CHAPTER 2

EXPERIMENTAL EVALUATION and RESULTS

2.1. Experimental evaluation

ELCO Grade 8 standoff screws have been evaluated at Virginia Polytechnic Institute and State University and ELCO labs in three different ways, depending on the objective of the tests. Those tests are as follows:

- Push-out tests;
- Full scale short span open-web joist tests;
- Simple shear and tension tests.

Push-out tests are the primary way of evaluating the strength of standoff screws due to their relative simplicity and economy, as compared to full-scale tests. The role of full-scale tests has been primarily to verify the results obtained from the push-out tests. There has been a limited number of tests done on full-scale specimens, mostly due to their cost and the lack of time and space required for their casting and testing. All of the push-out and full-scale tests were done at Virginia Polytechnic Institute and State University.

Simple shear and tension tests on ELCO Grade 8 standoff screws were all done in ELCO laboratories. The purpose of these tests was mainly to evaluate the quality of the production process. This primarily concerns proving that screws have the required specified strength and investigating the strength variability among the screws within the same production batch or the variation of strength between batches. These tests were also helpful in determining the relationship between shear and tensile strength of the screw, investigating the effect of screw length on its tensile and shear strength, etc.

2.1.1. Push-out Tests

A total of 254 push-out tests were done using ELCO Grade 8 screws by Hankins et al. (1994), Alander et al. (1998), Webler et al. (2000), and Mujagic et al. (2000). Procedures did not differ conceptually, and the basics of how the tests were conducted will be presented here. Detailed descriptions of instrumentation and test set-ups for each specific series is discussed in corresponding reports. Typical push-out specimen configuration is shown in

Figure 1.5. Vertical load applied on the steel section is representing the horizontal load resisted by shear connectors in a composite floor section.

Deck sheets of appropriate deck profiles were cut to the size of 36 by 36 in. for each test. A few of the specimens were of a slightly lesser width. Deck sheets were attached to top chord sections by predetermined number of standoff screws; a typical top chord section is shown in Figure 2.1.

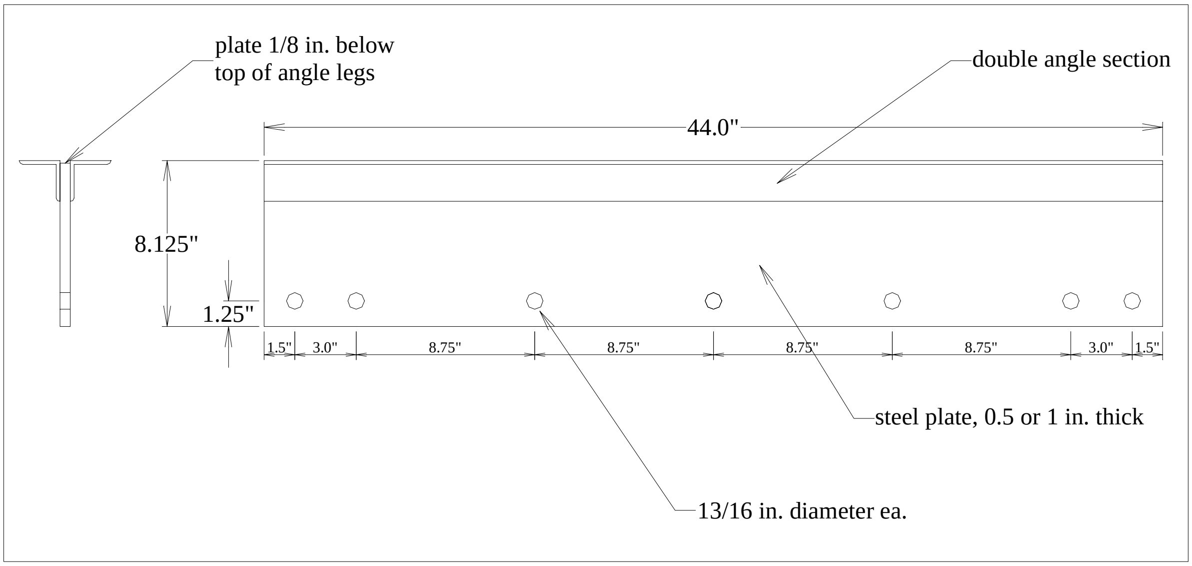

Figure 2.1 Typical Top Chord Section (Alander et al. 1998)

Both ½ in. and 1 in. plates were used in fabrication of top chord sections. Based on previous experiences, in many cases where ½ in. plate was used, two single angle sections were welded on each side of the steel section to prevent premature top chord buckling type of failure, which is not applicable to actual composite joist floors. Initially, the steel plate used was not of full length, which contributed to the number of top chord buckling failures that occurred. The plate was later changed to full-length. Double angle sections simulating top-chord angles in composite joists varied in size and thickness from 2L 1.25x1.25x0.109 to 2L 3.0x3.0x0.313.

Four holes were cut in each deck, two on each side of the top chord, with the purpose of placing a nail into the slab following the curing stage, which would hold the extended probe of potentiometer, measuring the displacement. Slabs in a few of specimens did not contain steel deck. A test specimen, as shown in Figure 1.5, has two halves, thus two slabs were cast for each test and were bolted together prior to the test. Reinforced slabs were reinforced by wire mesh. In addition to wire mesh, the size of which varied from test to test, most of the reinforced slabs also contained no. 4 rebar. The amount of welded fabric used was determined in accordance with provisions of ACI 318-95 Section 7.12.2.1(c) (ACI 1995). The requirement contained therein states that the area of temperature and shrinkage reinforcement vs. gross concrete area may not be less than 0.0014 and should be determined from the Equation 2.1.

$$\rho_{min} = \frac{0.0018x60{,}000}{f_y} \tag{2.1}$$

where:

ρ_{min} =ratio of temperature and shrinkage reinforcement area vs. gross concrete area

f_y = yield strength stress of reinforcement (ksi)

Yield stress in steel for this purpose was assumed to be at least 65,000 psi, as specified by ASTM A185 (ASTM 1993). Specimens cast by Hankins were all reinforced by welded wire fabric (WWF 6x6-W1.4xW1.4). No. 4 rebar was used in order to avoid longitudinal slab splitting. The amount of this reinforcement required was calculated based on Equation 2.2, which is found in Part 3, Section 3.1., of BS 5950 (The Steel Construction Institute 1990).

$$V_r = L\left(0.03\eta f_{cu} A_{cv} + 0.7 A_{sv} f_y\right) \tag{2.2}$$

where:

V_r = total combined shear resistance of each shear plane (kips/in.)

L = longitudinal length of shear plane (in.)

η = 1.0 for normal weight concrete and 0.8 for lightweight concrete

f_{cu} = strength of concrete cube (ksi)

$\approx 1.25 f'_c$

A_{cv} = cross-sectional area of concrete per unit length of each shear plane (in.^{2}/in.)

A_{sv} = amount of steel reinforcement crossing each shear plane (in.^{2}/in.)

= area of welded wire fabric and reinforcing bars crossing each shear plane

f_y = yield strength of steel reinforcement (ksi)

Removable cold-formed steel pour-stops were attached as concrete formwork. Small size aggregate, not exceeding 0.75 in. in diameter, was used in the concrete cast into push-out slabs. The slabs and the cylinders were generally cured for seven days, being covered by plastic sheeting and periodically watered. Next, specimens were air cured for at least 21 days.

Where solid slabs were cast and deck was not used, wooden forms were placed on the top chord sections as confinement for concrete casting. A typical push-out test set-up is summarized in Figures 2.2, 2.3, and 2.4. The basic concept is subjecting the push-out specimen to the vertical load applied by hydraulic ram. Elastomeric bearing pads (1 in. thick) were placed underneath each slab to insure that the slabs were uniformly loaded along their bottom surfaces. The swivel and the loading plates, which were placed atop the steel section, insured that the load from the hydraulic ram was evenly distributed between the two halves of the specimen, and that the axial load indeed remained axial, as opposed to allowing the ram to extend against the specimen at an angle. The hydraulic ram applying the axial load was suspended from the cross-head that was fixed to the loading frame. To better simulate an actual composite joist situation, another hydraulic apparatus was used to apply a load whose axis of action was perpendicular to the slab surface (Figure 2.3). This represents gravity load in a composite joist set-up. The apparatus consisted of a smaller hydraulic ram and two shorter W-sections that were used to distribute normal load along the length of top chords.

The load distribution frame surrounded the specimen horizontally. As shown in Figure 2.3, the frame restrained the specimen from lateral movement and provided support for normal load apparatus. Many specimens were braced against lateral movement by attaching the bracing arm to the columns of the steel frame on one side and to the top of the top chord section on the other side. Ideally, bracing does not add to the total capacity of the specimen, and its effect on the capacity in these tests were negligible. Whenever lateral bracing was used, the specimen was rotated by 90 degrees to facilitate the attachment of the bracing arms to the frame. This concept is illustrated in Figure 2.4. To prevent specimens from failing by longitudinal rib splitting, which is not an applicable mode of failure in regular composite joist section due to sufficient concrete area on both sides of the joist, a special apparatus was used by Alander et al. (1998) on some of his tests. This apparatus, illustrated in Figure 2.5, consisted of single angle sections, which were placed on sides of each slab, and were held in place by snug tightening, keeping the slabs from separating apart. A rubber pad was placed between angles and slabs at each location, preventing the slab from being damaged.

The three quantities measured during the test were axial load, normal load, and slab vs. top chord relative slip. The axial load was measured with a load cell placed between the hydraulic ram and cross-head, as shown in Figure 2.2. Most often this was a 500-kip load cell, but depending on the expected load, load cells with lesser capacities were used as well. Normal load was measured by a 50-kip load cell which was placed in between the normal load distribution frame and the hydraulic ram. Finally, slips were measured using linear potentiometers. These instruments were attached to the top chord by C-clamps, and their extendable arm was attached to a nail inserted through the pre-cut hole in the deck. Slips were measured at four evenly distributed locations at each slab.

