CHAPTER 3
TEST RESULTS

3.1 General

The complete data for each test is presented in a three-page data pack consisting of a summary sheet, Load vs. Slip plots, and the raw data. A sample data pack is shown in the Appendix. The data packs for all 106 pushout tests are presented in a separate volume (Alander, et al 1998b). The data report should be referred to as the results of each series are discussed.

3.1.1 Description of Data Pack

The first page of each data pack is a summary sheet. The summary sheet is divided into five sections: the test identification information, the specimen description, the test results, sketches of the damage incurred from testing, and related comments.

Each test is identified by a test number as discussed in Chapter 2. The tests are further identified by a test designation developed by Hankins (1994) that consists of seven terms. The first term identifies the type of shear connector used in that particular test. For each test in this study, the first term is "SC," which denotes the standoff screw. The next term defines the type of standoff screw used. This term is an "8" for every test, denoting the Elco Grade 8 standoff screw. The third term signifies the standoff length of each screw, in inches. The fourth term is the thickness in inches of the double angles used in the top chord section, also referred to as "base member thickness." The fifth term denotes the type of deck used. An "S" in this spot indicates "solid slab," i.e., no deck used. The sixth term is the total depth of the slab in inches. The seventh and final term represents the actual test sequence number within each test group, either a "1," "2," or "3." A test designation of "SC-8-2-0.109-0.6C-2.25-1" indicates that a two inch Elco

Grade 8 standoff screw was placed in a top chord section 0.109 in. thick and embedded in a 2.25 in. thick slab formed with 0.6C deck. The test was the first test of that particular test group.

The “Specimen Description” section of the summary sheet contains the physical dimensions and material properties of the specimen, as well as the information regarding any reinforcement used in the concrete slabs. The number of screws per specimen can be divided by two to find the number of screws in each slab. The yield stress and ultimate stress of each type of deck were determined by averaging the results of three tensile tests performed on coupons fabricated per ASTM A370. The values for the same material properties for the base members were provided by Nucor Corporation. The concrete compressive strength was determined by averaging the results of compression tests conducted on 4 in. by 8 in. cylinders per ASTM C192. Specimens were tested only after the concrete had cured for at least 28 days. The “Height Above Deck” value for the rebar is the height of slab bolster placed in the slab. “Mesh” refers to the size of welded wire fabric used, if any.

The “Test Results” section of the summary sheet lists the peak shear load, the corresponding potentiometer readings, and the peak shear load per screw. The peak shear load is the highest recorded shear load for a particular test. This value was recorded just before failure of the specimen. The peak shear load per screw is the peak shear load divided by the total number of screws for a particular specimen. The slip readings are identified by “SC1” through “SC8,” denoting “standoff screw location 1” through “standoff screw location 8.” The concrete slabs are identified as “A” and “B” to distinguish them from each other. The readings from SC1 through SC4 were from slab A, and the readings from SC5 through SC8 were from slab B for each test. The potentiometers were evenly spaced to obtain slip readings at several different locations on each slab. The general locations where slip readings were taken can be seen in Figure 3.1. Although the specimen in Figure 3.1 contains Vulcraft 1.0C deck, the potentiometer locations in specimens with other deck types were similar.

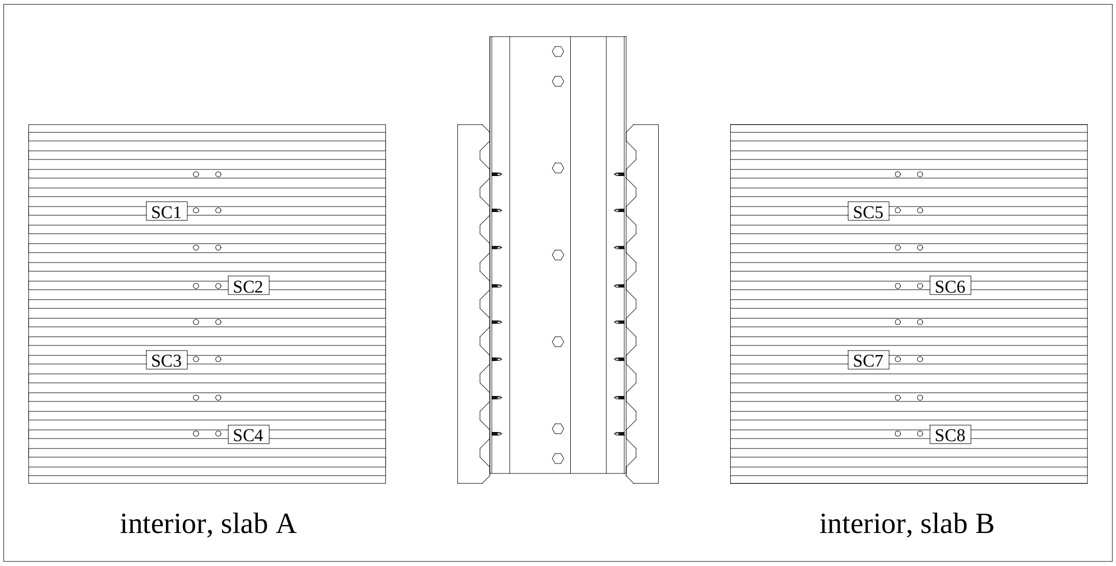

Figure 3.1 Locations of Potentiometers/Slip Readings

Following each test, the test specimens were dissembled and sketches of the damaged slabs were made. These sketches are shown on the summary sheet along with X's that symbolize screw shear. The tests were continued past initial failure so that the interior of the slabs could be viewed. However, since sides A and B never failed simultaneously, it was usually only possible to examine the interior of one of the slabs. Exterior cracking on the other slab was noted.

Also contained in the summary sheet are comments regarding the failure mode, screw rotation, and other notable occurrences during testing.

The second page of each data pack consists of the plots of the applied shear load vs. slip. Two plots were created for each test, one for each specimen half. The readings at SC1 through SC4 are contained in the Slab A plots; the readings at SC5 through SC8 are contained in the Slab B plots.

The third and final page of each data pack contains the raw data collected at each data point. The eight potentiometer readings were recorded, as well as the applied shear and normal loads. Data points were collected approximately every three minutes during the tests. Near the end of some tests, one or more potentiometers became dislodged due to increasing slip and at other times, the metal deck interfered with the slip readings. In either case, the slip data from the affected potentiometer(s) was truncated. The slip data was also truncated if the anchor nail that the potentiometer was connected to was embedded in a rib that failed during testing. (This phenomenon was experienced only in test groups D7 through D12.)

