THE EFFECT OF HIGH STRENGTH CONCRETE

ON THE BONDABILITY

OF PRESTRESSING

STRANDS

By

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Chapter 1

1. INTRODUCTION

1.1. BACKGROUND

Adequate bond between prestressing strand and concrete is essential for adequate structural performance and reliability of concrete members. Bond quality affects transfer and development lengths of prestressed members. If the bond between the strand and concrete is not enough, the transfer and development length of the member may exceed the code requirement. Hence non ductile failure occurs due to inadequate shear reinforcement provision.

Researchers found the current code equations governing the bond of strand have been shown to be inaccurate. Hence bond test is needed that will help to determine the effects on bond of variations in concrete properties or constituent materials. The Prestress Concrete Institute (PCI) financed projects that investigated strands manufactured by various manufacturers using various test methods. Research conducted by Cousin, Johnson and Zia indicates that the ACI code equations for bond might be inadequate and more research is needed to fully understand the bond mechanics between concrete and prestressing strand. According to Mote (2001), concrete strength would affect bond of prestessing strand.

1.2. OBJECTIVE

This research program is focused on determining what effects; variations in concrete properties have on bond, with primary emphasis on the variation in concrete strength. The variations in concrete properties are:

- Concrete strength ranging from 4 Ksi to 10 ksi at release.
- Air entrained concrete vs. non-air entrained concrete.

1.3 SCOPE

The scope of this experimental program includes;

1. The NASP Bond Pull-out test (The NASP Test) to measure:
    - Effects of varying strength concrete
    - Effects of air entrainment
    - Effects of high range Water Reducer's (HRWR)

That was used to determine what effects; if any, had on the bond between prestressing strand and concrete.

2. The effect of concrete strength on the bond of prestressing strand.
3. Laboratory trial batching of high performance concrete mixtures.
4. Casting high performance concrete in beams in the prestressing plant.

Concrete batching is required to determine mix proportions that are workable and reach target one day, 28 or 56 days compressive strength. One day concrete strength varied from 4 ksi to 10 ksi. And 28 or 56 days concrete strength varied from 6 ksi to 15 ksi.

Chapter 2

2. DEFINITIONS AND BACKGROUND

2.1 DEFINITIONS

2.1.1 Transfer Length

Transfer length is the length of strand required to transmit the prestressing force, after losses, in the prestressing strand to the concrete (Janney 1954, Hanson and Kaar 1959, Rose 1995).

2.1.2 Development Length

The development length of a prestressing strand is the sum of the transfer and the flexural bond length. The additional bonded length of strand required to anchor the strand when an external load is applied to the member is called the flexural bond length. The tension in the prestressing strand increases and generates additional anchoring forces if an external load is applied to a prestressing concrete member (Mote, 2001). The flexural bond length provides the additional anchorage requirements. The ACI 318-02 commentary (section 12.9) defines the development length as follows:

$$l_d = \left(\frac{f_{se}}{3}\right)d_b + \left(f_{ps} - f_{se}\right)d_b \qquad (2.2)$$

Where l_d is the development length of the strand in inches, fps is the stress in the prestressed reinforcement at the nominal strength of the member in ksi, fse is the effective pretensioning force in the prestressed reinforcement after all losses in ksi, and db is the nominal strand diameter in inches.

2.1.3 Pull-Out Strength

The pull-out strength of a strand is the amount of force produced between the concrete and prestressing strand over an embedded length of the strand when the strand is pulled out of the concrete. This research project conducted one type of pull out tests, the North American Strand Producers (NASP) Pullout Tests. In NASP Bond tests the strands were initially untensioned. The variables of each test will be described in detail in this chapter and the chapters that follow.

2.2 Bond Mechanics in Pull out Tests

Pull out tests assess the strand pulling force verses the resulting strand slippage. In this research program, NASP Bond Tests are evaluated. The NASP pullout Test measured the “free end slip.” “Free end slip” is the strand slip measured on the side opposite of the application of strand tension.

Simple pullout tests have been correlated with transfer length of prestressing strand in the past. It has advantage and disadvantage correlating pull out strength to transfer length.

The major advantage of correlating pull out strength to transfer length is that pull out tests are relatively easy to carry out. The equipments are simple and are cheaper than measuring transfer lengths of strand in beams.

The disadvantage of correlating pull out strength to transfer length is that the Hoyer’s effect which is the primary element of bond in the transfer zone is absent in simple pullout tests. As the strand diameter decreases and pulls away from the concrete causing a reverse Hoyer's effect. The presence of adhesion is another disadvantage in trying to correlate pullout strength to transfer length. As the strand slips relative to the concrete, adhesion does not make a contribution but it is of little concern since adhesion bond is broken before strands reach their maximum value.

2.3 Literature Review

2.3.1 Untensioned Pullout Strengths

In the past, tensioned and simple pullout tests have been performed on prestressing strand. In NASP Test strands are pulled out of a concrete specimen. The strand is initially untensioned in the simple pull out test. Simple pullout tests have been the majority of pullout tests conducted in the past.

This research project focus on a standardized prestressing strand pullout test that will be interrelated to the bond ability of prestressing strands. Research has been conducted to determine a reliable standardized test to evaluate the bond ability of prestressing strand. These tests include single specimens and concrete specimens.

2.3.1.1Untensioned Single Strand Pull-Out Tests

Russell and Paulsgrove (1999) conducted a test, the NASP Pull-out Test in which the pull-out force is reported at 0.01 in. free end slip, and maximum. The mortar used had a sand to cement ratio of 2:1 and a 0.45 water to cement ratio. The NASP tests were conducted with Type III cement except for the first series at Florida wire and cable test site (FWC) which was conducted with Type I cement. The tests were conducted at OU and FWC. The results indicate that for NASP test, the 0.10 in. and maximum pull-out forces may be better for determining bond acceptance since the range of values is wider. Russell and Paulsgrove concluded that the NASP test demonstrated less variation in data between test sites. Due to the larger range in values, they recommend the pull-out force at 0.10 in. of slip be for NASP test. The results are shown in Table 2.4, 2.5, and 2.6.

Table 2.1: NASP Test Maximum Pull-Out Force. (Russell and Paulsgrove 1999b)

Strand	OU Series I		OU Series II		FWC Series I		FWC Series II	
	Average	St. Dev.	Average	St. Dev.	Average	St. Dev.	Average	St. Dev.
	(K)	(%)	(K)	(%)	(K)	(%)	(K)	(%)
A	19.2	9.7	16.6	8.9	14.7	29.3	16.6	18.4
B	15.2	11.4	14.4	11.8	10.1	38.8	12.5	23.3
C	21.6	7.8	18.5	12.3	15	24.3	20.4	17.6
J	4.9	19.7	4.4	22	3.5	32.3	6.9	22.4
K	15.8	11.5	15.6	9.4	11.2	24.8	13.4	10.4
M	17.9	11	16.2	6.7	12.5	25.3	14	17.3
P	21.1	6.8	18.3	6.5	15.6	19.6	17.7	27.6
W	13.2	14.8	12.6	9	7.8	27.2	12.5	25.2
Z	7.9	16.3	9.1	13.7	6.1	26.9	11.3	17

Table 2.2: NASP Test 0.10 in. Slip Pull-Out Force. (Russell and Paulsgrove 1999b)

Strand	OU Series I		OU Series II		FWC Series I		FWC Series II	
	Average (K)	St. Dev. (%)	Average (K)	St. Dev. (%)	Average (K)	St. Dev. (%)	Average (K)	St. Dev. (%)
A	17.7	11.8	15.9	7.1	12.5	27.4	14.5	18.2
B	11.8	10.2	11.8	23.2	8	33.6	10.2	19
C	19.6	10	17.8	12.4	12.9	20.6	17	19.1
J	2.6	21.7	3.3	24	2.8	23.2	5	25.4
K	13.8	12.4	14.6	11.2	9.3	29.9	11.8	9.7
M	14.9	13.5	14.9	4.6	10.7	23.3	12.2	13.4
P	17.1	9.6	17.3	6.9	12.5	14.2	15.1	23.5
W	10.4	14.9	11.3	11	6.8	24.7	9.7	14.5
Z	5.7	21	7.9	13	5.2	26.2	7.8	17.3

Table 2.3: NASP Test 0.01 in. Slip Pull-Out Force. (Russell and Paulsgrove 1999b)

Strand	OU Series I		OU Series II		FWC Series I		FWC Series II	
	Average	St. Dev.	Average	St. Dev.	Average	St. Dev.	Average	St. Dev.
	(K)	(%)	(K)	(%)	(K)	(%)	(K)	(%)
A	15	16.3	11.2	37.4	9.9	28.6	11	15
B	9.7	10	9.5	23.7	7.3	32.5	8.4	15.5
C	15.5	8.8	14.4	15.4	11.3	15.9	14.1	18.2
J	2.3	31.4	3.3	28.4	3.4	31.4	4.6	19.2
K	11.1	18.7	11.9	14.5	8.2	34.2	9.1	8.9
M	11.2	24.8	11.9	6.7	9.1	29.7	10.3	10.9
P	9	14.7	13.7	10	8.8	17.2	12.4	16.9
W	8.9	8.8	9.8	10.4	6.1	17.9	7.8	9.3
Z	5.6	22.6	7.4	7.5	5.3	25	6.9	15

Table 2.4 NASP Test Results. (Brown 2003)

Strand	OU Series I		OU Series II		FWC Series I		FWC Series II	
	Average	St. Dev.	Average	St. Dev.	Average	St. Dev.	Average	St. Dev.
	(K)	(%)	(K)	(%)	(K)	(%)	(K)	(%)
AA	13.9	9.0	16.0	16.9	9.7	7.0	11.6	14.2
BB	6.8	10.6	10.4	9.3	5.4	10.7	8.9	11.7
CC	9.9	25.2	8.8	15.7	7.7	22.9	8.0	15.2
DD	14.3	4.2	15.3	11.5	10.9	7.7	11.5	14.6
EE	14.1	4.2	16.0	26.0	10.0	7.4	9.7	15.6
FF	6.3	6.5	8.3	15.6	7.3	5.5	8.7	14.9
GG	7.2	14.0	12.4	10.1	5.0	10.4	9.1	13.0
HH	11.1	9.0	10.3	15.9	9.5	9.1	8.1	19.6
II	3.0	10.7	5.3	15.9	3.7	6.6	5.7	13.0
JJ	19.7	7.1	17.6	17.9	14.9	5.9	13.0	23.0

Brown (2003) conducted NASP tests continuing the research by Russell and Paulsgrove. The procedures are identical to those previously discussed. Table 2.7 summarizes the results. This research results will be analyzed with Brown's research. The proposed NASP Test procedure resulting from the testing is given in Appendix B.

Table 2.5: NASP Test Results. (Brown 2003)

Strand	0.10 in. Slip Pull-Out Force				0.01 in. Slip Pull-Out Force			
	OU		FWC		OU		FWC	
	Avg.	St. Dev.	Avg.	St. Dev.	Avg.	St. Dev.	Avg.	St. Dev.
	(K)	(%)	(K)	(%)	(K)	(%)	(K)	(%)
AA	13.9	9	16	16.9	9.7	7	11.6	14.2
BB	6.8	10.6	10.4	9.3	5.4	10.7	8.9	11.7
CC	9.9	25.2	8.8	15.7	7.7	22.9	8	15.2
DD	14.3	4.2	15.3	11.5	10.9	7.7	11.5	14.6
EE	14.1	4.2	16	26	10	7.4	9.7	15.6
FF	6.3	6.5	8.3	15.6	7.3	5.5	8.7	14.9
GG	7.2	14	12.4	10.1	5	10.4	9.1	13
HH	11.1	9	10.3	15.9	9.5	9.1	8.1	19.6
II	3	10.7	5.3	15.9	3.7	6.6	5.7	13
JJ	19.7	7.1	17.6	17.9	14.9	5.9	13	23

2.4 Summary

Based on the research effort to date, two of the untensioned pulls out tests have shown promise at becoming the most reliable means of predicting bond behavior. The NASP test appears to be the most promising for standardized testing as a standardized test should be able to be a stand alone test. This research program is useful toward investigating the effect of high strength concrete on the bond ability of prestressing strands using the NASP bond test.

Chapter 3

3. EXPERIMENTAL PROGRAM

3.1 INTRODUCTION

The testing program was designed for:

- Laboratory trial batching of HPC mixtures
- NASP Tests in Concrete

The procedures for this project will be trial batching and NASP Testing. The trial batching was required to develop mixture designs to achieve desired strengths and workability for concrete mixtures used in the NASP tests and beams in prestressing plant. The results of the NASP testing will be used to analyze the effect of concrete strength on the bond strength of varying concrete properties.

3.2 SCOPE OF RESEARCH

The scope of the research includes:

1. Trial Batching of concretes C-N, C-I, C-II, C-III and C-IA to develop Concrete mixtures for
    - Fabrication of beams
    - NASP Tests in Concrete
2. NASP Test in Concrete to determine the effects of concrete strength on the bond of steel prestressing strand.
3. Variables
    - Concrete release strength

- Strand Source

Table 3.1A and 3.1B will describe the scope of the thesis.

Table 3.1A: Research Scope

Targeted Concrete Strengths (psi)			**NASP Tests in Concrete**
Concrete Type	**@ Release (1 day)**	**@ Design (28 or 56 day)**	**0.5 in.**
C-N	4,000	6,000	A, B, D, A6
C-I	6,000	10,000	A, B, D, A6
C-II	8,000	12,000	A, B, D, A6
C-III	10,000	15,000	A, B, D, A6
C-IA	6,000 A	10,000	A, B, D, A6

Table 3.1B: Research Scope

Targeted Concrete Strengths (psi)		Beam Tests Strands	
Concrete Type @ Release (1 day)	**@ Design (28 or 56 day)**	**R - Beams**	**I – Beams**
4,000	6,000	A, B, D, A6	_
6,000	10,000	A, B, D, A6	B, D
8,000	12,000	A, B, D, A6	_
10,000	15,000	A, B, D, A6	B, D
6,000 A	10,000	A, B, D, A6	_

4. Casting HPC concrete in beams in the prestressing plant.

3.3 TRIAL BATCHING

Concrete trial batching was required to attain desired strengths and workability for five types of concrete mixtures used in the NASP tests and beams in prestressing plant.

3.3.1. Materials

The materials used in the experimental procedures were Type III cement, coarse aggregate, fine aggregate, water, blast furnace slag, and chemical admixtures. The Type III cement was provided by Lafarge North America from their plant in Tulsa, Oklahoma. The cement is a Portland Type III cement meeting the specifications in ASTM C 150.

The coarse and fine aggregates were provided by Dolese Brothers Company from their Stillwater, Oklahoma plants. The blast furnace slag was supplied by Lafarge. The blast furnace was New cement.

The other chemical admixtures which includes normal range water reducer (WR) ,high range water reducers (HRWR), high early strength (HES) and air entraining admixtures (AE) were supplied by Master Builders .The normal range water reducer was polyheed 997. The high range water reducer was Glenuim 3400 for NASP testing. For preparing the preliminary mixture designs Glenium 3030 NS was used as HRWR. The air entraining admixture was AE-90.

The saturated surface dry (SSD) unit weights of the aggregates were used to compute the batch weight. The moisture content of the aggregate was measured and the batch weights were adjusted accordingly. The materials were handled in conformance with ASTM C 192.

The sand confirmed to ASTM C 33, the coarse aggregate ASTM, and the cement used conformed to ASTM C 150 requirements for Type III cement. The water was potable and suitable for making concrete.

The concretes were mixed in a pan mixer. At first, half of the water, all coarse aggregate were placed in the pan and mixed for a few seconds. Then all of the sand, cement and the remaining water were added and mixed for three minutes. Water reducing admixtures were added while the pan was revolving. The pan was set for three minutes without mixing and then mixed for another two minutes. The test specimens were made in conformance with ASTM C 192.

3.3.2 Where to begin?

A number of trial batching was conducted to establish the required mixture proportions. First, mixtures were selected based on the desired properties from previous work conducted by Grieve (2003). Table 3.2 shows Grieves Mix design. The mix proportions are based on different water to cement ratio. The first one is with w/c ratio of 0.36 to get one day concrete strength of 6,000 psi and the second one is with w/c ratio of 0.28 to get 8, 000 psi one day concrete strength. Trial batches were started out with mix design from Grieves.

Table 3.2. Grieve's Concrete Mix Design

		G3030-8-36-1	G3030-8-28-1
Mix Proportions	Cement (PCY)	800	800
	Coarse Agg. (PCY)	1800	1800
	Fine Agg. (PCY)	1144	1312
	Water (PCY)	288	224
	Glenium 3030 (fl. oz/cwt)	7.5	22.5
	w/cm	0.36	0.28

3.3.3 Trial Batches

Various mixture proportions were implemented in order to determine the effects of concrete strength and the age of the concrete. The ultimate goal of the concrete mixtures was to reach five desired compressive strength combinations with a workable mixture acquiring a slump of 6 to 8 in. One combination's target strengths were C-N (Normal concrete), 4,000 psi one day strength and 6,000 psi 28 or 56 day strength. The second combination's target strengths were C-I, 6,000 psi one day strength and 10,000 psi 28 or 56 day strength. Third combination's target strengths were C-IA (concrete with air), 6,000 psi one day strength and 10,000 psi 28 or 56 day strength and with 6 % air content. The fourth combination's target strengths were C-II, 8,000 psi one day strength and 14,000 psi 28 or 56 day strength. The last combination's target strengths were C-III, 10,000 psi one day strength and 18,000 psi 28 or 56 day strength. The mix designs for Concrete C-I and C-II were started out using Grieve's mix design. A number of trial batches were conducted changing the water to cement ratio and cement content for C-N and C- III. For example, to start with C-N, cement with 650 PCY was used and w/c ratio of 0.46 was used. To reach the strength, cement content was kept constant but the water to cement ratio was varied. The selected concrete mix proportions that result from trial batching are given in Table 3.3. The mix proportion and results of all trial batches conducted in the La b are specified in Appendix D.

Table 3.3 Mix Proportions from OSU Structures Lab

3.3.1. Concrete Mix Design for Concrete C-N		
Without Air Entrainment		
		Date:02/15/05
Mix Proportions	Cement (PCY)	650
	Coarse Agg. (PCY)	1800
	Fine Agg. (PCY)	1243
	Water (PCY)	298
	Glenium 3400 (fl. oz/cwt)	8
	w/cm	0.46

3.3.2. Concrete Mix Design for Concrete I		
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

3.3.3. Concrete Mix Design for Concrete I A		
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

3.3.4. Concrete Mix Design for Concrete II		
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	0.30

3.3.5. Concrete Mix Design for Concrete III		
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

3.3.4 Results from Trial Batches

Concrete mix designs were developed through trial batching. The results from trial batching are reported below along with the results of the fresh and hardened concrete properties. Fresh concrete properties include slump, unit weight, air temperature, and concrete temperature. Hardened concrete properties include concrete compressive strength at different age. The results from trial batching are given in Table 3.4.

Table 3.4. Test Results from Trial Batching

3.4.1- Fresh and Harden properties for Concrete C-N Without Air Entrainment			
			Date:02/15/05
Fresh Properties	Air Temperature (ºF)		82
	Relative Air Humidity (%)		24
	Concrete Temperature (ºF)		75
	Slump (in.)		10
	Unit Weight (pcf)		146.8
	Air Content (%)		2.5
Hardened Properties	Compressive Strength in psi	1 Day	4560

3.4.2- Fresh and Harden properties for Concrete I

Without Air Entrainment

			Date:06/14/04
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

3.4.3- Fresh and Harden properties for Concrete I A

With 6 % Total Air

			Date:06/17/04
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

3.4.4- Fresh and Harden properties for Concrete II

			Date:06/17/04
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	1 Day	5980
	using ACI method in psi	28 Day	7100

3.4.5 - Fresh and Harden properties for Concrete III			
			Date:6/16/2004
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

3.3.5 Summary and Conclusion from trial batching

The concrete trial batching was conducted in order to get desired five desired compressive strength with workable mixture to be applied in the NASP Bond Test and beams in Prestressing Plant. Materials, water to cement ratio, mineral and chemical admixtures had significant effects on the fresh and hardened properties of the concrete.

From the trial batching in the lab, the following wee concluded:

- For C-N, cement content of 650 PCY and w/c ratio of 0.46 will give the target strength of 4,000 psi one day strength.
- For C-I, cement content of 800 PCY and w/c ratio of 0.36 will give the target strength of 6,000 psi one day strength.
- For C-IA, cement content of 800 PCY and w/c ratio of 0.34, 1.875 fl. Oz AE-90 will give the target strength of 6,000 psi one day strength.
- For C-II, cement content of 800 PCY and w/c ratio of 0.30 will give the target strength of 8,000 psi one day strength.
- For C-III, cement content of 1000 PCYwith 10 % slag replacement and w/c ratio of 0.24 and 7 fl. Oz HES will give the target strength of 10,000 psi one day.
- Chemical and mineral admixtures had significant effects on the fresh and hardened concrete properties. The chemical admixtures were used to increase the slump of the fresh concrete and to get high early strength.
- As the strength of concrete was high, the dosage of high range water reducers increased in order to get the required slump.
- A high early strength admixture was used for concrete C-III in order to get one day strength of 10,000 psi.
- Based on the Master Builder's recommendation, the high range water reducer, Glenium 3030 was replaced by Glenium 3400 HES as it is a new product.
- Mineral admixture fly ash (Type C) and blast furnace slag (New Cement) were used to increase the compressive strengths of the concrete. Based on the trial

batches performed at OSU Lab as shown in Table 3.5, fly ash had a lower effect on the early compressive strength of concrete than blast furnace slag.

Table 3.5-Concrete Mix Design, Fresh and Harden properties for Concrete III-OSU

			6/9/2004	6/14/2004	6/10/2004	6/11/2004	6/16/2004
Mix Proportions	Cement (PCY)		1000	900	800	900	900
	10 % Fly Ash (PCY)		_	100	_	_	_
	10 % Slag (PCY)		_	_	_	100	100
	20 % Slag (PCY)		_	_	200	_	_
	Coarse Agg. (PCY)		1800	1800	1800	1800	1800
	Fine Agg. (PCY)		1141.7	1163.4	1141.7	1188.6	1188.6
	Water (PCY)		260	240	260	240	240
	Glenium 3030NS (fl. oz/cwt)		6.5	22	6.5	30	22
	Glenium 3200HES (fl. oz/cwt)		6.92	7	6.92	7	7
	Polyheed 997WR (fl.oz/cwt)		3	3	3	3	3
	w/cm		0.26	0.24	0.26	0.24	0.24
Fresh Properties	Air Temperature (ºF)		90	77	90	90	82
	Relative Air Humidity (%)		84	95	85	85	95
	Concrete Temperature (ºF)		85	90	85	86	90
	Slump (in.)		8.4	10	3	10	9.5
	Unit Weight (pcf)		157.70	159.70	154.68	159.68	157.70
	Air Content (%)		2.4	2.3	2.8	1.3	2.4
Hardened Properties	Compressive Strength in psi	1 Day	11,000	10,850	9890	12,080	11,150
		7 Day	13,460	14,340	13,040	14,330	13,850
		28 Day	14,660	16,570	14,170	16,900	16,210
		56	15,200	16,720	14,570	16,960	17,440

- The replacement of cement with 10 % blast furnace yielded the required 28 or 56 day strength as shown in Table 3.5. The 28 day compressive strength was 6.1 % greater than without cementitious replacement and 12.8 % more for 56 day.
- Water to cement ratio (w/c) and water to cementitious ratio (w/cm) had a significant effect on concrete strength. Decreasing the water to cement ratio increased the compressive strength of concrete.

