EVALUATION OF DECK FASTENERS
FUNCTIONING AS SHEAR CONNECTORS
FOR COMPOSITE STEEL JOISTS

by
Leonard D. Strocchia

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APPROVED:

W. Samuel Easterling, Chairman

Richard M. Barker

Thomas M. Murray

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Committee Chairman: W. Samuel Easterling
Civil Engineering

(ABSTRACT)

The use of deck fasteners as shear connectors for composite open web steel joists is studied. Results of thirty-six push-off tests are evaluated in terms of strength and behavior. Six types of deck fasteners are considered. They are:

1. #12-24 Teks/5 self-drilling, self-tapping screws.
2. 1/4-14 Teks/3 with a 1 1/4 in. stand-off sleeve.
3. 1/4-14 Teks/3 with a 1 3/4 in. stand-off sleeve.
4. 1/4-14 Teks/3 with a 2 1/4 in. stand-off sleeve.
5. 0.150 in. dia. air fired pins.

All push-off tests utilize Vulcraft 1.5 VL, 22 gage, composite deck. Several modifications to the typical push-off test arrangement are made, which will permit the test to more closely model the top chord of an open web steel joist.

It was found from the push-off test results that all of the deck fasteners, tested in this study, can obtain composite action for short span open web steel joists with the exception of 0.150 in. diameter air fired pins. A description and the results of each push-off test is included.
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CHAPTER 1
INTRODUCTION

Composite open web steel bar joists (composite joists) are not commonly used in the United States. Typically, in joist/slab construction, formed steel deck is fastened to the top chord of the joists. The deck is used as a stay-in-place form for the concrete slab and may or may not be designed compositely with the slab. A non-composite joist is designed to carry the total live and dead load. The deck and the deck fasteners provide lateral support for the joist.

For a joist slab system to act compositely, the slab, the deck and the joist must work together to resist bending as one unit. To achieve composite action, special attention must be given to the fastening details between the slab, deck and joist. This study investigates the feasibility of obtaining composite action for short span open web steel bar joists.

1.1 Background

A common type of floor system, whose popularity is increasing, is the slab supported by open web steel bar joists or simply steel joists. Steel joists are standardized parallel chord trusses whose web members are typically round bars, commonly arranged in a Warren truss configuration. The chords are typically light double angle sections or one continuous cold-formed section. Most types of
joists use round bars for the web members, others use small angles or other hot-rolled or cold-formed sections. Formed steel decks, either composite or non-composite, are usually attached to the top chord of the joist by puddle welding, self-tapping screws, or more recently by air or power driven pins. Concrete slabs are then poured on the deck. This type of arrangement between concrete and steel is one of the lightest and most economical concrete floor systems (McCormac 1989).

There are several advantages associated with using joist supported floor systems. Joists can be erected quickly and easily. Ceilings can easily be hung from the bottom chords. The open web accommodates the passage of piping, ducts and other mechanical or electrical conduits.

The first official joist was manufactured in 1923. It was a Warren truss type with round bars for the top and bottom chords with one continuous bent bar for the web. Soon after, in 1928, the Steel Joist Institute (SJI) was established. The SJI was responsible for preparing the first standard specification followed by the first standard series of joists, the S-series, and the first standard load table (Marcus 1981).

The SJI has made many advances to date. In 1953, a specification and load tables were developed for Longspan (L-series) joists. Several major changes took place in 1961 due the introduction of A36 and Grade 50 steels. The new J-series and LA-series (Fy=36 ksi) replaced the S-series and L-series respectively, and a new H-series, using Grade 50 steel, was introduced. Subsequently, the LH-series was developed which was the LA-series using Grade 50 steel. Deep Longspan joists (DLJ- and DLH-series) specification and load
tables were developed in 1970 (Marcus 1981). Each advancement introduced used high-strength steels which increased spans and reduced joist weight.

The next major advancement may be the development of an economical composite joist series which will again decrease the weight of the joist/slab floor system for a given span. With each economic improvement to the system comes complications in design, serviceability and constructibility. For example, deflections may be the controlling limit state, instead of strength, for long span joists using high-strength steels.

There are certain design constraints associated with composite joists. The major concern is providing an economical, feasible and practical shear connection system between the concrete slab and the joist top chord. Conventional shear connectors used for beams are welded studs, welded channels and wire spirals. These shear connection methods are not feasible for composite joists. The welded stud cannot be used because the top chord angles are too thin for a good weld quality to be obtainable. Even if a good weld quality was obtainable, another problem with the stud deals with the lack of stiffness of the top chord angles, thus allowing the stud to rotate easily and deform the angles upon loading of the joist. Welded channels or spirals is simply not economically feasible for the purposes of a shear connection system for a composite joist.

1.2 Literature Survey

Several shear connection systems, in lieu of the welded shear stud for composite open web steel joists, have been tested from the mid 1960’s to present. This section shall discuss various methods of obtaining composite
action in open web steel bar joists. Several shear connection systems are presented for composite joists; however, one study deals with obtaining composite action in beams using the deck profile and mechanical fasteners.

As reported by Tide and Galambos [1970], the first recorded tests on composite open web steel joists were performed by Lembeck [1965]. Lembeck tested and compared two conventional joists to three composite joists. Each test consisted of two joists, basically 12H6 type, spanning 20 ft. and spaced 2 ft. on center. A 2 1/2 in. slab was cast on standard corrugated deck. For the composite joist, the 12H6 was slightly modified. The shear connection between the slab and the steel was provided by inverting the top chord angles and extending the web 2 1/4 in. into the concrete slab. See Figure 1.1. Filler rods, 1/2 in. diameter, were welded to the top chord between panel points to provide additional shear connection. The corrugated deck was supported on the horizontal leg of the top chord angles.

The composite joist was found to have significant improvements over the conventional joist. Deflection was reduced by 20% and the moment capacity was increased by 14% due to the achieved composite action. End slip was negligible due to the extended web, thus it provided adequate shear connection.

Another early composite open web steel joist was tested without the use of shear connectors by Wang and Kaley [1967]. See Figure 1.2. This joist is identified as the "K-composite" system, devised and patented by Edward S. Klausner. This composite joist relies on bond between the concrete and the one piece, continuous cold-formed, dovetail trough top chord to transfer the horizontal shear. No decking was used in this system. The concrete was placed on wood forms which were constructed under the top chords of the joists. The
FIGURE 1.1 FIRST COMPOSITE JOIST
FIGURE 1.2 K-COMPOSITE JOIST
forms were removed after the concrete cured. The slab was also haunched for 3 ft. from the end to encase the entire top chord. The end seats were welded to the supporting girders to provide additional shear connection.

Wang and Kaley concluded from the K-composite test results, that the bond was sufficient to achieve composite action for the joist test. When it was compared to a similar non-composite joist, it was found that the deflections were reduced and the moment capacity was increased.

Another test conducted in this study, (Wang and Kaley 1967), used the same basic joist with a slab cast on corrugated deck, plug-welded with standard weld washers and standard spacing were used to fasten the deck to the top chord. This joist tended to act compositely until the welds failed. As Wang and Kaley report, "this indicates that the plug-welds served as shear connectors and the joist has composite capabilities because it produced composite action at low load levels." The extent of composite action depends on the strength and quantity of the welds connecting the deck to the top chord.

Tide and Galambos [1970] tested five composite joists using 3/8 in. diameter welded studs and modified 16H4 type joists with a 3 in. solid slab. The purpose of the research was to investigate the behavior of composite joists using welded shear studs.

Three tests used a 16 ft. joist with a double angle top chord. In each test, the quantity of shear studs was varied. The studs were 3/8 in. diameter and 2 1/2 in. long. The first test used three shear studs located at the panel points in each shear span, the second used four shear studs located between the panel points and the third used six shear studs, three groups of two located between the panel points.
The remaining two tests were identical and consisted of a 16 ft. joist with a continuous cold-formed top chord. Three 3/8 in. diameter studs, 3 in. long, were used in each shear span. The studs were located between the panel points.

Tide and Galambos concluded that the length of the stud appears to effect the stiffness of the composite joist. The longer the stud the less stiffness. This was concluded when they compared the 2-piece top chord joist with the 2 1/2 in. stud to the 1-piece top chord joist with the 3 in. stud. The lack of stiffness may be due to the attachment in the trough of the 1-piece top chord. Each connector did not carry the same amount of shear load along the span and the location of the stud did not seem to make a notable difference in behavior of the composite joist.

Scatter in the data was observed and was attributed to three factors. these were, the local inconsistencies in the concrete around the stud, the diameter of the stud to the top chord thickness ratio, which was quite large, and the imposed deformation of the top chord due to the stud.

Cran [1971] conducted push-off tests on five types of shear connectors for potential use in composite open web steel joists. The five types of shear connectors tested were:

1. 1/2 in. dia. welded studs.
2. 3/4 in. dia. puddle welds.
3. 2 in. inverted hat connectors.
4. 1 15/32 in. OD welding washers (plug-welds).
5. 3 in. deep, 4 in. wide corrugated strap.

All connectors were tested in conjunction with 1 1/2 in. deep, 22 gage metal decking.
The push-off tests consisted of two pieces of cold-formed steel (0.110 in. thick), representing the top chord of the open web steel joist, welded together with a 5 ft. length of deck fastened to each side by the various shear connectors. The results from the push-off tests indicate that the behavior of the puddle welds and the corrugated strap were not ideal for composite joist systems. The failure was brittle and occurred upon reaching maximum load.

The welded stud, 2 in. inverted hat and weld washer with plug-weld were deemed satisfactory shear connectors because they exhibited ductile behavior. They carried load through large imposed deformations.

A major concern for this study was the shear strength of the welded stud connected to the thin top chord, which had a diameter of stud to flange thickness ratio ($d_S/t_f$) of 4.5. Three composite joists were tested using the connectors previously mentioned and all three joists behaved compositely. Cran also developed a design method for composite joists based on the composite joist tests.

Previous research conducted by Goble [1968] focused on the shear connection strength of thin flanged composite specimens using welded shear studs. The push-off specimens used $1/2$, $5/8$, and $3/4$ in. diameter welded studs to determine a limiting ratio of the diameter of the stud to the thickness of the flange ratio, ($d_S/t_f$).

As a result of the push-off tests conducted, a limiting $d_S/t_f$ of 2.7 was determined. This ratio indicates the shift in failure mode, of the stud, from flange pullout to stud shear. For A36 steel flanges, a ratio of less than 2.7 manifests a stud shear failure mode, while a ratio greater than 2.7, tends to result in a failure mode of flange pullout.
El-Shihy [1986] conducted 83 push-off tests consisting of five types of mechanical shear connectors and two types of formed metal deck. The five types of mechanical connectors used were:

1. Shot-fired threaded studs.
2. Shot-fired nails.
3. Angle bracket shear connectors.
5. Self-tapping screws fixed shear stud.

The two types of deck tested in conjunction with the five types of connectors were:

1. 2 in. deep holorib re-entrant deck, 18 gage, ribs 6 in. on center.
2. 1 3/4 in. deep composite trapezoidal deck, 18 gage, ribs 8 3/4 in. on center.

Based on the results of the push-off tests, two beam tests were carried out.

Each beam test used two different connectors in each shear span. The first beam test used holorib deck fastened with shot-fired threaded studs and self-drilling, self-tapping screws in each shear span. The second beam test used the composite trapezoidal deck fastened with angle bracket shear connectors and self-drilling, self-tapping screws in each shear span. The shot fired nails and the self-tapping screw fixed shear studs were not used in the full size beam tests. The shot-fired nails do not provide adequate strength and the self-tapping screw fixed shear stud exhibited a brittle failure mode in the push-off tests.

The results of the two full size composite beam tests indicate that the shot-fired threaded studs and the angle bracket shear connectors provide adequate shear connections. The self-drilling, self-tapping screws behaved well for the first
test but in the second test, some of the screws sheared as the beam reached its yield stress. Both beams achieved full composite action.

El-Shihy concluded that both the holorib and the composite trapezoidal deck can adequately achieve composite action between the concrete and the beam for the short span (25 ft.) composite beams tested in his study. An adequate quantity of the shot-fired threaded studs, angle bracket shear connectors or self-drilling, self-tapping screws must be provided.

Unterkofler [1989] conducted 23 push-off tests and two full size composite open web steel joist tests. The push-off tests evaluated assorted steel deck profiles functioning as shear connectors for composite open web steel joists. Based on the push-off tests, a deck profile was selected for the full size test. The basic types of deck profiles tested were:

1. 1/2 in. keystone shape deck.
2. 7/8 in. seam shape deck.
3. 2 in. trapezoidal shape deck
4. 1 1/2 in. composite trapezoidal deck

The deck profiles were fastened to the push-off test base member by puddle welds.

As a result of the push-off tests, the 1 1/2 in. composite trapezoidal deck was selected for use in the two full size composite joist tests. The first test used two puddle welds in each rib along the span and the second test used two self-drilling, self-tapping screws in each rib along the span.

Unterkofler concluded that the shear connection system implementing the 1 1/2 in. deck, fastened by either 5/8 in. diameter puddle welds or #14 self-tapping screws, was adequate to develop composite action between the slab and
the open web steel joist. The fasteners would control the strength and the
stiffness of the connection system.

1.3 Scope of Research

This study deals with the evaluation of shear connection systems which
may be feasible, practical and economical in obtaining composite action in open
web steel bar joists. The study is the second phase of a project dealing with this
subject.

Phase I was conducted by Unterkofler [1989] and dealt with the feasibility
of using the deck profile, welded to the top chord, as a shear connection system.
Push-off tests were conducted to determine the relative shear strength of several
dock profiles. Two full scale composite joists were fabricated and tested, each
using Vulcraft 1.5 VL, 22 gage deck as the shear connection system, see Figure
1.3. One test used two 5/8 in. diameter puddle welds in each rib along the span,
to connect the deck to the top chord, and the other test used #14 self-tapping
screws. Both joists achieved composite action because the bottom chord yielded
or fractured before the shear connection system between the slab and the top
chord failed.

This study is Phase II and is concerned with evaluating the shear capacity
of Vulcraft 1.5 VL deck fastened to the top chord of a joist with various fasteners
while carrying a concrete slab. The evaluation was carried out by conducting 36
push-off tests. Push-off tests are small scale tests used to determine the shear
capacity of shear connector systems used in composite construction. In the
process improvements to the push-off testing procedure was attempted.
FIGURE 1.3 FULL SIZE COMPOSITE OPEN WEB STEEL JOIST

C = CONCRETE COMPRESSION
T = STEEL TENSION
V = VERTICAL BEAM SHEAR
V_h = HORIZONTAL BEAM SHEAR
R = END REACTION
Push-off tests were conducted to quantify the strength and stiffness of the deck system used in composite joists. The push-off tests also compared various deck and fastener configurations to determine which configuration is the most efficient and feasible.

Thirteen push-off series, totalling 36 push-off specimens were tested to failure. Two basic categories of fastening systems were investigated in this study. The first consists of fastening the deck to the top chord with fasteners that are flush to the deck after installation. These fasteners are self-tapping screws, air fired pins and puddle welds. For these fasteners to be stressed by horizontal beam shear, the shear force must first be transferred to the deck profile and then to the fastener and ultimately to the top chord. Minimal interaction occurs between the concrete and the fastener.

The second category of fasteners act as shear transfer devices as well as fastening the deck to the top chord. These fasteners are self-tapping screws with stand-off sleeves around the shaft of the screw. The stand-off sleeve prevents the head of the screw from being driven flush to the deck during installation and also acts as a mechanism to clamp the deck to the top chord. The lengths of the stand-off sleeves investigated in this study are 1 1/4, 1 3/4, and 2 1/4 inches. Hence, these fasteners are embedded in the concrete and horizontal beam shear will be transferred to both the fastener and the deck profile simultaneously.

To simulate actual conditions which occur in a composite joist, modifications were made to the push-off specimens and the testing procedure. The result was the development of a push-off test which may predict the failure load of a shear connection system in a full scale composite joist.
CHAPTER 2
Push-off Test Improvements

2.1 General

Three modifications to the push-off specimens and set-up were made in this study, which result in an improved experimental model. The three modifications were, the use of light gage angles to represent the top chord of the joist, the application of a normal load to the slab to simulate gravity load on the joist, and constructing the specimens from two identical pieces.

2.1.1 Joist Top Chord Representation

For series 1 and 2, the deck was fastened to the flange of a WT 5x11 which had a flange thickness of 0.375 inches. This particular arrangement does not truly represent the actual top chord of a typical K-series joist. A composite joist typically has equal leg angles, of thickness from 0.100 in. to 0.25 in., for the top chord. Therefore, it is appropriate to use the same type of angles for the built-up T-section base member of the push-off specimen.

This was done starting with series 3 and was continued until the last series. The most important property to simulate in the push-off test is the thickness of the top chord angles of a joist, for this study, the sponsor chose to use a 0.113 in. thick 11/2 in. equal leg angle. The base member of the push-off test is used to simulate the top chord of a joist. The thickness of the angle base member affects the behavior of all the fastening systems tested in this study.
2.2 Application of Normal Load to the Slab

To better simulate a full size composite joist test, an incremental uniform load was applied normal to the slabs of the push-off specimen, as the specimen was loaded with a vertical load. In previous push-off tests (Unterkofler, et. al. 1969), the concrete slab prematurely debonded from the deck, thus yielding poor results. This problem does not arise in a full size composite joist because the slab is forced to maintain contact with the deck due to the gravity loading. Therefore, it follows that the concrete slab of the push-off specimen should be prevented from separating from the deck by applying some sort of load normal to the slab.

To evaluate the validity of this concept, the first two push-off series used a self-contained reaction frame to apply a restraining point load. See Figure 2.1. This load was not measured but it prevented the concrete slabs from separating from the deck. This restraining point load was used on half of the first eight specimens tested to evaluate whether the results differed between those specimens with the restraining point load and those without it.

The largest difference was observed in series 1, which used #12, self-drilling, self-tapping screws. There were four specimens in this series and two of the four had the restraining point load applied normal to the slab at rib no. 1, (the top rib). The result was that the specimens with the restraining load had a greater stiffness and ultimate strength. Also, debonding did not occur until after the deck failed in bearing around the screws.

For series 2, the difference was not as dramatic. This series used #12, self-drilling, self-tapping screws with a 1 1/4 in. stand-off sleeve which resulted in the screw being embedded into the concrete within the rib. Again, there were four specimens in the series, of which two specimens had a restraining load and two
FIGURE 2.1 RESTRRAINING LOAD FRAME
did not. The specimens which had the restraining load applied displayed a stiffer
Load vs displacement response; however, the ultimate loads of the tested
specimens were not effected by the applied restraining load. A transverse crack
in the slab did develop at mid-height due to the restraining load. Therefore, in
series 3, the restraining point load was applied 12 in. from the top of slab at rib
no. 3.

