3	5240	142	77.2	10	8.03*	9.50	1.18	WF
D21	D61	S75-5.0N6-3	5240	142	63.8	10	38.34***	13.22	0.34	WP
	D62	S75-5.0N6-3	5240	142	63.8	10	38.34***	11.97	0.31	WP
	D63	S75-5.0N6-3	5240	142	63.8	10	38.34***	15.61	0.41	WF
D22	D64	W35-5.0N6-3	5240	142	77.2	10	8.03*	5.40	0.67	SS/WF
	D65	W35-5.0N6-3	5240	142	77.2	10	8.03*	6.68	0.83	RP/WF
	D66	W35-5.0N6-3	5240	142	77.2	10	8.03*	6.46	0.80	RP/WF
D23	D67	W75-5.0N6-3	5240	142	63.8	10	38.34***	11.29	0.29	RP/WP
	D68	W75-5.0N6-3	5240	142	63.8	10	38.34***	18.88	0.49	RP
	D69	W75-5.0N6-3	5240	142	63.8	10	38.34***	17.28	0.45	SS/WP/RP
D24	D70	M66-5.0N7-4.5	5000	142	62.5	10	6.24**	8.56	1.37	RC
	D71	M66-5.0N7-4.5	5000	142	62.5	10	6.24**	7.55	1.21	RC
	D72	M66-5.0N7-4.5	5000	142	62.5	10	6.24**	7.27	1.17	RC
D25	D73	M68-5.0N9-6	5000	142	65.6	10	4.34**	6.91	1.59	RC/WP
	D74	M68-5.0N9-6	5000	142	65.6	10	4.34**	6.17	1.42	RC
	D75	M68-5.0N9-6	5000	142	65.6	10	4.34**	5.58	1.29	RC
D26	D76	S64-5.0N6-2,5%	5000	142	65.8	5	29.08***	9.77	0.34	SS
	D77	S64-5.0N6-2,5%	5000	142	65.8	5	29.08***	22.54	0.78	SS
	D78	S64-5.0N6-2,5%	5000	142	65.8	5	29.08***	12.74	0.44	SS

Table 3.2 Composite Slab Test Results (cont'd.)

Series	Test	Test Designation	f'c (psi)	w (pcf)	F_u~ (ksi)	Normal Load (%)	Q_{AISC} (kips)	Q_e (kips)	Q_e/ Q_{AISC}	Failure Mode
D27	D79	S64-5.0N6-2,20%	5000	142	65.8	20	29.08***	23.12	0.80	CP?
	D80	S64-5.0N6-2,20%	5000	142	65.8	20	29.08***	19.35	0.67	CP?
	D81	S64-5.0N6-2,20%	5000	142	65.8	20	29.08***	24.39	0.84	CP?
D28	D82	W64-4.5N6-2,5%	4690	145	65.8	5	29.08***	13.90	0.48	RP/SS
	D83	W64-4.5N6-2,5%	4690	145	65.8	5	29.08***	18.85	0.65	RP/SS
	D84	W64-4.5N6-2,5%	4690	145	65.8	5	29.08***	10.10	0.35	RP/SS
D29	D85	W64-4.5N6-2,20%	4690	145	65.8	20	29.08***	10.79	0.37	RP/SS
	D86	W64-4.5N6-2,20%	4690	145	65.8	20	29.08***	20.71	0.71	RP/SS
	D87	W64-4.5N6-2,20%	4690	145	65.8	20	29.08***	19.91	0.68	RP/SS
D30	D88	S63-4.5N6-2,NH	4690	145	65.8	10	29.08***	17.31	0.60	SS
	D89	S63-4.5N6-2,NH	4690	145	65.8	10	29.08***	17.35	0.60	SS
	D90	S63-4.5N6-2,NH	4690	145	65.8	10	29.08***	18.52	0.64	SS
D31	D91	W63-4.5N6-2,NH	4690	145	65.8	10	29.08***	10.82	0.37	RP
	D92	W63-4.5N6-2,NH	4690	145	65.8	10	29.08***	11.35	0.39	RP
	D93	W63-4.5N6-2,NH	4690	145	65.8	10	29.08***	10.73	0.37	RP