3.4. NASP TESTS IN CONCRETE

The NASP Bond Test specimen designs were established to give an easy repeatable and simple test to assess the bond performance of strand. The NASP Bond Test can be simply conducted at most testing facilities. The test carriage, test specimen, and LVDT can be seen Figure 3.1.The bond tests were tested using similar procedures as in the NASP grout pullout testing by Russell and Paulsgrove (1999b).

In this research program, four different sources of North American seven wire strands were used. The NASP Bond Test engaged pulling a member of strand out of an 18 in. tall by 5 in. diameter cylinder of concrete. Load verses slip curves were produced with the resulting data.

3.4.1. Procedure

The first part of the NASP testing program was the fabrication of the NASP Bond Test specimens. One NASP Test consists of tests on six individual specimens. The next part is testing procedure. To allow for testing within the specified time range, the casts were spaced one hour apart. Strict control over testing and curing parameters were used.

3.4.1.1. Specimen Design

The Prestressing strands used in the testing program were seven wire low relaxation strands of 0.5 in. diameter and 0.6 in diameter. The NASP Bond Test specimen mold was made with 5 in. outer diameter, 1/8 in. thick, 18 in. long steel pipe. The tube was cut to 18 in. in length and conformed to ASTM A 513 Type I. The base of the cylinders was closed using ¼ in. thick steel plate that measured 6 in. by 6 in. that conformed to ASTM A 36. The strand was accommodated by the hole drilled in the center of the plat. The steel tube was welded to the base plate with a continuous weld.

Strand specimens for NASP Test were taken from four different reel of prestressing strand. Six strand specimens are required from the same reel in each test. The strand specimens conformed to ASTM A 416 and were used for prestressing application.

The bonded length of the strand was 16 in., with a 2 in. long bond breaker. A 1 ¾ '' long Styrofoam and tape were used to made the bond breaker which are attached to the strand. The specimens were placed vertical on a wooden block. The holes in the base plates were aligned with holes drilled in the wooden block to accommodate strand protruding from the bottom of the specimen. Thirty two in. of lengths of strand were placed in the tubes. The duct tape bond breaker rested on the base plate and located the strand vertically.

The mixed concrete poured were mixed and poured into the tubes. The concretes were mechanically consolidated by vibrator in conformance with ASTM C 192. After the mixture had been vibrated, the tops of the specimens received a trowel finish. Three 4 x 8 in. test cylinders were made according to ASTM in order to test compressive strength before pull-out tests, three compressive strength tests after two specimens of pullout tests performed and the last three compressive after four specimens of pullout test conducted. During batching, the slump, unit weight, air content, ambient temperature, concrete temperatures were recorded.

The concrete test specimens and the 4x8 in. test cylinders were cured in conformance with ASTM C 192. The concrete was cured at 73 ± 3^{0} F from the time of molding until the time of test.

3.4.1.2. Testing Procedure

The NASP testing apparatus used consisted of a load frame as shown in figure 3.1and 3.2. The testing was conducted with two test frames. The specimen molds were placed on a ¼ x 6x6 in. neoprene pad with a 9/16 in. hole. The neoprene rested on a ¾ x 6x 6 in. steel plate with a 9/16 in. hole. The plates rested on the upper loading frame. For test frame one, the upper loading frame consisted of two 1.25 in. thick plates connected with two channels as shown in the figure 3.1. The upper plate had a 17/16 in hole to attach the loading frame to the MTS console, and the lower plate had a 9/16 in. slot to place the specimens in the frame. The lower loading frame consisted of two 1.25 in. thick plates and two channels as depicted in the figures. The lower plate had a 17/16 in. hole to attach the loading frame to the MTS actuator and the upper plate had a 9/16 in. slot to place the specimens in the frame. Old test frame is used for NASP Bond test of Strand D for all types of concrete strengths.

Test frame two is needed for strands A (0.5 in.), A (0.6 in.), and B (0.5 in.).The capacity of old test fame is limited (25 Kips for the actuator) which was not enough for the above strands with HPC. Hence the new test frame was capable of running till 55 kips and used for the strands mentioned above. For test frame two, the upper loading frame consisted of two 2.5 in thick plates and two channels as depicted in the figure. The upper pale had four 1 in. hole to attach the loading frame to the MTS actuator and the lower plate had a 9/16 in. slot to place the specimens in the frame. The lower loading frame consisted of two 2.5 in. thick plates and two channels as shown in the figure 3.2. The lower plate had a 17/16 in. hole to attach the loading frame to the 1.5 in. plate and floor. The upper plate had a 9/16 in. slot to place the specimens in the frame.

The pulls out forces were measured through the load cell of the MTS controller. The relative movement of the strand was measured on the free end through an LVDT and on the fixed end by the MTS actuator.

The MTS actuator pulled the strand at a rate of 0.10 in per minute. For test frame one, the strand was loaded approximately 6 in. from the end of the specimen while for test frame two tensions was applied to the strand using a hydraulic actuator powered by a pump driven by an electric motor. In order to gather data consistent with previously conducted NSAP pullout Tests, displacement control was used to position the hydraulic actuator.

A desk top computer was used to control the NASP pullout Test. The computer provided the signal to the MTS controller that controlled the operation of the hydraulic actuator. The stroke rate was set at 0.1 in/minute. The test was run for seven to ten minutes.

The hydraulic actuator used is an MTS (MTS systems corporation, Minneapolis, Minnesota) series 204 double en double acting actuator. The actuator was rated at 25 kips with a 3 in diameter rod and a 6 in stroke length and 55 kips for test frame two with a 12 in. diameter rod and a 6 in stroke length. The hydraulic pump was powered by an electric motor. An MTS model AA10VS071DFR Control unit operated the pump. The position of the hydraulic actuator was controlled using an MTS Model 490.01 Controller.

The pull- out force, MTS stroke, and free end (top of the strand) strand end slip were collected in an electric data acquisition system. The data was recorded two timed per second. The data was then analyzed to determine the pullout force at 0.01 in. and 0.1 in of free end strand slip. The loading rate was also determined from the data recorded.

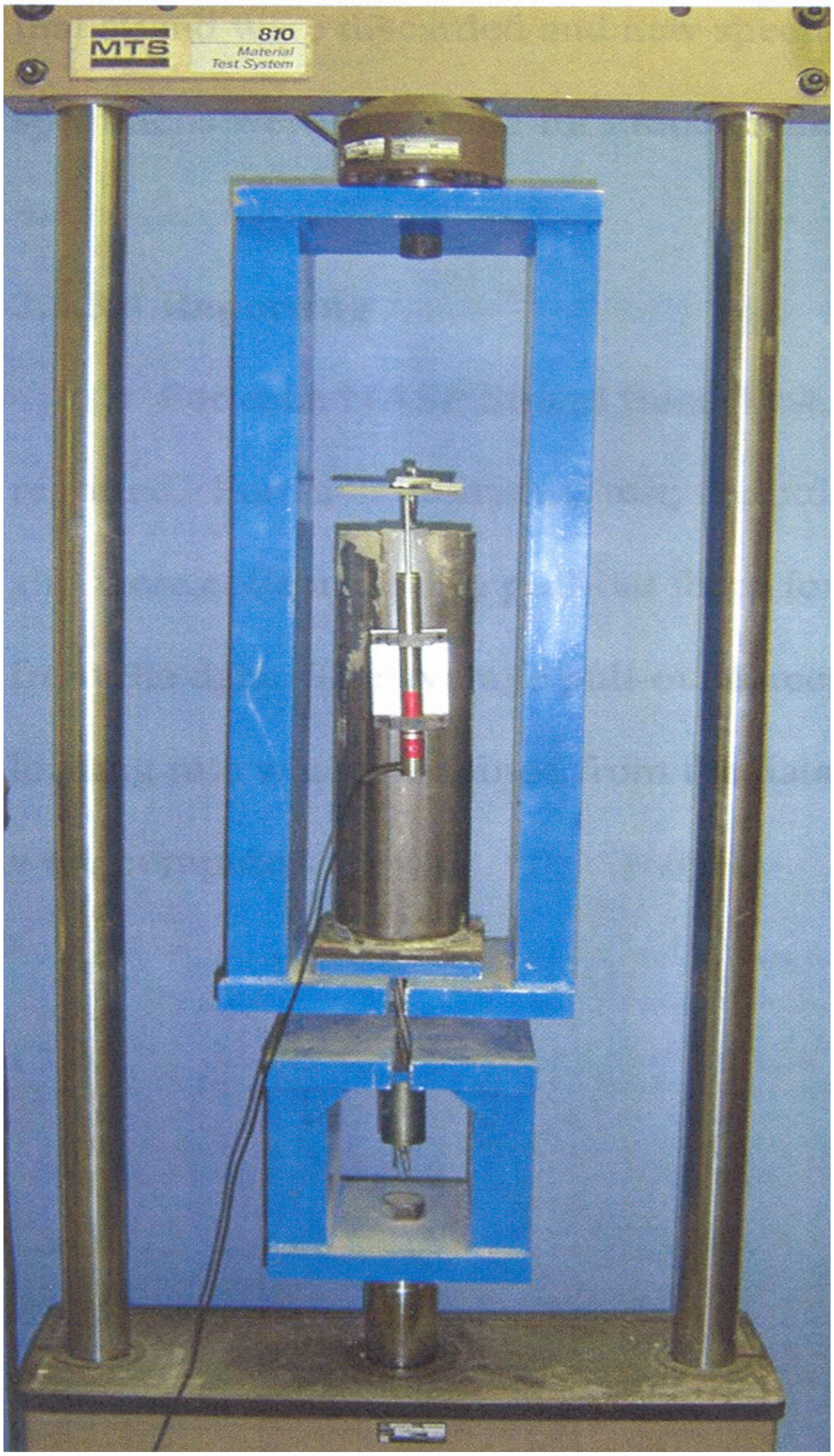

Figure 3.1 Old Test Set Up

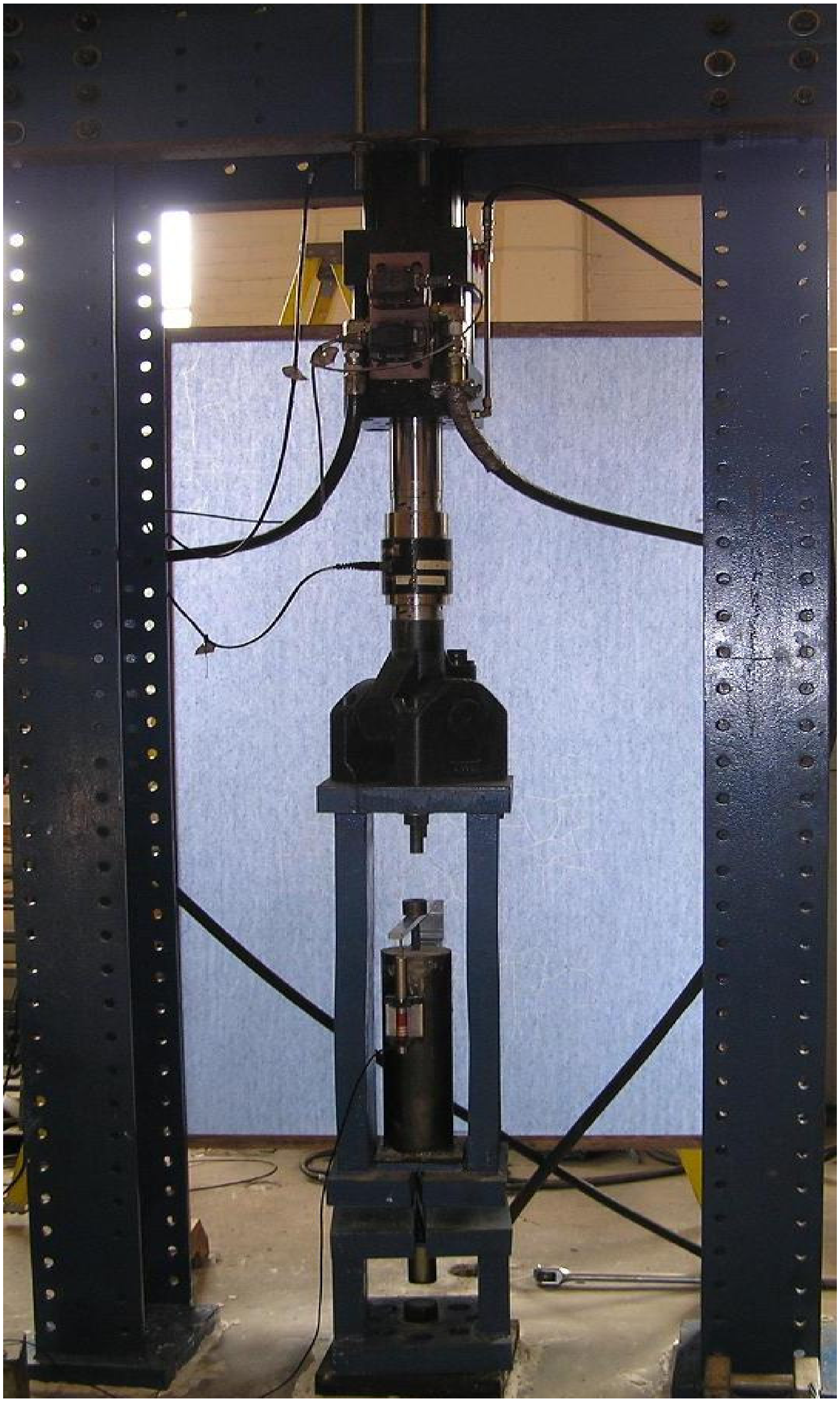

Figure 3.2 New Test Set Up

3.4.2 Materials

3.4.2.1 Strand Source

Strands from four different sources were assessed to measure the different strand behaviors. The NASP Bond test was conducted using four of the strand sources. The strand sources used in all tests were in "as received" from manufacturer condition. All of the strands were cut to length using a table mounted cut-off saw. Clean plastic sheet was used to minimize dust and grease contamination. Once the strand was cut to desired lengths, the ends were beveled using a table-mounted sander to minimize handling risks from steel splintering.

3.4.2.2. Strand Source specimen Identification

The strands were labeled as follows: for the 0.5 in. strands A, B, C, D and for the 0.6 in strand A. The strand designations were assigned by and the manufacturing sources were anonymous except to the principal investigator. In both pullout tests, the letter designations above were used.

3.5 CONCRETE PRODUCTION AT PRECAST PLANT

3.5.1. Trial Batching

A number of trial batches for the plant batching were conducted at OSU laboratory to get the desired concrete strengths. To start with, the mix design from the laboratory and the materials from the plant were used. This is because the aggregate types were different, mixing procedures was different and curing condition was not according to ASTM requirement. To obtain one day strength of 10,000 for Concrete C-III was a problem at the plant especially during spring 2004. Hence changes were made to mix design for C-III that is the w/cm ratio was decreased and more HES dosage was used. Special treatment was given for the concrete cylinders by using steam curing during the whole night.

The trial batches done for the plant batching are indicated in Table 3.5.

Table 3.5.1. Trial Batches made at OSU laboratory and materials from Plant

		C-I			C-IA		
		7/8/2004	7/20/2004	7/27/2004	7/8/2004	7/20/2004	7/27/2004
Mix Proportions	Cement (PCY)	800	800	800	800	800	800
	Coarse Agg. (PCY)	1800	1800	1800	1800	1800	1800
	Fine Agg. (PCY)	1148	1191	1191	1137	1140	1140
	Water (PCY)	288	272	272	225	224	224
	Glenium 3030NS (fl. oz/cwt)	8	8	8	18	18	18
	MB-AE 90 (fl.oz/cwt)	3	_	_	3	2.5	_
	Polyheed 997 (fl.oz/cwt)	_	3	_	2.5	3	_
	w/cm	0.36	0.34	0.34	0.28	0.28	0.28
Fresh Properties	Air Temperature (ºF)	_	79	_	_	79	_
	Relative Air Humidity (%)	_	72	_	_	72	_
	Concrete Temperature (ºF)	_	98	_	_	98	_
	Slump (in.)	6.5	9.25	4.0	4.5	9.75	10
	Unit Weight (pcf)	149.50	145.20	150.88	150.50	145.12	154.12
	Air Content (%)	1.4	5.0	2.7	1.4	6.1	1.9
Compressive Strength in psi	1 Day	5165	6190	_	6220	6320	_
Calculated unit weight(PCF)		149.48	150.48		146.74	146.81	
Required Air content(%)		2	2		6	6	

Table 3.5.2. Trial Batches made at OSU laboratory and materials from Plant

		C-II		C-III		
		7/8/2004	7/20/2004	7/8/2004	7/20/2004	8/5/2004
Mix Proportions	Cement (PCY)	800	800	900	900	900
	Slag(pcy)	_	_	100	100	100
	Coarse Agg. (PCY)	1800	1800	1800	1800	1700
	Fine Agg. (PCY)	1270	1319	1102	1102	1200
	Water (PCY)	240	224	240	240	240
	Glenium 3030NS (fl. oz/cwt)	22	22	20	20	7
	Glenium 3400 (fl. oz/cwt)	_	_	7	7	13
	Polyheed 997 (fl.oz/cwt)	3	3	3	3	_
	w/cm	0.3	0.28	0.24	0.24	0.24
Fresh Properties	Air Temperature (°F)	_	79	_	79	75
	Relative Air Humidity (%)	_	72	_	72	83
	Concrete Temperature (°F)	_	98	_	99	96
	Slump (in.)	9.5	10	10.0	10.0	9.0
	Unit Weight (pcf)	154.00	151.92	156.60	154.28	152.76
	Air Content (%)	2.5	2.5	1.4	2.4	2.4
Compressive Strength in psi	1 Day	7630	7650	8,920	10,200	11,240
Calculated unit weight(PCF)		152.22	153.44	153.41	153.41	153.33
Required Air content(%)		2	2	2	2	2

3.5.2 Results of Production Batching

After conducting a number of trial batches for plant batching, concrete mix designs were selected to carry out rectangular and I beams for other related research work. The mixture designs are given in chapter 4.

Chapter 4

4. TEST RESULTS

4.1 INTRODUCTION

This chapter presents the test results from:

- NASP Bond Tests in concrete.
- Fresh and hardened concrete properties from NASP Bond Test.
- Fresh and hardened concrete properties for concrete cast in beams at Coreslab structures.

4.2 CONCRETE BATCHING

Five different concretes, based principally on targeted release strengths were made in both the laboratory and the precast /prestressed concrete plant. The mix designs used for each were developed through trial batching described in chapter 3. Some alternations to the laboratory mix design were required for implementation at the precast plant.

The five concrete mixtures are designated as C-N, C-I, C-IA, C-II and C-III, with targeted release strengths of 4,000 psi, 6,000 psi , 6,000 psi with air entrainment, 8,000 psi, and 10,000 psi. The various concrete designations and targeted strengths are shown in Table 3.1.

The concrete mixtures were used for the NASP Tests in concrete, for the rectangular beams cast at Coreslab structures, Inc. and for the I-beams, also cast at Coreslab structures, Inc. in Oklahoma City. Table 3.1 shows the concrete type, the strands that were tested in the NASP Bond Tests in concrete and the beams that were fabricated.

Concrete mix designs were developed through trial batching described in chapter 3. In this chapter, the results from NASP Bond Test in concrete are reported first. Along with the results of the bond tests, the mix designs and the fresh and hardened properties of concrete are also reported.

The mix designs and concrete properties from concrete cast for beam fabrication are reported after the NASP test results.

4.3. RESULTS FROM NASP BOND TESTS

NASP Pull out Tests were conducted on four strand samples with four different concrete strengths for each strand and two testing frames in conformance with the procedures defined in Appendix B. Six specimens from each of the four strand sources were tested for a total of 21 tests. Each specimen had a bonded length of 16 in. The tests were run for ten minutes and data points were collected every ten seconds. The tables show the pullout forces at two different intervals. The intervals include the pullout forces at 0.01 in. of slip and 0.1 in. of slip. The concrete compressive strength were tested before NASP test begins after conducting 3 NASP tests and during the last NASP load tests. The load rate and forces at free end strand slips were calculated from the data collected. The load rate was the load verses load rate curve. The flat portion of the curve was also the maximum loading rate of the specimen. Appendix E contains graphs of slip verses load and load verses load rate. The compressive strength value used in the graphs is the value midway through the testing of the individual frame.

4.3.1. Results from the standardized NASP Bond Tests

The Standardized NASP Bond Test features a grout matrix to pull the strand from Tests performed in this thesis research feature NASP Bond Tests in concrete. The concrete matrix represents a deviation from the Standardized NASP Bond Test.

As part of related research performed and reported Chandran (2006), the Standardized NASP Bond Test was performed on strands that were used in this research. Table 4.1 reports the results of the Standardized NASP Bond Tests. From these results, NCHRP ID strands A, B, and D were chosen from the samples of 0.5 in. diameter strands. Strand A (or A6) was chosen from the available 0.6 in. diameter strands.

Table 4.1: NASP RESULTS SUMMARY at OSU Laboratory

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

4.3.2. NASP Bond Tests in Concrete on strand D

Table 4.2 reports the results of NASP Bond Test in concrete on strand D. The table shows that the NASP Bond Test gave pull-out results as low as 6,660 with concrete strength equal to 4,560 psi to a high of 11,560 with concrete strength of 9,883 psi. Note from Table 4.1, strand D when tested in grout had an average pull out value of approximate 6,900 lbs. Note that OT was used for strand D.

Table 4.2. NASP Pull- Out Test Summary, Strand D

Concrete Type	STRAND ID	Testing Date	NASP Tests				w/c	Test Frame
			Concrete Strength f_c' (psi)	Pull Out Force at 0.1" slip	STDEV	C.O.V. (%)		
C-N	D	5-Feb-05	4,733	7,479	248	3.32	0.45	OT
C-N	D	16-Feb-05	4,558	6,661	259	3.88	0.46	OT
C-I	D	8-Feb-05	7,191	8,961	1055	11.78	0.36	OT
C-I	D	18-Feb-05	7,405	9,512	836	8.79	0.38	OT
C-I	D	23-Feb-05	6,546	7,387	496	6.71	0.4	OT
C-I	D	3-Mar-05	6,143	6,737	609	9.04	0.4	OT
C-II	D	12-Feb-05	8,483	10,263	1237	12.05	0.3	OT
C-II	D	17-Feb-05	8,420	9,966	820	8.23	0.32	OT
C-III	D	18-Feb-05	9,883	11,557	1386	11.99	0.26	OT

(OT – refers to Old test set up)

4.3.3. NASP Bond Tests in Concrete on strand A (0.5 in.)

Table 4.3 reports the results of NASP Bond Test in concrete on strand A (0.5 in.). The table shows that the NASP Bond Test gave pull-out results as low as 23,580 with concrete strength equal to 4,550 psi to a high of 35,290 with concrete strength of 11,640 psi. Note from Table 4.1, strand A when tested in grout had an average pull out value of approximate 20,070 lbs. Note that NT was used for strand A.