3.2 Test Results

The test results for each series of tests are presented in this section. To accurately compare the test results within a test series, as well as between series, the results must be normalized to minimize the effects of different concrete compressive strengths. The results for peak shear load per screw were normalized to 4 ksi through the use of the following formula (Hankins 1994):

$$V_n = V_a \sqrt{\frac{4000}{f'_c}} \tag{3.1}$$

where:

V_n = normalized shear strength of standoff screw, kips

V_a = actual shear strength of standoff screw (“peak shear load per screw”), kips

f'_c = concrete compressive strength, psi

For each series, there are two tables that summarize the test parameters and results. The first table consists of the data and results for each test, as well as averages for each test group, and the second contains the normalized average shear strength per screw for each group of tests.

In addition to the test parameters, these results tables contain the concrete compressive strength, peak shear load, peak shear load per screw, the average slip at the peak shear load, and the failure mode. The definitions of peak shear load and peak shear load per screw are presented in the previous section. The average slip at the peak shear load is the average of either the four slip readings taken from slab A, or the four slip readings taken from slab B. Because one side of the specimen always failed before the other (i.e. the two sides never failed simultaneously), the average slip was recorded from the side with the highest average from its four potentiometers. Generally, this was the side that ultimately failed first.

Five failure modes were observed in the pushout tests: screw shear, screw pullout, longitudinal splitting, rib failure, and top chord buckling. "Screw shear" means that the governing failure mode was that one or more screws failed in shear. "Screw pullout" refers to one or more screws pulling out of the base angle, without shearing off. This was primarily a failure mode in specimens with very thin base angles. The failure mode of "longitudinal splitting" consisted of the concrete slab cracking along the line of screws. This failure mode only occurred in under-reinforced solid slab specimens. The use of the term "rib failure" as a failure mode in these charts may actually include concrete cone failures. Generally a rib failure consists of the entire width of a rib shearing off in a specimen. As that type of failure did not occur in any of the tests performed in this study, the term "rib failure" was used to convey a very wide concrete cone failure in which the majority of one or more ribs sheared off. These types of failures were essentially limited to specimens containing Vulcraft 1.5VL deck. The last type of failure mode that was observed is that of "top chord buckling." This phenomenon was identical to the top chord buckling that developed in some of Hankins tests (1994), and is explained in greater detail in Section 1.2.

3.2.1 Preliminary Series Test Results

This section contains the data and results for the preliminary series of tests. The preliminary series consisted of 11 groups of tests, or 27 total tests. The top chord section for all preliminary series tests was identical so that the effects of increasing steel reinforcement and different screw positions could be examined. Standoff screws were placed two per rib in each rib for all but two series. Four series of tests contained solid slabs and the remainder consisted of slabs formed with Vulcraft 1.0C, 26 ga. deck. The effects of deck lapping were also investigated. A complete discussion and list of the preliminary series test parameters is presented in Section 2.3.1. The results of each test in this series, as well as the average results for each group of tests, are presented in Tables 3.1 and 3.2, respectively.

Table 3.1 Preliminary Series Results

Test Number	Deck Type	Slab Depth (in.)	Screw Height (in.)	Screws Per Rib	Total Qty. Screws	Top Chord Thickness (in.)	Concrete f'c (psi)	Peak Shear Load (kips)	Peak Shear Load/Screw (kips)	Avg. Slip at Peak Shear Load	Failure Mode
P1-1	1.0C	3.25	3.0	2	32	0.187	4145	76.88	2.40	0.802	screw shear
P1-2	1.0C	3.25	3.0	2	32	0.187	4145	79.27	2.48	0.771	screw shear
P1-3	1.0C	3.25	3.0	2	32	0.187	4145	80.15	2.50	0.807	screw shear
P1 Avg.							*4145*	*78.77*	*2.46*	*0.793*	
P2-1	1.0C	3.25	3.0	2	32	0.187	4145	114.57	3.58	0.743	screw shear
P2-2	1.0C	3.25	3.0	2	32	0.187	4145	112.44	3.51	0.645	screw shear
P2-3	1.0C	3.25	3.0	2	32	0.187	4145	127.41	3.97	0.814	screw shear
P2 Avg.							*4145*	*118.14*	*3.69*	*0.734*	
P3-1	1.0C	3.25	3.0	2	32	0.187	4145	150.13	4.69	0.976	screw shear
P3-2	1.0C	3.25	3.0	2	32	0.187	4145	136.81	4.28	0.928	screw shear
P3-3	1.0C	3.25	3.0	2	32	0.187	4145	136.56	4.27	0.960	screw shear
P3 Avg.							*4145*	*141.17*	*4.41*	*0.955*	
P4-1	1.0C	3.25	3.0	2	32	0.187	4642	156.28	4.88	0.902	screw shear
P4-2	1.0C	3.25	3.0	2	32	0.187	4642	132.66	4.15	1.114	screw shear
P4-3	1.0C	3.25	3.0	2	32	0.187	4642	132.66	4.15	0.794	screw shear
P4 Avg.							*4642*	*140.53*	*4.39*	*0.937*	
P5-1	1.0C	3.25	3.0	1	16	0.187	5345	82.22	5.14	0.874	screw shear
P5-2	1.0C	3.25	3.0	1	16	0.187	5345	81.47	5.09	0.678	screw shear
P5 Avg.							*5345*	*81.85*	*5.12*	*0.776*	
P6-1	1.0C	3.25	3.0	1*	16	0.187	5345	82.60	5.16	0.964	screw shear
P6-2	1.0C	3.25	3.0	1*	16	0.187	5345	83.29	5.21	0.907	screw shear
P6 Avg.							*5345*	*82.95*	*5.19*	*0.936*	
P7-1	none	3.00	2.5	2	32	0.187	5352	83.92	2.62	0.059	longitudinal splitting
P7-2	none	3.00	2.5	2	32	0.187	5352	77.26	2.41	0.330	longitudinal splitting
P7 Avg.							*5352*	*80.59*	*2.52*	*0.195*	
P8-1	none	3.00	2.5	2	32	0.187	5352	131.72	4.12	0.257	longitudinal splitting
P8-2	none	3.00	2.5	2	32	0.187	5352	127.07	3.97	0.632	long. split./screw shr.
P8 Avg.							*5352*	*129.40*	*4.05*	*0.445*	
P9-1	none	3.00	2.5	2	32	0.187	5352	151.82	4.74	0.152	top chord buckling
P9-2	none	3.00	2.5	2	32	0.187	5352	204.64	6.40	0.518	screw shear
P9-3	none	3.00	2.5	2	32	0.187	5352	204.64	6.40	0.740	screw shear
P9 Avg.							*5352*	*204.64***	*6.40***	*0.629***	
P10-1	none	3.00	2.5	2	32	0.187	3236	231.59	7.24	0.696	screw shear
P10-2	none	3.00	2.5	2	32	0.187	3236	233.29	7.29	0.633	screw shear
P10 Avg.							*3236*	*232.44*	*7.27*	*0.665*	
P11-1	1.0C	3.25	3.0	2	32	0.187	3210	107.09	3.35	0.650	screw shear
P11-2	1.0C	3.25	3.0	2	32	0.187	3210	107.78	3.37	0.692	screw shear
P11 Avg.							*3210*	*107.44*	*3.36*	*0.671*	

