ASSESSING THE BOND QUALITY
OF PRESTRESSING STRANDS
USING NASP BOND TEST

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CHAPTER I

1.0 INTRODUCTION

Prestressed concrete, a blend of concrete and high strength steel finds application in a variety of structural elements. Since the construction of the Philadelphia Walnut Lane Bridge in 1949, the use of this technology has grown popular in the bridges in North America. With the advent of high strength concrete and high strength steel, the industry has taken strides. Prestressed concrete has found its application in many structural components used in modern construction.

For prestressed concrete members to act as structural components, it is necessary for the prestressing strand to bond with the surrounding concrete to maintain structural integrity. With a wide variety of prestressing strands available, it has become necessary to wisely predict the bonding abilities of the prestressing strand with concrete. Improper bond of prestressing strands with concrete has persuaded researchers to investigate the problem. This research work makes an effort to understand the bonding abilities of prestressing strand using a test method called the NASP Bond Test and relating them to prototype prestressed concrete beams.

1.1 BACKGROUND

Research in the area of bond characteristics of prestressing strand with concrete dates back to 1954 when studies were conducted on the bond characteristics of prestressing strands (Janney 1954). With technological advances in the material science, further studies were conducted over the past sixty years investigating various aspects of bond.

In order to understand the bonding abilities of prestressing strand, it is important to assess the transfer length, or the length at which the effective prestress is transferred to concrete. Accepted design expressions in ACI-318 and AASHTO LRFD Bridge Code for transfer lengths in prestressing strands involve only the strand diameter as variable. Researchers (Buckner 1994; Cousins 1990; Lane 1998; Mitchell 1993) have found that the transfer length may not be just a function of the strand diameter, but a function of the concrete strengths as well.

Though several studies have been done, an accepted test procedure to predict the bonding abilities of the strand has not yet been established. Researchers (Brown 2003; Cousins 1992; Ferzli 2000; Logan 1997) have conducted extensive studies on the reliability and repeatability of various strand pull out tests which were widely used. Among the strand pull out tests, the North American Strand Producer's (NASP) Bond test has shown convincing results (Brown 2003).

1.2 RESEARCH OBJECTIVES

The primary objective of this research program is to modify a strand pull out test that can produce repeatable and reproducible results. Secondly, the outcome from the standardized test procedure is compared to prestressed concrete beams made with varying concrete strengths, varying strand sources, and other research. The pull out test is related to prototype beams to better understand the bond characteristics of prestressing strand.

1.3 TESTING PROGRAM

The experimental program consisted of two main phases. In the first phase, NASP pull out test was conducted on twelve different strand sources which included both 0.5 in (12.7mm) and 0.6in (15.2mm) diameter strands. To standardize the test procedure, two strand samples were tested for varying water to cement ratios of 0.40, 0.45, and 0.50. The test was conducted using load control and displacement control before finalizing the procedure. A total of 233 individual NASP pull out tests were conducted in mortar as a part of the present testing program. The testing program also included 126 NASP pull out tests in concrete with varying strengths.

In the second phase, prestressed concrete beams were made using different types of strands and various concrete release strengths. A total of forty three rectangular shaped beams and eight I-shaped beams were made to measure the transfer length of the strands at release and at later stages.

1.4 SCOPE

This research program included the two major phases of experimental research

1. NASP Bond test
2. Measurement of transfer lengths

The NASP Bond test was conduced on twelve different sources of strands which included 0.5 and 0.6 in. diameters. The test was standardized in mortar using two strand sources with varying mortar strengths from 4000 to 6000 psi, and different loading methods which included load control and displacement control. The test was also performed at Purdue University and University of Arkansas after standardizing the procedure at Oklahoma State University. The NASP Bond test was also performed in concrete using three 0.5 in. diameter strands and one 0.6 in. diameter strand. The NASP Test performed in concrete had concrete strengths varying from 4000 to 10,000 psi concrete.

The measurement of transfer lengths were made on prestressed concrete rectangular and I-shaped beams. The transfer lengths were measured on three 0.5 in. diameter strands and one 0.6 in. diameter strand. The measurements were made using Detachable Mechanical (DEMEC) strain gauges and end slip of the strands using reference clamps.

1.5 THESIS ORGANIZATION

This thesis is organized into five chapters. The first chapter is an introduction to the background of the work and research objectives. The second chapter deals with the previous significant research work done in the area of bond of prestressing strand with concrete. The third chapter deals with the NASP Bond Test, the experimental program, procedures, results and discussion. The fourth chapter deals with NASP Bond test in concrete, the experimental program, procedures, results and discussion. The fifth chapter discusses the Transfer Length measurements on prestressed concrete beams, the experimental program, test results, and discussion of results. The sixth chapter summarizes the results and makes recommendations for future studies.

CHAPTER II

2.0 LITERATURE REVIEW

This chapter outlines the major previous experimental research work done previously in transfer length and bond tests of prestressing strands. In this chapter, emphasis is given in defining various terminology used.

The bond quality of prestressing strands is of major concern, as there is a bond length required to transmit the effective prestressing force from the strand to the concrete which is called the transfer length. As of now, there are no acceptance criteria or a standardized test procedure for the bond performance of the prestressing strands. It is therefore necessary to have a test procedure that will help in understanding the bond performance of the prestressing strand.

In order to understand the transfer length in prestressing strands, it is inevitable to appreciate the various bond mechanisms that prevail between the strand and the concrete.

2.1 BOND MECHANISMS

The three bond mechanisms that prevail between the prestressing strand and the concrete are (Hanson 1959; Russell 1992)

1. Adhesion
2. Hoyer's Effect
3. Mechanical Interlocking

2.1.1 Adhesion

An adhesive force prevails between the concrete and the steel prestressing strand in the absence of relative movement. However, adhesion cannot exist in the presence of a relative movement between the concrete and the strand. Within the transfer zone, adhesion is not a major contributor for bond between the concrete and the prestressing strand, although the contribution is of minor significance in the central region where the strand stresses are uniform. The relative slip of the strand and the bond stress were plotted by researchers (Russell 1992) and is shown in Fig. 2.1. It can be seen that adhesion inhibits the relative movement of the strand to the concrete until a threshold level of some critical bond stress. Reaching the critical bond stress, adhesive force is lost and the contribution becomes insignificant.

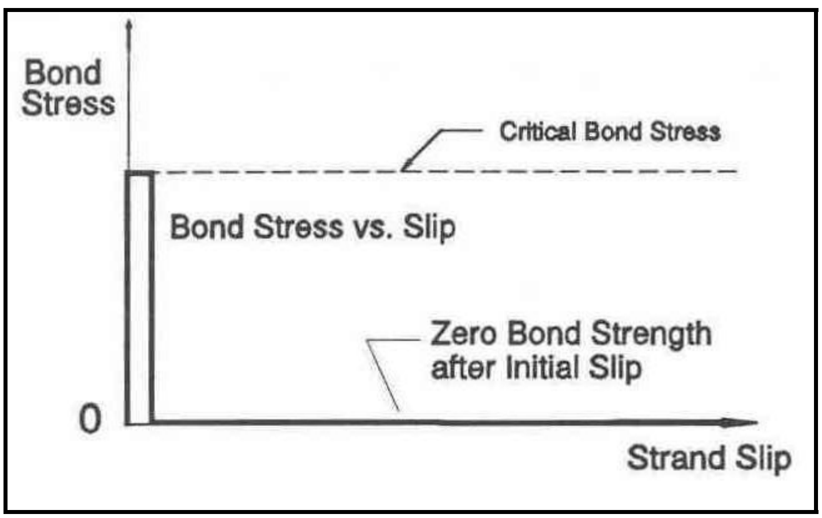


Figure 2.1: Bond Stress and Strand Slip (Russell 1992)

2.1.2 Hoyer's Effect

Studies (Hoyer 1939) investigated the mechanism that prevailed between the smooth prestressing steel wires and concrete. Hoyer's effect or wedge action is a phenomenon that prevails in the transfer zone which occurs when the prestressed strand is detensioned or released. When the strand is tensioned, the diameter of the strand reduces which can be assessed by the Poisson's ratio of the strand. Once the strand is released from tension, the strand attempts to regain its original dimension. The concrete surrounding the strand inhibits lateral expansion of the strand. The restraint acts as radial forces on the strand causing frictional resistance in the longitudinal direction. This frictional force holds the prestressing strand preventing it from a relative movement with respect to the surrounding concrete. This action is termed as Hoyer's effect or the wedge action. Though the presence of the Hoyer's effect has been theorized, it is difficult to find experimental evidence for the existence of this mechanism. Earlier studies (Russell 1992) are shown in Fig. 2.2 which illustrates the wedging action theorized by E. Hoyer and characterized as "Hoyer's Effect"

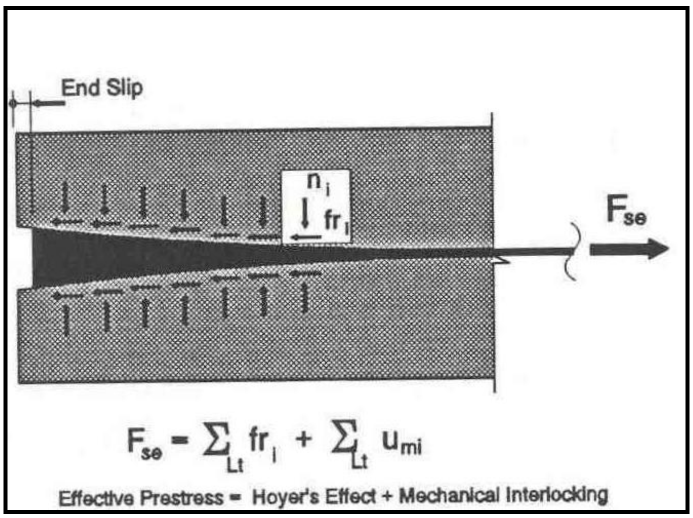


Figure 2.2: Hoyer's Effect (Russell 1992)

2.1.3 Mechanical Interlock

In pretensioned concrete, after the concrete is cast surrounding the seven wire prestressing strand, the concrete flows into the interstices or the crevices of the strand. Once the concrete hardens, ridges are formed around the strand preventing the strand from moving without twisting. This mechanism called mechanical interlocking which helps prevent the prestressing strand from slipping and unwinding. The seven wire prestressing strand contains a single wire at the center called the "king wire". The six other wires surround the king wire in a helical fashion. A component of the normal force acts in the longitudinal direction of the strand. This force component helps resist relative slip between the strand and the concrete. "*Mechanical interlock will develop in pretensioned members only if twisting of the strand is prevented*" (Gross 1995)

Figure 2.3 illustrates the mechanism where the ridges around the strand resist the prestressing steel in tension from twisting.

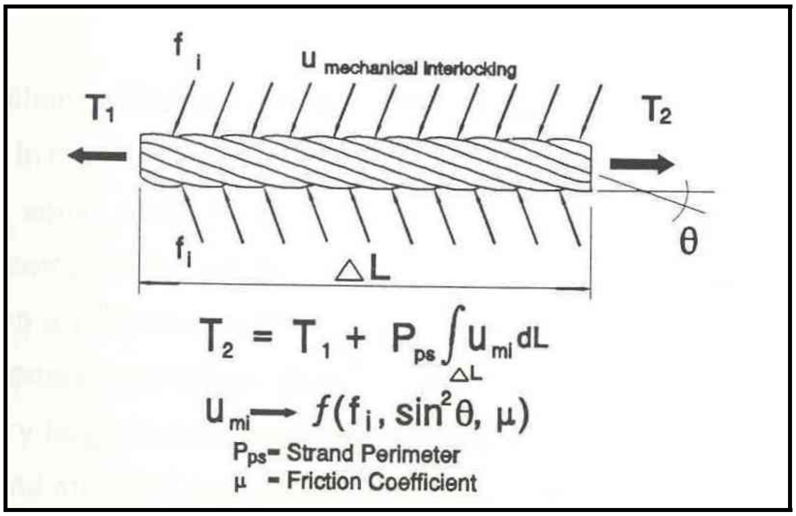


Figure 2.3: Mechanical Interlocking (Russell 1992)

Figure 2.4 illustrates the contribution of the bond stresses discussed earlier in bond mechanisms. The contribution from Hoyer's effect and the mechanical interlocking is difficult to quantify (Russell 1992) in the transfer zone. Figure 2.4 shows the variation of the stress levels in the prestressing steel in the transfer zone, where the end slip has occurred.

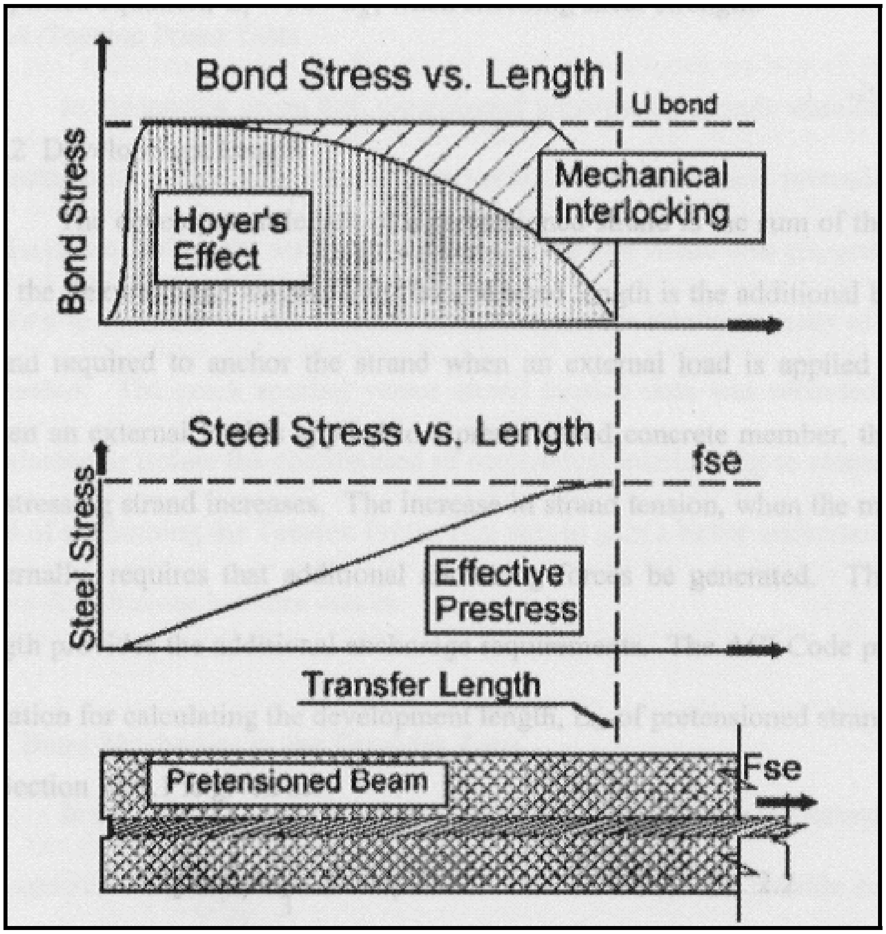


Figure 2.4: Stress Distribution in steel (Russell & Burns 1993)

2.2 TRANSFER LENGTH

In pretensioned concrete, transfer length is the distance required to transmit the effective prestressing force from the strand to the concrete. The transfer is attained through the bond mechanisms discussed earlier in Section 2.1. The region of concrete spanned by the transfer length is called as the transfer zone.

As per ACI Code provisions (ACICommittee 2002), transfer length is *"the distance over which the strand should be bonded to the concrete to develop the prestress* f_{se} *in the strand.*" The current ACI Code provisions provide the transfer length distance for a seven wired prestressing strand which is given by:

$$L_t = \left(f_{se} / 3 \right) \times d_b$$

Where L_t, is the transfer length in inches

f_{se} is the effective stress in the strand in ksi

d_b is the nominal strand diameter in inches

Figure 2.5 reproduces from ACI Code the variation of stresses in the prestressing steel along the length of the beam. It can be seen in Fig. 2.5 that the transfer length is the distance at which the stresses in the steel reach an effective prestress of f_{se} at the development length is the length required in the member to reach the stress in the steel at nominal strength of f_{ps}.

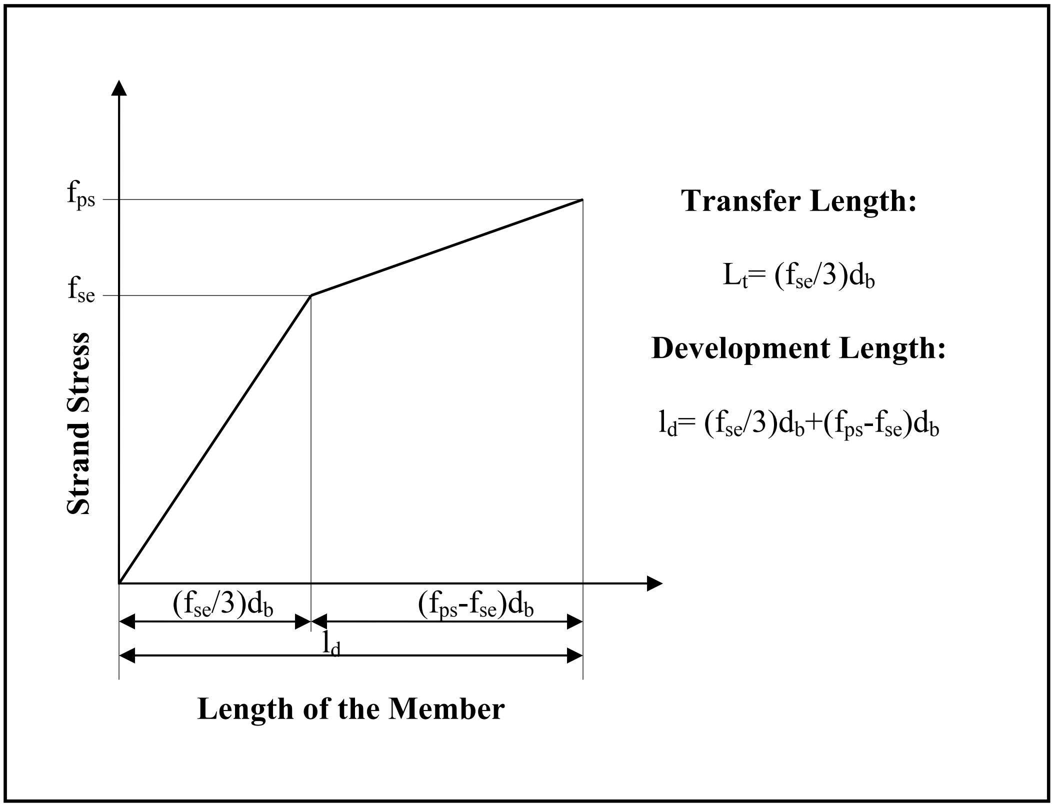


Figure 2.5: Relationship between steel stress and length (Reproduced from ACI 318-02, R-12.9)

2.2.1 Importance of Transfer Length

In most design cases, an accurate assessment of transfer length is neither a necessity, nor a design requirement. The significance of transfer length is predominant in assessing the cracking loads. It is shown in studies (Russell 1992; Russell 1996) that the transfer zone is susceptible to cracking as the stress in the steel has not reached its effective prestress. Previous studies conducted by Russell in 1992 also concluded that the anchorage failures are prevented if the cracks do not propagate through the transfer zone.

Assessing the transfer length of the pretensioned member will help to estimate the type of failure.

2.3 BACKGROUND

2.3.1 Mitchell, Cook, Khan, Tham (1993)

The experimental research (Mitchell 1993) conducted in Canada investigated the influence of high strength concrete on transfer and development length of pretensioning strand. Twenty two concrete beams were tested with concrete strengths at release varying from 3050 to 7250 psi. (21 to 50 MPa) The research investigated 3/8, ½, and 0.60 in. (9.5, 12.7, 15.24 mm) diameter strands. To determine the transfer length from the concrete strain measurements, a slope-intercept method was employed where the transfer length is measured from the end of the beam to the intercept of the line in the transfer region and a horizontal line in the constant strain region. For all the test beams, the strands were released in a gradual manner. The research showed convincing relationship between concrete strengths and transfer lengths. The authors suggested the transfer length relationship as a function of the concrete strength, strand diameter, and the stress in the strand at transfer as:

$$L_t = \left(\frac{f_{pi} \times d_b}{3}\right) \times \sqrt{\left(\frac{3}{f'_{ci}}\right)}$$

They also suggested a simpler form of the equation for checking the stresses near the end of the members for shorter transfer lengths as

$$L_t = (50 \times d_b) \times \sqrt{\left(\frac{3}{f'_{ci}}\right)}$$

where, f_{pi} Stress in the strand immediately after transfer (ksi)

d_b Diameter of the strand (inches)

f'_{ci} Concrete compressive strength at the time of release

2.3.2 Tabatabai & Dickson (1993)

A historical perspective of the prestressing strand development length equation in the AASHTO Bridge specifications was studied for this research program. The AASHTO Equation for transfer length was

$$L_t = f_{se}/3$$

the present ACI 318-05 code expression for Transfer length.

To understand the above code expression, researchers studied some of the previous works (Cousins 1990; Deatherage and Burdette 1991; Hanson 1959; Lane 1992; Mattock 1962; Russell 1992; Shahawy 1992). The authors plotted the transfer lengths based on the strand diameter to emphasize on the scatter in the data. The plot presented (Tabatabai 1993) is shown in Fig. 2.6.

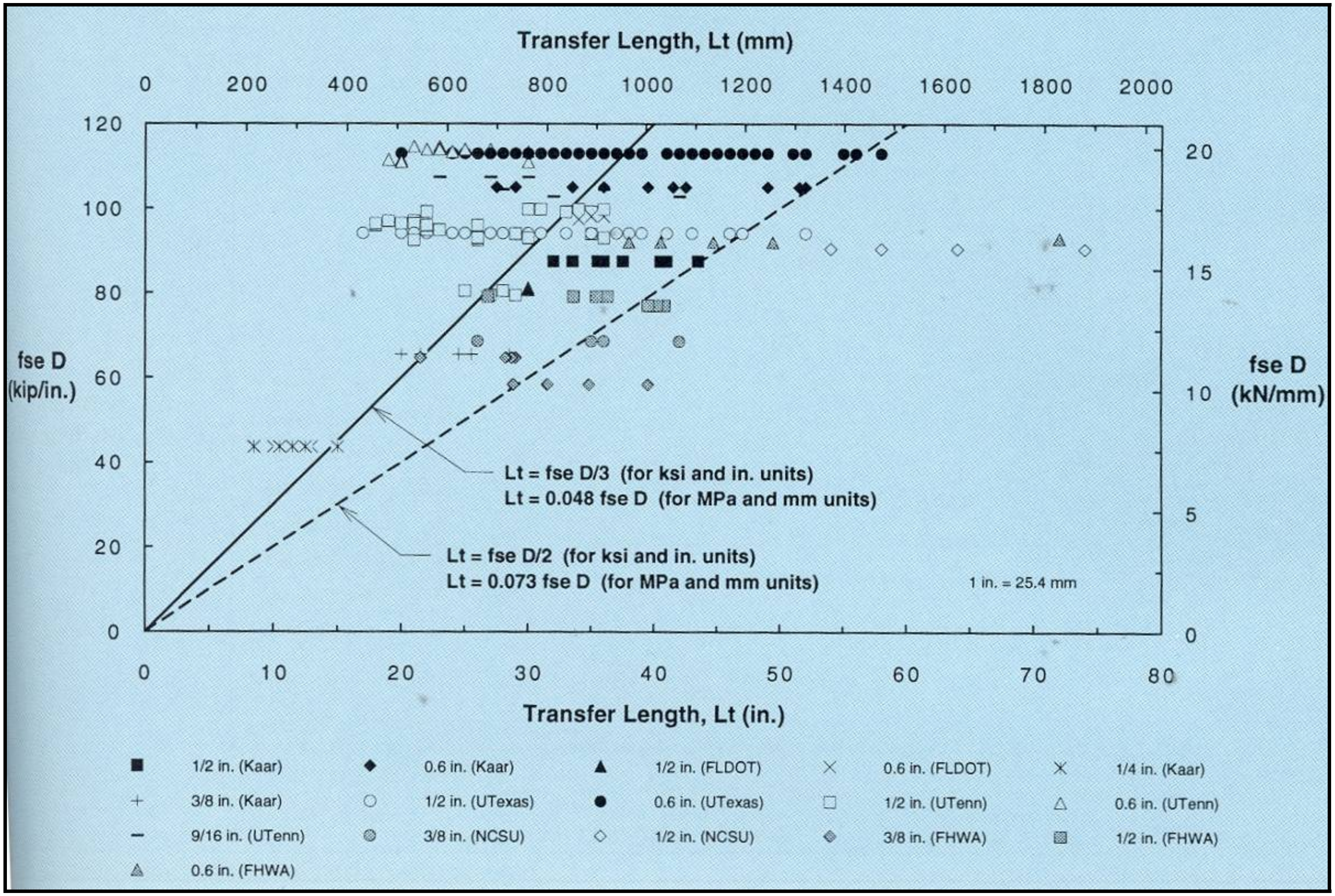


Figure 2.6: Transfer lengths and Strand Diameters (Tabatabai 1993)

In Fig. 2.6 the data has got significant scatter for a particular strand diameter. The data included experimental research data conducted from 1959 through 1993 on Grade 250 and 270 ksi strands. The researchers concluded that the transfer length equation was based on the equilibrium of the force in the strand and the product of the strand circumference, strand bond stress which was taken as 400 psi, and the transfer length. The researchers commented that the code expression of $L_t = \left(f_{se}/3 \right) \times d_b$ represents the "approximate midrange" of all the values and $L_t = \left(f_{se}/2 \right) \times d_b$ (Russell 1992) represents an "approximate maximum" transfer length.

2.3.3 Russell & Burns (1996)

The emphasis of this work (Russell 1996) was to measure the transfer length of 0.5 in. and 0.6 in. (12.7 and 15.2 mm) diameter strands and to recommend revisions for the existing transfer length expressions. The research variables included strand spacing, debonding the strand, confining the reinforcement, number of strands per specimen, and size and shape of the cross section. The average transfer length measurements performed on 34 ends of pretensioned specimens for 0.5 in. strands was 29.5 in. (749 mm) with a 6.9 in. (175 mm) standard deviation and the average transfer length performed on 40 ends of 0.6 in. strands was 40 in. (1.02 m) with a standard deviation of 6.8 in. (170 mm). It was also concluded that the transfer length for debonded strands were shorter than the fully bonded strands. Because the mechanisms of transfer for 0.6 in. diameter strands were similar to that of the 0.5 in. diameter strands, and because the 0.6 in. strands were found to transfer the prestressing forces effectively, the use of 0.6 in. diameter strands in pretensioned concrete was recommended. The researchers approved the transfer length expression to remain as a function of the diameter of the strand based on the experimental work. Among other findings by the researchers, larger cross sections had shorter transfer lengths than specimens with smaller cross sections.

From the data examined and in comparing their data with historical data for transfer length, the researchers concluded that the ACI equation was unconservative. Recommendations were given to change the ACI equation of transfer length to a rational and safe expression:

$$L_t = \left(f_{se}/2 \right) \times d_b$$

where, L_t : Transfer length in inches

f_{se} : Effective stress in the strand after prestress losses in ksi

d_b : Diameter of the strand in inches

2.3.4 Russell & Burns (1997)

This research paper (Russell 1997) reported the results from an experimental program that measured the transfer lengths of 0.5 in. (12.7mm) and 0.6 in. (15.2mm) diameter seven wire Grade 270 low relaxation pretensioned strands. In the experimental program, 18 single strand specimens were tested. Among the 18 specimens tested, 14 were fully bonded and the remaining four had a plastic debonding material wrapped for 8 in. (203mm) from the ends of the member. All the beams were made from rectangular cross sections with concrete strength at release ranged from 4000 psi (28 MPa) and 6000 psi (41 Mpa). Concrete surface strains were measured from the sides of the beam using Detachable Mechanical (DEMEC) strain gauges. End slip measurements of the strands were also taken using dial gauges and steel rulers. To measure the transfer lengths, concrete surface strains were plotted along the length of the beam. The transfer lengths were measured from this plot using the 95% Average Maximum Strain (AMS) method.

95% Average Maximum Strain Method

In this method, the numerical average of the strains in the strain plateau is computed. A line is drawn at the 95% of this average maximum strain. The distance from the end of the member to the point where the strain profile meets with the 95% average line is the transfer length. It was found from this experimental work that, the average transfer length for 0.5 in. (12.7 mm) diameter strands was 33.6 in. (854mm) and the average transfer length for 0.6 in. (15.2 mm) diameter was 39.7 in. (1008 mm) indicating an increase in the transfer length with strand diameter. This research work concludes that a noticeable difference in transfer lengths exists between the live end and the dead ends. Further, the use of 0.6 in. (15.2 mm) strands was recommended as the transfer lengths were proportionally comparable to the 0.5 in. (12.7 mm) strands.

2.3.5 Rose & Russell (1997)

This experimental program (Rose 1997) included the evaluation of three different bond performance tests and their ability to predict the bond characteristics. Simple pull out tests, tensioned pull out tests, and measured strand end slips were performed on strand samples. The test results were later compared with the transfer lengths with varying strand surface conditions.

The specimens for transfer length measurements were cast using a 4000 psi (28 MPa) release strength concrete at 17 ft (5.2 m) length and 24 ft (7.3 m) length depending on the surface treatment of the strand. All the beams had two 0.5 in. (12.7 mm) strands on the tension side. From the studies it was seen that the beams with weathered strands had shortest transfer length exhibiting a superior bond performance with concrete compared to the acid cleaned strands and the "as received" strands.

To carry out simple pull out tests, pull out blocks having 2 x 3 x 4 ft (0.61 x 0.91 x 1.22 m) dimensions were cast with 12 strands. The strands were cast vertically on a 4 x 3 grid pattern with a 9 in. (229 mm) spacing having an embedded length of 18 in. (457 mm) in concrete. The pull out test was performed after 3 days from casting. Both ends of the strands were attached with linear potentiometers and mechanical dial gauges to measure the displacement of the strand with reference to the concrete. The strands were pulled in a continuous manner using a hydraulic actuator until the free end slip exceeded one inch (25.4 mm) and the strand slip recorded in real time.

Tensioned pull out tests were performed for different strand surface condition. The test was performed by gradually releasing tension on one side of the specimen using jacking bolts. Apart from linear potentiometers to measure strand slips, load cells and electrical resistance strain gauges (ERSG) were used to measure the tension.

Researchers from this experimentation work concluded that the strand end slips made a reliable correlation with the transfer length. Figure 2.7 shows the transfer lengths plotted against the end slip measured by various researchers. The surface conditions of the strand affected the bond performance of the pretensioned strand. It was concluded that a roughened surface condition enhances the bond and the lubricated surface hinders the bond performance. The tensioned pull out test was found to be difficult to perform and the results were inconsistent. The simple pull out test did not demonstrate any correlation or reproducibility with the pretensioned bond. Strand end slip at release proved to be a reliable assessment for the bond performance of the strand.

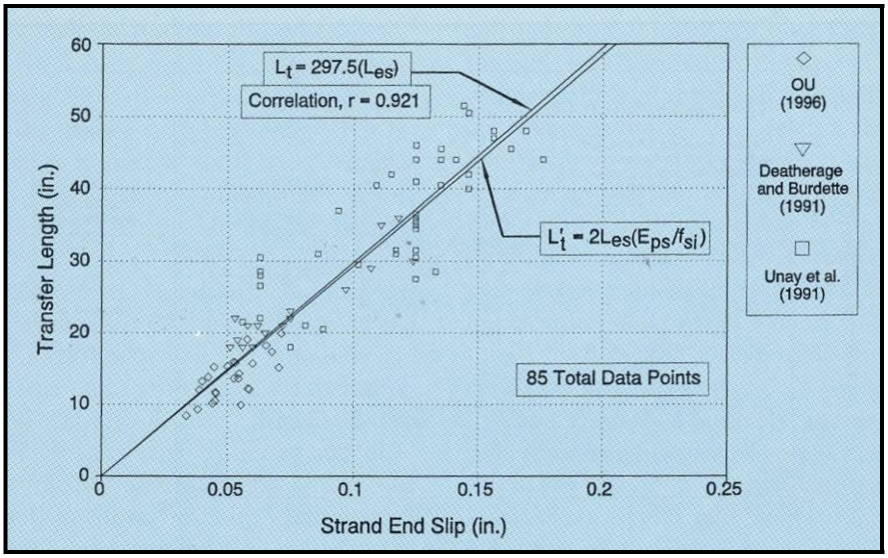


Figure 2.7: End Slips and Transfer Lengths (Rose 1997)

2.3.6 Kahn, Dill, Reutlinger (2002)

To verify the transfer and development length equations of AASHTO, the researchers conducted an experimental study with four AASHTO Type II girders with design concrete strengths varying from 10,140 to 14,490 psi. (70 to 100 MPa) (Kahn 2002) The transfer lengths were measured from the concrete surface strains using the 95% AMS method and using end clamps on the strands. A direct pull out test performed using an embedment length of 18 in. in concrete blocks demonstrated "good bond".

It was concluded that the 0.6 in. diameter strands exhibited good bonding with concrete and recommended for use in the industry. The results indicated that the transfer lengths were 41 to 51% less than the calculated AASHTO 1996 equation.

2.3.7 Barnes, Grove and Burns (2003)

An experimental assessment of factors affecting the transfer length of prestressed concrete beams was conducted with 36 precast AASHTO Type I girders with 0.6 in.

(15.2 mm) diameter strands (Barnes 2003). The concrete strengths varied from 5700 to 14,700 psi (39 to 101 MPa). Among the research variables, the surface condition of strands was taken into consideration apart from the methods of prestress release. As a result of this study, transfer lengths were measured for 184 of the 192 transfer zones. One half of the specimens were prestressed with strands having a bright strand condition and the other half with rusted condition. This study also explored the possibilities of various types of prestress release methods. The prestress release for one set of specimens were achieved by simultaneous release at all ends by different welders and for another set of specimens, the prestress release was achieved by cutting the strands at different times. The transfer length was measured using the 95% Average Maximum strain method. Apart from the experimental work, a finite element model was developed and analyzed to study the discrepancy between the strain profile measured along the line of gage points and the actual stress profile of the prestressing strands.

The conclusions of this research work reported that on an average, the transfer length increases 10 to 20% over time. The researchers concluded that the surface conditions of the strand cannot be relied upon to reduce the transfer lengths. The prestress release methods did not have significant impact on concrete release strengths higher than 7000 psi (48 MPa) for transfer lengths of bright strands. From the experimental work, it was also concluded that the sudden prestress release resulted in transfer lengths 30 to 50% higher than those associated with gradual prestress release.

2.3.8 Kose and Burkett (2005)

This study investigated the effects of transfer and development length of fully bonded and debonded 0.6 in. diameter prestressing strands in AASHTO Type I , I-beams

(Kose 2005). The results were then used to evaluate the code requirement for 0.6 in. diameter prestressing strand. A total of 36 beams were fabricated and tested. The beams had concrete strengths varying from 5050 psi to 7480 psi. The fabrication of beams was done with a combination of bright and rusty 0.6in diameter strands with varying concrete strength and debonding percentages. Effects were studied on the horizontal web reinforcements on transfer and development lengths. In the strand pattern for some beams, not all the strands were stressed to 75% of f_{pu}, the top strands being pretensioned only 34% of f_{pu}. Transfer lengths were measured using the smoothed concrete surface strain profile using the 95% AMS method. DEMEC readings were taken on the beams at long time intervals to study the long term effects on transfer lengths.

It was seen in this research that the transfer length increases with time and it ranges from 8 to 12%. The results also show that the transfer length is higher for debonded strands as well. It was also concluded that none of the short or long term transfer length values exceeded the value predicted by Buckner or Lane equations. The authors also comment that Lane equation is extremely conservative. The authors suggest that the code requirement for a fully bonded strand is adequate and the additional FHWA requirement to increase the code value by 1.6 is not necessary. It was also concluded that the Buckner and the Lane equations are very conservative for beams containing debonded strands. It was also observed that the crack widths were smaller for beams that contained the horizontal reinforcement bars.

2.3.9 Expressions for Transfer Lengths

Table 2.1 shows the expressions for transfer lengths recommended by various researchers over years. It can be seen that the contribution of the concrete strength is not prevalent in all the expressions though the diameter of the strand and the effective prestress force remains in most of the recommended expressions.

Table 2.1: Expressions for Transfer Lengths		
Author	**Year**	**Recommended Transfer Length Equation**
AASHTO / ACI 318	1963	$L_t = \left(\frac{f_{se}}{3}\right) \times D$ $L_t \cong 50 \times D$
Martin & Scott	1976	$L_t = 80 \times D$
Cousins et al	1990	$L_t = \left(\frac{U_t' \times \sqrt{f'_{ci}}}{2 \times B}\right) + \left(\frac{f_{se} \times A_{strand}}{\pi \times d_b \times U_t' \times \sqrt{f'_{ci}}}\right)$
Russell & Burns	1993	$L_t = \left(\frac{f_{se}}{2}\right) \times d_b$
Mitchell et al	1993	$L_t = \left(\frac{f_{si} \times d_b}{3}\right) \times \sqrt{\left(\frac{3}{f'_{ci}}\right)}$
Burdette et al	1994	$L_t = \left(\frac{f_{si}}{3}\right) \times d_b$
Buckner	1994	$L_t = \left(\frac{1250 \times f_{si} \times d_b}{E_c}\right)$ $L_t \cong \frac{f_{si}}{3} \times d_b$
Lane, S. N	1998	$L_t = \left(\frac{4 \times f_{pt} \times D}{f'_c}\right) - 5$

Where,

D, d_b : Diameter of the strand (in)

f'_c : Compressive strength of concrete (ksi)

f'_{ci} : Initial compressive strength, at release (ksi)

f_{se} : Effective prestress after losses (ksi)

f_{si} : Effective prestress after detensioning (ksi)

E_c : Modulus of Elasticity of concrete (psi)

A_{strand} : Area of the strand (sq. in.)

U'_t : Bond Stress (psi)

B : 300 psi/in

2.4 PULL OUT TESTS

2.4.1 Cousins, Badeaux, Moustafa (1992)

This experimental research (Cousins 1992) aimed at the comparative study between a test methodology introduced, and a direct tension pull out test. The objective of the research was to develop a standard test for determining the bonding characteristics of epoxy coated and uncoated prestressing strands to concrete and to correlate them to the transfer lengths. Low relaxation Grade 270 prestressing strands with both uncoated and epoxy coated grit impregnated strands were used for the test program. Strands were pretensioned to simulate the mechanical interlocking and the Hoyer's effects as explained in Section 2.1. After pretensioning the strands to the desired levels, a concrete block with 8 x 8 x 12 inches was cast within 24 hours around the strand. The concrete after curing for 3 days was later tested using a hydraulic actuator which was used to force the concrete block off the strand. The load vs. strand slip was recorded with respect to the concrete to determine the force at which the failure occurs. LVDTs were used to monitor the slips at both the dead and the live end of the strand together with load cells to monitor the load.

It was concluded from this research that the standard test gives higher bond stress at initial strand slip than the direct tension pull out test. It was also seen that the transfer length made with 3/8 in diameter uncoated strand resulted in a smaller bond stress than that from the standard results. The authors also concluded that the grit density variations and rusting of strand result in high standard deviations. The research did not provide significant relationship of the test with the transfer lengths.

2.4.2 Logan (1997)

Logan, together with an advisory group of researchers conducted an experimental study (Logan 1997) to understand the bond behavior of prestressing strands with concrete in prestressed concrete applications. A series of Moustafa pull out tests were done as a part of the program to understand the bond quality with transfer and development characteristics. In order to conduct the research, six 0.5 in. diameter strands were used from various manufacturers in North America.

To conduct the Moustafa pull out tests, strand specimens which are 34 in. long were saw-cut, towel wiped, and straightened for bow before casting. The strands were embedded in a block with light reinforcement and concrete with 4000 psi one day strength and 28 day strength of 6000 psi. The concrete test beams were single strand beams cast in 90 ft lengths and later saw-cut into five 18 ft long individual beams. A sudden prestress release using flame cutting was performed on all the test beams.

Logan concluded from this research that Moustafa test is a reliable test to predict the flexural behavior of beams. He observed that the strands having 36 kips or more of pull out capacity had less transfer length than predicted by the ACI equation and the transfer length stabilized in 21 days. The strands having pull-out capacities less than 12 kips equaled the ACI transfer length equation at release however, the transfer lengths increased over time. The research also concluded that the color of the strand, surface residue from the wipe test, and the lay or pitch of the strands did not reflect on the bond potential of the strands. It was also evident that some of the "as received" specimens outperformed the strands which had light rust on the surface. Logan recommended that the 0.5 in. diameter strands used in the industry require a pull-out capacity of 36 kips with a 10% coefficient of variation for a sample set of six. The author recommends that the Moustafa test should be performed for repeatability with different concrete mixtures.

2.4.3 Ferzli, Y. (2000)

The research program inspects the Moustafa Pull out test in assessing the bond performance of prestressing strand with concrete (Ferzli 2000). The research variables included strands from five different manufacturers for pull out tests and for flexural tests consisting of single and double strand beams. A total of 24 rectangular beams and 72 pull out tests were conducted.

The study concluded that the Moustafa Pull out capacity is inversely proportional to the transfer length. However, results did not show strong correlations between the Moustafa Test and transfer length. Ferzli concluded that the Moustafa Test was unacceptable as a test method to assess the bond performance of prestressing strand with concrete. Regardless, the author recommends Moustafa test as a preliminary test procedure to assess the general bond qualities of prestressing strands. The experimental work showed that the strand slip increases over time and can grow upto 33% of its release value. The author recommended a more reliable test method with fewer variables than the Moustafa Test.

2.4.4 NASP Round II (1999)

The North American Strand Producer's (NASP) funded two research projects (NASP Round I, II) to evolve a standardized test procedure to understand the bond characteristics of prestressing strands. The program investigated various pull out tests including Moustafa Pull out test, Post Tensioning Institute (PTI) Bond test, and friction bond pull out test, (Paulsgrove 1999) which were conducted at University of Oklahoma and Florida Wire & Cable Inc.

During the NASP Round I series, a friction bond test was conducted after mechanically splicing the strands together. Strands were mechanically spliced by a mechanical coupling that hydraulically compressed to its strands. The test measured the force required to pull the splice apart. The spliced strands were placed in a hydraulic device exerted a uniaxial tension. These results did not show convincing degree of reproducibility.

The PTI Bond test measured the pull out value for 0.10 in. (2.54 mm) slip using the procedures by the Post Tensioning Institute (PTI). The PTI specimens were cast in 5 in. diameter and 18 in. tall steel casings with a strand located concentrically in the specimen. The steel casings were welded to a base plate 6 in. by 6 in. by 0.25 in. thickness. A 9/16 diameter hole accommodated the strand to pass through the mould. The strand had a total length of 40 in. with an effective embedment length of sixteen in. The mould was filled with "neat cement grout" after placing the strands in position. Due to shrinkages high as 0.5 in. in a specimen, the specimens had to be flushed with mortar after 30 minutes of pouring the moulds. When the grout attains strength in the range of 3500 to 4000 psi the PTI Bond test is conducted. A displacement controlled test method is employed with a rate of loading of 0.1 in. per minute. The free end slip is digitally recorded using an LVDT attached on the strand and measured relative to the top of the flushed mortar.

The NASP test employed similar procedures as the PTI bond test, except for a few variations. Sand was added to the mortar mix to reduce the amount of shrinkage and provide more consistency within the mix which also included Type III cement and water. Apart from slight variations in placement and the vibration techniques, the test methodology was similar.

The NASP Round II test program compared the data from both the test sites for Moustafa, PTI and NASP Bond test. The results from the data are presented to understand the reproducibility of the test methods in Figs. 2.8 through 2.10. The results from OU and FWC are compared for Moustafa, PTI, and NASP Bond test. Figure 2.11 shows the coefficient of regression of all the test methods during NASP Round II. The PTI and the Moustafa bond test reported the maximum force at 0.1 in free end slip, whereas, the NASP test reports the data for 0.1 in. free end slip as they showed the least variation in the data. Recommendations were made to further conduct research in the NASP bond test as a strand bond acceptance test.

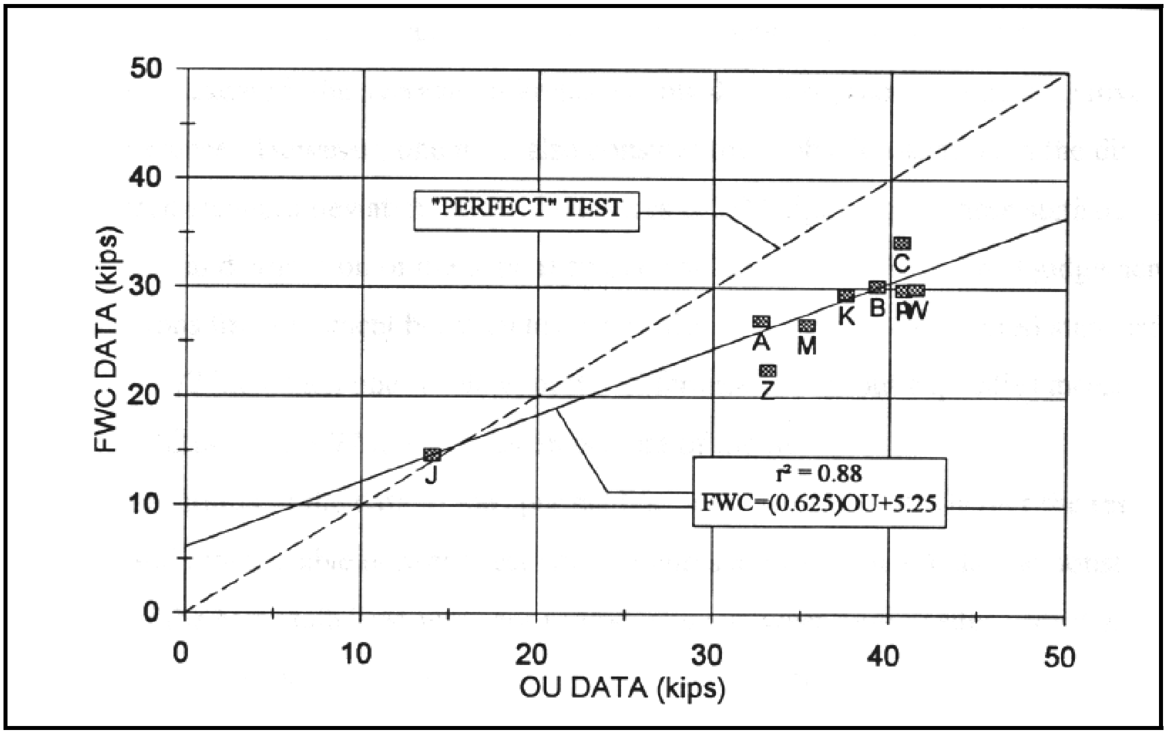


Figure 2.8: Moustafa Test Results from OU and FWC (Paulsgrove 1999)

TABLE 3.2
PTI BOND TEST RESULTS
MAXIMUM PULL-OUT CAPACITIES
NASP ROUND TWO TESTING

	OU TEST DATA (sample size = 6; 5 for K)			FWC TEST DATA (sample size = 6)		
STRAND	PULL-OUT (kips)	Std. Dev. (kips)	C.V. (%)	PULL-OUT (kips)	Std. Dev. (kips)	C.V. (%)
A	12.61	0.84	6.7	14.19	0.84	5.9
B	11.70	0.89	7.6	14.88	1.29	8.7
C	13.41	1.22	9.1	15.34	2.00	13.1
J	5.08	0.93	18.4	5.98	0.85	14.1
K	12.62	1.25	9.9	14.49	1.84	12.7
M	12.03	1.38	11.4	14.13	1.02	7.2
P	13.83	1.03	7.5	16.60	1.79	10.8
W	11.01	1.17	10.6	12.70	2.21	17.4
Z	9.80	0.82	8.4	7.95	0.83	10.4
AVERAGE	11.34	1.06	9.96	12.92	1.41	11.14

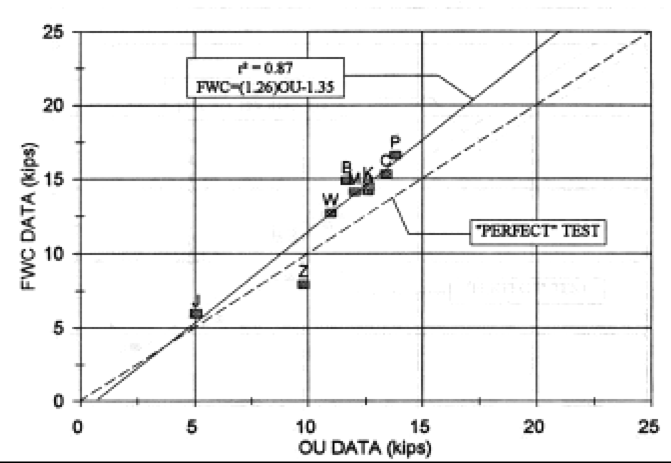


Figure 2.9: PTI Test Results from OU and FWC (Paulsgrove 1999)

TABLE 3.6
NASP ROUND TWO TESTING
NASP BOND TEST RESULTS - SERIES ONE
PULL-OUT FORCE AT 0.10 in. SLIP

	OU TEST DATA (sample size = 6)			FWC TEST DATA (sample size = 6)		
STRAND	PULL-OUT (kips)	Std. Dev. (kips)	C.V. (%)	PULL-OUT (kips)	Std. Dev. (kips)	C.V. (%)
A	17.70	2.09	11.8	12.48	3.42	27.4
B	11.81	1.20	10.2	8.02	2.69	33.6
C	19.57	1.96	10.0	12.85	2.64	20.6
J	2.61	0.57	21.7	*2.77*	*0.64*	*23.2*
K	13.76	1.71	12.4	9.32	2.79	29.9
M	14.87	2.01	13.5	10.69	2.49	23.3
P	17.12	1.65	9.6	12.47	1.77	14.2
W	10.35	1.54	14.9	6.77	1.67	24.7
Z	5.68	1.19	21.0	5.17	1.36	26.2

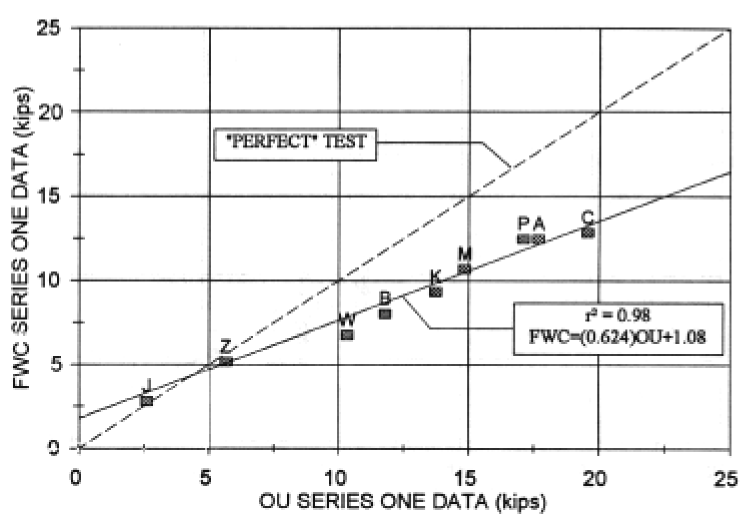


Figure 2.10: NASP Test Results from OU and FWC (Paulsgrove 1999)

TABLE 3.11 NASP TESTING ROUND TWO SUMMARY OF REGRESSION ANALYSIS							
Data Comparison	Moustafa	PTI Pull-Out			NASP Pull-Out		
	Maximum Strand Force	Maximum Strand Force	Force at 0.10 in. SLIP	Force at 0.01 in. SLIP	Maximum Strand Force	Force at 0.10 in. SLIP	Force at 0.01 in. SLIP
	r^2	r^2	r^2	r^2	r^2	r^2	r^2
Series 1 vs. Series 1							
OU vs. FWC	0.88	0.87	0.90	0.73	0.97	0.98	0.90
OU vs. STRESSCON	0.92						
STRESSCON vs. FWC	0.94						
OU Series 1 vs. OU Series 2					0.97	0.97	0.71
OU Series 1 vs. FWC Series 2					0.87	0.97	0.72
r^2 (coefficient of determination) regression about "best fit" line							

Figure 2.11: Summary of Regression Analysis (Paulsgrove 1999)

2.4.5 Brown & Russell (2003)

Studies were conducted as a part of the NASP Round III at Oklahoma University (OU) and Florida Wire & Cable (FWC) to investigate the NASP, PTI and Moustafa bond tests (Brown 2003). Ten samples of strands were tested at OU and FWC to investigate the reproducibility of all the test procedures.

Moustafa tests performed as a part of this research conformed to Logan (Logan 1997) test methodology. All the 10 strand specimens were tested for Moustafa pull out test. Each Moustafa block contained 18 strands and a total of 60 strands were tested in all. These tests were performed both at OU as well as at FWC. The results obtained from this test method is listed in Table 2.2

Table 2.2: Maximum Pull Out Values for Moustafa Test (kips) (Sample Size=6)								
Strand ID	Max. Pull out Value		Standard Deviation		Coeff. Of Variation		f'c	
	OU	FWC	OU	FWC	OU	FWC	OU	FWC
AA	33.04	26.60	1.052	5.612	3.2	21.1	4220	4270
BB	29.47	28.24	2.27	1.524	7.7	5.4	4220	4270
CC	31.12	22.18	2.41	1.024	7.7	4.6	4220	4270
DD	36.45	27.17	3.84	1.709	10.5	6.3	4970	4270
EE	37.44	25.97	2.283	1.767	6.1	6.8	4970	4270
FF	22.60	21.02	1.059	1.899	4.7	9	4970	4270
GG	26.33	26.20	3.646	0.729	13.8	2.8	3580	4270
HH	35.05	25.14	2.609	1.397	7.4	5.6	3580	4270
II	18.91	13.43	2.214	1.746	11.7	13	4340	4270
JJ	25.07	31.93	2.424	2.918	9.7	9.1	3580	4270

The PTI Bond test procedure was similar to the NASP Round I, Round II methodology as explained earlier. The neat cement grout was poured into the specimen cylinder and the test was conducted at a loading rate of 0.1 in. per minute. The tests were conducted at University of Oklahoma and Florida Wire & Cable to check for the repeatability of the test method. The results from the PTI Bond test are presented in Table 2.3

Table 2.3: Average PTI Pull Out Values (kips) at 0.1" slip									
Strand ID	NASP Value		Sample Size		Standard Deviation		Coeff. Of Variation		f'c
	OU	FWC	OU	FWC	OU	FWC	OU	FWC	OU
AA	9.64	11.23	6	6	0.58	1.90	6.0	16.9	3450
BB	6.68	7.13	6	6	0.64	1.51	9.6	21.2	3470
CC	5.62	7.93	6	6	0.86	2.23	15.3	28.1	3440
DD	6.14	11.01	6	6	1.21	2.70	19.7	24.6	3540
EE	6.94	10.12	6	6	0.53	2.25	7.7	22.2	3560
FF	4.58	7.34	6	6	0.55	2.89	11.9	39.4	3450
GG	7.21	7.34	6	6	0.38	1.13	5.2	15.4	3650
HH	9.01	8.61	6	6	1.26	1.62	14.0	18.9	3670
II	5.50	5.00	6	6	0.45	2.92	8.1	58.5	3510
JJ	7.41	10.67	6	6	0.70	4.00	9.6	67.5	3490

The NASP Pull out tests were conducted at OU and FWC on all the strand sources. The test was conducted in a sand cement mortar using a displacement controlled testing at a rate of 0.1 in. per minute. The NASP test procedure was not modified from the NASP Round II procedures. Table 2.4 reports the average of NASP pull out value at 0.1 in. of free end slip on a sample size of six specimens at OU and FWC.

Table 2.4: Average NASP Pull Out Values (kips) at 0.1" slip

Strand ID	NASP Value		Sample Size		Standard Deviation		Coeff. Of Variation		f'c
	OU	FWC	OU	FWC	OU	FWC	OU	FWC	OU
AA	13.93	15.97	6	6	1.248	2.694	9	16.9	4370
BB	6.75	10.37	6	6	0.719	0.963	10.6	9.3	3810
CC	9.93	8.80	6	4	2.506	1.379	25.2	15.7	3970
DD	14.35	15.26	6	6	0.598	1.754	4.2	11.5	4150
EE	14.09	16.02	6	6	0.587	4.168	4.2	26	4320
FF	6.31	8.29	6	6	0.409	1.291	6.5	15.6	3900
GG	7.17	12.41	6	6	1.004	1.259	14	10.1	3730
HH	11.12	10.29	6	6	1.002	1.639	9	15.9	4100
II	2.98	5.30	6	6	0.319	0.843	10.7	15.9	4000
JJ	19.68	17.61	6	6	1.401	3.153	7.1	17.9	4220

The results from the research program concluded that the Moustafa pull out test was not a reliable test for bond. A coefficient of determination of 0.0476 was seen when plotting the data between OU and FWC. However, the test was able to relatively predict the bond performance ranking. The authors suggested that "*until instability in the data from various test locations is resolved, the test should not be relied upon to be a determinant of adequate bonding.*"

The PTI bond test was not too different as far as reliability to produce reproducible results is concerned. The correlation of determination for the PTI bond test was reported as 0.2104 when the data was plotted between OU and FWC. The problem of shrinkage was considered as the cause of inconsistency in the test procedure.

The NASP test "outperformed" the other bond tests, showing a strong correlation between both locations having an R^2 value of 0.776. The test proved as a reliable predictor for bond when compared to other testing procedures. The researchers recommended that the NASP test should be investigated further to make stronger conclusions.

The NASP test was related to the transfer length measurements taken on single and double strand beams. The results from the tests are reproduced in Tables 2.5 and 2.6. Beams were made using Strands AA, FF, HH, and II. The transfer lengths were measured on the single and double strand beams at release and at 28 days. The Tables 2.5 and 2.6 consolidates the transfer lengths measured on the beams and the corresponding pull out values for a particular strand based on Moustafa, PTI and NASP Pull out tests conducted at OU and FWC.

Table 2.5: Average Transfer Length and Pull Out Values in Single Strand Beams (Brown 2003)											
Strand	**Average Transfer Lengths at Release(in.)**	**Average Transfer Lengths at 28d (in.)**	**Average NASP P.O. Test (lbs)**	**Moustafa P.O. Test (lbs.)**	**Avg. NASP PO Test @ OU (lbs)**	**Avg. NASP PO Test @ FWC (lbs)**	**Avg Moustafa PO Test @ OU (lbs)**	**Avg Moustafa PO Test @ FWC (lbs)**	**Avg. PTI PO Test @ OU (lbs)**	**Avg PTI PO Test @ FWC (lbs)**	**Average PTI Bond Test**
AA	10.65	16.2	14947	29819	13926	15967	33041	26597	9640	11233	10437
FF	21.11	31.17	7302	21810	6311	8292	22596	21023	4581	7342	5962
HH	20.12	30.17	10707	30096	11122	10292	35048	25144	9011	8608	8810
II	25.73	39.24	4140	16080	2980	5300	18912	13247	5502	4990	5246

Table 2.6: Average Transfer Length and Pull Out Values in Double Strand Beams (Brown 2003)											
Strand	**Average Transfer Lengths at Release(in.)**	**Average Transfer Lengths at 28d (in.)**	**Average NASP P.O. Test (lbs)**	**Moustafa P.O. Test (lbs.)**	**Avg. NASP PO Test @ OU (lbs)**	**Avg. NASP PO Test @ FWC (lbs)**	**Avg Moustafa PO Test @ OU (lbs)**	**Avg Moustafa PO Test @ FWC (lbs)**	**Avg. PTI PO Test @ OU (lbs)**	**Avg PTI PO Test @ FWC (lbs)**	**Average PTI Bond Test**
AA	13.06	17.44	14947	29819	13926	15967	33041	26597	9640	11233	10437
FF	22.87	24.19	7302	21810	6311	8292	22596	21023	4581	7342	5962
HH	22.38	26.25	10707	30096	11122	10292	35048	25144	9011	8608	8810
II	41.29	42.71	4140	16080	2980	5300	18912	13247	5502	4990	5246

The NASP test showed the highest correlation between the pull out value and the transfer lengths measured at release and at 28 days. A correlation of determination of 0.86 was seen on the strands when the NASP values and the transfer lengths at release was plotted for the single and double strand beams. Similar analysis on the transfer length and the pull out values were done using the Moustafa pull out test and the PTI bond test. The correlation of determination for Moustafa pull out test was reported as 0.61 and for PTI bond test was 0.70. This further evidenced that the NASP bond test is a better predictor for bond than Moustafa and the PTI bond test. The correlation plots for Moustafa, PTI, and NASP Bond tests and transfer lengths are plotted in Figs. 2.12, 2.13, and 2.14 respectively.

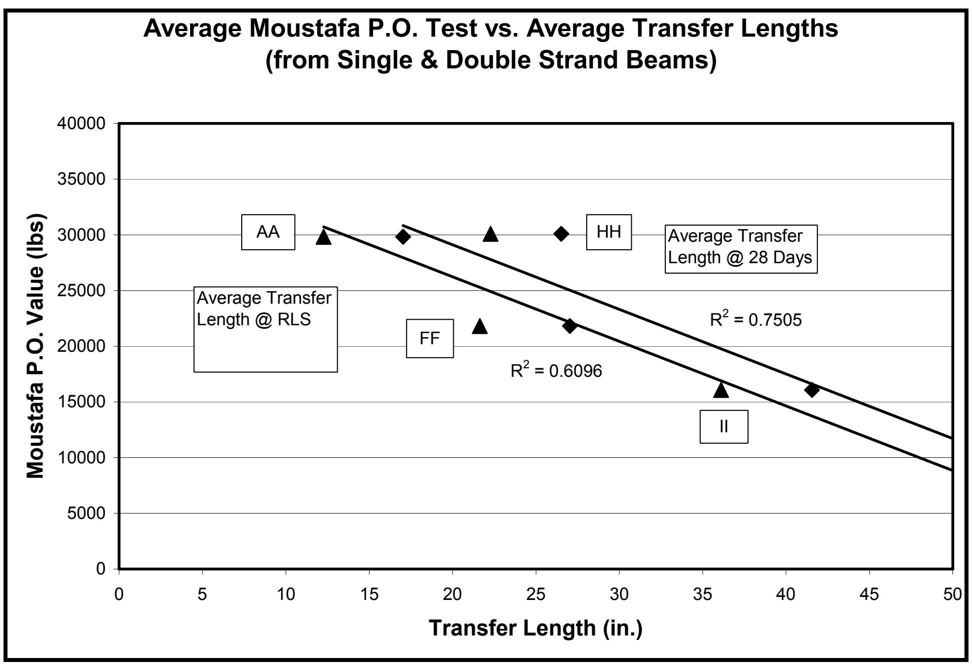


Figure 2.12: Moustafa Pull out and Transfer Lengths (Brown 2003)

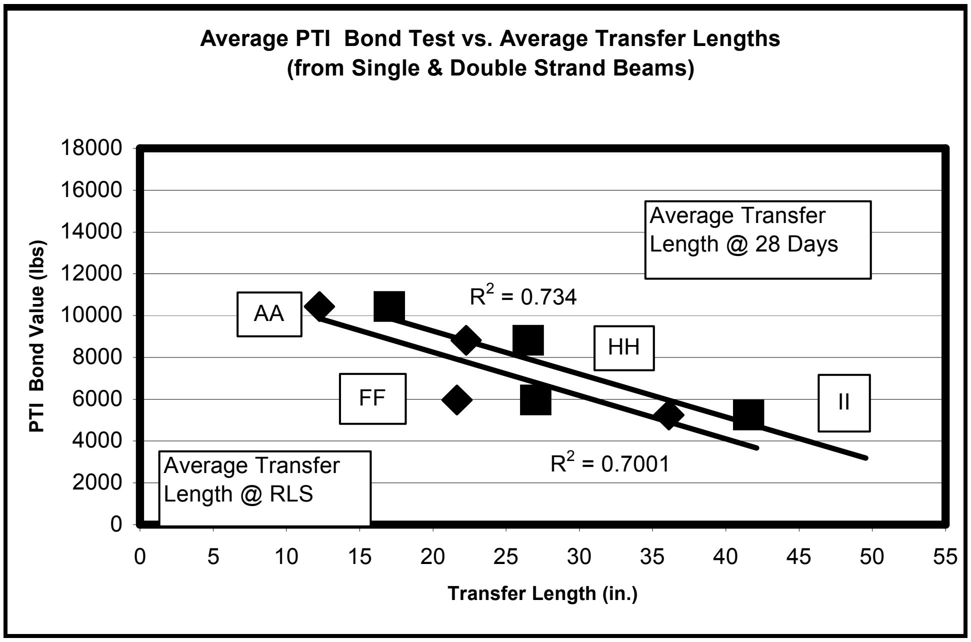


Figure 2.13: PTI Bond Test and Transfer Lengths (Brown 2003)

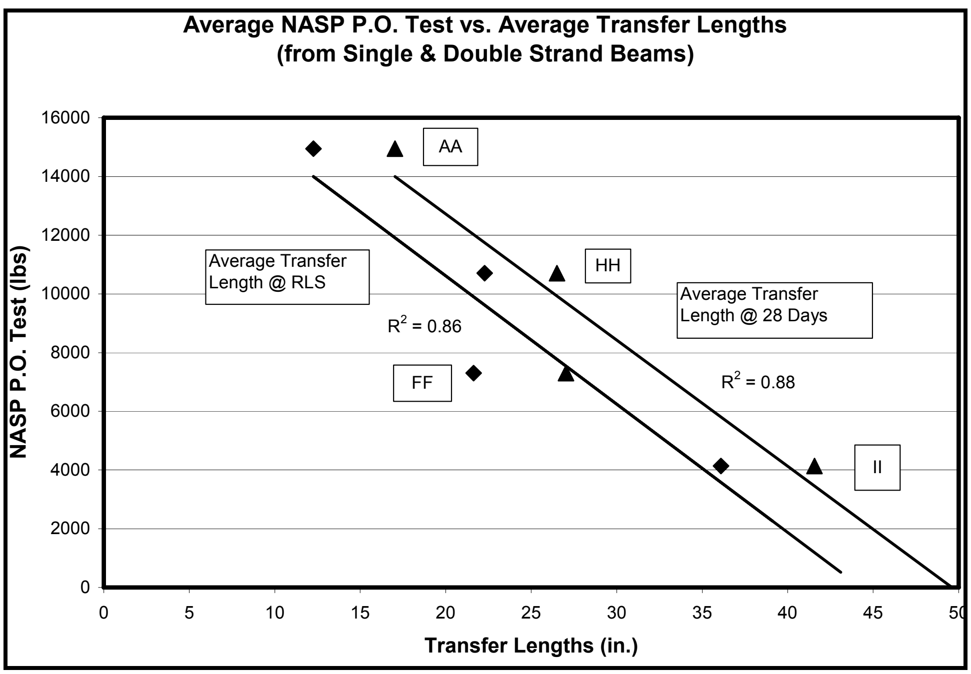


Figure 2.14: NASP Pull out and Transfer Lengths (Brown 2003)

2.5 SUMMARY

Considerable efforts has been made to predict the transfer length of prestressing strands with normal and high strength concrete with a variety of variables. A range of transfer length equations have been suggested by various researchers, some considering the effects of concrete strengths. To relate the measured transfer lengths, and to identify the "bond-ability" of various prestressing strands, several pull out tests were conducted in the past. These tests include Moustafa Pull out test, PTI Bond test, and NASP pull out tests. Among these tests, the NASP pull out test show convincing results. However, a standardized acceptance procedure to quantify the prestressing strands is unavailable in spite of the scatter in the transfer length data.

The ACI does not detail any procedure to check the quality of the bond, though in the commentary R12.9 it says "For bonded applications, quality assurance procedures should be used to confirm that the strand is capable of adequate bond. The precast concrete manufacturer may rely on certification from the strand manufacturer that the strand has bond characteristics that comply with this section". The ACI admits that the expression for transfer length is based on the experimental work on members prestressed with clean ¼, 3/8 and ½ inch strands, though there is a widespread use of the 6/10inch strand in the precast industry.

CHAPTER III

3.0 THE NASP BOND TEST

The objective of this research was to determine whether, through some additional refinement, the NASP Pull out test is suitable for adoption to assess the ability of prestressing strand to bond with concrete. The objective is fulfilled in two parts:

a) Refining the test to further "tighten" some of the test parameters to help ensure the test is both repeatable & reproducible, and;
b) Round Robin Blind testing trials between Oklahoma State University, Purdue University, and University of Arkansas.

3.1 SCOPE OF RESEARCH

The scope of research devoted to the NASP Bond test can be broken down into two key phases.

a) Development Phase where the NASP Test protocol was refined to limit variation in underlying properties of the grout, and other factors that can influence variability in the test result.

The NASP bond test is a test procedure used to understand the bonding abilities of prestressing strands with concrete. Figure 3.1 shows the NASP specimen mounted on the loading frame. The test is carried out by casting the prestressing strands in concrete mortar enclosed in a cylindrical steel form with a base plate. The strand is pulled out from the concrete mortar at a loading rate of 0.1 in./min using a hydraulic system after curing for 24 ± 2 hours. The pull-out force is measured in real time along with the relative movement of the free end of the strand to the specimen. The end slip is measured on the free end (the end opposite to the loading end) of the strand using a linear variable differential transducer (LVDT) attached on the NASP specimen. The NASP Bond Test records the pull-out force that corresponds to 0.10 in. of free end slip. One single NASP Bond Test consists of six or more individual test specimens.

Figure 3.1: NASP Specimen on the loading frame

b) Test the NASP Bond test through Round Robin Blind trials at Oklahoma State University, Purdue University, and University of Arkansas

The NASP Bond test in mortar was performed on ten 0.5 in. diameter and two 0.6 in. diameter Grade 270 low relaxation strands. The NASP bond test was performed in a cement mortar mix with a sample size of 6 or 12 specimens. To substantiate the repeatability of the bond test, tests were conducted at Purdue University for five 0.5 in. diameter strand. The NASP Tests were also conducted in mortar for six strand samples at University of Arkansas. Table 3.1 shows the strands tested using the NASP Bond test at various locations. The table also lists the NASP ID (Round III and Round IV) and the NCHRP ID.

Table 3.1: Strands tested to determine the reproducibility

STRAND DIAMETER (IN)	NASP ROUND III ID	NASP ROUND IV ID	NCHRP OSU ID	Locations		
				OSU	Purdue	Arkansas
0.5		A	C	x	x	x
0.5		B		x		
0.5	FF	C	D	x	x	x
0.5	II	D	E	x	x	x
0.5		E		x		
0.5		F		x		
0.5	AA	G	A	x	x	
0.5		H		x		
0.5		I		x		x
0.5		J	B	x	x	
0.6		K		x	x	
0.6		L	A	x	x	

3.2 PRIOR DEVELOPMENT OF NASP BOND TEST

3.2.1 Development of NASP Bond Test

The NASP Bond test took its shape in the present form after a series of tests conducted during the Round Robin trials. The NASP test conducted in the Round I, Round II, and Round III investigated the repeatability and reproducibility of the test method together with comparing the test method with the Moustafa Pull out test and the PTI Bond test. Further discussion relating the NASP Rounds II and III is reported in Chapter 2. It is seen from the previous research that the NASP Bond test is a better predictor for bond than the other tests used. The NASP bond test also showed convincing results when compared to the transfer lengths measured on the prestressed concrete beams.

3.2.2 NASP Test Protocol prior to Current Research

The changes in the NASP Test procedures from the Round III testing conducted in previous research program are discussed in this section. The current NASP Test protocols and the test protocols in 2001 are reported in Appendix B. Though the underlying methodology in the procedure has not changed significantly, there are changes in the sample preparation and the test procedures.

The NASP protocols in 2001 specified the sample preparation where the cement mortar had a sand-cement-water ratio of 2:1:0.45 and a target one day mortar cube strength of 3500 to 5000 psi. The wider range in the mortar cube strength proved to affect the NASP values. The current research targets a closer range (4750 ± 250 psi) of mortar cube strength during the test and does not specify the mix proportions. The current research targets a flow range of 100 to 125 whereas the flow measurements were not made during the Round III trials. The protocols prior to the current research did not specify the method in which the strands were cut from the reel. The current research specifies that the strand shall be taped at the cutting ends to avoid spalling of the individual wires in the strand. The strand is centered in a steel casing 5 in. outer diameter with a 16 in. bond length. The cement mortar is cast and consolidated in the steel casing.

The NASP protocols in 2001 did not specify the frame used for loading the NASP specimen. The loading frames used in the Round III trials were more “flexible” when compared to the frame used in the current research which is “rigid”. The loading rate of 0.1 in/min remains the same, and the NASP value is reported as the load at which the free end slip is 0.1 in. The average of six or more NASP specimens is reported as the NASP value for the strand.

Studies conducted earlier in the NASP Round II, concluded that the least variation in the NASP values is exhibited for the 0.1 in. of end slip. The largest variation was reported in the 0.01 in. of free end slip. The recommendations from these studies resulted in reporting the NASP values as the force required to induce a 0.1 in. of free end slip.

The Moustafa Test and the PTI Bond test procedures, used to identify the bonding of prestressing strands with concrete was neither repeatable nor reproducible when compared to the NASP Bond test. Further discussion regarding the issue is discussed in Chapter 2.

3.3 MATERIAL PROPERTIES

3.3.1 Prestressing Strands

All prestressing strands used for this research program were seven wire 270 ksi Low relaxation strands from manufacturers in North America. The strands conformed to ASTM A416 specifications for Low relaxation strands. The prestressing strands had a nominal diameter of 0.5 in. (12.7 mm) or 0.6 in. (15.2 mm).

The NCHRP and the NASP designations of the strands used for the research program is reported in Table 3.1. Some of the strands used in the current research program included the strands used during the Round III trials. The strand designations for the Round III trials are also reported in Table 3.1

3.3.2 Cement

The cement used for the testing program was Type III cement from Lafarge North America. The Portland Type III cement used conformed to ASTM C 150. The detailed chemical analysis of the cement used is reported in Appendix H. The Type III cement used for the NASP tests was enclosed and sealed in steel barrels to control the moisture content of the cement.

3.3.3 Fine Aggregates

The fine aggregates used for the NASP testing was supplied by Dolese Brothers from their plant at Stillwater. The fine aggregates used was natural quartz and had a specific gravity of 2.63 and the absorption content of 0.5%. The gradation of the fine aggregates is reported in Table 3.2. The fineness modulus of the fine aggregates used is 2.51.

Table 3.2: Sieve Analysis of Fine Aggregates used for NASP Tests			
Sieve	% Passing	Sand Retained	Cum. % Retained
3/8	100	0	0
#4	99.5	0.5	0.5
#8	96.4	3.6	4.1
#16	89.9	10.1	14.2
#30	46.4	53.6	67.8
#50	13.7	86.3	154.1
#100	2.9	97.1	251.2
#200	0.3	99.7	
Pan	0	100	

3.3.4 Mortar

The mortar used for the NASP test had various strengths. The mortar mix design for w/c of 0.4, 0.45, and 0.5 are detailed in Table 3.3

Table 3.3: Mortar Mix Proportions in lb/ft^3 for NASP Testing			
Material	w/c= 0.4	w/c= 0.45	w/c= 0.5
Cement	41.4	39.7	38.8
Fine Aggregates	82.8	79.4	77.5
Water	16.5	17.9	19.4

The w/c of 0.45 was chosen for the Round Robin testing. The rest of the mix proportions were used to evaluate the effects mortar strengths can have on the NASP test. The mix proportion in Table 3.3 for w/c of 0.45 yields one day mortar strength of 4750 ± 250 psi and a flow of 100 to 125. For preparing 12 NASP specimens, a volume of 2.7 ft^3 of mortar is batched.

3.4 SAMPLE PREPARATION

To perform the NASP test, six or more NASP samples are required as shown in Fig. 3.2. The sample preparation of the NASP specimens is discussed in this section.

Figure 3.2: NASP Specimen

3.4.1 Strand Preparation

The strands used in individual NASP tests were cut from the same reel of strand. The strands were cut and handled with care to avoid placing surface contaminants on the strands. The strands were cut using an abrasive saw blade, after firmly taping the cut ends with an adhesive tape to prevent destranding. The strands were cut to lengths of 32 in. One end of the strand was ground to ensure that the king wire had greater exposure than the other wires in the strand as seen in Figure 3.3. This detail ensures more standardized reading of strand end slips.

Figure 3.3: Strand embedded in NASP specimen

Exposing the king wire more than the surrounding wires helped in attaching the end slip measuring device to the specimen. It was seen that there could be relative movement of wires in a strand if the strands are not ground, which may result in inconsistent results.

3.4.2 Steel Casing

To perform the NASP test in mortar and concrete, the 4.75 in. (120.65 mm.) inner diameter and 5.00 in. (127 mm.) outer diameter steel tubing was 20 ft (6.1 m) long. The tubing was cut at 18 in. lengths using a band saw. The center of the base plate was drilled with either a 5/8 in. or 9/16 in. drill bit depending on the diameter of the strand (0.5 in. or 0.6 in.) used for testing. The base plates were then welded to the tubes using a jig to ensure 90 degrees between the base plate and the steel casing. Figure 3.4 shows the NASP mould cylinder on the jig used for welding the base plate and the cylinder.

Figure 3.4: NASP Specimen Cylinder on the jig

3.4.3 Bond Breakers

Bond breakers made from Styrofoam 2 in. in length were attached to the seven wire prestressing strands immediately adjacent to the base plate of the test specimen. The bond beakers served to avoid any stress concentration near the base of the specimen. Figure 3.5 shows the cut strand sample with the 2 in. bond breaker. The bond breakers are covered with masking tape to avoid water in the mortar mix to impregnate into the Styrofoam.

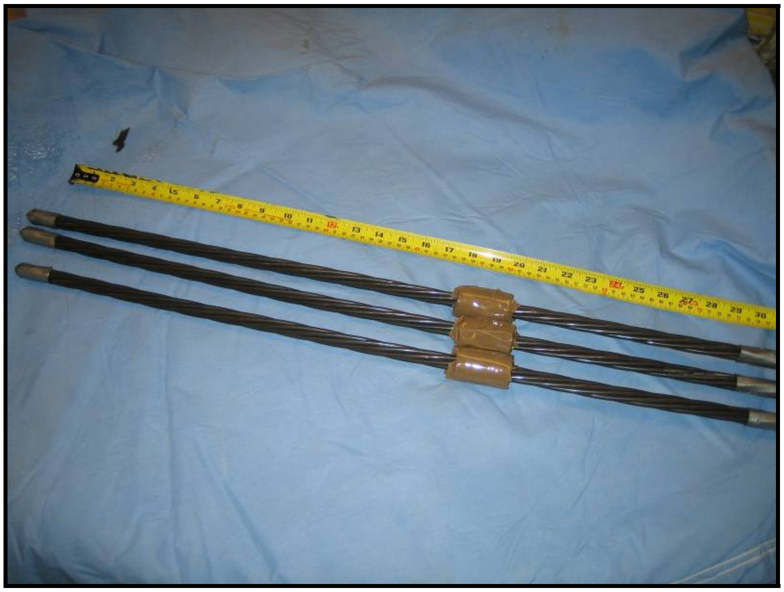


Figure 3.5: Specimen strands and bond breakers

3.4.4 Mortar Batching

The mixing procedures conformed to ASTM C 192. Corrections were made to account for moisture in the fine aggregates. Approximately 2.7 ft^3 of mortar was batched to prepare 12 NASP specimens. The batch weights were calculated after correcting for the moisture content in the fine aggregates from the saturated surface dry (SSD) weights. A water to cement ratio of 0.45 was maintained for the mortar mixtures for tests conforming to standardized test protocols. The materials were handled in conformance with ASTM C 192. Corrections for moisture in the fine aggregates were done after placing them in sealed containers. The sample collected for assessing the moisture was taken after quartering the sample in conformance with ASTM C 702.

After placing the measured water in the pan mixer, cement was added, with the mixer running. After one minute and 30 seconds of mixing, the sand is added to the mixer without stopping the mixer. After adding the sand, all materials are mixed for two minutes. Mixing is then stopped for one minute in conformance with ASTM C 192. During that time, the pan mixer is raised to clean the blades. The contents are again mixed for one minute, after which the Flow test is conducted on the mortar in conformance with ASTM C 1437 (Figure 3.6). If the flow of the mortar is within 100 to 125, the mixing is stopped. If the flow is less than 100, the mixing time is increased to one more minute until the required flow is achieved. If the required flow is not achieved, then the batch mixture is discarded. Unit weight is also measured. If the unit weight of the fresh mortar is not close to the unit weight measured routinely during trial batching or previous mixtures, the fresh mortar is discarded.

Figure 3.6: Flow Test

3.4.5 Preparing the NASP Specimens

The NASP steel casings are placed on a wooden box to pass the strand through the specimen. Figure 3.8 shows the NASP specimens on the wooden box. The strands are placed in the steel casings and steel plate aligners are placed on the specimen to avoid any possible movement of the strand during the casting. The mortar is placed in the steel casing in two lifts; each layer is consolidated using an electric handheld vibrator. The three feet long and one inch square electric vibrator was used in conformance with ASTM C 192. Figure 3.7 shows the NASP specimens during casting. Curing conditions near 73.4 °F and 100 % Relative Humidity are maintained. Curing conforms to ASTM C 192. The NASP specimens are removed from the curing room after 22 to 23 hours. Figure 3.8 shows the NASP specimens which are ready to be tested.

Figure 3.7: Preparing the NASP Specimens

Figure 3.8: NASP Specimens on the wooden box after curing

3.4.5.1 Mortar Cubes, ASTM C 109

Mortar cubes were prepared as in Fig. 3.9 to test the strength of the mortar at three stages while performing the NASP tests. The mortar cubes were prepared in conformance with ASTM C 109. The 24 hour target strength of the mortar cubes is 4750 ± 250 psi. If the mortar strength falls outside of this range, variations in pull-out force may be caused by variations in mortar strength.

Three mortar cubes were tested in conformance with ASTM C 109 for compressive strength after 22 hours of curing, before starting the NASP Bond test. Midway through the NASP Bond test, three more mortar cubes are tested for compressive strength. After the NASP pull out test, a set of three mortar cubes are tested and reported. The compressive strength of mortar reported for the NASP Bond test, are for the mortar cubes tested halfway through the Bond test.

Figure 3.9: Fresh Mortar Cubes

3.4.5.2 Unit Weights, ASTM C 138

Fresh unit weight of the mortar is measured in a 0.1 ft^3 bucket. Hardened unit weights of the mortar cubes were measured and recorded prior to the testing for strength, after 22 hours.

3.4.6 Importance of Consolidation

To further understand the significance of the spread in the test data for a particular NASP test conducted, the NASP specimens were split open to closely observe possible air pockets or voids due to insufficient consolidation of the mortar mix. The Figures 3.10, 3.11, and 3.12 show the photographs taken on the NASP split specimens. The specimens were removed from their steel casings using a grinder and cut to 9 in. lengths using a concrete saw cutter. Specimens were split open by performing the concrete cylinder tensile test ASTM C 496.

The split specimens shown in the figures are for Strand G. Figure 3.10 shows the Specimen # 6 in Batch 15 N which had a w/c of 0.45 and the highest NASP value of 23,505 lb. Figure 3.11 shows the close to average value in Batch 23 N which had a w/c of 0.50 and the NASP value of Specimen # 1 was 16,196 lb, and the group average value was 16,360 lb. The Figure 3.12 shows the split specimen for the lowest NASP value in Batch 15 N of 19,531 lb. It can be seen from the figures that there are no significant air voids or lack of consolidation for the NASP specimens. From the observations, it was concluded that the NASP specimen consolidation was adequate.

Figure 3.10: NASP Split Specimen for High value

Figure 3.11: NASP Split Specimen for Average value

Figure 3.12: NASP Split Specimen for low value

3.5 TEST PROCEDURES FOR THE NASP BOND TEST

The NASP bond test is performed from 22 hours to 26 hours after the hydration of the cement. The NASP specimen is mounted on a rigid steel frame. The details of the section dimensions of the rigid frame for the NASP test is shown in Fig. 3.13. The 7 in. tall portion of the NASP rigid frame does not have torsional restraint. Figure 3.14 shows the NASP specimen and the attaching plates and chuck for the support reactions.