Table 4.3. NASP Pull- Out Test Summaries; Strand A (0.5")

Concrete Type	STRAND ID	Testing Date	NASP Tests				w/c	Test Frame
			Concrete Strength f_c' (psi)	Pull Out Force at 0.1" slip	STD EV	C.O.V (%)		
C-N	A (0.5 ")	7-Sep-05	4,553	23,583	5568	23.61	0.425	NT
C-I	A (0.5 ")	10-Sep-05	6,937	26,353	1039	3.94	0.38	NT
C-II	A (0.5 ")	9-Sep-05	8,061	30,684	4549	14.83	0.36	NT
C-III	A (0.5 ")	9-Sep-05	11,643	35,288	4165	11.8	0.235	NT

(NT – refers to New test set up)

4.3.4. NASP Bond Tests in Concrete on strand B (0.5 in.)

Table 4.4 reports the results of NASP Bond Test in concrete on strand B (0.5 in.). The table shows that the NASP Bond Test gave pull-out results as low as 22,550 with concrete strength equal to 3,490 psi to a high of 34,330 with concrete strength of 10,040 psi. Note from Table 4.1, strand B when tested in grout had an average pull out value of approximate 20,210 lbs. Note that NT was used for strand B.

Table 4.4 NASP Pull- Out Test Summary, Strand B (0.5 in.)

Concrete Type	STRAND ID	Testing Date	NASP Tests				w/c	Test Frame
			Concrete Strength f_c' (psi)	Pull Out Force at 0.1" slip	STDEV	C.O.V (%)		
C-N	B	11-Aug-05	3,485	22,546	2762	12.25	0.46	NT
C-I	B	13-Aug-05	5,491	30,796	2515	8.17	0.4	NT
C-II	B	13-Aug-05	7,268	28,780	2230	7.75	0.32	NT
C-III	B	25-Aug-05	10,036	34,334	2640	7.69	0.24	NT

(NT – refers to New test set up)

4.3.5. NASP Bond Tests in Concrete on strand A (0.6 in.)

Table 4.5 reports the results of NASP Bond Test in concrete on strand A (0.6 in.). The table shows that the NASP Bond Test gave pull-out results as low as 11,610 with concrete strength equal to 2,230 psi to a high of 28,740 with concrete strength of 10,340 psi. Note from Table 4.1, strand B when tested in grout had an average pull out value of approximate 18,290 lbs. Note that NT was used for strand A (0.6 in.)

Table 4.5 NASP Pull- Out Test Summaries; Strand A (0.6")

Concrete Type	STRAND ID	Testing Date	NASP Tests				w/c	Test Frame
			Concrete Strength f_c' (psi)	Pull Out Force At 0.1" slip	STDEV	C.O.V (%)		
C-N	A (0.6 ")	5-Aug-05	2,230	11,607	662	5.71	0.46	NT
C-I	A (0.6 ")	30-Aug-05	4,965	23,129	1442	6.24	0.38	NT
C-II	A (0.6 ")	1-Sep-05	8,789	24,839	1772	7.13	0.28	NT
C-III	A (0.6 ")	30-Aug-05	10,341	28,735	2331	8.11	0.23 5	NT

(NT – refers to New test set up)

4.3.6 NASP Bond Tests on Mortar, Strand B (0.5 in.)

Table 4.6 reports the results of NASP Bond Test in mortar on strand B (0.5 in.). The table shows that the NASP Bond Test gave equal results for both Old Test set up and New test set up of an average pull out value of 23,300 psi with mortar.

Table 4.6 NASP Pull- Out Test on Mortar, Strand B

Concrete Type	STRAND ID	Testing Date	NASP Tests				w/c	Test Frame
			Concrete Strength f_c' (psi)	Pull Out Force at 0.1" slip	STDEV	C.O.V (%)		
Mortar	B	27-Aug-05	4,636	23,521	383	1.63	0.425	OT
Mortar	B	27-Aug-05	4,636	23,091	911	3.94	0.425	NT

4.4 CONCRETE PROPERTIES FOR NASP BOND TESTS

The concrete mix designs for the NASP Bond tests were based on trial batches performed at OSU laboratory. The mix designs, fresh and hardened properties for each batch of concrete are reported in Tables below.

Table 4.7. Concrete Mix design, fresh and Hardened Properties for NASP Bond Tests

Concrete C-N

Mix Proportions			C-N Date: 08/03/05	C-N Date: 02/15/05	C-N Date: 08/03/05	C-N Date 08/10/05	C-N Date: 09/06/05
Mix Proportions	Cement (PCY)		650	650	650	650	650
	Coarse Agg. (PCY)		1800	1800	1800	1800	1800
	Fine Agg. (PCY)		1259	1243	1243	1243	1300
	Water (PCY)		292	298	298	298	276
	Glenium 3400 (fl. oz/cwt)		8	8	8	8	8
	w/cm		0.45	0.46	0.460	0.46	0.425
	Air Temperature (ºF)		78	82	79	77	73
	Relative Humidity (%)		22	24	72	28	76
Fresh Properties	Concrete Temperature (ºF)		71	75	80	81	76
	Slump (in.)		10	10	8	8.25	10.5
	Unit Weight (pcy)		147.8	146.8	141.8	147.8	145.8
	Air Content (%)		4.5	2.5	5	2.9	3.9
Hardened Properties	Compressive Strength in psi	1 Day	4730	4560	2230	3485	4550

Table 4.8 Concrete Mix design, fresh and Hardened Properties for NASP Bond Tests							
Concrete C-I							
Mix Proportions			C-I	C-I	C-I	C-I	C-I
			Date: 02/07/05	Date: 02/17/05	Date: 08/12/05	Date: 08/29/05	Date: 09/09/09
Mix Proportions	Cement (PCY)		800	800	800	800	800
	Coarse Agg. (PCY)		1800	1800	1800	1800	1800
	Fine Agg. (PCY)		1144	1102	1060	1102	1102
	Water (PCY)		288	304	320	304	304
	Glenium 3400 (fl. oz/cwt)		8	16	8	8	8
	w/cm		0.36	0.38	0.40	0.38	0.38
	Air Temperature (ºF)		77	84	77	81	91
	Relative Humidity (%)		22	21	28	64	21
Fresh Properties	Concrete Temperature (ºF)		72	73	80	81	82
	Slump (in.)		9.5	10	10.25	10	10
	Unit Weight (pcy)		147.8	151.8	146.8	145.8	147.8
	Air Content (%)		3	1.5	1.4	1.0	2.4
Hardened Properties	Compressive Strength in psi	1 Day	7190	7405	5490	4965	6940

Table 4.9.Concrete Mix design, fresh and Hardened Properties for NASP Bond Tests

Concrete C-II

Mix Proportions		C-II	C-II	C-II	C-II	C-II	C-II
		Date:02/09/05	Date:02/11/05	Date:02/16/05	Date:08/12/05	Date:08/30/05	Date:09/08/05
Cement (PCY)		800	800	800	800	800	800
Coarse Agg. (PCY)		1800	1800	1800	1800	1800	1800
Fine Agg. (PCY)		1270	1270	1234	1230	1102	1314
Water (PCY)		240	240	298	256	304	224
Glenium 3400 (fl. oz/cwt)		16	16	8	8	8	8
w/cm		0.30	0.30	0.46	0.32	0.38	0.28
Air Temperature (ºF)		66	72	82	81	91	81
Relative Humidity(%)		25	24	24	62	21	58
Concrete Temperature (ºF)		70	70	70	80	82	82
Slump (in.)		8	9.75	9.5	6	10	8
Unit Weight (pcy)		151.8	151.8	152.8	153.8	147.8	151.8
Air Content (%)		2.7	0.8	1.0	3.0	2.4	4.0
Compressive Strength in psi	1 Day	9780	8480	8420	7270	6940	8790

Table 4.10 Concrete Mix design, fresh and Hardened Properties for NASP Pull-Out Tests Concrete C-III

Mix Proportions			C-III Date: 02/17/05	C-III Date: 08/24/05	C-III Date: 08/29/05	C-IIII Date: 09/08/05
Mix Proportions	Cement (PCY)		900	900	900	900
	Slag(PCY)		100	100	100	100
	Coarse Agg. (PCY)		1800	1800	1800	1800
	Fine Agg. (PCY)		1048	1097	1110	1110
	Water (PCY)		260	240	235	235
	Glenium 3400 (fl. oz/cwt)		18	18	18	18
	Glenium 3200 (fl. oz/cwt)		7	7	7	7
	Polyheed 997 (fl. oz/cwt)		3	3	3	3
	w/cm		0.260	0.24	0.235	0.235
Fresh Properties	Air Temperature (ºF)		84	73	81	79
	Relative Humidity(%)		21	72	52	62
	Concrete Temperature (ºF)		78	83	81	83
	Slump (in.)		10.5	8.5	10	8
	Unit Weight (pcy)		156.8	154.8	153.8	158.8
	Air Content (%)		0.8	2.2	2.5	2.0
	Compressive Strength in psi	9,860	4,560		10,340	11,640

4.5. Results of concrete cast at Precast Plant

Rectangular and I beams for other related research work were constructed using the mix designs prepared from trial batches at the plant. The mixture designs, the fresh and hardened concrete properties are given in tables below.

Table 4.11 Concrete Mix Design, Fresh and Harden properties for Concrete IA

Core Slab Structures, Oklahoma City- Summer 2004

With 6% Total Air

			Date:07/27
Mix Proportions	Cement (PCY)		800
	Coarse Agg. (PCY)		1814.4
	Fine Agg. (PCY)		1128.5
	Water (PCY)		218.79
	Glenium 3030NS (fl. oz/cwt)		8
	Polyheed 997 (fl.oz/cwt)		3
	w/cm		0.2735
Fresh properties	Concrete Temperature (°F)		84
	Slump (in.)		6.5
	Unit Weight (pcf)		147.9
	Air Content (%)		5.6
	Moisture Content of Rock (%)		0.002
	Moisture Content of Sand (%)		4.3
Hardened Properties	Compressive Strength in psi	1 Day	7960
		7 Day	9070
		14 day	9100
		28 Day	10,250
		56 Day	11,420
	Tensile Strength in psi	28 Day	820
	Modulus of Elasticity (psi)	28 Day	5680
	Calculated Modulus of elasticity using ACI method(psi)	28 Day	6010

Table 4.12. Concrete Mix Design, Fresh and Harden properties for Concrete II

Core Slab Structures, Oklahoma City- Summer 2004

With No Air Entrainment

			Date:07/29/04	Date:08/12/04
Mix Proportions	Cement (PCY)		800	800
	Coarse Agg. (PCY)		1805	1803.6
	Fine Agg. (PCY)		1218.9	1163.4
	Water (PCY)		276.92	269.21
	Glenium 3030 (fl. oz/cwt)		14	4
	w/cm		0.346	0.337
Fresh Properties	Concrete Temperature (ºF)		90	83
	Slump (in.)		9.5	8.25
	Unit Weight (pcy)		151.38	149.6
	Air Content (%)		0.7	1.4
	Moisture Content of Rock (%)		0.8	0.6
	Moisture Content ofSand (%)		7.5	4.2
Hardened Properties	Compressive Strength in psi	1 Day	8570	5410
		7 Day	11,000	7,310
		14 day	11,240	7,640
		28 Day	12,680	7,910
		56 Day	13,490	8,220
	Tensile Strength in psi	28 Day	915	560
	Modulus of Elasticity	28 Day	5945	5110
	Calculated Modulus of elasticity Using ACI method(psi)	28 Day	6920	5470

Table 4.13. Concrete Mix Design, Fresh and Harden properties for Concrete I

Core Slab Structures, Oklahoma City – Summer 2004

Without Air Entrainment				
			Date:08/02/04	Date:08/12/04
Mix Proportions	Cement (PCY)		800	800
	Coarse Agg. (PCY)		1702.9	1698.4
	Fine Agg. (PCY)		1202.5	1211.6
	Water (PCY)		303.18	300.57
	Glenium 3400 (fl. oz/cwt)		5	5
	w/cm		0.379	0.376
Fresh Properties	Concrete Temperature (ºF)		90	82
	Slump (in.)		9.5	5.75
	Unit Weight (pcf)		148.78	149.6
	Air Content (%)		1.5	1.2
	Moisture Content of Rock (%)		0.2	0.6
	Moisture Content of Sand (%)		3.5	4.2
Hardened Properties	Compressive Strength in psi	1 Day	6183	4855
		7 Day	7110	6450
		14 day	7690	6940
		28 Day	8360	7510
		56 Day	8500	8040
	Tensile Strength in psi	28 Day	660	480
	Modulus of Elasticity	28 Day	5350	5140
	Calculated Modulus of elasticity Using ACI method(psi)	28 Day	5470	5230

Table 4.14. Concrete Mix Design, Fresh and Harden properties for Concrete III

Core Slab Structures, Oklahoma City – Summer 2004

Without Air Entrainment

		Date: 08/09/04	Date: 08/12/04
Cement (PCY)		900	902.5
Slag(PCY)		100	100
Coarse Agg. (PCY)		1746.5	1718.4
Fine Agg. (PCY)		1182.7	1187.5
Water (PCY)		250.75	247.6
Glenium 3200 (fl. oz/cwt)		7	8
Glenium 3400 (fl. oz/cwt)		5.43	1.6
w/cm		0.251	0.247
Concrete Temperature (ºF)		109	82
Slump (in.)		8.5	10.5
Unit Weight (pcf)		151.1	151.1
Air Content (%)		1.9	1.4
Moisture Content of Rock (%)		1.0	0.6
Moisture Content of Sand (%)		4.5	4.2
Compressive Strength in psi	1 Day	9710	9150
	7 Day	11,630	11,550
	14 day	12,320	12,680
	28 Day	12,650	12,770
	56 Day	14,470	14,610
Tensile Strength in psi	28 Day	870	900
Modulus of Elasticity	28 Day	6870	7180
Calculated Modulus of elasticity Using ACI method(psi)	28 Day	7370	7410

Table 4.15. CoresLab Structures Concrete Mix Design, Fresh and Harden properties for Concrete I –ID-6-5-1			
		Without Air Entrainment – Spring 2005	
			Date:03/15/05
Mix Proportions	Cement (PCY)		800
	Coarse Agg. (PCY)		1713.3
	Fine Agg. (PCY)		1215.3
	Water (PCY)		300.55
	Glenium 3400 (fl. oz/cwt)		5
	w/cm		0.376
Fresh Properties	Concrete Temperature (ºF)		58
	Slump (in.)		9
	Unit Weight (pcy)		148.12
	Air Content (%)		2
Hardened Properties	Compressive Strength in psi	1 Day	5492
		14 day	7260
		28 Day	8560
		56 Day	9840
	Tensile strength in psi	28 Day	610

Table 4.16. CoresLab Structures Concrete Mix Design, Fresh and Harden properties for Concrete I- IB6-5-1

		Without Air Entrainment – Spring 2005	
			Date:03/17/05
Mix Proportions	Cement (PCY)		800.8
	Coarse Agg. (PCY)		1718.3
	Fine Agg. (PCY)		1227.1
	Water (PCY)		303.7
	Glenium 3400 (fl. oz/cwt)		5
	w/cm		0.379
Fresh Properties	Concrete Temperature (°F)		64
	Slump (in.)		8.25
	Unit Weight (pcy)		148.12
	Air Content (%)		2.8
Hardened Properties	Compressive Strength in psi	1 Day	5810
		14 day	7860
		28 Day	8750
		56 Day	9350
	Tensile strength in psi	28 Day	510

Table 4.17 CoresLab Structures Concrete Mix Design, Fresh and Harden properties for Concrete I- IA-6-6-1

		Without Air Entrainment – Spring 2005	
			Date:03/22/05
Mix Proportions	Cement (PCY)		801.4
	Coarse Agg. (PCY)		1704.6
	Fine Agg. (PCY)		1211.44
	Water (PCY)		303.34
	Glenium 3400 (fl. oz/cwt)		5
	w/cm		0.380
Fresh Properties	Concrete Temperature (ºF)		60
	Slump (in.)		5
	Unit Weight (pcy)		147.5
	Air Content (%)		4.1
Hardened Properties	Compressive Strength in psi	1 Day	4381
		7 Day	6872
		14 day	7620
		28 Day	8450
		56 Day	8990
	Tensile strength in psi	28 Day	790

Table 4.18 CoresLab Structures Concrete Mix Design, Fresh and Harden properties for Concrete III – ID-10-5-1

			Without Air Entrainment – Spring 2005
			Date:03/15/05
Mix Proportions	Cement (PCY)		906.7
	Slag(PCY)		106.7
	Coarse Agg. (PCY)		1760
	Fine Agg. (PCY)		1182.8
	Water (PCY)		217.79
	Glenium 3200 (fl. oz/cwt)		2.25
	Glenium 3400 (fl. oz/cwt)		5
	w/cm		0.215
Fresh Properties	Concrete Temperature (ºF)		58
	Slump (in.)		11.25
	Unit Weight (pcy)		150.88
	Air Content (%)		0.75
Hardened Properties	Compressive Strength in psi	1 Day	8,225
		7 Day	12,975
		14 day	13877
		28 Day	13790
		56 Day	14160
	Tensile Strength in psi	28 Day	880

Table 4.19 CoresLab Structures Concrete Mix Design, Fresh and Harden properties for Concrete III –IB-10-5-1			
			Without Air Entrainment – Spring 2005
			Date:03/17/05
Mix Proportions	Cement (PCY)		910
	Slag(PCY)		100
	Coarse Agg. (PCY)		1758.3
	Fine Agg. (PCY)		1188.11
	Water (PCY)		255.13
	Glenium 3200 (fl. oz/cwt)		7
	Glenium 3400 (fl. oz/cwt)		4.9
	w/cm		0.253
Fresh Properties	Concrete Temperature (ºF)		64
	Slump (in.)		10
	Unit Weight (pcy)		150.8
	Air Content (%)		3.3
Hardened Properties	Compressive Strength in psi	1 Day	7,615
		7 Day	9,120
		14 day	10980
		28 Day	12830
		56 Day	13490
	Tensile Strength in psi	28 Day	860

Table 4.20 CoresLab Structures Concrete Mix Design, Fresh and Harden properties for Concrete III – IA-10-6-1			
	Without Air Entrainment – Spring 2005		
			Date:04/12/05
Mix Proportions	Cement (PCY)		916.7
	Slag(PCY)		106.7
	Coarse Agg. (PCY)		1768.7
	Fine Agg. (PCY)		1139.4
	Water (PCY)		244.1
	Glenium 3200 (fl. oz/cwt)		7
	Glenium 3400 (fl. oz/cwt)		5.9
	w/cm		0.239
Fresh Properties	Concrete Temperature (ºF)		63
	Slump (in.)		10.25
	Unit Weight (pcy)		151.88
	Air Content (%)		2.5
Hardened Properties	Compressive Strength in psi	1 Day	10,480
		7 Day	12,530
		14 day	14090
		28 Day	15050
		56 Day	14990
	Tensile Strength in psi	28 Day	870

Table 4.21. CoresLab Structures Concrete Mix Design, Fresh and Harden properties for Concrete III – IA-10-6-2

			Without Air Entrainment – Spring 2005
			Date:04/12/05
Mix Proportions	Cement (PCY)		910
	Slag(PCY)		106.7
	Coarse Agg. (PCY)		1768.7
	Fine Agg. (PCY)		1152.3
	Water (PCY)		244.5
	Glenium 3200 (fl. oz/cwt)		7
	Glenium 3400 (fl. oz/cwt)		5.9
	w/cm		0.240
Fresh Properties	Concrete Temperature (ºF)		63
	Slump (in.)		10.25
	Unit Weight (pcy)		153.39
	Air Content (%)		1.4
Hardened Properties	Compressive Strength in psi	1 Day	10,590
		7 Day	12,830
		14 day	14180
		28 Day	13190
		56 Day	14930
	Tensile Strength in psi	28 Day	760

4.6 SUMMARY

- In this chapter the results for NASP Bond test in concrete and concrete cast at precast Plant were discussed. For each of the concrete batches made, the date, concrete type, mix design, fresh and hardened properties were reported.
- NASP pullout tests were performed after obtaining the concrete mixture design. Two Test set up were used to do the testing. For strand D, the old MTS test setup was used while the new test set up was used for strand A (0.6 “), A (0.5”) and B. The purpose of conducting the NASP test was to evaluate the relative difference between strands.
- The gathered data is evaluated in Tables 4.1 through 4.6. The average results are shown in Table 4.22.

Table 4.22 Average NASP Results

Strand Source	0.1 in. free end slip NASP
	Pullout strengths (S.D.), kips
A (0.6 ")	22.08 (697.48)
A (0.5 ")	28.98 (1952.73)
B	29.11 (228.01)
D	8.72 (406.23)

- The relative difference between strands from different source was evaluated using the results from the NASP Bond Tests. The average bond strengths for strand A (0.5 “) and strand B were higher than the average bond strength of for strand A (0.6 “) and D. When strand A (0.6 “) was compared to strand D, the average bond strength of both strand A (0.6”) was higher than the average bond strength of both strand D. As strand A (0.5 “) was compared to strand B, the average bond strength of both were almost similar.
- In all sources of strands, concrete compressive strength has significant effect on the bond performance. NASP Pullout tests performed with Concrete C-III had higher value than NASP Pullout tests performed with Concrete C-II, NASP Pullout tests performed with Concrete C-I and NASP Pullout tests performed with Concrete C-N. Also NASP Pullout tests performed with Concrete C-II had higher value than NASP Pullout tests performed with Concrete C-I and NASP Pullout tests performed with Concrete C-N. Strands with Concert C-I has higher NASP pullout value than concrete C-N.

Chapter 5

5. DISCUSSION OF TEST RESULTS

5.1 INTRODUCTION

This Chapter analyzes the data and discusses the results from the experimental program. Specifically, the effects of concrete strength on the bond of prestressing strands are discussed. Further more, the successes and failures of making suitable HPC in both Lab and plant are discussed.

5.2 THE EFFECT OF CONCRETE STRENGTH ON THE BOND OF PRESTRESSING STRANDS

In all sources of strands, concrete compressive strength has significant effect on the bond performance. NASP bond tests performed with Concrete C-III had higher value than NASP bond tests performed with Concrete C-II, NASP bond tests performed with Concrete C-I and NASP bond tests performed with Concrete C-N. Also NASP bond tests performed with Concrete C-II had higher value than NASP bond tests performed with Concrete C-I and NASP bond tests performed with Concrete C-N. Strands with Concert C-I has higher NASP bond value than concrete C-N.

5.2.1 NASP Force vs. Concrete Strength, f'_{ci}

The NASP forces and compressive strength of concrete were related in this testing program. The 0.1 in. free end slip varied approximately linearly with the compressive strength of the specimens for all strands sources. The regression analysis resulted in a good correlation of data for all strands. The linear regression analysis graphs for concrete compressive strength f'c and NASP bond force at 0.1 in. of free end slip are shown in Figure 5.1 through 5.4 and the power regression, R^2 and best fit power equation are indicated in Figure 5.5 through 5.8. Table 5.1 gives the results for the regression analysis.

