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DEVELOPMENT OF STANDARD FOR LIFTING LOOPS IN PRECAST DECK BEAMS

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16. Abstract

Prestressing strands, bent into loops and cast within beams, are the most common anchorage system used for handling precast beams. No national guidance exists for the design of lifting loops in members that are shallower than 24 inches. To address this shortcoming, the 2003 IDOT Prestressed Concrete Manual provided requirements for lifting loops that were derived from experience and best engineering judgment. An experimental research program was conducted at the University of Illinois to investigate the performance and capacity of lifting loops cast in deck beams, and also on the rupture strength of strand loops that protrude from heavily confined specimens. The key variables in the deck beam tests were the shape of the lifting loop, depth of embedment, side edge distance, number of strands per loop, number of lifting loops in a corner of a beam, and angle of pull. The key variables in the strand rupture tests were the number of strands per lifting loop, the uniformity of strand shape, the constraint of strands by a conduit, and the shape of the contact surface of the lifting device.

The results of these experiments, in conjunction with a review of previous work and field practices, support and help justify the recent changes to IDOT lifting loop design requirements as presented in the 2007 ABD Memorandum 07.2. In the absence of another suitable design, a lifting loop must satisfy the IDOT requirements of a minimum 60-degree lift angle, a minimum 6-inch edge clearance, and an embedment depth that is at least equal to the overall depth of the member less 4 inches. The test results demonstrated the benefit of using multiple stands per lifting loop, multiple lifting loops in a corner of a beam, higher lift angles, and conduit to help ensure more uniform shape and engagement of strands. The results of this research have reinforced IDOT's current design requirements for lifting loops and revealed the need for a national standard.

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EXECUTIVE SUMMARY

Prestressing strands, bent into loops and cast within beams, are the most common anchorage system used for handling precast beams. However, no national guidance is documented for the design of lifting loops in members that are shallower than 24 inches. To address this shortcoming, the 2003 IDOT Prestressed Concrete Manual provided requirements for lifting loops that were derived from best engineering judgment and field experience. In order to review and inform requirements for the design and placement of lifting loops, an experimental research program was conducted in the Newmark Laboratory at the University of Illinois. Two types of experiments were performed. A total of 16 pullout-type tests were conducted on lifting loops that were cast into precast deck beams; the capacity of these loops was expected to be controlled by the failure of the concrete in which they were cast (See Table 6). In these tests, the loops were pulled at an angle of either 45 or 60 degrees from the horizontal, and the beam test specimens were designed to represent IDOT precast deck beams. A total of 10 strand rupture type tests were conducted to investigate the factors that affect the fracture strength of single to multi-strand bundle loops (See Table 16). This summary describes each of these series of experiments, presents the primary variables and key observations, and assesses the implications of the results on lifting loop design and placement requirements.

The 16 tests on lifting loops cast into deck beams, herein referred to as deck beam tests, were performed using four different beam specimens. The deck beams were designed to replicate IDOT standard 11”x48” and 17”x48” precast deck beams. The overall objective of these tests was to investigate the performance and capacity of lifting loop configurations that are in IDOT specifications and the variation of those specifications that are often used in practice. The variables examined in this study included: (i) distance from the loop to the side of the beam, (ii) number of strands in a loop, (iii) shape of lifting loop (parallel, tied, or flared legs), (iv) concrete strength, (v) location of surrounding reinforcement, (vi) lifting angle, (vii) embedment depth, and (viii) number of separate loops at a single lifting point.

Each of the test beams had four lifting points, one in each corner, such that four test results were obtained from each deck beam specimen. Each lifting point (lifting loop configuration) consisted of one or two strand bundles where there were either two or three strands in each bundle. In this report, a lifting loop point is defined by (the number of loops in a corner) x (the number of strands in each loop). Thus, a 2 x 3 configuration would represent two lifting loops in a corner with three strands in each loop. Since the number of tests (16) was quite limited given the number of variables being studied in this program, the research program was conducted in a progressive manner where the results from earlier tests were used to inform later tests. The characteristics (specimen details and key test variables) for the deck beam testing program are summarized below:

First series of deck beam tests, 11-1 and 17-1 (8 lifting loop tests)

- 1x2 loop embedded 6 inches (11-inch-deep deck beam)
- 1x2 loop embedded 12 inches (17-inch-deep deck beam)

Key variables being studied:

- Edge distance; Leg shape of loops (parallel or tied shaped)

Second series of deck beam tests, 17-2 and 17-3 (8 lifting loop tests)

- 1x3 loop embedded 12 inches
- 2x3 loop embedded 12 inches
- 1x3 loop embedded 13 inches
- 2x3 loop embedded 13 inches

Key variables being studied:

- Transverse reinforcement (U-bar) placement; Number of strands per loop; Number of loops per corner (or lift point); Angle of pull (45 degrees and 60 degrees); Flared loop legs

Based on the results of these tests, the following observations were made:

- The specifications for lifting loops in ABD Memorandum 07.2 were deemed acceptable for ultimate and serviceability limit state capacities.
- The distance from the lifting loop to the edge of the beam significantly influences the serviceability limit state; a lifting loop placed closer to the edge of the beam causes cracking and cover spalling to initiate at low load levels.
- The use of three over two strands in a loop resulted in a modest increase in ultimate capacity and a slight increase in the measured cracking load. An even greater beneficial effect resulted from having multiple lifting loops in a corner of a deck beam at a single pick up location.
- A lifting loop with parallel legs was observed to perform better than a lifting loop with tied legs.
- The location of transverse reinforcement relative to the location of the lifting loop has little effect on the performance of the lifting loop capacity.
- The strength of concrete at the time of lifting increases the cracking load and ultimate capacity of the lifting loop.
- The lifting angle significantly influences the vertical lifting capacity of a lifting loop.

The progress of damage in all of these 16 deck beam tests was quite similar, as characterized by six stages: (i) shape changing and full engagement – where the loop changes shape from a semi-circle with vertical legs embedded into the concrete to where the strands are tightly bent around the loading pin and straighten out towards where they are embedded into the concrete; (ii) a linear elastic response – where damage is limited to further plastic deformations of the strand around the loading pin and minor crushing at where the strands enter the concrete; (iii) first cracking – where a top crack develops along the longitudinal axis and extending from the outside leg; (iv) formation of cracked triangular wedge – which begins to define a complete cracking surface that extends from the top of the beam and wraps around its side; (v) damage progression with strengthening – where there is considerable movement of the strands along a vertical plane in the beam, often leading to spalling of the triangular wedge, and (vi) post-peak behavior – which was typically quite ductile with a significant capacity available at even twice the deformation associated with the peak load.

The key variables in the 10 strand rupture tests were the number of strands per lifting loop, the uniformity of strand shape, the use of a conduit to constrain the strands, and the shape of the contact surface with the lifting device. The results from these tests indicate that:

- Strands must be similar in length. If the strands are different lengths, then the capacity of a multi-strand loop could be very similar to that of a single-strand loop.
- The use of a conduit, as per ABD Memorandum 07.2, was observed to sufficiently constrain strands such that all strands within the same loop would be close to fully engaged in the lifting process.
- The use of a lifting hook, as opposed to a 2-inch diameter pin, creates two points of stress concentrations at the side edges of the hook, thus significantly reducing the loads at when the first wire will rupture in a strand as well as when the ultimate strand rupture capacity is reached.

- Even with the use of these lower hook-controlled capacities, the measured strand rupture strengths were still more than four times the IDOT-specified load for a three-strand loop.

CONTENTS

CHAPTER 1 INTRODUCTION AND PROBLEM STATEMENT

1.1 MOTIVATION FOR THIS STUDY

For the handling of prestressed beams and slabs, the most common type of embedded anchor consists of prestressing strands that have been bent into loops and cast within these beams and slabs. Within this report, this type of anchor is referred to as a lifting loop and is defined to consist of one or more strands bundled together to form a single entity. More than one lifting loop may be placed and engaged at each lifting point, such as in the corners of the deck beams where the use of two side-by-side lifting loops can be required. The following nomenclature has been adopted within this report to define the number of loops and number of strands per loop at each lifting point: a x b, where “a” indicates the number of loops in a corner and “b” indicates the number of strands per loop.

For example: a 2 x 3 configuration would represent two lifting loops in a corner with three strands in each loop.

Limited guidance for the fabrication and placement of these lifting loops has led to many different practices in the field, with uncertain levels of safety and occasional significant problems and failures. This study was particularly motivated by the following concerns:

- A lack of specifications exist for the design of lifting loops for use in shallow precast deck beams. The minimum embedment depth for lifting loops in the PCI Design Handbook 5th Edition was 16 inches. In the PCI Design Handbook 6th Edition, the minimum embedment depth was increased to 24 inches. Consequently, no national guidance exists for the design and use of lifting loops in shallow deck beams including the 11, 17, and 21-inch thick precast deck beams that are commonly used in the State of Illinois.

- The Prestressed Concrete Manual published in 2003 by the Illinois Department of Transportation (IDOT), referred to as 2003 IDOT Prestressed Concrete Manual herein, provides requirements for lifting loops in shallow precast deck beams, but these requirements are solely based on experience and best engineering judgment, and not on supporting experimental test data. Consequently, uncertainty exists regarding the level of safety provided by fulfilling these requirements.

- The primary producers of Illinois precast bridge products do not follow the same procedures in the fabrication of lifting loops, and this has led to significant variations in lifting loop details. As a result, IDOT officials have questioned what level of specification is needed for the state standard. In addition to uncertainties as to the influence of lifting loop shape, uncertainties are also associated with the influence of the following on lifting loop performance: shape of the lifting device (hook or diameter of pin), use of conduit or pipe to constrain the strands, use of multi-strand loops, use of multiple loops in each corner of a beam, lifting angle, and other reinforcement details.

- There have been significant problems in the field, including the failure of lifting loops as shown in Figure 1.

Figure 1. Lifting loop strand rupture failures in field (courtesy of IDOT).

- Specifications for the design of lifting loops have focused on overall capacity. An additional design consideration is their performance under service loads. It is desirable that lifting will not cause significant cracking or other types of damage that could potentially degrade the long term performance of the lifted structure.

- While the large factor of safety of four, which is typically applied in components of a lifting assembly, should guarantee that life and product safety is never a concern, precast products are not always handled in the intended manner. This is illustrated in Figure 2, in which only one of the two end loops is being engaged in the lifting process. A similar situation can occur in four point lifts on deck beams as equilibrium can be satisfied when only one of two lifting loops is engaged at each end of the member.

Figure 2. Girder suspended by two out of four lifting loops (Birrcher).

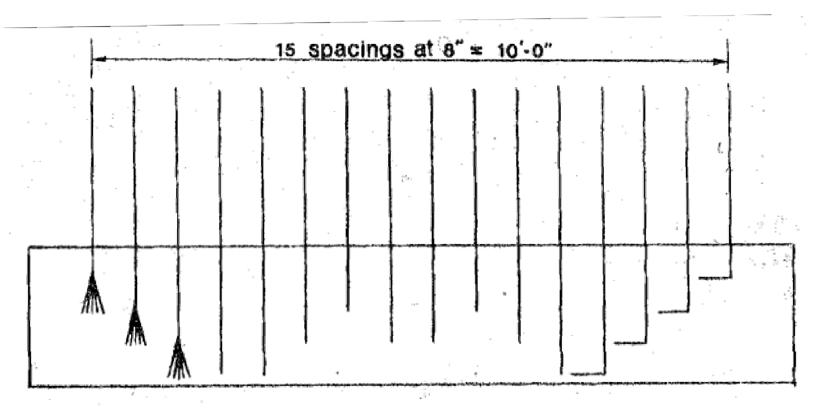
The combination of concerns presented above, and in particular the lack of national provisions and data for the design, fabrication, and placement of lifting loops in deck beams, is a strong motivation for the experimental investigation that is presented in this report.

1.2 SUMMARY OF PREVIOUS RESEARCH

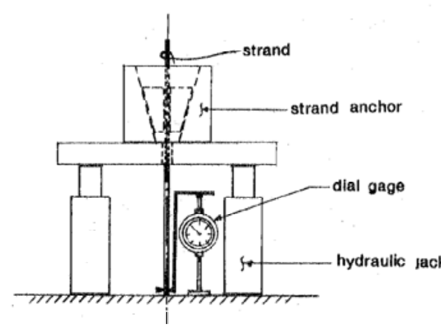
The most significant previous study on the capacity of lifting loops was led by Saad Moustafa and conducted at Concrete Technology Associates (CTA) as summarized in their Technical Bulletin 74-B5, May 1974. In the CTA research program, 272 tests were conducted to evaluate straight (vertical) pullout capacity, nine tests were conducted to evaluate the influence of pin diameter on strand rupture strength, and six tests were conducted to evaluate the influence of angle of pull on pullout capacity. Each of these test series is summarized below followed by the CTA loop production guidelines. The provisions in PCI Design Handbooks have been largely based upon the results of this test series, making their presentation particularly relevant.

1.2.1 Straight Pull Embedment Tests (272 tests)

In this large series of tests, the influence of embedment depth, shape of embedded end, strand surface condition, strand diameter, and concrete strength were examined. The embedment depths were 12, 18, 24, and 30 inches. The end anchorage condition consisted of straight ends (simple cut), broom (last 6 inches unwound), and bent (90 degree bend with 6 inch extension). Both bright (clean) and slightly rusted 270 ksi strands were used, of diameters of 3/8”, 7/16”, and 1/2”. The strands were anchored in blocks that were 12” wide, by 26” deep, by 12’ long, with 16 strands in each specimen as shown in Figure 3(a). The test setup is shown in Figure 3(b). Normal weight concrete was used in this study. In 192 of these tests, a specified concrete strength of 6000 psi was used, while for 80 of the tests, a specified concrete strength of 3000 psi was used.



(a)



(b)

Figure 3. (a) CTA test specimen arrangement (b) CTA test setup (Moustafa, 1974).

Of particular interest to this study is the pullout capacity of the ½” diameter 270 ksi strands since this is the diameter of the strand to be used in lifting loops for deck beams. The results from these tests for the specified 6000 psi concrete are given in Table 1 and for the specified 3000 psi concrete are shown in Table 2. These tables present the embedment depth, end anchorage condition, strand condition, concrete strength, and whether or not the strands “Broke (B)” or “Slipped (S).” While not clearly specified in the report, it is interpreted that “Slipped (S)” refers to when there had been significant and abrupt movement of the protruding end of the strand relative to the top surface of the concrete (perhaps 0.1 to 0.2 inches) such that bond was certainly lost over the majority of the straight length of the embedded strand.

Table 1. Summary of CTA Pullout Tests on 1/2 Inch Strand (f'_c = 6000 psi) (Moustafa, 1974)

Shape	Embend. Length (in)	Surface Condition	Concrete Strength (psi)	Ultimate Pullout Strength (kips)	Failure*
Straight	18	Bright	5970	39.6	(S)
				38.6	B
			5970	38.4	(S)
				38.4	(S)
		Rusted	5970	42.3	B
				41.0	B
			5970	41.6	(S)
				41.0	(S)
	18	Bright	6800	37.2	(S)
				39.6	B
			6250	38.1	B
				35.8	(S)
		Rusted	6800	40.0	B
				40.0	B
			6250	39.1	B
				43.6	B
	24	Bright	7520	39.7	B
				39.0	B
			8110	41.6	B
				41.9	B
		Rusted	7520	40.3	B
				42.2	B
			8110	41.6	B
				41.6	B
Broom	18	Bright	6800	34.6	B
				39.0	B
			6250	36.7	(S)
				33.5	B
		Rusted	6800	39.0	B
				38.1	B
			6250	40.5	B
					B

Shape	Embend. Length (in)	Surface Condition	Concrete Strength (psi)	Ultimate Pullout Strength (kips)	Failure*
90° Bend	12	Bright	6800	41.9	B
				39.0	B
			6250	38.0	B
				40.0	B
		Rusted	6800	39.0	B
				38.1	B
			6250	41.0	B
				42.9	B
	18	Bright	7600	40.3	B
				37.0	B
			6010	34.5	(S)
				31.9	(S)
		Rusted	7600	42.9	B
				42.3	B
			6010	37.7	(S)
				37.1	(S)
	24	Bright	5970	40.0	B
				40.0	B
			5970	42.3	B
				41.0	B
		Rusted	5970	40.0	B
				41.0	B
			5970	42.9	B
				42.9	B
	30	Bright	7520	41.0	B
				39.7	B
			8110	41.6	B
				41.9	B
		Rusted	7520	41.0	B
				41.6	B
			8110	41.6	B
				41.6	B

* B = Broke, (S) = Slipped

It is expected that the first embedment depth in Table 1 for the straight strands was 12 inches, and not 18 inches as presented in the CTA report. As shown in Table 1 (f'_c specified = 6000 psi), in only four of 64 cases was the capacity less than 36 kips (86% of the 42 kip specified tensile strength (270 ksi) of a ½” diameter strand). The embedment conditions in these four cases were:

• 18 inch embedment; straight end, rusted, slipped (35.8 kip capacity)
• 18 inch embedment; broom end; bright; broke (34.6 kip capacity)
• 18 inch embedment; 90° end; bright, broke (34.5 kip capacity)
• 18 inch embedment; 90° end; bright, broke (31.9 kip capacity)

Table 2. Summary of CTA Pullout Tests on 1/2 Inch Strand (f'_c = 3000 psi) (Moustafa. 1974)

Shape	Embend. Length (in)	Surface Condition	Concrete Strength (psi)	Ultimate Pullout Strength (kips)	Failure*
Straight	30	Bright	3000	37.0	(S)
				37.5	(S)
		Rusted	3000	35.0	(S)
				30.0	(S)
	24	Bright	3000	32.0	(S)
				34.5	(S)
		Rusted	3000	41.0	(S)
				38.0	(S)
	18	Bright	3000	26.0	(S)
				19.5	(S)
		Rusted	3000	26.5	(S)
				27.0	(S)

* B = Broke, (S) = Slipped

Shape	Embend. Length (in)	Surface Condition	Concrete Strength (psi)	Ultimate Pullout Strength (kips)	Failure*
18" Str. + 6" Broom	24	Bright	3000	40.0	(S)
				43.5	B
		Rusted	3000	42.5	B
				42.5	B
12" Str. + 6" Broom	18	Bright	3000	30.5	(S)
				33.0	(S)
		Rusted	3000	40.0	(S)
				41.0	(S)
6" Long 90° bend	18	Bright	3000	40.0	(S)
				36.0	(S)
		Rusted	3000	43.0	B
				43.0	B
	12	Bright	3000	32.0	(S)
				32.0	(S)
		Rusted	3000	35.0	(S)
				34.5	(S)

* B = Broke, (S) = Slipped

As shown in Table 2 (f'_c specified = 3000 psi and actual unknown), in 15 of 32 cases the capacity was less than 36 kips. The lowest four were all from an 18-inch-deep embedment, with straight ends, with two of these four being bright and two of these four being rusted. The capacities of these four ranged from 19.5 to 26.5 kips. It is interesting to note that the capacity of the four strands with 12-inch embedment and 90-degree bends were all equal to or above 32 kips (75% of 1/2 inch 270 ksi strand rupture strength).

Based on these results, the CTA report suggested the minimum development lengths given in Table 3 for a ½-inch strand as a function of end condition, strand condition, and concrete strength. Despite the very large number of tests conducted by CTA and the richness of the test data, it is important to note that the spacing of strands, angle of pull, side distances, and other test parameters do not replicate that which is used for the anchorage of lifting loops in deck beams. Thus, the observations about the recommended minimum embedment depth should be taken with this in mind.

Table 3. CTA Recommendations for Development Length (Moustafa 1974)

Strand Diameter (in)	Concrete Strength (psi)	Suface Condition	Development Length (in)		
			Straight	Broom	90° Bend
1/2	3000	Bright	36	24	24
		Rusted	36	24	18
	≥ 6000	Bright	24		24
		Rusted	24		24

1.2.2 Influence of Pin Diameter on Rupture Strength (9 tests)

CTA also conducted a series of tests to evaluate the influence of pin-anchor diameter on the strength at strand rupture. The test setup and results are shown in Figure 4. The strand rupture strength was observed to increase with pin diameter. When bent around a 1-inch pin, rupture occurred at about 75% of the specified tensile strength of the 270 ksi strand. When bent around a 3-inch pin, strand rupture occurred at about 90 percent of the 270 ksi strand.

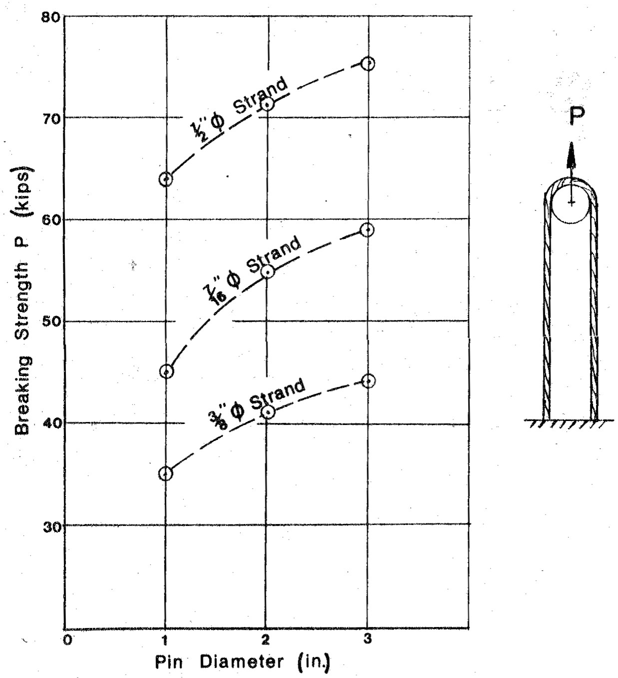


Figure 4. Influence of pin diameter on strand rupture capacity (Moustafa 1974).

1.2.3 Influence of Angle of Pull on Strength (six tests)

CTA also investigated the influence of angle of pull on strand pullout strength in a series of six tests, one each at 90°, 75°, 60°, 45°, 30°, and 15° from the horizontal. These tests were conducted using a single ½-inch-diameter strand loop and a 3-inch-diameter pin. The results illustrated that there was no reduction in diagonal pullout capacity except for the most severe pull angle of 15 degrees in which case the capacity was still 69 kip; the uniaxial rupture strength of a ½-inch-diameter 270 ksi strand is 82 kips (2 x 0.153 in^2 x 270 ksi).

1.2.4 Guidelines for Multi-Loop Fabrication

The CTA report emphasized the importance of ensuring that strands in the same combined loop have a similar shape and length. The report stated that “The shape and length of the exposed portions of the strands should be uniform and equal to insure that each strand carries its share of the load. The first strand to pick up the load will stretch until the other strand carries its share of the load. The strand’s ability to adjust is easily understood by calculating the total stretch of the strand with a safe elongation of 1%...A strand length tolerance of ½-inch for a 50-inch strand would result in a load distribution comparable to that of a 10-inch strand with a 0.1 inch tolerance” (Moustafa, 1974). Note that the term “strand” has been used to replace the term “loop” in this quote to be consistent with the definition of loop the authors use in this report.

The report recommended the following procedure for multi-strand loop fabrication:

1. Strands are cut to a predetermined length.
2. The ends of the strands are passed through a forged steel socket (Anderson post-tension anchor socket used at CTC) that is welded to a steel workbench.
3. The ends of the strand are pulled through until the strand has been drawn up in a loop against a bent rebar mounted at the face of the ring. This rebar acts as a gage in setting all the loops in exactly the same position in the ring.
4. The loose ends of the strand are then anchored in place by wrapping them through three slightly offset posts.
5. After that, a wire tie is made around the two strands projecting through the ring on the opposite side of the loop. A double wrap of wire is first made around a single strand, and then the two strands are tied together with two additional wraps. The two wraps around one strand prevent the wire tie from slipping from position. Other ties are then made down the loop as needed.
6. If a precast item is expected to be stored in the yard for three months or more, the exposed ends of completed loops are dipped in protective paint.
7. The method of making lifting loops described above is simple and economical, and the resulting loops are almost identical. However, extreme care is also important in the installation of multiple loops.

The CTA report was the most significant test series that was found in the public literature.

1.3 SCOPE AND OBJECTIVE OF THIS STUDY

To develop a best practice for the design, fabrication, placement, and use of lifting loops in the state of Illinois that also considers producer practices and constraints, an experimental research investigation was conducted that had the following objectives:

- Determine the ultimate capacity and an appropriate serviceability limit state for lifting loops in prestressed concrete deck members. This includes the loops and practices in the 2003 IDOT Prestressed Concrete Manual as well as variations on these that could be expected by producers.
- Determine the influence of the distance from a lifting loop to the edge of a beam on both the ultimate and serviceability limit state capacities.
- Determine what capacity is gained by placing more than one strand in a lifting loop and having multiple lifting loops in a corner of a deck beam at a single pick up location.
- Determine the effect of tying the legs of the lifting loop together, as shown in Figures 10 and 11.
- Determine the effect of the strength of concrete at the time of lifting.
- Determine the effect of surrounding reinforcement placement.
- Determine the effect of lifting angle on capacity.
- Determine the effect of flaring the legs of the lifting loop, as shown in Figure 13.
- Determine the benefit of housing the strands of a lifting loop in a thin walled electrical conduit.
- Determine the negative effect of offsetting the strands from one another in the same lifting loop.

CHAPTER 2 REVIEW OF DESIGN REQUIREMENTS AND FIELD PRACTICE

Guidance for the design and placement of lifting loops is provided in the Precast/Prestressed Concrete Institute (PCI) Design Handbook as well as several IDOT documents and memorandums. The guidance in the PCI Design Handbook is quite brief, and only gives minimum embedment depth, end anchorage conditions, and strand group effects. Two other PCI-produced documents expand on the content contained within the PCI Design Handbooks with regards to lifting loops: “Erection Safety for Precast and Prestressed Concrete” (1995) and “Erectors’ Manual – Standards and Guidelines for the Erection of Precast Concrete Products” (1999). The later was updated from the original document titled “Recommended Practice for Erection of Precast Concrete” (1985). In light of these guidelines, the IDOT document titled “Prestressed Concrete Manual” contains specifications for the design of lifting loops in all IDOT precast products. Two relevant memorandums to this document will be referenced throughout this report: “All Bridge Designers (ABD) Memorandum 07.2” (ABD Memorandum 07.2) and “All Bridge Designers (ABD) Memorandum 08.2” (ABD Memorandum 08.2). These two memorandums present considerably more prescriptive information, providing not only the depth of embedment and anchorage details, but also side and end distances, and requirements for longitudinal and transverse reinforcement. This prescriptive information is provided for each type of precast deck beam and other bridge members that are used in the state of Illinois. The bases of these requirements are experience and best engineering judgment; these requirements have not been sufficiently validated by an experimental testing program.

The requirements in the PCI Design Handbook and in the IDOT specifications are presented in the following section. This is followed by the results of a survey on the practices of producers of precast deck beams for the state of Illinois.

2.1 PCI DESIGN HANDBOOK

The PCI Design Handbook addresses lifting loops made from prestressing strands. There have been several important changes in the design requirements for lifting loops in the last three Editions of the PCI Design Handbook, namely the 4th, 5th, and 6th Editions. The most recent design recommendations from the 6th Edition are presented below.

The design of lifting loops for handling prestressed concrete deck members is contained within Chapter 5, Product Handling and Erection Bracing. Section 5.3.4.2 addresses lifting loops made from prestressing strand. The PCI Design Handbook 6th Edition states:

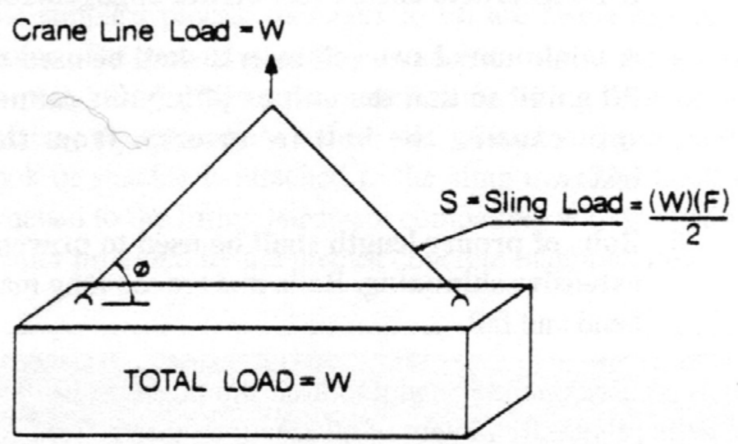
> “Since lifting devices are subject to dynamic loads, ductility of the material is a requirement. Deformed reinforcing bars should not be used as the deformations result in stress concentrations from the shackle pin…
>
> Prestressing strand, both new and used, may be used for lifting loops. The capacity of a lifting loop embedded in concrete is dependent upon the strength of the strand, length of embedment, the condition of the strand, the diameter of the loop, and the strength of concrete.
>
> As a result of observations of lifting loop behavior during the past few years, it is important that certain procedures be followed to prevent both strand slippage and strand failure. Precast producers’ tests and/or experience offer the best guidelines for the load capacity to use. A safety factor of 4 against slippage or breakage should

be used. In lieu of test data, the recommendations listed below should be considered when using strand as lifting loops.

1. Minimum embedment for each leg of the loop should be 24 in.
2. The strand surface must be free of contaminants, such as form oil, grease, mud, or loose rust, which could reduce the bond of the strand to the concrete.
3. The diameter of the hook or fitting around which the strand lifting eye will be placed should be at least four times the diameter of the strand being used.
4. Heavily corroded strand or strand of an unknown size and strength should not be used."

The PCI Design Handbook, in absence of specific experimental test data or experience, recommends that the safe load on a single ½-inch diameter, 270 ksi strand loop satisfying the above criteria should not exceed 8 kips. The safe working load of multiple strands in a single lifting loop is indicated to be conservatively obtained by using the multiplication factors of 1.7 for a two strand loop, and 2.2 for a three strand loop. The handbook states that each strand should have the same shape but more detailed guidance is not presented for what is deemed close enough to be considered the same shape. It also states that thin walled conduit should be used to reduce potential overstress. Additionally, multiple strands legs are suggested to be flared to allow for better consolidation.

Table 4. Two Point Lifting, and Corresponding Demand on One Loop Relative to a Lifting Angle (Blodgett, K. et al.)



	Multiplication Factor "F" for the total load on the hoisting sling with an inclination = ø					
ø	90°	75°	60°	45°	30°*	15°*
F	1.00	1.04	1.16	1.41	2.00	3.86

Note: ø usually not less than 60° to 70°
* Not recommended

A significant change was made from the 5th to 6th Edition that is very relevant to the design of lifting loops for shallow deck beams. The minimum embedment depth in the 5th

Edition was 16 inches and this embedment was to be terminated with a 6-inch hook bent at 80-100 degrees about a minimum 2-inch radius (made mechanically without heating). This contrasts to the minimum embedment of 24 inches with a straight end that is now given in the 6th Edition. This change was made because strands in the field slipped when only the 16- inch embedment length was used.

In the 4th Edition, the recommended safe lifting load on a single 270 ksi 1/2 inch strand was 10 kips, not 8 kips as recommended in the 5th and 6th Editions. The 4th Edition also states that this load can be achieved with an embedment depth of only 10 inches. However, there was no limitation on the number of strands in the lifting loop. For example, if two strands are used, then a working load of 20 kips can presumably be utilized. The significant changes from the 4th through to the 6th Edition are indicative of the insufficiency of the current basis for design provisions and thereby the uncertainty in what is the most appropriate guidance to provide.

The PCI Design Handbook recommendations are derived from several documents published by PCI and other technical journal papers, but little of this is supported by test data. The documents pertaining to erection procedures are “Erection Safety for Precast and Prestressed Concrete,” and “Erectors’ Manual – Standards and Guidelines for the Erection of Precast Concrete Products.” The later document was published in 1999, a 2nd Edition, which stemmed from the original document published in 1985 titled “Recommended Practice for Erection of Precast Concrete.” This document specifically addresses lifting loops made from prestressing strand in the chapter titled “Rigging, Handling, and Installation.” In contrast to what is considered to be common understanding, the document states that the angle of incline of lifting has little effect on the strand lifting loop capacity if the angle from the horizontal is more than about 20 degrees. This recommendation presumably stems from the results of the CTA testing program. Conversely, several statements contained within this document are not contained within the PCI Design Handbook; the critical elements of which are summarized below:

- Strand loops are not recommended when a severe lateral load is to be applied to it (e.g. when rotation is required), as the bending may cause local concrete crushing around the loop.
- The hook placed through the lifting loop for hoisting must be of sufficient capacity for the load yet be able to slip easily into the loop. Otherwise, it is desirable to use a properly sized shackle.
- Care should be taken when fabricating the lifting loop to ensure that all strands are bent the same to ensure equal load sharing between the strands.
- Multiple strands in a lifting loop should be tied securely together so that they all nearly fully participate in supporting the load.
- The projecting loop should use a thimble eye protector or be placed inside of a hose or pipe so that the capacity of the lifting loop will not be significantly reduced.
- The diameter of the lifting loop should be at least 4 inches, but smaller diameter loops can be used with a reduction factor.

Many of these ideas clearly stem from the findings presented in the CTA report. It should be noted, however, that the geometric details used in the CTA study do not capture the full complexity of lifting loops that are used in real structures and thus the applicability of these requirements to lifting loops is uncertain.

Table 5. Capacity of ½-inch Diameter, 270 ksi Strands Used as Lifting Loops (Blodgett, K. et al.)

Lifting Angle	Embedment Length (in.)	Single Loop (kips)	Double Loop (kips)	Triple Loop (kips)
45 degrees	16	5	8.5	11.5
	22	8	13	17.5
	28	10	18	23
	34	11	23	29
Vertical	16	7.5	12.5	16.5
	22	11.5	19	24.5
	28	15.5	25.5	33
	34	16	32.5	41

1. These values are limited by slippage rather than strand strength, with a factor of safety of 4. For other strand diameters, multiply table values by 0.75 for 3/8 in. diameter, 0.85 for 7/16 in. diameter, and 1.1 for 0.6 in. diameter.

2. Minimum f'c = 3000 psi.

3. Multiple strand loops must be fabricated to ensure equal force on each strand.

It is recommended that a deck beam have four lifting loops, one in each corner. However, it is incorrect to assume that each of the four lifting loops will equally share the load. Rather, two lifting loops may support the entire weight of the structure, while the other two lifting loops only maintain balance, see Figure 5. This concept was conveyed in the PCI publication “Erection Safety for Precast and Prestressed Concrete” within Chapter 4: Equipment – Wire Rope Slings.

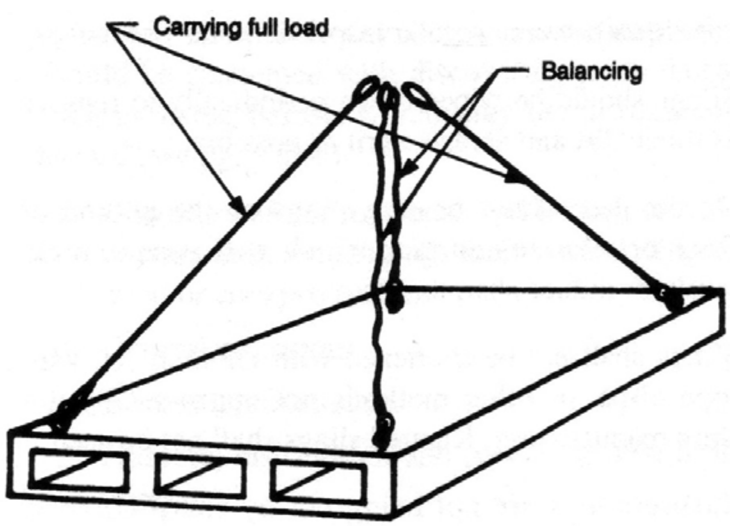


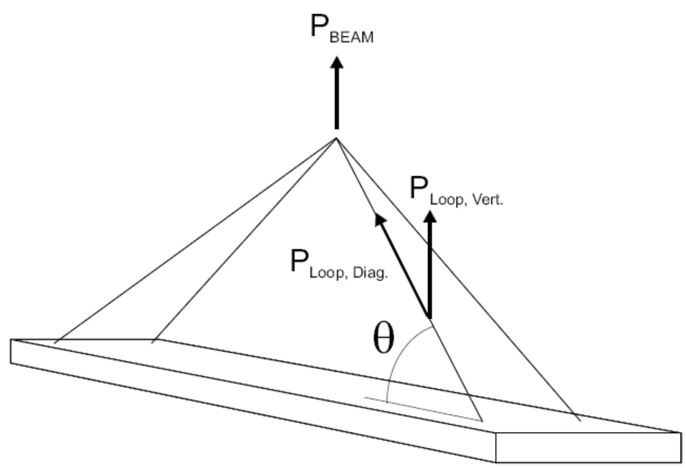
Figure 5. On a rigid object, the load could be carried on only two legs of the sling while other legs only serve to balance (Pickell et al.).

2.2 IDOT DESIGN REQUIREMENTS

The 2003 IDOT Prestressed Concrete Manual provides guidelines and requirements for precast products. This manual includes requirements for the fabrication and placement of lifting loops that are fabricated from prestressing strand. Lifting loops are addressed in the 2003 IDOT Prestressed Concrete Manual, Section 2, Figure 2.3.35, as shown in Figure 7 of this report. These figures depict lifting loop dimensions, placement, and safe working loads.

The dimensions of a lifting loop are shown in Figure 7. This illustrates that all lifting loops should have a 3-inch radius (Cold bent) loop that protrudes a minimum of 4 inches from the top of the beam. With regards to the embedment depth, for shallow 11-inch-deep members, a minimum embedment depth of 8 inches is specified, and for all other members a minimum embedment depth of 14 inches is specified. The minimum lifting angle is given as 45 degrees from the horizontal. The guidelines also state that a 6-inch 90 degree hook shall be provided at the base of each lifting loop leg.

The lifting loop strand is specified to be placed 6 inches from the edge or side of the beam and directly in the middle of the end block region, which is the solid portion of the end of the beam where no voids are present. In beams that are completely solid (i.e. IDOT 11-inch-deep sections), lifting loops are to be placed 15 inches from the end of the beam. The document does not indicate that the 6 inches of edge clearance is a minimum. Additionally, the document specifies that four lifting loops are to be placed in the beam, two at each end.

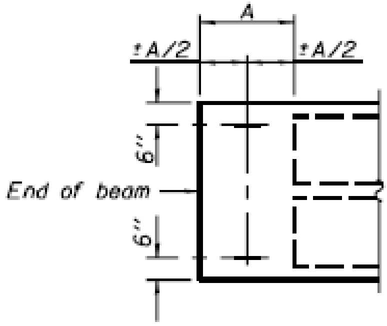


$$P_{Loop,\ Diag} = (P_{BEAM} / 4)\ \mathrm{Sin}(\theta)$$

$$P_{Loop,\ Vert.} = (P_{BEAM} / 4)$$

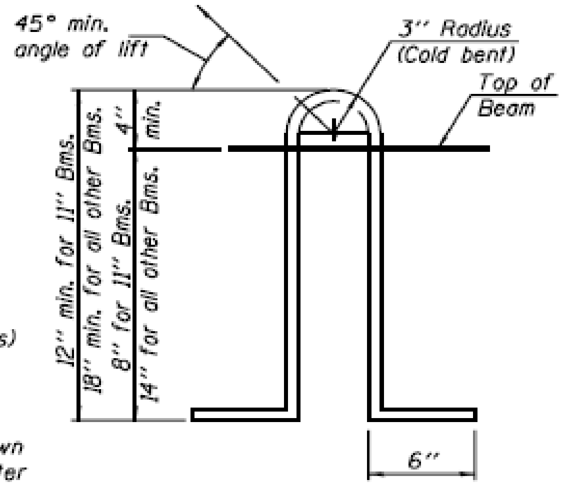
Figure 6. Angle of lift on shallow prestressed deck beams.

Figure 7 indicates that the number of strands to use in each lifting loop is based on beam gross weight. For a beam weighing 40,000 pounds or less, two ½-inch 270 ksi strands should be used. For a beam weighing between 40,000 and 60,000 pounds, three ½-inch 270 ksi strands should be used. Therefore, if a total of four lifting loops are used, then each two strand lifting loop needs to be capable of carrying a safe working load of 10,000 pounds, and each three-strand lifting loop must be capable of carrying a safe working load of 15,000 pounds.



BEAM PLAN
(showing locations of lifting loops)

Each beam shall have four Lifting Loops, two cast in each end as shown above. Loops shall be burned off after beams have been erected.



LIFTING LOOP DETAIL

Lifting Loops shall be made up of ½" ϕ - 270 ksi prestressing strands. See table for number of strands per loop.

LIFTING LOOP TABLE
(showing required size)

Gross Weight of Beam (Lbs.)	Strands Required at each point of lifting - 270 ksi.
40,000	2 - ½" ϕ
60,000	3 - ½" ϕ

LIFTING LOOP
ALTERNATE (1)

Figure 2.3.35

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Figure 7. 2003 IDOT Prestressed Concrete Manual Figure 2.3.35.

In a related but separate document, the Manual for Fabrication of Precast Prestressed Concrete Products (2007) specifies tolerances for the placement and detailing of lifting loops. It states that a lifting loop shall be placed within +/- 3 inches of that specified for the distance from the end of the beam (end distance), and shall be placed +/- 1 inch from the specified distance from the edge or side of the beam (edge distance). It also states that lifting loops can be embedded much further than the recommended minimum providing that there is sufficient clearance to the base of the deck beam. It also states that the projection of the lifting loop extending above the top of the concrete must be 6 inches minimum and 12 inches maximum.

2.3 DESIGN REQUIREMENTS IN OTHER STATES

While shallow deck members are used across the nation, details of lifting loops or lifting devices are seldom presented in state design manuals. Rather, the responsibility for the design of lifting loops is frequently delegated to the design engineer of record. Frequent reference is made in state documents to the PCI Design Handbook for lifting loop design. As previously stated, the guidelines in the PCI Design Handbook are limited. Of the reviewed literature, the IDOT manuals appear to provide the most detailed guidance for the design and placement of lifting loops, particularly for loops to be used in shallow members.

2.4 FIELD PRACTICE

A survey was conducted to compare the similarities and differences of the methods of constructing lifting loops and handling shallow deck beams that are used in the supply of precast products in the State of Illinois. This survey was completed about the practices at Prestress Engineering Corporation (PEC), St. Louis Prestress, County Materials, and Egyptian Concrete Company.

This survey aimed to assess fabricators' discrepancies on the shape of lifting loops and other design details because it was hypothesized that these details could have a significant effect on the capacity, serviceability, and consolidation of concrete around embedded strands. For example, some fabricators indicated it is necessary to tie the legs together when the lifting loop has long legs because the flexibility of the strand causes the legs to become non-uniform and to flare outward making it difficult to fit the loop inside the beam. It was also reported as difficult to bend the strands precisely so that the legs remain parallel as they enter the concrete, and thus the legs are simply tied together to overcome this. However, IDOT does not permit tying of lifting loop legs; therefore, this demonstrates improper fabricator practice.

As a related side note, the shallow lifting loops that were created for this experimental testing program had embedment depths of 6 inches and 12 inches and proved challenging to form due to the strands desire to straighten after bending. The strands legs were found to be too short to simply tie together with rebar ties and had to be over bent so they would relax to a desired shape. It likely takes significant experience, as alluded to in the CTA recommendations, to do this effectively.

Some producers utilize a heavy schedule 40 pipe around the strands while others use a thin walled electrical conduit. Some fabricators do not utilize any pipe, while others use a pipe or conduit only when a certain number of strands are being used to form the loop. Smaller deck beams may only call for two or three strands in a lifting loop, and therefore some fabricators believe that they do not need to use a pipe or conduit. One fabricator indicated that they used thin walled conduit because they felt that the conduit conforms to the strands more easily and thus aligns the strands to prevent uneven loading between the strands. Another fabricator indicated that they use heavy schedule 40 pipe because it would reduced the stress concentration around the point of lifting. In both cases, the intent of the conduit or pipe is recognized to hold the strands together in a uniform lifting loop. It was also noted that the pipe helps maintain the lifting loop shape during fabrication.

The type of lifting mechanism varies between fabricators and contractors. As previously stated, the PCI Design Handbook recommends that the diameter of the lifting mechanism be at least 4 times that of the diameter of the strand used to make the lifting loop. Therefore, a lifting loop made from ½" diameter strand should be lifted using a pin that is at least 2 inches in diameter. Most fabricators do not always follow this guideline; it is not known whether erection contractors are following this guideline in the field. Lifting hooks are frequently used in the field and they have a flat contact surface, not circular as suggested in the PCI Design Handbook. The use of hooks is expected to lead to stress concentrations in more severely bent strands at the edges of the flat portion of the lifting hook.

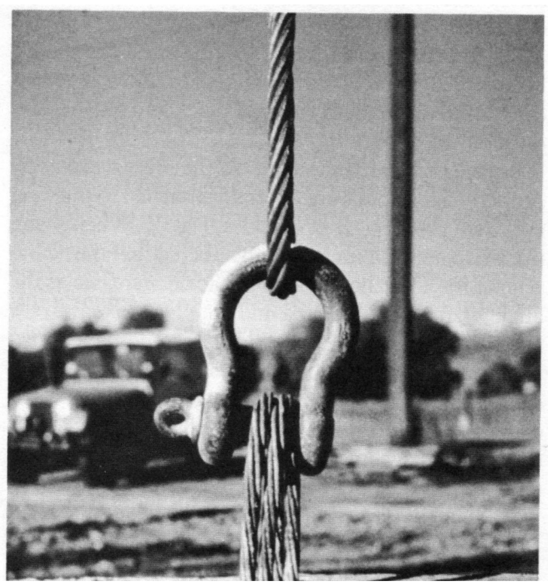


Figure 8. A shackle is used to attach the lifting sling to the strand loop embedded in the precast unit (Blodgett, K. et al.).