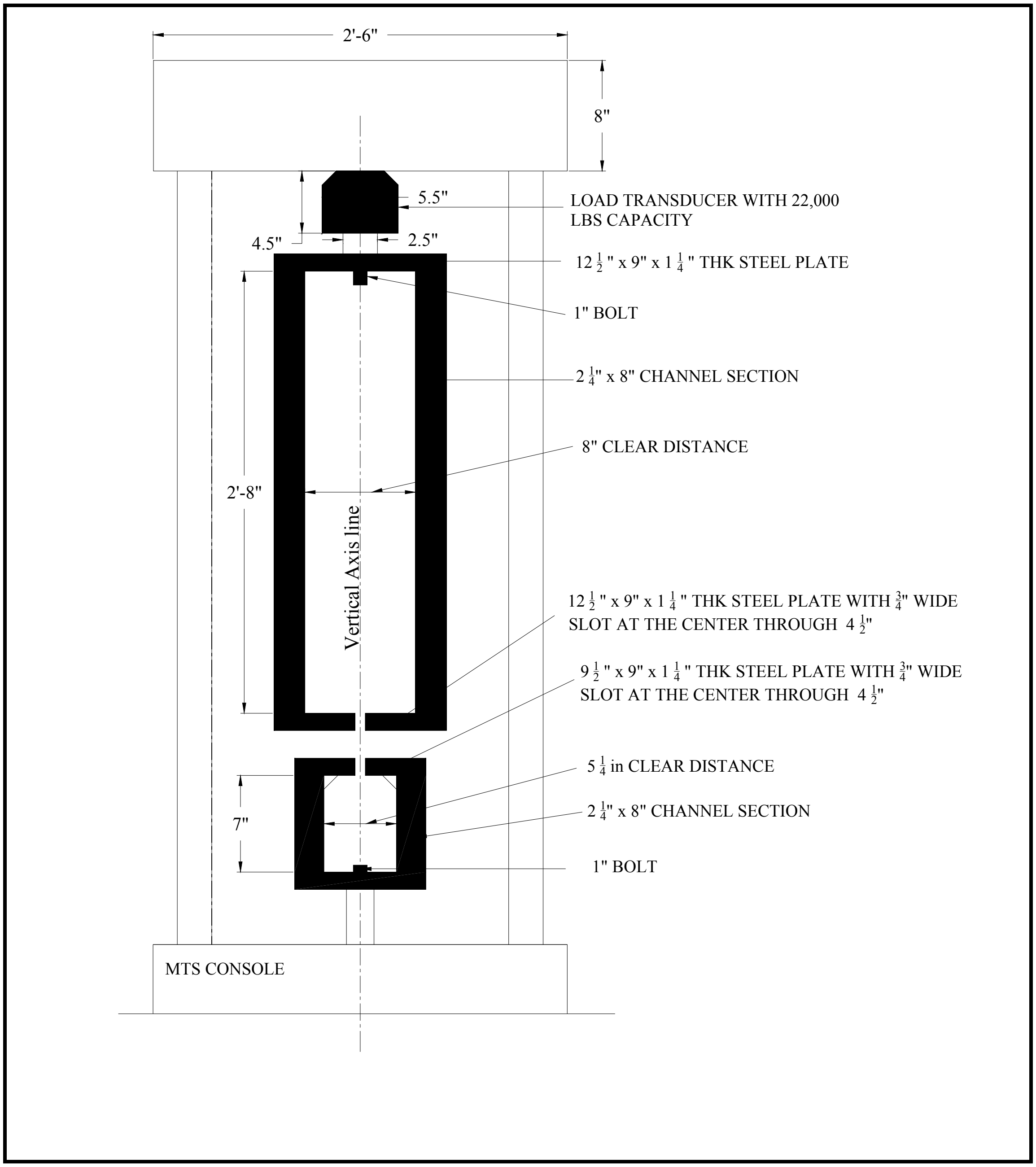


Figure 3.13: Schematic Diagram of NASP Test Setup

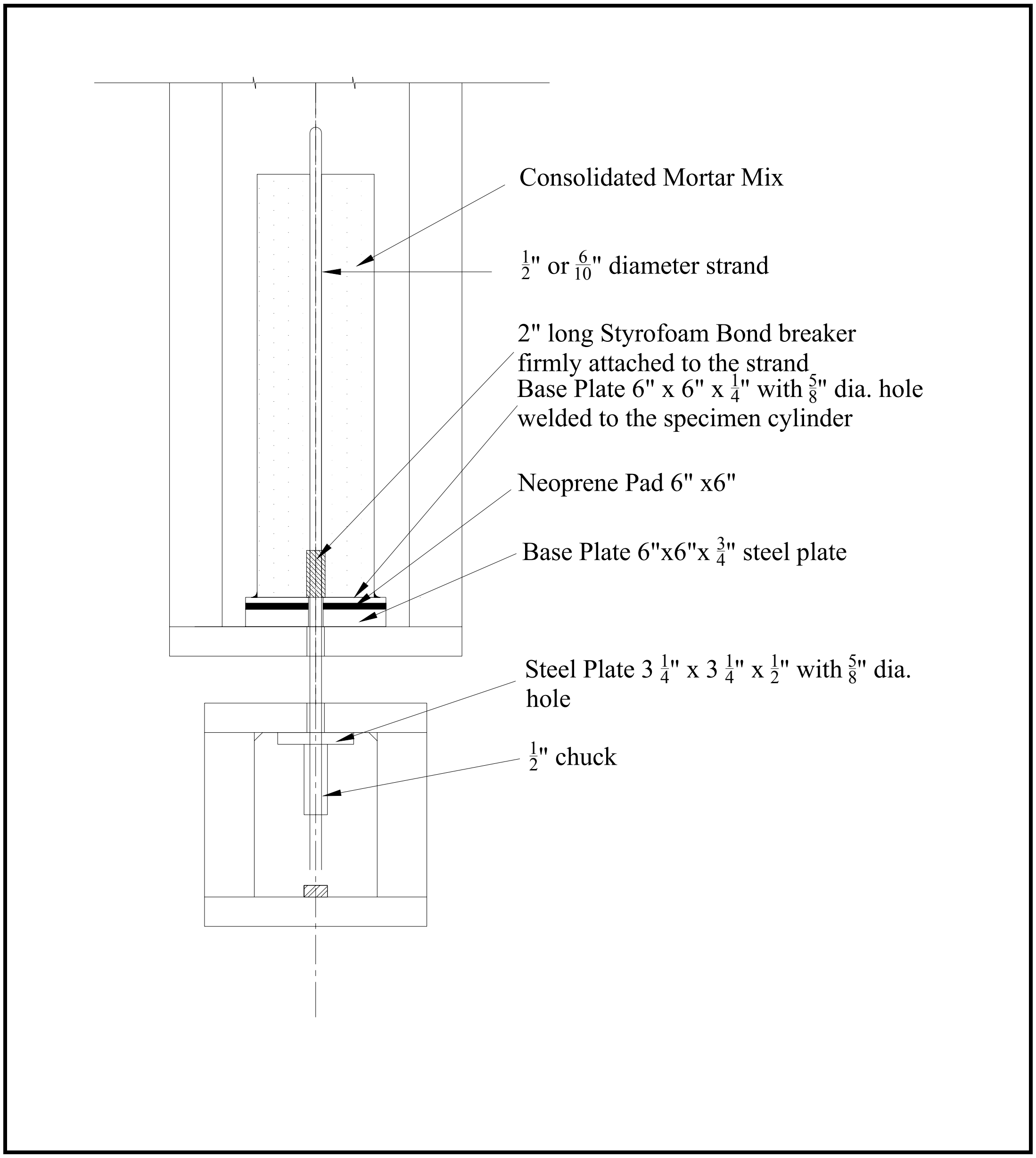


Figure 3.14: Details of NASP Test Specimen

Figure 3.15 and 3.16 shows the LVDT attachment on the NASP specimen to measure the free end slip on the specimen. The figures show the end slip measuring attachment to the NASP specimen by means of a magnetic base. The lever which rests on the rounded strand specimen is leveled. The LVDT is attached by means of a magnetic base on the NASP specimen where the distance of the LVDT to the mid of the strand equals the distance from the pivot point of the measuring attachment.

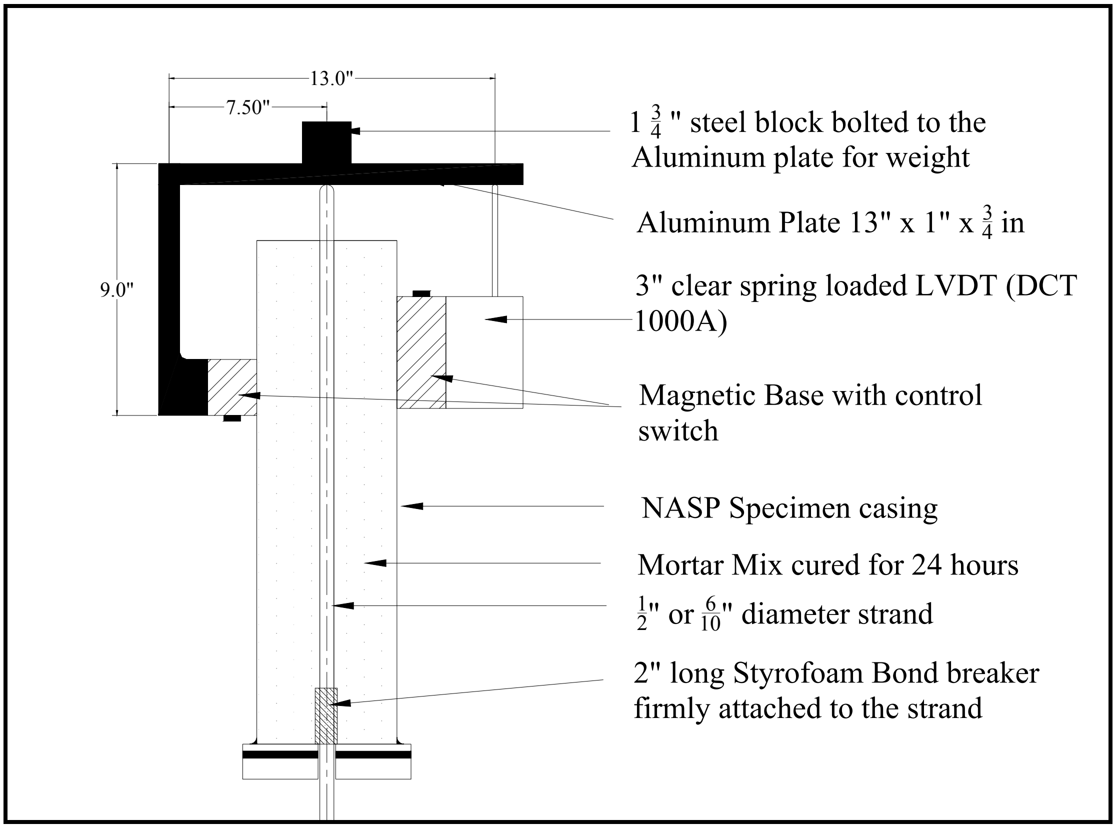


Figure 3.15: Details of End Slip measuring on NASP Specimen

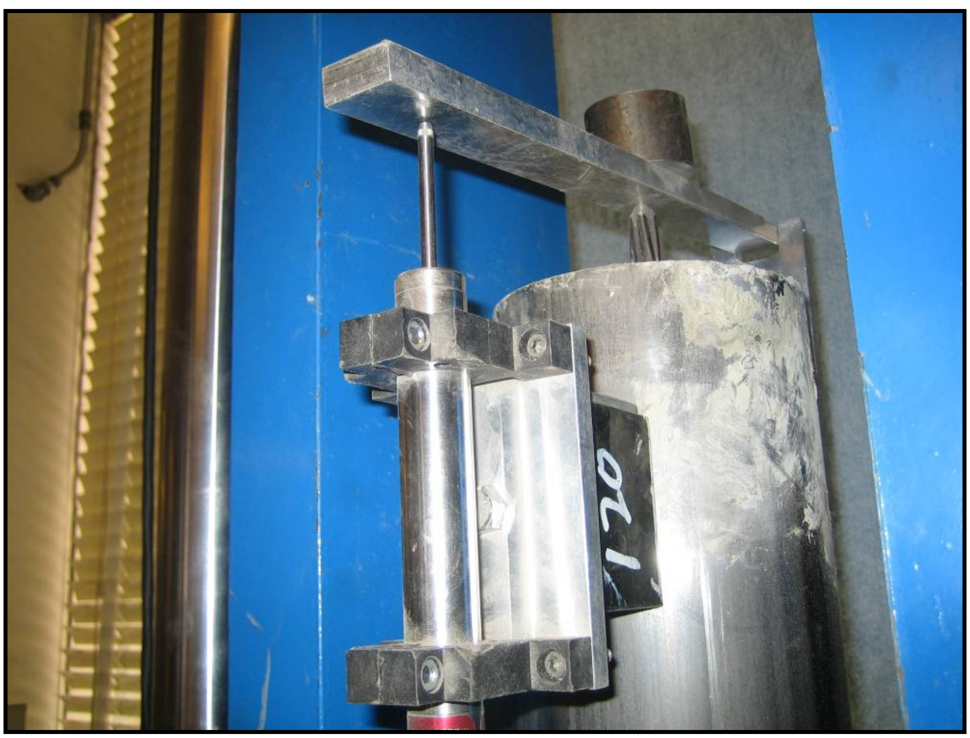


Figure 3.16: LVDT attachment on the NASP Specimen

The NASP specimen is mounted on the rigid frame as shown in Fig. 3.17. The loading control is performed by an MTS System controller. The following procedure was followed for all the NASP Bond tests.

1. Warm up the hydraulic actuator for 10 to 15 minutes.
2. Check the following in the controller settings. The controller used is Test Star IIs on an MTS 810 Test system.
    a. Loading ramp up rate of 0.1 in./min
    b. Data acquisition of 6 or 8 Hz (data points per second)
    c. Test is carried out for 10 minutes or until the load cell reaches its capacity (22,000LB)
3. Check for any oil leakage in the hydraulic system.
4. Mount the specimen on the frame by placing the neoprene pad and the base plate.
5. Raise the piston to a datum level.
6. Attach the base plate for the chuck and place the chuck to ensure that the three jaws of the chuck are on an even plane.
7. Attach the LVDT support system and level and plumb.
8. Mount the LVDT (RDP Type DCT 1000A) level and plumb.
9. Run the controller and report the load at 0.01 in. strand axial slip and 0.1 in. axial slip.

Figure 3.17: NASP Specimen on the Test Frame

3.6 TESTING TO FURTHER REFINE THE NASP TEST PROTOCOLS

3.6.1 Mortar Strength

Variations to mortar strength were brought about by varying the w/c. The three different w/c ratios were used; 0.40, 0.45, and 0.50. Two different types of strands were selected to study the effects mortar strengths can have on the NASP pull out values. The 2001 NASP protocols attached in Appendix B had a range of mortar strengths from 3500 to 5000 psi. The wide spread in the mortar range posed a larger spread in the NASP values. It was seen that the mortar strength had significant effects towards the NASP pull out values. Studies conducted in this research helped in identifying a closer range of mortar strengths which in turn resulted in more consistent NASP values.

3.6.2 Load control vs. Displacement control

Though the 2001 NASP test protocols attached in Appendix B specified using the displacement control of 0.1 in/min, to refine the test methodology, studies were conducted to understand the effects of controlling the NASP test in load control and displacement control. The load control of 5000 lb/min. and a displacement control of 0.1 in/min were performed on the NASP specimens.

3.6.3 Mortar Flow

The mortar flow was not specified in the NASP 2001 protocols. It was observed that a consistent mix and proper consolidation is necessary to improve the test procedure. The mortar flow served as a basis to understand the consistency of the mix. Trial batches with w/c of 0.40, 0.45, and 0.50 were made to specify the mortar flow range required for the NASP testing.

3.6.4 Curing Temperature

The curing temperatures of the mortar cubes have effects towards the strength of one day mortar cubes. Studies were conducted as a part of this research to identify the effects mortar strengths can have towards curing temperatures. A range of curing temperatures from 70 °F to 93 °F was chosen to understand the strength variations with temperatures.

3.6.5 Loading Rate

Though the applied loading was displacement control, the loading rate of the test was calculated. The loading rate is reported for all the NASP tests as the rate of lbs. per minute when the axial load on the specimen is between 4000 to 6000 lbs.

$$\text{Loading rate, lb/min} = \frac{P_{4000} - P_{6000}}{t_{4000} - t_{6000}} \times 60$$

Where, P_{4000} and P_{6000} are the exact loads at 4000 and 6000 lbs and t_{4000} and t_{6000} the respective times in seconds.

3.7 RESULTS FROM NASP BOND TEST CONDUCTED AT OKLAHOMA STATE UNIVERSITY

The following section reports the summary of the results from the NASP Bond test conducted at Oklahoma State University. The Round Robin trials for the NASP tests were conducted at Purdue University and University of Arkansas. The results from those locations are presented later along with discussions. Since significant refinements to the NASP protocol involved in the mortar properties, the results include both the results on mortar and their effects on NASP tests. The results of mortar strength on various w/c are also presented in the section. The variations NASP tests can have on displacement controlled and load controlled testing are reported. The effects of the mortar curing temperature to the corresponding strength are also studied.

3.7.1 Results from tests for material properties of Mortar

Three different w/c ratios were tested to assure variation in mortar strength. Table 3.4 shows the results from the trail batches and the NASP batches conducted at OSU. Batches are numbered 1 thorough 39. The batch number extends with A, B, or C if the batching is conducted for various w/c. The batch numbers will follow with "N" if the batch is made for a NASP Bond test. The one day compressive strengths are measured on mortar cubes with a sample size of three or more mortar cubes. The strengths are reported in Table 3.4. The one day compressive strength is measured at 24 ± ½ hr. except when mentioned explicitly. The mortar flow and the fresh unit weight is also reported in Table 3.4.

The batches 1B through 5B had one day compressive strengths less than 4500 with a w/c of 0.45. For batches from 8N, for the same w/c of 0.45, the strengths were higher than 4500. The reason can be attributed to the change in the cement source from the batches. For the first 7 mortar batches, the Type III cement used was from an unknown source. The change in the cement source resulted in the variation in mortar strength from the first 7 batches to the rest of the mortar batching.

Table 3.4: Summary of Mortar Batching Results						
Batch Number	**W/C**	**1Day Comp Strength (psi)**	**ST DEV (psi)**	**Number of Mortar Cubes**	**Flow**	**Fresh Unit Wt (pcf)**
Batch 1A	0.40	5227	113	3	87	142.60
Batch 1B	0.45	3770	94	3	111	141.40
Batch 1C	0.50	3018	22	3	-	141.50
Batch 2A	0.40	4999	51	3	95	141.82
Batch 2B	0.45	3991	33	3	111.5	141.73
Batch 2C	0.50	3006	26	3	-	141.00
Batch 3A	0.40	4792	115	3	72	142.94
Batch 3B	0.45	3979	93	3	103	140.50
Batch 3C	0.50	2982	41	3	-	140.79
Batch 4A	0.40	5078	94	3	74	142.92
Batch 4B	0.45	3981	181	3	93	140.89
Batch 4C	0.50	3195	108	3	107	140.57
Batch 5A	0.40	5279	251	3	59	142.98
Batch 5B	0.45	4212	64	3	69	142.44
Batch 5C	0.50	3344	45	3	113	140.39
Batch 6	0.475	3551	99	3	105	142.42
Batch 7	0.475	3613	113	3	93	142.03
Batch 8N	0.45	4765	85	5	104.5	141.01
Batch 9	0.45	4779	113	6	116.5	140.38
Batch 10	0.45	4938	126	5	113	142.62
Batch 11N	0.45	4730	125	6	119	140.18
Batch 12	0.45	4280	125	3	125	141.47
Batch 13	0.45	4966	163	3	121	140.63
Batch 14N	0.45	4953	197	5	113	139.21
Batch 15N	0.45	4815	111	5	103	141.28
Batch 16A	0.40	6042	47	3	97	142.29
Batch 16B	0.45	4652	47	3	107	141.57
Batch 16C	0.50	3772	32	3	132	138.91
Batch 17N	0.45	4484	168	5	97	138.07
Batch 18	0.50	4003	40	3	149	139.03
Batch 19	0.50	3893	44	3	150	138.31
Batch 20	0.50	3853	174	3	158	138.52
Batch 21 N	0.50	4043	115	5	136	136.00
Batch 22 N	0.50	4117	109	5	139	139.00
Batch 23 N	0.50	3981	131	5	139	136.28

Table 3.4: Summary of Mortar Batching Results						
Batch Number	W/C	1Day Comp Strength (psi)	ST DEV (psi)	Number of Mortar Cubes	Flow	Fresh Unit Wt (pcf)
Batch 24N	0.40	5763	76	5	95	139.25
Batch 25	0.45	4726	93	5	119	139.88
Batch 26	0.45	4913	56	5	123	139.25
Batch 27N	0.45	4933	167	5	119	138.83
Batch 28N	0.45	4843	70	5	120	138.57
Batch 29N	0.45	4723	227	5	111	138.43
Batch 30N	0.45	4723	97	5	110	138.76
Batch 31N	0.45	4927	24	5	109	140.34
Batch 32N [1]	0.45	5395	38	4	117	139.67
Batch 33N [1]	0.45	7291	274	3	120	138.67
Batch 34N	0.45	4659	78	5	122	139.99
Batch 35N	0.45	4659	162	5	113	139.81
Batch 36N	0.45	4451	115	5	130	137.65
Batch 37N	0.45	4724	64	5	118	137.73
Batch 38N	0.45	4153	106	5	128	138.45
Batch 39N	0.45	4303	95	5	119	138.55

Notes:
1: The NASP test was not reported as the test had to be delayed due to electrical problems
N in a Batch Number represents NASP Test
Reported STDEV is for the Mortar Strengths

3.7.2 Results from NASP Bond Test

After consistent mortar properties could be obtained reliably, the NASP test was performed on ten 0.5 in. diameter strands and two 0.6 in. diameter strands. The NASP test procedures conformed to the procedure detailed in Section 3.4 and the NASP protocol in Appendix B. The summary of the test results from OSU are shown in Table 3.5. The individual test results for each NASP test and the load slip curves are included in Appendix A.

The Table 3.5 is organized according to the NASP batch numbers conducted at OSU. The corresponding w/c and the mortar strength at 24 hours are reported in the table. The NASP Round IV strand ID and the corresponding NCHRP strand ID are mentioned in the table. The pull out force is reported to the nearest 10 lbs. “N” represents the number of NASP specimens tested for each batch. The standard deviation is also reported as “S” in lbs. The summary sheet in Table 3.5 also reports if the test was conducted as a load control (LC) or a displacement controlled (DC) testing.

Table 3.5: NASP Results Summary									
Batch #	w/c	Mortar Strength $\bar{f}'_{ci}$ (psi)	NASP IV STRAND ID	NCHRP ID	Strand Diameter (in.)	NASP Test Results			LC/DC
						Pull Out Force at 0.1" slip (lbs.)	N	S (lbs.)	
8N	0.45	4765	C	D	0.5	6,870	12	861	DC
11N	0.45	4730	G	A	0.5	20,710	11	1604	DC
14N	0.45	4953	G	A	0.5	20,010	12	3088	LC
15N	0.45	4815	G	A	0.5	21,930	6	1106	LC
15N	0.45	4815	G	A	0.5	21,190	6	1333	DC
17N	0.45	4484	C	D	0.5	8,710	5	432	LC
17N	0.45	4484	C	D	0.5	6,910	5	338	DC
21N	0.5	4043	G	A	0.5	20,060	12	1129	LC
22N	0.5	4117	C	D	0.5	6,110	12	421	DC
23N	0.5	3981	G	A	0.5	16,360	12	1629	DC
24N	0.4	5763	C	D	0.5	8,420	12	415	DC
27N	0.45	4933	K		0.6	19,010	5	4311	DC
27N	0.45	4933	L	A	0.6	17,960	6	1292	DC
28N	0.45	4843	K		0.6	22,420	5	1964	DC
28N	0.45	4843	L	A	0.6	18,610	6	717	DC
29N	0.45	4723	A	C	0.5	14,130	6	1144	DC
29N	0.45	4723	E		0.5	15,950	6	1266	DC
30N	0.45	4723	J	B	0.5	19,330	5	808	DC
30N	0.45	4723	E		0.5	17,210	6	823	DC
31N	0.45	4927	J	B	0.5	21,090	6	733	DC
31N	0.45	4927	A	C	0.5	13,300	6	1763	DC
34N	0.45	4659	H		0.5	15,940	6	1153	DC
34N	0.45	4659	F		0.5	13,570	6	968	DC
35N	0.45	4659	H		0.5	18,080	6	1202	DC
35N	0.45	4659	F		0.5	16,540	6	684	DC
36N	0.45	4451	I		0.5	12,100	6	1455	DC
36N	0.45	4451	B		0.5	13,440	6	1243	DC
37N	0.45	4724	I		0.5	14,710	6	1181	DC
37N	0.45	4724	B		0.5	15,600	6	1044	DC
38N	0.45	4153	K		0.6	19,510	12	2079	DC
39N	0.45	4303	D	E	0.5	5,240	6	635	DC

3.8 DISCUSSION OF RESULTS FROM NASP BOND TEST CONDUCTED AT OKLAHOMA STATE UNIVERSITY

3.8.1 Mortar Strength and Water to Cement Ratio

The relationship between compressive strength and w/c has been established. Figure 3.18 compares $\bar{f}'_{ci}$ vs. w/c and the test results show strong relation in this aspect. As illustrated, compressive strengths decrease with increasing w/c. In Fig. 3.18, the data for the average mortar cubes listed in Table 3.4 is split into two data sets for regression analyses. The first analysis is conducted for the batches 1 through 7. The second analysis is conducted for the batches 8 through 39. The reason for this split is because of the variation in the cement source for the first seven batches. The coefficient of determination of 0.96 is seen when the average compressive strength of three or more mortar cubes are plotted against the corresponding water to cement ratios for the first seven batches. For batches 7 through 39, the coefficient of determination R^2 is 0.81.

Table 3.6 summarizes the mortar strength results for batches from 8N through 39N. The average one day mortar strengths ($\overline{X}$) for w/c of 0.40, 0.45, and 0.50 and the corresponding standard deviation (S) and the number of batches made (N) are tabulated in Table 3.6. It is seen that the average one day compressive strength for w/c of 0.45 is 4700

Table 3.6: Summary of Mortar Strength Results for batches 8N through 39 N

w/c	N	$\overline{X}$ (psi)	S (psi)
0.4	2	5902	197
0.45	23	4700	227
0.5	7	3952	119

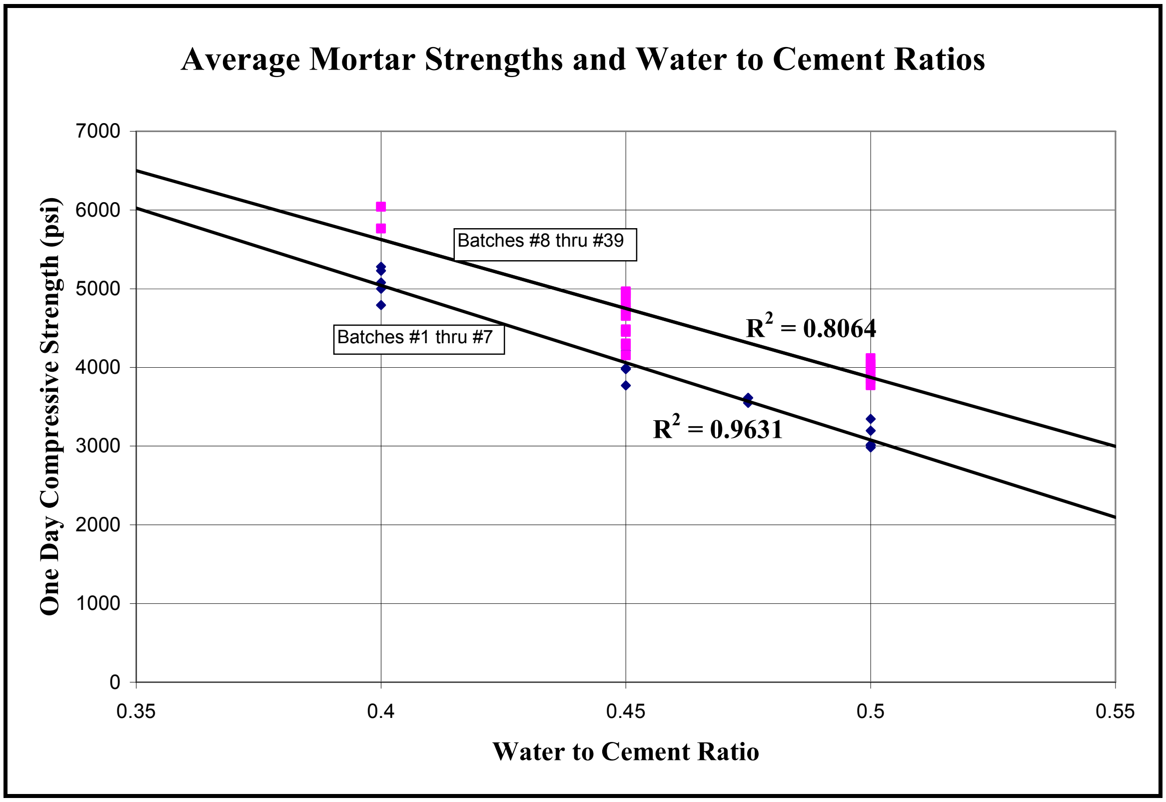


Figure 3.18: Mortar Strengths and w/c

3.8.2 Mortar Flow

Flow of the fresh mortar was measured for every trial batch and the NASP batches as explained in Section 3.4. With increase in the amount of water in mortar mix, the flow tends to be higher. Figure 3.19 shows that the flow increases with the w/c. A coefficient of determination of 0.586 is seen in this relation. The measured flow decrease significantly over time in the fresh state from one trail to another. The flow measurements were made in conformance with ASTM C 1437. The data presented in Fig. 3.19 is reported in Table 3.4 which reports only the flow measurement that was taken in the first trial.

The average flow for w/c 0.40, 0.45, and 0.50 and the corresponding standard deviations for all the batches are tabulated in Table 3.7.

In order to have a consistent mortar mix, it is necessary to have a flow range. A flow range of 100 to 125 is specified in the NASP test protocols to achieve a consistent mix proportion in the NASP specimens. As illustrated in Table 3.7, the specified flow range falls in the range of ($\bar{X} \pm S$) for w/c 0.45. A flow which is out of range from the mix proportion could indicate a problem with the mixture constituents.

Table 3.7: Summary of Flow Results for all batches

w/c	N	$\bar{X}$	S
0.4	7	83	15
0.45	30	113	12
0.5	9	136	17

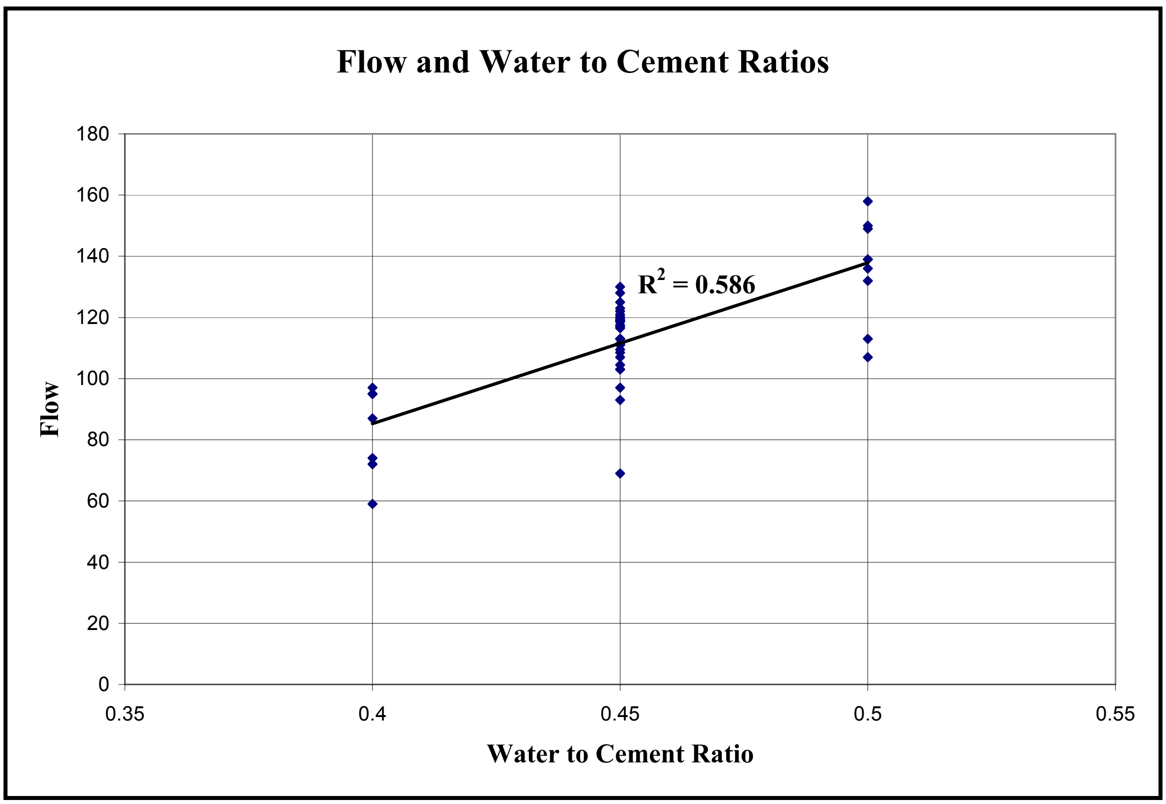


Figure 3.19: Flow and Water to Cement Ratios

3.8.3 Curing Temperature

As the 24 hour compressive strengths had considerable effects with the curing temperature, trial batches were made to study the optimal curing temperature range for

NASP specimens. Trial batches were made and mortar cubes were cured at a range of temperatures from 70 to 95 °F. The batches that involved in this study were Batch 25, 26, 28N, 29N, 30N, and 31N. Mortar cubes were cured at various temperatures to study the effects. Table 3.8 shows the temperature and the corresponding mortar strength for individual mortar cubes. The ASTM curing conditions were maintained in the laboratory curing room with 70 to 73 °F curing temperature. The results demonstrated in Figure 3.20 shows that compressive strengths increase with increase in curing temperature. From the data, to achieve compressive strengths between 4750±250 psi, the curing temperature should be maintained at 70±3 °F.

Table 3.8: Compressive strength in psi of individual mortar cubes with varying temperature

Cube Number	ASTM	80°F	81°F	89°F	90°F	92°F
1	4819	5056	5060	5297	5440	5236
2	4726	5099	5075	5262	5450	5266
3	4633	4893	4985	5347		5095
4	4895					
5	4870					
6	4976					
Average (psi)	**4820**	**5016**	**5040**	**5302**	**5445**	**5199**
S (psi)	**124**	**109**	**48**	**42**	**7**	**91**

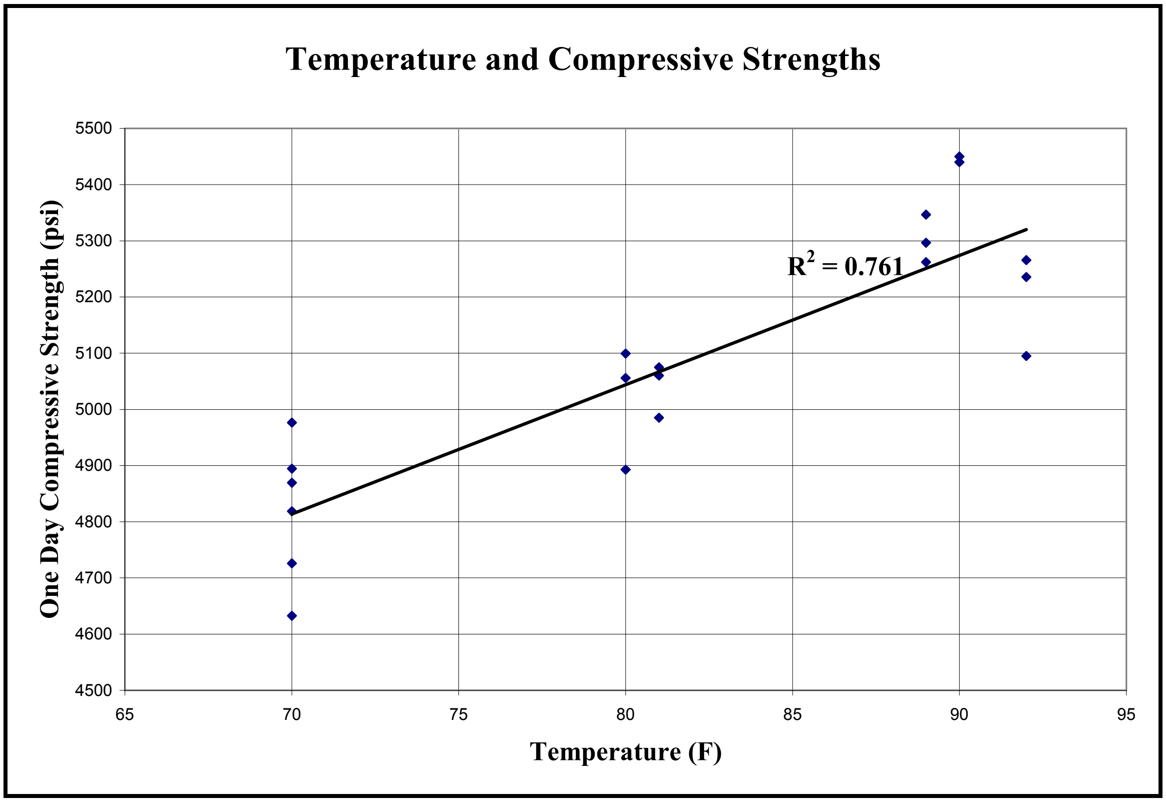


Figure 3.20: Temperature and Compressive Strengths

3.8.4 Fresh Unit Weight and Water to Cement Ratio

The fresh unit weight was measured on every mortar batch made. The average $\overline{X}$, standard deviation S, and the number of specimens N are tabulated in Table 3.9. Table 3.9 does not show significant change in the fresh unit weight data for w/c of 0.45 and 0.5. The fresh unit weight data presented in Table 3.4 for each of the batches is plotted against the w/c in Fig. 3.21. The experimental data has a coefficient of determination R^2 of 0.24, leading to a weak correlation between the mortar unit weight and w/c. It was observed that the fresh unit weight is not a strong predictor to understand the mortar properties. However, the present NASP protocols recommend having a unit weight to that is close to the observed unit weights during trial batching. There are no set limits for unit weights for the NASP test protocols.

Table 3.9: Summary of Fresh Unit Weight for all batches			
w/c	N	$\overline{X}$ (pcf)	S (pcf)
0.4	7	142.11	1.33
0.45	30	139.93	1.39
0.5	12	139.19	1.77

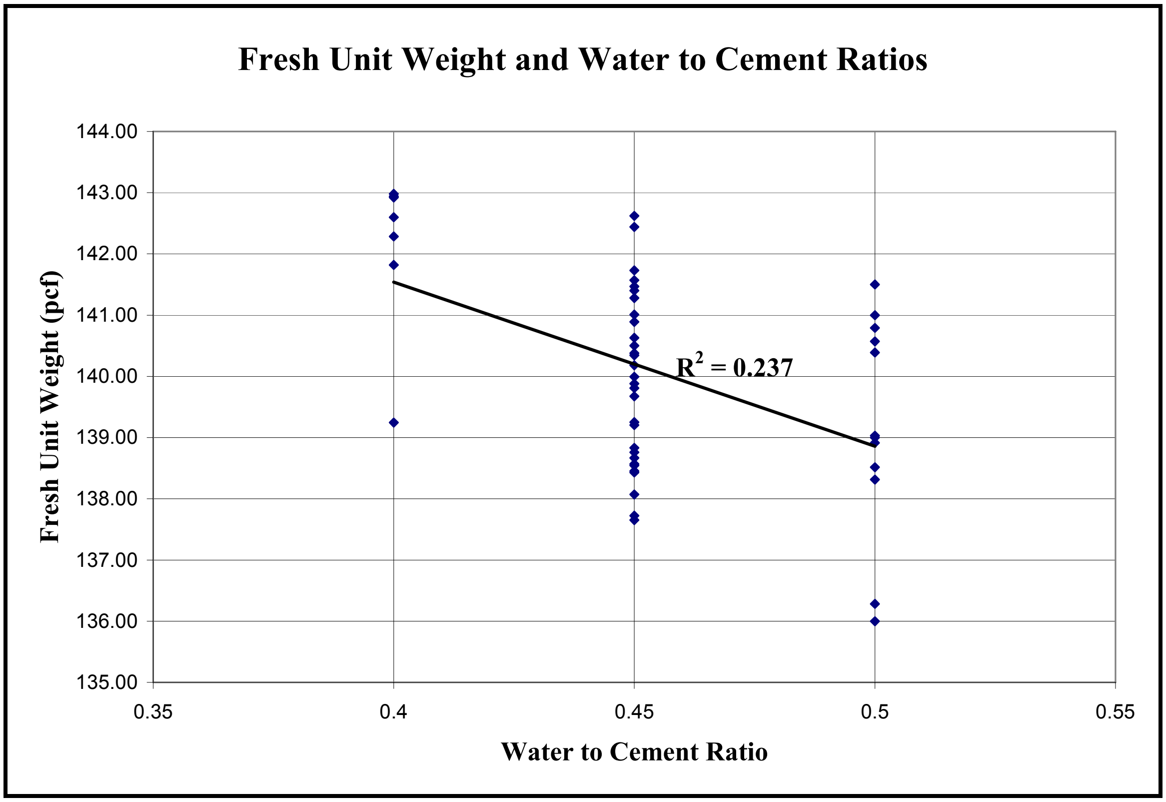


Figure 3.21: Unit Weight and Water to Cement Ratios

3.8.5 Effects of Mortar Strength on NASP Bond Test

To study the effects of NASP bond test on mortar strengths, tests were conducted on NASP Strand C and G. The test was conducted using water to cement ratios targeting a range of mortar cube strengths from 4000 to 6000 psi. for NASP Strand C. The Figure 3.22 shows the relationship of NASP bond test value and the mortar strength for two types of 0.5 in. diameter strands. The results demonstrate that the coefficient of determination is 0.9666 representing a strong correlation in the test data for Strand D, and a "perfect" correlation for Strand A. The batch numbers for each of the data point is shown in Figure 3.20. The individual NASP values for the strands were chosen from Table 3.10. The average NASP value plotted in Figure 3.22 include only the tests conducted in displacement control.

The mortar strength plays a critical role in the NASP pull out value. With higher mortar strengths, the NASP values tend to be higher. The effect is more predominant on higher bonding strands where the linear regression line is steeper when compared to strands with moderate bonding. For the same differential compressive strength, the strands with moderate bonding might not have significant effects on the NASP value when compared to the high bonding strands. For example, the moderate bonding Strand C can have a NASP value range 6700 to 7370 lbs. and the high bonding Strand G can have a NASP value range 19370 to 22270 lbs for mortar strengths between 4500 to 5000 psi. With lower mortar strengths, it becomes hard to predict the NASP value for a variety of strands as there is a possibility of having "too many similar values" for various types of strands. On the other hand, with higher mortar strengths, the NASP test becomes more difficult to perform as there is a need for machines with higher capacities. The mortar strength range of 4750±250 psi helps in identifying the NASP value for a wide variety of high bonding and low bonding strands. A mortar strength range between 4500 to 5000 psi with a consistent mortar mix is easily achievable in laboratory conditions.

Table 3.10: Results of NASP Bond test with varying mortar strength on NASP Strands C and G

Batch #	w/c	$\bar{f}'_{ci}$ (psi)	NASP (lbs.)	DC/LC
Strand C				
8N	0.45	4765	6,870	DC
17N	0.45	4484	8,710	LC
17N	0.45	4484	6,910	DC
22N	0.5	4117	6,110	DC
24N	0.4	5763	8,420	DC
Strand G				
11N	0.45	4730	20,710	DC
14N	0.45	4953	20,010	LC
15N	0.45	4815	21,930	LC
15N	0.45	4815	21,190	DC
21N	0.5	4043	20,060	LC
23N	0.5	3981	16,360	DC

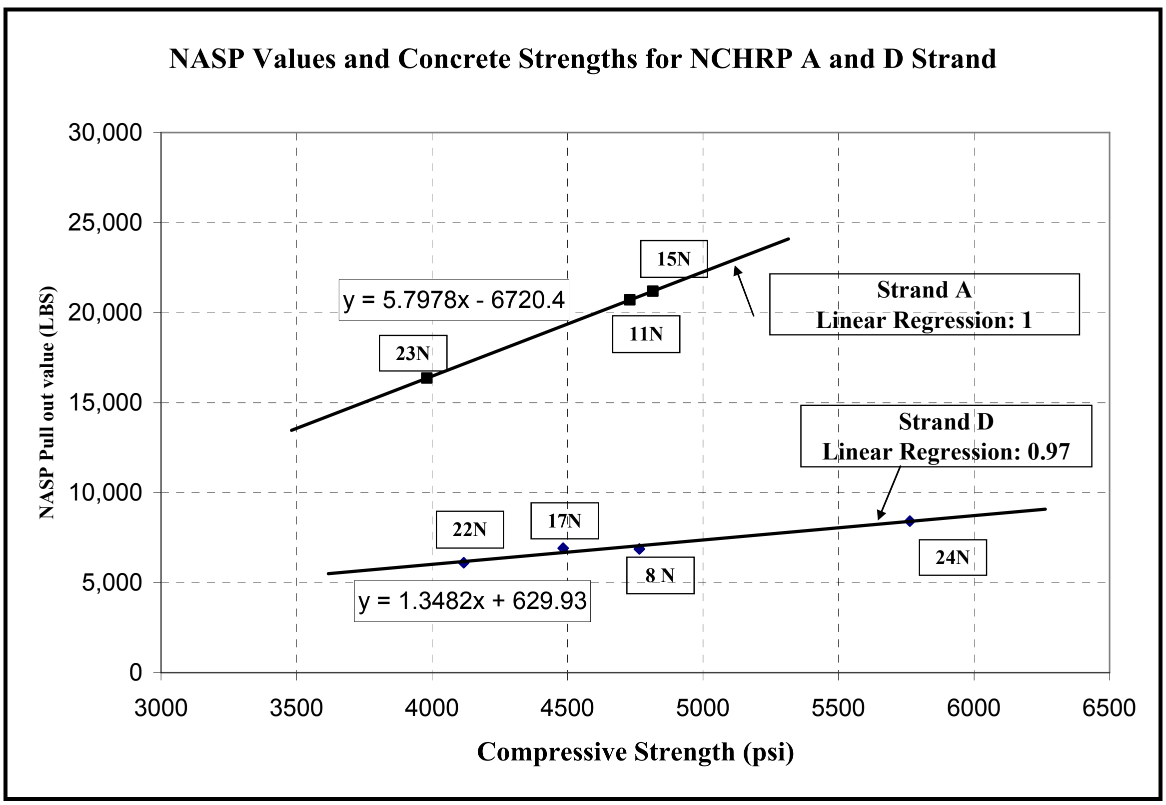


Figure 3.22: NASP Pull out Values for varying Mortar Strengths

3.8.6 Load Control vs. Displacement Control

Though the NASP test method in 2001 specified the loading rate as 0.1 in/min, studies were conducted in the present research program to compare the loading rate with 5000 lb/min. The displacement controlled loading rate and the load controlled loading rate showed significant differences in the NASP test. Figures 3.23 and 3.24 shows the load slip curves for Strand C which was tested for load control and displacement control respectively. It can be seen from the load-slip curves for Batch 17 N that the strand shows a “softening” nature when tested in Displacement control. The NASP pull out value seen for load controlled testing is higher than the same test conducted with displacement control. For the Figures 3.23 and 3.24 the average NASP pull out values at 0.1 in. slip were 8710 and 6910 LB for load and displacement control respectively. The individual NASP values for each of the strands can be found in Appendix A.

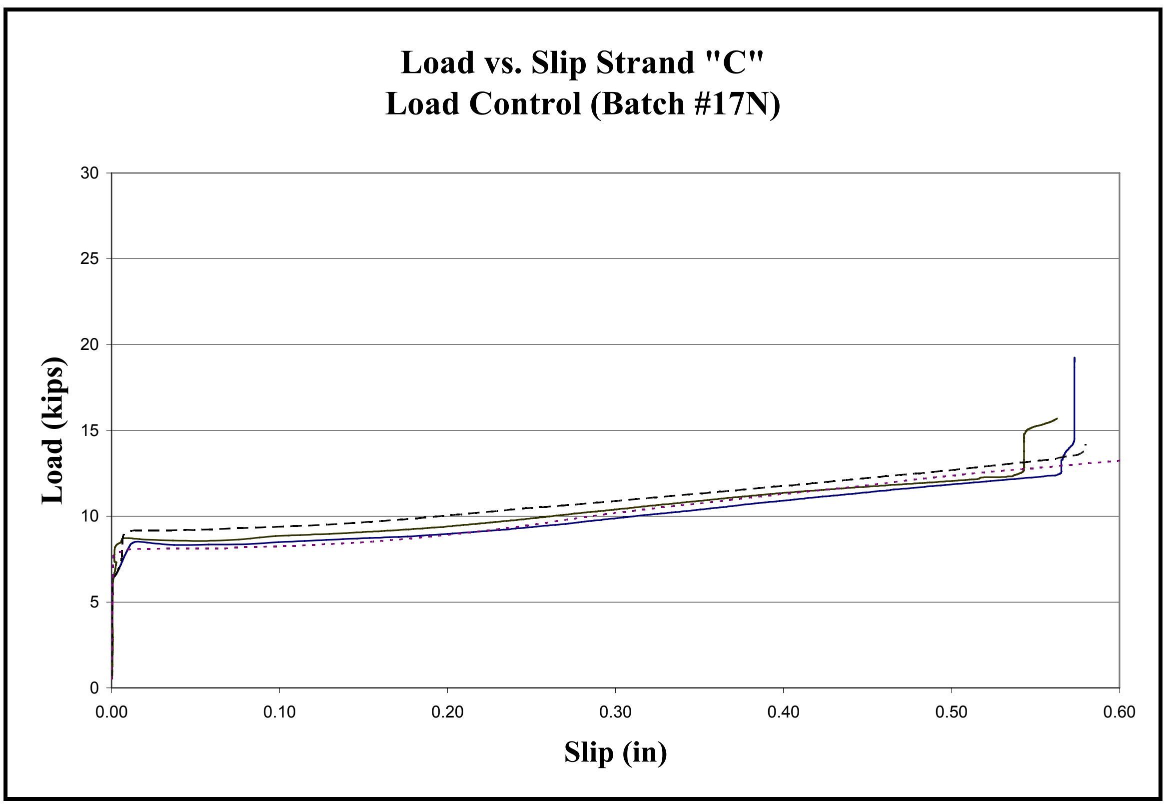


Figure 3.23: Load Slip Curve for Strand “C” in Load Controlled testing

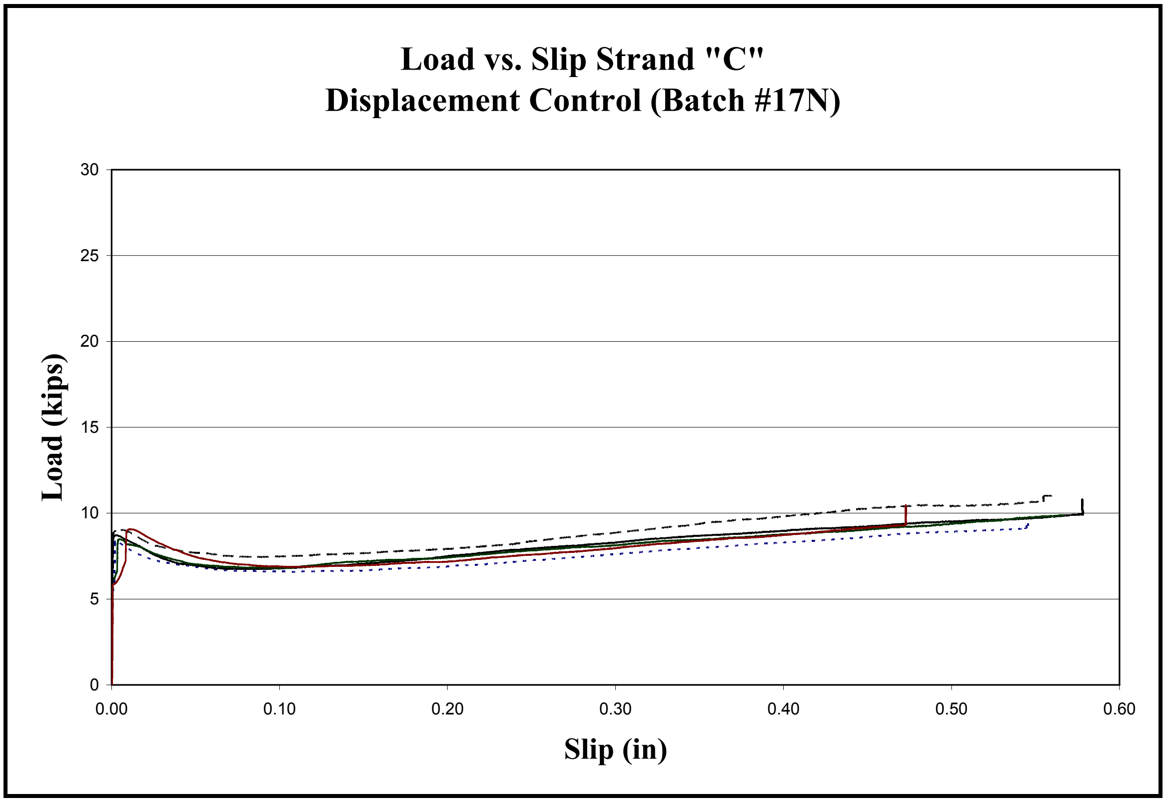


Figure 3.24: Load Slip Curve for Strand "C" in Displacement Controlled testing

3.8.7 Importance of Loading Rate

Though the NASP test is standardized as a displacement controlled loading procedure, the loading rate is calculated on each of the specimen from the time increment between 4000 and 6000 lbs. as discussed in earlier section. The NASP test results in Appendix A, reports the loading rate on all the tests conducted. Studies compiled in earlier research work (Grieve 2004) reports that significance of loading rate on the NASP Bond test. The studies were not performed using the present NASP protocols. The strands used in this study were the NASP strand C and Strand G which were called as "FF" and "AA" respectively during the NASP Round III. The Figs. 3.25 and 3.26 show the variation of the loading rate on the NASP values. The data graphed in the figures are labeled in the respective plots. Grieve reports that "*Based on regression analysis, the* *correlation between NASP bond forces and loading rate is relatively small when all data is considered. Although the correlation does increase when looking at OSU data only, the data does not support a strong relationship between the loading rate and NASP bond force*."

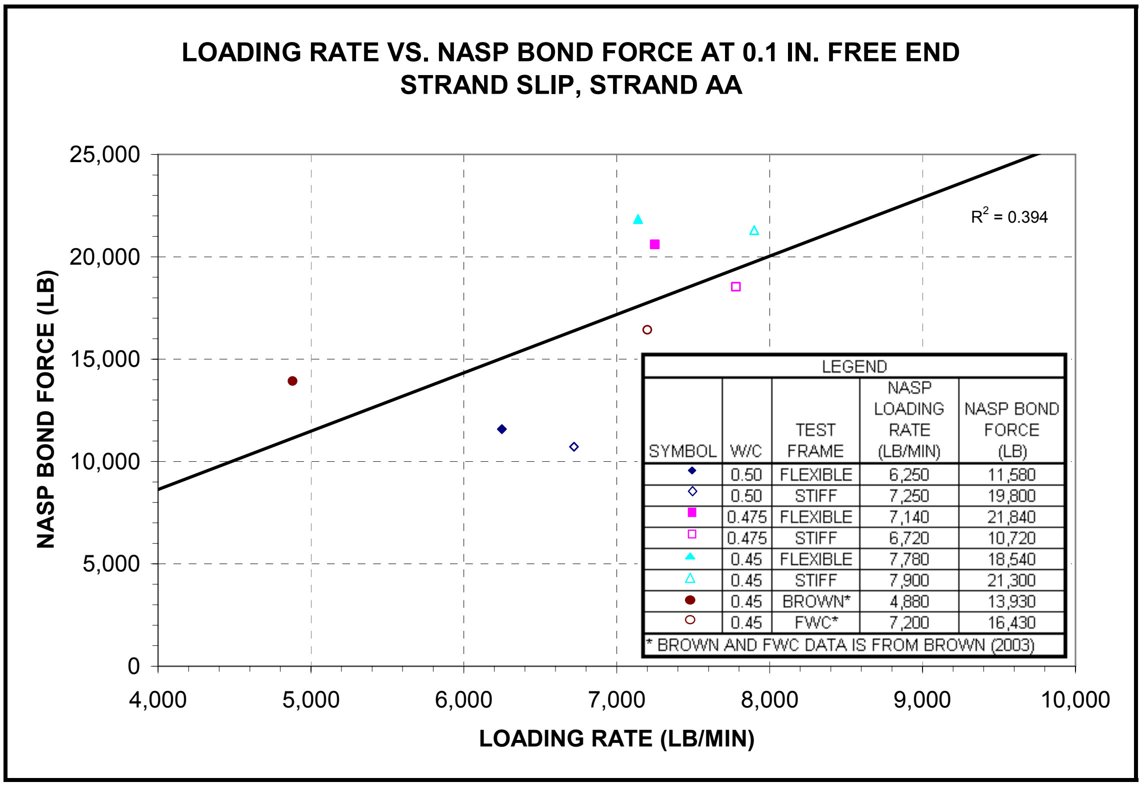


Figure 3.25: Loading Rate and NASP Bond Force for Strand AA (Grieve 2004)

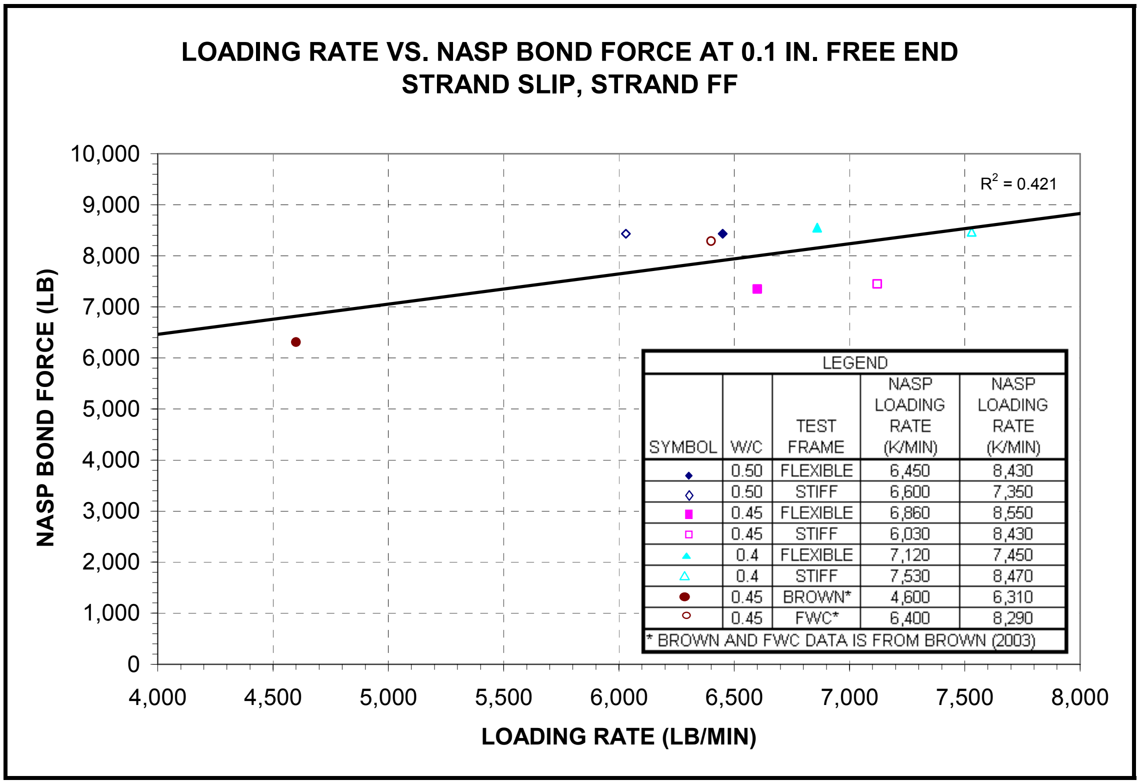


Figure 3.26: Loading Rate and NASP Bond Force for Strand FF (Grieve 2004)

In the current NASP test protocol, the maximum loading rate for a specimen during the NASP test is limited to 8000 lb/min. While conducting the test at OSU using the NASP protocols dictated in earlier section, all the loading rates were within 8000 lb/min when computed from the time increment between 4000 and 6000 lbs.

3.9 REPROCUCIBILITY OF THE NASP BOND TEST BETWEEN SITES

After standardizing the NASP test protocols from Oklahoma State University (OSU), the test was conducted at Purdue University (PU) and University of Arkansas (U of A) to verify the reproducibility of the NASP Bond test. The NASP test procedures at PU and U of A were "identical" to the tests standardized at OSU. The results from the other sites together with the results from OSU are presented in Table 3.11. The NASP Round IV designation is presented on Table 3.11. The NASP tests were conducted at PU for Strands A, C, D, G, J, and K and the tests were conducted at U of A for Strands A, C, D, and I.

In Table 3.11, some of the NASP tests reported did not conform to the mortar strength requirement of 4750±250 psi. For such tests, the NASP values are omitted for comparisons regarding reproducibility. However, for Strand D the data is considered for comparisons as the tests conducted at OSU and PU had mortar strengths of 4303 and 4000 psi respectively. Though NASP test protocols recommend to repeat the test if the mortar strength falls outside 4750±250 psi, further tests were not conducted on Strand D due to lack of availability of the strand. For the test conducted at PU for Strand K, though the strength requirement did not meet the NASP criteria, the data is considered for understanding the reproducibility of the NASP Bond test.

Table 3.11: NASP Results Summary from OSU, PU, and U of A							
NASP ROUND IV STRAND ID	Strand Diameter (in)	NASP Test Results at OSU		NASP Test Results at PU		NASP Test Results at U of A	
		Mortar Strength $\bar{f}'_{ci}$ (psi)	Pull Out Force at 0.1" slip (lbs)	Mortar Strength $\bar{f}'_{ci}$ (psi)	Pull Out Force at 0.1" slip (lbs)	Mortar Strength $\bar{f}'_{ci}$ (psi)	Pull Out Force at 0.1" slip (lbs)
A	0.50	4723	14130	4498	14270	4670	14240
A	0.50	4927	13300	4810	15150		
Avg.			**13715**		**14710**		**14240**
C	0.50	4765	6870	4665	7280	4700	8600
C	0.50			***4365***	***9770*** [1]		
C	0.50			4767	9970		
Avg.			**6870**		**8625**		**8600**
D	0.50	***4303***	***5240***	***4000***	***6070***	4630	7270
G	0.50	4730	20710	4847	20880		
G	0.50	4815	21190	***4318***	***16,470*** [1]		
G	0.50			4638	18880		
Avg.			**20950**		**19880**		
I	0.50	***4451***	***12,100*** [1]			4700	12350
I	0.50	4724	14710				
Avg.			**14710**				**12350**
J	0.50	4723	19330	4893	22700		
J	0.50	4927	21090	4798	22280		
Avg.			**20210**		**22490**		
K	0.60	4843	22420	***4356***	***19130***		
K	0.60	4933	19010				
K	0.60	***4153***	***19,510*** [1]				
Avg.			**20715**		**19,130**		
L	0.60	4933	17960	4628	15450		
L	0.60	4843	18610				
Avg.			**18,,285**		**15,450**		

Notes:
1: The results were omitted as $\bar{f}'_{ci}$ was out of range

The results presented in Table 3.11 are graphically represented along with the coefficient of determination, R^2 values in Figs. 3.27 and 3.28. The data used to plot the figures are the average values at various locations of a particular type of strand reported in Table 3.11. The data points omitted for plotting the figures are reported as footnotes in Table 3.11.

Figure 3.27 plots the average NASP values from OSU against the average NASP values from PU. The individual NASP strand designation is labeled in Fig. 3.27. A linear regression line and a "perfect fit" line are plotted in the figure. It is observed that the test results match very close with the "perfect fit" line with an R^2 value of 0.92. The data set can be considered as "identical" when the test is performed between the two sites.

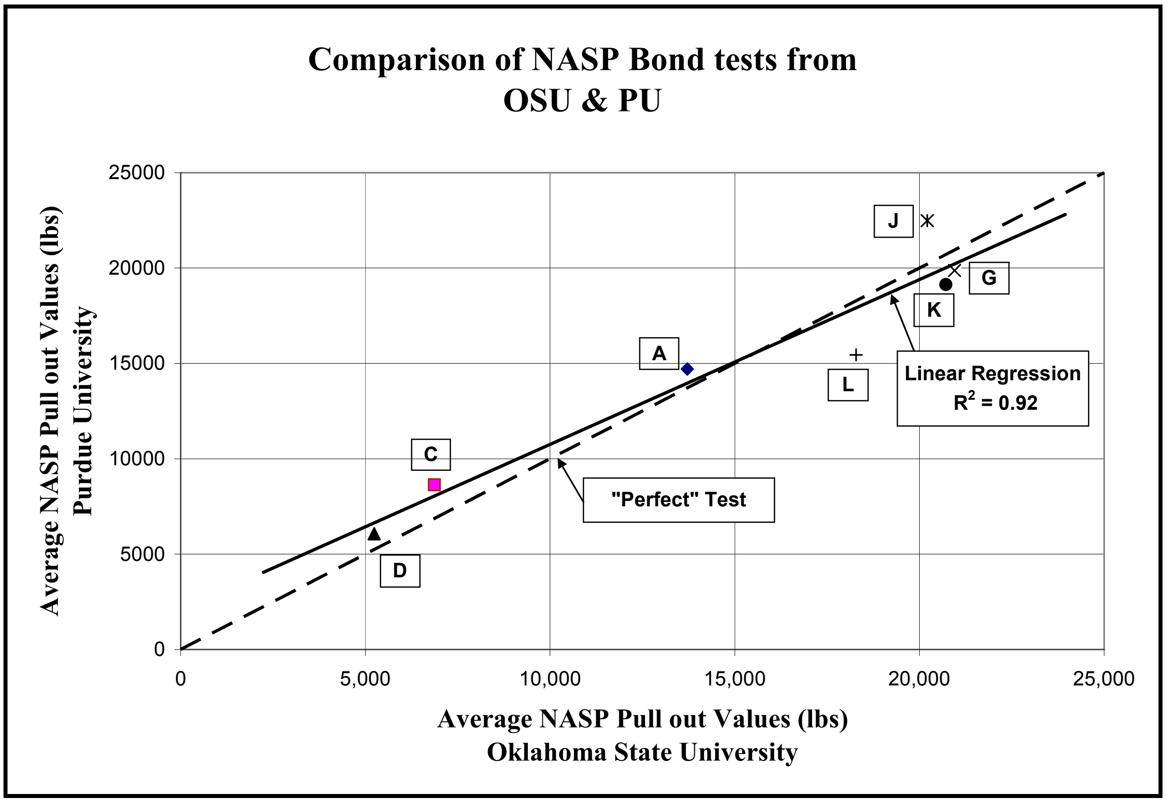


Figure 3.27: Comparison of NASP Bond test from OSU and PU

The data in Table 3.11 for the NASP Bond tests conducted at OSU and U of A are presented in Fig 3.28. The four different strand sources were tested between the sites to understand the reproducibility of the test method. The R^2 value for this data set is 0.89

showing a high correlation between the data. It is observed that the linear regression line in Fig 3.28 does not match very closely with the "perfect fit" line, however the test results are convincing as far as reproducibility is concerned based on the R^2 value.

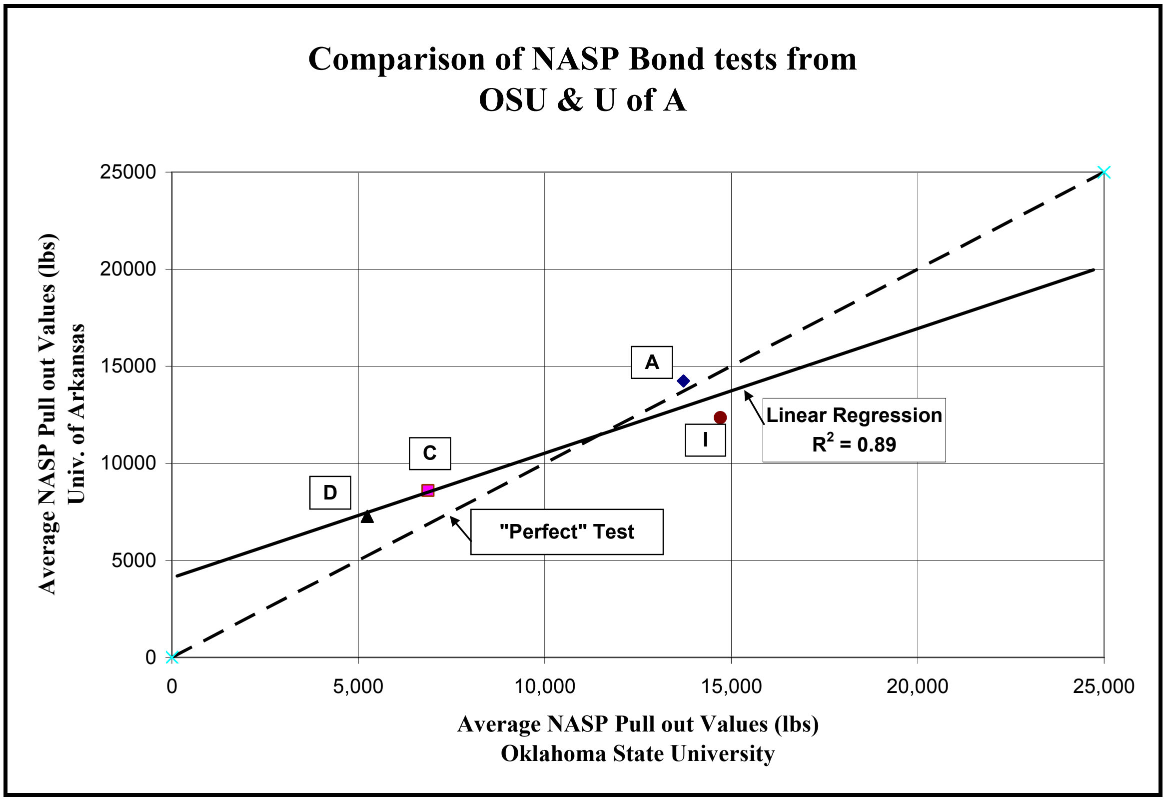


Figure 3.28: Comparison of NASP Bond test from OSU and U of A

3.10 SUMMARY & CONCLUSIONS

The NASP Bond test performed in this research program was conducted on ten 0.5 in. diameter and two 0.6 in. diameter strands. The test was conducted on some strand samples at Purdue University and University of Arkansas, apart from the tests performed at Oklahoma State University.

The NASP Bond test protocols was decided based on tests conducted on two different 0.5 in. strand sources at OSU. A mortar flow range of 100 to 125 shall be obtained during batching without which the mortar shall be discarded. A target mortar cube strength of 4750 ± 250 psi shall be reached during the testing of the NASP specimen within 24 hours after cement hydration. The specimen shall be mounted on a testing frame with a capacity of 22,000 LB or more with a data acquisition system which can procure data in real time with a capability of at least one data point per second. The free end slip of the specimen shall be measured using an LVDT mounted on the specimen. The specimen shall be loaded at a rate of 0.1 in/minute for ten minutes. The NASP value shall be reported as the load that is required to displace the free end by 0.1 in. Three mortar cubes shall be tested before started the NASP test, three midway during the test, and three cubes after the test. The NASP result reported for the mortar strength shall be the average of the three mortar cubes tested midway during the NASP test.

The NASP test procedure was standardized after conducting the studies for flow, compressive strengths, consolidation, and temperature. Some of the strands had a "softening" behavior of having a lower NASP value at 0.1 in. slip when compared to 0.01 in. slip after performing the NASP Bond test based on the present protocols. This characteristic was seen for NASP Strands C and D. Both these strands performed in the lower ranking for strands with NASP pull out forces of 6870 and 5240 LB respectively. Though it might seem that the softening nature causes the low values, there is insufficient number of strands with similar characteristic to comment on the issue.

The NASP Bond test procedure has proved to be a repeatable test method within various locations. Historically, NASP Test has performed high above other tests in bond of prestressing strands like the Moustafa test and the PTI Bond test. This research work has further reinforced the idea of the need to accept the NASP Bond test as a standard test in bond for prestressed concrete applications.

CHAPTER IV

4.0 NASP TESTS IN CONCRETE

The NASP Bond test protocol was modified to test the strand in concrete in place of mortar. This chapter will discuss and report the results of the NASP test conducted in Concrete. The modified NASP test in concrete was performed on three 0.5 in. diameter (12.7mm) and one 0.6 in. diameter (15.2mm) strands in concrete with varying strengths. The concrete used for the modified NASP test had strengths varying from 4 to 10 ksi.

4.1 SCOPE OF RESEARCH

The modified NASP test was conducted in concrete to understand the effects of varying concrete strengths on the bond of prestressing strands. The test procedure was identical to the NASP Test protocols discussed in Chapter 3 except that concrete with varying strengths were used instead of cement sand mortar. The NASP Tests in concrete were conducted on three 0.5 in. diameter strands with NASP strand designations G, J, and C and one 0.6 in. diameter strand with NASP ID L. The corresponding NCHRP IDs are A, B, D for 0.5 in. diameter strands and NCHRP ID A for 0.6 in. diameter strand. The number of NASP tests conducted on concrete for varying concrete strengths is reported in Table 4.1. Each test listed in Table 4.1 contains six or more NASP specimens. The target concrete strengths for each of the test were 4, 6, 8, and 10 ksi.

Table 4.1: Number of NASP Tests conducted in Concrete for varying concrete target strengths						
NASP ROUND IV ID	NCHRP ID	Strand Diameter (inches)	Target Concrete Strengths (ksi)			
			4	6	8	10
G	A	0.5	1	1	1	1
J	B	0.5	1	1	1	1
C	D	0.5	2	4	2	1
L	A	0.6	1	1	1	1

4.2 RESEARCH VARIABLES

The standardized NASP Bond test procedure is performed in cement sand grout. The NASP test protocols do not depend on the tests conducted in concrete. The NASP tests were conducted in concrete to study the effects the test procedure has on varying concrete strengths. The test conducted in concrete is not a standard bond test, but a modified test procedure. The concrete strengths used for the modified NASP test in concrete varied from 4 to 10 ksi.

4.3 MATERIAL PROPERTIES

4.3.1 Prestressing Strands

All prestressing strands used for this research program were seven wire Grade 270 low relaxation strands from manufacturers in North America. The strands conformed to ASTM A416 attached in Appendix J. The prestressing strands had a nominal diameter of 0.5 in. (12.7 mm) or 0.60 in. (15.2 mm). The nominal cross sectional area was 0.153 sq in. (98.7 mm^2) for 0.5 in. diameter strands and 0.217 sq in (140 mm^2) for 0.60 in. diameter strand. The modulus of elasticity of the prestressing strands was estimated as 28,500 ksi (196.3 GPa) for both 0.5 in. and 0.6 in. diameter strands.

4.3.2 Concrete Mixtures

The concrete mixtures used for making the NASP specimens in concrete included Type III cement from Lafarge North America, coarse and fine aggregate from Dolese Bros. Co., cement slag from Lafarge North America, and admixtures from Degussa Admixtures Inc. Admixtures used included high range water reducers (HRWR), normal range water reducers (NRWR), and air entraining admixtures (AEA). Table 4.2 gives the mix proportions and the target fresh and hardened properties for the concrete cast in the modified NASP specimens. The mix proportions were named based on the target one day strength. The mix proportion C-0 targets a concrete strength of 4 ksi at release. Similarly, C-I, C-II, and C-III targets strengths of 6, 8, and 10 ksi at release. The concrete mix C-IA, has a target release strength of 6 ksi with air entraining admixture. Detailed trial batching was performed (Tessema 2006) to arrive at the concrete mix proportions and the target fresh and hardened properties. The results and discussion on the concrete mix proportions is beyond the scope of this thesis.

Table 4.2: Concrete Mix Proportions for Prestressed Beams					
Material	**C-0**	**C-I**	**C-IA**	**C-II**	**C-III**
Cement (PCY)	650	800	800	800	900
Cement Slag (PCY)					100
Coarse Aggregates (PCY)	1800	1703	1800	1805	1747
Fine Aggregates (PCY)	1243	1203	922	1219	1183
Water (PCY)	298	303	272	277	251
Glenium 3200 (fl oz/cm. wt)			10	14	7
Glenium 3400 (fl oz/cm. wt)	8	5			5.5
Polyheed 997 (fl oz/cm. wt)			3		
MB-AE 90 (fl oz/cm. wt)			1.88		
Target Properties for Fresh and Hardened Concrete					
1 Day Strength (ksi)	4	6	6	8	10
28 Day Strength (ksi)	6	8	8	10	16
56 Day Strength (ksi)	8	10	10	14	18
Slump (in)	8	8	8	8	9
Unit Weight (pcf)	145	148	148	150	157
Air Content (%)	2	2	8	2	2

4.4 PROCEDURE FOR NASP BOND TEST IN CONCRETE

The NASP Bond Test tests the bondability of the 0.5 in. and 0.6 in. prestressing strands that conform to ASTM A 416. The test is carried out by casting the prestressing strands in concrete enclosed in a cylindrical steel form with a base plate. The mix proportions used for conducting the modified NASP test in concrete are shown in Table 4.2. The strand is pulled out from the concrete at a loading rate of 0.1 in./min using a hydraulic system after curing for 24 ± 2 hours. The pull-out force is measured in real time along with the relative movement of the free end of the strand to the specimen. The NASP Bond Test records the pull-out force that corresponds to 0.10 in. of free end slip.

One single NASP Bond Test consists of six individual test specimens. Pull-out results from each test are averaged to provide the NASP Bond value.

4.4.1 Test Methodology and Sample Preparation

4.4.1.1 Sample Preparation

The NASP Bond tests conducted in concrete used the same procedure as explained in Section 3.4. in Chapter 3. The handling and preparation of the strands, the steel casing and the bond breakers were identical to the NASP Tests conducted in sand-cement mortar.

4.4.1.2 Concrete Batching

The concrete batching was conducted in a pan mixer. The mixing procedures used for the NASP Bond test conformed to ASTM C 192. The fresh concrete is placed in two layers; each layer is consolidated using a handheld electric vibrator. The slump, unit weight, and air content are measured as per ASTM C 143, ASTM C 138, and ASTM C 231 respectively. The NASP specimens and the test cylinders were cured in conformance with ASTM C 192. The compressive strength testing was conducted during the time of the NASP test, in conformance with ASTM C 39. The NASP specimens are then kept in a Laboratory curing room for 22 to 24 hours from the time of hydration. Curing conditions near 73.4 °F and 100 % Relative Humidity are maintained.

4.4.2 Modified NASP Bond Test in Concrete

The modified NASP bond test is performed at 24±2 hrs. after the hydration of the cement. The NASP specimen in concrete is mounted on a rigid steel frame in the same manner described for the NASP Bond test (in mortar). The test procedure employed was identical to the standardized NASP Bond test explained in Chapter 3.

4.5 NASP RESULTS IN CONCRETE

The NASP Bond test standardized in mortar was conducted in concrete to understand the effect of the concrete strengths on NASP test. The results from this experimental testing are summarized along with the NASP value of the strand in the standardized NASP test in Table 4.3. The table reports the w/cm ratio as there were pozzolanic materials added for some of the concrete mixtures which are reported in Table 4.2. The detailed NASP results, the load vs. slip plots, and concrete mixture details are reported in Tessema (2006). The concrete strengths reported in Table 4.3 is the average strength of three or more concrete specimens tested during the NASP test. The number of specimens tested (N) and the standard deviation (S) are reported for the modified NASP test in concrete.

Table 4.3: NASP Results in Concrete									
Strand ID			Concrete			NASP Test Results			
NCHRP ID	NASP IV STRAND ID	Strand Diameter (in.)	w/cm	Concrete Strength $\bar{f}'_{ci}$ (ksi)	$\sqrt{\bar{f}'_{ci}}$ $\left(\sqrt{ksi}\right)$	NASP in Mortar (kips)	Pull Out Force at 0.1" slip (kips)	N	S (ksi)
A	G	0.5	0.425	4.52	2.13	20.95	23.58	6	0.66
A	G	0.5	0.38	7.02	2.65		26.35	6	1.44
A	G	0.5	0.36	8.05	2.84		30.68	6	1.77
A	G	0.5	0.235	11.79	3.43		35.29	6	2.33
B	J	0.5	0.46	3.56	1.89	20.21	22.55	6	5.57
B	J	0.5	0.4	5.58	2.36		30.8	6	1.04
B	J	0.5	0.32	7.11	2.67		28.78	6	4.55
B	J	0.5	0.24	10.06	3.17		34.33	6	4.17
D	C	0.5	0.45	4.71	2.17	6.87	7.48	6	2.76
D	C	0.5	0.46	4.56	2.13		6.66	6	2.52
D	C	0.5	0.36	6.99	2.64		8.96	6	2.23
D	C	0.5	0.38	7.34	2.71		9.51	6	2.64
D	C	0.5	0.4	6.13	2.48		6.74	6	0.25
D	C	0.5	0.3	8.67	2.94		10.26	6	0.26
D	C	0.5	0.32	8.34	2.89		9.97	6	1.06
D	C	0.5	0.26	9.95	3.15		11.56	6	0.84
A	L	0.6	0.46	2.23	1.49	18.29	11.6	6	0.61
A	L	0.6	0.38	5.02	2.24		23.13	6	1.24
A	L	0.6	0.28	8.79	2.96		24.84	6	0.82
A	L	0.6	0.235	10.42	3.23		28.74	6	1.39

4.6 DISCUSSION OF TEST RESULTS

4.6.1 NASP Pull out Values and Concrete Strengths for NCHRP Strand A

Figure 4.1 shows the NASP pull out values in concrete against the corresponding concrete strengths for NCHRP Strand A. The linear regression line and the power regression curve are plotted on the figure. The coefficients of determination R^2 values for both the regressions are reported as 0.96 and 0.94 respectively. The linear and the power best fit equations are reported in the figure. It is seen that with the increase in concrete strength results in a higher NASP pull out value for NCHRP Strand A. The NASP value for the standardized test for the NCHRP Strand A is 20.95 kips. The data reported in Fig. 4.1 is reported in Table 4.3.

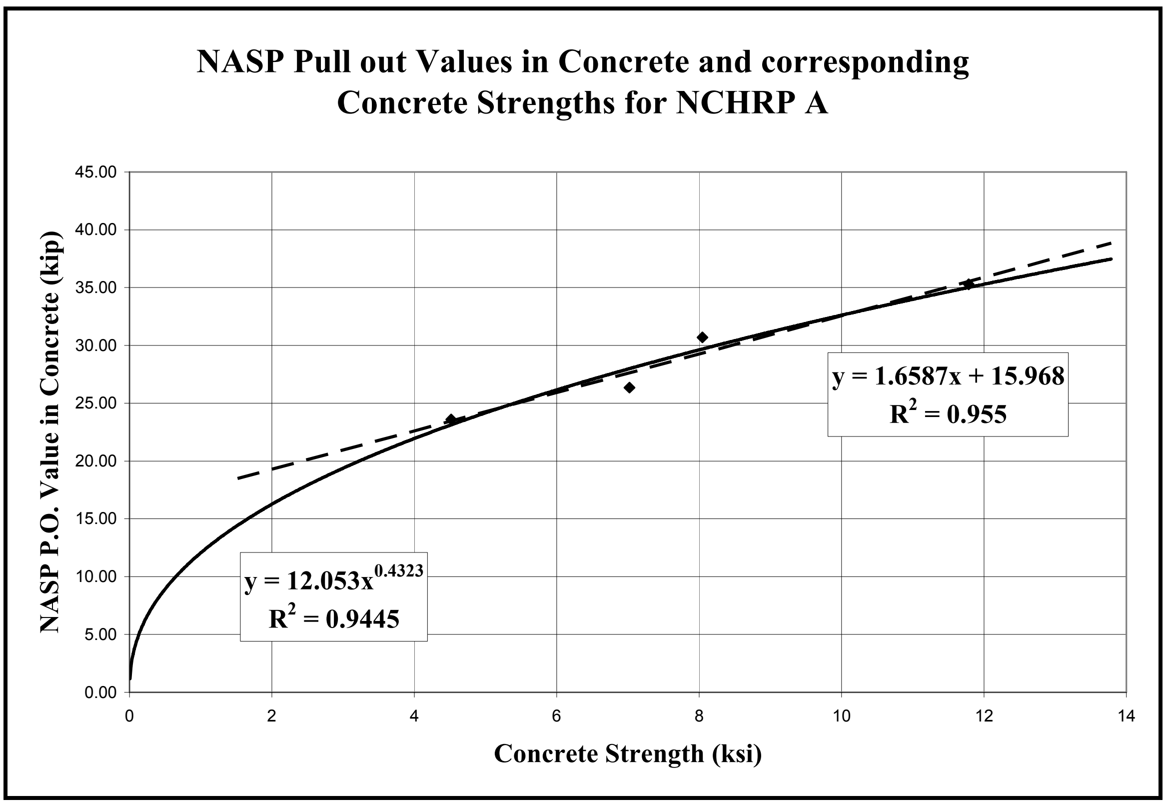


Figure 4.1: NASP in Concrete for NCHRP Strand A

4.6.2 NASP Pull out Values and Concrete Strengths for NCHRP Strand B

Figure 4.2 shows the NASP pull out values in concrete against the corresponding concrete strengths for NCHRP Strand B. The linear regression line and the power regression curve are plotted on the figure. The coefficients of determination R^2 values for both the regressions are reported as 0.79 and 0.83 respectively. It is seen that with the increase in concrete strength results in a higher NASP pull out value for NCHRP Strand B. The NASP value for the standardized test for the NCHRP Strand B is 20.21 kips. The data reported in Fig. 4.2 is reported in Table 4.3

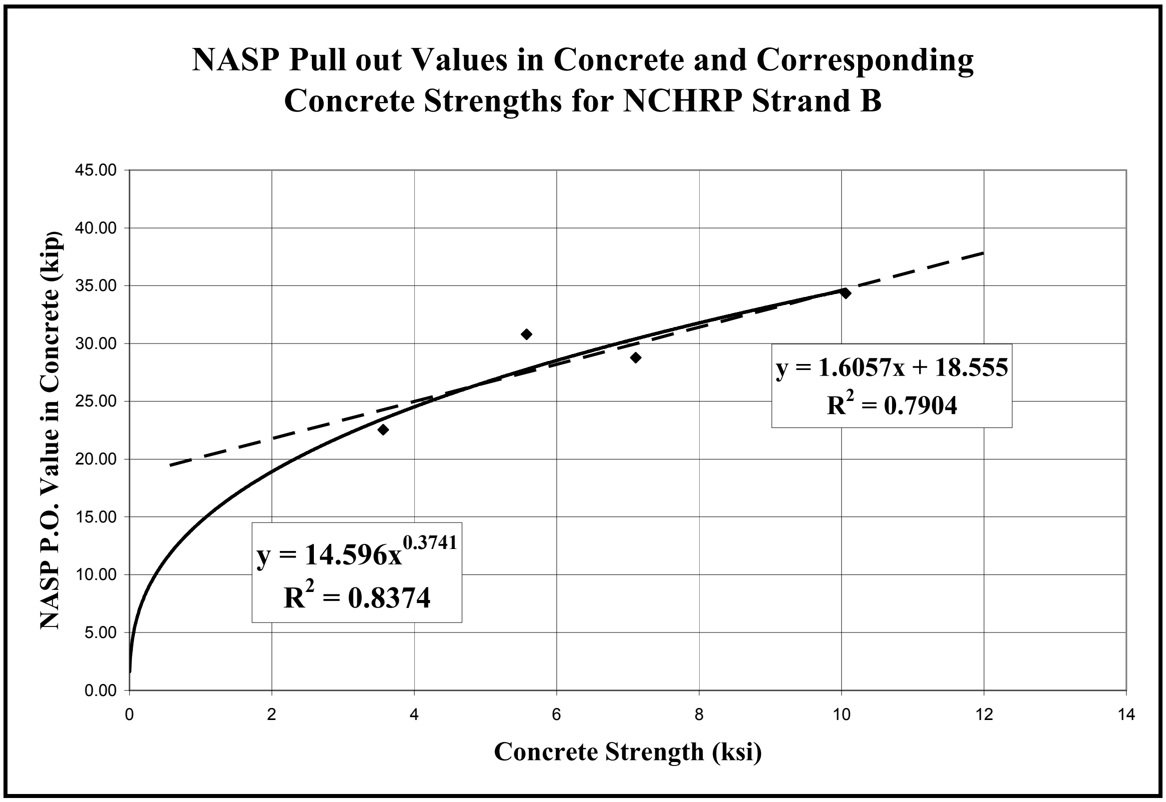


Figure 4.2: NASP in Concrete for NCHRP Strand B

4.6.3 NASP Pull out Values and Concrete Strengths for NCHRP Strands A/B

As the NASP standardized tests in mortar resulted in close NASP pull out values of 20.95 and 20.21 kips for NCHRP Strands A and B, the results are treated together in Fig. 4.3. A total of eight data points shown in Table 4.3 from the modified tests conducted in concrete are plotted in Fig. 4.3. The linear and the power regression curves result in an R^2 value of 0.82. The data show that the NASP pull out value in concrete strength is a function of the concrete strengths.

