RESEARCH AND TESTING AGREEMENT

THIS RESEARCH AND TESTING AGREEMENT (the “Agreement”), effective as of the 8th day of August, 2011 (the “Effective Date”), is by and between Prestressed Concrete Institute, an Illinois not-for-profit corporation located at 200 West Adams Street, Suite 2100, Chicago, IL 60606 (hereinafter referred to as "PCI") and Kansas State University, a public institution of higher education organized under the laws of the State of Kansas, located at 2 Fairchild Hall, Manhattan, KS 66506-1103 (hereinafter referred to as "University").

In consideration of the premises, the mutual covenants herein contained and intending to be legally bound, the parties hereto agree as follows:

Article 1 – Definitions

1.1 "Project" shall mean the performance of the scope work as defined in the research proposal entitled Determination of Acceptance Criteria for Prestressing Strand in Pretensioned Applications and dated May 6, 2011. The scope of work is incorporated herein by reference as set forth in full in Attachment A.

1.2 "Agreement Term" is from the Effective Date through March 1, 2014

1.3 “Principal Investigator” shall mean the individual(s) identified as such in the research proposal for Project, who is/are the University faculty and/or staff member(s) responsible for supervision and administration of the Project.

1.4 “Intellectual Property” shall mean individually and collectively all inventions, improvements, copyrights, patents, proprietary information or discoveries that are conceived or made (i) by University or (ii) jointly by PCI and University in performance of Project.

1.5 “Report” shall mean the periodic or final summary of work performed by University related to the Project.

1.6 “Material Breach” shall mean any event, situation, or condition which causes the Project to be significantly modified, delayed or cancelled. It may also mean any situation in which the Project results may be published or disclosed to parties in a way that is contrary to the terms and conditions contained in this Agreement.

1.7 “Completion of Work” shall mean the completion of goals, objectives and other measurements as defined in Attachment A.

1.8 “Acceptance of Final Paper” shall mean the acceptance by PCI of the results of the Project in its sole discretion.
Article 2 – Conduct of Project

2.1 University shall use reasonable efforts to commence the Project promptly after the Effective Date.

2.2 In the event that the Principal Investigator becomes unable or unwilling to continue Project, and a mutually acceptable substitution is not available, University and/or PCI shall have the option to terminate said Project, subject to the provisions of Article 8, by giving written notice to the other party of such termination.

2.3 PCI shall promptly provide University with such information or documents of whatever form or nature, or undertake such actions, as University may reasonably require in order to conduct the Project.

Article 3 - Reports and Conferences

3.1 Project reports will be provided by University to PCI as set forth in the Project proposal and a final report will be submitted by University at the conclusion of the Agreement Term or earlier termination of this Agreement.

3.2 PCI shall have the right to reproduce, publish, and disseminate any written reports or other materials delivered to PCI by the University pursuant to this Agreement as set deliverables specified in Attachment A. Ownership and copyright for such reports or other deliverables shall vest in PCI.

3.3 During the Agreement Term, representatives of University will meet with representatives of PCI at such reasonable times and places as set forth in the Project proposal to discuss the progress and results of, as well as ongoing plans or agreed upon changes in the Project.

Article 4 – Compensation and Expenses

4.1 It is agreed to and understood by the parties hereto that except as may be otherwise agreed by the parties in writing, total costs to PCI for the Project hereunder shall not exceed the sum of Two hundred ninety five thousand five hundred thirty dollars ($295,530.00). This is a fixed-price award. Payment to University shall be made by PCI according to the following schedule:

25% of costs of Tasks 1 through 8 upon execution of contract
90% of costs of Tasks 1 through 8 upon submittal of Task 8 draft report
25% of costs of Tasks 9 through 11 upon notice to proceed with Task 9
90% of costs of Tasks 9 through 11 upon submittal of Task 11 draft report
25% of costs of Tasks 12 through 13 upon notice to proceed with Task 12
90% of costs of Tasks 12 through 13 upon submittal of Task 13 draft report
100% of total program authorized costs upon final acceptance of Task 14 final
report and Task 15 summary paper

4.2 University shall retain title to all equipment, materials, and supplies purchased and/or fabricated by it with funds provided by PCI under this Agreement unless otherwise stated in Attachment A.

Article 5 – Publicity and Use of Name

5.1 Neither party shall be allowed to use the name of the other party or its representatives, in any advertising regarding the Project without the prior written consent of the other party. The University shall identify PCI as the sponsor in any publicity, advertising or news release regarding the Project. PCI shall be allowed to use the name of the University and the Principal Investigator for announcements of the project and for project updates to the PCI membership and such announcements and updates shall not be considered advertising.