NOTES:
~ F_u (measured stud property provided by manufacturer)
SS = Stud Shearing
SR = Stud Rupture
RP = Rib Punching
WF = Weld Failure
WP = Weld Porosity
TR = Tee Rotation
RC = Rib Cracking

Q_{AISC} = AISC predicted load per stud
Q_e = Experimental load per stud

$* = 0.5A_{sc}\sqrt{f'_c E_c}$ (SRF = 1.0)
$** = SRF \times 0.5A_{sc}\sqrt{f'_c E_c}$
$*** = A_{sc}F_u$

on the flange of a WT6x17.5 (t_f = 0.52 in.), approximately half-way between the center and edge of the flange, had an average stud strength of 26.49 k. Series 3 (Tests 7 – 9), in which each stud was welded half-way between the center and edge of the flange of a WT6x13 (t_f = 0.38 in.), had an average stud strength of 25.68 k. Series 4 (Tests 10 – 12), which used a WT8x28.5 (t_f = 0.715 in.), had an average stud maximum test strength of 25.28 k.

As seen in Fig. 3.1, which is a plot of stud strength vs. flange thickness, flange thickness does not cause any significant difference in stud strength. Also, the stud

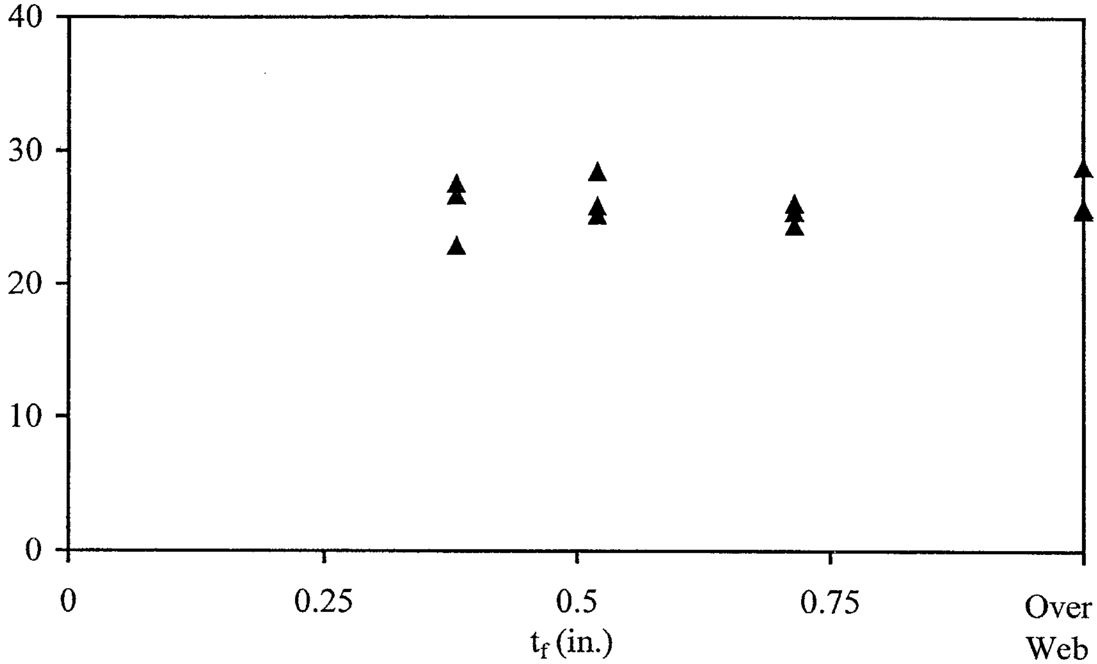

Fig. 3.1 Stud Strength vs. Flange Thickness (Solid Slab Tests)

strengths were underestimated by the equations for stud strength from Ollgaard et al (1971). The average load at stud failure for Series 1-4 was about 90% of the measured tensile strength (A_sF_u) of the stud. Slips of failed studs in Series 1-4 ranged from about 0.4 in. to 0.5 in.