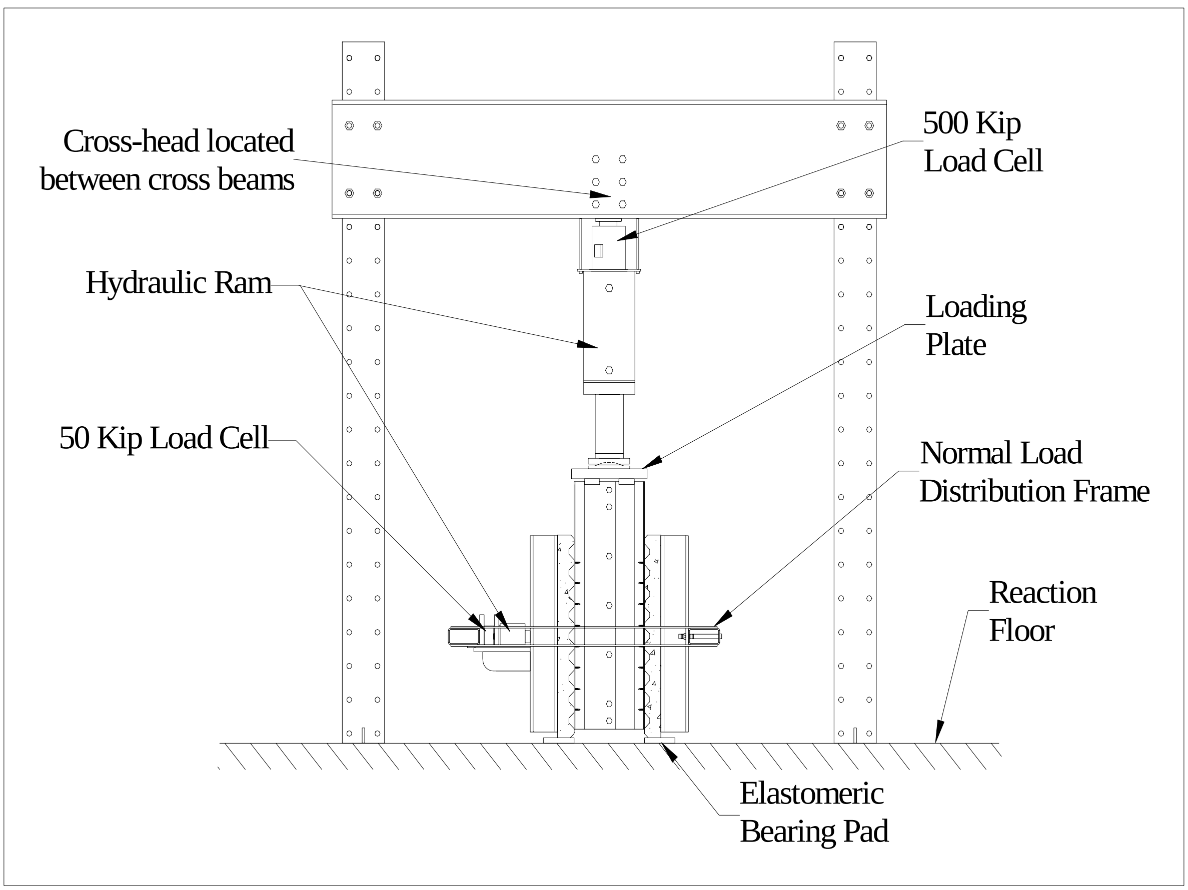

Figure 2.2 Typical Test Setup (Alander et al. 1998)

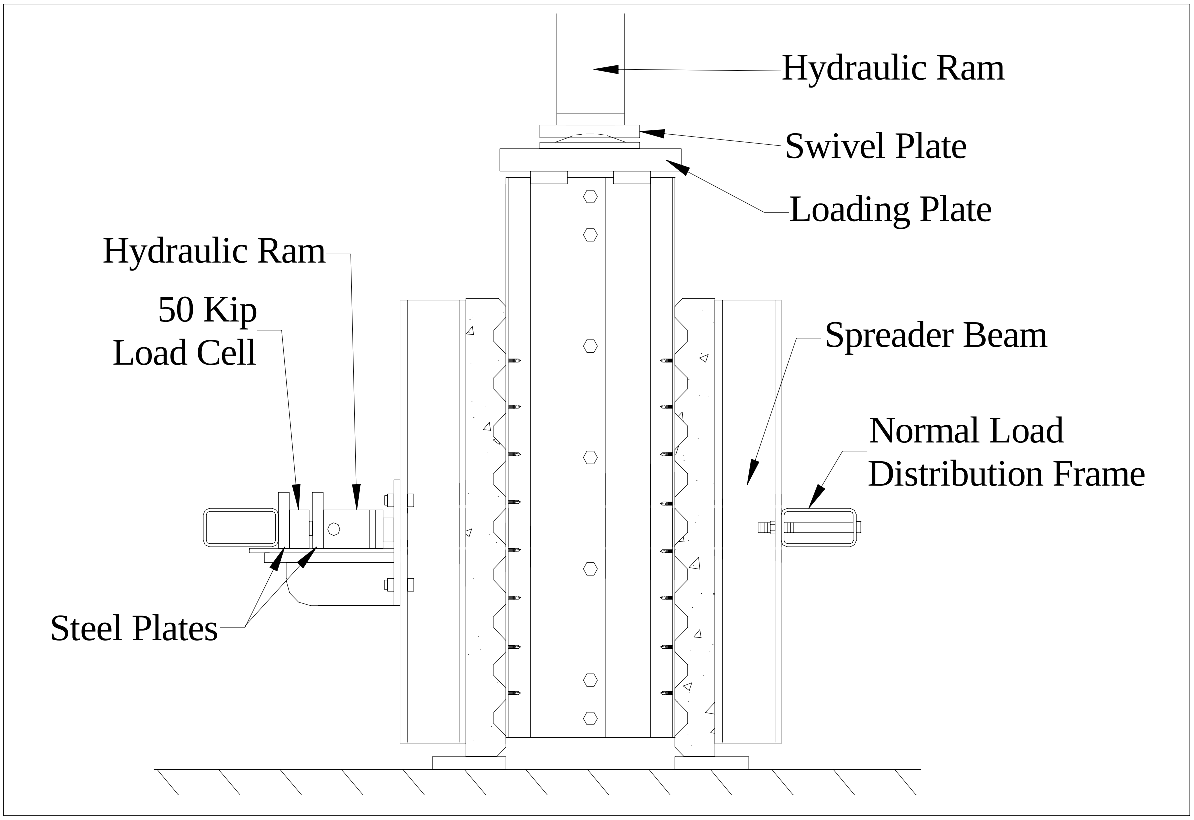

Figure 2.3 Test Setup Detail (Alander et al. 1998)

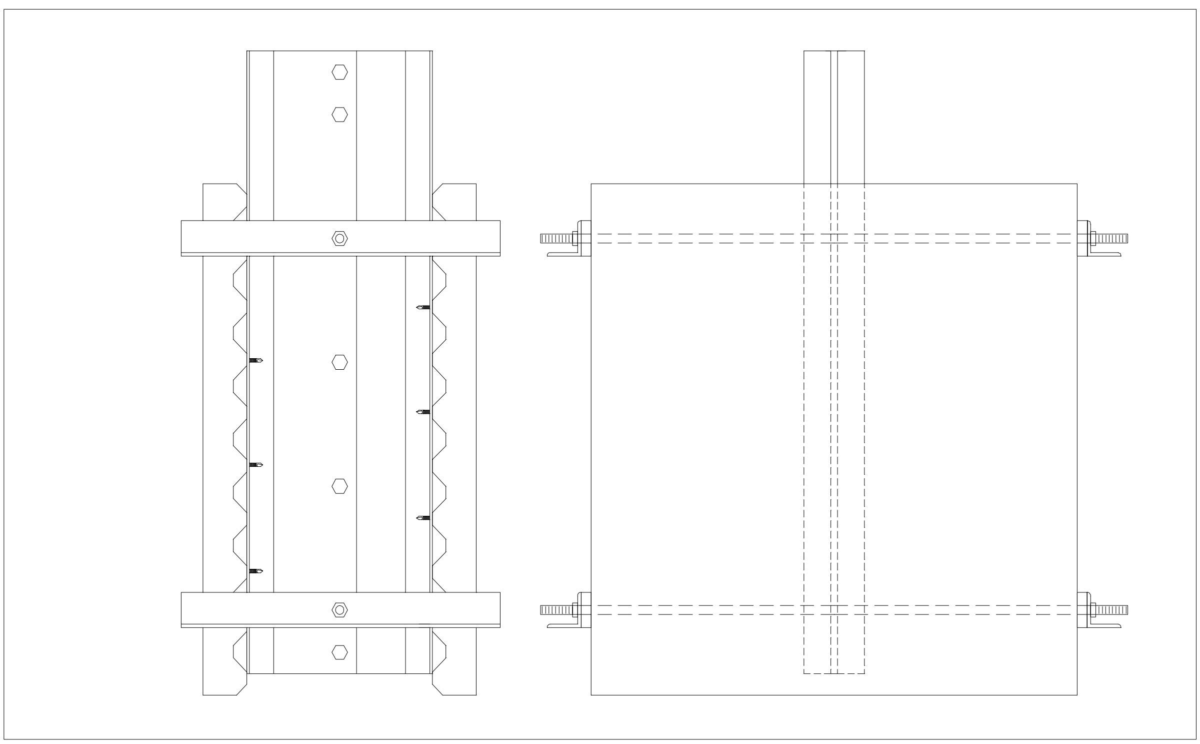

Figure 2.4 Apparatus Used to Limit Longitudinal Splitting (Alander et al. 1998)

The data acquisition systems used were either System 4000 or System 5000, both manufactured by the Vishay Measurements Group. The loading scheme for all the tests was relatively similar. Axial load would be applied in increments of 5 – 10 kips, and normal load would be kept at 10% of the magnitude of the applied axial load. After each loading application, the system was left to stabilize for about three minutes, at which point all the measurements would be recorded, and the next higher load would be applied. After failure occurred, the specimen was unloaded and removed from the frame. Generally, two specimens were tested for a given configuration. In the event that these specimens yielded two significantly different behaviors, the third specimen was tested. If the two axial load capacities are within ten percent of one another, the two tests were considered acceptable.

2.1.2. Full-Scale Tests

The full-scale short span open web joist tests were performed within CSJ test series, and six of those tests featured ELCO Grade 8 standoff screws. Detailed procedures of, nomenclature, and other specific issues pertaining to each test were given in corresponding reports by Lauer et al. (1996) and Mujagic et al. (2000). A brief overview of the tests performed will be given here.

The tests performed were either single or double joist tests. The double joist tests generally involved thinner top chord angle thicknesses, and single joist tests were done mainly using joists with relatively thicker top chord angles. The load distribution system, which consisted of beams, plates, rubber pads, and rollers, was placed at the top of each specimen, which ultimately resulted in eight concentrated point loads placed at joist panel points. The load distribution systems for single and double joist specimens were different. Configuration of the load distribution system was also contingent upon joist size and number of panels, as well as practical considerations such as test safety and stability. The loading distribution system of characteristic single joist and double joist tests are shown in Figure 2.5.

The specimens were cast and cured using procedures similar to those applicable to push-out specimens. Full-scale specimens, however, were reinforced by wire mesh only. In full-scale tests, however, loads, deflections, and strains were recorded at the casting stage as well. The loads were recorded by placing load cells under the joist seats. Deflections were recorded using linear displacement transducers placed at mid-span, and quarter-span points along the joist span. Strains were recorded by placement of strain gages at appropriate points of interest along the joist span. Loads, strains, and slips due to placement of load distribution system were all recorded. Slips were measured using linear potentiometers, which were installed in the same way as for push-out specimens. All four quantities were also measured in the loading phase.