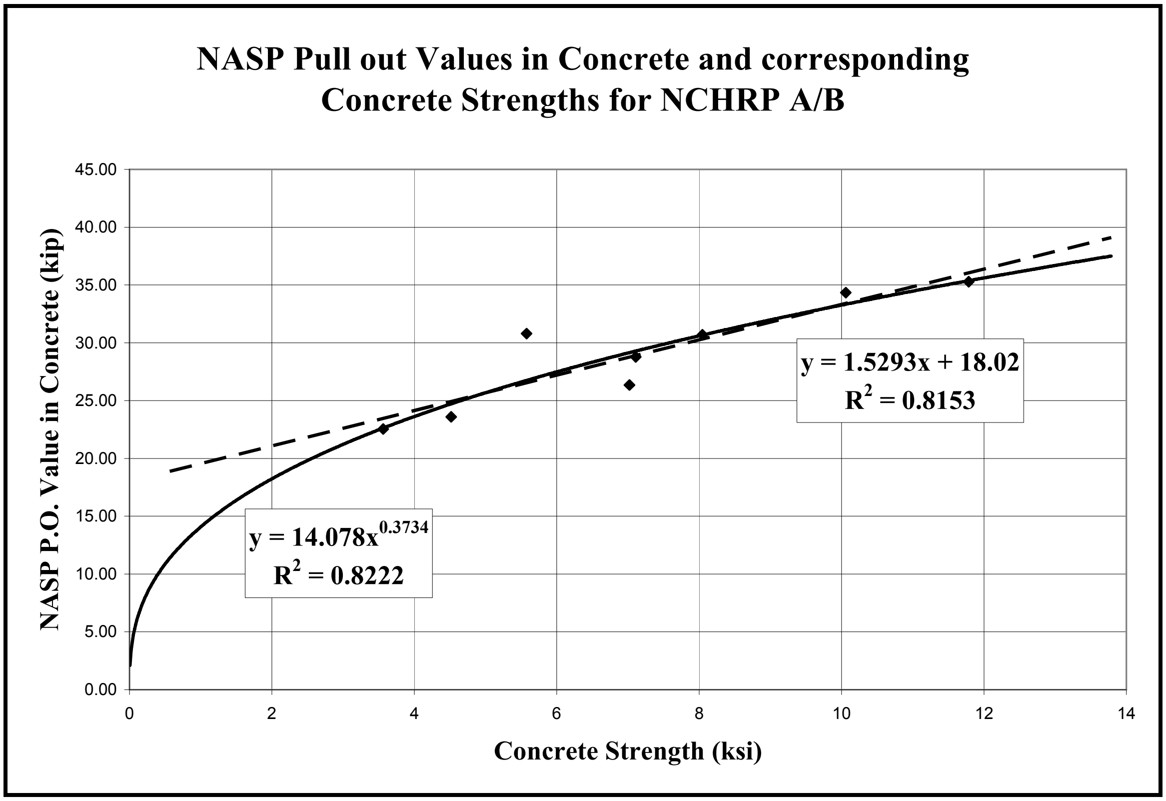


Figure 4.3: NASP in Concrete for NCHRP Strand A/B

4.6.4 NASP Pull out Values and Concrete Strengths for NCHRP Strand D

The data from Table 4.3 for NCHRP Strand D is plotted against the concrete strengths in Fig. 4.4. The NCHRP Strand D was among the moderate performer with a low NASP value of 6.87 kips in the standardized test. The relationship of this strand with the NASP pull out values and the corresponding concrete strengths, shown in Fig. 4.4 shows an R^2 value of 0.89 and 0.84 for the linear and the power regression model. The best fit equations for the results are also presented in Fig. 4.4.

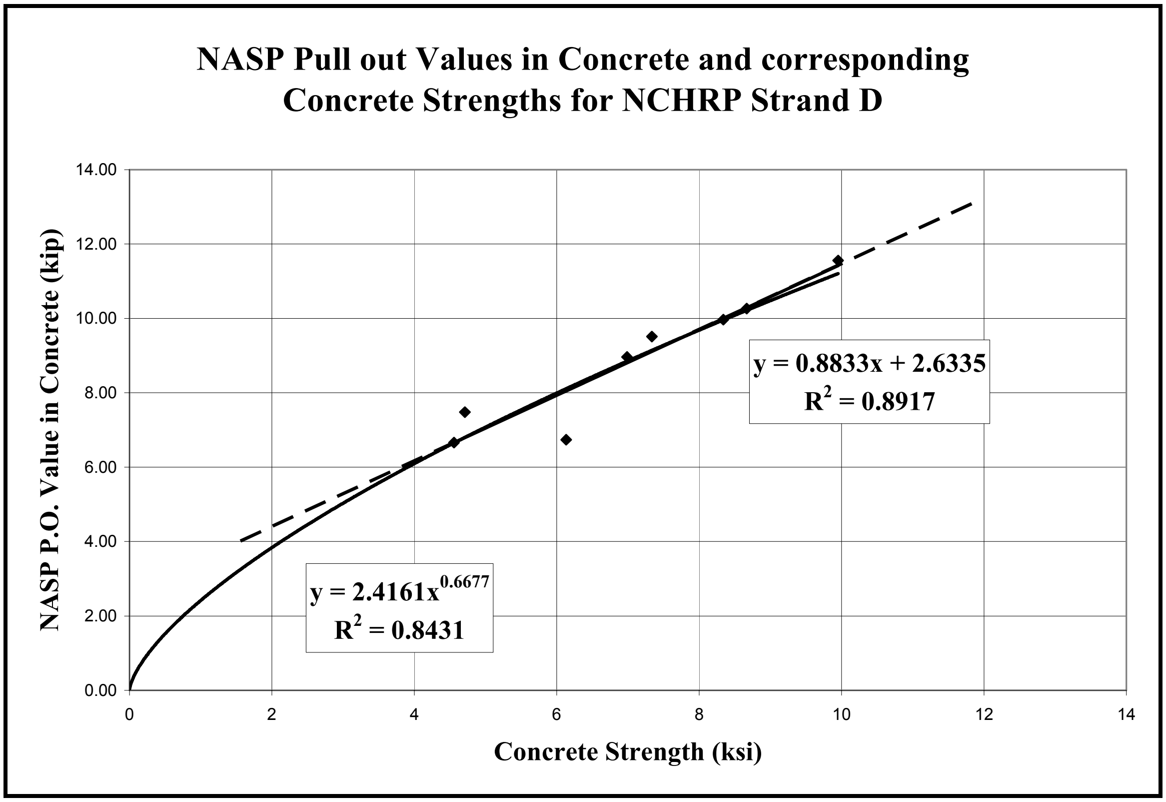


Figure 4.4: NASP in Concrete for NCHRP Strand D

4.6.5 NASP Pull out Values and Concrete Strengths for 0.6 in. NCHRP Strand A

The results from the modified NASP pull out values in concrete and the corresponding concrete strengths are plotted in Fig. 4.5 for the 0.6 in. diameter NCHRP Strand A. The standardized NASP test resulted in a NASP value of 18.29 kips. The linear and the power regression models are presented in Fig. 4.5. The R^2 values are 0.86 and 0.92 for the linear and the power regression models respectively.

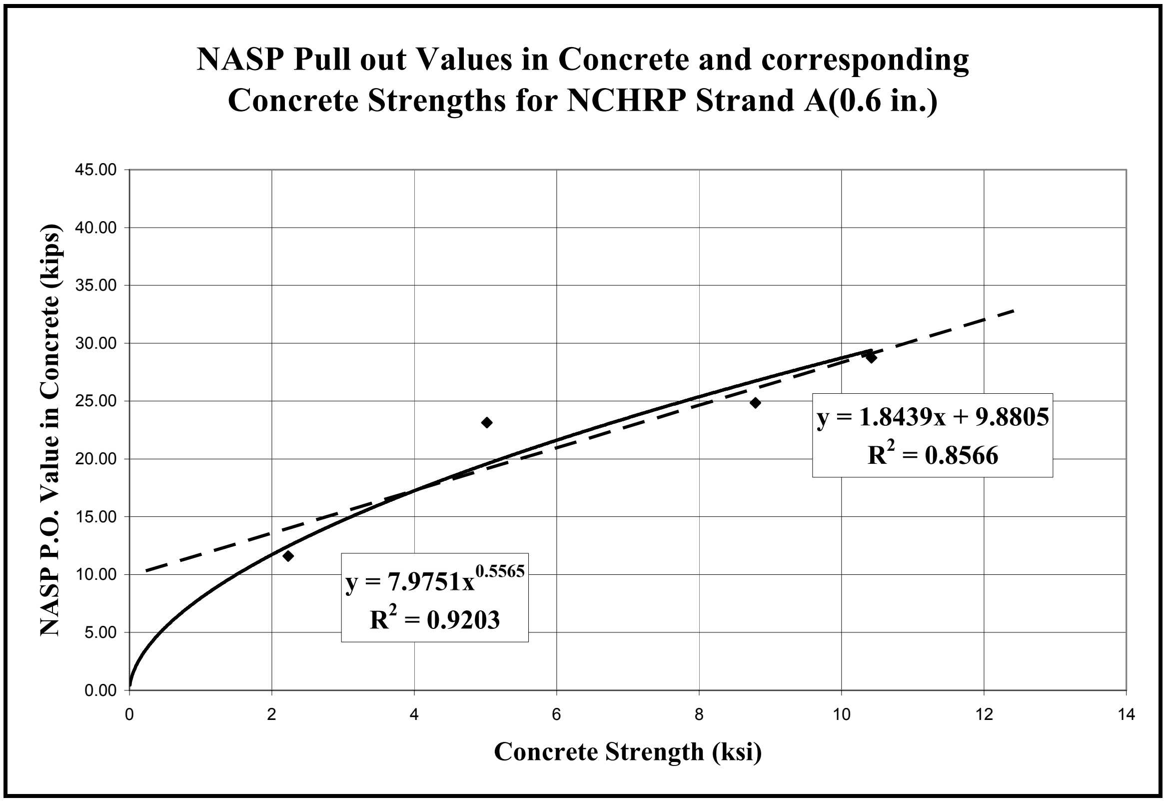


Figure 4.5: NASP in Concrete for 0.6 in NCHRP Strand A

4.6.6 NASP Pull out Values and $\sqrt{\bar{f}'_{ci}}$

The NASP pull out values and the square root of the concrete strengths are presented for all the strands tested in concrete in Fig. 4.6. The linear best fit lines are plotted in the figure with the corresponding R^2 values for all the four strands tested in the modified NASP test in concrete. As seen in Fig. 4.6, the best fit curves tend to have a steeper slope for strands with higher NASP values in the same range of concrete strengths. The figure evidence that the NASP value increases with increase in concrete strengths, and the high performing strands have a steeper best fit line. This shows that for a given change in the concrete strength, the NASP results can have a higher variation for the high performing strands (strands with higher NASP values) when compared to the moderate performing strands (strands with lower NASP values).

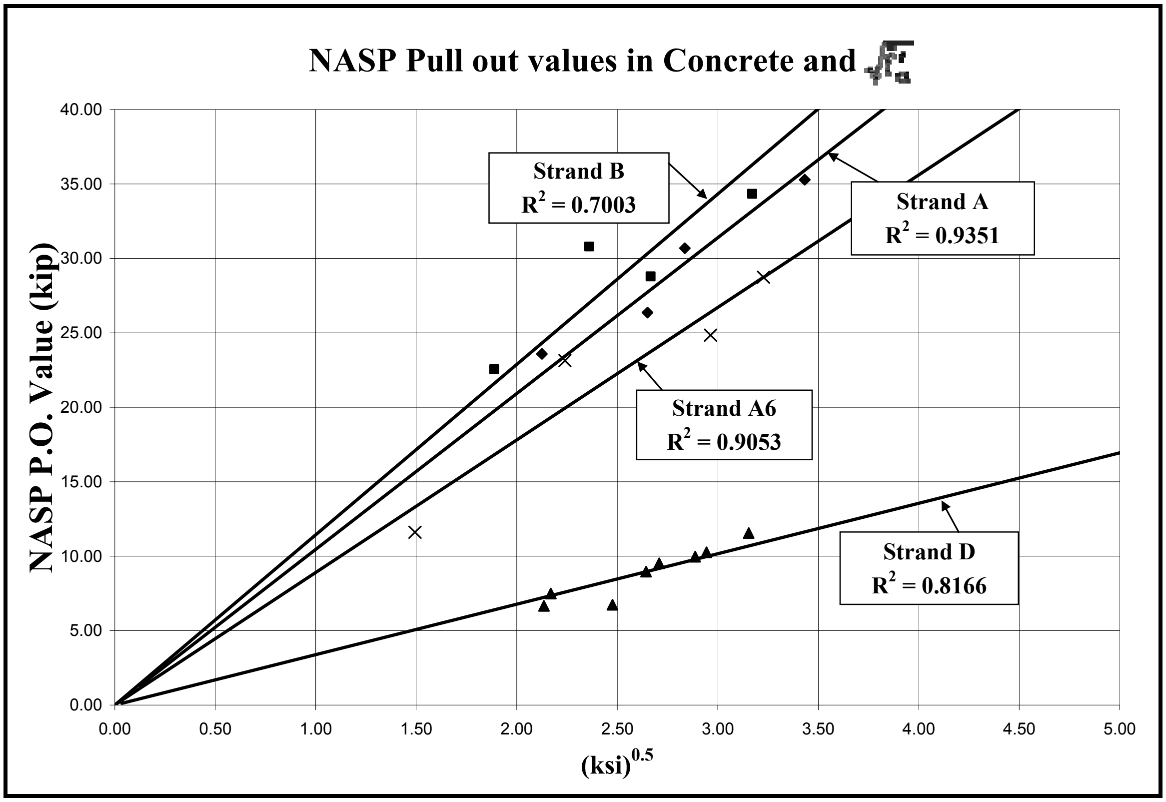


Figure 4.6: NASP Pull out values and $\sqrt{f'_{ci}}$ for all strands

4.6.7 NASP Pull out Values and Concrete strengths for all strands

The data presented in Table 4.3, and discussed in sections 4.6.1 through 4.6.5 are presented together in Fig. 4.7. The figure includes four 0.5 in. diameter strands and one 0.6 in. diameter strands. The concrete strength during the modified NASP test is plotted against the normalized NASP values. The NASP values are normalized by dividing the NASP result in concrete from the test over the NASP value from the standardized test in mortar. The results for the NASP results in concrete and the standardized test are presented in Table 4.3. Assuming a power regression fit, the R^2 value for the test data show 0.80. The high R^2 value shows that the power regression equation closely agrees with the test data.

$$\frac{(NASP_{concrete})}{NASP} = 0.49139 \bar{f}'^{\,0.51702}_{ci}$$

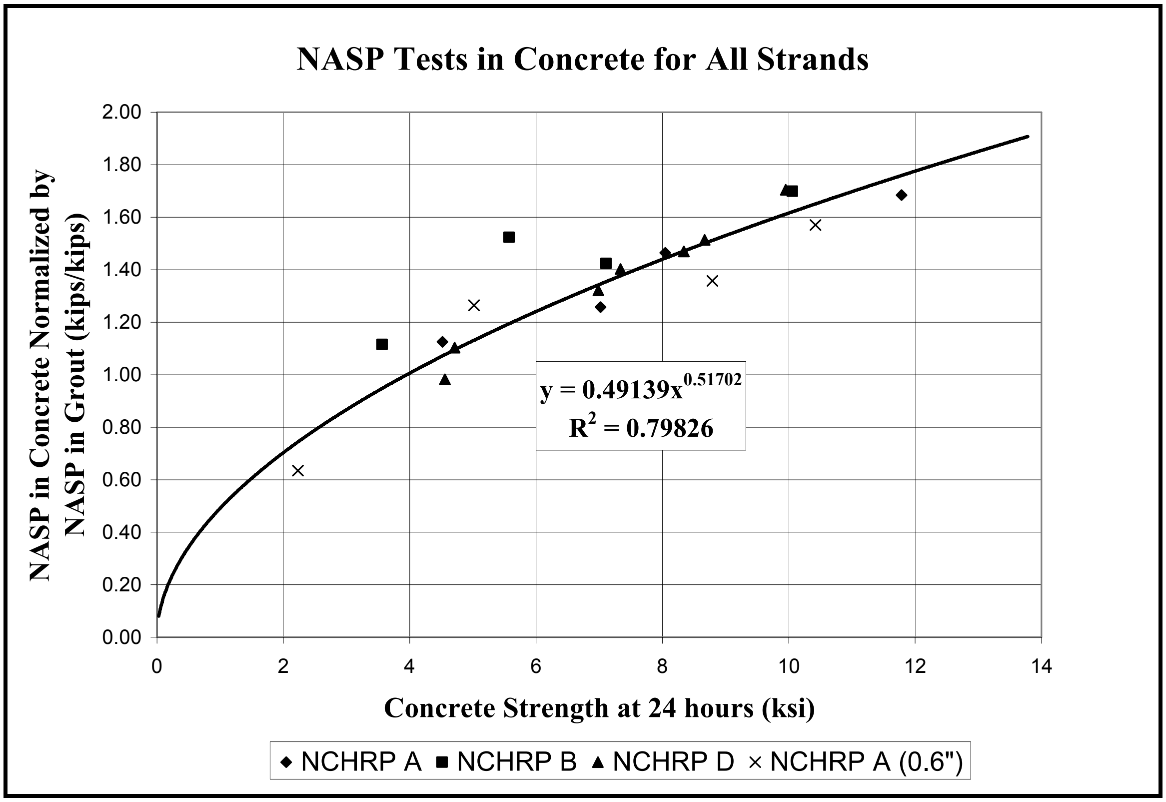


Figure 4.7: Normalized NASP Pull out values concrete strengths

The equation is modified to fit the NASP values as a function of the square root of concrete strengths. The Fig. 4.8 plots the NASP pull out values normalized in grout plotted against the square root of the concrete strength. The linear regression results in the following equation

$$\frac{(NASP_{concrete})}{NASP} = 0.51\sqrt{f'_{ci}}$$

If the NASP result in concrete and the NASP result from the standardized test is the same, the NASP test in concrete has to be conducted for 4 ksi concrete. Recalling from Chapter 3, the NASP test in mortar specifies a strength range of 4.75±0.25 ksi. The reason for the higher strength requirement in mortar is due to the lack of coarse aggregates in the mix. The models show that the coarse aggregates in the concrete mix helps in additional bond with the concrete.

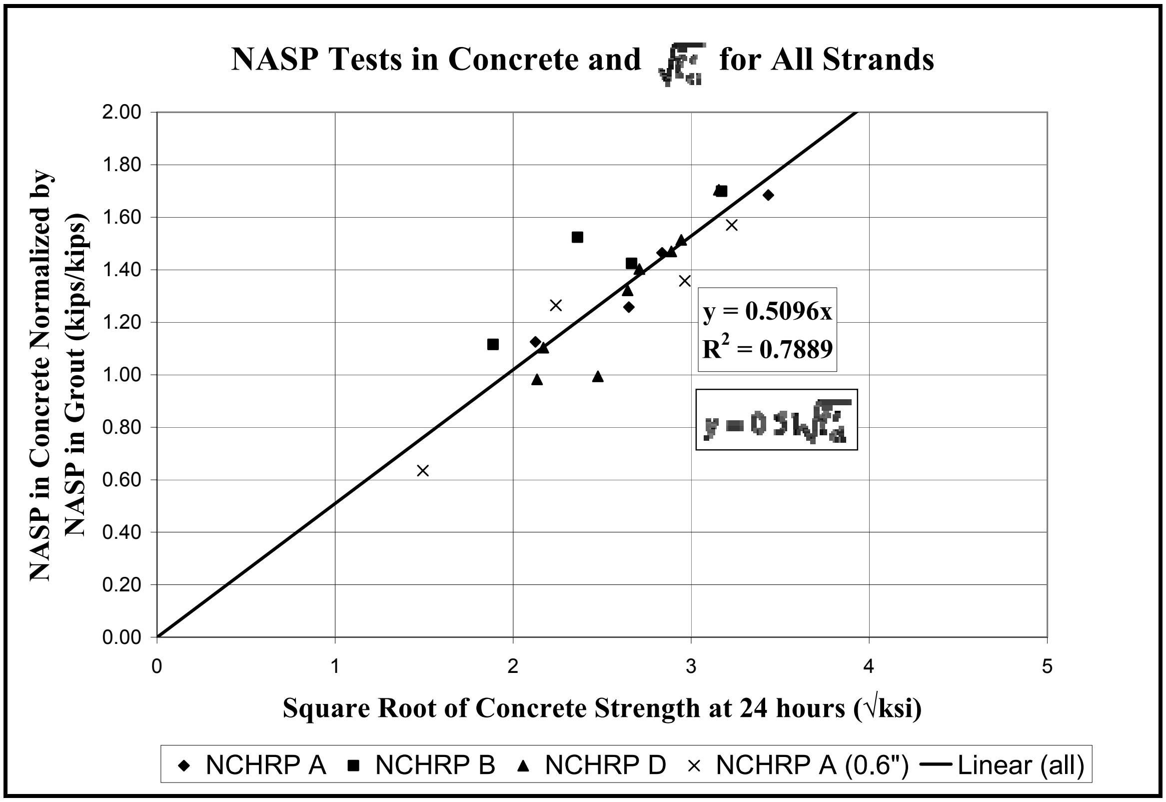


Figure 4.8: Normalized NASP Pull out values and $\sqrt{f'_{ci}}$

4.7 SUMMARY AND CONCLUSIONS

The modified NASP test in concrete was conducted on three 0.5 in. diameter strands and one 0.6 in. diameter strand. The tests were conducted in concrete using the NASP test protocols discussed in Chapter 3. The purpose of the study was to understand the effects of high concrete strength on the NASP test.

The modified NASP test was conducted for a particular type of strand with varying concrete strengths. The test results show that the concrete strength contributes to the NASP test results in concrete. The higher concrete strength results in higher NASP results in the modified test. The data shows that the linear regression lines are steeper for high bonding strands when compared to the strands with lower NASP values.

Normalizing the modified test results with the standard NASP test, results in the following relationship with the concrete strength

$$\frac{(NASP_{concrete})}{NASP} = 0.51\sqrt{\bar{f}'_{ci}}$$

Using this equation, it is possible to predict the standardized NASP value in mortar if the test is conducted in concrete as per the specifications discussed in Chapter 3.

CHAPTER V

5.0 TRANSFER LENGTHS AND COMPARISONS TO NASP TESTS

The research aims to assess the effects of varying concrete strengths on strand bond. The beams were made with a target one day concrete strength of 4000, 6000, 8000 and 10,000 psi. The 6000 psi release strength concrete beams were made using air entrained and non-air entrained concrete to study its effects on transfer lengths. The prototype beams had different strand patterns and two different cross sectional shapes. A total of 43 rectangular shaped beams and eight I-shaped beams were cast using four different strand sources. The rectangular shaped beams manufactured for this research program included beams with two bottom strands alone, and beams with two bottom strands and two top strands. Beams were also cast using 0.6 in. diameter strands. The I-shaped beams were made using 0.5 in. and 0.6 in. diameter strands. Three different sources for 0.5 in. diameter strands with varying bond properties and one source for 0.6 in. diameter strand were employed in this research program.

Transfer lengths at release and at longer time intervals were measured on all beams by measuring strand end slips. Comparisons were also performed on measuring the transfer lengths using the concrete surface strains. The beams were cast at Core Slab Structures Inc. at Oklahoma City, Oklahoma.

5.1 SCOPE OF RESEARCH

Transfer lengths were measured on pretensioned beams made with concrete of various strengths. The research program included the fabrication and casting on the rectangular shaped and I-shaped prestressed concrete beams. Three different 0.5 in. diameter strands were used Strand A, Strand B, and Strand D. Strand A and B are "good performers" as measured by the NASP Bond test. Strand A has an average NASP value of 20.95 kips and Strand B has an average NASP value of 20.21 kips. Strand D, the "moderate performer" has an average NASP value of 6.87 kips. The 0.6 in diameter Strand A which had a NASP value of 18.29 kips was used in transfer length testing as well.

Table 5.1 presents the scope of the number of beams fabricated for measuring the transfer lengths on the prototype beams. Following describes the basic types of beams that were made.

1. Rectangular shaped prestressed concrete beams (both 0.5 and 0.6 in.)
    a) Two strand beams (Two bottom strands alone)
    b) Four strand beams (Two bottom strands and two top strands)
2. I-shaped prestressed concrete beams
    a) 0.5 in. diameter strands (Five strand beams)
    b) 0.6 in. diameter strands (Four strand beams)

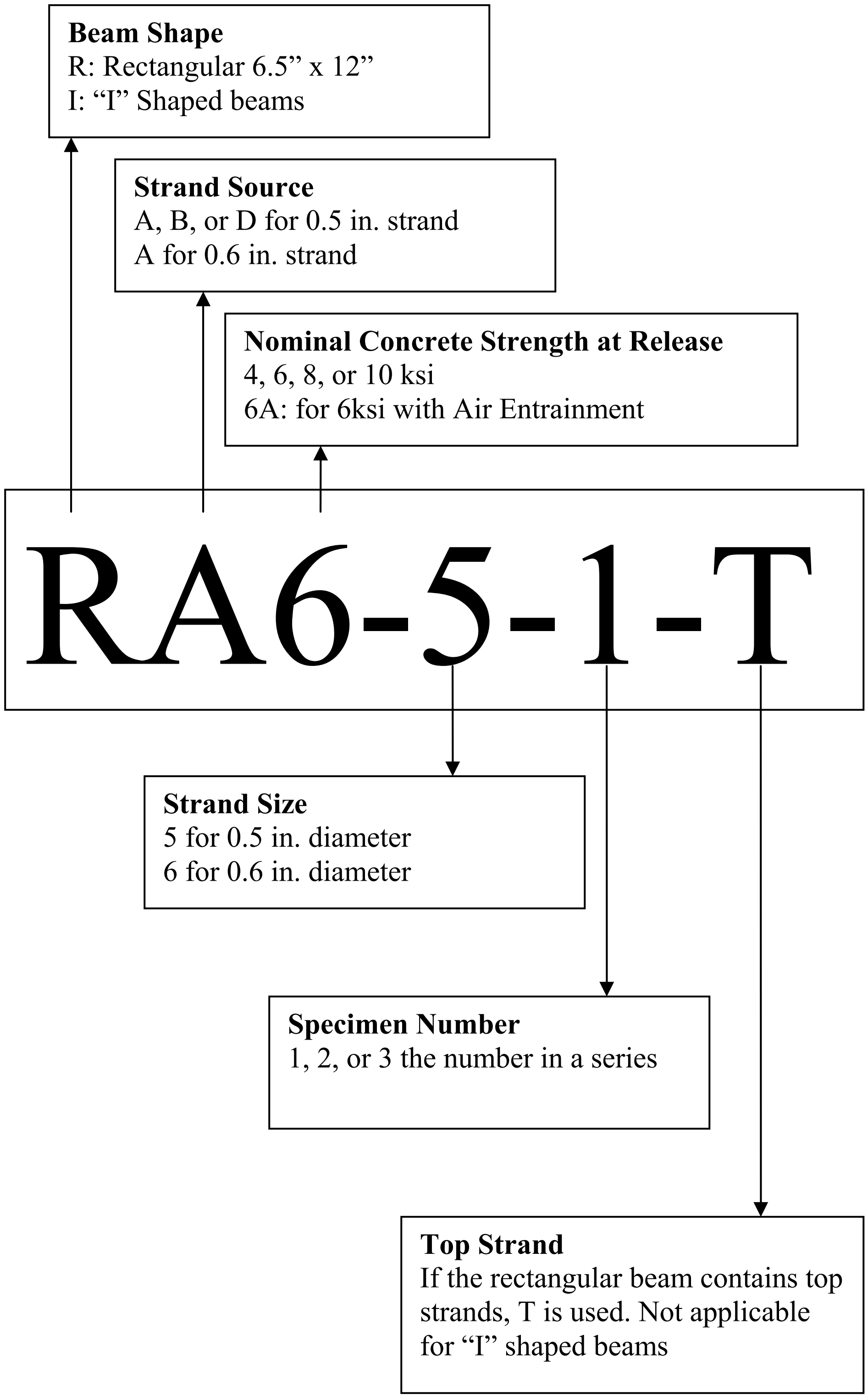
Table 5.1: Scope of Transfer Length testing						
Target Release Strength (ksi)	**Concrete Design Strength (ksi)**	**Target Air Content (%)**	**½ in diameter Strands**			**0.6 in diameter Strands**
			Strand A	**Strand B**	**Strand D**	**Strand A**
Two Strand Rectangular Beams						
4	8	2	0	2	2	2
6	10	2	2	0	2	3
6	10	6	2	0	2	0
8	14	2	2	0	2	3
10	16	2	2	0	2	3
Four Strand Rectangular Beams						
6	10	2	2	0	2	0
8	14	2	2	0	2	0
10	16	2	2	0	2	0
I-Shaped Beams						
6	10	2	1	0	1	2
10	16	2	1	0	1	2

5.2 RESEARCH VARIABLES

Research variables are concrete release strength, strand source, strand diameter, and number of strands and the cross sectional shape of the beam which included 6.5 x 12 in. rectangular shaped beams and 24 in. deep I-shaped beams. The concrete beams had targeted release strengths of 4, 6, 8, and 10 ksi. The beams with release strength of 6 ksi were made using both air entrained and non-air entrained concrete. The strands used for beams with bottom strands alone had strands from four different sources which included 0.5 in. diameter and 0.6 in. nominal diameter. The strands with four strands had two bottom strands and two top strands. The I-shaped beams were cast using 0.5 in. diameter strands and 0.6 in. diameter strands. Parameters like strand handling, test location and curing procedures were held constant throughout the testing program.

5.2.1 Beam Number Identification

The prototype beams manufactured for this research program uses the following designation for identifying the beams by including the various research variables.



5.3 MATERIAL PROPERTIES

All prestressing strands used for this research program are seven wire 270 ksi low relaxation strands from manufacturers in North America. The strands conformed to ASTM A416 specifications. The prestressing strands haave a nominal diameter of 0.5 in. (12.7 mm) or 0.60 in. (15.2 mm). The nominal cross sectional area is 0.153 sq in. (98.7 mm^2) for 0.5 in. diameter strands and 0.217 sq in. (140 mm^2) for 0.60 in. diameter strand. The modulus of elasticity of the prestressing strands is 28,500ksi (196.3 GPa) for both 0.5 in. and 0.6 in. diameter strands.

The concrete mixtures used for making the prestressed concrete beams at Coreslab Structures, Oklahoma City included Type III cement from Lafarge North America, Coarse and fine aggregate from Dolese Brothers, cement slag from Lafarge North America, and admixtures like high range and low range water reducers and air entraining admixtures from Degussa Admixtures Inc.

5.4 PROCEDURE FOR CASTING THE PRESTRESSED CONCRETE BEAMS

5.4.1 Rectangular Shaped Beams

The rectangular shaped beams are made with a 6.5 x 12 in. cross section and 17 ft lengths. The rectangular beams were made with two different types of strand configuration shown in Figs. 5.1 and 5.2. For one set of beams, two strands were used. For the other set, four strands were used. For beams with two strands, two #6 bars were placed for 16 ft and 8 in. The beams with four strands had the two #6 bars for 6 ft and 8 in. # 3 ties were placed in both the type of beams at 6 in. spacing. For beams fabricated using the 0.6 in. diameter strands, the two strand configuration was used throughout the research.

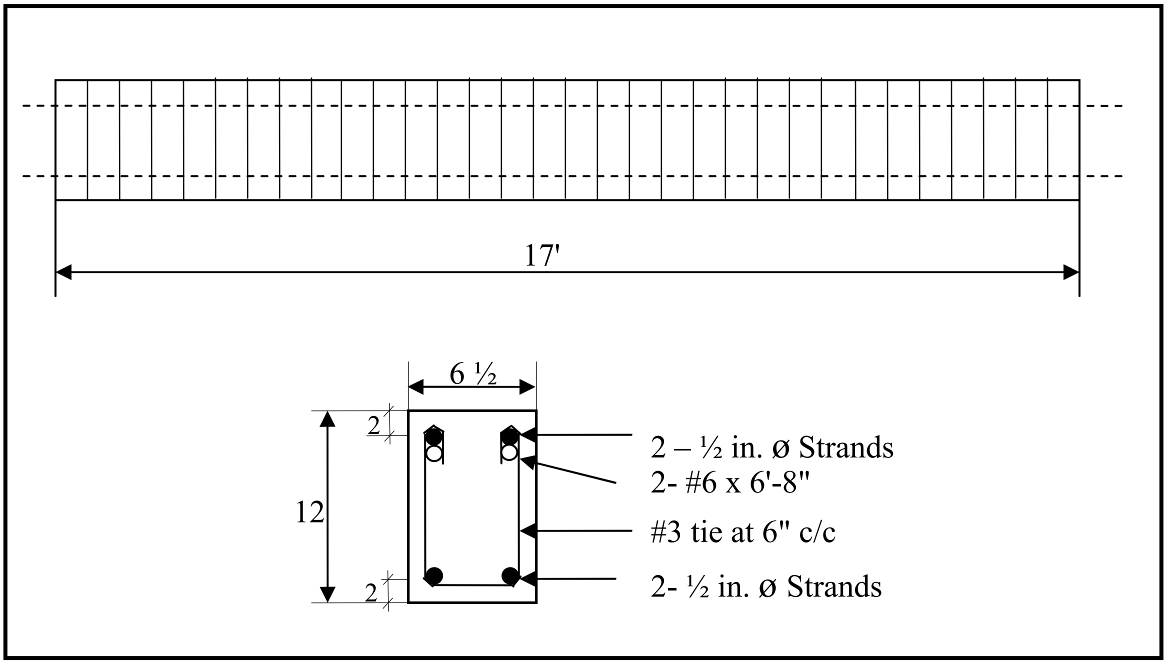


Figure 5.1: Details of Four Strand Beams

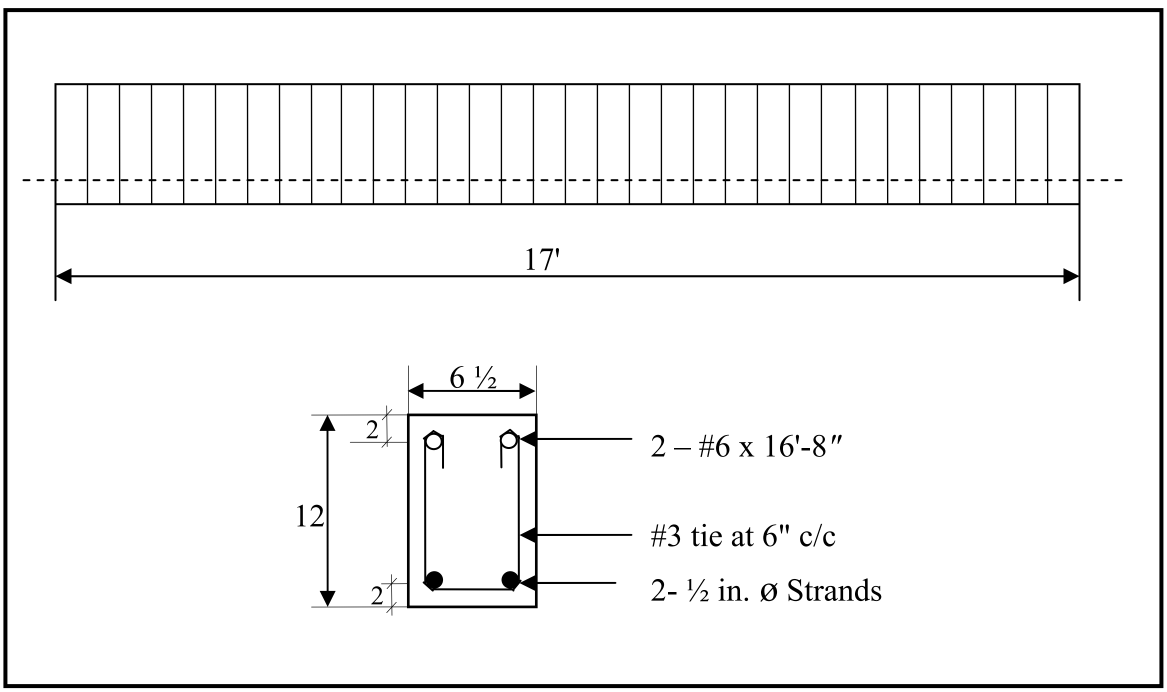


Figure 5.2: Details of Two Strand Beams


Figure 5.3: Fabrication of Rectangular beams

5.4.2 I-Shaped Beams

The cross section of the I-shaped beams is shown in Figure 5.4. The beams cast were with either five 0.5 in. diameter strands or four 0.6 in. diameter strands. The I-shaped beams made with 0.5 in. diameter strands had four strands cast in the bottom bulb and one strand near the top. The beams cast with 0.6 in. diameter strands had three strands in the bottom bulb and one strand at the top. #3 ties were placed at 7 in. on center throughout the beam. Longtudinal bars #4 x 96 in. were placed as shown. Two bars were placed at the South end of every beam, and four bars were placed at the North end. Each longitudinal bar were anchored at the end of the beams with a standard 180° hook. The deck slab contained #3 bars at every 9 in. Two #3 straight bars were placed in the longitudinal direction in the deck slab. Internal hoop reinforcements made from #3 bars were placed in the form of triangular cages at both the ends of the beam at 4 in. on center for a distance of 64 in.

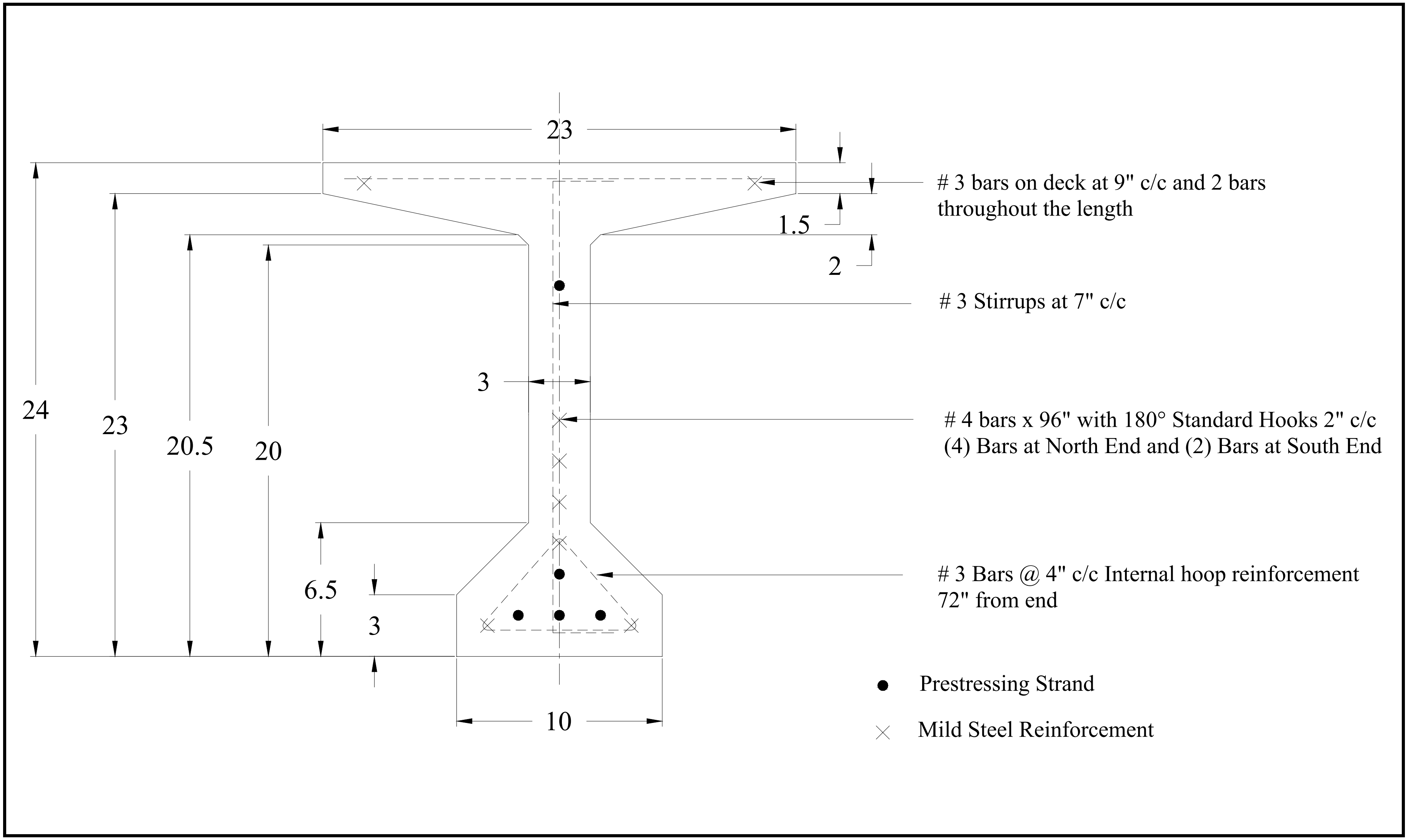


Figure 5.4: Details of I-Shaped Beams

5.4.3 Fabrication Procedures

The formwork was placed in position for the beams depending on the casting layout. Form oil was applied on the prestressing bed and all places where the formwork was made of sheet metal. For I-shaped beams the side forms were made of sheet metal. Wood forms were used for the rectangular beams

Strands were cut to lengths at Oklahoma State University and transported to Core Slab Structures Inc. Strands were placed in the forms and tensioned, care was taken to avoid contamination on the strand from dirt, oil or moisture.

Splice chucks were used for the 0.5 in. diameter strands cast in rectangular forms as limited length of the "test" strand were available.

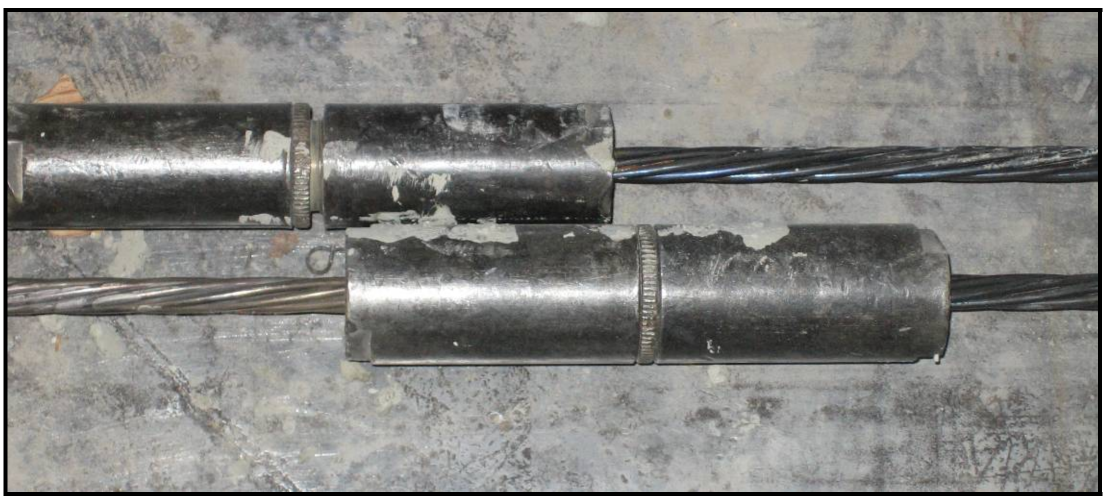


Figure 5.5: Splice Chucks on ½ in diameter strands

During the very first strand tensioning for the rectangular beam the measured elongations did not match the calculated elongations for the applied load. Upon checking the winding of the strand patterns, it was discovered that strands with opposite lays were spliced together. As strands were tensioned, the strands themselves were unwound, resulting in a tension force much smaller than expected.

After the strands and chucks were placed in position, the strands were then stressed to 75% of f_{pu}. The expected elongations were calculated and compared to the elongations measured on the prestressing bed at the "live end" (The end where the hydraulic ram is placed to stress the strands)

$$\Delta = \frac{PL}{AE}$$

Where, Δ is the elongation in inches.

A is the cross sectional area of the strand.

0.153 sq.in for 0.5 in. diameter strands

0.217 sq.in. for 0.6 in. diameter strands.

E is the modulus of elasticity taken generically as 28,500 ksi

L is the Gauge length, measured from the end of the far end chuck to the point where the elongation measurements are taken.

P is the load in lb.

The elongations were measured from a datum mark made on the prestressing bed at a distance of about 3 to 4 ft from the live end of the bed. The strands were stressed to an initial level of 2000 lb. Once the force on the strand reached 2000 lb, the strand was marked using a permanent marker coinciding with the datum level marking on the prestressing bed. The strand was then stressed to a stress of 0.75 f_{pu} or 202.5 ksi. The elongation was then measured as the distance the mark on the strand moved from the datum marking on the prestressing bed. Figure 5.6 shows the prestressing of the 0.5 in. diameter I-shaped beams using hydraulic jack.


Figure 5.6: Prestressing the strands using hydraulic ram

5.4.4 Concrete Batching

After placing the reinforcements, the concrete was made in the batching plant. The fresh properties of concrete - slump, unit weight, and air content were measured and checked before placing the concrete. Extensive trial batching was performed (Tessema 2006) to understand the fresh and hardened properties of the concrete mix designs. If the fresh properties of unit weight, slump, or air content did not meet with the design expectations, the concrete was not used and batching was repeated. After meeting the target fresh properties, concrete was placed using a "Tuckerbilt" concrete placement vehicle and thoroughly consolidated. Concrete cylinders were then made at the site and placed in the same prestressing bed as the test beams till detensioning. Steam curing was done if the ambient temperatures were low. The test beams together with the concrete cylinders were kept under cover.

Figure 5.7: Vibrating concrete on I-beams

5.5 PROCEDURE FOR MEASURING TRANSFER LENGTHS

The transfer lengths of the prestressed concrete beams were measured using two methods:

1) End slip measurements, and;
2) Concrete surface strain profiles.

The transfer lengths were measured from the slip of the strand into the concrete which was measured on all the beams for all the strands. The concrete surface strain method was used for one specimen on all the beams made with the variety of research variable discussed earlier.

5.5.1 Instrumentation and Procedure for End Slip Measurements

The difference of the end slips measured using an analog micrometer before and after de-tensioning from two individuals is averaged, for each end of the strand, on every beam made. Initial strand elongations were measured as described in Section 5.4.3. The strains were measured from the 2000 lb. initial force to the final force of 75% f_{pu} depending on the diameter of the strand. Figure 5.8 shows the end slip measurement on a rectangular beam using the analog micrometer. The analog micrometer measured to the pricision of 0.001 in. The two individuals measuring the slip came to close agreement in the values within 0.003 in. This is based on an average calculation for standard deviation from end slip measurements of 0.0015. The data is found is Appendix G.

Reference end clamps were firmly attached to the strands at an approximate distance of one inch from the end of the beams as shown in Fig. 5.8. Reference end clamps were attached to all the strands at both the ends of all the beams. The reference clamps were made at OSU for both 0.5 in. diameter and 0.6 in. diameter strands.

Figure 5.8: End Slip Measurement using analog micrometer

The measured strand slips are directly related to strand transfer length. This relationship was theorized (Anderson and Anderson 1976) and confirmed experimentally (Rose 1997)

Figures 5.9(a) and 5.9(b) illustrate the variation of the prestressing stress through the transfer length. As discussed in Chapter 2, transfer length L_t is the length required to reach the effective prestress on the strand, f_{se}. Fig. 5.9(a) shows the initial losses due to elastic shortening (ES) only. Seating losses are accounted for in the strand elongation measurements made at tensioning and are not reflected in Fig. 5.9 (a). After detensioning, the strand stress is reduced by ES.

Figure 5.9(b) shows the effective prestress on the strand after all the losses, f_{se}. Measured transfer lengths increases over time duet to time depended effects and as the strand stabilizes to an effective prestress.

The following equations presented shows the theoretical relationship for the end slip over the transfer lengths (Rose 1997)

$$L_{es} = \Delta_{ps} - \Delta_{c}$$

$$L_{es} = \int_{0}^{L_t} [\varepsilon_{si} - \varepsilon_{s}(x)]dx - \int_{0}^{L_t} \varepsilon_{c}(x)dx$$

Where,

L_{es}= Strand End Slip

L_t= Transfer length

Δ_c= Total Elastic Shortening of concrete in through the transfer zone

Δ_{ps}= Total Elastic Shortening of the prestressing strand through the transfer zone

ε_{si}= Initial Strain in the steel prior to release

$\varepsilon_c(x)$= Concrete Strain after transfer varying with distance from end of the member

$\varepsilon_s(x)$= Stress in the strand after transfer varying with distance from end of the member.

Assuming a linear variation of steel and concrete strains, in the transfer zone, as in Figs. 5.9(a) and 5.9(b), the above equation can be simplified as:

$$L_{es} = \frac{L_t}{2}\left(\frac{f_{si}}{E_{ps}}\right)$$

Where

E_{ps}= Modulus of elasticity of the strand

f_{si}=Stress in the strand before detensioning.

$$. \quad L_t = 2L_{es}\left(\frac{E_{ps}}{f_{si}}\right)$$

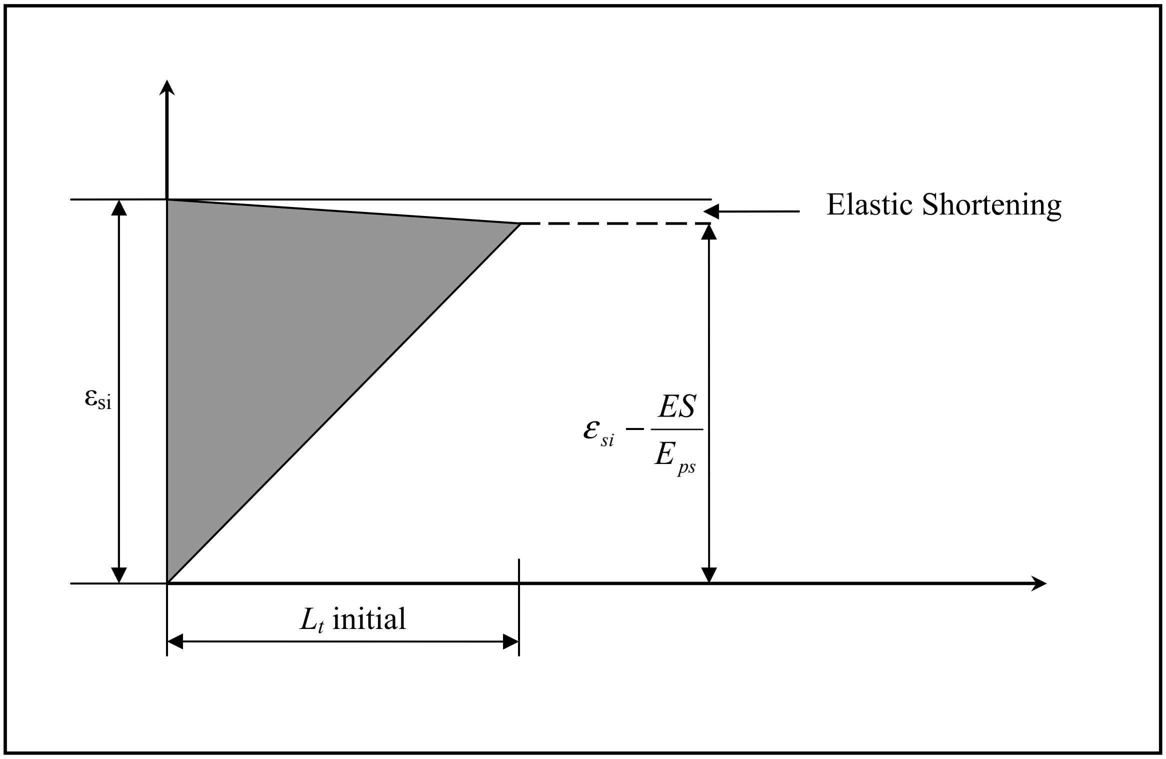


Figure 5.9a: Strand Stress Variation with Length after Elastic Shortening

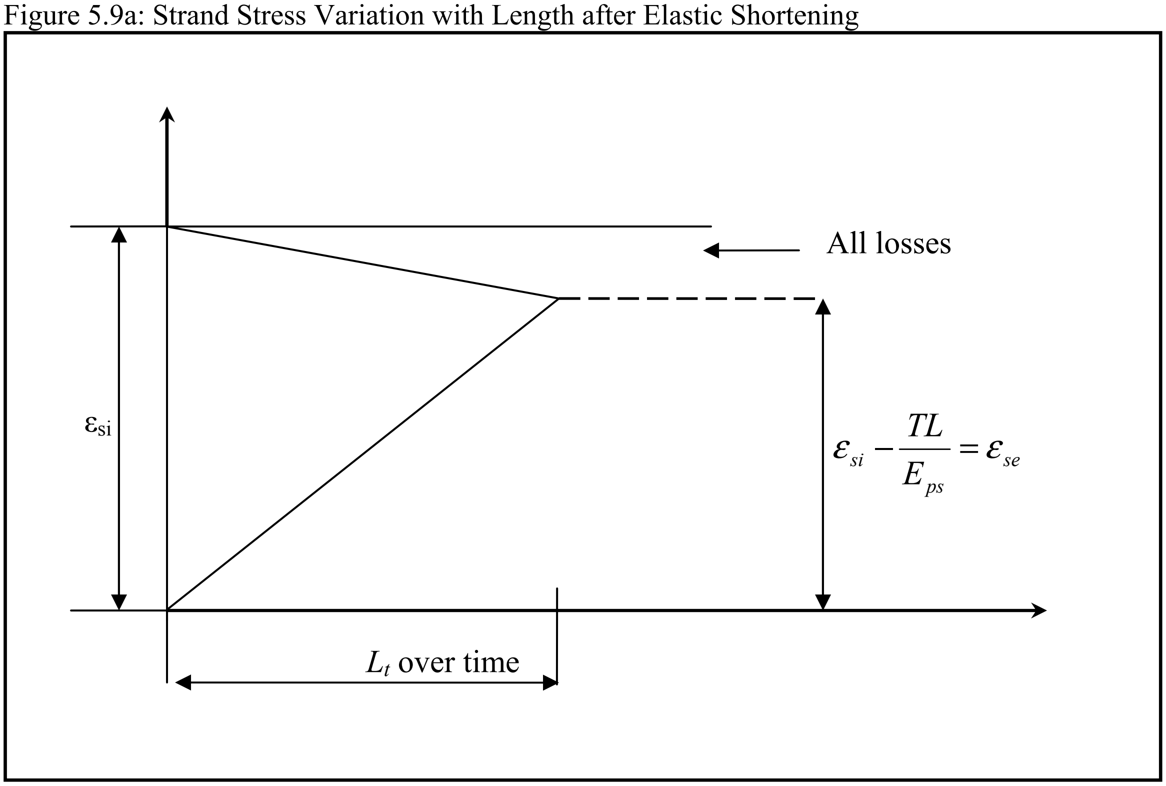


Figure 5.9b: Strand Stress Variation with Length after all losses

5.5.2 Instrumentation and Transfer Lengths from Concrete Surface Strains

After curing the beams for 12 hours or more, the end and side forms of the beams are stripped. The DEMEC (Detachable Mechanical) target points are glued using epoxy and hardener to the hardened concrete surface at four inches from the bottom for rectangular beams with bottom strands only, and at ten inches from the bottom for rectangular beams with both top and bottom strands at 100 mm interval horizontally. The target points are glued at a distance of two inches from the corner on the slanting face for I-shaped beams. The target points are glued on both sides of the beams for 80 in. from each end.

After attaching the DEMEC target points using epoxy glue, DEMEC readings are taken using DEMEC Strain Gauge shown in Figure 5.10 between every 200 mm interval. The DEMEC readings were taken till the two individuals came to a close agreement with the values. After the initial readings are taken, the strand is flame cut between the dead men such that the strands in the beams are not affected by any physical damage at the ends. After flame cutting, the DEMEC readings are once again taken by two individuals. The strain profile is then plotted along the length of the beam from the data. The strain profile for each beam is the average of two sides of the beam taken by two people independently.

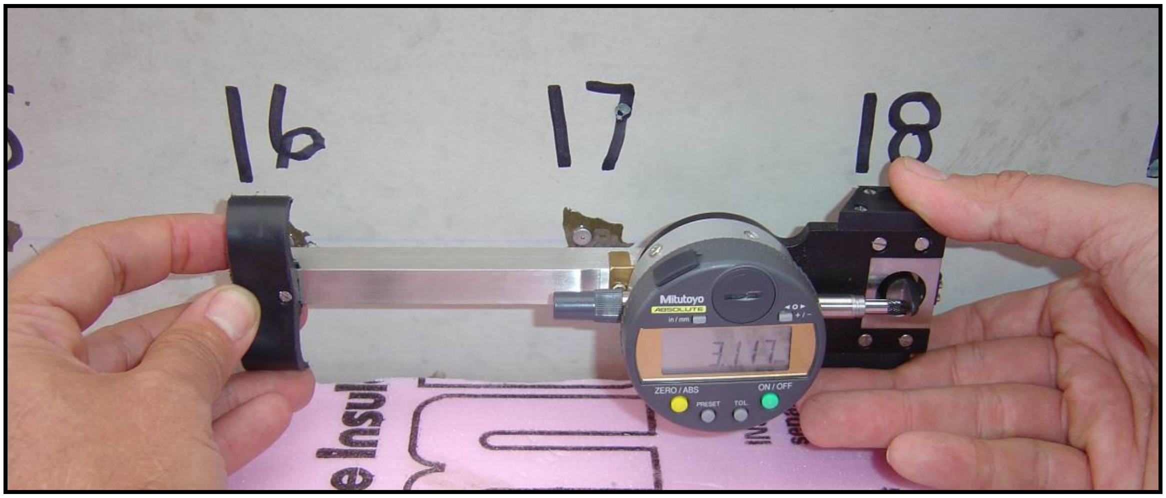


Figure 5.10: Concrete surface strain measurements using DEMEC gauge

From the DEMEC measurement, the strains are calculated by multiplying with the DEMEC calibration constant. The concrete strains are plotted along the length of the beam from the north end as well as the south end. The strain profile is "smoothed" by averaging three points. The Average Mean Strain is found out by averaging the points on the strain plateau on North side and the South side independently. The measured transfer length from DEMEC is the location where the 95%AMS line intersects the Smoothed Strain profile. Figure 5.11 shows the comparison between the "smoothed' and the "un-smoothed" profiles.

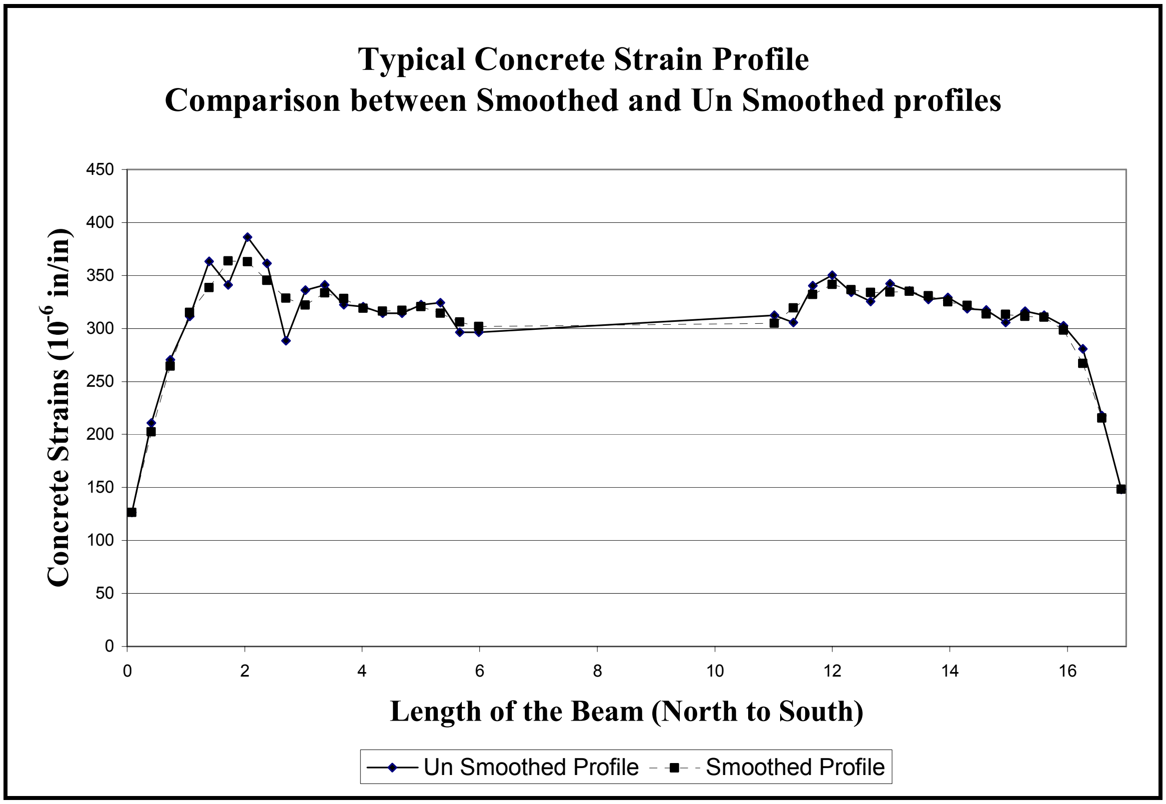


Figure 5.11: Typical Concrete Strain Profile

5.6 TEST RESULTS FROM TRANSFER LENGTH MEASUREMENTS

The following section reports the transfer lengths from the slip of the strand and the transfer lengths from the concrete surface strain measurements discussed in earlier section. The section also reports the effect of transfer lengths over time.

5.6.1 Summary of Transfer Length at Release

Tables 5.2 through 5.9 report the end slips and the corresponding transfer lengths at release for pretensioned concrete beams made at Coreslab Structures Inc. The average transfer length $\overline{\overline{X}}$ reported in the tables is the average in inches for that particular strand at specific release strength. The standard deviation S is reported in inches for the data set from a single type of beam. The measured release strength, $\bar{f}'_{ci}$ reported in psi is the average of three or more 4 x 8 in. cylinders placed in the same environmental conditions as the beams. The 56 day strength $\bar{f}'_{c}(56)$ reported in Table 5.2 through 5.7 is the average of three cylinders placed in laboratory curing conditions. Stand A and Strand B are reported in the same table because of their bond capability, as measured by the NASP Bond test is nearly identical.

Table 5.2: Summary of Transfer Length at Release from End Slips for Bottom "A/B" Strands (0.5 in. diameter)									
Beam Number	**Location**	**N Slip (in)**	**S Slip (in)**	**N L_t (in)**	**S L_t (in)**	$\bar{\bar{X}}$	S	$\bar{f}'_{ci}$	$\bar{f}'_c(56d)$
RB4-5-1	East	0.062	0.066	17.06	18.31	20.12	2.56	4033	7050
	West	0.071	0.066	19.78	18.66				
RB4-5-2	East	0.087	0.081	24.13	22.47				
	West	0.065	0.080	18.1	22.45				
RA6-5-1	East	0.075	0.073	20.66	20.24	18.02	2.23	6183	8500
	West	0.064	0.058	17.68	16.16				
RA6-5-2	East	0.058	0.043	15.94	11.78				
	West	0.062	0.066	17.12	18.23				
RA6-5-1T	East	0.071	0.068	19.39	18.7				
	West	0.074	0.068	20.62	18.93				
RA6-5-2T	East	0.069	0.069	18.7	18.84				
	West	0.068	0.058	19.07	16.27				
RA8-5-1	East	0.045	0.049	12.01	13.09	13.63	1.32	8570	13490
	West	0.054	0.052	14.58	13.9				
RA8-5-2	East	0.052	0.044	13.9	11.74				
	West	0.059	0.046	15.93	12.42				
RA8-5-1T	East	0.006	0.046	**(a)**	12.51				
	West	0.015	0.055	**(b)**	14.71				
RA8-5-2T	East	0.054	0.058	14.52	15.6				
	West	0.046	0.050	12.55	13.36				
RA10-5-1	East	0.093	0.021	**(c)**	**(d)**	13.72	2.27	9711	14470
	West	0.084	0.049	**(e)**	13.57				
RA10-5-2	East	0.046	0.055	12.75	15.25				
	West	0.047	0.054	12.75	14.8				
RA10-5-1T	East	0.064	0.044	17.74	12.06				
	West	0.065	0.041	18.16	11.32				
RA10-5-2T	East	0.044	0.043	12.2	11.78				
	West	0.041	0.052	11.46	14.53				

(a): L_t of 1.48 in. not included
(b): L_t of 5.26 in. not included
(c): L_t of 25.65 in. not included
(d): L_t of 5.82 in. not included
(e): L_t of 22.89 in. not included

Table 5.3: Summary of Transfer Length at Release from End Slips for Bottom "D" Strands (0.5 in. diameter)									
Beam Number	**Location**	**N Slip (in)**	**S Slip (in)**	**N L_t (in)**	**S L_t (in)**	$\bar{\bar{X}}$	S	$\bar{f}'_{ci}$	$\bar{f}'_c(56d)$
RD4-5-1	East	0.113	0.114	31.69	32.11	32.90	2.64	4033	7050
	West	0.125	0.110	33.88	29.93				
RD4-5-2	East	0.131	0.179	36.9	**(a)**				
	West	0.175	0.180	**(b)**	**(c)**				
RD6-5-1	East	0.109	0.111	29.88	30.42	26.19	2.99	6183	8500
	West	0.113	0.095	30.6	25.71				
RD6-5-2	East	0.093	0.110	25.35	30.15				
	West	0.095	0.104	25.84	28.29				
RD6-5-1T	East	0.088	0.092	23.89	25.12				
	West	0.086	0.097	23.43	26.59				
RD6-5-2T	East	0.094	0.073	25.53	19.93				
	West	0.090	0.087	24.67	23.71				
RD8-5-1	East	0.078	0.077	21.16	20.89	20.94	6.05	8570	13490
	West	0.069	0.070	19.13	19.41				
RD8-5-2	East	0.061	0.079	16.79	21.43				
	West	0.038	0.047	10.54	13.17				
RD8-5-1T	East	0.128	0.107	35.63	29.78				
	West	0.057	0.095	15.94	26.34				
RD8-5-2T	East	0.070	0.104	20.87	21.99				
	West	0.052	0.082	18.99	23.01				
RD10-5-1	East	0.085	0.059	23.48	16.16	18.36	3.72	9711	14470
	West	0.104	0.063	28.59	17.54				
RD10-5-2	East	0.051	0.070	13.95	19.33				
	West	0.057	0.062	15.74	17.12				
RD10-5-1T	East	0.079	0.059	21.76	16.22				
	West	0.077	0.064	21.1	17.4				
RD10-5-2T	East	0.059	0.055	16.36	15.25				
	West	0.062	0.061	17.13	16.58				

(a): Excessive movement of the beams during flame cutting, L_t observed as 50.43 in.
(b): Excessive movement of the beams during flame cutting, L_t observed as 47.48 in.
(c): Excessive movement of the beams during flame cutting, L_t observed as 48.98 in.

Table 5.4: Summary of Transfer Length at Release from End Slips for Air Entrained Concrete beams

Beam Number	Location	N Slip (in)	S Slip (in)	N L_t (in)	S L_t (in)	$\overline{\overline{X}}$	S	$\bar{f}'_{ci}$	$\bar{f}'_c(56d)$
RA6A-5-1	East	0.070	0.064	19.26	17.47	20.49	3.39	7960	11420
	West	0.058	0.065	16.22	17.88				
RA6A-5-2	East	0.096	0.082	26.41	22.63				
	West	0.082	0.077	22.6	21.42				
RD6A-5-1	East	0.130	0.108	36.25	30.04	26.26	6.93	7960	11420
	West	0.127	0.104	34.55	28.15				
RD6A-5-2	East	0.076	0.078	21.16	21.79				
	West	0.073	0.067	19.79	18.36				

Table 5.5: Summary of Transfer Length at Release from End Slips for Top "A" Strand (0.5 in. diameter)

Beam Number	Location	N Slip (in)	S Slip (in)	N L_t (in)	S L_t (in)	$\overline{\overline{X}}$	S	$\bar{f}'_{ci}$	$\bar{f}'_c(56d)$
RA6-5-1T	East	0.077	0.070	21.03	19.11	19.04	2.07	6183	8500
	West	0.071	0.075	19.47	20.58				
RA6-5-2T	East	0.069	0.069	17.07	16.52				
	West	0.068	0.058	21.82	16.71				
RA8-5-1T	East	0.049	0.055	13.38	14.88	14.55	1.96	8570	13490
	West	0.038	0.051	10.74	14.42				
RA8-5-2T	East	0.064	0.058	17.61	15.7				
	West	0.054	0.052	15.12	14.56				
RA10-5-1T	East	0.052	0.047	14.93	13.5	12.90	1.65	9711	14470
	West	0.052	0.040	14.53	11.32				
RA10-5-2T	East	0.037	0.039	10.63	11.2				
	West	0.050	0.047	14.11	12.99				

Table 5.6: Summary of Transfer Length at Release from End Slips for Top "D" Strands (0.5 in. diameter)									
Beam Number	**Location**	**N Slip (in)**	**S Slip (in)**	**N L_t (in)**	**S L_t (in)**	$\bar{\bar{X}}$	S	$\bar{f}'_{ci}$	$\bar{f}'_c(56d)$
RD6-5-1T	East	0.100	0.177	27.91	21.46	23.76	3.03	6183	8500
	West	0.099	0.073	27.52	20.26				
RD6-5-2T	East	0.085	0.072	23.7	20.2				
	West	0.085	0.091	23.61	25.43				
RD8-5-1T	East	0.081	0.060	22.06	16.45	22.64	4.68	8570	13490
	West	0.064	0.069	17.61	18.84				
RD8-5-2T	East	0.102	0.087	27.82	23.71				
	West	0.105	0.095	28.67	25.94				
RD10-5-1T	East	0.062	0.057	16.79	15.56	15.93	2.22	9711	14470
	West	0.064	0.060	17.27	16.32				
RD10-5-2T	East	0.070	0.055	18.98	15.02				
	West	0.060	0.042	16.19	11.29				

Table 5.7: Summary of Transfer Length at Release from End Slips for Bottom "A" Strands (0.6 in. diameter)

Beam Number	Location	N Slip (in)	S Slip (in)	N L_t (in)	S L_t (in)	$\bar{\bar{X}}$	S	$\bar{f}'_{ci}$	$\bar{f}'_c(56d)$
RA4-6-1	East	0.122	0.093	35.3	26.88	29.50	3.67	4033	7050
	West	0.112	0.082	31.54	23.09				
RA4-6-2	East	0.103	0.108	29.93	31.23				
	West	0.109	0.098	30.55	27.46				
RA6-6-1	East	0.098	0.102	28.91	29.94	29.85	3.04	4855	8040
	West	0.104	0.090	30.55	26.44				
RA6-6-2	East	0.116	0.097	34.07	28.46				
	West	0.100	0.108	29.23	31.73				
RA6-6-3	East	0.085	0.118	24.92	34.66				
	West	0.091	0.111	26.73	32.61				
RA8-6-1	East	0.094	0.093	27.25	27.11	27.06	3.45	5413	8220
	West	0.099	0.106	29.17	31.24				
RA8-6-2	East	0.099	0.093	28.71	27.11				
	West	0.094	0.082	27.69	24.28				
RA8-6-3	East	0.096	0.103	27.98	29.88				
	West	0.059	0.090	17.62	26.65				
RA10-6-1	East	0.065	0.076	18.95	22.01	19.74	3.56	9150	14610
	West	0.073	0.076	21.11	21.84				
RA10-6-2	East	0.066	0.078	19.24	22.59				
	West	0.042	0.073	12	20.97				
RA10-6-3	East	0.064	0.084	18.66	24.49				
	West	0.048	0.073	14.03	20.97				

Table 5.8: Summary of Transfer Length at Release for I Beams from End Slips for Bottom B,D, and A Strand									
Beam Number	**Location**	**N Slip (in)**	**S Slip (in)**	**N L_t (in)**	**S L_t (in)**	$\bar{\bar{X}}$	S	$\bar{f}'_{ci}$	$\bar{f}'_c(56d)$
IB6-5-1	East	0.062	0.025	16.12	6.42	10.77	5.43	5810	9350
	West	0.038	0.011	17.82	2.9				
	Cent.	0.040	0.035	10.93	9.45				
	Midd	0.041	0.024	16	6.48				
IB10-5-1	East	0.043	0.047	11.14	12.45	10.59	2.15	7615	13490
	West	0.038	0.037	10.03	5.8				
	Cent.	0.043	0.022	11.6	12.45				
	Midd	0.041	0.027	11.31	9.9				
ID6-5-1	East	0.090	0.045	24.47	12.23	18.49	9.88	5492	9840
	West	0.083	0.009	23.47	2.56				
	Cent.	0.096	**(a)**	26.69	**(a)**				
	Midd	0.101	0.039	28.96	11.04				
ID10-5-1	East	0.070	0.070	19.03	19.03	20.82	2.8	8225	14160
	West	0.072	0.083	20.34	23.61				
	Cent.	0.057	0.076	15.99	21.13				
	Midd	0.082	0.084	23.51	23.94				
IA6-6-1	East	0.073	0.065	18.36	16.33	21.17	4.68	4381	8990
	West	0.120	0.089	29.83	22.21				
	Cent.	0.079	0.079	20.15	20.15				
IA6-6-2	East	0.038	0.056	9.62	14.18	16.04	4.49	4381	8990
	West	0.062	0.078	15.48	19.47				
	Cent.	0.089	0.059	22.58	14.92				
IA10-6-1	East	0.038	0.086	9.4	21.15	13.29	5.91	10480	14990
	West	0.058	0.023	14.35	5.81				
	Cent.	0.040	0.074	10.19	18.85				
IA10-6-2	East	0.073	0.043	17.94	10.64	14.72	3.46	10590	14930
	West	0.056	0.044	13.85	10.76				
	Cent.	0.070	0.068	17.83	17.32				

(a): Spalling of concrete surface during flame cutting

Table 5.9: Summary of Transfer Length at Release for I Beams from End Slips for Top Strands									
Beam Number	Location	N Slip (in)	S Slip (in)	N Lt (in)	S Lt (in)	$\overline{\overline{X}}$	S	$\bar{f}'_{ci}$	$\bar{f}'_c(56d)$
IA6-6-1	Top	0.092	0.038	22.84	9.36	18.57	6.23	4381	8990
IA6-6-2	Top	0.081	0.088	20.22	21.84				
IA10-6-1	Top	0.015	0.007	3.82	1.91	2.87	1.35	10480	14990
IA10-6-2	Top	0.037	0.036	9.30	9.04	9.17	0.18	10590	14930
IB6-5-1	Top	0.072	0.023	21.43	6.16	13.80	10.80	5810	9350
IB10-5-1	Top	0.072	0.054	19.29	14.33	16.81	3.50	7615	13490
ID6-5-1	Top	0.122	0.101	36.25	29.99	33.12	4.4	5492	9840
ID10-5-1	Top	**(a)**	0.056	**(a)**	16.86	16.86	-	8225	14160

(a): End Clamp loosed during detensioning

Tables 5.10 through 5.12 reports the transfer lengths measured from the concrete surface strains and the transfer length measured using end slips on the pretensioned beams. The data reported in end slip is the average transfer length of the east and the west strand for north and the south end independently. For beams with top strands, the Tables 5.10 through 5.12 reports the transfer lengths for the top strands. The tables are separated for each type of strand.

Table 5.10: Summary of Transfer Lengths at Release Strands "A/B"					
Beam	Location	End Slips		DEMEC	
		N (in.)	S (in.)	N (in.)	S (in.)
RB4-5-1	Bot.	18.4	18.5	24.2	27.1
RB4-5-2	Bot.	21.1	22.5		
RA6A-5-1	Bot.	17.7	17.7	16	17.5
RA6A-5-2	Bot.	24.5	22		
RA6-5-1	Bot.	19.2	18.2		
RA6-5-2	Bot.	16.5	15		
RA6-5-1-T	Top	20.3	19.8		
RA6-5-2-T	Top	19.4	16.6		
RA8-5-1	Bot.	13.3	13.5	14.3	12
RA8-5-2	Bot.	14.9	12.1		
RA8-5-1-T	Top	12.1	14.7	12	15.6
RA8-5-2-T	Top	16.4	15.1		
RA10-5-1	Bot.	24.3	9.7	24.3	14.4
RA10-5-2	Bot.	12.8	15		
RA10-5-1-T	Top	14.7	12.4	12.5	11.7
RA10-5-2-T	Top	12.4	12.1		
IB6-5-1	Bot.	12.2		15.2	
IB10-5-1	Bot.	11.1		11	

Table 5.11: Summary of Transfer Lengths at Release Strands "D"					
Beam	**Location**	**End Slips**		**DEMEC**	
		N (in.)	**S (in.)**	**N (in.)**	**S (in.)**
RD4-5-1	Bot.	32.8	31	25.6	24.8
RD4-5-2	Bot.	36.9			
RD6A-5-1	Bot.	35.4	29.1	39	26.4
RD6A-5-2	Bot.	20.5	20.1		
RD6-5-1	Bot.	30.2	28.1		
RD6-5-2	Bot.	25.6	29.2		
RD6-5-1-T	Top	27.7	20.9		
RD6-5-2-T	Top	23.7	22.8		
RD8-5-1	Bot.	20.2	20.2	11.3	18.5
RD8-5-2	Bot.	13.7	17.3		
RD8-5-1-T	Top	19.8	17.6	12.4	12
RD8-5-2-T	Top	28.2	24.8		
RD10-5-1	Bot.	26	16.9	23.4	19.4
RD10-5-2	Bot.	14.8	18.2		
RD10-5-1-T	Top	17	15.9	16.1	15.7
RD10-5-2-T	Top	17.6	13.2		
ID6-5-1	Bot.	25.2		25.9	
ID10-5-1	Bot.	17.5		19.7	

Table 5.12: Summary of Transfer Lengths at Release For bottom Strand "A" (0.6 in.)				
Beam	End Slips		DEMEC	
	N (in.)	S (in.)	N (in.)	S (in.)
RA4-6-1	33.4	25.0	31.4	30.3
RA4-6-2	30.2	29.3		
RA6-6-1	29.7	28.2	22.4	21.1
RA6-6-2	31.7	30.1		
RA6-6-3	25.8	33.6		
RA8-6-1	28.2	29.2	19.5	22.0
RA8-6-2	28.2	25.7		
RA8-6-3	22.8	28.3		
RA10-6-1	20.0	21.9	16.6	15.0
RA10-6-2	15.6	21.8		
RA10-6-3	16.3	22.7		
IA6-6-2	24.3	26.1	15.9	16.2
IA10-6-1	18.0		11.3	
IA10-6-2	16.0		16.5	

5.6.2 Transfer Lengths over time

The Tables 5.13 through 5.16 reports the transfer length over time for rectangular shaped pretensioned beams with target release strengths of 6, 8, and 10 ksi. The transfer length at release and at approximately 60, 90, and 240 days from release is reported from the end slips. The results for the bottom strands A, D and 0.6 in. diameter A are tabulated in Tables 5.13, 5.14, and 5.15. The top strands are tabulated in Table 5.16.

Table 5.13: Summary of Transfer Length over time for 0.5 in. diameter "A/B" Strands in Rectangular beams								
Beam Number	Transfer Length at Release from End Slips (in.)		Transfer Length after approx. 60 days End Slips (in.)		Transfer Length after approx. 90 days End Slips (in.)		Transfer Length from approx. 240 days End Slips (in.)	
	North	South	North	South	North	South	North	South
	Average W & E		Average W & E		Average W & E		Average W & E	
RB4-5-1	18.42	18.48	22.11	20.52				
RB4-5-2	21.11	22.46	22.52	23.78				
Average	20.12		22.23					
RA6A-5-1	17.74	17.68	25.23	26.62	26.33	28.14	26.54	28.55
RA6A-5-2	24.50	22.02	28.92	27.72	31.41	29.03	31.75	29.38
Average	20.49		27.12		28.73		29.06	
RA6-5-1	19.17	18.20	33.07	28.86	33.07	29.55	33.69	30.03
RA6-5-2	16.53	15.01	26.57	20.82	26.56	23.38	27.95	23.52
RA6-5-1-T	20.00	18.82	31.92	26.29	34.06	28.36	34.06	28.56
RA6-5-2-T	18.89	17.55	45.33	35.77	47.82	42.71	49.55	43.34
Average	18.02		31.08		33.19		33.84	
RA8-5-1	13.30	13.50	15.59	21.13	17.68	21.46	24.91	22.54
RA8-5-2	14.92	12.08	22.07	19.24	23.69	19.71	35.23	19.98
RA8-5-1-T	3.37	13.61	11.59	21.29	11.66	25.11	12.80	27.27
RA8-5-2-T	13.54	14.48	22.03	24.25	23.31	25.40	24.05	25.33
Average	12.35		19.65		21.00		24.01	
RA10-5-1	24.27	9.69	23.92	9.83	24.13	12.11	24.34	13.14
RA10-5-2	12.75	15.02	16.47	16.67	18.05	17.23	19.15	17.30
RA10-5-1-T	17.95	11.69	19.00	14.40	19.07	15.30	19.62	15.93
RA10-5-2-T	11.83	13.16	16.28	16.01	16.56	16.29	17.33	16.43
Average	14.54		16.57		17.34		17.90	

Table 5.14: Summary of Transfer Length over time for 0.5 in. diameter “D” Strands in Rectangular beams

Beam Number	Transfer Length at Release from End Slips (in.)		Transfer Length after approx. 60 days End Slips (in.)		Transfer Length after approx. 90 days End Slips (in.)		Transfer Length after approx. 240 days End Slips (in.)	
	North	South	North	South	North	South	North	South
	Average W & E		Average W & E		Average W & E		Average W & E	
RD4-5-1	32.78	31.02	38.56	42.27				
RD4-5-2	42.19	49.70	63.04	51.81				
Average	38.93		48.92					
RD6A-5-1	35.40	29.10	37.39	34.47	39.40	36.41	39.94	37.16
RD6A-5-2	20.48	20.08	26.26	35.24	30.73	39.37	32.39	40.07
Average	26.26		33.34		36.48		37.39	
RD6-5-1	30.24	28.07	43.00	38.57	46.82	44.37	49.75	45.26
RD6-5-2	25.60	29.22	36.79	39.87	41.99	44.72	44.24	48.27
RD6-5-1-T	23.66	25.85	38.10	38.09	40.76	42.20	42.89	45.27
RD6-5-2-T	25.10	21.82	65.45	39.67	69.56	44.05		
Average	26.19		42.44		46.81		45.95	
RD8-5-1	20.15	20.15	28.34	26.55	32.66	30.33	39.08	34.54
RD8-5-2	13.66	17.30	34.14	46.08	36.82	47.73	37.38	50.41
RD8-5-1-T	25.78	28.06	23.98	38.41	30.63	41.05	27.73	44.59
RD8-5-2-T	19.93	22.50	49.52	32.36	50.91	33.26	52.86	35.00
Average	20.94		34.92		37.92		40.20	
RD10-5-1	26.03	16.85	26.31	25.27	26.45	26.51	30.24	27.14
RD10-5-2	14.85	18.23	17.47	20.16	18.71	22.30	22.30	22.03
RD10-5-1-T	21.43	16.81	23.51	19.77	23.51	21.63		23.77
RD10-5-2-T	16.74	15.92	24.05	23.01	25.98	23.01	28.18	23.01
Average	18.36		22.44		23.51		25.24	

Table 5.15: Summary of Transfer Length over time for 0.5 in. diameter "A" and "D" Top Strands in Rectangular beams Top Strands

Beam Number and Location		Transfer Length at Release from End Slips (in.)		Transfer Length after approx. 60 days End Slips (in.)		Transfer Length after approx. 90 days End Slips (in.)		Transfer Length after approx. 240 days End Slips (in.)	
		North	South	North	South	North	South	North	South
		Average W & E		Average W & E		Average W & E		Average W & E	
RA6-5-1-T	(Top)	20.25	19.84	33.01	32.69	34.46	34.96	34.60	34.89
RA6-5-2-T	(Top)	19.44	16.61	37.07	35.15	39.33	37.28	40.64	37.49
Average	(Top)	19.04		34.48		36.51		36.90	
RA8-5-1-T	(Top)	12.06	14.65	24.27	24.67	24.96	26.18	25.16	27.21
RA8-5-2-T	(Top)	16.37	15.13	27.30	27.30	28.20	28.68	28.96	29.44
Average	(Top)	14.55		25.88		27.00		27.69	
RA10-5-1-T	(Top)	14.73	12.41	21.59	18.79	22.16	19.43	22.16	19.70
RA10-5-2-T	(Top)	12.37	12.10	14.29	22.15	15.42	22.22	15.63	22.36
Average	(Top)	12.90		19.21		19.81		19.96	
RD6-5-1-T	(Top)	27.71	20.86	53.89	56.65	57.32	59.03	58.79	60.29
RD6-5-2-T	(Top)	23.66	22.81	49.07	48.64	57.90	53.33	63.27	54.49
Average	(Top)	23.76		52.06		56.89		59.21	
RD8-5-1-T	(Top)	19.84	17.64	35.57	35.90	40.15	39.59	41.18	42.47
RD8-5-2-T	(Top)	28.25	24.82	65.51	67.04	67.56	68.62	68.52	68.62
Average	(Top)	22.64		51.01		53.98		55.20	
RD10-5-1-T	(Top)	17.03	15.94	26.10	24.12	27.87	26.36	30.19	27.11
RD10-5-2-T	(Top)	17.58	13.15	24.81	23.58	26.30	24.95	26.58	26.99
Average	(Top)	15.93		24.65		26.37		27.72	

Table 5.16: Summary of Transfer Length over time for 0.6 in. diameter "A" Strands in Rectangular beams								
Beam Number	**Transfer Length at Release from End Slips (in.)**		**Transfer Length approx. after 60 days End Slips (in.)**		**Transfer Length approx. after 90 days End Slips (in.)**		**Transfer Length approx. After 240 days End Slips (in.)**	
	North	**South**	**North**	**South**	**North**	**South**	**North**	**South**
	Average W & E		**Average W & E**		**Average W & E**		**Average W & E**	
RA4-6-1 RA4-6-2	33.42 30.24	24.98 29.35						
	29.50							
RA6-6-1 RA6-6-2 RA6-6-3	29.73 31.65 25.83	28.19 30.10 33.63	36.87 47.03 39.73	41.73 46.36 44.60	39.00 49.24 44.08	44.45 48.20 44.82	40.85 52.18 44.96	55.13 49.37 45.93
Average	29.85		42.72		44.97		48.07	
RA8-6-1 RA8-6-2 RA8-6-3	28.21 28.20 22.80	29.17 25.70 28.26	42.46 42.68 36.85	41.87 38.55 44.00	43.87 46.28 41.17	43.26 42.35 46.93	45.48 46.35 43.00	43.41 42.37 49.22
Average	27.06		41.07		43.97		44.97	
RA10-6-1 RA10-6-2 RA10-6-3	20.03 15.62 16.34	21.92 21.78 22.73	25.69 20.99 24.46	25.77 25.99 28.82	28.08 26.14 26.13	28.82 29.47 32.30	29.98 26.79 27.73	32.15 30.70 33.32
Average	19.74		25.29		28.49		30.11	

5.7 DISCUSSION OF TRANSFER LENGTH MEASUREMENTS

Transfer lengths were measured from the end slips as explained in Section 5.5.3 on all the prestressed concrete beams. The results are detailed in Section 5.6. This section makes comparison between the transfer lengths at release and the concrete release strengths.