3.3.2 Effect of the Steel/Concrete Interface

It seems 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 (Tests 13 – 15) or Series 6 (Tests 16 – 18), which had sheet metal placed between the steel beam and concrete slab, with Series 7 (Tests 19 – 21), which had no sheet metal. These series have approximately the same concrete properties. Series 7 had an average shear stud strength of 29.18 k, which is 23% greater than the stud strength of Series 5 and 18% greater than Series 6. This demonstrates that when steel deck is used in composite slabs, even without a profile rolled in the deck as in Series 5 and 6, the stud strength is less than for a solid slab. This is believed to be due to a reduction in the frictional component of the strength. The use of sheet metal also decreased the slip at failure of the studs; slips at failure in Series 5 and 6 ranged from 0.3 in. to 0.4 in., which is less than in Series 1-4.

A comparison of Series 5 and 6, which both had flat sheet metal placed between the concrete slab and steel beam, shows that there is no significant change in stud strength when the steel beam/sheet metal interface is greased. The average stud strength when the interface was greased, in Series 5, was 23.79 k; when the interface was not greased, as in Series 6, the average stud strength was 24.79 k. However, one could argue that greasing the interface causes about a 4% reduction in stud strength, because of the decrease in friction at the interface.

3.3.3 Effect of Applying Normal Load

Series 7 (Tests 19 – 21), which had an applied normal load equal to 10% of the axial load, had higher stud strengths than Series 8 (Tests 22 – 24), which had no normal load applied. Series 7 had an average stud strength of 29.18 k, a 14% increase over

Series 8, which had an average stud strength of 25.68 k. It appears that applying a normal load increases the frictional resistance at the slab and beam interface, thereby increasing the *apparent* strength of the stud.

3.4 Discussion of Composite Slab Push-Out Test Results

3.4.1 Strong Position Studs

Strong position studs in 2 in. and 3 in. deck all exhibited stud shearing failures. Some of the tests had weld failures, or there was porosity in the welds, as indicated in Table 3.2. It is unknown whether or not the failures actually began as concrete pull-out failures because the load-slip plots and stud deformations for stud shearing and concrete pull-out failures are very similar. If the failures are concrete pull-out, a "cone" of concrete can be observed on the underside of the slab after failure has occurred. Upon failure of the specimens, either the concrete slab and deck were attached to the steel beam or the deck was firmly adhered to the concrete slab; thus, it was difficult to look for this type of failure.

Tests D79-D81, which had strong position studs in 2 in. deck with 20% normal load applied, had the highest strengths. In these tests, all studs remained attached to the steel beams upon failure, which was determined to occur when the load dropped by about 25% of the peak load. It is unknown what actually caused the failure of these specimens. A failure mode of concrete pull-out is usually assigned to strong position studs when stud shearing does not occur.

Many of the 7/8 in. diameter strong position studs exhibited weld failures; thus they are discussed separately in Section 3.4.5. A weld failure was classified when the stud failed at its base and carried with it a portion of the weld. When weld failures occurred, a large pit was usually left in the steel beam.

3.4.2 Weak Position Studs

Weak position studs in 2 in. and 3 in. deck all exhibited rib punching failures. Rib punching usually occurred around the initial peak load, and before an average of 0.2 in. of slip was reached. Typically, the load remained constant until a slip of 0.6 in. or more occurred. Thereafter, the load either fell steadily or there was an increase in load carrying capacity. It is believed that the increase in capacity at large slips came from the strength of the deck, because the studs began to push directly against the deck. However, it is unsafe to rely upon this larger load carrying capacity in design because the slips are grossly large. As discussed in Section 6.3.2, the maximum load reached at smaller slips should be used as the stud strength. Oftentimes, weak position studs failed by stud shearing after rib punching occurred. A few of the failure surfaces were slightly conical in shape, which is an indication of stud rupture (or tension) failures. A few of the tests had weld failures or porosity in the welds.