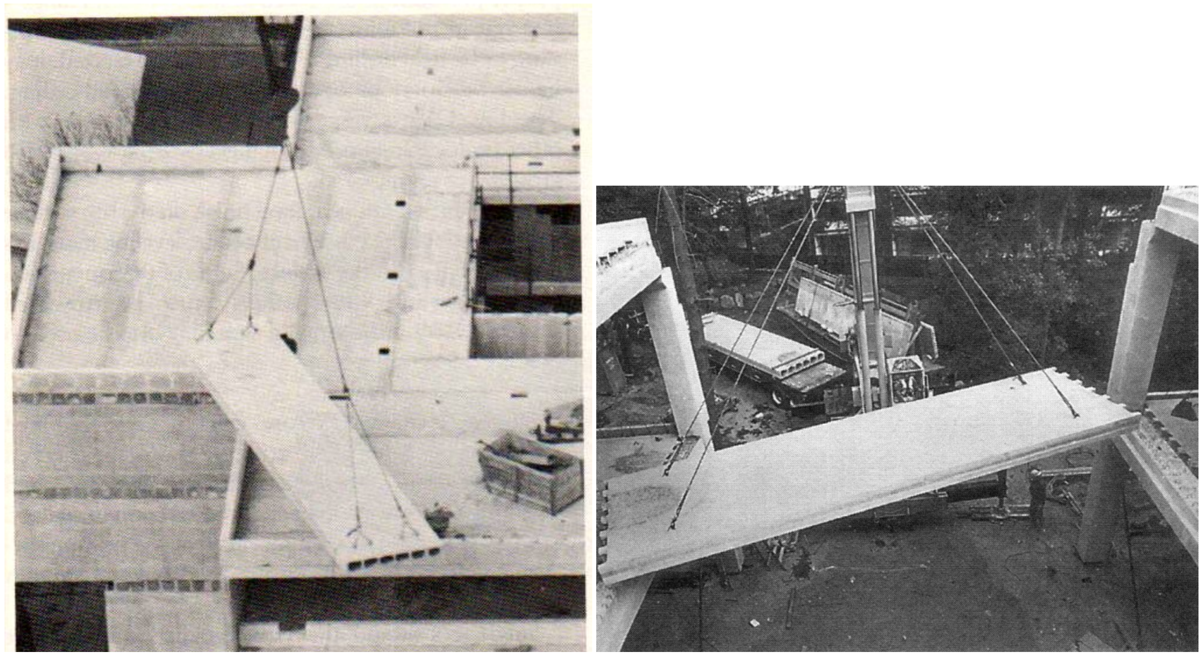


Figure 9. Precast deck beam suspended by four strand loops (Blodgett, K. et al.).

It is not possible to ensure that an erection contractor will lift the product at all four locations and do so in such a way that the load is equally shared. The 2003 IDOT Prestressed Concrete Manual specifies that all beams have four points of lifting, one lifting loop in each corner. The contractor is required to use all lifting loops provided but unfortunately some contractors do not follow the plans and use fewer lifting loops, thereby creating an unsafe condition. An example of this was previously presented in Figure 2, which shows a large bulb-T girder being lifted by only two lifting loops while the beam clearly provides four lifting loops. Similarly, a deck beam may only be supported by two out of four lifting loops, while the other two lifting loops balance the load in the air, as illustrated in Figure 5 and in the right side image in Figure 9. Thus, it is prudent to consider that while lifting loops are designed to provide a factor of safety of four against failure, this may be reduced to a factor of safety of two if unintended lifting practices are used.

CHAPTER 3 EXPERIMENTAL TESTING PROGRAM

3.1 TEST SCOPE AND VARIABLES

The specific objectives for this research study are presented in section 1.3 of this report. The primary objective was to generate experimental test data on fully representative deck beam specimens that would evaluate and inform the design and placement of lifting loops in deck beams. As previously indicated, the PCI Design Handbook minimum embedment depths of 16 inches (5th Edition) and 24 inches (6th Edition) are larger than can be accommodated in the commonly used 11, 17, and 21-inch (6th Edition) overall depth IDOT precast deck beams.

While the landmark CTA study was broad in scope and examined the pullout capacity of strands with embedment depths as low as 12 inches, the test setup was not designed to investigate the type of failures that would be expected to occur in deck beams. In the present study, the full geometry of prestressed deck beams and loading conditions were replicated to capture how the pullout capacity and performance under service loads would be influenced by the key variables for lifting loop design and placement within the geometry of a real deck beam. These tests were aimed at evaluating the influence of the shape of strands, number of strands per loop, use of multiple loops, distance to side of beam, reinforcement detailing, and angle of pull. In some of the test cases, more severe (unconservative) geometries were selected to capture potentially less conservative placement conditions in the field. Due to the significant costs associated with conducting tests on specimens with fully realistic geometries, it was not possible to populate a large test matrix as had been done in the CTA study. These two research studies (CTA's and IDOT's) are considered to be complementary, such that the combined data is effective for informing the design of lifting loops. As part of this present research study, a separate series of tests were conducted to examine the influence of the use of conduit, diameter of pin and shape of the lifting device, and number of strands in a loop on the rupture capacity of loops. In this report, these two segments of the testing program are referred to as the "deck beam" and "strand rupture" tests.

3.1.1 Testing Program

Due to the limitation in the number of tests that could be completed, the deck beam test program was conducted in two phases. In the first series of tests, a series of eight lifting loop pullout tests were completed on two deck beam specimens, 4 on an 11-inch-deep member (one on each corner) and 4 on a 17-inch-deep member (one in each corner). The geometry, placement, and reinforcing details for these lifting loops were selected to evaluate current IDOT requirements and field placement conditions. These tests were designed to investigate lifting loop designs for shallow members and so each lifting point was a single loop composed of the two strand minimum required in the 2003 IDOT specifications; designated as a 1 x 2 configuration in this report. The angle of pull in all of these tests was 45 degrees from the horizontal which is the flattest angle that would be expected in the field. The 11-inch-deep deck beam test specimen is designated as beam 11-1. This first 17-inch-deep deck beam test specimen is designated as beam 17-1.

The design of the subsequent experiments (or second phase) of the deck beam segment of this testing program was based on the results of this first series of tests and also aimed at investigating the capacity of loop configurations that were intended to support heavier loads. The depth of the specimens in this second series of tests was 17 inches, even when the loop configuration was designed for supporting the heavier load associated with deeper precast products. Consequently, these results were expected to lead to a conservative (lower bound) assessment of the capacity of these lifting loop configurations. The angle of pull used in these tests was both 45 degrees and 60 degrees. These second and third 17-inch-deep deck beam test specimens are designated as beams 17-2 and 17-3.

The overall deck beam testing program as well as the program for strand rupture tests is summarized below:

First series of deck beam tests, 11-1 and 17-1 (8 lifting loop tests)

- 1x2 loop embedded 6 inches (11-inch-deep deck beam)
- 1x2 loop embedded 12 inches (17-inch-deep deck beam)

Evaluate influence of the following variables

- Edge distance
- Leg shape of loops (parallel or tied legs)

Second series of deck beam tests, 17-2 and 17-3 (8 lifting loop tests)

- 1x3 loop embedded 12 inches
- 2x3 loop embedded 12 inches
- 1x3 loop embedded 13 inches
- 2x3 loop embedded 13 inches

Evaluate influence of the following variables

- U-bar placement
- Number of strands per loop
- Number of loops per corner (or lift point)
- Angle of pull (45 degrees and 60 degrees)
- Flared loop legs (defined in Section 3.2.8)

Strand rupture tests (10 lifting loop tests)

Evaluate influence of the following variables

- Number of strands per loop
- Influence of offset between strands contained within a single lifting loop
- Influence of use of thin-walled electrical conduit to encompass strands
- Influence of type of lifting mechanism, 2-inch diameter pin versus a hook

3.2 DESIGN OF DECK BEAM TEST SPECIMENS

The length of the deck beam test specimens was 15 feet. This was sufficiently long to fully replicate the beam end design details as well as to support the loading device that was used to pull on the lifting loops. The end regions were designed in accordance to the 2003 IDOT Prestressed Concrete Manual. The width of these end regions was 4 feet, so to represent IDOT 11x48 and 17x48 deck beams. The design of the deck beam reinforcement steel and the prestressing for these members were as given in Figures 2.3.1 and 2.3.5-6, of the 2003 IDOT Prestressed Concrete Manual. These figures are presented in Appendix A. For the 17-inch-deep deck beams, voids were included at the 2003 IDOT specified distance from the end of the member for beams 17-1 and 17-2 and at the 2007 IDOT specified distance for beam 17-3.

The placement of the lifting loops in the first series of tests (designated 11-1 and 17-1) were selected in accordance to the 2003 IDOT Prestressed Concrete Manual Section 2, Figure 2.3.35, as shown in Figure 7 of this report. For the second series of deck beam tests (17-2 and 17-3), the placement of the lifting loops followed the guidelines contained within the ABD Memorandum 07.2 as shown in Figure 24 and Figure 25 of this report. Figures 12 and 13 present common variables and terminology used to describe deck beam geometry.

The key variables used in the testing program are described below. The selected values used in each of the 16 tests are given in Table 6. The full reinforcement and material property details are presented in Appendix A.

Table 6. Test Matrix Variables

Loop ID	Beam Depth (in)	Shape	Side Dist. (in)	End Distance to Center of Loop (in)	Embedment Depth (in)	Angle (degrees)	Specified Concrete Strength (psi)	Lifting Loop Leg with Inward Movement Restrained by U-Bar*	End Block Length** (in)	# Strands / Lifting Loop	Lifting Loops in a Corner	Flaring (Degrees)	Vertical Load (First Cracking) (kips)	Vertical Load (Ultimate) (kips)
11-1 Loop #1	11	Parallel	3	15	6	45	4000	Inner Leg	N/A	2	1	0	18.8	27.4
11-1 Loop #2	11	Parallel	6	15	6	45	4000	Inner Leg	N/A	2	1	0	N/A	23.0
11-1 Loop #3	11	Tied	6	15	6	45	4000	Inner Leg	N/A	2	1	0	N/A	21.6
11-1 Loop #4	11	Tied	3	15	6	45	4000	Inner Leg	N/A	2	1	0	N/A	20.3
17-1 Loop #1	17	Parallel	3	9	12	45	4000	Inner Leg	18	2	1	0	25.1	35.3
17-1 Loop #2	17	Parallel	6	9	12	45	4000	Inner Leg	18	2	1	0	34.7	41.9
17-1 Loop #3	17	Tied	3	9	12	45	4000	Inner Leg	18	2	1	0	19.8	29.2
17-1 Loop #4	17	Tied	6	9	12	45	4000	Inner Leg	18	2	1	0	24.0	37.2
17-2 Loop#1	17	Parallel	4	9	12	45	4000	Inner Leg	18	3	2	0	33.8	69.9
17-2 Loop#2	17	Parallel	4	9	12	45	4000	Inner Leg	18	3	1	0	27.6	44.0
17-2 Loop#3	17	Parallel	4	9	12	45	4000	Both Legs	18	3	2	0	47.4	71.2
17-2 Loop#4	17	Parallel	4	9	12	45	4000	Both Legs	18	3	1	0	22.2	46.5
17-3 Loop #1	17	Parallel	6	15	13	60	5000	No Legs	30	3	1	0	49.8	100.0
17-3 Loop #2	17	Parallel	6	15	13	60	5000	No Legs	30	3	2	0	73.6	136.7
17-3 Loop #3	17	Flared	6	15	13	60	5000	No Legs	30	3	1	10	62.1	89.5
17-3 Loop #4	17	Flared	6	15	13	60	5000	No Legs	30	3	2	10	95.3	134.4

* See page 22 for description and page A-6 for illustration

** Pertains to beams with voids

3.2.1 Lifting Loop Shape

The 2003 IDOT Prestressed Concrete Manual specifies that the lifting loops should have parallel legs, but while not permitted by IDOT, it is common practice for fabricators to tie the legs together. These two shapes of the lifting loops, as shown in Figure 10, were investigated in the 11 and first 17-inch-deep deck beam. The straight part of the lifting loop that is embedded into the concrete is referred to as a leg. The legs are parallel as they enter the concrete, and can remain parallel, as shown in Figure 10(a) or can be brought together to form a tied lifting loop, as shown in Figure 10(b). Parts of the lifting loop shape are defined in Figure 11. In the second series of tests, deck beams 17-2 and 17-3, both parallel and flared legs were used. Flared lifting loop legs refers to offsetting each leg by about 10 degrees to aid consolidation around the lifting loop legs, as shown in Figure 13.

(a) Parallel legs

(b) Tied legs

Figure 10. As built lifting loops to be tested.

3.2.2 Placement of Lifting Loop

It was hypothesized that the distance from the center of the lifting loop to the edge or side of the beam could significantly affect the capacity and the serviceability performance of lifting loops. Therefore, lifting loops were placed in some cases at 3 inches from the side edge of the beam and in other cases at approximately 6 inches from the side edge of the beam (as specified by IDOT). Due to reinforcing cage constraints, these distances varied from the plan by as much as an inch in the built specimens. In the last two deck beams (17-2 and 17-3), the closest edge distance was selected to be 4 inches.

The end distance in this report refers to the longitudinal distance from the center of the lifting loop to the end of the beam, as seen in Figure 12. In the 11-inch deck beams, an end distance of 15 inches was used as per the IDOT requirements. Due to the presence of a void region in the 17-inch-deep deck beam, the end distance can be as short as 9 inches. This shorter end distance was used in the 17-1 and 17-2 deck beams. In the ABD Memorandum 07.2, the length of the solid region was increased and thereby a more advantageous end distance of 15 inches was used in beam 17-3 as per the new requirements.

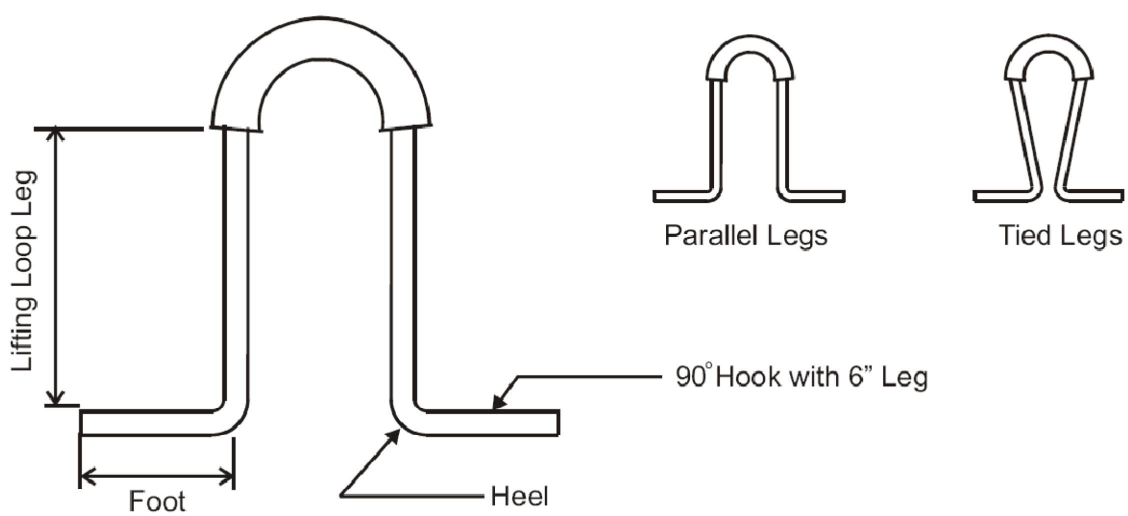


Figure 11. General lifting loop terminology.

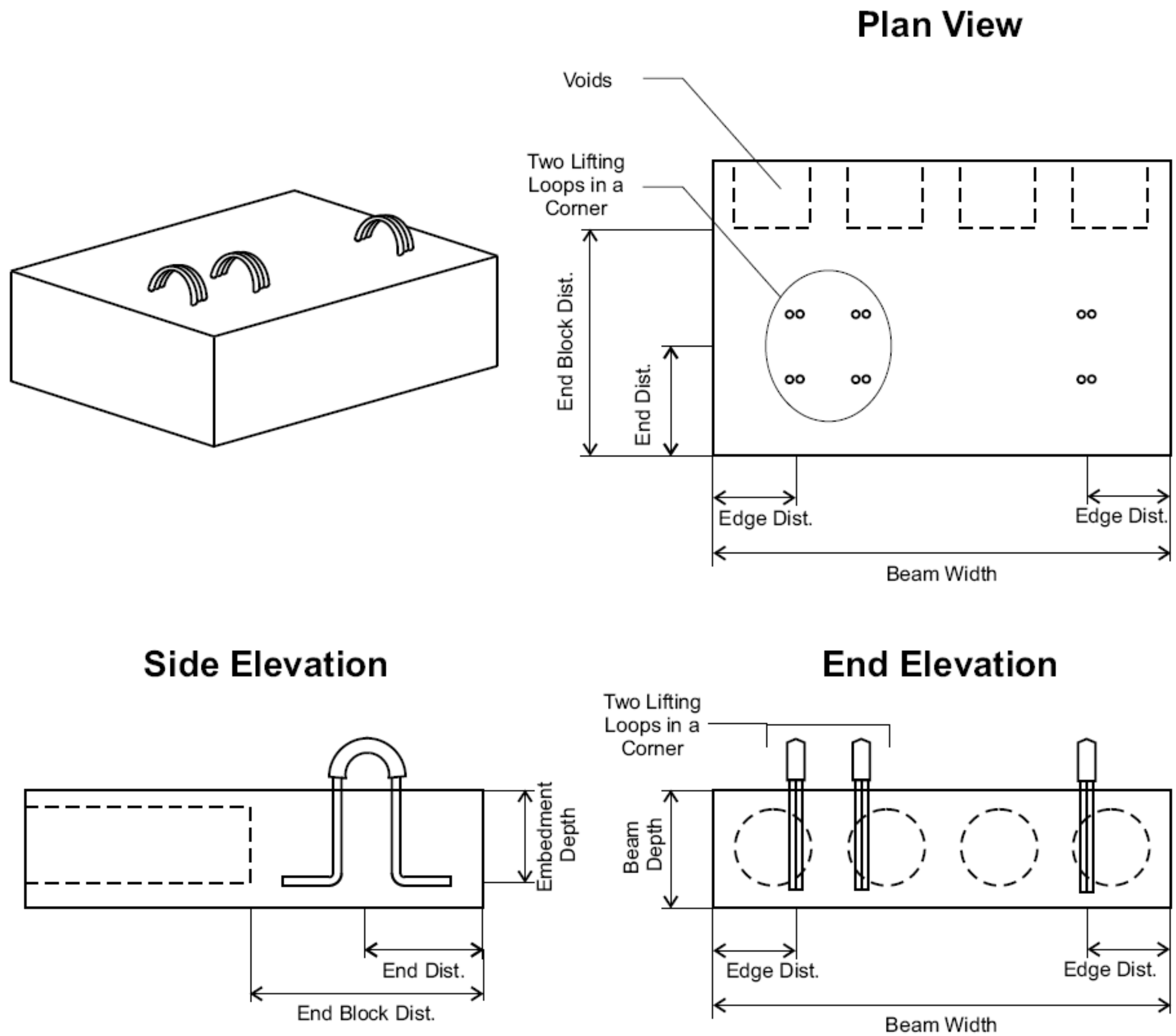


Figure 12. Common variables and terminology.

3.2.3 Embedment Depth

The embedment depth of the lifting loops was selected to be more shallow than those specified in the 2003 IDOT Prestressed Concrete Manual to account for unconservative field placement. Lifting loops contained within 11-inch-deep members were to be embedded approximately 6 inches and within 17-inch-deep members were to be embedded approximately 12 inches, which in both cases is 1 inch less than specified in the 2003 IDOT Prestressed Concrete Manual. For the third 17-inch deck beam, the embedment depth was increased to 13 inches to meet the required embedment depth according to the ABD Memorandum 07.2. It should be noted that the dimension tolerances in the short lifting loops are difficult to maintain. Since the feet of the lifting loop were not always parallel to the base of the form, the depth of the reported embedment should not be considered to be more accurate than 1 inch.

3.2.4 Angle of Pull

The angle of pull referred to in this report is defined as the minimum angle between the top (horizontal) plane of the deck beam and the direction of the pull of the lifting device. With this convention, a pure vertical lift would be characterized to be a 90-degree pull. The flatter the angle of pull, the greater would be the expected damage to the concrete as the horizontal component of the force from the strand on the concrete can lead to splitting of the concrete. The angle of pull in the majority of the tests was selected to be 45 degrees, which was the minimum angle specified in the 2003 IDOT Prestressed Concrete Manual, and was also expected to be the worst case field practice. In the ABD Memorandum 07.2, this minimum angle was increased to 60 degrees. In this testing program, a 45-degree pull angle was used for the tests in deck beams 11-1, 17-1, and 17-2, while a 60-degree angle was used for the tests in beam 17-3.

3.2.5 Concrete Strength

In the first three test specimens, the concrete strength was specified to achieve a target strength of approximately 4000 psi at the time of testing. This corresponds to the minimum specified strength at which a fabricator can lift precast deck beams from the prestressing bed. The desire in the last test was to achieve a target strength of 5000 psi at the time of testing, but the cast strength ended up being considerably stronger than this. The measured concrete strengths, and the strengths associated with each test, are presented in section 3.6. The concrete mix designs are presented in Appendix A.

3.2.6 Placement of Surrounding Reinforcing Steel (U-Bars)

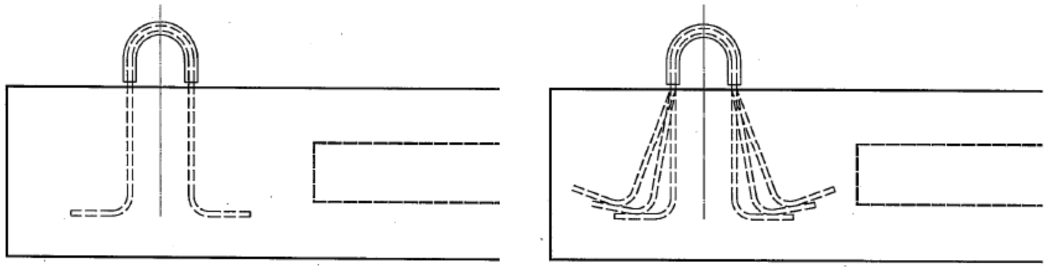
As per IDOT requirements, U-Shaped transverse bars (U-bars) were located in the end regions. One of the variables in the test then became the location of the lifting loop legs relative to the locations of the individual bars of the U-bar. When a lifting loop was placed between two U-bars, as used in the first eight lifting loop tests (specimens 11-1 and 17-1), only the inner (closer to middle of the beam) leg of the lifting loop legs was restrained from sliding inward longitudinally by the presence of that bar. In two of the next four tests, conducted on specimen 17-2, both legs of the lifting loop were restrained against inward movement by a U-bar. In the final series of deck beam tests (17-3), the lifting loops were placed such that the inward movement of each leg of a loop was not directly restrained by a U-bar.

3.2.7 Multiple Lifting Loops in a Corner

In the first series of tests (8 tests on specimens 11-1 and 17-1), a single loop was used at each lifting point. The other two test specimens (17-2 and 17-3) both contained 1 loop and 2 loop lifting point configurations. The use of multiple loops in each corner (or lifting point) was used to investigate both the strength enhancement provided by adding a second loop as well as any improvement in performance that would be realized under service load.

3.2.8 Flaring the Legs

The effect of flaring strands, as shown in Figure 13, was investigated through the testing completed on deck beam 17-3. It was hypothesized that flaring each leg outward by approximately 10 degrees would provide for better consolidation and thereby lead to greater measured capacities. Two lifting loops were flared while the other two were not. A lifting angle of 60 degrees was utilized in all four of these tests. All four lifting loops on the fourth deck beam were placed such that neither leg was restrained by the U-bars.



(a) (b)

Figure 13. Depicts flared lifting loop legs to enable better consolidation and limit stress concentrations in thin web members: (a) parallel legs (b) flared legs (IDOT).

3.3 FABRICATION AND TESTING OF DECK BEAM TEST SPECIMENS

The deck beams were constructed in the University of Illinois Newmark Structural Engineering Laboratory (NSEL). Abutments were fabricated and used to anchor the prestressing steel. Four to six 0.5-inch diameter 270 ksi low relax prestressing strands were each stretched to IDOT deck beams specifications of 30,900 pounds of force before casting the concrete. The prestressing services were provided by Prestress Engineering Corporation. The exact prestressing force varied from 30,900 pounds due to the large live seating losses that occur on a short prestressing bed length, which was approximately 18 feet. It was assessed that the strands remained stressed to within 5% of the target force.

Each deck beam had four lifting loop configurations, one located in each corner. The deck beam reinforcement cages were constructed away from the prestressing abutments and were lifted into location prior to stressing the strands, as seen in Figure 14.

3.3.1 Selection of the IDOT Deck Beam Section

The testing matrix called for two IDOT deck beam depths, an 11-inch and a 17-inch-deep beam. These are the shallowest members that IDOT has specified in their 2003 IDOT Prestressed Concrete Manual, and the members for which it was not possible to satisfy the PCI Design Handbook 5th Edition's minimum embedment requirement of 16 inches. IDOT's 11" x 48" and 17" x 48" prestressed deck beams were selected for use in this project. These beams have similar, but not identical, reinforcement layouts. The end region reinforcement layout was selected to follow the 2003 IDOT Prestressed Concrete Manual rather than to use the same detailing in all test specimens. There are several reinforcement differences between the two deck beams as described below. While every section is reinforced differently based on capacity and length, it was desired to incorporate the "weakest" reinforcement layout so that the measured lifting loop capacity would be a lower bound estimate of the likely capacity. The least number of prestressing strands in the 2003 IDOT Prestressed Concrete Manual were used in each of the test specimens as the compression from prestressing was expected to increase the capacity of the lifting loops. The 11-inch-deep member was designed to have four strands, while the 17-inch-deep members were designed to have six strands. The required layer of longitudinal top steel reinforcement was similarly provided in all test specimens. The 11-inch-deep member had eight #4 bars at 6 inches on center while the 17-inch-deep members had seven #5 bars at 7 inches on center.

One of the main differences between the 11-inch and 17-inch-deep beams was the presence of a void. The 17-inch-deep members had circular 10.5-inch diameter voids running along the length of the members. The number of voids depends on the width of the beam, and a 17" x 48" member has three 10.5-inch diameter voids. The voids begin at a specified distance from the end of the beam and are continuous throughout the length. This distance is referred to as the end block distance. The end block distance for 17-inch-deep members was 18 inches in the 2003 IDOT Prestressed Concrete Manual. This distance was used in the first two 17-inch deck beams, 17-1 and 17-2. An end block distance of 30 inches was used, according to the ABD Memorandum 07.2, for the final 17-inch deck beam, 17-3. The 2003 IDOT Prestressed Concrete Manual specifies that the lifting loops are to be placed in the middle of the end block. Therefore, the location of the lifting loop from the end of the beam is dependent on the end block distance. This is different from the 11-inch-deep members that are solid throughout their entire length, in which the lifting loops are specified to be located a minimum of 15 inches from the end of the beam. Once again, the test specimens were designed to replicate the details that are presented in the IDOT manual.

Another difference in the deck beam reinforcement requirements was the spacing of U-bar shear reinforcement. A U-bar is a reinforcing bar that is bent into the shape of a U, whereby two U-bars placed on opposite sides of the beam form a "closed" stirrup and are used to provide shear reinforcement and bursting reinforcement. The 2003 IDOT Prestressed Concrete Manual specifies that four U-bars are placed within the end block of the 17-inch-deep specimens. This means that four U-bars appropriately spaced must fit within the end block, whereas the 11-inch-deep members call for the U-bars to be spaced at 6 inches on center. It should be noted that the number of U-bars is dependent on the amount of shear reinforcement that is required by the designer, but once again this was kept at a minimum in this research study so that lower bound capacities would be measured.

The 11-inch and 17-inch-deep test specimens were fabricated so that the tests could be conducted using the same testing apparatus. This meant that the distance between the lifting loop and the dead end anchor remained constant for all lifting loops. Consequently, both specimens look very similar in their plan view, but the 11-inch members extends 6 inches on both ends to account for the increased end distance that is allowed by the 2003 IDOT Prestressed Concrete Manual. These short deck beams were fabricated with a "wing" extension in the middle of the beam so as to provide a sufficiently large region for the testing apparatus to sit on top of the test specimen. It was anticipated that the location of these "wings" would not interfere with the behavior of the lifting loop because they were located at least one beam depth away from the lifting loop, and a 45 degree shear cone failure would not intersect these "wings."

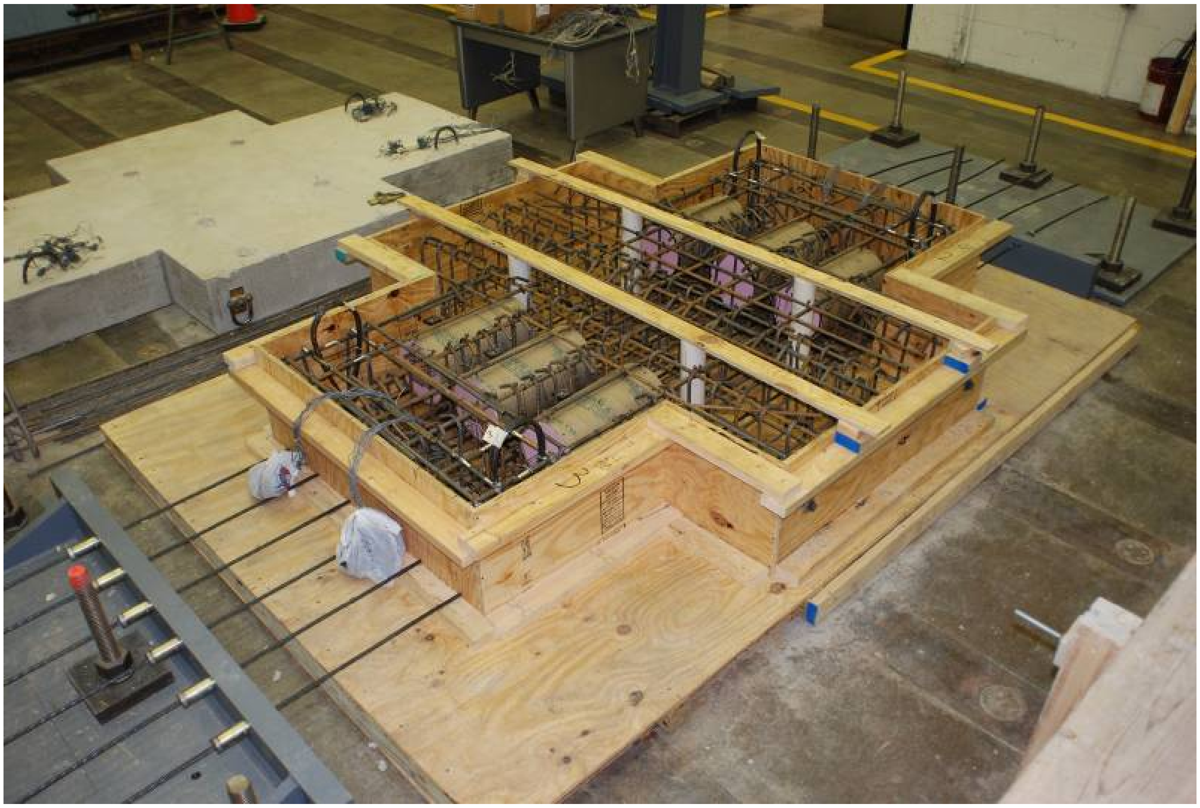


Figure 14. Deck beam casting.

Additional deformed bar reinforcement was added between the lifting loop and wings so as to provide sufficient moment and shear capacity to the beam section to prevent unwanted one-way shear and bending failures of the beam. Placement of the reinforcement was done in a manner such that no bars were placed in the lifting loop's expected "zone-of-influence," which was taken to be a 45-degree pullout cone extending upwards from the free ends of the 6-inch lifting loop extensions.

3.3.2 Creation of Setup for Deck Beam Tests

A loading setup capable of pulling a two strand loop to failure by rupture of the strands was created; the capacity of which could be beyond 165 kips. This was a very significant decision for the testing program as the maximum capacity of a single actuator in the laboratory was 100 kips, and two actuators were not available to be coupled for use in the testing. In order to provide the needed diagonal loading capacity, a specialized testing apparatus was designed and fabricated. While this apparatus served its purpose, if the authors were faced with a similar loading challenge in the future then the acquisition of a larger capacity actuator would be sought. This is because the design and fabrication of the loading setup was more involved than originally expected and this resulted in the testing program taking longer than desired and impacted the number of experiments that could be completed.

The testing apparatus employed a double-acting 50 ton jack with a mechanical lever arm to create a maximum pull capacity on a loop that could be in excess of 500 kips. The testing device is presented in Figure 15 and further described in Appendix C.

Figure 15. Deck beam testing apparatus.

The load was applied to the loop through a strut that was instrumented to also serve as a load cell. This strut was connected via a 2-inch diameter lifting pin to the loop at one end and connected to the loading apparatus at the other end with a 2.5-inch diameter pin. The load was measured through two 4.0” x 0.75” plates that spanned approximately 16 inches and were made from A36 steel. The two plates, referred to as arms, were used to serve as a load cell. A full load cell bridge was used that could account for eccentric loading and minor bending effects. The entire load cell assembly was calibrated in a MTS uniaxial testing frame up to a capacity of 150 kips. This limit was imposed in the calibration to guard against ovalling of the hole in the strut that holds the pin at the location of the lifting loop; the dimension and thus capacity of this end connection was limited by the dimensions of the protruding lifting loop.

The testing apparatus was a self equilibrating system, in which the specimen did not need to be tied down to the strong floor. The jack rested on top of the specimen and reacted against the top of the deck beam and the lifting plates that induced a diagonal pulling load on the lifting loop. A series of three load plates were connected to a single 2.5-inch diameter pin. Two plates were inclined at 45 degrees, one of which was the load cell arm and the other which was a strut that was anchored to the opposite end of the beam, which was referred to as the dead end of the specimen. These two plates form a triangular shaped truss on top of the specimen. The loading arm extended vertically through a wide flange W14x99 steel section that acted as a lever arm. The wide flange beam lever arm was oriented to bend about its weak axis to allow the loading plate to extend through the web.

The lever pivots about a column support which was located approximately 9 inches from the plane of the loading plates, and the jack was located on the opposite side approximately 27 inches from the plane of the load plates. Through simple statics, a load magnification factor of approximately 4 could be achieved through the use of this lever arm.

The loading jack was operated by an Instron controller in displacement control with an external 10-inch LVDT used in the control loop. The system was needed to induce large displacements on the lifting loop to reshape the loops along the axis of the loading and to investigate post peak behavior. The tested apparatus only facilitated approximately 1.5 inch of lifting loop displacement before a component of the system would begin to bear or lock up. This limitation was overcome by the progressive use of shims between the loading plates and the lever arm beam. In the testing, it was common to unload the specimen on two or three occasions to insert shims.

The direction of pull was in the plane of the side elevation. In the field, and depending on the type of lifting rig used, center point lifting rig, spreader beams, etc. the direction of pull may be inclined toward the center of the beam. The difference between what was used in the laboratory and in the field is not expected to be more than a few degrees and thus not significant.

3.3.3 Test Procedure for Deck Beam Tests

The testing apparatus was fabricated and assembled by the technicians in the CEE machine shop at the University of Illinois. Prior to the start of the test, the system was made snug which induced up to a 2 kip diagonal load in the strut that was loading the lifting loop. This was done to eliminate any gaps in the system and thus limit the number of times a shim would have to be added during the test.

Loading was started at a rate around 0.3 to 0.5 inches per minute of jack travel until 3-5 kips of diagonal load was reached and then it was slowed down to about 0.2 inches per minute. This loading rate was usually maintained until first cracking and triangular wedge spalling occurred. Loading was halted frequently as first cracking approached. First cracking was usually brittle and quick, and thus many pauses were needed in the displacement control loading to accurately capture when first cracking occurred. It was desired to not unload and shim the specimen until the triangular wedge spalling occurred or in some cases the ultimate load, but this could not be achieved in all tests.

Cracks were traced with a felt tip marker to make it easy to distinguish crack locations in pictures. The concrete cover was manually pulled off, specifically in areas surrounding the strands when it was desired to obtain a better photographic record of the damaged region. Throughout the loading history, qualitative notes and numerous photographs were taken to record behavior.

3.4 FABRICATION AND TESTING OF STRAND RUPTURE TEST SPECIMEN

The strand rupture tests were conducted in a uniaxial 600 kip MTS testing frame. The specimens were cast in 18-inch diameter circular sonotubes and were approximately 4 feet long. Each specimen has a single lifting loop fully embedded in it. The specimen had a slanted surface to simulate a 60 degree inclined lifting angle. A 2-inch diameter high yield strength threaded rod extended 12 inches out the opposite end of the specimen and was hydraulically gripped to the bottom of the testing frame to anchor each specimen. Longitudinal and spiral shear/confinement reinforcement was provided in each specimen to prevent unwanted cracking and slippage. Additionally, a grid of #3 reinforcing bars was provided at each end of the specimen to prevent unwanted cracking and restrain bursting forces that may develop. The lifting loop was embedded close to the full depth of the 4-foot long specimen to avoid a concrete pullout failure, and the legs of the strands entered the concrete as would be the case in a field application. The full reinforcing details for the test specimens and additional information about this test setup are provided in Appendix B.

3.4.1. Test Procedure for Strand Rupture Tests

The strand rupture test specimens were inserted into the MTS 600 kip testing frame using a fork lift truck. The test setup is presented in Figure 16. The load was measured through a load cell that was located in the upper cross head of the testing frame. Displacement was measured with a displacement transducer, or LVDT, that was located in the actuator on the testing frame. Only load and displacement were measured during these tests. A displacement loading rate of 0.15 inches per minute was used until the first couple of wires broke, and then it was increased to about 0.2 to 0.4 inches per minute until all wires were broken or the test stopped or other reasons. In most cases, the loading was only paused at the first wire rupture to take pictures and then at the end of the test when all the wires had failed.

Figure 16. Strand rupture test setup.

3.5 INSTRUMENTATION

A National Instruments LabView program was used to acquire data for both the deck beam and strand rupture tests. All data was recorded at 4 Hertz. As described earlier, the load was measured on the deck beams using two full bridge strain gauges. Additionally, two quarter bridge strain gauges were added to the outside of each arm of the load cell for comparison purposes, yet these strain gauges did not capture eccentric loading between the load cell arms and were thus were not needed for further data analysis.

Two 5-inch stroke string pots were used to measure the relative displacement of the lifting pin as shown in Figure 17. The string pots were mounted to a frame that was bolted to the top of the deck beam. One string pot measured the vertical displacement of the lifting pin and the other monitored the horizontal displacement. The location of the string pots were adjusted at the start of each test to ensure they were perpendicular to one another, in-plane with the lifting mechanism, and measuring data in a desired coordinate system. The string pots were driven with a DC power supply and the input voltage was continuously monitored during the test. The string pot raw voltage readings were converted to displacement measurements after the conclusion of the test. The combination of these two measurements also provided the displacement along direction of load application.

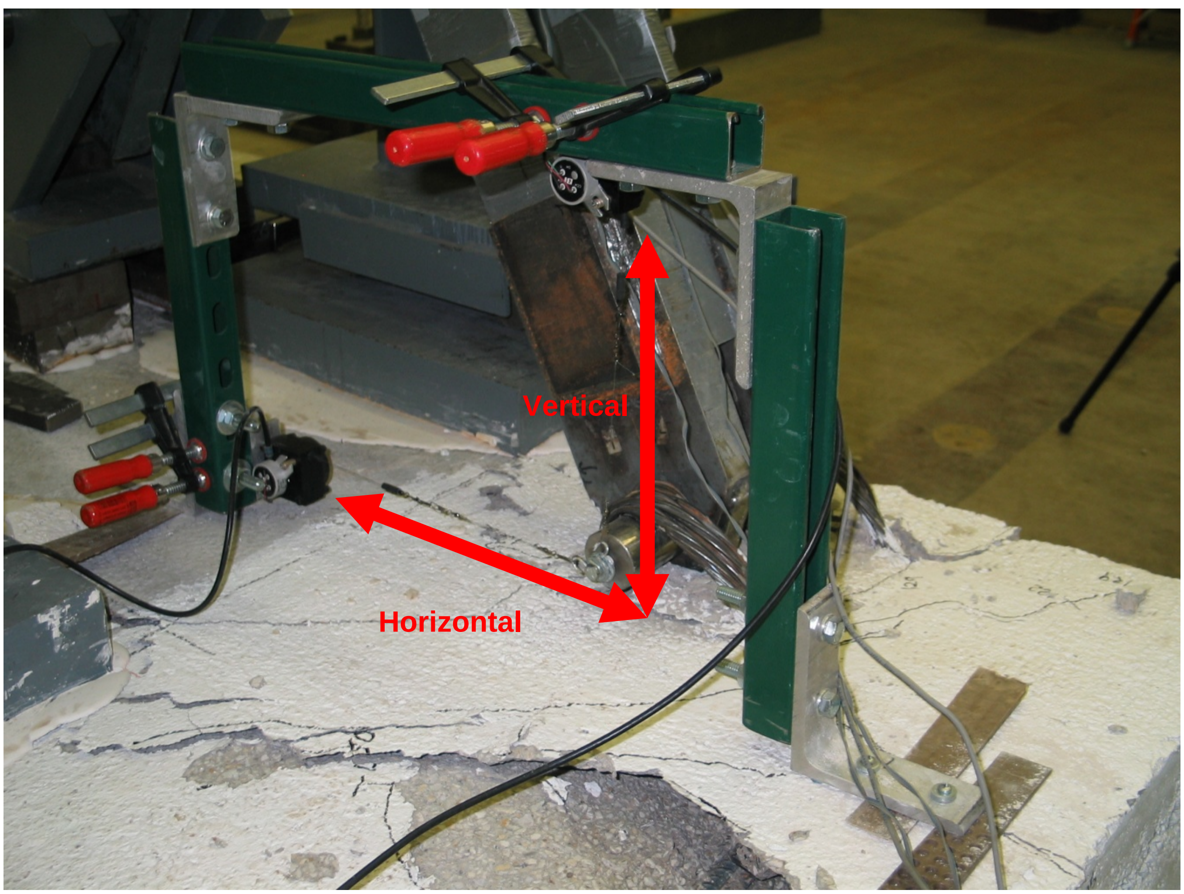


Figure 17. String pot locations, horizontal and vertical displacement measurements.

3.6 MEASURED STRENGTH OF CONCRETE IN DECK BEAM SPECIMENS

The compressive strength of the concrete was measured using test cylinders that were kept in the same laboratory space as the deck beam specimens and thus subjected to the same environmental conditions. The cylinders were stripped from their forms at the same time that the wet coverings and forms were removed from the deck beam test specimens, which was usually around three days after casting. The same concrete mix design was used for the first three deck beam test specimens (11-1, 17-1, and 17-2). In the first of these specimens (11-1), the compressive strength was measured using three test cylinders at 10, 21, 27, 46, and 124 days after casting. The results illustrated that the strength increased only marginally beyond 27 days. The compressive strength of the concrete at the time of each individual test was based on a linear interpolation between measured strength values. The total variation of the strengths over the four tests on 11-1 was 3970 – 4012 psi (3%). Given the slow rate of strength development and limited variation in strength over the duration of testing, the compressive strength was measured on fewer occasions for subsequent deck beam test specimens. The variation in strength of the concrete in the tests for specimen 17-1 was calculated to be 3934 to 3983 psi (1%), and the variation for specimen 17-2 was calculated to be 3914 to 4274 psi (8%). The somewhat larger variation in strength in specimen 17-2 was because the tests were conducted when the concrete was still quite young.

It was decided to change the mix design for specimen 17-3 with the intent of obtaining a compressive strength at the time of testing closer to 5000 psi. Two batch tests were conducted but the measured strengths were showing little change over what was observed for test specimens 11-1, 17-1, and 17-2. Because of this and the desire to cast specimen 17-3 without taking the time for additional batch testing, the authors decided to use a standard mix suggested by the concrete supplier that was to provide a “little” more strength. Unfortunately, this mix produced a compressive strength of 9279 psi at 38 days, which was at the end of the 12-day testing period for the tests on the 17-3 test specimens. Cylinder tests were not conducted at the start of this 12-day testing period, but given that the specimen was air cured from day three onwards, it is reasonable to expect that the compressive strength of the concrete for all of these four tests would be within a few percent of this 9279 psi value.

The tensile strength of the concrete was similarly assessed. Table 7 presents a summary of the measured compressive and tensile strength of the concrete, the age of the concrete for each test, and the associated interpolated strengths. The mix designs are presented in Appendix A.