Article 6 - Publications

6.1 University may catalog and place reports of the Project in the University library and may issue publications based on the Project. The Project research results not proprietary to PCI, may be used in University research and education programs. University shall provide PCI the opportunity to review any report or publication and will, upon the request of PCI, remove any PCI confidential information or withhold publication for up to sixty (60) days.

Article 7 – Intellectual Property

7.1 Title to all Intellectual Property developed in the course of performance of the Project, whether or not protectable by patent, trade secret, or copyright, shall reside in the party whose personnel conceived the subject matter and diligently pursued reducing the subject matter to practice, and such party may perfect legal protection therein in its own name and at its own expense. Jointly made or generated Intellectual Property shall be jointly owned by the parties unless otherwise agreed in writing.

7.2 The parties agree to disclose to each other, in writing, each and every invention which may be patentable or otherwise protectable under the United States Patent laws in Title 35, United States Code. The parties acknowledge that they will disclose inventions to each other and the awarding agency within two (2) months after their respective inventor(s) first disclose the invention in writing to the person(s) responsible for patent matters of the disclosing party. All written disclosures of such inventions shall contain sufficient detail of the invention, identification of any statutory bars, and shall be marked confidential, in accordance with 35 U.S.C. 205.

7.3 PCI shall receive the first option to negotiate for a license to commercialize the Intellectual Property of University, subject to any rights of the Government therein. PCI
is hereby granted an exclusive option to negotiate the terms for a license to Intellectual Property of University, for an initial option period of three (3) months after such invention has been reported to PCI.

7.4 The terms of subsequent licensing agreements for University owned and/or jointly owned Intellectual Property will be negotiated in good faith and by mutual agreement by the parties to this Agreement.

Article 8 – Agreement Term and Termination

8.1 This Agreement shall become effective upon the Effective Date and shall continue in effect for the Agreement Term unless sooner terminated in accordance with the provisions of this Article. The parties hereto may, however, extend the Agreement Term for additional periods as desired under mutually agreeable terms and conditions which the parties shall reduce to writing and sign.

8.2 Either party may terminate this Agreement upon thirty (30) days prior written notice in the event of a Material Breach by the other party of any term or provision hereof, provided such breach remains uncured at the end of said thirty (30) day period. Such notice of a breach shall include a reasonable description of the facts surrounding the alleged breach and a proposed course of action to cure said breach, if applicable.

8.3 PCI shall pay the University any costs which have accrued or been encumbered up to the actual date of termination under this Article and shall not be relieved of the obligation to pay such costs because of termination under this Article.

8.4 Termination of this Agreement by either party for any reason shall not affect the rights and obligations of the parties accrued prior to the effective date of termination of this Agreement.

8.5 No termination or expiration of this Agreement, however effectuated, shall release the parties hereto from their respective rights and obligations under Articles 3, 5, 6, 7, 8, 9, 10, 12, 13, 16, and 17, which such Articles shall survive in their entirety any termination or expiration of this Agreement.

Article 9 - Arbitration

9.1 In the event of any conflict or claim arising out of or relating to any provision of this Agreement or breach thereof, the parties shall make a good faith effort to resolve such conflict amicably between themselves, and if thereby failing, resolution by submission to mediation under the Construction Industry Mediation Rules of the American Arbitration Association, and if thereby failing, attempt resolution by non-binding arbitration under the Construction Industry Arbitration Rules of the American Arbitration Association. The location of any mediation or arbitration shall be mutually agreeable and shall not provide for the convenience of one party over the other, or shall be as determined by a
court having competent jurisdiction.

**Article 10 - Disclaimer of Warranties**

10.1 University disclaims any and all warranties, both express and implied, with respect to the services to be performed hereunder and any deliverables resulting therefrom, including their condition, conformity to any representation or description, the existence of any latent or patent defects therein, and their merchantability or fitness for a particular use or purpose.

**Article 11 - Insurance**

11.1 University shall maintain its coverage under the State of Kansas self-insurance plan for the duration of this Agreement. Notwithstanding any provision contained herein, University, and its employees, agents, representatives, consultants and lower-tier subcontractors and suppliers, are not insured by PCI, and are not covered under any policy of insurance that PCI has obtained or has in place.