Since a notable difference was observed with the application of a normal
restraining load, a more elaborate method was developed to apply a load normal
to the slab of the specimen. This method involved applying an incremental
uniform load normal to the slab. An incremental load was used because in a full
scale composite joist, the increase in gravity load results in an increase in the
horizontal shear forces between the slab and the top chord. A relationship exists
between gravity load and horizontal shear, but it depends on the depth of the
joist, the size of the bottom chord, the span of the joist, the slab thickness and
concrete strength.

For series 4 through 13, the incremental load was based on dimensions of
a joist that was tested in Phase I of this study. The normal load was based on a
12 in. joist, a 4 in. slab, bottom chord steel area of 1.748 in², and a span of 25
feet. The maximum applied normal load, to the joist, is taken as the load which
causes the bottom chord to yield in tension.

From the full scale test results, the uniform gravity load needed to yield the
bottom chord in tension was 1175 plf. The normal force/shear force relationship
is determined by multiplying the maximum uniform load by half the span of the
joist, then dividing it by the bottom chord yield load in tension. This is illustrated in
Figure 2.2.
W = 1175 PLF

\[ W = \frac{C = 87 \text{ kips}}{V_h = 7.0 \text{ kips/ft}} \]

SPAN/2 = 12.5 FT.

\[
\text{TOTAL GRAVITY LOAD} = \frac{(1175 \text{ plf})(12.5 \text{ ft})}{87 \text{ kips}} = 169 \text{ LBS.} \]

\[
\text{BOTTOM CHORD TENSION FORCE} = \text{KIP OF SHEAR} \]

**FIGURE 2.2** NORMAL LOAD RELATIONSHIP TO HORIZONTAL SHEAR
To apply the normal force/shear force relationship to the push-off specimens some manipulation is required because the specimen consists of two slabs and the normal force is applied by a reaction frame. A reaction frame applies an equal amount of load to both slabs simultaneously, see Figure 2.3. To distribute the load uniformly, a W6x25 spreader beam was placed vertically along the slab on both sides inside the reaction frame.

2.3 Use of T-sections

Each specimen consists of two identical pieces bolted together. Each piece consisted of either a WT-section or a built-up T-section referred to as a base member.

"Each base member, with the steel deck fastened to its flange, was placed in a wood form for casting of the concrete slab. This procedure allowed both slabs of a specimen to be cast simultaneously and in a horizontal position. This procedure eliminated some of the undesirable effects of procedures used in other research to cast push-off specimens either vertically or horizontally or on separate days.

Slabs, for push-off specimens, cast in a vertical position may result in an uneven distribution of aggregate as the larger aggregate would tend to settle to the bottom of the form. Some researchers, who used W-shape base members, avoided this potential problem by casting one slab of a specimen one day, then turned the specimen over and cast the other slab the next day. This procedure results in a push-off specimen with concrete slabs of two different concrete batches which is undesirable and time consuming. The procedure used in this study efficiently produces concrete slabs which are more like an actual deck slab than push-off specimens slabs produced using other procedures." (Unterkofler 1989)
NORMAL FORCE = \frac{85 \text{ LBS}}{500 \text{ LBS}} \times \frac{1000 \text{ LBS}}{1 \text{ KIP}} = 169 \text{ LBS/KIP}

FIGURE 2.3 NORMAL LOAD/VERTICAL SHEAR RELATIONSHIP
CHAPTER 3
PUSH-OFF TEST DETAILS

This chapter will describe the manner in which the push-off specimens were fabricated, instrumented and loaded. Details explaining the different parameters for each series will be discussed at the end of the chapter.

Push-off tests are small scale tests used to determine the capacity of shear connector systems used in composite joists or beams.

This study consists of 13 push-off test series. A push-off series is defined as a group of specimens which have the same parameters. For example, push-off series one consists of four specimens all of which have the same type of fasteners, base member, deck width and length. The push-off series are numbered 1 to 13. The specimens which comprise the series are designated by a number, which indicates the series, and a letter, which identifies each specimen in a series. For example, 1A is specimen “A” from series “1”.

3.1 Push-off Test Setup

Prior to testing, it is essential that the specimen rest firmly and square on a level surface. The stems of the T-sections must be a smooth and level surface. After grinding the stems, a 1/4 in. steel loading plate 3 in. x 3 in. was centered, on the finished surface, with respect to the vertical bolt line. See Figure 3.1. The double angles were deliberately cut shorter than the plate so that they would not interfere with the loading and all the load was put onto the loading plate only.
Figure 3.1 Specimen Loading Detail
When the preparatory work was completed, the specimen was lifted by a crane and centered in a Universal Testing Machine on an elastomeric pad. For series 4 to 13, the specimen was first placed in the normal load frame then into the Testing Machine.

3.1.1 Specimen Fabrication

A typical push-off specimen tested in this study is shown in Figure 3.2. The specimen consists of two pieces. Each piece is composed of a WT-section or a built-up T-section representing the top chord of a joist, formed steel deck and a concrete slab. The WT-section or the built-up T-section is referred to as the "base member".

For this study, three fabricating procedures were used. First, the base member for series 1 and 2 was a WT 5x11. The other two procedures fabricated the base member from a built-up T-section consisting of two equal leg angles welded to a plate.

The first fabricating procedure required the WT 5x11 to be cut 44 inches in length and the 3/4 in. diameter holes to be drilled in the stem eight inches on center. Each base member requires an exact counterpart. Vulcraft 1.5 VL x 22 gage deck was fastened to the flange of the WT-section as shown in the appendix figures titled "specimen layout". Push-off series 1 and 2 used #12 Teks/5 self-tapping screws to fasten the deck to the 3/8 in. thick flange of the base member. After the deck is fastened to the base member, it is placed in a wood form for casting of the concrete slab. The slab represents the concrete floor slab on a composite joist. The base member and the attached deck are shown in the form in Figures 3.3 and 3.4.
Figure 3.2 Push-Off Test Specimen
Figure 3.3 Push-Off Specimen Forms
Figure 3.4 Push-Off Specimen Form
To better represent the top chord of a joist, the base member was changed to a built-up T-section for series 3 to 13. Push-off series three had a unique base member which consisted of two 1 1/4 in. equal leg angles welded to a 1/4 in. plate 6 in. wide and 36 in. long. Push-off series 4 to 13 used the same type base member consisting of two 1 1/2 in. equal leg angles welded to a 1/2 in. plate 6 in. wide and 44 in. long.

Since the test specimen was expected to receive a load of up to 80 kips, the welds which attached the four angles to the two plates were designed to take a minimum of 80 kips. Therefore, each angle carries approximately 20 kips.

All the base members had 6-7/8 in. diameter holes 8 in. on center in the stem of the T-section, except for series 3 which had 5-7/8 in. diameter holes 8 in. on center.

A week after the concrete was placed in the form, the forms were removed and the two pieces which comprise a specimen were carefully assembled by bolting the two pieces together with A325 3/4 in. diameter bolts.

The specimen was adjusted to achieve maximum stability and squareness, then the bolts were tightened to prevent any slip which may occur between the two plates upon loading. The tops of the T-sections are fitted to be at the same elevation. This is accomplished by using a grinder and grinding the stems of the matching T-sections until they are flush to one another. This procedure enables an equal load to be distributed to each piece during loading of the specimen. The concrete was cured for a minimum of 28 days prior to testing.

3.1.2 Test Instrumentation

As a composite joist is loaded, the slab slips relative to the top chord of the joist as shown in Figure 3.5. Due to the loading, an end slip occurs between the
end of the slab and the end of the joist. The amount of end slip which occurs influences the stiffness of the composite joist. If no end slip is observed at failure, then the composite joist has the greatest possible stiffness.

To quantify the stiffness of the push-off specimen, "end slip" was measured as shown in Figure 3.6. Depending on the deck fastening system, a slip may occur between the concrete slab and the deck. This slip is called "deck slip" and is measured as shown in Figure 3.7.

Dial gages were used to measure the displacement between the concrete slab and the base member and the displacement between the deck and the concrete slab. The dials were set to zero, the loading plate was put into place, the normal load frame was set up and the specimen was ready to be loaded with the vertical load.

A 10 kips load cell was placed inside the normal load reaction frame to measure the amount of normal force which was applied to the slab.

3.1.3 Loading Procedure

Figure 3.8 shows all of the forces applied to the specimen during testing. The specimens were tested by applying a controlled vertical load to the loading plate. This vertical load causes shear forces to develop at the interface between the slab and the base member, thus representing the horizontal shear forces which arise due to bending of a composite joist. The setup assumes that each slab carries an equal distribution of the vertical load.
FIGURE 3.5 DEFLECTED JOIST SHOWING END SLIP

FBD (CUT AT 1-1)

C = CONCRETE COMPRESSION
T = STEEL TENSION
V = VERTICAL BEAM SHEAR
R = END REACTION
DIRECTION OF APPLIED LOAD

MAGNET

DIAL GAGE

--- INITIAL POSITION

--- FINAL POSITION

FIGURE 3.6 END SLIP MEASUREMENT
DIRECTION OF APPLIED LOAD

DIAL GAGE

--- INITIAL POSITION

--- FINAL POSITION

FIGURE 3.7 DECK SLIP MEASUREMENT
Figure 3.8 Specimen Loading Diagram
Both the vertical and normal load were applied incrementally. The load normal to the slab was applied uniformly. The vertical load was applied slowly until failure occurred. Each test typically took 60 to 70 minutes to complete.

3.1.4 Test Parameters

The main test parameter for this study was the type of deck fastener. The formed steel deck, Vulcraft 1.5 VL, was a constant for all tests. The deck was 22 gage (0.0295 in.) material, galvanized and contained embossments. A 12 in. deck length was used for all push-off series except the last two, series 12 and 13, which used a 24 in. deck length. The dimensions of the deck profile are shown in Figure 3.9. The different deck fasteners tested in series 1 to 13 are shown in Figure 3.10.

The self-tapping screws and the stand-off screws were produced by "Buildex". The self-tapping screw used in series 1 and 9 was 0.215 in. in diameter, nominally #12. They were installed by a screw gun and were driven flush to the deck as shown in Figures 3.11 and 3.12. The stand-off screws were also installed by a screw gun; however, the stand-off screw is installed such that the screw is left protruding due to the sleeve around its shaft. This allowed the screw to be embedded in the concrete as shown in Figures 3.11 and 3.12. The stand-off sleeve lengths were 1 1/4, 1 3/4, and 2 1/4 in. Series 3 and 4 used the stand-off screw with the 1 1/4 in. sleeve; however, the deck was inverted in series 4. See Figure 3.11.

The air fired pins were used in series 5 and 6 and supplied installed by "Pneutek". The diameter of the pin was 0.150 in. The head of the pin was fired flush to the deck.
VULCRAFT 1.5VL x 22 GA DECK (37 1/2" COVER)

FIGURE 3.9 VULCRAFT 1.5VL, 22 GA GALVANIZED COMPOSITE DECK
SERIES

1,9  
\#12-24 x 1.25"  
SELF-TAPPING SCREWS

2  
\#12-24 x 3" W/1 1/4"  
STAND-OFF SLEEVE

3,4  
1/4-14 x 2" W/1 1/4"  
STAND-OFF SLEEVE

7,13  
1/4-14 x 3" W/2 1/4"  
STAND-OFF SLEEVE

8  
1/4-14 x 3" W/1 3/4"  
STAND-OFF SLEEVE

5,6  
0.150" DIA. AIR FIRED PINS

10  
5/8" DIA. PUDDLE WELD

11,12  
3/4'-1" DIA. PUDDLE WELDS

FIGURE 3.10 DECK FASTENERS
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<tr>
<th>SPECIMEN MARK</th>
<th>PART</th>
<th>DECK TYPE</th>
<th>DECK LENGTH</th>
<th>DECK WIDTH</th>
<th>TYPE OF FASTENER</th>
<th>NO. OF FASTENERS PER SPECIMEN</th>
<th>NO. OF FASTENERS PER RIB</th>
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<td>12-24 x 1.25&quot;</td>
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<td>NO. OF FASTENERS PER RIB</td>
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The puddle welds were made without welding washers. The visible diameter ranged from 5/8 in to 3/4 in. for the nominal 5/8 in. diameter puddle welds and from 3/4 in to 1 in. for the nominal 3/4 in. diameter puddle welds.

For all but two series, series 12 and 13, the concrete slabs were 12 in. wide, 5 1/2 in. thick and varied in length from 34 1/2 in. to 39 inches. Series 12 and 13 had 24 in. wide, 36 in. long and 4 1/2 in. thick slabs.

The concrete compressive strength for all tests ranged from 3800 psi to 4800 psi. The concrete was obtained from a local ready-mix firm with a requested strength of 4000 psi. Test cylinders were cast at the same time as the push-off specimens and were kept in the same environment. The test cylinders were tested the same day as the specimen was tested.

Each series used two fasteners in each rib of the deck except for seven individual tests, in series 3, 4 and 6, where one fastener in each rib was used to determine an experimental failure load value for the fastener.

The load normal to the slab was applied the same manner for series 4 through 13. It was applied uniformly at 8.5% of the vertical load. For the first three series, a restraining point load was applied normal to the slab.

Series 5 through 13 have identical parameters except for the fasteners and deck length. A summary of all the push-off test parameters is shown in Table 3.1. The thickness of the connected part refers to the thickness of the base member where the fastener connects the deck to the base member. The deck length refers to the dimension of the deck parallel to the ribs and deck width refers to the dimension of the deck perpendicular to the ribs. All the deck/fastener systems are shown in Figure 3.11 and 3.12.
FIGURE 3.11 SERIES 1-6 DECK/FASTENER SYSTEMS
FIGURE 3.12 SERIES 7-13 DECK/FASTENER SYSTEMS
CHAPTER 4

Push-off Test Results

4.1 General

This chapter summarizes the experimental results. Complete data for each test is presented in the form of a data pack, which is contained in the appendix of this thesis. The data pack should be referred to as the results of each series are discussed in section 4.2.

4.1.1 Description of Data Pack

For each individual push-off test, a four page data pack was assembled and is located in the appendix. Each data pack consists of a summary sheet, a specimen layout drawing, observations drawing, and response plots.

The summary sheet lists all the parameters and results associated with each test. The specimen layout drawing displays a front and side view of one of the two identical sides of the specimen. The side view includes the concrete slab to show the thickness; however, the slab was removed in the front view to show detail. The specimen observation drawing shows the side view of the complete specimen after failure. On each side of the side view, a front view of the slab is shown to illustrate any concrete failure which may have occurred. A hatched region on the sketch designates a concrete failure plane.
Two plots were developed by the data recorded during the testing procedure. The two plots are load vs end slip and load vs deck slip. End slip and deck slip are described in section 3.1.2.

4.1.2 Definition of Results

Several test measurements were used to evaluate the specimens. Maximum load is the maximum vertical load obtained by the specimen. All other results presented in the appendix are with respect to the maximum load value. Maximum end slip and deck slip are the slips which were recorded when the specimen reached its maximum load. The average end slip and deck slip are the average of the values recorded at the front and back slab at maximum load. Load per foot of deck is the maximum load for the specimen, in kips, divided by two times the deck width, in feet. Load per fastener is the maximum load divided by the total number of fasteners for the specimen. This does not necessarily represent the capacity of the fastener but rather the load on the fastener at failure. The failure mode is the observed limit state of the deck/slab shear connection system to the base member. A summary of the results for all the push-off tests conducted in this study is shown in Table 4.1.

4.2 Push-off Series Results

The results of 13 push-off series, 36 individual tests, are will be presented in this section. For each series, a brief description, an observation, a description of the failure mode, an interpretation of the response plots and a comparison to other push-off series are discussed. To better understand the
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<th>Concrete Strength (psi)</th>
<th>Max. Load (kips)</th>
<th>Max. Ave. End Slip (in)</th>
<th>Load per Foot of Deck (k/ft)</th>
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<td>Max. Ave. End Slip (in)</td>
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<td>Load Per Fastener (kips)</td>
<td>Failure Mode</td>
</tr>
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discussion of each series, the data packs in the appendix should be referred to as needed.

4.2.1 Push-off Series 1

Series 1 consisted of four specimens, subdivided into two groups of two. Specimens 1B and 1D were tested with a restraining point load applied normal to the slab on each side at the rib nearest the top of the specimen. Specimens 1A and 1C were tested without the restraining load applied.

Two #12 self-tapping screws were placed in each rib to fasten the Vulcraft 1.5 VL deck to the flange of the WT 5x11. The screws were centered in each rib and placed 3 in. apart.

The limit state of the #12 screw, attached to the deck without the presence of the concrete slab, is bearing failure of the deck. The head of the screw is 1/4 inch in height and protrudes into the concrete slab. This adds strength to the connection and the specimen since the concrete around the head of the screw must break before a bearing failure can take place in the deck at the screw.

(Specimens 1A and 1C, no restraining load) In general, these specimens failed by a combination of deck debonding from the concrete, deck deformation at rib no. 1 (the top rib), and deck bearing at the screw locations. See Figures A.2 and A.8. Deck debonding occurred as the head of the fastener broke a portion of the concrete at nearly 70% of maximum load. As debonding continued, the slab moved away from the deck and deformation of the deck at the top rib was apparent. The deck began to fail in bearing around each screw after the concrete around the head failed. Deck bearing failure was the primary limit state of the specimens. The relation between load and end slip was essentially
linear up to 70% of maximum load and an end slip of 0.040 in., after which large slips resulted from a small increase in load, signifying that the specimen was losing stiffness. The portion of the curve after the linear region resembles a yield plateau and shows that the deck fastening system is ductile and capable of holding loads at an end slip near 0.100 inches. Deck slip was insignificant up to 90% of maximum load. When deck slip is first observed, failure of the specimen is eminent.

(Specimens 1B and 1D, restraining load applied) These specimens showed greater strength and stiffness due to the application of the restraining load. On the average, a 20% increase in strength was observed. This is shown in Figure 4.1. Deck debonding and deformation did not occur and the specimens failed due to deck bearing failure around each screw. See Figures A.5 and A.11.

The relation between load and end slip was essentially linear up to 85% of maximum load and an end slip of 0.020 in., after which a long yield plateau is observed. See Figures A.6 and A.12. These specimens were slightly more ductile than the first group.

Since the restraining load caused a significant difference in the behavior of the deck fastening system, the #12 self-tapping screws were retested in series 9, with an incremental uniform load applied normal to the slab and a base member which better represents the top chord of a joist.

4.2.2 Push-off Series 2

Series 2 was identical to series 1 except for the type of deck fasteners. The deck fasteners used were #12 self-drilling, self-tapping screws with a 1 1/4 in.
Figure 4.1 Effect of Normal Load
stand-off sleeve. The stand-off sleeve serves two purposes. First, it prevents the head of the screw from being driven flush to the deck surface during installation and second, it clamps the deck to the base member.

