CHAPTER 2
ELEMENTAL TESTS

2.1. General

Composite slab behavior is a function of interactions among the components of the slab. Two of the most important interactions that significantly affect the slab behavior are: (1) the shear bond interaction at the interface of steel deck and concrete and (2) the interaction among the concrete, steel deck and end anchorages at the supports. Therefore, two types of elemental tests were conducted in this study: *shear bond* and *end anchorage*. The purpose of these tests is to study more closely the strength and behavior of shear bond interaction and end anchorages. These tests will also provide interaction data required for the numerical analysis that will be described in detail in Chapter 3 and Chapter 4. Elemental tests used in this study are similar to the push-out and pull-out tests by Daniels (1988).

2.2. Review of Research on Elemental Tests for Shear Bond and End Anchorages

The shear bond, or m-k, method requires a substantial number of performance tests for the shear bond regression line, plus additional flexure tests if flexural failure occurs within the range of parameters tested. The problem becomes more pronounced with the recent findings of other parameters that have significant impact on the strength of composite slabs, such as load pattern, end anchorages and additional reinforcing bars. This finding drastically increases the number of performance tests the manufacturers have to perform (Daniels and Crisinel 1987, 1993; Patrick 1990; Patrick and Bridge 1990; Patrick and Poh 1990; Bode and Sauerborn 1992).

This fact motivates research toward an alternative solution which can reduce the number of performance tests required or replace them with smaller elemental tests that are less expensive. Such elemental tests were set forth, such as the pull-out test (Daniels 1988; Daniels and Crisinel 1993; Sonoda et al. 1994), slip-block test (Patrick 1990; Patrick and Poh 1990), concrete-block bending test (An and Cederwall 1992; An 1993), push-test (Veljkovic 1993), push-out test (Tagawa et al. 1994). These elemental test results are to be used in the analysis for the slab strength and stiffness. One may argue that these elemental test results may not directly represent the actual behavior of the composite slabs because all the affecting parameters are inseparable with each other, such as clamping force and curvature of the slab. Analytical models using shear bond elemental test results, however, have shown good agreement with the full-scale test results, which indicates that those elemental tests are applicable.

Another parameter that significantly affects the strength of composite slab systems is the end anchorage. The presence of end anchorages over the support has a favorable effect on the strength of the composite slabs because these end anchorages tend to block the relative slippage of the concrete to the steel sheeting (Stark 1978; Crisinel et al. 1986a, 1986b; O'Leary et al. 1987; Jolly and Lawson 1992). End anchorages can be in one of the following forms: headed shear studs welded through the deck to the supporting beams, hot rolled angles welded to the beams, or cold formed members, such as pour stops. Porter and Greimann (1984) reported an increase of 8% to 33% in composite slab strength when stud end anchorages are used.

The strength expression for the headed shear studs has been established by Ollgaard et al. (1971) and has been used in the AISC Specification. This expression, however, was derived in conjunction with composite beam design in which both the concrete and the steel deck slip toward the same direction relative to the supporting beam. This is not the case with composite slab action in which the concrete moves relatively to the steel sheeting. Therefore, elemental tests for this type of end anchorages are of interest.

When a longitudinal slip occurs in the composite slabs, the steel deck is being pulled-out from between the supporting beam and the concrete. The strength of the anchorage for the steel sheeting is therefore a function of the sheeting strength and thickness, and also the clamping force provided by the concrete and the steel beam due to the support reaction. Hence, elemental tests for the end anchorage are needed to determine the force provided by the anchorage to the steel deck. Very detailed and extensive elemental tests for the end anchorages were carried out by Daniels (1988). The results from both the pull-out (shear bond) tests and the push-out (end anchorage) tests were input to finite element analyses. The analytical results were reported to compare favorably to the results of full-scale slab tests.