University is an agency of the State of Kansas and thus can provide only the bond and insurance coverage permitted by Kansas statutes and regulations as follows:

**Insurance**

A. Workmen's compensation insurance is provided in accordance with Kansas statutes 44-501 et seq.

B. The State of Kansas insurance policy provides the following coverages for all State of Kansas owned self-propelled vehicles, such as cars; station wagons; buses; trucks; trailers; graders; tractors; scooters; motorcycles; mowers; forklifts; farm equipment and other self-propelled equipment.

<table>
<thead>
<tr>
<th>Coverage</th>
<th>Limitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Liability for Personal Injury</td>
<td>Amount of injury not to exceed $250,000 per person or $500,000 per accident.</td>
</tr>
<tr>
<td>2. Liability for Property Damage</td>
<td>Amount of damage not to exceed $50,000 per accident.</td>
</tr>
<tr>
<td>3. Medical Expenses</td>
<td>Amount of medical expenses not to exceed $5,000 per person.</td>
</tr>
<tr>
<td>4. Injury Caused by Uninsured Motorist</td>
<td>Amount of injury not to exceed $25,000 per person or $50,000 per accident. Covers only cars, station wagons, buses, pickup trucks, heavy-duty trucks, and certain other vehicles.</td>
</tr>
</tbody>
</table>
C. All other personal injury, property damage or other claims from Kansas State University employees or others arising out of or in connection with this project shall be determined in accordance with the terms of the Kansas Tort Claims Act, K.S.A. 75-6101 et seq. Under the Tort Claims Act, the State of Kansas has assumed liability for the negligent or wrongful acts and omissions of its employees and agents acting within their scope of responsibilities. The liability for claims within the scope of the Act may not exceed Five Hundred Thousand Dollars ($500,000) per occurrence.

11.2 Prior to commencement of the Project pursuant to this Agreement, University shall furnish PCI with a Certificate of Insurance Coverage letter.

Article 12 – Independent Contractor

12.1 In the conduct of the Project hereunder, University and PCI are and shall remain independent contractors and nothing herein shall be construed to create a partnership, agency or joint venture relationship between the parties. Neither party is authorized or empowered to act as agent for the other for any purpose and shall not on behalf of the other enter into any contract, warranty or representation as to any matter. Neither party shall be bound by the acts or conduct of the other. Each party shall be responsible for wages, hours, and conditions of employment of its personnel during the term of, and under, this Agreement.

Article 13 - Governing Law

13.1 This Agreement shall be governed by and construed in accordance with the laws of the State of Kansas.

Article 14 - Notices, Invoices, and Payments

14.1 Notices, invoices, communications and payments hereunder shall be deemed made if given in writing and addressed to the party to receive such notice, invoice, communication or payment at the address given below, or such other address as may hereafter be designated by notice in writing:

If to PCI:  
Roger Becker  
Precast/Prestressed Concrete Institute  
200 West Adams St.  
Suite 2100  
Chicago, IL 60606

If to University:  
Technical  
Kyle Riding  
Department of Civil Engineering
Article 15 - Force Majeure

15.1 In the event that either party is unable, wholly or in part, to carry out its obligations under this Agreement by reason of acts of God or public enemy, wars, insurrections, civil disturbances, epidemics, labor disputes, failure of government approval, accidents, failure of utilities, material shortages, fires, storms, floods and any other causes, whether of the kind enumerated herein or otherwise, not within the control of the party unable to perform, then the obligations of this Agreement shall be suspended during the reasonable continuance of any inability so caused.

Article 16 – Non-Discrimination

16.1 University and PCI shall not discriminate against any employee or applicant for employment because of race, color, sex, sexual preference, age, religion, national origin, disability, or because he or she is a disabled veteran or veteran of the Vietnam Era.

Article 17 - Assignment

17.1 This Agreement shall not be assigned by either party without the prior written consent of the other party hereto. This Agreement shall be binding upon and inure to the benefit of the respective successors and permitted assigns of the parties.

Article 18 - Agreement Modification

18.1 Any agreement to change the terms of this Agreement in any way shall be valid only if the change is made in writing and signed by a duly authorized representative of each party hereto.

Article 19 - Entire Agreement

19.1 This Agreement constitutes and expresses the entire agreement of the parties hereto with reference to the subject matter hereof, with all prior promises, undertakings, representations, agreements, understandings and arrangements relative thereto having been herein merged into this Agreement
IN WITNESS WHEREOF the parties have caused this Agreement to be executed, each by its duly authorized representative, to be effective as of the Effective Date defined herein.