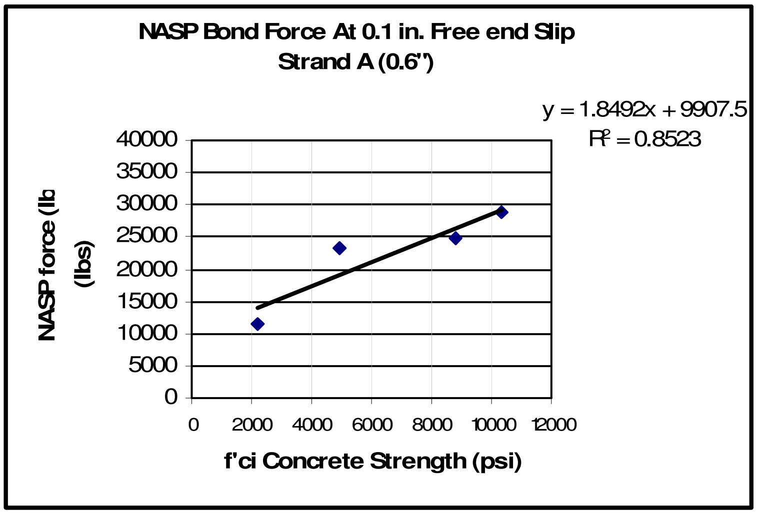

Figure 5.1.Linear Regression Analysis of the compressive strength of concrete and Bond force for Strand A (0.6").

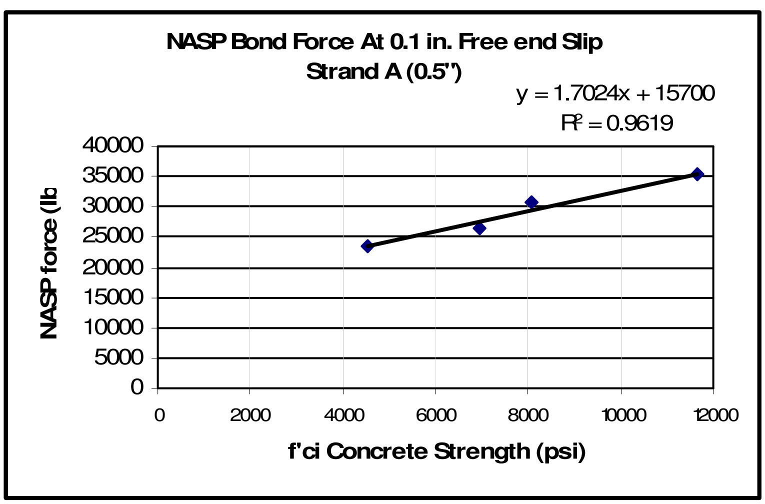

Figure 5.2. Linear Regression Analysis of the compressive strength of concrete and Bond force for Strand A (0.5").

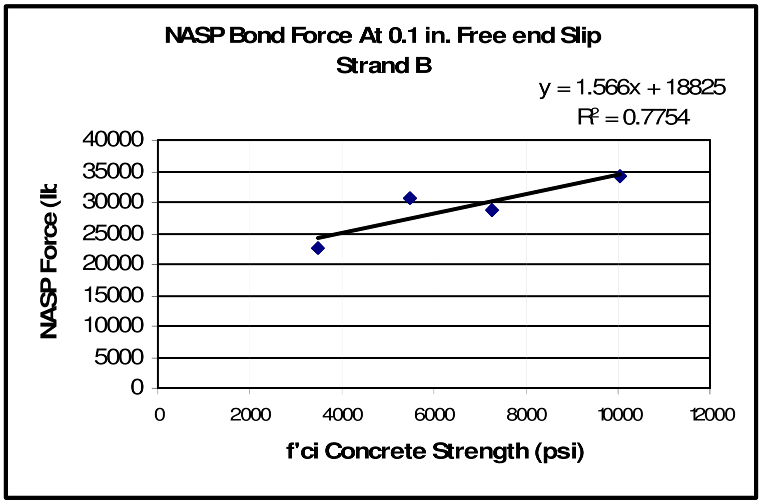

Figure 5.3. Linear Regression Analysis of the compressive strength of concrete and Bond force for Strand B.

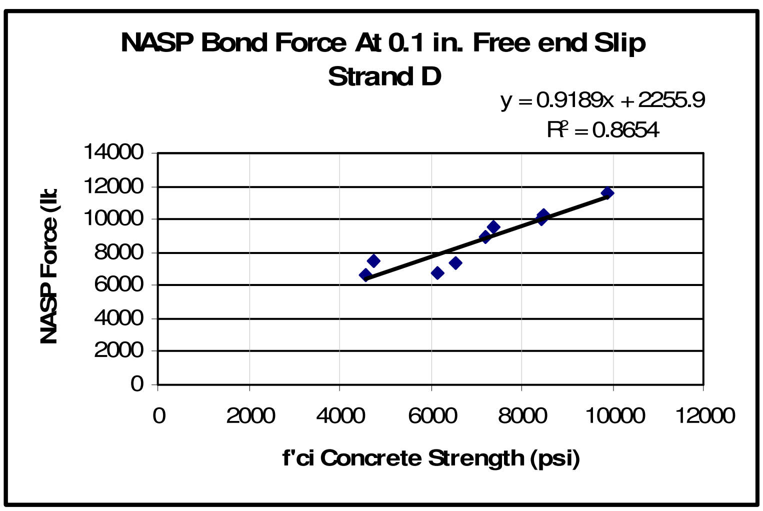

Figure 5.4. Linear Regression Analysis of the compressive strength of concrete and Bond force for Strand D.

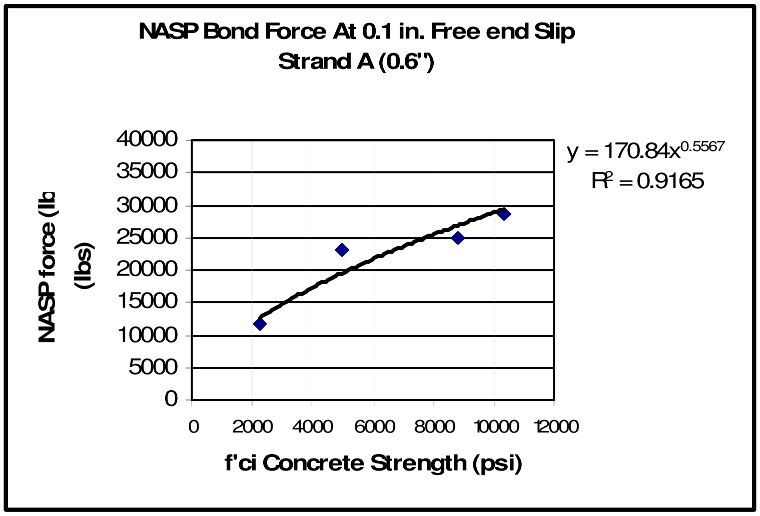

Figure 5.5.Power Regression Analysis of the compressive strength of concrete and Bond force for Strand A (0.6").

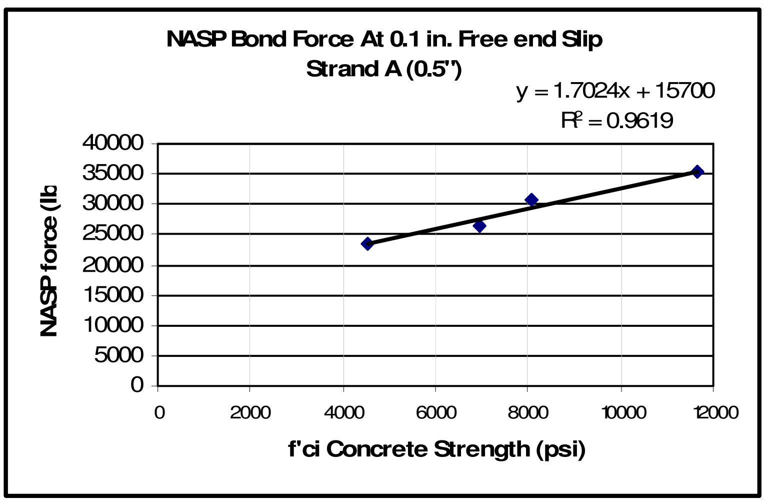

Figure 5.6. Power Regression Analysis of the compressive strength of concrete and Bond force for Strand A (0.5").

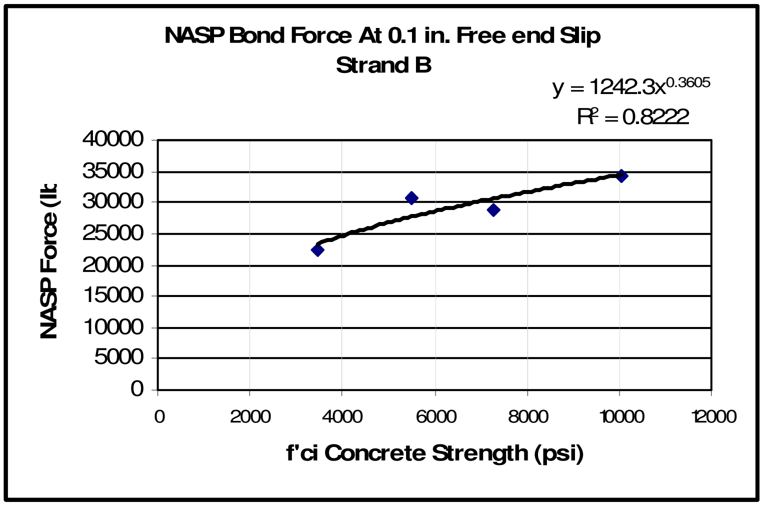

Figure 5.7. Power Regression Analysis of the compressive strength of concrete and Bond force for Strand B.

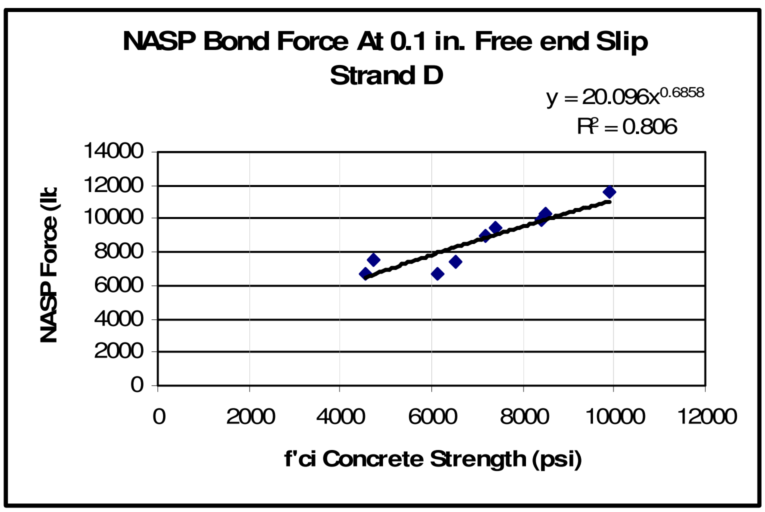

Figure 5.8. Power Regression Analysis of the compressive strength of concrete and Bond force for Strand D.

5.2.2 NASP Force vs. square root of Concrete Strength, f'_{ci}

In the same way, the NASP forces and the square root of concrete compressive strength were related in this testing program. The 0.1 in. free end slip varied approximately linearly with the square root of concrete compressive strength of the specimens for all strands sources. The regression analysis resulted in a good correlation of data for all strands. The linear regression analysis graphs for the square root of concrete compressive strength f'c and NASP bond force at 0.1 in. of free end slip are shown in Figure 5.9 through 5.12 .Table 5.1 gives the results for the regression analysis.

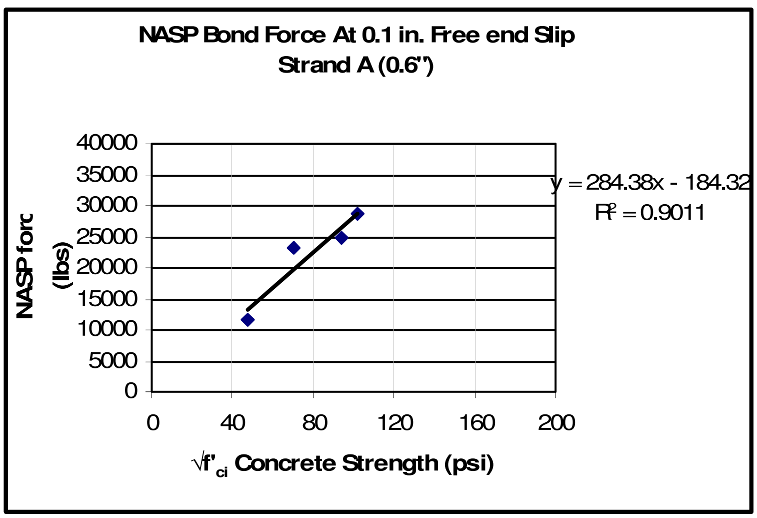

Figure 5.9 Linear Regression Analysis of square root of the compressive strength of concrete and Bond force for Strand A (0.6").

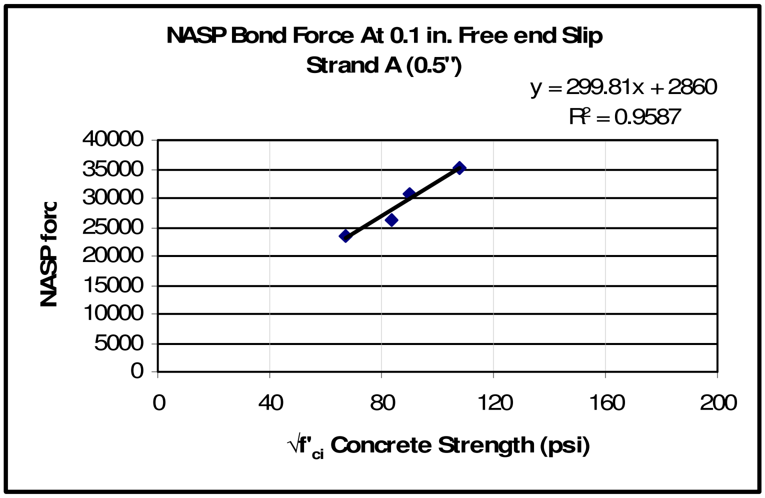

Figure 5.10 Linear Regression Analysis of square root of the compressive strength of concrete and Bond force for Strand A (0.5").

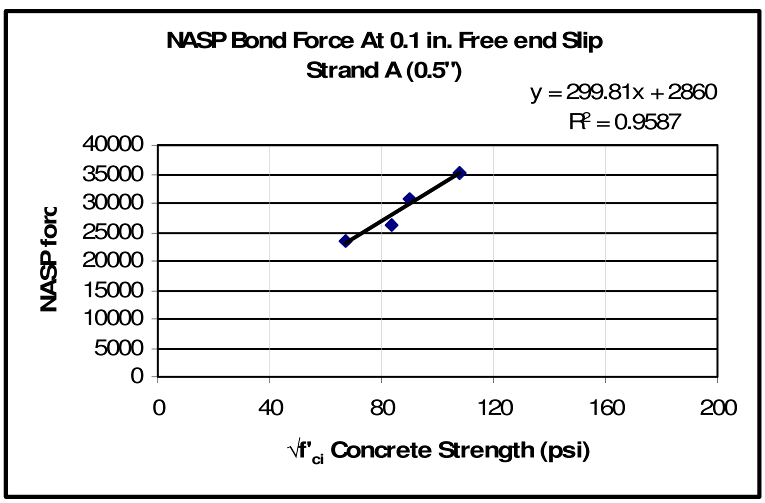

Figure 5.11 Linear Regression Analysis of square root of the compressive strength of concrete and Bond force for Strand B.

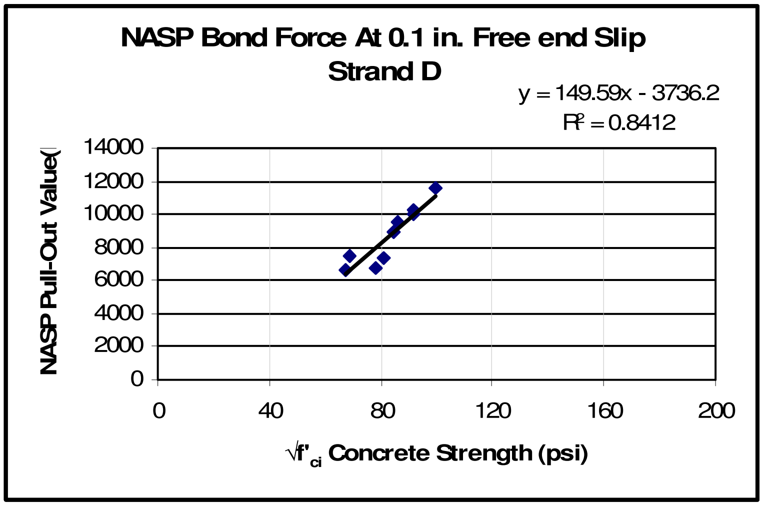

Figure 5.12 Regression Analysis of square root of the compressive strength of concrete and Bond force for Strand D.

Table 5.1. Results for Regression Analysis

	Strand A (0.6")			Strand A			Strand B			Strand D		
	√f'ci	f'ci	NASP P.O.	√f'ci	f'ci	NASP P.O.	√f'ci	f'ci	NASP P.O.	√f'ci		NASP P.O.
C-N	47.22	2230	11607	67.48	4553	23583	59.03	3485	22546	68.80	4733	7479
										67.51	4558	6661
C-I	70.46	4965	23129	83.29	6937	26353	74.10	5491	30796	84.80	7191	8961
										86.05	7405	9512
										80.91	6546	7387
										78.37	6143	6737
C-II	93.75	8789	24839	89.78	8061	30684	85.25	7268	28780	92.10	8483	10263
										91.76	8420	9966
C-III	101.69	10341	28735	107.90	11643	35288	100.18	10036	34334	99.41	9883	11557

5.2.2 Normalized value

All the results of 0.5 in. strands are combined to plot the normalized value verses concrete strength. Power regression was done to report R^2 and best fit equation. From the graph, the equation

$$\frac{(NASP)_C}{(NASP)\ Grout} = 0.5\sqrt{f'ci}$$

is obtained. Figure 5.13 shows the Normalized Value verses concrete strength. Power regression was done and R2 and best fit are reported on the graph.

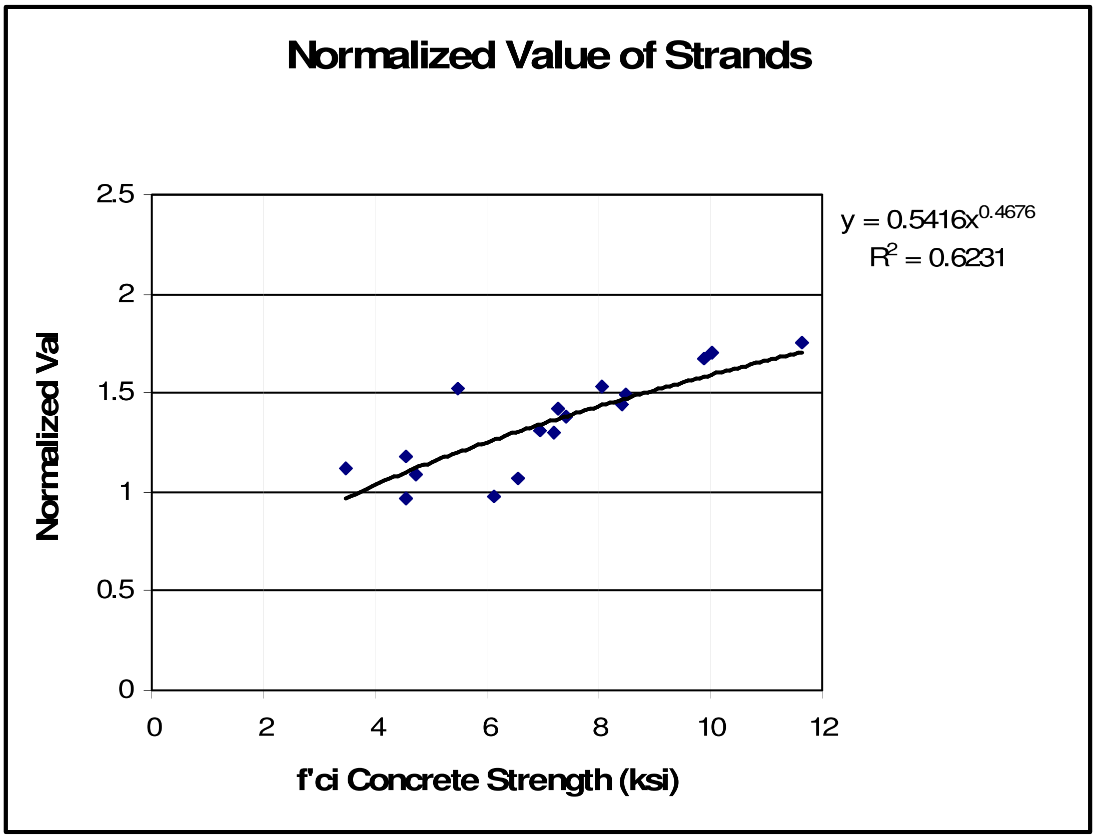

Figure 5.13 Regression Analysis of Normalized value vs. compressive strength of concrete for all strands.

Table 5.2. Normalized value and Concrete strength

$(NASP)_C$ / $(NASP)_G$	f'ci ksi
1.175035	4.553044
1.31303	6.936686
1.528827	8.060778
1.758231	11.6432
1.115578	3.484889
1.523793	5.490667
1.424063	7.268167
1.698872	10.03644
1.083889	4.73304
0.965422	4.558109
1.298768	7.190659
1.378579	7.405412
1.070609	6.546111
0.976375	6.142535
1.487406	8.483042
1.444354	8.419888
1.674944	9.883207

5.3 Discussion

- Concretes with desired compressive strength and workable mixture were obtained. The five desired concrete mixtures are repeatable able in the laboratory.
- Trial batches conducted at the lab were able be moved to the plant to perform big batches of concrete.
- Attaining 10,000 psi one day strength was difficult in the plant due to curing conditions.
- Special care was taken in the plant to ensure strength and workability. For example, the unit weight was one factor to insure we get the strength. If

the unit weight is lower than by 1 pcy , we did another concrete batch with reduced w/c ratio.

- The workability or the slump was inspected by observing the mix while the mixer was running. The dosage of HRWR was decided by looking the mix.
- It is my opinion that we can make HPC at the plant.

Chapter 6

6. SUMMARY AND CONCLUSION

6.1 SUMMARY

This research project involved trial concrete batching to develop mix designs for fabrication of beams and NASP Tests in concrete. NASP Test performed to determine the effects of concrete strength on the bond of steel prestressing strand. The two variables were strand source and concrete release strength. Fresh and hardened concrete properties from trial batching, NASP Tests and beams at the plant were recorded.

6.2 CONCLUSIONS

6.2.1 Concrete Batching

Five different concretes with targeted release strengths strength were attained both in the laboratory and precast/prestressed concrete plant. The five concrete mixtures are designated as C-N, C-I, C-IA, C-II and C-III with target release strengths of 4,000 psi, 6,000 psi, 6,000psi with air entrainment, 8,000 psi and 10,000 psi. NASP Tests in concrete were conducted using the developed concrete mix designs and beams at the plant were fabricated. Water to cement ratio, mineral and chemical admixtures had significant effects on the fresh and hardened properties of the concrete. Some alternations to the laboratory mix designs were done for implementation at the precast plant.

6.2.2. NASP TESTS IN CONCRETE

The results gathered from the NASP tests indicated that the NASP Test is effective in examining the effects on bond of varying concrete properties. Increasing concrete strength on the bond of steel had significant effect for each strand. From the NASP Test, the following were revealed.