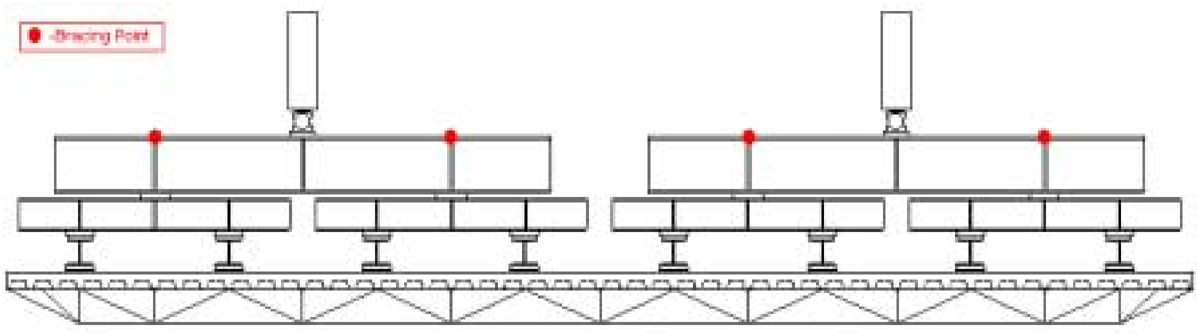

Figure 2.5a Double Joist Test (CSJ-12) Loading System Arrangements (Mujagic et al. 2000)

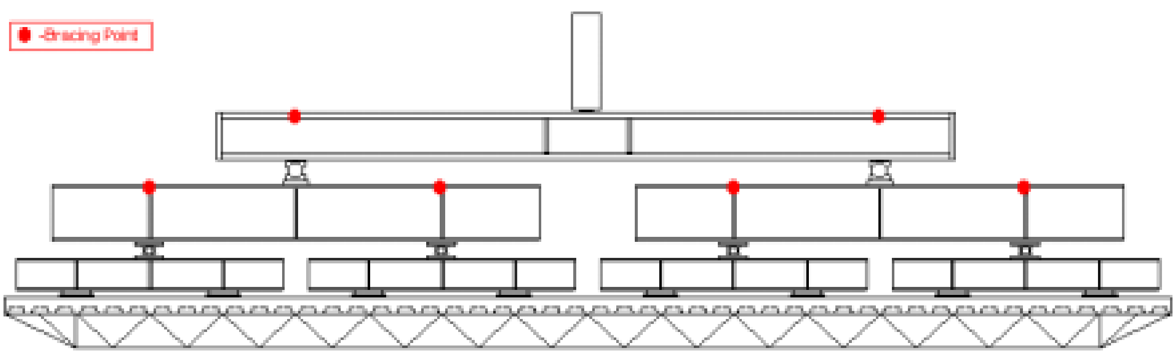

Figure 2.5b Single Joist Test (CSJ-13) Loading System Arrangements (Mujagic et al. 2000)

The specimens were loaded and unloaded according to predetermined loading schemes. The loading stages were determined and expressed as increments of allowable load calculated in Allowable Stress Design (ASD). After the specimen had reached 1.65 times ASD design load, loading stages were deflection controlled, usually in increments of 0.5 in. of live load deflection.

Although screw strengths cannot be explicitly measured in a full-scale test, they can be back-calculated based on the mode of failure of the specimen and maximum live load sustained. This was done for the joist specimens.

2.1.3. Simple Shear and Tensile Tests

Several different tests on ELCO Grade 8 standoff screws were performed at ELCO facilities in Rockford, IL. Shear tests, done in 1992, were performed by first drilling the screws through two metal plates, 6 in. long, 1.5 in. wide, and 0.187 in. thick, as shown in Figure 2.6. Plates were then pulled apart, which caused the screw to be loaded in shear. Four ELCO Grade 8, 2 in. long screws were pulled in this set of tests.

Later the same year a similar kind of test took place at ELCO facilities. This time however, the thickness of the metal plates varied. A total of 18 tests were performed, three with each plate thickness. Plate thicknesses ranged from 0.109 to 0.250 in. Screw lengths in these test results were not reported. However, due to the nature of the tests, in which load was applied through the threads, length of the shank is immaterial.

Tensile tests on 2 in. long ELCO Grade 8 standoff screws were performed the same year. Tests were done by first drilling the screw through a plate on one end and gripping the screw head on the other end, as illustrated in Figure 2.7. In these, tests the fixture was such that the only loaded part of the screw was its shank.

No other tests were done until 1998, when an additional set of shear and tensile tests was performed by ELCO. These tests were performed on screws of different lengths, and in compliance with International Conference of Building Officials' (ICBO) Acceptance Criteria for Tapping Screw Fasteners, AC118 (1996). The screws tested measured 2 and 4 in. in shank length. As reported later, the tensile tests for these screws were not carried out all the way to the failure. Specifically, as the applied load was approaching 10 kips, which was the limit of the load cell used, tests were discontinued in order to avoid the damage to the equipment. Although the ultimate tensile capacity results from these tests may be considered void, they will still be reported here, as the tensile yield strength of the screw should still be valid and may be used for comparison purposes. Apparatuses for yield and tensile strength are shown in Figures 2.8 and 2.9.

Additional tensile test results were reported in 1999. These tests were carried out in the same way as those from 1998 except that the shanks of the screws tested measured 2.5 and 3.0 in.

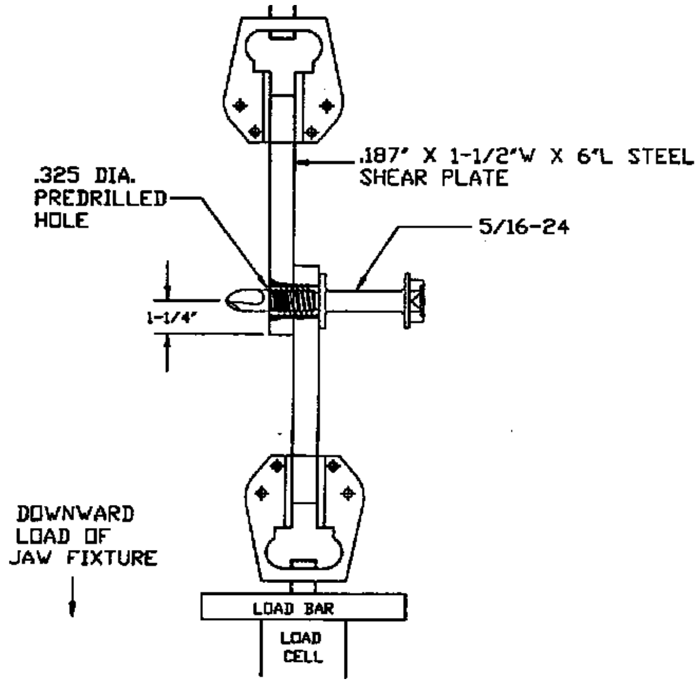

Figure 2.6 ELCO Single Lap Shear Test Apparatus (Mike Janusz - ELCO 1992)

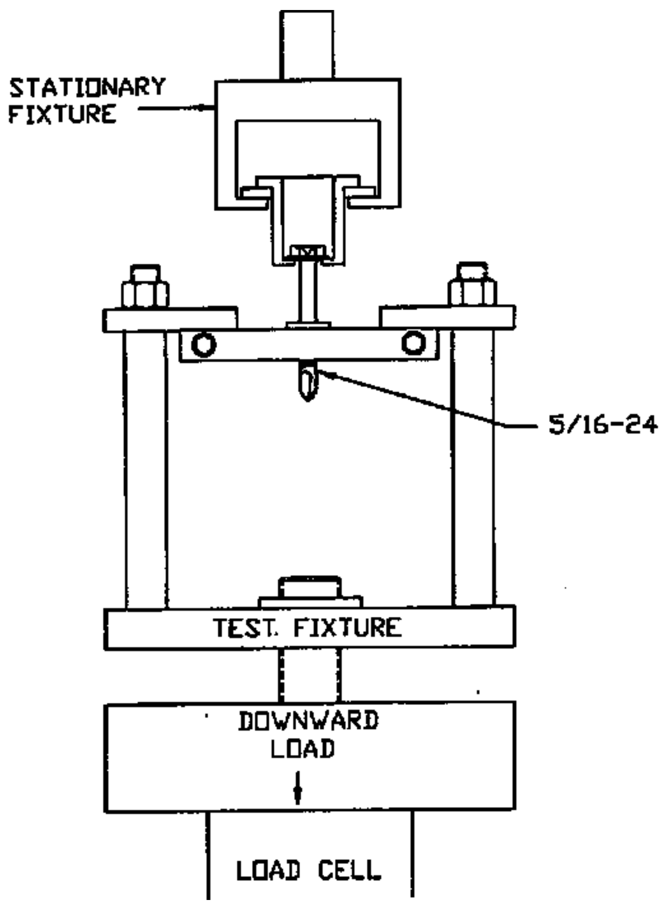

Figure 2.7 Tension Test Apparatus (Mike Janusz - ELCO 1992)

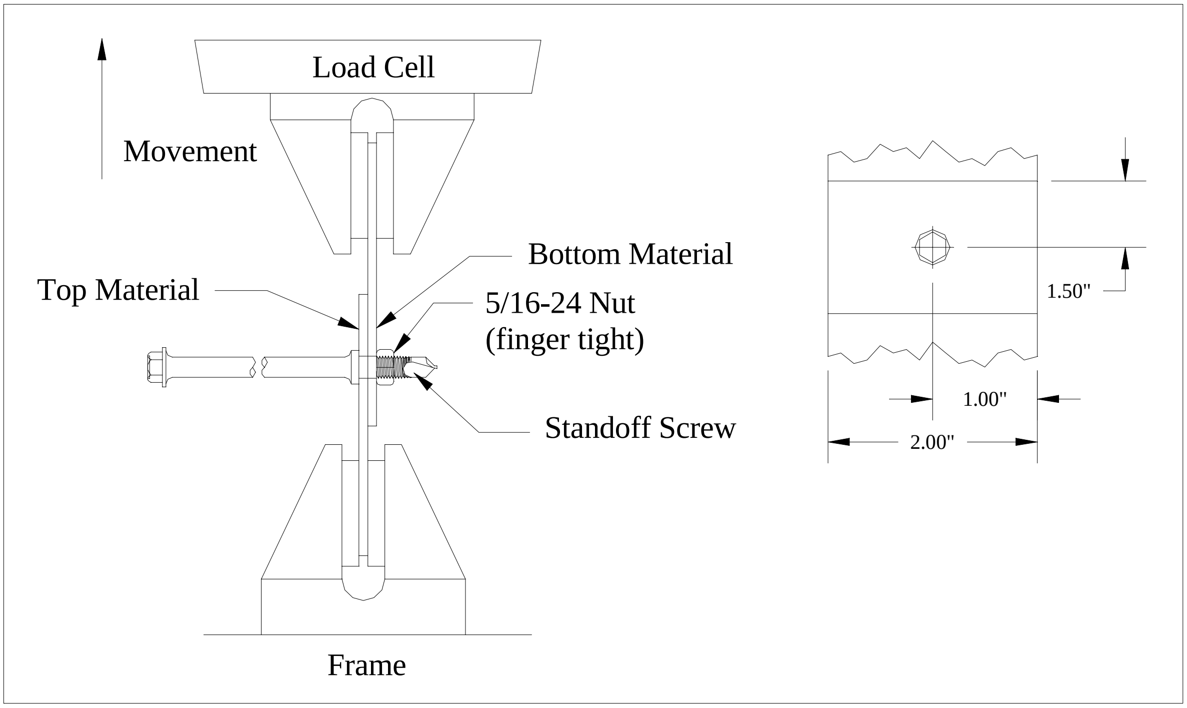

Figure 2.8 Shear Test Setup from (ELCO 1998-99)