The stand-off screw is embedded in the concrete 1 1/4 in. plus 1/4 in. for the head which yields a 1 1/2 in. total embedment length. Due to this arrangement, the fastener receives load from the concrete rather than the deck profile, which relieves the deck profile from carrying all of the load in the system. The deck profile tends to carry load toward the ends of its ribs (the region away from the screws).

The top of this fastener is even with the top of the ribs of the deck. All the specimens failed due to concrete shear across the top of the fasteners and continued across the entire length of the ribs of the deck, at each rib except rib no. 6 (the rib at the bottom of the specimen), in which all four fasteners sheared. See Figures A.14, A.17, A.20 and A.23. The specimens failed immediately upon reaching maximum load and a brittle failure occurred.

It should be noted that, the only possible limit state for rib no. 6 is fastener failure or deck bearing failure since rib no. 6 is not a typical rib but rather a solid mass of concrete. This situation was not modified until series 12 and 13.

The brittle nature of the specimen can be observed in the load-end slip plot comparing specimen 2B to 1B in Figure 4.2. Typically for series 2, as can be seen in Figures A.15, A.18, A.21 and A.24, when the end slip reached approximately 0.02 in., cracks in the concrete ribs developed and complete sudden failure followed. Deck slip was not observed, which supports the theory that the fasteners act as shear transfer devices and carry most of the load in this type of deck/fastener arrangement.
Figure 4.2 Load-End Slip Comparison of 1B and 2B
The application of the restraining load had minimal effect on this series, because debonding does not occur, thus does not affect the strength of the specimens. The specimens with the restraining load applied did have a slightly stiffer load-end slip response than those without it.

This series can be directly compared to series 1 since all parameters were the same except for the type of deck fastener. In comparison, series 2 had greater strength but less ductility. Series 2 failed at an end slip which was approximately 25% of the end slip which series 1 had at failure.

Since the limit state of series 2 was shear across the concrete rib and not screw failure, the stand-off screws have the potential to carry additional load. The stand-off screw can carry a higher load if concrete rib failure does not occur. Due to the thick base member, the stand-off screws in series 2 have the greatest stiffness. As opposed to tests which follow that use a thinner base member material.

There are several ways to try to avoid concrete rib failure. The basic principal is to increase the potential concrete rib failure plane. In series 4, the deck was inverted which increased the concrete failure plane across the rib. In series 7, the stand-off sleeve length was increased to 2 1/4 in. to get the top of the screw out of the concrete rib failure plane, which is across the top of the ribs of the deck, and embed it further into the solid portion of the slab.

4.2.3 Push-off Series 3

The intent of series 3 was to test the same deck fasteners as series 2 but to use a base member which more closely represents the joist top chord. It was felt
that the relatively thick flange of the WT 5x11 may have been influencing the test results.

The screw diameter inside the stand-off sleeve was increased from a nominal #12-24 to a nominal 1/4-14 self-tapping screw. A restraining point load was applied to all four specimens in this series at 12 in. below the top of the slabs. This height was selected because a transverse crack occurred in the slab at mid-height on specimens 2B and 2D due to the restraining load. The restraining load was thus moved closer to mid-height of the slabs to prevent the transverse crack from occurring.

To obtain an experimental ultimate shear value for the 1/4-14 stand-off screw, one fastener, instead of two, was placed in each rib of the deck. Two of the four specimens in the series, 3A and 3D, were arranged with one screw per rib and the other two specimens, 3B and 3C, were arranged with two screws in each rib.

While loading specimens 3A and 3D, it was observed that some of the screws were bending. This was observed at the exposed portion of the screw where the screw was attached to the base member. This behavior was not observed in series 2, because the thickness of the base member was 0.375 in., as opposed to this series, in which the base member thickness was 0.109 inches. See Figures A.26 and A.29.

The screws bent due to the lack of stiffness in the base member connection. Due to this bending of the screw, the thin angle base member was locally distorted around the screw. See Figure 4.3. All of the screws did not fail by direct shear, bending and tensile stresses ultimately failed some of the screws. A few screws failed by shear alone, this can be determined by observing the
failure surface of the screw. A shear failure has a shinney smooth surface and a bending-tension failure has a dull rough surface. The average experimental ultimate strength of the screw in this arrangement is 2.2 kips. This result is useful for analyzing tests in this study which use a 1/4-14 self-tapping flush screw inside the stand-off sleeve.

The load-end slip plots for the two specimens are surprisingly not similar as shown in Figures A.27 and A.30. For 3A, the Load-End Slip curve was smooth and consisted of a linear elastic region and a long yield plateau as expected for a plot of steel screw failure in shear. For 3D, the load-end slip curve was less stiff and more brittle. This difference is possibly due to minor concrete failure which occurred in the front slab of 3D, as shown in Figure A.29, but this does not explain the lack of stiffness.

Specimen 3B and 3C had two screws per rib. However, the specimens did not reach a failure load of twice the value that specimens 3A and 3D reached. The limit state was concrete shear of the rib at a load approximately 50% higher than observed in specimens 3A and 3D.

The failure mode was predominantly a concrete shear failure. The failure plane appeared to be limited in width to approximately 7 to 9 inches. See Figures A.32 and A.35. After failure occurred, the slabs were removed and it was observed that the stand-off screw bent inside the concrete rib which may have promoted concrete failure close to the screw locations. The concrete rib is too narrow to resist the bending of the screw. In the ribs which the concrete did not fail, it was observed that local cracking occurred in the concrete around the screw and the screw failed by a combination of bending and tensile stresses. The screw generally fractured 1/8 to 1/4 inches into the concrete rib.
The load-end slip plot was very linear up to 85% of maximum load and the response was as stiff in the elastic region as the specimens with one screw per rib as shown in Figure 4.4. Due to the brittle concrete failure, the specimens with two screws per rib were unable to achieve the ductility of the specimens with one screw per rib. Deck slip was insignificant for all specimens in this series.

4.2.4 Push-off Series 4

Series 4 used the same 1/4-14 self-tapping screws with a 1 1/4 in. stand-off sleeve as in series 3; however, in an attempt to prevent concrete failure, the Vulcraft 1.5 VL deck was inverted to increase the potential concrete rib failure plane. See Figure 4.5. By inverting the deck, the larger width rib is in contact with the base member instead of the narrow rib. If concrete failure is effectively prevented, screw shear failure should be the controlling limit state for the specimen.

Two of the four specimens, 4A and 4B, had one screw in each rib and the other two specimens, 4C and 4D, had two screws in each rib. This was done as in series 3, to evaluate the strength when the limit state is screw shear.

Specimens 4A and 4B exhibited a ductile screw failure. The average screw capacity was 2.4 kips which is slightly higher than the 2.2 kips achieved in series 3. During loading, it was observed that the screws bent, as in series 3. Upon removing the slab from the base member it was observed that the screw did not bend at all inside the concrete rib and the concrete was unscathed. All the screws did not fail at the interface of the of the base member and the deck, instead the screw fractured 1/8 in. into the concrete rib as in series 3. The screws
Figure 4.4 Load-End Slip Comparison of 3A and 3B
FIGURE 4.5 INVERTED DECK
failed due to bending and tensile stresses and the angle base member was locally deformed around the screw.

The load-end slip plots show that the system is non-linear from the onset of loading and continually loses stiffness as the load is increased as shown in Figures A.39 and A.42.

Specimens 4C and 4D had two screws in each rib. No concrete failure occurred, therefore they carried nearly twice as much load as those with one screw per rib. The specimens exhibited a ductile failure and the screws failed by a bent-tension failure. The ultimate strength of the screws were 2.2 kips, slightly less than the 2.4 kip value obtained from 4A and 4B.

Comparing load-end slip plots, the specimens with two screws per rib were stiffer and stronger than the specimens with one screw per rib. As shown in Figure 4.6, the curves display the same non-linear shape. Maximum end slip increased 40% and the strength increased 90% due to doubling the number of screws. Deck Slip was not as significant for the specimens with two screws per rib. See Figures A.39, 42, 45 and 48.

4.2.5 Push-off Series 5

Series 5 consisted of three identical specimens which used two 0.150 in. diameter air fired pins in each rib of the deck. The pins were installed by a PT-700U Pneutek Air/Safe fastening tool. This tool uses air pressure to safely fire hardened steel pins through the deck and into the base member.

Due to the installation process, the base member was damaged as shown in Figure 4.7, which hindered the performance of the fastening system. Since the
Figure 4.6 Load-End Slip Comparison of 4A and 4D
FIGURE 4.7  DAMAGED BASE MEMBER DUE TO PIN INSTALLATION
pin is anchored in the base member at a distance of "e" away from the deck connection, an eccentricity is developed which tends to tip the pin during loading.

The failure mode for the fastening system is deck bearing failure at the pins. The failure was extremely ductile and large end slips were recorded at maximum load. The ductility comes from the tipping of the pin and the gradual bearing failure. The average experimental ultimate capacity of the pins, connected to 22 gage deck, was 1.1 kips as determined from this series. The concrete did not have any noticeable effect on the pins strength mainly because the head of the pin was flush to the deck surface. Friction did have an effect on this deck fastening system. Friction is discussed in Section 5.1.5.

The load-end slip plot consisted of a linear elastic region and a large yield plateau. The data points displayed a smooth curve as shown in Figures A.51, 54 and 57. Deck slip was insignificant.

The air fired pins are a fast, clean and efficient deck fastening system; however, it is not a good fastening system for composite joists based on strength and the damage which can be done to the top chord of a joist. The imposed deformation of the top chord angles is detrimental to their function as compression members. This fastening system is not feasible for composite joist design in this study because they do not have the strength or the stiffness required.

4.2.6 Push-off series 6

In this series, the same air fired pins were used as in series 5 but only one pin was placed in each rib instead of two. The observations and failure mode are the same as series 5. The average experimental ultimate capacity of each pin in
this series was 1.2 kips, slightly higher than the results in series 5. The total
strength of these specimens were nearly half of the strength of the specimens in
series 5.

4.2.7 Push-off Series 7

Series 7 consisted of two identical specimens which used two 1/4-14 self-
tapping screws with a 2 1/4 in. stand-off sleeves in each rib. The intent of this
series was to anchor the head of the screw one inch above the top of the ribs of
the deck so that the screw failure can occur instead of concrete failure.

As observed for series 2 and 3, the concrete failure plane was across both
the tops of the screws and the ribs of the deck. By extending the stand-off sleeve
1 in. into the solid portion of the slab, the concrete failure plane may increase and
thus increase the strength of the concrete rib and cause the screw to fail.

The stand-off screws carried most of the load except towards the ends of
the ribs of the deck where the deck profile carried the load. All of the screws bent
at the exposed portion of the screw and the angle base member was locally
deformed.

The failure mode for this series was concrete shear across the ribs of the
deck. It was observed, after the specimens had failed, that the stand-off screw
bent inside the concrete rib which may have promoted concrete rib failure. The
concrete at the head of the stand-off screw failed just below the head and the
failure continued across the entire length of the ribs. See Figures A.68 and A.71.
A few screw failures were observed, but these typically occurred after the
concrete rib had failed. This occurred because the head of the stand-off screw
was above the concrete failure plane and when the rib failed, the stand-off screw
was still stuck into the solid portion of the slab. This improved the ductility of the specimen. Upon removing the slabs after failure, it was observed that all of the stand-off screws were tilted inside the concrete.

The behavior was reasonably ductile, considering that the failure mode was concrete cracking. Deck slip was insignificant but started at 80% of maximum load. The load-end slip plot for 7A consists of a nearly linear region followed by a non-linear region of rapidly decreasing stiffness. See Figure A.69. The load-end slip plot for 7B is not as linear as 7A and does not have as long of a plateau. See Figure A.72.

4.2.8 Push-off Series 8

Series 8 was the same as series 7 except that the stand-off sleeves were 1 3/4 in. instead of 2 1/4 inches.

The head of the stand-off screw was embedded into the slab 1/2 in. above the top of the rib of the deck. The limit state was concrete shear across the ribs of the deck. The failure plane started under the heads of the screws and continued across the length of the ribs (see Figures A.74 and A.77).

The load-end slip plot consists of two parts, a linear portion and a short plateau. Series 8 followed the same load-end slip curve as series 7, but failure occurred at less of a load and end slip as shown in Figure 4.8.

4.2.9 Push-off Series 9

Series 9 used the same #12 self-tapping screws as those tested in series 1. The screws were installed such that the head of the screw is flush to the
Figure 4.8 Load-End Slip Comparison of 7A and 8A
deck surface. There are two major differences between series 1 and 9, they are as follows:

1. The thickness of the base member at the screw connection was reduced to 0.113 in. in series 9 instead of 0.375 in. in series 1.

2. An incremental uniform load was applied normal to the slab in series 9, instead of a restraining point load in series 1.

The limit state was deck bearing failure around each fastener. As in series 1, the head of the screw protrudes into the concrete 1/4 in., thus the concrete around the head must crush or crack before a bearing failure can take place.

For specimen 9B, two ribs out of 10 exhibited a concrete rib failure across the length of the rib. The typical concrete failure for series 9, was observed starting at the head of the screw and continued at 45° until it reached the inclined portion of the rib. See Figures A.80 and A.83. Minimal deck debonding and deformation occurred only at rib no. 1 near maximum load.

The load-end slip plot for series nine was similar to those for 1B and 1D with minor inconsistencies in the stiffness at low loads. Both specimen 1B and 1D had a restraining load applied. See Figure 4.9. Series nine was less stiff at lower loads due to the incremental normal load instead of a large fixed restraining load. Series nine had nearly the same strength as 1B and 1D, but series nine is more ductile. The behavior of the two specimens in series 9 were more consistent with each other as opposed to 1B and 1D which are not very similar in strength, stiffness or ductility.
Figure 4.9 Load-End Slip Comparison of 1B, 1D and 9A
4.2.10 Push-off Series 10

Series 10 used two nominally 5/8 in. diameter puddle welds in each rib of the deck as the fastening system. The deck was welded to the thin angle base member which caused minor difficulty during fabrication. A 3/32 in. diameter welding rod with 45 D.C. amps were used to weld the deck to the base member.

The welded connection is extremely stiff as compared to the #12 self-tapping screws used in series 9, which does not necessarily mean that the system is stiff. As the base member is loaded and the load is transferred to the deck through the welds, the deck and the weld displace together with the base member. This is slightly different than the behavior of #12 self-tapping screws, since the screws will generally displace more than the deck profile upon loading due to the small bearing area on the deck.

Due to the stiff weld connection, the concrete failed across the ribs of the deck as shown in Figure A.86 and A.89. Concrete failure across the ribs of the deck was not typically observed in series 9. Each rib was stressed more in series 9 than in series 10, yet a concrete failure was not observed in series 9 and was in series 10.

Part of the explanation involves the strength of the concrete. Series 9 had a concrete strength of 4150 psi and series 10 had a concrete strength of 3600 psi. However, this difference in strength is not enough to account for the difference in failure modes of the two series. The stiff weld connection promoted early concrete failure to occur. No bearing failure was observed except at rib no. 6 which is expected. Two welds on each specimen failed due to poor weld penetration into the base member. Minor deck debonding and deformation occurred before maximum load.
4.2.11 Push-off Series 11

Series 11 was a repeat of series 10 except the puddle weld size was increased to nominally 3/4 inches in diameter.

The failure mode was the same as in series 10, brittle concrete rib failure. Minor deck debonding and deformation was also observed. Series 11 did achieve a slightly higher load and a stiffer response due to the increase in weld size, but the specimens in series 11 failed at approximately the same end slip as series 10. See Figure 4.10.

The welds were not stressed to their capacity because the concrete rib failed before the welds. The deck/weld configuration has the potential to carry additional load if the concrete rib failure can be avoided.

4.2.12 Push-off Series 12

Series 12 used 3/4 in. diameter puddle welds as in series 11. Series 12 is the first set of push-off tests to change the length and the width of the deck since series 4. The length of the deck was increased to 24 in. to prevent concrete rib failure or to determine the effective width of the concrete failure plane.

The end conditions of the deck was modified for series 12. In previous tests, the concrete rib at rib no. 6 was unable to fail as a rib normally would in a composite joist. In series 12, rib no. 6 was removed so that all the concrete ribs of the push-off specimen have an equal chance to fail in the same manner. See Figure A.98. The results of series 12 more closely represent what occurs in the actual composite joist. Thus, the results should match the performance of the deck/slab system in full scale composite joist 2 ft. on center.
Figure 4.10 Load-End Slip Comparison of 10B and 11B
The puddle welds again provided a strong and stiff connection to the base member. As a result, the welds did not fail and all of the concrete ribs failed, including rib no. 5 as predicted by the modification. Weld failure occurred on specimen 12B due to poor weld penetration, not due to bearing failure. The weld metal did not successfully bond to the base member metal, but, each 3/4 in. weld did carry up to 2.4 kips before it failed which is 85% of the weld strength exhibited on specimen 12A.

The Load-End Slip plot was linear up to 90% of maximum load, after which an extremely small plateau developed before failure. See Figures A.99 and A.102. Series 12 was less stiff than series 11, but had greater strength due to the increase in deck length. Although series 12 was less stiff, it had the same or less end slip at failure than series 11 as shown in Figure 4.11.

4.2.13 Push-off Series 13

The purpose of series 13 was to retest the 1/4-14 self-tapping screws with a 2 1/4 in. stand-off sleeve, used in series 7, with a 24 in. deck length. The 24 in. deck length was used instead of the 12 in. deck length because in series 7 the failure mode was concrete shear across the entire length of the rib. By providing additional length to the concrete rib, the limit state of the specimen will possibly change from a brittle concrete rib failure to a ductile screw failure, which will improve the overall strength of the specimens in this series.

The primary failure mode observed was screw failure. Some stand-off screws failed by shear and others failed by a combination of bending and tension. All of the screws bent at the exposed portion of the screw, but not inside the concrete rib. Three out of the 10 ribs on specimen 13A exhibited a concrete
Figure 4.11 Load-End Slip Comparison of 11B and 12A
The load-end slip plots are linear up to 40 kips then the specimens begins to lose stiffness as the load is increased. Series 13 was as ductile as series 7 as shown in Figure 4.12. Specimen 13A failed at approximately the same end slip as specimen 7A.

By increasing the deck length, series 13 exhibited an average increase of 20% in strength over series 7. The stand-off screws were loaded to nearly 3 kips each at failure, which is surprising considering that on previous tests using the same 1/4-14 stand-off screw, the highest screw strength obtained was only 2.4 kips.

4.3 Summary of Results

Due to the thick base member, the stand-off screws in series 2 have the greatest stiffness, as opposed to the tests which followed that used a thinner base member material. Due to the thin base member, the 1/4-14 self-tapping screw with a stand-off sleeve was typically bent at the exposed portion of the screw and locally distorted the angle base member for all tests which use such a fastener.