- The NASP bond forces at 0.01 in. and 0.10 in. free end slip varied linearly with the compressive strength of the specimens for all of the strands.
- The compressive strength of concrete is affecting the NASP bond force according to the regression analysis of the data.

6.3 RECOMMENDATIONS

High performance concrete could be developed in the laboratory as well as in the precast/prestessed plant. High strength concrete also has significant effect on the bond ability of prestressing strands.

References

1. American Concrete Institute (1995). Building Code Requirements for Structural Concrete (ACI 318-95/318R-95), Farmington Hills, Michigan.

2. ACI Committee 318, “Building Code Requirements for Structural Concrete (ACI 318-95) and Commentary (ACI 318R-95)”, American Concrete Institute, Farmington Hills, MI, 1995.

3. Brown, M.D. (2003) “Evaluation of Test Methods in Accessing Bond Quality of Prestressing Strand,” Master’s Thesis. University of Oklahoma, Norman, Oklahoma.

4. Hanson, N.W. and Kaar P.H. (1959). “ Flexural Bond Tests of Pretensioned Prestressed Beams”, *Journal of the American Concrete Institute*, Proceedings Vol. 55, No. 7, January, pp. 183-802.

5. Janney, J.R. (1954). “ Nature of Bond in Pre-Tensioned Prestressed Concrete,” *Journal of American Concrete Institute*, Proceedings Vol. 50, No. 9, May, pp.717-736.

6. Logan, R.D., “Acceptance Criteria for Bond Quality of Strand for Pretensioned Prestressed Concrete Applications”, *PCI Journal*, March-April 1997, pp.52-90.

7. Mote, J., “Bond Mechanics of Steel Prestressing Strand”, Graduate Thesis for the University of Oklahoma, 2001.

8. Rose, D. R. “Measurements of Bond Performance; Correlation of Pull-out Strength with Transfer Length,” Graduate Thesis for the University of Oklahoma, 1995

9. Russell, B. W. and Paulsgrove, G.A.(1999). “ NASP Strand Bond Testing, Round One, Pull-out Tests and Friction Bond Tests of Untensioned Strand, “ Final Report 99-03, Fears Structural Engineering Laboratory, University Of Oklahoma, July.

10. Russell, B. W. and Burns, N. H. (1997). “Measured Transfer Lengths on Pretensioned Concrete Elements, “Journal of Structural Engineering, Vol. 123, No. 5, May, pp.541-549.

11. Grieve, C.B., (2004) “Investigating the Effects of Mortar Strenght and Loading rate on the NASP Bond Test.” Master’s Thesis. Oklahoma State University, Oklahoma.