* two screws per rib, every other rib

** does not include specimen that failed by top chord buckling

Table 3.2 Preliminary Series Average Results

Test Group	Deck Type	Slab Depth (in.)	Screw Height (in.)	Screws Per Rib	Top Chord Thickness (in.)	Concrete f'c (psi)	Peak Shear Load/Screw (kips)	Normalized Peak Shear Load/Screw (kips)
P1	1.0C	3.25	3.0	2	0.187	4145	2.46	2.42
P2	1.0C	3.25	3.0	2	0.187	4145	3.69	3.63
P3	1.0C	3.25	3.0	2	0.187	4145	4.41	4.33
P4	1.0C	3.25	3.0	2	0.187	4642	4.39	4.08
P5	1.0C	3.25	3.0	1	0.187	5345	5.12	4.43
P6	1.0C	3.25	3.0	1*	0.187	5345	5.18	4.48
P7	none	3.00	2.5	2	0.187	5352	2.52	2.18
P8	none	3.00	2.5	2	0.187	5352	4.04	3.50
P9	none	3.00	2.5	2	0.187	5352	6.40**	5.53**
P10	none	3.00	2.5	2	0.187	3236	7.26	8.08
P11	1.0C	3.25	3.0	2	0.187	3210	3.36	3.75

* two screws per rib, every other rib
** does not include specimen that failed by top chord buckling

The standoff screws performed very poorly in the unreinforced specimens (groups P1 and P7). The unreinforced solid slabs, as well as those with only welded wire fabric, were the only specimens to fail by longitudinal splitting. Some degree of longitudinal splitting was evident in all the test groups except P4 and P10, which contained the most reinforcement in the preliminary series. All the tests in the preliminary series utilized the apparatus to limit the longitudinal splitting of the slabs, as described in Section 2.4. Test P9-1 prematurely failed by top chord buckling; therefore the data from that test was not included in the average for test group P9. The remainder of the tests failed primarily by screw shear.

It is evident in looking at the results from test groups P1 through P4 that the presence of welded wire fabric and reinforcing bars greatly increased the strength of the test specimens that utilized steel deck. However, there is a point where additional reinforcement does not contribute to additional shear strength of the screws. This is clear since the average peak shear load from P4 is actually lower than that of P3, despite twice as much reinforcement. In contrast, the solid slab specimens, P7 through P10, consistently increased with the addition of reinforcement.

Lapping the deck, as in P11, does not appear to have any significant effect on the shear strength of the screws. The effect of deck lapping may be more noticeable when embossments are present in the deck. In comparing groups P5 and P6, there seems to be no significant difference in staggering the screws, one per rib, versus pairing the screws in every other rib. However, it is evident that placing the screws two per rib in each rib does reduce the strength per screw in slabs utilizing steel deck. This would indicate the presence of grouping effects. The relatively high slip values at the peak shear load, in each test group except P7, reflect the tremendous ductility of the Elco Grade 8 standoff screws. The failure mode of longitudinal splitting, observed in P7 and P8, was not a ductile failure.

3.2.2 Series A Test Results

Test series A consisted of eight groups of tests, or 17 total tests. The deck type for series A was Vulcraft 0.6C, 28 ga. and the top chord section varied between three different sizes. The standoff screws were placed in a staggered position and varying quantities of screws were tested. Each slab in series A contained sufficient reinforcement to prevent longitudinal splitting. A complete discussion and list of the test parameters for series A is presented in Section 2.3.2. The results of each test in series A, as well as the average results for each group of tests, are presented in Tables 3.3 and 3.4, respectively.

The three failure modes that were observed in series A were screw pullout, screw shear and top chord buckling. Screw pullout failure occurred in tests with a 0.109 in. top chord thickness. Extensive rotation of the screws and base angles was observed in these tests. This rotation caused the screws to be loaded primarily in tension, leading to the pullout failure. The tests in groups A2, A5, A7 and A8 all failed by screw shear. The thicker base angles limited any significant rotation, thereby causing the screws to be loaded more in shear. All four tests in groups A3 and A4 failed by top chord buckling. Since this failure mode does not reflect upon the shear strength of the Elco Grade 8 standoff screw, nor does it represent a typical failure mode in an interior composite joist, these tests will not be evaluated or analyzed in this study. Although screw shear and screw pullout were the governing failure modes, concrete cone failures were observed in some tests and the concrete surrounding the base of the screws was damaged in each test.