UNIVERSITY:

By: ______________________________
   Paul R. Lowe

Title: Assistant Vice President for Research

Date: ____________________________

PRESTRESSED CONCRETE INSTITUTE:

By: ______________________________

Title: ______________________________

Date: ____________________________
Attachment A
DETERMINATION OF ACCEPTANCE CRITERIA FOR PRESTRESSING STRAND IN PRETENSIONED APPLICATIONS

Project Proposal

Submitted by:

Kansas State University
University Transportation Center

May 6, 2011

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**PROJECT SUMMARY**

The objective of this research project is to quantify the repeatability and reproducibility of the Standard Test Method for the Bond of Prestressing Strands (STSB) test method being considered by ASTM. In Phase 1, testing will be performed in order to determine if the test is sufficiently rugged to ensure reproducibility of test results between different laboratories, and possible modifications suggested if shown by testing that these would lead to increased reproducibility. The reproducibility of the test will then be established through Round Robin testing. Phases II and III outlined in the proposal are geared towards determining an appropriate threshold acceptance value for prestressing steel strand to ensure reliable bonding performance in concrete beams. The key to being able to set a reasonable threshold value with a high confidence level is to maximize the repeatability and reproducibility of the test.

**WORK PLAN**

**Phase I: Determination of Standard Test Method for the Bond of Prestressing Strands Precision Statement**

**TASK 1: LITERATURE REVIEW**

A thorough literature review will be conducted of previous studies that were used in the development of the STSB test, including variations in the methods and materials used and the resulting changes in measured pullout values. The researchers will contact the PI’s and former graduate students at other universities who have conducted the STSB to get additional feedback about potential difficulties in meeting the current test parameters (time, strength, flow, loading rate, etc.). Data from these research programs will be examined regarding the applicability of a threshold acceptance value, especially those that performed both the STSB test and beam tests where the transfer length has been measured. The data obtained in the literature review will be used to guide the ruggedness testing in Task 3.

In addition to reviewing published literature, the PI’s will contact researchers who are currently conducting research that involves STSB testing to identify any difficulties that other researchers are currently having with the test and to possibly obtain additional information about un-published correlations of the STSB test with structural performance. For example, the Missouri Institute of Science and Technology was recently awarded a Jenny Fellowship at the 2011 PCI Committee Days for work that will include correlation of the STSB test with members with different concrete mixtures. The PI’s plan to have numerous dialogues with the MIST researchers and plan to coordinate activities whenever possible.

Furthermore, the statistical basis used for establishing safety criteria for reinforced and prestressed concrete members will be documented. This will include the confidence levels used for the current concrete and steel strength design criteria.

**TASK 2: PRESTRESSED STRAND SELECTION AND SAMPLE COLLECTION**

Obtaining prestressed strand that will have a pullout strength between 10,500 and 12,000 lbs will be one of the most difficult yet important aspects of the proposed work. Sample strands from all domestic strand producers will be requested and tested using the STSB test method to determine if any currently available strands have pullout values near the proposed threshold value. All of the domestic strand
producers have been contacted, and have agreed to supply strand for this study. All will provide the strand for free, however some of the producers require shipping costs (see letters). A total of $4000 is included in the budget to pay for strand requisition.

The initial screening process will involve testing two (2) strand samples from each strand plant using the STSB procedure in order to quickly identify the lowest bonding available sources. Testing 2 specimens from each source will allow the research team to quickly compare strand bond ranges using mortar from the same mortar batch. The researchers will request that the strand supplier provide these samples from a larger reel of strand which will be reserved for possible additional use in this study.

Ideally, the researchers would like to identify 3 strand sources with pullout values less than 17,500 pounds: one between 10,500 and 12,500 pounds, one between 12,500 and 15,000 pounds, and one between 15,000 and 17,500 pounds. Although strands with pullout values greater than 17,500 pounds are available in the marketplace, the PIs believe that these would perform well in most products and therefore would not be advantageous for use in this study.

The confidentiality of the strand source will be maintained, and will only be known by the PI. A minimum of 3000 ft of each of the three strand sources will be obtained, so that additional tests can be conducted on the same strand used in this study. Once a strand is ordered and received, the strand will be labeled with a strand ID, with the correlation between label and manufacturer known only to the PI. Cages to store the coiled strand will be built. The strand will be kept indoors and covered in plastic. Additionally, dehumidifiers will be placed in the storage room to minimize changes to the surface condition of the strand.