Appendix A

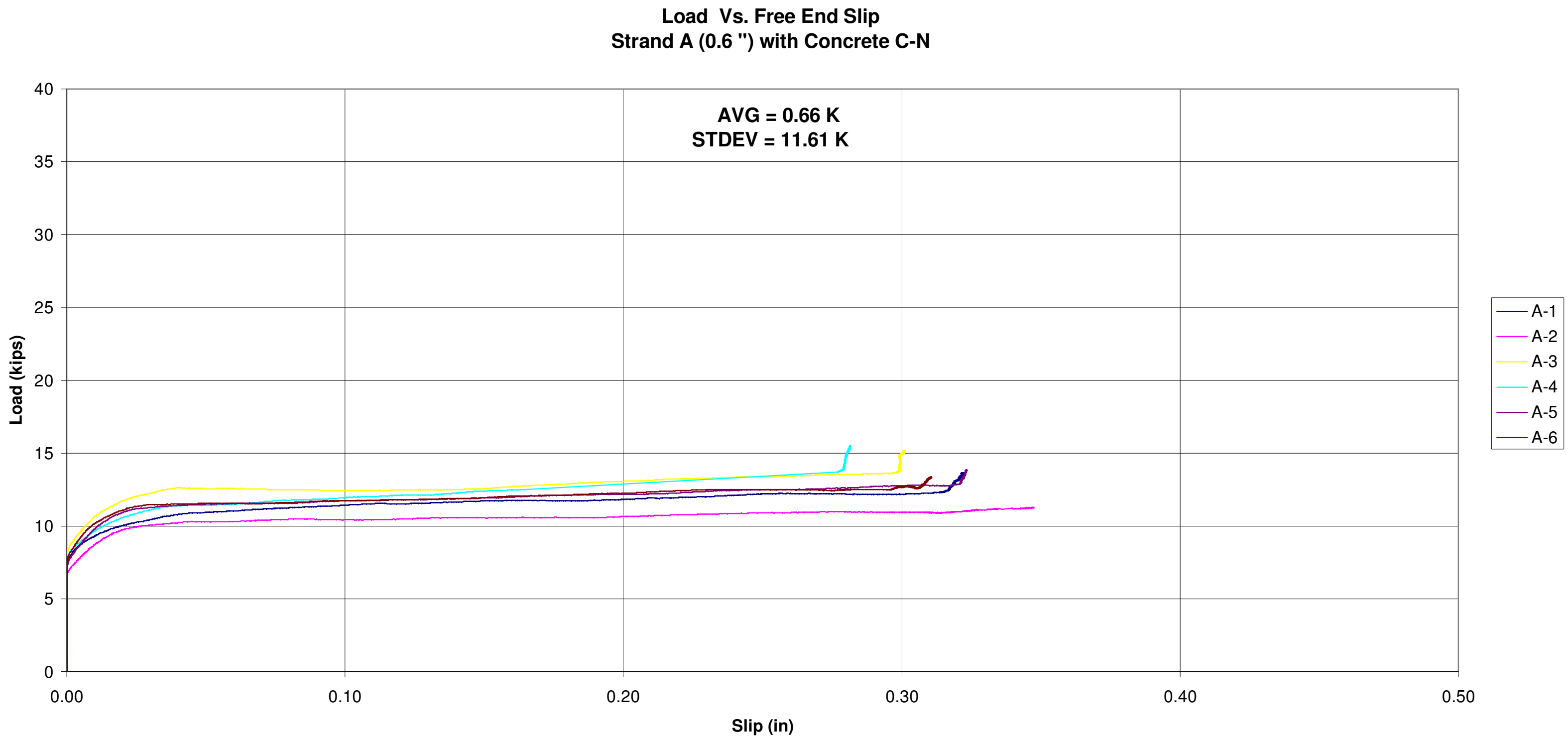

Figure A.1 NASP Result Strand "A (0.6 in.)", C-N

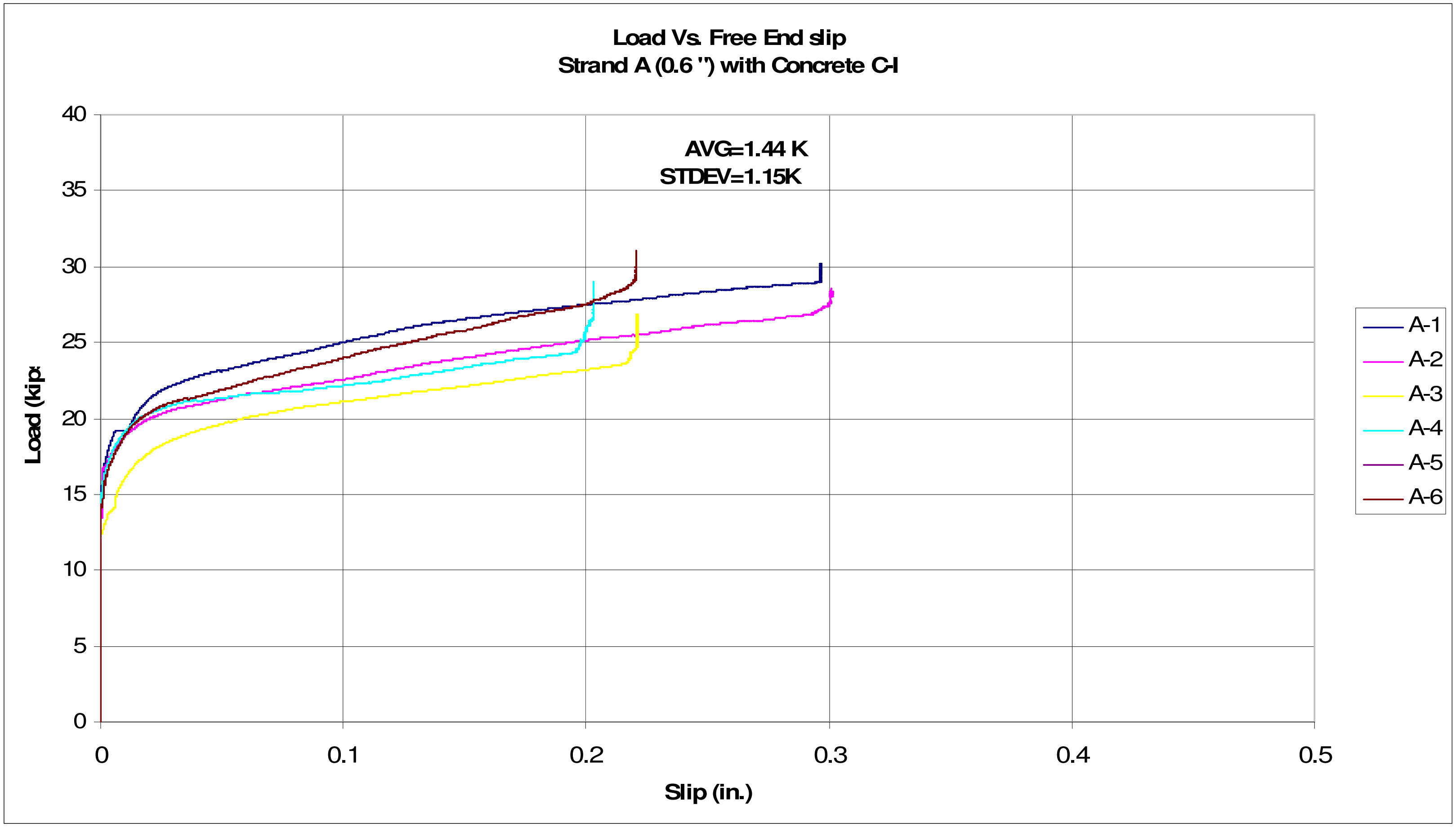

Figure A.2 NASP Result Strand "A (0.6 in.)", C-I

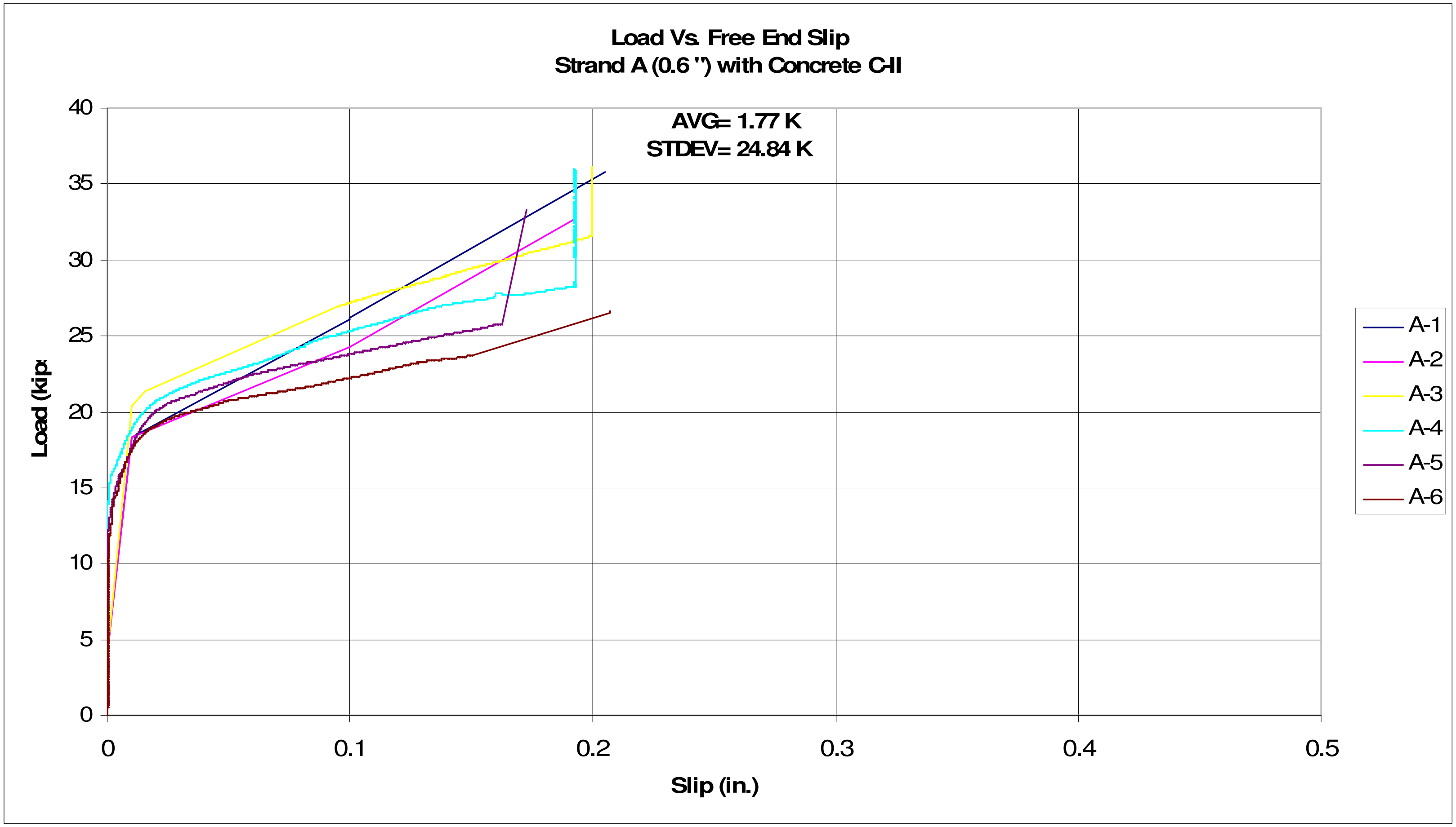

Figure A.3 NASP Result Strand "A (0.6 in.)", C-II

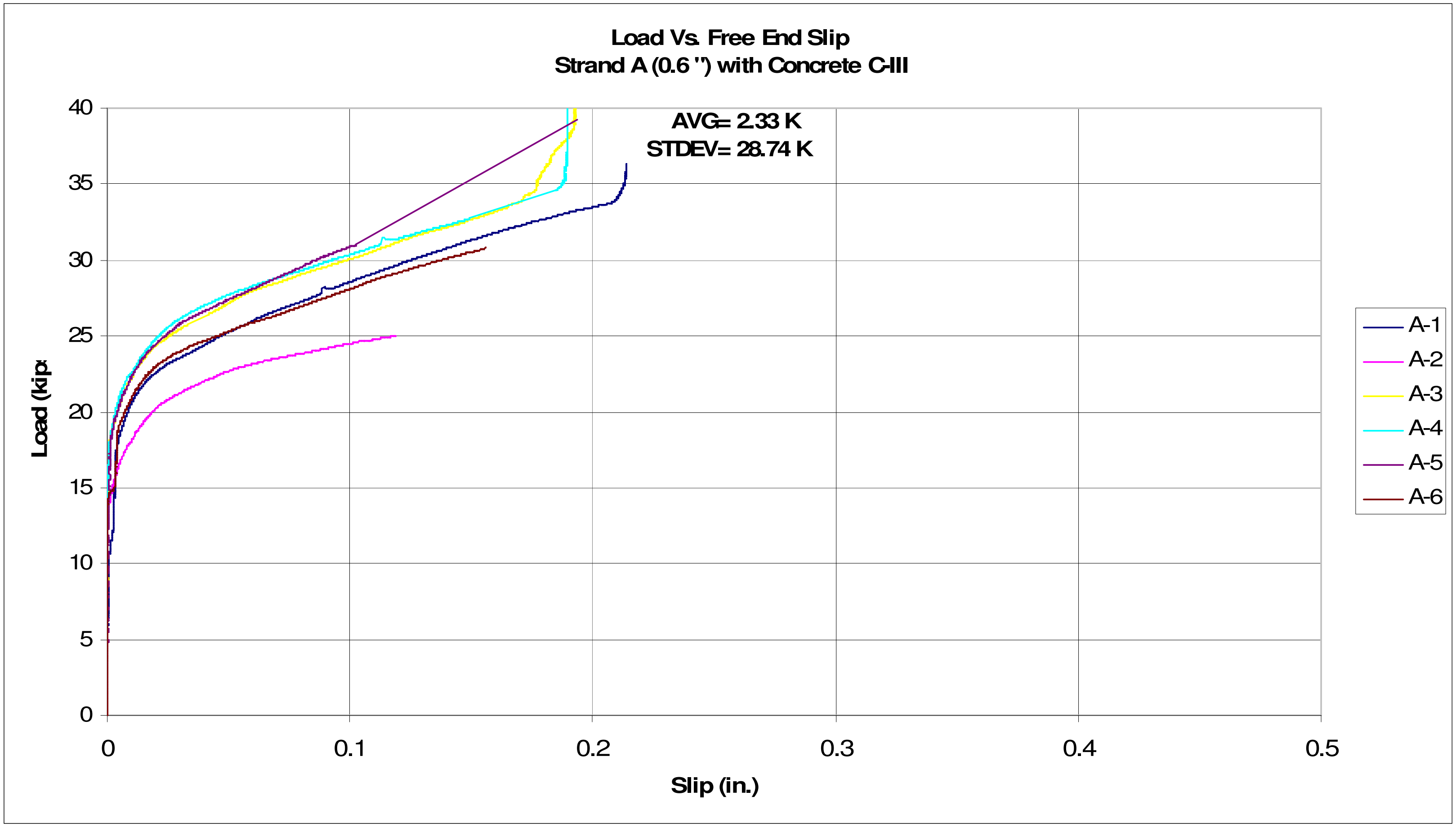

Figure A.4 NASP Result Strand "A (0.6 in.)", C-III

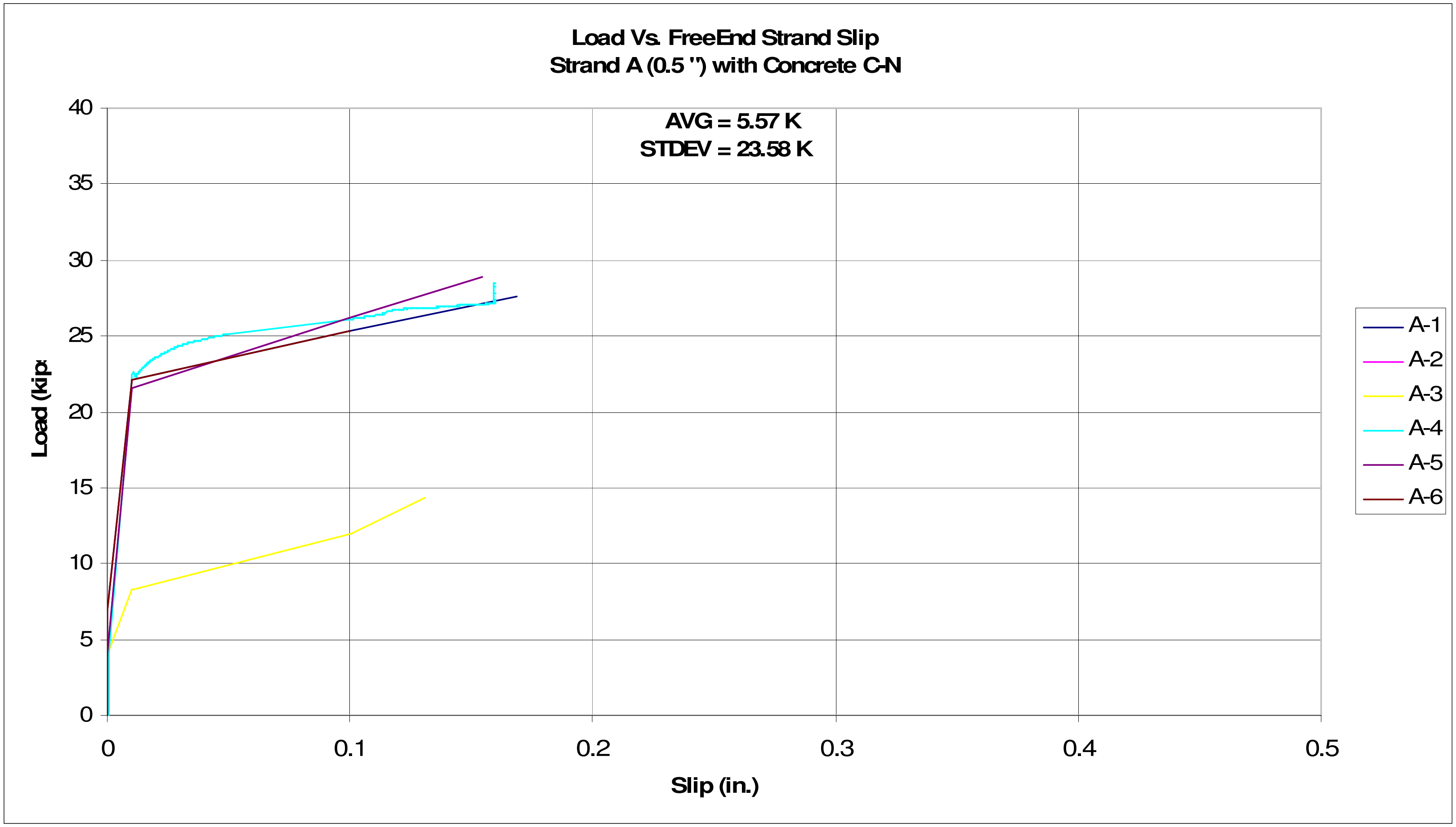

Figure A.5 NASP Result Strand "A (0.5 in.)", C-N

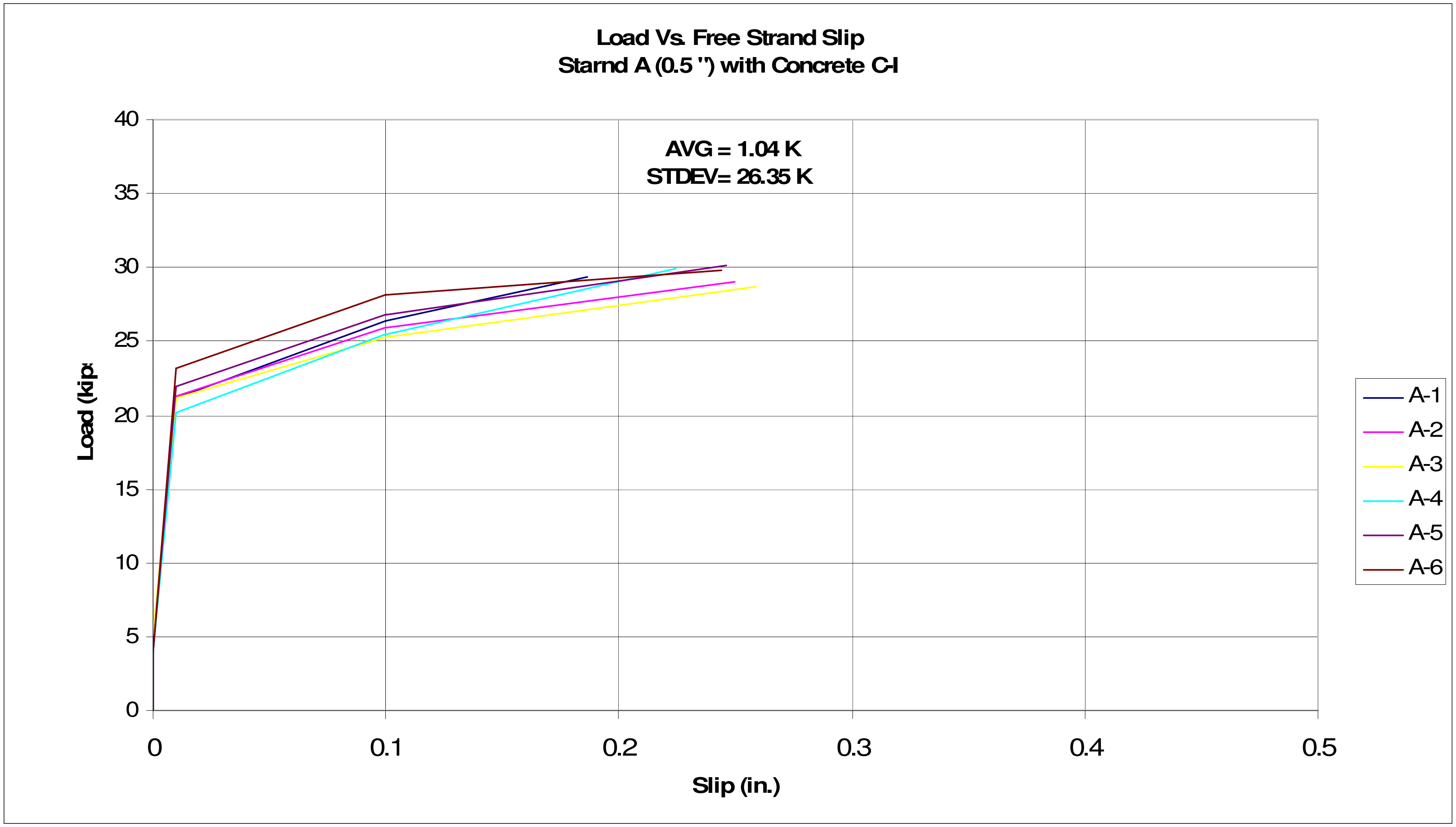

Figure A.6 NASP Result Strand "A (0.5 in.)", C-I

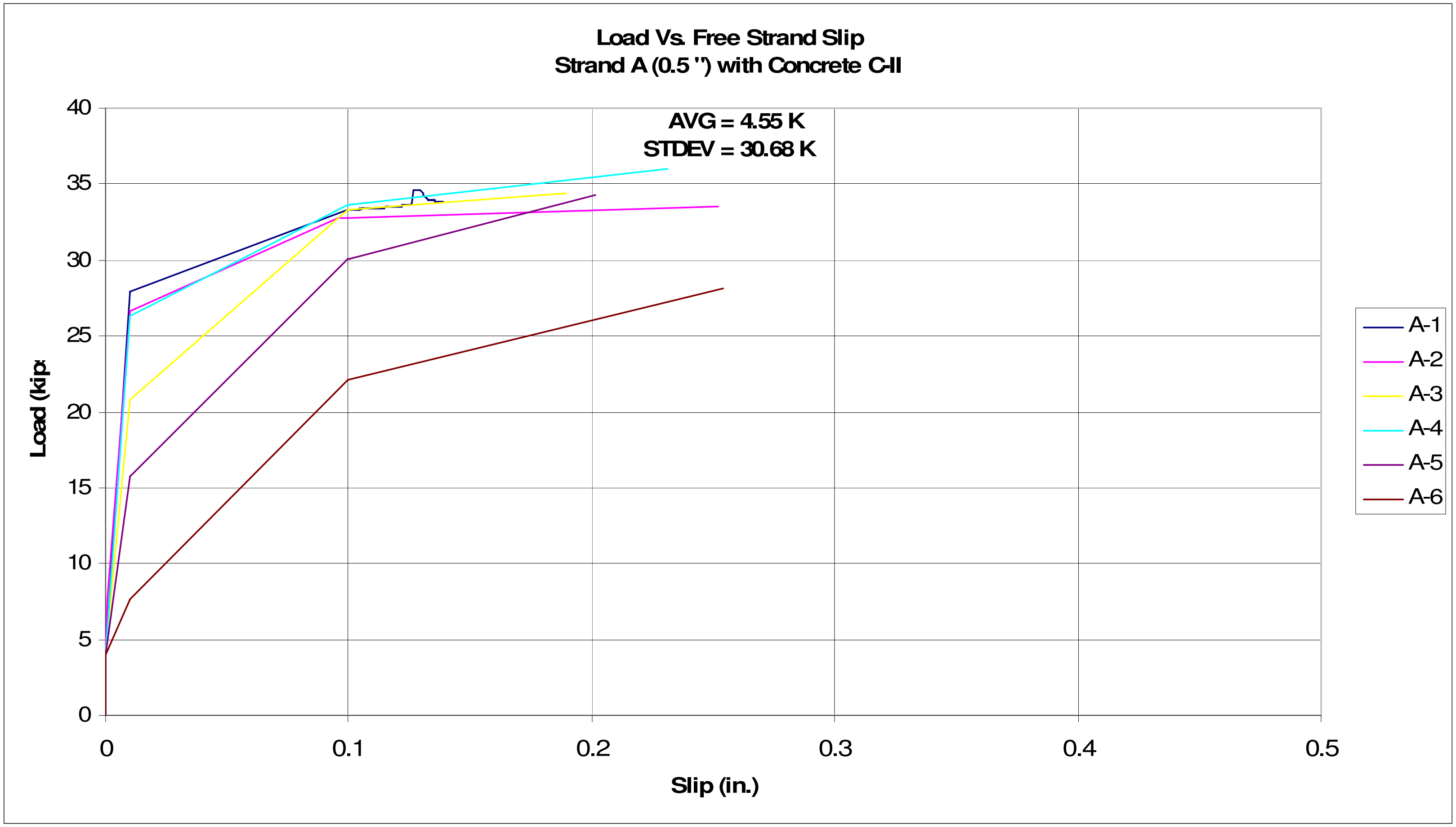

Figure A.7 NASP Result Strand "A (0.5 in.)", C-II

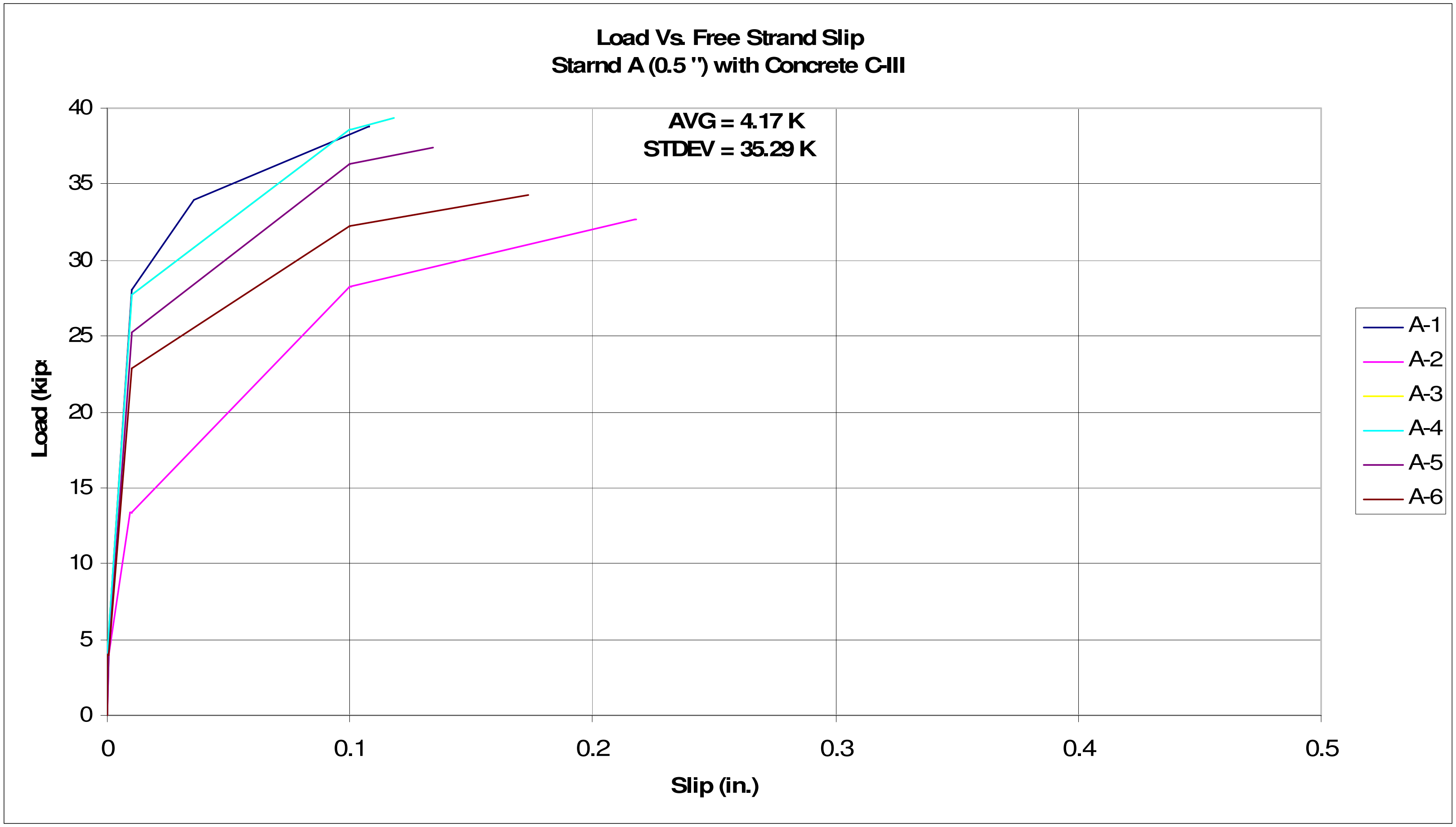

Figure A.8 NASP Result Strand "A (0.5 in.)", C-III

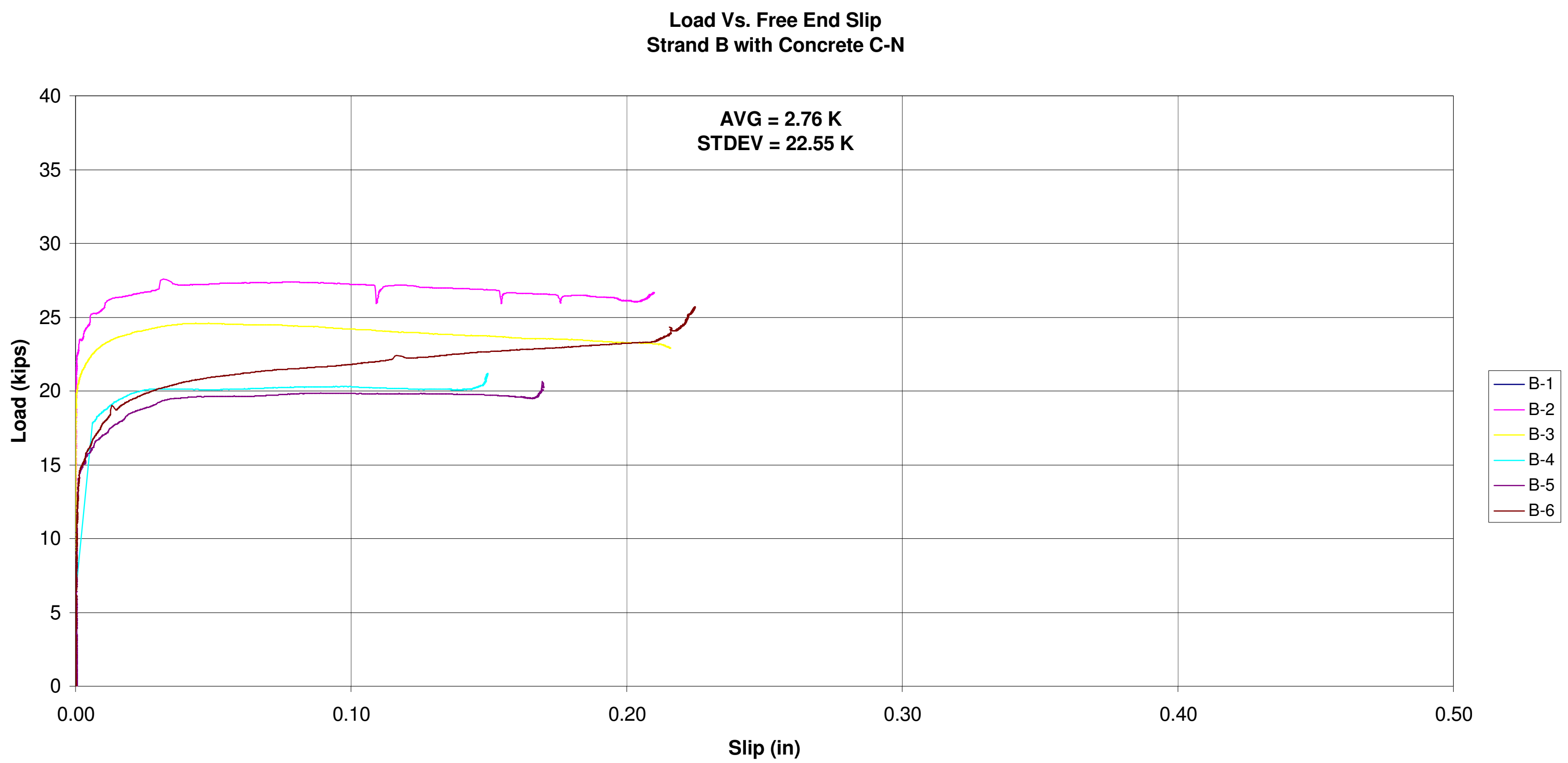

Figure A.9 NASP Result Strand B, C-N

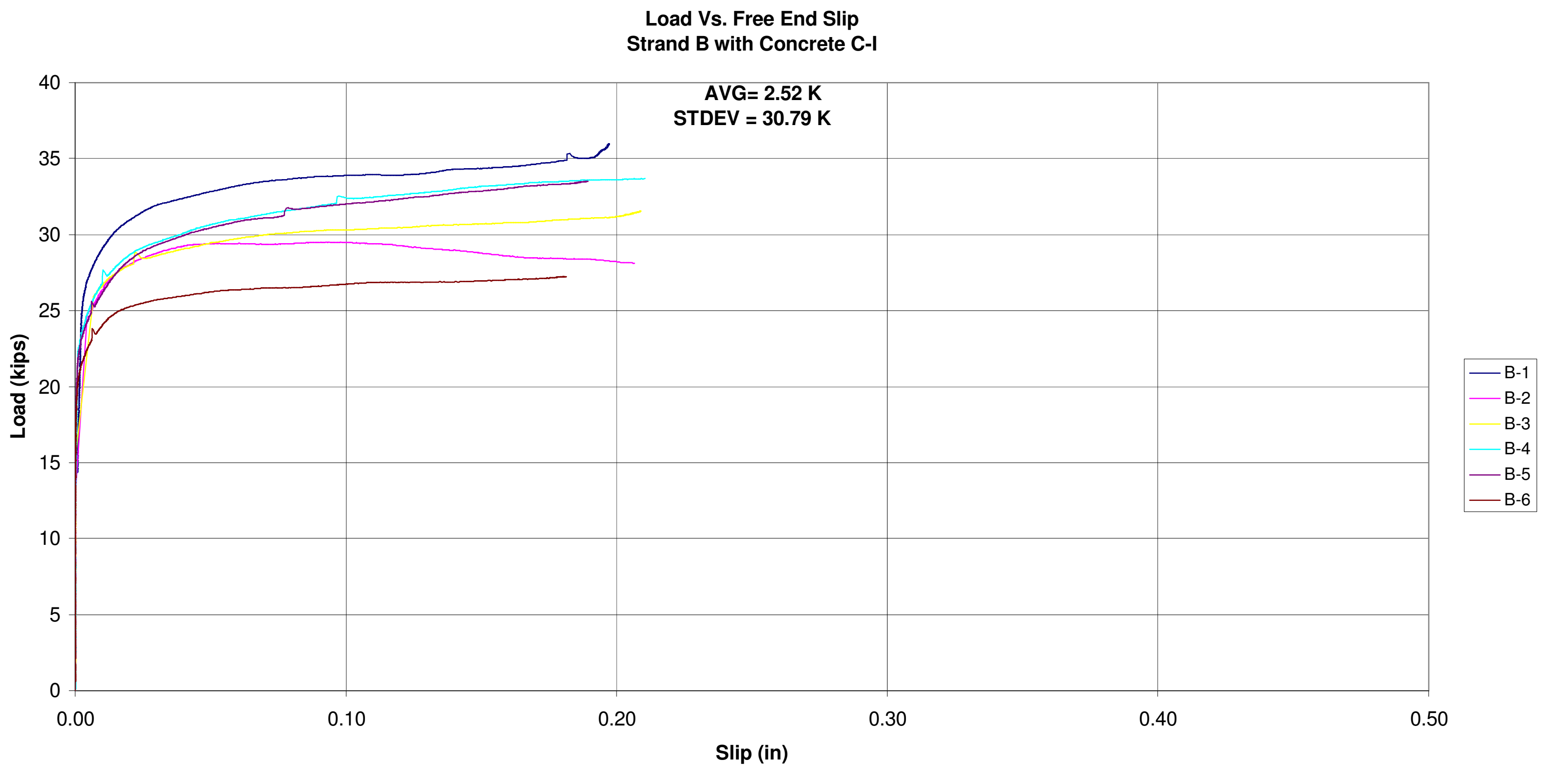

Figure A.10 NASP Result Strand B, C-I

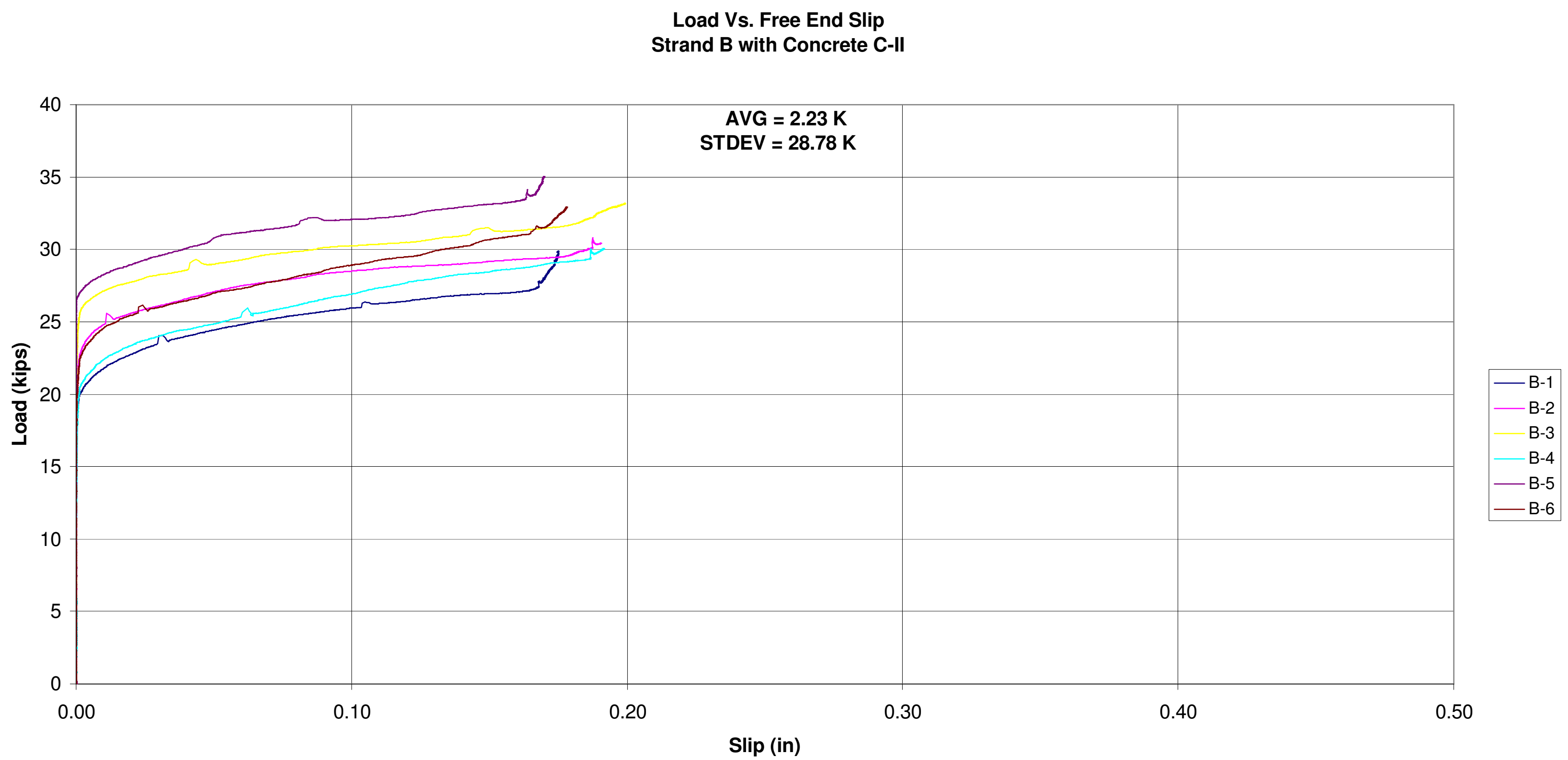

Figure A.11 NASP Result Strand B, C-II

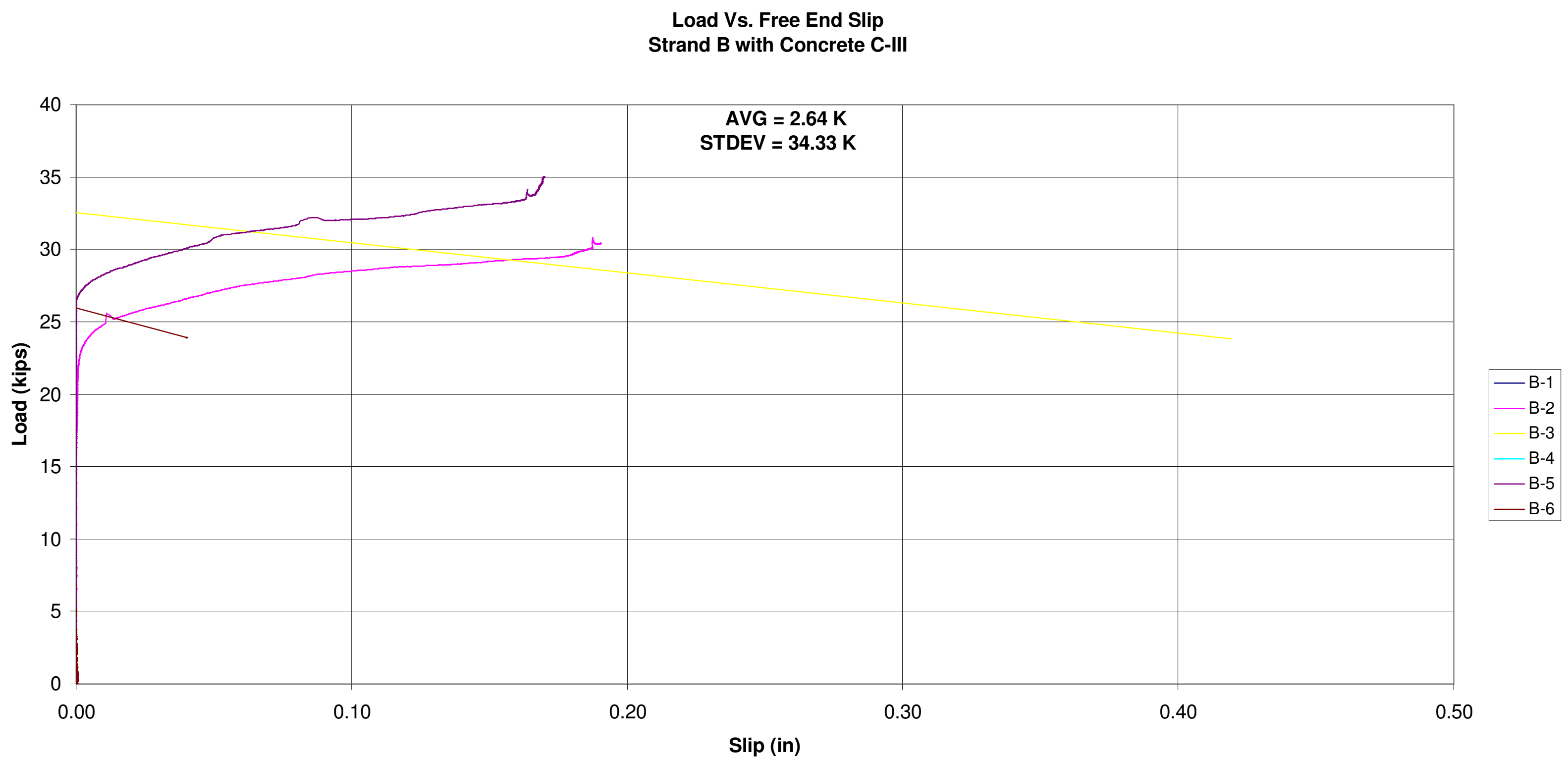

Figure A.12 NASP Result Strand B, C-III

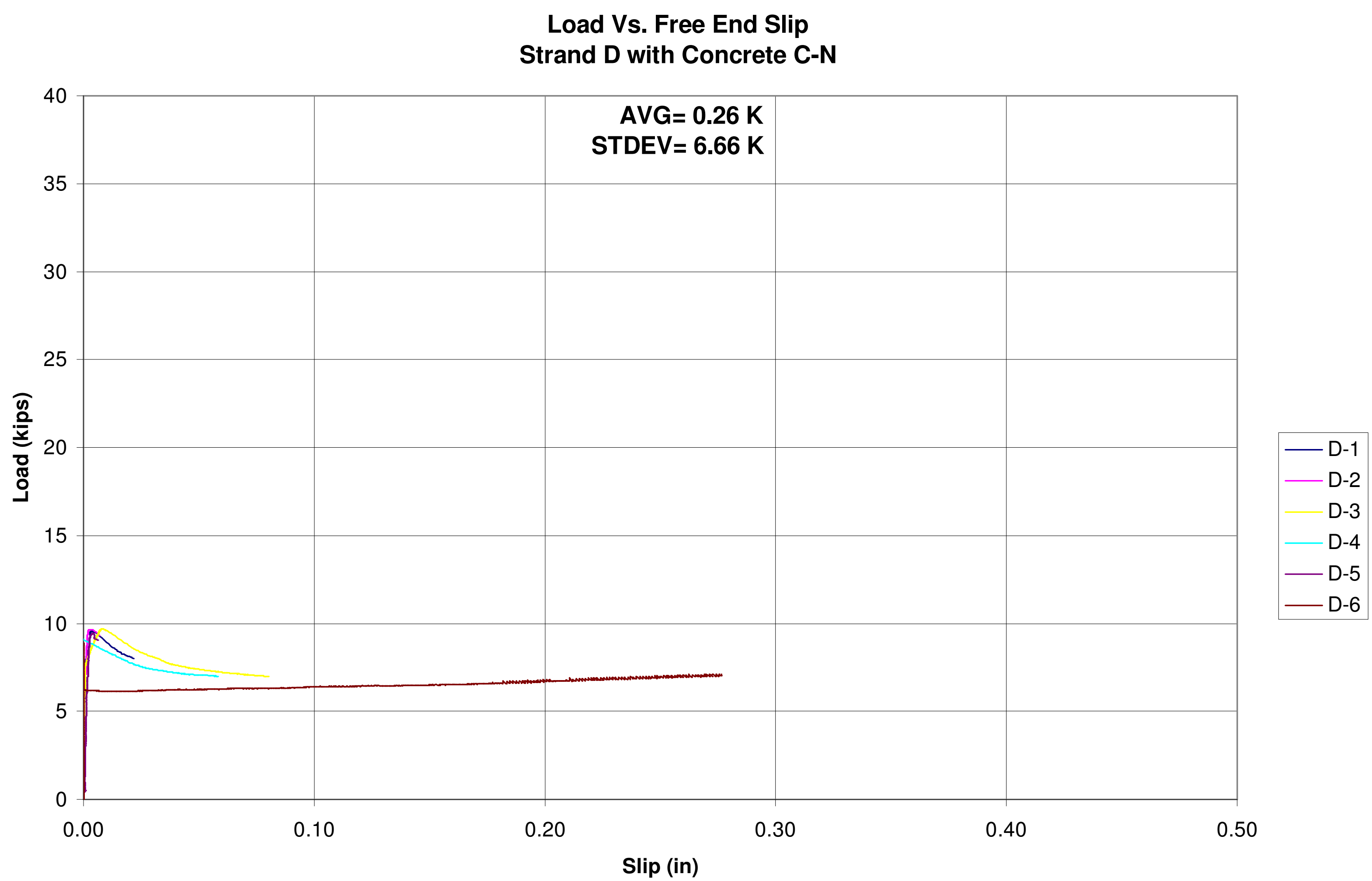

Figure A.13 NASP Result Strand D, C-N

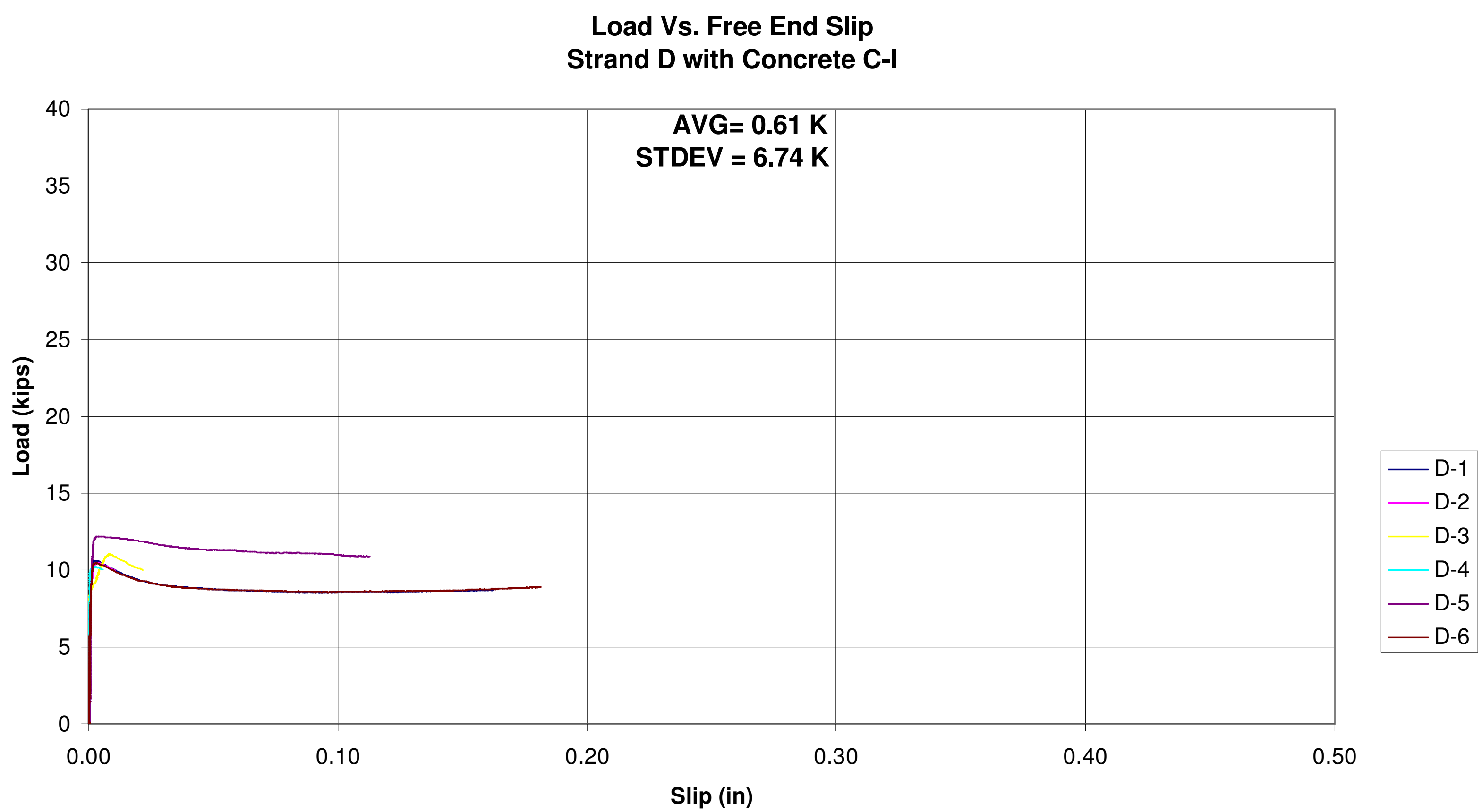

Figure A.14 NASP Result Strand D, C-I

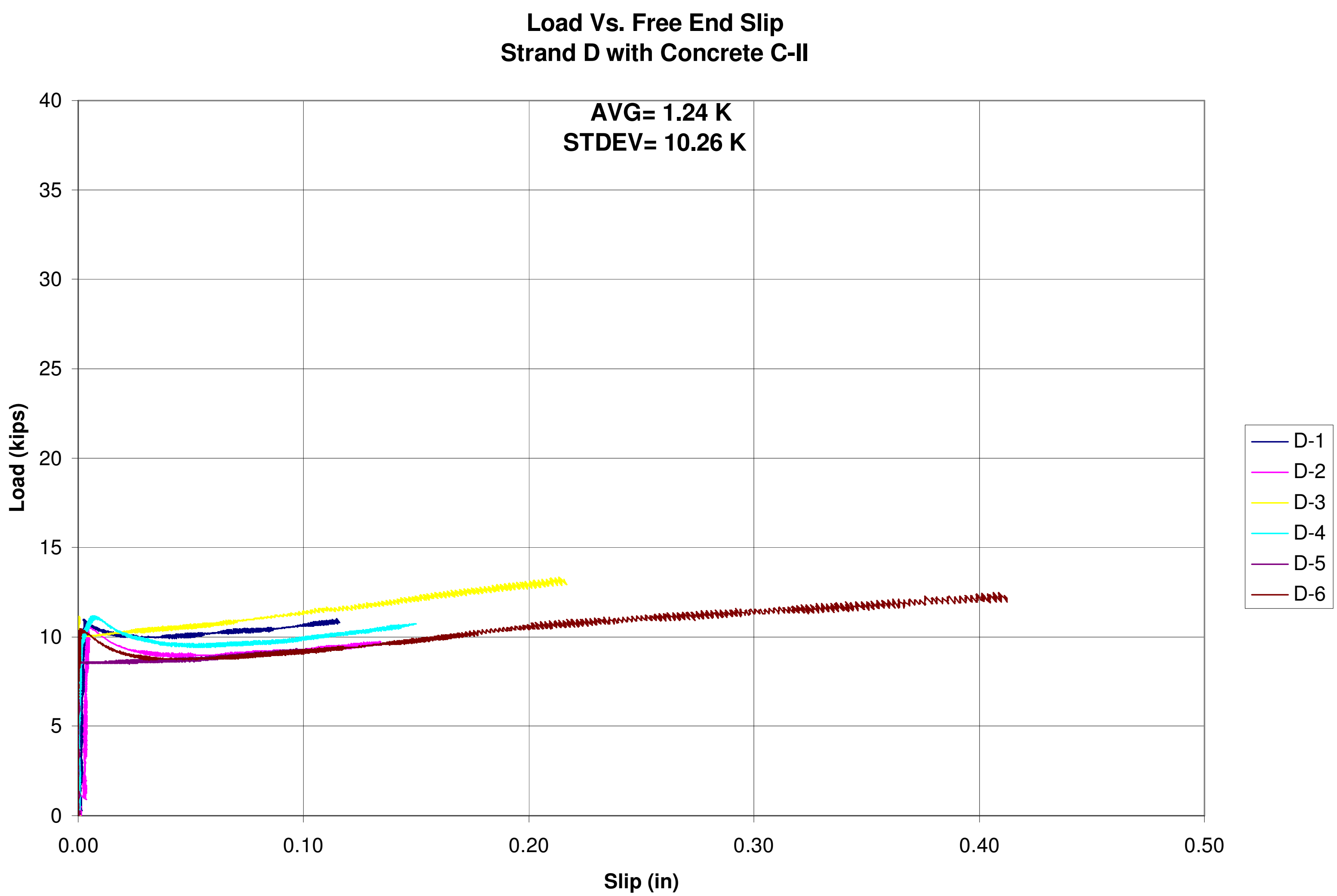

Figure A.15 NASP Result Strand D, C-II

Appendix B

NASP STRAND BOND TEST (DRAFT)

The NASP Protocol is modified in that concrete is being used instead of the grout specified in the test protocol.

Standard Test Method to Access 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. (12.7mm) seven wire strand to bond with concrete. The method tests the bond ability 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 with a bonded length of 16 in. (400 mm). The constituents and proportions for the concrete 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 concrete at a prescribed rate of loading. The pull-out force id recorded at 0.10 in. (2.5 mm) of total slip. A single NASP Bond Test shall consist of 6 of 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 of use in pretensioned or post-tensioned applications. Strand specimens for s 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 Mixture Constituents and Proportions. The concrete mixture shall consist of sand, aggregate, cement and water mixed thoroughly. The batch weight for sand and aggregate 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 and aggregate 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 portable and suitable for making concrete.

4.3 Mixing. The concrete the test specimens shall be made in conformance with ASTM C 192. Measurements of slump and air content are required.

4.4 Curing. The concrete test specimens shall be cured in conformance with ASTM C 192. The concrete 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.

4.5 Concrete Strength. Concrete strength shall be evaluated in conformance with ASTM C 192.

4.6 Test specimens shall not be made by casting one single strand concentrically in concrete within a 5 in. (125 mm) diameter steel casing as described in figure 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 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. form 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 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. 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.

5.6 If the hardened concrete 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 0.1 in. between the strand and the hardened concrete.

6.3 For the NASP Bond Test, compute the average pull-out force from the individual testes 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.

Appendix C

Table C.1.1 Sieve Analysis for Dolese Fine Aggregate - OSU Laboratory					
Sieve Size	Weight	Percent	Percent	Fineness	Percent
	Retained	Retained	Coarser	modulus	Passing
	(g)	(%)	(%)		(%)
No. 4	5.7	1.14	1.14	1.14	98.86
No.8	10.9	2.18	3.32	4.46	96.68
No.16	49.3	9.86	13.18	17.64	86.82
No.30	140.3	28.06	41.24	58.88	58.76
No.50	195	39	80.24	139.12	19.76
No.100	89.9	17.98	98.22	237.34	1.78
No.200	8.3	1.66	81.9	221.02	18.1
pan	0.6	0.12	100	337.34	0
Fineness modulus =		2.21			

Table C.1.2 Sieve Analysis for Dolese Fine Aggregate - OSU Laboratory					
Sieve Size	Weight	Percent	Percent	Fineness	Percent
	Retained	Retained	Coarser	modulus	Passing
	(g)	(%)	(%)		(%)
No. 4	1.7	0.34	0.34	0.34	99.66
No.8	13.5	2.7	3.04	3.38	96.96
No.16	49.8	9.96	13	16.38	87