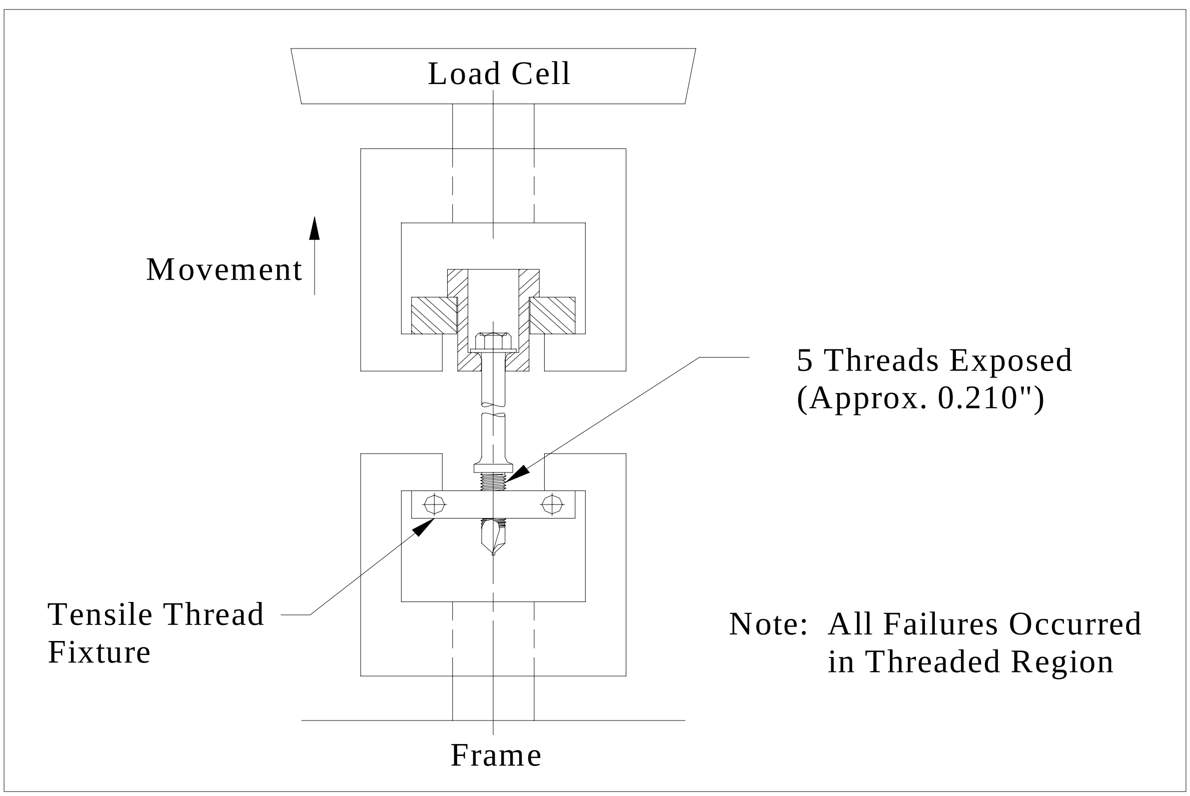

Figure 2.9 Tensile Test Setup (ELCO 1998-99)

2.2. Test Results

In this section, a summary is provided of all the available results of experimental evaluation of ELCO Grade 8 standoff screws. The results shown correspond with the test descriptions, provided in previous sections of this chapter. Only the data of interest to this study will be shown here. For instance, push-out test results reported here will contain capacities, key variables, and applicable material properties. For other information about particular push-out tests, such as damage drawings, or slip at certain load, one should consult the appropriate report containing the information. A similar approach will be taken in presenting the results for other types of tests.

2.2.1. Push-out Test Results

Results for all the push-out tests are reported in data-pack format. A push-out data pack, a sample of which is shown in Appendix A-1, contains information on measured slips at every load level during the test, concrete compressive strength, base metal and deck tensile strength at yield and rupture, specimen damage, etc. It also provides load vs. slip plots and a complete reference for all the test variables. The Table 2.1 summarizes the results of all the push-out tests at Virginia Tech that featured ELCO Grade 8 standoff screws. Although not all of the tests were used in the development of analytical models, as outlined in Chapter 3, all are presented here for informational purposes. The data shown in Table 2.1 were collected from the research reports of Hankins et al. (1994), Alander et al. (1998b), Webler et al. (2000), and Mujagic et al. (2000).

Two base angle thicknesses are reported for series C9R tests. The reason for this is a fabrication error that led to installation of angles of different thicknesses to each half of the specimen. Both angle thicknesses are reported. All of the variables reported in Table 2.1 are self-explanatory except Distance Between Rows of Screws Within a Rib, l_s. This variable is only applicable to those specimens that have two or more screws per rib per angle, where screws are installed in more than one row perpendicular to the rib and parallel to the direction of the member. This statement is illustrated in Figure 2.10.

Tests F5-1 and F5-2 contain a mark "x" next to their reported values of maximum measured shear capacity. This mark serves as a reminder that the reported value is only maximum measured load, rather than the capacity, as the test was terminated before failure took place in order to prevent damage to the equipment due to exceeding safe allowable load levels.

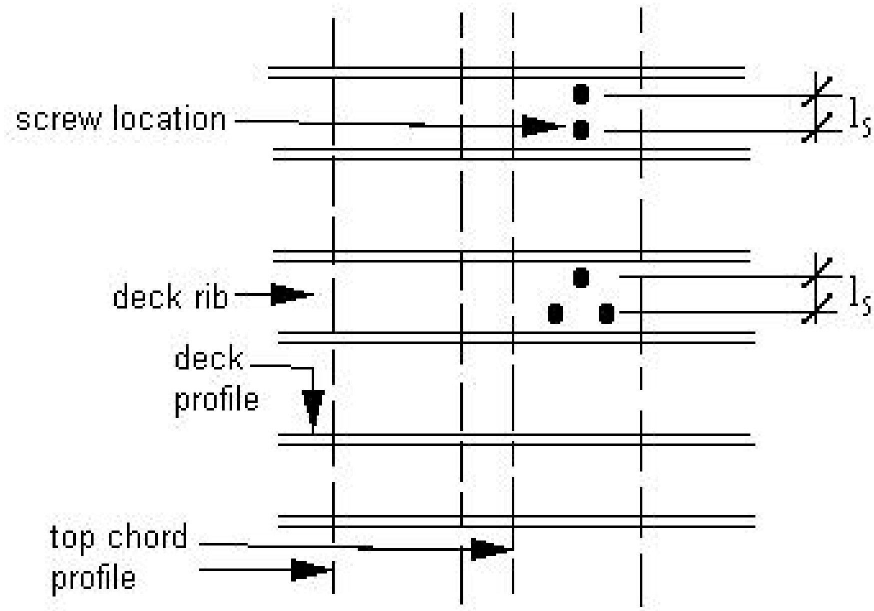

Figure 2.10 Distance Between Rows of Screws Within a Rib, l_s

2.2.2. Full-Scale Test Results

Results of the full-scale tests were reported in a manner similar to the push-out tests. Specifically, all the load, strain, slip, and deflection data were presented in tabular form. Plots showing load vs. slip, load vs. strain, and load vs. deflection were presented as well. All the pivotal data and comparison of theoretical vs. experimental values were shown on summary sheets. An example of a full-scale data-pack is shown in Appendix A-2. Results of full-scale tests shown here contain only data relevant to evaluation of the performance of ELCO Grade 8 standoff screws. Reported shear load carried by shear connectors at the maximum recorded gravity load carried by the specimen does not necessarily always reflect the capacity of the shear connectors. The geometric parameters for the full-scale tests are shown in Table 2.2. Back-calculated values of load carried by screws, shown in Table 2.3, reflect the screw capacity only in tests where the mode of failure was failure of shear connections. This will be further discussed in Chapter 3 when presenting the analytical study. The data shown in Tables 2.2 and 2.3 were collected from the research reports of Lauer et al. (1994) and Mujagic et al. (2000).