5.7.1 Transfer Length for Rectangular Beams

Figures 5.12 through 5.17 show the variation of transfer length in rectangular beams with increase in concrete release strengths. The strand designations shown on the charts represents the NCHRP Strand IDs.

Figures 5.12 through 5.17 shows the variation transfer lengths can have on concrete release strengths. The data presented in the figures are reported in Section 5.6.1. The data reported in the figures contain the transfer length data measured from end slips. The regression analysis is performed on the data set to show the variations transfer lengths can have over the measured concrete release strengths, $\bar{f}'_{ci}$. The data in the plot contains only the bottom strands in rectangular beams. The data presented in Figs. 5.12 through 5.17 do not include the transfer length data from beams fabricated with Air Entraining Admixture.

Figure 5.12 presents the data for both Strand A and Strand B. The data show a coefficient of determination of 0.64 for transfer lengths over the concrete strengths. Due to the spalling of the surface concrete while measuring the end slips, transfer lengths of 25.65, 22.89, and 5.82 in. were not included for the $\bar{f}'_{ci}$ of 9711 psi. The transfer length of 11.78 in. was omitted in the 6183 psi data set. However, the data is shown in the figure as an omitted data set.

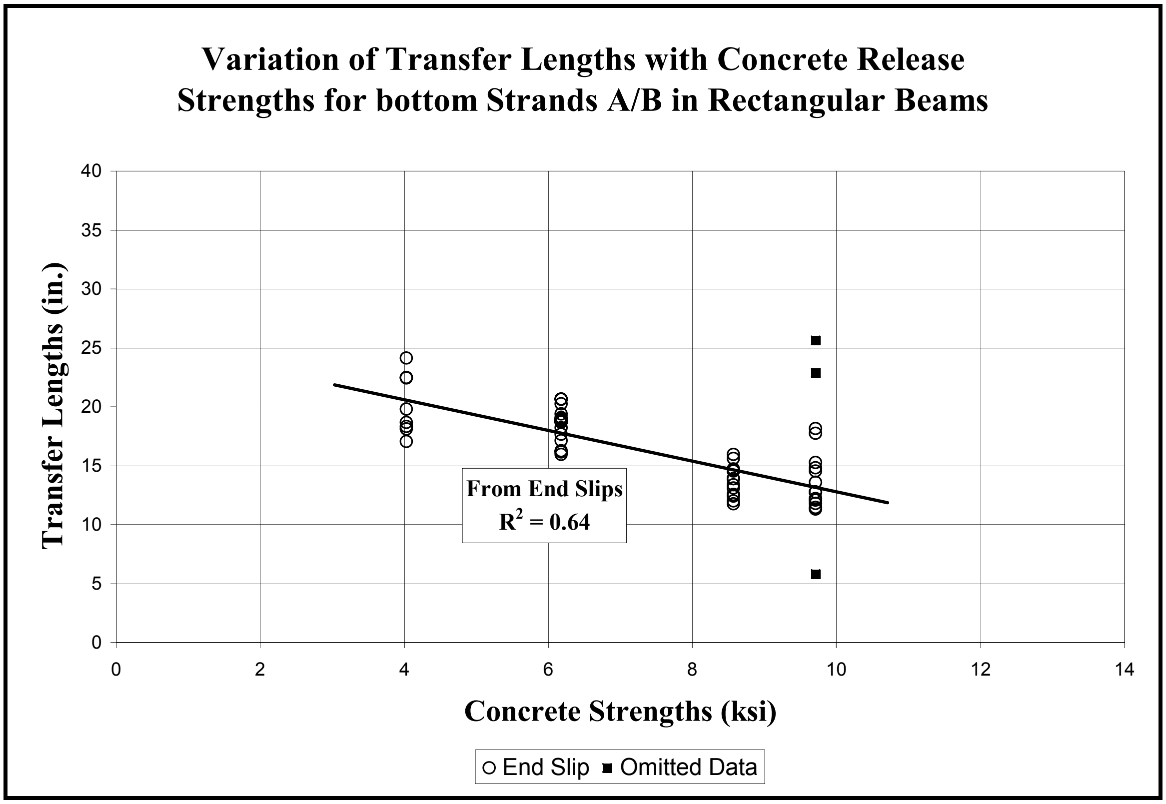


Figure 5.12: Transfer Length vs. $\bar{f}'_{ci}$ for Strands A/B in Rectangular Beams

The data presented in Fig. 5.12 included all the data for all strands. The data for the east and the west strand is averaged and presented in Fig. 5.13 to represent single transfer length measurement for the North and South end independently. The regression analysis performed with the overall average of transfer length results in an R^2 value of 0.95 showing a higher correlation with averaged values in transfer lengths for Strand A/B.

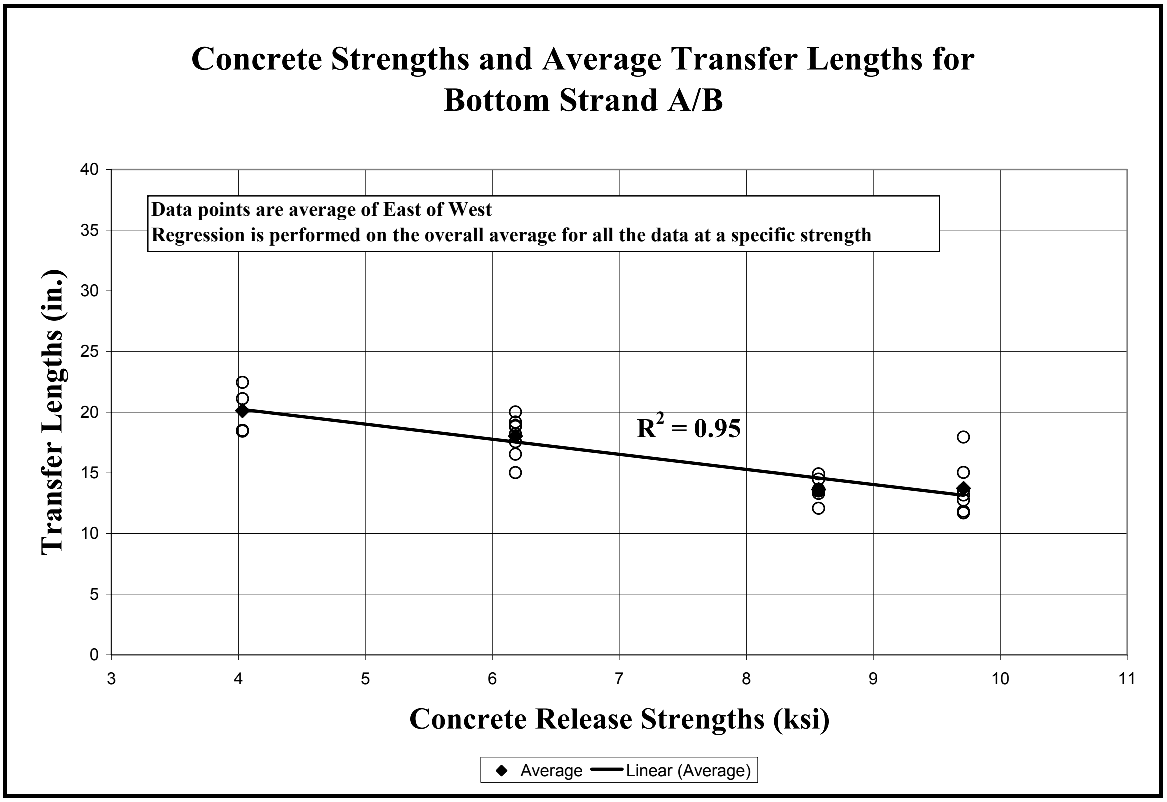


Figure 5.13: Average Transfer Length vs. $\bar{f}'_{ci}$ for Strands A/B in Rectangular Beams

Figure 5.14 plots the variation of concrete release strength with the transfer lengths on Strand D. The correlation for the transfer length measurements made using end slips is 0.66 for the set of data presented in the figure. The transfer length measurements with larger variations are not included in the data set. The higher variation in the data set is an inherent property of the transfer length measurements. The data presented in Fig. 5.15 shows the averaged data between the east and the west strands on each end of a particular beam. For the overall average transfer length measurements for Strand D at a particular concrete strength, the R^2 value increases to 0.98 showing a high correlation in the data.

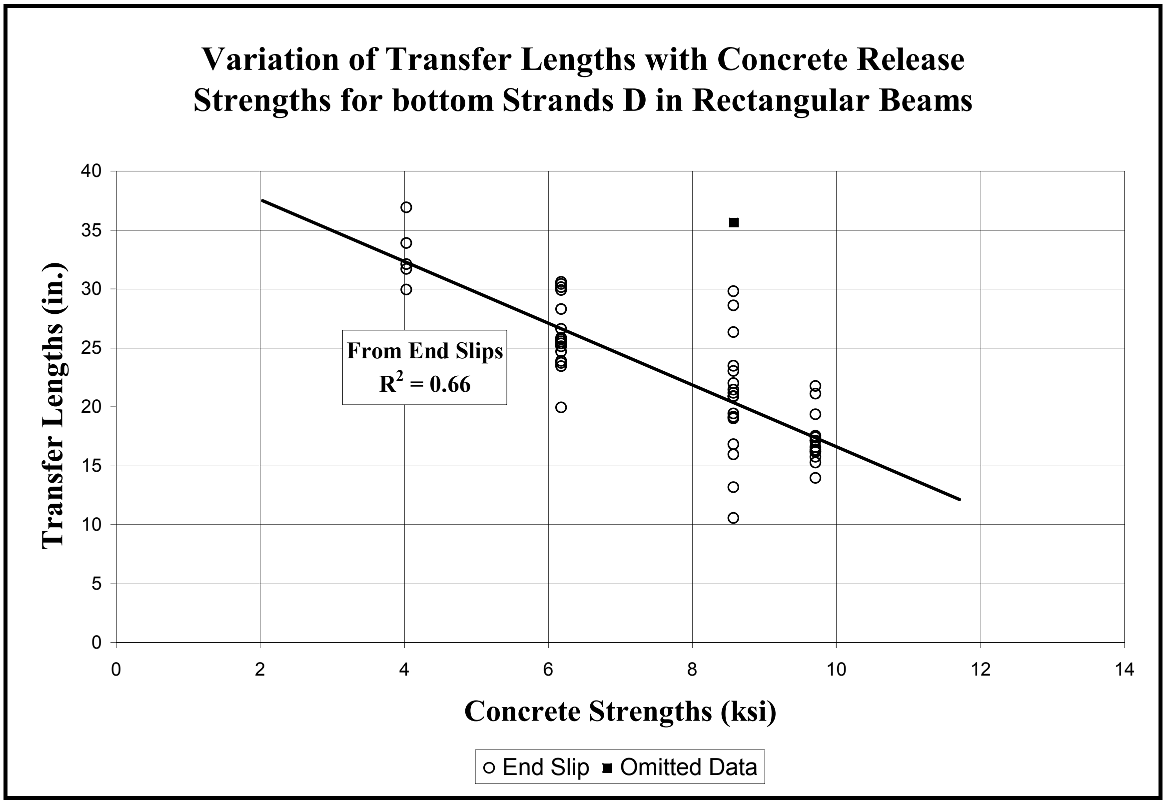


Figure 5.14: Transfer Length vs. $\bar{f}'_{ci}$ for Strand D in Rectangular Beams

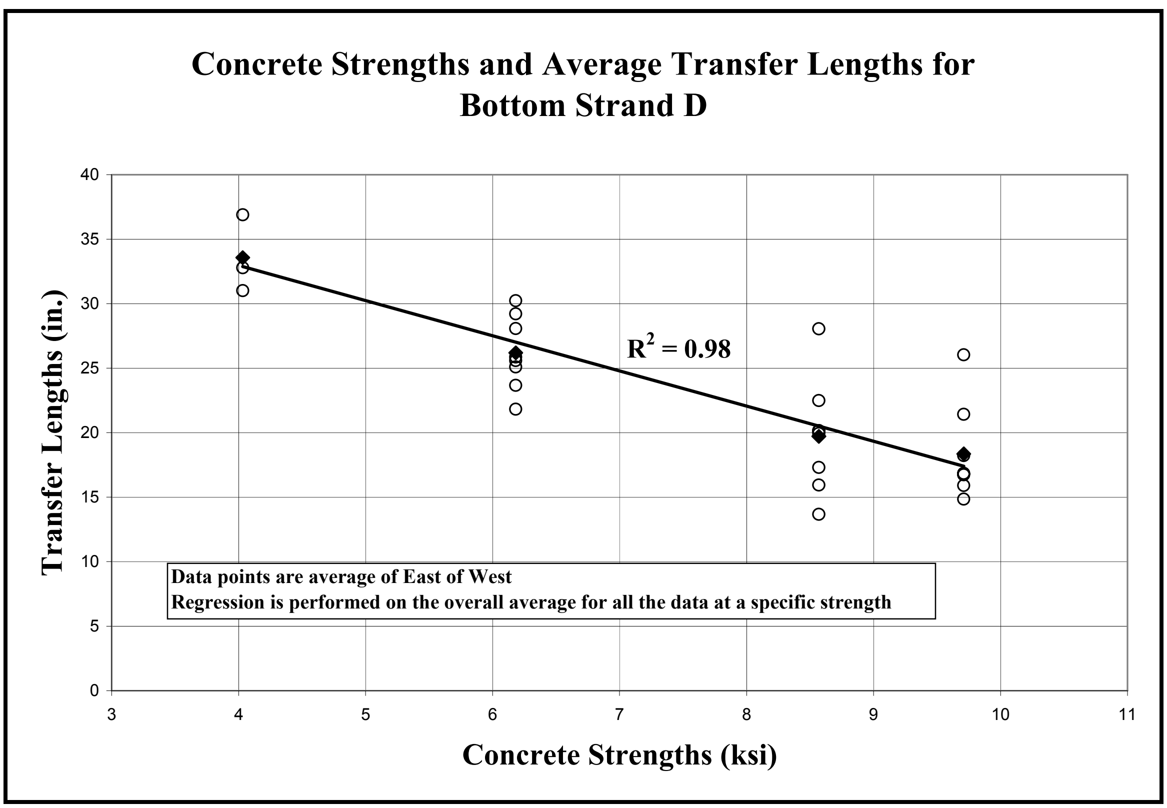


Figure 5.15: Average Transfer Length vs. $\bar{f}'_{ci}$ for Strand D in Rectangular Beams

The variation of transfer lengths and $\bar{f}'_{ci}$ for 0.6 in. diameter Strand A is presented in Fig. 5.16. The R^2 value of 0.64 indicates that the concrete strength has significant effects on the transfer length measurements. The averaged data for each end of the beam is represented in Fig. 5.17 where the R^2 value increases further to 0.97.

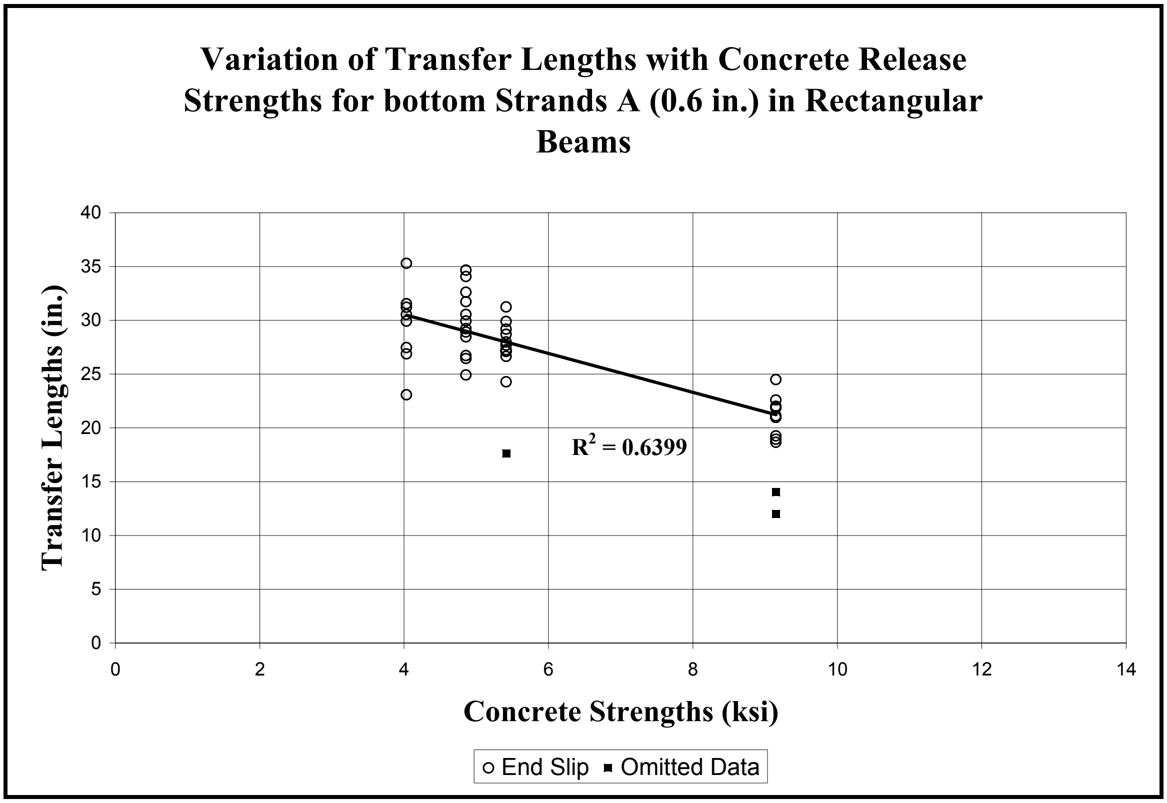


Figure 5.16: Transfer Length vs. $\bar{f}'_{ci}$ for Strand A (0.6 in.) in Rectangular Beams

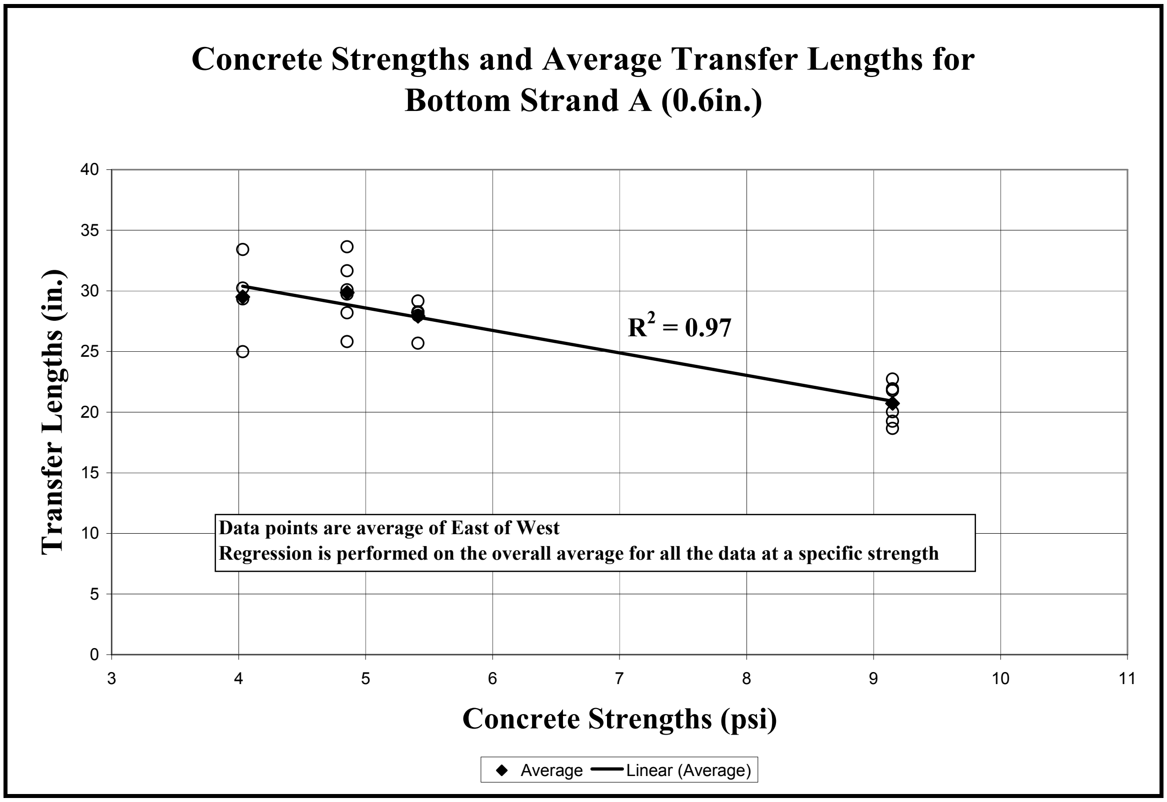


Figure 5.17: Average Transfer Length vs. $\bar{f}'_{ci}$ for Strand A (0.6 in.) in Rectangular Beams

The variations reported in this section for the transfer lengths measured are principally caused by the variations in the end slip and not from the measurement techniques discussed in previous section. The variations observed in this data conform to the variations in the transfer lengths observed in the past. The scatter in the transfer lengths reported from various studies (Tabatabai 1993) for 0.5 in. diameter strands were approximately between 15 to 75 in. as seen in Fig. 2.6 in Chapter 2.

The effect of transfer lengths on the concrete strength is significant on all the strands used in the prototype beams. The relationship is not too strong because of the inherent nature in the variations of transfer lengths. If the data used is the average transfer length for a particular concrete strength, the R^2 could be much higher.

5.7.2Transfer Length for I-shaped beams

The variations of transfer lengths with concrete release strengths for the I-shaped beams are shown in Figures 5.22, 5.23 and 5.24. It is observed that the Figs. 5.22 and 5.23 have two types of concrete release strengths. The correlations between them are not plotted as there are not three or more release strength data points. Figure 5.24 plots data for three types of concrete release strengths. As two of the release strength data is very close to each other 10480 and 10590 psi, the R^2 is not reported as there is no sufficient spread in the concrete strengths.

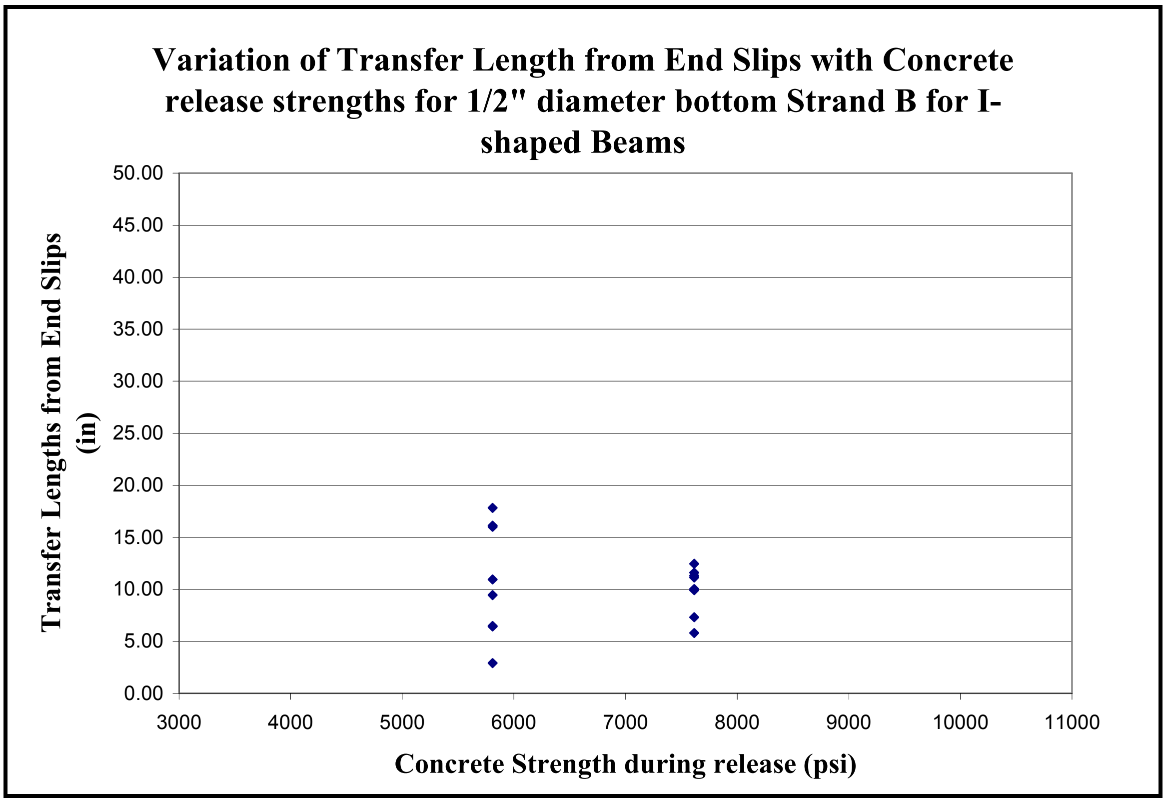


Figure 5.18: Transfer Lengths and Concrete Strengths for Strand B in I-beams

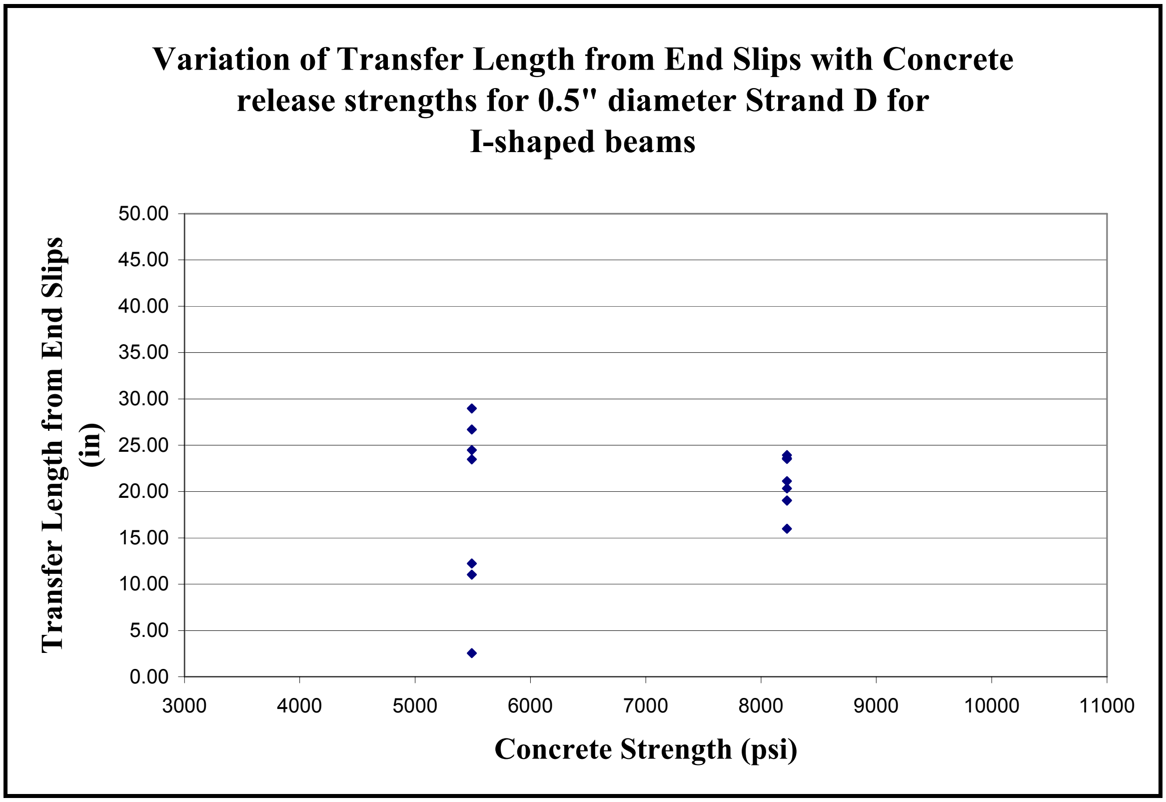


Figure 5.19: Transfer Lengths and Concrete Strengths for Strand D in I-beams

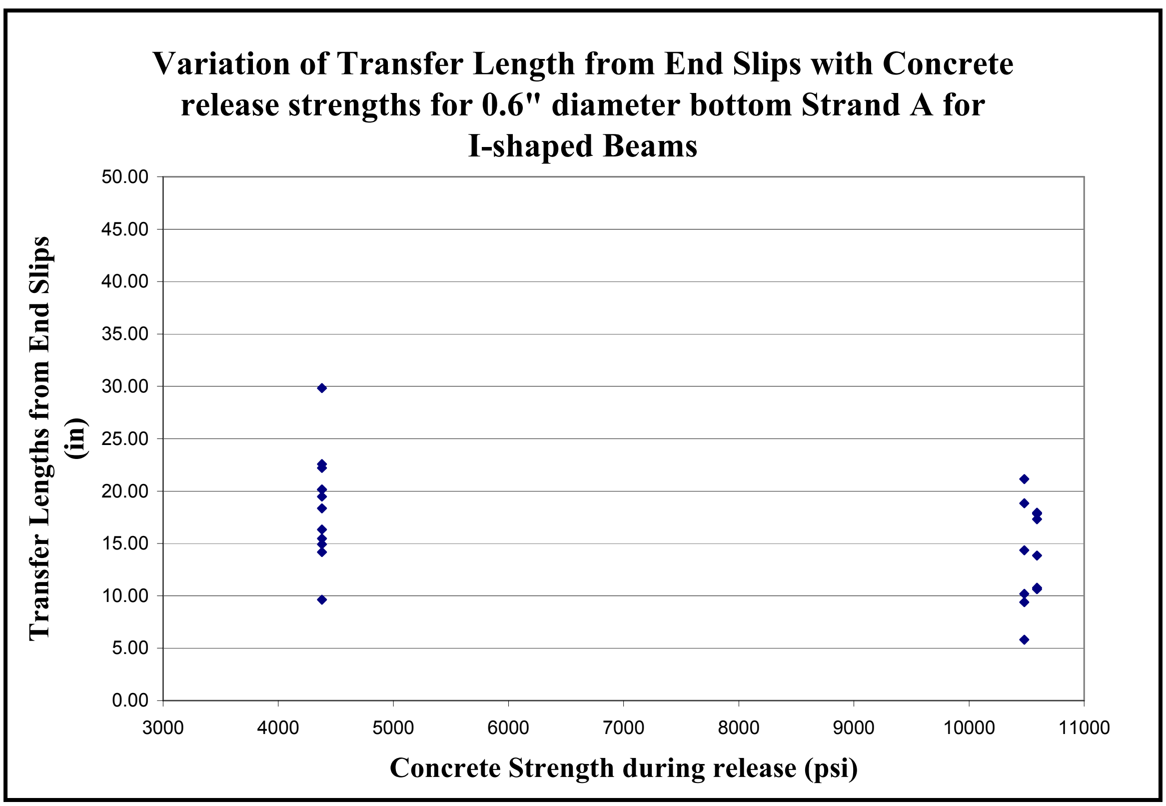


Figure 5.20: Transfer Lengths and Concrete Strengths for 0.6 in diameter Strand A in I-beams

A similar trend in the transfer length measurements measured on rectangular beams with high scatter in the transfer length data is observed for the I-shaped beams as well. The inherent nature of the transfer length measurement is the cause for the variations. The measuring techniques do not cause the transfer length measurements to scatter.

5.7.3 Transfer Lengths over time

The increase in transfer lengths over time is reported in Section 5.6. The results from the data reported are presented in the following charts.

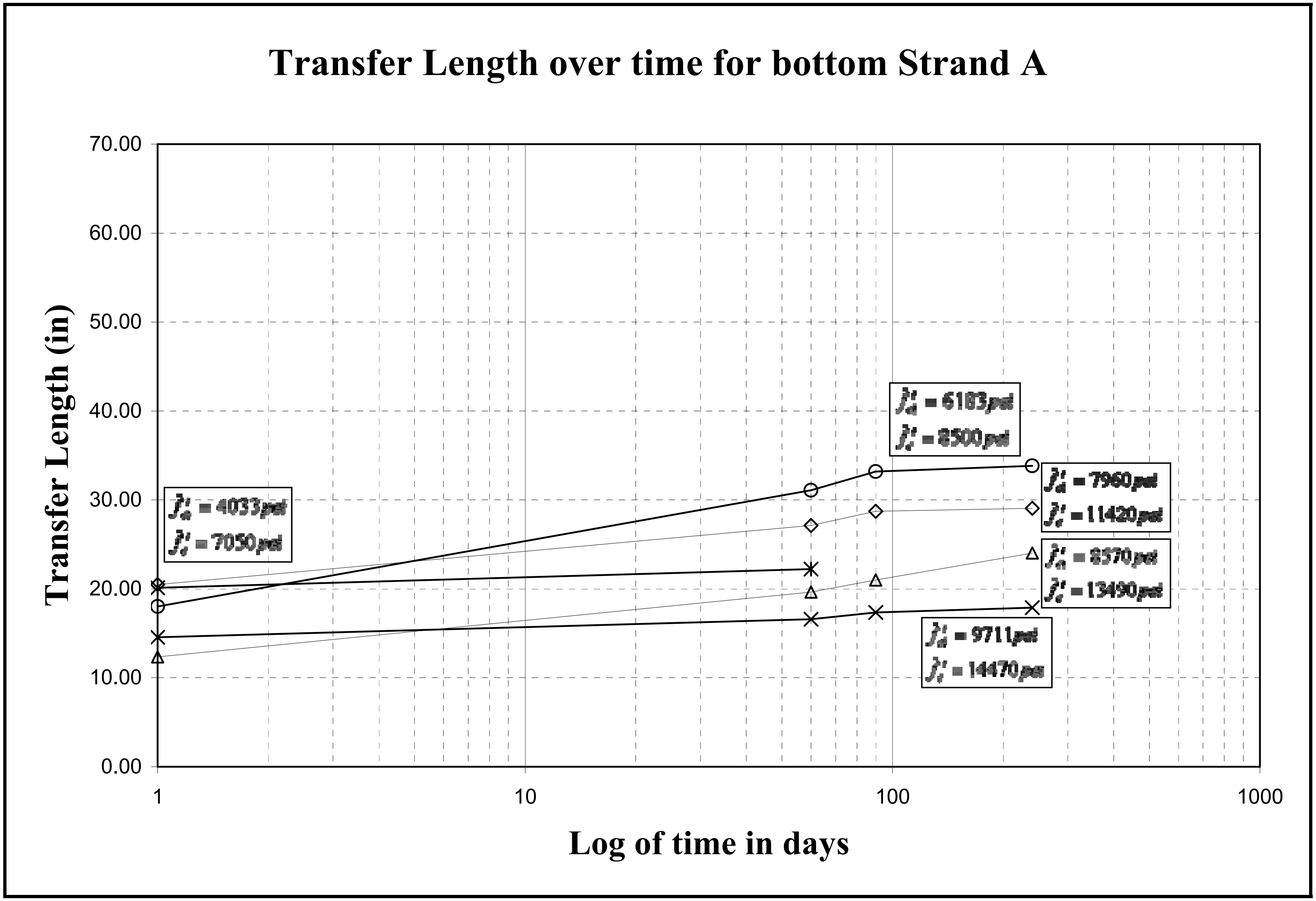


Figure 5.21: Transfer Length over time for Bottom Strand A

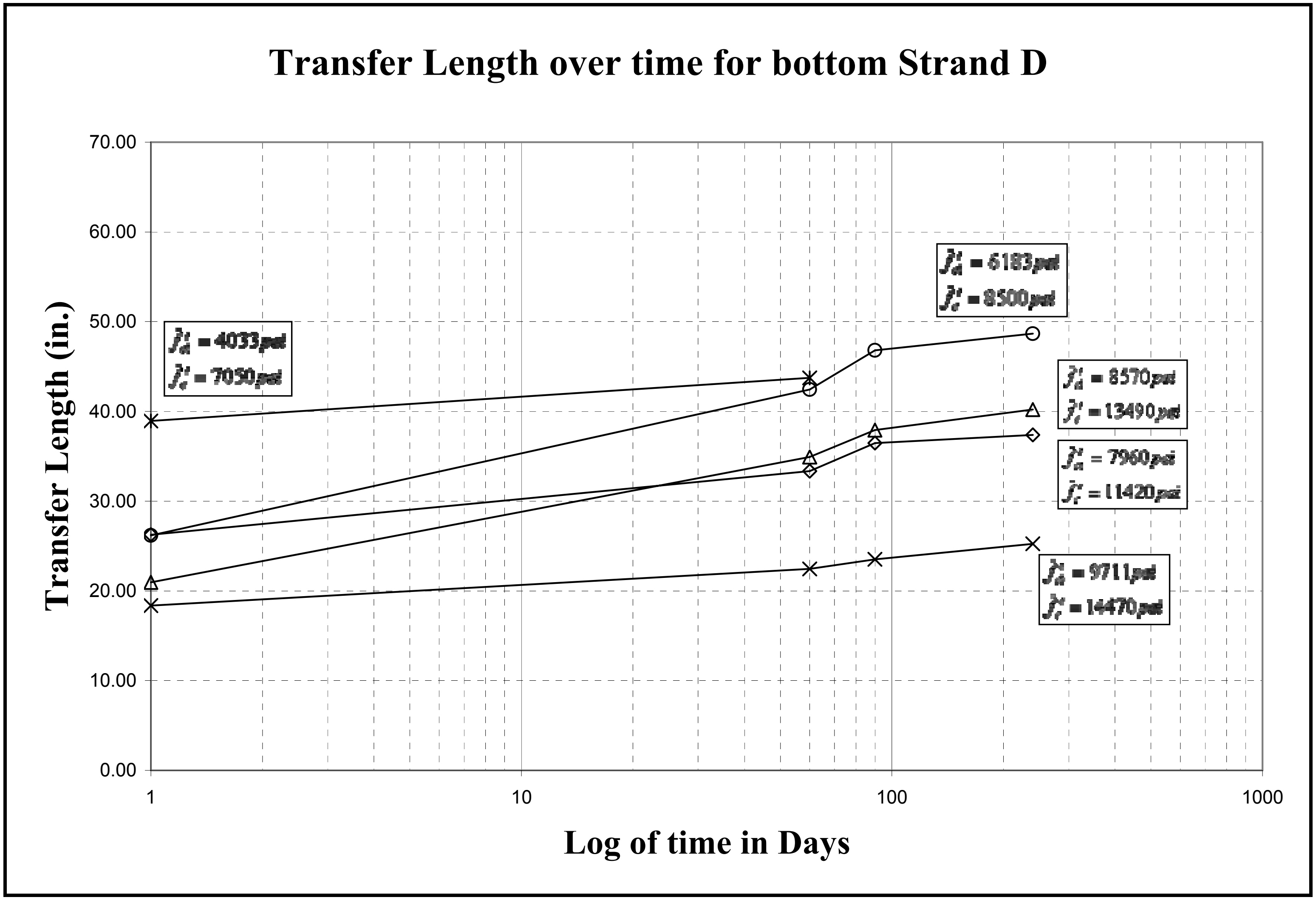


Figure 5.22: Transfer Lengths over time for Bottom Strand D

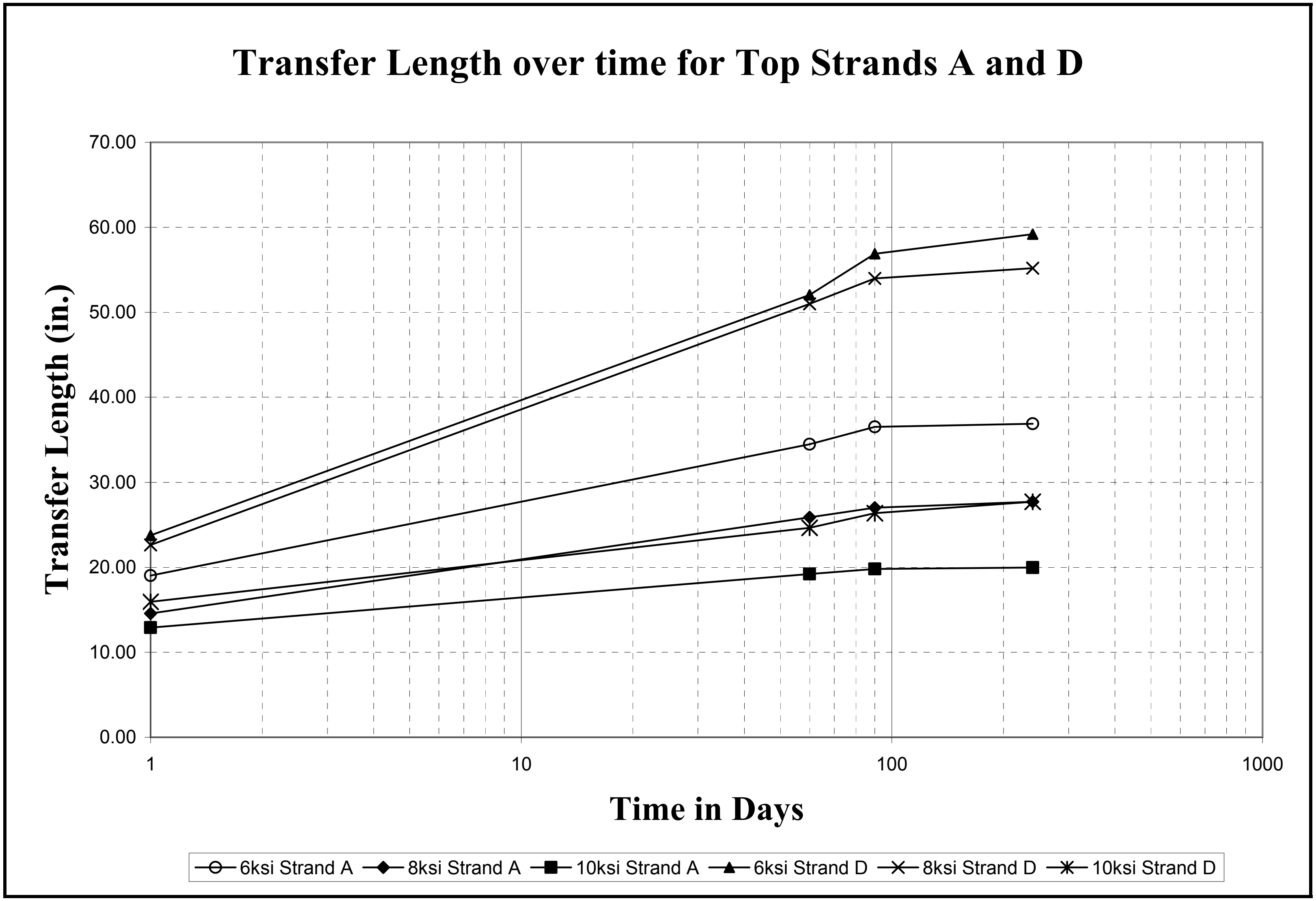


Figure 5.23: Transfer Lengths over time for Top Strands A and D

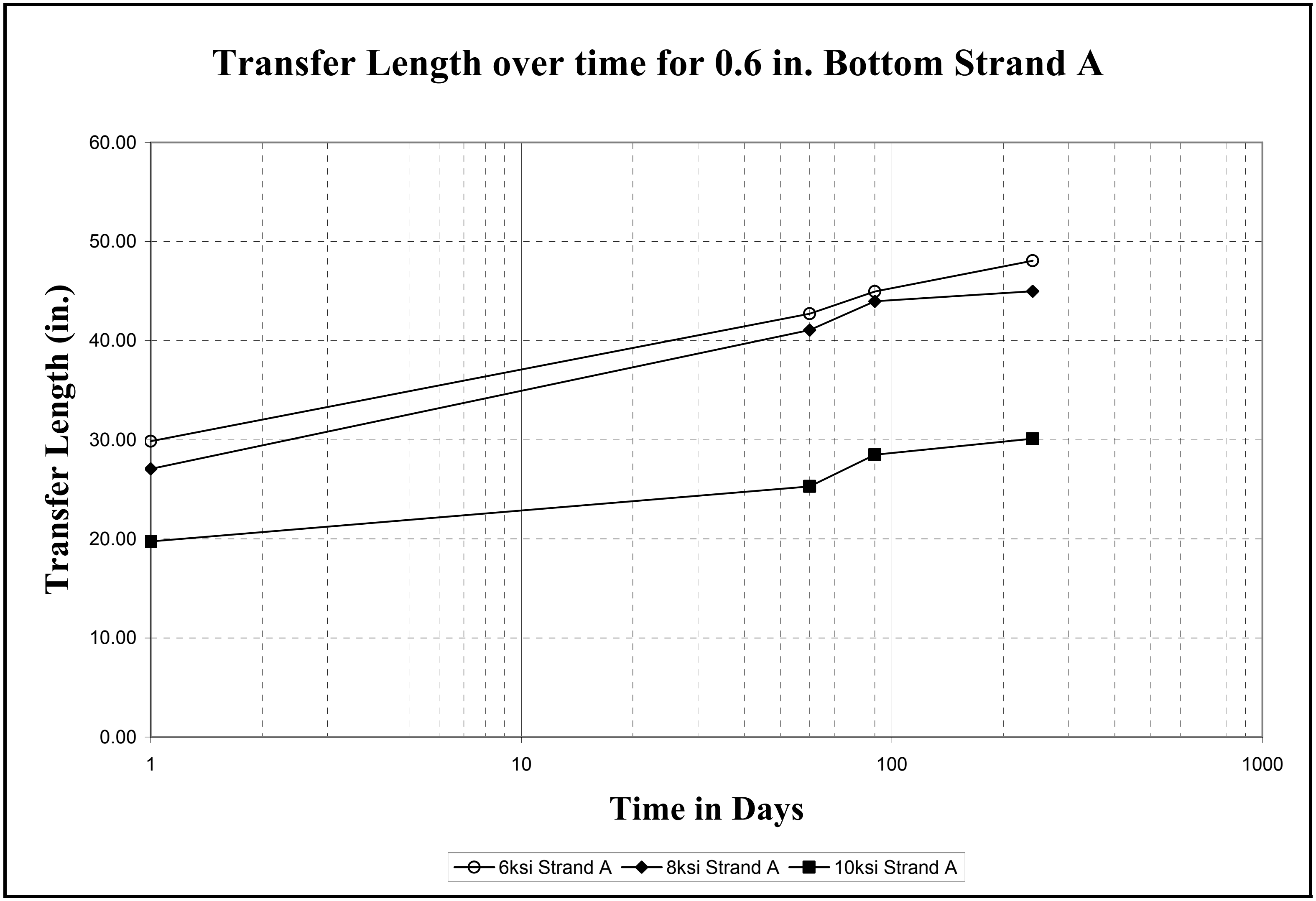


Figure 5.24: Transfer Lengths over time for Bottom Strand A (0.6 in.)

For Strand A, the high performing strand, and Strand D, the moderate performer, the increase in transfer lengths over time for the bottom strand beams is similar. For target release strength of 6 ksi, the increase in transfer length over approximately 240 days is 42% for both Strand A and D. For target release strengths of 6ksi with air entrainment and 8 ksi beams, the increase in transfer length over 240 days is 88% for Strand A and 86% for Strand D, and 94% for Strand A, and 92% for Strand D respectively. For high strength concrete, with target release strength of 10 ksi, the increase is 23% and 37% for Strand A and D respectively.

The increase in transfer lengths for the top strands in rectangular beams is more significant than the bottom strands. The increase in transfer lengths is higher on moderate performing strands when compared to the high performers. For 6, 8, and 10 ksi release strengths, the increase is 94%, 90%, and 55% for Strand A, and 149%, 144%, and 74% for Strand D for the top strands alone.

The increase in transfer lengths for 0.6 in. diameter bottom strands is lower when compared to the 0.5 in. diameter strands. The increase of 61%, 66%, and 53% is observed on 6 ksi, 8 ksi, and 10 ksi target release strength beams.

5.7.4 Comparing Transfer Lengths from End Slips and DEMEC

As discussed, the transfer lengths were measured from the end slips and the concrete surface strains. Table 5.17 compares the differences in measurements from end slips and concrete surface strains.

Table 5.17: Transfer Lengths from End Slips and Concrete Surface Strains

Beam	Location	End Slips (in.)	DEMEC (n.)
RB4-5-1	North	18.42	24.18
RB4-5-1	South	18.48	27.11
IB6-5-1	North	12.19	15.22
IB10-5-1	North	11.10	11.02
RA6A-5-1	North	17.74	16.01
RA6A-5-1	South	17.68	17.47
RA8-5-1	North	13.30	14.31
RA8-5-1	South	13.50	12.00
RA10-5-1	North	24.27	24.34
RA10-5-1	South	9.69	14.37
RA8-5-1-T	North	12.06	12.02
RA8-5-1-T	South	14.65	15.61
RA10-5-1-T	North	14.73	12.45
RA10-5-1-T	South	12.41	11.69
RD4-5-1	North	32.78	25.57
RD4-5-1	South	31.02	24.79
RD6A-5-1	North	35.40	39.01
RD6A-5-1	South	29.10	26.35
RD8-5-1	North	20.15	11.32
RD8-5-1	South	20.15	18.49
RD10-5-1	North	26.03	23.38
RD10-5-1	South	16.85	19.42
RD8-5-1-T	North	19.84	12.38
RD8-5-1-T	South	17.64	11.96
RD10-5-1-T	South	17.03	16.09
RD10-5-1-T	South	15.94	15.67
ID6-5-1	North	25.23	25.90
ID10-5-1	North	17.50	19.72
RA4-6-1	North	33.42	31.43
RA4-6-1	South	24.98	30.26
RA6-6-1	North	29.73	22.40
RA6-6-1	South	28.19	21.14
RA8-6-1	North	29.17	19.46
RA8-6-1	South	28.21	21.95
RA10-6-1	North	20.03	16.63
RA10-6-1	South	21.92	14.96
IA6-6-2	North	24.27	15.89
IA6-6-2	South	26.11	16.19
IA10-6-1	North	17.95	11.31
IA10-6-2	North	15.98	16.54

The results in Table 5.17 are used to analyze the correlation between the data. The coefficient of determination between the transfer lengths inferred from end slip reference clamps and the concrete surface strain profiles are reported in Table 5.18 for each strand groups. It is seen that the “B” Strand group shows a high correlation value R^2 of 0.9627 and the 0.6 in. diameter Strand A shows the lowest value of 0.4743. The correlation coefficients of the 0.5 in. diameter Strands A and D are 0.7704 and 0.708 respectively. The Figure 5.25 plots all the data from the End slips and DEMEC readings in Table 5.18. A coefficient of determination, 0.542 is seen for the data set. The reason for a low coefficient of determination is because of the low correlations seen for the 0.6 in. diameter strands.

The 0.5 in. diameter strands showed a better correlation in transfer lengths between the end slips and concrete surface strains than the 0.6 in. diameter strands.

Table 5.18: Coefficient of Determination of transfer length between End Slips and Surface Strains for Strand Groups

Strands	Diameter (in)	Correlation Coefficients (R^2)
A	0.5	0.7704
B	0.5	0.9627
D	0.5	0.7080
A	0.6	0.4743
A,B,D	0.5	0.6735

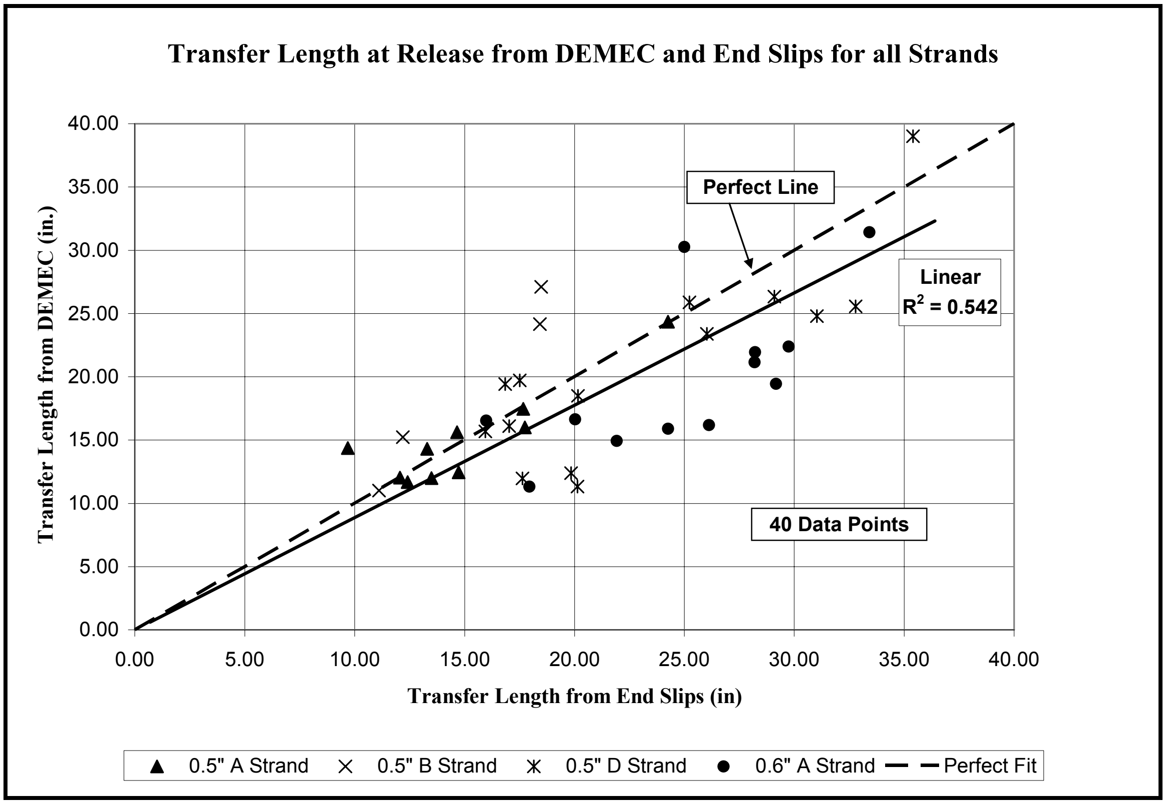


Figure 5.25: Comparing transfer lengths from DEMEC and End Slips

5.7.5 Scatter of the Transfer Length data

Transfer length measurements have always shown a considerable amount of scatter in the data. The research conducted (Russell 1992; Tabatabai 1993) in a historical perspective discussed in Chapter 2 shows the variability the transfer length measurements can have on a particular strand diameter.

While flame cutting, the strands experience a violent reaction which cause the beams to move for considerable lengths. Some of the strands were detensioned to avoid a violent reaction. As the stress relieving methods were not consistent throughout the testing program, scatter in the transfer lengths can be attributed the same reason. It is observed in Figs. 5.26 and 5.27 that the beam on picture RD4-5-1 moved about 12 in.

after flame cutting. (The reference position seen at the end of the beam on Fig. 5.26 is at point 4 on the beam. Each of the points are 100 mm away from each other.)

Figure 5.26: Reference position before flame cutting for RD4-5-1

Figure 5.27: Moved RD4-5-1 after flame cutting

In order to understand the scatter in the data, histograms are constructed using the transfer lengths at release for some strand groups. In order to construct a histogram, a significant amount of data points are necessary. The histograms shown in Figures 5.28 though 5.33 are constructed for strand groups with concrete release strength of 6000 psi and 10, 000 psi on 0.5 in. diameter NCHRP Strands A, B, D and 0.6 in. diameter NCHRP A. The histograms in Figs. 5.28 through 5.33 show the transfer length at release plotted against the number of transfer lengths inferred from the end slip of the strands using reference clamps. The transfer lengths are plotted in a range of three inches. The histograms show the average value (X) and the range of the average from the standard deviation (σ). The data for plotting the histograms include only the bottom strands. The beams are grouped in similar concrete release strengths and same source of strand.

It can be seen that the transfer length reduces with increase in concrete release strength between the charts. The data shows a significant scatter among each data set, though there is no general trend among the data.

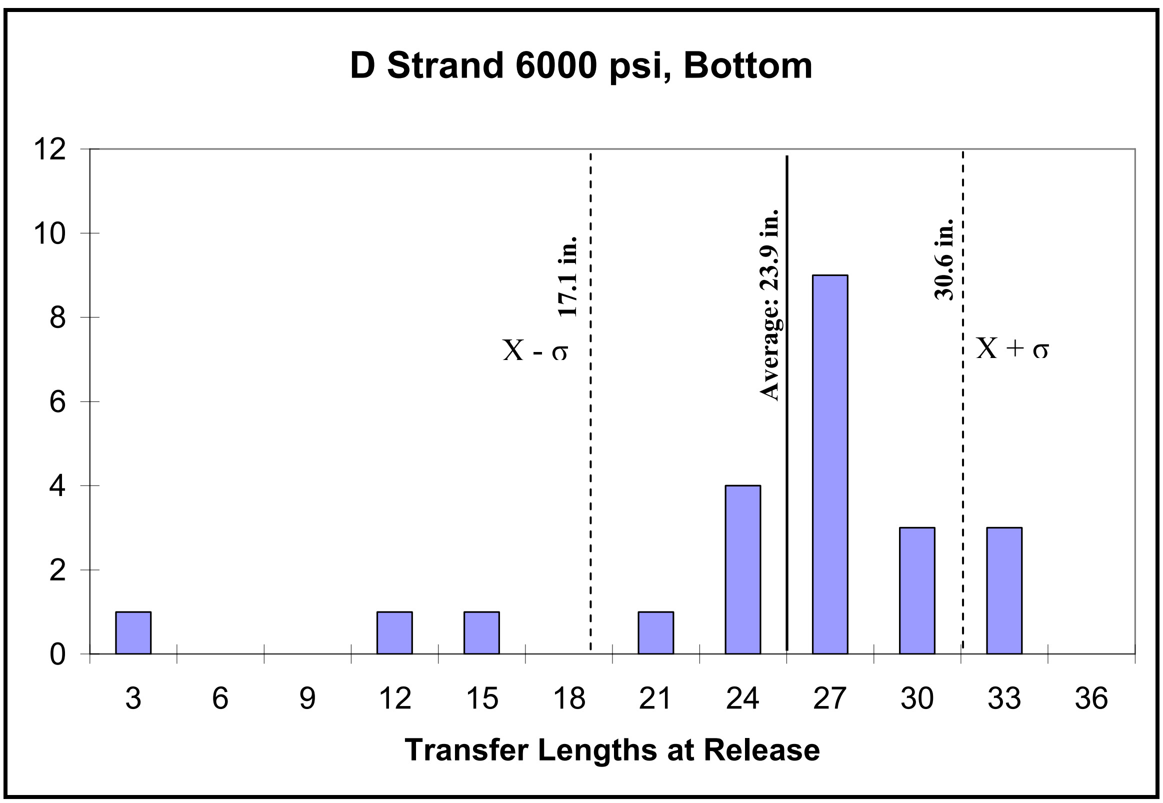


Figure 5.28: NCHRP bottom Strand D in Beams with 6000 psi release

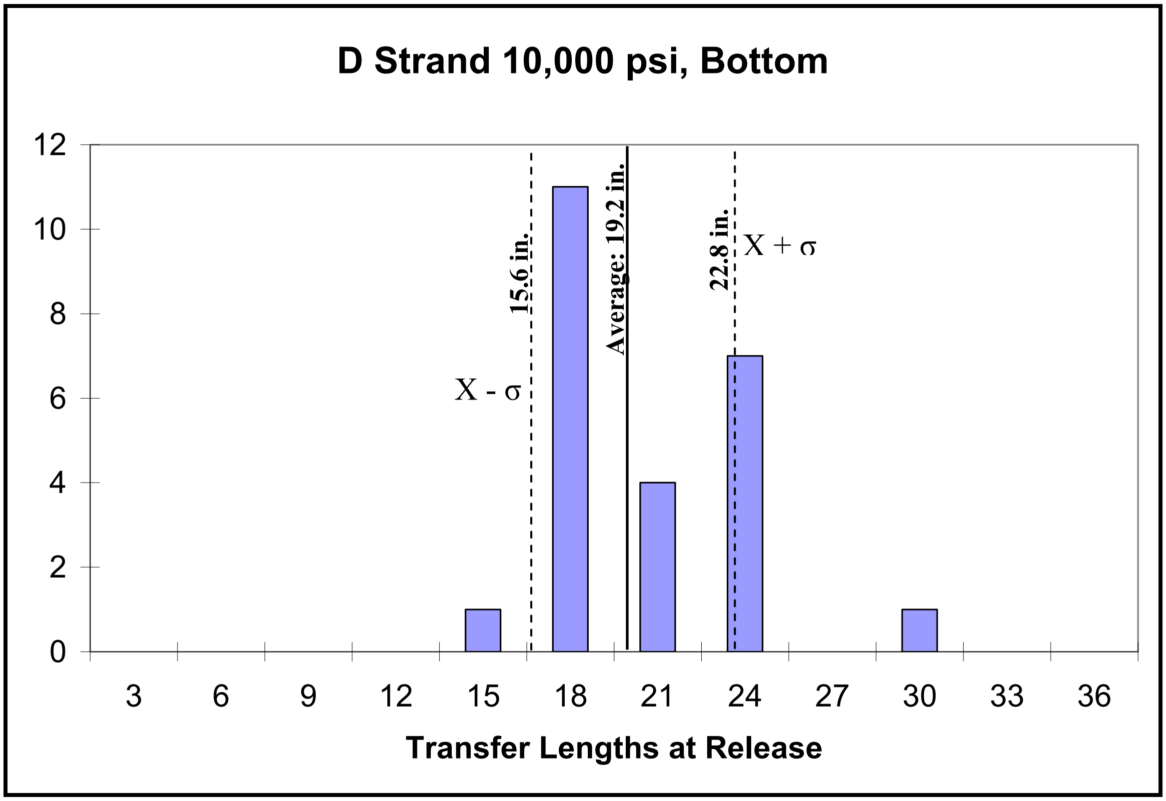


Figure 5.29: NCHRP bottom Strand D in Beams with 10,000 psi release

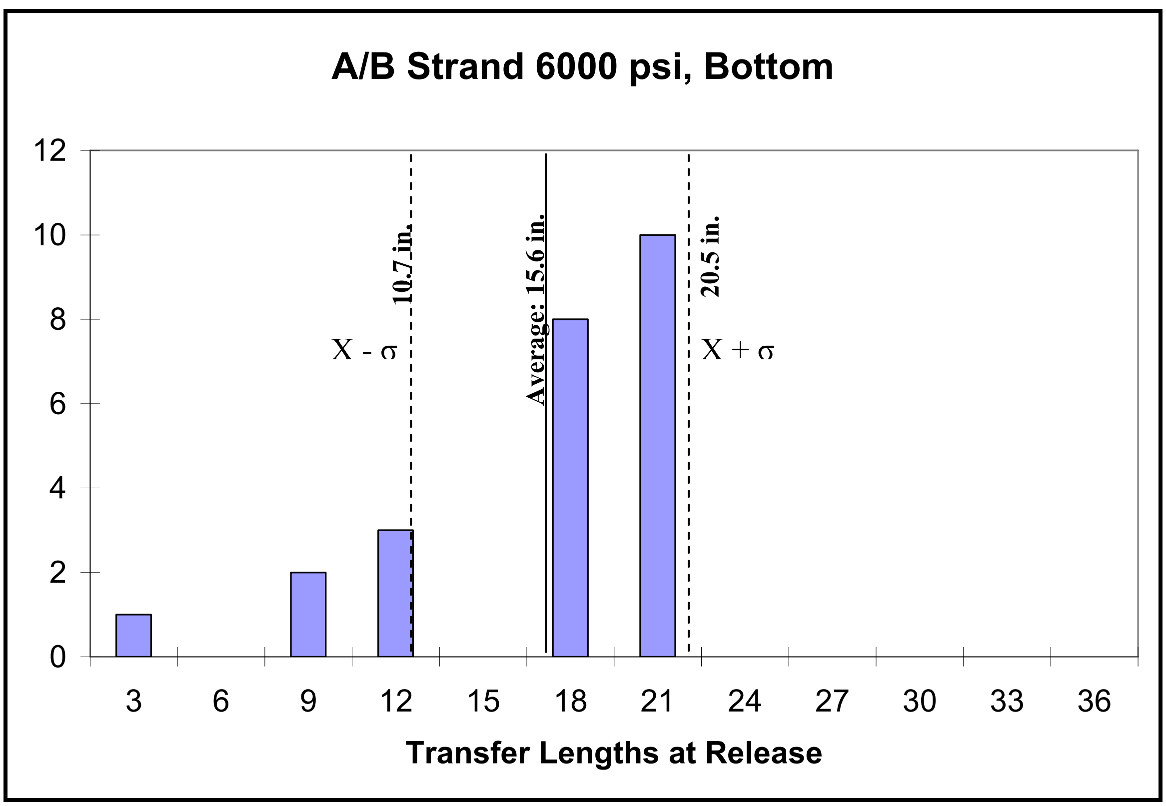


Figure 5.30: NCHRP bottom Strand A/B in Beams with 6000 psi release

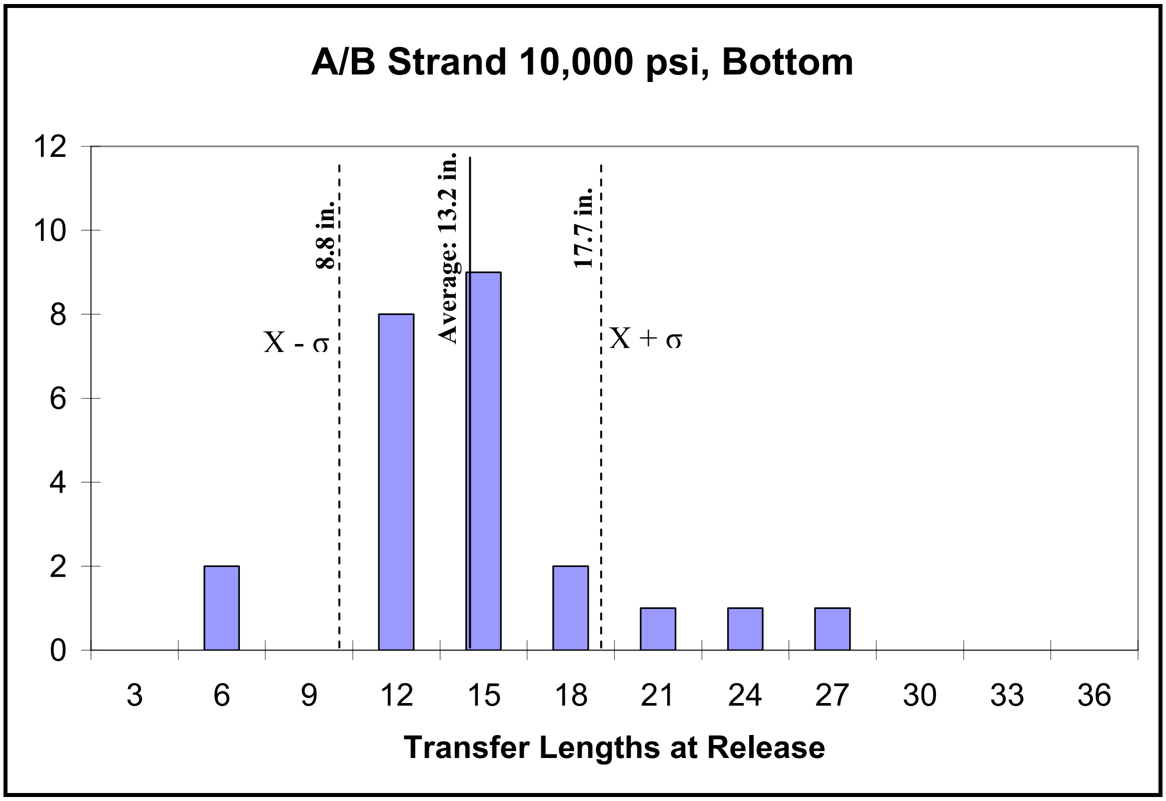


Figure 5.31: NCHRP bottom Strand A/B in Beams with 10,000 psi release

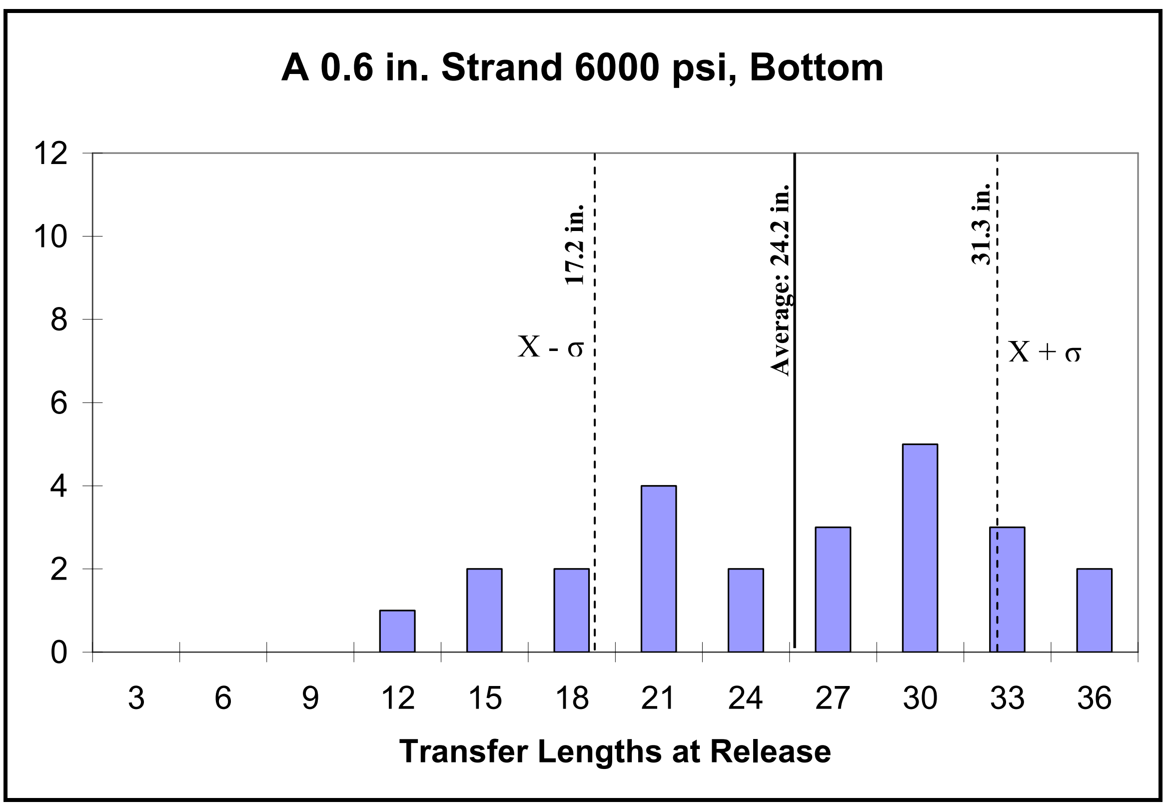


Figure 5.32: NCHRP bottom Strand A (0.6 in.dia.) in Beams with 6000 psi release

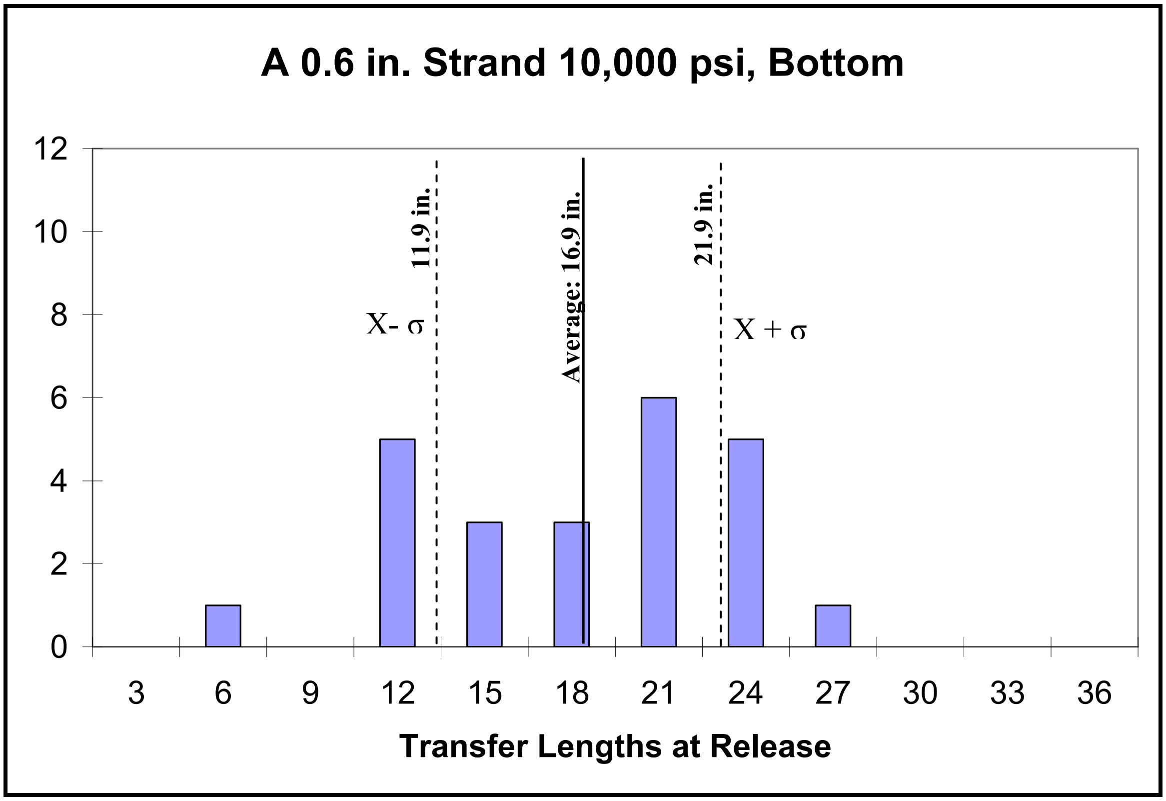


Figure 5.33: NCHRP bottom Strand A (0.6 in.dia.) in Beams with 10,000 psi release

5.8 DISCUSSION OF TRANSFER LENGTHS AND NASP RESULTS

The transfer lengths reported in earlier section is related to the concrete strengths and the NASP pull out test data discussed in earlier chapters. The transfer lengths at release from the bottom strands in rectangular beams are plotted against the corresponding one day release strength for the prototype beams made with various concrete strengths. Figure 5.34 show the linear regression lines for the three types of strands used in the beams. The data for Strands A and B are treated together. The figure contains the transfer length data for the east and the west strands for each end of the beams at release. The overall average of the transfer lengths for a particular concrete strength is also reported in the figure. The R^2 values are computed from the overall averages for a concrete strength. The R^2 values are 0.95, 0.98, and 0.97 for Strands A/B, Strand D, and 0.6 in. diameter Strand A respectively. The regression lines for the three different types of strands used show that the increase in concrete strengths decreases the transfer lengths of the beams. It is noted that the regression lines does not follow a parallel fit between strands.

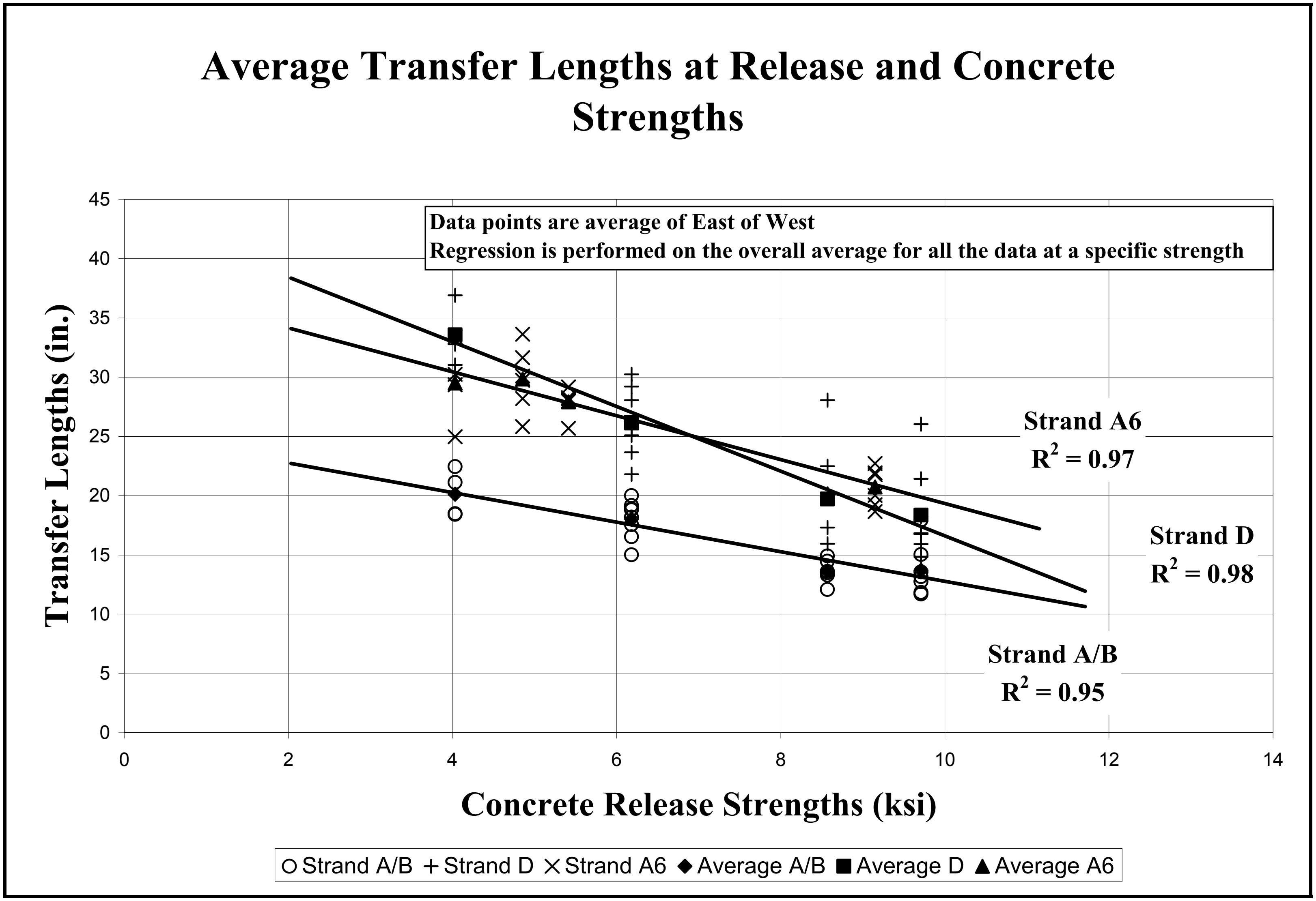


Figure 5.34: Linear Regression for Transfer Lengths and f'_{ci}

Though the linear regression model presented show correlations, a power model is also presented in Fig. 5.35. The power regression model show similar correlations for all the strands.

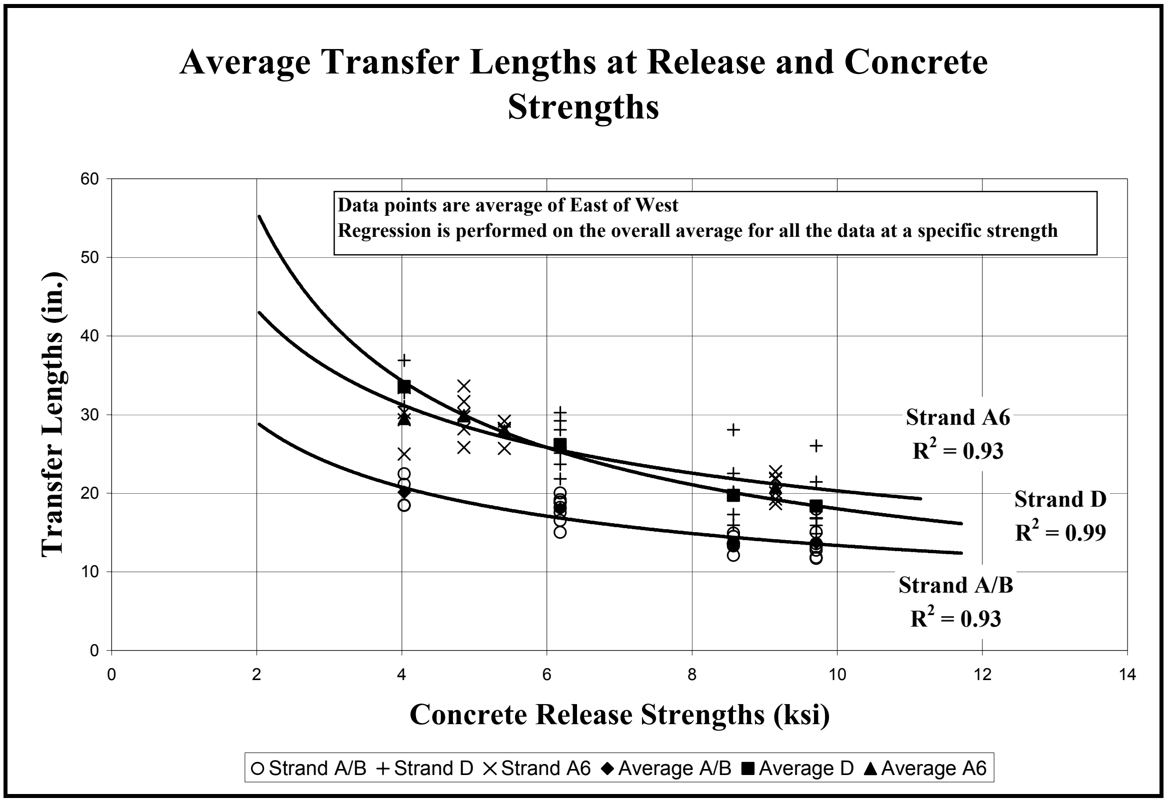


Figure 5.35: Power Regression for Transfer Lengths and f'_{ci}

The bond stress u_t is a function which is inversely proportional to the transfer lengths. The power regression performed is to identify if a similar trend is seen for the transfer lengths against the concrete strengths.

The transfer lengths after 60 days from release are plotted against the 56 day concrete strengths. The transfer lengths plotted are the average transfer lengths of the west and the east strands for a particular beam. The R^2 reported is based on the overall averages for transfer length. Though it may seem that the transfer lengths and the concrete strengths will have higher correlations over time, the data does not confirm a stronger correlation when compared to the initial same comparison of transfer length data vs. release strength. An observation on Fig. 5.36 show that the regression line for the 0.6 in. diameter strand does not cross with the Strand D. The decreasing trend of the transfer lengths with increase in concrete strength is observed from the data after 60 days from release. The R^2 values for the transfer lengths at release and after 60 days are same for Strands A/B and Strand A6. However, the correlations are not strong for Strand D.