No.30	148.6	29.72	42.72	59.1	57.28
No.50	186.4	37.28	80	139.1	20
No.100	90.5	18.1	98.1	237.2	1.9
No.200	9	1.8	99.9	239	0.1
pan	0.5	0.1	100	337.2	0
		Fineness modulus =	2.39		

Table C.1.3 Sieve Analysis for Dolese Fine Aggregate - OSU Laboratory					
Sieve Size	Weight	Percent	Percent	Fineness	Percent
	Retained	Retained	Coarser	modulus	Passing
	(g)	(%)	(%)		(%)
No. 4	4.4	0.88	0.88	0.88	99.12
No.8	10.2	2.04	2.92	3.8	97.08
No.16	50.8	10.16	13.08	16.88	86.92
No.30	144.8	28.96	42.04	58.92	57.96
No.50	188.3	37.66	79.7	138.62	20.3
No.100	90.4	18.08	97.78	236.4	2.22
No.200	10.5	2.1	99.88	238.5	0.12
pan	0.6	0.12	100	336.4	0
		Fineness modulus =	2.39		

Table C.1.4 Sieve Analysis for Dolese Coarse Aggregate - OSU Laboratory

Sieve Size	Weight	Percent	Percent	Fineness	Percent
	Retained	Retained	Coarser	Modulus	Passing
	(g)	(%)	(%)		(%)
1 in	0	0	0	0	100
¾ in	0	0	0	0	100
½ in	0	0	0	0	100
3/8 in	71.6	7.2	7.2	7.2	92.84
No. 4	820.4	82.0	89.2	96.4	10.8
pan	108	10.8	100.0	196.4	0

Table C.1.5 Sieve Analysis for Dolese Coarse Aggregate - OSU Laboratory

Sieve Size	Weight	Percent	Percent	Fineness	Percent
	Retained	Retained	Coarser	Modulus	Passing
	(g)	(%)	(%)		(%)
1 in	0	0	0	0	100
3/4 in	0	0	0	0	100
1/2 in	0	0	0.0	0.0	100
3/8 in	42.1	4.2	4.2	4.2	95.79
No. 4	849.9	85.0	89.2	93.4	10.8
pan	108	10.8	100.0	193.4	0

Table C.1.6 Sieve Analysis for Dolese Coarse Aggregate - OSU Laboratory

Sieve Size	Weight	Percent	Percent	Fineness	Percent
	Retained	Retained	Coarser	Modulus	Passing
	(g)	(%)	(%)		(%)
1 in	0	0	0	0	100
¾ in	0	0	0	0	100
½ in	0	0.383	0.383	0.383	99.617
3/8 in	38.3	3.8	4.2	4.6	95.787
No. 4	853.7	85.4	89.6	94.2	10.417
pan	108	10.8	100.0	193.8	0

Table C.1.7 Sieve Analysis for Fine Aggregate - Coreslab Structures					
Sieve Size	Weight	Percent	Percent	Fineness	Percent
	Retained	Retained	Coarser	modulus	Passing
	(g)	(%)	(%)		(%)
No. 4	2.8	0.56	0.56	0.56	99.44
No.8	21.2	4.24	4.8	5.36	95.2
No.16	66.4	13.28	18.08	23.44	81.92
No.30	127.1	25.42	43.5	66.94	56.5
No.50	168.0	33.6	77.1	144.04	22.9
No.100	100.6	20.12	97.22	241.26	2.78
No.200	13.1	2.62	99.84	341.1	0.16
pan	0.8	0.16	100	441.1	0
Fineness modulus =		3.41			

Table C.1.8 Sieve Analysis for Fine Aggregate - Coreslab Structures					
Sieve Size	Weight	Percent	Percent	Fineness	Percent
	Retained	Retained	Coarser	modulus	Passing
	(g)	(%)	(%)		(%)
No. 4	4.7	0.94	0.94	0.94	99.06
No.8	19.2	3.84	4.78	5.72	95.22
No.16	62.1	12.42	17.2	22.92	82.8
No.30	122.8	24.56	41.76	64.68	58.24
No.50	171.6	34.32	76.08	140.76	23.92
No.100	105.3	21.06	97.14	237.9	2.86
No.200	13.7	2.74	99.88	337.78	0.12
pan	0.6	0.12	100	437.78	0
Fineness modulus =		3.38			

Table C.1.9 Sieve Analysis for Fine Aggregate - Coreslab Structures					
Sieve Size	Weight	Percent	Percent	Fineness	Percent
	Retained	Retained	Coarser	modulus	Passing
	(g)	(%)	(%)		(%)
No. 4	5.7	1.14	1.14	1.14	98.86
No.8	21.2	4.24	5.38	6.52	94.62
No.16	64.4	12.88	18.26	24.78	81.74
No.30	127.1	25.42	43.68	68.46	56.32
No.50	168	33.6	77.28	145.74	22.72
No.100	100	20	97.28	243.02	2.72
No.200	13.1	2.62	99.9	245.64	0.1
pan	0.5	0.1	100	343.02	0
Fineness modulus =		2.46			

Table C.1.10 Sieve Analysis for Washed Coarse Aggregate - Coreslab Structures

Sieve Size	Percent	Percent	Percent
	Retained	Coarser	Passing
	(%)	(%)	(%)
1 in	0	0	100.0
3/4 in	0	0	100.0
1/2 in	5.82	5.82	94.2
3/8 in	36.2	42.1	58.0
No. 4	56.0	98.1	1.9
pan	1.9	100.0	0.0

Table C.1.11 Sieve Analysis for Washed Coarse Aggregate - Coreslab structures

Sieve Size	Percent	Percent	Percent
	Retained	Coarser	Passing
	(%)	(%)	(%)
1 in	0	0	100.0
3/4 in	0	0	100.0
1/2 in	2.99	3.0	97.0
3/8 in	32.8	35.8	64.2
No. 4	61.8	97.6	2.4
pan	2.4	100.0	0.0

Table C.1.12 Sieve Analysis for Washed Coarse Aggregate - Coreslab structures

Sieve Size	Percent	Percent	Percent
	Retained	Coarser	Passing
	(%)	(%)	(%)
1 in	0	0	100
3/4 in	0	0	100
1/2 in	3.952	3.952	96.048
3/8 in	39.5	43.5	56.528
No. 4	54.0	97.5	2.5
pan	2.5	100.0	0.0

Table C.1.13 Sieve Analysis for Coarse Aggregate - Coreslab structures

Sieve Size	Percent	Percent	Percent
	Retained	Coarser	Passing
	(%)	(wt. %)	(%)
1 in	0	0	100.0
3/4 in	0	0	100.0
1/2 in	9.2	9.2	90.8
3/8 in	46.2	55.4	44.6
No. 4	42.4	97.9	2.1
pan	2.2	100.0	0.0

Table C.1.14 Sieve Analysis for Coarse Aggregate - Coreslab structures

Sieve Size	Percent	Percent	Percent
	Retained	Coarser	Passing
	(%)	(wt. %)	(%)
1 in	0	0	100.0
3/4 in	0.0	0	100.0
1/2 in	8.2	8.2	91.8
3/8 in	53.4	61.6	38.4
No. 4	35.8	97.4	2.6
pan	2.6	100.0	0.0