Table 7. Summary of Concrete Strengths

Compression | **Split Tensile Test** | **Test Day Strengths - Linear Interpolation**

11-1 Deck Beam

Compressive Strength

Day	Load (lb)	Strength (psi)
0		0
10	81085	2868
21	101022	3573
27	108433	3835
46	112347	3973
124	118067	4176

Split Tensile Test

Day	Load (lb)	Strength (psi)
0	0	0
46	48337	427
124	48284	427

Test Day Strengths

Pour Date	7/13/2007							
Test ID	Test Date #1	Days	Compressive	Tensile	Test Date #2	Days	Compressive	Tensile
11-1 Loop #2	10/18/2007	97	4106	427	10/24/2007	103	4121	427
11-1 Loop #3	8/27/2007	45	3970	427	10/10/2007	89	4085	427
11-1 Loop #1	10/15/2007	94	4098	427	N/A	N/A	N/A	N/A
11-1 Loop #4	9/12/2007	61	4012	427	10/8/2007	87	4080	427

17-1 Deck Beam

Compressive Strength

Day	Load (lb)	Strength (psi)
0	0	0
10	87505	3095
21	105067	3716
99	112703	3986

Split Tensile Test

Day	Load (lb)	Strength (psi)
0	0	0
99	48140	426

Test Day Strengths

Pour Date	8/7/2007			
Test ID	Test Date	Days	Compressive	Tensile
17-1 Loop #2	11/1/2007	86	3941	426
17-1 Loop #1	10/30/2007	84	3934	426
17-1 Loop #4	11/13/2007	98	3983	426
17-1 Loop #3	11/8/2007	93	3965	426

17-2 Deck Beam

Compressive Strength

Day	Load (lb)	Strength (psi)
0	0	0
8	98765	3493
28	132760	4695

Split Tensile Test

Day	Load (lb)	Strength (psi)
0	0	0
63	44237	391

Test Day Strengths

Pour Date	1/14/2008			
Test ID	Test Date	Days	Compressive	Tensile
17-2 Loop#2	1/29/2008	15	3914	391
17-2 Loop#4	2/2/2008	19	4154	391
17-2 Loop#1	1/31/2008	17	4034	391
17-2 Loop#3	2/4/2008	21	4274	391

17-3 Deck Beam

Compressive Strength

Day	Load (lb)	Strength (psi)
0	0	0
38	262360	9279
97	282700	9998

Split Tensile Test

Day	Load (lb)	Strength (psi)
0	0	0
97	67262	595

Test Day Strengths

Pour Date	3/18/2008			
Test ID	Test Date	Days	Compressive	Tensile
17-3 Loop #1	4/13/2008	26	9279*	595
17-3 Loop #3	4/23/2008	36	9279*	595
17-3 Loop #2	4/15/2008	28	9279*	595
17-3 Loop #4	4/25/2008	38	9279*	595

* Strength measured at the end of the 17-3 deck beam tests, assumed for all four tests, no linear interpolation

CHAPTER 4 RESULTS FROM TESTING PROGRAM ON DECK BEAMS

4.1 TYPICAL BEHAVIOR FOR A DECK BEAM LIFTING LOOP TEST

The 16 lifting loop tests conducted in the Newmark Laboratory at the University of Illinois exhibited similar stages of damage development and comparable shapes of load-deformation responses. A good example of a typical load-deformation response is shown in Figure 18.

At the start of each test, the lifting pin was placed mechanically snug up against the lifting loop to ensure the maximum stroke capacity from the testing apparatus could be used. During this procedure, a maximum load of 1 to 2 kips of diagonal load was introduced into the system. During this process, only a minor distortion of the loop was seen. This initial load was fully included in the measured force, as illustrated in the minor offset in Figure 18.

Stage 1: Shape Changing and Full Engagement – As the lifting loop was loaded, its shape changed from a semicircle to a loop that wraps around the loading pin, and with straightening, strands from the pin to just above where the strands enter the concrete. The overall stiffness of the lifting loop was low because the bending stiffness of prestressing strands is quite low. As more deformation was introduced into the system, the strands began to straighten out further and wrap more tightly around the lifting pin. Since the strands are comprised of seven twisted wires, some of the strands bent around the lifting pin tend to unwind as the strands were seated around the lifting pin. Consequently not all seven wires were directly engaged by the lifting pin, and thus significant displacement was needed to engage all of the wires in a strand. Additionally, if all the strands in a lifting loop were not the same shape or they were slightly offset from one another due to construction tolerances, then significantly more displacement was needed to fully engage all the strands and wires in a lifting loop. During this first stage of loading, much of the measured displacement was attributed to fully engaging all of the strands. The first inch of horizontal displacement in Figure 18 can be attributed to this first stage of shape changing and full engagement.

Stage 2: Linear-Elastic Response – Once the strands had bent sufficiently around the lifting pin, the load-displacement response of the loop became much stiffer. As shown in Figure 18, it became nearly five times stiffer than that in the first stage. This stage is characterized as the linear elastic response although the strands have already plastically deformed to seat around the lifting pin. During this stage, the strands have deformed sufficiently to induce small localized crushing and flaking surrounding the strand entrance in the concrete but the level of this damage was considered insignificant. This region of damage extended around the strand entrance by approximately a 0.5 inch radius.

Stage 3: First Cracking – The next stage in the behavior is distinguished by first cracking. This stage is very important because it is a measure of a serviceability limit state for the lifting loop; the owner may specify that a deck beam should not crack considerably during lifting. Although, the load at which this event occurred varied somewhat between the test specimens, the location and size of the cracks in each test were very similar. First cracking always initiated from the rear strand entrance, the one closest to the end of the beam. If there were two lifting loops in the corner of a beam, the crack initiated from the lifting loop closest to the edge of the beam. In all cases, the formation of this crack was quick and sometimes hard for an observer to catch.

Stage 4: Formation of Cracked Triangular Wedge – The next stage was determined to be when a distinctive triangular shape of cover concrete begins to crack and/or spall off the specimen, as illustrated in Figure 19. The triangular wedge is a continuation of first cracking that wraps over the side of the beam and tapers longitudinally down the beam.

This formation was usually quite abrupt, and a significant drop in diagonal load of 10 to 20 kips was almost always observed. This drop in load is illustrated in Figure 18. Eventually, what began as the triangular wedge crack, transformed into a chunk of the cover that falls off the deck beam either at the end of the formation of the complete crack or later in the loading process.

Stage 5: Damage Progression with Strengthening – Although the formation of the triangular wedge created the single most abrupt drop in load throughout the entire test, the lifting loop almost always continued to support a higher load than that when the formation of the triangular wedge was complete. However, significant additional cracking and the progression of severe damage was typically associated with this final increase in capacity. The extent of the cracking was highly dependent on the test variables such as edge distance, number of lifting loops in a corner of a deck beam, embedment depth, etc. As the ultimate capacity was approached, it was observed that the rear lifting loop leg (closest to the end of the beam), pulls through the concrete in an attempt to become parallel with the front leg. Furthermore, the front lifting loop leg remains stationary and did not pull through the concrete. This pattern of development was reasonably consistent regardless of the reinforcement layout surrounding the lifting loop.

Stage 6: Post-Peak Behavior – After the ultimate load has been achieved, the response was rather ductile with a significant component of the capacity of the loop being available even at twice the deformation associated with peak load. This can also be seen in Figure 18 where several inches of displacement are achieved before there was a 40% reduction in capacity.

As previously mentioned, the specimen was unloaded, shimmed, and reloaded as needed to impose additional displacement. The load-deformation response in Figure 18 shows two occasions when this specimen was unloaded. The envelope of the response suggests that the overall response was not affected by this unloading and reload process as would be expected.

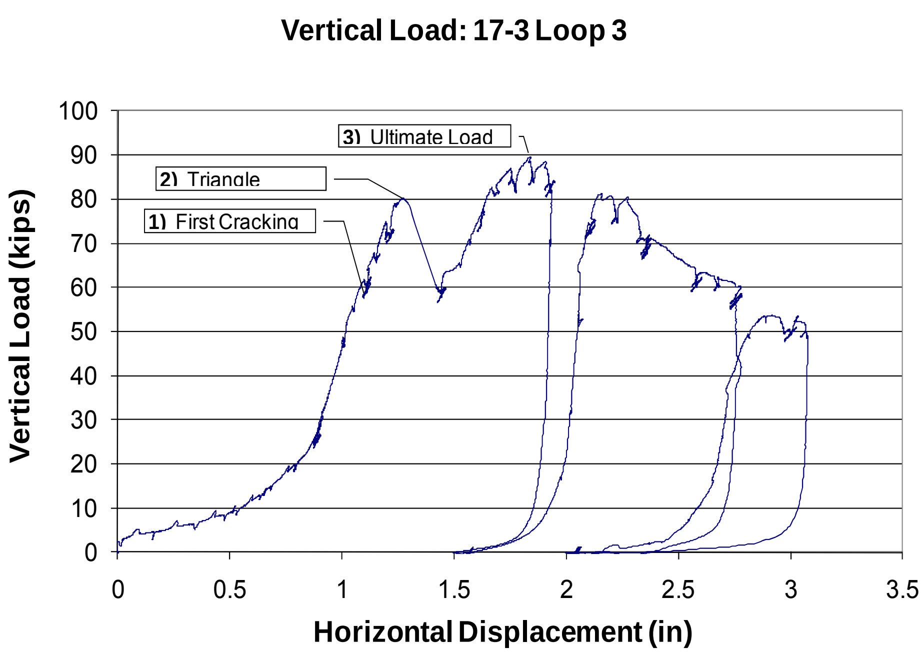


Figure 18. Load displacement plot of a typical lifting loop.

Figure 19. Crack pattern of triangular wedge.

4.2 SUMMARY AND DISCUSSION OF RESULTS

A summary of the 16 deck beam test results along with all dependent variables are included in Table 8. Section 4.2 presents an examination of the subsets of test results and a discussion of the observed influence of key variables on the measured capacity and performance of the tested lifting loops. The following section, 4.3, discusses the implications of the results.

Table 8. Deck Beam Test Results Summary

Loop ID	Cast Day	Test Day	Specified Concrete Strength (psi)	Test Day Concrete Strength (psi)	Test Day Tensile Strength (psi)	Beam Depth (in)	Embedment Depth (in)	Actual Embedment Depth (in)	End Block Length (in)	End Distance to Center of Loop (in)	Side Dist. (in)	Actual Side Dist. (in)	Shape	Lifting Loops in a Corner	# Strands / Lifting Loop	Flaring (Degrees)	Lifting Loop Leg with Inward Movement Restrained by U-Bar	Diagonal Load (kips)			Vertical Load (kips)			
																		First Cracking	Wedge Spalling	Ultimate	Angle (degrees)	First Cracking	Wedge Spalling	Ultimate
11-1 Loop #1	7/13/2007	10/15/2007	4000	4098	427	11	6	5.63 - 6.63	N/A (1'3")	15	3	4.25	Parallel	1	2	0	Inner Leg	26.6	28.4	38.7	45	18.8	20.1	27.4
11-1 Loop #2		10/18/2007 10/24/2007	4000	4106	427	11	6	5.63 - 6.25	N/A (1'3")	15	6	6.06	Parallel	1	2	0	Inner Leg	N/A*	32.5	32.5	45	N/A	23.0	23.0
11-1 Loop #3		8/27/2007 10/10/2007	4000	3970	427	11	6	5.88 - 6.13	N/A (1'3")	15	6	6.25	Tied	1	2	0	Inner Leg	N/A	N/A	30.5	45	N/A	N/A	21.6
11-1 Loop #4		9/12/2007 10/8/2007	4000	4012	427	11	6	6.13 - 6.38	N/A (1'3")	15	3	4.00	Tied	1	2	0	Inner Leg	N/A	N/A	28.7	45	N/A	N/A	20.3
17-1 Loop #1	8/7/2007	10/30/2007	4000	3934	426	17	12	11.75 - 13.25	18	9	3	3.88	Parallel	1	2	0	Inner Leg	35.5	45.6	49.9	45	25.1	32.2	35.3
17-1 Loop #2		11/1/2007	4000	3941	426	17	12	12.25 - 13.25	18	9	6	6.00	Parallel	1	2	0	Inner Leg	49.1	59.3	59.3	45	34.7	41.9	41.9
17-1 Loop #3		11/8/2007	4000	3965	426	17	12	13.00 - 13.50	18	9	3	3.75	Tied	1	2	0	Inner Leg	28.0	31.4	41.3	45	19.8	22.2	29.2
17-1 Loop #4		11/13/2007	4000	3983	426	17	12	12.50 - 13.00	18	9	6	6.00	Tied	1	2	0	Inner Leg	34.0	40.5	52.6	45	24.0	28.6	37.2
17-2 Loop#1	1/14/2008	1/31/2008	4000	4034	391	17	12	11.13 - 11.88	18	9	4	4.13	Parallel	2	3	0	Inner Leg	47.8	N/A	98.9	45	33.8	N/A	69.9
17-2 Loop#2		1/29/2008	4000	3914	391	17	12	11.63 - 12.50	18	9	4	3.75	Parallel	1	3	0	Inner Leg	39.1	45.0	62.2	45	27.6	31.8	44.0
17-2 Loop#3		2/4/2008	4000	4274	391	17	12	11.63 - 12.13	18	9	4	4.00	Parallel	2	3	0	Both Legs	67.0	95.4	100.7	45	47.4	67.5	71.2
17-2 Loop#4		2/2/2008	4000	4154	391	17	12	12.25 - 12.88	18	9	4	3.63	Parallel	1	3	0	Both Legs	31.4	47.4	65.7	45	22.2	33.5	46.5
17-3 Loop #1	3/18/2008	4/13/2008	5000	9279	595	17	13	11.88 - 12.38	30	15	6	4.25	Parallel	1	3	0	No Legs	57.5	63.5	115.5	60	49.8	55.0	100.0
17-3 Loop #2		4/15/2008	5000	9279	595	17	13	12.63 - 13.13	30	15	6	4.00	Parallel	2	3	0	No Legs	85.0	138.0	157.8	60	73.6	119.5	136.7
17-3 Loop #3		4/23/2008	5000	9279	595	17	13	12.00 - 12.63	30	15	6	4.50	Flared	1	3	10	No Legs	71.7	92.0	103.4	60	62.1	79.7	89.5
17-3 Loop #4		4/25/2008	5000	9279	595	17	13	11.63 - 12.13	30	15	6	4.88	Flared	2	3	10	No Legs	110	128.5	155.2	60	95.3	111.3	134.4

Notes:

1.) For beams 11-1, 17-1 and 17-2, the angle of pull began at close to 45 degrees but was closer to 50 degrees at the time that the ultimate capacity was realized; it is suggested to consider these to be 45 degree lifts for making a conservative estimates of vertical lift capacity

The results from the first two deck beam tests are summarized in Table 9. The first two deck beams were constructed to investigate the effect of edge distance (distance from the center of the lifting loop to the side or edge of the beam) and the configuration of the lifting loop legs (parallel or tied legs) on performance. All tests were conducted on single lifting loops composed of two strands. The results in Table 9 have been normalized with respect to the square root of the compressive strength of the concrete. This normalization approach was adopted as most of the damage states in the concrete were principally induced by concrete splitting, which is proportional to the tensile strength and by common convention the square root of the compressive strength. The column "crack vertical load" refers to the vertical component of the load acting on the lifting loop (normalized) at the observed first cracking, while "wedge vertical load" and "ultimate vertical load" are the same normalized vertical loads for when the triangular wedge and ultimate capacity was reached. From this table, it is observed that the overall capacity of lifting loops with parallel legs were higher than those with tied legs. Additionally, lifting loops that were placed closer to the edge of the beam performed worse, with the only exception being the lifting loops in the 11-inch deck beam with parallel legs. However, this exception is associated with a retest, in which the actual ultimate load may have been reached during the first test, and only the retested values are presented in the following tables.

Table 9. Comparison of First Two Deck Beams

Deck Beam Depth	Edge Distance (Actual)	Crack Vertical Load $P_{u,vert} / \sqrt{f_c}$		Wedge Vertical Load $P_{u,vert} / \sqrt{f_c}$		Ultimate Vertical Load $P_{u,vert} / \sqrt{f_c}$	
		(1 x 2)		(1 x 2)		(1 x 2)	
(in)	(in)	Tied	Parallel	Tied	Parallel	Tied	Parallel
11"	6" (6.25", 6.06")	N/A	N/A	N/A	0.36	0.34	0.36
	3" (4.00", 4.25")	N/A	0.29	N/A	0.31	0.32	0.43
17"	6" (6.00", 6.00")	0.38	0.55	0.45	0.67	0.59	0.67
	3" (3.75", 3.88")	0.31	0.40	0.35	0.51	0.46	0.56

N/A = Data not available

Table created from 11-1 and 17-1 tests

One of the research objectives was to assess performance when the loop is located closer to the side edge of the test beam. The load at which cracking occurs based on the edge distance can only be investigated using the first 17-inch-deep deck beam test results because these points were not clearly captured in tests on the 11-inch-deep test specimen. A reduction from an edge distance of approximately 6 inches to that of a little less than 4 inches resulted in reductions of 18% and 27% to the first cracking load and reductions of 22% and 24% to the triangular wedge cracking load. This data suggests that lifting loops placed less than 6 inches from the edge of the beam have significantly reduced serviceability limit states.

A summary of the results from the second 17-inch-deep deck beam tests is presented in Table 10. These tests investigated the deck beam, the number of lifting loops in a corner of a deck beam, and the position of the U-bar relative to the lifting loop. It was hypothesized that if both legs of the lifting loop were restrained by the U-bar, then the loads at initial cracking and triangular wedge cracking may be increased. However, the results do not identify this trend but rather indicate that the placement of U-bars has very little impact on both the serviceability performance and the capacity of lifting loops. This observation does not suggest that additional reinforcement (i.e. mesh reinforcement) would not improve lifting loop performance, but rather that only horizontal transverse bars, in particular U-bars as specified in the design manual, were not observed to have a significant effect.

The other variable that was tested in the second 17-inch-deep deck beam was the number of lifting loops in a corner of a deck beam. Two of the tests had two three-strand lifting loops (2x3) in a corner of the deck beam while the other two locations had single three-strand lifting loops (1x3). The tests whereby two lifting loops were placed in the corner of a beam were expected to have a much higher capacity, and they did, as presented in Table 10. Interestingly and perhaps more importantly, the two lifting loop configurations were observed to have much higher cracking strengths as shown. This is not surprising as the load was shared between the two lifting loops and thereby the contact stresses that led to crack formation would not be expected to occur until higher total load levels. In practice, the load share may depend on the details of the loading device which is not presented in IDOT specifications.

Table 10. Comparison of Second 17-inch-deep Deck Beam

Deck Beam Depth (in)	Legs Restrained by Rebar	Crack Vertical Load $P_{u,vert} / \sqrt{f_c}$		Wedge Vertical Load $P_{u,vert} / \sqrt{f_c}$		Ultimate Vertical Load $P_{u,vert} / \sqrt{f_c}$	
		(1 x 3)	(2 x 3)	(1 x 3)	(2 x 3)	(1 x 3)	(2 x 3)
17"	Both Legs	0.34	0.72	0.52	1.03	0.72	1.09
	One Leg	0.44	0.53	0.51	N/A	0.70	1.10

N/A = Data not available

Table created from 17-2 tests

Table 11 compares the results from the lifting loops tests in the first two 17-inch deep deck beams that were tested. The lifting loops in the first of these beams (17-1) were made with two strands, while the lifting loops in the second beam (17-2) had three strands. According to Table 11, the number of strands in a loop had some effect, albeit scattered, on the cracking load of the deck beams. Some scatter in the pattern is not surprising since concrete tensile driven failure loads have a high degree of variability. Conversely, the ultimate strength clearly increases as the number of strands in a loop increases; the ratios of the strengths of two and three-strand loops were similar to those in the PCI Design Handbook in which strength multipliers of 1.7 and 2.2 are used for two and three-strand loops.

Table 11. Comparison of Number of Strands in a Lifting Loop

Deck Beam Depth (in)	Edge Distance (Actual) (in)	Crack Vertical Load $P_{u,vert} / \sqrt{f_c}$		Wedge Vertical Load $P_{u,vert} / \sqrt{f_c}$		Ultimate Vertical Load $P_{u,vert} / \sqrt{f_c}$	
		(1 x 2)	(1 x 3)	(1 x 2)	(1 x 3)	(1 x 2)	(1 x 3)
17"	6" (6.00", 3.75")	0.55	0.44	0.67	0.51	0.67	0.70
	3" (3.88", 3.63")	0.40	0.34	0.51	0.52	0.56	0.72

Table created from 17-1 and 17-2 tests

In the third 17-inch-deep specimen, the investigators flared the strands to see if this would have an impact on the serviceability or ultimate capacity, since this flaring technique is widely used. Table 12 examines the results from this series of lifting loop tests. With regards to the first cracking load and the triangular wedge cracking load, the lifting loops with flared strands performed better; however, in terms of ultimate load they performed worse. The latter may be because using multiple legs encouraged cracking to extend between these legs and thereby developing a larger plane of weakness. Flaring of strands may be of greatest advantage when the legs are longer (thin webbed members) and when consolidation is of utmost importance.

Lifting loop configurations that were composed of two lifting loops in a corner of the deck beam demonstrated much greater load carrying capacity. The inner lifting loop was fully confined and much stiffer, and as a result carried more load initially, until cracking occurred. Upon approaching the ultimate capacity, it was noted that most two lifting loop specimens (2x3) demonstrated a complete “cone” separation from the rest of the beam suggesting that the lifting loop was sufficiently anchored in the concrete, as shown in Figure 20.

Table 12. Comparison of Flared Legs versus Parallel

Deck Beam Depth (in)	Flared Legs (10 degrees)	Crack Vertical Load $P_{u,vert} / \sqrt{f_c}$		Wedge Vertical Load $P_{u,vert} / \sqrt{f_c}$		Ultimate Vertical Load $P_{u,vert} / \sqrt{f_c}$	
		(1 x 3)	(2 x 3)	(1 x 3)	(2 x 3)	(1 x 3)	(2 x 3)
17"	Yes	0.64	0.99	0.83	1.16	0.93	1.40
	No	0.52	0.76	0.57	1.24	1.04	1.42

Table created from 17-3 tests

The final variable that was investigated was the angle of pull. The final four lifting loops were tested at an angle of 60 degrees from the horizontal, whereas all the other specimens were tested at a 45 degree angle. The results from this series of tests have been summarized in Table 13. When examining these results, it should be noted that the vertical component of the inclined tension acting on the loop is a function of the angle of pull. The ratio of the sine of 60 and 45 degrees is 1.22, so a 22% increase in vertical load capacity would be associated with no increase in capacity along the line of action of the inclined pull. When comparing the first cracking load for all the specimens, the ratio of normalized load between the 60 and 45 degree tests ranged between 1.05 and 1.87 (average of four tests = 1.46). This suggests that with a higher angle of pull, there was a slight trend to have a higher first cracking load. The ratio of the normalized load at which the triangular wedge cracking occurred was somewhat lower, between 1.17 and 1.63 (average of four tests = 1.29). The ratio of the normalized load at ultimate capacity factor ranged from 1.27 to 1.48 (average of four tests = 1.33). This suggests only a minor benefit to ultimate capacity from pulling at a higher angle beyond consideration of the difference due to the sine of the angle of pull. These results show that the angle of pull is a significant factor in determining the vertical load at which service limit states and the ultimate capacity is reached, with most of this increase being purely due to the sine of the angle of lift.

Table 13. Comparison of Lifting Angle and Number of Lifting Loops per Corner of a Beam

Deck Beam Depth (in)	Angle of Pull (From Horizontal)	Crack Vertical Load $P_{u,vert} / \sqrt{f_c}$		Wedge Vertical Load $P_{u,vert} / \sqrt{f_c}$		Ultimate Vertical Load $P_{u,vert} / \sqrt{f_c}$	
		(1 x 3)	(2 x 3)	(1 x 3)	(2 x 3)	(1 x 3)	(2 x 3)
17"	60	0.52	0.76	0.57	1.24	1.04	1.42
		0.64	0.99	0.83	1.16	0.93	1.40
17"	45	0.44	0.53	0.51	N/A	0.70	1.10
		0.34	0.72	0.52	1.03	0.72	1.09

N/A = Data not available

Table created from 17-2 and 17-3 tests

Figure 20. Two lifting loops in a corner of a deck beam demonstrating a “cone” separation, concrete intact surround loop.

4.3 IMPLICATIONS OF RESULTS

As presented in Section 4.1, the six stages in the deck beam lifting loop tests were characterized as shape changing and full engagement, linear elastic response, first cracking, formation of cracked triangular wedge, damage progression with strengthening, and post-peak behavior. Section 4.2 examined the influence of lifting loop configuration and placement on the loads at first cracking, triangular web formation, and ultimate for subsets of the deck beam test data. Section 4.3 will assess the overall implications of the results on the factors of safety for different lifting loop configurations and details, as well as provide suggestions for best practice. While the lifting loop design requirements have focused on providing a factor of four against failure, the results of the research clearly indicate that serviceability limit states should also be considered, so this will also be examined; cracking of the beam under service loads could create a water migration pathway that could lead to durability concerns.

Table 14 presents a summary of the approximate maximum gross weights of prestressed concrete deck beams used in the state of Illinois. The calculated values were derived from ABD Memorandum 08.2. For the maximum permitted length, and thus weight, of each deck beam, the load per loop configuration is presented in Table 14 for when the load is equally shared between four points and also when the load is shared between two points. The latter is also being provided because it is recognized that poor lifting practices may lead to twice the anticipated load per loop configuration being applied. For example, the heaviest 17-inch-deep precast deck beam used in state of Illinois practice weighs approximately 29.5 kips. If the weight of this deck beam was equally shared by four loop configurations, then the demand on each would be 7.4 kips. If the weight were shared between two loop configurations, then the demand on each would be 14.8 kips. It should be noted that these weights are approximate since the solid end regions and diaphragms were not considered because they vary between designs.

The factor of safety (F.S.) associated with cracking and failure for each deck beam is presented in Table 15. This F.S. is the measured vertical capacity per loop divided by the demand per loop where this demand is taken as one-fourth of the total maximum weight of each type of deck beam (using the common equal load sharing assumption). As an example, the measured ultimate strength from the 17-1 Loop #2 test of 41.9 kips would lead to a F.S. of 5.7 (41.9/7.4). The factors of safety for the deck beams of equivalent depth to the test specimens are shown in bold text and are most suited for assessing the factors of safety. The PCI Design Handbook 6th Edition states that a factor of safety of 4 should be applied to all lifting inserts to prevent slippage and breakage. The F.S. calculated from the ultimate strengths measured in this research illustrate that this is basically achieved for members of the same depth as well as quite often for members of somewhat deeper than those used in the experiments. The latter is particularly true for two loop configurations and when IDOT-specified dimensional requirements were satisfied. While there is no guidance in codes for what factor of safety should be achieved for serviceability limit states, a F.S. of 2 seems reasonable and would be generally supported by the results of this research.

When interpreting the results from this table, it is important to note that many of these lifting loop configurations and placements were selected to capture unconservative fabrication practices, such as by placing the loop closer to the edge of the beam than permitted by IDOT standards and that the angle of pull was 45 degrees for most specimens, while 60 degrees is now the IDOT required minimum. Conversely, Table 15(b) presents the results from the 17-3 deck beam lifting loops tests, all of which satisfy the current requirements of the ABD Memorandum 07.2 and thereby not capturing unconservative fabrication practices. Since the concrete strength of the 17-3 deck beam was considerably higher than anticipated, the values in Table 15(b) have been prorated downwards to account for the higher than target tensile strength of the concrete; this multiplication factor was taken as the ratio of the square root of the compressive target and measured strength which is 0.73 ($\sqrt{(5000/9273)}$).

An assessment of IDOT specifications based on the results presented in this section is given in section 6 of this report.

Based on the results of the deck beam tests, the following suggestions and observations are made regarding the design and performance of lifting loops:

1.) Lifting loops should be placed at least 6 inches from the side edge of the deck beam. A tolerance of plus or minus 1 inch should be applied to this limit because the results indicate a significant drop in the cracking and ultimate loads by reducing the edge distance from 6 inches to 4 inches.

2.) An increase in the number of strands in a loop from two to three resulted in a slight increase in the measured cracking load and a modest increase in the lifting capacity of a loop. The observed ratio of strength gain from two to three strand loops was similar to that given in the PCI Design Handbook 6th Edition of 1.29 (2.2/1.7). Furthermore, if two or more strands are specified, then they should be constrained to ensure that they are all engaged in the lifting process, such as through the use of an electrical conduit as discussed in section 5.

3.) The angle of lifting has a significant effect on the vertical load at which cracking and the ultimate capacity is reached. An increase in lifting angle from 45 to 60 degrees is expected to increase these strengths and thus the factor of safety at least proportionately to the sine of the angle of the lift (sin(60°)/sin(45°) = 1.22.

4.) Additional lifting capacity and the factor of safety against cracking can better be achieved by increasing the number of lifting loops in a corner of the deck beam, rather than through increasing the number of strands in a lifting loop. Beams that have two lifting loops in a corner of the beam ensure that at the least, there is one lifting loop that is sufficiently confined within the end of the deck beam because it is placed farther away from the edge of the beam.

5.) The tests did not indicate that the lifting loop's proximity to the void region or reinforcement played a significant role in when cracking occurred or in the capacity of the lifting loop. However, special attention should be taken when placing the lifting loops in reinforcing cages so that minimum tolerances are met, specifically the edge distance.

Table 14. IDOT Deck Beam Weights

IDOT Beam Weights

Deck Beam	Maximum Length (feet) with a 25 psf wearing suface*	Weight (lbs/foot)		Lift Loop Depth	Gross Weight**	Demand per Loop	
		net	solid	(in.)	(kips)	4 loops (kips)	2 loops (kips)
11 x 48	26	-	535	7	13.9	3.5	7.0
11 x 52	27	-	580	7	15.7	3.9	7.8
17 x 36	46	492	621	13	22.6	5.7	11.3
17 x 48	46	642	834	13	29.5	7.4	14.8
21 x 36	58	550	771	17	31.9	8.0	16.0
21 x 48	58	708	1033	17	41.1	10.3	20.5
27 x 36	72	594	986	23	42.8	10.7	21.4
27 x 48	72	731	1323	23	52.6	13.2	26.3
33 x 36	86	669	1211	29	57.5	14.4	28.8
33 x 48	87	806	1623	29	70.1	17.5	35.1
42 x 36	102	781	1548	38	79.7	19.9	39.8
42 x 48	104	919	2073	38	95.6	23.9	47.8

* Approximate span length from ABD Memorandum 08.2

** Lower limit, does not consider solid beam regions, i.e. end block and diaphrams

Table 15(a). Safe Working Lifting Loads

Loop ID	Depth of Beam	# Loops x # Strands per Loop	Test Vertical Load: First Cracking	Test Vertical Load: Ultimate	Calculated F.S. (Cracking) 11 x 52 **	17 x 48 **	21 x 48 **	27 x 48 **	33 x 48 ***	42 x 48 ***	Calculated F.S. (Ultimate) 11 x 52 **	17 x 48 **	21 x 48 **	27 x 48 **	33 x 48 ***	42 x 48 ***
Maximum Self-Weight of Beam (kips)*					14	30	41	53	70	96	14	30	41	53	70	96
Demand Per Loop Based on Equal Share on Four Loops (kips)					3.5	7.4	10.3	13.2	17.5	23.9	3.5	7.4	10.3	13.2	17.5	23.9
11-1 Loop #1	11	1 x 2	18.8	27.4	**5.4**	-	-	-	-	-	**7.9**	-	-	-	-	-
11-1 Loop #2	11	1 x 2	-	23.0	-	-	-	-	-	-	**6.6**	-	-	-	-	-
11-1 Loop #3	11	1 x 2	-	21.6	-	-	-	-	-	-	**6.2**	-	-	-	-	-
11-1 Loop #4	11	1 x 2	-	20.3	-	-	-	-	-	-	**5.8**	-	-	-	-	-
17-1 Loop #1 $*_4$	17	1 x 2	25.1	35.3	-	**3.4**	-	-	-	-	-	**4.8**	-	-	-	-
17-1 Loop #2 $*_4$	17	1 x 2	34.7	41.9	-	**4.7**	-	-	-	-	-	**5.7**	-	-	-	-
17-1 Loop #3 $*_4$	17	1 x 2	19.8	29.2	-	**2.7**	-	-	-	-	-	**4.0**	-	-	-	-
17-1 Loop #4 $*_4$	17	1 x 2	24.0	37.2	-	**3.3**	-	-	-	-	-	**5.0**	-	-	-	-
17-2 Loop#1	17	2 x 3	33.8	69.9	-	-	-	-	**1.9**	**1.4**	-	-	-	-	**4.0**	**2.9**
17-2 Loop#2	17	1 x 3	27.6	44.0	-	**3.7**	**2.7**	**2.1**	-	-	-	**6.0**	**4.3**	**3.3**	-	-
17-2 Loop#3	17	2 x 3	47.4	71.2	-	-	-	-	**2.7**	**2.0**	-	-	-	-	4.1	**3.0**
17-2 Loop#4	17	1 x 3	22.2	46.5	-	**3.0**	**2.2**	**1.7**	-	-	-	**6.3**	**4.5**	**3.5**	-	-
17-3 Loop #1 $*_5$	17	1 x 3	49.8	100.0	-	**6.7**	**4.9**	**3.8**	-	-	-	**13.5**	**9.7**	**7.6**	-	-
17-3 Loop #2 $*_5$	17	2 x 3	73.6	136.7	-	-	-	-	**4.2**	**3.1**	-	-	-	-	**7.8**	**5.7**
17-3 Loop #3 $*_5$	17	1 x 3	62.1	89.5	-	**8.4**	**6.0**	**4.7**	-	-	-	**12.1**	**8.7**	**6.8**	-	-
17-3 Loop #4 $*_5$	17	2 x 3	95.3	134.4	-	-	-	-	**5.4**	**4.0**	-	-	-	-	**7.7**	**5.6**

F.S. Is below 2

F.S. Is below 4

Table 15(b). Safe Working Lifting Loads for Current IDOT Design Specification ABD Memorandum 07.2

Loop ID	Depth of Beam	# Loops x # Strands per Loop	Adjusted Test Vertical Load (multiplied by 0.73) $*_5$: First Cracking	Adjusted Test Vertical Load (multiplied by 0.73) $*_5$: Ultimate	Calculated F.S. (Cracking) 17 x 48 **	21 x 48 **	27 x 48 **	33 x 48 ***	42 x 48 ***	Calculated F.S. (Ultimate) 17 x 48 **	21 x 48 **	27 x 48 **	33 x 48 ***	42 x 48 ***
Maximum Self-Weight of Beam (kips)*					30	41	53	70	96	30	41	53	70	96
Demand Per Loop Based on Equal Share on Four Loops (kips)					7.4	10.3	13.2	17.5	23.9	7.4	10.3	13.2	17.5	23.9
17-3 Loop #1 $*_5$	17	1 x 3	36.4	73.0	**4.9**	**3.5**	**2.8**	-	-	**9.9**	**7.1**	**5.5**	-	-
17-3 Loop #2 $*_5$	17	2 x 3	53.7	99.8	-	-	-	**3.1**	**2.2**	-	-	-	**5.7**	**4.2**
17-3 Loop #3 $*_5$	17	1 x 3	45.3	65.4	**6.1**	**4.4**	**3.4**	-	-	**8.9**	**6.4**	**5.0**	-	-
17-3 Loop #4 $*_5$	17	2 x 3	69.5	98.1	-	-	-	**4.0**	**2.9**	-	-	-	**5.6**	**4.1**

F.S. Is below 2

F.S. Is below 4

* Beam weights derived from ABD Memorandum 08.2, neglecting solid beam regions, i.e. end blocks, transverse ties, diaphrams

** Beams weighing under 60 kips need 2 loops in each end of beam (ABD Memorandum 07.2)

*** Beams weighing over 60 kips need 4 loops in each end of beam (ABD Memorandum 07.2)

$*_4$ 17-1 lifting loops represent the lifting loop design prior to ABD Memorandum 07.2 and thus should be compared to gross beam weights below 40,000 lb

$*_5$ The presented F.S. for the 17-3 test results should be multiplied by 0.73 to project down to the results for a test on a 5000 psi specimen.

CHAPTER 5 RESULTS FROM STRAND RUPTURE EXPERIMENTS

5.1 TYPICAL BEHAVIORS IN STRAND RUPTURE EXPERIMENTS

A series of 10 strand rupture tests were conducted using a MTS 600 kip uniaxial testing frame. This section briefly describes these tests and their results.

Initially, the lifting loops deformed and attempted to straighten out under very little load, similar to that observed in the deck beam tests. Once the wires and strands were fully engaged, the initial stiffness of the lifting loop was very similar to that of the deck beam lifting loops. Concrete splitting failures were prevented by casting these strands deeply into heavily confined concrete. Consequently, in all cases, the capacity of these loops was controlled by the strands' rupturing as was the intent of this segment of the research program.

After the strands were fully engaged, a load was reached where typically one of the wires in a seven wire strand would rupture with an associated drop in load of approximately 10 kips. This point was defined as the strand rupture serviceability limit. The rupture of the first strand was the result of a stress concentration, in which the wire was being pinched around the lifting mechanism. After the first wire ruptured, the response of the lifting loops were quite different depending on such factors as the presence of an offset between the strands, the presence of thin walled conduit, and the shape of the lifting device.

The test matrix and loads at first wire rupture and maximum are presented in Table 16. This is followed by a discussion of the influence of key test variables on the observed response.

Table 16. Strand Rupture Test Results Summary

Test ID	# Strands	Pipe	Offset	Angle of Pull	Lifting Mech.	Diagonal Load		Vertical Load		Test Date
						First Wire Rupture (kips)	Max Load (kips)	First Wire Rupture (kips)	Max Load (kips)	
1A-1	1	None	uniform	60	2" Pin	64.1	64.1	55.5	55.5	6/13/2008
1B-1	2	None	uniform	60	2" Pin	103.0	103.0	89.2	89.2	6/13/2008
1C-1	3	None	uniform	60	2" Pin	69.5	128.6	60.2	111.4	6/13/2008
1Co-1	3	None	offset*	60	2" Pin	61.9	69.0	53.6	59.8	6/13/2008
2C-2	3	None	uniform	60	Hook	71.9	90.3	62.3	78.2	6/16/2008
2Co-1	3	None	offset*	60	Hook	46.2	72.3	40.0	62.6	6/16/2008
2A-1	3	1.25" dia. Conduit	uniform	60	2" Pin	146.5	163.2	126.9	141.3	6/13/2008
2A-2	3	1.25" dia. Conduit	uniform	60	2" Pin	-	157.0**	-	136.0**	6/16/2008
2B-1	3	1.25" dia. Conduit	uniform	60	Hook	90.3	107.6	78.2	93.2	6/17/2008
2B-2	3	1.25" dia. Conduit	uniform	60	Hook	102.1	102.6	88.4	88.9	6/17/2008

* Each of the three strands is offset by 0.0", 0.5", and 1.0" respectively

** Not a single wire ruptured during this test

5.1.1 Number of Strands

The number of strands in a lifting loop was observed to have little effect on when the first wire would rupture. This was as expected due to the sensitively of load share to the uniformity of the length of strands in a lifting loop. After the first wire ruptured, additional displacement occurred and redistributed the force to the remaining wires. As load was increased, additional wires were observed to typically break one at a time, but sometimes two or three would snap at a given load. As more wires ruptured, the displacement needed to break the next wire usually increased due to less pinching between the wires.

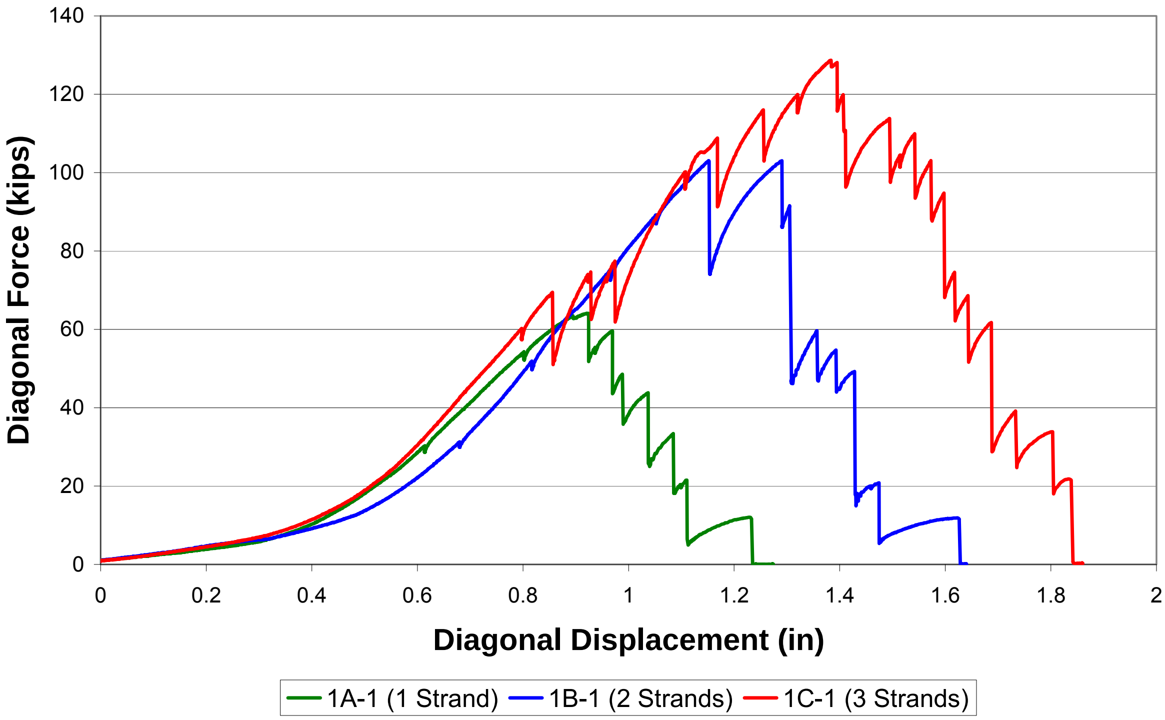


Figure 21. Strand rupture results for lifting loops made from 1, 2, and 3 strands.

5.1.2 Role of Conduit

A significant increase in performance was observed when the strands in a lifting loop were encased within a short length of thin walled electrical conduit. The conduit does not increase the capacity directly; however, it ensures that the strands in the lifting loop are of similar shape and constrained to produce a more uniform engagement of the strands. Since the distribution of lifting force between the strands was more even, the first wire would break closer to the ultimate capacity of the lifting loop, thus increasing the serviceability limit state for strand rupture type failures. It may be hypothesized that the large stress concentration at the lifting mechanism interface was deforming and stressing the conduit, while evenly distributing the overall lifting force to the strands.

5.1.3 Offset between Strands

The offset, or difference in length between the protruded strands, was observed to strongly influence the behavior. When there was a significant offset between the strands in a lifting loop, nearly all of the load was supported by one strand and the behavior was similar to a single strand lifting loop whereby the ultimate load was only a little above that at which the first wire ruptured, and there was a plateau in the overall response. The lifting pin would cause all of the strands in the first loop to rupture and then proceed to rupture the strands in the next shortest strand. This type of behavior was observed when only a 0.5 inch offset was present between the strands, thus proving that the alignment of lifting loop strands is very important. It should be noted that the circumferential distance of the part of the strands that protruded above the concrete surface was only about 12-16 inches (1:1 ratio of width to height), which did not provide sufficient ductility for load sharing between offset strands, as was observed in this testing program.

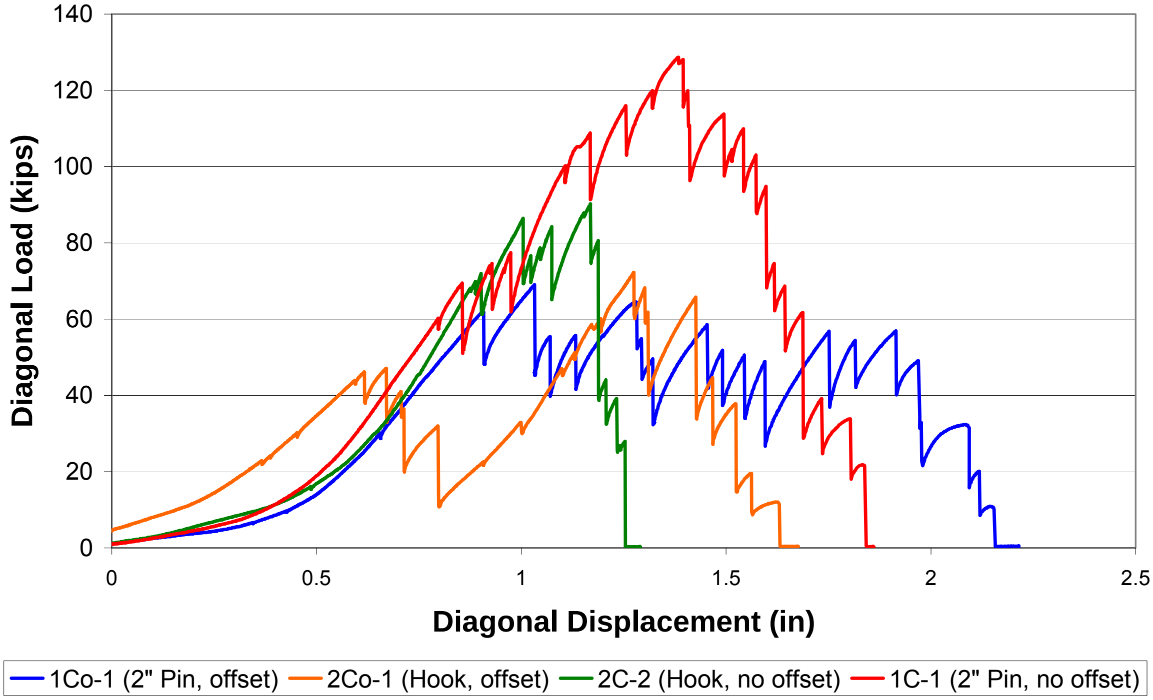


Figure 22. Strand rupture results for lifting loops with and without an offset between adjacent strands.

5.1.4 Lifting Mechanism

The shape of the contact surface between the lifting device and the strands (2-inch diameter pin or hook) significantly affected the serviceability limit state of a lifting loop as well as its ultimate capacity. A hook-type lifting mechanism usually has a flat contact surface and thus creates a sharp bend in the strand. This flat surface was observed to lead to pinching of the strands on both sides of the contact surface. This pinching was more severe than with the use of a round lifting pin for which there is a stress concentration at the very top of the pin. Thus, the serviceability limit state occurred at a lower load when a hook was used. The shape of the lifting mechanism had a very dramatic effect on capacity of the lifting loop as summarized in Table 16 and presented in Figure 23. Table 16 also demonstrates that the performance of a loop improved when lifted by the pin rather than the hook (even with conduit).