Table 3.3 Series A Results

Test Number	Deck Type	Slab Depth (in.)	Screw Height (in.)	Screws Per Rib	Total Qty. Screws	Top Chord Thickness (in.)	Concrete f'c (psi)	Peak Shear Load (kips)	Peak Shear Load/Screw (kips)	Avg. Slip at Peak Shear Load	Failure Mode
A1-1	0.6C	2.25	2.0	0.5*	12	0.109	4775	53.27	4.44	0.596	screw pullout
A1-2	0.6C	2.25	2.0	0.5*	12	0.109	4775	45.41	3.78	0.603	screw pullout
A1-3	0.6C	2.25	2.0	0.5*	12	0.109	5531	56.21	4.68	0.729	screw pullout
A1 Avg.							*5027*	*51.63*	*4.30*	*0.643*	
A2-1	0.6C	2.25	2.0	0.5*	12	0.187	4775	66.52	5.54	0.889	screw shear
A2-2	0.6C	2.25	2.0	0.5*	12	0.187	4775	63.88	5.32	0.571	screw shear
A2 Avg.							*4775*	*65.20*	*5.43*	*0.730*	
A3-1	0.6C	2.75	2.5	1	22	0.109	5491	65.58	2.98	NA	top chord buckling
A3-2	0.6C	2.75	2.5	1	22	0.109	5491	70.85	3.22	NA	top chord buckling
A3 Avg.							*NA*	*NA*	*NA*	*NA*	
A4-1	0.6C	2.75	2.5	1	22	0.187	5491	113.37	5.15	NA	top chord buckling
A4-2	0.6C	2.75	2.5	1	22	0.187	5491	116.08	5.28	NA	top chord buckling
A4 Avg.							*NA*	*NA*	*NA*	*NA*	
A5-1	0.6C	2.75	2.5	1	22	0.250	5491	100.18	4.55	0.510	screw shear
A5-2	0.6C	2.75	2.5	1	22	0.250	5491	90.45	4.11	0.489	screw shear
A5 Avg.							*5491*	*95.32*	*4.33*	*0.499*	
A6-1	0.6C	2.25	2.0	1	22	0.109	5080	90.58	4.12	0.742	screw pullout
A6-2	0.6C	2.25	2.0	1	22	0.109	5080	90.58	4.12	0.564	screw pullout
A6 Avg.							*5080*	*90.58*	*4.12*	*0.653*	
A7-1	0.6C	2.25	2.0	1	22	0.187	5080	114.00	5.18	0.844	screw shear
A7-2	0.6C	2.25	2.0	1	22	0.187	5080	119.03	5.41	0.672	screw shear
A7 Avg.							*5080*	*116.52*	*5.30*	*0.758*	
A8-1	0.6C	2.25	2.0	1	22	0.250	5080	111.36	5.06	0.501	screw shear
A8-2	0.6C	2.25	2.0	1	22	0.250	5080	114.76	5.22	0.591	screw shear
A8 Avg.							*5080*	*113.06*	*5.14*	*0.546*	

* one screw per rib, every other rib
NOTE: Specimens that failed by top chord buckling were not included in analysis

Table 3.4 Series A Average Results

Test Group	Deck Type	Slab Depth (in.)	Screw Height (in.)	Screws Per Rib	Top Chord Thickness (in.)	Concrete f'c (psi)	Peak Shear Load/Screw (kips)	Normalized Peak Shear Load/Screw (kips)
A1	0.6C	2.25	2.0	0.5*	0.109	5027	4.30	3.84
A2	0.6C	2.25	2.0	0.5*	0.187	4775	5.43	4.97
A3	0.6C	2.75	2.5	1	0.109	NA	NA	NA
A4	0.6C	2.75	2.5	1	0.187	NA	NA	NA
A5	0.6C	2.75	2.5	1	0.250	5491	4.33	3.70
A6	0.6C	2.25	2.0	1	0.109	5080	4.12	3.65
A7	0.6C	2.25	2.0	1	0.187	5080	5.30	4.70
A8	0.6C	2.25	2.0	1	0.250	5080	5.14	4.56

*one screw per rib, every other rib
NOTE: Specimens that failed by top chord buckling were not included in analysis

In series A, as in series B, C and D, the test group sequence was organized such that the parameters for two or three consecutive groups were identical with the exception of base angle thickness. The peak shear loads were consistently higher in specimens with 0.187 in. base angle thicknesses than in those with 0.109 in. or 0.250 in. base angles.

This is due to the fact that this medium base angle thickness is flexible enough to allow some rotation, but not overly flexible so as to cause tensile loading. The rotation allowed by the 0.187 in. base angles enabled the screws to be loaded both in shear and tension. The screws in the thinner base angles were loaded primarily in tension and the screws in the thicker base angles were loaded primarily in shear. Larger slip values were consistently observed in the tests with 0.187 in. top chord thicknesses, as well. Interestingly, in looking at the average results from A5 and A8, it would appear that a longer screw length actually decreases the strength of the Elco Grade 8 standoff screw in Vulcraft 0.6C deck. These two test groups varied only in screw height and slab depth. The ductility of the standoff screws in Vulcraft 0.6C deck is exhibited in the presence of a plateau in the load vs. slip plots for these tests, contained in the data report (Alander, et al 1998b).

3.2.3 Series B Test Results

Pushout test series B consisted of 22 tests in 11 groups and was conducted to evaluate the performance of the Elco Grade 8 standoff screw in specimens utilizing Vulcraft 1.0C, 26 ga. deck. This test series was performed to examine the effects of different top chord thicknesses, screw heights, slab depths, and screw quantities. Welded wire fabric was the only reinforcement used in the series B test specimens. The apparatus to limit the extent of longitudinal splitting was used in each test in this series. A complete discussion and list of the test parameters for series B is contained in Section 2.3.3. The results of each test in series B, as well as the average results for each group of tests, are presented in Tables 3.5 and 3.6, respectively.