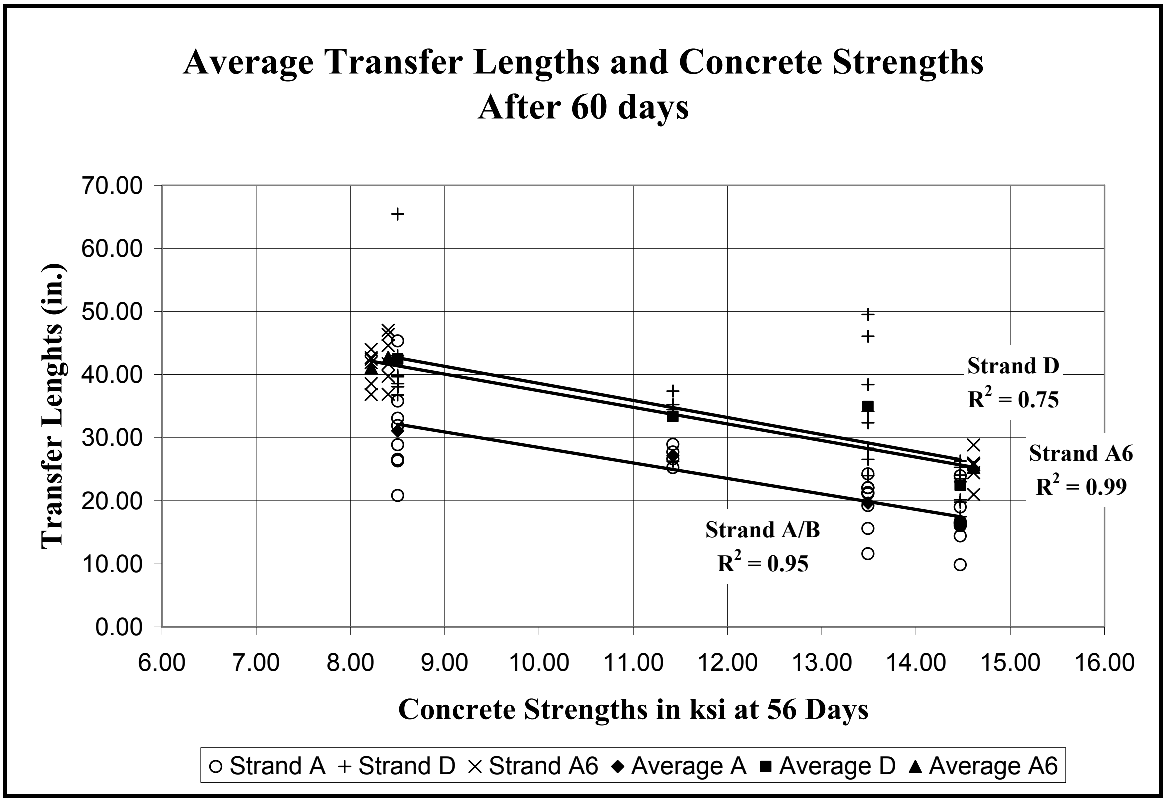


Figure 5.36: Transfer Lengths and Concrete Strengths after 60 days

Chapter 4 results show that the bond stress in the NASP tests in concrete are directly proportional to $\overline{f'_{ci}}$. Transfer length is proportional to end slip, L_{es}. Both L_t and L_{es} are inversely related to the bond stress u_t in the transfer zone. Therefore it is logical to plot the inverse of the end slip with concrete strengths.

Due to the high variations in the transfer lengths, the end slips L_{es} is plotted against the concrete strength for the prototype beams. As discussed earlier, end slip is the quantity measured and the transfer length is only an inference made from the end slips and the elongations. Figure 5.37 plots the average end slip at each end of the prototype beam against the concrete release strengths for each of the strands independently. The regression is preformed based on the overall averages for a concrete strength. For Strand A/B, Strand D, and 0.6 in. diameter Strand A, the R^2 values are 0.93, 0.98, and 1.0 respectively. The experimental data shows that the increase in concrete strength results in a lower slip. A power regression is assumed for the relationship between the end slips and the concrete strengths.

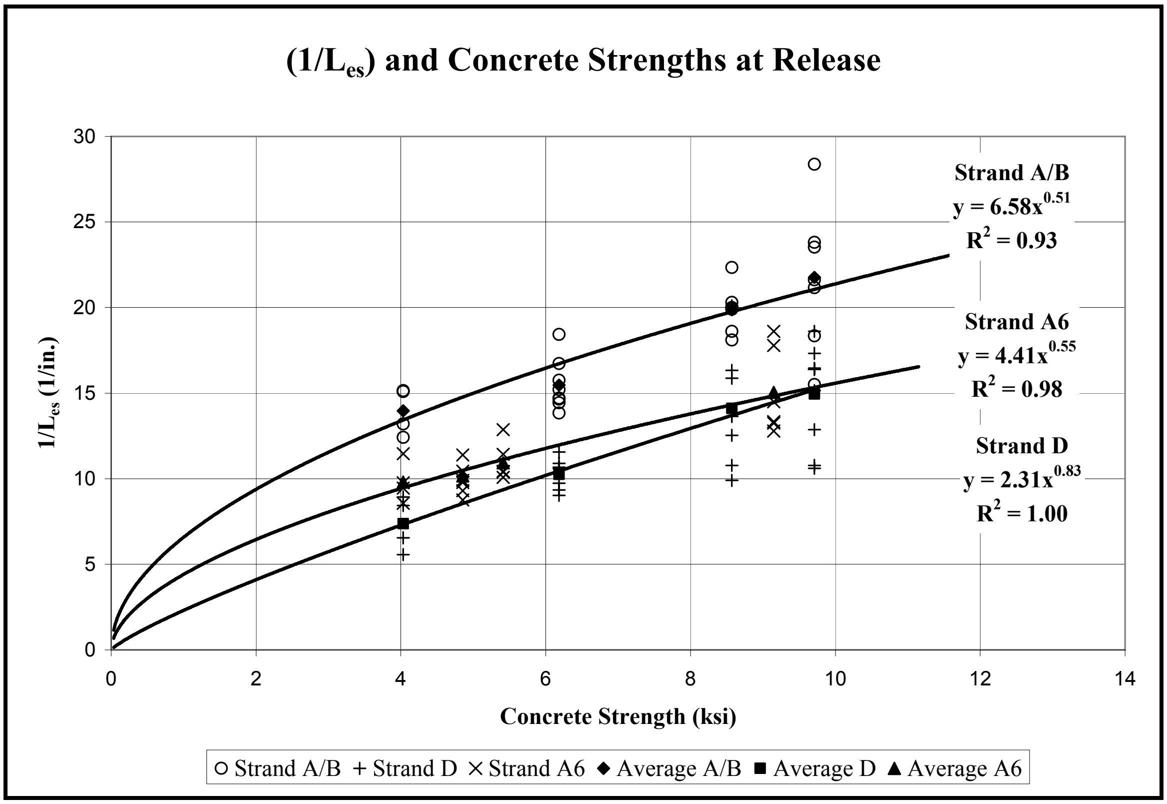


Figure 5.37: Inverse of End Slips and Concrete Release Strengths

The bond stress u_t is approximately proportional to the inverse of the end slips.

$$u_t = \frac{f_{se}^* \times A_{ps}}{l_t} = \frac{f_{se}^* \times A_{ps} \times \varepsilon_{si}}{2 \times L_{es}} \Rightarrow u_t \propto \left(\frac{1}{L_{es}}\right),$$

provided f_{se}, ε_{si} are approximately constant.

$$f_{se}^{*} \equiv f_{si} - ES = \varepsilon_{si} E_{ps} \left[\frac{1}{A_{tr}} + \frac{e_{tr}^{2}}{I_{tr}} \right]$$

Where,

u_t = Bond Stress

f_{se}^{*} = Effective prestress after elastic shortening

A_{ps} = Area of the prestressing strand

ε_{si} = Initial Strain in the strand

E_{ps} = Modulus of Elasticity of the Prestressing Strand

e_{tr} = Transformed Eccentricity

A_{tr} = Transformed Area

I_{tr} = Transformed Moment of Inertia

By plotting the bond stresses using the above method, against the concrete strengths correlations between bond stress and concrete strength is greater than R^2 for L_t vs. $\overline{f'_{ci}}$

The NASP test results discussed in Chapters three and four related the standardized NASP test to the modified NASP test conducted in concrete. The transfer length measurements made on the bottom strands for the rectangular prototype beams are related to the corresponding NASP value in concrete.

Table 5.19 reports the transfer lengths measured using end slips on Strands A/B, Strand D and Strand A (0.6 in.) and the corresponding concrete release strength. The transfer lengths reported in Table 5.19 reports only the transfer lengths on the bottom strands in rectangular beams. The same data is reported in Tables 5.2 through 5.9 with the beam designations. The following equation is used to interpolate the NASP values in concrete ($NASP_c$) from the concrete release strength on the prototype beams. The $NASP_c$ value is determined by the following equation:

$$\frac{(NASP_{concrete})}{NASP} = 0.49139\bar{f}'^{0.51702}_{ci}$$

Table 5.19: Interpolated NASP Values in Concrete from the Equation			
$\bar{f}'_{ci}$ **(ksi)**	L_t **(in.) (From End Slips)**	**($1/L_{es}$) (1/in.)**	$NASP_c$ **(kips)**
Strand A/B			
4.033	20.12	13.97	21.46
6.183	18.02	15.47	25.63
8.57	13.63	19.88	30.17
9.711	13.71	21.76	32.12
Strand D			
4.033	33.57	7.37	7.04
6.183	26.19	10.26	8.71
8.57	19.71	14.10	10.26
9.711	18.36	14.95	10.92
Strand A (0.6 in.)			
4.033	29.50	11.77	18.73
4.855	29.85	12.20	20.55
5.413	27.92	13.12	21.70
9.15	20.73	18.05	28.22

The data presented in Table 5.19 is graphically represented in Fig. 5.38. The data is presented for three of the strands independently. The end slip data for the 0.6 in. diameter strand is multiplied by 1.2 to correct for the bond area when comparing with the 0.5 in. diameter strands. The power regression equation has an R^2 value of 0.63.

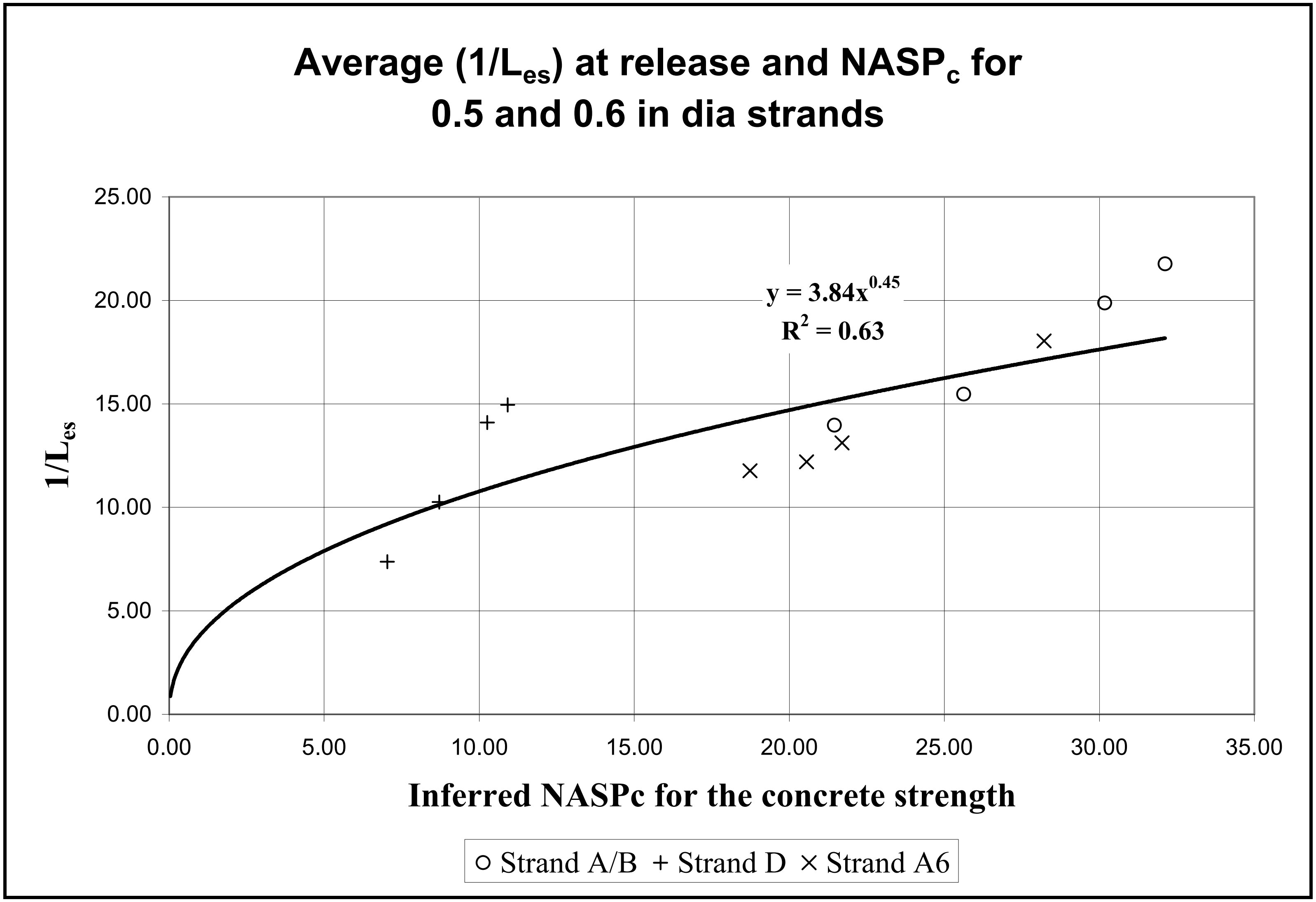


Figure 5.38: Transfer Lengths and Interpolated NASP Values

From the experimental data, observations can be made on the end slips with a known concrete strength and NASP values. AS the NASP value in concrete is a function of the concrete strength, predictions can be made on the transfer lengths.

5.9 SUMMARY AND CONCLUSIONS

The transfer length has significant scatter in the data as seen in past research conducted. The transfer length inferred using the strand end slip measurements and the concrete surface strain readings are not highly correlated, though the correlations are strong for 0.5 in. diameter strands. The 0.6 in. diameter strands did not show strong correlations among the data.

The transfer length decreases with increase in concrete strengths. The observations are evident for all the strands used in this research. The transfer length increases over time.

The NASP Pull out value is reliable to predict the transfer lengths. It is seen that an increase in the NASP pull out value shows a decrease in transfer length for both low and high strength concrete beams.

The NASP pull out values in concrete also show that the high NASP value in concrete has lower transfer length and the low NASP values have higher transfer lengths.

The NASP value can be used as a reliable predictor for understanding the bonding abilities of prestressing strands.

CHAPTER VI

6.0 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

This research program included setting the protocols for the NASP Pull out test methodology, conducting the NASP Bond test in concrete, and measuring the transfer lengths on rectangular and I-shaped prestressed concrete beams. The NASP bond test was conducted at three different locations to understand the repeatability of the Bond test. The NASP Bond test developed in cement-sand mortar was then conducted on concrete with varying strengths to correlate the results with transfer length measurements.

The NASP Bond test was conducted using ten 0.5 in. diameter strand samples and two 0.6 in. diameter strand samples. The transfer length measurements were made on rectangular and I-shaped prestressed concrete beams with four different strand sources, four different target release strengths, and effects of air entrainments. Some rectangular shaped beams had two strands at the bottom and some of the beams contained two strands at the bottom and two strands at the top. The transfer lengths were determined using the end slip of the strands after detensioning using clamps attached on the strand. The transfer lengths were also measured using the concrete surface strain measurements.

6.1 CONCLUSIONS

1. The NASP Bond test is a repeatable and reliable test method.
2. The NASP Bond test can be performed on 0.5 in. and 0.6 in. diameter Grade 270 low relaxation strands.

3. The NASP Bond value increases with increase in mortar strength.
4. The NASP Bond test shows higher correlations than the Moustafa Tests and the PTI Bond test conducted in the past.
5. The NASP Test method can be used as a standardized test method.
6. The NASP Bond test can predict the bond qualities of 0.5 in. and 0.6 in. diameter prestressing strands.
7. The NASP Bond test performed in concrete can be related to the standardized NASP test performed in mortar using:

$$\frac{(NASP_{concrete})}{NASP} = 0.51\sqrt{f'_{ci}}$$

8. The transfer length is a function of the concrete strength. Higher the concrete strength, lower the transfer lengths.
9. The pull out force from the NASP bond test is inversely proportional to the transfer lengths.
10. The transfer length increases over time and is significant for strands with lower NASP pull out values.

6.2 RECOMMENDATIONS

1. The ACI 318 code equation for the transfer length should have a factor that will include the concrete strength at release.
2. The NASP Bond test should be accepted as a standard test for bond in prestressing strands for prestressed concrete applications.
3. Further NASP tests will have to be conducted to predict the performance on Grade 300 strands.

REFERENCES

ACI Committee. (2002). "Building Code Requirements for Structural Concrete (ACI 318-02) and Commentary (ACI 318R-02)." ACI, Farmington Hills, Michigan.

Anderson, A. R., and Anderson, R. G. (1976). "An Assuance Criterion for Flexural Bond in Pretensioned Hollow Core Units." *ACI Journal*, 72(8), 457-464.

Barnes, R. W., Grove,J.W., Burns,N.H. (2003). "Experimental assessment of factors affecting transfer length." *ACI STRUCTURAL JOURNAL*, 100(6), 740-748.

Brown, M. D. (2003). "Evaluation of Test Methods in Assessing Bond Quality of Prestressing Strand," University of Oklahoma, Norman.

Buckner, C. D. (1994). *An Analysis of Transfer and Development Lengths for Pretensioned Concrete Structures*, Federal Highway Administration (FHWA).

Cousins, T., Johnston, D., and Zia, P. (1990). "Transfer and Development Length of Epoxy Coated Prestressing Strand." *PCI Journal*, 35(4), 92-103.

Cousins, T. E., Badeaux,M.H., Moustafa,S. (1992). "Proposed Test for Determining Bond Charactersitics of Prestressing Strand." *PCI JOURNAL*, 37(1), 66-73.

Deatherage, J. H., and Burdette, E. G. (1991). "Development Length and Lateral Spacing Requirements of Prestressing Strand for Prestressed Concrete Bridge Products", Final Report Submitted to Precast/Prestressed Concrete Institute." University of Tennessee, Knoxville, TN.

Ferzli, Y. (2000). "Validation of acceptance criteria for the bond of prestressing strands ", University of Oklahoma, Norman.

Grieve, C. B. (2004). "Investigating the effect of mortar strength and loading rate on the NASP bond test," Oklahoma State University, Stillwater.

Gross, S. P., Burns,N.H. (1995). "Transfer and Development Length OF15.2 mm (0.6 in.) Diameter Prestressing Strand in High Performance Concrete: Results of the Hoblitzell-Buckner Beam Tests." *580-2*, University of Texas at Austin, Austin.

Hanson, N. W. a. K., P. H. (1959). "Flexural Bond Tests on Pretensioned Prestressed Beams." *ACI Journal*, 55(7), 783-802.

Hoyer, E., Friedrich, E. . (1939). "Beitrag zur Frage der Haftspannung in Eisenbetonbauteilen." *Beton und Eisen*, 50(9), 717-736.

Janney, J. R. (1954). "Nature of Bond in Pre-Tensioned Prestressed Concrete." *Journal of AMERICAN CONCRETE INSTITUTE*, 50(9), 717-736.

Kahn, L. F., Dill,J.C., Reutlinger,C.G. (2002). "Transfer and Development Length of 15-mm Strand in High Performance Concrete Girders." *JOURNAL OF STRUCTURAL ENGINEERING-ASCE*, 128(7), 913-921.

Kose, M. M., Burkett,W.R. (2005). "Evaluation of code requirement for 0.6 in. (15 mm) prestressing strand." *ACI STRUCTURAL JOURNAL*, 102(3), 422-428.

Lane, S. N. "Transfer Lengths of Uncoated and Epoxy-Coated Strands in Rectangular Prestressed Concrete Specimens." *Proceedings of International Conference-Bond in Concrete*, RIGA Techical University, Riga, Latvia.

Lane, S. N. (1998). *A new development length equation for pretensioned strands in bridge beams and piles*, McLean, VA : [Springfield, Va. : Federal Highway Administration ; Available through the National Technical Information Service, 1998].

Logan, D. R. (1997). "Acceptance Criteria for Bond Quality of Strand for Pretensioned Prestressed Concrete Applications." *PCI JOURNAL*, 42(2), 52-90.

Mattock, A. H. (1962). "Proposed Redraft of Section 2611-Bond, letter to W. Burr Bennett, Jr." *ACI Committee 323*.

Mitchell, D., Cook, W.D., Khan, A.A.,Tham, T. (1993). "Influence of High Strength Concrete on Transfer and Development Length of Pretensioning Strand." *PCI JOURNAL*, 38(3), 52-66.

Paulsgrove, G. A. R., B.W., . (1999). "NASP Strand Bond Testing, Round Two, Assessing Repeatability and Reproducibility of the Moustafa Test, the PTI Test, and the NASP Bond Test." University of Oklahoma, Norman.

Rose, D. R., Russell, B.W. (1997). "Investigation of standardized tests to measure the bond performance of prestressing strand." *PCI JOURNAL*, 42(4), 56-80.

Russell, B. W. (1992). "Design Guidelines for Transfer, Development and Debonding of Large Diameter Seven Wire Strands in Pretensioned Concrete Girders," University of Texas, Austin.

Russell, B. W., Burns, N. H. . (1997). "Measurement of transfer lengths on pretensioned concrete elements." *JOURNAL OF STRUCTURAL ENGINEERING-ASCE*, 123(5), 541-549.

Russell, B. W., Burns, N.H. . (1996). "Measured transfer lengths of 0.5 and 0.6 in strands in pretensioned concrete." *PCI JOURNAL*, 41(5).

Shahawy, M. A., Issa, M,. & Batchelor, B. (1992). "Strand Transfer Lengths in Full Scale AASHTO Prestressed Concrete Girders." *PCI JOURNAL*, 37(3), 84-96.

Tabatabai, H. D., T. J. . (1993). "The History of the Prestressing Strand Development Length Equation." Construction Technology Laboratories, Virginia.

Tessema, E. (2006). "The Effect of High Strength Concrete on the Bondability of Prestressing Strands."

APPENDIX A
NASP TEST RESULTS

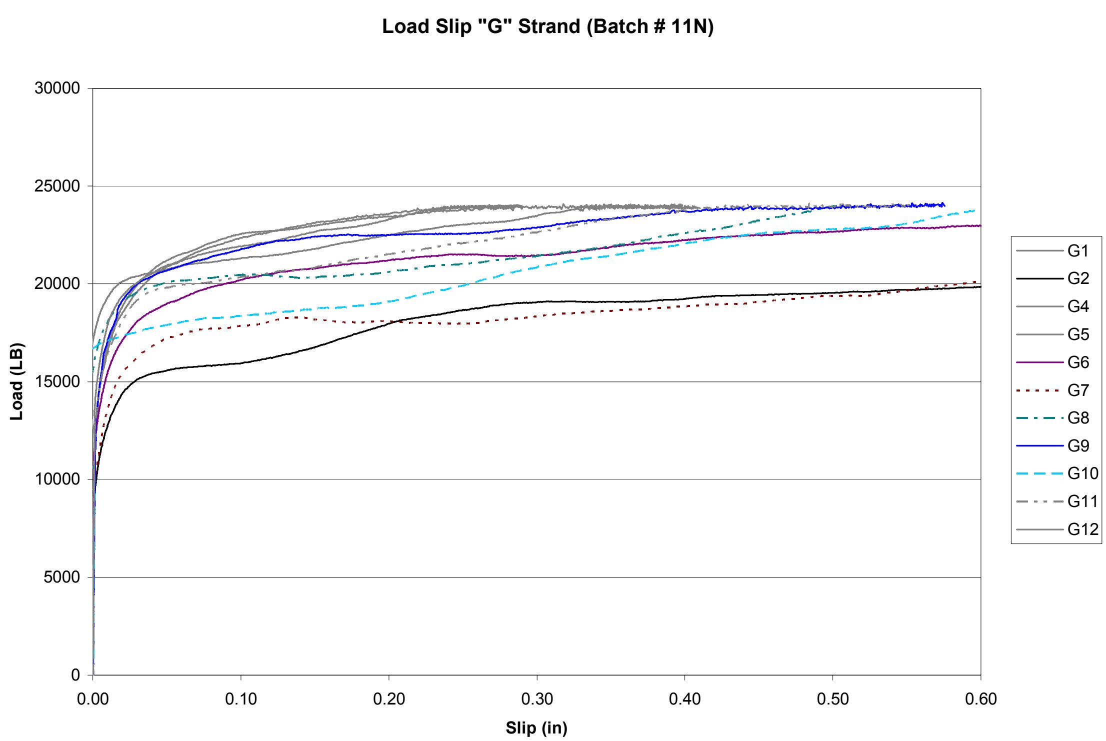
Batch Number:	**11 N**
Control Type:	Displacement
Testing Date:	23-Jan-04
NASP Strand ID:	G

W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.45	1	4410			G1	7895	19352	21320
	2	4280			G2	6667	12760	15949 [1]
	3	4472			G3	7383	4795	11330 [2]
	4		4671		G4	7482	16616	21904
	5		4764		G5	6869	16880	22548
	6		4649		G6	7150	15549	20205
	7		4937		G7	7,150	13,605	17,853
	8		4528		G8	7,050	18,100	20,463
	9		4834		G9	6,869	17,127	21,783
	10			5100	G10	7,261	17,133	18,365
	11			4921	G11	7,090	16,415	20,347
	12			5120	G12	7,694	17,932	22,360
	AVG	**4387**	**4730**	**5047**	**AVG**	**7,198**	**16,871**	**20,715**
	ST. DEV.	**98**	**145**	**109**	**ST. DEV**	**368**	**1,550**	**1,604**
	C.O.V.	**2.23%**	**3.08%**	**2.17%**	**C.O.V.**	**5.11%**	**9.19%**	**7.74%**

*Loading Rate from 4000 to 6000 lbs

[1:] The loading rate of 0.1 in/min was not followed. Data Discarded in Results

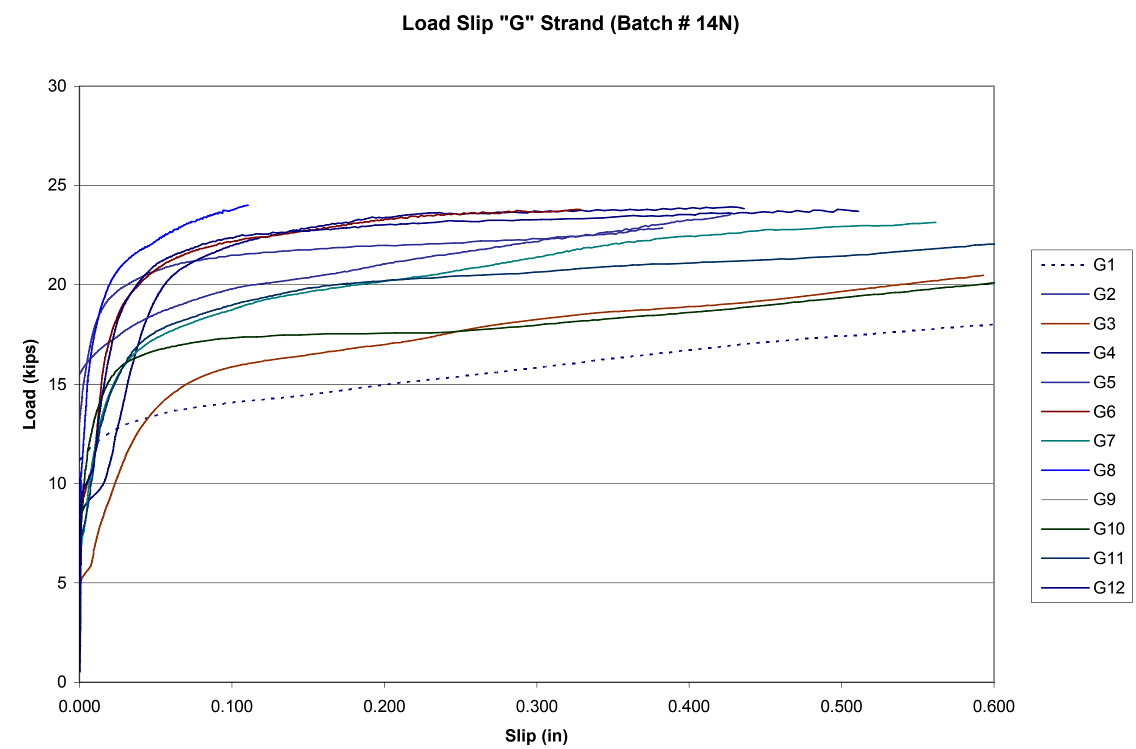
[2:] A displacement of 0.1" shown at an early stage.



Batch Number:	**14 N**
Control Type:	Load
Testing Date:	3-Feb-2004
NASP Strand ID:	G

W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.45	1	4719			G1	4987	12016	14076
	2	4673			G2	5019	17882	21499
	3		4882		G3	4989	6842	15867
	4		5113		G4	5000	9443	21970
	5		4803		G5	5008	16506	19794
	6		4758		G6	4996	11583	22179
	7		5207		G7	4994	11702	18753
	8			5197	G8	4994	17563	23766
	9			5045	G9	5023	20027	23502
	10				G10	4998	13273	17328
	11				G11	4994	11426	18987
	12				G12	4994	11343	22369
	AVG	**4696**	**4953**	**5121**	**AVG**	**5,000**	**13300**	**20007**
	ST. DEV.	**33**	**197**	**107**	**ST. DEV**	**11**	**3882**	**3088**
	C.O.V.	**0.70%**	**3.99%**	**2.10%**	**C.O.V.**	**0.23%**	**29.19%**	**15.43%**

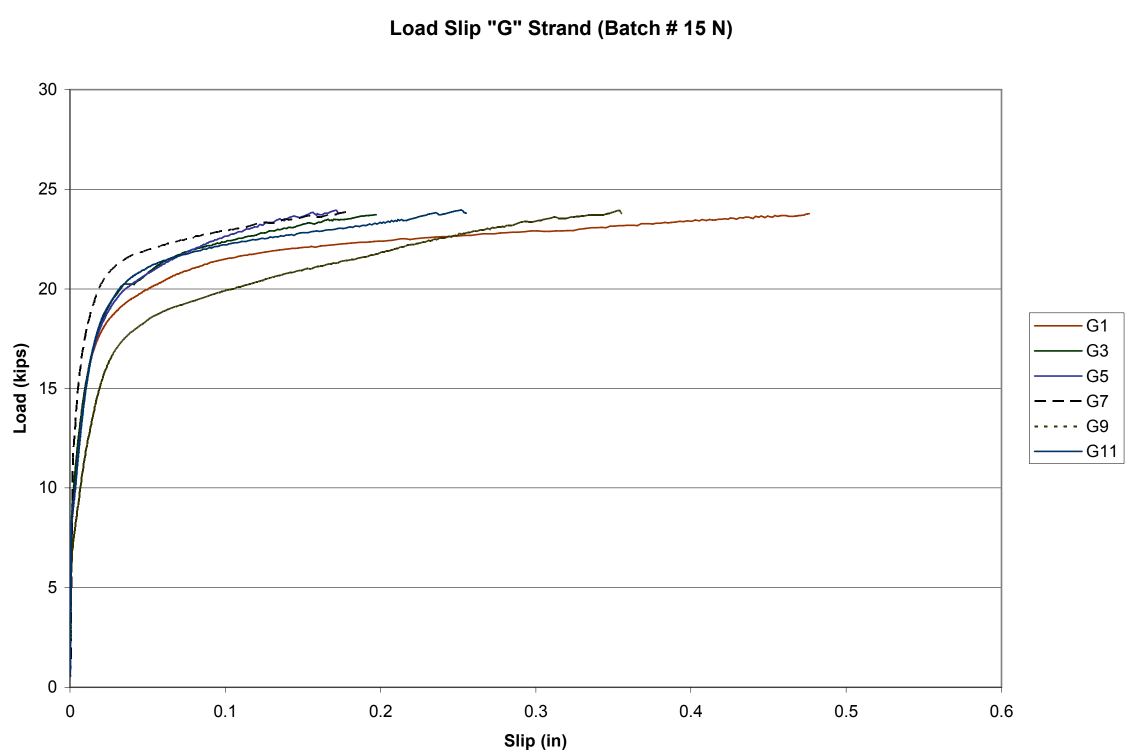
*Loading Rate from 4000 to 6000 lbs



Batch Number:	**15 N**
Control Type:	Load
Testing Date:	5-Feb-04
NASP Strand ID:	G

W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.45	1	4482			G1	4996	15124	21494
	2	4570			G2			
	3		4828		G3	5000	15143	22354
	4		4911		G4			
	5		4929		G5	5023	14849	22645
	6		4738		G6			
	7		4671		G7	5025	17676	22947
	8			5064	G8			
	9			4927	G9	4975	11733	19900
	10				G10			
	11				G11	4965	14795	22218
	12				G12			
	AVG	**4526**	**4815**	**4996**	**AVG**	**4,997**	**14887**	**21926**
	ST. DEV.	**62**	**111**	**97**	**ST. DEV**	**24**	**1890**	**1106**
	C.O.V.	**1.37%**	**2.30%**	**1.94%**	**C.O.V.**	**0.49%**	**12.70%**	**5.05%**

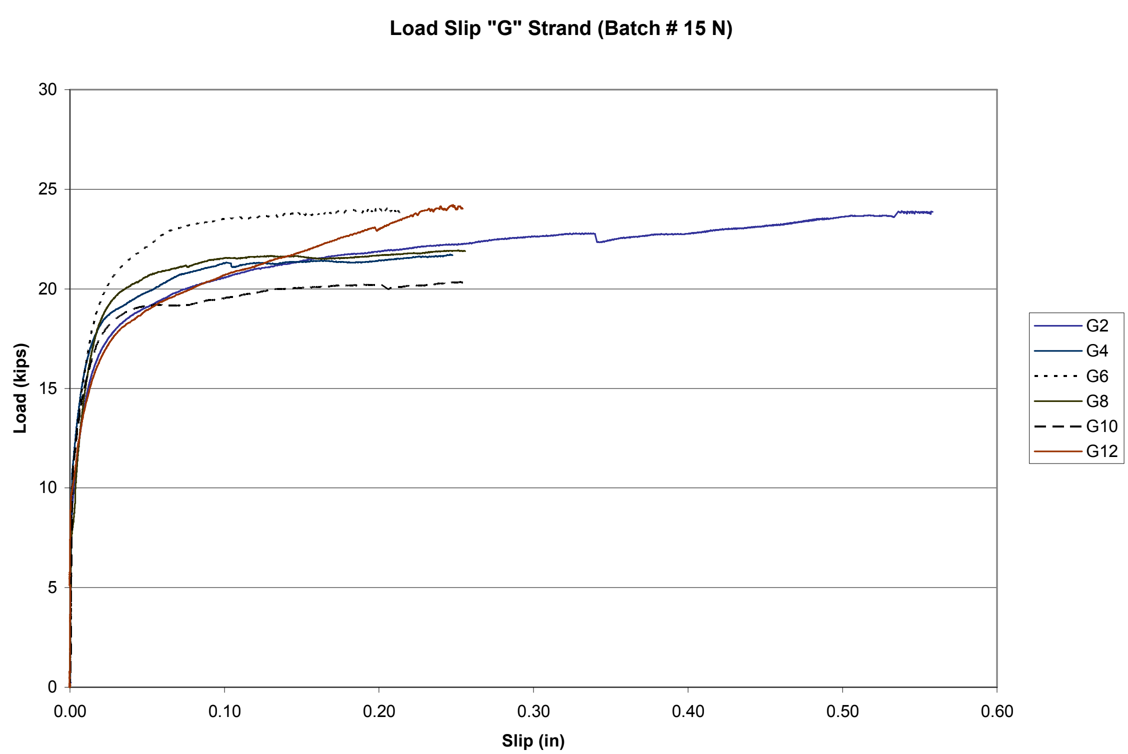
*Loading Rate from 4000 to 6000 lbs



Batch Number:	**15 N**
Control Type:	Displacement
Testing Date:	5-Feb-04
NASP Strand ID:	G

W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.45	1	4482			G1			
	2	4570			G2	6904	14346	20571
	3		4828		G3			
	4		4911		G4	7625	16070	21280
	5		4929		G5			
	6		4738		G6	7071	16045	23505
	7		4671		G7			
	8			5064	G8	7340	15030	21544
	9			4927	G9			
	10				G10	7375	15242	19531
	11				G11			
	12				G12	7418	14136	20691
	AVG	**4526**	**4815**	**4996**	**AVG**	**7,289**	**15145**	**21187**
	ST. DEV.	**62**	**111**	**97**	**ST. DEV**	**259**	**818**	**1333**
	C.O.V.	**1.37%**	**2.30%**	**1.94%**	**C.O.V.**	**3.55%**	**5.40%**	**6.29%**

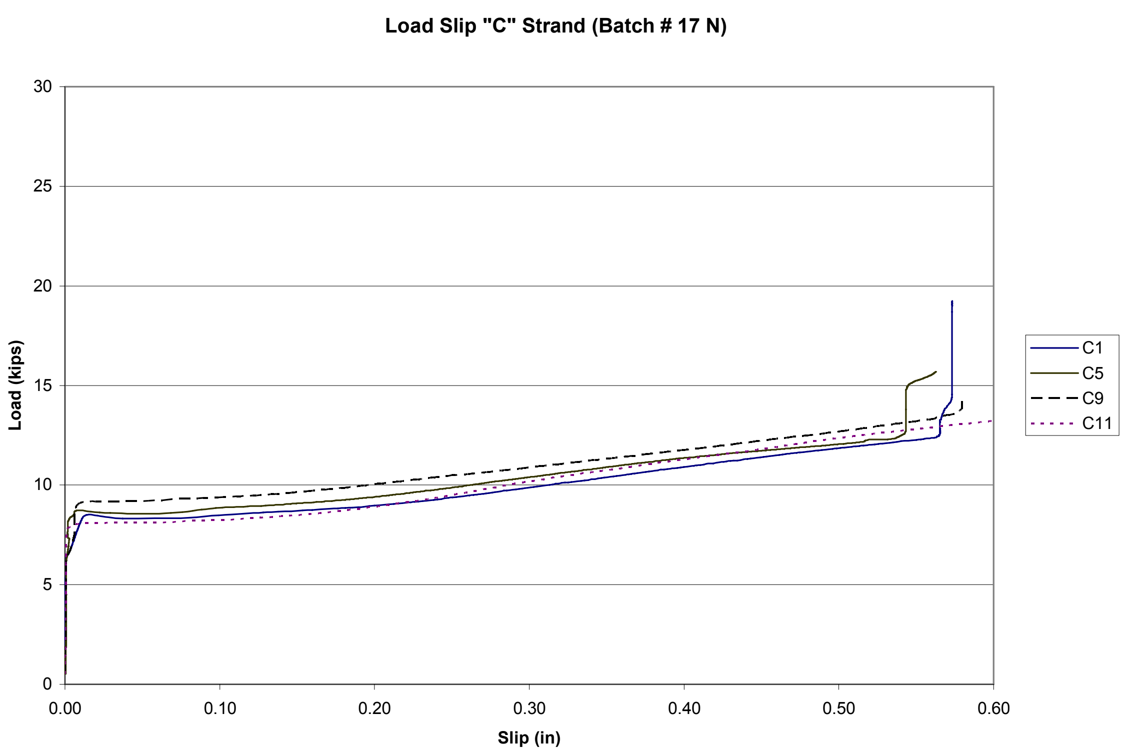
*Loading Rate from 4000 to 6000 lbs



Batch Number:	**17 N**
Control Type:	Load
Testing Date:	10-Feb-04
NASP Strand ID:	C

W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.45	1	4174			C1	5021	8122	8488
	2	4438			C2			
	3		4339		C3 [1]			
	4		4339		C4			
	5		4609		C5	5009	8724	8857
	6		4422		C6			
	7		4710		C7	5001	8256	8589
	8			4666	C8			
	9			4747	C9	4999	9102	9382
	10				C10			
	11				C11	5003	8060	8252
	12				C12			
	AVG	**4306**	**4484**	**4706**	**AVG**	**5,006**	**8453**	**8714**
	ST. DEV.	**187**	**168**	**57**	**ST. DEV**	**9**	**447**	**432**
	C.O.V.	**4.33%**	**3.74%**	**1.22%**	**C.O.V.**	**0.18%**	**5.28%**	**4.96%**

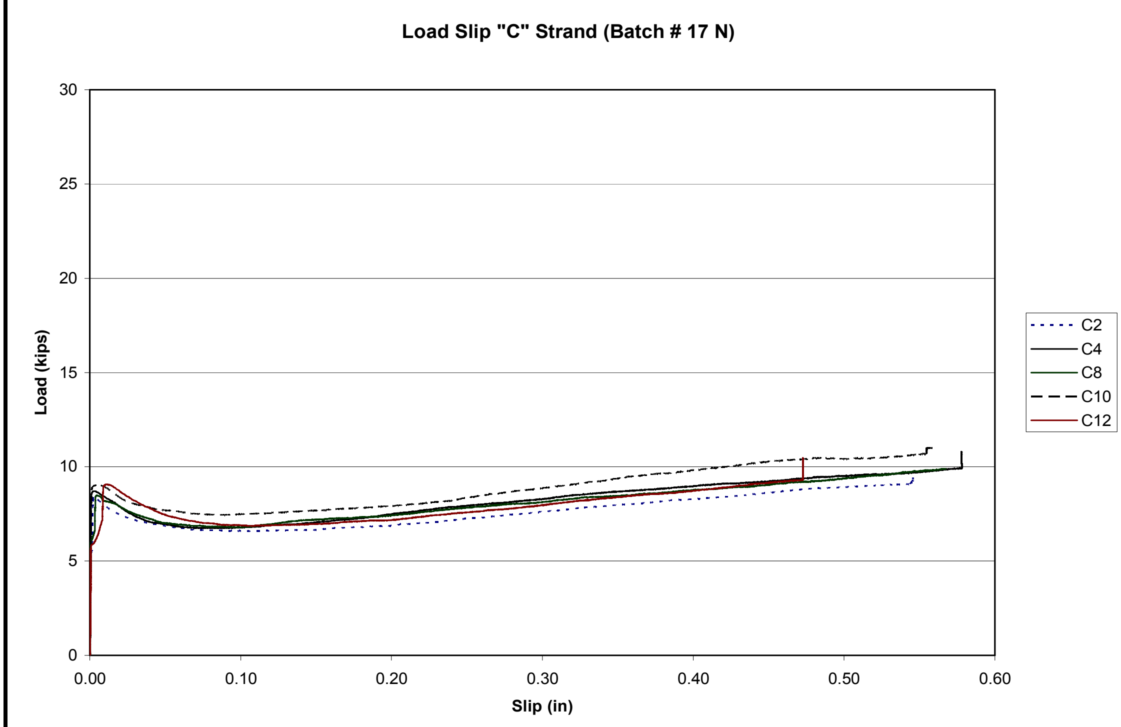
*Loading Rate from 4000 to 6000 lbs
[1:] Wrong loading rate of 0.5kips/sec



Batch Number:	**17 N**
Control Type:	Displacement
Testing Date:	10-Feb-04
NASP Strand ID:	C

W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.45	1	4174			C1			
	2	4438			C2	7176	7924	6588
	3		4339		C3			
	4		4339		C4	7372	8400	6785
	5		4609		C5			
	6		4422		C6	7440	7508	[1]
	7		4710		C7			
	8			4666	C8	6948	8182	6783
	9			4747	C9			
	10				C10	7216	8929	7477
	11				C11			
	12				C12	6944	9036	6899
	AVG	**4306**	**4484**	**4706**	**AVG**	**7,183**	**8330**	**6906**
	ST. DEV.	**187**	**168**	**57**	**ST. DEV**	**207**	**587**	**338**
	C.O.V.	**4.33%**	**3.74%**	**1.22%**	**C.O.V.**	**2.89%**	**7.05%**	**4.89%**

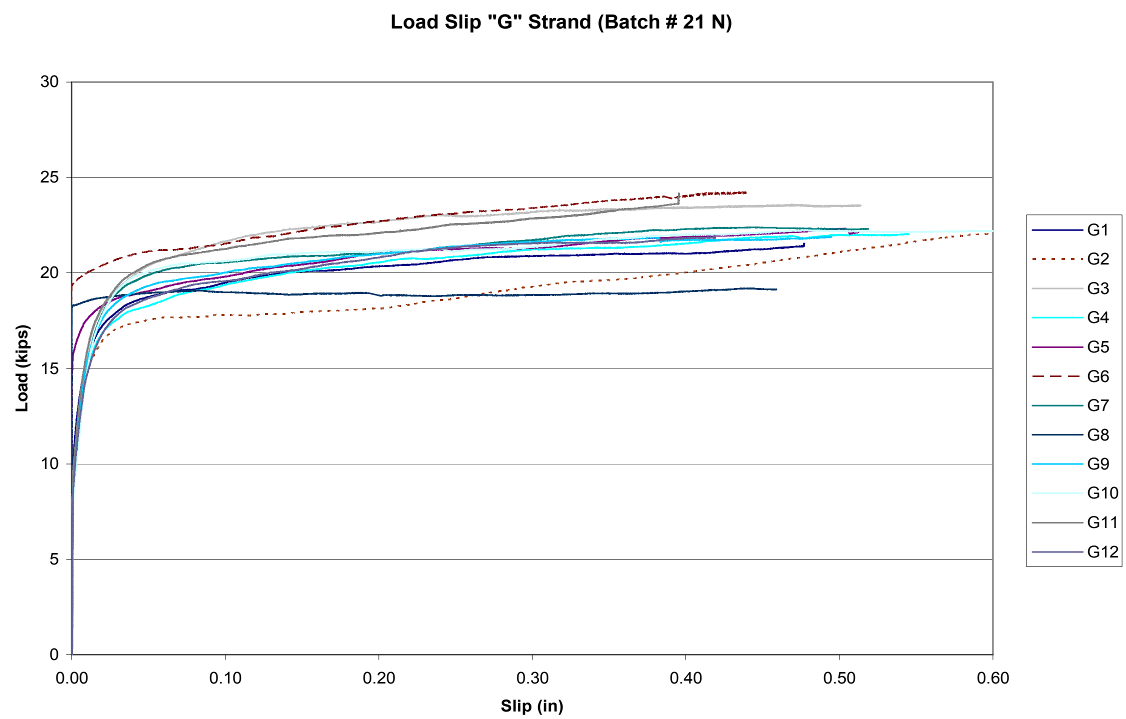
*Loading Rate from 4000 to 6000 lbs
[1]: Only six of the seven wires were pulled.



Batch Number:	**21 N**
Control Type:	Load
Testing Date:	17-Feb-04
NASP Strand ID:	G

W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.50	1	3695			G1	7319	15450	19499
	2	3765			G2	7693	14694	17793
	3		4096		G3	7442	15766	21648
	4		4142		G4	7378	14799	19377
	5		4133		G5	7857	17557	19814
	6		3969		G6	7512	20010	21520
	7		3878		G7	7322	15062	20549
	8			4104	G8	7224	18530	18993
	9			3941	G9	7185	15333	20025
	10				G10	7475	14841	20630
	11				G11	7670	15891	21264
	12				G12	7540	14665	19581
	AVG	**3730**	**4043**	**4023**	**AVG**	**7,468**	**16050**	**20058**
	ST. DEV.	**49**	**115**	**116**	**ST. DEV**	**201**	**1728**	**1129**
	C.O.V.	**1.32%**	**2.85%**	**2.87%**	**C.O.V.**	**2.69%**	**10.77%**	**5.63%**

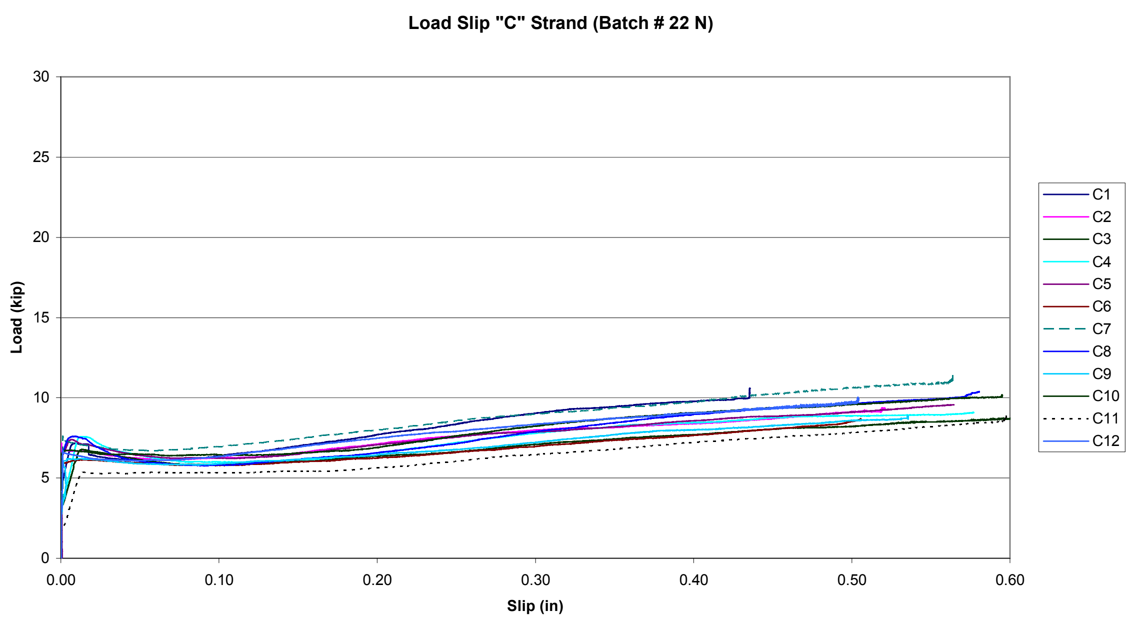
*Loading Rate from 4000 to 6000 lb



Batch Number:	**22 N**
Control Type:	Displacement
Testing Date:	18-Feb-04
NASP Strand ID:	C

W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.50	1	4043			C1	7369	7149	6396
	2	3962			C2	7325	6682	6264
	3		3949		C3	6924	6210	5836
	4		4196		C4	7185	7241	6002
	5		4126		C5	7635	7267	6255
	6		4087		C6	4555	6108	5793
	7		4227		C7	7369	7127	6954
	8			4271	C8	7449	7584	5811
	9			4416	C9	5570	6184	5883
					C10	6845	6685	6442
					C11	774	4650	5328
					C12	6924	6397	6346
	AVG	**4003**	**4117**	**4344**	**AVG**	**6,327**	**6,607**	**6,109**
	ST. DEV.	**58**	**109**	**102**	**ST. DEV**	**1,963**	**788**	**421**
	C.O.V.	**1.44%**	**2.65%**	**2.36%**	**C.O.V.**	**31.03%**	**11.93%**	**6.88%**

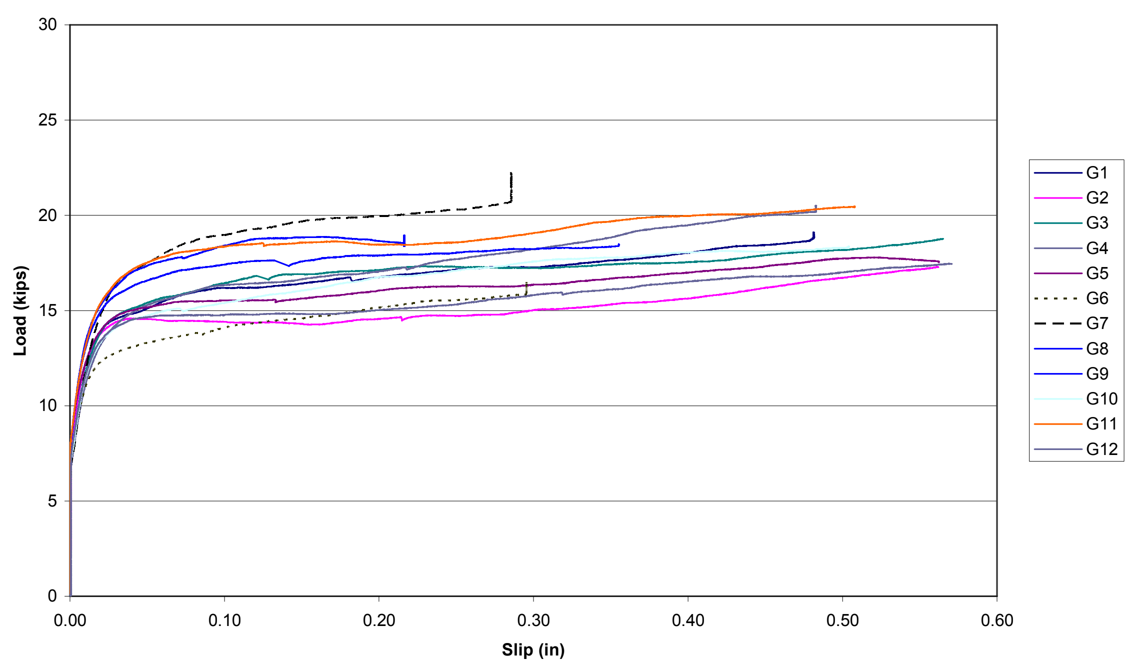
*Loading Rate from 4000 to 6000 lb



Batch Number:	**23 N**
Control Type:	Displacement
Testing Date:	26-Feb-04
NASP Strand ID:	G

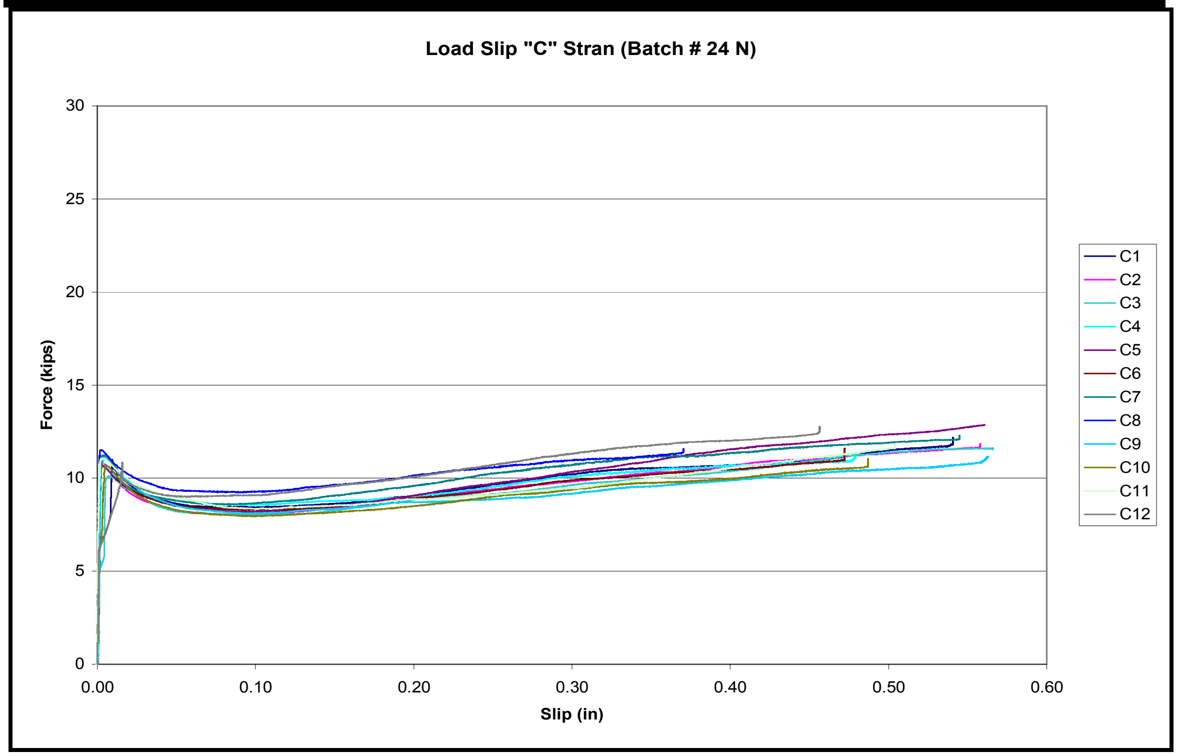
W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.50	1	3532			G1	7538	12159	16196
	2	3553			G2	7540	12210	14403
	3		3773		G3	7275	11725	16442
	4		3957		G4	7419	11119	16341
	5		4023		G5	7543	12219	15527
	6		4124		G6	7590	10978	14112
	7		4029		G7	7422	11798	18968
	8			3936	G8	7696	13308	18410
	9			3947	G9	7357	12987	17417
	10				G10	7321	11439	15389
	11				G11	7312	13077	18361
	12				G12	7470	11523	14770
	AVG	**3542**	**3981**	**3941**	**AVG**	**7,457**	**12045**	**16361**
	ST. DEV.	**15**	**131**	**8**	**ST. DEV**	**128**	**764**	**1629**
	C.O.V.	**0.42%**	**3.29%**	**0.20%**	**C.O.V.**	**1.72%**	**6.34%**	**9.96%**
*Loading Rate from 4000 to 6000 lb								

Load Slip "G" Strand (Batch # 23 N)



Batch Number:	**24 N**
Control Type:	Displacement
Testing Date:	3-Mar-04
NASP Strand ID:	C

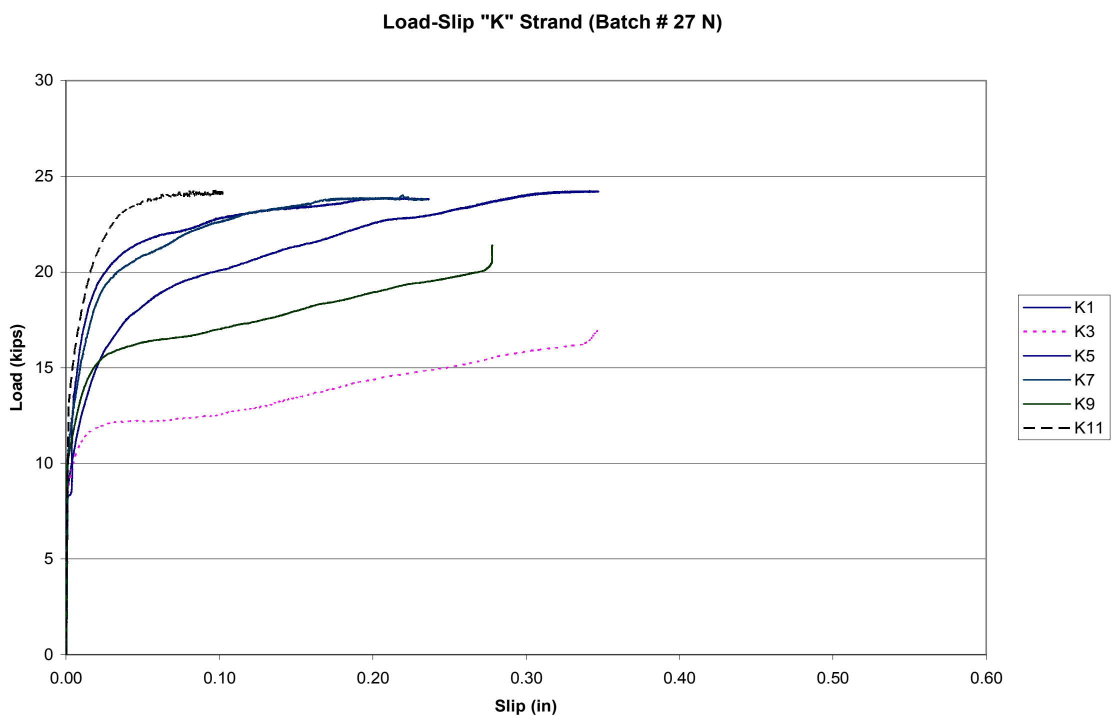
W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.40	1	6194			C1	7774	10622	8432
	2	5914			C2	7644	10323	8067
	3		5782		C3	7521	10004	8067
	4		5846		C4	7568	10184	8593
	5		5642		C5	7426	10098	8202
	6		5753		C6	7758	10638	8315
	7		5791		C7	8010	10780	8659
	8			5775	C8	7790	10869	9282
	9			6207	C9	7934	10619	8095
	10				C10	8033	10347	7965
	11				C11	7731	10641	8337
	12				C12	7670	8367	9081
	AVG	**6054**	**5763**	**5991**	**AVG**	**7,738**	**10291**	**8425**
	ST. DEV.	**198**	**76**	**305**	**ST. DEV**	**188**	**665**	**415**
	C.O.V.	**3.28%**	**1.31%**	**5.09%**	**C.O.V.**	**2.44%**	**6.46%**	**4.93%**
*Loading Rate from 4000 to 6000 lb								



Batch Number:	**27 N**
Control Type:	Displacement
Testing Date:	21-May-04
NASP Strand ID:	K

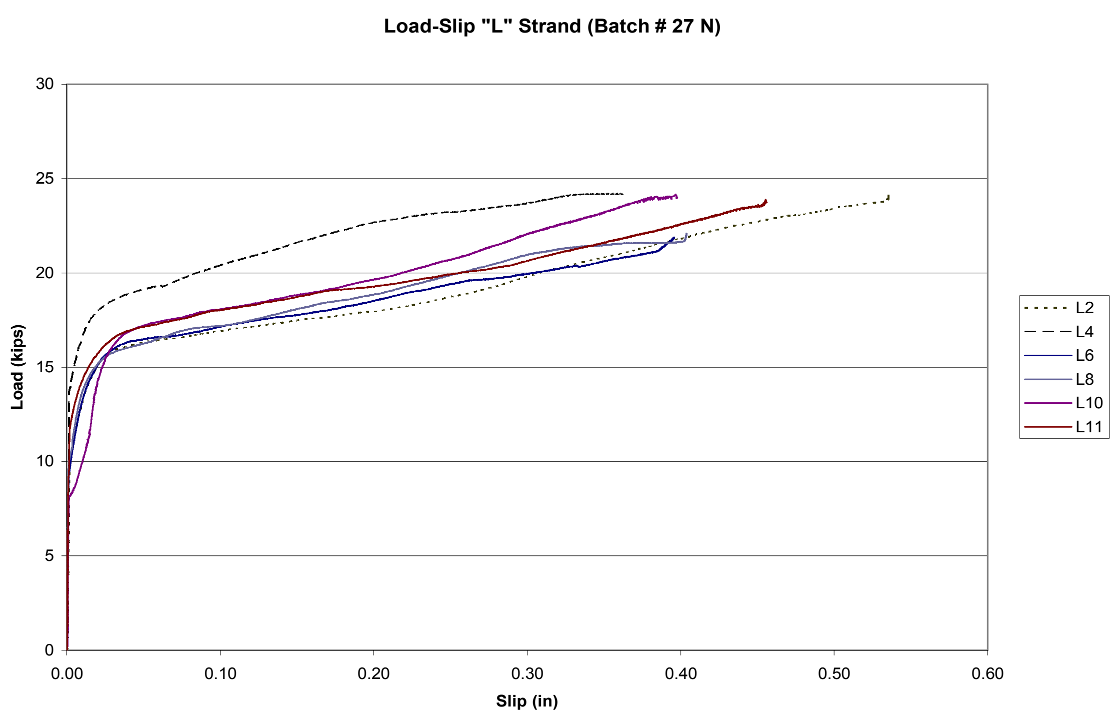
W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.45	1	4937			K1	15346	12496	**20076**
	2	4690			K2			
	3		4987		K3	7248	11116	12553
	4		5111		K4			
	5		4731		K5	7504	16388	22814
	6		4786		K6			
	7		5053		K7	8197	15361	22618
	8			4974	K8			
	9			4949	K9	7748	13461	17008
	10				K10			
	11				K11	8321	17872	*
	12				K12			
	AVG	**4813**	**4933**	**4961**	**AVG**	**9061**	**14449**	**19014**
	ST. DEV.	**175**	**167**	**18**	**ST. DEV**	**3106**	**2538**	**4311**
	C.O.V.	**3.63%**	**3.38%**	**0.36%**	**C.O.V.**	**34.28%**	**17.57%**	**22.67%**

*Loading Rate from 4000 to 6000 lb



Batch Number:	**27 N**
Control Type:	Displacement
Testing Date:	21-May-04
NASP Strand ID:	L

W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.45	1	4937			L1			
	2	4690			L2	8407	13084	16904
	3		4987		L3			
	4		5111		L4	8627	16574	20397
	5		4731		L5			
	6		4786		L6	8026	13183	17136
	7		5053		L7			
	8			4974	L8	7657	13683	17190
	9			4949	L9			
	10				L10	8210	9959	18083
	11				L11			
	12				L12	8517	14270	18029
	AVG	**4813**	**4933**	**4961**	**AVG**	**8241**	**13459**	**17956**
	ST. DEV.	**175**	**167**	**18**	**ST. DEV**	**358**	**2139**	**1292**
	C.O.V.	**3.63%**	**3.38%**	**0.36%**	**C.O.V.**	**4.34%**	**15.89%**	**7.20%**
*Loading Rate from 4000 to 6000 lb								

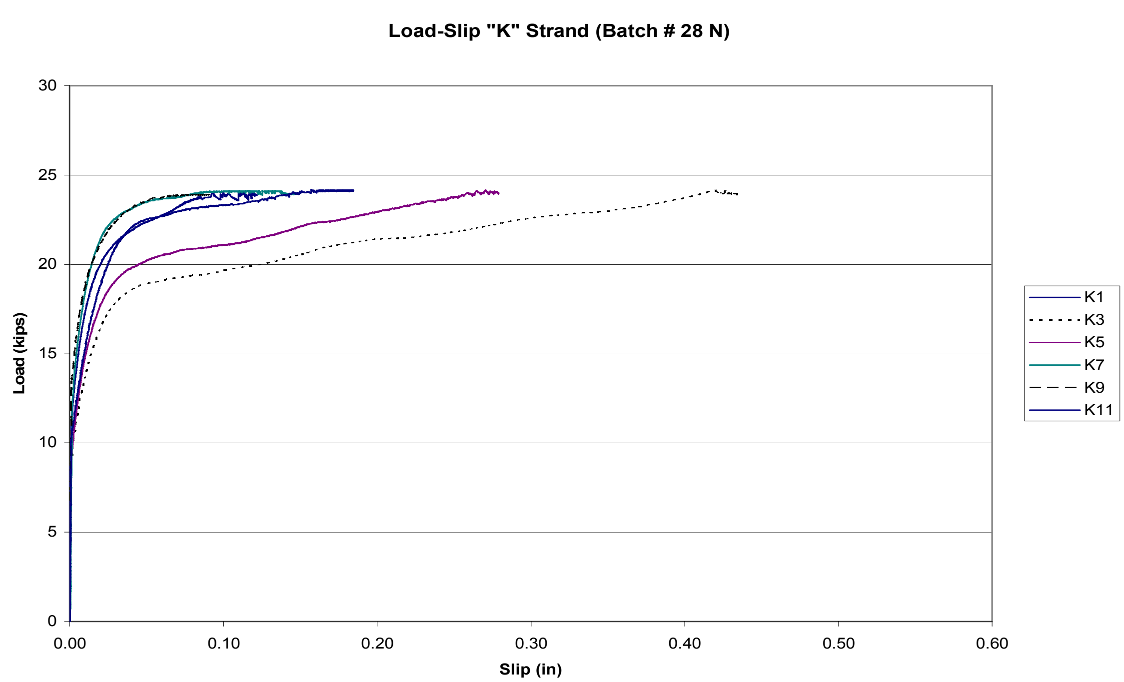


Batch Number:	**28 N**
Control Type:	Displacement
Testing Date:	24-May-04
NASP Strand ID:	K

W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.45	1	4665			K1	8173	17277	24008
	2	4814			L2			
	3		4955		K3	8493	13649	19656
	4		4852		L4			
	5		4780		K5	7844	14783	21074
	6		4791		L6			
	7		4836		K7	8322	18347	24059
	8			5019	L8			
	9			5125	K9	8463	18711	[1]
	10				L10			
	11				K11	8229	15219	23297
	12				L12			
	AVG	**4740**	**4843**	**5072**	**AVG**	**8,254**	**16331**	**22419**
	ST. DEV.	**106**	**70**	**75**	**ST. DEV**	**237**	**2071**	**1964**
	C.O.V.	**2.23%**	**1.44%**	**1.47%**	**C.O.V.**	**2.87%**	**12.68%**	**8.76%**

*Loading Rate from 4000 to 6000 lb

[1]: Exceeded the capacity of the machine 24,000 LBS

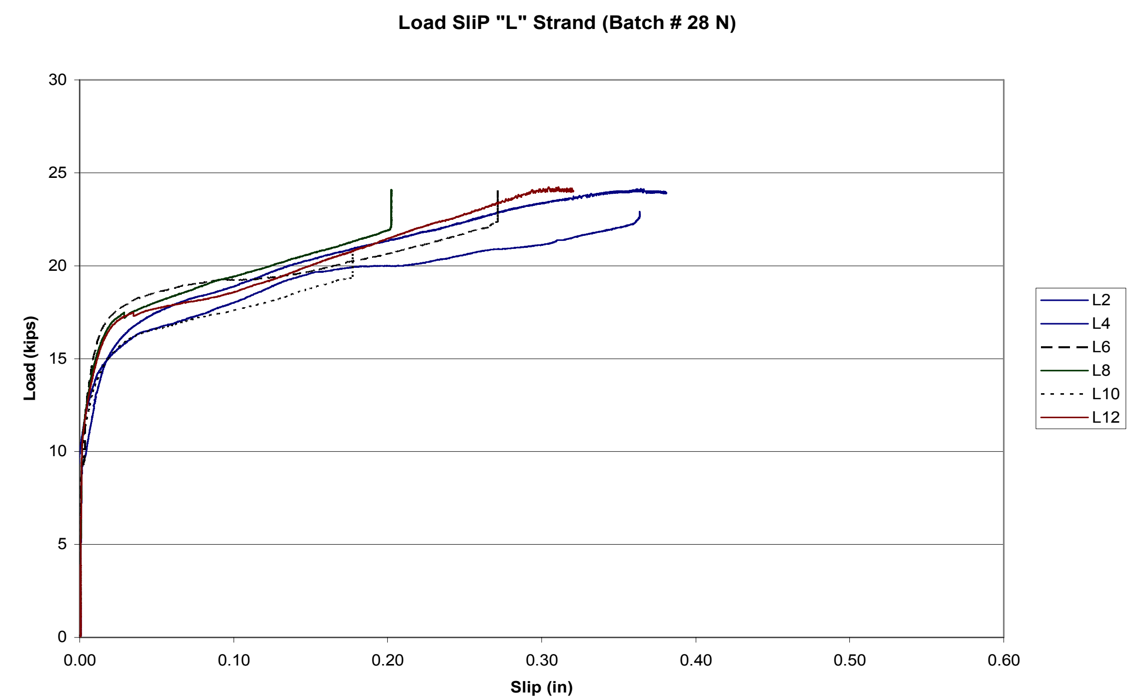


Batch Number:	**28 N**
Control Type:	Displacement
Testing Date:	24-May-04
NASP Strand ID:	L

W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.45	1	4665			K1			
	2	4814			L2	7948	13825	18000
	3		4955		K3			
	4		4852		L4	8214	12648	18876
	5		4780		K5			
	6		4791		L6	7963	15424	19241
	7		4836		K7			
	8			5019	L8	8492	14851	19425
	9			5125	K9			
	10				L10	8281	13529	17581
	11				K11			
	12				L12	8159	14538	18563
	AVG	**4740**	**4843**	**5072**	**AVG**	**8,176**	**14136**	**18614**
	ST. DEV.	**106**	**70**	**75**	**ST. DEV**	**205**	**1001**	**717**
	C.O.V.	**2.23%**	**1.44%**	**1.47%**	**C.O.V.**	**2.51%**	**7.08%**	**3.85%**

*Loading Rate from 4000 to 6000 lb

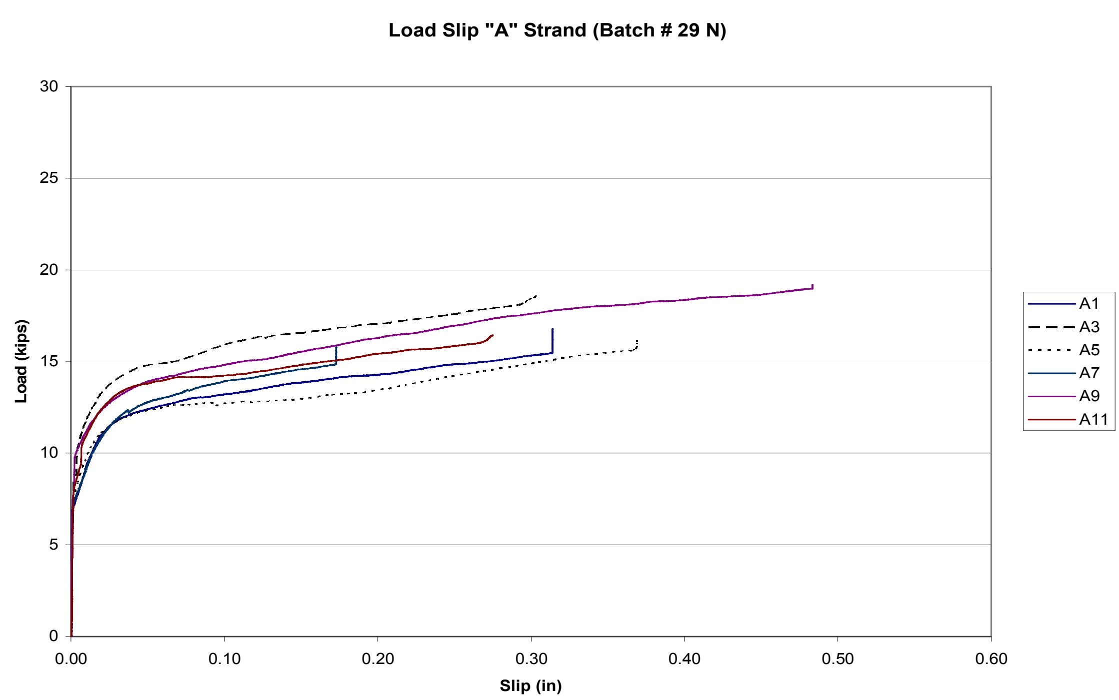
[1]: Exceeded the capacity of the machine 24,000 LBS



Batch Number:	**29 N**
Control Type:	Displacement
Testing Date:	26-May-04
NASP Strand ID:	A

W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.45	1	4240			A1	6693	9287	13210
	2	4641			E2			
	3		4486		A3	6820	11854	15908
	4		4681		E4			
	5		4568		A5	6933	9747	12713
	6		4817		E6			
	7		5064		A7	6932	9122	13929
	8			4960	E8			
	9			4999	A9	7069	11163	14816
	10				E10			
	11				A11	7331	10958	14233
	12				E12			
	AVG	**4440**	**4723**	**4980**	**AVG**	**6,963**	**10355**	**14135**
	ST. DEV.	**284**	**227**	**27**	**ST. DEV**	**220**	**1122**	**1144**
	C.O.V.	**6.39%**	**4.81%**	**0.54%**	**C.O.V.**	**3.16%**	**10.84%**	**8.09%**

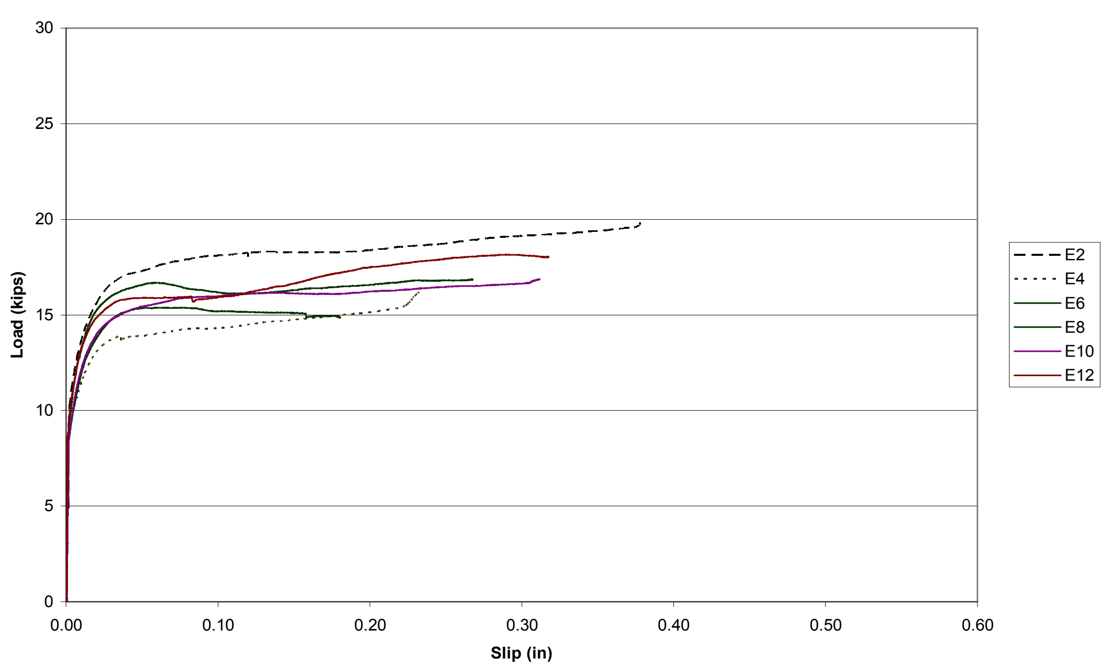
*Loading Rate from 4000 to 6000 lb



Batch Number:	**29 N**
Control Type:	Displacement
Testing Date:	26-May-04
NASP Strand ID:	E

W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.45	1	4240			A1			
	2	4641			E2	7112	13644	18117
	3		4486		A3			
	4		4681		E4	7227	11466	14311
	5		4568		A5			
	6		4817		E6	7164	11928	15188
	7		5064		A7			
	8			4960	E8	7013	13169	16171
	9			4999	A9			
	10				E10	6892	12136	15984
	11				A11			
	12				E12	7285	13210	15922
	AVG	**4440**	**4723**	**4980**	**AVG**	**7,115**	**12592**	**15949**
	ST. DEV.	**284**	**227**	**27**	**ST. DEV**	**144**	**865**	**1266**
	C.O.V.	**6.39%**	**4.81%**	**0.54%**	**C.O.V.**	**2.03%**	**6.87%**	**7.94%**
*Loading Rate from 4000 to 6000 lb								

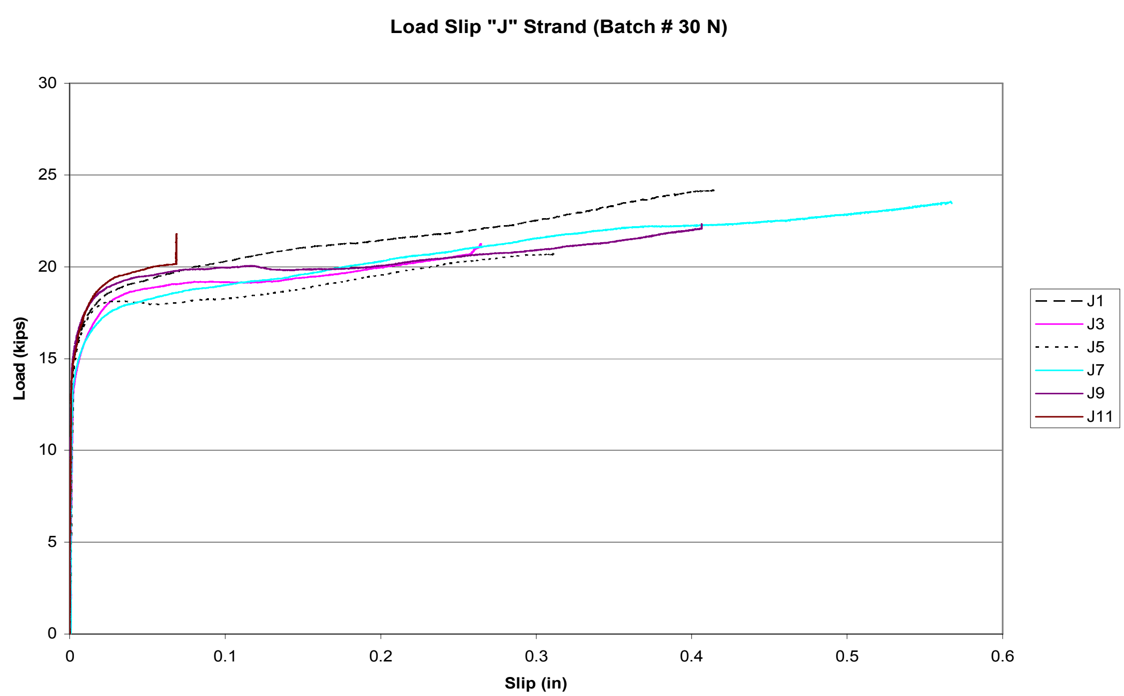
Load Slip "E" Strand (Batch # 29 N)



Batch Number:	**30 N**
Control Type:	Displacement
Testing Date:	27-May-04
NASP Strand ID:	J

W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.45	1	4459			J1	7735	17086	20281
	2	4341			E2			
	3		4629		J3	7712	15950	19170
	4		4614		E4			
	5		4770		J5	7443	16930	18250
	6		4771		E6			
	7		4833		J7	7742	15936	18992
	8			4933	E8			
	9			4887	J9	7400	17526	19966
	10				E10			
	11				J11	7805	17475	[1]
	12				E12			
	AVG	**4400**	**4723**	**4910**	**AVG**	**7,639**	**16817**	**19332**
	ST. DEV.	**84**	**97**	**33**	**ST. DEV**	**172**	**714**	**808**
	C.O.V.	**1.90%**	**2.05%**	**0.67%**	**C.O.V.**	**2.25%**	**4.24%**	**4.18%**

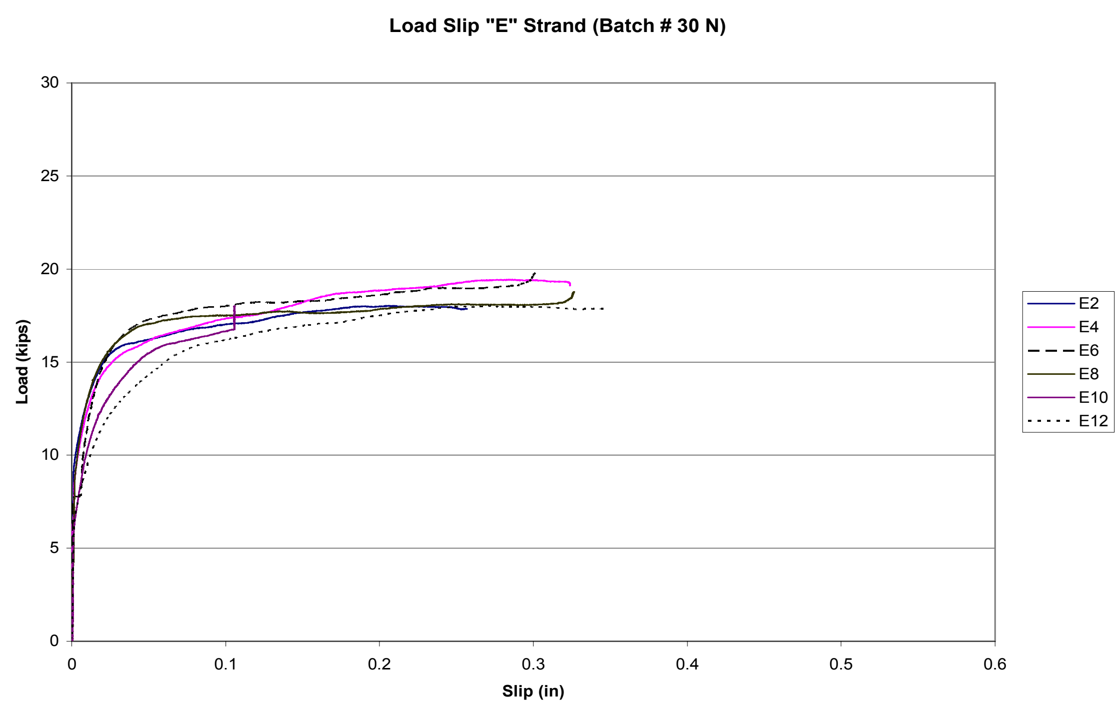
*Loading Rate from 4000 to 6000 lb
[1]: Specimen lost contact with LVDT



Batch Number:	**30 N**
Control Type:	Displacement
Testing Date:	27-May-04
NASP Strand ID:	E

W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.45	1	4459			J1			
	2	4341			E2	7206	12889	17026
	3		4629		J3			
	4		4614		E4	7157	12421	17340
	5		4770		J5			
	6		4771		E6	7071	11424	18016
	7		4833		J7			
	8			4933	E8	7120	12938	17496
	9			4887	J9			
	10				E10	7014	13522	17730
	11				J11			
	12				E12	7473	12523	15682
	AVG	**4400**	**4723**	**4910**	**AVG**	**7,173**	**12620**	**17215**
	ST. DEV.	**84**	**97**	**33**	**ST. DEV**	**161**	**702**	**823**
	C.O.V.	**1.90%**	**2.05%**	**0.67%**	**C.O.V.**	**2.25%**	**5.56%**	**4.78%**

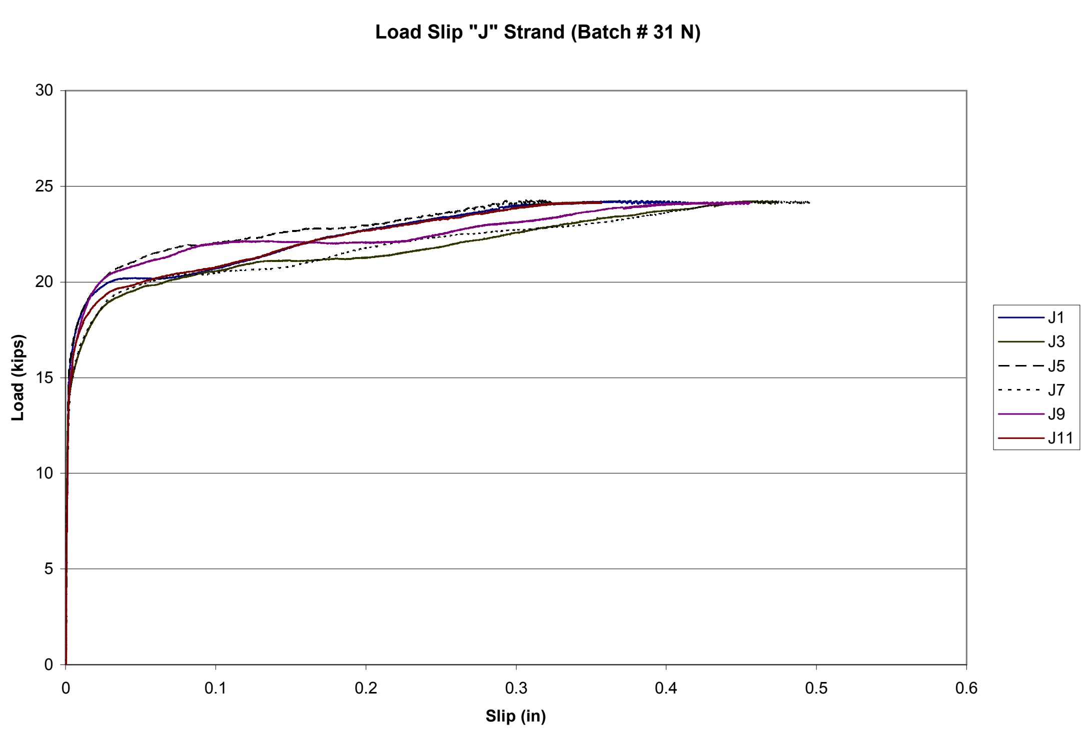
*Loading Rate from 4000 to 6000 lb



Batch Number:	**31 N**
Control Type:	Displacement
Testing Date:	28-May-04
NASP Strand ID:	J