2.3. Shear Bond Elemental Tests

The shear bond interaction at the interface of steel deck and concrete can be separated into three components, namely, the chemical bonding, mechanical interlocking, and friction between the two materials. The first component is the type of bond that is developed through a chemical process as the concrete cured. This component of interaction is brittle in nature, and once it is broken it can not be restored. The mechanical interlocking gains its strength from the interlocking action between the concrete and the steel deck due to the embossments. This action is directly affected by the embossment shape and steel deck thickness. Finally, the presence of the friction between the concrete and the steel deck is due to the presence of internal pressure between the two materials. Unlike the first, the last two components are always present although they may change in magnitude. The shear bond elemental tests were designed to obtain as much information as possible about these three components.

2.3.1. Specimen Description and Test Set Up

The specimens were cast in a horizontal position so as to simulate the actual casting position for a composite slab. The size of the specimen was made 1 ft wide by 2 ft long such that it has at least one complete typical shape of the deck profile. To prevent the deck from being bent during handling, which may result in the loss of the chemical bonding, each piece of deck was fastened to a steel plate. Concrete cover above the deck was at least 2 in. to provide enough bearing area for testing. After the concrete had cured, the specimens were coupled back to back. Finally, banding strips were used to keep the concrete from falling off from the deck during handling and storing. These strips were removed before the test.

Test parameters considered were concrete compressive strength, steel deck strength, thickness, rib height, profile shape and embossment type as given in Table 2-1. The profile shapes and embossment types that were used are illustrated in Fig. 2-1 and Fig. 2-2, respectively.

A single test frame was designed to handle both the shear bond and end anchorage tests. The test set up for the shear bond test as shown in Fig 2-3, is intended to apply axial force, i.e., to pull the steel deck out from the concrete. This axial force was applied through a ram that was operated manually. The magnitude of the load applied was measured through a loading rod that was instrumented with strain gages and calibrated as a tensile load cell.

Table 2-1. Test Parameters

ID#	Concrete	Steel Deck					Internal
	fc'	fy	Thicknss	Rib ht.	Profile	Emboss.	Pressure
	(psi)	(ksi)	(in)	(in)	Shape	type	(psf) **
SB1-1	3850	50.3	0.031	2.00	1	3	500
SB1-2	3850	50.3	0.031	2.00	1	3	300
SB1-3	3850	50.3	0.031	2.00	1	3	100
SB2-1	3850	45.4	0.034	2.00	1	1	500
SB2-2	3850	45.4	0.034	2.00	1	1	300
SB2-3	3850	45.4	0.034	2.00	1	1	100
SB2-4	3850	45.4	0.034	2.00	1	1	300*
SB2-5	3850	45.4	0.034	2.00	1	1	100*
SB3-1	3850	46.5	0.047	2.00	1	2	500
SB3-2	3850	46.5	0.047	2.00	1	2	300
SB3-3	3850	46.5	0.047	2.00	1	2	100
SB3-4	3850	46.5	0.047	2.00	1	2	300*
SB4-1	4710	55.5	0.034	3.00	2	3	500
SB4-2	4710	55.5	0.034	3.00	2	3	300
SB4-3	4710	55.5	0.034	3.00	2	3	100
SB5-1	4710	52.1	0.056	3.00	2	3	500
SB5-2	4710	52.1	0.056	3.00	2	3	300
SB5-3	4710	52.1	0.056	3.00	2	3	100
SB6-1	4710	50.8	0.034	2.00	3	_	500
SB6-2	4710	50.8	0.034	2.00	3	_	300
SB6-3	4710	50.8	0.034	2.00	3	_	100
SB7-1	3840	48.2	0.056	6.00	4	_	300
SB7-2	3840	48.2	0.056	6.00	4	_	100
SB8-1	3840	49.6	0.057	4.50	5	_	300
SB8-2	3840	49.6	0.057	4.50	5	_	200
SB8-3	3840	49.6	0.057	4.50	5	_	128

* initial pressure, no further adjustment

** internal pressure at the interface of steel deck-concrete

For profile shapes and embossment types, refer to Fig. 2-1 and Fig. 2-2, respectively

For shear bond tests, a pair of additional frames is added to induced lateral force (Fig. 2-4). The lateral force is applied by tightening the nuts in the rods. This lateral force is to simulate internal pressure that is developed on the interface between the deck and the concrete. Load cells were installed in the lateral frames, as indicated in Fig. 2-4, to measure the magnitude of the lateral load applied.