Table 2.1 Push-out Test Results

Test Number	Deck Type	Bottom Rib Width, w_{r1} (in.)	Top Rib Width, w_{r2} (in.)	Rib Height, h_r (in)	Screw Height, h_s (in.)	Number of Screws per Rib, N	Top Chord Thickness, t_{tc} (in.)	Distance Between Rows of Screws within a Rib, l_s (in.)	Concrete Compressive Strength, f'c (psi)	Peak Shear Load Per Screw, R_n (kips)	Observed Failure Mode
P-3-1	1.0C	0.90	2.77	1.00	2.0	1	0.123	0.00	4300	3.86	screw pullout
P-3-2	1.0C	0.90	2.77	1.00	2.0	1	0.123	0.00	4100	3.69	screw pullout
P-3-3	1.0C	0.90	2.77	1.00	2.0	1	0.123	0.00	4300	3.53	screw pullout
1-1-1	none	n/a	n/a	n/a	2.0	n/a	0.109	n/a	3900	5.21	screw shear
1-1-2	none	n/a	n/a	n/a	2.0	n/a	0.109	n/a	3900	5.19	top chord buckling
1-1-3	none	n/a	n/a	n/a	2.0	n/a	0.109	n/a	3900	5.50	screw shear
1-2-1	none	n/a	n/a	n/a	2.0	n/a	0.123	n/a	3800	6.50	longitudinal splitting
1-2-2	none	n/a	n/a	n/a	2.0	n/a	0.123	n/a	3800	5.14	top chord buckling
1-2-3	none	n/a	n/a	n/a	2.0	n/a	0.123	n/a	3800	5.46	screw shear
1-3-1	none	n/a	n/a	n/a	2.0	n/a	0.123	n/a	3400	6.09	longitudinal splitting
1-3-2	none	n/a	n/a	n/a	2.0	n/a	0.170	n/a	3900	7.05	screw shear
1-3-3	none	n/a	n/a	n/a	2.0	n/a	0.170	n/a	3900	6.71	top chord buckling
1-3-4	none	n/a	n/a	n/a	2.0	n/a	0.170	n/a	3900	6.58	top chord buckling
1-4-1	none	n/a	n/a	n/a	2.0	n/a	0.205	n/a	3500	7.23	longitudinal splitting
1-4-2	none	n/a	n/a	n/a	2.0	n/a	0.205	n/a	3900	7.36	screw shear
1-4-3	none	n/a	n/a	n/a	2.0	n/a	0.205	n/a	3900	7.60	screw shear
1-5-1	none	n/a	n/a	n/a	2.0	n/a	0.238	n/a	3600	5.74	screw shear
1-5-2	none	n/a	n/a	n/a	2.0	n/a	0.238	n/a	3900	6.26	screw shear
1-5-3	none	n/a	n/a	n/a	2.0	n/a	0.238	n/a	3900	5.90	screw shear
1-6-1	none	n/a	n/a	n/a	2.0	n/a	0.170	n/a	3400	5.50	longitudinal splitting
1-6-2	none	n/a	n/a	n/a	2.0	n/a	0.170	n/a	3900	5.19	longitudinal splitting
1-6-3	none	n/a	n/a	n/a	2.0	n/a	0.170	n/a	3900	5.17	longitudinal splitting
1-6-4	none	n/a	n/a	n/a	2.0	n/a	0.170	n/a	3900	5.08	longitudinal splitting
2-1-1	0.6C	0.75	1.75	0.56	1.5	1	0.109	0.00	7000	3.64	cone pullout
2-1-2	0.6C	0.75	1.75	0.56	1.5	1	0.109	0.00	7000	3.62	cone pullout
2-1-3	0.6C	0.75	1.75	0.56	1.5	1	0.109	0.00	7000	3.56	cone pullout
2-2-1	0.6C	0.75	1.75	0.56	1.5	1	0.155	0.00	7000	4.01	cone pullout
2-2-2	0.6C	0.75	1.75	0.56	1.5	1	0.155	0.00	7000	4.17	cone pullout
2-2-3	0.6C	0.75	1.75	0.56	1.5	1	0.155	0.00	7000	3.98	cone pullout
2-3-1	0.6C	0.75	1.75	0.56	1.5	1	0.205	0.00	7000	4.37	cone pullout
2-3-2	0.6C	0.75	1.75	0.56	1.5	1	0.205	0.00	7000	3.88	cone pullout
2-3-3	0.6C	0.75	1.75	0.56	1.5	1	0.205	0.00	7000	4.03	cone pullout
2-4-1	0.6C	0.75	1.75	0.56	1.5	1	0.250	0.00	7000	3.80	cone pullout
2-4-2	0.6C	0.75	1.75	0.56	1.5	1	0.250	0.00	7000	4.12	cone pullout
2-4-3	0.6C	0.75	1.75	0.56	1.5	1	0.250	0.00	7000	3.72	cone pullout
3-1-1	1.0C	0.90	2.77	1.00	2.0	1	0.109	0.00	4900	3.64	top chord buckling
3-1-2	1.0C	0.90	2.77	1.00	2.0	1	0.109	0.00	4900	3.33	top chord buckling
3-1-3	1.0C	0.90	2.77	1.00	2.0	1	0.109	0.00	4900	3.43	top chord buckling
3-2-1	1.0C	0.90	2.77	1.00	2.0	1	0.155	0.00	4900	4.40	cone pullout
3-2-2	1.0C	0.90	2.77	1.00	2.0	1	0.155	0.00	4900	4.38	cone pullout
3-2-3	1.0C	0.90	2.77	1.00	2.0	1	0.155	0.00	4800	4.17	screw shear
3-3-1	1.0C	0.90	2.77	1.00	2.0	1	0.205	0.00	4600	4.77	cone pullout
3-3-2	1.0C	0.90	2.77	1.00	2.0	1	0.205	0.00	4600	4.41	screw shear
3-3-3	1.0C	0.90	2.77	1.00	2.0	1	0.205	0.00	4600	4.67	screw shear
3-4-1	1.0C	0.90	2.77	1.00	2.0	1	0.250	0.00	4800	4.19	screw shear
3-4-2	1.0C	0.90	2.77	1.00	2.0	1	0.250	0.00	4600	3.70	screw shear
3-4-3	1.0C	0.90	2.77	1.00	2.0	1	0.250	0.00	4600	4.48	cone pullout
4-1-1	1.5VL	1.75	2.50	1.50	2.0	1	0.109	0.00	5400	3.98	top chord buckling
4-1-2	1.5VL	1.75	2.50	1.50	2.0	1	0.109	0.00	5400	4.30	top chord buckling
4-1-3	1.5VL	1.75	2.50	1.50	2.0	1	0.109	0.00	5400	4.33	top chord buckling
4-2-1	1.5VL	1.75	2.50	1.50	2.0	1	0.155	0.00	5100	4.79	cone pullout
4-2-2	1.5VL	1.75	2.50	1.50	2.0	1	0.155	0.00	5300	4.87	cone pullout
4-2-3	1.5VL	1.75	2.50	1.50	2.0	1	0.155	0.00	5300	5.13	cone pullout
4-3-1	1.5VL	1.75	2.50	1.50	2.0	1	0.243	0.00	5300	4.58	cone pullout
4-3-2	1.5VL	1.75	2.50	1.50	2.0	1	0.245	0.00	5300	4.75	cone pullout
4-3-3	1.5VL	1.75	2.50	1.50	2.0	1	0.239	0.00	5300	4.88	cone pullout
4-4-1	1.5VL	1.75	2.50	1.50	2.0	1	0.252	0.00	4800	4.92	cone pullout
4-4-2	1.5VL	1.75	2.50	1.50	2.0	1	0.252	0.00	4800	4.24	screw shear
4-4-3	1.5VL	1.75	2.50	1.50	2.0	1	0.252	0.00	4800	4.85	cone pullout
5-1-1	1.5VL	1.75	2.50	1.50	2.5	1	0.109	0.00	4400	5.01	screw pullout
5-1-2	1.5VL	1.75	2.50	1.50	2.5	1	0.109	0.00	4400	4.87	screw pullout
5-1-3	1.5VL	1.75	2.50	1.50	2.5	1	0.109	0.00	4400	5.01	screw pullout
5-2-1	1.5VL	1.75	2.50	1.50	2.5	1	0.155	0.00	4400	5.46	cone pullout
5-2-2	1.5VL	1.75	2.50	1.50	2.5	1	0.155	0.00	4400	5.50	cone pullout

Table 2.1 Push-out Test Results (continued)