Two modifications were made to series 4 push-off test which was typical for series 4 through 13. The modifications are as follows:

1. The base members consisted of two 1 1/2 in. equal leg angles with a thickness of 0.113 in. welded to a 1/2 in. plate 6 in. wide and 44 in. long.

2. An incremental uniform load was applied normal to the push-off specimen slabs.
Figure 4.12 Load-End Slip Comparison of 7A and 13A
Series 4 is the strongest deck/fastener system which was tested in this study with a 12 in. length deck. In comparison to series 3, series 4 is stronger, stiffer and more ductile as shown in Figure 4.13. Series 4 carried higher loads at a larger end slip than series 3, which makes it a superior fastening system. In fact, the specimens in series 4 with one screw per rib nearly obtained the same maximum load as series 3 with two screws per rib.

In comparison to other tests, series 7 is much stronger and ductile than series 3, which used 1 1/4 in. stand-off screws, but series 7 has the same stiffness at low loads. Series 7 is not as strong, ductile or stiff as series 4. All three Load-End Slip plots are shown in Figure 4.14.

Comparing the load-end slip behavior for series 9 against the other fastening systems, series 9 has two good features, a smooth well behaved curve and good ductility. Series nine has 85% of the strength of series 4, 90% of the strength of series 7, and as strong as series 8. Series 9 does have the same stiffness as the others as shown in Figure 4.15; however, series nine loses its stiffness at a lower load than the others.

As shown in Figure 4.16, series 10 has less strength and ductility than series 9, but has the same stiffness at low loads. Series 10 is compared to series 9 because both fastening systems are flush to the deck and rely on the deck profile to transfer the load to the fasteners. Both the fasteners have minimal interaction with the concrete, thus a direct comparison is justified.

Series 12 achieved nearly the same load per specimen as series 4. Each fastener was stressed more in series 12 because there were 4 less fasteners than in series 4. In conclusion, the deck profile successfully acted as a shear transfer device, and the limit state was concrete rib failure, not deck failure.
Figure 4.13 Load-End Slip Comparison of 3B and 4D
Figure 4.14 Load-End Slip Comparison of 3B, 4D and 7A
Figure 4.15 Load-End Slip Comparison of 4D, 7A, 8A and 9A
Figure 4.16 Load-End Slip Comparison of 9A and 10B
The specimens in series 13 obtained the highest load out of any other series tested in this study. A comparison of the load-end slip plots is made between the two best fastening systems, series 13 and series 4, in Figure 4.17. Series 4 has greater stiffness at lower loads, but it loses its stiffness at a lower load compared to series 13. Series 4 has greater ductility, but series 13 has greater strength. Both series 4 and 13 have excellent behavior properties for achieving composite action in joists. The behavior is ideal for a shear connection system because both systems provide enough strength to achieve composite action and their load-end slip response is a well-behaved smooth curve which exhibits ductility, which is a preferred failure mode for a shear connection system.

A load-end slip plot showing the six strongest fastening systems is shown in Figure 4.18.
Figure 4.17 Load-End Slip Comparison of 4D and 13A
Figure 4.18 Load-End Slip Comparison of 4D, 7A, 8B, 9A, 12A and 13A
CHAPTER 5
ANALYSIS AND INTERPRETATIONS OF RESULTS

5.1 Analysis of Failure

This section will present the analysis used to determine calculated strengths for each push-off specimen tested in this study. Two basic concepts are implemented, concrete shear strength and fastener strength. The term fastener strength is used instead of screw shear strength, weld strength or deck bearing strength because the fastener systems behave differently in a deck/slab application than they do if only used to connect steel to steel.

The concrete shear strength calculations are based on the American Concrete Institute (ACI) Building Code 1989. The nominal strength of the stand-off screws was obtained from the Buildex Engineering Department literature. (Buildex supplied the self-drilling, self-tapping screws for this project). The nominal strength of the Pneutek air fired pins was obtained from Pneutek literature. The strength of the 12-24 self-tapping screws and the puddle welds were determined from the Steel Deck Institute (SDI) Diaphragm Design Manual [1987]. The ultimate shear strengths for the fasteners tested in this study are shown in Table 5.1. A table listing the primary limit states of the tests conducted in this study are shown in Table 5.2.

There were two basic methods which were used to analyze the failure of the specimens tested in this study. The two methods are presented in the following paragraphs.
### Table 5.1 Ultimate Shear Strengths

<table>
<thead>
<tr>
<th>Fastener Type</th>
<th>Ultimate Shear Strength (lbs)</th>
<th>Reference</th>
<th>Limit State</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-24 (Flush)</td>
<td>1400</td>
<td>SDI</td>
<td>Deck bearing</td>
</tr>
<tr>
<td>12-24 (SO)</td>
<td>2100</td>
<td>Buildex</td>
<td>Screw shear</td>
</tr>
<tr>
<td>1/4-14 (SO)</td>
<td>2600</td>
<td>Buildex</td>
<td>Screw shear</td>
</tr>
<tr>
<td>0.150&quot; Dia. Pins</td>
<td>918</td>
<td>Pneutek</td>
<td>Deck bearing</td>
</tr>
<tr>
<td>5/8&quot; Dia. weld</td>
<td>2230</td>
<td>SDI</td>
<td>Weld failure</td>
</tr>
<tr>
<td>3/4&quot; Dia. weld</td>
<td>2670</td>
<td>SDI</td>
<td>Weld failure</td>
</tr>
</tbody>
</table>

SO = Stand-off screw

SDI = Steel Deck Institute (Shear Diaphragm Manual)
### Table 5.2 Primary Limit States

<table>
<thead>
<tr>
<th>Series</th>
<th>Fastener Type</th>
<th>Primary Limit State</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12-24 (flush)</td>
<td>Deck bearing</td>
</tr>
<tr>
<td>2</td>
<td>12-24 W/1 1/4&quot; SO</td>
<td>Concrete shear</td>
</tr>
<tr>
<td>3 (1 screw/rib)</td>
<td>1/4-14 W/1 1/4&quot; SO</td>
<td>Screw shear</td>
</tr>
<tr>
<td>3</td>
<td>1/4-14 W/1 1/4&quot; SO</td>
<td>Concrete shear</td>
</tr>
<tr>
<td>4 (1 screw/rib)</td>
<td>1/4-14 W/1 1/4&quot; SO</td>
<td>Screw shear</td>
</tr>
<tr>
<td>4</td>
<td>1/4-14 W/1 1/4&quot; SO</td>
<td>Screw shear</td>
</tr>
<tr>
<td>5</td>
<td>0.150&quot; dia. pins</td>
<td>Deck bearing</td>
</tr>
<tr>
<td>6 (1 pin/rib)</td>
<td>0.150&quot; dia. pins</td>
<td>Deck bearing</td>
</tr>
<tr>
<td>7</td>
<td>1/4-14 W/2 1/4&quot; SO</td>
<td>Concrete shear</td>
</tr>
<tr>
<td>8</td>
<td>1/4-14 W/1 3/4&quot; SO</td>
<td>Concrete shear</td>
</tr>
<tr>
<td>9</td>
<td>12-24 (flush)</td>
<td>Deck bearing</td>
</tr>
<tr>
<td>10</td>
<td>5/8&quot; dia. welds</td>
<td>Concrete shear</td>
</tr>
<tr>
<td>11</td>
<td>3/4&quot; dia. welds</td>
<td>Concrete shear</td>
</tr>
<tr>
<td>12</td>
<td>3/4&quot; dia. welds</td>
<td>Concrete shear</td>
</tr>
<tr>
<td>13</td>
<td>1/4-14 W/2 1/4&quot; SO</td>
<td>Screw shear</td>
</tr>
</tbody>
</table>

**NOTE:** All push-off series used 2 fasteners in each rib except where noted.
Failure Analysis Method 1

This failure analysis method is used for analysis of series 2, 3, 7, 8, 10, 11 and 12 in which the strength of the specimen was a combination of concrete shear strength and screw shear strength. The ultimate strength of the specimen is the sum of the two strengths:

\[ V_U = \Sigma V_C + \Sigma P_{\text{screw shear}} \]

where,

- \( V_U \) = the ultimate strength of the push-off specimen.
- \( V_C \) = the concrete shear failure load for one rib.
- \( P_{\text{screw shear}} \) = the screw capacity in shear.
- \( V_C = 2 A_C \sqrt{f'_C} \)
- \( A_C \) = the area of the concrete failure plane.
- \( f'_C \) = concrete compressive strength.

Failure Analysis Method 2

This failure analysis method is used for analysis of series 3(1 screw/rib), 4, 5, 6, 9 and 13, in which the failure of the specimen was fastener failure only. This is represented symbolically as follows:

\[ V_U = \Sigma P_{\text{fastener strength}} \]
where,

\[ P_{\text{fastener strength}} = \text{the strength of the fastener as determined by Table 5.1.} \]

The results of the analyses are presented in Table 5.3.

5.1.1 Push-off Series 1. The same fasteners used in push-off series 1 were used in series 9. The improved application of the normal force was used in series 9, therefore series 9 and not series 1 will be analyzed.

5.1.2 Push-off Series 2. For series 2 the typical failure was concrete shear across the ribs of the deck and screw shear in rib no. 8, therefore, failure analysis method 1 was used. The values used for analysis are as follows:

\[
\begin{align*}
&f'_c = 4450 \text{ psi} \\
&A_c = (2.5'(12") = 30 \text{ in}^2 \\
&P_{\text{screw shear}} = 2.1 \text{ kips.}
\end{align*}
\]

Typically, 10 ribs failed in concrete shear and 4 screws failed, resulting in a calculated strength of 48.4 kips. The average experimental strength was 45.4 kips which results in an experimental/calculated strength ratio of 0.94. The discrepancy can be primarily attributed to variation in the concrete shear areas of the ribs.
Table 5.3  Summary of Tested and Calculated Strengths

<table>
<thead>
<tr>
<th>Series</th>
<th>Average Experimental Strength</th>
<th>Average Calculated Strength</th>
<th>Experimental Calculated</th>
<th>Failure Analysis Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1#</td>
<td>36.2</td>
<td>32.4</td>
<td>1.12</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>45.4</td>
<td>48.4</td>
<td>0.94</td>
<td>1</td>
</tr>
<tr>
<td>3*</td>
<td>22.0</td>
<td>26.0</td>
<td>0.85</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>32.5</td>
<td>31.4</td>
<td>1.04</td>
<td>1</td>
</tr>
<tr>
<td>4*</td>
<td>28.6</td>
<td>31.2</td>
<td>0.92</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>51.0</td>
<td>62.4</td>
<td>0.82</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>26.2</td>
<td>23.0</td>
<td>1.14</td>
<td>2</td>
</tr>
<tr>
<td>6*</td>
<td>14.2</td>
<td>11.5</td>
<td>1.23</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>48.7</td>
<td>47.9</td>
<td>1.02</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>46.4</td>
<td>47.9</td>
<td>0.97</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>45.0</td>
<td>32.4</td>
<td>1.39</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>36.6</td>
<td>41.5</td>
<td>0.88</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>41.2</td>
<td>43.3</td>
<td>0.95</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>56.0</td>
<td>62.5</td>
<td>0.90</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>58.9</td>
<td>52.0</td>
<td>1.13</td>
<td>2</td>
</tr>
</tbody>
</table>

NOTE:  
# - no normal load applied.  
* - 1 screw per rib was used.
5.1.3 Push-off Series 3. The specimens with one screw per rib exhibited screw failure. The screw failure was not typically in shear, but rather in a bent-tension mode. A bent-tension failure is characterized by a combination of bending and tension action. The bending in the screw is due to the rotation of the screw in the thin base material. The published shear value for a 1/4-14 self-tapping stand-off screw is 2.6 kips. The ultimate load of the specimen is determined by failure analysis method 2, which is the shear value per screw multiplied by the total number of screws used in the specimen. Thus, the calculated strength is 26.0 kips.

The average experimental strength obtained for series 3 with one screw per rib is 22.0 kips, which results in an experimental/calculated strength ratio of 0.85. The difference is largely due to the different conditions in which the screws failed. The published shear value was determined by a direct shear test using a clevis type arrangement. Due to the flexibility in the base member and the concrete in the push-off test, the screws were loaded in a manner that differed from the manufacturer's strength tests. The discrepancies between the test and calculated strengths is attributed to this difference.

The specimens with two screws per rib failed by a combination of concrete shear in the rib and screw shear. Failure analysis method 1 was used to analyze these specimens. Typically 7 ribs failed in concrete shear and 6 screws failed. The analysis results in an average value of 31.4 kips. The average experimental strength was 32.5 kips which results in an experimental/calculated strength ratio of 1.04.

The concrete rib did not fail across its entire length because of the flexibility of the stand-off screw which promoted concrete failure. The average concrete
failure plane area per rib was \((2.4 \text{ in.}) \times (8 \text{ in.})\) or 19.2 in\(^2\). Some concrete ribs did fail across the entire length. See Figure A.32 and A.35.

Perhaps the stand-off screws in the ribs which failed across the entire rib were stiffer and did not bend inside the concrete rib. The stiffness of the stand-off screw depends on two variables. First, the location of the slit in the sleeve and second, the tightness in which the sleeve is clamped to the base member.

If the slit of the sleeve is in the direction of the loading, the stand-off screw has the least stiffness. All other slit locations will provide greater stiffness. If the sleeve is clamped securely to the thin angle base member, the sleeve will add to the rigidity of the connection during loading. As the stand-off screw bends due to loading, the sleeve will tend to inhibit the local distortions in the angle. If the sleeve is clamped too tight, the sleeve may be damaged which will again hinder the stiffness of the stand-off screw.

Any of these situations may have occurred to some of the stand-off screws, which may account for the tendency of the concrete to fail within a limited area near the stand-off screw locations. The concrete rib does not provide enough strength to prevent the stand-off screws from bending inside the concrete.

5.1.4 Push-off Series 4. The specimens with one and two 1/4-14 stand-off screw per rib failed by screw shear. In this series, the deck was inverted which increased the amount of concrete in the rib. The increase of concrete in the rib provided better support to the stand-off screw and did not allow the stand-off screw to bend inside the concrete; however, the stand-off screw did bend at the exposed portion.
The experimental screw failure load for the specimens with one stand-off screw per rib was 2.4 kips, which is greater than the experimental screw failure load for the same stand-off screw in series 3 with one stand-off screw per rib. The increase in strength is attributed to the increase of concrete in the rib which increased the stiffness of the stand-off screw in the concrete. No concrete cracks were observed around the stand-off screw after failure as they were in series 3.

Using method 1 to analyze the strength of the specimens with one stand-off screw per rib and an ultimate shear strength of the screw of 2.6 kips, the specimens had a calculated strength of 31.2 kips. The average experimental strength was 28.6 kips, which yields an experimental/calculated ratio of 0.92.

For the specimens in series 4 with two stand-off screws per rib, the average experimental strength of the stand-off screw was 2.125 kips, which is also less than the tabulated 2.6 kips. Using method 1, and 2.6 kips as the ultimate shear strength of the stand-off screw, the calculated strength is 62.4 kips. The average experimental strength was 51.0 kips which results in an experimental/calculated ratio of 0.82. The low experimental strength is attributed to the combination of bending and tension which is caused by the rotation permitted by the thin base member. It was observed that the screw typically fractured 1/8 in. into the concrete rib, which confirms that bending stresses are present.

5.1.5 Push-off Series 5 and 6. Series 5 used two air fired pins in each rib and series 6 used one air fired pin in each rib. The limit state for both series 5 and 6 was deck bearing failure at the pin locations. Preutek's published ultimate shear load for the 0.150 in. diameter pin, fastened to 22 gage deck, is 0.918 kips. The
average experimental strength was 1.100 kips. The increase in strength may have been due to the frictional forces which develop between the deck and the base member upon the application of the normal load. The frictional force is easily calculated for series 5 and 6 because the air fired pin does not clamp the deck to the base member with an appreciable force. In other series, the fastener tends to clamp the deck to the base member with an unknown high clamping force.

An investigation was made to determine the frictional forces. To determine frictional forces, one needs to determine the coefficient of friction between the deck and the base member. This was accomplished by placing the deck on the base member in a horizontal position. The base member was then lifted at one end until the deck began to slide. The tangent of the angle at which the base member makes with the horizontal, when the deck initially slides, is taken as the coefficient of friction. As a result of this friction test, the coefficient of friction was calculated as 0.5.

Applying the coefficient of friction to the push-off tests conducted in this series, the frictional force between the deck and the base member, due only to the normal load, is 0.5 multiplied by the normal load. For each increase in the vertical load increment, the normal load is increased by 8.5% and accordingly the frictional forces increase 4.25% of the vertical load. Thus upon loading the specimen with a vertical load, 95.75% is distributed to the pins and 4.25% is lost to friction.

The frictional forces may account for part of the reason why the pins failed at a higher load than predicted by the published value. Due to friction, the pin failure strength should have increased from 0.918 kips to 0.960 kips. Using failure
method 2 for series 5, and a pin strength of 0.960 kips, the calculated failure strength was 23.0 kips. The average experimental strength was 26.2 kips which yields an experimental/calculated ratio of 1.14. The analysis still underestimates the failure load. For series 6 the experimental/calculated ratio increased to 1.23.

5.1.6 Push-off Series 7 and 8. Method 1 was used to analyze the failure load for both series 7 and 8. The typical failure was shearing of 10 concrete ribs and 4 screws. Accordingly, the calculated strength of the specimen is 47.9 kips. The average experimental strengths for series 7 and 8 are 48.7 kips and 46.4 kips respectively, which gives experimental/calculated ratios of 1.02 and 0.97.

The values used in calculating the failure load using method one are given as follows:

\[ f'_C = 3900 \text{ psi} \]
\[ A_c = (2.5\text{''})(12\text{''}) = 30 \text{ in}^2 \]
\[ P_{\text{screw shear}} = 2.6 \text{ kips} \]

5.1.7 Push-off Series 9. The failure mode for series 9 was deck bearing failure around each screw. The presence of the concrete slab increased the load carrying capacity of the screw over the tabulated capacity because the head of the screw was embedded in the concrete 1/4 in.

The theoretical strength of one of the #12-24 self-tapping screws, flush to the 22 gage deck, was determined from the SDI Diaphragm Design Manual [1987]:

\[ P_u = 1.25 \times F_y \times t \times (1 - 0.005 \times F_y) \]
where

\[
F_y = 47 \text{ ksi (as determined from tensile coupon tests)}
\]
\[
t = 0.030 \text{ in. (measured thickness)}
\]
\[
P_U = 1.25(47)(0.030)(1-0.005(47)) = 1.35 \text{ kips}
\]

Using method 1, the calculated strength of the specimen is 32.4 kips. The average experimental strength for series 9 was 45.0 kips, which yields an experimental/calculated ratio of 1.39. The increase in strength is due to the presence of the concrete and the normal load. For the specimens in series 1, which did not have the restraining load applied, the average experimental strength was 36.2 kips which yields an experimental/calculated ratio of 1.12. The application of the incremental uniform load greatly increased the carrying capacity of the fastener system.