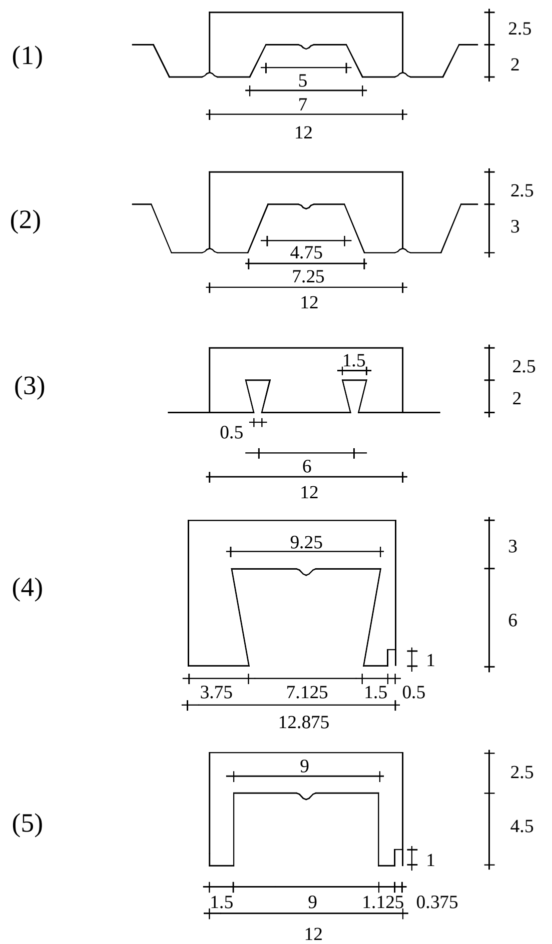

Figure 2-1. Profile shapes (all dimensions are in inches)