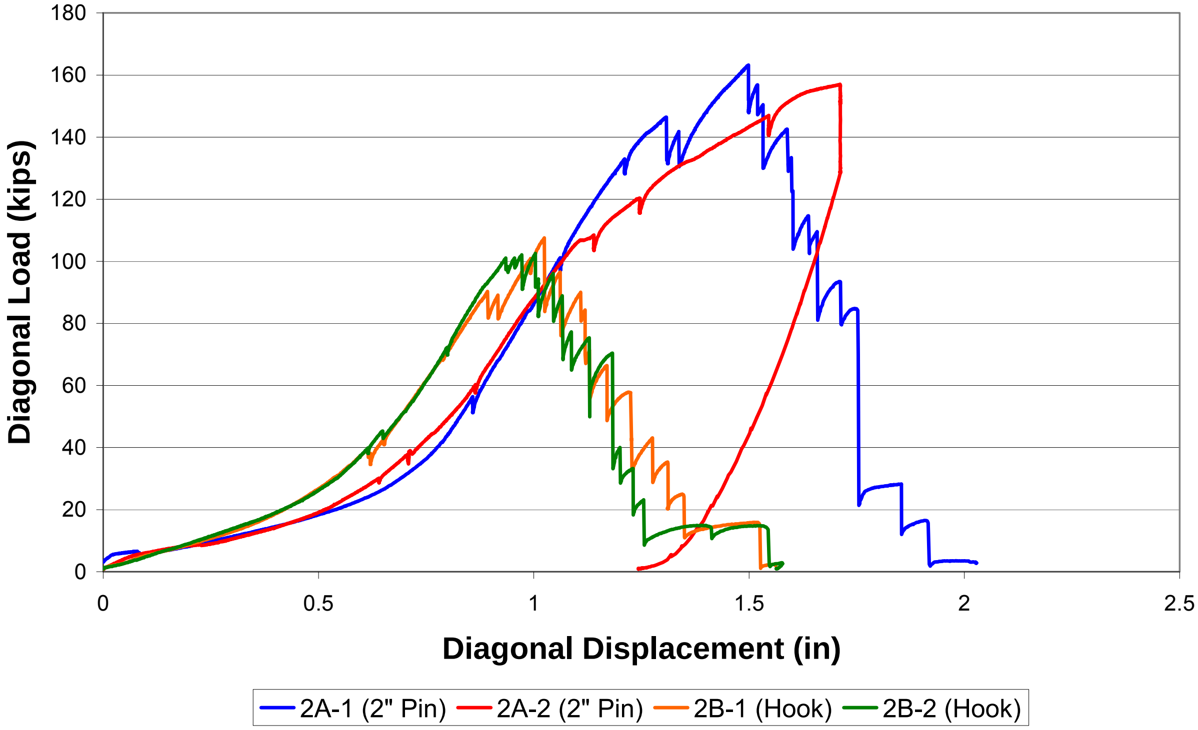


Figure 23. Strand rupture results for lifting loops loaded with a 2-inch pin and hook.

5.2 SUMMARY, DISCUSSION, AND IMPLICATIONS OF RESULTS

The results from the strand rupture tests are summarized in Table 16. The first three specimens were constructed to investigate the benefit of using multiple strands in a lifting loop. Tests were conducted with one, two, and three strands, and their corresponding vertical ultimate loads were 55.5, 89.2, and 111.4 kips respectively. As expected, it is clear from these tests that adding strands increases the strand rupture capacity of a lifting loop when similar shaped strands are used.

The results from the tests with the lifting hook indicate that a hook induces a larger stress concentration around the strands. This leads to lower loads at which an individual wire will rupture as well as much lower strand rupture capacities in comparison to those observed for when a two-inch-diameter pin was used. Since the curvature at the edge of a hook is tighter than when a pin of sufficient capacity is used, it is expected to always induce a greater stress concentration, one on either side of the contact surface. Therefore, using a hook is expected to always lead to poorer performance than when a suitable pin is used. It is difficult to control what type of device will be used to lift the beam throughout its lifespan and thus it is appropriate to be conservative in assessing the safe working load from tests in which a hook was used.

The presence of an offset plays a significant role in the behavior of a lifting loop. It should be noted that the ability of an offset strand to deform is a function of the total length of strand that extends out of the concrete. In the case of these tests, the strands were bent about a 6-inch diameter and maintained a 1:1 ratio of height to width. Therefore, approximately 12 inches of strand extended beyond the surface of the concrete. In this situation, the total elongation of the strand associated with a small strain was not sufficient to ensure engagement of multiple strands before wires broke in the shortest strands. This was well illustrated by the two tests that were constructed with offset strands. The first wire broke at 61.9 and 46.2 kips in these two tests; the single strand test had a wire break at 64.1 kips. However, the ultimate loads for the two offset tests were 69.3 and 72.3 kips, which is no better than that for a single strand lifting loop. The effect of an offset suggests that having uniform strands is critical for obtaining the desired capacity from multiple strand loops. The use of a thin-walled electrical conduit was observed to provide an effective way to ensure that all strands will be of similar length and sufficiently engaged in the lifting process. This can be achieved by bending all of the strands at the same time within the conduit. The results from the specimens with conduit suggest that all three strands were close to fully engaged prior to failure, with the exception of the specimens that were conducted with a hook. In particular, specimen 2A-1 achieved a first wire rupture load of 146.5 kips which has a factor of 2.3 times greater than a single strand.

CHAPTER 6 SUGGESTIONS FOR PRACTICE

6.1 ASSESSMENT OF IDOT PRACTICE AND SUGGESTIONS

Towards the end of this research project, an ABD Memorandum 07.2 was published with new lifting loop requirements, as presented in Figures 24 and 25. These can be directly compared to the 2003 IDOT Prestressed Concrete Manual requirements that were presented in Figures 7 and 8. There were several changes in requirements between the 2003 IDOT Prestressed Concrete Manual and 2007 ABD Memorandum 07.2, which were informed in part by results from earlier tests in this research program.

The minimum angle of lift was increased from 45 degrees to 60 degrees. The minimum embedment depth of lifting loops in 11-inch-deep beams was decreased from 8 to 7 inches, and the minimum embedment depth of lifting loops in 17-inch-deep beams was decreased from 14 to 13 inches. The “Lifting Loop Detail” in Figure 24 indicates that a 1.25-inch diameter conduit is required. Additionally, in accordance to the ABD Memorandum 07.2, all lifting loops are now to be placed 15 inches from the end of the beam. This is different from the 2003 IDOT Prestressed Concrete Manual which required that lifting loops be placed in the middle of the end block region which could have been as small as 18 inches long and resulted in the lifting loop being placed at 9 inches from the end of the beam. Additionally, the ratio of the height of the lifting loop (distance of the lifting loop that extends out of the concrete) to the width between the two legs has been specified as 1:1 in the ABD Memorandum 07.2. By comparison, in the earlier 2003 IDOT Prestressed Concrete Manual, as long as the minimum embedment was satisfied, the minimum height of the lifting loop was 4 inches.

Perhaps the most significant change between the 2003 and 2007 requirements is the number of required stands per lifting loop and number of lifting loops in a corner of a beam. The 2003 Prestressed Concrete Manual specifies that four loops should be placed in all beams, one in each corner, where the number of strands in each loop is specified as a function of the gross weight. For beams weighing 40,000 pounds or less, two strands are sufficient; whereas for beams weighing between 40,000 and 60,000 pounds, three strands would be needed for all lifting loops. In accordance with the ABD Memorandum 07.2, three strands are required for all lifting loops, regardless of the gross weight. The number of lifting loops required in each corner is specified according to the gross weight. For example, if a beam weighs 60,000 pounds or less, four lifting loops, one in each corner, made from three 0.5-inch diameter strands are required. If a beam weighs between 60,000 and 120,000 pounds, then eight lifting loops are required, two in each corner.

Based on the results from the strand rupture tests that were presented in Table 16, and using a factor of four against rupture, the measured safe working load of a single three-strand loop (with a conduit and assuming the more severe case of a lift with a hook) is 22 kips. Since this is greater than the IDOT working load capacity of 15 kips, the strand rupture test results support the ABD Memorandum 07.2 requirements.

Table 14 presented the measured safe working loads from the lifting loop deck beam tests. These loads were calculated using a factor of safety of two against cracking (serviceability state) and four against failure (ultimate limit state). The results from these tests are now used to assess the safety of the IDOT specified working load capacities. This will be done separately for single three-strand loops (specified 15 kip working load capacity) and dual three-strand loops (specified 30 kip working load capacity).

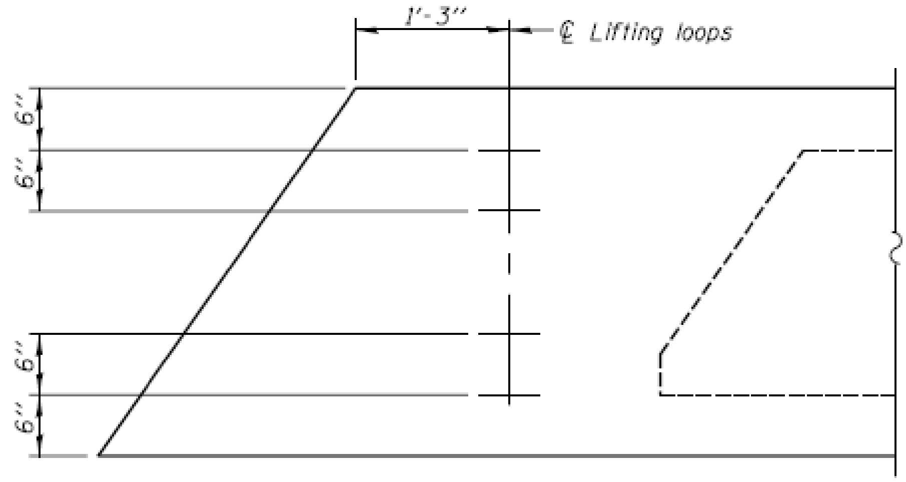
6.1.1 Working Load Capacity of a Single 3 Strand Loop (1 x 3)

ABD Memorandum 07.2 specifies that the working load capacity of a single three strand loop is to be taken as 15 kips. The safety of this limit can be evaluated using the results from the 17-3 deck beam tests in which the requirements of this memorandum were met. The minimum measured cracking load from the 17-3 deck beam tests was 49.8 kips which provides a safe working vertical load capacity of 24.9 kips when a factor of safety of two is used for serviceability. The minimum measured ultimate capacity was 89.5 kips which provides a safe working vertical load capacity of 22.4 kips when a factor of safety of four is used against failure. Since these two quantities are both greater than the 15 kips given in this memorandum, even after proration by the square root of f'_C to a 5000 psi concrete, the working load capacity as specified in ABD Memorandum 07.2 for members weighing less than 60,000 pounds is deemed to be conservative.

6.1.2 Working Load Capacity of Two 3 Strand Loops (2 x 3)

ABD Memorandum 07.2 specifies that the working load capacity of a configuration of two three-strand loops is to be taken as 30 kips. In the deck beam testing program, four experiments were conducted where there were configurations of two loops with three strands. In two of these cases, the 2003 IDOT Prestressed Concrete Manual details were used and thus the placement geometry did not satisfy the ABD Memorandum 07.2 requirements. In the other two cases, these requirements were satisfied and the minimum measured working load capacity was 33.6 kips (ultimate / 4). Since this test result was from a 9279 psi concrete, then the capacity prorated by the square root of the compressive strength for a 5000 psi concrete would be 25 kips. This would provide a factor of safety of at least 4 for all members weighing up to 100 kips for a 13-inch embedment.

Members that would be greater than 100 kips would be required by IDOT ABD Memorandum 07.2 to have an embedment depth of at least 38 inches. As illustrated in Table 8, the load carrying capacity was measured to increase significantly with embedment. It is therefore expected that since a 25 kip load carrying capacity was obtained with a 13-inch embedment in a 17-inch deep beam, a 30 kips load carrying capacity would be achieved when a 38-inch embedment depth was used. Thus, and based on the presented deck beam test results, the ABD Memorandum 07.2 is considered to be conservative for members weighing between 60,000 and 120,00 pounds when a factor of safety of 4 for ultimate and 2 for service is used.



PLAN VIEW
(Showing lifting loop locations)

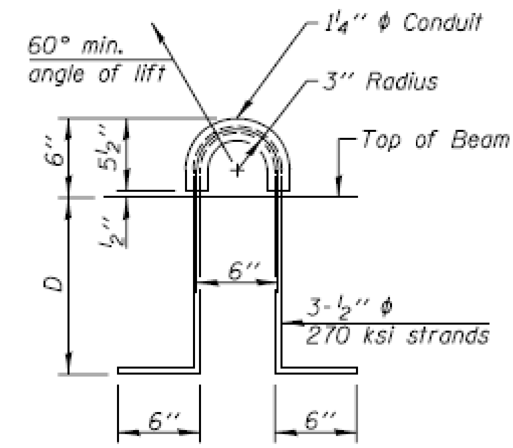
TABLE A

Beam	Net Weight (lbs/ft)	Solid Weight (lbs/ft)	D
11x48	-	535	7''
11x52	-	580	7''
17x36	492	621	1'-1''
17x48	642	834	1'-1''
21x36	550	771	1'-5''
21x48	708	1033	1'-5''
27x36	594	986	1'-11''
27x48	731	1323	1'-11''
33x36	669	1211	2'-5''
33x48	806	1623	2'-5''
42x36	781	1548	3'-2''
42x48	919	2073	3'-2''

TABLE B

No. of loops each end of beam	Gross wt. of beam (lbs)
2*	60000
4	120000

* Use outermost lifting loop locations



LIFTING LOOP DETAIL

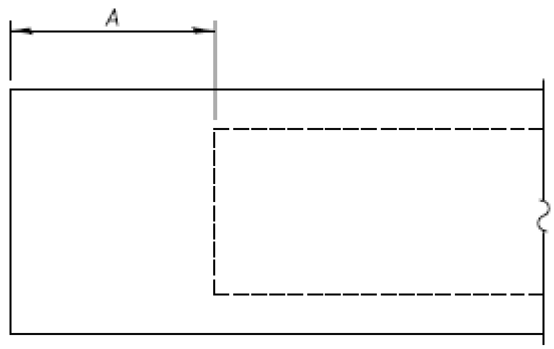
Note:

Table A provides the lifting loop embedment depth and the weights of the net and solid sections of the beam used to calculate the gross weight of the beam.

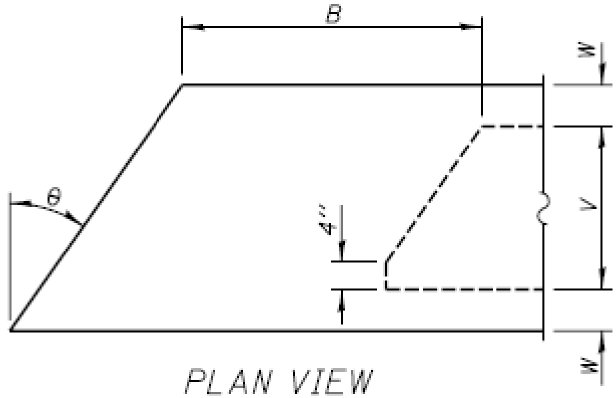
Table B shows the number of lifting loops required at each end of the beam.

LIFTING LOOP
FOR DECK BEAMS

Figure 24. ABD Memorandum 07.2 – lifting loop for deck beams (2007).



PLAN VIEW
(No skew)



PLAN VIEW
(Skewed)

DIMENSIONS TABLE

Beam	A (in.)	W (in.)	V (in.)
11x48 ; 11x52	-	-	-
17x36	30	7	22
17x48	30	8	32
21x36	30	7	22
21x48	30	8	32
27x36	30	6	24
27x48	30	6	36
33x36	36	6	24
33x48	36	6	36
42x36	42	6	24
42x48	42	6	36

Note:
For skewed deck beams, dimension B, in inches, is the larger of the following two equations:

$$B = \frac{A}{\cos\theta} - W(\tan\theta)$$

$$B = 27 + V(\tan\theta)$$

END BLOCK DETAILS

Figure 25. ABD Memorandum 07.2 – end block details (2007).

CHAPTER 7 SUGGESTIONS FOR FUTURE RESEARCH

This research examined the performance and capacity of lifting loops that were embedded 6 to 13 inches deep in precast deck beams and located within 3 to 6 inches of the side of beams. The loops were all anchored with 6-inch extensions on approximately 90 degree bends and had straight legs spaced on 6 inches that either ran parallel into the beams or were tied together at their base. Two or three strands were located in each lifting loop, and one or two lifting loops were used in each corner of the deck beam. The angle of pull on the lifting loops ranged from 45 to 60 degrees. A series of experiments were also conducted to evaluate the influence of key factors on the strand rupture capacity of loops, including the number and uniformity of strands, the use of a conduit to constrain strands, and the shape of the contact point of the lifting device. These experiments were selected to investigate the influence of key parameters that encompassed current, suggested, and potentially unconservative fabrication practices. A total of 16 pullout tests were conducted on lifting loops cast in deck beams, and 10 tests were conducted to investigate strand rupture failures.

The suggestions for practice presented in Chapter 6 are applicable for the characteristics of the lifting loops used in this study. The following suggestions are made for future investigations.

<u>Mesh Reinforcement:</u> It is hypothesized that an L-shaped segment of mesh reinforcement placed along the side and across the top of deck beams in the vicinity of lifting loops would significantly reduce the extension of cracking and would be worthwhile to investigate.

<u>Placement of Lifting Loops:</u> Lifting loops placed near the corners of deck beams are susceptible to earlier cracking, and this cracking leads to the type of concrete splitting driven failures that were observed throughout this research program. If the width of the beam permits, then an increase in side cover is expected to lead to an increase in both serviceability and ultimate strengths. This should be investigated if current capacities prove inadequate for future heavier members.

<u>More Extensive Parametric Study:</u> As described in this report, the breadth of the parametric study on lifting loops in deck beams was limited. Consequently, the examination of the influence of a key variable was often coupled with other variations in the testing program which made it less clear that the effect of the one variable was fully assessed. The depths of test specimens and embedment were also limited, such that the design of lifting loops for deeper members has not yet been fully explored. The effects of other variables such as concrete strength and level of prestressing also still need to be studied.

<u>Fabrication of Lifting Loops:</u> As part of this study, lifting loops were manufactured by three different groups. It became evident that manufacturing specified and uniformly shaped lifting loops requires experience, a standardized procedure, and a jig. The CTA recommendations in section 1.2 presented one such procedure. The use of a conduit or electrical pipe helps ensure that multiple strands within a loop are sufficiently close in overall length so that all strands will adequately share load in the lifting process. An examination and standardization of fabrication procedures would ensure the production of lifting loops that meet specifications.

<u>Pipe Versus Conduit and Contact Surface of Lifting Mechanism:</u> This experimental research program investigated the behavior of lifting loops constrained within thin walled electrical conduits. Fabricators also use heavy schedule 40 pipe to constrain strands in lifting loops. It is not known whether the use of pipe or conduit would better reduce the stress concentrations that the wires are exposed to. These stress concentrations are a function of not only where pipe or conduit is used, but also the number of strands per loop

and more importantly the shape of the contact surface of the lifting device. This would be useful to examine in a larger parametric study on the rupture strength of strands.

Study and Improvement of Handling Practices: The handling practices for beams can impact the demands of lifting loops by a 3 to 1 ratio. The use of appropriate rigging equipment that uniformly distributes the load between all provided loops and that ensures the angles of all pulls are greater than 60 degrees is expected to lead to about one-third of the demand per loop as would be the case when the loading at the end of one beam could be supported entirely by one lifting location and when the angle of lift is at 45 degrees. A better understanding of handling practices would facilitate improved requirements and monitoring procedures.

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APPENDIX A: DECK BEAM TESTS

Summary of 11-1 Deck Beam Tests

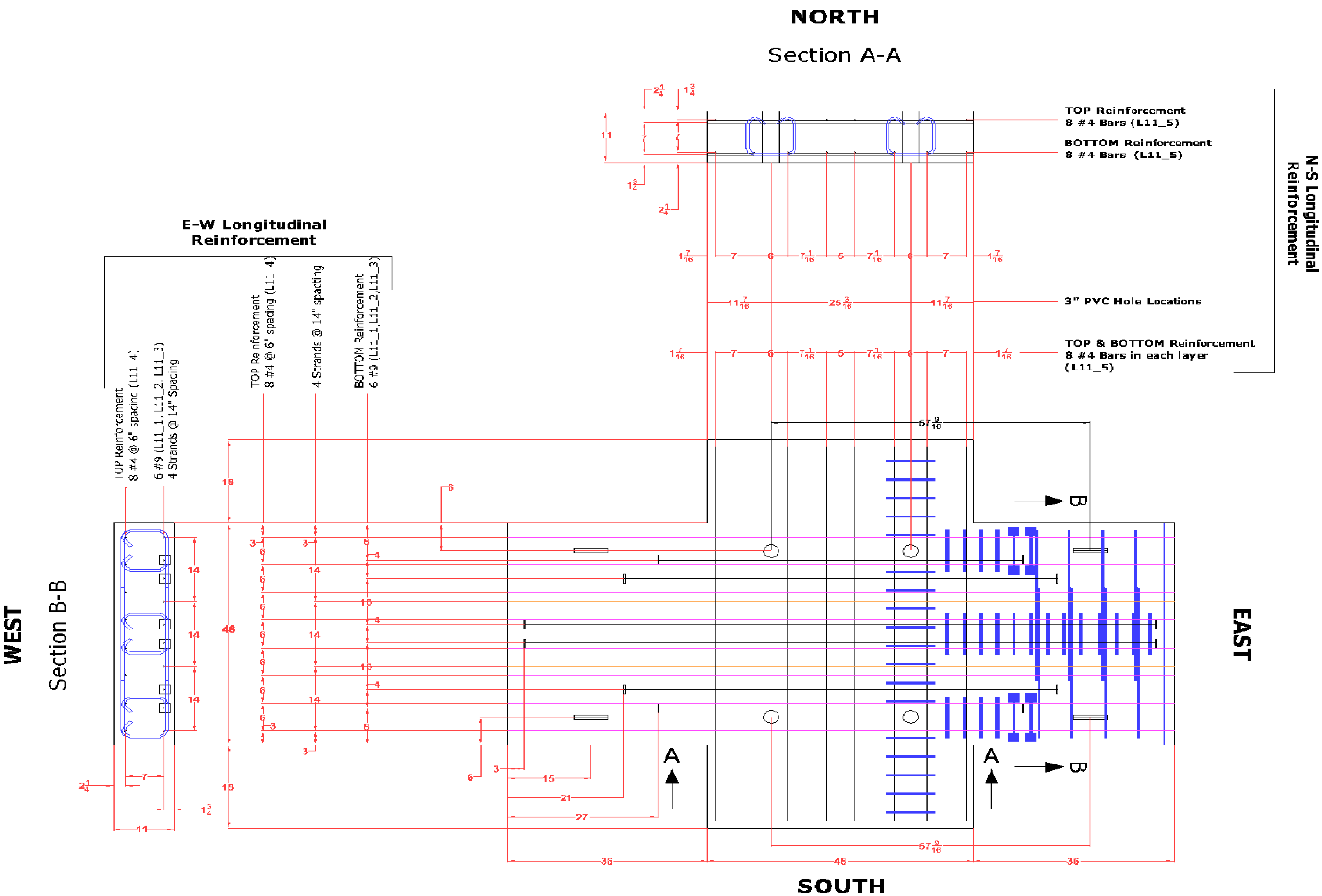
Loop ID	Cast Day	Test Day	Specified Concrete Strength (psi)	Test Day Concrete Strength (psi)	Test Day Tensile Strength (psi)	Beam Depth (in)	Embedment Depth (in)	Actual Embedment Depth (in)	End Block Length (in)	End Distance to Center of Loop (in)	Side Dist. (in)	Actual Side Dist. (in)	Shape	Lifting Loops in a Corner	# Strands / Lifting Loop	Flaring (Degrees)	Lifting Loop Leg with Inward Movement Restrained by U-Bar	Diagonal Load (kips)			Vertical Load (kips)			
																		First Cracking	Wedge Spalling	Ultimate	Angle (degrees)	First Cracking	Wedge Spalling	Ultimate
11-1 Loop #1	7/13/2007	10/15/2007	4000	4098	427	11	6	5.63 - 6.63	N/A (1'3")	15	3	4.25	Parallel	1	2	0	Inner Leg	26.6	28.4	38.7	45	18.8	20.1	27.4
11-1 Loop #2		10/18/2007 10/24/2007	4000	4106	427	11	6	5.63 - 6.25	N/A (1'3")	15	6	6.06	Parallel	1	2	0	Inner Leg	N/A*	32.5	32.5	45	N/A	23.0	23.0
11-1 Loop #3		8/27/2007 10/10/2007	4000	3970	427	11	6	5.88 - 6.13	N/A (1'3")	15	6	6.25	Tied	1	2	0	Inner Leg	N/A	N/A	30.5	45	N/A	N/A	21.6
11-1 Loop #4		9/12/2007 10/8/2007	4000	4012	427	11	6	6.13 - 6.38	N/A (1'3")	15	3	4.00	Tied	1	2	0	Inner Leg	N/A	N/A	28.7	45	N/A	N/A	20.3

Notes:

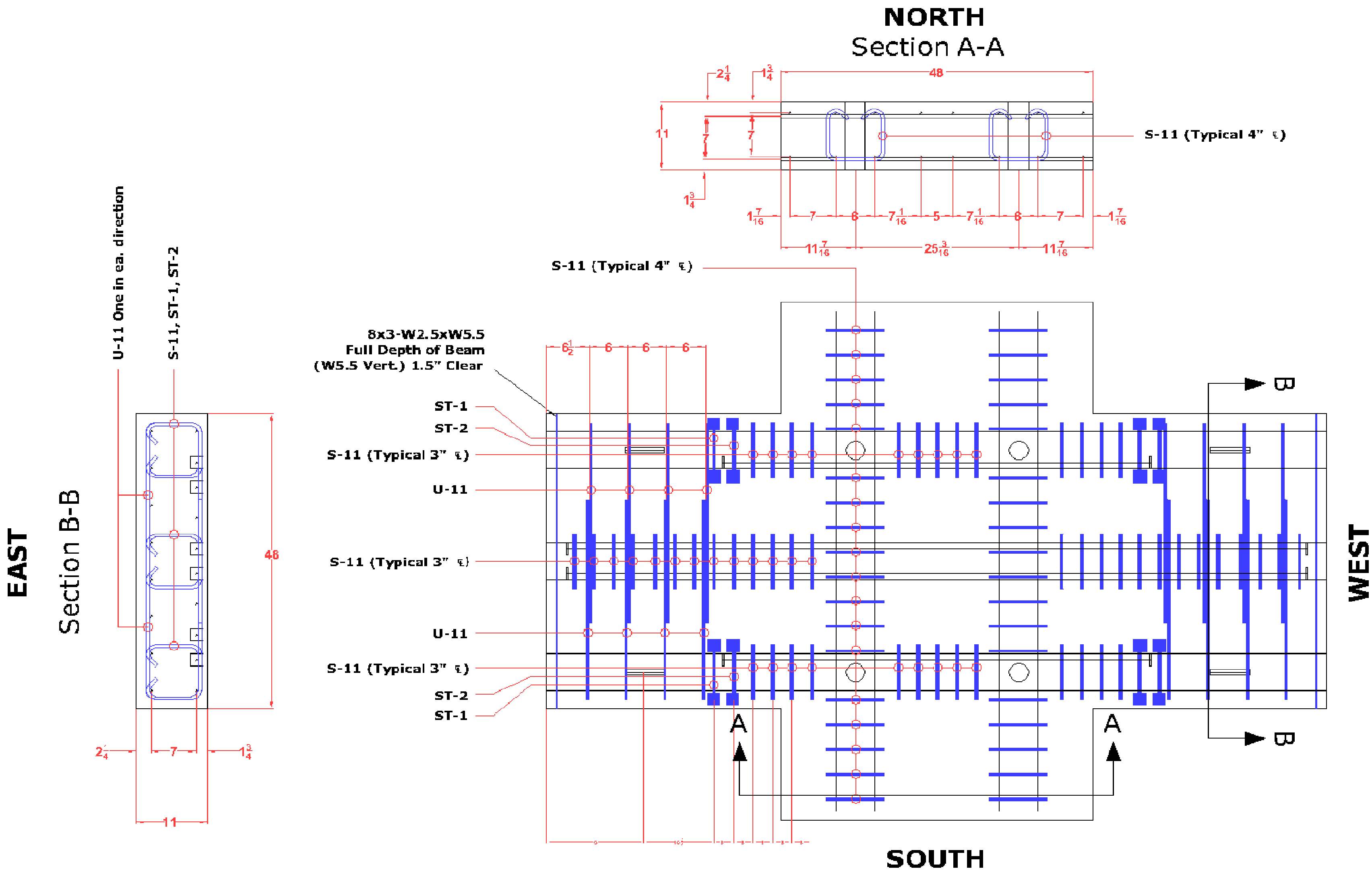
1.) For beams 11-1, 17-1 and 17-2, the angle of pull began at close to 45 degrees but was closer to 50 degrees at the time that the ultimate capacity was realized; it is suggested to consider these to be 45 degree lifts for making a conservative estimates of vertical lift capacity

Mix "A"

Sand (FA-01)	1172	lb
Coarse (Chips CM-16)	1825	lb
Cement	550	lb
Water	29.8	gal
Admixtures		
Air	1.4	oz
WRDA 82	3.5	oz
Properties		
w/c	0.45	
Target Compressive Strength	4000	psi



11-1 Deck Beam Geometry



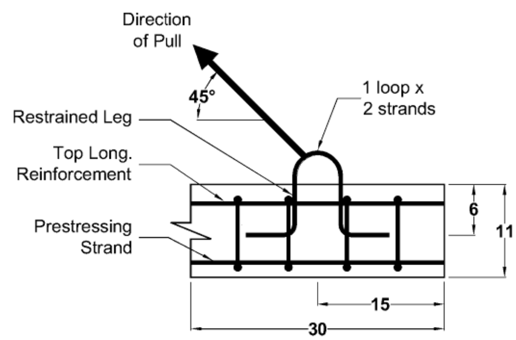
11-1 Deck Beam Geometry

Test ID: 11-1 Lifting Loop #1

11" x 48" Deck Beam
Lifting Angle: 45 degrees
Cast Date: 7-13-2007
Test Date: 10-15-2007

Lifting Loop Characteristics
Embedment Depth 6" (5.63" – 6.50")
1 Loop x 2 Strands
Legs Parallel (Figure 12Figure 11)

Specimen Characteristics
Concrete Mix "A" (C-2)
Concrete Strength 4098 psi
End Block Length N/A
End Distance to Center of Loop 15"
Side Distance 3" (4.25")
One Leg Restrained by U-Bar

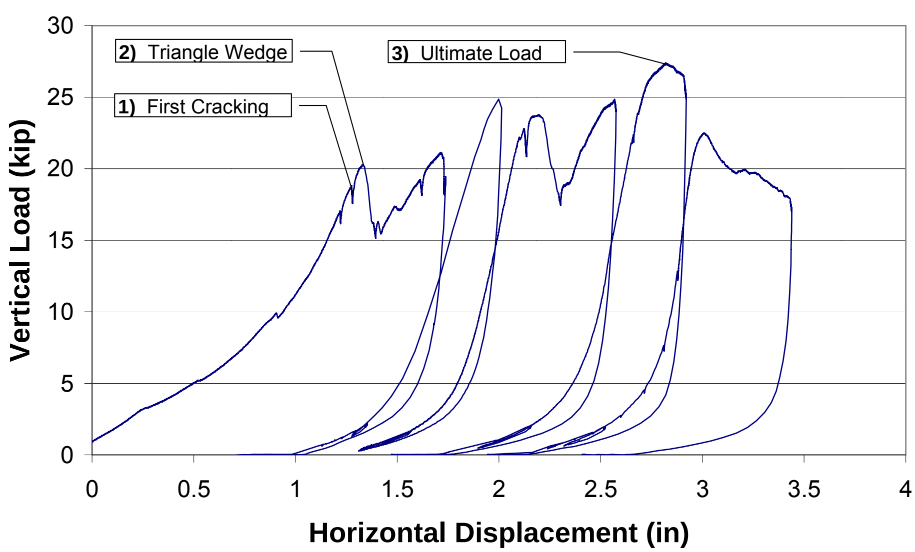


*Please refer to Figure 11Figure 12 for variable definitions

Test Summary

	Load Stage	Diagonal Load (kip)	Vertical Load (kip)
1	First Cracking	26.6	18.8
2	Wedge Cracking	28.4	20.1
3	Ultimate	38.7	27.4

Vertical Load: 11-1 Loop 1



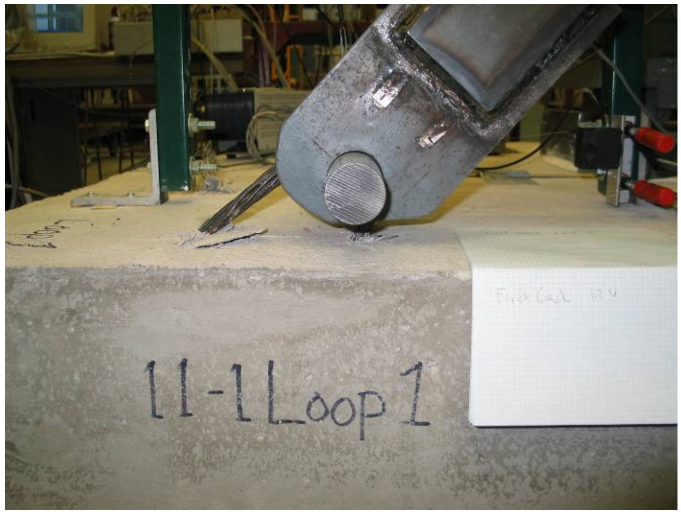


Figure 1: First Cracking (Stage 1)

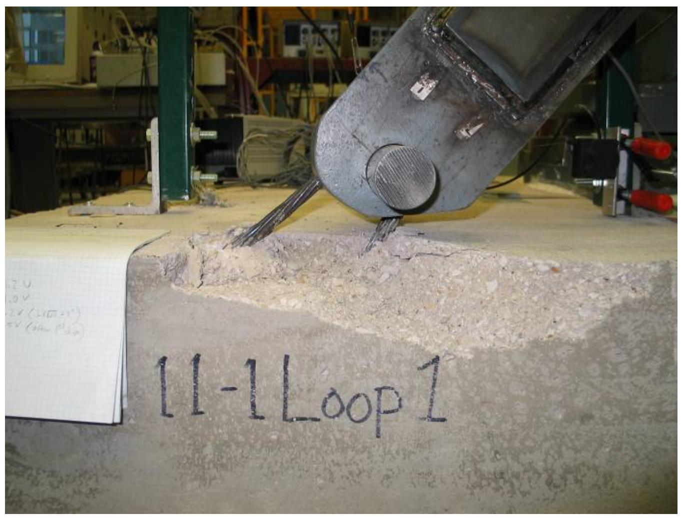
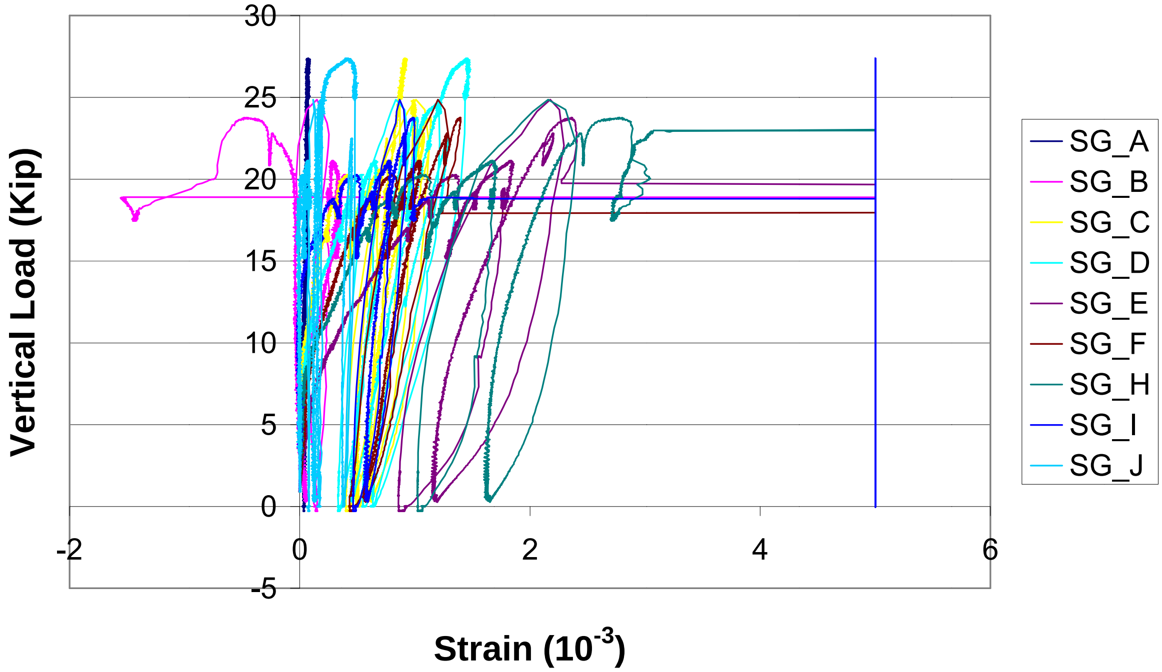


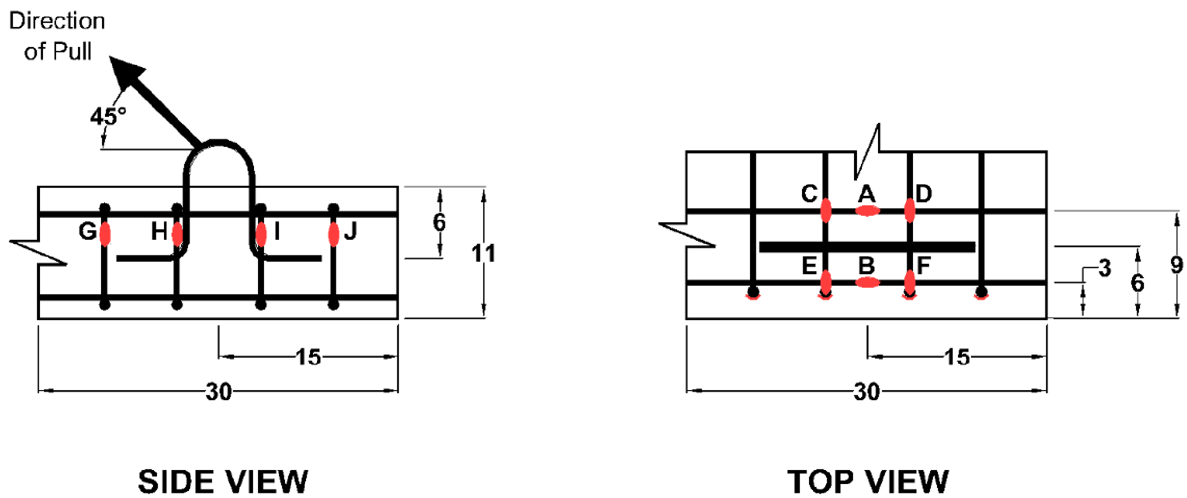
Figure 2: Triangle Wedge Cracking (Stage 2)

Figure 3: Failure (Stage 3)

Strain Gauge Data: 11-1 Loop 1



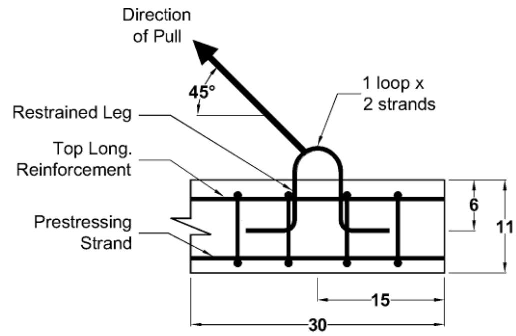
Strain Gauge Orientation Diagram



Test ID: 11-1 Lifting Loop #2

11” x 48” Deck Beam
Lifting Angle: 45 degrees
Cast Date: 7-13-2007
Test Date: 10-18-2007, 10-24-2007

Lifting Loop Characteristics
Embedment Depth 6” (5.63” – 6.25”)
1 Loop x 2 Strands
Legs Parallel (Figure 12Figure 11)



Specimen Characteristics
Concrete Mix “A” (C-2)
Concrete Strength 4106 psi
End Block Length N/A
End Distance to Center of Loop 15”
Side Distance 6” (6.06”)
One Leg Restrained by U-Bar

*Please refer to Figure 11Figure 12 for variable definitions

Test Summary

	Load Stage	Diagonal Load (kip)	Vertical Load (kip)
1	First Cracking	N/A	N/A
2	Wedge Cracking	32.5	23.0
3	Ultimate	32.5	23.0

Vertical Load: 11-1 Loop 2

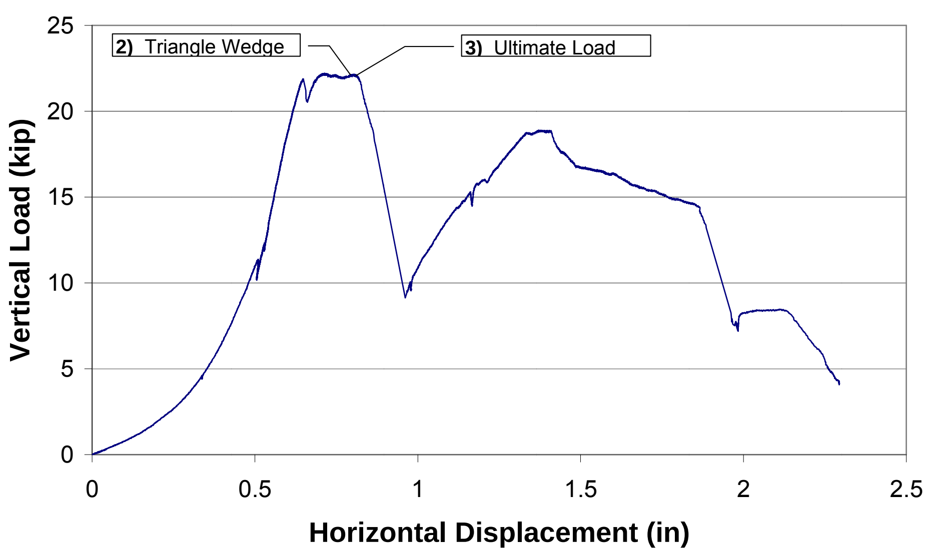
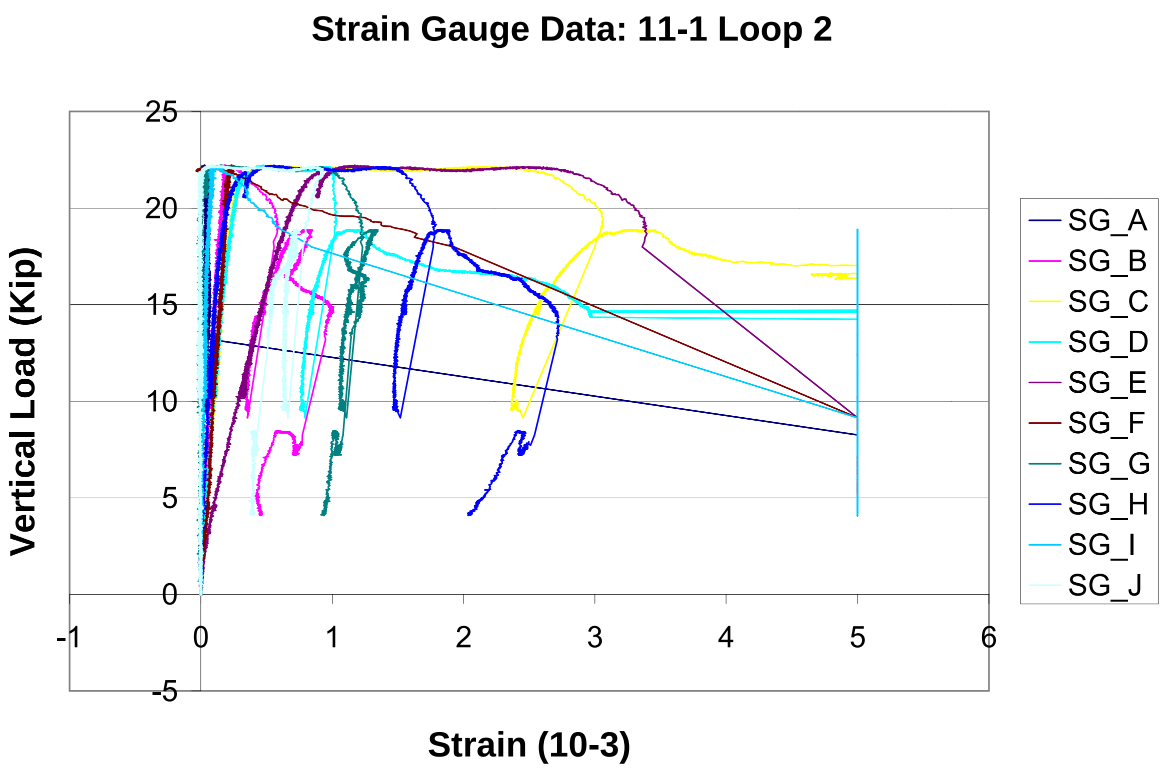
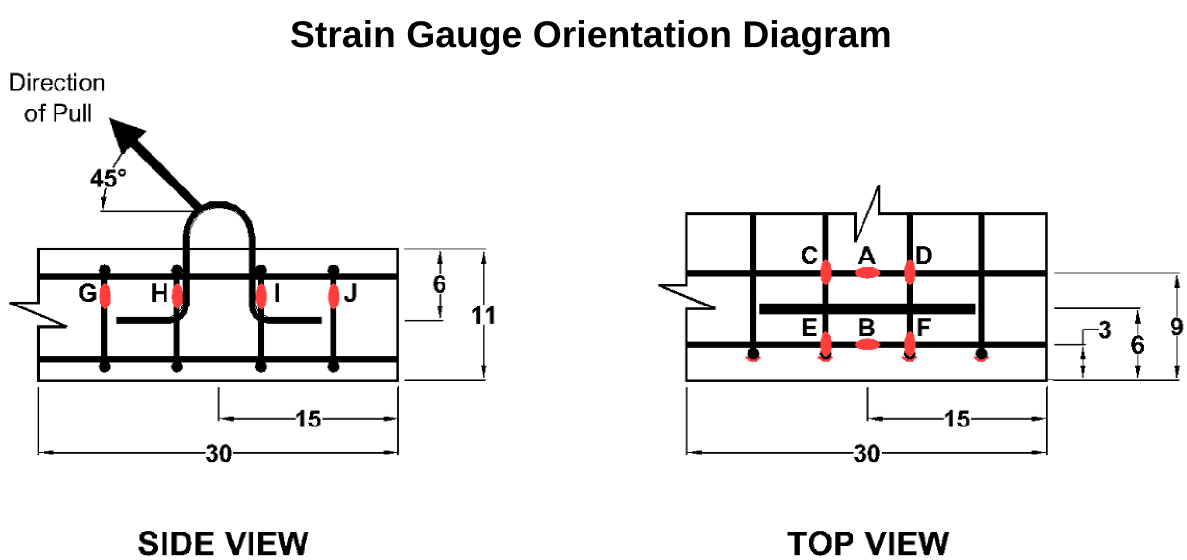