Table C.1.15 Sieve Analysis for Coarse Aggregate - Coreslab structures

Sieve Size	Percent	Percent	Percent
	Retained	Coarser	Passing
	(%)	(wt. %)	(%)
1 in	0.0	0.0	100.0
3/4 in	0.0	0.0	100.0
1/2 in	5.5	5.5	94.5
3/8 in	55.4	60.9	39.1
No. 4	36.5	97.4	2.6
pan	2.6	100.0	0.0

Appendix D

Table D.1.1. Concrete Mix Design, Fresh and Harden 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

Table D.1.2. Concrete Mix Design, Fresh and Harden 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

Table D.1.3. Concrete Mix Design, Fresh and Harden 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		0.30
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

Table D.1.4. Concrete Mix Design, Fresh and Harden 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)		157.70
	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

Table D.2.1. Concrete Mix Design, Fresh and Harden properties for Concrete IA Core Slab Structures, Oklahoma City- Summer 2004			
With 6% Total Air			
			Date:07/27
Mix Proportions	Cement (PCY)		800
	Coarse Agg. (PCY)		1814.4
	Fine Agg. (PCY)		1128.5
	Water (PCY)		218.79
	Glenium 3030NS (fl. oz/cwt)		8
	Polyheed 997 (fl.oz/cwt)		3
	w/cm		0.2735
Fresh properties	Concrete Temperature (ºF)		84
	Slump (in.)		6.5
	Unit Weight (pcf)		147.9
	Air Content (%)		5.6
	Moisture Content of Rock (%)		0.002
	Moisture Content of Sand (%)		4.3
Hardened Properties	Compressive Strength in psi	1 Day	7960
		7 Day	9070
		14 day	9100
		28 Day	10,250
		56 Day	11,420
	Tensile Strength in psi	28 Day	820
	Modulus of Elasticity (psi)	28 Day	5680
	Calculated Modulus of elasticity using ACI method(psi)	28 Day	6010

Table D.2.2. Concrete Mix Design, Fresh and Harden properties for Concrete II

Core Slab Structures, Oklahoma City- Summer 2004, With No Air Entrainment

			Date:07/29/04	Date:08/12/04
Mix Proportions	Cement (PCY)		800	800
	Coarse Agg. (PCY)		1805	1803.6
	Fine Agg. (PCY)		1218.9	1163.4
	Water (PCY)		276.92	269.21
	Glenium 3030 (fl. oz/cwt)		14	4
	w/cm		0.346	0.337
Fresh Properties	Concrete Temperature (ºF)		90	83
	Slump (in.)		9.5	8.25
	Unit Weight (pcy)		151.38	149.6
	Air Content (%)		0.7	1.4
	Moisture Content of Rock (%)		0.8	0.6
	Moisture Content ofSand (%)		7.5	4.2
Hardened Properties	Compressive Strength in psi	1 Day	8570	5410
		7 Day	11,000	7,310
		14 day	11,240	7,640
		28 Day	12,680	7,910
		56 Day	13,490	8,220
	Tensile Strength in psi	28 Day	915	560
	Modulus of Elasticity	28 Day	5945	5110
	Calculated Modulus of elasticity Using ACI method(psi)	28 Day	6920	5470

Table D.2.3. Concrete Mix Design, Fresh and Harden properties for Concrete I

Core Slab Structures, Oklahoma City – Summer 2004, Without Air Entrainment

			Date:08/02/04	Date:08/12/04
Mix Proportions	Cement (PCY)		800	800
	Coarse Agg. (PCY)		1702.9	1698.4
	Fine Agg. (PCY)		1202.5	1211.6
	Water (PCY)		303.18	300.57
	Glenium 3400 (fl. oz/cwt)		5	5
	w/cm		0.379	0.376
Fresh Properties	Concrete Temperature (ºF)		90	82
	Slump (in.)		9.5	5.75
	Unit Weight (pcf)		148.78	149.6
	Air Content (%)		1.5	1.2
	Moisture Content of Rock (%)		0.2	0.6
	Moisture Content of Sand (%)		3.5	4.2
Hardened Properties	Compressive Strength in psi	1 Day	6183	4855
		7 Day	7110	6450
		14 day	7690	6940
		28 Day	8360	7510
		56 Day	8500	8040
	Tensile Strength in psi	28 Day	660	480
	Modulus of Elasticity	28 Day	5350	5140
	Calculated Modulus of elasticity Using ACI method(psi)	28 Day	5470	5230

Table D.2.4. Concrete Mix Design, Fresh and Harden properties for Concrete III Core Slab Structures, Oklahoma City – Summer 2004			
Without Air Entrainment			
		Date:08/09/04	Date:08/12/04
Cement (PCY)		900	902.5
Slag(PCY)		100	100
Coarse Agg. (PCY)		1746.5	1718.4
Fine Agg. (PCY)		1182.7	1187.5
Water (PCY)		250.75	247.6
Glenium 3200 (fl. oz/cwt)		7	8
Glenium 3400 (fl. oz/cwt)		5.43	1.6
w/cm		0.251	0.247
Concrete Temperature (ºF)		109	82
Slump (in.)		8.5	10.5
Unit Weight (pcf)		151.1	151.1
Air Content (%)		1.9	1.4
Moisture Content of Rock (%)		1.0	0.6
Moisture Content of Sand (%)		4.5	4.2
Compressive Strength in psi	1 Day	9710	9150
	7 Day	11,630	11,550
	14 day	12,320	12,680
	28 Day	12,650	12,770
	56 Day	14,470	14,610
Tensile Strength in psi	28 Day	870	900
Modulus of Elasticity	28 Day	6870	7180
Calculated Modulus of elasticity Using ACI method(psi)	28 Day	7370	7410

Table D.3.1 CoresLab Structures Concrete Mix Design, Fresh and Harden properties for Concrete I

			Without Air Entrainment – Spring 2005
			Date:03/15/05
Mix Proportions	Cement (PCY)		800
	Coarse Agg. (PCY)		1713.3
	Fine Agg. (PCY)		1215.3
	Water (PCY)		300.55
	Glenium 3400 (fl. oz/cwt)		5
	w/cm		0.376
Fresh Properties	Concrete Temperature (°F)		58
	Slump (in.)		9
	Unit Weight (pcy)		148.12
	Air Content (%)		2
Hardened Properties	Compressive Strength in psi	1 Day	5492
		14 day	7260
		28 Day	8560
		56 Day	9840
	Tensile strength in psi	28 Day	610

Table D.3.2 CoresLab Structures Concrete Mix Design, Fresh and Harden properties for Concrete I

			Without Air Entrainment – Spring 2005
			Date:03/17/05
Mix Proportions	Cement (PCY)		800.8
	Coarse Agg. (PCY)		1718.3
	Fine Agg. (PCY)		1227.1
	Water (PCY)		303.7
	Glenium 3400 (fl. oz/cwt)		5
	w/cm		0.379
Fresh Properties	Concrete Temperature (°F)		64
	Slump (in.)		8.25
	Unit Weight (pcy)		148.12
	Air Content (%)		2.8
Hardened Properties	Compressive Strength in psi	1 Day	5810
		14 day	7860
		28 Day	8750
		56 Day	9350
	Tensile strength in psi	28 Day	510

Table D.3.3 CoresLab Structures Concrete Mix Design, Fresh and Harden properties for Concrete I

		Without Air Entrainment – Spring 2005	
			Date:03/22/05
Mix Proportions	Cement (PCY)		801.4
	Coarse Agg. (PCY)		1704.6
	Fine Agg. (PCY)		1211.44
	Water (PCY)		303.34
	Glenium 3400 (fl. oz/cwt)		5
	w/cm		0.380
Fresh Properties	Concrete Temperature (ºF)		60
	Slump (in.)		5
	Unit Weight (pcy)		147.5
	Air Content (%)		4.1
Hardened Properties	Compressive Strength in psi	1 Day	4381
		7 Day	6872
		14 day	7620
		28 Day	8450
		56 Day	8990
	Tensile strength in psi	28 Day	790

Table D.3.4 CoresLab Structures Concrete Mix Design, Fresh and Harden properties for Concrete III

		Without Air Entrainment – Spring 2005	
			Date:04/15/05
Mix Proportions	Cement (PCY)		906.7
	Slag(PCY)		106.7
	Coarse Agg. (PCY)		1760
	Fine Agg. (PCY)		1182.8
	Water (PCY)		217.79
	Glenium 3200 (fl. oz/cwt)		2.25
	Glenium 3400 (fl. oz/cwt)		5
	w/cm		0.215
Fresh Properties	Concrete Temperature (ºF)		58
	Slump (in.)		11.25
	Unit Weight (pcy)		150.88
	Air Content (%)		0.75
Hardened Properties	Compressive Strength in psi	1 Day	8,225
		7 Day	12,975
		14 day	13877
		28 Day	13790
		56 Day	14160
	Tensile Strength in psi	28 Day	880

Table D.3.5 CoresLab Structures Concrete Mix Design, Fresh and Harden properties for Concrete III

			Without Air Entrainment – Spring 2005
			Date:03/17/05
Mix Proportions	Cement (PCY)		910
	Slag(PCY)		100
	Coarse Agg. (PCY)		1758.3
	Fine Agg. (PCY)		1188.11
	Water (PCY)		255.13
	Glenium 3200 (fl. oz/cwt)		7
	Glenium 3400 (fl. oz/cwt)		4.9
	w/cm		0.253
Fresh Properties	Concrete Temperature (ºF)		64
	Slump (in.)		10
	Unit Weight (pcy)		150.8
	Air Content (%)		3.3
Hardened Properties	Compressive Strength in psi	1 Day	7,615
		7 Day	9,120
		14 day	10980
		28 Day	12830
		56 Day	13490
	Tensile Strength in psi	28 Day	860

Table D.3.6 CoresLab Structures Concrete Mix Design, Fresh and Harden properties for Concrete III			
	Without Air Entrainment – Spring 2005		
			Date:04/12/05
Mix Proportions	Cement (PCY)		916.7
	Slag(PCY)		106.7
	Coarse Agg. (PCY)		1768.7
	Fine Agg. (PCY)		1139.4
	Water (PCY)		244.1
	Glenium 3200 (fl. oz/cwt)		7
	Glenium 3400 (fl. oz/cwt)		5.9
	w/cm		0.239
Fresh Properties	Concrete Temperature (ºF)		63
	Slump (in.)		10.25
	Unit Weight (pcy)		151.88
	Air Content (%)		2.5
Hardened Properties	Compressive Strength in psi	1 Day	10,480
		7 Day	12,530
		14 day	14090
		28 Day	15050
		56 Day	14990
	Tensile Strength in psi	28 Day	870

Table D.3.7 CoresLab Structures Concrete Mix Design, Fresh and Harden properties for Concrete III

			Without Air Entrainment – Spring 2005
			Date:04/12/05
Mix Proportions	Cement (PCY)		910
	Slag(PCY)		106.7
	Coarse Agg. (PCY)		1768.7
	Fine Agg. (PCY)		1152.3
	Water (PCY)		244.5
	Glenium 3200 (fl. oz/cwt)		7
	Glenium 3400 (fl. oz/cwt)		5.9
	w/cm		0.240
Fresh Properties	Concrete Temperature (ºF)		63
	Slump (in.)		10.25
	Unit Weight (pcy)		153.39
	Air Content (%)		1.4
Hardened Properties	Compressive Strength in psi	1 Day	10,590
		7 Day	12,830
		14 day	14180
		28 Day	13190
		56 Day	14930
	Tensile Strength in psi	28 Day	760

Table D.4.1- Trail Mix Design, Fresh and Harden 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(ksi)	1 Day	5495
		28 Day	5755
	Calculated Modulus of elasticity using ACI method(ksi)	1 Day	4640
		28 Day	5615

Table D.4.2- Trail Mix Design, Fresh and Harden 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 ksi	1 Day	4780
		28 Day	6120
	Calculated Modulus of elasticity	1 Day	4690
	using ACI method in ksi	28 Day	5610

Table D.4.3- Trail Mix Design, Fresh and Harden 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		0.30
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 ksi	1 Day	5880
		28 Day	7140
	Calculated Modulus of elasticity using ACI method in ksi	1 Day	5980
		28 Day	7100

Table D.4.4-Trial Mix Designs, Fresh and Harden properties for Concrete III

OSU Lab, With No Air Entrainment

			6/7/2004	6/8/2004	6/9/2004	6/10/2004	6/11/2004	6/12/2004	6/14/2004	6/16/2004
Mix Proportions	Cement (PCY)		900	900	1000	800	900	1000	900	900
	10 % Fly Ash (PCY)		_	100	_	_	_	_	100	_
	10 % Slag (PCY)		100	_	_	_	100	_	_	100
	20 % Slag (PCY)		_	_	_	200	_	_	_	_
	Coarse Agg. (PCY)		1800	1800	1800	1800	1800	1800	1800	1800
	Fine Agg. (PCY)		1141.7	1141.7	1141.7	1141.7	1188.6	1194.3	1163.4	1188.6
	Water (PCY)		260	260	260	260	240	240	240	240
	Glenium 3030NS (fl. oz/cwt)		6.5	6.5	6.5	6.5	30	24	22	22
	Glenium 3200HES (fl. oz/cwt)		6.92	7	6.92	6.92	7	7	7	7
	Polyheed 997WR (fl.oz/cwt)		3	3	3	3	3	3	3	3
	w/cm		0.260	0.26	0.26	0.26	0.24	0.24	0.24	0.24
Fresh Properties	Air Temperature (ºF)		73	77	90	90	90	90	77	82
	Relative Air Humidity (%)		86	64	84	85	85	85	95	95
	Concrete Temperature (ºF)		85	90	85	85	86	90	90	90
	Slump (in.)		7.5	8.5	8.4	3	10	9	10	9.5
	Unit Weight (pcf)		153.80	151.60	157.70	154.68	159.68	158.68	159.70	157.70
	Air Content (%)		2.5	3	2.4	2.8	1.3	2.3	2.3	2.4
Hardened Properties	Compressive Strength in psi	1 Day	10,500	10,550	11,000	9890	12,080	13,190	10,850	11,150
		7 Day	12,890	13,570	13,460	13,040	14,330	15,890	14,340	13,850
		28 Day	14,030	14,850	14,660	14,170	16,900	16,480	16,570	16,210
		56 Day	14,810	15,880	15,200	14,570	16,960	16,620	16,720	17,440

Table D.5.1. Trial Batches made at OSU laboratory and materials from Coreslab Structures

		C-I			C-IA		
		7/8/2004	7/20/2004	7/27/2004	7/8/2004	7/20/2004	7/27/2004
Mix Proportions	Cement (PCY)	800	800	800	800	800	800
	Coarse Agg. (PCY)	1800	1800	1800	1800	1800	1800
	Fine Agg. (PCY)	1148	1191	1191	1137	1140	1140
	Water (PCY)	288	272	272	225	224	224
	Glenium 3030NS (fl. oz/cwt)	8	8	8	18	18	18
	MB-AE 90 (fl.oz/cwt)	3	_	_	3	2.5	_
	Polyheed 997 (fl.oz/cwt)	_	3	_	2.5	3	_
	w/cm	0.36	0.34	0.34	0.28	0.28	0.28
Fresh Properties	Air Temperature (ºF)	_	79	_	_	79	_
	Relative Air Humidity (%)	_	72	_	_	72	_
	Concrete Temperature (ºF)	_	98	_	_	98	_
	Slump (in.)	6.5	9.25	4.0	4.5	9.75	10
	Unit Weight (pcf)	149.50	145.20	150.88	150.50	145.12	154.12
	Air Content (%)	1.4	5.0	2.7	1.4	6.1	1.9
Compressive Strength in psi	1 Day	5165	6190	_	6220	6320	_
Calculated unit weight(PCF)		149.48	150.48		146.74	146.81	
Required Air content(%)		2	2		6	6	

Table D.5.2. Trial Batches made at OSU laboratory and materials from Coreslab Structures

			C-II		C-III		
			7/8/2004	7/20/2004	7/8/2004	7/20/2004	8/5/2004
Mix Proportions	Cement (PCY)		800	800	900	900	900
	Slag(pcy)		_	_	100	100	100
	Coarse Agg. (PCY)		1800	1800	1800	1800	1700
	Fine Agg. (PCY)		1270	1319	1102	1102	1200
	Water (PCY)		240	224	240	240	240
	Glenium 3030NS (fl. oz/cwt)		22	22	20	20	7
	Glenium 3400 (fl. oz/cwt)		_	_	7	7	13
	Polyheed 997 (fl.oz/cwt)		3	3	3	3	_
	w/cm		0.3	0.28	0.24	0.24	0.24
Fresh Properties	Air Temperature (ºF)		_	79	_	79	75
	Relative Air Humidity (%)		_	72	_	72	83
	Concrete Temperature (ºF)		_	98	_	99	96
	Slump (in.)		9.5	10	10.0	10.0	9.0
	Unit Weight (pcf)		154.00	151.92	156.60	154.28	152.76
	Air Content (%)		2.5	2.5	1.4	2.4	2.4
Compressive Strength in psi		1 Day	7630	7650	8,920	10,200	11,240
Calculated unit weight(PCF)			152.22	153.44	153.41	153.41	153.33
Required Air content(%)			2	2	2	2	2

Table D.6.1. Concrete Mix design, fresh and Hardened Properties for NASP Pull-Out Tests

Concrete C-N

	Mix Proportions		C-N Date: 08/03/05	C-N Date: 02/15/05	C-N Date: 08/03/05	C-N Date: 08/10/05	C-N Date: 09/06/05
Mix Proportions	Cement (PCY)		650	650	650	650	650
	Coarse Agg. (PCY)		1800	1800	1800	1800	1800
	Fine Agg. (PCY)		1259	1243	1243	1243	1300
	Water (PCY)		292	298	298	298	276
	Glenium 3400 (fl. oz/cwt)		8	8	8	8	8
	w/cm		0.45	0.46	0.460	0.46	0.425
	Air Temperature (ºF)		78	82	79	77	73
	Relative Humidity(%)		22	24	72	28	76
Fresh Properties	Concrete Temperature (ºF)		71	75	80	81	76
	Slump (in.)		10	10	8	8.25	10.5
	Unit Weight (pcy)		147.8	146.8	141.8	147.8	145.8
	Air Content (%)		4.5	2.5	5	2.9	3.9
Hardened Properties	Compressive Strength in psi	1 Day	4730	4560	2230	3485	4550

Table D.6.1. Concrete Mix design, fresh and Hardened Properties for NASP Pull-Out Tests

Concrete C-N							
Mix Proportions			C-N Date: 08/03/05	C-N Date: 02/15/05	C-N Date: 08/03/05	C-N Date: 08/10/05	C-N Date: 09/06/05
Mix Proportions	Cement (PCY)		650	650	650	650	650
	Coarse Agg. (PCY)		1800	1800	1800	1800	1800
	Fine Agg. (PCY)		1259	1243	1243	1243	1300
	Water (PCY)		292	298	298	298	276
	Glenium 3400 (fl. oz/cwt)		8	8	8	8	8
	w/cm		0.45	0.46	0.460	0.46	0.425
	Air Temperature (ºF)		78	82	79	77	73
	Relative Humidity(%)		22	24	72	28	76
Fresh Properties	Concrete Temperature (ºF)		71	75	80	81	76
	Slump (in.)		10	10	8	8.25	10.5
	Unit Weight (pcy)		147.8	146.8	141.8	147.8	145.8
	Air Content (%)		4.5	2.5	5	2.9	3.9
Hardened Properties	Compressive Strength in psi	1 Day	4730	4560	2230	3485	4550

Table D.6.2 Concrete Mix design, fresh and Hardened Properties for NASP Pull-Out Tests							
Concrete C-I							
Mix Proportions			C-I	C-I	C-I	C-I	C-I
			Date: 02/07/05	Date: 02/17/05	Date: 08/12/05	Date: 08/29/05	Date: 09/09/09
Mix Proportions	Cement (PCY)		800	800	800	800	800
	Coarse Agg. (PCY)		1800	1800	1800	1800	1800
	Fine Agg. (PCY)		1144	1102	1060	1102	1102
	Water (PCY)		288	304	320	304	304
	Glenium 3400 (fl. oz/cwt)		8	16	8	8	8
	w/cm		0.36	0.38	0.40	0.38	0.38
	Air Temperature (ºF)		77	84	77	81	91
	Relative Humidity (%)		22	21	28	64	21
Fresh Properties	Concrete Temperature (ºF)		72	73	80	81	82
	Slump (in.)		9.5	10	10.25	10	10
	Unit Weight (pcy)		147.8	151.8	146.8	145.8	147.8
	Air Content (%)		3	1.5	1.4	1.0	2.4
Hardened Properties	Compressive Strength in psi	1 Day	7190	7405	5490	4965	6940

Table D.6.3.Concrete Mix design, fresh and Hardened Properties for NASP Pull-Out Tests

Concrete C-II

Mix Proportions		C-II	C-II	C-II	C-II	C-II	C-II
		Date:02/09/05	Date:02/11/05	Date:02/16/05	Date:08/12/05	Date:08/30/05	Date:09/08/05
Cement (PCY)		800	800	800	800	800	800
Coarse Agg. (PCY)		1800	1800	1800	1800	1800	1800
Fine Agg. (PCY)		1270	1270	1234	1230	1102	1314
Water (PCY)		240	240	298	256	304	224
Glenium 3400 (fl. oz/cwt)		16	16	8	8	8	8
w/cm		0.30	0.30	0.46	0.32	0.38	0.28
Air Temperature (ºF)		66	72	82	81	91	81
Relative Humidity (%)		25	24	24	62	21	58
Concrete Temperature (ºF)		70	70	70	80	82	82
Slump (in.)		8	9.75	9.5	6	10	8
Unit Weight (pcy)		151.8	151.8	152.8	153.8	147.8	151.8
Air Content (%)		2.7	0.8	1.0	3.0	2.4	4.0
Compressive Strength in psi	1 Day	9780	8480	8420	7270	6940	8790

Table D.6.4.Concrete Mix design, fresh and Hardened Properties for NASP Pull-Out Tests, Concrete C-II

			C-III	C-III	C-III	C-IIII
			Date: 02/17/05	Date: 08/24/05	Date: 08/29/05	Date: 09/08/05
Mix Proportions	Cement (PCY)		900	900	900	900
	Slag(PCY)		100	100	100	100
	Coarse Agg. (PCY)		1800	1800	1800	1800
	Fine Agg. (PCY)		1048	1097	1110	1110
	Water (PCY)		260	240	235	235
	Glenium 3400 (fl. oz/cwt)		18	18	18	18
	Glenium 3200 (fl. oz/cwt)		7	7	7	7
	Polyheed 997 (fl. oz/cwt)		3	3	3	3
	w/cm		0.260	0.24	0.235	0.235
Fresh Properties	Air Temperature (ºF)		84	73	81	79
	Relative Humidity(%)		21	72	52	62
	Concrete Temperature (ºF)		78	83	81	83
	Slump (in.)		10.5	8.5	10	8
	Unit Weight (pcy)		156.8	154.8	153.8	158.8
	Air Content (%)		0.8	2.2	2.5	2.0
	Compressive Strength in psi	9,860	4,560		10,340	11,640

Vita

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