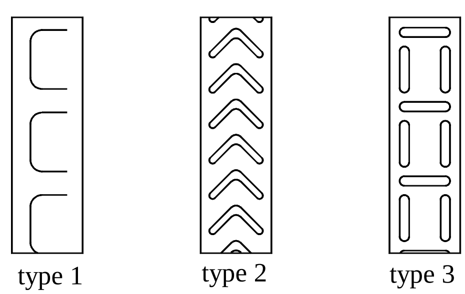

Figure 2-2. Embossment types

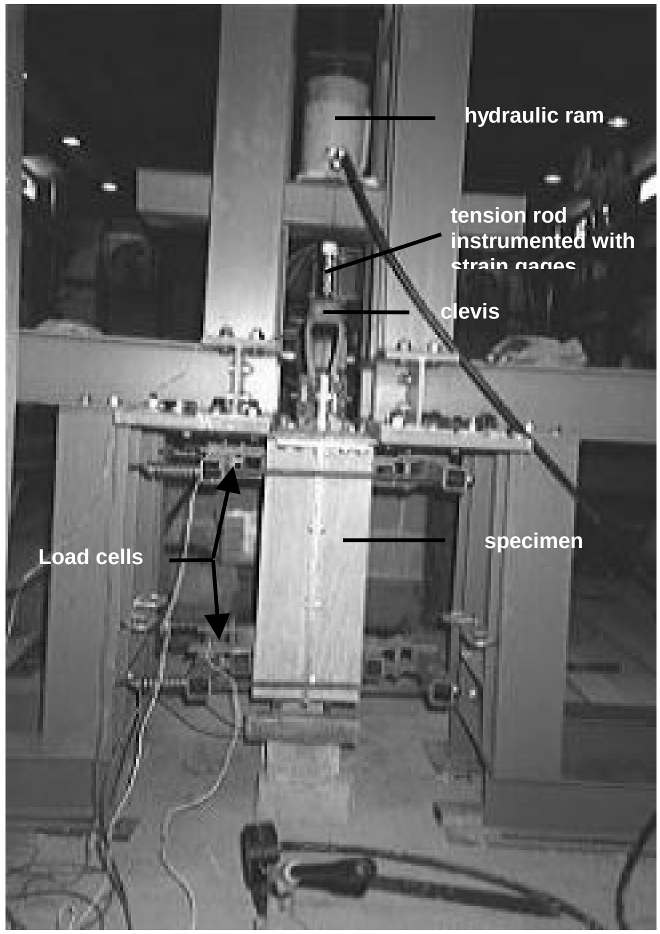

Figure 2-3. Shear bond test

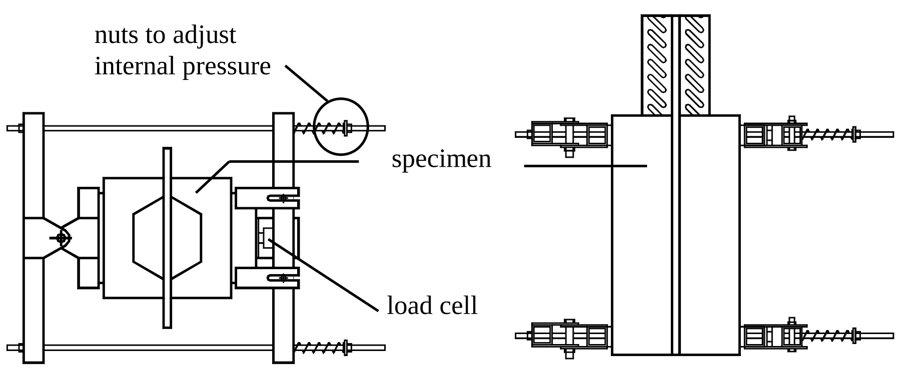

Figure 2-4. Shear bond specimen with frames for lateral force

2.3.2. Test Procedure

The test was performed by applying lateral and axial forces simultaneously. The lateral force is to produce internal pressure between the steel deck and concrete. The values of these internal pressures are listed in Table 2-1. These internal pressures were obtained by adjusting the nuts on the threaded rod of the lateral frame. The pressures were monitored from the load reading obtained from the load cells placed in the lateral frame as shown in Fig. 2-5.

The axial force was applied by using a hydraulic ram. This axial force pulls the steel deck out of the specimen, and therefore produces shearing stress on the interface between the concrete and steel deck.

At the bottom side of the specimen, slip transducers were placed to measure the slip between the concrete and the steel deck. The loads applied along with the corresponding slip were recorded. The tests were stopped after 1 in. of slip was reached where a relatively constant plateau was achieved.

2.3.3. Test Results

A summary of the test results is listed in Table 2-2. Plots of shear stress vs. slip for specimen SB2-2-A and SB6-1-B are shown in Figs. 2-5 and 2-6. In specimen SB2-2-A, as shown in Fig. 2-5, chemical bond can be observed as the vertical line at zero slip. At a shear stress level of 6.86 psi, this chemical bond failed which caused a sharp drop in the shear stress value. Beyond this point, the strength was due to the mechanical interlocking and friction. Some specimens, however, did not show a clear chemical bond response. This has been caused by a loss of chemical bond during handling.

The typical characteristic of this shear bond interaction is that after the loss of the chemical bond, the strength increases until the ultimate (peak) shear stress value and it is followed by a descending curve until it reaches a relatively long horizontal plateau at the end of the descending curve. The ascending and the descending curve represent the action of the mechanical interlocking, when the concrete tries to over-ride the embossment. In this action, the steel deck stiffness that is characterized by the thickness and rib height plays an important role. After the concrete completely over-rides the embossment of the deck, the resistant to the slip is relatively constant, in which case a horizontal plateau is resulted.

In the case with un-embossed deck, the response is very brittle as shown in Fig. 2-6. A horizontal plateau was obtained directly after the failure of chemical bond. This is because of the absence of mechanical interlocking due to the lack of embossments. The plateau is due to friction between the steel deck and concrete as observed from the test results that an increase in the lateral pressure results in a higher shear bond strength, in particular, in the plateau portion of the response. This fact is due to the friction between the two materials.