Figure 1: First Cracking (Stage 1)

Figure 2: Triangle Wedge Cracking (Stage 2)

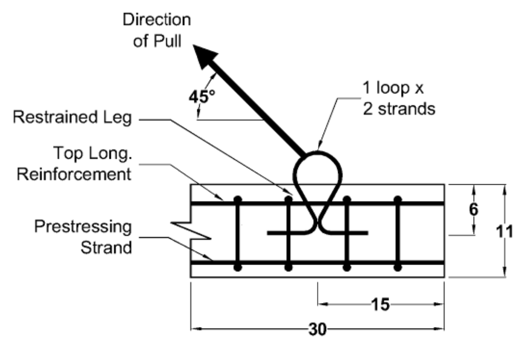

Figure 3: Failure (Stage 3)


Strain Gauge Data: 11-1 Loop 2
Vertical Load (Kip)
Strain (10-3)
25
20
15
10
5
0
-5
-1
0
1
2
3
4
5
6
SG_A
SG_B
SG_C
SG_D
SG_E
SG_F
SG_G
SG_H
SG_I
SG_J


Strain Gauge Orientation Diagram
Direction of Pull
45°
G
H
I
J
6
11
15
30
SIDE VIEW
C
A
D
E
B
F
3
6
9
15
30
TOP VIEW

Test ID: 11-1 Lifting Loop #3

11" x 48" Deck Beam
Lifting Angle: 45 degrees
Cast Date: 7-13-2007
Test Date: 8-27-2007, 10-10-2007



Lifting Loop Characteristics
Embedment Depth 6" (5.88" – 6.50")
1 Loop x 2 Strands
Legs Tied (Figure 12Figure 11)

Specimen Characteristics
Concrete Mix "A" (C-2)
Concrete Strength 3970 psi
End Block Length N/A
End Distance to Center of Loop 15"
Side Distance 6" (6.25")
One Leg Restrained by U-Bar

*Please refer to Figure 11Figure 12 for variable definitions

Test Summary

	Load Stage	Diagonal Load (kip)	Vertical Load (kip)
1	First Cracking	N/A	N/A
2	Wedge Cracking	N/A	N/A
3	Ultimate	30.5	21.6

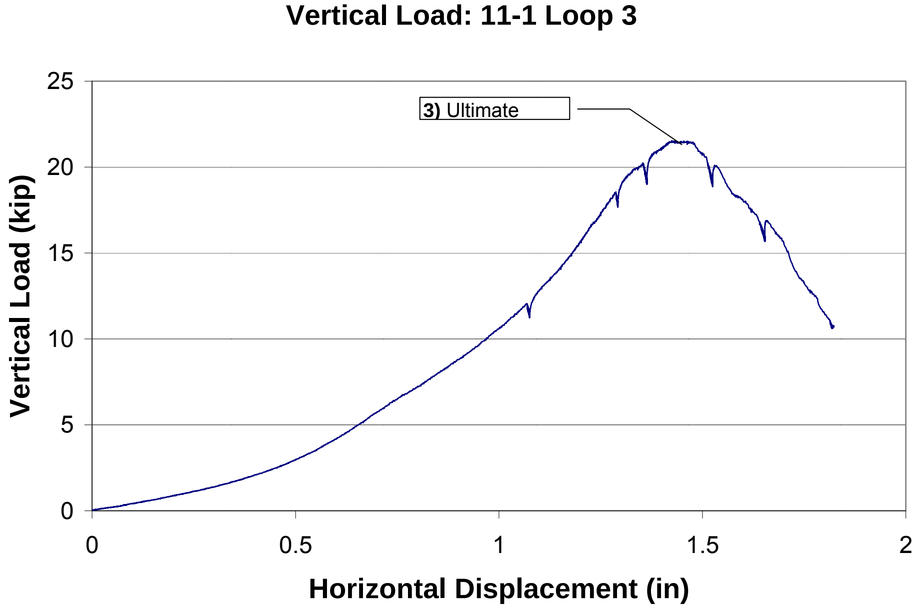


Figure 1: First Cracking (Stage 1)

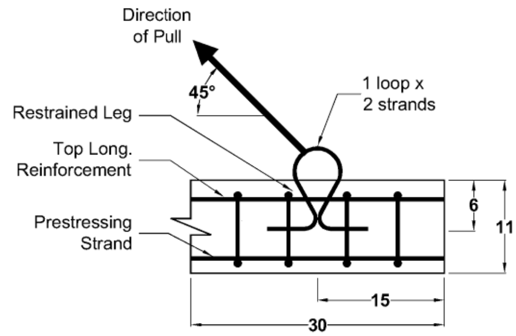
Figure 2: Triangle Wedge Cracking (Stage 2)

Figure 3: Failure (Stage 3)

Test ID: 11-1 Lifting Loop #4

11” x 48” Deck Beam
Lifting Angle: 45 degrees
Cast Date: 7-13-2007
Test Date: 9-12-2007, 10-8-2007

Lifting Loop Characteristics
Embedment Depth 6” (5.88” – 6.13”)
1 Loop x 2 Strands
Legs Tied (Figure 12Figure 11)



Specimen Characteristics
Concrete Mix “A” (C-2)
Concrete Strength 4012 psi
End Block Length N/A
End Distance to Center of Loop 15”
Side Distance 3” (4.0”)
One Leg Restrained by U-Bar

*Please refer to Figure 11Figure 12 for variable definitions

Test Summary

	Load Stage	Diagonal Load (kip)	Vertical Load (kip)
1	First Cracking	N/A	N/A
2	Wedge Cracking	N/A	N/A
3	Ultimate	28.7	20.3

Vertical Load: 11-1 Loop 4

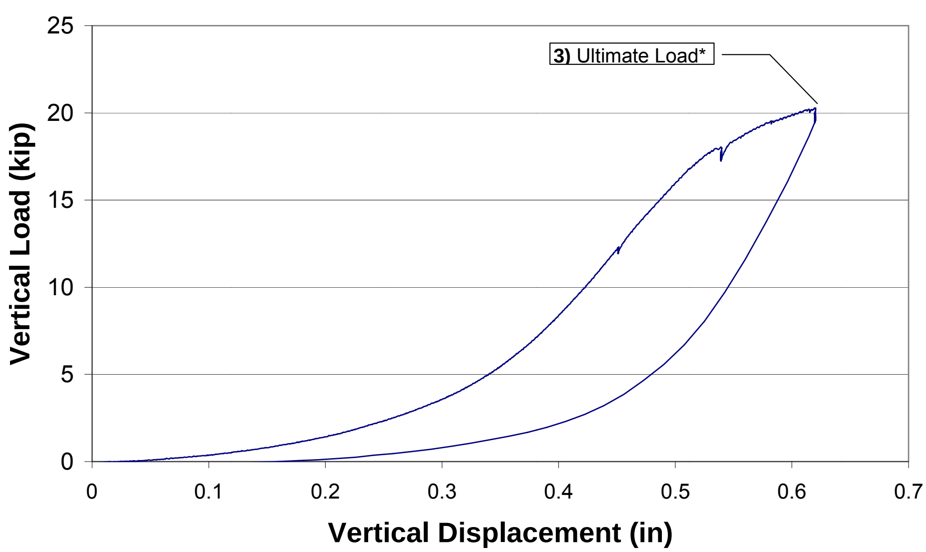


Figure 1: First Cracking (Stage 1)

Figure 2: Triangle Wedge Cracking (Stage 2)

Figure 3: Failure (Stage 3)

Summary of 17-1 Deck Beam Tests

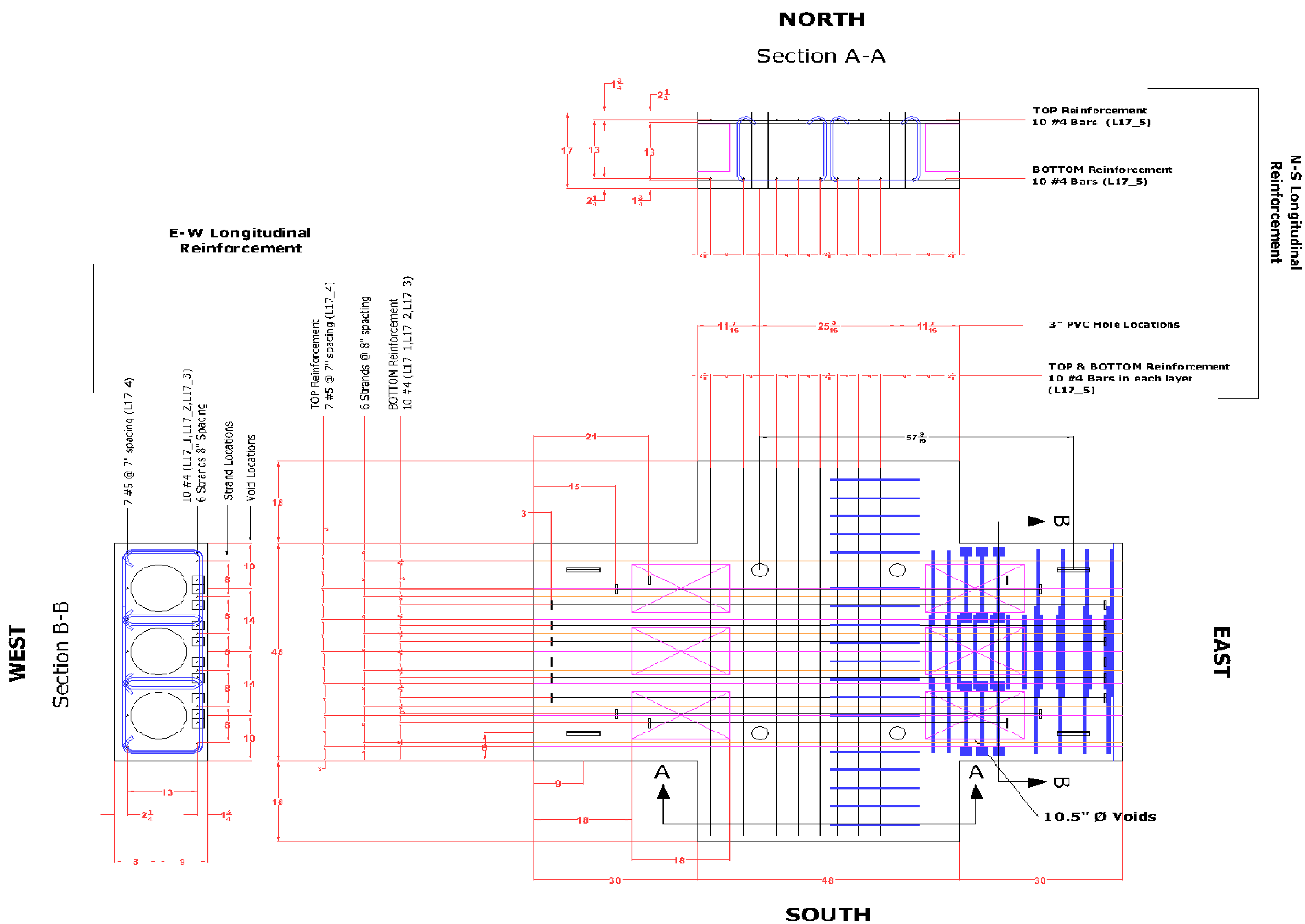
Loop ID	Cast Day	Test Day	Specified Concrete Strength (psi)	Test Day Concrete Strength (psi)	Test Day Tensile Strength (psi)	Beam Depth (in)	Embedment Depth (in)	Actual Embedment Depth (in)	End Block Length (in)	End Distance to Center of Loop (in)	Side Dist. (in)	Actual Side Dist. (in)	Shape	Lifting Loops in a Corner	# Strands / Lifting Loop	Flaring (Degrees)	Lifting Loop Leg with Inward Movement Restrained by U-Bar	Diagonal Load (kips)			Vertical Load (kips)			
																		First Cracking	Wedge Spalling	Ultimate	Angle (degrees)	First Cracking	Wedge Spalling	Ultimate
17-1 Loop #1	8/7/2007	10/30/2007	4000	3934	426	17	12	11.75 - 13.25	18	9	3	3.88	Parallel	1	2	0	Inner Leg	35.5	45.6	49.9	45	25.1	32.2	35.3
17-1 Loop #2		11/1/2007	4000	3941	426	17	12	12.25 - 13.25	18	9	6	6.00	Parallel	1	2	0	Inner Leg	49.1	59.3	59.3	45	34.7	41.9	41.9
17-1 Loop #3		11/8/2007	4000	3965	426	17	12	13.00 - 13.50	18	9	3	3.75	Tied	1	2	0	Inner Leg	28.0	31.4	41.3	45	19.8	22.2	29.2
17-1 Loop #4		11/13/2007	4000	3983	426	17	12	12.50 - 13.00	18	9	6	6.00	Tied	1	2	0	Inner Leg	34.0	40.5	52.6	45	24.0	28.6	37.2

Notes:

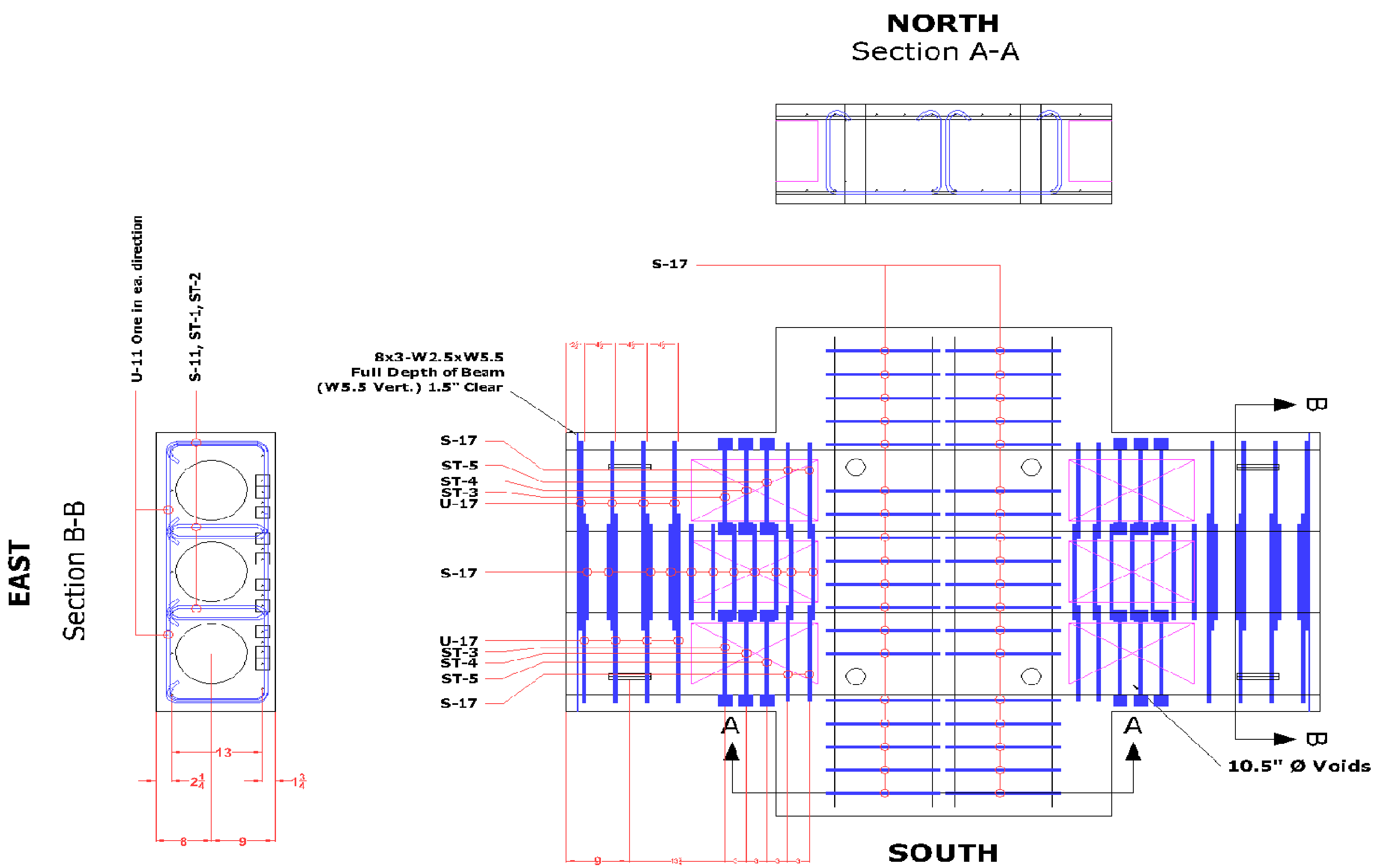
1.) For beams 11-1, 17-1 and 17-2, the angle of pull began at close to 45 degrees but was closer to 50 degrees at the time that the ultimate capacity was realized; it is suggested to consider these to be 45 degree lifts for making a conservative estimates of vertical lift capacity

Mix "A"

Sand (FA-01)	1172	lb
Coarse (Chips CM-16)	1825	lb
Cement	550	lb
Water	29.8	gal
Admixtures		
Air	1.4	oz
WRDA 82	3.5	oz
Properties		
w/c	0.45	
Target Compressive Strength	4000	psi



17-1 and 17-2 Deck Beam Geometry

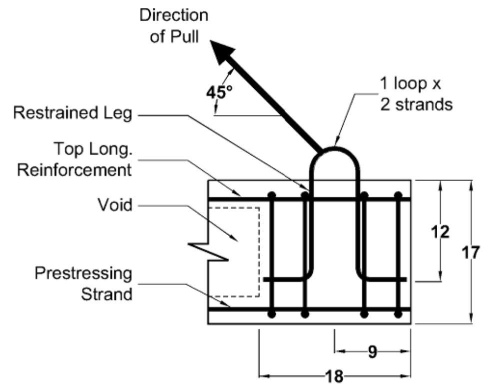


17-1 and 17-2 Deck Beam Geometry

Test ID: 17-1 Lifting Loop #1

17” x 48” Deck Beam
Lifting Angle: 45 degrees
Cast Date: 8-7-2007
Test Date: 10-30-2007

Lifting Loop Characteristics
Embedment Depth 12” (11.75” – 13.25”)
1 Loop x 2 Strands
Legs Parallel (Figure 12Figure 11)



Specimen Characteristics
Concrete Mix “A” (C-2)
Concrete Strength 3943 psi
End Block Length 18”
End Distance to Center of Loop 9”
Side Distance 3” (3.875”)
One Leg Restrained by U-Bar

*Please refer to Figure 11Figure 12 for variable definitions

Test Summary

	Load Stage	Diagonal Load (kip)	Vertical Load (kip)
1	First Cracking	35.5	25.1
2	Wedge Cracking	45.6	32.2
3	Ultimate	49.9	35.3

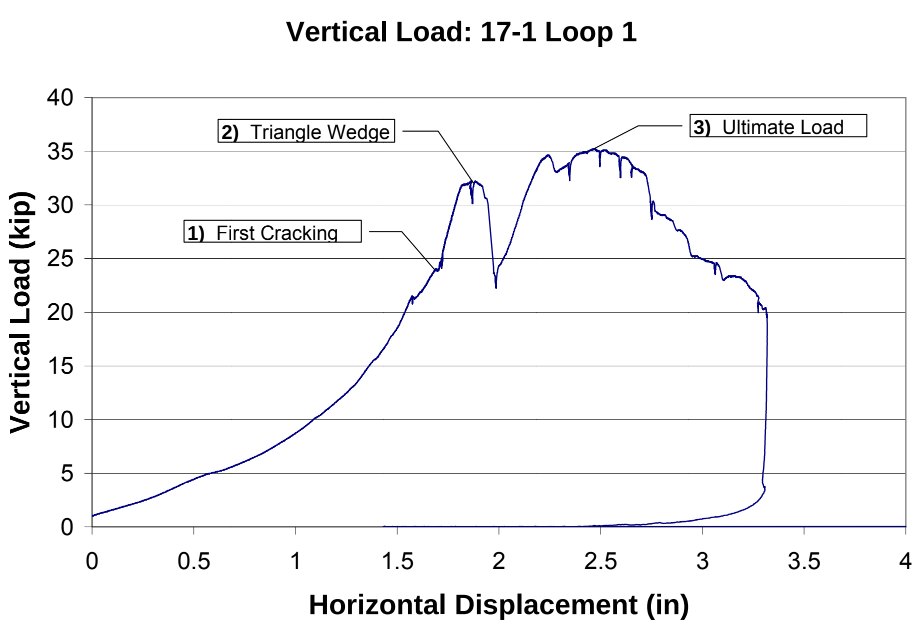


Figure 1: First Cracking (Stage 1)

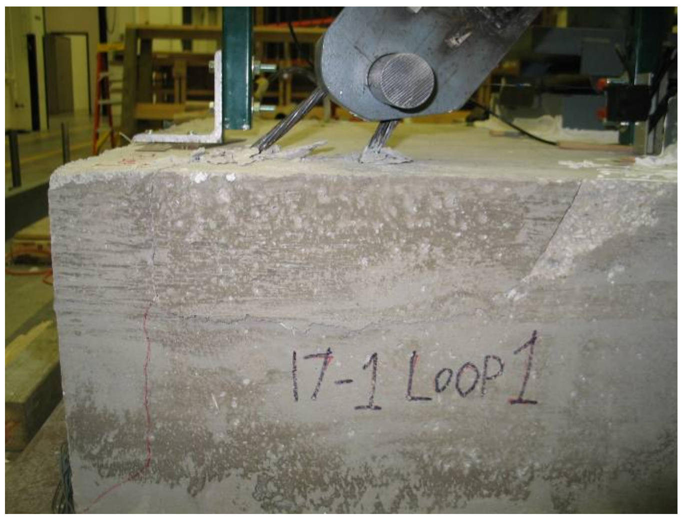
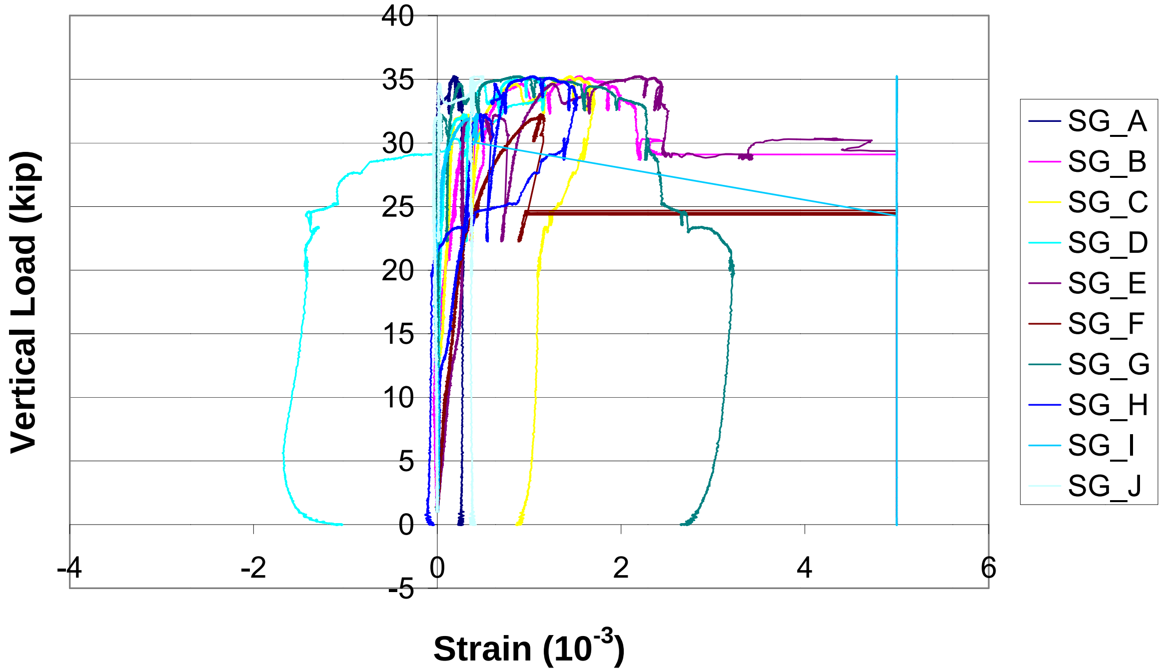


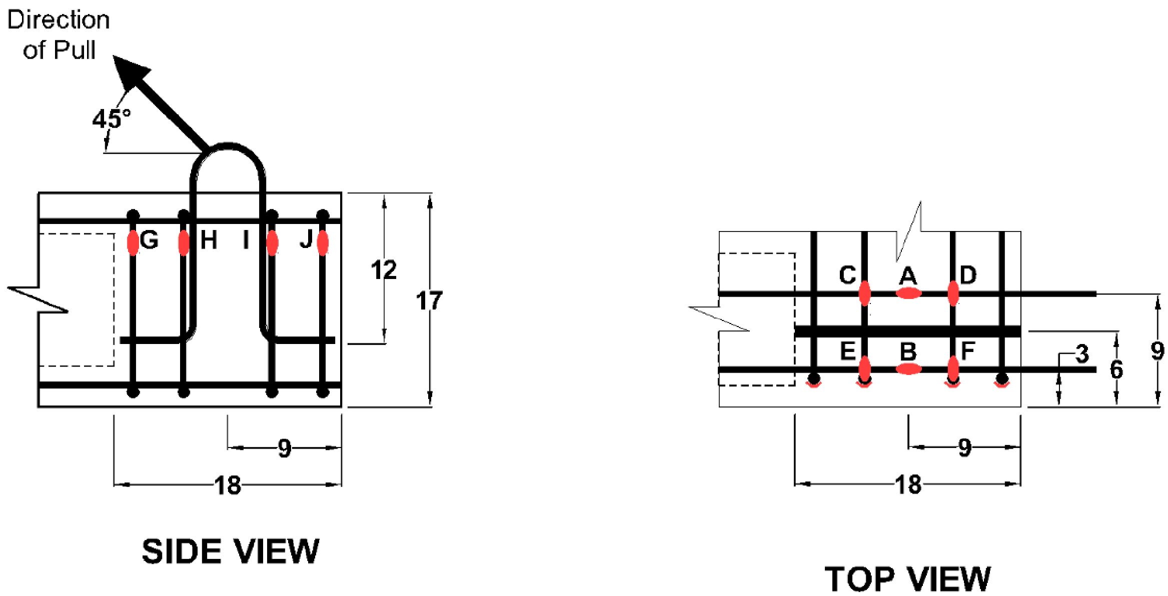
Figure 2: Triangle Wedge Cracking (Stage 2)

Figure 3: Failure (Stage 3

Strain Gauge Data: 17-1 Loop 1



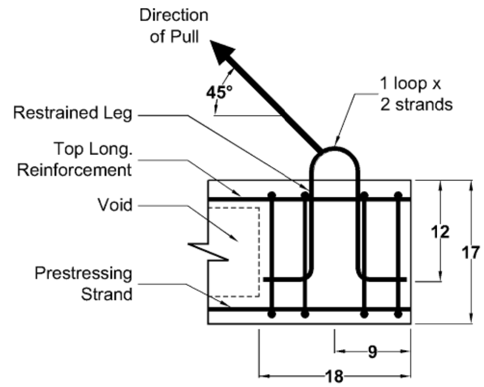
Strain Gauge Orientation Diagram



Test ID: 17-1 Lifting Loop #2

17” x 48” Deck Beam
Lifting Angle: 45 degrees
Cast Date: 8-7-2007
Test Date: 11-1-2007

Lifting Loop Characteristics
Embedment Depth 12” (12.5” – 13.25”)
1 Loop x 2 Strands
Legs Parallel (Figure 12Figure 11)



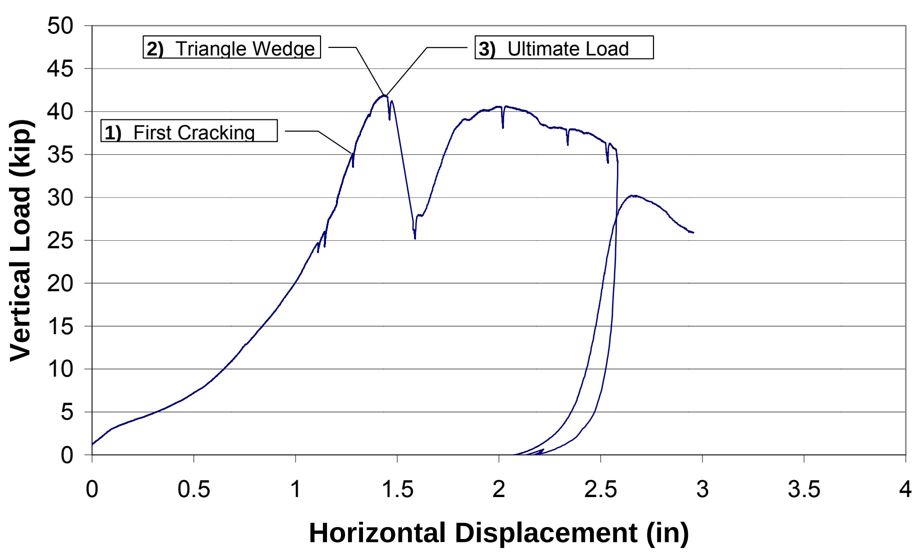
Specimen Characteristics
Concrete Mix “A” (C-2)
Concrete Strength 3941 psi
End Block Length 18”
End Distance to Center of Loop 9”
Side Distance 6” (6.0”)
One Leg Restrained by U-Bar

*Please refer to Figure 11Figure 12 for variable definitions

Test Summary

	Load Stage	Diagonal Load (kip)	Vertical Load (kip)
1	First Cracking	49.1	34.7
2	Wedge Cracking	59.3	41.9
3	Ultimate	59.3	41.9

Vertical Load: 17-1 Loop 2



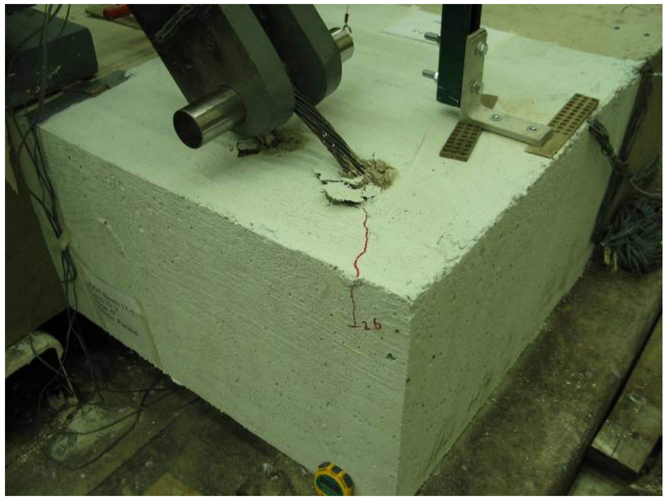
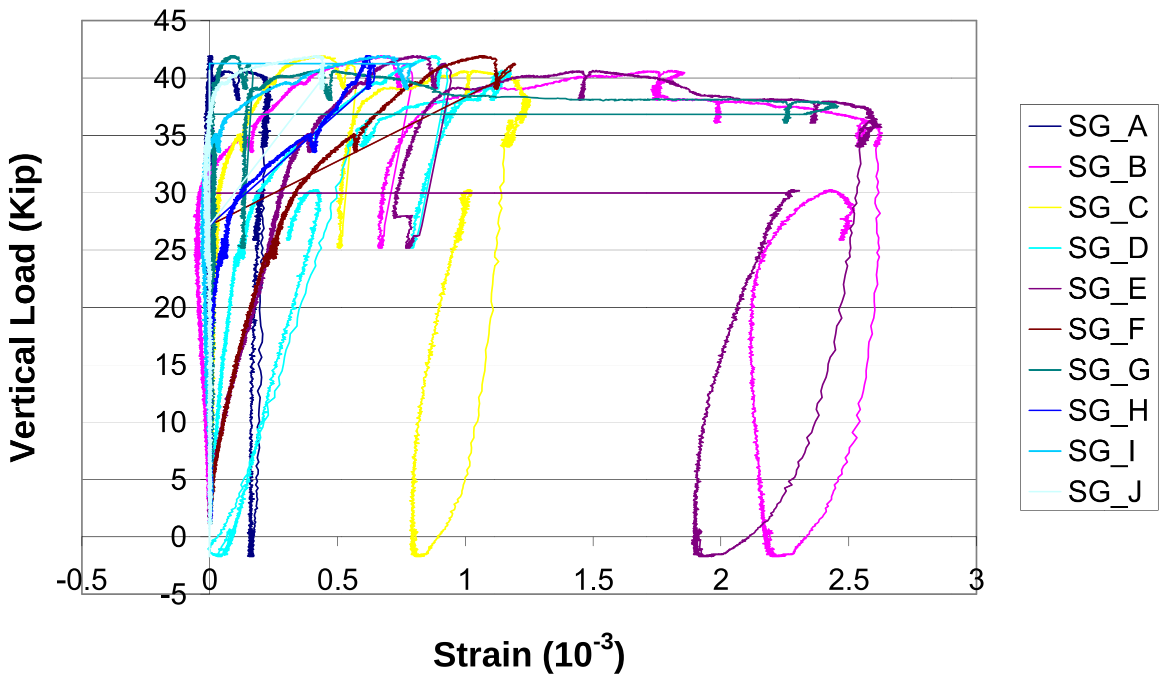


Figure 1: First Cracking (Stage 1)

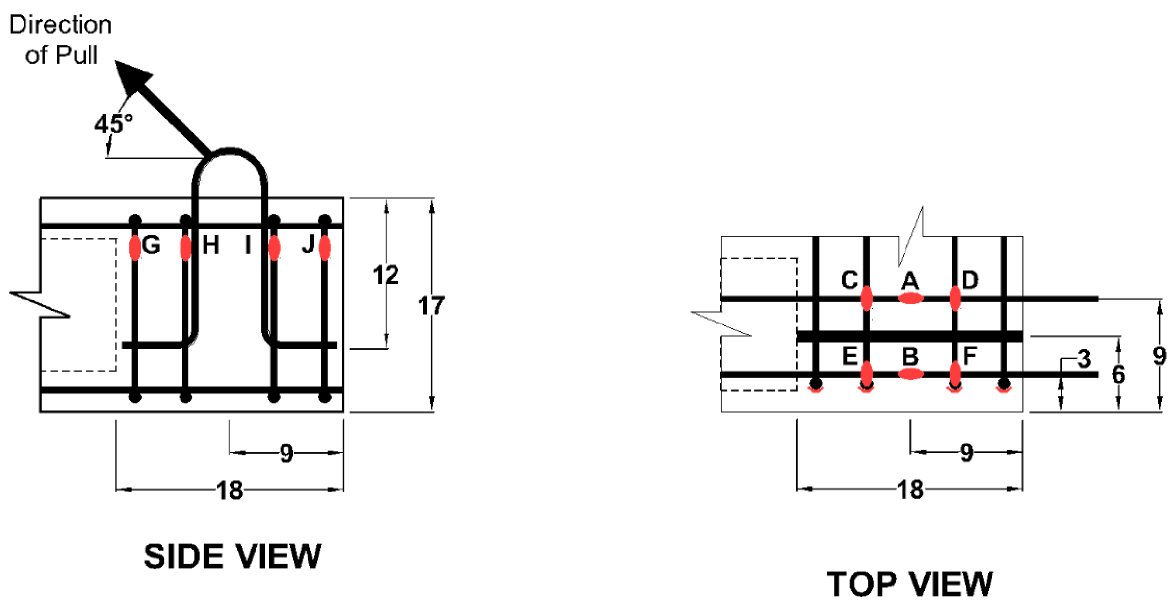
Figure 2: Triangle Wedge Cracking (Stage 2)

Figure 3: Failure (Stage 3)

Strain Gauge Data: 17-1 Loop 2



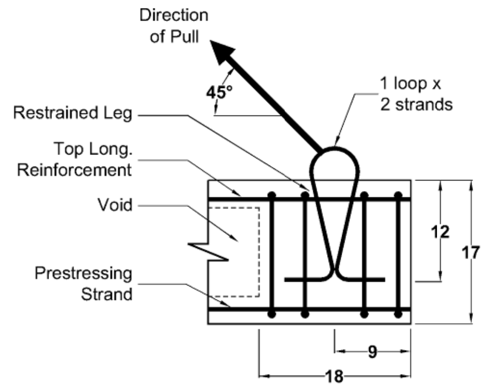
Strain Gauge Orientation Diagram



Test ID: 17-1 Lifting Loop #3

17" x 48" Deck Beam
Lifting Angle: 45 degrees
Cast Date: 8-7-2007
Test Date: 11-8-2007

Lifting Loop Characteristics
Embedment Depth 12" (13.0" – 13.5")
1 Loop x 2 Strands
Legs Tied (Figure 12Figure 11)



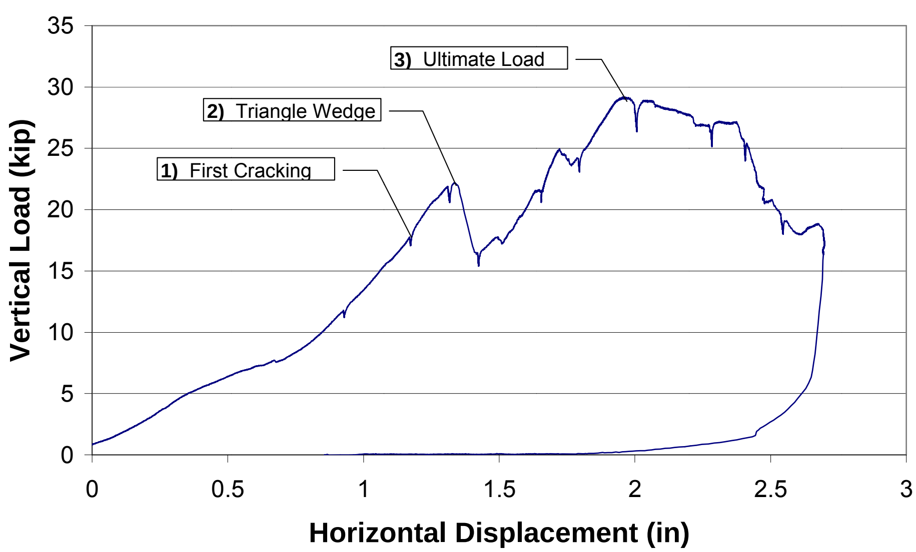
Specimen Characteristics
Concrete Mix "A" (C-2)
Concrete Strength 3965 psi
End Block Length 18"
End Distance to Center of Loop 9"
Side Distance 3" (3.75")
One Leg Restrained by U-Bar

*Please refer to Figure 11Figure 12 for variable definitions

Test Summary

	Load Stage	Diagonal Load (kip)	Vertical Load (kip)
1	First Cracking	28.0	19.8
2	Wedge Cracking	31.4	22.2
3	Ultimate	41.3	29.2

Vertical Load: 17-1 Loop 3



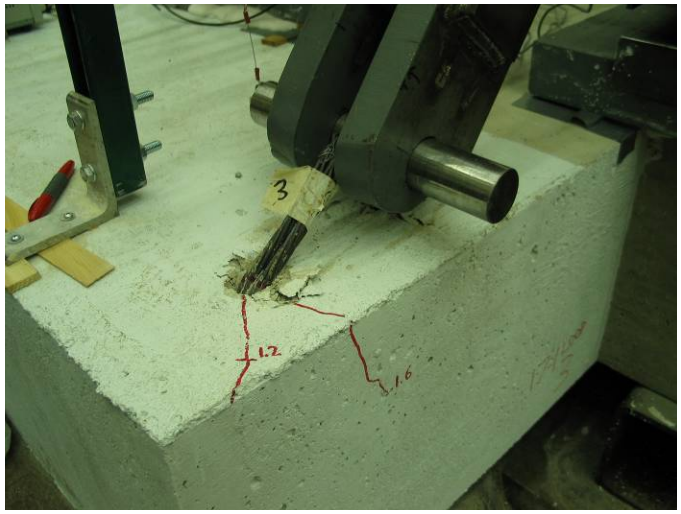


Figure 1: First Cracking (Stage 1)

Figure 2: Triangle Wedge Cracking (Stage 2)

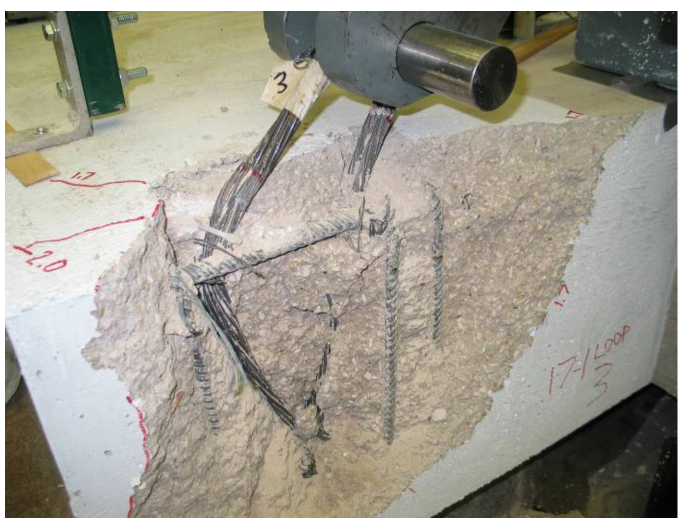
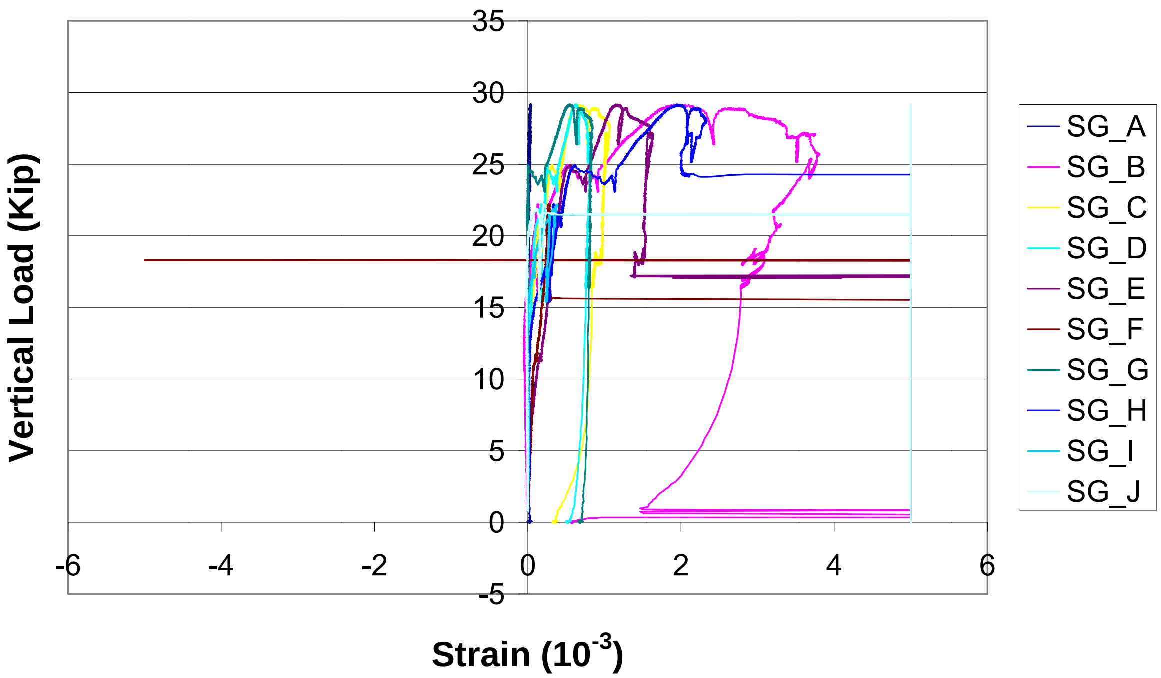
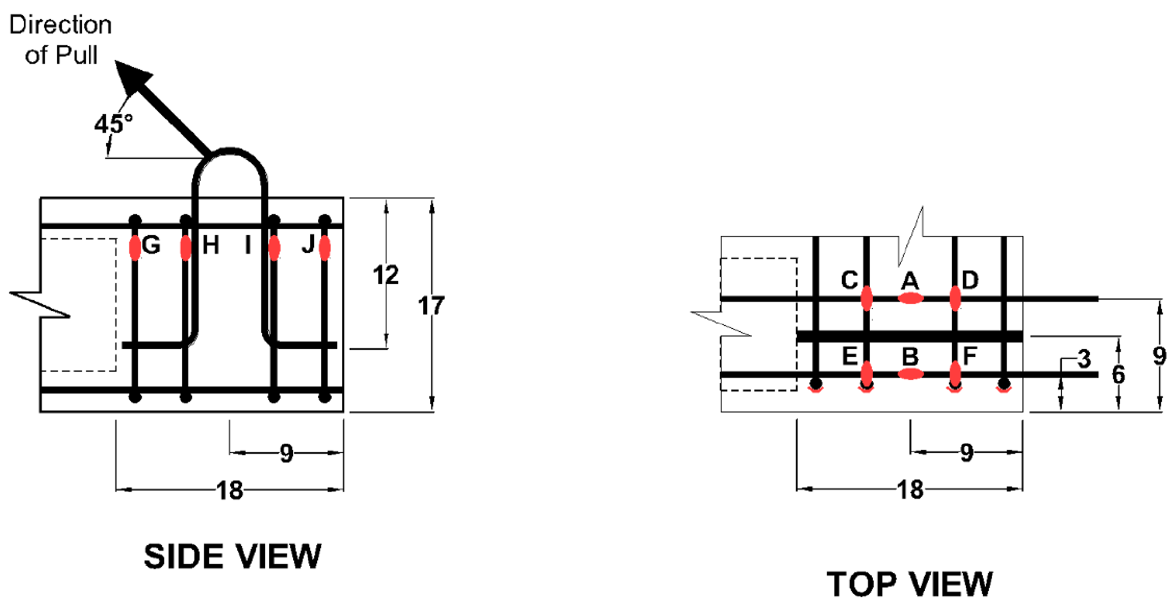