3.4.3 Effect of the Stud Head

There is some debate as to whether or not a shear stud in a push-out test is subjected to tensile forces and if so, how much. If the stud is in tension, as well as bending and shear, its strength would be less than if it is only in bending and shear.

A stud can be put into tension either by the "anchorage effect", which occurs when the concrete puts forces on the stud underneath the stud head, or by friction forces along the stud shank.

In Series D30 and D31, the heads were cut off the studs and the stud shanks were greased to prevent the stud from being subjected to these tensile forces. Studs in Series D30 were placed in the strong position, while studs in Series D31 were placed in the weak position.

From Table 3.3, the results of Series D30 and D31 are compared to results of tests that had similar test parameters and were done on studs with heads. The only parameters that varied were concrete strength and slab depth. The slab depths were either 5 3/4 in. or 6 in.; this difference is believed to be negligible. Also, 20 gauge deck was used in all of the tests in Table 3.3, except for Lyons Series 2, which used 22 gauge deck. This difference is negligible because the studs were in the strong position, where deck thickness does not seem to affect stud strength.

The average strength of the strong position headed studs in Lyons Series 2 was 19.67 k. The average strength of the strong position studs without heads in Series D30 was 17.73 k, a 9.9% reduction in strength.

Table 3.3 Effect of Stud Head on Stud Strength

Series	Headed?	$Q_{e\ ave.}$
R-R Series D30 f'_c=4690 psi	NO HEAD	17.73 k
Lyons Series 2 f'_c=4560 psi	HEADED	19.67 k
R-R Series D31 f'_c=4690 psi	NO HEAD	10.97 k
Lyons Series 21 f'_c=2716 psi	HEADED	12.67 k

The average strength of the weak position headed studs in Lyons Series 21 was 12.67 k. The average strength of the weak position studs without heads in Series D31 was 10.97 k, a 13.4% reduction in strength. However, Lyons Series 21 only had a concrete strength of 2720 psi, much less than the concrete strength of 4690 psi in Series D31. If Lyons' tests had a concrete strength equal to the tests on studs without heads, this difference in strength may have been even greater. It is reasonable to conclude that the stud strength is increased considerably by the heads on strong position studs, and even more so on weak position studs.

The hypothesis for these tests on studs without heads was that eliminating tensile forces on the stud would increase the stud strength. This was not the case, however. By cutting the head off the stud, the stud went from being "fixed" – "fixed-collar" to being "fixed" – "free". Because the support conditions on the stud were changed so drastically by cutting off their heads, this kind of test, although interesting in nature, cannot be used to determine the extent to which tension in the stud affects stud strength.

3.4.4 Deep Deck Tests

A limited number of tests using deep, narrow deck profiles, intended for use as roof decks, have been conducted at VT (Widjaja 1997). Six new push-out tests were done to determine the potential usefulness of these profiles in composite beams. Series D24 used 3/4 in. x 6 in. studs and 4 1/2 in. deep deck, which is shown in Fig. 2.2, and Series D25 used 3/4 in. x 8 in. studs and 6 in. deep deck, which is shown in Fig. 2.2. The average strength of a stud in Series D24 was 7.79 k and in Series D25 was 6.22 k. All specimens failed by rib cracking (also called “rib shearing”). The ribs cracked at very low loads, usually before the first load reading at 10 k was taken. The cracks usually formed in the bottom rib first, across the top of the rib; this caused a crack along the surface of the slab perpendicular to the applied axial load. This was sometimes accompanied by deck debonding. After the ribs were cracked substantially, they began to “rotate”. This caused the slab to “bow” away from the beam. When this happened, loading the specimen axially caused the normal load readings to increase because the “bowing” of the slab was severe enough to push against the normal load apparatus.