Table 2-2. Summary of shear bond test results

ID#	Max. Shear before slip (psi) (chemical bond)		Max. Shear after slip (psi)	Constant Shear (plateau) (psi)	Slip at Max. Shear (in)	
	A	B			A	B
SB1-1	6.87	8.10	8.25	5.95	0.160	0.102
SB1-2	6.03	5.81	6.67	4.32	0.124	0.154
SB1-3	7.07	7.07	6.23	2.25	0.208	0.041
SB2-1	4.44	5.75	7.19	3.92	0.094	0.093
SB2-2	6.86	5.09	6.49	3.60	0.119	0.167
SB2-3	2.85	3.22	5.02	2.03	0.159	0.067
SB2-4	4.40	4.15	5.60	3.19	0.151	0.129
SB2-5	4.87	2.87	4.80	2.73	0.085	0.142
SB3-1	9.78	9.36	12.17	8.78	0.064	0.104
SB3-2	9.88	6.81	11.92	6.10	0.062	0.166
SB3-3	7.97	9.83	8.67	3.27	0.126	0.226
SB3-4	7.07	6.02	10.45	6.21	0.094	0.103
SB4-1	7.05	9.18	10.59	6.20	0.031	0.072
SB4-2	6.91	7.03	8.79	3.70	0.057	0.057
SB4-3	3.38	5.53	6.93	1.50	0.061	0.088
SB5-1	4.46	5.43	15.17	6.00	0.064	0.067
SB5-2	3.88	8.06	15.44	4.50	0.078	0.095
SB5-3	3.73	2.89	12.76	2.00	0.112	0.062
SB6-1	11.59	10.54	10.54	6.50	0.102	0.004
SB6-2	9.50	8.91	10.00	5.00	0.699	1.001
SB6-3	7.48	7.38	7.38	5.80	0.005	0.216
SB7-1	10.78	17.66	21.12	7.66	0.431	0.235
SB7-2	17.99	12.49	17.99	8.70	0.195	0.476
SB8-1	11.34	13.18	11.34	5.27	0.108	0.082
SB8-2	11.65	11.40	11.40	4.06	0.065	0.106
SB8-3	10.30	14.53	15.55	3.99	0.004	0.204