Figure 3: Failure (Stage 3)

Strain Gauge Data: 17-1 Loop 3



Strain Gauge Orientation Diagram

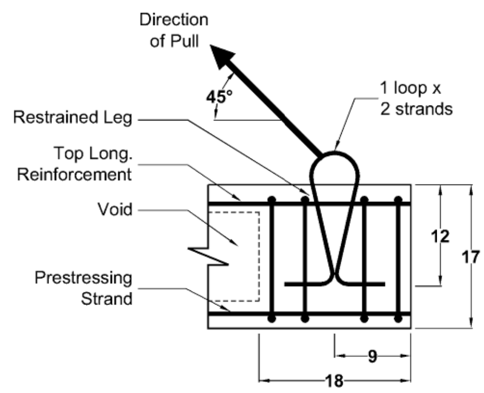


Test ID: 17-1 Lifting Loop #4

17” x 48” Deck Beam
Lifting Angle: 45 degrees
Cast Date: 8-7-2007
Test Date: 11-13-2007

Lifting Loop Characteristics
Embedment Depth 12” (13.0” – 13.5”)
1 Loop x 2 Strands
Legs Tied (Figure 12Figure 11)

Specimen Characteristics
Concrete Mix “A” (C-2)
Concrete Strength 3983 psi
End Block Length 18”
End Distance to Center of Loop 9”
Side Distance 6” (6.0”)
One Leg Restrained by U-Bar

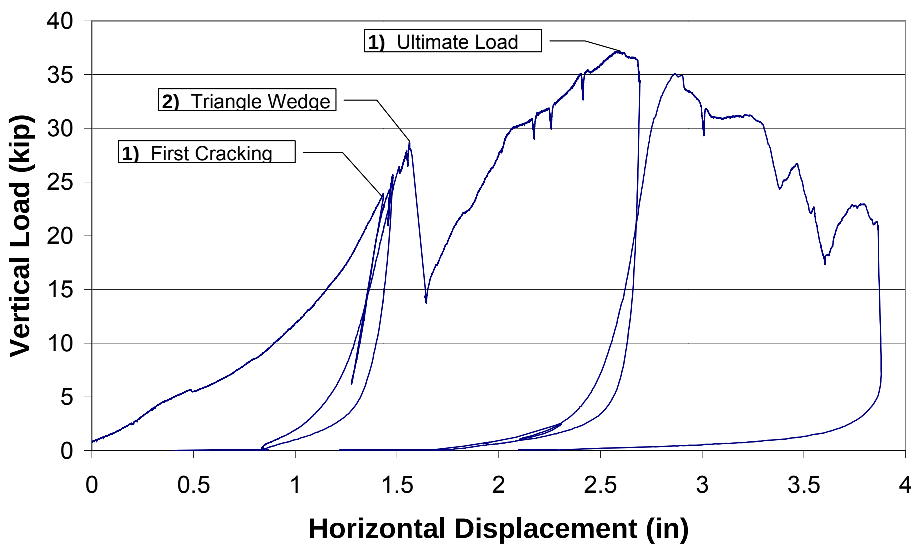


*Please refer to Figure 11Figure 12 for variable definitions

Test Summary

	Load Stage	Diagonal Load (kip)	Vertical Load (kip)
1	First Cracking	34.0	24.0
2	Wedge Cracking	40.5	28.6
3	Ultimate	52.6	37.2

Vertical Load: 17-1 Loop 4



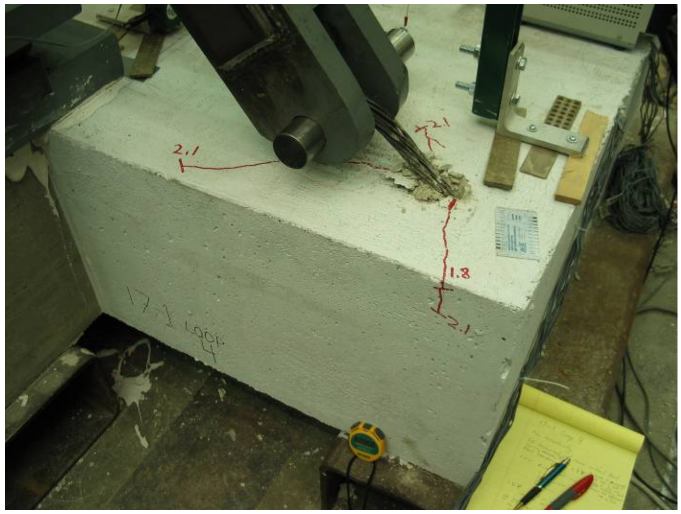


Figure 1: First Cracking (Stage 1)

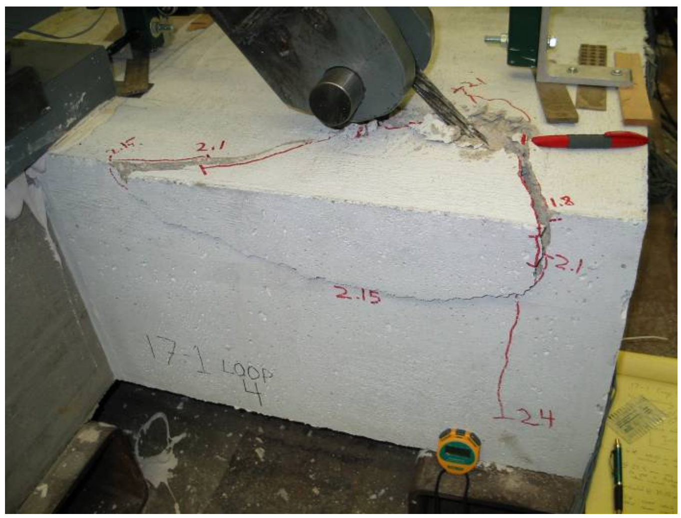
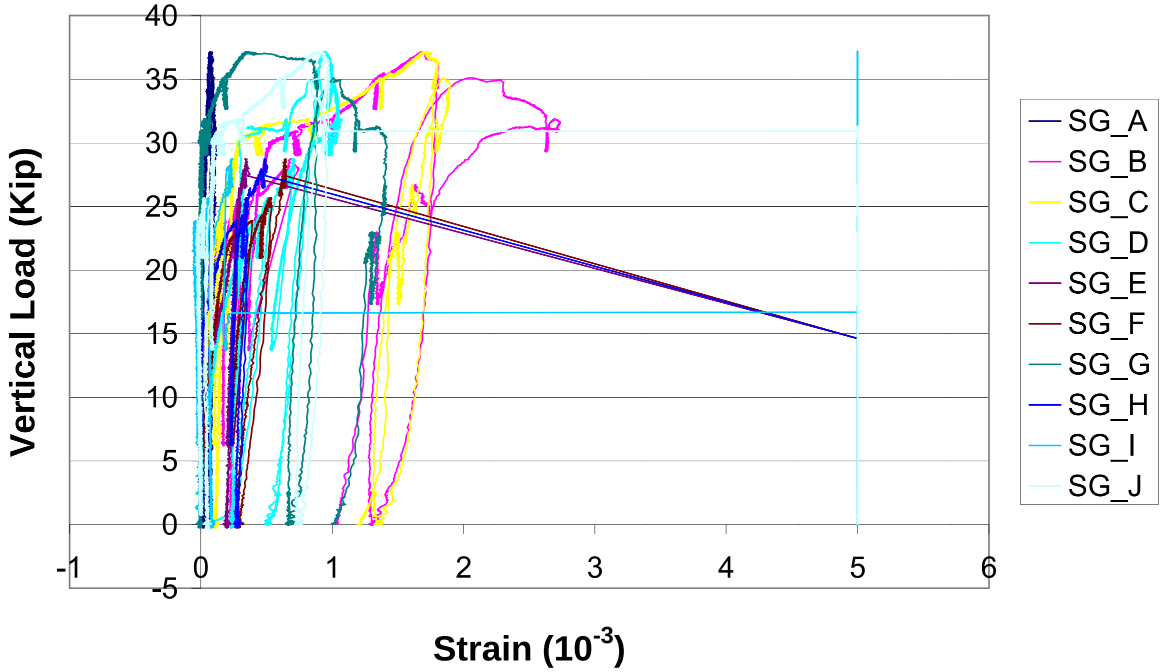


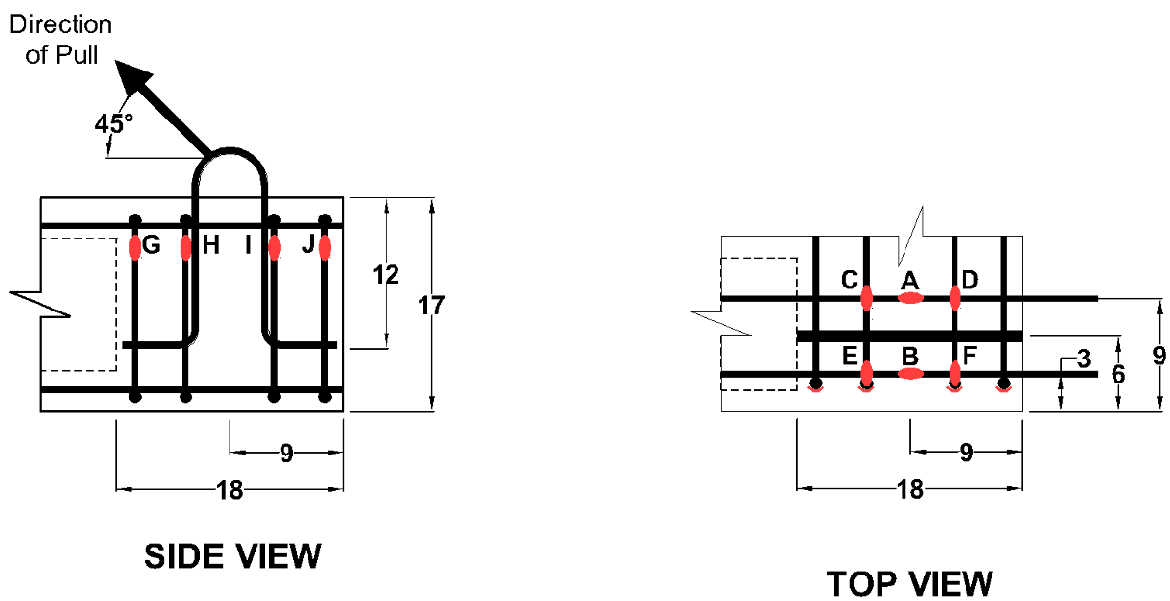
Figure 2: Triangle Wedge Cracking (Stage 2)

Figure 3: Failure (Stage 3)

Strain Gauge Data: 17-1 Loop 4



Strain Gauge Orientation Diagram



Summary of 17-2 Deck Beam Tests

Loop ID	Cast Day	Test Day	Specified Concrete Strength (psi)	Test Day Concrete Strength (psi)	Test Day Tensile Strength (psi)	Beam Depth (in)	Embedment Depth (in)	Actual Embedment Depth (in)	End Block Length (in)	End Distance to Center of Loop (in)	Side Dist. (in)	Actual Side Dist. (in)	Shape	Lifting Loops in a Corner	# Strands / Lifting Loop	Flaring (Degrees)	Lifting Loop Leg with Inward Movement Restrained by U-Bar	Diagonal Load (kips)			Vertical Load (kips)			
																		First Cracking	Wedge Spalling	Ultimate	Angle (degrees)	First Cracking	Wedge Spalling	Ultimate
17-2 Loop#1	1/14/2008	1/31/2008	4000	4034	391	17	12	11.13 - 11.88	18	9	4	4.13	Parallel	2	3	0	Inner Leg	47.8	N/A	98.9	45	33.8	N/A	69.9
17-2 Loop#2		1/29/2008	4000	3914	391	17	12	11.63 - 12.50	18	9	4	3.75	Parallel	1	3	0	Inner Leg	39.1	45.0	62.2	45	27.6	31.8	44.0
17-2 Loop#3		2/4/2008	4000	4274	391	17	12	11.63 - 12.13	18	9	4	4.00	Parallel	2	3	0	Both Legs	67.0	95.4	100.7	45	47.4	67.5	71.2
17-2 Loop#4		2/2/2008	4000	4154	391	17	12	12.25 - 12.88	18	9	4	3.63	Parallel	1	3	0	Both Legs	31.4	47.4	65.7	45	22.2	33.5	46.5

Notes:

1.) For beams 11-1, 17-1 and 17-2, the angle of pull began at close to 45 degrees but was closer to 50 degrees at the time that the ultimate capacity was realized; it is suggested to consider these to be 45 degree lifts for making a conservative estimates of vertical lift capacity

*See A-18 and A-19 for 17-2 Deck Beam Geometry

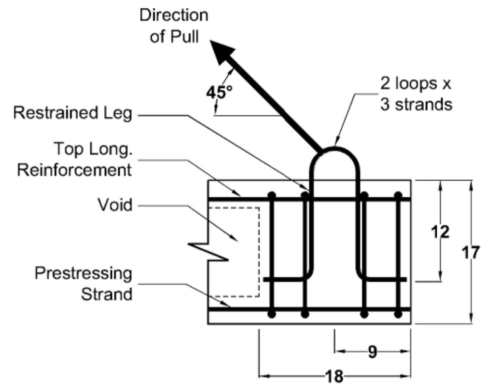
Mix "A"

Sand (FA-01)	1172	lb
Coarse (Chips CM-16)	1825	lb
Cement	550	lb
Water	29.8	gal
Admixtures		
Air	1.4	oz
WRDA 82	3.5	oz
Properties		
w/c	0.45	
Target Compressive Strength	4000	psi

Test ID: 17-2 Lifting Loop #1

17" x 48" Deck Beam
Lifting Angle: 45 degrees
Cast Date: 1-14-2008
Test Date: 1-31-2008

Lifting Loop Characteristics
Embedment Depth 12" (11.13" – 11.88")
2 Loops x 3 Strands
Legs Parallel (Figure 12Figure 11)



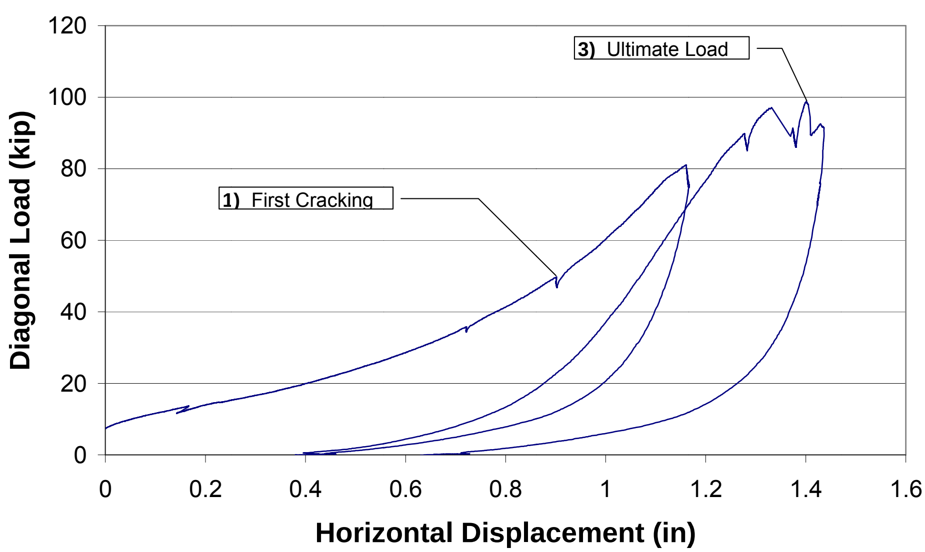
Specimen Characteristics
Concrete Mix "A" (C-2)
Concrete Strength 3983 psi
End Block Length 18"
End Distance to Center of Loop 9"
Side Distance 4" (4.13")
One Leg Restrained by U-Bar

*Please refer to Figure 11Figure 12 for variable definitions

Test Summary

	Load Stage	Diagonal Load (kip)	Vertical Load (kip)
1	First Cracking	47.8	33.8
2	Wedge Cracking	N/A	N/A
3	Ultimate	98.9	69.9

Vertical Load: 17-2 Loop 1



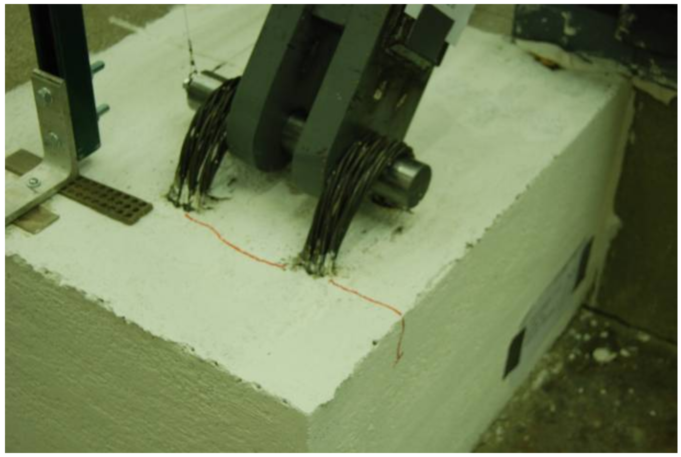


Figure 1: First Cracking (Stage 1)

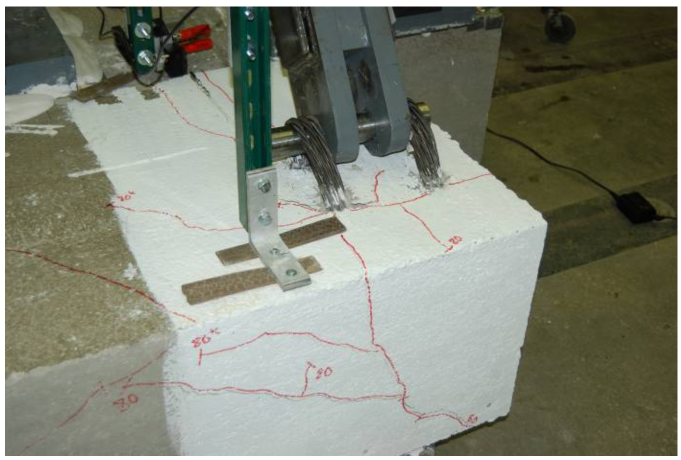


Figure 2: Additional Cracking

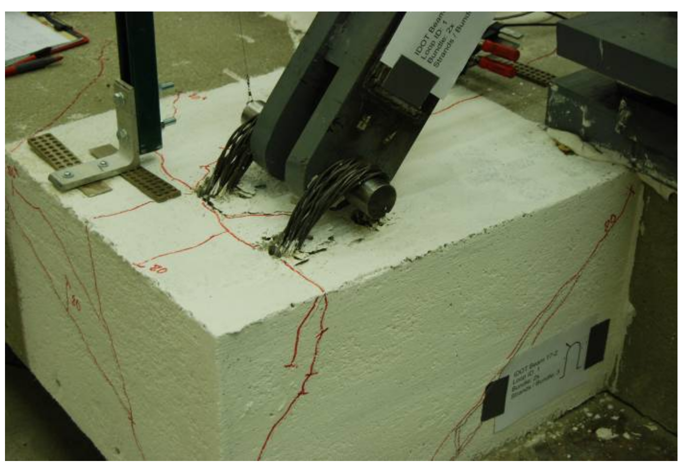
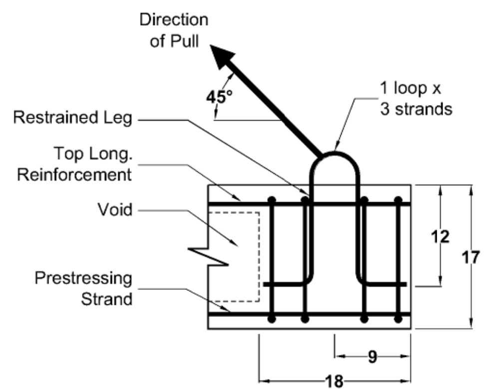


Figure 3: Failure (Stage 3)

Test ID: 17-2 Lifting Loop #2

17” x 48” Deck Beam
Lifting Angle: 45 degrees
Cast Date: 1-14-2008
Test Date: 1-29-2008

Lifting Loop Characteristics
Embedment Depth 12” (11.63” – 12.5”)
1 Loop x 3 Strands
Legs Parallel (Figure 12Figure 11)



Specimen Characteristics
Concrete Mix “A” (C-2)
Concrete Strength 3941 psi
End Block Length 18”
End Distance to Center of Loop 9”
Side Distance 4” (3.75”)
One Leg Restrained by U-Bar

*Please refer to Figure 11Figure 12 for variable definitions

Test Summary

	Load Stage	Diagonal Load (kip)	Vertical Load (kip)
1	First Cracking	39.1	27.6
2	Wedge Cracking	45.0	31.8
3	Ultimate	62.2	44.0

Vertical Load: 17-2 Loop 2

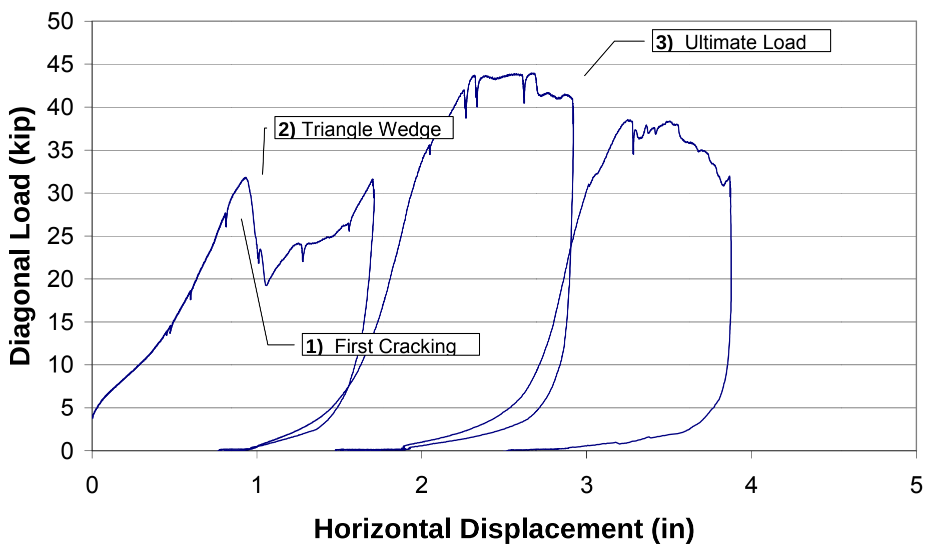


Figure 1: First Cracking (Stage 1)

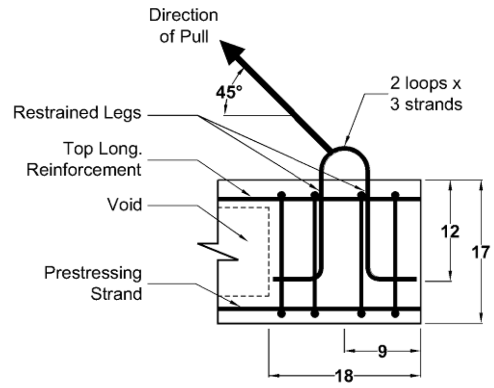
Figure 2: Triangle Wedge Cracking (Stage 2)

Figure 3: Failure (Stage 3)

Test ID: 17-2 Lifting Loop #3

17” x 48” Deck Beam
Lifting Angle: 45 degrees
Cast Date: 1-14-2008
Test Date: 2-4-2008

Lifting Loop Characteristics
Embedment Depth 12” (11.63” – 12.13”)
2 Loops x 3 Strands
Legs Parallel (Figure 12Figure 11)



Specimen Characteristics
Concrete Mix “A” (C-2)
Concrete Strength 3965 psi
End Block Length 18”
End Distance to Center of Loop 9”
Side Distance 4” (4.0”)
Both Legs Restrained by U-Bar

*Please refer to Figure 11Figure 12 for variable definitions

Test Summary

	Load Stage	Diagonal Load (kip)	Vertical Load (kip)
1	First Cracking	67.0	47.4
2	Wedge Cracking	95.4	67.5
3	Ultimate	100.7	71.2

VerticalLoad: 17-2 Loop 3

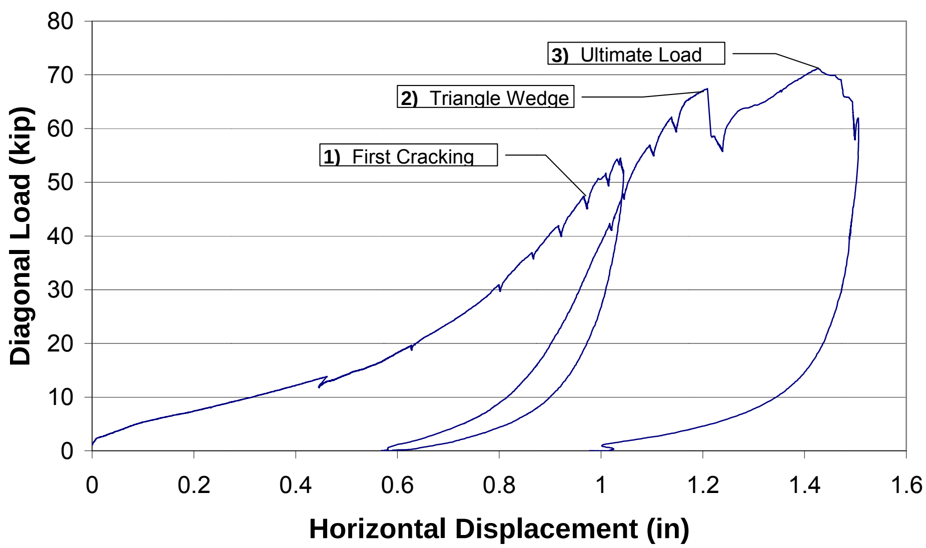


Figure 1: First Cracking (Stage 1)

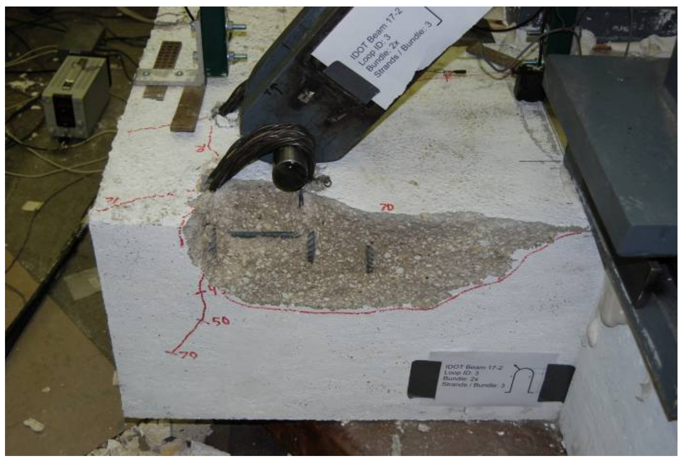


Figure 2: Triangle Wedge Cracking (Stage 2)

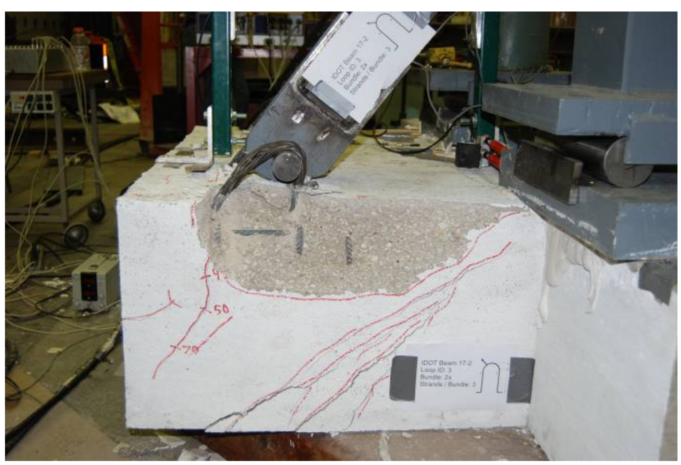


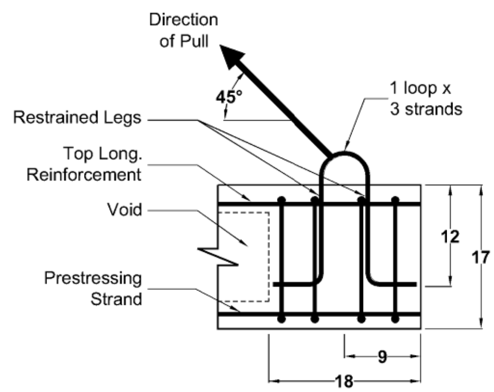
Figure 3: Failure (Stage 3)

Test ID: 17-2 Lifting Loop #4

17” x 48” Deck Beam
Lifting Angle: 45 degrees
Cast Date: 1-14-2008
Test Date: 2-2-2008

Lifting Loop Characteristics
Embedment Depth 12” (12.25” – 12.88”)
1 Loop x 3 Strands
Legs Parallel (Figure 12Figure 11)

Specimen Characteristics
Concrete Mix “A” (C-2)
Concrete Strength 3934 psi
End Block Length 18”
End Distance to Center of Loop 9”
Side Distance 4” (3.63”)
Both Legs Restrained by U-Bar



*Please refer to Figure 11Figure 12 for variable definitions

Test Summary

	Load Stage	Diagonal Load (kip)	Vertical Load (kip)
1	First Cracking	31.4	22.2
2	Wedge Cracking	47.4	33.5
3	Ultimate	65.7	46.5

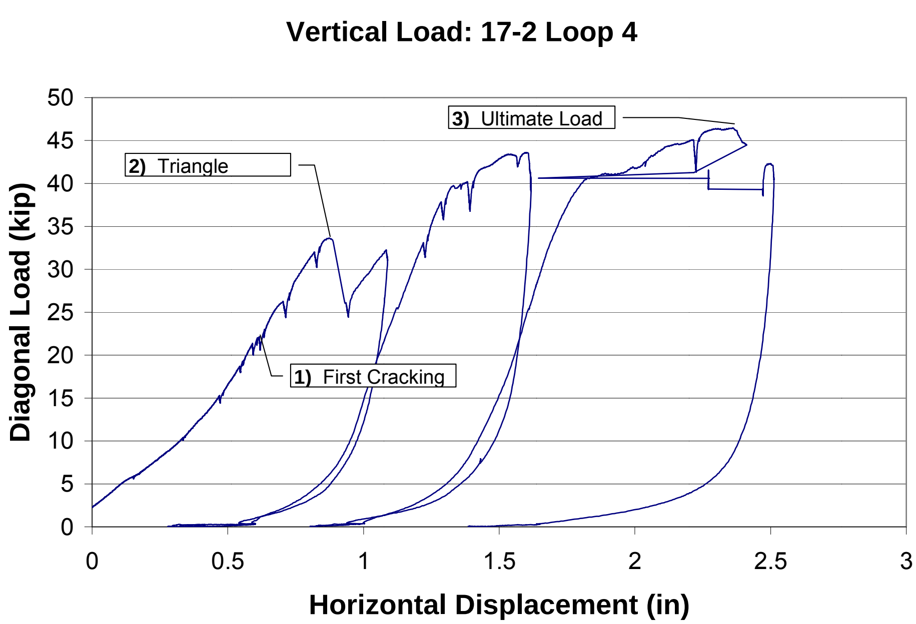


Figure 1: First Cracking (Stage 1)

Figure 2: Triangle Wedge Cracking (Stage 2)

Figure 3: Failure (Stage 3)

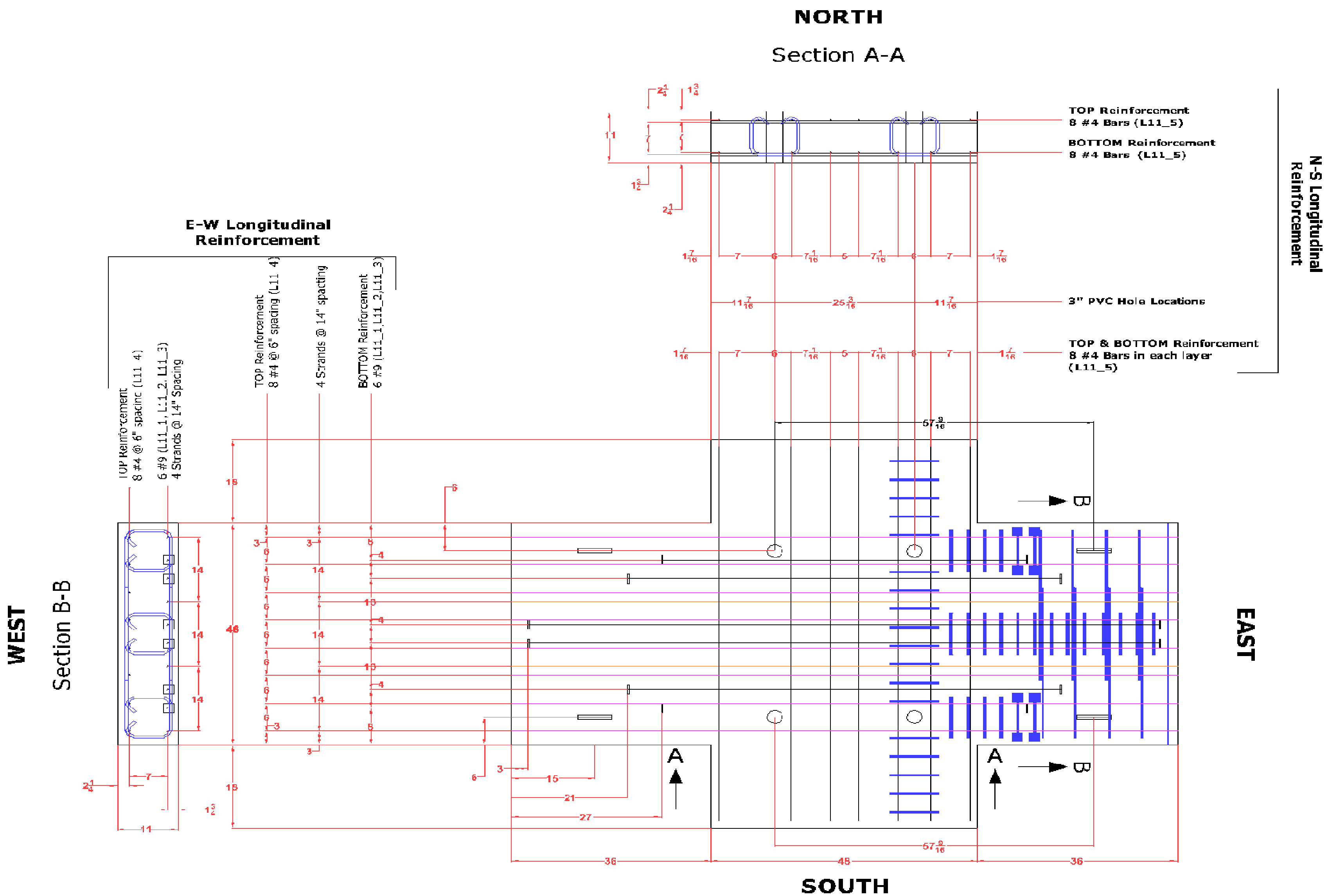
Summary of 17-3 Deck Beam Tests

Loop ID	Cast Day	Test Day	Specified Concrete Strength (psi)	Test Day Concrete Strength (psi)	Test Day Tensile Strength (psi)	Beam Depth (in)	Embedment Depth (in)	Actual Embedment Depth (in)	End Block Length (in)	End Distance to Center of Loop (in)	Side Dist. (in)	Actual Side Dist. (in)	Shape	Lifting Loops in a Corner	# Strands / Lifting Loop	Flaring (Degrees)	Lifting Loop Leg with Inward Movement Restrained by U-Bar	Diagonal Load (kips)			Vertical Load (kips)			
																		First Cracking	Wedge Spalling	Ultimate	Angle (degrees)	First Cracking	Wedge Spalling	Ultimate
17-3 Loop #1	3/18/2008	4/13/2008	5000	9279	595	17	13	11.88 - 12.38	30	15	6	4.25	Parallel	1	3	0	No Legs	57.5	63.5	115.5	60	49.8	55.0	100.0
17-3 Loop #2		4/15/2008	5000	9279	595	17	13	12.63 - 13.13	30	15	6	4.00	Parallel	2	3	0	No Legs	85.0	138.0	157.8	60	73.6	119.5	136.7
17-3 Loop #3		4/23/2008	5000	9279	595	17	13	12.00 - 12.63	30	15	6	4.50	Flared	1	3	10	No Legs	71.7	92.0	103.4	60	62.1	79.7	89.5
17-3 Loop #4		4/25/2008	5000	9279	595	17	13	11.63 - 12.13	30	15	6	4.88	Flared	2	3	10	No Legs	110	128.5	155.2	60	95.3	111.3	134.4

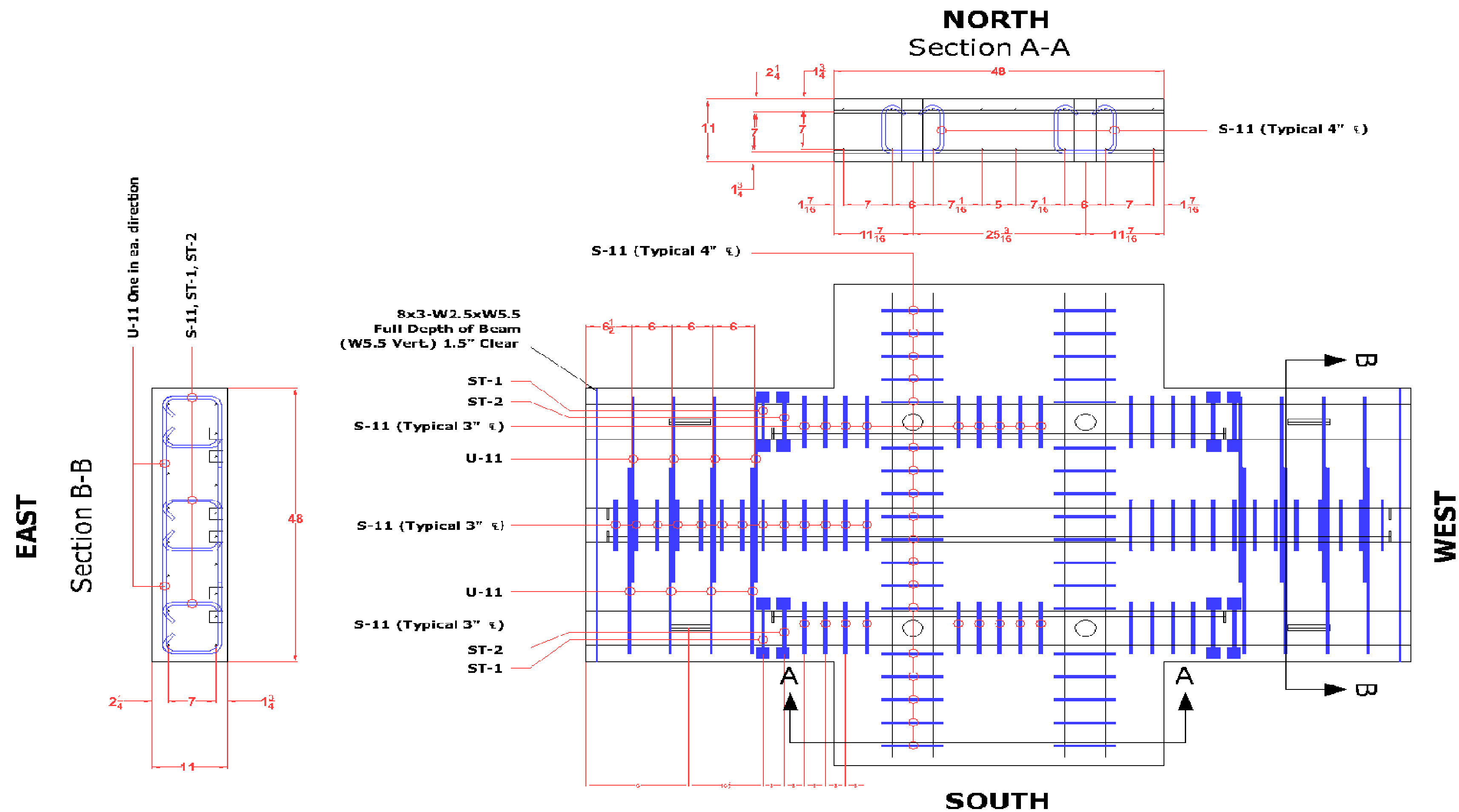
Mix "B"

Sand (FA-01)	1025	lb
Coarse (Chips CM-16)	1773	lb
Cement	735	lb
Water	34.9	gal
Admixtures		
Air	0.25	oz
Masterpave	3.5	oz
Properties		
w/c	0.40	
Target Compressive Strength	5000*	psi

* Target strength at 14 days



17-3 Deck Beam Geometry



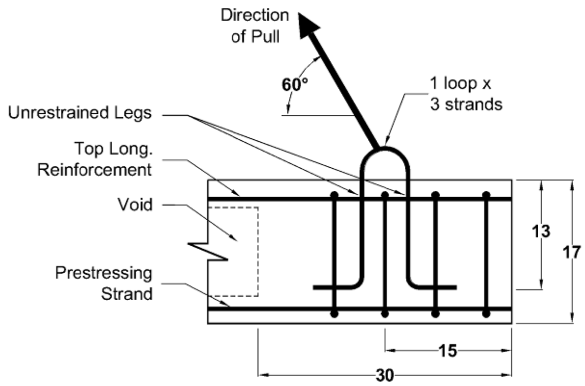
17-3 Deck Beam Geometry

Test ID: 17-3 Lifting Loop #1

17” x 48” Deck Beam
Lifting Angle: 60 degrees
Cast Date: 3-18-2008
Test Date: 4-13-2008

Lifting Loop Characteristics
Embedment Depth 13” (11.88” – 12.38”)
1 Loop x 3 Strands
Legs Parallel (Figure 12Figure 11)

Specimen Characteristics
Concrete Mix “B” (C-2)
Concrete Strength 9279 psi
End Block Length 30”
End Distance to Center of Loop 15”
Side Distance 6” (4.25”)
U-Bar Placed In Middle of Lifting Loop



*Please refer to Figure 11Figure 12 for variable definitions

Test Summary

	Load Stage	Diagonal Load (kip)	Vertical Load (kip)
1	First Cracking	57.5	49.5
2	Wedge Cracking	63.5	55.0
3	Ultimate	115.5	100.0

Vertical Lifting Load: 17-3 Loop 1

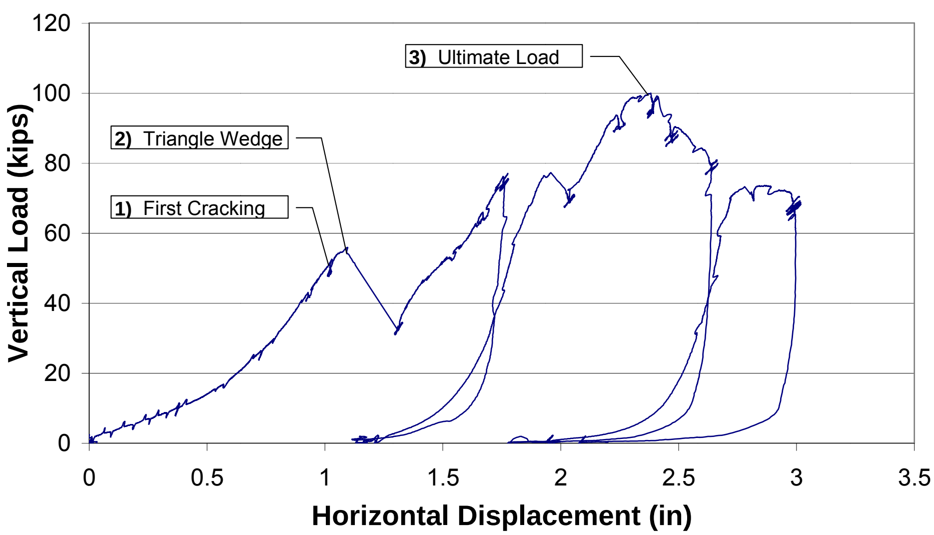


Figure 1: First Cracking (Stage 1)

Figure 2: Triangle Wedge Cracking (Stage 2)