Table 3.5 Series B Results

Test Number	Deck Type	Slab Depth (in.)	Screw Height (in.)	Screws Per Rib	Total Qty. Screws	Top Chord Thickness (in.)	Concrete f'c (psi)	Peak Shear Load (kips)	Peak Shear Load/Screw (kips)	Avg. Slip at Peak Shear Load	Failure Mode
B1-1	1.0C	2.25	2	1	16	0.109	4324	51.63	3.23	1.018	screw pullout
B1-2	1.0C	2.25	2	1	16	0.109	4324	49.50	3.09	1.024	screw pullout
B1 Avg.							*4324*	*50.57*	*3.16*	*1.021*	
B2-1	1.0C	2.25	2	1	16	0.187	4324	56.03	3.50	0.768	screw shear
B2-2	1.0C	2.25	2	1	16	0.187	4324	58.79	3.67	0.709	screw shear
B2 Avg.							*4324*	*57.41*	*3.59*	*0.739*	
B3-1	1.0C	2.25	2	1	16	0.250	4324	54.40	3.40	0.625	screw shear
B3-2	1.0C	2.25	2	1	16	0.250	4324	51.40	3.21	0.596	screw shear
B3 Avg.							*4324*	*52.90*	*3.31*	*0.611*	
B4-1	1.0C	2.75	2.5	1	16	0.109	3780	57.79	3.61	0.828	screw pullout
B4-2	1.0C	2.75	2.5	1	16	0.109	3780	62.56	3.91	1.195	screw pullout
B4 Avg.							*3780*	*60.18*	*3.76*	*1.012*	
B5-1	1.0C	2.75	2.5	1	16	0.187	3780	73.74	4.61	0.920	screw shear
B5-2	1.0C	2.75	2.5	1	16	0.187	3780	73.37	4.59	0.954	screw shear
B5 Avg.							*3780*	*73.56*	*4.60*	*0.937*	
B6-1	1.0C	2.75	2.5	1	16	0.250	3780	63.94	4.00	0.630	screw shear
B6-2	1.0C	2.75	2.5	1	16	0.250	3780	62.94	3.93	0.631	screw shear
B6 Avg.							*3780*	*63.44*	*3.97*	*0.631*	
B7-1	1.0C	3.25	3	1	16	0.109	3780	60.30	3.77	0.807	screw pullout
B7-2	1.0C	3.25	3	1	16	0.109	3780	58.17	3.64	0.767	screw pullout
B7 Avg.							*3780*	*59.24*	*3.70*	*0.787*	
B8-1	1.0C	3.25	3	1	16	0.187	3780	77.39	4.84	0.962	screw shear
B8-2	1.0C	3.25	3	1	16	0.187	3780	77.26	4.83	0.894	screw shear
B8 Avg.							*3780*	*77.33*	*4.83*	*0.928*	
B9-1	1.0C	3.25	3	1	16	0.250	4748	70.10	4.38	0.652	screw shear
B9-2	1.0C	3.25	3	1	16	0.250	4748	70.10	4.38	0.673	screw shear
B9 Avg.							*4748*	*70.10*	*4.38*	*0.663*	
B10-1	1.0C	3.25	3	2	32	0.163	4748	111.93	3.50	0.591	screw shear
B10-2	1.0C	3.25	3	2	32	0.163	4748	108.29	3.38	0.727	top chord buckling
B10 Avg.							*4748*	*110.11*	*3.44*	*0.659*	
B11-1	1.0C	3.25	3	2	32	0.313	4775	95.47	2.98	0.448	screw shear
B11-2	1.0C	3.25	3	2	32	0.313	4775	102.13	3.19	0.382	screw shear
B11 Avg.							*4775*	*98.80*	*3.09*	*0.415*	

Table 3.6 Series B Average Results

Test Group	Deck Type	Slab Depth (in.)	Screw Height (in.)	Screws Per Rib	Top Chord Thickness (in.)	Concrete f'c (psi)	Peak Shear Load/Screw (kips)	Normalized Peak Shear Load/Screw (kips)
B1	1.0C	2.25	2.0	1	0.109	4324	3.16	3.04
B2	1.0C	2.25	2.0	1	0.187	4324	3.59	3.45
B3	1.0C	2.25	2.0	1	0.250	4324	3.31	3.18
B4	1.0C	2.75	2.5	1	0.109	3780	3.76	3.87
B5	1.0C	2.75	2.5	1	0.187	3780	4.60	4.73
B6	1.0C	2.75	2.5	1	0.250	3780	3.97	4.08
B7	1.0C	3.25	3.0	1	0.109	3780	3.70	3.81
B8	1.0C	3.25	3.0	1	0.187	3780	4.83	4.97
B9	1.0C	3.25	3.0	1	0.250	4748	4.38	4.02
B10	1.0C	3.25	3.0	2	0.163	4748	3.44	3.16
B11	1.0C	3.25	3.0	2	0.313	4775	3.09	2.83

The failure modes observed in series B were screw pullout, screw shear, and top chord buckling. Test B10-2 was the only test to fail by top chord buckling. Although this failure mode does not reflect upon the strength of the Elco Grade 8 standoff screw, the results from this test were acceptable since the load vs. slip plot had already plateaued and failure of the screws was imminent. The peak shear load from this test was also in good agreement with the first test from group P10. As in series A, the specimens with the 0.109 in. top chord section failed by screw pullout and the remainder of the tests failed by screw shear. Concrete cone failures were observed and local crushing of the concrete was evident around the base of the screws.

Test groups B1-B9 all contained one screw per rib and 16 total screws. The tests with 0.187 in. base angles again reached higher shear loads than did similar tests with thicker or thinner top chord sections. The tests with 0.250 in. base angles reached the next highest shear load, and the tests having 0.109 in. base angles reached the lowest average peak shear load. Increasing the screw height and slab depth appears to increase the shear strength of the standoff screws to a point. The tests with 2.5 in. standoff screws reached significantly higher loads than those with 2.0 in. screws. However, there was no significant difference in strength between the 2.5 in. standoff screws and the 3.0 in. standoff screws. This indicates the existence of a certain screw embedment depth above which there is no significant increase in shear strength. This embedment depth is generally 1.5 in. above the top of the deck profile. Test groups B10 and B11 each contained two screws per rib and 32 total screws. Both groups had a lower peak shear load per screw compared to similar tests with only one screw per rib. Test group B10 reached a higher average peak shear load than did B11 due to the thinner base material and subsequent screw rotation.

The tests with base angle thickness of at least 0.250 in. consistently failed at lower slip readings than did the tests with thinner base angles. Although longitudinal splitting was not a governing failure mode, it was observed to some degree in each test in series B. This was due to the use of only welded wire fabric as reinforcement in the concrete slabs. Local crushing of the concrete around the base of the screws was also observed and concrete cone failures occurred. The flattening out of the load vs. slip plots indicates the good ductility of the standoff screw in Vulcraft 1.0C deck.

3.2.4 Series C Test Results

Test series C consisted of 16 tests organized into eight test groups. This series was performed to compare the effects of varying base angle thickness and grouping the screws in Vulcraft 1.5C deck.. Screws were placed one per rib, two per rib, and four per rib in different tests. Sufficient reinforcement was placed in the slabs to prevent longitudinal splitting of the concrete. A complete discussion and list of the test parameters for series C is presented in Section 2.3.4. The results of each test in series C, as well as the average results for each group of tests, are presented in Tables 3.7 and 3.8, respectively.