A and B indicate the two specimen halves

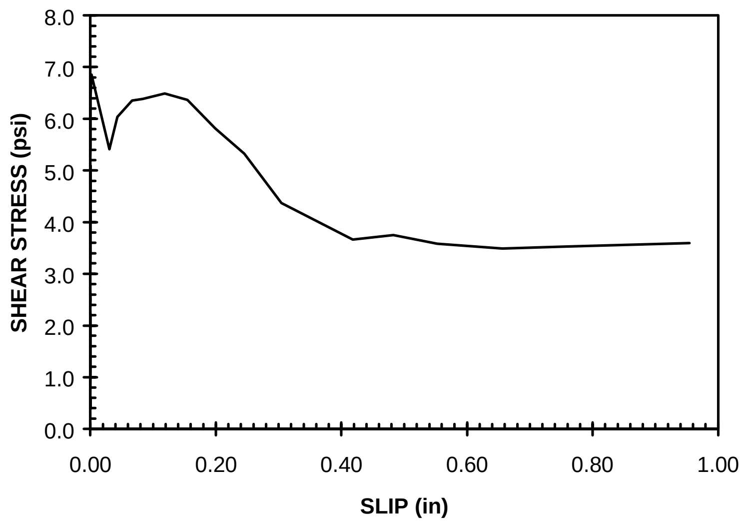

Figure 2-5. Shear stress vs. slip of specimen SB2-2-A

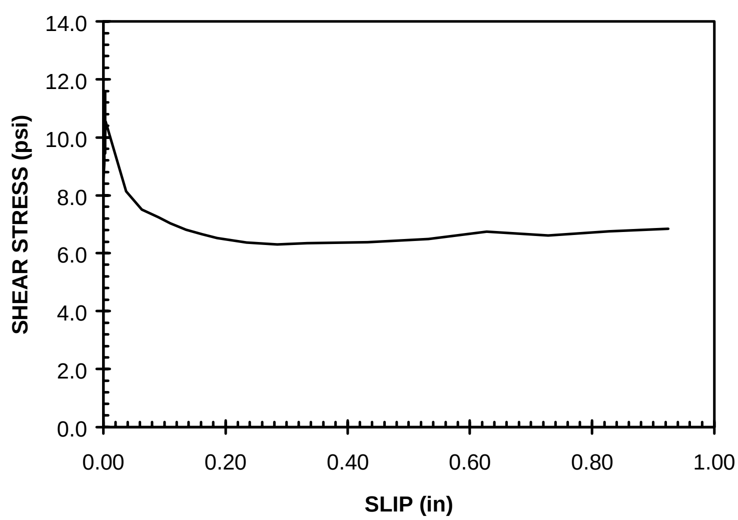

Figure 2-6. Shear stress vs. slip of specimen SB6-1-B

2.4. End Anchorage Elemental Tests

Three types of end anchorages were tested: headed shear studs, pour stops, and a combination of the two.

2.4.1. Specimen Description and Test Set Up

Similar to the shear bond specimens, the end anchorage specimens were cast in a horizontal position. The width of the specimens was 3 ft and the concrete cover above the deck was at least 2 in. to provide enough bearing area for testing. Details of end anchorage tested are illustrated in Fig. 2-7. In specimens EA2 and EA3, the deck was puddle welded to the beam and fillet welds were used for the pour stop. After the concrete had cured, the specimens were coupled back to back. Parameters of the tests are listed in Table 2-3.

For end anchorage tests, the shear bond test frame was used with a slight modification. A pair of rods was used to pull the deck out from the specimens. Figure 2-8 shows the test set up. A hydraulic ram, operated by an electric powered hydraulic pump, was put on top of the load cells and an additional frame, as shown in Fig. 2-8, was added to hold the ram. A load beam, made from a box section, was placed on top of the ram. In the space between the two specimens, several displacement transducers were placed to measure the relative slip of the concrete to the deck, and the deck to the beam.