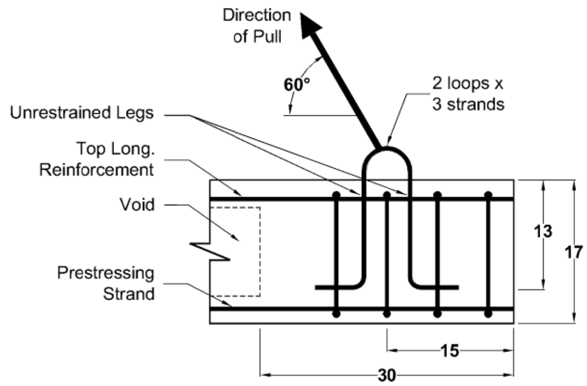
Figure 3: Failure (Stage 3)

Test ID: 17-3 Lifting Loop #2

17” x 48” Deck Beam
Lifting Angle: 60 degrees
Cast Date: 3-18-2008
Test Date: 4-15-2008

Lifting Loop Characteristics
Embedment Depth 13” (12.63” – 13.13”)
2 Loops x 3 Strands
Legs Parallel (Figure 12Figure 11)

Specimen Characteristics
Concrete Mix “B” (C-2)
Concrete Strength 9279 psi
End Block Length 30”
End Distance to Center of Loop 15”
Side Distance 6” (4.0”)
U-Bar Placed In Middle of Lifting Loop



*Please refer to Figure 11Figure 12 for variable definitions

Test Summary

	Load Stage	Diagonal Load (kip)	Vertical Load (kip)
1	First Cracking	85.0	73.8
2	Wedge Cracking	138.0	119.5
3	Ultimate	157.8	136.7

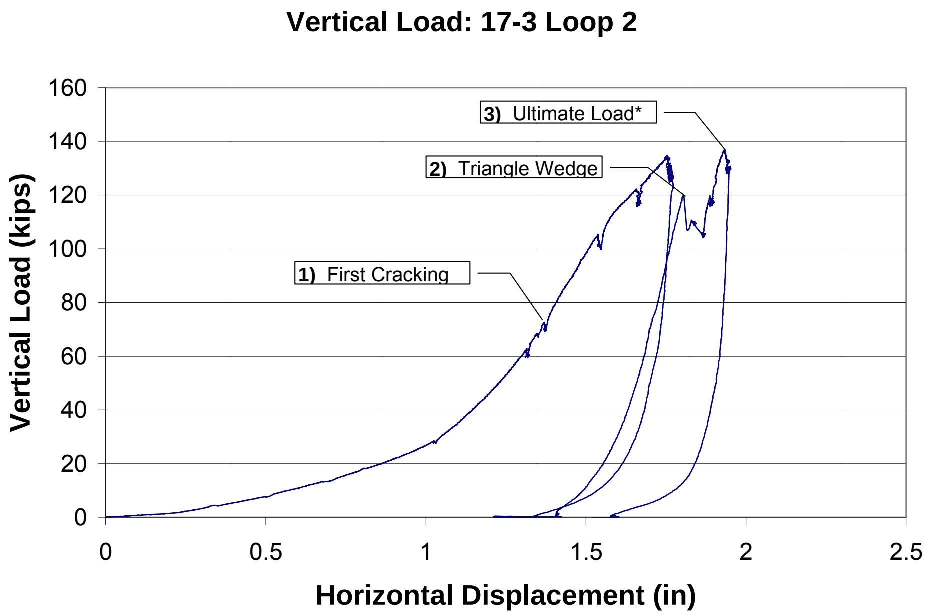


Figure 1: First Cracking (Stage 1)

Figure 2: Triangle Wedge Cracking (Stage 2)

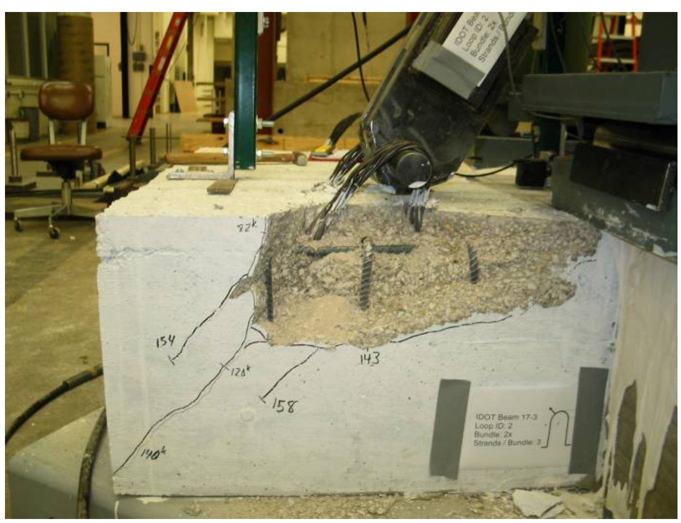


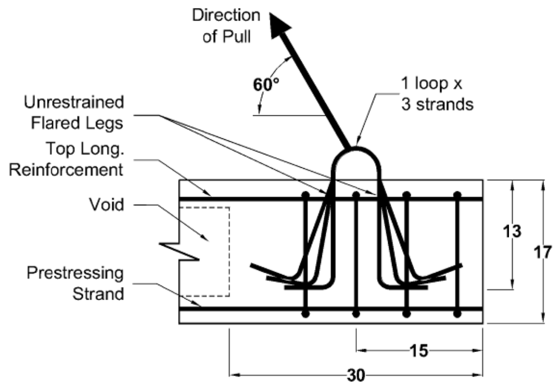
Figure 3: Failure (Stage 3)

Test ID: 17-3 Lifting Loop #3

17" x 48" Deck Beam
Lifting Angle: 60 degrees
Cast Date: 3-18-2008
Test Date: 4-23-2008

Lifting Loop Characteristics
Embedment Depth 13" (12.0" – 12.63")
1 Loop x 3 Strands
Legs Flared 10 Degrees

Specimen Characteristics
Concrete Mix "B" (C-2)
Concrete Strength 9279 psi
End Block Length 30"
End Distance to Center of Loop 15"
Side Distance 6" (4.5")
U-Bar Placed In Middle of Lifting Loop

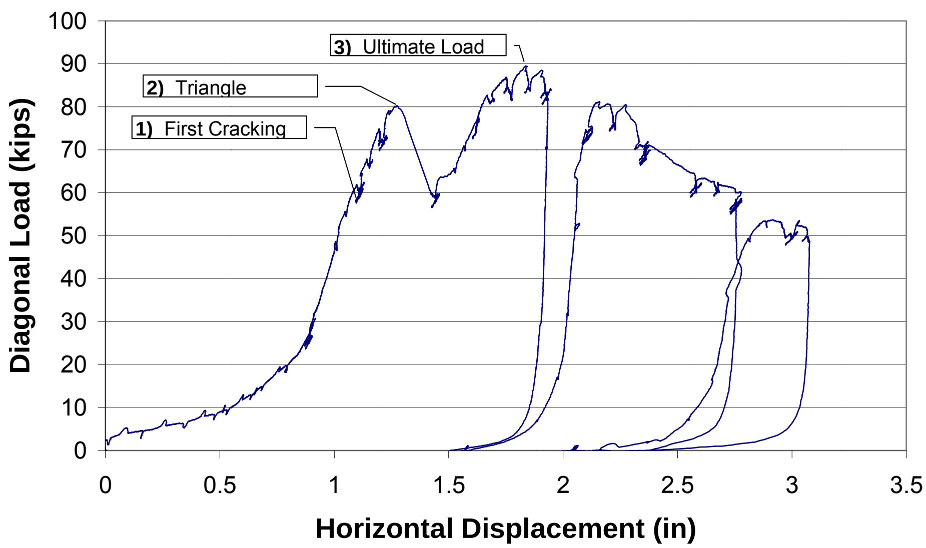


*Please refer to Figure 11Figure 12 for variable definitions

Test Summary

	Load Stage	Diagonal Load (kip)	Vertical Load (kip)
1	First Cracking	71.7	62.1
2	Wedge Cracking	92.0	79.7
3	Ultimate	103.4	89.5

Vertical Load: 17-3 Loop 3



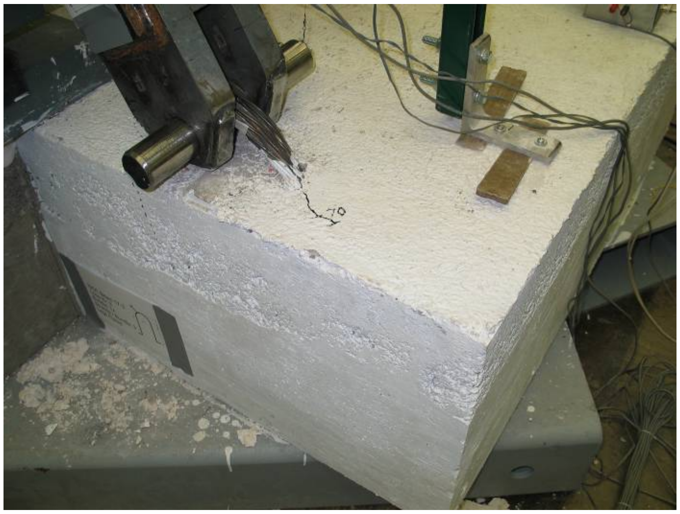


Figure 1: First Cracking (Stage 1)

Figure 2: Triangle Wedge Cracking (Stage 2)

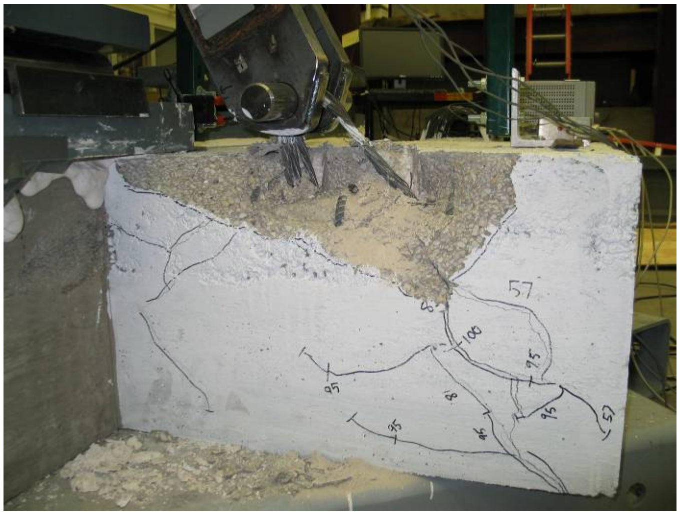


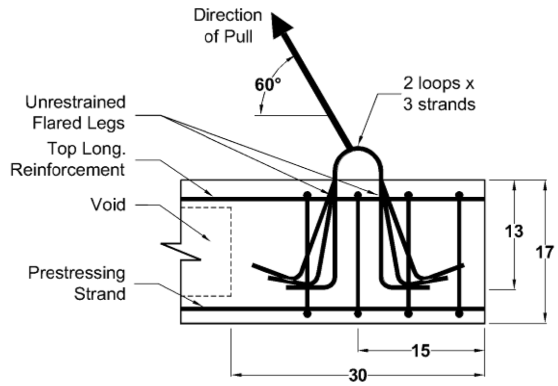
Figure 3: Failure (Stage 3)

Test ID: 17-3 Lifting Loop #4

17" x 48" Deck Beam
Lifting Angle: 60 degrees
Cast Date: 3-18-2008
Test Date: 4-25-2008

Lifting Loop Characteristics
Embedment Depth 13" (11.63" – 12.13")
2 Loops x 3 Strands
Legs Flared 10 Degrees

Specimen Characteristics
Concrete Mix "B" (C-2)
Concrete Strength 9279 psi
End Block Length 30"
End Distance to Center of Loop 15"
Side Distance 6" (4.88")
U-Bar Placed In Middle of Lifting Loop



*Please refer to Figure 11Figure 12 for variable definitions

Test Summary

	Load Stage	Diagonal Load (kip)	Vertical Load (kip)
1	First Cracking	110.0	95.3
2	Wedge Cracking	128.5	111.3
3	Ultimate	155.2	134.4

*Load Cell Saturated

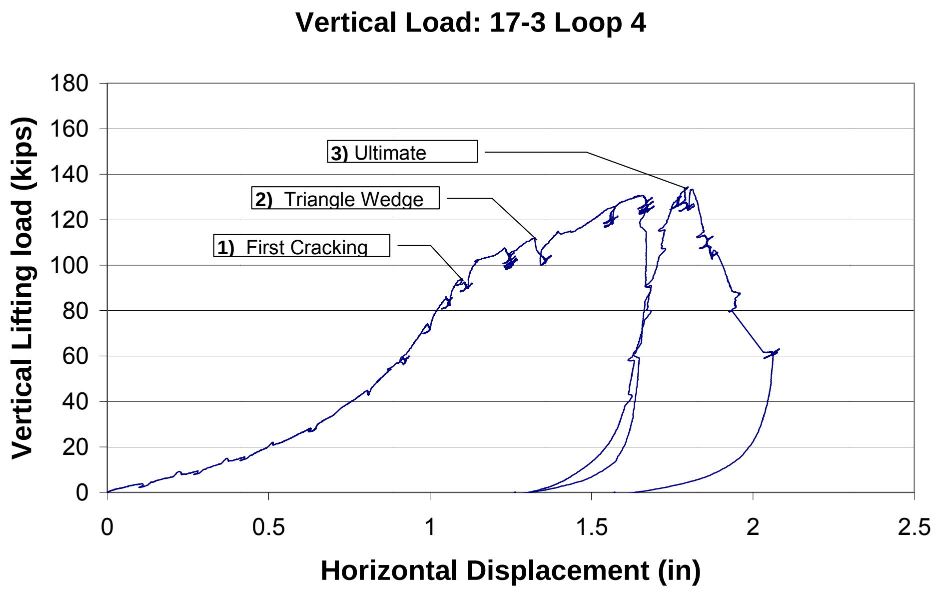


Figure 1: First Cracking (Stage 1)

Figure 2: Triangle Wedge Cracking (Stage 2)

Figure 3: Failure (Stage 3)

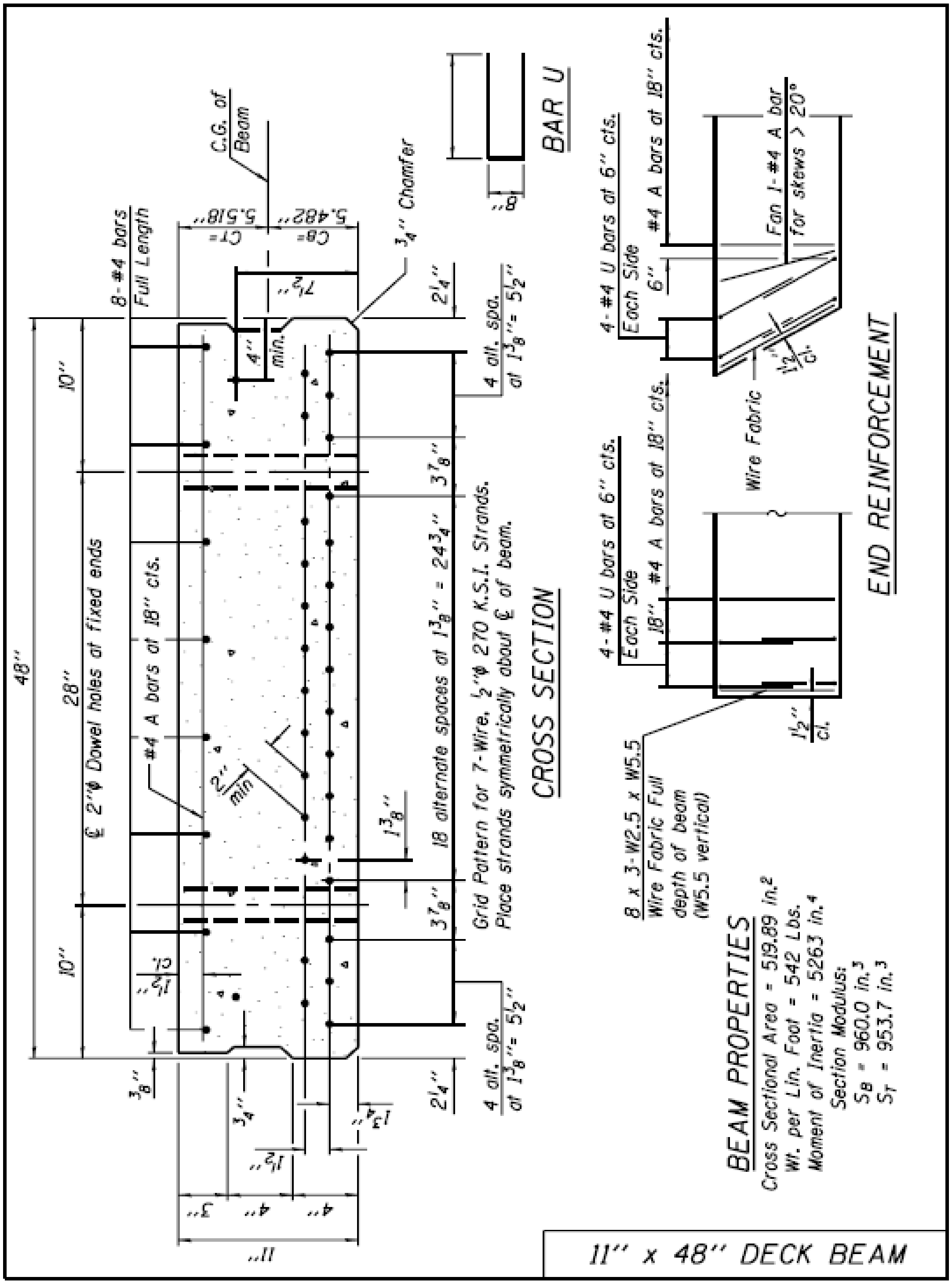

BAR U
C.G. of Beam
CT= 5.518''
CB= 5.482''
3/4'' Chamfer
8-#4 bars Full Length
10''
28''
10''
48''
℄ 2''φ Dowel holes at fixed ends
#4 A bars at 18'' cts.
4 alt. spa. at 1 3/8'' = 5 1/2''
18 alternate spaces at 1 3/8'' = 24 3/4''
Grid Pattern for 7-Wire, 1/2''φ 270 K.S.I. Strands.
Place strands symmetrically about ℄ of beam.
CROSS SECTION
4-#4 U bars at 6'' cts. Each Side
#4 A bars at 18'' cts.
Fan 1-#4 A bar for skews > 20°
Wire Fabric
END REINFORCEMENT
8 x 3-W2.5 x W5.5 Wire Fabric Full depth of beam (W5.5 vertical)
BEAM PROPERTIES
Cross Sectional Area = 519.89 in.^{2}
Wt. per Lin. Foot = 542 Lbs.
Moment of Inertia = 5263 in.^{4}
Section Modulus:
S_B = 960.0 in.^{3}
S_T = 953.7 in.^{3}
11'' x 48'' DECK BEAM

Figure 2.3.1

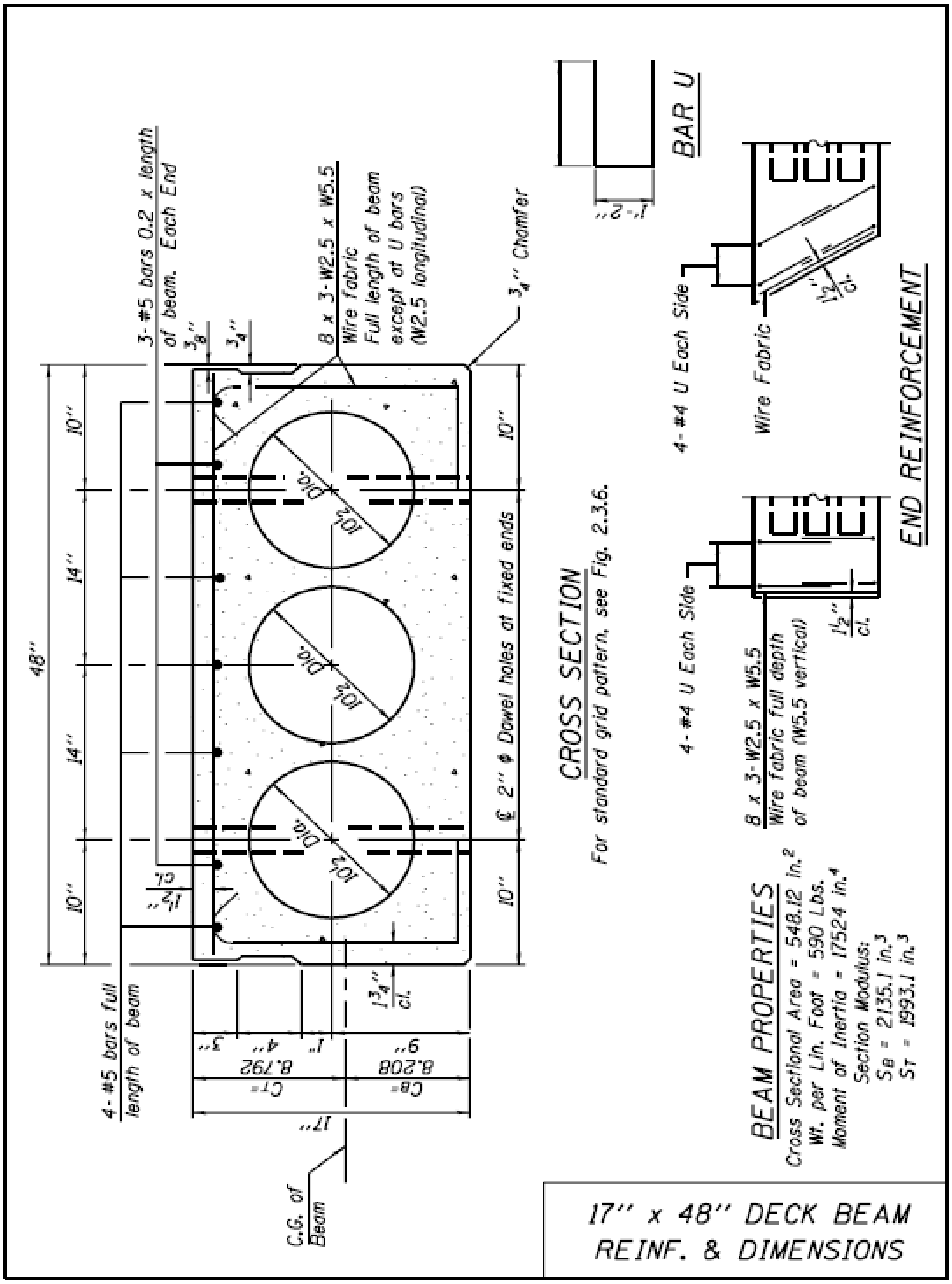

3- #5 bars 0.2 x length of beam. Each End
8 x 3-W2.5 x W5.5 Wire fabric Full length of beam except at U bars (W2.5 longitudinal)
3/4'' Chamfer
BAR U
1'-2''
4- #4 U Each Side
Wire Fabric
1 1/2'' cl.
END REINFORCEMENT
10'' 14'' 14'' 10''
48''
10 1/2'' Dia.
℄ 2'' ϕ Dowel holes at fixed ends
CROSS SECTION
For standard grid pattern, see Fig. 2.3.6.
4- #4 U Each Side
8 x 3-W2.5 x W5.5 Wire fabric full depth of beam (W5.5 vertical)
1 1/2'' cl.
BEAM PROPERTIES
Cross Sectional Area = 548.12 in.²
Wt. per Lin. Foot = 590 Lbs.
Moment of Inertia = 17524 in.⁴
Section Modulus:
SB = 2135.1 in.³
ST = 1993.1 in.³
4- #5 bars full length of beam
1 3/4'' cl.
3'' 4'' 1'' 9''
CT= 8.792
CB= 8.208
17''
C.G. of Beam
17'' x 48'' DECK BEAM
REINF. & DIMENSIONS

Figure 2.3.5

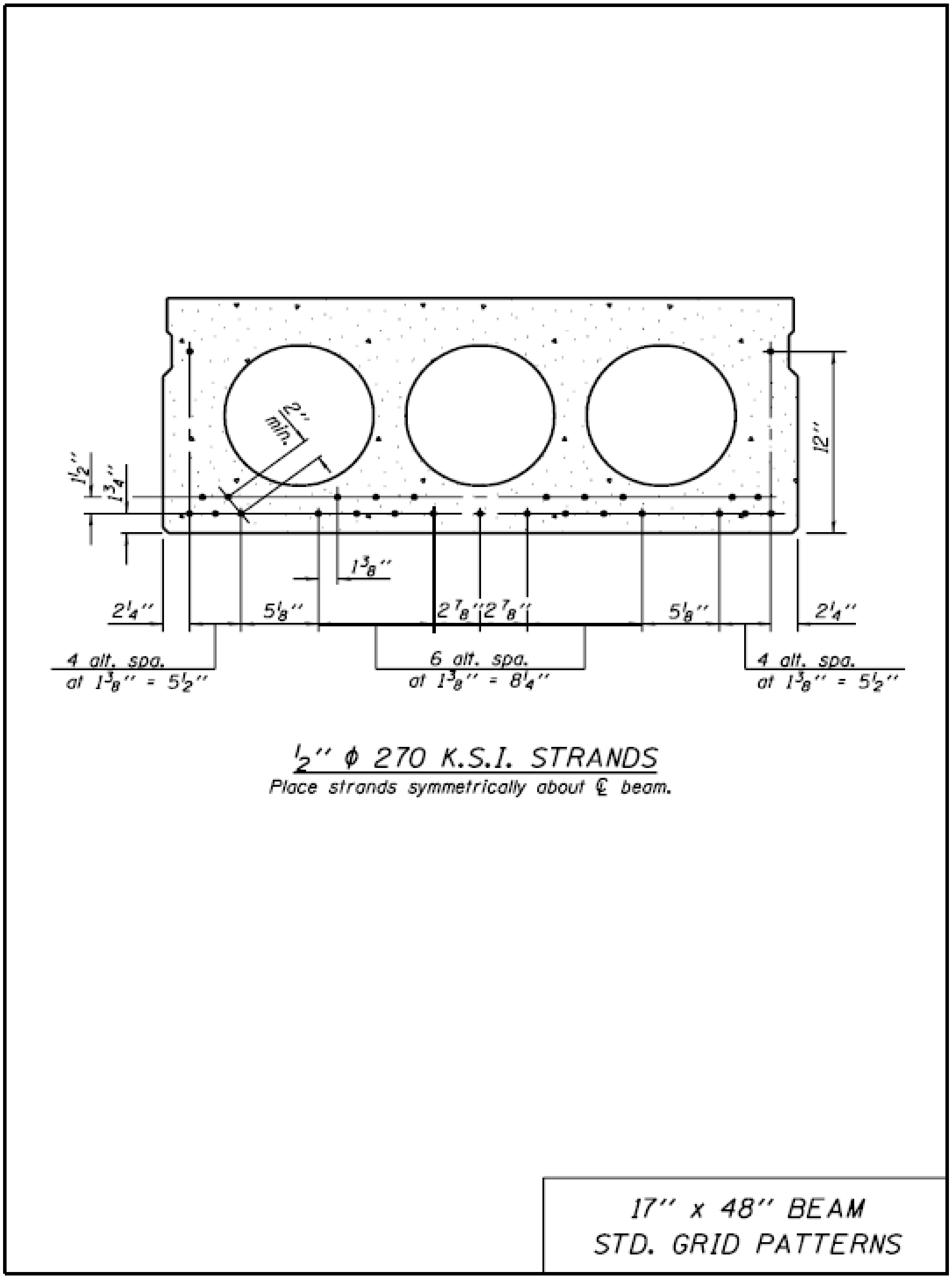

2" min.
1/2"
1 3/4"
12"
1 3/8"
2 1/4"
5 1/8"
2 7/8"
2 7/8"
5 1/8"
2 1/4"
4 alt. spa. at 1 3/8" = 5 1/2"
6 alt. spa. at 1 3/8" = 8 1/4"
4 alt. spa. at 1 3/8" = 5 1/2"
1/2" ϕ 270 K.S.I. STRANDS
Place strands symmetrically about ℄ beam.
17" x 48" BEAM
STD. GRID PATTERNS

Figure 2.3.6

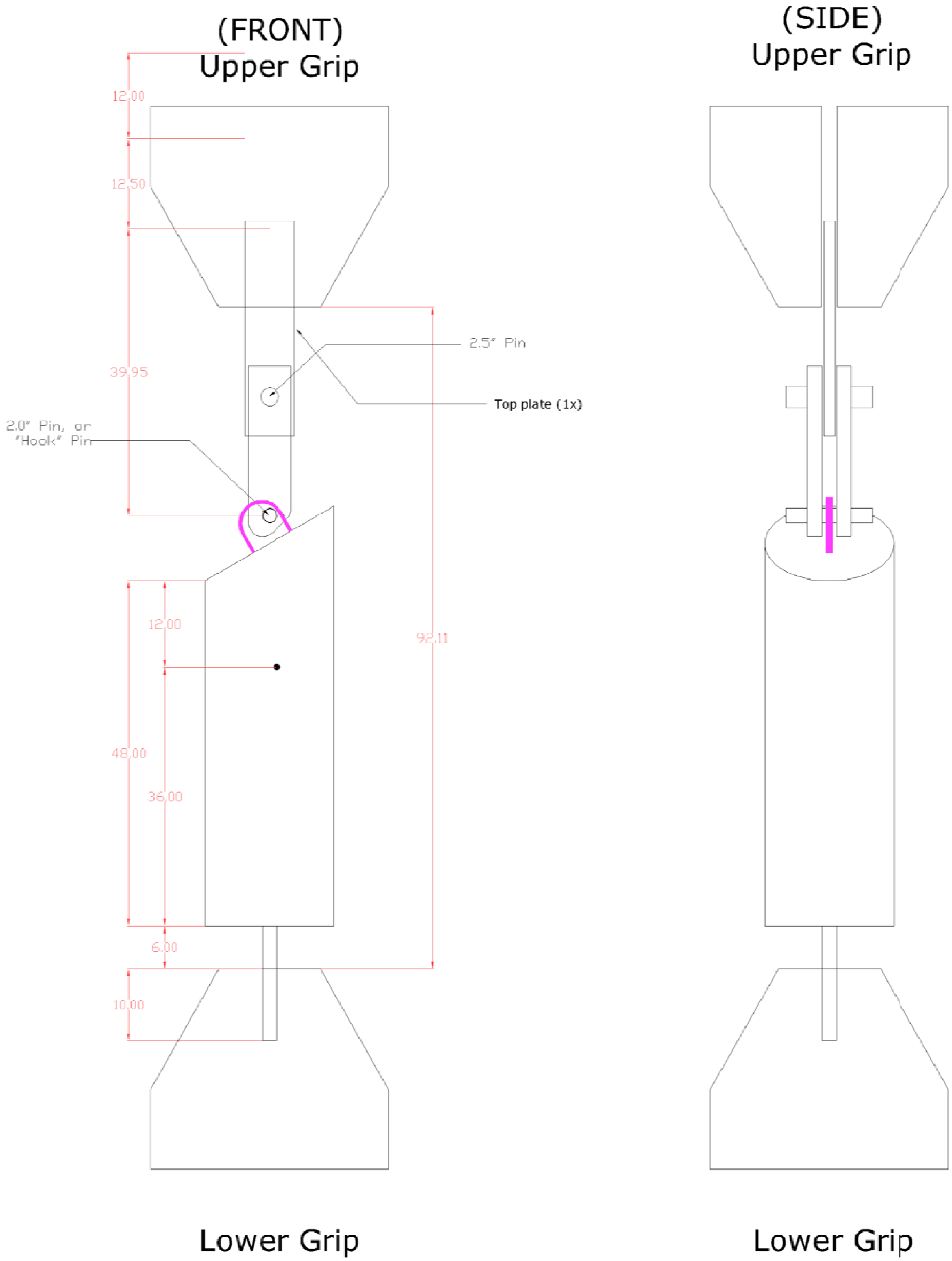
APPENDIX B STRAND RUPTURE TESTS

Strand Rupture Test Results Summary

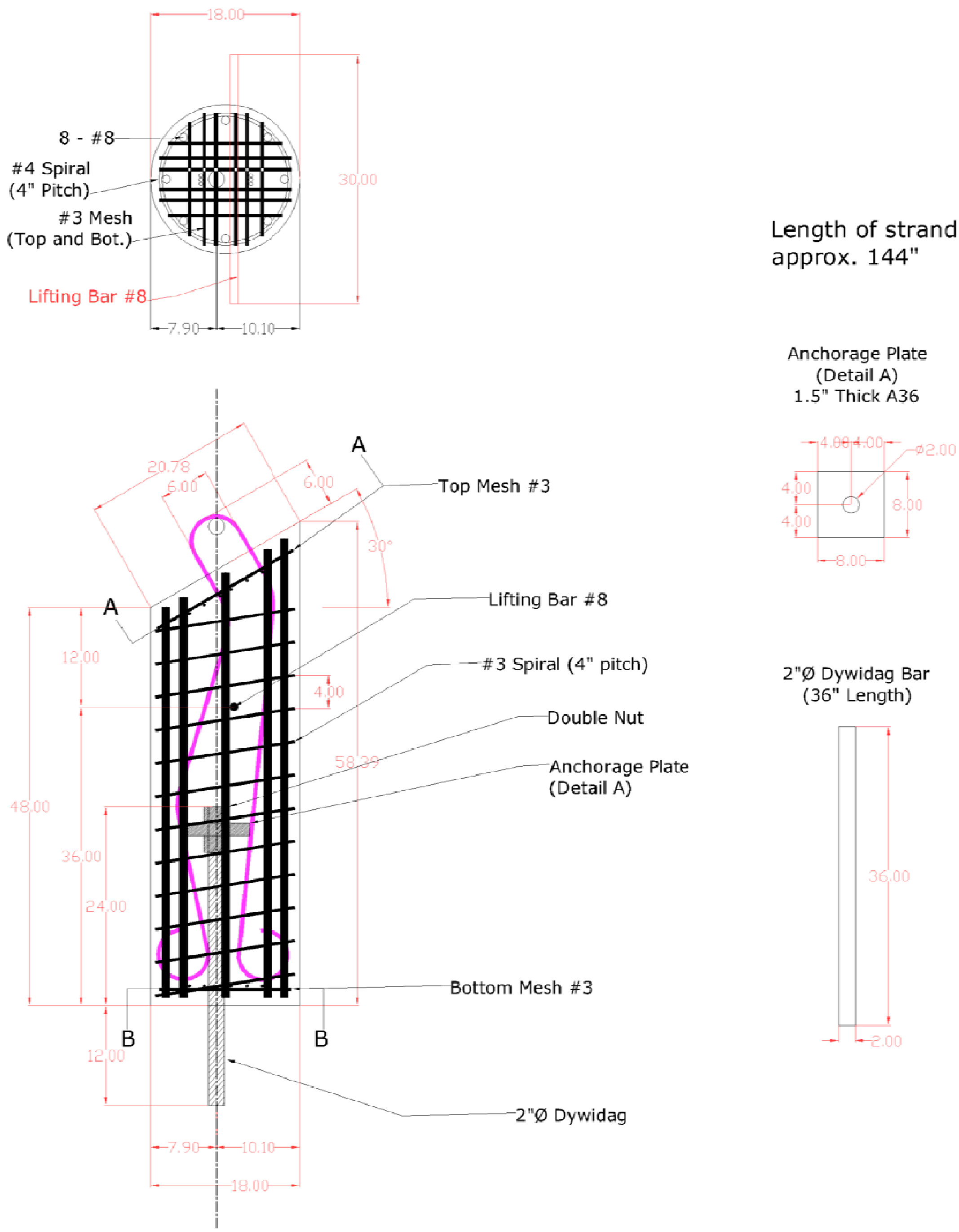
Test ID	# Strands	Pipe	Offset	Angle of Pull	Lifting Mech.	Diagonal Load		Vertical Load		Test Date
						First Wire Rupture (kips)	Max Load (kips)	First Wire Rupture (kips)	Max Load (kips)	
1A-1	1	None	uniform	60	2" Pin	64.1	64.1	55.5	55.5	6/13/2008
1B-1	2	None	uniform	60	2" Pin	103.0	103.0	89.2	89.2	6/13/2008
1C-1	3	None	uniform	60	2" Pin	69.5	128.6	60.2	111.4	6/13/2008
1Co-1	3	None	offset*	60	2" Pin	61.9	69.0	53.6	59.8	6/13/2008
2C-2	3	None	uniform	60	Hook	71.9	90.3	62.3	78.2	6/16/2008
2Co-1	3	None	offset*	60	Hook	46.2	72.3	40.0	62.6	6/16/2008
2A-1	3	1.25" dia. Conduit	uniform	60	2" Pin	146.5	163.2	126.9	141.3	6/13/2008
2A-2	3	1.25" dia. Conduit	uniform	60	2" Pin	-	157.0**	-	136.0**	6/16/2008
2B-1	3	1.25" dia. Conduit	uniform	60	Hook	90.3	107.6	78.2	93.2	6/17/2008
2B-2	3	1.25" dia. Conduit	uniform	60	Hook	102.1	102.6	88.4	88.9	6/17/2008

* Each of the three strands is offset by 0.0", 0.5", and 1.0" respectively

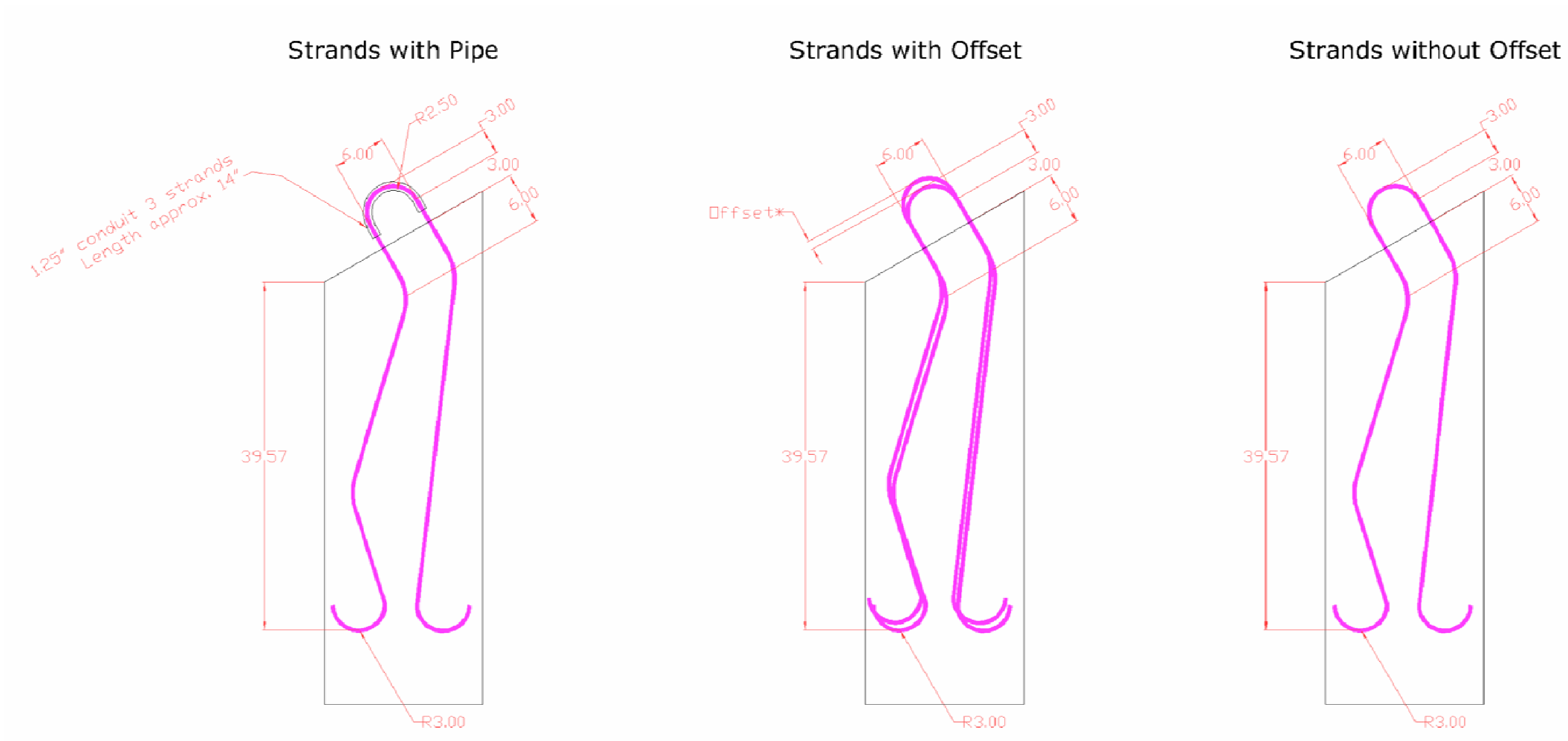
** Not a single wire ruptured during this test



Strand Rupture Test Geometry



Strand Rupture Specimen Geometry



Strand Rupture Specimen Geometry

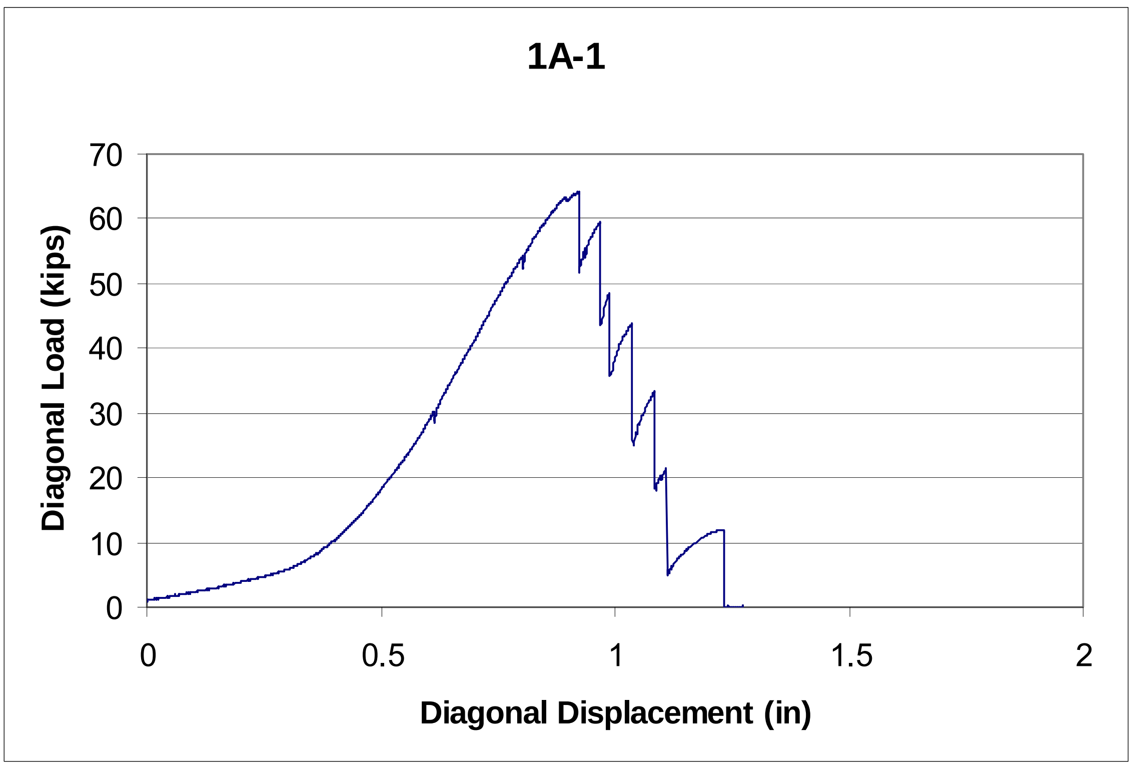
Test ID: 1A-1

Lifting Angle 60 degrees
Test Date: 6/13/2008

Lifting Loop Characteristics

Number of Strands:	1
Pipe:	None
Offset:	Uniform
Lifting Mechanism:	2” Pin

Test ID	Diagonal Load		Vertical Load	
	First Wire Rupture (kips)	Max Load (kips)	First Wire Rupture (kips)	Max Load (kips)
1A-1	64.1	64.1	55.5	55.5



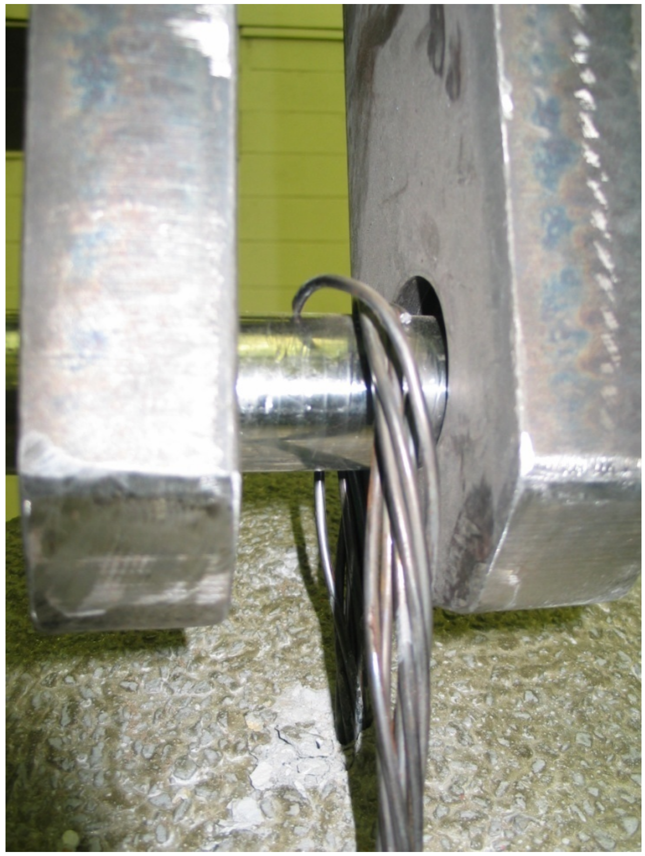


Figure 1: 1A-1

Figure 2: 1A-1

Test ID: 1B-1

Lifting Angle 60 degrees
Test Date: 6/13/2008

Lifting Loop Characteristics

Number of Strands:	2
Pipe:	None
Offset:	Uniform
Lifting Mechanism:	2” Pin

Test ID	Diagonal Load		Vertical Load	
	First Wire Rupture (kips)	Max Load (kips)	First Wire Rupture (kips)	Max Load (kips)
1B-1	103.0	103.0	89.2	89.2