W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.45	1	4680			J1	7844	18209	20714
	2	4850			A2			
	3		4937		J3	7648	16512	20562
	4		4901		A4			
	5		4920		J5	7584	18245	22050
	6		4964		A6			
	7		4914	5061	J7	7729	16743	20457
	8			5026	A8			
	9				J9	7996	17812	22000
	10				A10			
	11				J11	7071	17535	20756
	12				A12			
	AVG	**4765**	**4927**	**5043**	**AVG**	**7,645**	**17509**	**21090**
	ST. DEV.	**120**	**24**	**25**	**ST. DEV**	**317**	**736**	**733**
	C.O.V.	**2.52%**	**0.49%**	**0.49%**	**C.O.V.**	**4.15%**	**4.20%**	**3.47%**

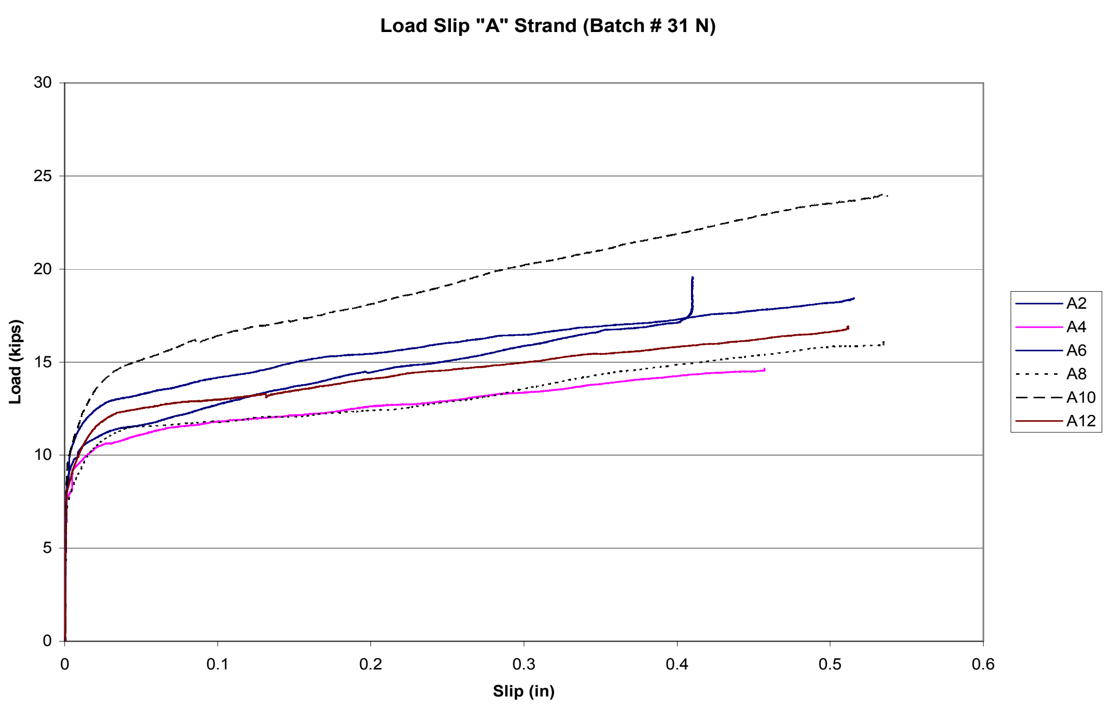
*Loading Rate from 4000 to 6000 lb



Batch Number:	**31 N**
Control Type:	Displacement
Testing Date:	28-May-04
NASP Strand ID:	A

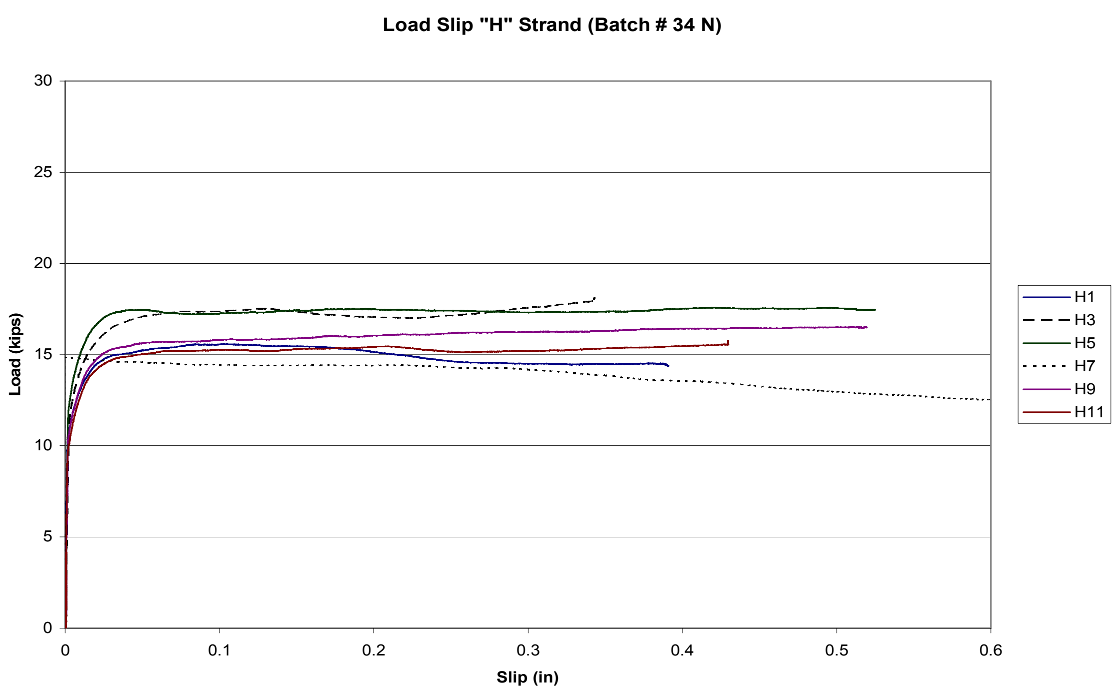
W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.45	1	4680			A1			
	2	4850			J2	7270	11467	14166
	3		4937		A3			
	4		4901		J4	6570	9605	11801
	5		4920		A5			
	6		4964		J6	6572	10291	12718
	7		4914	5061	A7			
	8			5026	J8	6792	9188	11737
	9				A9			
	10				J10	7045	11807	16410
	11				A11			
	12				J12	6972	10162	12987
	AVG	**4765**	**4927**	**5043**	**AVG**	**6,870**	**10420**	**13303**
	ST. DEV.	**120**	**24**	**25**	**ST. DEV**	**278**	**1028**	**1763**
	C.O.V.	**2.52%**	**0.49%**	**0.49%**	**C.O.V.**	**4.05%**	**9.87%**	**13.25%**

*Loading Rate from 4000 to 6000 lb



Batch Number:	**34 N**
Control Type:	Displacement
Testing Date:	10-Jun-04
NASP Strand ID:	H

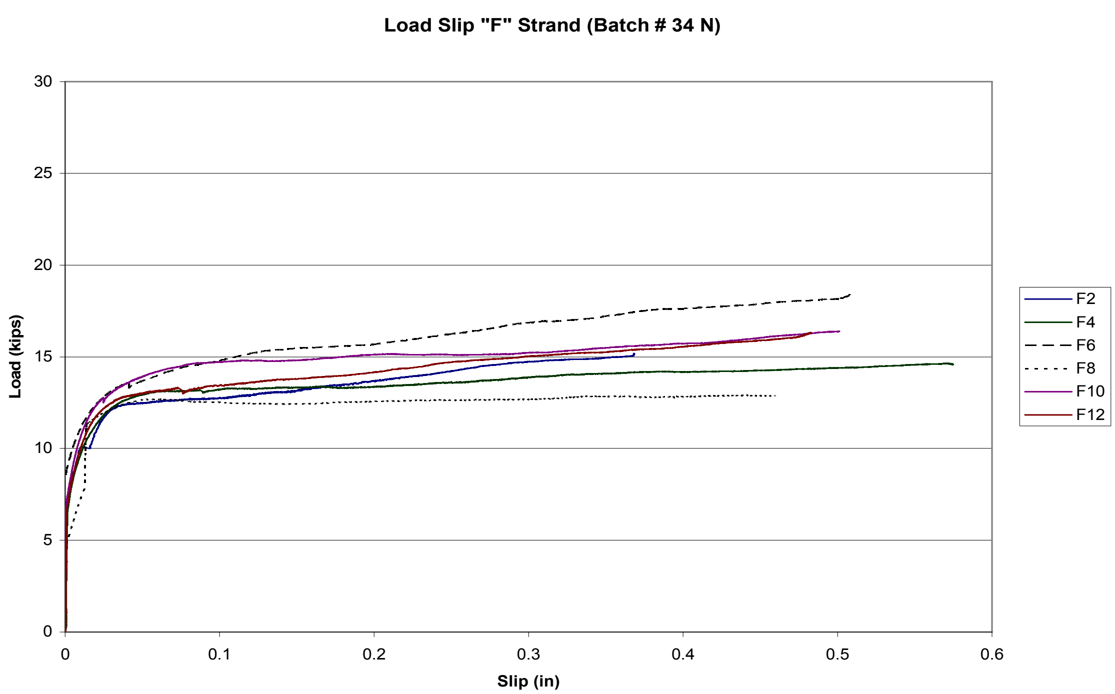
W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.45	1	4307			H1	7917	13128	15558
	2	4446			F2			
	3		4717		H3	8081	14131	17362
	4		4575		F4			
	5		4651		H5	8149	15081	17232
	6		4757		F6			
	7		4594		H7	7547	14773	14415
	8			4738	F8			
	9			4849	H9	7001	13231	15802
	10				F10			
	11				H11	7230	12749	15254
	12				F12			
	AVG	**4376**	**4659**	**4794**	**AVG**	**7,654**	**13849**	**15937**
	ST. DEV.	**99**	**78**	**78**	**ST. DEV**	**472**	**955**	**1153**
	C.O.V.	**2.26%**	**1.68%**	**1.63%**	**C.O.V.**	**6.17%**	**6.90%**	**7.24%**
*Loading Rate from 4000 to 6000 lb								



Batch Number:	**34 N**
Control Type:	Displacement
Testing Date:	10-Jun-04
NASP Strand ID:	F

W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.45	1	4307			H1			
	2	4446			F2	7138	10062	12763
	3		4717		H3			
	4		4575		F4	7383	9678	13209
	5		4651		H5			
	6		4757		F6	7085	11095	14787
	7		4594		H7			
	8			4738	F8	6262	7260	12510
	9			4849	H9			
	10				F10	6533	10653	14703
	11				H11			
	12				F12	6583	10010	13434
	AVG	**4376**	**4659**	**4794**	**AVG**	**6,831**	**9793**	**13568**
	ST. DEV.	**99**	**78**	**78**	**ST. DEV**	**433**	**1340**	**968**
	C.O.V.	**2.26%**	**1.68%**	**1.63%**	**C.O.V.**	**6.34%**	**13.69%**	**7.14%**

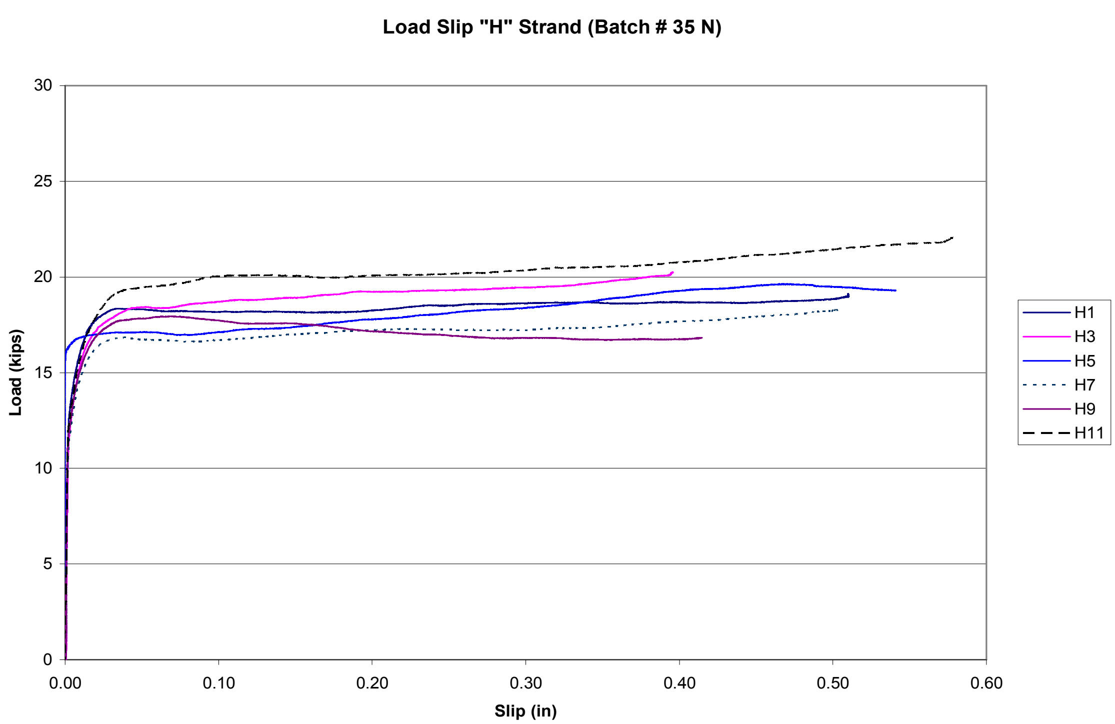
*Loading Rate from 4000 to 6000 lb



Batch Number:	**35 N**
Control Type:	Displacement
Testing Date:	11-Jun-04
NASP Strand ID:	H

W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.45	1	4316			H1	7625	16132	18168
	2	4513			F2			
	3		4620		H3	7378	15463	18710
	4		4760		F4			
	5		4662		H5	7661	16847	17123
	6		4413		F6			
	7		4839		H7	7144	14728	16687
	8			5017	F8			
	9			5064	H9	7931	15168	17736
	10				F10			
	11				H11	7813	15797	20041
	12				F12			
	AVG	**4414**	**4659**	**5041**	**AVG**	**7592**	**15689**	**18077**
	ST. DEV.	**139**	**162**	**33**	**ST. DEV**	**289**	**748**	**1202**
	C.O.V.	**3.15%**	**3.48%**	**0.66%**	**C.O.V.**	**3.80%**	**4.77%**	**6.65%**

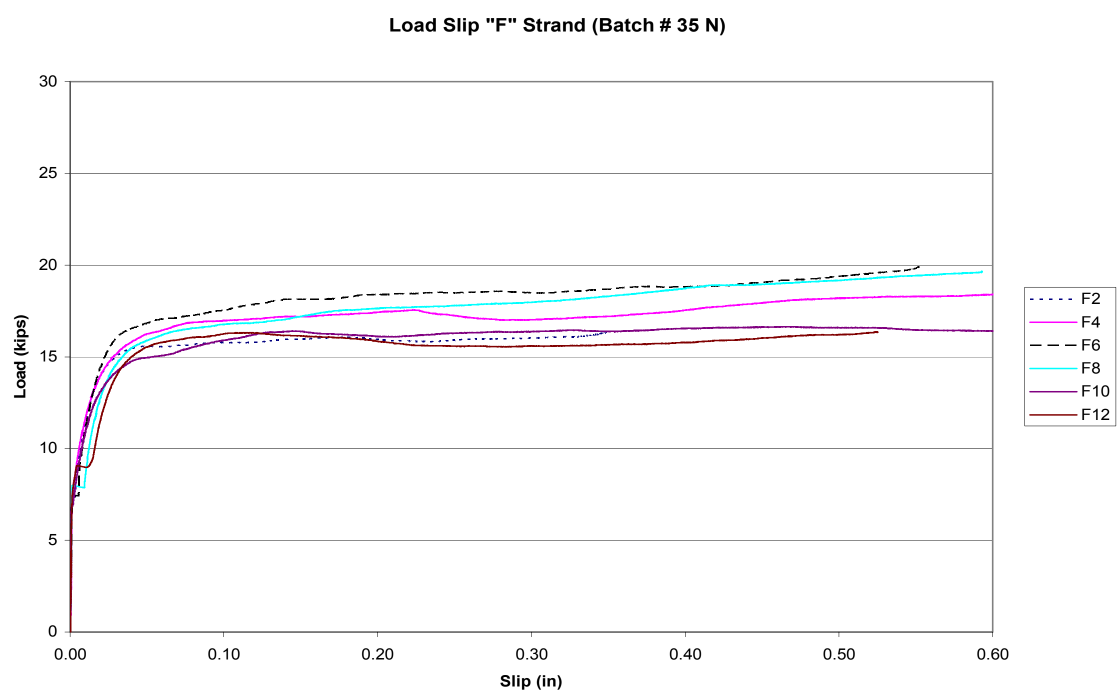
*Loading Rate from 4000 to 6000 lb



Batch Number:	**35 N**
Control Type:	Displacement
Testing Date:	11-Jun-04
NASP Strand ID:	F

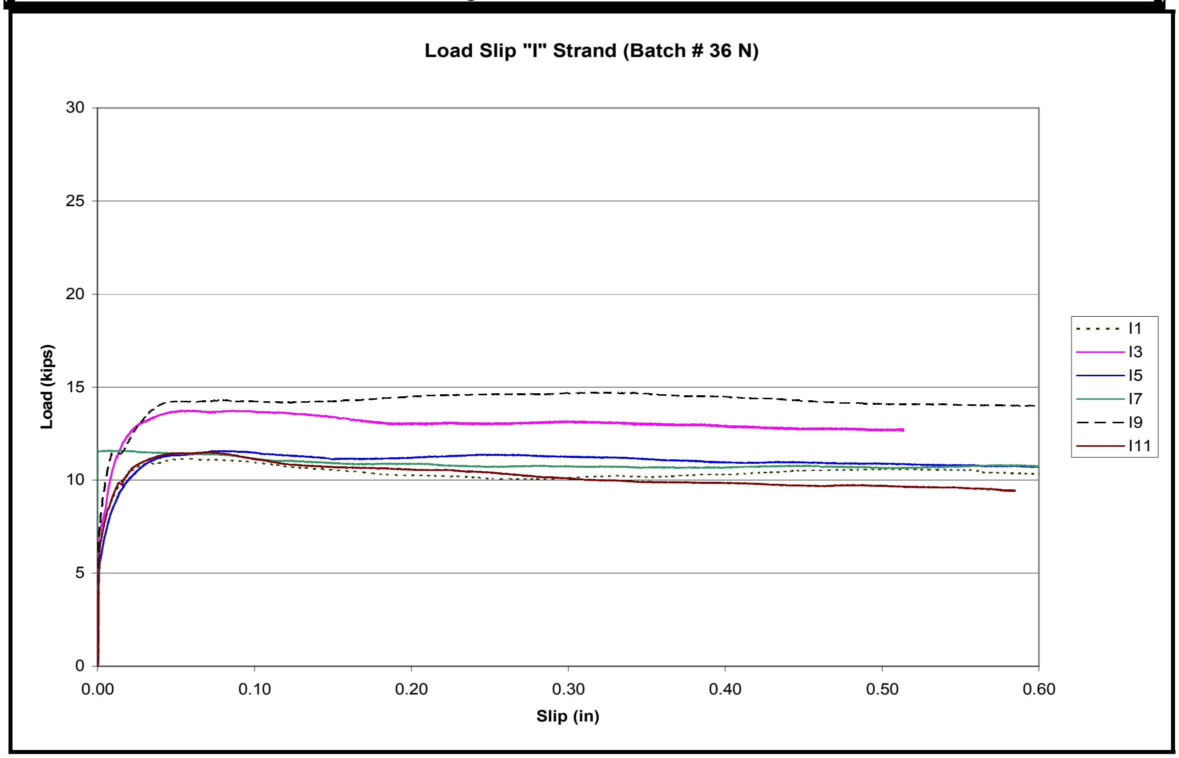
W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.45	1	4316			H1			
	2	4513			F2	6699	11471	15768
	3		4620		H3			
	4		4760		F4	6915	11674	16975
	5		4662		H5			
	6		4413		F6	6996	11085	17545
	7		4839		H7			
	8			5017	F8	7304	8566	16772
	9			5064	H9			
	10				F10	7068	10979	15903
	11				H11			
	12				F12	7013	8988	16249
	AVG	**4414**	**4659**	**5041**	**AVG**	**6999**	**10460**	**16535**
	ST. DEV.	**139**	**162**	**33**	**ST. DEV**	**197**	**1335**	**684**
	C.O.V.	**3.15%**	**3.48%**	**0.66%**	**C.O.V.**	**2.82%**	**12.76%**	**4.14%**

*Loading Rate from 4000 to 6000 lb



Batch Number:	**36 N**
Control Type:	Displacement
Testing Date:	14-Jun-04
NASP Strand ID:	I

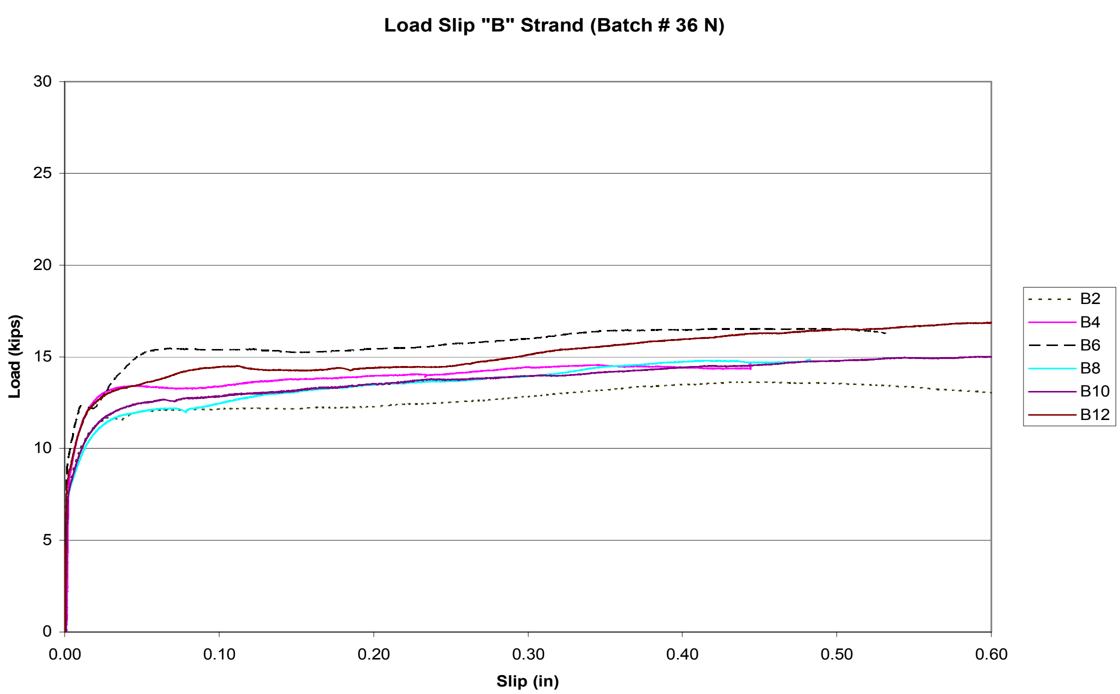
W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.45	1	4297			I1	7319	9092	10942
	2	4215			B2			
	3		4542		I3	7303	10659	13694
	4		4475		B4			
	5		4495		I5	7073	8538	11481
	6		4490		B6			
	7		4251		I7	7457	11561	11156
	8			**4731**	B8			
	9			4451	I9	7631	11490	14222
	10				B10			
	11				I11	7042	9224	11136
	12				B12			
	AVG	**4256**	**4451**	**4591**	**AVG**	**7305**	**10094**	**12105**
	ST. DEV.	**58**	**114**	**198**	**ST. DEV**	**225**	**1312**	**1455**
	C.O.V.	**1.36%**	**2.57%**	**4.31%**	**C.O.V.**	**3.08%**	**12.99%**	**12.02%**
*Loading Rate from 4000 to 6000 lb								



Batch Number:	**36 N**
Control Type:	Displacement
Testing Date:	14-Jun-04
NASP Strand ID:	B

W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.45	1	4297			I1			
	2	4215			B2	7090	9959	12161
	3		4542		I3			
	4		4475		B4	7585	11105	13375
	5		4495		I5			
	6		4490		B6	7387	12293	15375
	7		4251		I7			
	8			4731	B8	7156	9413	12450
	9			4451	I9			
	10				B10	6533	9729	12852
	11				I11			
	12				B12	7407	11075	14445
	AVG	**4256**	**4451**	**4591**	**AVG**	**7193**	**10596**	**13443**
	ST. DEV.	**58**	**114**	**198**	**ST. DEV**	**370**	**1089**	**1243**
	C.O.V.	**1.36%**	**2.57%**	**4.31%**	**C.O.V.**	**5.14%**	**10.27%**	**9.24%**

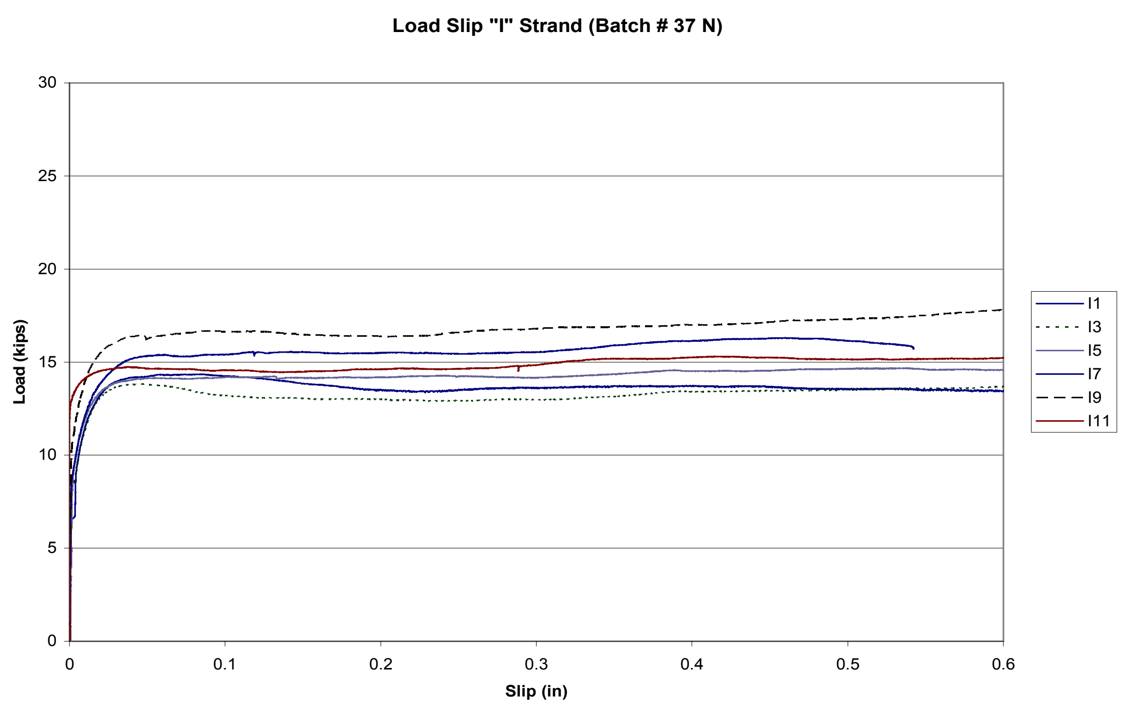
*Loading Rate from 4000 to 6000 lb



Batch Number:	**37 N**
Control Type:	Displacement
Testing Date:	15-Jun-04
NASP Strand ID:	I

W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.45	1	4537			I1	7795	11466	14250
	2	4619			B2			
	3		4621		I3	7511	11338	13196
	4		4743		B4			
	5		4782		I5	7365	11948	14181
	6		4709		B6			
	7		4766		I7	7622	12073	15405
	8			4883	B8			
	9			4809	I9	8003	13947	16631
	10				B10			
	11				I11	7667	14142	14569
	12				B12			
	AVG	**4578**	**4724**	**4846**	**AVG**	**7661**	**12486**	**14705**
	ST. DEV.	**58**	**64**	**52**	**ST. DEV**	**222**	**1240**	**1181**
	C.O.V.	**1.27%**	**1.35%**	**1.08%**	**C.O.V.**	**2.90%**	**9.93%**	**8.03%**

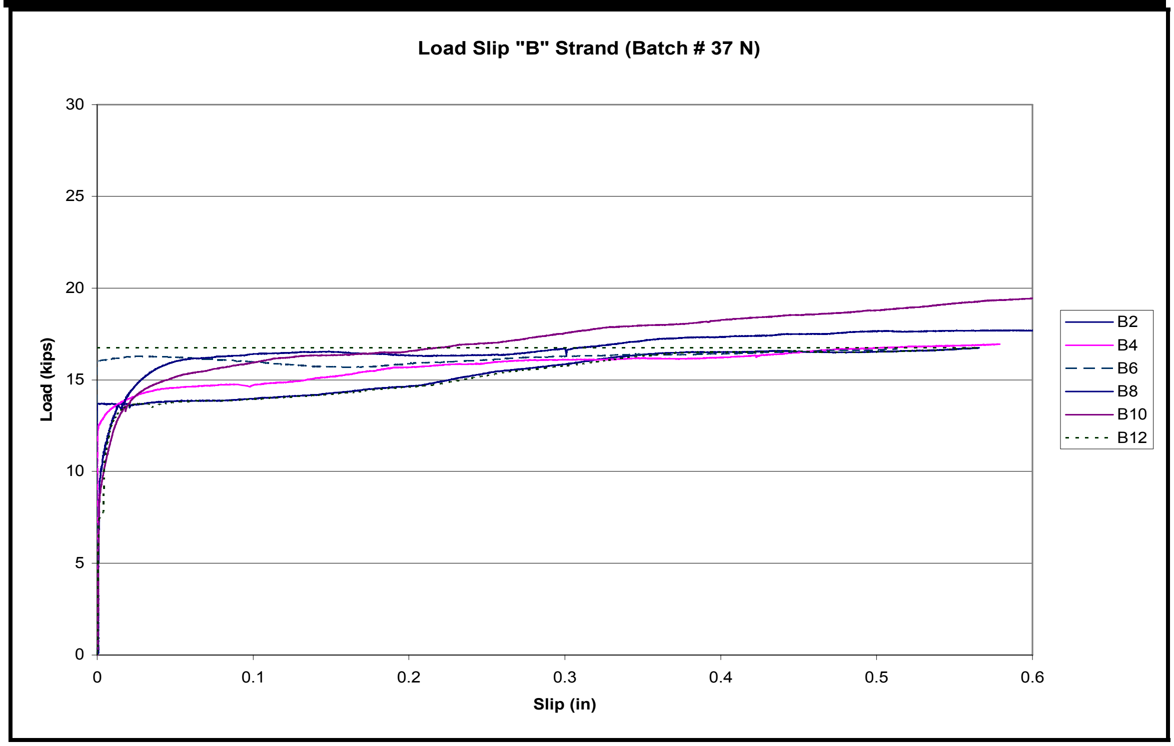
*Loading Rate from 4000 to 6000 lb



Batch Number:	**37 N**
Control Type:	Displacement
Testing Date:	15-Jun-04
NASP Strand ID:	B

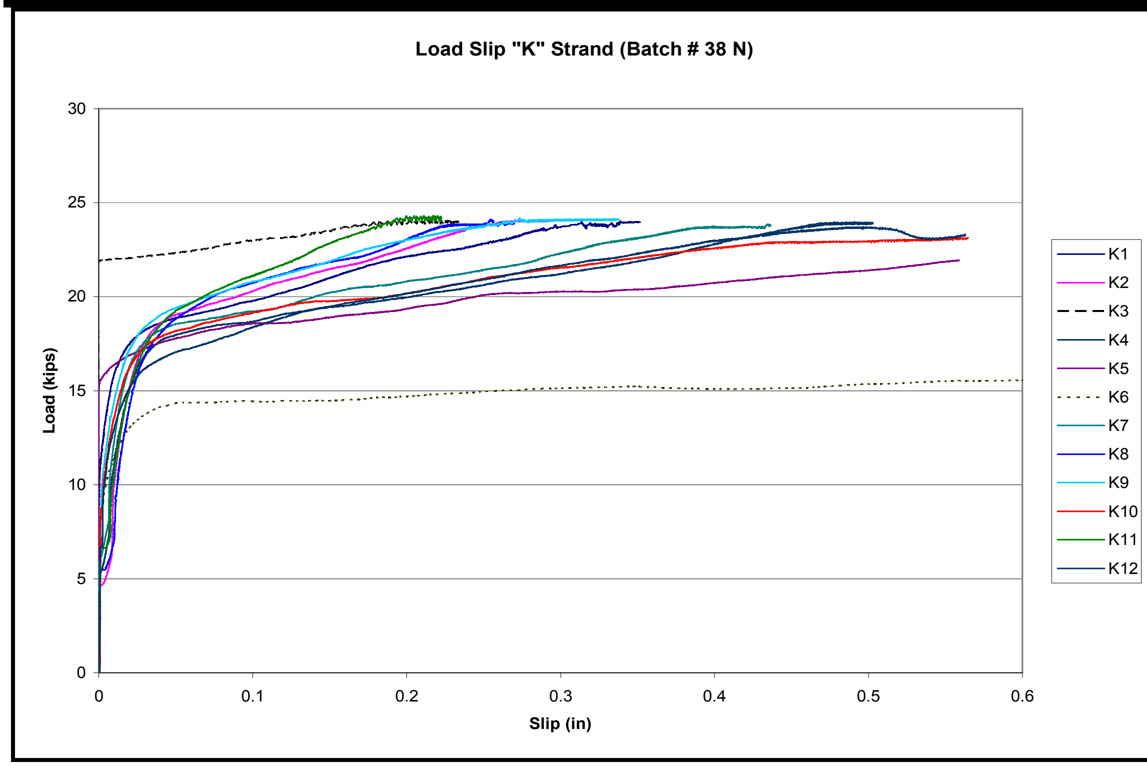
W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.45	1	4537			I1			
	2	4619			B2	7417	13685	13964
	3		4621		I3			
	4		4743		B4	7378	13468	14701
	5		4782		I5			
	6		4709		B6	7494	16146	15979
	7		4766		I7			
	8			4883	B8	7680	12872	16403
	9			4809	I9			
	10				B10	7478	12097	15935
	11				I11			
	12				B12	5572	10038	16633
	AVG	**4578**	**4724**	**4846**	**AVG**	**7170**	**13051**	**15603**
	ST. DEV.	**58**	**64**	**52**	**ST. DEV**	**790**	**2009**	**1044**
	C.O.V.	**1.27%**	**1.35%**	**1.08%**	**C.O.V.**	**11.02%**	**15.39%**	**6.69%**

*Loading Rate from 4000 to 6000 lb



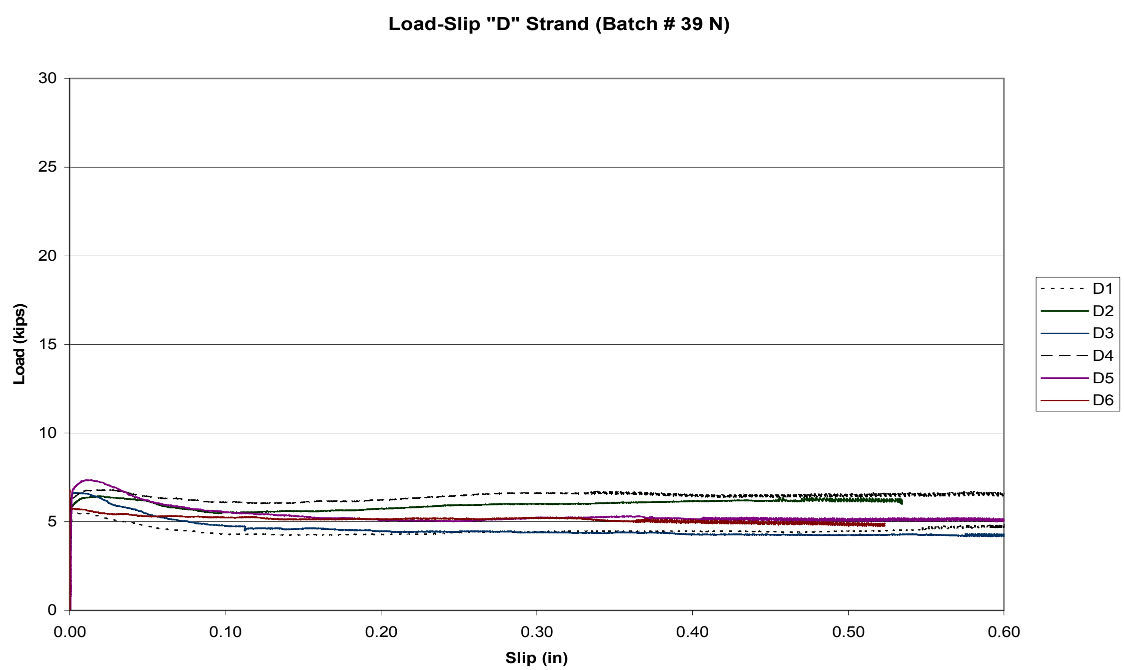
Batch Number:	**38 N**
Control Type:	Displacement
Testing Date:	16-Jun-04
NASP Strand ID:	K

W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.45	1	4240			K1	8300	15893	19778
	2	4476			K2	6930	10017	20291
	3		4028		K3	7769	22014	23002
	4		4089		K4	7206	11069	18665
	5		4309		K5	8081	16368	18570
	6		4149		K6	7900	11474	14433
	7		4191		K7	7937	12303	19207
	8			4456	K8	6903	7052	20744
	9			4244	K9	7918	14461	20804
	10				K10	8077	13579	19146
	11				K11	8185	10484	21107
	12				K12	8286	12978	18367
	AVG	**4358**	**4153**	**4350**	**AVG**	**7791**	**13141**	**19509**
	ST. DEV.	**167**	**106**	**150**	**ST. DEV**	**500**	**3818**	**2079**
	C.O.V.	**3.83%**	**2.56%**	**3.44%**	**C.O.V.**	**6.42%**	**29.05%**	**10.65%**
*Loading Rate from 4000 to 6000 lb								



Batch Number:	**39 N**
Control Type:	Displacement
Testing Date:	16-Jun-04
NASP Strand ID:	D

W/C	COMP. STRENGTH (PSI)				SAMPLE ID	LOADING RATE(LB/MIN)	LOAD (LB) STRAND SLIP	
	CUBE	23 hours	24 hours	25 Hours			0.01 IN	0.10 IN
0.45	1	4226			D1	6150	5451	4300
	2	4347			D2	5303	6341	5508
	3		4316		D3	6572	6593	4764
	4		4356		D4	6636	6739	6102
	5		4388		D5	6567	7324	5547
	6		4142		D6	6279	5671	5230
	7		4314					
	8			4473				
	9			4530				
	10							
	11							
	12							
	AVG	**4287**	**4303**	**4501**	**AVG**	**6251**	**6353**	**5242**
	ST. DEV.	**85**	**95**	**40**	**ST. DEV**	**502**	**697**	**635**
	C.O.V.	**1.99%**	**2.21%**	**0.89%**	**C.O.V.**	**8.03%**	**10.97%**	**12.12%**
*Loading Rate from 4000 to 6000 lb								



APPENDIX B
NASP TEST PROTOCOLS

NASP STRAND BOND TEST (DRAFT)

Standard Test Method to Assess the Bond of 0.5 in. (12.7 mm) Seven Wire Strand with Cementitious Materials

1. Scope

1.1 This test method provides a means to assess the ability of 0.5 in. (12.7 mm) seven wire strand to bond with concrete and other cementitious products. The method tests the bondability of strands that are made and intended for use as prestressing strands that conform to ASTM A 416.

1.2 This test does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the use of this test method to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Reference Documents

2.1 ASTM A 416
2.2 ASTM C 33
2.3 ASTM C 150
2.4 ASTM C 192

3. Summary of the Test Method

Test specimens are prepared by casting a single, 0.5 in. (12.7 mm) seven wire strand into a cylinder of concrete mortar with a bonded length of 16 in. (400 mm). The constituents and proportions for the concrete mortar mixture are prescribed. The concrete in the specimen is cured for approximately one day under controlled conditions. The specimen is tested at one day of age by pulling the strand through the mortar at a prescribed rate of loading. The pull-out force is recorded at 0.10 in. (2.5 mm) of total slip. A single NASP Bond Test shall consist of 6 or more individual pull-out tests. The strand for the NASP Bond Test shall be taken from the same lot or reel of strand.

4. Preparation of Test Specimens

4.1 Strand Specimens. The strand shall conform to ASTM A 416 and shall be intended for use in pretensioned or post-tensioned applications. Strand specimens for a single NASP Strand Bond Test shall be taken from the same lot or the same reel of prestressing strand. A minimum of six strand specimens are required for a single NASP Strand Bond Test.

4.1 Concrete Mortar Mixture Constituents and Proportions. The concrete mortar mixture shall consist of sand, cement and water mixed thoroughly in the following proportions: 2 parts sand, 1 part cement and 0.45 parts water. The sand shall conform to ASTM C 33 requirements for **Fine Aggregate.** The batch weight for sand shall be computed using the aggregate's unit weight at saturated surface dry (SSD) conditions. In computing weights for mixture proportions, the moisture content within the sand shall be accurately sampled and measured. The mixture proportions shall be corrected for the moisture content measured in the sand prior to mixing. Batch materials shall be handled in conformance with ASTM C 192. The cement shall conform to ASTM C 150 requirements for Type III cement. The water shall be potable and suitable for making concrete.

4.2 Mixing. The concrete mortar and the test specimens shall be made in conformance with ASTM C 192. Measurements of slump and air content are not required.

4.2 Curing. The concrete mortar and test specimens shall be cured in conformance with ASTM C 192. The concrete mortar shall be cured at 73 ± 3• F (23 ± 2• C) from the time of molding until the moment of test. Storage during the curing period shall be in a vibration-free environment.

4.3 Mortar Strength. Concrete mortar strength shall be evaluated in conformance with ASTM C 109 using 2 in. (51 mm) mortar cubes, except that the mixture proportions for the mortar are given in Section 4.1 and flow measurement shall not be required. The average mortar cube strength at the time of the NASP Bond Test shall not be less than 3500 psi (500 kPa). Mortar cube strength shall not exceed 5000 psi (700 kPa) at the time of the NASP test.

4.4 Test specimens shall be made by casting one single strand concentrically in concrete mortar within a 5 in. (125 mm) diameter steel casing as described in Fig. 1. The length of the steel tube shall be 18 in. as shown. The bonded length of the strand shall be 16 in., with a 2 in. long bond breaker as shown in the figure. The steel casing shall have sufficient rigidity to prevent radial cracking in the specimen during testing. The test specimen shall be cast with the longitudinal axis of the strand and the steel casing in the vertical position. Test specimens shall be mechanically consolidated by vibration in conformance with ASTM C 192.

5. Test Procedure.

5.1 Timing of the Test. The NASP Bond Test shall be conducted 24 ± 2 hrs. from the time of casting the specimens.

5.2 Instrumentation and measurement. The pull-out force shall be measured by a calibrated load measuring device, either electronically or hydraulically, or in combination of hydraulics and electronics. Pull-out force shall be measured to the nearest 10 lb increments. The relative movement of the strand to the hardened concrete mortar shall be measured. This measurement is typically called the "free-end slip" and shall be measured to 0.01 in. The slip shall be measured by a calibrated device.

5.3 Strand shall be pulled from the concrete by reacting against the transverse steel plate. The loading shall be controlled by strand displacement measured at the point where the load is applied to the strand. The displacement rate shall be 0.1 in. per minute (2.5 mm per minute).

5.4 The strand shall be loaded at a distance approximately 6 in. from the end of the specimen.

5.5 The pull-out force shall be recorded when the opposite end of the strand, or the "free end" achieves a total displacement of 0.10 in. relative to the hardened concrete mortar.

5.6 If the hardened concrete mortar exhibits cracking in two or more of the six individual tests, then all results of NASP Strand Bond Test shall be discarded and new specimens prepared for a new NASP Strand Bond Test.

6. Reporting.

6.1 Sample Size. A single NASP Strand Bond Test shall consist of a minimum of six (6) individual tests conducted on single strand specimens.

6.2 For each individual test, report the pull-out force that corresponds to a relative displacement of 0.10 in. between the strand and the hardened concrete mortar.

6.3 For the NASP Bond Test, compute the average pull-out force from the individual tests and report the value as the average value for the NASP Bond Test. If one of the specimens exhibited radial cracking during testing, disregard the pull-out value of that specimen when reporting results. If two or more of the specimens exhibit radial cracking, the entire results should be disregarded and the NASP Bond Test performed again in its entirety.

7. Acceptance

7.1 The strand shall be accepted for pretensioned and post-tensioned prestressed applications when the average value of the NASP Strand Bond Test is not less than _________ lbs and no individual test result is less than __________lbs.

DRAFT
Bruce W. Russell, Ph.D., P.E.
August 30, 2001

NASP STRAND BOND TEST (DRAFT)

Standard Test Method to Assess the Bond of 0.5 in. (12.7 mm) and 0.6 in. (15.24 mm) Seven Wire Strand with Cementitious Materials

1. Scope

1.1 This test method provides a means to assess the ability of 0.5 in. (12.7 mm) and 0.6 in. (15.24 mm) seven wire strand to bond with concrete and other cementitious products. The method tests the bondability of strands that are made and intended for use as prestressing strands that conform to ASTM A 416.

1.2 This test does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the use of this test method to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Reference Documents

2.1 ASTM A 416
2.2 ASTM C 33
2.3 ASTM C 150
2.4 ASTM C 192
2.5 ASTM C 1437
2.6 ASTM C 305
2.7 ASTM C 109

3. Summary of the Test Method

Test specimens are prepared by casting a single, 0.5 in. (12.7 mm) and 0.6 in. (15.24 mm) seven wire strand into a cylinder of concrete mortar with a bonded length of 16 in. (400 mm). The constituents and proportions for the concrete mortar mixture are prescribed. The concrete in the specimen is cured for approximately one day under controlled conditions. The specimen is tested at one day of age by pulling the strand through the mortar at a prescribed rate of loading. The pull-out force is recorded at 0.10 in. (2.5 mm) of total slip. A single NASP Bond Test shall consist of 6 or more individual pull-out tests. The strand for the NASP Bond Test shall be taken from the same lot or reel of strand.

4. Preparation of Test Specimens

4.1 Strand Specimens. The strand shall conform to ASTM A 416 and shall be intended for use in pretensioned or post-tensioned applications. Strand specimens for a single NASP Strand Bond Test shall be taken from the same lot or the same reel of prestressing strand. A minimum of six strand specimens are required for a single NASP Strand Bond Test.

4.2 Concrete Mortar Mixture Constituents and Proportions. The concrete mortar mixture shall consist of sand, cement and water mixed thoroughly in the following proportions: 2 parts sand, 1 part cement and 0.45 parts water. The sand

DRAFT

shall conform to ASTM C 33 requirements for Fine Aggregate. The batch weight for sand shall be computed using the aggregate's unit weight at saturated surface dry (SSD) conditions. In computing weights for mixture proportions, the moisture content within the sand shall be accurately sampled and measured. The mixture proportions shall be corrected for the moisture content measured in the sand prior to mixing. Batch materials shall be handled in conformance with ASTM C 192. The cement shall conform to ASTM C 150 requirements for Type III cement. The water shall be potable and suitable for making concrete.

4.3 Mixing and Flow Rate. The concrete mortar and the test specimens shall be made in conformance with ASTM C 192. Measurements of slump and air content are not required. The flow should be measured according to the procedure described in ASTM C 1437. The recommended flow rate is between 100 and 125.

4.4 Consolidation. Concrete should be consolidated just enough to ensure perfect between strand and the surrounding concrete.

4.5 Curing. The concrete mortar and test specimens shall be cured in conformance with ASTM C 192. The concrete mortar shall be cured at 73 ± 3EF (23 ± 2EC) from the time of molding until the moment of test. Storage during the curing period shall be in a vibration-free environment.

4.6 Unit Weight of Mortar Cubes. Measure and record fresh unit weight of mortar cubes. In addition, unit weight of hardened cubes will be measured prior to testing under compression.

4.7 Mortar Strength. Concrete mortar strength shall be evaluated in conformance with ASTM C 109 using 2 in. (51 mm) mortar cubes, except that the mixture proportions for the mortar are given in Section 4.1 and flow measurement shall not be required. The average mortar cube strength at the time of the NASP Bond Test shall not be less than 4500 psi. Mortar cube strength shall not exceed 5000 psi at the time of the NASP test. If the minimum target value of 4500psi is not achieved, NASP testing will be performed regardless and the data should be reported. On the other hand, if mortar strength exceeds 5000psi, repeat the NASP test.

4.8 Test specimens shall be made by casting one single strand concentrically in concrete mortar within a 5 in. (125 mm) diameter steel casing as described in Fig. B.1. The length of the steel tube shall be 18 in. as shown. The bonded length of the strand shall be 16 in., with a 2 in. long bond breaker as shown in the figure. The steel casing shall have sufficient rigidity to prevent radial cracking in the specimen during testing. The test specimen shall be cast with the longitudinal axis of the strand and the steel casing in the vertical position. Test specimens shall be mechanically consolidated by vibration in conformance with ASTM C 192.

5. Test Procedure.

5.1 Timing of the Test. The NASP Bond Test shall be conducted 24 ± 2 hrs. from the time of casting the specimens.

5.2 Stiff test frame (as shown in Fig. B.2) or equivalent to stiff test frame (equivalent to stiff test frame means test frame without torsional restraint) should be used for the NASP Bond Test

5.3 Instrumentation and measurement. The pull-out force shall be measured by a calibrated load measuring device, either electronically or hydraulically, or in combination of hydraulics and electronics. Pull-out force shall be measured to the nearest 10 lb increments. The relative movement of the strand to the hardened concrete mortar shall be measured. This measurement is typically called the "free-end slip" and shall be measured to 0.01 in. The slip shall be measured by a calibrated device.

5.4 Strand shall be pulled from the concrete by reacting against the transverse steel plate. The loading shall be controlled by strand displacement measured at the point where the load is applied to the strand. The displacement rate shall be 0.1 in. per minute (2.5 mm per minute).

5.5 The strand shall be loaded at a distance approximately 6 in. from the end of the specimen.

5.6 The pull-out force shall be recorded when the opposite end of the strand, or the "free end" achieves a total displacement of 0.10 in. relative to the hardened concrete mortar.

5.7 If the hardened concrete mortar exhibits cracking in two or more of the six individual tests, then all results of NASP Strand Bond Test shall be discarded and new specimens prepared for a new NASP Strand Bond Test.

6. Reporting.

6.1 Sample Size. A single NASP Strand Bond Test shall consist of a minimum of six (6) individual tests conducted on single strand specimens.

6.2 For each individual test, report the pull-out force that corresponds to a relative displacement of 0.10 in. between the strand and the hardened concrete mortar.

6.3 For the NASP Bond Test, compute the average pull-out force from the individual tests and report the value as the average value for the NASP Bond Test. If one of the specimens exhibited radial cracking during testing, disregard the pull-out value of that specimen when reporting results. If two or more of the specimens exhibit radial cracking, the entire results should be disregarded and the NASP Bond Test performed again in its entirety.

7. Acceptance

7.1 The strand shall be accepted for pretensioned and post-tensioned prestressed applications when the average value of the NASP Strand Bond Test is not less than _________ lbs and no individual test result is less than __________lbs.

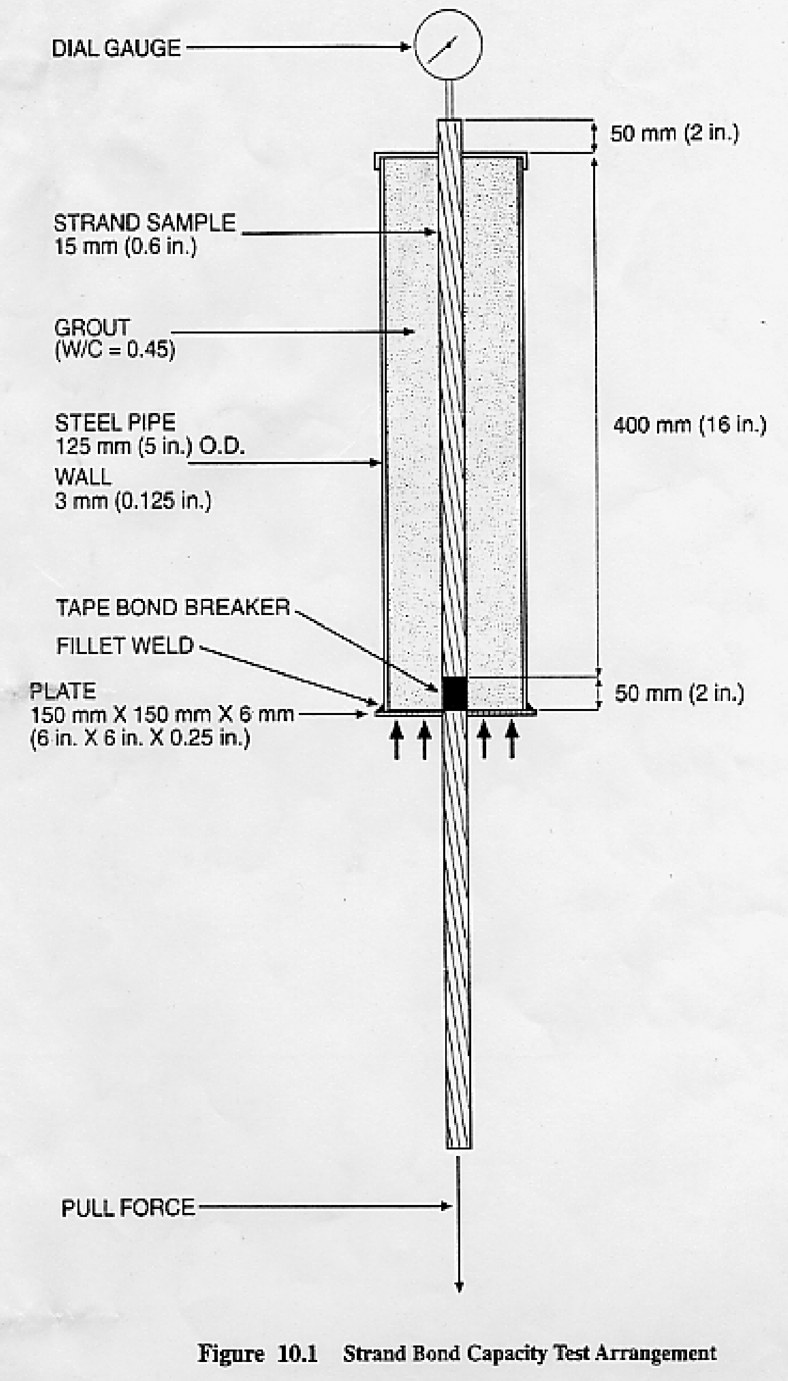
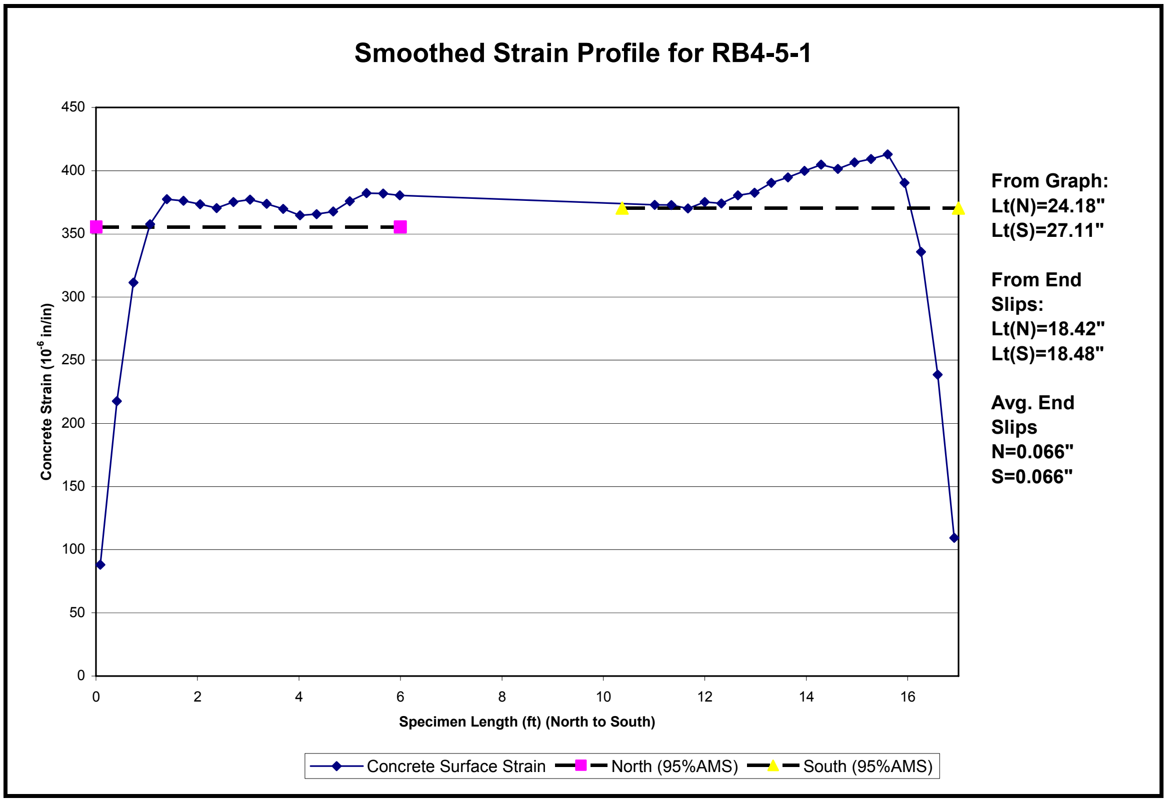


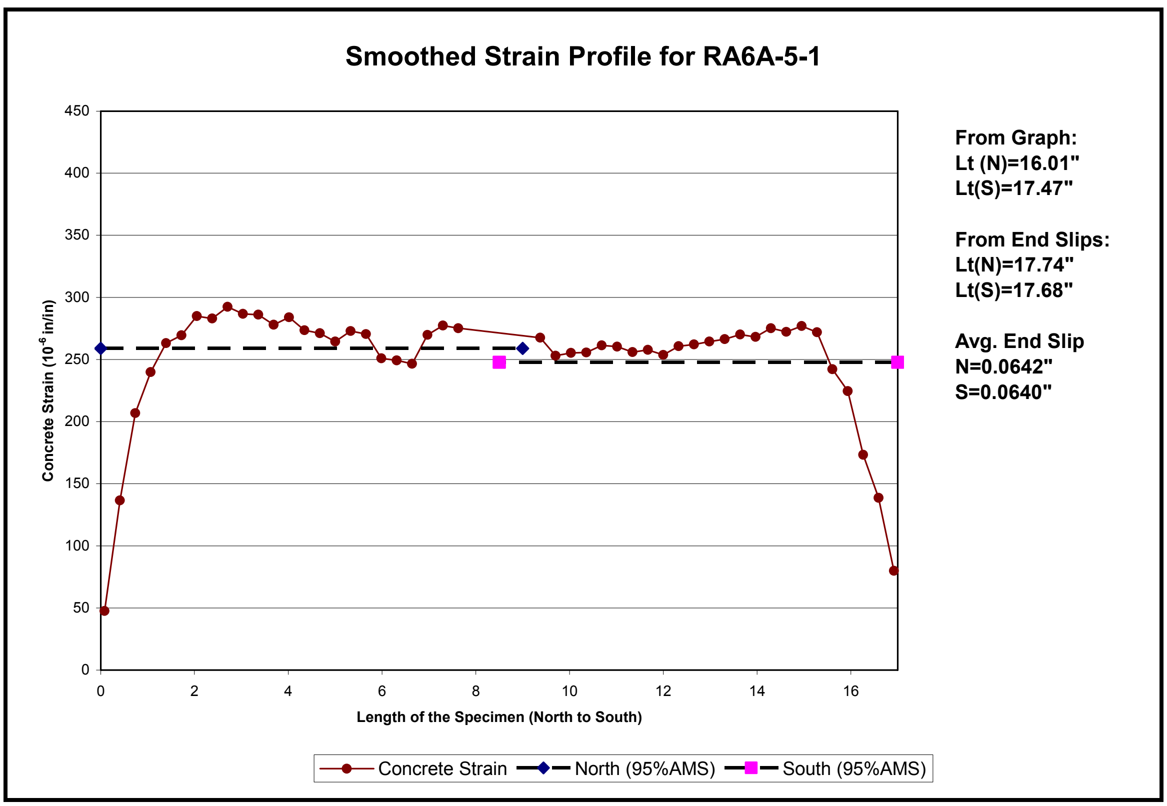
Figure 10.1 **Strand Bond Capacity Test Arrangement**

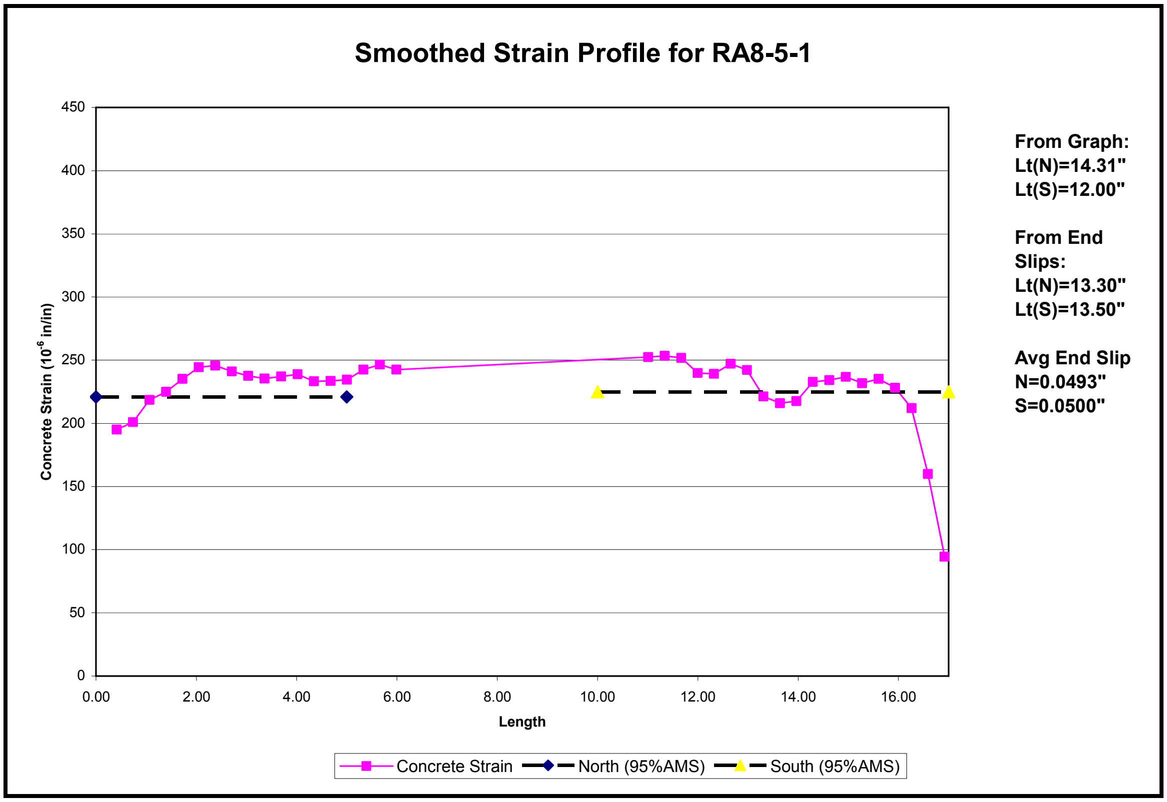
Figure B.1. NASP Test Setup

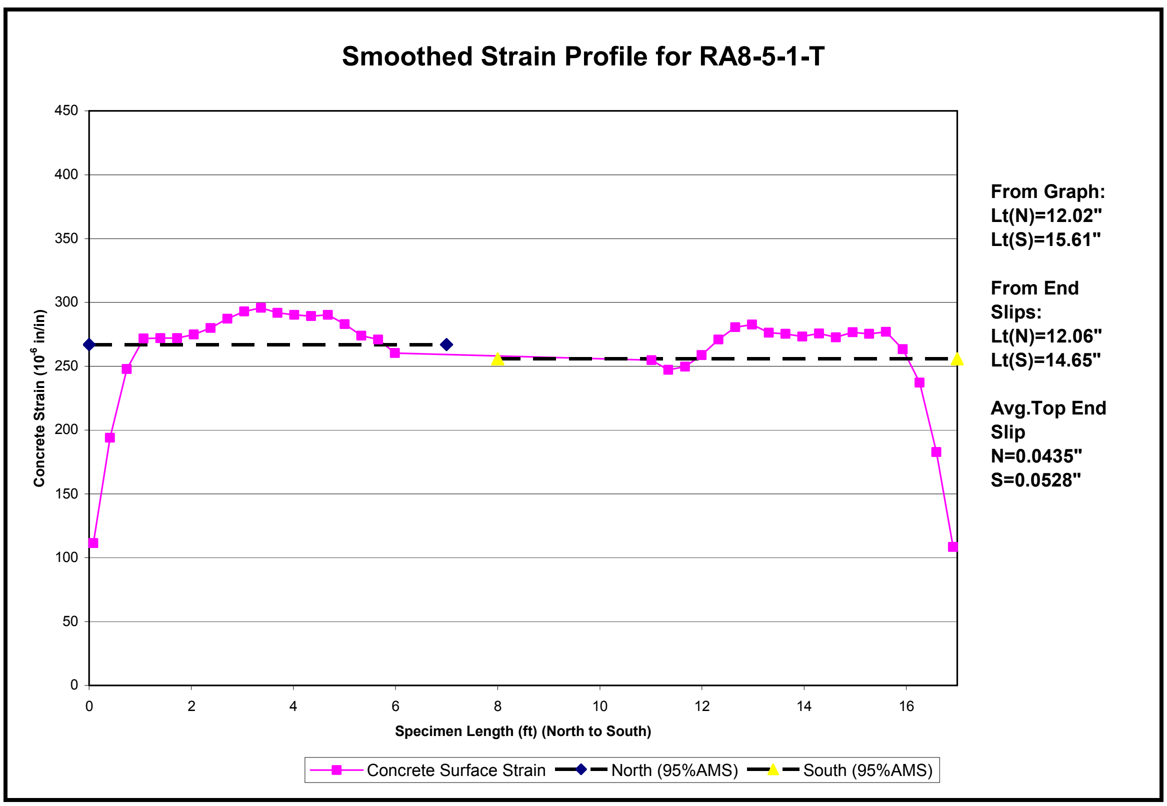
Figure. B.2. Typical Stiff Test Frame to Conduct NASP Bond Test

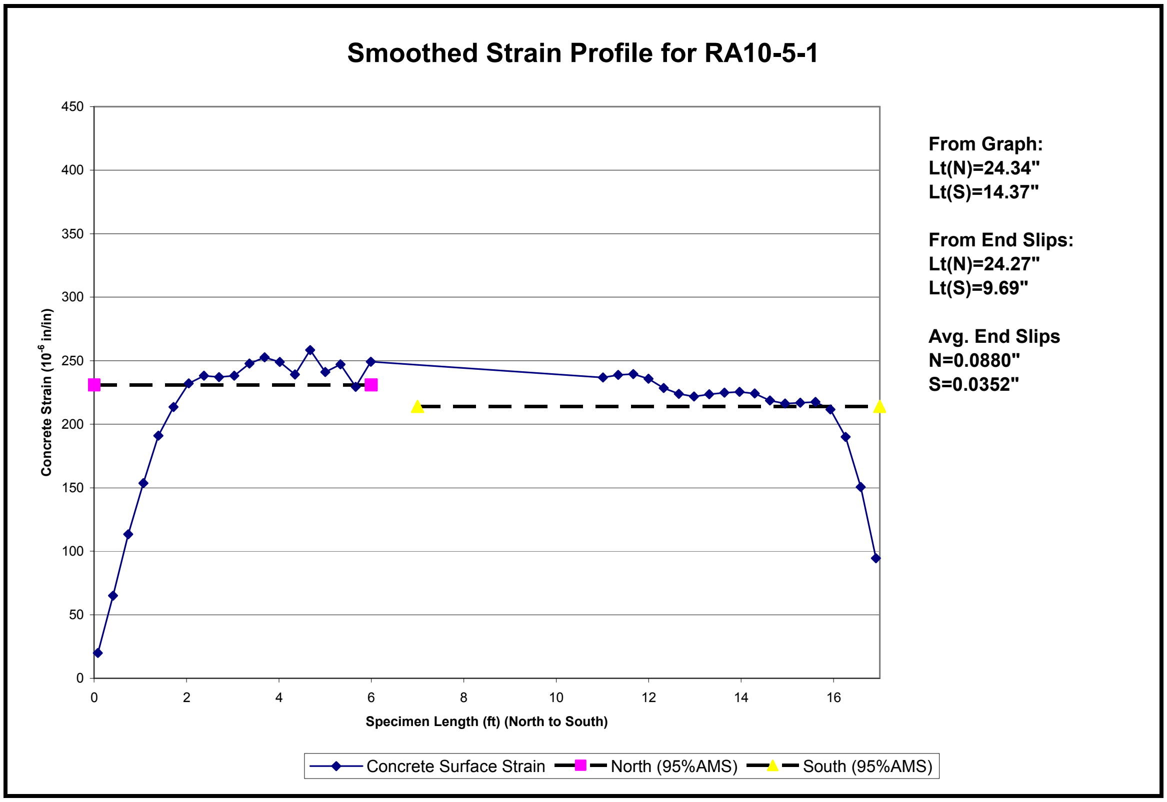
APPENDIX C
SMOOTHED STRAIN PROFILES FOR 0.5 IN. DIAMETER STRANDS “A” AND “B” IN RECTANGULAR BEAMS

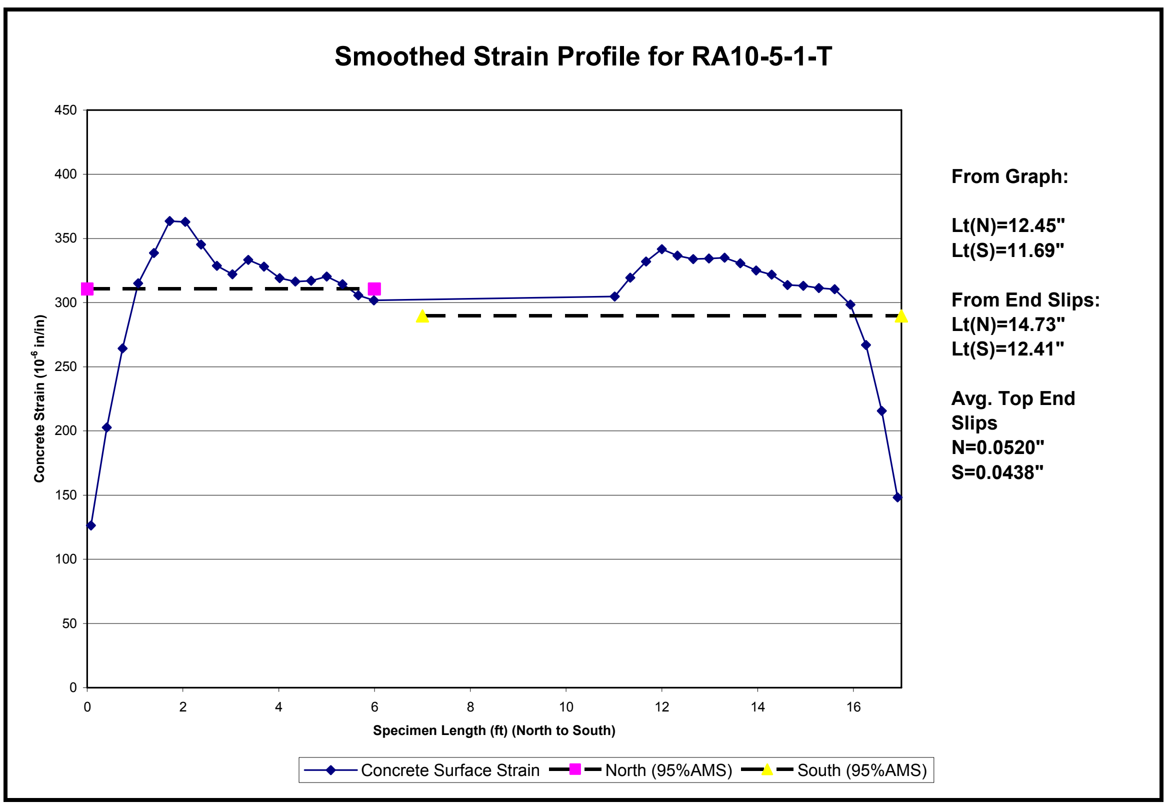

Smoothed Strain Profile for RB4-5-1
Concrete Strain (10^{-6} in/in)
Specimen Length (ft) (North to South)
Concrete Surface Strain
North (95%AMS)
South (95%AMS)
From Graph:
Lt(N)=24.18"
Lt(S)=27.11"
From End Slips:
Lt(N)=18.42"
Lt(S)=18.48"
Avg. End Slips
N=0.066"
S=0.066"


Smoothed Strain Profile for RA6A-5-1
Concrete Strain (10^{-6} in/in)
Length of the Specimen (North to South)
Concrete Strain
North (95%AMS)
South (95%AMS)
From Graph:
Lt (N)=16.01"
Lt(S)=17.47"
From End Slips:
Lt(N)=17.74"
Lt(S)=17.68"
Avg. End Slip
N=0.0642"
S=0.0640"

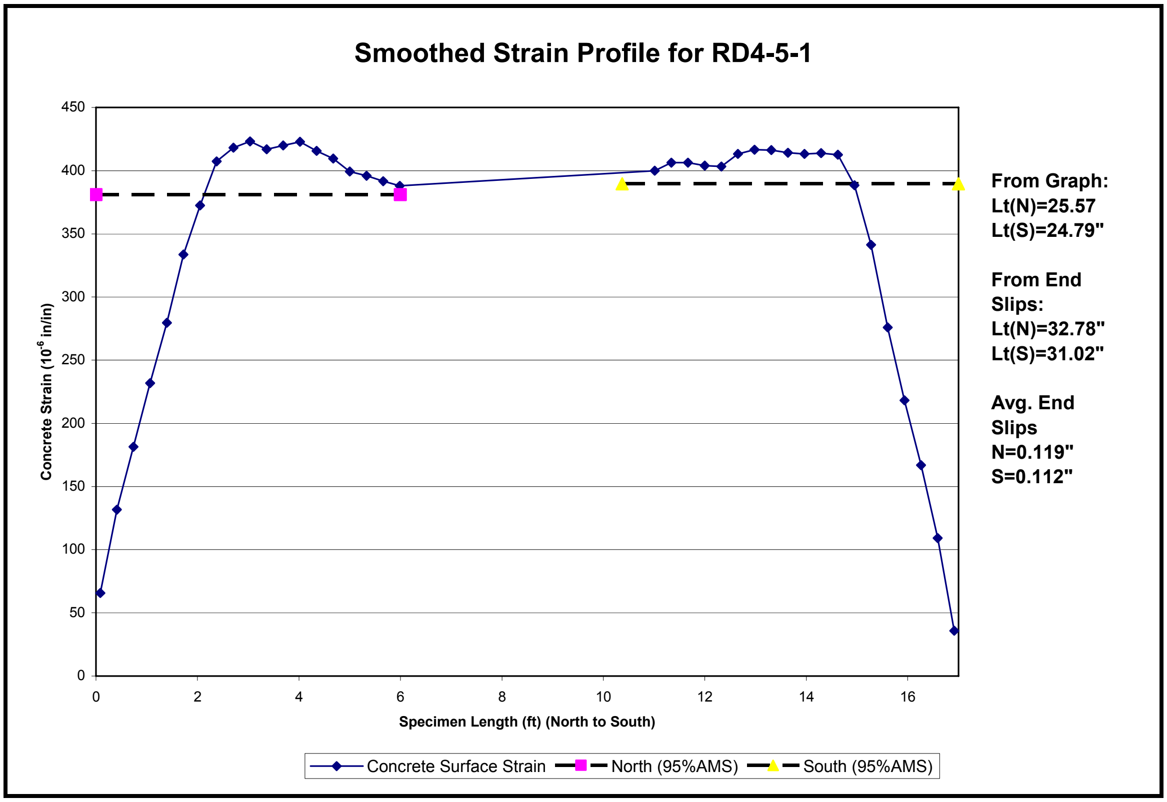

Smoothed Strain Profile for RA8-5-1
Concrete Strain (10^{-6} in/in)
Length
Concrete Strain
North (95%AMS)
South (95%AMS)
From Graph:
Lt(N)=14.31"
Lt(S)=12.00"
From End Slips:
Lt(N)=13.30"
Lt(S)=13.50"
Avg End Slip
N=0.0493"
S=0.0500"

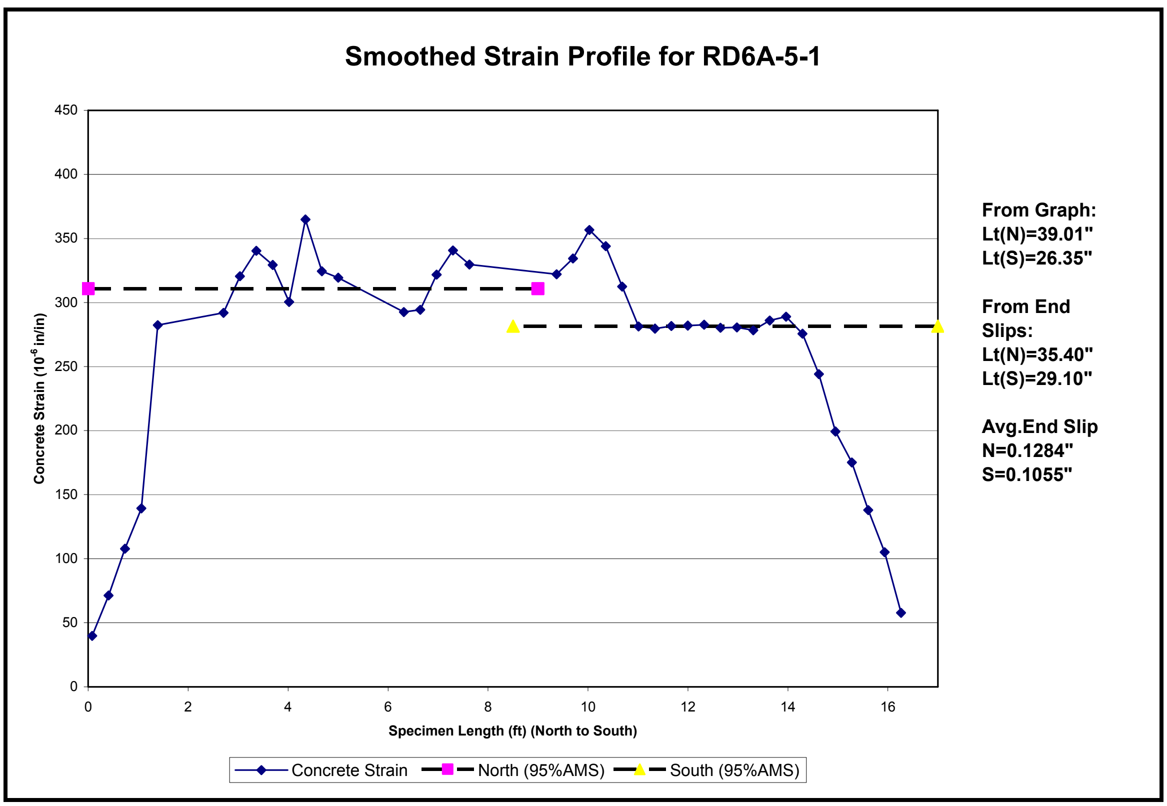

Smoothed Strain Profile for RA8-5-1-T
Concrete Strain (10^{-6} in/in)
Specimen Length (ft) (North to South)
Concrete Surface Strain
North (95%AMS)
South (95%AMS)
From Graph:
Lt(N)=12.02"
Lt(S)=15.61"
From End Slips:
Lt(N)=12.06"
Lt(S)=14.65"
Avg.Top End Slip
N=0.0435"
S=0.0528"

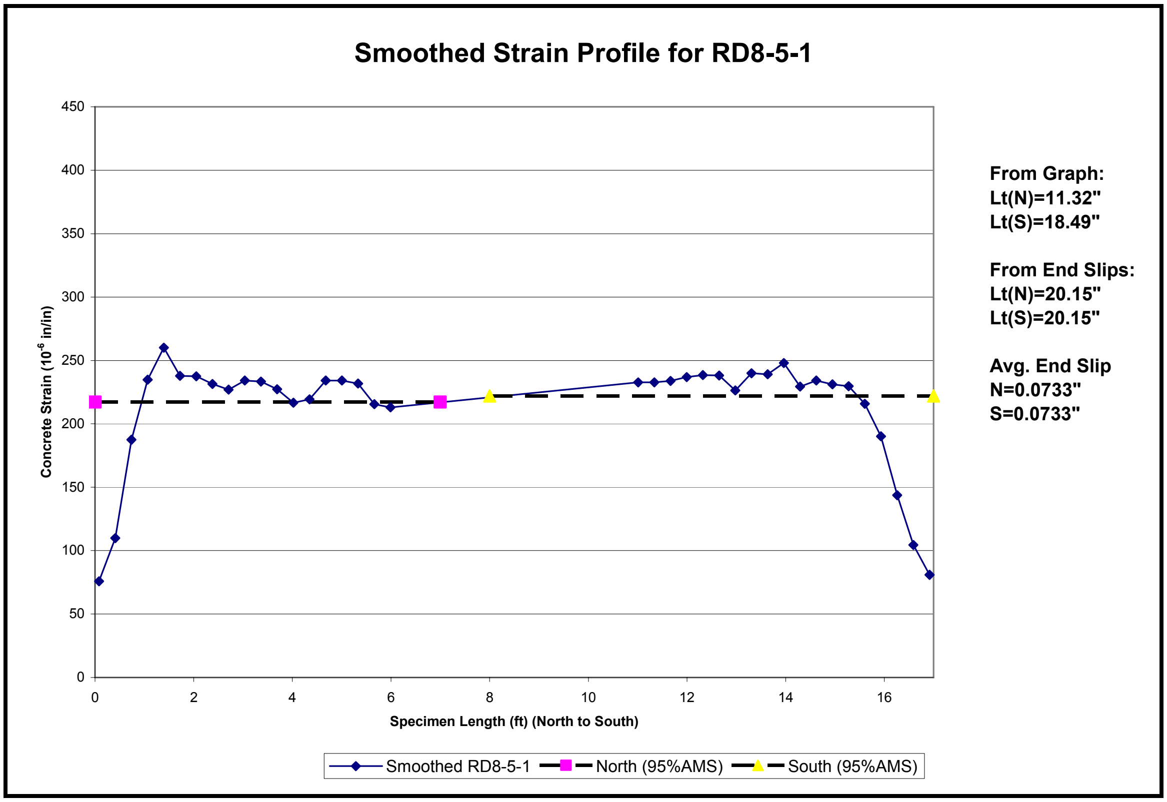

Smoothed Strain Profile for RA10-5-1
Concrete Strain (10^-6 in/in)
Specimen Length (ft) (North to South)
Concrete Surface Strain
North (95%AMS)
South (95%AMS)
From Graph:
Lt(N)=24.34"
Lt(S)=14.37"
From End Slips:
Lt(N)=24.27"
Lt(S)=9.69"
Avg. End Slips
N=0.0880"
S=0.0352"


Smoothed Strain Profile for RA10-5-1-T
Concrete Strain (10^-6 in/in)
Specimen Length (ft) (North to South)
Concrete Surface Strain
North (95%AMS)
South (95%AMS)
From Graph:
Lt(N)=12.45"
Lt(S)=11.69"
From End Slips:
Lt(N)=14.73"
Lt(S)=12.41"
Avg. Top End Slips
N=0.0520"
S=0.0438"