Test Number	Deck Type	Bottom Rib Width, w_{r1} (in.)	Top Rib Width, w_{r2} (in.)	Rib Height, h_r (in)	Screw Height, h_s (in.)	Number of Screws per Rib, N	Top Chord Thickness, t_{tc} (in.)	Distance Between Rows of Screws within a Rib, l_s (in.)	Concrete Compressive Strength, f'c (psi)	Peak Shear Load Per Screw, R_n (kips)	Observed Failure Mode
5-2-3	1.5VL	1.75	2.50	1.50	2.5	1	0.155	0.00	4400	5.55	cone pullout
5-3-1	1.5VL	1.75	2.50	1.50	2.5	1	0.205	0.00	4400	5.11	cone pullout
5-3-2	1.5VL	1.75	2.50	1.50	2.5	1	0.205	0.00	4400	5.46	screw shear
5-3-3	1.5VL	1.75	2.50	1.50	2.5	1	0.205	0.00	4400	5.21	cone pullout
P1-1	1.0C	0.90	2.77	1.00	3.0	2	0.187	0.00	4100	2.40	screw shear
P1-3	1.0C	0.90	2.77	1.00	3.0	2	0.187	0.00	4100	2.50	screw shear
P2-1	1.0C	0.90	2.77	1.00	3.0	2	0.187	0.00	4100	3.58	screw shear
P2-2	1.0C	0.90	2.77	1.00	3.0	2	0.187	0.00	4100	3.51	screw shear
P2-3	1.0C	0.90	2.77	1.00	3.0	2	0.187	0.00	4100	3.97	screw shear
P3-1	1.0C	0.90	2.77	1.00	3.0	2	0.187	0.00	4100	4.69	screw shear
P3-2	1.0C	0.90	2.77	1.00	3.0	2	0.187	0.00	4100	4.28	screw shear
P3-3	1.0C	0.90	2.77	1.00	3.0	2	0.187	0.00	4100	4.27	screw shear
P4-1	1.0C	0.90	2.77	1.00	3.0	2	0.187	0.00	4600	4.88	screw shear
P4-2	1.0C	0.90	2.77	1.00	3.0	2	0.187	0.00	4600	4.15	screw shear
P4-3	1.0C	0.90	2.77	1.00	3.0	2	0.187	0.00	4600	4.15	screw shear
P5-1	1.0C	0.90	2.77	1.00	3.0	1	0.187	0.00	5300	5.14	screw shear
P5-2	1.0C	0.90	2.77	1.00	3.0	1	0.187	0.00	5300	5.09	screw shear
P6-1	1.0C	0.90	2.77	1.00	3.0	1	0.187	0.00	5300	5.16	screw shear
P6-2	1.0C	0.90	2.77	1.00	3.0	1	0.187	0.00	5300	5.21	screw shear
P7-1	none	n/a	n/a	n/a	2.5	2	0.187	n/a	5400	2.62	longitudinal splitting
P7-2	none	n/a	n/a	n/a	2.5	2	0.187	n/a	5400	2.41	longitudinal splitting
P8-1	none	n/a	n/a	n/a	2.5	2	0.187	n/a	5400	4.12	longitudinal splitting
P8-2	none	n/a	n/a	n/a	2.5	2	0.187	n/a	5400	3.97	long. split./screw shear
P9-1	none	n/a	n/a	n/a	2.5	2	0.187	n/a	5400	4.74	top chord buckling
P9-2	none	n/a	n/a	n/a	2.5	2	0.187	n/a	5400	6.40	screw shear
P9-3	none	n/a	n/a	n/a	2.5	2	0.187	n/a	5400	6.40	screw shear
P10-1	none	n/a	n/a	n/a	2.5	2	0.187	n/a	3200	7.24	screw shear
P10-2	none	n/a	n/a	n/a	2.5	2	0.187	0.00	3200	7.29	screw shear
P11-1	1.0C	0.90	2.77	1.00	3.0	2	0.187	0.00	3200	3.35	screw shear
P11-2	1.0C	0.90	2.77	1.00	3.0	2	0.187	0.00	3200	3.37	screw shear
A1-1	0.6C	0.75	1.75	0.56	2.0	1	0.109	0.00	4800	4.44	screw pullout
A1-2	0.6C	0.75	1.75	0.56	2.0	1	0.109	0.00	4800	3.78	screw pullout
A1-3	0.6C	0.75	1.75	0.56	2.0	1	0.109	0.00	5500	4.68	screw pullout
A2-1	0.6C	0.75	1.75	0.56	2.0	1	0.187	0.00	4800	5.54	screw shear
A2-2	0.6C	0.75	1.75	0.56	2.0	1	0.187	0.00	4800	5.32	screw shear
A3-1	0.6C	0.75	1.75	0.56	2.5	1	0.109	0.00	5500	2.98	top chord buckling
A3-2	0.6C	0.75	1.75	0.56	2.5	1	0.109	0.00	5500	3.22	top chord buckling
A4-1	0.6C	0.75	1.75	0.56	2.5	1	0.187	0.00	5500	5.15	top chord buckling
A4-2	0.6C	0.75	1.75	0.56	2.5	1	0.187	0.00	5500	5.28	top chord buckling
A5-1	0.6C	0.75	1.75	0.56	2.5	1	0.250	0.00	5500	4.55	screw shear
A5-2	0.6C	0.75	1.75	0.56	2.5	1	0.250	0.00	5500	4.11	screw shear
A6-1	0.6C	0.75	1.75	0.56	2.0	1	0.109	0.00	5100	4.12	screw pullout
A6-2	0.6C	0.75	1.75	0.56	2.0	1	0.109	0.00	5100	4.12	screw pullout
A7-1	0.6C	0.75	1.75	0.56	2.0	1	0.187	0.00	5100	5.18	screw shear
A7-2	0.6C	0.75	1.75	0.56	2.0	1	0.187	0.00	5100	5.41	screw shear
A8-1	0.6C	0.75	1.75	0.56	2.0	1	0.250	0.00	5100	5.06	screw shear
A8-2	0.6C	0.75	1.75	0.56	2.0	1	0.250	0.00	5100	5.22	screw shear
B1-1	1.0C	0.90	2.77	1.00	2.0	1	0.109	0.00	4300	3.23	screw pullout
B1-2	1.0C	0.90	2.77	1.00	2.0	1	0.109	0.00	4300	3.09	screw pullout
B2-1	1.0C	0.90	2.77	1.00	2.0	1	0.187	0.00	4300	3.50	screw shear
B2-2	1.0C	0.90	2.77	1.00	2.0	1	0.187	0.00	4300	3.67	screw shear
B3-1	1.0C	0.90	2.77	1.00	2.0	1	0.250	0.00	4300	3.40	screw shear
B3-2	1.0C	0.90	2.77	1.00	2.0	1	0.250	0.00	4300	3.21	screw shear
B4-1	1.0C	0.90	2.77	1.00	2.5	1	0.109	0.00	3800	3.61	screw pullout
B4-2	1.0C	0.90	2.77	1.00	2.5	1	0.109	0.00	3800	3.91	screw pullout
B5-1	1.0C	0.90	2.77	1.00	2.5	1	0.187	0.00	3800	4.61	screw shear
B5-2	1.0C	0.90	2.77	1.00	2.5	1	0.187	0.00	3800	4.59	screw shear
B6-1	1.0C	0.90	2.77	1.00	2.5	1	0.250	0.00	3800	4.00	screw shear
B6-2	1.0C	0.90	2.77	1.00	2.5	1	0.250	0.00	3800	3.93	screw shear
B7-1	1.0C	0.90	2.77	1.00	3.0	1	0.109	0.00	3800	3.77	screw pullout
B7-2	1.0C	0.90	2.77	1.00	3.0	1	0.109	0.00	3800	3.64	screw pullout
B8-1	1.0C	0.90	2.77	1.00	3.0	1	0.187	0.00	3800	4.84	screw shear
B8-2	1.0C	0.90	2.77	1.00	3.0	1	0.187	0.00	3800	4.83	screw shear
B9-1	1.0C	0.90	2.77	1.00	3.0	1	0.250	0.00	4700	4.38	screw shear

Table 2.1 Push-Out Test Results (continued)

Test Number	Deck Type	Bottom Rib Width, w_{r1} (in.)	Top Rib Width, w_{r2} (in.)	Rib Height, h_r (in)	Screw Height, h_s (in.)	Number of Screws per Rib, N	Top Chord Thickness, t_{tc} (in.)	Distance Between Rows of Screws within a Rib, l_s (in.)	Concrete Compressive Strength, f'c (psi)	Peak Shear Load Per Screw, R_n (kips)	Observed Failure Mode
B9-2	1.0C	0.90	2.77	1.00	3.0	1	0.250	0.00	4700	4.38	screw shear
B10-1	1.0C	0.90	2.77	1.00	3.0	2	0.163	0.00	4700	3.50	screw shear
B10-2	1.0C	0.90	2.77	1.00	3.0	2	0.163	0.00	4700	3.38	top chord buckling
B11-1	1.0C	0.90	2.77	1.00	3.0	2	0.313	0.00	4800	2.98	screw shear
B11-2	1.0C	0.90	2.77	1.00	3.0	2	0.313	0.00	4800	3.19	screw shear
B12-1	1.0C	0.90	2.77	1.00	2.5	1	0.109	0.00	6600	3.58	screw pullout
B12-2	1.0C	0.90	2.77	1.00	2.5	1	0.109	0.00	6600	4.09	screw pullout
B13-1	1.0C	0.90	2.77	1.00	2.5	1	0.187	0.00	7000	5.52	screw shear
B13-2	1.0C	0.90	2.77	1.00	2.5	1	0.187	0.00	7000	4.87	screw shear
B14-1	1.0C	0.90	2.77	1.00	2.5	2	0.109	0.00	6500	3.64	screw pullout
B14-2	1.0C	0.90	2.77	1.00	2.5	2	0.109	0.00	6500	3.70	screw pullout
B14R-1	1.0C	0.90	2.77	1.00	2.5	2	0.109	0.00	5900	3.75	screw pullout
B14R-2	1.0C	0.90	2.77	1.00	2.5	2	0.109	0.00	5900	3.71	screw pullout
B14RR-1	1.0C	0.90	2.77	1.00	2.5	2	0.109	0.00	5100	3.66	screw pullout
B14RR-2	1.0C	0.90	2.77	1.00	2.5	2	0.109	0.00	5100	3.83	screw pullout
B15-1	1.0C	0.90	2.77	1.00	2.5	2	0.187	0.00	6700	4.74	screw shear
B15-2	1.0C	0.90	2.77	1.00	2.5	2	0.187	0.00	6700	5.01	screw shear
B15R-1	1.0C	0.90	2.77	1.00	2.5	2	0.187	0.00	5500	5.17	screw shear
B15R-2	1.0C	0.90	2.77	1.00	2.5	2	0.187	0.00	5500	5.11	screw shear
B15RR-1	1.0C	0.90	2.77	1.00	2.5	2	0.187	0.00	5100	4.46	screw shear
B15RR-2	1.0C	0.90	2.77	1.00	2.5	2	0.187	0.00	5100	4.6	screw shear
B16-1	1.0C	0.90	2.77	1.00	2.5	2	0.250	0.00	7300	3.31	screw shear
B16-2	1.0C	0.90	2.77	1.00	2.5	2	0.250	0.00	7300	3.44	screw shear
B16R-1	1.0C	0.90	2.77	1.00	2.5	2	0.250	0.00	5500	3.33	screw shear
B16R-2	1.0C	0.90	2.77	1.00	2.5	2	0.250	0.00	5500	3.05	screw shear
B16R-3	1.0C	0.90	2.77	1.00	2.5	2	0.250	0.00	5500	2.92	screw shear
B16RR-1	1.0C	0.90	2.77	1.00	2.5	2	0.250	0.00	5000	3.59	screw shear
B16RR-2	1.0C	0.90	2.77	1.00	2.5	2	0.250	0.00	5000	3.56	screw shear
C1-1	1.5C	3.50	4.25	1.50	3.0	1	0.109	0.00	5800	4.05	screw shear
C1-2	1.5C	3.50	4.25	1.50	3.0	1	0.109	0.00	5800	4.04	screw shear
C1R-1	1.5C	3.50	4.25	1.50	3.0	1	0.109	0.00	4100	5.40	screw shear
C1R-2	1.5C	3.50	4.25	1.50	3.0	1	0.109	0.00	4100	4.65	screw shear
C1R-3	1.5C	3.50	4.25	1.50	3.0	1	0.109	0.00	4100	5.06	screw shear
C2-1	1.5C	3.50	4.25	1.50	3.0	1	0.187	0.00	5800	5.16	screw shear
C2-2	1.5C	3.50	4.25	1.50	3.0	1	0.187	0.00	5800	5.36	screw shear
C2R-1	1.5C	3.50	4.25	1.50	3.0	1	0.187	0.00	4100	5.87	screw shear
C2R-2	1.5C	3.50	4.25	1.50	3.0	1	0.187	0.00	4100	5.69	screw shear
C3-1	1.5C	3.50	4.25	1.50	3.0	1	0.250	0.00	4300	4.70	screw shear
C3-2	1.5C	3.50	4.25	1.50	3.0	1	0.250	0.00	4300	4.11	screw shear
C4-1	1.5C	3.50	4.25	1.50	3.0	2	0.109	0.00	4300	4.24	screw shear/pullout
C4-2	1.5C	3.50	4.25	1.50	3.0	2	0.109	0.00	4300	4.57	screw pullout
C5-1	1.5C	3.50	4.25	1.50	3.0	2	0.187	0.00	4300	5.50	screw shear/cone pullout
C5-2	1.5C	3.50	4.25	1.50	3.0	2	0.187	0.00	4300	5.66	screw shear/cone pullout
C6-1	1.5C	3.50	4.25	1.50	3.0	2	0.250	0.00	4300	4.57	screw shear/cone pullout
C6-2	1.5C	3.50	4.25	1.50	3.0	2	0.250	0.00	4300	4.11	screw shear
C7-1	1.5C	3.50	4.25	1.50	3.5	4	0.163	1.20	4300	3.90	screw shear/cone pullout
C7-2	1.5C	3.50	4.25	1.50	3.5	4	0.163	1.20	4300	4.75	screw shear
C8-1	1.5C	3.50	4.25	1.50	3.5	4	0.250	1.20	3900	4.08	screw shear
C8-2	1.5C	3.50	4.25	1.50	3.5	4	0.250	1.20	3900	3.63	screw shear
C9-1	1.5C	3.50	4.25	1.50	3.0	4	0.163	1.20	5400	3.42	concrete cone pullout
C9-2	1.5C	3.50	4.25	1.50	3.0	4	0.163	1.20	5400	3.08	concrete cone pullout
C9R-1	1.5C	3.50	4.25	1.50	3.0	4	0.163/0.250	1.20	4400	3.44	concrete cone pullout
C9R-2	1.5C	3.50	4.25	1.50	3.0	4	0.163/0.250	1.20	4400	3.54	concrete cone pullout
C10-1	1.5C	3.50	4.25	1.50	3.0	4	0.250	1.20	5400	3.45	concrete cone pullout
C10-2	1.5C	3.50	4.25	1.50	3.0	4	0.250	1.20	5400	3.73	concrete cone pullout
C10R-1	1.5C	3.50	4.25	1.50	3.0	4	0.250	1.20	4200	3.96	concrete cone pullout
C10R-2	1.5C	3.50	4.25	1.50	3.0	4	0.250	1.20	4200	3.59	concrete cone pullout
C10R-3	1.5C	3.50	4.25	1.50	3.0	4	0.250	1.20	4200	3.72	concrete cone pullout
D1-1	1.5VL	1.75	2.50	1.50	3.0	1	0.109	0.00	3600	4.09	screw pullout
D1-2	1.5VL	1.75	2.50	1.50	3.0	1	0.109	0.00	3600	3.88	screw pullout
D2-1	1.5VL	1.75	2.50	1.50	3.0	1	0.187	0.00	3600	5.80	screw shear
D2-2	1.5VL	1.75	2.50	1.50	3.0	1	0.187	0.00	3600	5.51	screw shear
D3-1	1.5VL	1.75	2.50	1.50	3.0	1	0.250	0.00	3600	4.72	screw shear
D3-2	1.5VL	1.75	2.50	1.50	3.0	1	0.250	0.00	3600	5.62	screw shear