**TASK 3: RUGGEDNESS TESTING**

**MORTAR MATERIALS**

In order for the STSB to be effective as a means to distinguish between poor-bonding and good-bonding strand, the test must be repeatable and reproducible. Therefore, it stands to reason that the medium that the strand is placed in for the testing should be as consistent as possible from lab to lab. Testing done by the PIs has shown that the sand and cement used can affect the measured STSB pullout strength, as shown in Table 1.

**Table 1 - Pullout strength results from different combinations of sand and cement with the same strand source**

<table>
<thead>
<tr>
<th>Sand Source</th>
<th>Mix 1</th>
<th>Mix 2</th>
<th>Mix 3</th>
<th>Mix 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>Stresscon</td>
<td>Dolese</td>
<td>Dolese</td>
<td>Stresscon</td>
</tr>
<tr>
<td>Cement</td>
<td>Ashgrove</td>
<td>Ashgrove</td>
<td>Ashgrove</td>
<td>Monarch</td>
</tr>
<tr>
<td>Sand to Cement Ratio</td>
<td>2.27 : 1</td>
<td>1.5 : 1</td>
<td>2.0 : 1</td>
<td>2.11 : 1</td>
</tr>
<tr>
<td>w/c ratio</td>
<td>0.50</td>
<td>0.50</td>
<td>0.49</td>
<td>0.46</td>
</tr>
<tr>
<td>Mortar Flow</td>
<td>100</td>
<td>102</td>
<td>101</td>
<td>105</td>
</tr>
<tr>
<td>Avg. Load at 0.1 inches slip (pounds)</td>
<td>13,515</td>
<td>15,675</td>
<td>12,070</td>
<td>16,100</td>
</tr>
<tr>
<td>Avg. Top Settlement (inches)</td>
<td>0.20</td>
<td>0.27</td>
<td>0.25</td>
<td>0.05</td>
</tr>
</tbody>
</table>
The pullout strength values shown in Table 1 were significantly different (about 25% from the high to low value), even though both sands were natural river sands that met ASTM C 33 and the cements both met the ASTM C 150 Type III specifications. The Standard Test Method for the Bond of Prestressing Strands (STSB) only contains the requirement for the sand to meet the ASTM C 33 requirements (ASTM C 33 2003). Therefore, there exists the fundamental assumption that any sand which conforms to ASTM C33 can be used, including manufactured sands such as crushed limestone (which are included in C33). Other sand parameters besides the gradation may likely affect the pullout strength, such as the sand hardness which is mainly a function of the mineralogy and the angularity. It is expected that more angular aggregates could provide greater mechanical interlock with the strand. It is believed that the STSB test as currently written allows for too much variation in mortar materials and consequently the STSB pullout values. It is proposed to standardize the sand source and gradation for the STSB test method, eliminating one very significant source of variability.

The STSB method was developed after it was determined that tests using only paste did not give reliable results and that a mortar based test was needed. Currently, the STSB allows the cement-sand ratio to be any value as long as the strength is reached in the time specified and the flow requirements are met. This means that you could use a mixture with only 3 grains of sand in the entire mortar, and if you met the strength and flow requirements, the test would meet the STSB specification. Although using a mortar with that little sand is impractical and would make it more difficult to meet the strength time window, it illustrates the point that fixing the cement-sand ratio would only serve to reduce the variability seen and improve the test.

In this study, the PIs will use only sand from the Dolese sand plant in Guthrie, OK. The sand will be dried and sieved to a standard gradation that will be set equal to the average gradation from the Guthrie plant over a 6-month period. Additionally, a fixed sand-cement ratio will be established which gives a mortar flow of 105 ± 3 and also meets the strength window of 4500 psi to 5000 psi at 22-24 hours. The proposed mixture proportions to use for the testing and the specification will be presented to the industry advisory council for discussion and approval before proceeding to the round robin testing.

There are currently no requirements for the fineness of the Type III cement specified by ASTM C 150, just minimum mortar cube strengths, which are much lower than what is specified by the STSB test at 24 hrs. The fineness of the cement will influence both the required w/c required to achieve the desired fluidity and the bleeding rate of the mortar. Excess bleed water will tend to leak out of the canister as it wicks through the strand interstices and down the middle wire in the strand. Figure 1 shows STSB test specimens made with the same strand but with two different Type III cements which led to pore water leaking through strand interstices in specimen b, creating a top settlement of approximately 0.25 inches rather than the 0.05 inches seen in specimen a. Although it is believed that the fineness and cement chemistry can affect the pullout strength values, it is currently unknown how much of an impact the cement chemistry and fineness have on the pullout strength. As it is impractical to standardize the cement source because of variations in the cement with time, even from the same plant, it is proposed to first use the STSB on 6 different cements with different fineness and chemistries to determine if any additional limits on the cement are needed.
STSB test specimens fabricated using two different Type III cements, which resulted in a) very low settlement and b) a high amount of settlement.