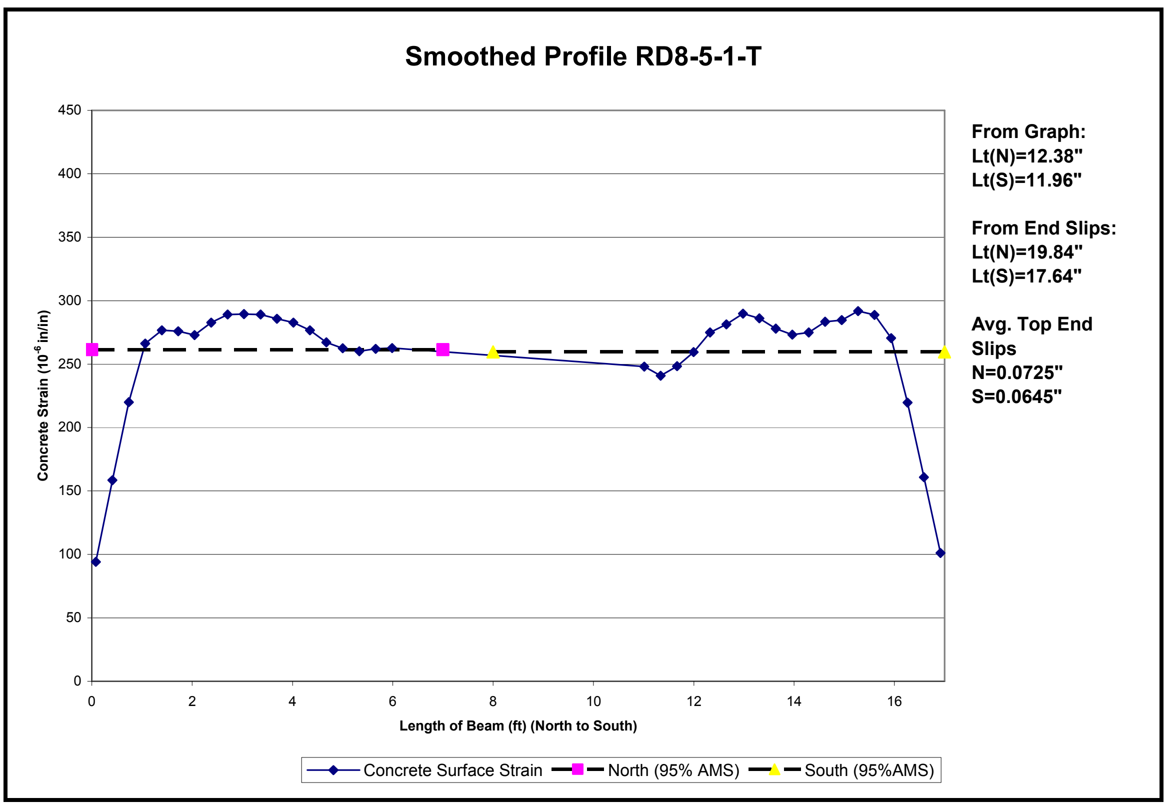
APPENDIX D
SMOOTHED STRAIN PROFILES FOR 0.5 IN. DIAMETER STRAND "D" IN RECTANGULAR BEAMS


Smoothed Strain Profile for RD4-5-1
Concrete Strain (10^{-6} in/in)
Specimen Length (ft) (North to South)
Concrete Surface Strain
North (95%AMS)
South (95%AMS)
From Graph:
Lt(N)=25.57
Lt(S)=24.79"
From End
Slips:
Lt(N)=32.78"
Lt(S)=31.02"
Avg. End
Slips
N=0.119"
S=0.112"

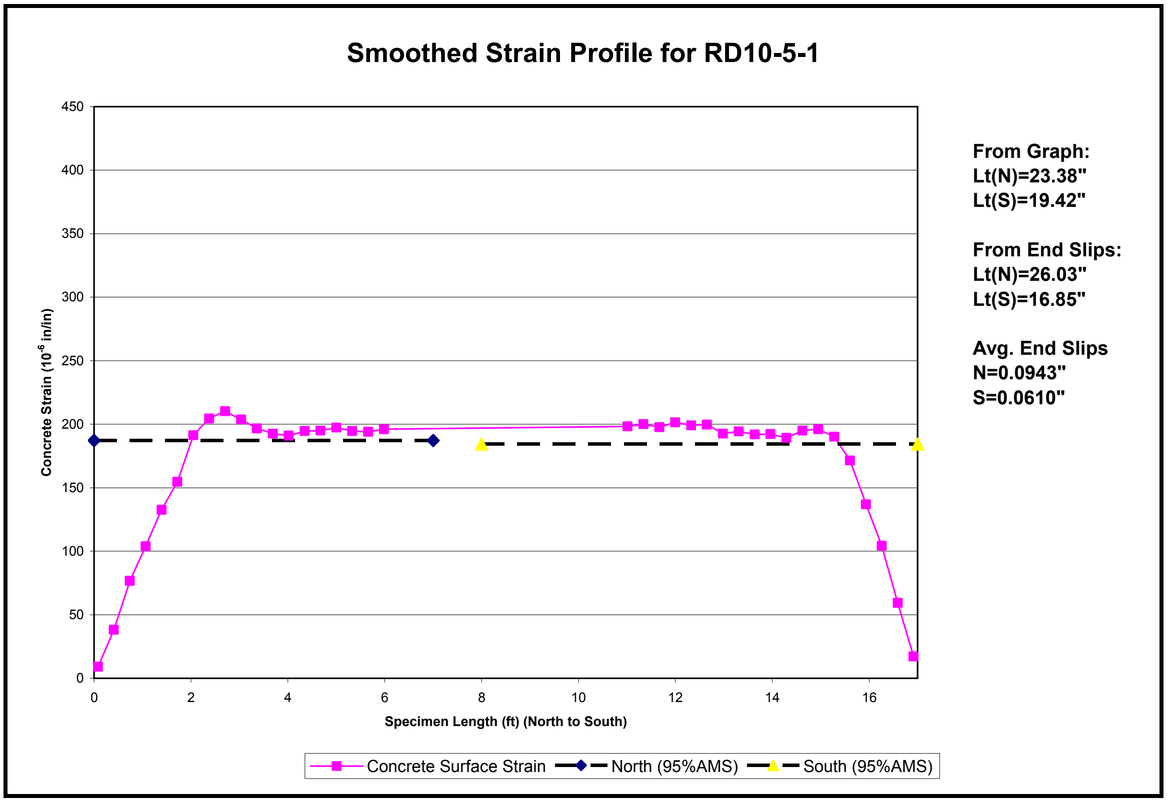

Smoothed Strain Profile for RD6A-5-1
Concrete Strain (10^{-6} in/in)
Specimen Length (ft) (North to South)
Concrete Strain
North (95%AMS)
South (95%AMS)
From Graph:
Lt(N)=39.01"
Lt(S)=26.35"
From End
Slips:
Lt(N)=35.40"
Lt(S)=29.10"
Avg.End Slip
N=0.1284"
S=0.1055"



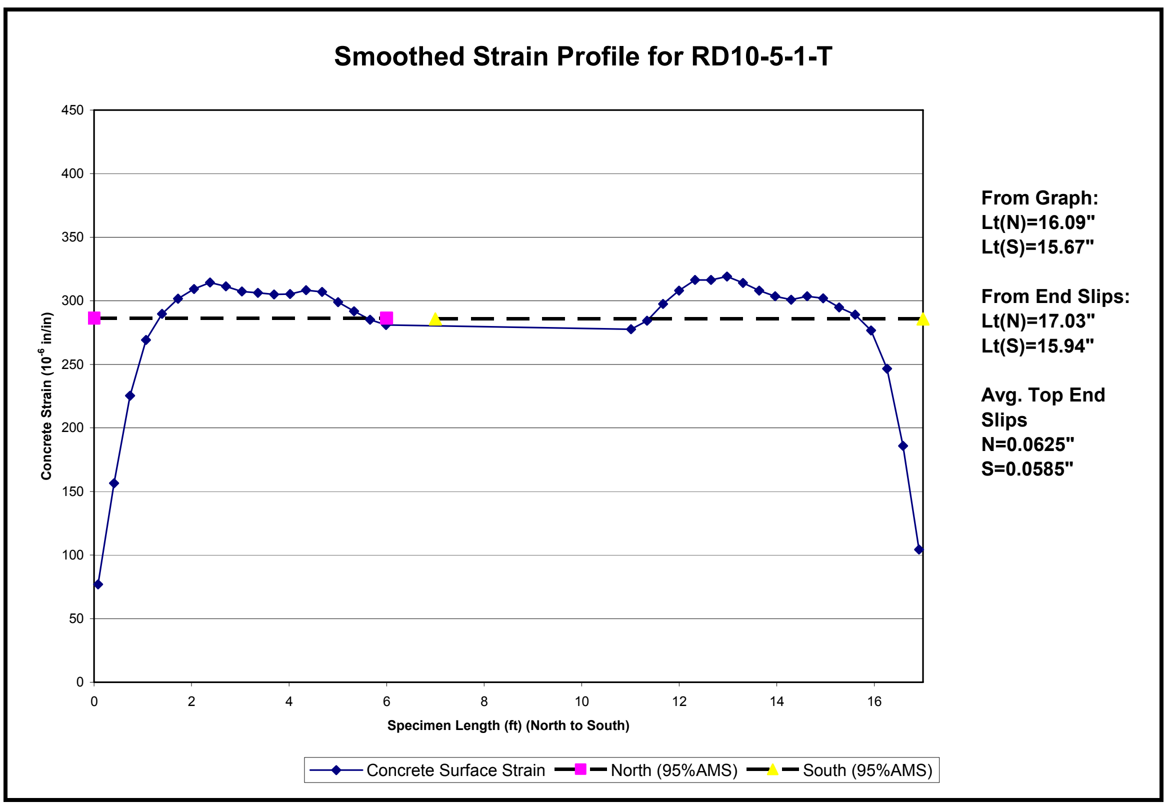
Smoothed Strain Profile for RD8-5-1
Concrete Strain (10^{-6} in/in)
Specimen Length (ft) (North to South)
Smoothed RD8-5-1
North (95%AMS)
South (95%AMS)
From Graph:
Lt(N)=11.32"
Lt(S)=18.49"
From End Slips:
Lt(N)=20.15"
Lt(S)=20.15"
Avg. End Slip
N=0.0733"
S=0.0733"



Smoothed Profile RD8-5-1-T
Concrete Strain (10^{-6} in/in)
Length of Beam (ft) (North to South)
Concrete Surface Strain
North (95% AMS)
South (95%AMS)
From Graph:
Lt(N)=12.38"
Lt(S)=11.96"
From End Slips:
Lt(N)=19.84"
Lt(S)=17.64"
Avg. Top End Slips
N=0.0725"
S=0.0645"

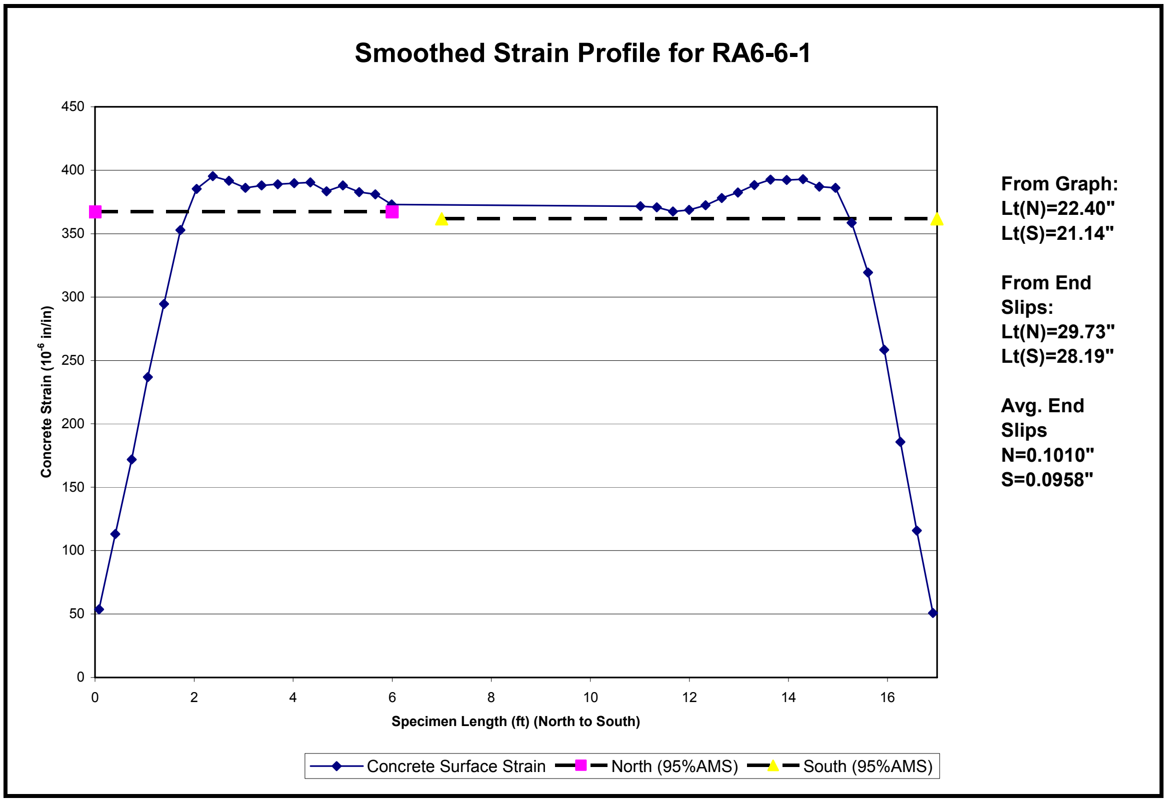


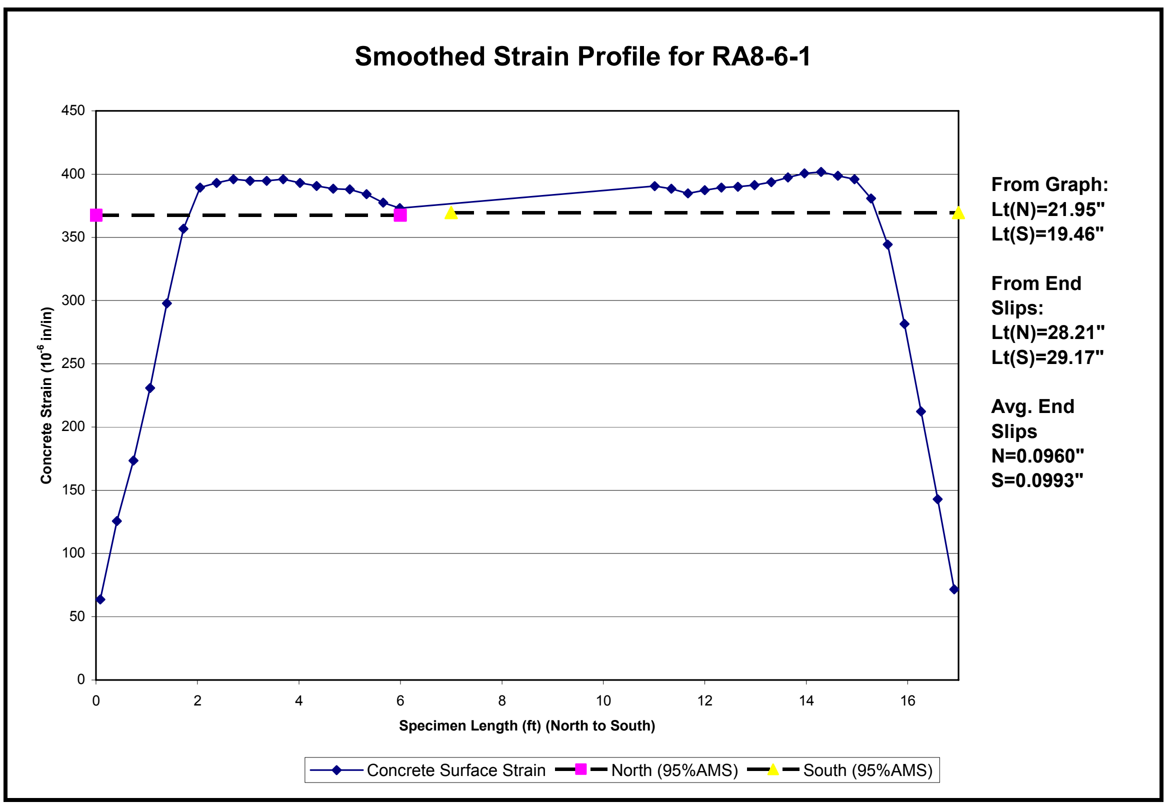
Smoothed Strain Profile for RD10-5-1
Concrete Strain (10^{-6} in/in)
Specimen Length (ft) (North to South)
Concrete Surface Strain
North (95%AMS)
South (95%AMS)
From Graph:
Lt(N)=23.38"
Lt(S)=19.42"
From End Slips:
Lt(N)=26.03"
Lt(S)=16.85"
Avg. End Slips
N=0.0943"
S=0.0610"

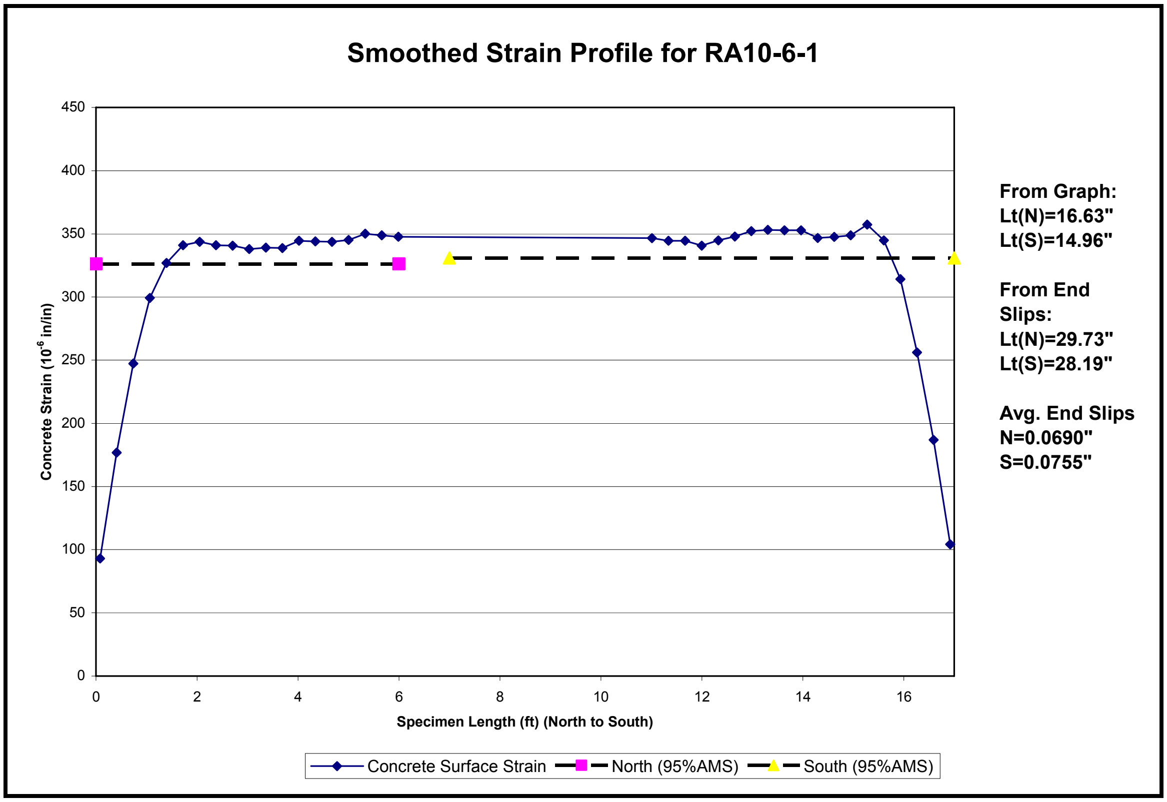


Smoothed Strain Profile for RD10-5-1-T
Concrete Strain (10^{-6} in/in)
Specimen Length (ft) (North to South)
Concrete Surface Strain
North (95%AMS)
South (95%AMS)
From Graph:
Lt(N)=16.09"
Lt(S)=15.67"
From End Slips:
Lt(N)=17.03"
Lt(S)=15.94"
Avg. Top End Slips
N=0.0625"
S=0.0585"

APPENDIX E
SMOOTHED STRAIN PROFILES FOR 0.6 IN. DIAMETER STRAND “A” IN RECTANGULAR BEAMS

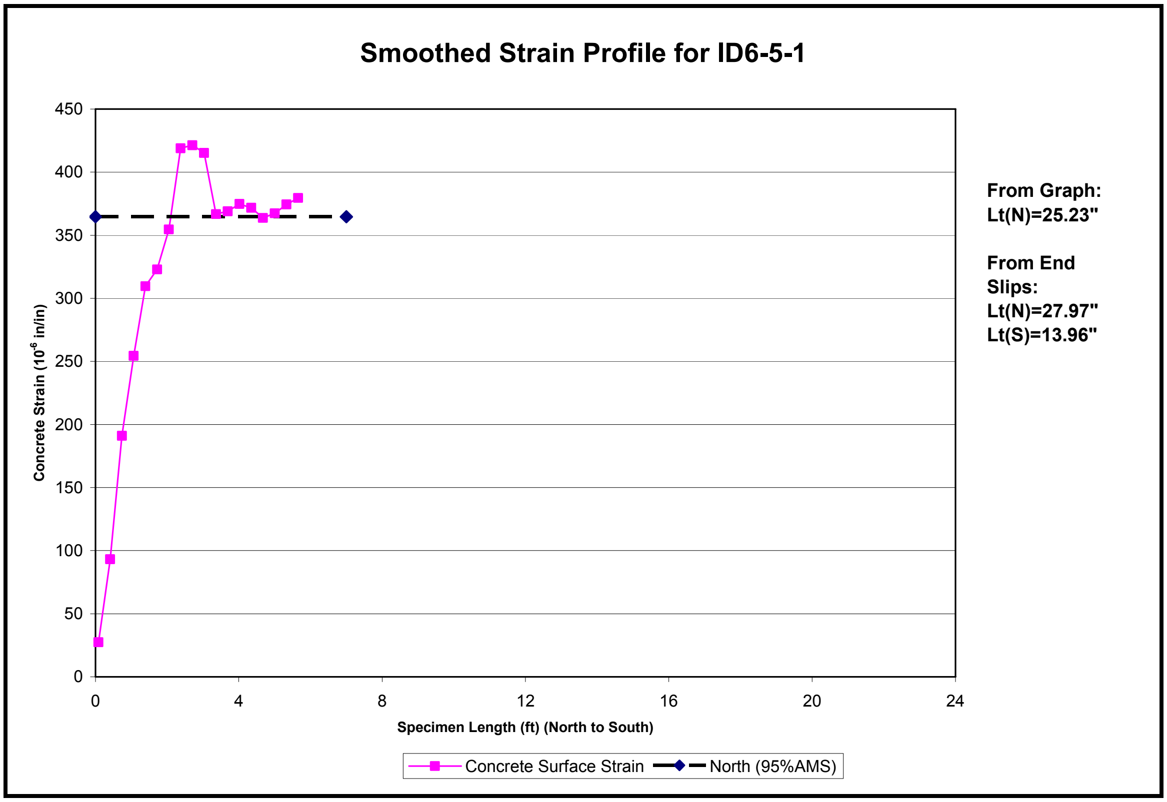

Smoothed Strain Profile for RA6-6-1
Concrete Strain (10^{-6} in/in)
Specimen Length (ft) (North to South)
Concrete Surface Strain
North (95%AMS)
South (95%AMS)
From Graph:
Lt(N)=22.40"
Lt(S)=21.14"
From End Slips:
Lt(N)=29.73"
Lt(S)=28.19"
Avg. End Slips
N=0.1010"
S=0.0958"

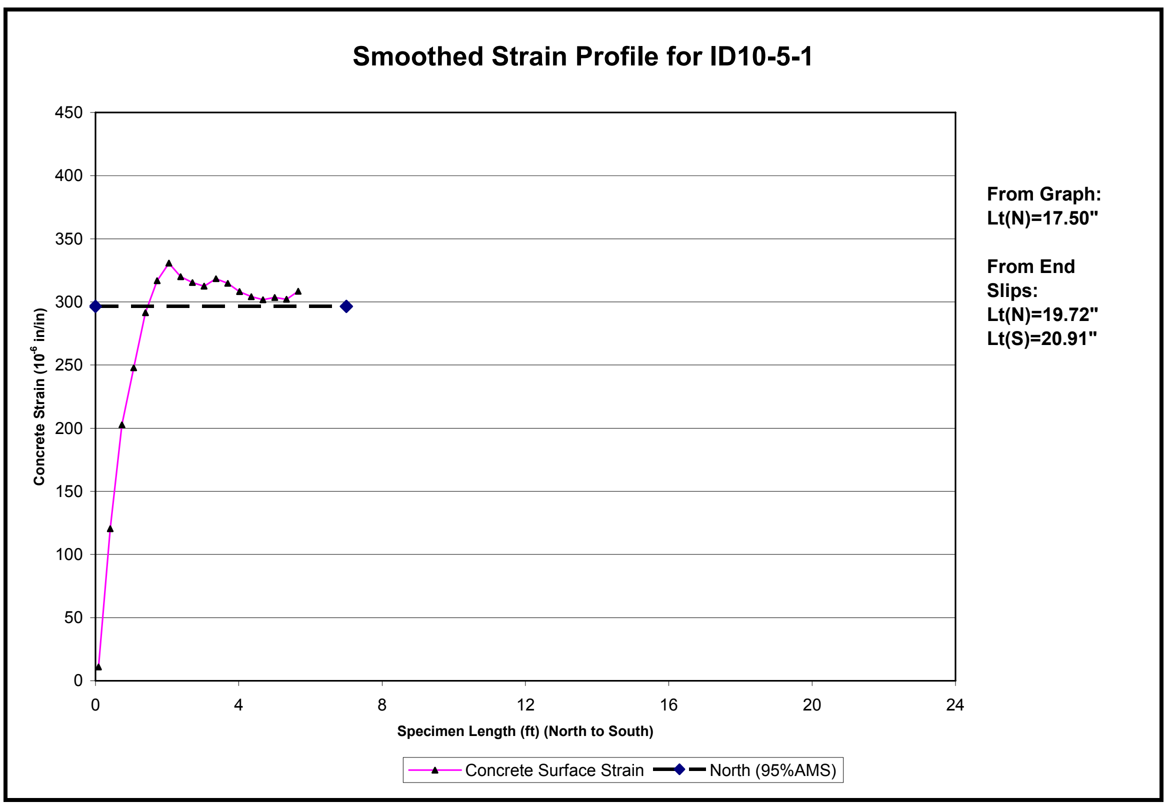

Smoothed Strain Profile for RA8-6-1
Concrete Strain (10^{-6} in/in)
Specimen Length (ft) (North to South)
Concrete Surface Strain
North (95%AMS)
South (95%AMS)
From Graph:
Lt(N)=21.95"
Lt(S)=19.46"
From End Slips:
Lt(N)=28.21"
Lt(S)=29.17"
Avg. End Slips
N=0.0960"
S=0.0993"

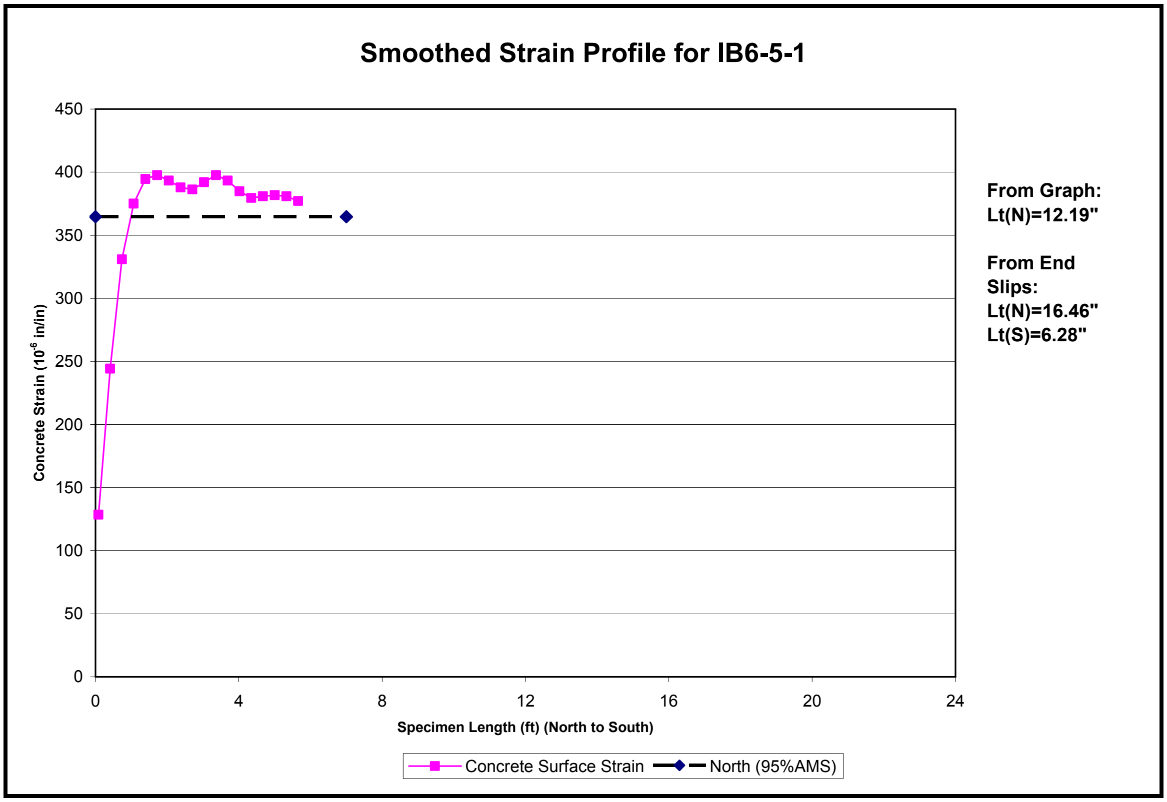


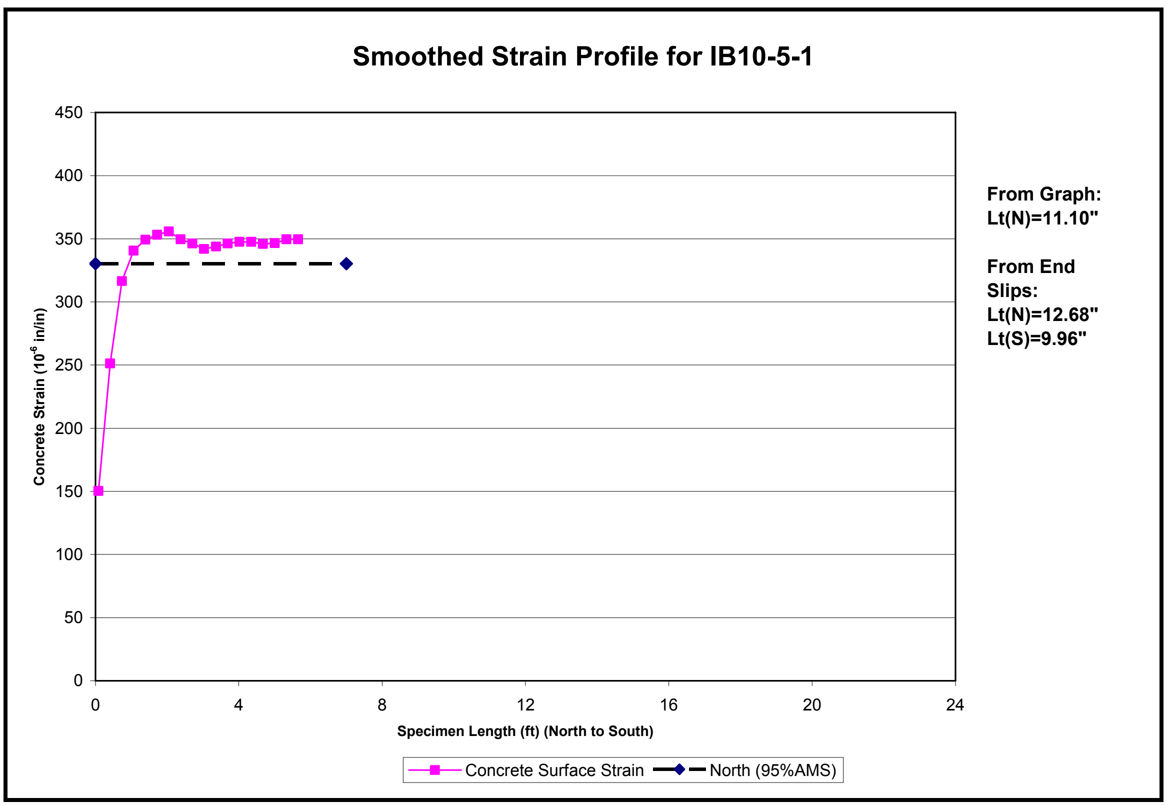
Smoothed Strain Profile for RA10-6-1
Concrete Strain (10^-6 in/in)
450
400
350
300
250
200
150
100
50
0
0
2
4
6
8
10
12
14
16
Specimen Length (ft) (North to South)
Concrete Surface Strain
North (95%AMS)
South (95%AMS)
From Graph:
Lt(N)=16.63"
Lt(S)=14.96"
From End Slips:
Lt(N)=29.73"
Lt(S)=28.19"
Avg. End Slips
N=0.0690"
S=0.0755"

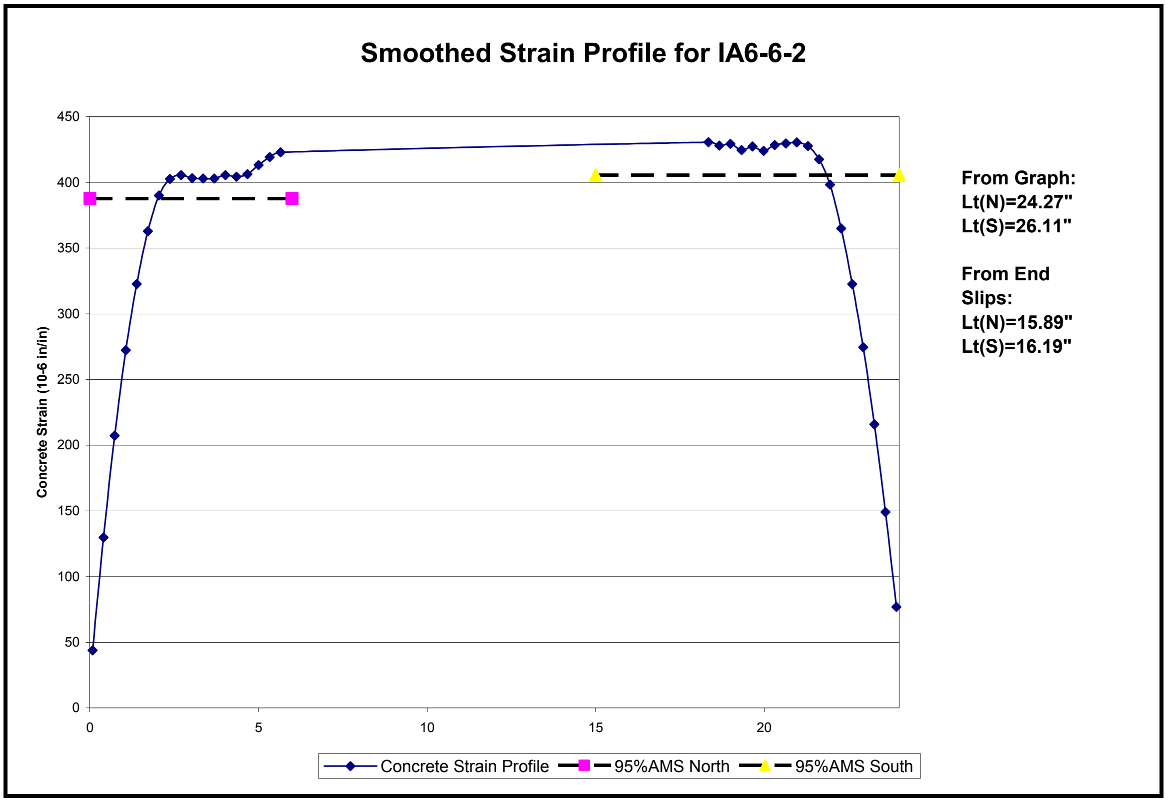
APPENDIX F
SMOOTHED STRAIN PROFILES FOR ALL STRANDS IN I-SHAPED BEAMS


Smoothed Strain Profile for ID6-5-1
Concrete Strain (10^{-6} in/in)
Specimen Length (ft) (North to South)
Concrete Surface Strain
North (95%AMS)
From Graph:
Lt(N)=25.23"
From End Slips:
Lt(N)=27.97"
Lt(S)=13.96"

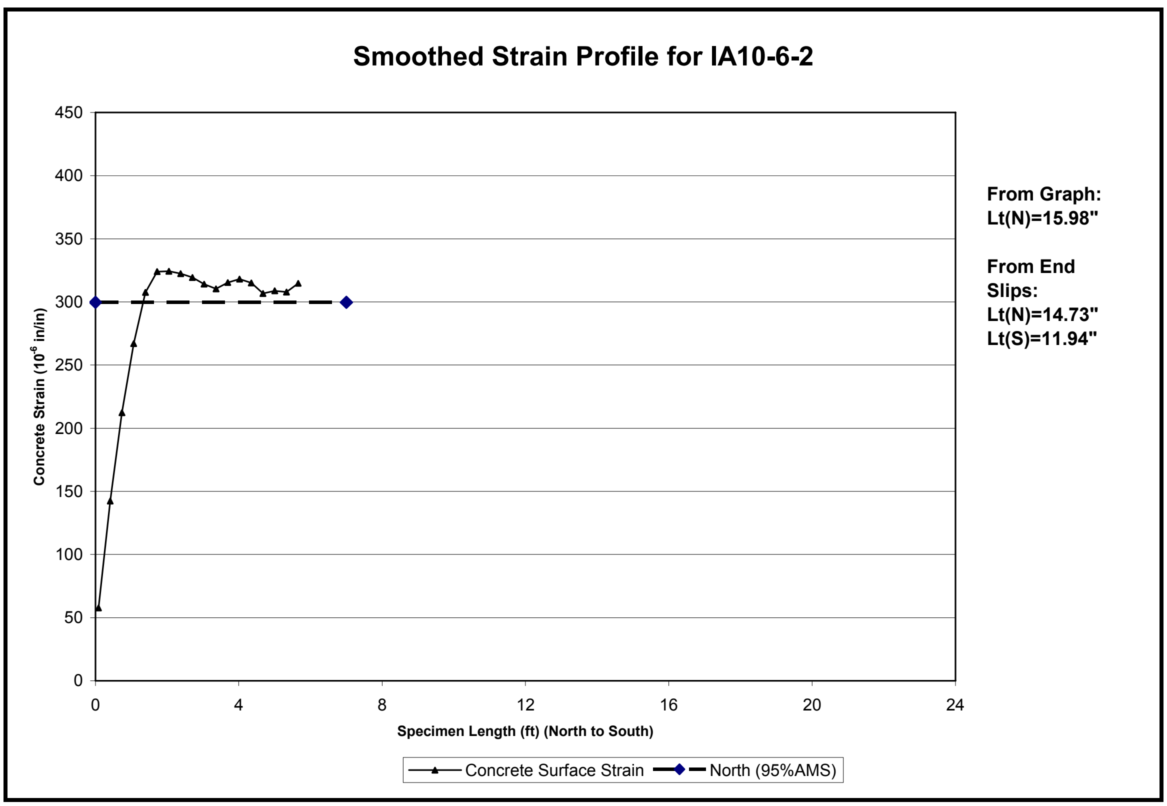

Smoothed Strain Profile for ID10-5-1
Concrete Strain (10^{-6} in/in)
Specimen Length (ft) (North to South)
Concrete Surface Strain
North (95%AMS)
From Graph:
Lt(N)=17.50"
From End Slips:
Lt(N)=19.72"
Lt(S)=20.91"


Smoothed Strain Profile for IB6-5-1
450
400
350
300
250
200
150
100
50
0
Concrete Strain (10^{-6} in/in)
0
4
8
12
16
20
24
Specimen Length (ft) (North to South)
Concrete Surface Strain
North (95%AMS)
From Graph:
Lt(N)=12.19"
From End
Slips:
Lt(N)=16.46"
Lt(S)=6.28"


Smoothed Strain Profile for IB10-5-1
450
400
350
300
250
200
150
100
50
0
Concrete Strain (10^{-6} in/in)
0
4
8
12
16
20
24
Specimen Length (ft) (North to South)
Concrete Surface Strain
North (95%AMS)
From Graph:
Lt(N)=11.10"
From End
Slips:
Lt(N)=12.68"
Lt(S)=9.96"



Smoothed Strain Profile for IA6-6-2
Concrete Strain (10-6 in/in)
450
400
350
300
250
200
150
100
50
0
0
5
10
15
20
Concrete Strain Profile
95%AMS North
95%AMS South
From Graph:
Lt(N)=24.27"
Lt(S)=26.11"
From End
Slips:
Lt(N)=15.89"
Lt(S)=16.19"



Smoothed Strain Profile for IA10-6-2
Concrete Strain (10-6 in/in)
450
400
350
300
250
200
150
100
50
0
0
4
8
12
16
20
24
Specimen Length (ft) (North to South)
Concrete Surface Strain
North (95%AMS)
From Graph:
Lt(N)=15.98"
From End
Slips:
Lt(N)=14.73"
Lt(S)=11.94"

APPENDIX G
END SLIP DATA

End Slip Data for Beam -RB4-5-1

Date cast: 31-Mar-05 Date tested: 1-Apr-05

Slip Reading on 20-Jul-05

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Hema	NW	0.218	0.148	0.070	NW	0.139	0.139	0.139	0.080
	NE	0.233	0.171	0.062	NE	0.154	0.154	0.154	0.079
	SW	0.573	0.507	0.066	SW	0.496	0.496	0.496	0.078
	SE	0.509	0.443	0.066	SE	0.439	0.439	0.439	0.069

Bottom	Strand End	Initial	After Release	Difference
Eden	NW	0.219	0.148	0.071
	NE	0.233	0.172	0.061
	SW	0.575	0.508	0.067
	SE	0.507	0.441	0.066

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.071	0.001
	NE	0.062	0.001
	SW	0.066	0.001
	SE	0.066	0.000

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#5	31-Mar-05	B	East	16.1875	0.007211
#5	31-Mar-05	B	West	16	0.007127

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	19.78	17.06	18.66	18.31	Bottom
111	22.31	21.91	21.89	19.14	Bottom

End Slip Data for Beam -RB4-5-2

Date cast: 31-Mar-05 Date tested: 1-Apr-05

Slip Reading on 22-Jul-05

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Hema	NW	0.208	0.143	0.065	NW	0.134	0.134	0.134	0.075
	NE	0.218	0.130	0.088	NE	0.13	0.13	0.130	0.087
	SW	0.229	0.150	0.079	SW	0.146	0.146	0.146	0.084
	SE	0.303	0.221	0.082	SE	0.216	0.216	0.216	0.087

Bottom	Strand End	Initial	After Release	Difference
Eden	NW	0.209	0.145	0.064
	NE	0.216	0.130	0.086
	SW	0.230	0.149	0.081
	SE	0.303	0.223	0.080

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.0645	0.001
	NE	0.0870	0.001
	SW	0.0800	0.001
	SE	0.0810	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#5	31-Mar-05	B	East	16.1875	0.007211
#5	31-Mar-05	B	West	16	0.007127

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	18.10	24.13	22.45	22.47	Bottom
113	20.91	24.13	23.43	24.13	Bottom

End Slip Data for Beam -RD4-5-1

Date cast: 31-Mar-05 Date tested: 1-Apr-05

Slip Reading on 21-Jul-05

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Kiran	NW	0.657	0.534	0.123	NW	0.519	0.519	0.519	0.140
	NE	0.639	0.526	0.113	NE	0.500	0.500	0.500	0.139
	SW	0.481	0.372	0.109	SW	0.324	0.324	0.324	0.158
	SE	0.466	0.351	0.115	SE	0.318	0.318	0.318	0.148

Bottom	Strand End	Initial	After Release	Difference
Amol	NW	0.660	0.534	0.126
	NE	0.639	0.527	0.112
	SW	0.482	0.371	0.111
	SE	0.466	0.353	0.113

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.125	0.002
	NE	0.113	0.001
	SW	0.110	0.001
	SE	0.114	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#5	1-Apr-05	D	East	15.9375	0.0071
#5	1-Apr-05	D	West	16.5	0.00735

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	33.88	31.69	29.93	32.11	Bottom
111	37.96	39.16	42.86	41.69	Bottom

End Slip Data for Beam -RD4-5-2

Date cast: 31-Mar-05 Date tested: 1-Apr-05

Bottom	Strand End	Initial	After Release	Difference
Kiran	NW	1.249	1.076	0.173
	NE	0.248	0.118	0.130
	SW	0.211	0.033	0.178
	SE	0.246	0.069	0.177

Slip Reading on 25-Jul-05

Top	KIR	EDEN	AVERAGE
NW	0.974	0.974	0.974
NE	0.068	0.068	0.068
SW	0.031	0.031	0.031
SE	0.054	0.054	0.054

Bottom	Strand End	Initial	After Release	Difference
Amol	NW	1.251	1.075	0.176
	NE	0.250	0.118	0.132
	SW	0.214	0.032	0.182
	SE	0.247	0.066	0.181

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.175	0.002
	NE	0.131	0.001
	SW	0.180	0.003
	SE	0.179	0.003

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#5	31-Mar-05	D	East	15.9375	0.0071
#5	31-Mar-05	D	West	16.5	0.00735

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	47.48	36.90	48.98	50.43	Bottom
116	75.10	50.99	49.39	54.23	Bottom

End Slip Data for Beam -RA4-6-1

Date cast: 31-Mar-05 Date tested: 1-Apr-05

Dev Length Test 12-Aug-05

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Kiran	NW	0.206	0.096	0.110	NW			0.040	0.167
	NE	0.092	-0.029	0.121	NE			0.967	-0.874
	SW	0.662	0.580	0.082	SW			0.570	0.091
	SE	0.686	0.596	0.090	SE			0.576	0.111

Bottom	Strand End	Initial	After Release	Difference
Amol	NW	0.208	0.094	0.114
	NE	0.094	-0.028	0.122
	SW	0.659	0.577	0.082
	SE	0.688	0.593	0.095

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.112	0.003
	NE	0.122	0.001
	SW	0.082	0.000
	SE	0.093	0.004

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#5	31-Mar-05	D	East	15.75	0.006884
#5	31-Mar-05	D	West	16.25	0.007102

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	31.54	35.30	23.09	26.88	Bottom
134	47.03	36.61	25.49	32.25	Bottom

End Slip Data for Beam -RA4-6-2

Date cast: 31-Mar-05 Date tested: 1-Apr-05

Slip Reading on 15-Aug-05

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
	NW	0.210	0.102	0.108	NW			0.054	0.156
	NE	0.220	0.117	0.103	NE			0.112	0.109
	SW	0.116	0.018	0.098	SW			0.015	0.100
Kiran	SE	0.169	0.061	0.108	SE			0.036	0.132

Bottom	Strand End	Initial	After Release	Difference
	NW	0.209	0.100	0.109
	NE	0.221	0.118	0.103
	SW	0.114	0.017	0.097
Amol	SE	0.166	0.059	0.107

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.109	0.001
	NE	0.103	0.000
	SW	0.098	0.001
	SE	0.108	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#5	31-Mar-05	D	East	15.75	0.006884
#5	31-Mar-05	D	West	16.25	0.007102

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	30.55	29.93	27.46	31.23	Bottom
137	43.79	31.52	28.16	38.21	Bottom

End Slip Data for Beam -RA6A-5-1

Date cast: 27-Jul-04 Date tested: 28-Jul-04

Slip Reading on 4-Mar-05

Bottom	Strand End	Initial	After Release	Difference	Bottom	KIR	EDEN	AVERAGE	Difference
ET	NW	0.820	0.757	0.063	NW	0.729	0.730	0.730	0.088
	NE	0.817	0.747	0.070	NE	0.714	0.712	0.713	0.104
	SW	0.801	0.739	0.062	SW	0.698	0.700	0.699	0.104
	SE	0.814	0.751	0.063	SE	0.710	0.709	0.710	0.103

Slip Reading on 5-Nov-04

Bottom	Strand End	Initial	After Release	Difference	Bottom	KIR	EDEN	AVERAGE	Difference
KS	NW	0.817	0.757	0.060	NW	0.730	0.731	0.731	0.088
	NE	0.815	0.747	0.068	NE	0.713	0.714	0.714	0.103
	SW	0.803	0.739	0.064	SW	0.700	0.701	0.701	0.102
	SE	0.811	0.749	0.062	SE	0.712	0.710	0.711	0.102

Bottom	Strand End	Initial	After Release	Difference
KC	NW	0.817	0.766	0.051
	NE	0.816	0.747	0.069
	SW	0.804	0.735	0.069
	SE	0.812	0.748	0.064

Bottom	Strand End	Initial	After Release	Difference
JH	NW	0.818	0.758	0.060
	NE	0.819	0.746	0.073
	SW	0.802	0.739	0.063
	SE	0.814	0.749	0.065

Data Analysis: Differences

Bottom	Strand End	Average Differenc	Standard Deviation
	NW	0.058	0.005
	NE	0.070	0.002
	SW	0.065	0.003
	SE	0.064	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#1	27-Jul-04	A	East	16.375	0.00726911
#1	27-Jul-04	A	West	16.25	0.00721362

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	16.22	19.26	17.88	17.47	Bottom
101	24.26	28.41	28.28	28.00	Bottom
220	24.54	28.55	28.70	28.41	Bottom

End Slip Data for Beam -RA6A-5-2

Date cast: 27-Jul-04 Date tested: 28-Jul-04

Bottom	Strand End	Initial	After Release	Difference	Bottom	KIR	EDEN	AVERAGE	Difference
					Slip Reading on		4-Mar-05		
Eden	NW	0.835	0.755	0.080	NW	0.730	0.729	0.730	0.107
	NE	0.834	0.736	0.098	NE	0.711	0.711	0.711	0.124
	SW	0.800	0.724	0.076	SW	0.701	0.698	0.700	0.103
	SE	0.817	0.736	0.081	SE	0.707	0.708	0.708	0.110

Bottom	Strand End	Initial	After Release	Difference	Bottom	KIR	EDEN	AVERAGE	Difference
					Slip Reading on		5-Nov-04		
Krista	NW	0.835	0.756	0.079	NW	0.730	0.732	0.731	0.105
	NE	0.833	0.737	0.096	NE	0.712	0.712	0.712	0.123
	SW	0.801	0.723	0.078	SW	0.703	0.705	0.704	0.098
	SE	0.818	0.735	0.083	SE	0.704	0.707	0.706	0.112

Bottom	Strand End	Initial	After Release	Difference
Kiran	NW	0.837	0.754	0.083
	NE	0.836	0.739	0.097
	SW	0.803	0.725	0.078
	SE	0.818	0.736	0.082

Bottom	Strand End	Initial	After Release	Difference
Josh	NW	0.837	0.753	0.084
	NE	0.835	0.742	0.093
	SW	0.804	0.727	0.077
	SE	0.818	0.735	0.083

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.082	0.002
	NE	0.096	0.002
	SW	0.077	0.001
	SE	0.082	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#1	7/27/2004	A	East	16.375	0.007269
#1	27-Jul-04	A	West	16.25	0.007214

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	22.60	26.41	21.42	22.63	Bottom
101	29.11	33.70	27.17	30.88	Bottom
220	29.53	33.98	28.42	30.33	Bottom

End Slip Data for Beam -RD6A-5-1

Date cast: 27-Jul-04 Date tested: 28-Jul-04

Bottom	Strand End	Initial	After Release	Difference	Bottom	KIR	EDEN	AVERAGE	Difference
					Slip Reading on		4-Mar-05		
Eden	NW	0.809	0.679	0.130	NW	0.664	0.662	0.663	0.146
	NE	0.818	0.688	0.130	NE	0.672	0.673	0.673	0.144
	SW	0.837	0.733	0.104	SW	0.702	0.709	0.706	0.132
	SE	0.820	0.709	0.111	SE	0.682	0.680	0.681	0.138

Bottom	Strand End	Initial	After Release	Difference	Bottom	KIR	EDEN	AVERAGE	Difference
					Slip Reading on		5-Nov-04		
Krista	NW	0.808	0.678	0.130	NW	0.667	0.667	0.667	0.142
	NE	0.816	0.686	0.130	NE	0.673	0.672	0.673	0.144
	SW	0.839	0.733	0.106	SW	0.709	0.707	0.708	0.129
	SE	0.817	0.709	0.108	SE	0.685	0.683	0.684	0.135

Bottom	Strand End	Initial	After Release	Difference
Kiran	NW	0.809	0.688	0.121
	NE	0.815	0.686	0.129
	SW	0.835	0.735	0.100
	SE	0.822	0.715	0.107

Bottom	Strand End	Initial	After Release	Difference
Josh	NW	0.810	0.683	0.127
	NE	0.816	0.686	0.130
	SW	0.837	0.733	0.104
	SE	0.817	0.713	0.104

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.127	0.004
	NE	0.130	0.001
	SW	0.104	0.003
	SE	0.108	0.003

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#1	7/27/2004	D	East	16.125	0.007158
#1	27-Jul-04	D	West	16.5625	0.007352

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	34.55	36.25	28.15	30.04	Bottom
101	38.63	40.16	35.09	37.72	Bottom
220	39.72	40.16	35.77	38.56	Bottom

End Slip Data for Beam -RD6A-5-2

Date cast: 27-Jul-04 Date tested: 28-Jul-04

Bottom	Strand End	Initial	After Release	Difference	Bottom	KIR	EDEN	AVERAGE	Difference
					Slip Reading on 04 March 2005				
Eden	NW	0.818	0.746	0.072	NW	0.710	0.707	0.709	0.111
	NE	0.818	0.741	0.077	NE	0.695	0.692	0.694	0.124
	SW	0.829	0.760	0.069	SW	0.700	0.698	0.699	0.129
	SE	0.848	0.764	0.084	SE	0.684	0.687	0.686	0.162

Bottom	Strand End	Initial	After Release	Difference	Bottom	KIR	EDEN	AVERAGE	Difference
					Slip Reading on 05 Nov 2004				
Krista	NW	0.819	0.745	0.074	NW	0.713	0.714	0.714	0.106
	NE	0.818	0.743	0.075	NE	0.702	0.699	0.701	0.117
	SW	0.828	0.761	0.067	SW	0.699	0.699	0.699	0.129
	SE	0.846	0.753	0.093	SE	0.690	0.691	0.691	0.157

Bottom	Strand End	Initial	After Release	Difference
Kiran	NW	0.818	0.745	0.073
	NE	0.817	0.743	0.074
	SW	0.829	0.759	0.070
	SE	0.845	0.780	0.065

Bottom	Strand End	Initial	After Release	Difference
Josh	NW	0.821	0.749	0.072
	NE	0.818	0.741	0.077
	SW	0.825	0.761	0.064
	SE	0.849	0.779	0.070

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.073	0.001
	NE	0.076	0.002
	SW	0.067	0.003
	SE	0.078	0.013

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#1	27-Jul-04	D	East	16.125	0.007158
#1	27-Jul-04	D	West	16.5625	0.007352

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	19.79	21.16	18.36	21.79	Bottom
101	28.70	32.76	35.02	43.73	Bottom
220	30.06	34.72	35.02	45.12	Bottom

End Slip Data for Beam -RA6-5-1

Date cast: 2-Aug-04 Date tested: 3-Aug-04

Slip Reading on 0 4-Mar-05

Bottom	Strand End	Initial	After Release	Difference	Bottom	KIR	EDEN	AVERAGE	Difference
Kiran	NW	0.837	0.772	0.065	NW	0.719	0.722	0.721	0.117
	NE	0.851	0.776	0.075	NE	0.725	0.724	0.725	0.127
	SW	0.829	0.771	0.058	SW	0.733	0.734	0.734	0.094
	SE	0.836	0.762	0.074	SE	0.711	0.713	0.712	0.123

Slip Reading on 5-Nov-04

Bottom	Strand End	Initial	After Release	Difference	Bottom	KIR	EDEN	AVERAGE	Difference
Josh	NW	0.838	0.775	0.063	NW	0.725	0.724	0.725	0.113
	NE	0.851	0.777	0.074	NE	0.725	0.725	0.725	0.126
	SW	0.827	0.768	0.059	SW	0.735	0.737	0.736	0.092
	SE	0.833	0.761	0.072	SE	0.713	0.713	0.713	0.122

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.064	0.001
	NE	0.075	0.001
	SW	0.058	0.001
	SE	0.073	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#3	8/2/2004	A	East	16.25	0.007214
#3	8/2/2004	A	West	16.3125	0.007241

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	17.68	20.66	16.16	20.24	Bottom
95	31.21	34.93	25.41	33.69	Bottom
214	32.31	35.07	26.10	33.96	Bottom

End Slip Data for Beam -RA6-5-2

Date cast: 2-Aug-04 Date tested: 3-Aug-04

Slip Reading on 04 March 2005

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Kiran	NW	0.732	0.671	0.061	NW	0.633	0.630	0.632	0.100
	NE	0.683	0.627	0.056	NE	0.580	0.583	0.582	0.102
	SW	0.779	0.713	0.066	SW	0.684	0.684	0.684	0.094
	SE	0.797	0.755	0.042	SE	0.721	0.721	0.721	0.076

Slip Reading on 05 Nov 2004

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Josh	NW	0.731	0.668	0.063	NW	0.634	0.635	0.635	0.097
	NE	0.684	0.625	0.059	NE	0.587	0.590	0.589	0.095
	SW	0.778	0.712	0.066	SW	0.685	0.683	0.684	0.094
	SE	0.796	0.753	0.043	SE	0.723	0.721	0.722	0.075

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.062	0.001
	NE	0.058	0.002
	SW	0.066	0.000
	SE	0.043	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#3	8/2/2004	A	East	16.25	0.007214
#3	8/2/2004	A	West	16.3125	0.007241

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	17.12	15.94	18.23	11.78	Bottom
95	26.79	26.34	26.10	20.66	Bottom
214	27.62	28.28	26.10	20.93	Bottom

End Slip Data for Beam -RA6-5-1-T

Date cast: 2-Aug-04 Date tested: 3-Aug-04

Top (Kiran)	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
					Slip Reading on 04 March 2005				
	NW	0.840	0.769	0.071	NW	0.718	0.717	0.718	0.122
	NE	0.845	0.766	0.079	NE	0.714	0.713	0.714	0.131
	SW	0.783	0.710	0.073	SW	0.650	0.647	0.649	0.136
	SE	0.777	0.706	0.071	SE	0.658	0.658	0.658	0.119

Top (Josh)	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
					Slip Reading on 05 Nov 2004				
	NW	0.838	0.768	0.070	NW	0.718	0.717	0.718	0.122
	NE	0.843	0.768	0.075	NE	0.715	0.714	0.715	0.130
	SW	0.785	0.709	0.076	SW	0.647	0.650	0.649	0.136
	SE	0.776	0.707	0.069	SE	0.657	0.658	0.658	0.119

Bottom (Kiran)	Strand End	Initial	After Release	Difference	Bottom	KIR	EDEN	AVERAGE	Difference
					Slip Reading on 04 March 2005				
	NW	0.836	0.764	0.072	NW	0.710	0.707	0.709	0.128
	NE	0.887	0.817	0.070	NE	0.770	0.770	0.770	0.118
	SW	0.897	0.828	0.069	SW	0.795	0.797	0.796	0.100
	SE	0.94	0.873	0.067	SE	0.835	0.835	0.835	0.107

Bottom (Josh)	Strand End	Initial	After Release	Difference	Bottom	KIR	EDEN	AVERAGE	Difference
					Slip Reading on 05 Nov 2004				
	NW	0.837	0.762	0.075	NW	0.708	0.710	0.709	0.128
	NE	0.889	0.817	0.072	NE	0.771	0.768	0.770	0.119
	SW	0.895	0.829	0.066	SW	0.795	0.797	0.796	0.100
	SE	0.943	0.873	0.070	SE	0.838	0.835	0.837	0.105

Data Analysis: Differences

Top	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.071	0.001
	NE	0.077	0.003
	SW	0.075	0.002
	SE	0.070	0.001

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.074	0.002
	NE	0.071	0.001
	SW	0.068	0.002
	SE	0.068	0.002

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#3	2-Aug-04	A	East-T	16.5	0.007325
#3	2-Aug-04	A	West-T	16.3125	0.007241
#3	8/2/2004	A	East-B	16.5	0.007325
#3	8/2/2004	A	West-B	16.0625	0.00713

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	19.47	21.03	20.58	19.11	Top
1	20.62	19.39	18.93	18.70	Bottom
95	33.56	35.63	37.42	32.36	Top
95	33.56	35.36	37.42	32.49	Top
214	35.76	32.36	28.05	28.67	Bottom
214	35.90	32.22	28.05	29.08	Bottom

End Slip Data for Beam -RA6-5-2-T

Date cast: 2-Aug-04 Date tested: 3-Aug-04

Top	Strand End	Initial	After Release	Difference	Slip Reading on 04 March 2005: Top	KIR	EDEN	AVERAGE	Difference
	NW	0.843	0.763	0.080	NW	0.698	0.700	0.699	0.143
	NE	0.844	0.783	0.061	NE	0.690	0.691	0.691	0.154
	SW	0.820	0.759	0.061	SW	0.637	0.640	0.639	0.182
Kiran	SE	0.766	0.706	0.060	SE	0.678	0.675	0.677	0.091

Top	Strand End	Initial	After Release	Difference	Slip Reading on 09 Nov 2004: Top	KIR	EDEN	AVERAGE	Difference
	NW	0.840	0.762	0.078	NW	0.702	0.704	0.703	0.139
	NE	0.844	0.780	0.064	NE	0.697	0.695	0.696	0.148
	SW	0.820	0.760	0.060	SW	0.637	0.639	0.638	0.182
Josh	SE	0.769	0.708	0.061	SE	0.677	0.680	0.679	0.089

Bottom	Strand End	Initial	After Release	Difference	Slip Reading on 04 March 2005: Bottom	KIR	EDEN	AVERAGE	Difference
	NW	0.861	0.795	0.066	NW	0.681	0.683	0.682	0.180
	NE	0.858	0.791	0.067	NE	0.679	0.682	0.681	0.178
	SW	0.859	0.800	0.059	SW	0.696	0.693	0.695	0.165
Kiran	SE	0.850	0.781	0.069	SE	0.701	0.702	0.702	0.149

Bottom	Strand End	Initial	After Release	Difference	Slip Reading on 09 Nov 2004: Bottom	KIR	EDEN	AVERAGE	Difference
	NW	0.863	0.793	0.070	NW	0.689	0.686	0.688	0.175
	NE	0.859	0.789	0.070	NE	0.688	0.687	0.688	0.171
	SW	0.859	0.802	0.057	SW	0.699	0.700	0.700	0.160
Josh	SE	0.850	0.781	0.069	SE	0.701	0.701	0.701	0.149

Data Analysis: Differences

Top	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.079	0.001
	NE	0.062	0.002
	SW	0.060	0.001
	SE	0.061	0.001

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.068	0.003
	NE	0.068	0.002
	SW	0.058	0.001
	SE	0.069	0.000

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#3	2-Aug-04	A	East-T	16.5	0.007325
#3	2-Aug-04	A	West-T	16.3125	0.007241
#3	8/2/2004	A	East-B	16.5	0.007325
#3	8/2/2004	A	West-B	16.0625	0.00713

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	
1	21.82	17.07	16.71	16.52	Top
1	19.07	18.70	16.27	18.84	Bottom
95	38.25	40.41	50.27	24.30	Top
95	48.95	46.69	44.74	40.68	Bottom
214	39.36	41.91	50.13	24.85	Top
214	50.49	48.60	46.14	40.55	Bottom

End Slip Data for Beam -RD6-5-1

Date cast: 2-Aug-04 Date tested: 3-Aug-04

Slip Reading on 04 March 2005

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Eden	NW	0.812	0.700	0.112	NW	0.617	0.615	0.616	0.196
	NE	0.812	0.702	0.110	NE	0.645	0.642	0.644	0.169
	SW	0.865	0.771	0.094	SW	0.700	0.697	0.699	0.167
	SE	0.828	0.717	0.111	SE	0.665	0.662	0.664	0.165

Slip Reading on 05 Nov2004

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Krista	NW	0.812	0.699	0.113	NW	0.632	0.631	0.632	0.181
	NE	0.812	0.704	0.108	NE	0.651	0.648	0.650	0.163
	SW	0.866	0.771	0.095	SW	0.700	0.701	0.701	0.165
	SE	0.828	0.717	0.111	SE	0.669	0.667	0.668	0.160

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.113	0.001
	NE	0.109	0.001
	SW	0.095	0.001
	SE	0.111	0.000

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#3	8/2/2004	D	East	16.4375	0.007297
#3	8/2/2004	D	West	16.5625	0.007352

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	30.60	29.88	25.71	30.42	Bottom
95	49.10	44.54	44.88	43.85	Bottom
214	53.32	46.18	45.43	45.09	Bottom

End Slip Data for Beam -RD6-5-2

Date cast: 2-Aug-04 Date tested: 3-Aug-04

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
					Slip Reading on 04 March 2005				
Eden	NW	0.717	0.621	0.096	NW	0.560	0.557	0.559	0.158
	NE	0.751	0.658	0.093	NE	0.585	0.585	0.585	0.166
	SW	0.665	0.560	0.105	SW	0.490	0.492	0.491	0.174
	SE	0.654	0.544	0.110	SE	0.473	0.475	0.474	0.180

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
					Slip Reading on 05 Nov 2004				
Krista	NW	0.716	0.622	0.094	NW	0.565	0.568	0.567	0.150
	NE	0.751	0.659	0.092	NE	0.595	0.592	0.594	0.158
	SW	0.664	0.561	0.103	SW	0.503	0.506	0.505	0.160
	SE	0.654	0.544	0.110	SE	0.485	0.488	0.487	0.168

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.095	0.001
	NE	0.093	0.001
	SW	0.104	0.001
	SE	0.110	0.000

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#3	8/2/2004	D	East	16.4375	0.007297
#3	8/2/2004	D	West	16.5625	0.007352

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	25.84	25.35	28.29	30.15	Bottom
95	42.98	45.50	47.20	49.34	Bottom
214	40.80	43.17	43.52	45.91	Bottom

End Slip Data for Beam -RD6-5-1-T

Date cast: 2-Aug-04 Date tested: 3-Aug-04

Top	Strand End	Initial	After Release	Difference	Slip Reading on 04 March 2005 Top	KIR	EDEN	AVERAGE	Difference
Eden	NW	0.799	0.702	0.097	NW	0.590	0.588	0.589	0.211
	NE	0.805	0.708	0.097	NE	0.597	0.598	0.598	0.209
	SW	0.732	0.660	0.072	SW	0.570	0.569	0.570	0.162
	SE	0.769	0.693	0.076	SE	0.501	0.502	0.502	0.269

Top	Strand End	Initial	After Release	Difference	Slip Reading on 09 Nov 2004 Top	KIR	EDEN	AVERAGE	Difference
Krista	NW	0.801	0.701	0.100	NW	0.594	0.595	0.595	0.206
	NE	0.808	0.706	0.102	NE	0.604	0.601	0.603	0.204
	SW	0.731	0.658	0.073	SW	0.575	0.575	0.575	0.157
	SE	0.771	0.694	0.077	SE	0.506	0.504	0.505	0.265

Bottom	Strand End	Initial	After Release	Difference	Slip Reading on 04 March 2005 Bottom	KIR	EDEN	AVERAGE	Difference
Eden	NW	0.819	0.733	0.086	NW	0.655	0.656	0.656	0.164
	NE	0.845	0.756	0.089	NE	0.692	0.695	0.694	0.150
	SW	0.823	0.725	0.098	SW	0.658	0.661	0.660	0.163
	SE	0.824	0.732	0.092	SE	0.654	0.657	0.656	0.169

Bottom	Strand End	Initial	After Release	Difference	Slip Reading on 09 Nov 2004 Bottom	KIR	EDEN	AVERAGE	Difference
Krista	NW	0.819	0.734	0.085	NW	0.666	0.668	0.667	0.152
	NE	0.842	0.756	0.086	NE	0.699	0.696	0.698	0.146
	SW	0.821	0.725	0.096	SW	0.669	0.666	0.668	0.155
	SE	0.824	0.732	0.092	SE	0.670	0.670	0.670	0.154

Data Analysis: Differences

Top	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.099	0.002
	NE	0.100	0.004
	SW	0.073	0.001
	SE	0.077	0.001

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.086	0.001
	NE	0.088	0.002
	SW	0.097	0.001
	SE	0.092	0.000

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#3	2-Aug-04	D	East-T	16.0625	0.00713
#3	2-Aug-04	D	West-T	16.125	0.007158
#3	8/2/2004	D	East-B	16.5	0.007325
#3	8/2/2004	D	West-B	16.4375	0.007297

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	
1	27.52	27.91	20.26	21.46	Top
1	23.43	23.89	26.59	25.12	Bottom
95	57.42	57.22	43.73	74.33	Top
95	41.66	39.87	42.35	42.05	Bottom
214	58.95	58.62	45.26	75.31	Top
214	44.81	40.96	44.54	46.01	Bottom

End Slip Data for Beam -RD6-5-2-T

Date cast: 2-Aug-04 Date tested: 3-Aug-04

Slip Reading on 04 March 2005

Top (Eden)	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
	NW	0.832	0.748	0.084	NW	0.613	0.616	0.615	0.219
	NE	0.851	0.767	0.084	NE	0.618	0.616	0.617	0.233
	SW	0.823	0.731	0.092	SW	0.574	0.577	0.576	0.247
	SE	0.803	0.729	0.074	SE	0.658	0.661	0.660	0.143

Slip Reading on 05 Nov 2004

Top (Krista)	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
	NW	0.835	0.750	0.085	NW	0.660	0.663	0.662	0.172
	NE	0.849	0.764	0.085	NE	0.610	0.607	0.609	0.242
	SW	0.822	0.732	0.090	SW	0.624	0.624	0.624	0.199
	SE	0.801	0.731	0.070	SE	0.620	0.619	0.620	0.183

Slip Reading on 04 March 2005

Bottom (Eden)	Strand End	Initial	After Release	Difference	Bottom	KIR	EDEN	AVERAGE	Difference
	NW	0.828	0.739	0.089	NW				
	NE	0.875	0.781	0.094	NE	0.687	0.690	0.689	0.185
	SW	0.865	0.779	0.086	SW	0.610	0.612	0.611	0.255
	SE	0.918	0.844	0.074	SE				

Slip Reading on 05 Nov 2004

Bottom (Krista)	Strand End	Initial	After Release	Difference	Bottom	KIR	EDEN	AVERAGE	Difference
	NW	0.830	0.739	0.091	NW	0.575	0.573	0.574	0.255
	NE	0.872	0.779	0.093	NE	0.621	0.619	0.620	0.254
	SW	0.867	0.780	0.087	SW	0.703	0.701	0.702	0.164
	SE	0.917	0.845	0.072	SE	0.759	0.760	0.760	0.158

Data Analysis: Differences

Top	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.085	0.001
	NE	0.085	0.001
	SW	0.091	0.001
	SE	0.072	0.003

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.090	0.001
	NE	0.094	0.001
	SW	0.087	0.001
	SE	0.073	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#3	2-Aug-04	D	East-T	16.0625	0.00713
#3	2-Aug-04	D	West-T	16.125	0.007158
#3	8/2/2004	D	East-B	16.5	0.007325
#3	8/2/2004	D	West-B	16.4375	0.007297

Data Analysis: Inferred Transfer Lengths (in)

	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length
Top	23.61	23.70	25.43	20.20
Bottom	24.67	25.53	23.71	19.93
Top	48.06	67.74	55.46	51.19
Bottom	69.89	69.22	44.95	43.14
Top	61.19	65.35	69.01	39.97
Bottom		50.51	69.89	

End Slip Data for Beam -RA8-5-1

Date cast: 29-Jul-04 Date tested: 30-Jul-04

Slip Reading on 4-Mar-05

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Eden	NW	0.894	0.84	0.054	NW	0.800	0.798	0.799	0.096
	NE	0.885	0.839	0.046	NE	0.795	0.798	0.797	0.089
	SW	0.865	0.814	0.051	SW	0.780	0.779	0.780	0.085
	SE	0.884	0.834	0.050	SE	0.801	0.801	0.801	0.082

Slip Reading on 5-Nov-04

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Krista	NW	0.895	0.841	0.054	NW	0.819	0.817	0.818	0.077
	NE	0.886	0.843	0.043	NE	0.830	0.832	0.831	0.055
	SW	0.865	0.813	0.052	SW	0.785	0.788	0.787	0.079
	SE	0.881	0.834	0.047	SE	0.802	0.802	0.802	0.081

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.054	0.000
	NE	0.045	0.002
	SW	0.052	0.001
	SE	0.049	0.002

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#2	7/29/2004	A	East	16.6875	0.007408
#2	7/29/2004	A	West	16.6875	0.007408

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	14.6	12.0	13.9	13.1	Bottom
99	20.7	14.7	21.2	21.7	Bottom
218	25.8	24.0	23.1	22.0	Bottom

End Slip Data for Beam -RA8-5-2

Date cast: 29-Jul-04 Date tested: 30-Jul-04

Slip Reading on 04 March 2005

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Kiran	NW	0.903	0.839	0.064	NW	0.815	0.812	0.814	0.088
	NE	0.932	0.879	0.053	NE	0.758	0.755	0.757	0.173
	SW	0.859	0.809	0.050	SW	0.775	0.773	0.774	0.081
	SE	0.861	0.809	0.052	SE	0.789	0.787	0.788	0.067

Slip Reading on 05 Nov 2004

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Josh	NW	0.900	0.846	0.054	NW	0.819	0.817	0.818	0.084
	NE	0.927	0.877	0.050	NE	0.837	0.838	0.838	0.092
	SW	0.851	0.809	0.042	SW	0.775	0.777	0.776	0.079
	SE	0.849	0.814	0.035	SE	0.787	0.789	0.788	0.067

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.059	0.007
	NE	0.052	0.002
	SW	0.046	0.006
	SE	0.044	0.012

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#2	7/29/2004	A	East	16.6875	0.007408
#2	7/29/2004	A	West	16.6875	0.007408

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	15.93	13.90	12.42	11.74	Bottom
99	22.54	24.84	21.33	18.09	Bottom
218	23.76	46.71	21.87	18.09	Bottom

End Slip Data for Beam -RA8-5-1-T

Date cast: 29-Jul-04 Date tested: 30-Jul-04

					Slip Reading on 04 March 2005				
Top	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
	NW	0.842	0.804	0.038	NW	0.763	0.762	0.763	0.080
	NE	0.894	0.848	0.046	NE	0.795	0.795	0.795	0.102
	SW	0.942	0.890	0.052	SW	0.848	0.847	0.848	0.094
Kiran	SE	0.907	0.855	0.052	SE	0.807	0.805	0.806	0.102

					Slip Reading on 05 Nov 2004				
Top	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
	NW	0.843	0.805	0.038	NW	0.763	0.764	0.764	0.079
	NE	0.899	0.847	0.052	NE	0.796	0.795	0.796	0.101
	SW	0.941	0.891	0.050	SW	0.850	0.848	0.849	0.093
Josh	SE	0.909	0.852	0.057	SE	0.811	0.813	0.812	0.096

					Slip Reading on 04 March 2005				
Bottom	Strand End	Initial	After Release	Difference	Bottom	KIR	EDEN	AVERAGE	Difference
	NW	0.874	0.854	0.020	NW	0.822	0.820	0.821	0.053
	NE	0.866	0.862	0.004	NE	0.826	0.823	0.825	0.043
	SW	0.881	0.826	0.055	SW	0.779	0.781	0.780	0.101
Kiran	SE	0.829	0.786	0.043	SE				

					Slip Reading on 05 Nov 2004				
Bottom	Strand End	Initial	After Release	Difference	Bottom	KIR	EDEN	AVERAGE	Difference
	NW	0.873	0.854	0.019	NW	0.820	0.823	0.822	0.052
	NE	0.868	0.861	0.007	NE	0.829	0.828	0.829	0.039
	SW	0.881	0.827	0.054	SW	0.787	0.789	0.788	0.093
Josh	SE	0.833	0.783	0.050	SE				

Data Analysis: Differences

Top	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.038	0.000
	NE	0.049	0.004
	SW	0.051	0.001
	SE	0.055	0.004

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.020	0.001
	NE	0.006	0.002
	SW	0.055	0.001
	SE	0.046	0.005

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#2	29-Jul-04	A	East-T	16.5	0.007325
#2	29-Jul-04	A	West-T	15.9375	0.007075
#2	29-Jul-04	A	East-B	16.75	0.007436
#2	29-Jul-04	A	West-B	16.6875	0.007408

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	10.74	13.38	14.42	14.88	Top
1	5.26	1.48	14.71	12.51	Bottom
99	22.33	27.58	26.15	26.21	Top
99	14.17	10.36	25.11		Bottom
218	22.62	27.71	26.57	27.85	Top
218	14.17	11.43	27.27		Bottom

End Slip Data for Beam -RA8-5-2-T

Date cast: 29-Jul-04 Date tested: 30-Jul-04

Top	Strand End	Initial	After Release	Difference	Slip Reading on 04 March 2005 Top	KIR	EDEN	AVERAGE	Difference
Kiran	NW	0.810	0.758	0.052	NW	0.707	0.708	0.708	0.103
	NE	0.818	0.752	0.066	NE	0.712	0.712	0.712	0.106
	SW	0.926	0.874	0.052	SW	0.823	0.825	0.824	0.102
	SE	0.919	0.860	0.059	SE	0.807	0.809	0.808	0.110

Top	Strand End	Initial	After Release	Difference	Slip Reading on 05 Nov 2004 Top	KIR	EDEN	AVERAGE	Difference
Josh	NW	0.811	0.756	0.055	NW	0.709	0.710	0.710	0.101
	NE	0.817	0.754	0.063	NE	0.715	0.716	0.716	0.102
	SW	0.926	0.875	0.051	SW	0.824	0.827	0.826	0.101
	SE	0.917	0.861	0.056	SE	0.811	0.813	0.812	0.106

Bottom	Strand End	Initial	After Release	Difference	Slip Reading on 04 March 2005 Bottom	KIR	EDEN	AVERAGE	Difference
Kiran	NW	0.830	0.785	0.045	NW	0.738	0.735	0.737	0.094
	NE	0.822	0.768	0.054	NE	0.738	0.736	0.737	0.085
	SW	0.863	0.816	0.047	SW	0.769	0.771	0.770	0.095
	SE	0.863	0.806	0.057	SE	0.770	0.769	0.770	0.093

Bottom	Strand End	Initial	After Release	Difference	Slip Reading on 05 Nov 2004 Bottom	KIR	EDEN	AVERAGE	Difference
Josh	NW	0.830	0.782	0.048	NW	0.740	0.741	0.741	0.090
	NE	0.822	0.768	0.054	NE	0.737	0.740	0.739	0.084
	SW	0.866	0.814	0.052	SW	0.768	0.766	0.767	0.098
	SE	0.863	0.804	0.059	SE	0.773	0.771	0.772	0.091

Data Analysis: Differences

Top	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.054	0.002
	NE	0.064	0.002
	SW	0.052	0.001
	SE	0.058	0.002

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.046	0.002
	NE	0.054	0.000
	SW	0.050	0.004
	SE	0.058	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#2	29-Jul-04	A	East-T	16.5	0.007325
#2	29-Jul-04	A	West-T	15.9375	0.007075
#2	29-Jul-04	A	East-B	16.75	0.007436
#2	29-Jul-04	A	West-B	16.6875	0.007408

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	15.12	17.61	14.56	15.70	Top
1	12.55	14.52	13.36	15.60	Bottom
99	28.55	27.85	28.41	28.94	Top
99	24.16	22.46	26.32	24.48	Bottom
218	29.12	28.81	28.83	30.04	Top
218	25.24	22.86	25.51	25.15	Bottom

End Slip Data for Beam -RD8-5-1

Date cast: 29-Jul-04 Date tested: 30-Jul-04

Slip Reading on 04 March 2005

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Eden	NW	0.877	0.776	0.101	NW	0.735	0.733	0.734	0.144
	NE	0.877	0.785	0.092	NE	0.738	0.737	0.738	0.140
	SW	0.856	0.762	0.094	SW	0.727	0.727	0.727	0.129
	SE	0.849	0.775	0.074	SE	0.727	0.728	0.728	0.123

Slip Reading on 05 Nov 2004

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Krista	NW	0.879	0.777	0.102	NW	0.748	0.745	0.747	0.132
	NE	0.878	0.787	0.091	NE	0.744	0.744	0.744	0.134
	SW	0.855	0.760	0.095	SW	0.738	0.739	0.739	0.117
	SE	0.851	0.776	0.075	SE	0.739	0.741	0.740	0.110

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.102	0.001
	NE	0.092	0.001
	SW	0.095	0.001
	SE	0.075	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#2	7/29/2004	D	East	16.5	0.007325
#2	7/29/2004	D	West	16.25	0.007214

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	28.14	24.98	26.20	20.34	Bottom
99	36.46	36.45	32.44	30.04	Bottom
218	39.92	38.23	35.63	33.45	Bottom

End Slip Data for Beam -RD8-5-2

Date cast: 29-Jul-04 Date tested: 30-Jul-04

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
					Slip Reading on 04 March 2005				
Eden	NW	0.841	0.804	0.037	NW	0.728	0.725	0.727	0.116
	NE	0.861	0.798	0.063	NE	0.705	0.702	0.704	0.157
	SW	0.838	0.792	0.046	SW	0.728	0.725	0.727	0.113
	SE	0.855	0.776	0.079	SE	0.600	0.599	0.600	0.255

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
					Slip Reading on 05 Nov 2004				
Krista	NW	0.843	0.804	0.039	NW	0.730	0.733	0.732	0.111
	NE	0.859	0.799	0.060	NE	0.704	0.701	0.703	0.158
	SW	0.840	0.791	0.049	SW	0.732	0.733	0.733	0.107
	SE	0.854	0.776	0.078	SE	0.612	0.614	0.613	0.242

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.038	0.001
	NE	0.061	0.002
	SW	0.047	0.002
	SE	0.079	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#2	7/29/2004	D	East	16.5	0.007325
#2	7/29/2004	D	West	16.25	0.007214

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	10.54	16.79	13.17	21.43	Bottom
99	30.64	43.01	29.53	65.94	Bottom
218	32.02	42.73	31.19	69.63	Bottom

End Slip Data for Beam -RD8-5-1-T

Date cast: 29-Jul-04 Date tested: 30-Jul-04

Top (Eden)	Strand End	Initial	After Release	Difference
	NW	0.823	0.757	0.066
	NE	0.864	0.771	0.093
	SW	0.846	0.777	0.069
	SE	0.840	0.775	0.065

Slip Reading on 04 March 2005

Top	KIR	EDEN	AVERAGE	Difference
NW	0.680	0.678	0.679	0.143
NE	0.695	0.692	0.694	0.158
SW	0.680	0.677	0.679	0.168
SE	0.693	0.690	0.692	0.143

Top (Krista)	Strand End	Initial	After Release	Difference
	NW	0.821	0.758	0.063
	NE	0.839	0.771	0.068
	SW	0.846	0.777	0.069
	SE	0.829	0.774	0.055

Slip Reading on 05 Nov 2004

Top	KIR	EDEN	AVERAGE	Difference
NW	0.684	0.684	0.684	0.138
NE	0.696	0.696	0.696	0.156
SW	0.691	0.690	0.691	0.156
SE	0.700	0.701	0.701	0.134

Bottom (Eden)	Strand End	Initial	After Release	Difference
	NW	0.838	0.792	0.046
	NE	0.905	0.772	0.133
	SW	0.855	0.759	0.096
	SE	0.843	0.735	0.108

Slip Reading on 04 March 2005

Bottom	KIR	EDEN	AVERAG	Difference
NW	0.751	0.748	0.750	0.100
NE	0.764	0.765	0.765	0.136
SW	0.700	0.697	0.699	0.157
SE	0.679	0.678	0.679	0.164

Bottom (Krista)	Strand End	Initial	After Release	Difference
	NW	0.861	0.792	0.069
	NE	0.895	0.772	0.123
	SW	0.856	0.762	0.094
	SE	0.842	0.736	0.106

Slip Reading on 05 Nov 2004

Bottom	KIR	EDEN	AVERAG	Difference
NW	0.753	0.750	0.752	0.098
NE	0.778	0.777	0.778	0.123
SW	0.712	0.715	0.714	0.142
SE	0.690	0.688	0.689	0.154

Data Analysis: Differences

Top	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.064	0.002
	NE	0.081	0.018
	SW	0.069	0.000
	SE	0.060	0.007

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.057	0.016
	NE	0.128	0.007
	SW	0.095	0.001
	SE	0.107	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#2	29-Jul-04	D	East-T	16.4375	0.007297
#2	29-Jul-04	D	West-T	16.5	0.007325
#2	29-Jul-04	D	East-B	16.1875	0.007186
#2	29-Jul-04	D	West-B	16.25	0.007214

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	17.61	22.06	18.84	16.45	Top
1	15.94	35.63	26.34	29.78	Bottom
99	37.68	42.62	42.46	36.73	Top
99	27.17	34.09	39.37	42.72	Bottom
218	39.05	43.31	45.74	39.19	Top
218	27.73	37.71	43.53	45.65	Bottom

End Slip Data for Beam -RD8-5-2-T

Date cast: 29-Jul-04 Date tested: 30-Jul-04

Top (Eden)	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
					Slip Reading on 04 March 2005				
	NW	0.865	0.761	0.104	NW	0.600	0.599	0.600	0.267
	NE	0.862	0.761	0.101	NE	0.630	0.627	0.629	0.235
	SW	0.821	0.727	0.094	SW	0.609	0.612	0.611	0.211
	SE	0.840	0.755	0.085	SE	0.550	0.551	0.551	0.291

Top (Krista)	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
					Slip Reading on 05 Nov 2004				
	NW	0.867	0.761	0.106	NW	0.604	0.603	0.604	0.263
	NE	0.864	0.762	0.102	NE	0.633	0.630	0.632	0.232
	SW	0.822	0.726	0.096	SW	0.611	0.611	0.611	0.211
	SE	0.842	0.754	0.088	SE	0.550	0.550	0.550	0.291

Bottom (Eden)	Strand End	Initial	After Release	Difference	Bottom	KIR	EDEN	AVERAGE	Difference
					Slip Reading on 04 March 2005				
	NW	0.828	0.761	0.067	NW	0.654	0.657	0.656	0.174
	NE	0.835	0.76	0.075	NE	0.630	0.628	0.629	0.207
	SW	0.845	0.762	0.083	SW	0.715	0.717	0.716	0.128
	SE	0.864	0.785	0.079	SE	0.741	0.739	0.740	0.124

Bottom (Krista)	Strand End	Initial	After Release	Difference	Bottom	KIR	EDEN	AVERAGE	Difference
					Slip Reading on 05 nov 2004				
	NW	0.830	0.760	0.070	NW	0.657	0.655	0.656	0.173
	NE	0.837	0.762	0.075	NE	0.644	0.641	0.643	0.194
	SW	0.843	0.760	0.083	SW	0.716	0.716	0.716	0.128
	SE	0.864	0.785	0.079	SE	0.754	0.751	0.753	0.112