Table 3.7 Series C Results

Test Number	Deck Type	Slab Depth (in.)	Screw Height (in.)	Screws Per Rib	Total Qty. Screws	Top Chord Thickness (in.)	Concrete f'c (psi)	Peak Shear Load (kips)	Peak Shear Load/Screw (kips)	Avg. Slip at Peak Shear Load	Failure Mode
C1-1	1.5C	3.25	3.0	1	10	0.109	5756	40.45	4.05	0.118	screw shear
C1-2	1.5C	3.25	3.0	1	10	0.109	5756	40.39	4.04	0.560	screw shear
C1 Avg.							*5756*	*40.42*	*4.04*	*0.339*	
C2-1	1.5C	3.25	3.0	1	10	0.187	5756	51.63	5.16	0.435	screw shear
C2-2	1.5C	3.25	3.0	1	10	0.187	5756	53.58	5.36	0.648	screw shear
C2 Avg.							*5756*	*52.61*	*5.26*	*0.541*	
C3-1	1.5C	3.25	3.0	1	10	0.250	4310	46.98	4.70	0.502	screw shear
C3-2	1.5C	3.25	3.0	1	10	0.250	4310	41.08	4.11	0.207	screw shear
C3 Avg.							*4310*	*44.03*	*4.40*	*0.355*	
C4-1	1.5C	3.25	3.0	2	20	0.109	4310	84.86	4.24	0.707	screw shear/pullout
C4-2	1.5C	3.25	3.0	2	20	0.109	4310	91.33	4.57	0.579	screw pullout
C4 Avg.							*4310*	*88.10*	*4.40*	*0.643*	
C5-1	1.5C	3.25	3.0	2	20	0.187	4310	109.98	5.50	0.816	screw shr./rib failure
C5-2	1.5C	3.25	3.0	2	20	0.187	4310	113.19	5.66	0.646	screw shr./rib failure
C5 Avg.							*4310*	*111.59*	*5.58*	*0.731*	
C6-1	1.5C	3.25	3.0	2	20	0.250	4310	91.33	4.57	0.738	screw shr./rib failure
C6-2	1.5C	3.25	3.0	2	20	0.250	4310	82.10	4.11	0.719	screw shear
C6 Avg.							*4310*	*86.72*	*4.34*	*0.729*	
C7-1	1.5C	3.75	3.5	4	40	0.163	4271	156.15	3.90	0.773	screw shr./rib failure
C7-2	1.5C	3.75	3.5	4	40	0.163	4297	189.94	4.75	1.024	screw shear
C7 Avg.							*4284*	*173.05*	*4.33*	*0.898*	
C8-1	1.5C	3.75	3.5	4	40	0.250	3926	163.25	4.08	0.592	screw shear
C8-2	1.5C	3.75	3.5	4	40	0.250	3926	145.35	3.63	0.392	screw shear
C8 Avg.							*3926*	*154.30*	*3.86*	*0.492*	

Table 3.8 Series C Average Results

Test Group	Deck Type	Slab Depth (in.)	Screw Height (in.)	Screws Per Rib	Top Chord Thickness (in.)	Concrete f'c (psi)	Peak Shear Load/Screw (kips)	Normalized Peak Shear Load/Screw (kips)
C1	1.5C	3.25	3.0	1	0.109	5756	4.04	3.37
C2	1.5C	3.25	3.0	1	0.187	5756	5.26	4.39
C3	1.5C	3.25	3.0	1	0.250	4310	4.40	4.24
C4	1.5C	3.25	3.0	2	0.109	4310	4.41	4.24
C5	1.5C	3.25	3.0	2	0.187	4310	5.58	5.38
C6	1.5C	3.25	3.0	2	0.250	4310	4.34	4.18
C7	1.5C	3.75	3.5	4	0.163	4284	4.33	4.18
C8	1.5C	3.75	3.5	4	0.250	3926	3.86	3.89

The failure modes observed in series C were screw shear, screw pullout, and rib failure. Unlike in series A and B, specimens with 0.109 in. base angles did not fail solely by screw pullout. The increased amount of concrete surrounding the screws in series C restricted the rotation of the screws, resulting in more screw shear failures. The relatively lower average slips in this series also indicate this limited screw rotation. Rib failures occurred only in specimens with at least two screws per rib.

Once again, the specimens with the top chord thickness of 0.187 in. failed at higher shear loads than did those with somewhat thicker or thinner base angles. The reduction in shear strength per screw that results from grouping was not as drastic in this series as in other series. The wide rib width of the Vulcraft 1.5C deck may account for this. Concrete cone failures were observed and local crushing of the concrete was evident around the base of the screws. As before, the ductility of the standoff screws can be deduced from the load vs. slip plots contained in the data report (Alander, et al 1998b).

3.2.5 Series D Test Results

Test series D consisted of 12 groups of tests, or 24 total tests, that were conducted on specimens utilizing Vulcraft 1.5VL, 22 ga. deck. The effects of grouping the screws, different screw positions, and different base angle sizes were investigated. Screws were placed one per rib, two per rib, four per rib, and six per rib in different tests. The concrete slabs were sufficiently reinforced with welded wire fabric and rebar to prevent longitudinal splitting. A complete discussion and list of the test parameters for series D is presented in Section 2.3.5. The results of each test in series D, as well as the average results for each group of tests, are presented in Tables 3.9 and 3.10, respectively.