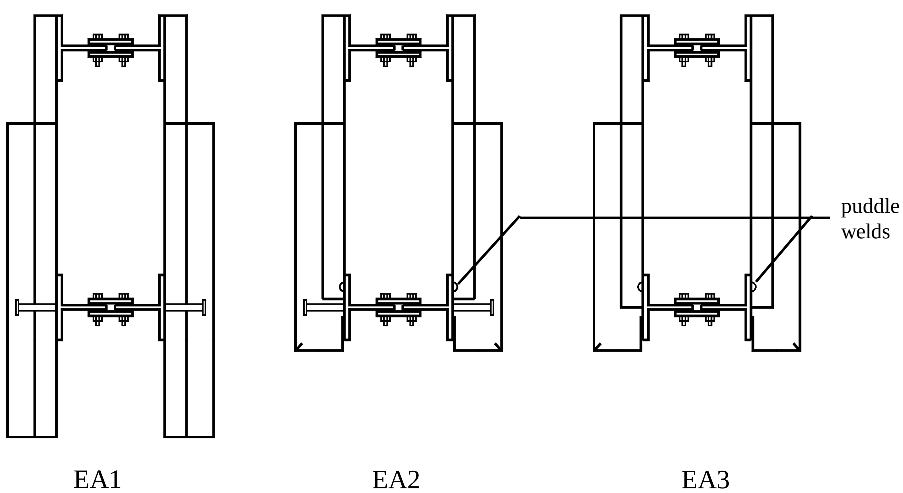

Figure 2-7. Details of the end anchorage specimens

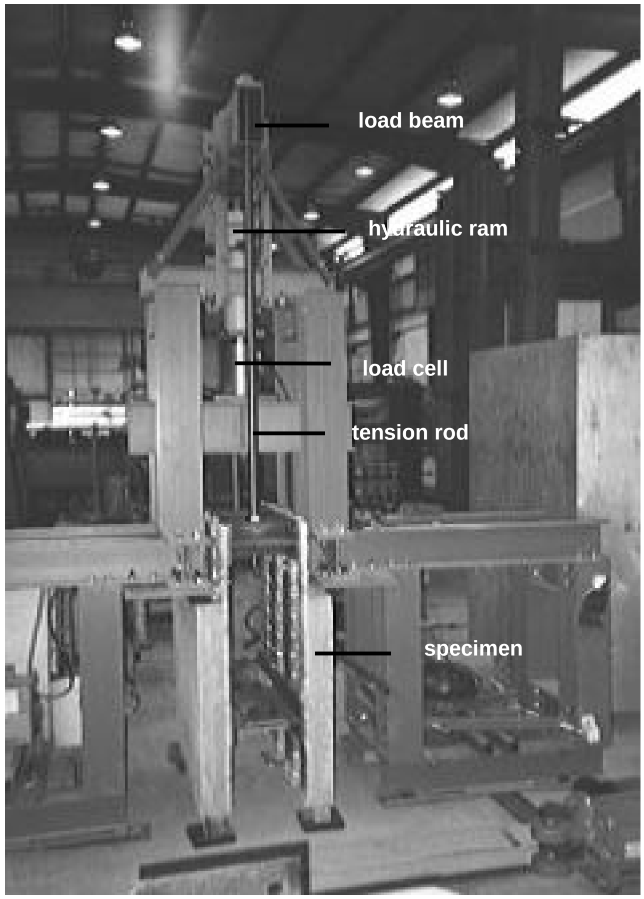

Figure 2-8. End anchorage test

Table 2-3. Test Parameters

ID#	Concrete fc' (psi)	Deck fy (ksi)	Deck Thicknss (in)	Deck Emboss. Type	Deck Rib ht. (in)	Deck Profile Type	End Anchor. Type	No. of Studs /side	No. of Puddle Welds on deck*	Fillet Weld on pour stop
EA1-1	4050	45.4	0.034	2	2.00	1	S	2	_	_
EA1-2	4050	45.4	0.034	2	2.00	1	S	2		
EA2-1	4050	45.4	0.034	2	2.00	1	PS	2	4	1" - 12"
EA2-2	4050	45.4	0.034	2	2.00	1	PS	2	4	1" - 12"
EA3-1	4050	45.4	0.034	2	2.00	1	P	_	4	1" - 12"
EA3-2	4050	45.4	0.034	2	2.00	1	P		4	1" - 12"

End anchorage types: S=shear studs, P=pour stop, PS=pour stop and shear studs
Embossment and profile type, refer to Fig. 2-2 and 2-1, respectively
* Puddle weld: 3/4" visible diameter

2.4.2. Test Procedure

In this test, there was no lateral force applied to the specimens. The axial force from the ram was incremented with an interval of 5 minutes to allow the system to settle. The load and the corresponding slips were recorded and the test was stopped when failure occurred as indicated by a consistently decreasing resistance to load.

As shown in Fig. 2-8, the ram pushes the load beam upward during the load test and the two rods held by this beam will pull the steel deck out of the specimens. The concrete part of the specimen is sustained by the frame.

2.4.3. Test Results

A summary of the test results is given in Table 2-4. Figure 2-9 and 2-10 show load vs. deck to concrete slip for specimen EA1-1-B (shear stud end anchorages) and specimen EA2-1-A (shear stud and pour stop). The failure mode in the later specimen is deck tearing around the weld, which is typical for other specimens with deck welded to the beam. The shear studs in this case do not give significant contribution to the strength because they were not welded through the deck.

Table 2-4. Summary of the end anchorage test results

ID#	Max. Load per Stud or Weld (k)	Computed Strength	
		Stud (k)	Weld (k)
EA1-1	10.45	26.59	_
EA1-2	9.90	26.59	_
EA2-1	6.87	26.59	3.03
EA2-2	7.16	26.59	3.03
EA3-1	5.86	_	3.03
EA3-2	5.70	_	3.03

In EA1 group of specimens, in which the studs were welded through the deck, the typical response of load vs. slip shows relatively ductile plateau. The failure was due to steel deck tearing and pilling in front and behind the studs, respectively. In EA2 group of specimens, the fact that strength of the specimens was considerably lower than in the EA1 was because the studs were not welded through the deck. Another cause was the relatively short distance of the steel deck puddle weld to the end of the deck (1.5 in). Therefore, the behavior of EA2 specimens are similar to those of EA3, where ductile plateau can not be maintained as soon as the deck tearing propagates to the edge.