Data Analysis: Differences

Top	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.105	0.001
	NE	0.102	0.001
	SW	0.095	0.001
	SE	0.087	0.002

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.068	0.002
	NE	0.075	0.000
	SW	0.083	0.000
	SE	0.079	0.000

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#2	29-Jul-04	D	East-T	16.4375	0.007297
#2	29-Jul-04	D	West-T	16.5	0.007325
#2	29-Jul-04	D	East-B	16.1875	0.007186
#2	29-Jul-04	D	West-B	16.25	0.007214

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	28.67	27.82	25.94	23.71	Top
1	18.99	20.87	23.01	21.99	Bottom
99	71.68	63.45	57.48	79.76	Top
99	47.96	53.86	35.49	31.03	Bottom
218	72.77	64.27	57.61	79.62	Top
218	48.10	57.61	35.49	34.51	Bottom

End Slip Data for Beam -RA10-5-1

Date cast: 9-Aug-04 Date tested: 10-Aug-04

Slip Reading on 4-Mar-05

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Kiran	NW	0.823	0.739	0.084	NW	0.742	0.743	0.743	0.081
	NE	0.842	0.75	0.092	NE	0.745	0.747	0.746	0.096
	SW	0.851	0.801	0.050	SW	0.788	0.790	0.789	0.062
	SE	0.821	0.801	0.020	SE	0.790	0.787	0.789	0.033

Slip Reading on 9-Nov-04

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Josh	NW	0.823	0.740	0.083	NW	0.743	0.741	0.742	0.081
	NE	0.842	0.749	0.093	NE	0.748	0.748	0.748	0.094
	SW	0.852	0.803	0.049	SW	0.794	0.795	0.795	0.057
	SE	0.822	0.800	0.022	SE	0.790	0.791	0.791	0.031

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.084	0.001
	NE	0.093	0.001
	SW	0.049	0.001
	SE	0.021	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#4	8/9/2004	A	East	16.25	0.007214
#4	8/9/2004	A	West	16.4375	0.007297

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	22.89	25.65	13.57	5.82	Bottom
92	22.20	26.06	15.62	8.59	Bottom
207	22.06	26.62	17.13	9.15	Bottom

End Slip Data for Beam -RA10-5-2

Date cast: 9-Aug-04 Date tested: 10-Aug-04

Bottom	Strand End	Initial	After Release	Difference	Slip Reading on 04 March 2005 Top	KIR	EDEN	AVERAGE	Difference
Kiran	NW	0.914	0.868	0.046	NW	0.837	0.836	0.837	0.078
	NE	0.876	0.83	0.046	NE	0.813	0.814	0.814	0.062
	SW	0.927	0.871	0.056	SW	0.861	0.861	0.861	0.065
	SE	0.873	0.818	0.055	SE	0.813	0.812	0.813	0.061

Bottom	Strand End	Initial	After Release	Difference	Slip Reading onDev Length Top			AVERAGE	Difference
Josh	NW	0.914	0.867	0.047	NW			0.834	0.080
	NE	0.874	0.828	0.046	NE			0.809	0.066
	SW	0.924	0.872	0.052	SW			0.844	0.082
	SE	0.874	0.819	0.055	SE			0.813	0.061

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.047	0.001
	NE	0.046	0.000
	SW	0.054	0.003
	SE	0.055	0.000

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#4	8/9/2004	A	East	16.25	0.007214
#4	8/9/2004	A	West	16.4375	0.007297

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	12.75	12.75	14.80	15.25	Bottom
92	21.93	18.30	22.34	16.77	Bottom
207	21.24	17.05	17.68	16.91	Bottom

End Slip Data for Beam -RA10-5-1-T

Date cast: 9-Aug-04 Date tested: 10-Aug-04

Slip Reading on 04 March 2005

Top	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Kiran	NW	0.815	0.763	0.052	NW	0.735	0.735	0.735	0.081
	NE	0.797	0.742	0.055	NE	0.719	0.721	0.720	0.076
	SW	0.849	0.809	0.040	SW	0.784	0.781	0.783	0.066
	SE	0.878	0.832	0.046	SE	0.805	0.806	0.806	0.073

Slip Reading on 05 Nov 2004

Top	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Josh	NW	0.817	0.765	0.052	NW	0.735	0.735	0.735	0.081
	NE	0.794	0.745	0.049	NE	0.719	0.721	0.720	0.076
	SW	0.848	0.807	0.041	SW	0.785	0.787	0.786	0.063
	SE	0.879	0.831	0.048	SE	0.804	0.804	0.804	0.075

Slip Reading on 04 March 2005

Bottom	Strand End	Initial	After Release	Difference	Bottom	KIR	EDEN	AVERAGE	Difference
Kiran	NW	0.906	0.842	0.064	NW	0.835	0.836	0.836	0.072
	NE	0.913	0.849	0.064	NE	0.842	0.845	0.844	0.069
	SW	0.855	0.813	0.042	SW	0.800	0.801	0.801	0.054
	SE	0.858	0.814	0.044	SE	0.796	0.797	0.797	0.061

Slip Reading on 05 Novt 2004

Bottom	Strand End	Initial	After Release	Difference	Bottom	KIR	EDEN	AVERAGE	Difference
Josh	NW	0.909	0.843	0.066	NW	0.837	0.839	0.838	0.070
	NE	0.912	0.848	0.064	NE	0.844	0.846	0.845	0.068
	SW	0.854	0.815	0.039	SW	0.804	0.802	0.803	0.052
	SE	0.856	0.813	0.043	SE	0.799	0.798	0.799	0.059

Data Analysis: Differences

Top	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.052	0.000
	NE	0.052	0.004
	SW	0.040	0.001
	SE	0.047	0.001

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.065	0.001
	NE	0.064	0.000
	SW	0.041	0.002
	SE	0.044	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#4	9-Aug-04	A	East-T	15.6875	0.006964
#4	9-Aug-04	A	West-T	16.125	0.007158
#4	8/9/2004	A	East-B	16.25	0.007214
#4	8/9/2004	A	West-B	16.125	0.007158

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	14.53	14.93	11.32	13.50	Top
1	18.16	17.74	11.32	12.06	Bottom
92	22.63	21.68	17.46	21.40	Top
92	19.42	18.71	14.39	16.22	Bottom
207	22.63	21.68	18.44	20.97	Top
207	20.12	19.13	15.09	16.77	Bottom

End Slip Data for Beam -RA10-5-2-T

Date cast: 9-Aug-04 Date tested: 10-Aug-04

Top	Strand End	Initial	After Release	Difference	Slip Reading on 04 March 2005 Top	KIR	EDEN	AVERAGE	Difference
Kiran	NW	0.845	0.793	0.052	NW	0.765	0.766	0.766	0.079
	NE	0.819	0.782	0.037	NE	0.788	0.787	0.788	0.032
	SW	0.897	0.850	0.047	SW	0.813	0.812	0.813	0.084
	SE	0.852	0.814	0.038	SE	0.778	0.781	0.780	0.074

Top	Strand End	Initial	After Release	Difference	Slip Reading on 05 Nov 2004 Top	KIR	EDEN	AVERAGE	Difference
Josh	NW	0.844	0.795	0.049	NW	0.768	0.767	0.768	0.077
	NE	0.820	0.783	0.037	NE	0.788	0.786	0.787	0.032
	SW	0.896	0.850	0.046	SW	0.814	0.814	0.814	0.083
	SE	0.855	0.815	0.040	SE	0.779	0.779	0.779	0.074

Bottom	Strand End	Initial	After Release	Difference	Slip Reading on 04 March 2005 Bottom	KIR	EDEN	AVERAGE	Difference
Kiran	NW	0.902	0.862	0.040	NW	0.840	0.839	0.840	0.062
	NE	0.924	0.881	0.043	NE	0.862	0.861	0.862	0.063
	SW	0.938	0.885	0.053	SW	0.871	0.870	0.871	0.067
	SE	0.927	0.885	0.042	SE	0.875	0.875	0.875	0.052

Bottom	Strand End	Initial	After Release	Difference	Slip Reading on 05 Nov 2004 Bottom	KIR	EDEN	AVERAGE	Difference
Josh	NW	0.901	0.859	0.042	NW	0.844	0.845	0.845	0.057
	NE	0.924	0.879	0.045	NE	0.862	0.862	0.862	0.062
	SW	0.936	0.885	0.051	SW	0.872	0.870	0.871	0.066
	SE	0.926	0.883	0.043	SE	0.875	0.876	0.876	0.051

Data Analysis: Differences

Top	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.050	0.002
	NE	0.037	0.000
	SW	0.047	0.001
	SE	0.039	0.001

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.041	0.001
	NE	0.044	0.001
	SW	0.052	0.001
	SE	0.043	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#4	9-Aug-04	A	East-T	15.6875	0.006964
#4	9-Aug-04	A	West-T	16.125	0.007158
#4	8/9/2004	A	East-B	16.25	0.007214
#4	8/9/2004	A	West-B	16.125	0.007158

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	
1	14.11	10.63	12.99	11.20	Top
1	11.46	12.20	14.53	11.78	Bottom
92	21.51	9.33	23.05	21.40	Top
92	15.93	17.19	18.44	14.14	Bottom
207	22.07	9.19	23.47	21.25	Top
207	17.32	17.33	18.58	14.28	Bottom

End Slip Data for Beam -RD10-5-1

Date cast: 9-Aug-04 Date tested: 10-Aug-04

Slip Reading on 04 March 2005

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Eden	NW	0.885	0.781	0.104	NW	0.775	0.774	0.775	0.110
	NE	0.947	0.876	0.071	NE				0.961
	SW	0.852	0.789	0.063	SW	0.760	0.761	0.761	0.093
	SE	0.879	0.82	0.059	SE	0.773	0.776	0.775	0.104

Slip Reading on 09 Nov 2004

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Krista	NW	0.883	0.780	0.103	NW	0.779	0.778	0.779	0.106
	NE	0.974	0.875	0.099	NE	0.874	0.875	0.875	0.086
	SW	0.854	0.790	0.064	SW	0.761	0.762	0.762	0.091
	SE	0.878	0.820	0.058	SE	0.778	0.778	0.778	0.101

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.104	0.001
	NE	0.085	0.020
	SW	0.063	0.001
	SE	0.059	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#4	8/9/2004	D	East	16.3125	0.007241
#4	8/9/2004	D	West	16.3125	0.007241

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	28.59	23.48	17.54	16.16	Bottom
92	29.14	23.75	25.27	27.76	Bottom
207	30.24		25.55	28.72	Bottom

End Slip Data for Beam -RD10-5-2

Date cast: 9-Aug-04 Date tested: 10-Aug-04

Slip Reading on 04 March 2005

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Eden	NW	0.905	0.848	0.057	NW	0.819	0.819	0.819	0.087
	NE	0.89	0.841	0.049	NE	0.815	0.817	0.816	0.075
	SW	0.922	0.861	0.061	SW	0.848	0.848	0.848	0.075
	SE	0.924	0.854	0.070	SE	0.838	0.840	0.839	0.085

Slip Reading on 09 Nov 2004

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Krista	NW	0.906	0.849	0.057	NW	0.829	0.832	0.831	0.075
	NE	0.892	0.840	0.052	NE	0.830	0.831	0.831	0.061
	SW	0.923	0.860	0.063	SW	0.849	0.849	0.849	0.074
	SE	0.924	0.854	0.070	SE	0.837	0.835	0.836	0.088

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.057	0.000
	NE	0.051	0.002
	SW	0.062	0.001
	SE	0.070	0.000

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#4	8/9/2004	D	East	16.3125	0.007241
#4	8/9/2004	D	West	16.3125	0.007241

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	15.74	13.95	17.12	19.33	Bottom
92	20.71	16.71	20.30	24.30	Bottom
207	23.89	20.71	20.58	23.48	Bottom

End Slip Data for Beam -RD10-5-1-T

Date cast: 9-Aug-04 Date tested: 10-Aug-04

Top	Strand End	Initial	After Release	Difference	Top (Slip Reading on 04 March 2005)	KIR	EDEN	AVERAGE	Difference
Eden	NW	0.809	0.745	0.064	NW	0.712	0.709	0.711	0.099
	NE	0.812	0.750	0.062	NE	0.691	0.689	0.690	0.123
	SW	0.831	0.770	0.061	SW	0.725	0.722	0.724	0.107
	SE	0.837	0.780	0.057	SE	0.747	0.745	0.746	0.092

Top	Strand End	Initial	After Release	Difference	Top (Slip Reading on 05 Nov 2004)	KIR	EDEN	AVERAGE	Difference
Krista	NW	0.810	0.747	0.063	NW	0.714	0.716	0.715	0.095
	NE	0.813	0.752	0.061	NE	0.701	0.704	0.703	0.110
	SW	0.830	0.771	0.059	SW	0.725	0.726	0.726	0.105
	SE	0.839	0.782	0.057	SE	0.749	0.750	0.750	0.088

Bottom	Strand End	Initial	After Release	Difference	Bottom (Slip Reading on 04 March 2005)	KIR	EDEN	AVERAGE	Difference
Eden	NW	0.848	0.77	0.078	NW				
	NE	0.897	0.818	0.079	NE				
	SW	0.913	0.85	0.063	SW	0.821	0.823	0.822	0.092
	SE	0.89	0.832	0.058	SE	0.808	0.811	0.810	0.081

Bottom	Strand End	Initial	After Release	Difference	Bottom (Slip Reading on 05 Nov 2004)	KIR	EDEN	AVERAGE	Difference
Krista	NW	0.847	0.771	0.076	NW	0.767	0.768	0.768	0.080
	NE	0.896	0.818	0.078	NE	0.806	0.806	0.806	0.091
	SW	0.914	0.850	0.064	SW	0.825	0.828	0.827	0.087
	SE	0.891	0.832	0.059	SE	0.821	0.820	0.821	0.070

Data Analysis: Differences

Top	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.064	0.001
	NE	0.062	0.001
	SW	0.060	0.001
	SE	0.057	0.000

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.077	0.001
	NE	0.079	0.001
	SW	0.064	0.001
	SE	0.059	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#4	9-Aug-04	D	East-T	16.5	0.007325
#4	9-Aug-04	D	West-T	16.5625	0.007352
#4	9-Aug-04	D	East-B	16.25	0.007214
#4	9-Aug-04	D	West-B	16.4375	0.007297

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	17.27	16.79	16.32	15.56	Top
1	21.10	21.76	17.40	16.22	Bottom
92	25.71	30.04	28.56	24.17	Top
92	21.93	25.09	23.85	19.41	Bottom
207	26.93	33.45	29.11	25.12	Top
207			25.08	22.46	Bottom

End Slip Data for Beam -RD10-5-2-T

Date cast: 9-Aug-04 Date tested: 10-Aug-04

Slip Reading on 04 March 2005

Top	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
	NW	0.897	0.838	0.059	NW	0.807	0.805	0.806	0.091
	NE	0.874	0.805	0.069	NE	0.772	0.769	0.771	0.105
	SW	1.064	1.023	0.041	SW	0.979	0.976	0.978	0.087
Eden	SE	0.900	0.845	0.055	SE	0.790	0.789	0.790	0.112

Slip Reading on 09 Nov 2004

Top	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
	NW	0.896	0.836	0.060	NW	0.809	0.806	0.808	0.089
	NE	0.876	0.806	0.070	NE	0.770	0.772	0.771	0.104
	SW	1.064	1.022	0.042	SW	0.987	0.989	0.988	0.076
Krista	SE	0.902	0.847	0.055	SE	0.795	0.793	0.794	0.107

Slip Reading on 04 March 2005

Bottom	Strand End	Initial	After Release	Difference	Bottom	KIR	EDEN	AVERAGE	Difference
	NW	0.942	0.879	0.063	NW	0.837	0.834	0.836	0.106
	NE	0.912	0.853	0.059	NE	0.811	0.814	0.813	0.099
	SW	1	0.94	0.060	SW				
Eden	SE	0.849	0.795	0.054	SE	0.750	0.749	0.750	0.099

Slip Reading on 09 Nov 2004

Bottom	Strand End	Initial	After Release	Difference	Bottom	KIR	EDEN	AVERAGE	Difference
	NW	0.941	0.879	0.062	NW	0.847	0.846	0.847	0.095
	NE	0.910	0.851	0.059	NE	0.817	0.818	0.818	0.094
	SW	1.001	0.940	0.061	SW				
Krista	SE	0.849	0.793	0.056	SE	0.767	0.765	0.766	0.083

Data Analysis: Differences

Top	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.060	0.001
	NE	0.070	0.001
	SW	0.042	0.001
	SE	0.055	0.000

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.062	0.001
	NE	0.059	0.000
	SW	0.061	0.001
	SE	0.055	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#4	9-Aug-04	D	East-T	16.5	0.007325
#4	9-Aug-04	D	West-T	16.5625	0.007352
#4	8/9/2004	D	East-B	16.25	0.007214
#4	8/9/2004	D	West-B	16.4375	0.007297

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	16.19	18.98	11.29	15.02	Top
1	17.13	16.36	16.58	15.25	Bottom
92	24.21	28.40	20.67	29.22	Top
92	26.04	25.92		23.01	Bottom
207	24.62	28.53	23.53	30.45	Top
207	29.05	27.31		27.59	Bottom

End Slip Data for Beam -RA6-6-1

Date cast: 12-Aug-04 Date tested: 13-Aug-04

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
					Slip Reading on	4-Mar-05			
Kiran	NW	0.898	0.793	0.105	NW	0.761	0.761	0.761	0.136
	NE	0.959	0.861	0.098	NE	0.815	0.818	0.817	0.142
	SW	0.983	0.895	0.088	SW	0.815	0.812	0.814	0.170
	SE	0.695	0.594	0.101	SE	0.490	0.493	0.492	0.205

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
					Slip Reading on	9-Nov-04			
Josh	NW	0.895	0.792	0.103	NW	0.767	0.764	0.766	0.131
	NE	0.958	0.860	0.098	NE	0.825	0.824	0.825	0.134
	SW	0.984	0.892	0.092	SW	0.834	0.831	0.833	0.151
	SE	0.697	0.595	0.102	SE	0.546	0.544	0.545	0.151

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.104	0.001
	NE	0.098	0.000
	SW	0.090	0.003
	SE	0.102	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#5	12-Aug-04	D	East	15.8125	0.006781
#5	12-Aug-04	D	West	15.875	0.006808

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	30.55	28.91	26.44	29.94	Bottom
89	38.49	39.52	44.36	44.54	Bottom
204	39.81	41.88	49.94	60.32	Bottom

End Slip Data for Beam -RA6-6-2

Date cast: 12-Aug-04 Date tested: 13-Aug-04

Slip Reading on 04 March 2005

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Kiran	NW	0.830	0.732	0.098	NW	0.668	0.665	0.667	0.164
	NE	0.880	0.766	0.114	NE	0.691	0.688	0.690	0.191
	SW	0.908	0.800	0.108	SW	0.725	0.725	0.725	0.182
	SE	0.888	0.792	0.096	SE	0.736	0.733	0.735	0.154

Slip Reading on 09 Nov 2004

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Josh	NW	0.831	0.730	0.101	NW	0.675	0.674	0.675	0.156
	NE	0.880	0.763	0.117	NE	0.703	0.700	0.702	0.179
	SW	0.905	0.797	0.108	SW	0.730	0.730	0.730	0.177
	SE	0.889	0.792	0.097	SE	0.737	0.738	0.738	0.151

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.100	0.002
	NE	0.116	0.002
	SW	0.108	0.000
	SE	0.097	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#5	12-Aug-04	D	East	15.8125	0.006781
#5	12-Aug-04	D	West	15.875	0.006808

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	29.23	34.07	31.73	28.46	Bottom
89	45.83	52.65	51.85	44.54	Bottom
204	48.18	56.19	53.32	45.42	Bottom

End Slip Data for Beam -RA6-6-3

Date cast: 12-Aug-04 Date tested: 13-Aug-04

Slip Reading on 04 March 2005

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
	NW	0.830	0.742	0.088	NW	0.668	0.671	0.670	0.162
	NE	0.831	0.744	0.087	NE	0.687	0.685	0.686	0.144
	SW	0.882	0.769	0.113	SW	0.730	0.733	0.732	0.149
Kiran	SE	0.819	0.701	0.118	SE	0.655	0.658	0.657	0.163

Slip Reading on 09 Nov 2004

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
	NW	0.833	0.739	0.094	NW	0.674	0.676	0.675	0.157
	NE	0.828	0.746	0.082	NE	0.685	0.688	0.687	0.143
	SW	0.879	0.770	0.109	SW	0.735	0.737	0.736	0.145
Josh	SE	0.820	0.703	0.117	SE	0.659	0.660	0.660	0.160

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.091	0.004
	NE	0.085	0.004
	SW	0.111	0.003
	SE	0.118	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#5	12-Aug-04	D	East	15.8125	0.006781
#5	12-Aug-04	D	West	15.875	0.006808

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	26.73	24.92	32.61	34.66	Bottom
89	45.98	42.18	42.45	47.19	Bottom
204	47.59	42.33	43.77	48.08	Bottom

End Slip Data for Beam -RA8-6-1

Date cast: 12-Aug-04 Date tested: 13-Aug-04

Slip Reading on 04 March 2005

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Eden	NW	0.891	0.792	0.099	NW	0.729	0.730	0.730	0.162
	NE	0.857	0.764	0.093	NE	0.712	0.709	0.711	0.148
	SW	0.892	0.786	0.106	SW	0.746	0.747	0.747	0.146
	SE	0.860	0.765	0.095	SE	0.711	0.708	0.710	0.150

Slip Reading on 09 Nov 2004

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Krista	NW	0.891	0.793	0.098	NW	0.737	0.734	0.736	0.156
	NE	0.860	0.766	0.094	NE	0.716	0.715	0.716	0.143
	SW	0.893	0.788	0.105	SW	0.747	0.744	0.746	0.147
	SE	0.858	0.767	0.091	SE	0.712	0.711	0.712	0.148

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.099	0.001
	NE	0.094	0.001
	SW	0.106	0.001
	SE	0.093	0.003

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#5	12-Aug-04	D	East	16	0.006861
#5	12-Aug-04	D	West	15.75	0.006754

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	29.17	27.25	31.24	27.11	Bottom
89	46.05	41.68	43.53	43.00	Bottom
204	47.82	43.14	43.23	43.58	Bottom

End Slip Data for Beam -RA8-6-2

Date cast: 12-Aug-04 Date tested: 13-Aug-04

Slip Reading on 04 March 2005

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Eden	NW	0.882	0.790	0.092	NW	0.725	0.724	0.725	0.159
	NE	0.890	0.792	0.098	NE	0.735	0.732	0.734	0.157
	SW	0.838	0.755	0.083	SW	0.698	0.695	0.697	0.141
	SE	0.836	0.742	0.094	SE	0.685	0.688	0.687	0.148

Slip Reading on 09 Nov 2004

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Krista	NW	0.885	0.790	0.095	NW	0.725	0.725	0.725	0.159
	NE	0.890	0.791	0.099	NE	0.732	0.735	0.734	0.157
	SW	0.836	0.755	0.081	SW	0.696	0.697	0.697	0.141
	SE	0.833	0.741	0.092	SE	0.689	0.689	0.689	0.146

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.094	0.002
	NE	0.099	0.001
	SW	0.082	0.001
	SE	0.093	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#5	12-Aug-04	D	East	16	0.006861
#5	12-Aug-04	D	West	15.75	0.006754

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	27.69	28.71	24.28	27.11	Bottom
89	46.94	45.62	41.60	43.09	Bottom
204	47.08	45.62	41.60	43.14	Bottom

End Slip Data for Beam -RA8-6-3

Date cast: 12-Aug-04 Date tested: 13-Aug-04

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
					Slip Reading on 04 March 2005				
Kiran	NW	0.824	0.766	0.058	NW	0.695	0.695	0.695	0.130
	NE	0.831	0.735	0.096	NE	0.668	0.665	0.667	0.163
	SW	0.869	0.779	0.090	SW	0.698	0.695	0.697	0.172
	SE	0.873	0.771	0.102	SE	0.711	0.709	0.710	0.164

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
					Slip Reading on 09 Nov 2004				
Josh	NW	0.826	0.765	0.061	NW	0.703	0.702	0.703	0.123
	NE	0.828	0.732	0.096	NE	0.673	0.670	0.672	0.158
	SW	0.867	0.777	0.090	SW	0.709	0.712	0.711	0.158
	SE	0.874	0.771	0.103	SE	0.710	0.713	0.712	0.162

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.059	0.002
	NE	0.096	0.000
	SW	0.090	0.000
	SE	0.103	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#5	12-Aug-04	D	East	16	0.006861
#5	12-Aug-04	D	West	15.75	0.006754

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	17.62	27.98	26.65	29.88	Bottom
89	36.27	46.06	46.64	47.22	Bottom
204	38.50	47.51	50.78	47.66	Bottom

End Slip Data for Beam -RA10-6-1

Date cast: 12-Aug-04 Date tested: 13-Aug-04

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
					Slip Reading on 04 March 2005				
Eden	NW	0.873	0.802	0.071	NW	0.769	0.772	0.771	0.104
	NE	0.865	0.798	0.067	NE	0.758	0.760	0.759	0.103
	SW	0.861	0.787	0.074	SW	0.745	0.746	0.746	0.117
	SE	0.889	0.814	0.075	SE	0.783	0.785	0.784	0.105

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
					Slip Reading on 09 Nov 2004				
Krista	NW	0.875	0.800	0.075	NW	0.769	0.771	0.770	0.104
	NE	0.859	0.796	0.063	NE	0.773	0.772	0.773	0.090
	SW	0.863	0.786	0.077	SW	0.761	0.764	0.763	0.100
	SE	0.889	0.813	0.076	SE	0.789	0.791	0.790	0.099

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.073	0.003
	NE	0.065	0.003
	SW	0.076	0.002
	SE	0.076	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#5	8/12/2004	D	East	16	0.006861
#5	8/12/2004	D	West	16.125	0.006915

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	21.11	18.95	21.84	22.01	Bottom
89	30.08	26.09	28.78	28.86	Bottom
204	29.94	30.02	33.70	30.61	Bottom

End Slip Data for Beam -RA10-6-2

Date cast: 12-Aug-04 Date tested: 13-Aug-04

Slip Reading on 04 March 2005

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Eden	NW	0.904	0.861	0.043	NW	0.814	0.815	0.815	0.089
	NE	0.958	0.892	0.066	NE	0.860	0.863	0.862	0.096
	SW	0.861	0.790	0.071	SW	0.753	0.754	0.754	0.109
	SE	0.882	0.804	0.078	SE	0.777	0.780	0.779	0.103

Slip Reading on 09 Nov 2004

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Krista	NW	0.903	0.863	0.040	NW	0.816	0.817	0.817	0.087
	NE	0.956	0.890	0.066	NE	0.865	0.863	0.864	0.093
	SW	0.863	0.789	0.074	SW	0.760	0.759	0.760	0.103
	SE	0.881	0.804	0.077	SE	0.780	0.782	0.781	0.101

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.042	0.002
	NE	0.066	0.000
	SW	0.073	0.002
	SE	0.078	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#5	8/12/2004	D	East	16	0.006861
#5	8/12/2004	D	West	16.125	0.006915

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	12.00	19.24	20.97	22.59	Bottom
89	25.16	27.11	29.65	29.30	Bottom
204	25.74	27.84	31.38	30.02	Bottom

End Slip Data for Beam -RA10-6-3

Date cast: 12-Aug-04 Date tested: 13-Aug-04

Slip Reading on 04 March 2005

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Eden	NW	0.822	0.772	0.050	NW	0.723	0.725	0.724	0.098
	NE	0.838	0.774	0.064	NE	0.743	0.747	0.745	0.093
	SW	0.823	0.750	0.073	SW	0.702	0.705	0.704	0.119
	SE	0.849	0.763	0.086	SE	0.738	0.735	0.737	0.111

Slip Reading on 09 Nov 2004

Bottom	Strand End	Initial	After Release	Difference	Top	KIR	EDEN	AVERAGE	Difference
Krista	NW	0.822	0.775	0.047	NW	0.730	0.730	0.730	0.092
	NE	0.838	0.774	0.064	NE	0.749	0.751	0.750	0.088
	SW	0.821	0.749	0.072	SW	0.707	0.709	0.708	0.114
	SE	0.846	0.764	0.082	SE	0.739	0.739	0.739	0.109

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NW	0.048	0.002
	NE	0.064	0.000
	SW	0.073	0.001
	SE	0.084	0.003

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
#5	12-Aug-04	D	East	16	0.006861
#5	12-Aug-04	D	West	16.125	0.006915

Data Analysis: Inferred Transfer Lengths (in)

Beam Age (Days)	NW Transfer Length	NE Transfer Length	SW Transfer Length	SE Transfer Length	Location
1	14.03	18.66	20.97	24.49	Bottom
89	26.61	25.65	32.97	31.63	Bottom
204	28.34	27.11	34.27	32.36	Bottom

End Slip Data for Beam -IB6-5-1

Date cast: 17-Mar-05 Date tested: 18-Mar-05

Bottom	Strand End	Initial	After Release	Difference	Testing	Diff
	NE	0.518	0.456	0.062	0.437	0.081
	NC	0.573	0.533	0.040	0.52	0.053
	NW	0.455	0.388	0.067	0.365	0.09
	NM	0.856	0.797	0.059	0.774	0.082
Kiran	NT	0.633	0.553	0.080	0.499	0.134

Bottom	Strand End	Initial	After Release	Difference
	NE	0.517	0.456	0.061
	NC	0.573	0.532	0.041
	NW	0.454	0.386	0.068
	NM	0.853	0.796	0.057
Amol	NT	0.632	0.552	0.080

Bottom	Strand End	Initial	After Release	Difference	Testing	Diff
	SE	0.659	0.633	0.026	0.609	0.050
	SC	0.784	0.749	0.035	0.724	0.060
	SW	0.704	0.695	0.009	0.69	0.014
	SM	0.546	0.522	0.024	0.494	0.052
Kiran	ST	0.733	0.709	0.024	0.647	0.086

Bottom	Strand End	Initial	After Release	Difference
	SE	0.658	0.635	0.023
	SC	0.783	0.748	0.035
	SW	0.707	0.694	0.013
	SM	0.544	0.521	0.023
Amol	ST	0.731	0.709	0.022

Data Analysis: Differences

Bottom	Strand End	Average Difference
	NE	0.062
	NC	0.040
	NW	0.068
	NM	0.058
	NT	0.080

Strand End	Average Difference	Standard Deviation of Difference
SE	0.025	0.002
SC	0.035	0.000
SW	0.011	0.003
SM	0.024	0.001
ST	0.023	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
	17-Mar-05	D	East	8.75	0.007629
	17-Mar-05	D	Central	8.5	0.007411
	17-Mar-05	D	West	8.6875	0.007575
	17-Mar-05	D	Middle	8.3125	0.007248
	17-Mar-05	D	Top	8.5625	0.007466

Data Analysis: Inferred Transfer Lengths (in)

	NE Transfer Length	NC Transfer Length	NW Transfer Length	NM Transfer Length	NT Transfer Length
Bottom	16.12	10.93	17.82	16.00	21.43
	21.23	14.30	23.76	22.63	35.90

	SE Transfer Length	SC Transfer Length	SW Transfer Length	SM Transfer Length	ST Transfer Length
Bottom	6.42	9.45	2.90	6.48	6.16
	13.11	16.19	3.70	14.35	23.04

End Slip Data for Beam -IB10-5-1

Date cast: 15-Mar-05 Date tested: 16-Mar-05

Bottom	Strand End	Initial	After Release	Difference	Testing	Diff
	NE	0.745	0.7	0.045	0.685	0.06
	NC	0.995	0.951	0.044	0.906	0.089
	NW	0.695	0.656	0.039	0.621	0.074
	NM	0.75	0.709	0.041	0.693	0.057
Eden	NT	0.624	0.552	0.072	0.537	0.087

Bottom	Strand End	Initial	After Release	Difference
	NE	0.741	0.701	0.040
	NC	0.996	0.954	0.042
	NW	0.696	0.659	0.037
	NM	0.747	0.706	0.041
Hema	NT	0.624	0.552	0.072

Bottom	Strand End	Initial	After Release	Difference	Testing	Diff
	SE	0.817	0.770	0.047	0.702	0.115
	SC	0.980	0.958	0.022	0.942	0.038
	SW	0.942	0.905	0.037	0.888	0.054
	SM	0.887	0.860	0.027	0.845	0.042
Eden	ST	0.784	0.730	0.054	0.703	0.081

Bottom	Strand End	Initial	After Release	Difference
	SE	0.818	0.770	0.048
	SC	0.979	0.958	0.021
	SW	0.945	0.907	0.038
	SM	0.888	0.862	0.026
Hema	ST	0.786	0.733	0.053

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NE	0.043	0.004
	NC	0.043	0.001
	NW	0.038	0.001
	NM	0.041	0.000
	NT	0.072	0.000

Strand End	Average Difference	Standard Deviation of Difference
SE	0.047	0.001
SC	0.022	0.001
SW	0.037	0.001
SM	0.027	0.001
ST	0.054	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
	15-Mar-05	D	East	8.75	0.007629
	15-Mar-05	D	Central	8.5	0.007411
	15-Mar-05	D	West	8.6875	0.007575
	15-Mar-05	D	Middle	8.3125	0.007248
	15-Mar-05	D	Top	8.5625	0.007466

Data Analysis: Inferred Transfer Lengths (in)

	NE	NC	NW	NM	NT
	Transfer Length	Transfer Length	Transfer Length	Transfer Length	Transfer Length
Bottom	11.14	11.60	10.03	11.31	19.29
	15.73	24.02	19.54	15.73	23.31
	SE	SC	SW	SM	ST
	Transfer Length	Transfer Length	Transfer Length	Transfer Length	Transfer Length
Bottom	12.45	5.80	9.90	7.31	14.33
	30.15	10.25	14.26	11.59	21.70

End Slip Data for Beam -ID6-5-1

Date cast: 15-Mar-05 Date tested: 16-Mar-05

Bottom	Strand End	Initial	After Release	Difference	Dev Length	Diff
	NE	0.671	0.579	0.092	0.541	0.130
	NC	0.791	0.695	0.096	0.593	0.198
	NW	0.634	0.551	0.083	0.519	0.115
	NM	0.54	0.44	0.100	0.411	0.129
Kiran	NT	0.811	0.691	0.120	0.566	0.245

Bottom	Strand End	Initial	After Release	Difference
	NE	0.668	0.580	0.088
	NC	0.790	0.694	0.096
	NW	0.632	0.550	0.082
	NM	0.542	0.440	0.102
Amol	NT	0.811	0.688	0.123

Bottom	Strand End	Initial	After Release	Difference	Dev Length	Diff
	SE	0.683	0.638	0.045	0.513	0.170
	SC					
	SW	0.887	0.878	0.009	0.855	0.032
	SM	0.070	0.030	0.040	0.977	-0.907
Kiran	ST	0.866	0.768	0.098	0.636	0.230

Bottom	Strand End	Initial	After Release	Difference
	SE	0.682	0.637	0.045
	SC			
	SW	0.885	0.876	0.009
	SM	0.068	0.031	0.037
Amol	ST	0.869	0.766	0.103

Data Analysis: Differences

Bottom	Strand End	Average Difference
	NE	0.090
	NC	0.096
	NW	0.083
	NM	0.101
	NT	0.122

Bottom	Strand End	Average Difference
	SE	0.045
	SC	
	SW	0.009
	SM	0.039
	ST	0.101

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
	15-Mar-05	D	East	8.4375	0.007357
	15-Mar-05	D	Central	8.25	0.007193
	15-Mar-05	D	West	8.0625	0.00703
	15-Mar-05	D	Middle	8	0.006975
	15-Mar-05	D	Top	7.6875	0.006703

Data Analysis: Inferred Transfer Lengths (in)

	NE Transfer Length	NC Transfer Length	NW Transfer Length	NM Transfer Length	NT Transfer Length
Release	24.47	26.69	23.47	28.96	36.25
Testing	35.34	55.05	32.72	36.99	73.10

	SE Transfer Length	SC Transfer Length	SW Transfer Length	SM Transfer Length	ST Transfer Length
Release	12.23		2.56	11.04	29.99
Testing	46.22		9.10	-260.06	68.63

End Slip Data for Beam -ID10-5-1

Date cast: 15-Mar-05 Date tested: 16-Mar-05

Bottom	Strand End	Initial	After Release	Difference	Testing	Diff
	NE	0.783	0.713	0.070	0.674	0.109
	NC	0.823	0.765	0.058	0.683	0.14
	NW	0.78	0.709	0.071	0.638	0.142
	NM	0.789	0.707	0.082	0.643	0.146
Hema	NT	0.772				

Bottom	Strand End	Initial	After Release	Difference
	NE	0.783	0.713	0.070
	NC	0.825	0.768	0.057
	NW	0.780	0.708	0.072
	NM	0.790	0.708	0.082
Eden	NT	0.775		

Bottom	Strand End	Initial	After Release	Difference	Testing	Diff
	SE	0.850	0.779	0.071	0.766	0.084
	SC	0.899	0.823	0.076	0.694	0.205
	SW	0.845	0.763	0.082	0.737	0.108
	SM	0.789	0.705	0.084	0.604	0.185
Hema	ST	0.855	0.798	0.057	0.735	0.120

Bottom	Strand End	Initial	After Release	Difference
	SE	0.849	0.780	0.069
	SC	0.898	0.822	0.076
	SW	0.848	0.764	0.084
	SM	0.789	0.706	0.083
Eden	ST	0.855	0.799	0.056

Data Analysis: Differences

Bottom	Strand End	Average Difference
	NE	0.070
	NC	0.057
	NW	0.072
	NM	0.082
	NT	

Strand End	Average Difference	Standard Deviation of Difference
SE	0.070	0.001
SC	0.076	0.000
SW	0.083	0.001
SM	0.084	0.001
ST	0.056	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
	15-Mar-05	D	East	8.4375	0.007357
	15-Mar-05	D	Central	8.25	0.007193
	15-Mar-05	D	West	8.0625	0.00703
	15-Mar-05	D	Middle	8	0.006975
	15-Mar-05	D	Top	7.6875	0.006703

Data Analysis: Inferred Transfer Lengths (in)

	NE Transfer Length	NC Transfer Length	NW Transfer Length	NM Transfer Length	NT Transfer Length
Bottom	19.03	15.99	20.34	23.51	
	29.63	38.93	40.40	41.86	
	SE Transfer Length	**SC Transfer Length**	**SW Transfer Length**	**SM Transfer Length**	**ST Transfer Length**
Bottom	19.03	21.13	23.61	23.94	16.86
	22.84	57.00	30.73	53.04	35.81

End Slip Data for Beam -IA6-6-1

Date cast: 15-Mar-05 Date tested: 16-Mar-05

Bottom	Strand End	Initial	After Release	Difference	Testing	Diff
	NE	0.867	0.795	0.072		
	NC	0.856	0.777	0.079		
	NW	0.849	0.73	0.119		
	NM			0.000		
Eden	NT	0.722	0.631	0.091	0.455	0.267

Bottom	Strand End	Initial	After Release	Difference
	NE	0.865	0.792	0.073
	NC	0.859	0.780	0.079
	NW	0.848	0.728	0.120
	NM			0.000
Hema	NT	0.722	0.630	0.092

Bottom	Strand End	Initial	After Release	Difference	Testing	Diff
	SE	0.374	0.309	0.065	0.229	0.145
	SC	0.411	0.330	0.081	0.433	-0.022
	SW	0.489	0.399	0.090	0.606	-0.117
	SM			0.000		
Eden	ST	0.633	0.596	0.037	0.51	0.123

Bottom	Strand End	Initial	After Release	Difference
	SE	0.372	0.308	0.064
	SC	0.408	0.331	0.077
	SW	0.487	0.399	0.088
	SM			0.000
Hema	ST	0.636	0.598	0.038

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NE	0.073	0.001
	NC	0.079	0.000
	NW	0.120	0.001
	NM	0.000	0.000
	NT	0.092	0.001

Strand End	Average Difference	Standard Deviation of Difference
SE	0.065	0.001
SC	0.079	0.003
SW	0.089	0.001
SM	0.000	0.000
ST	0.038	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
	22-Mar-05	A	East	8.5625	0.007897
	22-Mar-05	A	Central	8.5	0.00784
	22-Mar-05	A	West	8.6875	0.008013
	22-Mar-05	A	Top	8.6875	0.008013

Data Analysis: Inferred Transfer Lengths (in)

	NE Transfer Length	NC Transfer Length	NW Transfer Length	NT Transfer Length
Release	18.36	20.15	29.83	22.84
Testing				66.64
	SE Transfer Length	SC Transfer Length	SW Transfer Length	ST Transfer Length
Release	16.33	20.15	22.21	9.36
Testing	36.72			30.70

End Slip Data for Beam -IA6-6-2

Date cast: 15-Mar-05 Date tested: 16-Mar-05

Bottom	Strand End	Initial	After Release	Difference	During Testing	Diff.
	NE	0.889	0.851	0.038	0.782	0.107
	NC	0.899	0.811	0.088	0.759	0.140
	NW	0.92	0.858	0.062	0.800	0.120
	NM			0.000		
Eden	NT	0.821	0.74	0.081	0.237	0.584
Bottom	Strand End	Initial	After Release	Difference		
	NE	0.886	0.848	0.038		
	NC	0.897	0.808	0.089		
	NW	0.919	0.857	0.062		
	NM			0.000		
Hema	NT	0.820	0.739	0.081		
Bottom	Strand End	Initial	After Release	Difference	During Testing	Diff.
	SE	0.717	0.662	0.055	0.604	0.113
	SC	0.680	0.622	0.058	0.584	0.096
	SW	0.708	0.632	0.076	0.557	0.151
	SM			0.000		
Eden	ST	0.739	0.649	0.090		
Bottom	Strand End	Initial	After Release	Difference		
	SE	0.718	0.661	0.057		
	SC	0.682	0.623	0.059		
	SW	0.711	0.631	0.080		
	SM			0.000		
Hema	ST	0.736	0.651	0.085		

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NE	0.038	0.000
	NC	0.089	0.001
	NW	0.062	0.000
	NM	0.000	0.000
	NT	0.081	0.000

Strand End	Average Difference	Standard Deviation of Difference
SE	0.056	0.001
SC	0.059	0.001
SW	0.078	0.003
SM	0.000	0.000
ST	0.088	0.004

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
	22-Mar-05	A	East	8.5625	0.007897
	22-Mar-05	A	Central	8.5	0.00784
	22-Mar-05	A	West	8.6875	0.008013
	22-Mar-05	A	Top	8.6875	0.008013

Data Analysis: Inferred Transfer Lengths (in)

	NE Transfer Length	NC Transfer Length	NW Transfer Length	NT Transfer Length
Release	9.62	22.58	15.48	20.22
Testing	27.10	35.72	29.95	
	SE Transfer Length	SC Transfer Length	SW Transfer Length	ST Transfer Length
Release	14.18	14.92	19.47	21.84
Testing	28.62	24.49	37.69	0.00

End Slip Data for Beam -IA10-6-1

Date cast: 12-Apr-05 Date tested: 13-Apr-05

Bottom	Strand End	Initial	After Release	Difference
Hema	NE	0.208	0.168	0.040
	NC	0.227	0.185	0.042
	NW	0.255	0.196	0.059
	NM			0.000
	NT	0.331	0.317	0.014

Bottom	Strand End	Initial	After Release	Difference
Eden	NE	0.206	0.170	0.036
	NC	0.225	0.187	0.038
	NW	0.255	0.198	0.057
	NM			0.000
	NT	0.331	0.315	0.016

Bottom	Strand End	Initial	After Release	Difference
Eden	SE	0.671	0.587	0.084
	SC	0.413	0.339	0.074
	SW	0.582	0.561	0.021
	SM			0.000
	ST	0.817	0.810	0.007

Bottom	Strand End	Initial	After Release	Difference
Hema	SE	0.674	0.587	0.087
	SC	0.412	0.338	0.074
	SW	0.584	0.558	0.026
	SM			0.000
	ST	0.817	0.809	0.008

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NE	0.038	0.003
	NC	0.040	0.003
	NW	0.058	0.001
	NM	0.000	0.000
	NT	0.015	0.001

Strand End	Average Difference	Standard Deviation of Difference
SE	0.086	0.002
SC	0.074	0.000
SW	0.023	0.004
SM	0.000	0.000
ST	0.007	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
	22-Mar-05	A	East	8.75	0.008084
	22-Mar-05	A	Central	8.5	0.007853
	22-Mar-05	A	West	8.75	0.008084
	22-Mar-05	A	Top	8.5	0.007853

Data Analysis: Inferred Transfer Lengths (in)

	NE Transfer Length	NC Transfer Length	NW Transfer Length	NT Transfer Length
Bottom	9.40	10.19	14.35	3.82
	SE Transfer Length	**SC Transfer Length**	**SW Transfer Length**	**ST Transfer Length**
Bottom	21.15	18.85	5.81	1.91

End Slip Data for Beam -IA10-6-2

Date cast: 12-Apr-05 Date tested: 13-Apr-05

Bottom	Strand End	Initial	After Release	Difference	Testing	Diff
Kiran	NE	0.761	0.686	0.075	0.67	0.091
	NC	0.69	0.618	0.072	0.492	0.198
	NW	0.57	0.515	0.055	0.487	0.083
	NM			0.000		
	NT	0.931	0.895	0.036	0.839	0.092

Bottom	Strand End	Initial	After Release	Difference
Amol	NE	0.759	0.689	0.070
	NC	0.687	0.619	0.068
	NW	0.572	0.515	0.057
	NM			0.000
	NT	0.930	0.893	0.037

Bottom	Strand End	Initial	After Release	Difference	Testing	Diff
Eden	SE	0.343	0.302	0.041	0.300	0.043
	SC	0.672	0.605	0.067	0.151	0.521
	SW	0.228	0.183	0.045		
	SM			0.000		
	ST	0.251	0.215	0.036	0.175	0.076

Bottom	Strand End	Initial	After Release	Difference
Hema	SE	0.345	0.300	0.045
	SC	0.673	0.604	0.069
	SW	0.228	0.186	0.042
	SM			0.000
	ST	0.251	0.216	0.035

Data Analysis: Differences

Bottom	Strand End	Average Difference	Standard Deviation of Difference
	NE	0.073	0.004
	NC	0.070	0.003
	NW	0.056	0.001
	NM	0.000	0.000
	NT	0.037	0.001

Strand End	Average Difference	Standard Deviation of Difference
SE	0.043	0.003
SC	0.068	0.001
SW	0.044	0.002
SM	0.000	0.000
ST	0.036	0.001

Elongation Data

Cast	Date	Strand	Location	Elongation	Strain
	22-Mar-05	A	East	8.75	0.008084
	22-Mar-05	A	Central	8.5	0.007853
	22-Mar-05	A	West	8.75	0.008084
	22-Mar-05	A	Top	8.5	0.007853

Data Analysis: Inferred Transfer Lengths (in)

	NE Transfer Length	NC Transfer Length	NW Transfer Length	NT Transfer Length
Bottom	17.94	17.83	13.85	9.30
	22.51	50.43	20.53	23.43

	SE Transfer Length	SC Transfer Length	SW Transfer Length	ST Transfer Length
Bottom	10.64	17.32	10.76	9.04
	10.64	132.68		19.36

APPENDIX H
MORTAR BATCHING RESULTS

Batch Number	1A			
w/c	0.4	Volume:	0.15	ft^3
MC:	0.28%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1117.2	2.7182		2.7182
Fine Agg.	2234.4	5.4364	-0.0121	5.4243
Water	445.9	1.0849	0.0121	1.0969

Batch Number	1B			
w/c	0.45	Volume:	0.15	ft^3
MC:	0.28%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	2.6092		2.6092
Fine Agg.	2144.8	5.2184	-0.0116	5.2068
Water	482.6	1.1742	0.0116	1.1858

Batch Number	1C			
w/c	0.5	Volume:	0.15	ft^3
MC:	0.28%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1046.4	2.5459		2.5459
Fine Agg.	2092.7	5.0916	-0.0113	5.0803
Water	523.2	1.2730	0.0113	1.2843

	1A	**1B**	**1C**
Fresh Unit Wt. (PCF)	142.6	141.4	141.5
Flow	87	111	*
ASTM C 109 (lbs)	5227	3770	3018

*Flow was not measured as the mortar mix overflowed from the flow table.

Batch Number	2A			
w/c	0.4	Volume:	0.15	ft^3
MC:	0.34%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1117.2	2.7182		2.7182
Fine Agg	2234.4	5.4364	-0.0088	5.4275
Water	445.9	1.0849	0.0088	1.0937

Batch Number	2B			
w/c	0.45	Volume:	0.15	ft^3
MC:	0.34%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	2.6092		2.6092
Fine Agg	2144.8	5.2184	-0.0085	5.2099
Water	482.6	1.1742	0.0085	1.1826

Batch Number	2C			
w/c	0.5	Volume:	0.15	ft^3
MC:	0.34%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1046.4	2.5459		2.5459
Fine Agg	2092.7	5.0916	-0.0083	5.0833
Water	523.2	1.2730	0.0083	1.2812

	2A	**2B**	**2C**
Fresh Unit Wt. (PCF)	141.82	141.73	141.0
Flow	95	111.5	*
ASTM C 109 (lbs)	4999	3991	3006

Batch Number	3A			
w/c	0.4	Volume:	0.15	ft^3
MC:	0.61%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1117.2	2.7182		2.7182
Fine Agg	2234.4	5.4364	0.0057	5.4420
Water	445.9	1.0849	-0.0057	1.0792

Batch Number	3B			
w/c	0.45	Volume:	0.15	ft^3
MC:	0.61%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	2.6092		2.6092
Fine Agg	2144.8	5.2184	0.0055	5.2238
Water	482.6	1.1742	-0.0055	1.1687

Batch Number	3C			
w/c	0.5	Volume:	0.15	ft^3
MC:	0.61%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1046.4	2.5459		2.5459
Fine Agg	2092.7	5.0916	0.0053	5.0969
Water	523.2	1.2730	-0.0053	1.2676

	3A	**3B**	**3C**
Fresh Unit Wt. (PCF)	141.94	140.50	140.79
Flow	72	103	*
ASTM C 109 (lbs)	4792	3979	2982

Batch Number	4A			
w/c	0.4	Volume:	0.15	ft^3
MC:	0.29%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1117.2	2.7182		2.7182
Fine Agg	2234.4	5.4364	-0.0115	5.4248
Water	445.9	1.0849	0.0115	1.0964

Batch Number	4B			
w/c	0.45	Volume:	0.15	ft^3
MC:	0.29%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	2.6092		2.6092
Fine Agg	2144.8	5.2184	-0.0111	5.2073
Water	482.6	1.1742	0.0111	1.1852

Batch Number	4C			
w/c	0.5	Volume:	0.15	ft^3
MC:	0.29%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1046.4	2.5459		2.5459
Fine Agg	2092.7	5.0916	-0.0108	5.0808
Water	523.2	1.2730	0.0108	1.2838

	4A	**4B**	**4C**
Fresh Unit Wt. (PCF)	142.92	140.89	140.57
Flow	74	93	107
ASTM C 109 (lbs)	5078	3981	3195

Batch Number	5A			
w/c	0.4	Volume:	0.15	ft^3
MC:	0.29%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1117.2	2.7182		2.7182
Fine Agg	2234.4	5.4364	-0.0115	5.4248
Water	445.9	1.0849	0.0115	1.0964

Batch Number	5B			
w/c	0.45	Volume:	0.15	ft^3
MC:	0.29%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	2.6092		2.6092
Fine Agg	2144.8	5.2184	-0.0111	5.2073
Water	482.6	1.1742	0.0111	1.1852

Batch Number	5C			
w/c	0.5	Volume:	0.15	ft^3
MC:	0.29%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1046.4	2.5459		2.5459
Fine Agg	2092.7	5.0916	-0.0108	5.0808
Water	523.2	1.2730	0.0108	1.2838

	5A	**5B**	**5C**
Fresh Unit Wt. (PCF)	142.98	142.44	140.39
Flow	59	69	113
ASTM C 109 (lbs)	5279	4212	3344

Batch Number	6			
w/c	0.475	Volume:	0.15	ft^3
MC:	0.30%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1055.25	2.5675		2.5675
Fine Agg	2110.5	5.1349	-0.0104	5.1245
Water	501.24	1.2195	0.0104	1.2299

Batch Number	7			
w/c	0.475	Volume:	0.15	ft^3
MC:	0.30%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1055.25	2.5675		2.5675
Fine Agg	2110.5	5.1349	-0.0104	5.1245
Water	501.24	1.2195	0.0104	1.2299

Batch Number	8N			
w/c	0.45	Volume:	2.98	ft^3
MC:	0.15%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	53.7614		53.761
Fine Agg	2144.8	107.5228	-0.3715	107.151
Water	482.6	24.1936	0.3715	24.565

	6	**7**	**8N**
Fresh Unit Wt. (PCF)	142.42	142.03	141.01
Flow	105	93	105
ASTM C 109 (lbs)	3551	3613	4765

Batch Number	9			
w/c	0.45	Volume:	0.15	ft^3
MC:	0.26%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	2.6092		2.609
Fine Agg	2144.8	5.2184	-0.0126	5.206
Water	482.6	1.1742	0.0126	1.187

Batch Number	10			
w/c	0.45	Volume:	0.15	ft^3
MC:	0.30%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	2.6092		2.609
Fine Agg	2144.8	5.2184	-0.0105	5.208
Water	482.6	1.1742	0.0105	1.185

Batch Number	11N			
w/c	0.45	Volume:	2.77	ft^3
MC:	0.24%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	50.0090		50.009
Fine Agg	2144.8	100.0179	-0.2597	99.758
Water	482.6	22.5050	0.2597	22.765

	9	**10**	**11N**
Fresh Unit Wt. (PCF)	140.38	142.62	140.18
Flow	117	113	119
ASTM C 109 (lbs)	4779	4938	4730

Batch Number	12			
w/c	0.45	Volume:	0.15	ft^3
MC:	0.11%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	2.6092		2.609
Fine Agg	2144.8	5.2184	-0.0203	5.198
Water	482.6	1.1742	0.0203	1.194
Batch Number	13			
w/c	0.45	Volume:	0.15	ft^3
MC:	0.21%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	2.6092		2.609
Fine Agg	2144.8	5.2184	-0.0151	5.203
Water	482.6	1.1742	0.0151	1.189
Batch Number	14N			
w/c	0.45	Volume:	2.72	ft^3
MC:	0.28%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	49.0724		49.072
Fine Agg	2144.8	98.1448	-0.2148	97.930
Water	482.6	22.0835	0.2148	22.298

	12	13	14N
Fresh Unit Wt. (PCF)	141.47	140.63	139.21
Flow	125	121	113
ASTM C 109 (lbs)	4280	4966	4953

Batch Number		15N		
w/c	0.45	Volume:	2.72	ft^3
MC:	0.22%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	49.0724		49.072
Fine Agg	2144.8	98.1448	-0.2754	97.869
Water	482.6	22.0835	0.2754	22.359
Batch Number		**16A**		
w/c	0.4	Volume:	0.15	ft^3
MC:	0.33%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1117.2	2.7182		2.7182
Fine Agg	2234.4	5.4364	-0.0095	5.4269
Water	445.9	1.0849	0.0095	1.0944
Batch Number		**16B**		
w/c	0.45	Volume:	0.15	ft^3
MC:	0.33%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	2.6092		2.6092
Fine Agg	2144.8	5.2184	-0.0091	5.2093
Water	482.6	1.1742	0.0091	1.1833
Batch Number		**16C**		
w/c	0.5	Volume:	0.15	ft^3
MC:	0.33%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1046.4	2.5459		2.5459
Fine Agg	2092.7	5.0916	-0.0089	5.0827
Water	523.2	1.2730	0.0089	1.2818

	15N	**16A**	**16B**	**16C**
Fresh Unit Wt. (PCF)	141.28	142.29	141.57	138.91
Flow	103	97	107	132
ASTM C 109 (lbs)	4815	6042	4652	3772

Batch Number		17N		
w/c	0.45	Volume:	2.72	ft^3
MC:	0.25%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	49.0724		49.072
Fine Agg	2144.8	98.1448	-0.2490	97.896
Water	482.6	22.0835	0.2490	22.333

Batch Number		18		
w/c	0.5	Volume:	0.15	ft^3
MC:	0.26%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1046.4	2.5459		2.5459
Fine Agg	2092.7	5.0916	-0.0123	5.0793
Water	523.2	1.2730	0.0123	1.2852

Batch Number		19		
w/c	0.5	Volume:	0.15	ft^3
MC:	0.26%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1046.4	2.5459		2.5459
Fine Agg	2092.7	5.0916	-0.0123	5.0793
Water	523.2	1.2730	0.0123	1.2852

Batch Number		20		
w/c	0.5	Volume:	0.15	ft^3
MC:	0.26%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1046.4	2.5459		2.5459
Fine Agg	2092.7	5.0916	-0.0123	5.0793
Water	523.2	1.2730	0.0123	1.2852

	17N	**18**	**19**	**20**
Fresh Unit Wt. (PCF)	138.07	139.03	138.31	138.52
Flow	97	149	150	158
ASTM C 109 (lbs)	4484	4003	3893	3853

Batch Number	21N			
w/c	0.5	Volume:	2.72	ft^3
MC:	0.25%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1046.4	47.8826		47.883
Fine Agg	2092.7	95.7607	-0.2344	95.526
Water	523.2	23.9413	0.2344	24.176

Batch Number	22N			
w/c	0.5	Volume:	2.72	ft^3
MC:	0.46%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1046.4	47.8826		47.883
Fine Agg	2092.7	95.7607	-0.0419	95.719
Water	523.2	23.9413	0.0419	23.983

Batch Number	23N			
w/c	0.5	Volume:	2.72	ft^3
MC:	0.28%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1046.4	47.8826		47.883
Fine Agg	2092.7	95.7607	-0.2096	95.551
Water	523.2	23.9413	0.2096	24.151

	21N	**22N**	**23N**
Fresh Unit Wt. (PCF)	136.00	139.00	136.28
Flow	136	139	139
ASTM C 109 (lbs)	4043	4117	3981

Batch Number		24N		
w/c	0.4	Volume:	2.72	ft^3
MC:	0.26%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1117.2	51.1224		51.122
Fine Agg	2234.4	102.2448	-0.2442	102.001
Water	445.9	20.4041	0.2442	20.648

Batch Number		25		
w/c	0.45	Volume:	2.72	ft^3
MC:	0.19%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	2.6092		2.6092
Fine Agg	2144.8	5.2184	-0.0163	5.2021
Water	482.6	1.1742	0.0163	1.1904

Batch Number		26		
w/c	0.45	Volume:	2.72	ft^3
MC:	0.18%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	2.6092		2.6092
Fine Agg	2144.8	5.2184	-0.0167	5.2016
Water	482.6	1.1742	0.0167	1.1909

	24N	**25**	**26**
Fresh Unit Wt. (PCF)	139.25	139.88	139.25
Flow	95	119	123
ASTM C 109 (lbs)	5763	4726	4913

Batch Number	27N			
w/c	0.45	Volume:	2.72	ft^3
MC:	0.19%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	49.0724		49.072
Fine Agg	2144.8	98.1448	-0.2988	97.846
Water	482.6	22.0835	0.2988	22.382

Batch Number	28N			
w/c	0.45	Volume:	2.72	ft^3
MC:	0.19%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	49.0724		49.072
Fine Agg	2144.8	98.1448	-0.2988	97.846
Water	482.6	22.0835	0.2988	22.382

Batch Number	29N			
w/c	0.45	Volume:	2.72	ft^3
MC:	0.17%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	49.0724		49.072
Fine Agg	2144.8	98.1448	-0.3223	97.823
Water	482.6	22.0835	0.3223	22.406

	27N	**28N**	**29N**
Fresh Unit Wt. (PCF)	138.83	138.57	138.43
Flow	119	120	111
ASTM C 109 (lbs)	4933	4843	4723

Batch Number		30N		
w/c	0.45	Volume:	2.72	ft^3
MC:	0.69%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	49.0724		49.072
Fine Agg	2144.8	98.1448	0.1855	98.330
Water	482.6	22.0835	-0.1855	21.898

Batch Number		31N		
w/c	0.45	Volume:	2.72	ft^3
MC:	2.80%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	49.0724		49.072
Fine Agg	2144.8	98.1448	2.2461	100.391
Water	482.6	22.0835	-2.2461	19.837

Batch Number		32N		
w/c	0.45	Volume:	2.72	ft^3
MC:	2.32%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	49.0724		49.072
Fine Agg	2144.8	98.1448	1.7792	99.924
Water	482.6	22.0835	-1.7792	20.304

	30N	**31N**	**32N**
Fresh Unit Wt. (PCF)	138.76	140.34	139.67
Flow	110	109	117
ASTM C 109 (lbs)	4723	4927	5395

Batch Number		**33N**		
w/c	0.45	Volume:	2.72	ft^3
MC:	3.87%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	49.0724		49.072
Fine Agg	2144.8	98.1448	3.2936	101.438
Water	482.6	22.0835	-3.2936	18.790

Batch Number		**34N**		
w/c	0.45	Volume:	2.72	ft^3
MC:	6.18%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	49.0724		49.072
Fine Agg	2144.8	98.1448	5.5469	103.692
Water	482.6	22.0835	-5.5469	16.537

Batch Number		**35N**		
w/c	0.45	Volume:	2.72	ft^3
MC:	5.63%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	49.0724		49.072
Fine Agg	2144.8	98.1448	5.0120	103.157
Water	482.6	22.0835	-5.0120	17.071

	33N	**34N**	**35N**
Fresh Unit Wt. (PCF)	138.67	139.99	139.81
Flow	120	122	113
ASTM C 109 (lbs)	7291	4659	4659

Batch Number		**36N**		
w/c	0.45	Volume:	2.72	ft^3
MC:	4.14%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	49.0724		49.072
Fine Agg	2144.8	98.1448	3.5576	101.702
Water	482.6	22.0835	-3.5576	18.526
Batch Number		**37N**		
w/c	0.45	Volume:	2.72	ft^3
MC:	3.03%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	49.0724		49.072
Fine Agg	2144.8	98.1448	2.4699	100.615
Water	482.6	22.0835	-2.4699	19.614
Batch Number		**38N**		
w/c	0.45	Volume:	2.72	ft^3
MC:	10.25%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	49.0724		49.072
Fine Agg	2144.8	98.1448	9.5210	107.666
Water	482.6	22.0835	-9.5210	12.562

	36N	**37N**	**38N**
Fresh Unit Wt. (PCF)	137.65	137.73	138.45
Flow	130	118	128
ASTM C 109 (lbs)	4451	4724	4153

Batch Number	39N			
w/c	0.45	Volume:	1.44	ft^3
MC:	4.12%		AC:	0.50%
Material	**PCY**	**KG**	**Correction**	**Batch Wts**
Cement	1072.4	25.8627		25.863
Fine Agg	2144.8	51.7255	1.8642	53.590
Water	482.6	11.6387	-1.8642	9.775

	39N
Fresh Unit Wt. (PCF)	138.55
Flow	119
ASTM C 109 (lbs)	4303

APPENDIX I
TYPE III CEMENT PROPERTIES USED FOR NASP BATCHINGS

LAFARGE NORTH AMERICA
Cement

River Region, Tulsa Plant
2609 North 145th East Ave.
Tulsa, Oklahoma 74116
918-437-3902

Shipped: ________
Silo: | B
Car: ________
Quantity: ________

Production Date: 10-Dec-03

Mill Anal # 37965
CERT # T303009

LABORATORY TEST REPORT FOR TYPE III LA PORTLAND CEMENT

Chemical Tests		Specification
SiO2:	20.09	20.0 Min.
Al2O3:	4.48	6.0 Max.
Fe2O3:	2.91	6.0 Max.
CaO:	64.66	
MgO:	2.45	6.0 Max.
SO3:	2.50	3.0 Max.
LOI:	1.29	3.0 Max
Na2O:	0.25	
K2O:	0.50	
Na2O eq.:	0.58	
Ins. Res.:	0.18	0.75 Max
C3S:	69	
C2S:	5	
C3A:	7	
C4AF:	9	

Physical Tests / Specification

SPECIFIC GRAVITY: 3.15

COMPRESSIVE STRENGTHS - (psi)

1 DAY:	3850	
3 DAY:	5120	
7 DAY:	5640	
28 DAY:		

SETTING TIME (Vicat) - (mins)

		Specification
INITIAL:	80	60 Min.
FINAL:	180	600 Max.
FALSE SET:	92.8 %	50 Min.
BLAINE:	5700	2800 Min.
% 325 MESH	97.07 %	
% EXPANSION:	0.002	0.80 Max.
% AIR:	9.1	12 Max.

LAFARGE NORTH AMERICA, Cements are guaranteed to comply with the current A Specifications C150; FEDERAL Specifications SS-C 1960/3B; and AASHTO Specification M85.

MILL TEST REPORT DATE: 01/05/2004

Subscribed and sworn before me this 28 day of January 2004

[signature]
Notary Public

CATHY ROBERSON NOTARY PUBLIC # 03001211 EXP. 3/05/07 IN AND FOR STATE OF OKLAHOMA OSAGE COUNTY

Lafarge North America
[signature]
Nicholas Rice, QC Mgr

LAFARGE NORTH AMERICA
Cement

River Region, Tulsa Plant
2609 North 145th East Ave.
Tulsa, Oklahoma 74116
918-437-3902

Shipped: ________
Silo:
Car: ________
Quantity: ________

Production Date: 12/1-12/31
Mill Anal #: 12/1-12/31
CERT #: T32004013

LABORATORY TEST REPORT FOR TYPE III PORTLAND CEMENT

Chemical Tests		Specification
SiO2:	20.3	
Al2O3:	4.2	6.0 Max.
Fe2O3:	2.8	6.0 Max.
CaO:	64.2	
MgO:	2.4	6.0 Max.
SO3:	3.3	3.5 Max.
LOI:	1.5	3.0 Max.
Na2O:	0.22	
K2O:	0.54	
Na2O eq.:	0.57	
Ins. Res.:	0.32	0.75 Max
C3S:	65	
C2S:	9	
C3A:	6	15 Max.
C4AF:	8	

Physical Tests		Specification
SPECIFIC GRAVITY:	3.15	
COMPRESSIVE STRENGTHS - (psi)		
1 DAY:	3880	1740 Min.
3 DAY:	5670	3480 Min.
7 DAY:	6350	
Prev. Month 28 DAY:	7100	
SETTING TIME (Vicat) - (mins)		
INITIAL:	122	45 Min.
FINAL:	195	375 Max
FALSE SET:	71 %	50 Min.
BLAINE:	562	
% 325 MESH	98 %	
% EXPANSION:	-0.02	0.80 Max.
% AIR:	9	12 Max.

The cements represented by this analysis are certified to comply with current ASTM C150 and AASHTO M85 specifications.

MILL TEST REPORT DATE: 01/10/2005

Subscribed and sworn

before me this ______day of

______________19___

Notary Public

CATHY ROBERSON NOTARY PUBLIC # 03001211 EXP. 3/05/07 IN AND FOR STATE OF OKLAHOMA OSAGE COUNTY

Lafarge North America

Timothy W. Rawisky
Quality Coordinator

APPENDIX J
CONCRETE MIX PROPORTIONS FROM OSU LABORATORY

Concrete Mix Design, Fresh and Hardened properties for Concrete I OSU Lab			
Without Air Entrainment			
			Date:06/14/04
Mix Proportions	Cement (PCY)		800
	Coarse Agg. (PCY)		1800
	Fine Agg. (PCY)		1144
	Water (PCY)		288
	Glenium 3030NS (fl. oz/cwt)		8
	Polyheed 997 WR(fl.oz/cwt)		3
	w/cm		0.36
Fresh Properties	Air Temperature (ºF)		81
	Relative Air Humidity (%)		95
	Concrete Temperature (ºF)		90
	Slump (in.)		8.5
	Unit Weight (pcf)		148.68
	Air Content (%)		2.6
Hardened Properties	Compressive Strength in psi	1 Day	6050
		3 Day	7460
		7 Day	8000
		28 Day	8810
		56 Day	9860
	Tensile Strength	1 Day	540
		28 Day	610
	Modulus of Elasticity(psi)	1 Day	5495
		28 Day	5755
	Calculated Modulus of elasticity using ACI method(psi)	1 Day	4640
		28 Day	5615

2- Concrete Mix Design, Fresh and Hardened properties for Concrete I A OSU Lab With 6% Total Air			
			Date:06/17/04
Mix Proportions	Cement (PCY)		800
	Coarse Agg. (PCY)		1800
	Fine Agg. (PCY)		922
	Water (PCY)		272
	Glenium 3030NS (fl. oz/cwt)		10
	Polyheed 997 (fl.oz/cwt)		3
	MB-AE 90 (fl.oz/cwt)		1.875
	w/cm		0.34
Fresh Properties	Air Temperature (ºF)		82
	Relative Air Humidity (%)		95
	Concrete Temperature (ºF)		90
	Slump (in.)		8
	Unit Weight (pcf)		146.68
	Air Content (%)		5.9
Hardened Properties	Compressive Strength in psi	1 Day	6400
		3 Day	7570
		7 Day	8480
		28 Day	9170
		56 Day	9740
	Tensile Strength in psi	1 Day	590
		28 Day	615
	Modulus of Elasticity in psi	1 Day	4780
		28 Day	6120
	Calculated Modulus of elasticity using ACI method in psi	1 Day	4690
		28 Day	5610

3- Concrete Mix Design, Fresh and Hardened properties for Concrete II
OSU Lab

Without Air Entrainment

			Date:06/17/04
Mix Proportions	Cement (PCY)		800
	Coarse Agg. (PCY)		1800
	Fine Agg. (PCY)		1270
	Water (PCY)		240
	Glenium 3030NS (fl. oz/cwt)		20
	Polyheed 997 WR(fl.oz/cwt)		3
	w/cm		0.3
Fresh Properties	Air Temperature (ºF)		82
	Relative Air Humidity (%)		95
	Concrete Temperature (ºF)		90
	Slump (in.)		8
	Unit Weight (pcf)		152.68
	Air Content (%)		1.8
Hardened Properties	Compressive Strength in psi	1 Day	9230
		3 Day	10910
		7 Day	12,230
		28 Day	13,010
		56 Day	13,790
	Tensile Strength in psi	1 Day	720
		28 Day	880
	Modulus of Elasticity in psi	1 Day	5880
		28 Day	7140
	Calculated Modulus of elasticity using ACI method in psi	1 Day	5980
		28 Day	7100

4 - Concrete Mix Design, Fresh and Hardened properties for Concrete III OSU Lab			
Without Air Entrainment			
			6/16/2004
Mix Proportions	Cement (PCY)		900
	10 % Fly Ash (PCY)		_
	10 % Slag (PCY)		100
	20 % Slag (PCY)		_
	Coarse Agg. (PCY)		1800
	Fine Agg. (PCY)		1188.6
	Water (PCY)		240
	Glenium 3030NS (fl. oz/cwt)		22
	Glenium 3200HES (fl. oz/cwt)		7
	Polyheed 997WR (fl.oz/cwt)		3
	w/cm		0.24
Fresh Properties	Air Temperature (ºF)		82
	Relative Air Humidity (%)		95
	Concrete Temperature (ºF)		90
	Slump (in.)		9.5
	Unit Weight (pcf)		157.7
	Air Content (%)		2.4
Hardened Properties	Compressive Strength in psi	1 Day	11,150
		7 Day	13,850
		28 Day	16,210
		56 Day	17,440
	Modulus of Elasticity	28 Day	7590
	Calculated Modulus	28 Day	8320

APPENDIX K
COPY OF ASTM A 416

Designation: A 416 – 90a

Standard Specification for Steel Strand, Uncoated Seven-Wire for Prestressed Concrete[1]

This standard is issued under the fixed designation A 416; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue that has been adopted by the Department of Defense.

1. Scope

1.1 This specification covers two types and two grades of seven-wire, uncoated steel strand for use in pretensioned and post-tensioned prestressed concrete construction. The two types of strand are low-relaxation and stress-relieved (normal-relaxation). Low-relaxation strand shall be regarded as the standard type. Stress-relieved (normal-relaxation) strand will not be furnished unless specifically ordered, or by arrangement between purchaser and supplier. Grade 250 and Grade 270 have minimum ultimate strengths of 250 000 psi (1725 MPa) and 270 000 psi (1860 MPa), respectively, based on the nominal area of the strand.

1.2 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are provided for information only.

2. Referenced Documents

2.1 *ASTM Standards:*

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[2]

E 328 Methods for Stress-Relaxation Tests for Materials and Structures[3]

2.2 *U.S. Military Standards:*

MIL-STD-129 Marking for Shipment and Storage[4]

MIL-STD-163 Steel Mill Products Preparation for Shipment and Storage[4]

2.3 *U.S. Federal Standard:*

Fed. Std. No. 123 Marking for Shipments (Civil Agencies)[4]

3. Terminology

3.1 *Description of Term Specific to This Standard:*

3.1.1 *strand*—all strand shall be of the seven-wire type having a center wire enclosed tightly by six helically placed outer wires with uniform pitch of not less than 12 and not more than 16 times the nominal diameter of the strand.

Discussion—The direction of lay may be either right- or left-hand. However, strands of different lays should not be spliced together.

4. Ordering Information

4.1 Orders for seven-wire low-relaxation or stress-relieved (normal-relaxation) strand under this specification should include the following information:

4.1.1 Quantity (feet),

4.1.2 Diameter of strand,

4.1.3 Grade of strand,

4.1.4 Type of strand,

4.1.5 Packaging,

4.1.6 ASTM designation and year of issue, and

4.1.7 Special requirements, if any.

Note 1—A typical ordering description is as follows: 84 000 ft., ½ in., Grade 270 low-relaxation strand, in 12 000-ft reelless packs to ASTM A 416–______.

5. Materials and Manufacture

5.1 *Base Metal*—The base metal shall be carbon steel of such quality that when drawn to wire, fabricated into strand, and then thermally treated, shall have the properties and characteristics prescribed in this specification.

5.2 *Wire*—The wire from which the strand is to be fabricated shall be round and have a dry-drawn finish.

Note 2—This product is a composite of seven wires and is produced to mechanical properties only, the chemistry of all wires or any individual wire is not pertinent to this application, and heat identity is not necessarily maintained. It is possible that wire from more than one heat may be used in the manufacture of a reel or pack. Traceability is based on pack identity as maintained and reported by the manufacturer.

5.3 *Treatment*—After stranding, low-relaxation strand shall be subjected to a continuous thermal-mechanical treatment to produce the prescribed mechanical properties. For stress-relieved (normal-relaxation) strand, only thermal treatment is necessary. Temper colors that may result from the thermal operation are considered normal for the finished appearance of this strand.

6. Mechanical Properties

6.1 Methods of testing for mechanical properties are described in Annex A7 of Test Methods and Definitions A 370. Low-relaxation strand shall also be tested as prescribed in Methods E 328.

6.2 *Breaking Strength*—The breaking strength of the finished strand shall conform to the requirements prescribed in Table 1.

6.3 *Yield Strength*—Yield strength is measured at 1 % extension under load and is recorded in pounds (kN). The initial loads for testing and the minimum yield strength are percentages of the minimum breaking strength listed in Table 2, which are 90 % and 85 % for low-relaxation and

[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.05 on Steel Reinforcement.

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[2] *Annual Book of ASTM Standards*, Vol 01.03.

[3] *Annual Book of ASTM Standards*, Vol 03.01.

[4] Available from Standardization Documents Order Desk, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094.

TABLE 1 Breaking Strength Requirements

Nominal Diameter of Strand, in.	Nominal Diameter of Strand, mm	Breaking Strength of Strand, lbf (kN)	Nominal Steel Area of Strand, in.² (mm²)	Nominal Weight of Strands lb/1000 ft (kg/1000 m)
		Grade 250		
¼ (0.250)	6.35		0.036 (23.22)	122 (182)
5/16 (0.313)	7.94		0.058 (37.42)	197 (294)
⅜ (0.375)	9.53		0.080 (51.61)	272 (405)
7/16 (0.438)	11.11		0.108 (69.68)	367 (548)
½ (0.500)	12.70		0.144 (92.90)	490 (730)
(0.600)	15.24		0.216 (139.35)	737 (1094)
⅜ (0.375)	9.53		0.085 (54.84)	290 (432)
7/16 (0.438)	11.11		0.115 (74.19)	390 (582)
½ (0.500)	12.70		0.153 (98.71)	520 (775)
(0.600)	15.24		0.217 (140.00)	740 (1102)

stress-relieved (normal-relaxation) strand, respectively.

6.3.1 The extension under load shall be measured by an extensometer calibrated with the smallest division not larger than 0.0001 in./in. of gage length.

6.4 *Elongation*—The total elongation under load shall not be less than 3.5 %. In practice the total elongation value may be determined by adding to the 1.0 % yield extension the percent extension or movement between the jaws gripping the strand after yield determination. The percent is calculated on the new base length of jaw-to-jaw distance.

6.5 *Relaxation Properties*—Low-relaxation strand shall have relaxation losses of not more than 2.5 % when initially loaded to 70 % of specified minimum breaking strength or not more than 3.5 % when loaded to 80 % of specified minimum breaking strength of the strand after 1000 h tested under the conditions listed in 6.5.1 through 6.5.7.

6.5.1 If required, relaxation evidence shall be provided from the manufacturer's records of tests on similarly dimensioned strand of the same grade.

6.5.2 The temperature of the test piece shall be maintained at 68 ± 3.5°F (20 ± 2°C).

6.5.3 The test piece shall not be subjected to loading prior to the relaxation test.

6.5.4 The initial load shall be applied uniformly over a period of not less than 3 min and not more than 5 min, and the gage length shall be maintained constant; load relaxation readings shall commence 1 min after application of the total load.

6.5.5 Over-stressing of the test sample during the loading operation shall not be permitted.

6.5.6 The duration of the test shall be 1000 h or a shorter computed period extrapolated to 1000 h which can be shown by records to provide similar relaxation values.

6.5.7 The test gage length should be at least 60 times the nominal diameter. If this gage length exceeds the capacity of the extensometer or testing machine, then a minimum gage length of 40 times the nomimal diameter may be substituted.

7. Dimensions and Permissible Variations

7.1 The size of the finished strand shall be expressed as the nominal diameter of the strand in fractions or decimal fractions of an inch.

7.2 The diameter of the center wire of any strand must be larger than the diameter of any outer wire in accordance with Table 3.

7.3 *Permissible Variations in Diameter:*

7.3.1 All Grade 250 strand shall conform to a size tolerance of ±0.016 in. (±0.41 mm) from the nominal diameter measured across the crowns of the wires.

7.3.2 All Grade 270 strand shall conform to a size tolerance of +0.026, −0.006 in. (+0.66, − 0.15 mm) from

TABLE 2 Yield Strength Requirements

Nominal Diameter of Strand, in.	Nominal Diameter of Strand, mm	Initial Load, lbf (kN)	Minimum Load at 1 % Extension, lbf (kN): Normal-Relaxation	Minimum Load at 1 % Extension, lbf (kN): Low-Relaxation
		Grade 250		
¼ (0.250)	6.35	900 (4.0)	7 650 (34.0)	8 100 (36.0)
5/16 (0.313)	7.94	1 450 (6.5)	12 300 (54.7)	13 050 (58.1)
⅜ (0.375)	9.53	2 000 (8.9)	17 000 (75.6)	18 000 (80.1)
7/16 (0.438)	11.11	2 700 (12.0)	23 000 (102.3)	24 300 (108.1)
½ (0.500)	12.70	3 600 (16.0)	30 600 (136.2)	32 400 (144.1)
(0.600)	15.24	5 400 (24.0)	45 900 (204.2)	48 600 (216.2)
		Grade 270		
⅜ (0.375)	9.53	2 300 (10.2)	19 550 (87.0)	20 700 (92.1)
7/16 (0.438)	11.11	3 100 (13.8)	26 350 (117.2)	27 900 (124.1)
½ (0.500)	12.70	4 130 (18.4)	35 100 (156.1)	37 170 (165.3)
(0.600)	15.24	5 860 (26.1)	49 800 (221.5)	52 740 (234.6)

TABLE 3 Diameter Relation Between Center and Outer Wires

Nominal Diameter of Strands, in.	Nominal Diameter of Strands, mm	Minimum Difference Between Center Wire Diameter and Diameter of Any Outer Wire, in.	Minimum Difference Between Center Wire Diameter and Diameter of Any Outer Wire, mm
	Grade 250		
¼ (0.250)	6.35	0.001	0.0254
5/16 (0.313)	7.94	0.0015	0.0381
⅜ (0.375)	9.53	0.002	0.0508
7/16 (0.438)	11.11	0.0025	0.0635
½ (0.500)	12.70	0.003	0.0762
(0.600)	15.24	0.004	0.1016
	Grade 270		
⅜ (0.375)	9.53	0.002	0.0508
7/16 (0.438)	11.11	0.0025	0.0635
½ (0.500)	12.70	0.003	0.0762
(0.600)	15.24	0.004	0.1016

the nominal diameter measured across the crowns of the wire.

7.3.3 Variation in cross-sectional area and in unit stress resulting therefrom shall not be cause for rejection provided that the diameter differences of the individual wires and the diameters of the strand are within the tolerances specified.

7.4 Specially dimensioned low relaxation and stress-relieved (normal-relaxation) strands with nominal diameters up to 0.750 in. (19.05 mm) may be employed, providing that the breaking strength is defined, and the yield strength, as defined in 6.3, is not less than 90 % and 85 % of the specified minimum breaking strength for low-relaxation and stress-relieved (normal relaxation) strands, respectively. All other requirements shall apply.

8. Workmanship, Finish, and Appearance

8.1 *Joints:*

8.1.1 There shall be no strand joints or strand splices in any length of the completed strand unless specifically permitted by the purchaser.

8.1.2 During the process of manufacture of individual wires for stranding, welding is permitted only prior to or at the size of the last thermal treatment, for example, patenting or control cooling. There shall be no welds in the wire after it has been drawn through the first die in the wire drawing except as provided in 8.1.3.

8.1.3 During fabrication of the strand, butt-welded joints may be made in the individual wires, provided there is not more than one such joint in any 150-ft. (45-m) section of the completed strand.

8.1.4 When specifically ordered as "Weldless," a product free of welds shall be furnished. When "Weldless" is specified, the strand is produced as one continuous length with no welds as allowed by 8.1.3.

8.2 The finished strand shall be uniform in diameter and shall be free of imperfections not consistent with good commercial stranding practice.

8.3 When the strand is cut without seizings, the wire shall not fly out of position. If any wire flies out of position and can be replaced by hand, the strand will be considered satisfactory.

8.4 The strand shall not be oiled or greased. Slight rusting, provided it is not sufficient to cause pits visible to the unaided eye, shall not be cause for rejection.

9. Sampling

9.1 Test specimens may be cut from either end of the strand package. Any specimen found to contain a wire joint should be discarded and a new specimen obtained.

10. Number of Tests

10.1 One specimen for test shall be taken from each 20-ton (18-Mg) production lot of finished strand.

11. Inspection

11.1 If outside inspection is required, the manufacturer shall afford the inspector representing the purchaser all reasonable facilities to satisfy that the material is being furnished in accordance with this specification. All tests and inspections shall be made at the place of manufacture prior to shipment, unless otherwise agreed upon at the time of purchase, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

Note 3—The purchaser should state, at the time of order, whether outside inspection is required or waived.

12. Rejection

12.1 Failure of any test specimen to comply with the requirements of the specification shall constitute grounds for rejection of the lot represented by the specimen.

12.2 The lot may be resubmitted for inspection by testing a sample from each reel or pack and sorting out nonconforming material.

12.3 In case there is a reasonable doubt in the initial testing as to the ability of the strand to meet any requirement of this specification, two additional tests shall be made on a sample of strand from the same reel or pack, and if failure occurs in either of these tests, the strand shall be rejected.

13. Certification

13.1 If outside inspection is waived, a manufacturer's certification that the material has been tested in accordance with and meets the requirements of this specification shall be the basis of acceptance of the material. The certification shall include the specification number, year-date of issue, and revision letter, if any.

13.2 The manufacturer shall, when requested in the order, furnish a representative load-elongation curve for each size and grade of strand shipped.

13.3 When the modulus of elasticity of a seven-wire strand is provided, the cross-sectional area used to compute that modulus shall also be provided. The area provided in the certification shall be the area used to calculate the modulus of elasticity.

14. Packaging and Marking

14.1 The strand shall be furnished on reels or in reelless packs having a minimum core diameter of 24 in. (610 mm), unless otherwise specified by the purchaser. Lengths on reels or in reelless packs shall be as agreed upon at the time of purchase. The strand shall be well protected against mechanical injury in shipping as agreed upon at the time of purchase. Each reel or reelless pack shall have two strong tags securely fastened to it showing the length, size, type, grade, ASTM designation A 416, and the name or mark of the manufacturer. One tag shall be positioned where it will not be inadvertently lost during transit, such as the core of a reelless pack. The other should be on the outside where it will be accessible for easy identification.

14.2 *For Government Procurement Only*—When specified in the contract or order, and for direct procurement by or direct shipment to the U. S. government, material shall be preserved, packaged, and packed in accordance with the requirements of MIL-STD-163. The applicable levels shall be as specified in the contract. Marking for shipment of such material shall be in accordance with Fed. Std. No. 123 for civil agencies and MIL-STD-129 for military agencies.

VITA

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Thesis: ASSESSING THE BOND QUALITY OF PRESTRESSING STRANDS USING NASP BOND TEST

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Scope and Method of Study:

In prestressed concrete, effective transfer of prestressing force to surrounding concrete is essential to achieve strength and integrity within the structure. Bonding of prestressing strands with concrete has been of concern to engineers for years. This research program conducted an experimental program to address the issue on bond qualities of prestressing strands. The research work investigates the NASP Bond test procedure, which was conceived by researchers in the past and standardized during the present program. The test results are correlated to transfer lengths measured on prototype beams.

Findings and Conclusions:

The test method showed strong correlation between different testing sites indicating that the test is reliable as a standardized bond test. Results from the research showed that the NASP pull out value had direct effects towards transfer length. The results also indicate that the transfer length is a function of concrete strengths.

ADVISER'S APPROVAL: ______________________________