Table 2.1 Push-Out Test Results (continued)

Test Number	Deck Type	Bottom Rib Width, w_{r1} (in.)	Top Rib Width, w_{r2} (in.)	Rib Height, h_r (in)	Screw Height, h_s (in.)	Number of Screws per Rib, N	Top Chord Thickness, t_{tc} (in.)	Distance Between Rows of Screws within a Rib, l_s (in.)	Concrete Compressive Strength, f'c (psi)	Peak Shear Load Per Screw, R_n (kips)	Observed Failure Mode
D4-1	1.5VL	1.75	2.50	1.50	3.0	2	0.109	0.00	3600	4.12	screw pullout
D4-2	1.5VL	1.75	2.50	1.50	3.0	2	0.109	0.00	3600	3.98	screw pullout
D5-1	1.5VL	1.75	2.50	1.50	3.0	2	0.187	0.00	5400	5.47	concrete cone pullout
D5-2	1.5VL	1.75	2.50	1.50	3.0	2	0.187	0.00	5400	4.32	concrete cone pullout
D5R-1	1.5VL	1.75	2.50	1.50	3.0	2	0.187	0.00	3200	4.20	concrete cone pullout
D5R-2	1.5VL	1.75	2.50	1.50	3.0	2	0.187	0.00	3200	4.16	concrete cone pullout
D6-1	1.5VL	1.75	2.50	1.50	3.0	2	0.250	0.00	5400	4.10	concrete cone pullout
D6-2	1.5VL	1.75	2.50	1.50	3.0	2	0.250	0.00	5400	4.10	concrete cone pullout
D6R-1	1.5VL	1.75	2.50	1.50	3.0	2	0.250	0.00	3100	3.77	screw shear
D6R-2	1.5VL	1.75	2.50	1.50	3.0	2	0.250	0.00	3100	4.15	screw shear
D7-1	1.5VL	1.75	2.50	1.50	3.0	4	0.163	0.80	5400	2.37	concrete cone pullout
D7-2	1.5VL	1.75	2.50	1.50	3.0	4	0.163	0.80	5400	2.16	concrete cone pullout
D7R-1	1.5VL	1.75	2.50	1.50	3.0	4	0.163	0.80	3200	2.18	concrete cone pullout
D7R-2	1.5VL	1.75	2.50	1.50	3.0	4	0.163	0.80	3200	2.13	concrete cone pullout
D8-1	1.5VL	1.75	2.50	1.50	3.0	4	0.250	0.80	5400	2.51	concrete cone pullout
D8-2	1.5VL	1.75	2.50	1.50	3.0	4	0.250	0.80	5400	2.67	concrete cone pullout
D8R-1	1.5VL	1.75	2.50	1.50	3.0	4	0.250	0.80	3200	2.15	concrete cone pullout
D8R-2	1.5VL	1.75	2.50	1.50	3.0	4	0.250	0.80	3200	2.27	concrete cone pullout
D9-1	1.5VL	1.75	2.50	1.50	3.0	4	0.163	0.00	5100	1.92	concrete cone pullout
D9-2	1.5VL	1.75	2.50	1.50	3.0	4	0.163	0.00	5100	2.27	concrete cone pullout
D9R-1	1.5VL	1.75	2.50	1.50	3.0	4	0.163	0.00	3100	1.89	concrete cone pullout
D9R-2	1.5VL	1.75	2.50	1.50	3.0	4	0.163	0.00	3100	1.80	concrete cone pullout
D10-1	1.5VL	1.75	2.50	1.50	3.0	4	0.250	0.00	5100	2.30	concrete cone pullout
D10-2	1.5VL	1.75	2.50	1.50	3.0	4	0.250	0.00	5100	2.52	concrete cone pullout
D11-1	1.5VL	1.75	2.50	1.50	3.0	6	0.163	0.80	5100	1.59	concrete cone pullout
D11-2	1.5VL	1.75	2.50	1.50	3.0	6	0.163	0.80	5100	1.64	concrete cone pullout
D12-1	1.5VL	1.75	2.50	1.50	3.0	6	0.250	0.80	5100	1.63	concrete cone pullout
D12-2	1.5VL	1.75	2.50	1.50	3.0	6	0.250	0.80	5100	1.93	concrete cone pullout
D12R-1	1.5VL	1.75	2.50	1.50	3.0	6	0.250	0.80	3200	1.65	concrete cone pullout
D12R-2	1.5VL	1.75	2.50	1.50	3.0	6	0.250	0.80	3200	1.66	concrete cone pullout
E1-1	2VL	5.00	7.00	2.00	4.0	4	0.109	2.00	7400	3.54	top chord buckling
E1-2	2VL	5.00	7.00	2.00	4.0	4	0.109	2.00	7400	4.08	top chord buckling
E1R-1	2VL	5.00	7.00	2.00	4.0	4	0.109	2.00	4700	3.96	screw shear/pullout
E1R-2	2VL	5.00	7.00	2.00	4.0	4	0.109	2.00	4700	3.90	screw shear/pullout
E2-1	2VL	5.00	7.00	2.00	4.0	4	0.187	2.00	7200	6.01	screw shear
E2-2	2VL	5.00	7.00	2.00	4.0	4	0.187	2.00	7200	6.18	screw shear
E2R-1	2VL	5.00	7.00	2.00	4.0	4	0.187	2.00	5000	5.82	screw shear
E2R-2	2VL	5.00	7.00	2.00	4.0	4	0.187	2.00	5000	5.60	screw shear
E3-1	2VL	5.00	7.00	2.00	4.0	4	0.250	2.00	7200	4.15	screw shear
E3-2	2VL	5.00	7.00	2.00	4.0	4	0.250	2.00	7200	4.85	screw shear
E3R-1	2VL	5.00	7.00	2.00	4.0	4	0.250	2.00	5000	4.17	screw shear
E3R-2	2VL	5.00	7.00	2.00	4.0	4	0.250	2.00	5000	5.23	screw shear
E3R-3	2VL	5.00	7.00	2.00	4.0	4	0.250	2.00	5000	5.06	screw shear
E4-1	2VL	5.00	7.00	2.00	4.0	8	0.163	1.60	5000	4.29	concrete cone pullout
E4-2	2VL	5.00	7.00	2.00	4.0	8	0.163	1.60	5000	3.80	concrete cone pullout
E5-1	2VL	5.00	7.00	2.00	4.0	8	0.250	1.60	4800	3.50	concrete cone pullout
E5-2	2VL	5.00	7.00	2.00	4.0	8	0.250	1.60	4800	3.38	concrete cone pullout
E6-1	2VL	5.00	7.00	2.00	4.0	12	0.163	1.60	4900	2.77	concrete cone pullout
E6-2	2VL	5.00	7.00	2.00	4.0	12	0.163	1.60	4900	2.82	concrete cone pullout
E7-1	2VL	5.00	7.00	2.00	4.0	12	0.250	1.60	3800	2.62	cone pullout/shear
E7-2	2VL	5.00	7.00	2.00	4.0	12	0.250	1.60	3800	2.77	cone pullout/shear
F1-1	none	n/a	n/a	n/a	2.0	n/a	0.163	n/a	3800	6.79	screw shear
F1-2	none	n/a	n/a	n/a	2.0	n/a	0.163	n/a	3800	6.50	screw shear
F2-1	none	n/a	n/a	n/a	2.0	n/a	0.250	n/a	3700	7.61	screw shear
F2-2	none	n/a	n/a	n/a	2.0	n/a	0.250	n/a	3700	7.29	screw shear
F3-1	none	n/a	n/a	n/a	2.5	n/a	0.212	n/a	3800	7.01	screw shear
F3-2	none	n/a	n/a	n/a	2.5	n/a	0.212	n/a	3800	6.20	screw shear
F4-1	none	n/a	n/a	n/a	2.5	n/a	0.313	n/a	5100	6.02	screw shear
F4-2	none	n/a	n/a	n/a	2.5	n/a	0.313	n/a	5100	5.61	screw shear
F5-1	none	n/a	n/a	n/a	3.0	n/a	0.227	n/a	5700	x5.77	no failure observed
F5-2	none	n/a	n/a	n/a	3.0	n/a	0.227	n/a	5700	x4.64	no failure observed
F6-1	none	n/a	n/a	n/a	3.0	n/a	0.375	n/a	5600	6.17	screw shear
F6-2	none	n/a	n/a	n/a	3.0	n/a	0.375	n/a	5600	6.03	screw shear