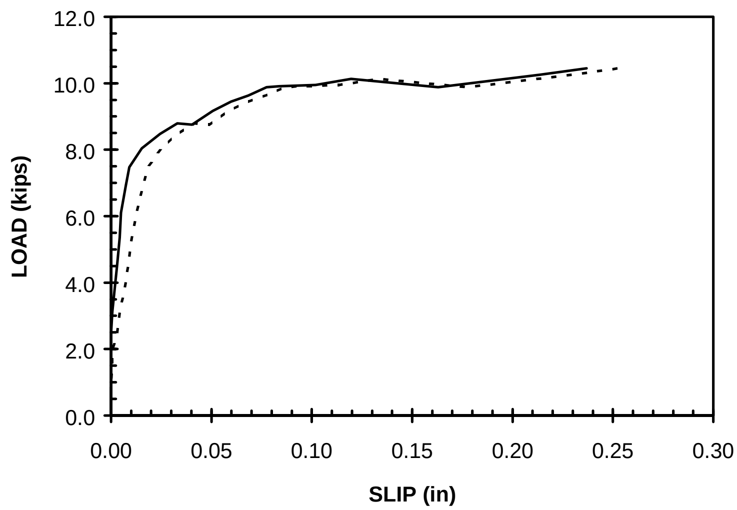

Figure 2-9. Load vs. deck to concrete slip of specimen EA1-1-B

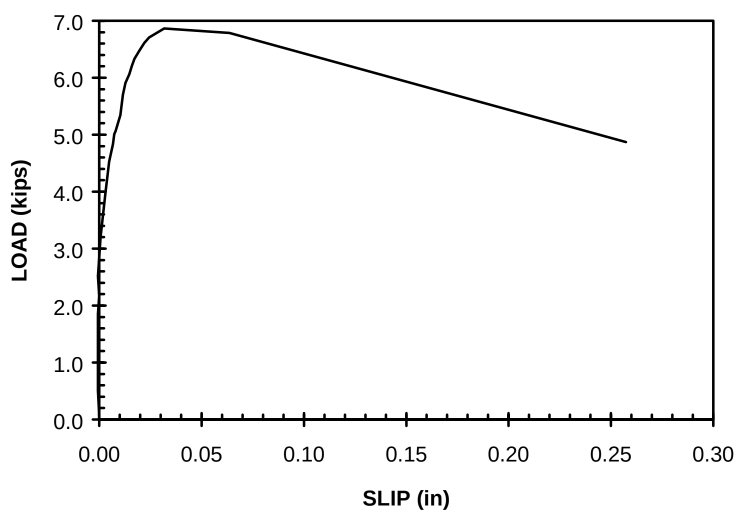

Figure 2-10. Load vs. deck to concrete slip of specimen EA2-1-A

2.5. Concluding Remarks

Based on the results of the shear bond test, it can be concluded that the shear bond strength is influenced by the internal pressure developed between the deck and the concrete. A more accurate determination of the internal pressure will lead to a more accurate shear bond strength prediction. This raises new issues on the relation of the internal pressure to the shear bond strength as well as the determination of the internal pressure.

From the comparison shown in Table 2-4, it can be noted that the strength of the puddle welds that were resulted from the tests are approximately double to the computed single weld strength values (LRFD Cold-Formed, 1991). The strength of the anchorage by the shear stud, however, is less than half of the single stud strength computed by using the AISC (1993) specifications. In the first case, the higher strength was suspected due to the clamping effect on the deck between the concrete and the steel beam. In the later case, the lower strength was caused by the deck tearing rather than the stud shearing.