5.1.8 Push-off Series 10 and 11. The limit state for series 10 was concrete rib failure. Typically, the steel deck at rib no. 1 experienced minor deformation which relieved stress on the concrete rib and the puddle weld. Minor concrete cracking occurred at rib no. 1; however, complete rib failure occurred at rib no.'s 2, 4, and 5 on both sides of the specimen. A weld failure occurred at rib no. 3 (one side only) and bearing failures at rib no. 6 (front and back). See Figures A.86 and A.89.

The theoretical strength of the 5/8 in diameter puddle weld as determined by the SDI Diaphragm Design Manual (1987) is:

\[
P_U = 2.2 F_U t d
\]
where,

\[ F_U = 54 \text{ ksi (as determined from tensile coupon tests)} \]
\[ t = 0.030 \text{ in. (as determined by a micrometer)} \]
\[ d = 0.625 \text{ in.} \]
\[ P_U = 2.2 (0.030)(54)(0.625) = 2.23 \text{ kips} \]

\[ f_{c r} \]
\[ d = 0.75 \text{ in.} \]
\[ P_U = 2.2 (0.030)(54)(0.75) = 2.67 \text{ kips} \]

Method 1 was used to analyze series 10 and 11 with a slight modification. Since rib no. 1 deformed and concrete rib failure did not occur, a deck deformation failure load, for rib no. 1, of 1.7 kips was used in the calculations. This value was selected upon in depth analysis of the experimental failure load. The resulting calculated strengths are 41.5 kips and 43.3 kips respectively. The average experimental strengths were 36.6 kips and 41.2 kips respectively, which results in an experimental/calculated strength ratio of 0.88 and 0.95.

The values used in the failure method were:

\[ f'_{c} = 3700 \text{ psi} \]
\[ A_c = (2.5'')(12'') = 30 \text{ in}^2 \]

5.1.9 Push-off Series 12. Due to the modifications of the deck width and deck length, all the concrete ribs failed in the same manner for specimen 12A. Specimen 12B will not be analyzed since the welds failed prematurely due to poor weld quality. The concrete rib failure plane ranged from 15 to 22 inches in length and 2.5 inches in width. See Figure A.98.
The strength of the 3/4 in. puddle weld was calculated as 2.67 kips. If the concrete rib failed across its entire length, the concrete rib capacity in shear would be 8.30 kips. Since there are two welds per rib, the rib capacity for the welds is 5.34 kips. According to the respective capacities of the ribs of the deck and the welds, the controlling limit state should be weld failure.

At the failure load, each rib was carrying 5.6 kips, which is greater than the weld capacity. Thus the welds should have failed, but they did not. Instead the concrete ribs failed with an average concrete shear area of 18.8 in\(^2\). Summing up the concrete rib failures yields a calculated strength of 62.5 kips. The experimental strength for 12A was 56.0 kips, which results in an experimental/calculated strength ratio of 0.90. The increase in weld strength may be due to the variation in weld size which ranged from 5/8 in. to 1 in. It is felt that the stiff weld connection promoted concrete failure to occur within a limited width and not across the entire length of the rib.

5.1.10 Push-off Series 13. The failure mode for series 13 was shear of the 1/4-14 self-tapping 2 1/4 in. stand-off screw. The published ultimate shear value for this screw is 2.6 kips. Therefore, the calculated strength for the specimen is 52.0 kips, using method 2. The average experimental strength for the specimen was 58.85 kips, which yields an experimental/calculated ratio of 1.13. This discrepancy is difficult to explain, however, even though the stand-off screws bent at the exposed portion of the screw, it is felt that the screws in this series failed by direct shear rather than a bent-tension failure as observed in series 3 and 4. This may have increased the carrying capacity of the stand-off screw.
5.2 Interpretation of Results

For a joist to achieve full composite action, the shear connection system between the slab and the top chord must be able to resist the horizontal shear forces at the ultimate failure load of the composite joist. It is also important for the shear connection system to fail in a ductile failure mode. A sudden, brittle limit state is to be avoided in the design of floor systems whenever possible. Therefore, two main characteristics are essential for a good shear connection system in a composite joist, strength and ductility.

As a benchmark, the required strength required to be resisted for a typical composite joist is approximately 7.0 kips/ft along the span. This value was obtained from phase I of this study, in which two full size 12 in. composite joist tests were conducted. The shear connection strength required to achieve full composite action was the tension yield strength of the bottom chord divided by half of the span length. The actual calculation is:

\[ V_h = A_S F_y = (1.748 \text{ in}^2)(50 \text{ ksi}) = 87.4 \text{ kips} \]

Span/2 = 12.5 ft.

\[ V_h/\text{ft of deck} = (87.4 \text{ kips})/(12.5 \text{ ft}) = 7.0 \text{ kips/ft} \]

where,

- \(A_S\) = the area of the bottom chord of the joist.
- \(F_y\) = the nominal yield stress of the steel.
- \(V_h\) = the horizontal shear force which must be resisted from the point of maximum moment to zero moment.
The deck fastening systems are rated on a load per foot basis. Table 5.4 lists the push-off series in descending order based on the load per foot shear capacity. Only the systems with an average load per foot greater than 7.0 kips per foot will be listed. Series 1 and 2 will be excluded from the evaluation due to the thick base member.

In order to fairly evaluate the best fastening systems, the load per foot value needs to be adjusted to reflect the same number of fasteners per foot. For Vulcraft 1.5 VL deck, 4 fasteners per foot translates into 2 fasteners per rib. Due to the end conditions of the push-off specimens, the number of fasteners per foot varied as shown in Table 5.4. To adjust the results such that they are all based on 4 fasteners per foot, the "load per foot" value is divided by the "fasteners per foot" value and then is multiplied by 4. The adjusted results are displayed in Table 5.5.

To determine which fastener system is most ductile, Table 5.6 ranks the series by maximum average end slip at failure and also shows the failure mode of the series.

The results of these comparisons show that the superior fastening system is the 1/4-14 self-tapping screw with a 2 1/4 in. stand-off sleeve, because of its combined ductility and strength, as shown in Table 5.7. All of the fastener systems in Table 5.7 will can achieve full composite action.

The push-off test results for series 13, 4, 9 and 12 yield results that can be used to directly determine the actual shear connection strength in a full size composite joist. Series 4 and 9 push-off tests were independent of the deck length because either all screw failure or all deck bearing failures occurred. Series 12 and 13 will yield an accurate result for composite joists placed 24 in. on center. If the composite joists are placed closer that 24 in. on center, the push-off
Table 5.4 Push-off Series Ranked by Load/Ft

<table>
<thead>
<tr>
<th>Series</th>
<th>Identification</th>
<th>Fasteners (ft.)</th>
<th>Load (k/ft)</th>
<th>Load (k) Fasteners</th>
<th>Average End Slip (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>2 1/4&quot; SO, 24&quot; deck</td>
<td>3.53</td>
<td>10.4</td>
<td>2.95</td>
<td>0.155</td>
</tr>
<tr>
<td>4</td>
<td>1 1/4&quot; SO, 12&quot; deck</td>
<td>4.36</td>
<td>9.3</td>
<td>2.13</td>
<td>0.165</td>
</tr>
<tr>
<td>12</td>
<td>3/4&quot; welds, 12&quot; deck</td>
<td>3.53</td>
<td>9.1</td>
<td>2.59</td>
<td>0.057</td>
</tr>
<tr>
<td>7</td>
<td>2 1/4&quot; SO, 12&quot; deck</td>
<td>3.89</td>
<td>7.9</td>
<td>2.03</td>
<td>0.113</td>
</tr>
<tr>
<td>8</td>
<td>1 3/4&quot; SO, 12&quot; deck</td>
<td>3.89</td>
<td>7.5</td>
<td>1.93</td>
<td>0.110</td>
</tr>
<tr>
<td>9</td>
<td>#12-24, 12&quot; deck</td>
<td>3.89</td>
<td>7.3</td>
<td>1.88</td>
<td>0.198</td>
</tr>
</tbody>
</table>
**Table 5.5 Push-off Series Ranked by Load/Ft (Adjusted)**

<table>
<thead>
<tr>
<th>Rank</th>
<th>Series</th>
<th>Load Ft. (k/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13</td>
<td>11.8</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td>10.3</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>8.5</td>
</tr>
<tr>
<td>4</td>
<td>7</td>
<td>8.1</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>7.7</td>
</tr>
<tr>
<td>6</td>
<td>9</td>
<td>7.5</td>
</tr>
</tbody>
</table>
Table 5.6  Push-Off Series Ranked by End Slip

<table>
<thead>
<tr>
<th>Rank</th>
<th>Series</th>
<th>End Slip (inches)</th>
<th>Limit State</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9</td>
<td>0.198</td>
<td>Deck bearing failure</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>0.165</td>
<td>Screw failure</td>
</tr>
<tr>
<td>3</td>
<td>13</td>
<td>0.155</td>
<td>Screw failure</td>
</tr>
<tr>
<td>4</td>
<td>7</td>
<td>0.113</td>
<td>Concrete shear</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>0.110</td>
<td>Concrete Shear</td>
</tr>
<tr>
<td>6</td>
<td>12</td>
<td>0.057</td>
<td>Concrete shear</td>
</tr>
</tbody>
</table>
Table 5.7 Determination of the Most Effective Fastening System

<table>
<thead>
<tr>
<th>Series</th>
<th>Strength Rank</th>
<th>Ductility Rank</th>
<th>Combined Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>6</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>12</td>
<td>2</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>
test result will yield false results. Series 7 and 11, which use a 12 in. deck length, are best suited for determining the shear capacity of the deck fastening system for composite joists spaced closer than 24 in. on center.

Since the push-off test limit state, for series 4 and 9, was independent of the deck length, the results can be used for any joist spacing greater than 12 in. on center. The results of the push-off tests were independent of the deck length because series 4 exhibited only screw failure and series 9 exhibited only deck bearing failure, both of which are independent of the deck length.
CHAPTER 6  
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

The objective of this study was to evaluate the shear capacity of Vulcraft 1.5 VL deck fastened, to the top chord of an open web steel bar joist, with various fasteners. To evaluate the strength and the stiffness of the deck fastening systems, 13 push-off series, totalling 36 push-off tests, were conducted.

Six different deck fasteners were tested:

1. #12-24 Tek#5 self-drilling, self-tapping screws.
2. 1/4-14 Tek#3 with a 1 1/4" stand-off sleeve.
3. 1/4-14 Tek#3 with a 1 3/4" stand-off sleeve.
4. 1/4-14 Tek#3 with a 2 1/4" stand-off sleeve.
5. 0.150" diameter air fired pins.
6. Puddle welds (5/8" dia. and 3/4" dia.)

Vulcraft 1.5 VL deck was used with each series except for series 4, in which the deck was inverted. The deck lengths were all 12 in. except for series 12 and 13, in which a 24 in. deck length was used. The width varied between 33 and 37 inches.
The push-off specimen base members were a WT 5x11. To better represent the top chord of a joist the base member was changed and consisted of two 1 1/2 in. equal leg angles with a thickness of 0.113 in. welded to a PL 1/2" x 6" x 3'-8".

A restraining point load was applied to the first three push-off series to determine the effect on the behavior of the specimens. A significant effect was observed thus, an incremental uniform load was applied normal to the slabs of the push-off specimens, for series 4 through 13, to represent the uniform gravity load applied to a full size composite joist.

Two fasteners were placed in each rib of the deck for each push-off specimen except when an experimental fastener shear value needed to be determined. To determine an experimental shear value for the fasteners, one fastener, instead of two was placed in each rib, such that the limit state for the specimen would be shear of the fastener.

The push-off specimens were loaded to failure. End slip and deck slip were recorded at incremental load points. After failure, the slabs were removed and separated from the deck to observe the mode of failure.

Calculated strengths were determined using one of two failure analysis methods. The results were interpreted to determine which fastener system possessed the greatest strength and ductility.
6.2 Conclusions

Based on the 13 push-off series, the following conclusions have been drawn:

1. The Vulcraft 1.5 VL deck profile has the capacity to adequately carry horizontal shear forces to develop full composite action in joists. The controlling limit state for the deck/slab system is either the fastener connection strength or concrete rib shear. If the fastener provides adequate strength, the limit state is the shear of the concrete ribs across the top of the ribs of the deck, otherwise fastener strength controls.

2. The 1 3/4 and 2 1/4 in. stand-off screws have the potential to transfer the horizontal shear forces to the top chord of the joist. The 1 1/4 in. stand-off screws have the potential to transfer the horizontal shear forces to the top chord of the joist only if the deck is inverted.

3. The use of thin angles for the base member of the push-off tests influenced the strength and behavior of the fasteners due to its lack of stiffness.

4. The push-off tests using 1/4-14 self-tapping screw with a 2 1/4 in. stand-off sleeve and 24 in. deck length, was rated the most effective fastener system based on strength, stiffness and ductility.

5. The following deck fastener systems are capable of resisting 7.0 kips/ft or more, which is enough to achieve composite action for typical short span joists.

   A. Vulcraft 1.5 VL deck fastened with 1/4-14 self-tapping screws with a 2 1/4 in. stand-off sleeve.

   B. Inverted Vulcraft 1.5 VL deck fastened with 1/4-14 self-tapping screw with a 1 1/4 in. stand-off sleeve.
C. Vulcraft 1.5 VL deck fastened with 5/8 in. to 3/4 in. diameter puddle
welds.

D. Vulcraft 1.5 VL deck fastened with 1/4-14 self-tapping screws with a
1 3/4 in. stand-off sleeve.

E. Vulcraft 1.5 VL deck fastened with #12-24 self-tapping screws
driven flush to the deck.

6. The application of the incremental uniform normal load improved the
results of the push-off specimens, by simulating actual conditions which arise in a
full size joist.

7. The modifications made to series 12 and 13 greatly enhanced the
accuracy of the push-off test results as they compare to actual conditions in a full
size composite joist. This is because all the ribs of the push-off test specimen had
the potential to fail in the same manner. The push-off test setup for series 12 and
13 should be a model for future push-off tests that are intended to represent
similar systems.

8. Inverting the deck, which places the wide rib of the deck in contact with
the base member, increases the concrete rib strength.

9. The #12 self-tapping screw connection system is the most ductile. The
presence of the concrete slab and the normal load increased the load carrying
capacity.

10. Phase I tested two full size composite joists, one using 5/8" dia.
puddle weld and the other using #12 self-tapping screws as the connection
system. Both tests achieved composite action which is in accordance with the
results of the push-off series conducted in this study.
6.3 Recommendations

Based on the results of the push-off tests, the following recommendations are made:

1. A 12 in. composite joist with a span of 25 ft. and a bottom chord area of 1.748 in\(^2\), should be tested. The shear connection system should be either 1/4-14 x 2 1/4 in. stand-off screws or 3/4 in diameter puddle welds. The deck should be Vulcraft 1.5 VL deck. The purpose of this test would be to verify the modifications made to series 12 and 13, and to determine the accuracy of the push-off tests in determining the strength and stiffness of the deck fastening system. The 1/4-14 x 2 1/4 in. stand-off screw should be used over the weld because the stand-off screws yield the most consistent results and offer the best quality control.

2. If the modified push-off tests of series 12 and 13 successfully model the strength and stiffness of the full size composite joist test, then further push-off tests should be conducted using the modifications.

3. The push-off tests should be tested under cyclic loading to determine what effect it has on the strength and stiffness of the connection system.

4. Puddle welds should not be used for composite joists due to possible inconsistent weld quality and possible poor weldability to thin top chord angles. If a deck welding machine is used which lays welds of consistent quality, then welds will be a satisfactory deck fastening system. The system will still have a brittle behavior. Also the heat of the weld may distort the top chord angles.

5. The stand-off screws need to be modified. The slit in the sleeve may be detrimental to the stiffness of the stand-off screw. The diameter of the threaded
part should be increased and the stand-off shaft which is embedded into the concrete should be stiffer. The increased diameter will increase the shear capacity and the stiffer shaft will prevent the stand-off screw from bending inside the concrete rib.

6. Inverted Vulcraft 1.5 VL deck should be tested with other fasteners, for example self-tapping screws or modified stand-off screws.

7. Since the stand-off screw successfully acts as a shear transfer device, the type of deck may not be important for the strength of the connection system. Future push-off tests should try stand-off screws with other types of deck commonly used in joist/slab construction.

8. The angles of the base member should be welded to the plate of the base member according to the spacing of panel points or stitch locations in a typical small joist.
REFERENCES

American Concrete Institute (ACI 318-86), Detroit, MI.

Cran, J. A. (1971). "Design and testing composite open web steel joists." Proceedings of The First Specialty Conference on Cold-formed Steel Structures, University of Missouri-Rolla, Rolla, MO.


APPENDIX

Push-Off Test Data Packs
VULCRAFT PUSH-OFF TEST

SUMMARY SHEET

Specimen Mark: 1A Test Date: 2/15/90

Fastener: Type: 12-24x1 1/4 teks/5 Per Specimen: 24 Front: 12 Back: 12

Deck: Type of Deck: 1.5 VL x 22 GA Deck Width: 37.5" Deck Length: 12"

Base Member: Section: WT 5 x 11 Thickness of Connected Part: 0.375"

Concrete: Thickness: 5.5" Strength: 4700 psi

Max End Slip: Front: 0.122" Back: 0.182" Ave: 0.152"

Max Deck Slip: Front: 0.006" Back: -- Ave: 0.006"

Max. Load: 35.75 kips

Max. Load/Ft. of Deck: 5.720 kips/ft.

Max. Load/Fastener: 1.490 kips

Failure Mode: Bearing failure of the deck around the head and/or shank of fastener at all fastener locations except at rib no. 1. The concrete slab debonded from the deck at the top two ribs and the deck profile deformed at the top two ribs.
FIGURE A.1  SPECIMEN 1A LAYOUT

FRONT VIEW  SIDE VIEW

(CONC. SLAB REMOVED TO SHOW DETAIL)
Comments: The head of the fastener protrudes into the concrete such that the head breaks a portion of the concrete as shown. Concrete debonding occurs near maximum load and the deck deforms after maximum load. The deck failed in bearing around each fastener. The slab "peeled" away from the deck near maximum load as shown.