Table 3.9 Series D Results

Test Number	Deck Type	Slab Depth (in.)	Screw Height (in.)	Screws Per Rib	Total Qty. Screws	Top Chord Thickness (in.)	Concrete f'c (psi)	Peak Shear Load (kips)	Peak Shear Load/Screw (kips)	Avg. Slip at Peak Shear Load	Failure Mode
D1-1	1.5VL	3.25	3.0	1	10	0.109	3568	40.89	4.09	0.780	screw pullout
D1-2	1.5VL	3.25	3.0	1	10	0.109	3568	38.82	3.88	0.723	screw pullout
D1 Avg.							*3568*	*39.86*	*3.99*	*0.751*	
D2-1	1.5VL	3.25	3.0	1	10	0.187	3568	58.04	5.80	0.907	screw shear
D2-2	1.5VL	3.25	3.0	1	10	0.187	3568	55.10	5.51	0.866	screw shear
D2 Avg.							*3568*	*56.57*	*5.66*	*0.887*	
D3-1	1.5VL	3.25	3.0	1	10	0.250	3568	47.23	4.72	0.994	screw shear
D3-2	1.5VL	3.25	3.0	1	10	0.250	3568	56.16	5.62	0.995	screw shear
D3 Avg.							*3568*	*51.70*	*5.17*	*0.995*	
D4-1	1.5VL	3.25	3.0	2	20	0.109	3568	82.35	4.12	0.925	screw pullout
D4-2	1.5VL	3.25	3.0	2	20	0.109	3568	79.65	3.98	0.779	screw pullout
D4 Avg.							*3568*	*81.00*	*4.05*	*0.852*	
D5-1	1.5VL	3.25	3.0	2	20	0.187	5372	109.48	5.47	0.795	rib failure
D5-2	1.5VL	3.25	3.0	2	20	0.187	5372	86.43	4.32	0.761	rib failure
D5 Avg.							*5372*	*97.96*	*4.90*	*0.778*	
D6-1	1.5VL	3.25	3.0	2	20	0.250	5372	82.04	4.10	0.574	rib failure
D6-2	1.5VL	3.25	3.0	2	20	0.250	5372	82.04	4.10	0.452	rib failure
D6 Avg.							*5372*	*82.04*	*4.10*	*0.513*	
D7-1	1.5VL	3.75	3.0	4	40	0.163	5372	94.72	2.37	0.056	rib failure
D7-2	1.5VL	3.75	3.0	4	40	0.163	5372	86.31	2.16	0.096	rib failure
D7 Avg.							*5372*	*90.52*	*2.26*	*0.076*	
D8-1	1.5VL	3.75	3.0	4	40	0.250	5372	100.37	2.51	0.061	rib failure
D8-2	1.5VL	3.75	3.0	4	40	0.250	5372	106.84	2.67	0.085	rib failure
D8 Avg.							*5372*	*103.61*	*2.59*	*0.073*	
D9-1	1.5VL	3.75	3.0	4	40	0.163	5093	76.63	1.92	0.032	rib failure
D9-2	1.5VL	3.75	3.0	4	40	0.163	5093	90.70	2.27	0.046	rib failure
D9 Avg.							*5093*	*83.67*	*2.09*	*0.039*	
D10-1	1.5VL	3.75	3.0	4	40	0.250	5093	91.90	2.30	0.043	rib failure
D10-2	1.5VL	3.75	3.0	4	40	0.250	5093	100.75	2.52	0.068	rib failure
D10 Avg.							*5093*	*96.33*	*2.41*	*0.056*	
D11-1	1.5VL	3.75	3.0	6	60	0.163	5093	95.16	1.59	0.051	rib failure
D11-2	1.5VL	3.75	3.0	6	60	0.163	5093	98.43	1.64	0.022	rib failure
D11 Avg.							*5093*	*96.80*	*1.61*	*0.037*	
D12-1	1.5VL	3.75	3.0	6	60	0.250	5093	97.74	1.63	0.030	rib failure
D12-2	1.5VL	3.75	3.0	6	60	0.250	5093	115.95	1.93	0.095	rib failure
D12 Avg.							*5093*	*106.85*	*1.78*	*0.063*	

Table 3.10 Series D Average Results

Test Group	Deck Type	Slab Depth (in.)	Screw Height (in.)	Screws Per Rib	Top Chord Thickness (in.)	Concrete f'c (psi)	Peak Shear Load/Screw (kips)	Normalized Peak Shear Load/Screw (kips)
D1	1.5VL	3.25	3.0	1	0.109	3568	3.99	4.22
D2	1.5VL	3.25	3.0	1	0.187	3568	5.66	5.99
D3	1.5VL	3.25	3.0	1	0.250	3568	5.17	5.47
D4	1.5VL	3.25	3.0	2	0.109	3568	4.05	4.29
D5	1.5VL	3.25	3.0	2	0.187	5372	4.90	4.23
D6	1.5VL	3.25	3.0	2	0.250	5372	4.10	3.54
D7	1.5VL	3.75	3.0	4	0.163	5372	2.26	1.95
D8	1.5VL	3.75	3.0	4	0.250	5372	2.59	2.24
D9	1.5VL	3.75	3.0	4	0.163	5093	2.09	1.85
D10	1.5VL	3.75	3.0	4	0.250	5093	2.41	2.13
D11	1.5VL	3.75	3.0	6	0.163	5093	1.61	1.43
D12	1.5VL	3.75	3.0	6	0.250	5093	1.78	1.58

The failure modes observed in series D were screw pullout, screw shear, and rib failure. Screw pullout occurred in all tests with a 0.109 in. top chord thickness. Screw shear occurred only in specimens with one screw per rib and base angles greater than 0.109 in. Local concrete crushing was observed in the cases of screw shear and screw pullout. Rib failure was the failure mode in the remaining tests, which each contained at least two screws per rib. The deep, narrow ribs of the Vulcraft 1.5VL deck contributed to the tendency of the specimens to fail by rib failure.

Implementing two screws per rib generally reduced the shear strength of each standoff screw slightly. However, placing four or six screws per rib greatly reduced the shear strength of the screws. The greater number of screws per rib increased the likelihood of rib failure. The specimens with four or six standoff screws per rib were not ductile and failed at very low average slips. Good ductility was observed in the tests with one or two screws per rib.

In looking at test groups D1 through D6, the specimens with 0.187 in. thick top chord sections again carried the highest shear loads in comparison to those with the 0.109 in. and 0.250 in. thick top chords. These six groups of tests were not as likely to fail by rib failure as groups D6 through D12, and even those that did usually experienced some screw shear. No screw shear failure was observed in test groups D6 through D12. In these test groups, the thicker base material led to a higher peak shear load. This is because the thicker base angle limits the standoff screw rotation, thereby hindering the rib from being pulled out of the slab by the standoff screws. Screw position seemed to have a minor effect on the strength of the screws. In D7 and D8, the screws were positioned perpendicular to the ribs and in D9 and D10, the screws were positioned parallel with the ribs, as shown in section. Test groups D9 and D10 failed at lower shear loads than did their counterparts, D7 and D8, indicating that the parallel position is slightly weaker than the perpendicular position.