Table 2.2 Full-Scale Test Geometric Parameters

Test Designation	Deck Type	Bottom Rib Width, w_{r1} (in.)	Top Rib Width, w_{r2} (in.)	Top Chord Thickness, t_{tc} (in.)	Rib Height, h_r (in.)	Srew Height, h_s (in.)	Number of Screws Per Rib, N (in.)	Distance Between Rows of Screws Within a Rib, l_s (in.)
CSJ-8	1.0C	0.90	2.77	0.123	1.00	2.0	1*	0.00*
CSJ-9	1.0C	0.90	2.77	0.123	1.00	2.0	1*	0.00*
CSJ-10	0.6C	0.75	1.75	0.109	0.56	2.0	1*	0.00*
CSJ-11	1.5VL	1.75	2.50	0.250	1.50	2.5	1*	0.00*
CSJ-12	1.0C	0.90	2.77	0.138	1.00	2.5	1	0.00*
CSJ-13	2VL	5.00	7.00	0.313	2.00	4.0	4	2.50

Table 2.3 Full-Scale Test Results

Test Designation	Concrete Compresive Strength, f'_c (ksi)	Bottom Chord Yield Stress, F_y (ksi)	Total Gravity Load Capacity per Joist (kips)	Applied Gravity Load per Joist (kips)	Calculated Total Horizontal Shear per Joist (kips)	Number of Shear Connectors per Half per Joist	Average Maximum Measured Shear per Connector (kips)	Reported Mode of Failure
CSJ-8	3600	59.3	28.3	23.8	32.3	9	3.56	Top Chord Buckling
CSJ-9	4600	65.6	37.0	32.7	55.3	18	3.07	Bottom Chord Fracture
CSJ-10	5000	67.0	15.0	13.7	52.7	19	2.77	Top Chord Yielding
CSJ-11	4600	60.2	76.7	65.1	140.4	36	3.90	Shear Connection Failure
CSJ-12	5100	60.8	35.5	31.2	70.14	15	4.68	Bottom Chord Yielding
CSJ-13	3800	59.7	126.9	112.5	291.7	76	3.84	Screw Shear

2.2.3. Results of Shear and Tensile Tests

Results of the single lap shear tests performed by ELCO Textron in 1992, which featured test apparatus shown in Figure 2.6, are presented in Table 2.4. Although performed separately, results of the shear tests with 0.187 in. loading plate thickness are also included in this set of results as the setup did not vary significantly from that of the other tests included in Table 2.4. No specific information was reported on the screw diameter and cross-sectional area, but a cross-sectional area of 0.058 in.^{2} will be used when calculating tensile and shear stresses in ELCO Grade 8 standoff screws. The variation from this value was very negligible in any measurements taken on any other screws prior to and following this particular set of tests. Wherever screws sheared off, failure occurred through the threaded part of the screw, as anticipated. Figure 2.11 shows the plot of strength vs. metal thickness based on the average capacity at each metal thickness. It should be noted that a pullout failure is not failure of the standoff screw, but rather failure of the base material in which the standoff screw is embedded.

Table 2.4 ELCO Single Lap Shear Test Results (1992)

Metal Thickness (in.)	***Load at Failure (lbs)***	***Observed Failure Mode***	***Metal Thickness (in.)***	***Load at Failure (lbs)***	***Observed Failure Mode***
0.109	3,760	Screw pull-out	0.155	5,570	Screw shear
0.109	3,530	Screw shear, hole elongation	0.170	5,700	Screw shear
0.109	3,750	Screw shear, hole elongation	0.170	5,510	Screw shear
0.123	4,480	Screw pull-out	0.170	5,900	Screw shear
0.123	4,350	Screw pull-out	0.187	5,500	Screw shear
0.123	4,660	Screw pull-out	0.187	5,700	Screw shear
0.138	5,380	Screw pull-out, hole elongation	0.187	5,600	Screw shear
0.138	5,350	Screw shear, hole elongation	0.187	5,700	Screw shear
0.138	5,410	Screw shear, hole elongation	0.250	5,730	Screw shear
0.155	5,580	Screw shear	0.250	5,370	Screw shear
0.155	5,980	Screw shear	0.250	5,680	Screw shear

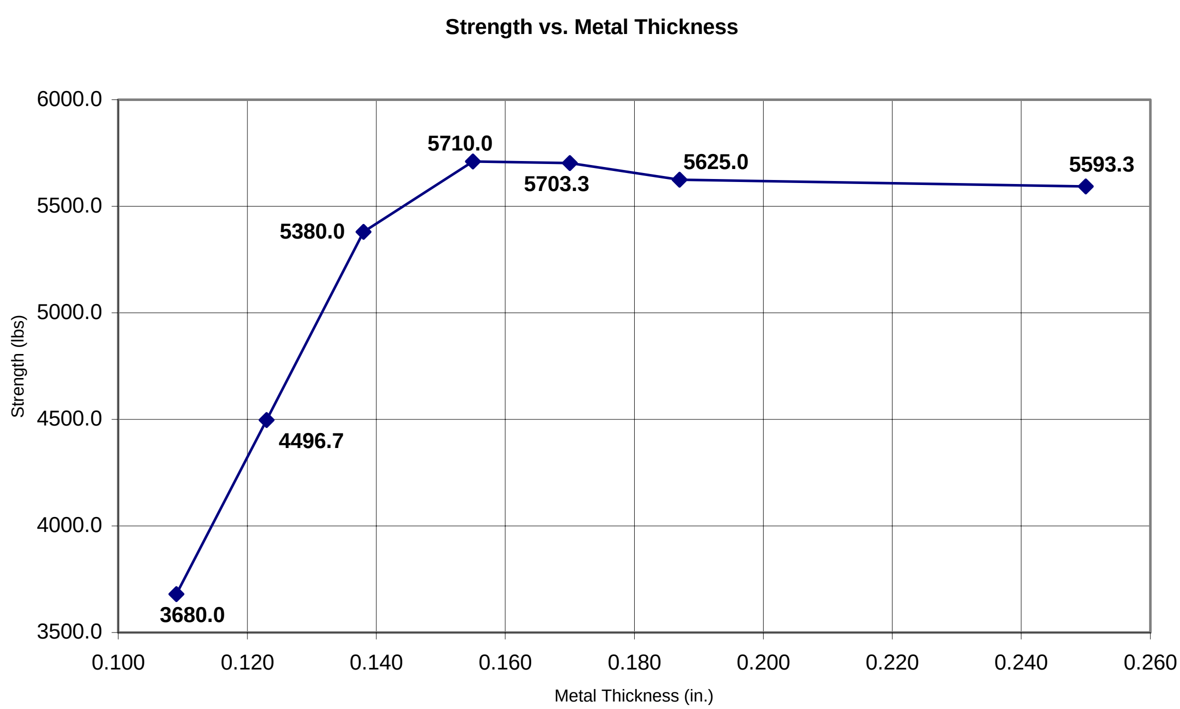

Figure 2.11 Strength vs. Metal Thickness Results Plot

Tensile tests corresponding to the apparatus shown in Figure 2.7, performed by ELCO Textron in 1992, are summarized in Table 2.5. An important point with these tests is that all of the screws broke through the shank rather than through the threads, as was characteristic for other tensile tests performed on ELCO Grade 8 standoff screws. The area of the standoff part was calculated based on the average diameter measured on 25 randomly selected screws.

Table 2.5 ELCO Tensile Tests on Grade 8 Standoff Screws

Screw 1	**Screw 2**	**Screw 3**	**Screw 4**
Strength = 10,450 lbs	Strength = 10,400 lbs	Strength = 10,500 lbs	Strength = 10,400 lbs
$\text{Strength}_{average}$ = 10438 lbs; Area = 0.06352 in.^{2}; $F_{u,average}$ = 164,300 psi			
All screws failed by shearing through the shank.			

The results presented in Tables 2.6 and 2.7 correspond with the tests shown in Figures 2.8 and 2.9, respectively. As indicated previously, peak tensile yield stress and load, as well as percent elongation for 2 and 4 in. long screws, shown in Table 2.7, should be ignored because the tests were terminated prior to the point at which screws ruptured. As shown in Table 2.7, the values of percent elongation and break stress were not reported for 2.5 and 3 in. screws, and are therefore not included with the rest of the results.

Table 2.6 Shear Test Results

Screw Standoff Length (in.)	**Cross-Sectional Area of the Screw (in^2)**	**Peak Load (lbs)**	**Peak Stress (lbs)**	**Elongation at Peak Load (in.)**	**Yield Load (lbs)**	**Yield Stress (psi)**
2.0	0.058	5819	100365	0.135	4916	84790
2.0	0.058	5928	102010	0.139	4862	83681
2.0	0.058	5769	99284	0.143	4888	84116
Average	0.058	5839	100553	0.139	4889	84196
4.0	0.058	5806	100147	0.136	4930	85029
4.0	0.058	5959	102549	0.132	4950	85194
4.0	0.058	5831	100352	0.130	4905	84406
Average	0.058	5865	101016	0.133	4928	84876

Table 2.7 Tensile Test Results

Screw Standoff Length (in.)	Cross-Sectional Area of the Screw (in^2)	Peak Load (lbs)	Peak Stress (psi)	Break Stress (psi)	Offset Yield Stress (psi)	% Elongation
2.0	0.058	9701	167258	137468	147633	14.8
2.0	0.058	9700	167237	134432	150837	13.1
2.0	0.058	9685	166985	123325	151005	15.4
2.0	0.058	9424	162470	128628	146360	12.7
2.0	0.058	9359	161365	133621	144297	10.0
Average	0.058	9574	165063	131495	148026	13.2
2.5	0.058	10510	181207	not reported	121136	n/r
2.5	0.058	10380	178966	not reported	158849	n/r
2.5	0.058	10420	179655	not reported	154516	n/r
Average	0.058	10437	179943	not reported	144834	n/r
3.0	0.058	10180	175517	not reported	137243	n/r
3.0	0.058	10330	178103	not reported	154794	n/r
3.0	0.058	10250	176724	not reported	149906	n/r
Average	0.058	10253	176782	not reported	147314	n/r
4.0	0.058	9300	160345	137862	145718	7.5
4.0	0.058	9765	168363	142045	151058	14.3
4.0	0.058	9899	170662	148596	151437	12.0
4.0	0.058	9526	164243	139351	147512	10.4
4.0	0.058	9572	165027	135594	149201	11.4
Average	0.058	9612	165728	140690	148985	11.1

Due to heat treatment procedures during screw production, the ultimate breaking stress in a screw can significantly vary depending on the location of the loaded cross-section. Specifically, standoff screw shanks are softer and thus will usually experience lower stresses at their breaking point. At the same time, threaded parts of the screw may experience significantly higher stresses. However, due to the fact that the standoff cross-sectional area is significantly higher than that of the threaded part, both parts should experience a similar load at their respective failures. Minimum specified tensile yield strength stress of a Grade 8 standoff screw is specified as 130 ksi. Minimum ultimate tensile strength stress is specified as 150 ksi (Janusz 2000). However, this stress within the same production run could vary from 150 to 175 ksi. This is not evidenced by the tests performed to date, as the ultimate tensile stresses were fairly uniform throughout the results obtained on different screw tests.