FIGURE A.2  SPECIMEN 1A OBSERVATIONS
FIGURE A.3 SPECIMEN 1A RESPONSE PLOTS
VULCRAFT PUSH-OFF TEST
SUMMARY SHEET

Specimen Mark: 1B Test Date: 2/22/90

Normal Load: Restraining point load applied 6' from top.

Fastener: Type: 12-24x1 1/4 teks/5 Per Specimen: 28, Front: 14, Back: 14

Deck: Type of Deck: 1.5 VL x 22 GA
Deck Width: 37.5", Deck Length: 12"

Base Member: Section: WT 5 x 11
Thickness of Connected Part: 0.375"

Concrete: Thickness: 5.5", Strength: 4700 psi

Max End Slip: Front: 0.178", Back: 0.155", Ave: 0.167"

Max Deck Slip: Front: 0.025", Back: --, Ave: 0.025"

Max. Load: 47.00 kips

Max. Load/Ft. of Deck: 7.520 kips/ft.

Max. Load/Fastener: 1.679 kips

Failure Mode: Bearing failure of the deck around the head and/or shank of fastener at all fastener locations except for the fastener locations above rib no. 1.
FIGURE A.4 SPECIMEN 1B LAYOUT

FRONT VIEW

SIDE VIEW

(CONC. SLAB REMOVED TO SHOW DETAIL)
Comments: A restraining point load was applied to rib no. 1 on each side. Debonding occurred after maximum load. The head of the fastener protrudes into the concrete such that the concrete in contact with the head was crushed as shown. The deck failed in bearing around each fastener.

FIGURE A.5 SPECIMEN 1B OBSERVATIONS
a) LOAD VS END SLIP

b) LOAD VS DECK SLIP

FIGURE A.6 SPECIMEN 1B RESPONSE PLOTS
VULCRAFT PUSH-OFF TEST
SUMMARY SHEET

Specimen Mark: 1C  Test Date: 2/22/90

Fastener: Type: 12-24 x 1 1/4 teks/5
Per Specimen: 28, Front: 14, Back: 14

Deck: Type of Deck: 1.5 VL x 22 GA
Deck Width: 37.5", Deck Length: 12"

Base Member: Section: WT 5 x 11
Thickness of Connected Part: 0.375"

Concrete: Thickness: 5.5", Strength: 4700 psi

Max End Slip: Front: 0.092", Back: 0.056", Ave: 0.074"

Max Deck Slip: Front: 0.016", Back: --, Ave: 0.016"

Max. Load: 36.70 kips

Max. Load/Ft. of Deck: 5.872 kips/ft.

Max. Load/Fastener: 1.311 kips

Failure Mode: Bearing failure of the deck around the head and/or shank of the fastener at all locations except at rib no. 1 and the fasteners above it. The concrete slab debonded from the deck at the rib no. 1 (front) after maximum load.
Figure A.7 Specimen 1C Layout

Front View

Side View

(Concrete slab removed to show detail)
Comments: The head of the fastener protrudes into the concrete such that the head breaks a portion of the concrete as shown. Concrete debonding occurs near maximum load and the deck deforms after maximum load. The deck failed in bearing around each fastener. The top four fasteners were basically ineffective as they only bent the decking locally as shown.

FIGURE A.8 SPECIMEN 1C OBSERVATIONS
FIGURE A.9 SPECIMEN 1C RESPONSE PLOTS
**VULCRAFT PUSH-OFF TEST**

**SUMMARY SHEET**

Specimen Mark: 1D  
Test Date: 2/22/90

Normal Load: Restraining point load applied 6" from top.

Fastener:  
Type: 12-24x1 1/4 teks/5  
Per Specimen: 26, Front: 12, Back: 14

Deck:  
Type of Deck: 1.5 VL x 22 GA  
Deck Width: 37.5", Deck Length: 12"

Base Member:  
Section: WT 5 x 11  
Thickness of Connected Part: 0.375"

Concrete:  
Thickness: 5.5", Strength: 4700 psi

Max End Slip:  
Front: 0.095", Back: 0.100", Ave: 0.098"

Max Deck Slip:  
Front: 0.005", Back: --, Ave: 0.005"

Max. Load: 39.90 kips

Max. Load/Ft. of Deck: 6.284 kips/ft.

Max. Load/Fastener: 1.535 kips

Failure Mode: Deck bearing failure around the head and/or shank of fastener at all fastener locations except at rib no. 1 and fasteners above it. Minor debonding occurred after maximum load.
Figure A.10 Specimen 1D Layout

Front View

Side View

(Cong. slab removed to show detail)
Comments: A restraining point load was applied to rib no. 1 on each side. Debonding occurred after maximum load. The head of the fastener protrudes into the concrete such that the head breaks a portion of the concrete as shown. The deck failed in bearing around each fastener. Two fasteners sheared, one at rib no. 2 (front) and the other at rib no. 5 (front).

FIGURE A.11 SPECIMEN 1D OBSERVATIONS
a) LOAD VS END SLIP

b) LOAD VS DECK SLIP

FIGURE A.12 SPECIMEN 1D RESPONSE PLOTS
VULCRAFT PUSH-OFF TEST

SUMMARY SHEET

Specimen Mark: 2A__ Test Date: 3/5/90

Fastener: Type: 12-24x3" teks/5 w/1 1/4" stand-off sleeve
Per Specimen: 24, Front: 12, Back: 12

Deck: Type of Deck: 1.5 VL x 22 GA
Deck Width: 37.5", Deck Length: 12"

Base Member: Section: WT 5 x 11
Thickness of Connected Part: 0.375"

Concrete: Thickness: 5.5", Strength: 4450 psi

Max End Slip: Front: 0.046", Back: 0.035", Ave: 0.041"

Max Deck Slip: Front: 0.000", Back: --, Ave: 0.000"

Max. Load: 49.98 kips

Max. Load/Ft. of Deck: 7.997 kips/ft.

Max. Load/Fastener: 2.083 kips

Failure Mode: Concrete shear across the top of the fasteners and the ribs of the deck at all ribs except rib no. 9, where the fasteners sheared.
FIGURE A.13 SPECIMEN 2A LAYOUT

FRONT VIEW

SIDE VIEW

(CONC. SLAB REMOVED TO SHOW DETAIL)
Comments: The self-tapping screw had a 1 1/4" steel sleeve around its shaft which held the deck down and allowed the fastener to be embedded into the concrete 1 1/2" (including the head height). This caused a failure plane to occur at the heads of the screws and the top of the ribs of the deck. All ribs failed by concrete shear except rib no. 6 (front and back) in which all four fasteners failed in shear. Debonding occurred after the concrete in the ribs of the deck sheared and there was minimal deck deformation.

FIGURE A.14 SPECIMEN 2A OBSERVATIONS
a) LOAD VS END SLIP

b) LOAD VS DECK SLIP

FIGURE A.15 SPECIMEN 2A RESPONSE PLOTS
VULCRAFT PUSH-OFF TEST
SUMMARY SHEET

Specimen Mark: __2B______  Test Date: __3/6/90__

Normal Load: __Restraining point load applied 6" from top__

Fastener: Type: __12-24x3" teks/5 w/1 1/4" stand-off sleeve__
Per Specimen: __24__, Front: __12__, Back: __12__

Deck: Type of Deck: __1.5 VL x 22 GA__
Deck Width: __37.5"__, Deck Length: __12"__

Base Member: Section: __WT 5 x 11__
Thickness of Connected Part: __0.375"__

Concrete: Thickness: __5.5"__, Strength: __4450 psi__

Max End Slip: Front: __0.009"__, Back: __0.017"__, Ave: __0.013"__

Max Deck Slip: Front: __0.010"__, Back: __---__, Ave: __0.010"__

Max. Load: __42.20 kips__

Max. Load/Ft. of Deck: __6.752 kips/ft__

Max. Load/Fastener: __1.758 kips__

Failure Mode: Concrete shear across the top of the fasteners and the ribs of the deck at all ribs except rib no. 6, where the fasteners sheared.
FRONT VIEW

(SIDE VIEW

(CONC. SLAB REMOVED TO SHOW DETAIL)

FIGURE A.16 SPECIMEN 2B LAYOUT
Comments: The self-tapping screw had a 1 1/4" steel sleeve around its shaft which held the deck down and allowed the fastener to be embedded into the concrete 1 1/2" (including the head height). This caused a failure plane to occur at the heads of the screws and the top of the ribs of the deck. All ribs failed by concrete shear except rib no. 6 (front and back) in which all four fasteners failed in shear. Debonding occurred after the concrete in the ribs of the deck sheared and there was minimal deck deformation. A restraining point load was applied normal to the slab at rib no. 1 on each side.
a) LOAD VS END SLIP

b) LOAD VS DECK SLIP

FIGURE A.18 SPECIMEN 2B RESPONSE PlOTS
VULCRAFT PUSH-OFF TEST
SUMMARY SHEET

Specimen Mark: 2C       Test Date: 3/6/90

Fastener: Type: 12-24x3" teks/5 w/1.1/4" stand-off sleeve
Per Specimen: 24, Front: 12, Back: 12

Deck: Type of Deck: 1.5 VL x 22 GA
Deck Width: 37.5", Deck Length: 12"

Base Member: Section: WT 5 x 11
Thickness of Connected Part: 0.375"

Concrete: Thickness: 5.5", Strength: 4450 psi

Max End Slip: Front: 0.019", Back: 0.037", Ave: 0.028"

Max Deck Slip: Front: 0.000", Back: --, Ave: 0.000"

Max. Load: 42.50 kips

Max. Load/Ft. of Deck: 6,800 kips/ft.

Max. Load/Fastener: 1,771 kips

Failure Mode: Concrete shear across the top of the fasteners and the ribs of the deck at all ribs except rib no. 6, where the fasteners sheared.
FRONT VIEW

SIDE VIEW

(CONC. SLAB REMOVED TO SHOW DETAIL)

FIGURE A.19 SPECIMEN 2C LAYOUT
Comments: The self-tapping screw had a 1 1/4" steel sleeve around its shaft which held the deck down and allowed the fastener to be embedded into the concrete 1 1/2" (including the head height). This caused a failure plane to occur at the heads of the screws and the top of the ribs of the deck. All ribs failed by concrete shear except rib no. 6 (front and back) in which all four fasteners failed in shear. Debonding occurred after the concrete in the ribs of the deck sheared and there was minimal deck deformation.

FIGURE A.20 SPECIMEN 2C OBSERVATIONS
FIGURE A.21 SPECIMEN 2C RESPONSE PLOTS
VULCRAFT PUSH-OFF TEST
SUMMARY SHEET

Specimen Mark: 2D  Test Date: 3/6/90

Normal Load: Restraining point load applied 6" from top.

Fastener: Type: 12-24x3" teks/5 w/1 1/4" stand-off sleeve
Per Specimen: 24, Front: 12, Back: 12

Deck: Type of Deck: 1.5 VL x 22 GA
Deck Width: 37.5", Deck Length: 12"

Base Member: Section: WT 5 x 11
Thickness of Connected Part: 0.375"

Concrete: Thickness: 5.5", Strength: 4450 psi

Max End Slip: Front: 0.035", Back: 0.010", Ave: 0.023"

Max Deck Slip: Front: 0.000", Back: --, Ave: 0.000"

Max. Load: 46.75 kips

Max. Load/Ft. of Deck: 7.480 kips/ft.

Max. Load/Fastener: 1.948 kips

Failure Mode: Concrete shear across the top of the fasteners and the ribs of the deck at all ribs except rib no. 6, where the fasteners sheared.
FIGURE A.22 SPECIMEN 2D LAYOUT

FRONT VIEW

SIDE VIEW

(CONC. SLAB REMOVED TO SHOW DETAIL)
Comments: The self-tapping screw had a 1 1/4" steel sleeve around its shaft which held the deck down and allowed the fastener to be embedded into the concrete 1 1/2" (including the head height). This caused a failure plane to occur at the heads of the screws and the top of the ribs of the deck. All ribs failed by concrete shear except rib no. 6 (front and back) in which all four fasteners failed in shear. Debonding occurred after the concrete in the ribs of the deck sheared and there was minimal deck deformation. A restraining point load was applied normal to the slab at rib no. 1 on each side.

FIGURE A.23 SPECIMEN 2D OBSERVATIONS
Figure A.24 Specimen 2D Response Plots

(a) Load vs End Slip

(b) Load vs Deck Slip

No observable deck slip.
VULCRAFT PUSH-OFF TEST
SUMMARY SHEET

Specimen Mark: 3A  Test Date: 4/2/90

Normal Load: Restraining point load applied to rib no. 3.

Fastener: Type: 1/4-14x2" teks/3 w/1 1/4" stand-off sleeve
Per Specimen: 10, Front: 5, Back: 5

Deck: Type of Deck: 1.5 VL x 22 GA
Deck Width: 30", Deck Length: 12"

Base Member: Section: 2-L1 1/4"x1 1/4"x0.109" welded to 1-PL1/4"x6"x36"
Thickness of Connected Part: 0.109"

Concrete: Thickness: 5.5", Strength: 4400 psi

Max. End Slip: Front: 0.190", Back: 0.275", Ave: 0.233"
Max. Deck Slip: Front: 0.000", Back: --, Ave: 0.000"

Max. Load: 20.08 kips
Max. Load/Ft. of Deck: 4.016 kips/ft.
Max. Load/Fastener: 2.008 kips

Failure Mode: Screw failure
FIGURE A.25 SPECIMEN 3A LAYOUT

FRONT VIEW

SIDE VIEW

(CONC. SLAB REMOVED TO SHOW DETAIL)
Comments: A restraining point load was applied normal to the slab at rib no. 3 on each side. Due to the thin base member, six of the 10 fasteners bent which caused local distortions in the angle base member. The other four fasteners failed by direct shear.

FIGURE A.26 SPECIMEN 3A OBSERVATIONS
a) LOAD VS END SLIP

b) LOAD VS DECK SLIP

FIGURE A.27 SPECIMEN 3A RESPONSE PLOTS
VULCRAFT PUSH-OFF TEST
SUMMARY SHEET

Specimen Mark: 3D                      Test Date: 4/10/90

Normal Load: Restraining point load applied to rib no. 3.

Fastener: Type: 1/4-14x2" teks / 3 w/ 1 1/4" stand-off sleeve
Per Specimen: 10, Front: 5, Back: 5

Deck: Type of Deck: 1.5 VL x 22 GA
Deck Width: 30", Deck Length: 12"

Base Member: Section: 2-L1 1/4"x1 1/4"x0.109" welded to 1-PL1/4"x6"x36"
Thickness of Connected Part: 0.109"

Concrete: Thickness: 5.5", Strength: 4550 psi

Max. End Slip: Front: 0.075", Back: 0.145", Ave: 0.110"

Max. Deck Slip: Front: 0.003", Back: --, Ave: 0.003"

Max. Load: 23.81 kips

Max. Load/Ft. of Deck: 4.762 kips/ft

Max. Load/Fastener: 2.381 kips

Failure Mode: Screw failure, minor concrete failure
FRONT VIEW
SIDE VIEW

(CONC. SLAB REMOVED TO SHOW DETAIL)

FIGURE A.28 SPECIMEN 3D LAYOUT
RIB NO.

1 2 3 4 5 6

CONCRETE SLAB
FRONT

FRONT

BACK

SCREW PULLOUT

CONCRETE SLAB
BACK

SIDE VIEW

Comments: A restraining point load was applied normal to the slab at rib no. 3 on each side. Concrete failed at rib no. 2 and no. 6 (front) as shown. The fastener at rib no. 3 (back) did not shear; however, upon separating the slab from the base member, it was observed that the screw was bent inside the concrete and was able to be pulled out. The limit state for this specimen was screw failure.

FIGURE A.29 SPECIMEN 3D OBSERVATIONS
Figure A.30 Specimen 3D Response Plots

a) Load vs End Slip

b) Load vs Deck Slip
VULCRAFT PUSH-OFF TEST

SUMMARY SHEET

Specimen Mark: 3B  Test Date: 4/5/90

Normal Load: Restraint point load applied to rib no. 3.

Fastener: Type: 1/4-14x2" teks/3 w/1 1/4" stand-off sleeve
Per Specimen: 20, Front: 10, Back: 10

Deck: Type of Deck: 1.5 VL x 22 GA
Deck Width: 30", Deck Length: 12"

Base Member: Section: 2-L1 1/4"x1 1/4"x0.109" welded to 1-PL 1/4"x6"x36"
Thickness of Connected Part: 0.109"

Concrete: Thickness: 5.5", Strength: 4400 psi

Max. End Slip: Front: 0.041", Back: 0.083", Ave: 0.062"

Max. Deck Slip: Front: 0.000", Back: --", Ave: 0.000"

Max. Load: 30.41 kips

Max. Load/Ft. of Deck: 6.082 kips/ft.

Max. Load/Fastener: 1.521 kips

Failure Mode: Concrete shear across the top to the fasteners with a width of 7.5 in. to 9 in. Four out of eight fasteners, in ribs 1 to 5 (front) sheared.
FIGURE A.31 SPECIMEN 3B LAYOUT
Comments: A restraining point load was applied normal to the slab at rib no. 3 on each side. The concrete in rib no. 6 is unable to shear, thus screw failure must occur. The concrete failure, which occurred at the ribs shown, was limited from 7.5' to 9'. The concrete did not fail across the entire 12' long rib. Screw failures occurred at rib no.'s 2 and 4 (back).

FIGURE A.32 SPECIMEN 3B OBSERVATIONS
FIGURE A.33 SPECIMEN 3B RESPONSE PLOTS

a) LOAD VS END SLIP

b) LOAD VS DECK SLIP

NO OBSERVABLE DECK SLIP
VULCRAFT PUSH-OFF TEST
SUMMARY SHEET

Specimen Mark: 3C          Test Date: 4/10/90

Normal Load: Restrainging point load applied to rib no. 3.

Fastener:
Type: 1/4-14x2" teks/3 w/1 1/4" stand-off sleeve
Per Specimen: 20, Front: 10, Back: 10

Deck:
Type of Deck: 1.5 VL x 22 GA
Deck Width: 30", Deck Length: 12"

Base Member:
Section: 2-L1 1/4"x1 1/4"x0.109" welded to 1-PL1/4"x6"x36"
Thickness of Connected Part: 0.109"

Concrete:
Thickness: 5.5", Strength: 4550 psi

Max. End Slip:
Front: 0.097", Back: 0.040", Ave: 0.069"

Max. Deck Slip:
Front: 0.000", Back: --, Ave: 0.000"

Max. Load:
34.64 kips

Max. Load/Ft. of Deck:
6.928 kips/ft.