3.3 Comparison of Results

To directly compare the test results of each series, the results must be normalized to remove the effects of different concrete compressive strengths. The normalized average standoff screw shear strengths for each test group are presented in Table 3.11.

It is quite clear from the results presented here, that the Elco Grade 8 standoff screw performs best in sufficiently reinforced solid slab geometries, such as P10. This is most likely due to the increased amount of concrete surrounding the standoff screw, especially around the base of the standoff shank. The concrete immediately around the base of the screw can not displace in solid slabs as it can when profiled steel deck is used. Therefore, the screw remains tightly embedded in the concrete until failure.

In the tests utilizing steel deck, the standoff screws performed best in medium thickness base angles (generally 0.187 in.) with only one screw per rib. The physical relationship between shear strength of the standoff screws and top chord thickness is discussed in Section 3.2.2. The normalized shear strength of the screws was generally lower in series B, most likely due to the smaller amount of steel reinforcement used in that series. The effects of grouping the screws were most significant in series D and least significant in series C. The width of the respective deck ribs influences these grouping effects.

The results of tests utilizing the 3.0 in. Elco Grade 8 standoff screw in series B, C, and D can be compared directly. In test groups B7-B9, C1-C3, and D1-D3 the 3.0 in.

standoff screws were placed one per rib in the same three base angles. Interestingly, the screws performed best in D1-D3 (Vulcraft 1.5VL deck). However, this type of deck is also most vulnerable to the effects of grouping the screws. Test groups C4-C6 and D4-D6 can also be compared directly since they both contain two screws per rib. Here, the screws performed better in test groups C4-C6 (Vulcraft 1.5C deck). And when the number of screws per rib increases to four, the advantage of using Vulcraft 1.5C deck is even more noticeable (test groups C7-C8 and D7-D10).

Table 3.11 Normalized Average Shear Strength

Test Group	Deck Type	Slab Depth (in.)	Screw Height (in.)	Screws Per Rib	Top Chord Thickness (in.)	Concrete f'c (psi)	Peak Shear Load/Screw (kips)	Normalized Peak Shear Load/Screw (kips)
P1	1.0C	3.25	3.0	2	0.187	4145	2.46	2.42
P2	1.0C	3.25	3.0	2	0.187	4145	3.69	3.63
P3	1.0C	3.25	3.0	2	0.187	4145	4.41	4.33
P4	1.0C	3.25	3.0	2	0.187	4642	4.39	4.08
P5	1.0C	3.25	3.0	1	0.187	5345	5.12	4.43
P6	1.0C	3.25	3.0	1	0.187	5345	5.18	4.48
P7	none	3.00	2.5	2	0.187	5352	2.52	2.18
P8	none	3.00	2.5	2	0.187	5352	4.04	3.50
P9	none	3.00	2.5	2	0.187	5352	6.40	5.53
P10	none	3.00	2.5	2	0.187	3236	7.26	8.08
P11	1.0C	3.25	3.0	2	0.187	3210	3.36	3.75
A1	0.6C	2.25	2.0	0.5	0.109	5027	4.30	3.84
A2	0.6C	2.25	2.0	0.5	0.187	4775	5.43	4.97
A3	0.6C	2.75	2.5	1	0.109	NA	NA	NA
A4	0.6C	2.75	2.5	1	0.187	NA	NA	NA
A5	0.6C	2.75	2.5	1	0.250	5491	4.33	3.70
A6	0.6C	2.25	2.0	1	0.109	5080	4.12	3.65
A7	0.6C	2.25	2.0	1	0.187	5080	5.30	4.70
A8	0.6C	2.25	2.0	1	0.250	5080	5.14	4.56
B1	1.0C	2.25	2.0	1	0.109	4324	3.16	3.04
B2	1.0C	2.25	2.0	1	0.187	4324	3.59	3.45
B3	1.0C	2.25	2.0	1	0.250	4324	3.31	3.18
B4	1.0C	2.75	2.5	1	0.109	3780	3.76	3.87
B5	1.0C	2.75	2.5	1	0.187	3780	4.60	4.73
B6	1.0C	2.75	2.5	1	0.250	3780	3.97	4.08
B7	1.0C	3.25	3.0	1	0.109	3780	3.70	3.81
B8	1.0C	3.25	3.0	1	0.187	3780	4.83	4.97
B9	1.0C	3.25	3.0	1	0.250	4748	4.38	4.02
B10	1.0C	3.25	3.0	2	0.163	4748	3.44	3.16
B11	1.0C	3.25	3.0	2	0.313	4775	3.09	2.83
C1	1.5C	3.25	3.0	1	0.109	5756	4.04	3.37
C2	1.5C	3.25	3.0	1	0.187	5756	5.26	4.39
C3	1.5C	3.25	3.0	1	0.250	4310	4.40	4.24
C4	1.5C	3.25	3.0	2	0.109	4310	4.41	4.24
C5	1.5C	3.25	3.0	2	0.187	4310	5.58	5.38
C6	1.5C	3.25	3.0	2	0.250	4310	4.34	4.18
C7	1.5C	3.75	3.5	4	0.163	4284	4.33	4.18
C8	1.5C	3.75	3.5	4	0.250	3926	3.86	3.89
D1	1.5VL	3.25	3.0	1	0.109	3568	3.99	4.22
D2	1.5VL	3.25	3.0	1	0.187	3568	5.66	5.99
D3	1.5VL	3.25	3.0	1	0.250	3568	5.17	5.47
D4	1.5VL	3.25	3.0	2	0.109	3568	4.05	4.29
D5	1.5VL	3.25	3.0	2	0.187	5372	4.90	4.23
D6	1.5VL	3.25	3.0	2	0.250	5372	4.10	3.54
D7	1.5VL	3.75	3.0	4	0.163	5372	2.26	1.95
D8	1.5VL	3.75	3.0	4	0.250	5372	2.59	2.24
D9	1.5VL	3.75	3.0	4	0.163	5093	2.09	1.85
D10	1.5VL	3.75	3.0	4	0.250	5093	2.41	2.13
D11	1.5VL	3.75	3.0	6	0.163	5093	1.61	1.43
D12	1.5VL	3.75	3.0	6	0.250	5093	1.78	1.58