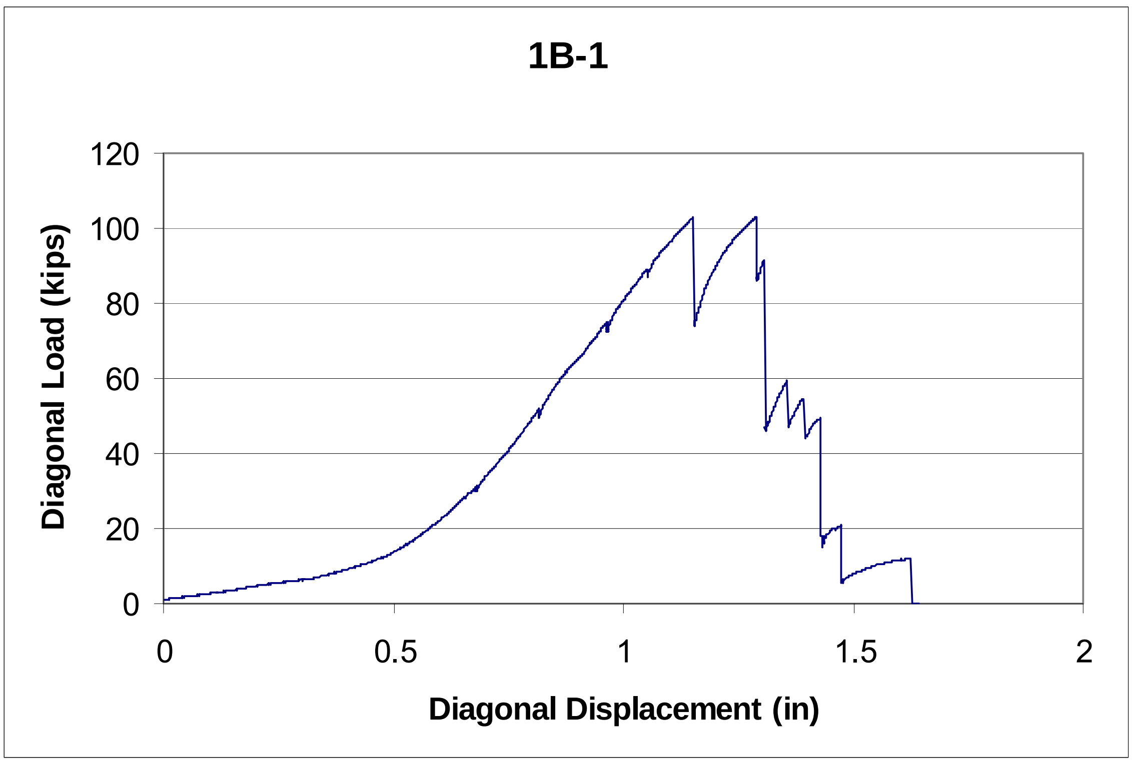


Figure 1: 1B-1

Figure 2: 1B-1

Test ID: 1C-1

Lifting Angle 60 degrees
Test Date: 6/13/2008

Lifting Loop Characteristics

Number of Strands:	3
Pipe:	None
Offset:	Uniform
Lifting Mechanism:	2” Pin

Test ID	Diagonal Load		Vertical Load	
	First Wire Rupture (kips)	Max Load (kips)	First Wire Rupture (kips)	Max Load (kips)
1C-1	69.5	128.6	60.2	111.4

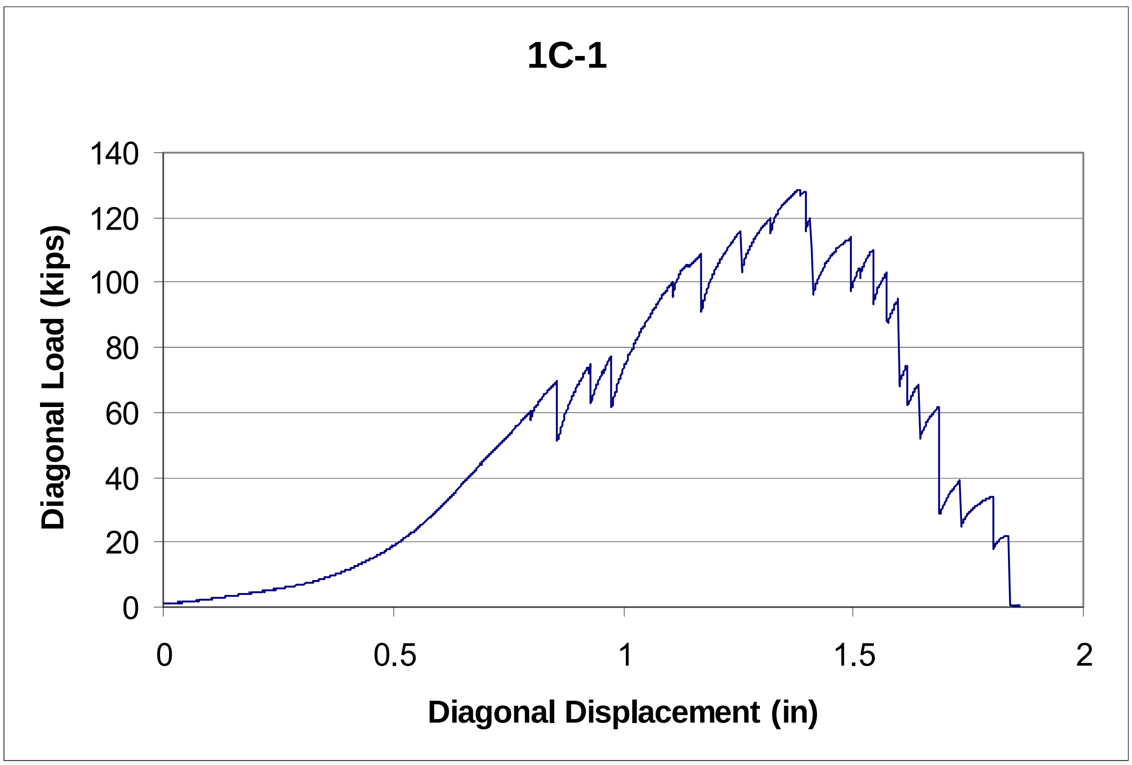



Figure 1: 1C-1

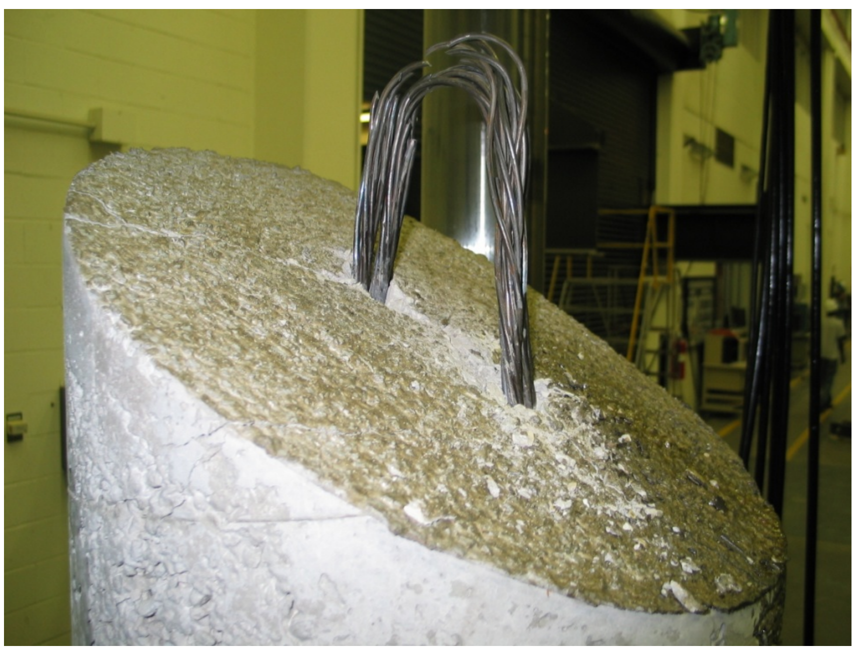


Figure 2: 1C-1

Test ID: 1Co-1

Lifting Angle 60 degrees
Test Date: 6/13/2008

Lifting Loop Characteristics

Number of Strands:	3
Pipe:	None
Offset:	3 strands offset by 0.5 inches
Lifting Mechanism:	2" Pin

Test ID	Diagonal Load		Vertical Load	
	First Wire Rupture (kips)	Max Load (kips)	First Wire Rupture (kips)	Max Load (kips)
1Co-1	61.9	69.0	53.6	59.8

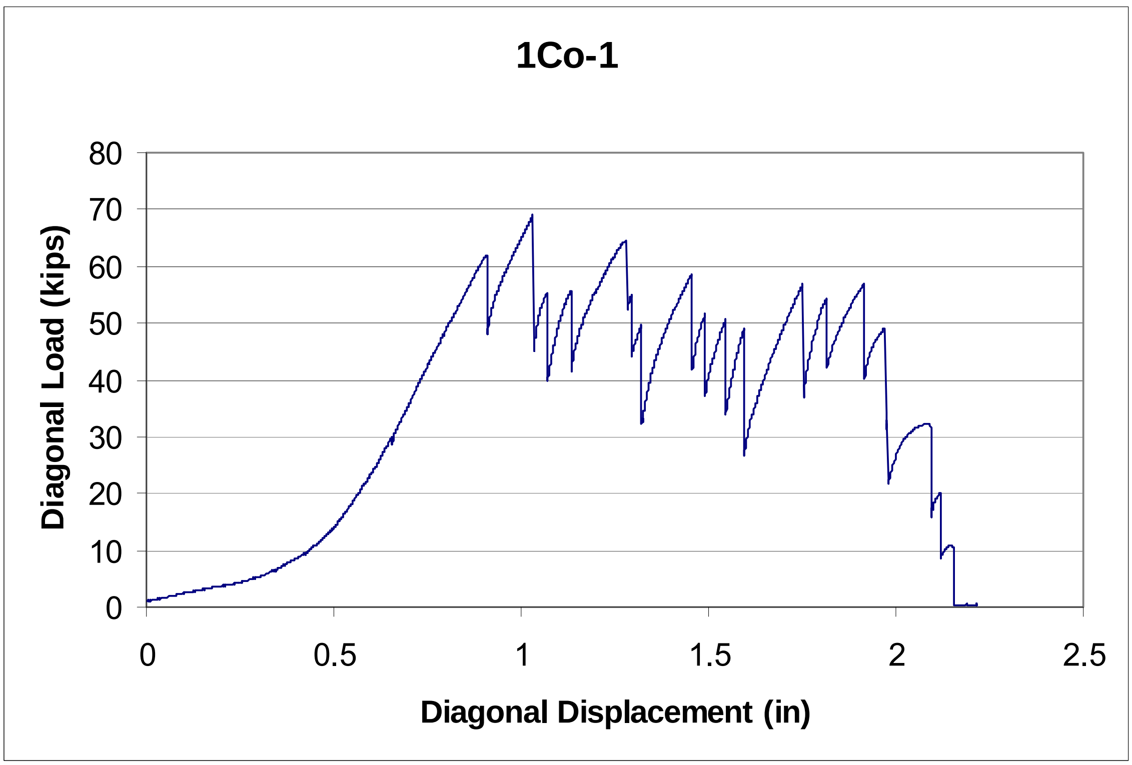


Figure 1: 1Co-1

Figure 2: 1Co-1

Test ID: 2C-2

Lifting Angle 60 degrees
Test Date: 6/16/2008

Lifting Loop Characteristics

Number of Strands:	3
Pipe:	None
Offset:	Uniform
Lifting Mechanism:	Hook

Test ID	Diagonal Load		Vertical Load	
	First Wire Rupture (kips)	Max Load (kips)	First Wire Rupture (kips)	Max Load (kips)
2C-2	71.9	90.3	62.3	78.2

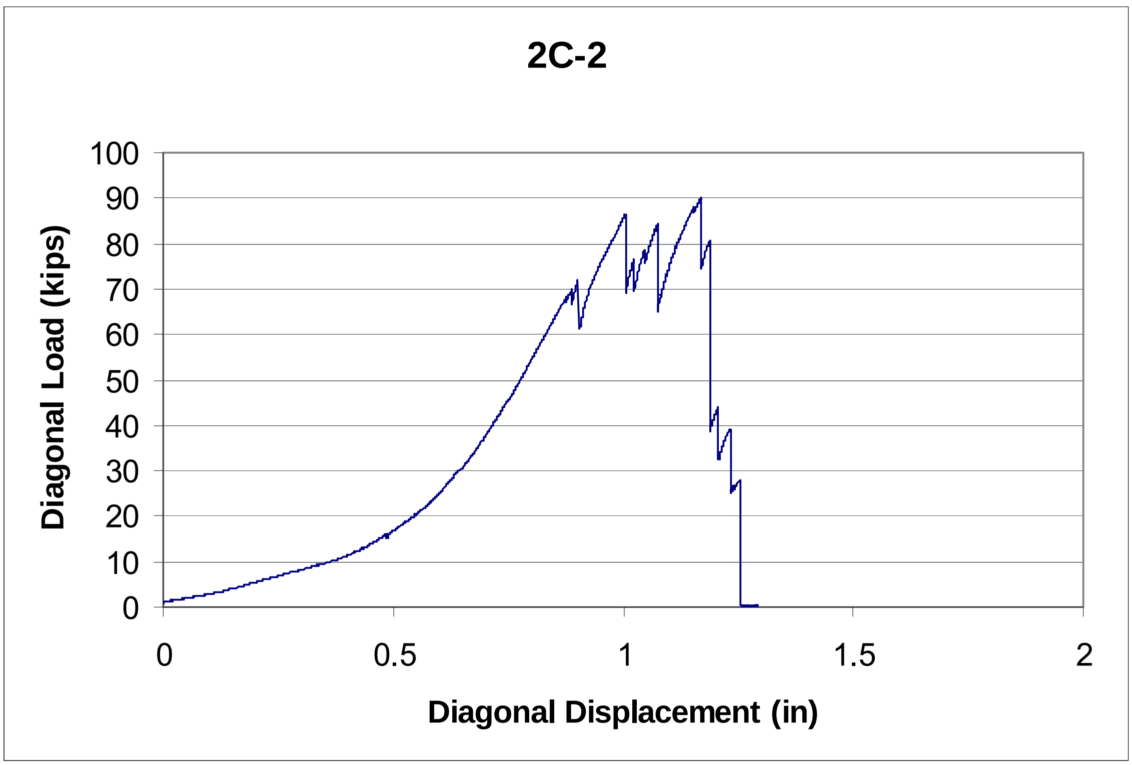


Figure 1: 2C-2

Figure 2: 2C-2

Test ID: 2Co-1

Lifting Angle 60 degrees
Test Date: 6/16/2008

<u>Lifting Loop Characteristics</u>

Number of Strands:	3
Pipe:	None
Offset:	3 strands offset by 0.5 inches
Lifting Mechanism:	Hook

Test ID	Diagonal Load		Vertical Load	
	First Wire Rupture (kips)	Max Load (kips)	First Wire Rupture (kips)	Max Load (kips)
2Co-1	46.2	72.3	40.0	62.6

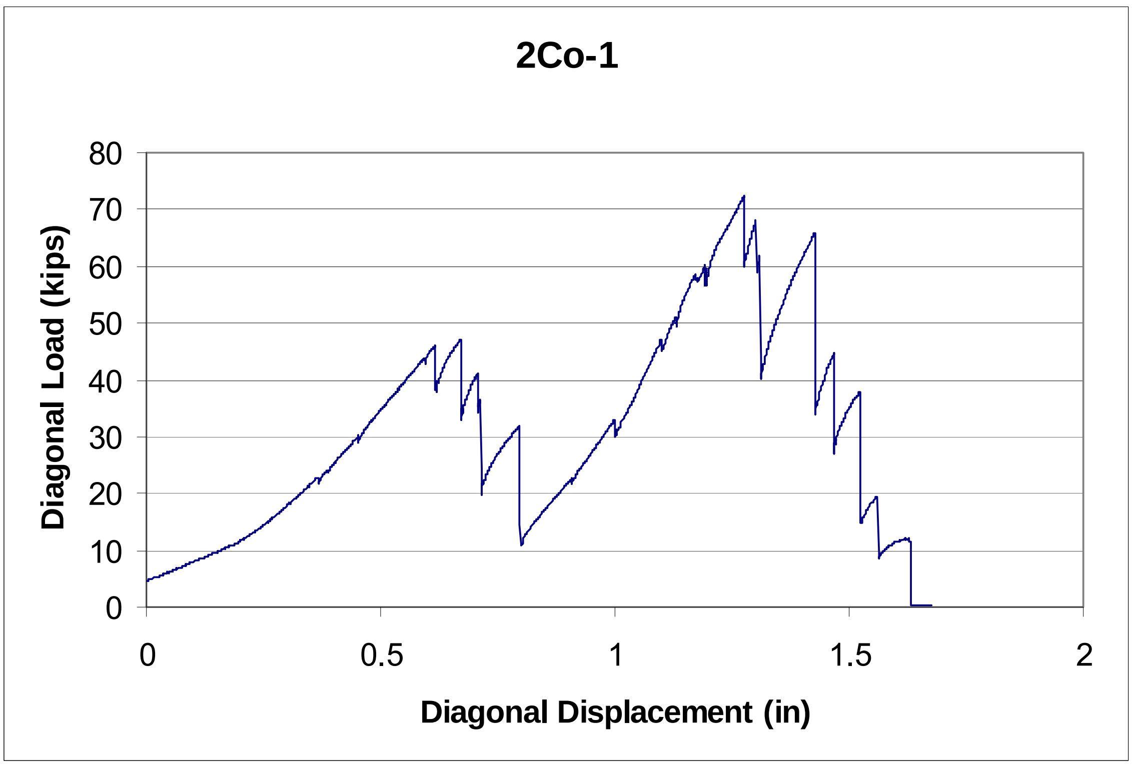


Figure 1: 2Co-1

Figure 2: 2Co-1

Test ID: 2A-1

Lifting Angle 60 degrees
Test Date: 6/13/2008

Lifting Loop Characteristics

Number of Strands:	3
Pipe:	1.25” dia. Conduit
Offset:	Uniform
Lifting Mechanism:	2” Pin

Test ID	Diagonal Load		Vertical Load	
	First Wire Rupture (kips)	Max Load (kips)	First Wire Rupture (kips)	Max Load (kips)
2A-1	146.5	163.2	126.9	141.3

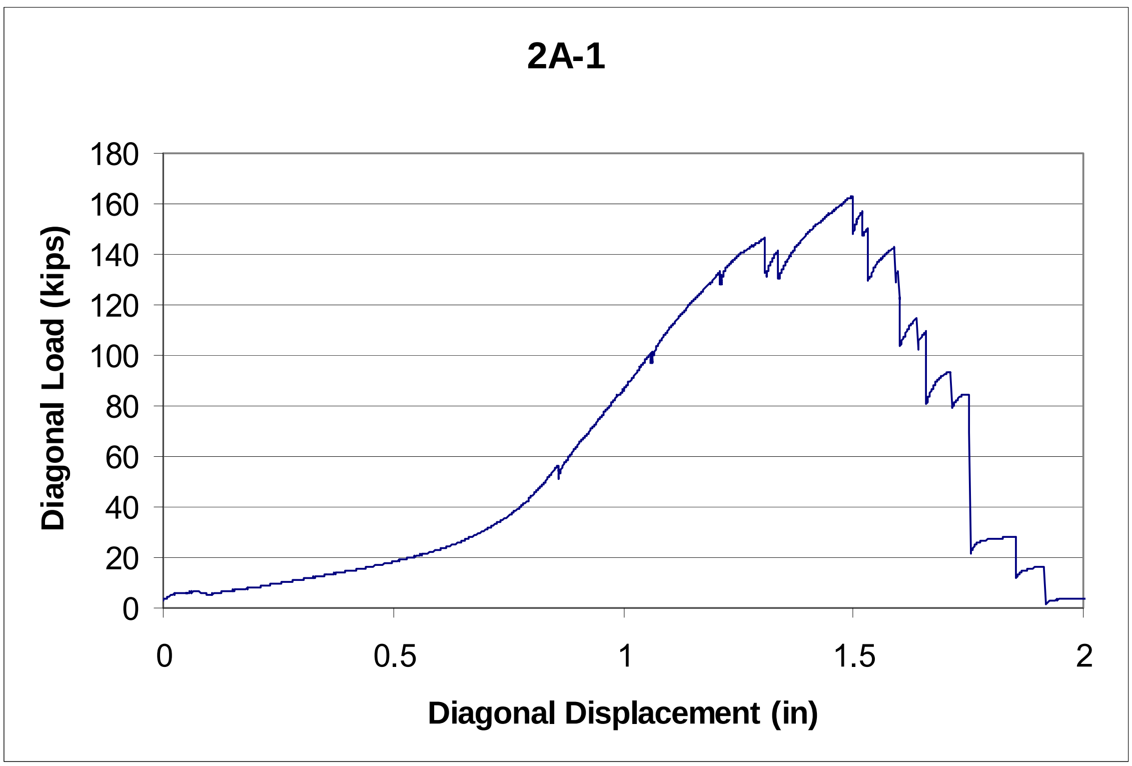


Figure 1: 2A-1

Figure 2: 2A-1

Test ID: 2A-2

Lifting Angle 60 degrees
Test Date: 6/16/2008

Lifting Loop Characteristics

Number of Strands:	3
Pipe:	1.25" dia. Conduit
Offset:	Uniform
Lifting Mechanism:	2" Pin

Test ID	Diagonal Load		Vertical Load	
	First Wire Rupture (kips)	Max Load (kips)	First Wire Rupture (kips)	Max Load (kips)
2A-2	-	157.0*	-	136.0*

* Not a single wire ruptured during this test

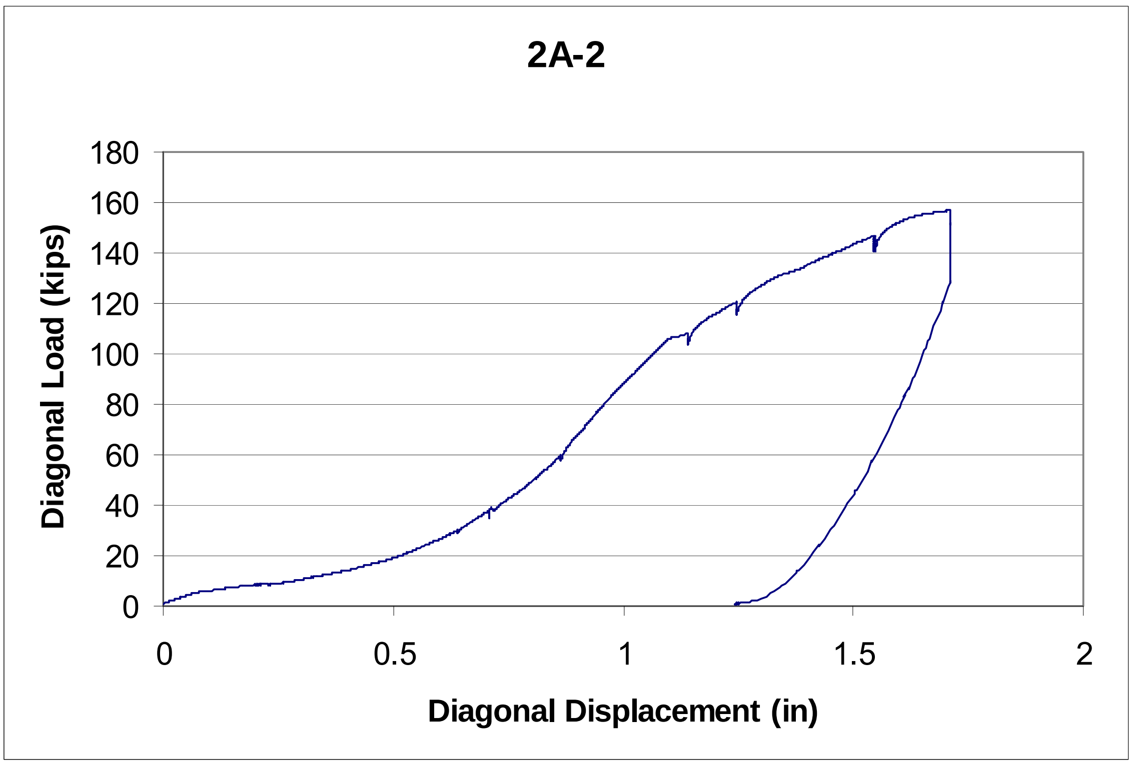


Figure 1: 2A-2

Figure 2: 2A-2

Test ID: 2B-1

Lifting Angle 60 degrees
Test Date: 6/17/2008

Lifting Loop Characteristics

Number of Strands:	3
Pipe:	1.25” dia. Conduit
Offset:	Uniform
Lifting Mechanism:	Hook

Test ID	Diagonal Load		Vertical Load	
	First Wire Rupture (kips)	Max Load (kips)	First Wire Rupture (kips)	Max Load (kips)
2B-1	90.3	107.6	78.2	93.2

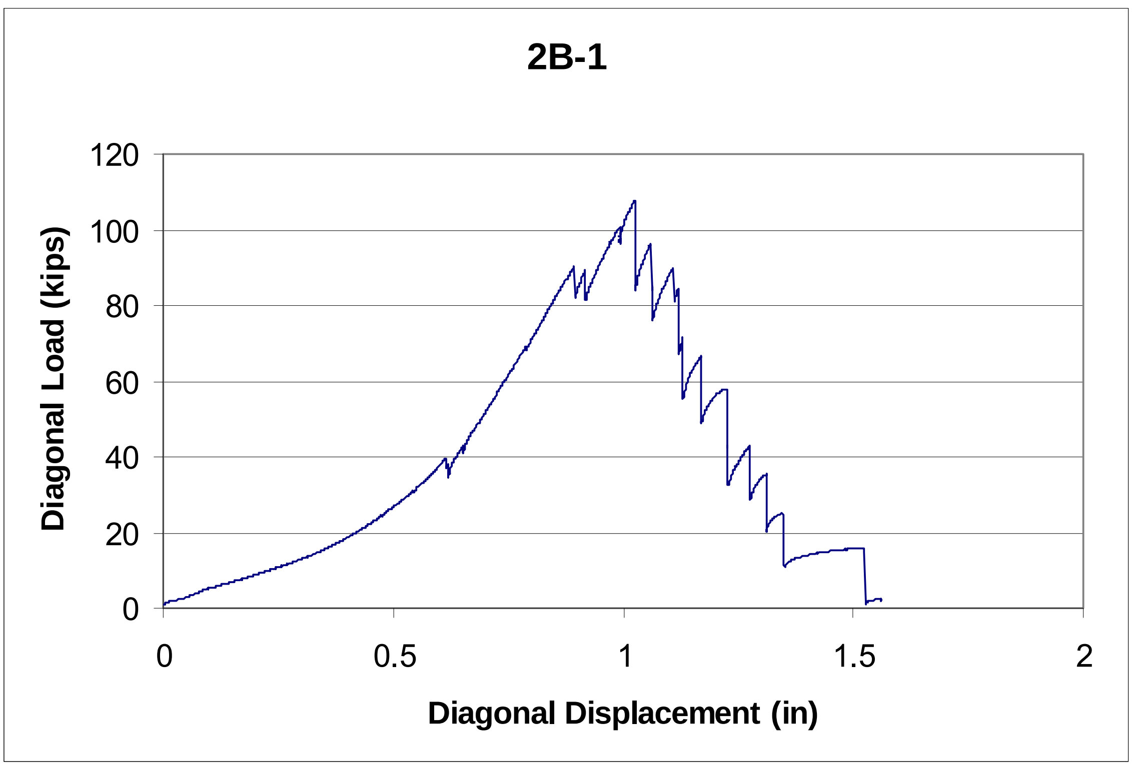


Figure 1: 2B-1

Figure 2: 2B-1

Test ID: 2B-2

Lifting Angle 60 degrees
Test Date: 6/17/2008

Lifting Loop Characteristics

Number of Strands:	3
Pipe:	1.25” dia. Conduit
Offset:	Uniform
Lifting Mechanism:	Hook

Test ID	Diagonal Load		Vertical Load	
	First Wire Rupture (kips)	Max Load (kips)	First Wire Rupture (kips)	Max Load (kips)
2B-2	102.1	102.6	88.4	88.9

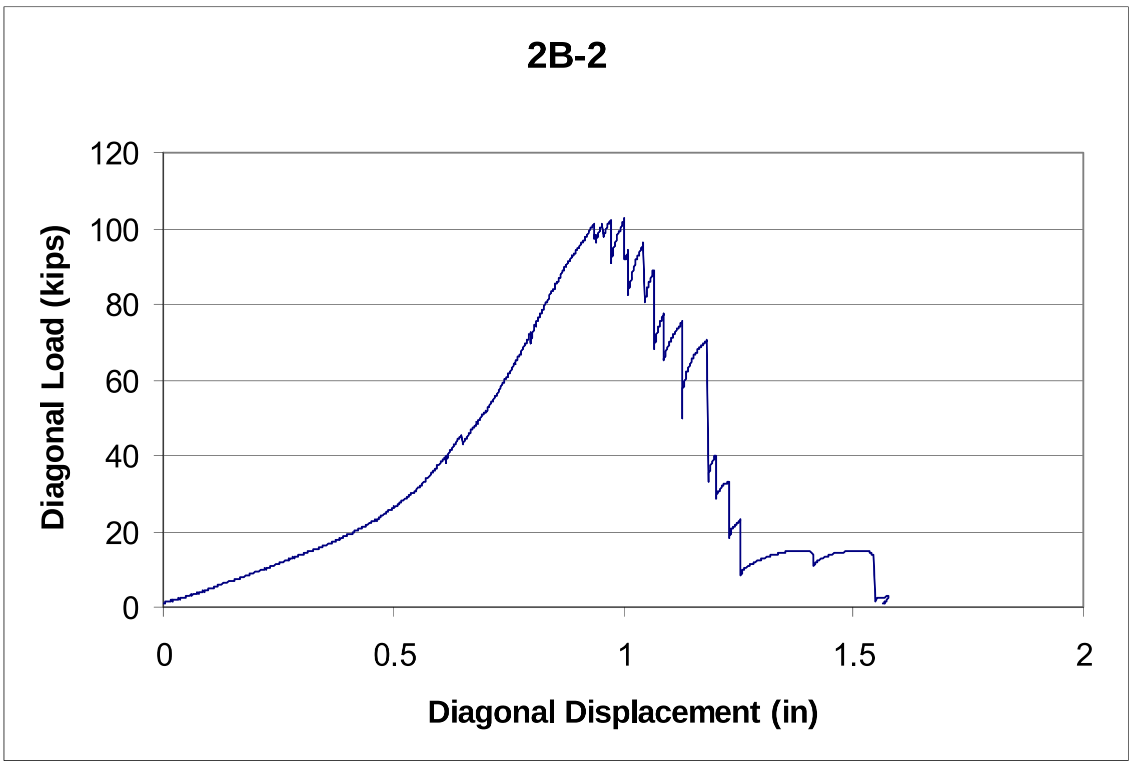
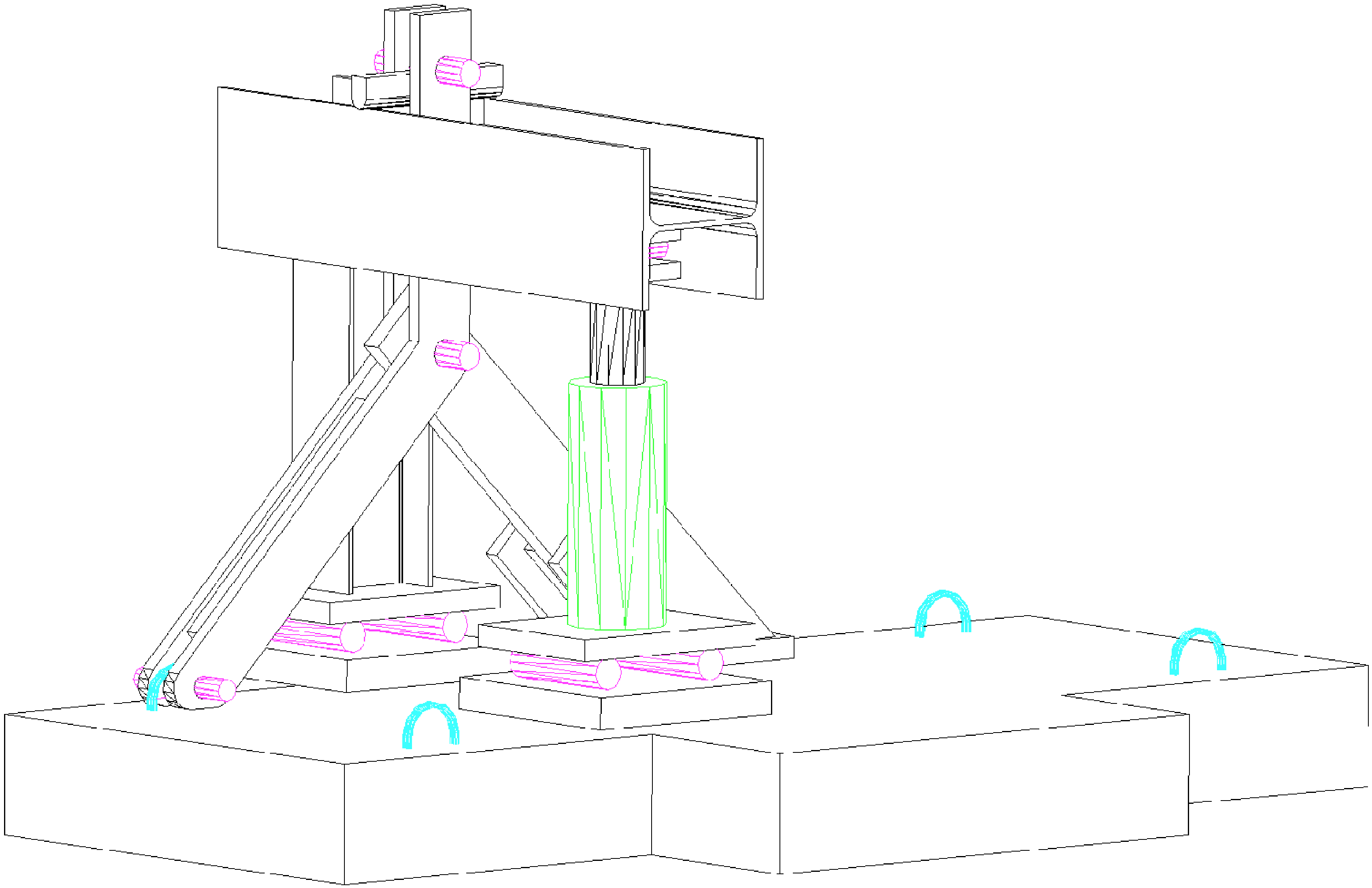


Figure 1: 2B-2

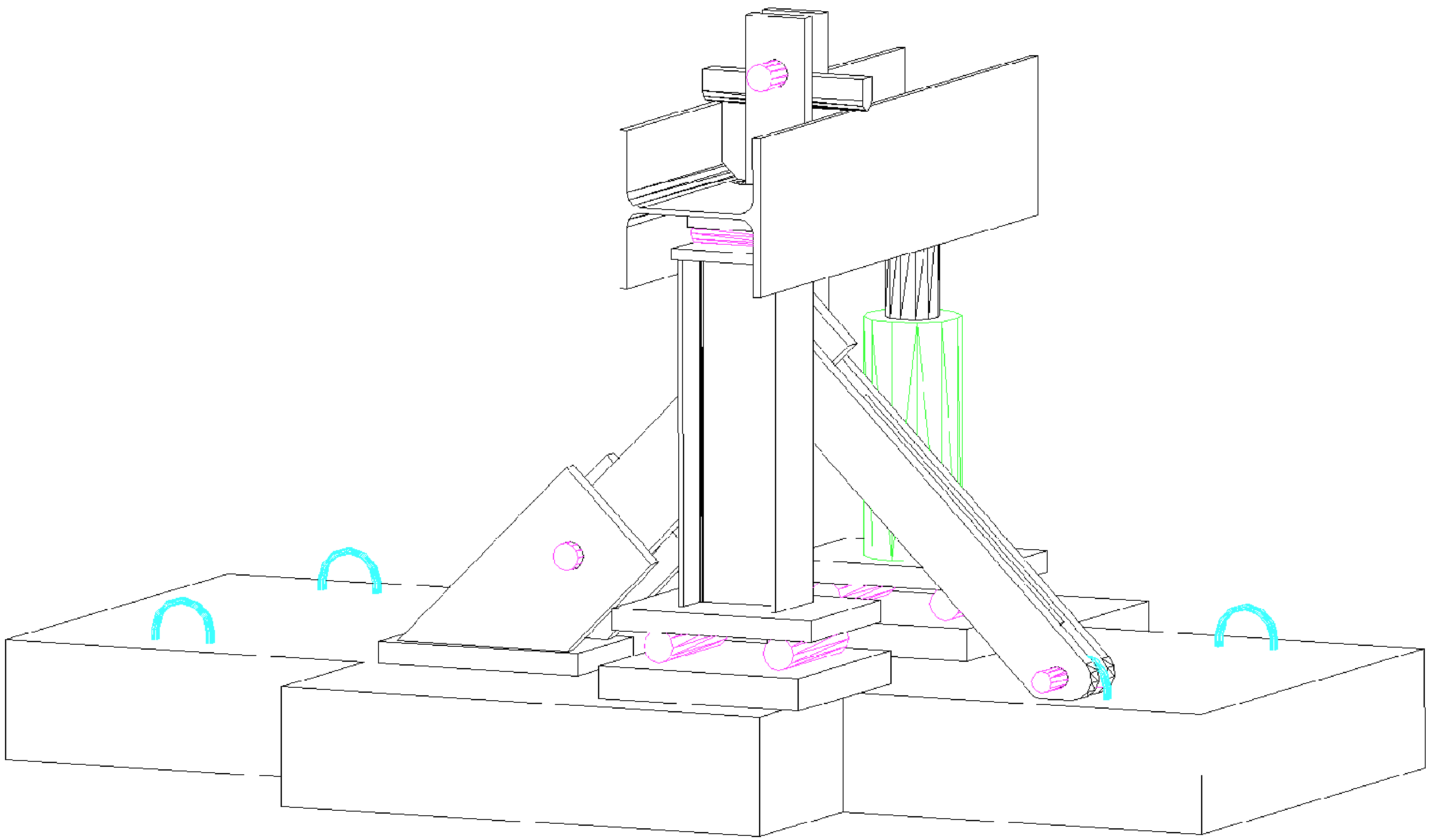
Figure 2: 2B-2

APPENDIX C TEST APPARATUS

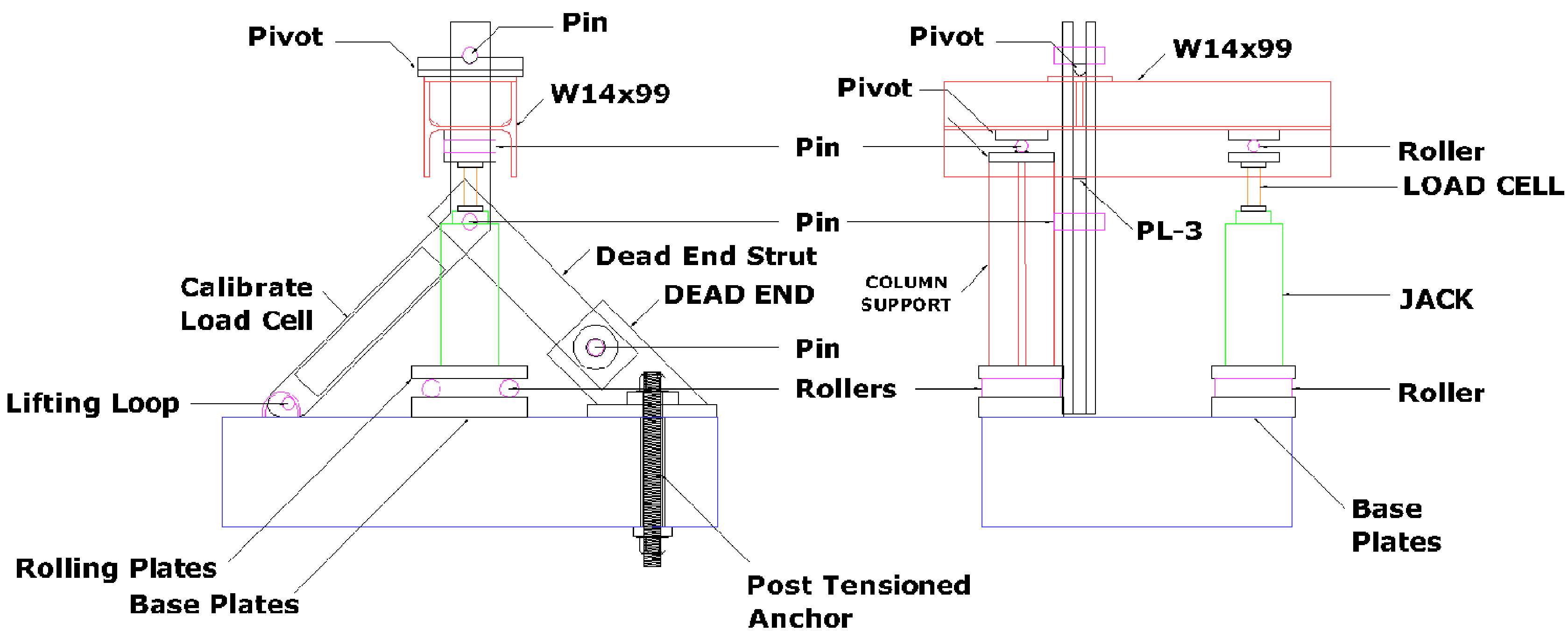
Test Apparatus



Test Apparatus

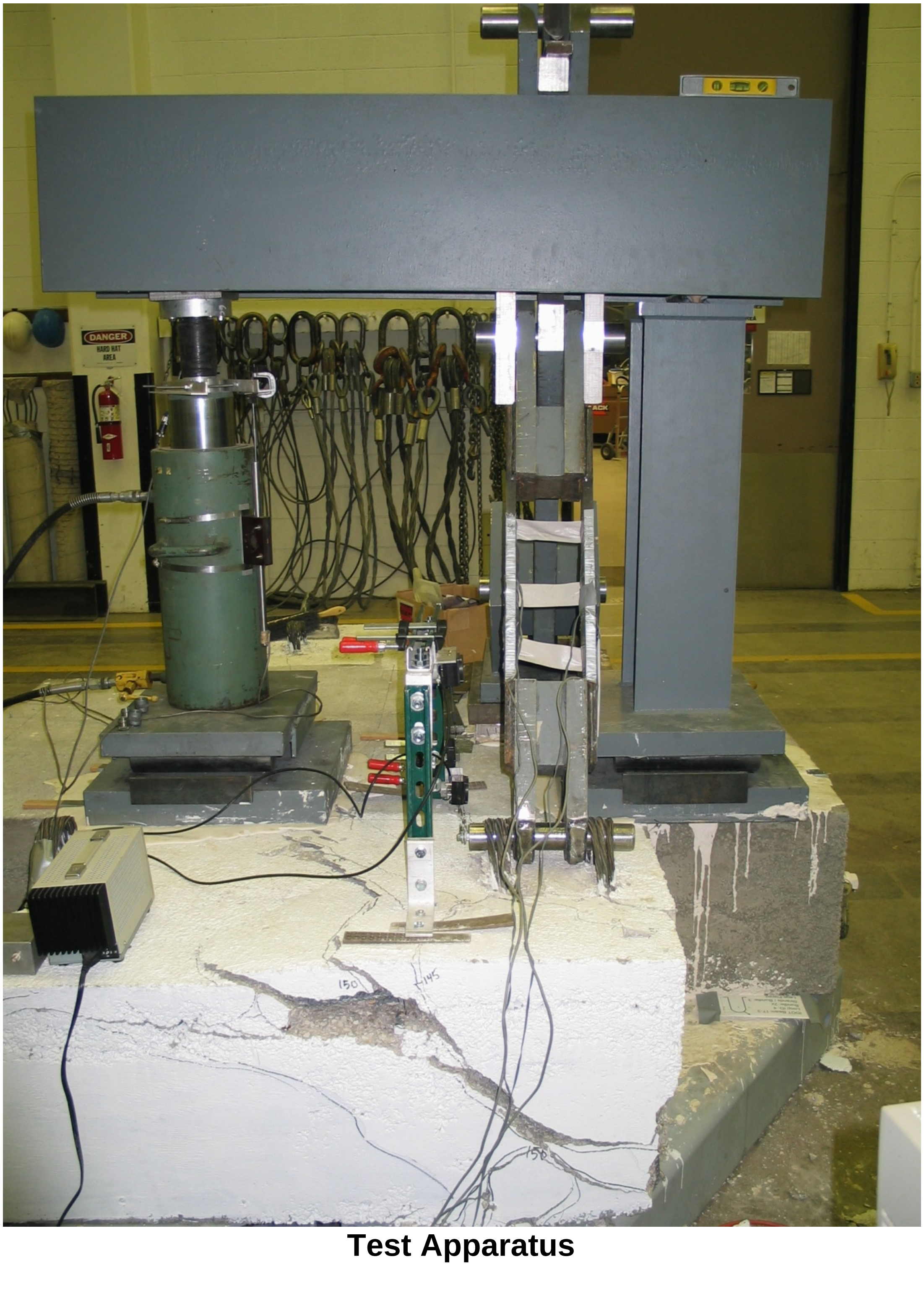


Test Apparatus Parts



Test Apparatus

Test Apparatus



Test Apparatus

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