Max. Load/Fastener:
1.732 kips

Failure Mode: Concrete shear across the top to the fasteners except for rib 4 (front) in which both fasteners in the rib failed. The effective width of the concrete failure ranged from 7 in. to 12 in. across the rib.
FIGURE A.34 SPECIMEN 3C LAYOUT

FRONT VIEW

SIDE VIEW

(CONC. SLAB REMOVED TO SHOW DETAIL)
Comments: A restraining point load was applied normal to the slab at rib no. 3 on each side. The concrete in rib no. 6 is unable to shear, thus screw failure must occur. Four of the ribs displayed a concrete failure across the entire 12' of the rib. Rib no. 4 (front) failed by screw shear only.

FIGURE A.35 SPECIMEN 3C OBSERVATIONS
a) LOAD VS END SLIP

b) LOAD VS DECK SLIP

FIGURE A.36 SPECIMEN 3C RESPONSE PLOTS
VULCRAFT PUSH-OFF TEST
SUMMARY SHEET

Specimen Mark: 4A_______ Test Date: 5/17/90

Normal Load: Incremental uniform load

Fastener: Type: 1/4-14x2" teks/3 w/1 1/4" stand-off sleeve
Per Specimen: 12____, Front: 6____, Back: 6____

Deck: Type of Deck: Inverted 1.5 VL x 22 GA
Deck Width: 33'____, Deck Length: 12'____

Base Member: Section: 2-L1 1/2"x1 1/2"x0.113" welded to 1-P 1/2"x6"x44"
Thickness of Connected Part: 0.113''____

Concrete: Thickness: 5.5''____, Strength: 4500 psi

Max. End Slip: Front: 0.109'', Back: 0.122'', Ave: 0.116''

Max. Deck Slip: Front: 0.112'', Back: --'', Ave: 0.112''

Max. Load: 28.25 kips

Max. Load/Ft. of Deck: 5.136 kips/ft.

Max. Load/Fastener: 2.354 kips

Failure Mode: Screw failure at all fastener locations
Figure A.37 Specimen 4A Layout
Comments: All fasteners bent as observed at the exposed portion of the fastener, due to the thin angle base member. All of the fasteners failed and no concrete failure was observed. Generally, the fasteners fractured 1/8" into the concrete and not at the interface between the deck and the angle base member. The angle base member bent locally due to the fastener.
FIGURE A.39 SPECIMEN 4A RESPONSE PLOTS

a) LOAD VS END SLIP

b) LOAD VS DECK SLIP
VULCRAFT PUSH-OFF TEST

SUMMARY SHEET

Specimen Mark: 4B  Test Date: 5/17/30

Normal Load: Incremental uniform load

Fastener: Type: 1/4-14 x 2" tek's/3 w/ 1 1/4" stand-off sleeve
Per Specimen: 12, Front: 6, Back: 6

Deck: Type of Deck: Inverted 1.5 VL x 22 GA
Deck Width: 33", Deck Length: 24"

Base Member: Section: 2-L1 1/2"x1 1/2"x0.113" welded to 1-P1/2"x6"x44"
Thickness of Connected Part: 0.113"

Concrete: Thickness: 5.5", Strength: 4500 psi

Max. End Slip: Front: 0.200", Back: 0.182", Ave: 0.191"

Max. Deck Slip: Front: 0.135", Back: --", Ave: 0.135"

Max. Load: 28.88 kips

Max. Load/Ft. of Deck: 5.251 kips/ft.

Max. Load/Fastener: 2.407 kips

Failure Mode: Screw failure at all fastener locations
FRONT VIEW

SIDE VIEW

(CONC. SLAB REMOVED TO SHOW DETAIL)

FIGURE A.40 SPECIMEN 4B LAYOUT
RIB NO.

1
2
3
4
5
6

CONCRETE SLAB
FRONT

FRONT
BACK

SIDE VIEW

CONCRETE SLAB
BACK

Comments: All fasteners bent as observed at the exposed portion of the fastener, due to the thin angle base member. All of the fasteners failed and no concrete failure was observed. Generally, the fasteners fractured 1/8" into the concrete and not at the interface between the deck and the angle base member. The angle base member bent locally due to the fastener.

FIGURE A.41 SPECIMEN 4B OBSERVATIONS
Figure A.42 Specimen 4B Response Plots

a) Load vs End Slip

b) Load vs Deck Slip
VULCRAFT PUSH-OFF TEST
SUMMARY SHEET

Specimen Mark: 4C________  Test Date: 5/16/90

Normal Load: Incremental uniform load

Fastener: Type: 1/4-14x2" teks/3 w/1 1/4" stand-off sleeve
Per Specimen: 24, Front: 12, Back: 12

Deck: Type of Deck: Inverted 1.5 VL x 22 GA
Deck Width: 33", Deck Length: 12"

Base Member: Section: 2-L1 1/2"x1 1/2"x0.113" welded to 1-PL1/2"x6"x44"
Thickness of Connected Part: 0.113"

Concrete: Thickness: 5.5", Strength: 4500 psi

Max. End Slip: Front: 0.165", Back: 0.139", Ave: 0.152"

Max. Deck Slip: Front: 0.050", Back: --", Ave: 0.050"

Max. Load: 47.19 kips

Max. Load/Ft. of Deck: 8.580 kips/ft.

Max. Load/Fastener: 1.966 kips

Failure Mode: Screw failure at all fastener locations
FIGURE A.43 SPECIMEN 4C LAYOUT

FRONT VIEW

(SIDE VIEW)

CONC. SLAB REMOVED TO SHOW DETAIL)
Comments: All fasteners bent as observed at the exposed portion of the fastener, due to the thin angle base member. All of the fasteners failed and no concrete failure was observed.

FIGURE A.44 SPECIMEN 4C OBSERVATIONS
a) LOAD VS END SLIP

b) LOAD VS DECK SLIP

FIGURE A.45 SPECIMEN 4C RESPONSE PLOTS
VULCRAFT PUSH-OFF TEST
SUMMARY SHEET

Specimen Mark: 4D______  Test Date: 5/16/90

Normal Load: Incremental uniform load

Fastener: Type: 1/4-14x2" teks/3 w/1 1/4" stand-off sleeve
Per Specimen: 24, Front: 12, Back: 12

Deck: Type of Deck: Inverted 1.5 HL x 22 GA
Deck Width: 33", Deck Length: 12"

Base Member: Section: 2-L1 1/2"x1 1/2"x0.113" welded to 1-PL1 1/2"x6"x44"
Thickness of Connected Part: 0.113"

Concrete: Thickness: 5.5", Strength: 4500 psi

Max. End Slip: Front: 0.135", Back: 0.220", Ave: 0.178"
Max. Deck Slip: Front: 0.040", Back: --", Ave: 0.040"

Max. Load: 54.81 kips


Max. Load/Fastener: 2.284 kips

Failure Mode: Screw failure at all fastener locations
FRONT VIEW

SIDE VIEW

(CONC. SLAB REMOVED TO SHOW DETAIL)

FIGURE A.46 SPECIMEN 4D LAYOUT
Comments: All fasteners bent as observed at the exposed portion of the fastener, due to the thin angle base member. All of the fasteners failed and no concrete failure was observed. Generally, the fasteners fractured 1/8" into the concrete and not at the interface between the deck and the angle base member.

FIGURE A.47 SPECIMEN 4D OBSERVATIONS
a) LOAD VS END SLIP

b) LOAD VS DECK SLIP

FIGURE A.48 SPECIMEN 4D RESPONSE PLOTS
VULCRAFT PUSH-OFF TEST

SUMMARY SHEET

Specimen Mark: 5A  Test Date: 6/5/90

Normal Load: Incremental uniform load

Fastener: Type: 0.15" dia. air fired pins (SDK32075)

Per Specimen: 24, Front: 12, Back: 12

Deck: Type of Deck: 1.5 VL x 22 GA

Deck Width: 37", Deck Length: 12"

Base Member: Section: 2-L1 1/2"x1 1/2"x0.113" welded to 1-PL 1/2"x6x44"

Thickness of Connected Part: 0.113"

Concrete: Thickness: 5.5", Strength: 4600 psi

Max. End Slip: Front: 0.265", Back: 0.200", Ave: 0.233"

Max. Deck Slip: Front: 0.009", Back: --, Ave: 0.009"

Max. Load: 25.40 kips

Max. Load/Ft. of Deck: 4.119 kips/ft.

Max. Load/Fastener: 1.058 kips

Failure Mode: Deck bearing failure around the head and/or shaft of the fastener at all fastener locations.
FRONT VIEW

SIDE VIEW

(CONC. SLAB REMOVED TO SHOW DETAIL)

FIGURE A.49 SPECIMEN 5A LAYOUT
Comments: The deck failed in bearing around each pin. No debonding or concrete failure was observed.

FIGURE A.50 SPECIMEN 5A OBSERVATIONS
FIGURE A.51 SPECIMEN 5A RESPONSE PLOTS

(a) LOAD VS END SLIP

(b) LOAD VS DECK SLIP
VULCRAFT PUSH-OFF TEST
SUMMARY SHEET

Specimen Mark: 5B  Test Date: 6/6/90

Normal Load: Incremental uniform load

Fastener: Type: 0.15" dia. air fired pins (SDK32075)
Per Specimen: 24, Front: 12, Back: 12

Deck: Type of Deck: 1.5 V, x 22 GA
Deck Width: 37", Deck Length: 12"

Base Member: Section: 2-L1 1/2"x1 1/2"x0.113" welded to 1-PL 1/2"x6"x44"
Thickness of Connected Part: 0.113"

Concrete: Thickness: 5.5"  Strength: 4600 psi

Max. End Slip: Front: 0.200", Back: 0.200", Ave: 0.200"

Max. Deck Slip: Front: 0.000", Back: --", Ave: 0.000"

Max. Load: 24.20 kips

Max. Load/Ft. of Deck: 3.924 kips/ft.

Max. Load/Fastener: 1.008 kips

Failure Mode: Deck bearing failure around the head and/or shaft of the fastener at all fastener locations.
FRONT VIEW

SIDE VIEW

(CONG. SLAB REMOVED TO SHOW DETAIL)

FIGURE A.52 SPECIMEN 5B LAYOUT
Comments: The deck failed in bearing around each pin. No debonding or concrete failure was observed.

FIGURE A.53 SPECIMEN 5B OBSERVATIONS
Figure A.54: Specimen 5B Response Plots

a) Load vs End Slip

- Front (circles)
- Back (triangles)
- Average (solid line)

End Slip (Inches)

b) Load vs Deck Slip

No Observable Deck Slip

Deck Slip (Inches)
VULCRAFT PUSH-OFF TEST
SUMMARY SHEET

Specimen Mark: 5C  Test Date: 6/6/90

Normal Load: Incremental uniform load

Fastener: Type: 0.15" dia. air fired pins (SDK32075)
Per Specimen: 24, Front: 12, Back: 12

Deck: Type of Deck: 1.5 VL x 22 GA
Deck Width: 37", Deck Length: 12"

Base Member: Section: 2-L1 1/2"x1 1/2"x0.113' welded to 1-PL 1/2"x6"x44'
Thickness of Connected Part: 0.113"

Concrete: Thickness: 5.5", Strength: 4600 psi

Max. End Slip: Front: 0.240", Back: 0.200", Ave: 0.220"
Max. Deck Slip: Front: 0.000", Back: --, Ave: 0.000"

Max. Load: 26.91 kips
Max. Load/Ft. of Deck: 4.688 kips/ft.
Max. Load/Fastener: 1.205 kips

Failure Mode: Deck bearing failure around the head and/or shaft of the fastener at all fastener locations.
FIGURE A.55 SPECIMEN 5C LAYOUT

FRONT VIEW

SIDE VIEW

(CONC. SLAB REMOVED TO SHOW DETAIL)
RIB NO.

1  2  3  4  5  6

CONCRETE SLAB FRONT  FRONT  BACK  CONCRETE SLAB BACK

SIDE VIEW

Comments: The deck failed in bearing around each pin. No debonding or concrete failure was observed.

FIGURE A.56 SPECIMEN 5C OBSERVATIONS
Figure A.57 Specimen 5C Response Plots

a) Load vs End Slip

- \( \circ \) Front
- \( \triangledown \) Back
- \(--\) Average

b) Load vs Deck Slip

No Observable Deck Slip
VULCRAFT PUSH-OFF TEST
SUMMARY SHEET

Specimen Mark:  6A________  Test Date:  6/15/90

Normal Load:  Incremental uniform load ________________

Fastener:  Type:  0.15" dia. air fired pins (SDK32075) ________________
Per Specimen:  12__, Front:  6__, Back:  6__

Deck:  Type of Deck:  1.5 VL x 22 GA ________________
Deck Width:  37"__, Deck Length:  12"__

Base Member:  Section:  2-L 1/2"x1 1/2"x0.113" welded to 1-PL 1/2"x6"x44"
Thickness of Connected Part:  0.113" ________________

Concrete:  Thickness:  5.5"__, Strength:  4350 psi ________________

Max. End Slip:  Front:  0.350"__, Back:  0.360"__, Ave:  0.355"

Max. Deck Slip:  Front:  0.001"__, Back:  0.005"__, Ave:  0.003"

Max. Load:  13.20 kips ________________

Max. Load/Ft. of Deck:  2.141 kips/ft. ________________

Max. Load/Fastener:  1.100 kips ________________

Failure Mode:  Deck bearing failure around the head and/or shaft of the fastener at all fastener locations.
FRONT VIEW

SIDE VIEW

(Conc. slab removed to show detail)

FIGURE A.58 SPECIMEN 6A LAYOUT
Comments: The deck failed in bearing around each pin. No debonding or concrete failure was observed.

FIGURE A.59 SPECIMEN 6A OBSERVATIONS
FIGURE A.60 SPECIMEN 6A RESPONSE PLOTS
VULCRAFT PUSH-OFF TEST
SUMMARY SHEET

Specimen Mark: SB__ Test Date: 6/15/90

Normal Load: Incremental uniform load

Fastener: Type: 0.15" dia. air fired pins (SDK32075)
Per Specimen: 12, Front: 6, Back: 6

Deck: Type of Deck: 1.5 VL x 22 GA
Deck Width: 37", Deck Length: 12"

Base Member: Section: 2-L1 1/2"x1 1/2"x0.113" welded to 1-PL1/2"x6"x44"
Thickness of Connected Part: 0.113"

Concrete: Thickness: 5.5", Strength: 4350 psi

Max. End Slip: Front: 0.190", Back: 0.380", Ave: 0.285"

Max. Deck Slip: Front: 0.000", Back: 0.000", Ave: 0.000"

Max. Load: 16.15 kips

Max. Load/Ft. of Deck: 2.619 kips/ft.

Max. Load/Fastener: 1.346 kips

Failure Mode: Deck bearing failure around the head and/or shaft of the fastener at all fastener locations.
FIGURE A.61 SPECIMEN 6B LAYOUT

FRONT VIEW

SIDES VIEW

(CONC. SLAB REMOVED TO SHOW DETAIL)
Comments: The deck failed in bearing around each pin. No debonding or concrete failure was observed.
a) LOAD VS END SLIP

b) LOAD VS DECK SLIP

FIGURE A.63 SPECIMEN 6B RESPONSE PLOTS
VULCRAFT PUSH-OFF TEST
SUMMARY SHEET

Specimen Mark: 6C  Test Date: 6/18/90

Normal Load: Incremental uniform load

Fastener: Type: 0.15" dia. air fired pins (SDK32075)
Per Specimen: 12, Front: 6, Back: 6

Deck: Type of Deck: 1.5 VL x 22 GA
Deck Width: 37", Deck Length: 12"

Base Member: Section: 2-L 1 1/2"x1 1/2"x0.113" welded to 1-PL 1/2"x6"x44"
Thickness of Connected Part: 0.113"

Concrete: Thickness: 5.5", Strength: 4350 psi

Max. End Slip: Front: 0.150", Back: 0.300", Ave: 0.225"

Max. Deck Slip: Front: 0.000", Back: 0.000", Ave: 0.000"

Max. Load: 13.50 kips

Max. Load/Ft. of Deck: 2.189 kips/ft.

Max. Load/Fastener: 1.125 kips

Failure Mode: Deck bearing failure around the head and/or shaft of the fastener at all fastener locations.
FRONT VIEW

SIDE VIEW

(CONC. SLAB REMOVED TO SHOW DETAIL.)

FIGURE A.64 SPECIMEN 6C LAYOUT
Comments: The deck failed in bearing around each pin. No debonding or concrete failure was observed.

FIGURE A.65 SPECIMEN 6C OBSERVATIONS
a) LOAD VS END SLIP

b) LOAD VS DECK SLIP

FIGURE A.66 SPECIMEN 6C RESPONSE PLOTS
VULCRAFT PUSH-OFF TEST
SUMMARY SHEET

Specimen Mark: 7A  Test Date: 7/3/90

Normal Load: Incremental uniform load

Fastener: Type: 1/4-14x3" teks/3 w/2 1/4" stand-off sleeve
Per Specimen: 24, Front: 12, Back: 12

Deck: Type of Deck: 1.5 VL x 22 GA
Deck Width: 37", Deck Length: 12"

Base Member: Section: 2-L 1 1/2"x1 1/2"x0.113" welded to 1-PL 1/2"x6"x44"
Thickness of Connected Part: 0.113"

Concrete: Thickness: 5.5", Strength: 3900 psi

Max. End Slip: Front: 0.191", Back: 0.122", Ave: 0.157"

Max. Deck Slip: Front: 0.025", Back: --, Ave: 0.025"

Max. Load: 51.01 kips

Max. Load/Ft. of Deck: 8.272 kips/ft.

Max. Load/Fastener: 2.125 kips

Failure Mode: Concrete shear across the top of the fasteners which continued across the ribs of the deck, except rib no. 6, in which the fasteners sheared.
FIGURE A.67 SPECIMEN 7A LAYOUT

FRONT VIEW  SIDE VIEW

(CONC. SLAB REMOVED TO SHOW DETAIL)
Comments: All the fasteners bent inside the concrete rib. Screw shear failure was observed as noted on the side view.

FIGURE A.68 SPECIMEN 7A OBSERVATIONS
Figure A.69 Specimen 7A Response Plots
VULCRAFT PUSH-OFF TEST

SUMMARY SHEET

Specimen Mark: 7B  
Test Date: 7/3/90

Normal Load: Incremental uniform load

Fastener: Type: 1/4-14x3" teks/3 w/2 1/4" stand-off sleeve
Per Specimen: 24, Front: 12, Back: 12

Deck: Type of Deck: 1.5 VL x 22 GA
Deck Width: 37", Deck Length: 12"

Base Member: Section: 2-L1 1/2"x1 1/2"x0.113" welded to 1-PL 1/2"x6"x44"
Thickness of Connected Part: 0.113"

Concrete: Thickness: 5.5", Strength: 3900 psi

Max. End Slip: Front: 0.105", Back: 0.030", Ave: 0.068"

Max. Deck Slip: Front: 0.009", Back: --, Ave: 0.009"

Max. Load: 46.37 kips

Max. Load/Ft. of Deck: 7.519 kips/ft.