The tests were terminated either after a considerable loss in load capacity, after the cracks were very severe, or after the ribs were disfigured. The studs remained attached, with very little bending, to the beams upon failure of the specimen.

The AISC equations underpredicted the stud strengths for the deep deck tests. The strength of the studs in Series D24, which used 4 1/2 in. deck, was an average of 25% greater than the strengths predicted by the AISC equations; the average stud strength in Series D25, which used 6 in. deck, was 43% greater than that predicted by

AISC. AISC gave low predictions of stud strength because these tests had very deep, narrow decks, which resulted in very low Stud Reduction Factors (*SRF*s) (0.20 for Series D24 and 0.14 for Series D25). One reason for the large discrepancy is that the AISC equations were not calibrated for use with such deep decks.

The average stud strength in Series D24 was $0.28A_sF_u$ and in Series D25 was $0.21A_sF_u$. These strengths are less than half of the stud strengths used in the more typical, shorter, wider profiles. One reason for these low strengths is the resultant force on the stud from the concrete is located far from the base of the stud because of the deep trough. From the bare stud test results, which are presented in Chapter 5, a resultant force acting between 1 in. and 1.5 in. from the base of the stud gives strengths similar to the strengths obtained from the push-out tests in Series D24 and D25.

It was decided that these profiles, which are intended for use as roof decks, are not efficient for use in composite floors with ribs perpendicular to the beams because of the low shear stud strength. The ribs are very narrow; the stud welding gun would not fit into the ribs, so the studs could not be welded through the deck. Holes had to be pre-drilled in the deck, the studs pre-welded to the beams, and the deck placed over the studs. If deep deck is to be used in practice, it may be beneficial to widen the troughs or to shape them similar to the 2 in. and 3 in. deck profiles in Fig. 2.2.

3.4.5 7/8 in. Diameter Studs

Twelve push-out tests were done on 7/8 in. diameter studs. Six tests used 2 in. deck, and six used 3 in. deck. It is important to note that, even under laboratory conditions, it was difficult to achieve reliable welds with the 7/8 in. studs welded through steel deck. Ten of the 12 tests either had weld failures or substantial weld porosity. Oftentimes, the entire surface of the failed stud was covered by huge holes or jagged pits in the weld. Sometimes the welds did not connect the entire stud to the beam (this is oftentimes called an "undercut weld"). The stud strengths in Series D17 were very variable. The stud strengths in Series D19, D21, and D23 were a little more consistent between like tests, but not as consistent as tests on smaller diameter studs.

It will be shown later that strong position studs with diameters 3/4 in. and less have strengths of approximately $0.7A_sF_u$, and weak position studs have strengths of approximately $0.5A_sF_u$. From Table 3.4, the average stud strength of 7/8 in. studs is about $0.37A_sF_u$, much less than that of 3/4 in. studs. This stud strength is relatively consistent, with no influence from the stud position. It is highly likely that if the welds were good, the stud strength would have been influenced by the stud position.

Table 3.4 Strengths of 7/8 in. Diameter Studs

Series	Stud Position	Deck Height (in.)	$Q_{e\ ave.}$ (k)	$Q_{e\ max}$ in Series (k)
D17	S	2	$0.36A_sF_u$	$0.49A_sF_u$
D19	W	2	$0.34A_sF_u$	$0.38A_sF_u$
D21	S	3	$0.35A_sF_u$	$0.41A_sF_u$
D23	W	3	$0.41A_sF_u$	$0.49A_sF_u$

The failed studs had the same deformed shape as 3/4 in. diameter studs, with the exception of the failed stud in Test D62. This stud was deformed very little, probably because this test had the lowest strength in its series. For the strong studs in 2 in. and 3 in. decks, the bottom 1.5 in. of the studs were bent, with the top of the studs remaining straight. For the weak studs in 2 in. deck, the bottom 2.5 in. of the studs were bent. For the weak studs in 3 in. deck, the bottom 3 in. of the studs were bent.