Max. Load/Fastener: 1.932 kips

Failure Mode: Concrete shear across the top of the fasteners which continued across the ribs of the deck, except rib no. 6, in which the fasteners sheared.
FRONT VIEW

SIDE VIEW

(CONC. SLAB REMOVED TO SHOW DETAIL)

FIGURE A.70 SPECIMEN 7B LAYOUT
Comments: All the fasteners bent inside the concrete rib. All ribs failed by concrete shear except rib no. 3 (back).

FIGURE A.71 SPECIMEN 7B OBSERVATIONS
a) LOAD VS END SLIP

b) LOAD VS DECK SLIP

FIGURE A.72 SPECIMEN 7B RESPONSE PLOTS
VULCRAFT PUSH-OFF TEST
SUMMARY SHEET

Specimen Mark: 8A  
Test Date: 7/16/90

Normal Load: Incremental uniform load

Fastener:  
Type: 1/4-14x3" teks/3 w/ 1 3/4" stand-off sleeve
Per Specimen: 24, Front: 12, Back: 12

Deck:  
Type of Deck: 1.5 VL x 22 GA
Deck Width: 37", Deck Length: 12"

Base Member:  
Section: 2-L1 1/2"x1 1/2"x0.113" welded to 1-PL 1/2"x6"x44"
Thickness of Connected Part: 0.113"

Concrete:  
Thickness: 5.5", Strength: 4100 psi

Max. End Slip:  
Front: 0.120", Back: 0.050", Ave: 0.085"

Max. Deck Slip:  
Front: 0.020", Back: --, Ave: 0.020"

Max. Load: 47.36 kips

Max. Load/Ft. of Deck: 7.680 kips/ft.

Max. Load/Fastener: 1.973 kips

Failure Mode: Concrete shear across the ribs of the deck.
FRONT VIEW  
SIDE VIEW

(CONC. SLAB REMOVED TO SHOW DETAIL)

FIGURE A.73 SPECIMEN 8A LAYOUT
Comments: The concrete sheared across the top of the deck and under the head of the fastener. Screw failure occurred at rib no. 5 (front) and rib no. 6 (front and back). The fastener fractured 1/8" into the concrete, minor bending of the fastener was observed.

FIGURE A.74 SPECIMEN 8A OBSERVATIONS
FIGURE A.75 SPECIMEN 8A RESPONSE PLOTS
VULCRAFT PUSH-OFF TEST
SUMMARY SHEET

Specimen Mark: 8B  Test Date: 7/16/90

Normal Load: Incremental uniform load

Fastener: Type: 1/4-14x3" teks/3 w/1 3/4" stand-off sleeve
Per Specimen: 24, Front: 12, Back: 12

Deck: Type of Deck: 1.5 VL x 22 GA
Deck Width: 37", Deck Length: 12"

Base Member: Section: 2-L1 1/2"x1 1/2"x0.113" welded to 1-PL 1/2"x6"x44"
Thickness of Connected Part: 0.113"

Concrete: Thickness: 5.5", Strength: 4100 psi

Max. End Slip: Front: 0.170", Back: 0.055", Ave: 0.113"
Max. Deck Slip: Front: 0.030", Back: --, Ave: 0.030"

Max. Load: 45.42 kips

Max. Load/Ft. of Deck: 7.365 kips/ft.

Max. Load/Fastener: 1.893 kips

Failure Mode: Concrete shear across the ribs of the deck.
FRONT VIEW

SIDE VIEW

(CONC. SLAB REMOVED TO SHOW DETAIL)

FIGURE A.76 SPECIMEN 8B LAYOUT
Comments: The concrete sheared across the top of the deck and under the head of the fastener. Screw failure occurred at rib no. 6 (front).

FIGURE A.77 SPECIMEN 8B OBSERVATIONS
FIGURE A.78 SPECIMEN 8B RESPONSE PLOTS

a) LOAD VS END SLIP

b) LOAD VS DECK SLIP
VULCRAFT PUSH-OFF TEST

SUMMARY SHEET

Specimen Mark: 9A  Test Date: 7/16/90

Normal Load: Incremental uniform load

Fastener:
Type: 12-24 x 1 1/4" teks/5
Per Specimen: 24, Front: 12, Back: 12

Deck:
Type of Deck: 1.5 VL x 22 GA
Deck Width: 37", Deck Length: 12"

Base Member:
Section: 2-L1 1/2"x1 1/2"x0.113" welded to 1-P'1/2"x6"x44"
Thickness of Connected Part: 0.113"

Concrete:
Thickness: 5.5", Strength: 4150 psi

Max. End Slip:
Front: 0.270", Back: 0.165", Ave: 0.218"

Max. Deck Slip:
Front: 0.070", Back: --, Ave: 0.070"

Max. Load: 45.67 kips

Max. Load/Ft. of Deck: 7.406 kips/ft.

Max. Load/Fastener: 1.903 kips

Failure Mode: Deck bearing failure at all fastener locations except at rib no. 1, due to deck deformation which relieved stress on the fasteners.
FIGURE A.79 SPECIMEN 9A LAYOUT
Comments: The head of the fastener protrudes into the concrete rib 1/4", thus breaks a portion of the rib as shown. The deck failed in bearing around each fastener. The deck debonded and deformed at rib no. 1 near maximum load.

FIGURE A.80 SPECIMEN 9A OBSERVATIONS
a) LOAD VS END SLIP

b) LOAD VS DECK SLIP

FIGURE A.81 SPECIMEN 9A RESPONSE PLOTS
VULCRAFT PUSH-OFF TEST

SUMMARY SHEET

Specimen Mark: 9B  Test Date: 7/16/90

Normal Load: Incremental uniform load

Fastener: Type: 12-24 x 1 1/4" teks/5
Per Specimen: 24, Front: 12, Back: 12

Deck: Type of Deck: 1.5 VL x 22 GA
Deck Width: 37", Deck Length: 12"

Base Member: Section: 2-L1 1/2"x1 1/2"x0.113" welded to 1-PL1/2"x6"x44"
Thickness of Connected Part: 0.113"

Concrete: Thickness: 5.5", Strength: 4150 psi

Max. End Slip: Front: 0.200", Back: 0.155", Ave: 0.178"

Max. Deck Slip: Front: 0.030", Back: --, Ave: 0.030"

Max. Load: 44.35 kips


Max. Load/Fastener: 1.848 kips

Failure Mode: Deck bearing failure at all fastener locations except at rib no. 1, due to deck deformation which relieved stress on the fasteners.
Comments: The head of the fastener protrudes into the concrete rib 1/4", thus breaks a portion of the rib as shown. The deck failed in bearing around each fastener. The deck debonded and deformed at rib no. 1 near maximum load. Two ribs exhibited concrete failure, rib no. 2 (front) and rib no. 4 (back).

FIGURE A.83 SPECIMEN 9B OBSERVATIONS
Figure A.84 Specimen 9B Response Plots
VULCRAFT PUSH-OFF TEST

SUMMARY SHEET

Specimen Mark: _10A_______  Test Date:  _7/23/90___

Normal Load: _incremental uniform load_____________________

Fastener: Type: _5/8" puddle welds_____________________
Per Specimen: _24__, Front: _12__, Back: _12__

Deck: Type of Deck: _1.5 VL x 22 GA_____________________
Deck Width: _37"___, Deck Length: _12"___

Base Member: Section: _2-L1 1/2"x1 1/2"x0.113" welded to 1-PL1/2"x6"x44"_
Thickness of Connected Part: _0.113"_____________________

Concrete: Thickness: _5.5"___, Strength: _3600 psi___

Max. End Slip: Front: _0.025"__, Back: _0.075"__, Ave: _0.050"__

Max. Deck Slip: Front: _0.003"__, Back: _0.050"__, Ave: _0.027"__

Max. Load: _35.11 kips___

Max. Load/Ft. of Deck: _5.694 kips/ft.___

Max. Load/Fastener: _1.463 kips____

Failure Mode: Concrete shear across the ribs of the deck except at rib no. 1 (front and back) and rib no. 3 (back). Rib no. 6 cannot fail by concrete shear, thus the deck failed in bearing around the welds.
FRONT VIEW
SIDE VIEW

(CONC. SLAB REMOVED TO SHOW DETAIL)

FIGURE A.85 SPECIMEN 10A LAYOUT
Comments: The puddle welds at rib no. 3 (back) failed due to poor penetration. The deck failed in bearing at rib no. 6 (front and back). All other ribs exhibited concrete failure.

FIGURE A.86 SPECIMEN 10A OBSERVATIONS
a) LOAD VS END SLIP

b) LOAD VS DECK SLIP

FIGURE A.87 SPECIMEN 10A RESPONSE PLOTS
**VULCRAFT PUSH-OFF TEST**

**SUMMARY SHEET**

Specimen Mark: 10B  
Test Date: 7/23/90

Normal Load: Incremental uniform load

Fastener: Type: 5/8" puddle welds
Per Specimen: 24, Front: 12, Back: 12

Deck: Type of Deck: 1.5 VL x 22 GA
Deck Width: 37", Deck Length: 12"

Base Member: Section: 2-L 1/2"x1 1/2"x0.113" welded to 1-PL 1/2"x6"x44"
Thickness of Connected Part: 0.113"

Concrete: Thickness: 5.5", Strength: 3600 psi

Max. End Slip: Front: 0.070", Back: 0.035", Ave: 0.053"

Max. Deck Slip: Front: 0.020", Back: 0.010", Ave: 0.015"

Max. Load: 38.04 kips

Max. Load/ Ft. of Deck: 6.169 kips/ft.

Max. Load/Fastener: 1.585 kips

Failure Mode: Concrete shear across the ribs of the deck except at rib no. 1 (front and back) and rib no. 3 (front). Rib no. 6 cannot fail by concrete shear, thus the deck failed in bearing around the welds.
FIGURE A.88 SPECIMEN 10B LAYOUT
Comments: The puddle welds at rib no. 3 (front) failed due to poor penetration. The deck failed in bearing at rib no. 6 (front and back). All other ribs exhibited concrete failure. Minor deck deformation at rib no. 1 at max load.

FIGURE A.89 SPECIMEN 10B OBSERVATIONS
Figure A.90 Specimen 10B Response Plots

(a) Load vs End Slip

(b) Load vs Deck Slip
# VULCRAFT PUSH-OFF TEST

## SUMMARY SHEET

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<td>Failure Mode:</td>
<td>Concrete shear across the ribs of the deck except at rib no. 1 (front and back) and rib no. 5 (front).</td>
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</tbody>
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FIGURE A.91 SPECIMEN 11A LAYOUT
RIB NO.

1
2
3
4
5
6

CONCRETE SLAB FRONT

FRONT

BACK

CONCRETE SLAB BACK

SIDE VIEW

Comments: Concrete failure occurred at every rib except rib no. 5 (front) and rib no. 6.

FIGURE A.92 SPECIMEN 11A OBSERVATIONS
FIGURE A.93 SPECIMEN 11A RESPONSE PLOTS

a) LOAD VS END SLIP

b) LOAD VS DECK SLIP
VULCRAFT PUSH-OFF TEST
SUMMARY SHEET

Specimen Mark: 11B  Test Date: 7/23/90

Normal Load: Incremental uniform load

Fastener: Type: 3/4" puddle welds
Per Specimen: 24, Front: 12, Back: 12

Deck: Type of Deck: 1.5 VL x 22 GA
Deck Width: 37", Deck Length: 12"

Base Member: Section: 2-L1 1/2"x1 1/2"x0.113" welded to 1-PL 1/2"x6"x44"
Thickness of Connected Part: 0.113"

Concrete: Thickness: 5.5", Strength: 3800 psi

Max. End Slip: Front: 0.087", Back: 0.036", Ave: 0.062"

Max. Deck Slip: Front: 0.009", Back: 0.003", Ave: 0.006"

Max. Load: 35.58 kips

Max. Load/Ft. of Deck: 6.256 kips/ft.

Max. Load/Fastener: 1.608 kips

Failure Mode: A combination of concrete shear across the ribs of the deck and weld failure.
FIGURE A.94 SPECIMEN 11B LAYOUT

FRONT VIEW

SIDE VIEW

(CONC. SLAB REMOVED TO SHOW DETAIL)
Comments: Concrete failure occurred at every rib except rib no. 4 (front) and rib no. 6. Rib no. 3 failed by both concrete shear and weld failure. Minor deck deformation occurred at rib no. 1 and 2 (back).

FIGURE A. 95 SPECIMEN 11B OBSERVATIONS
a) LOAD VS END SLIP

b) LOAD VS DECK SLIP

FIGURE A.96 SPECIMEN 11B RESPONSE PLOTS
VULCRAFT PUSH-OFF TEST
SUMMARY SHEET

Specimen Mark: 12A Test Date: 8/27/90

Normal Load: Incremental uniform load

Fastener: Type: 3/4" diameter puddle welds
Per Specimen: 20, Front: 10, Back: 10

Deck: Type of Deck: 1.5 VL x 22 GA
Deck Width: 34", Deck Length: 24"

Base Member: Section: 2-L 1 1/2" x 1 1/2" x 0.113" welded to 1-PL 1/2" x 0.113"
 Thickness of Connected Part: 0.113"

Concrete: Thickness: 4.5", Strength: 4800 psi

Max. End Slip: Front: 0.085", Back: 0.052", Ave: 0.069"

Max. Deck Slip: Front: 0.0015", Back: 0.0045", Ave: 0.003"

Max. Load: 56.03 kips


Max. Load/Fastener: 2.802 kips

Failure Mode: Concrete shear failure across the ribs of the deck.
FIGURE A.97 SPECIMEN 12A LAYOUT

FRONT VIEW

SIDE VIEW

(CONC. SLAB REMOVED TO SHOW DETAIL)
Comments: The specimen exhibited a brittle failure due to the concrete failure across the ribs of the deck. The width of the concrete failure ranged from 15° to 22°. No weld failure or deck bearing failure was observed.

FIGURE A.98 SPECIMEN 12A OBSERVATIONS
FIGURE A.99 SPECIMEN 12A RESPONSE PLOTS
VULCRAFT PUSH-OFF TEST
SUMMARY SHEET

Specimen Mark: 12B_________  Test Date: 8/27/90

Normal Load: Incremental uniform load ____________________________

Fastener: Type: 3/4" diameter puddle welds ________________________
Per Specimen: 20, Front: 10, Back: 10

Deck: Type of Deck: 1.5 VL x 22 GA ____________________________
Deck Width: 34",  Deck Length: 24"

Base Member: Section: 2-L1 1/2"x1 1/2"x0.113" welded to 1-PL 1/2"x6"x44"
Thickness of Connected Part: 0.113" __________________________

Concrete: Thickness: 4.5",  Strength: 4800 psi

Max. End Slip: Front: 0.040",  Back: 0.047",  Ave: 0.044"

Max. Deck Slip: Front: 0.003",  Back: 0.003",  Ave: 0.003"

Max. Load: 47.38 kips

Max. Load/Ft. of Deck: 8.361 kips/ft.

Max. Load/Fastener: 2.369 kips

Failure Mode: Weld failure for ribs 1, 2 and 3 (back) and concrete shear failure across the ribs of the deck at all other rib locations.
FRONT VIEW

SIDE VIEW

(CONC. SLAB REMOVED TO SHOW DETAIL)

FIGURE A.100 SPECIMEN 12B LAYOUT
The specimen exhibited a brittle failure due to the concrete failure across the ribs of the deck and weld failure at ribs 1, 2, and 3 (back). The welds failed due to poor penetration. There was no deck bearing failure at any welds.

**FIGURE A.101 SPECIMEN 12B OBSERVATIONS**
FIGURE A.102 SPECIMEN 12B RESPONSE PLOTS
VULCRAFT PUSH-OFF TEST
SUMMARY SHEET

Specimen Mark: 13A  Test Date: 8/28/90

Normal Load: Incremental uniform load

Fastener: Type: 1/4-14x3" teks/3 w/2 1/4" stand-off sleeve
Per Specimen: 20, Front: 10, Back: 10

Deck: Type of Deck: 1.5 VL x 22 GA
Deck Width: 34", Deck Length: 24"

Base Member: Section: 2-L1 1/2"x1 1/2"x0.113' welded to 1-PL1/2"x6"x44"
Thickness of Connected Part: 0.113"

Concrete: Thickness: 4.5", Strength: 4800 psi

Max. End Slip: Front: 0.150", Back: 0.150", Ave: 0.150"

Max. Deck Slip: Front: 0.000", Back: 0.004", Ave: 0.002"

Max. Load: 59.90 kips

Max. Load/Ft. of Deck: 10.571 kips/ft.

Max. Load/Fastener: 2.995 kips

Failure Mode: Screw shear at all fastener locations except ribs 3, 4 and 5 (front), in which the concrete sheared across the rib.
FRONT VIEW

SIDE VIEW

(CONC. SLAB REMOVED TO SHOW DETAIL)

FIGURE A.103 SPECIMEN 13A LAYOUT
Comments: The back slab failed solely by screw shear and the front slab failed by a combination of screw shear and concrete shear across the ribs of the deck. The screws started to bend at approximately 80% of failure load. The screws may not have failed by shear only, bending and tensile stress may have developed in the screw.

FIGURE A.104 SPECIMEN 13A OBSERVATIONS
FIGURE A.105 SPECIMEN 13A RESPONSE PLOTS

a) LOAD VS END SLIP

b) LOAD VS DECK SLIP
### VULCRAFT PUSH-OFF TEST
#### SUMMARY SHEET

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</table>
FRONT VIEW

SIDE VIEW

(Conc. slab removed to show detail)

FIGURE A.106 SPECIMEN 13B LAYOUT
Comments: The screws exhibited bending at approximately 80% of failure load. At failure all the fasteners failed and no concrete shear was observed. The screws may not have failed by shear only, bending and tensile stress may have developed in the screw. The bending on the screw is caused by the thin angle base member. The bending is observed at the part of the screw which is exposed.

FIGURE A.107 SPECIMEN 13B OBSERVATIONS
a) LOAD VS END SLIP

b) LOAD VS DECK SLIP

FIGURE A.108 SPECIMEM 13B RESPONSE PLOTS
VITA

Leonard D. Strocchia was born on August 12, 1966 in Queens, NY. He was raised in Long Island, NY and graduated from Herricks Senior High School in 1984. For his undergraduate studies, he attended The Citadel, Nassau Community College and Manhattan College. He obtained his B.S. degree in Civil Engineering from Manhattan College in May 1989. He obtained his M.S. degree in Civil Engineering from Virginia Polytechnic Institute and State University in October 1990.

He has accepted a job in the steel fabricating industry as a structural engineer and plans on obtaining his professional engineering license. He is to be married to Josephine Prisco on July 13, 1991.