**MEASUREMENT OF END-SLIP USING CENTER WIRE VS THE AVERAGE OUTER-WIRE SLIP**

STSB specifies that the pullout force be recorded when the free-end slip reaches 0.10 inches. Russell and Ramirez clearly indicate that this is measured to the center wire of the strand, as they grind the strand so that only the center wire will be measured, as shown in Figure 2. However, the PI’s have noted that the center wire can sometimes slip independently from the outer 6 wires during testing, thereby resulting in a lower pullout force (refer to Figure 3). This may be easily fixed by placing a small metal disc on top of the strand, so that the measured slip would not record independent center-wire movement. However, at least three comparison tests (3 groups of 6 specimens) should be conducted prior to making this proposed change to the test method to confirm that the pullout force for the outer 6 wires is the same as the slip of the center wire in typical cases without independent center-wire slip.

**Figure 1** – STSB test specimens fabricated using two different Type III cements, which resulted in a) very low settlement and b) a high amount of settlement

**Figure 2** – Picture of STSB strand Free-End, showing how the strands were ground to measure only the center wire displacement (B. Russell 2006)
RUGGEDNESS TESTING

Ruggedness testing will be performed according to ASTM E 1169 “Guide for Conducting Ruggedness Tests (ASTM E 1169 2007).” The ruggedness testing will determine what changes if any are needed to the proposed standard to avoid unnecessary variation in the measured pullout strength of the three selected strands.

10 tons of natural river sand will be procured for testing from the Dolese sand plant in Guthrie, OK, and kept at the Civil Infrastructure Systems Laboratory (CISL) at KSU. This is the same source used by Dr. Bruce Russell in the NASP testing program.

The STSB specimens will be placed in a curing room at 73 ± 3 °F, 100% relative humidity. The KSU moist room temperature is controlled using an American Cube Mold Moisture Room Control System that mixes hot and cold water which is then atomized with compressed air. Because the specimens are placed in a curing room having a temperature of 73 °F, the temperature inside the specimen will necessarily be higher than 73 °F because of the heat generated during the cement hydration. During recent STSB testing by RJ Peterman & Associates, Inc. the temperature of the steel cans during curing was measured to be in excess of 100°F, while the temperature of the 2” mortar cubes was less than 80°F, even though the specimens were placed in a temperature-controlled room kept at 73 ± 3 °F (23 ± 2 °C). Standardizing the mortar proportions will give similar mortar temperature histories for each test. The temperature of a seventh specimen (not used in the pullout testing but made with the same mortar and strand) will be measured to verify the consistent curing conditions from test to test. Because of their smaller size, the mortar cubes temperature will be much closer to that of the curing environment of 73 °F. Currently, no testing labs are using match curing systems for the mortar cubes. This means that depending on the actual temperature experienced in the mortar cubes, the compressive strength in the specimen could be 500-1000 psi higher than measured by the mortar cubes.
cured mortar cubes and mortar cubes made under standard curing temperatures will be tested on all specimens made and tested as part of the ruggedness testing.

Other researchers conducting the STSB test have found that the moisture content of the sand affects the consistency and quality control of the STSB values. The STSB test method does not require a particular starting moisture content, just that corrections should be made to the water content based on the sand moisture content in relation to its saturated surface dry condition. To ensure that the mortar trial batches are easily repeated during the STSB tests, the PIs will dry all sand prior to use, as this is an effective way to ensure consistency between mortar batches.

The current STSB procedure calls for mechanical vibration as specified in ASTM C 192 (ASTM C 192 2006). ASTM C 192 allows for internal or external mechanical vibration of the specimens, although internal vibration is most commonly used to prepare the specimens. It is expected that most labs testing the pullout strength would use internal vibration. ASTM C 192 does not specify a time of vibration. The time of vibration should be fixed. In the STSB PC Strand Pull-out Test Overview video by Bruce Russell and supplied to the PIs by Jon Cornelius of SUMIDEN, the average time of vibration for the 11 times that vibration was used and completely shown in the video was 3.5 seconds. The standard deviation for these vibrations was 0.57 seconds. The vibration time should be fixed to 3.5 ± 1 seconds, which is reasonable to allow for specimen consolidation, but not too large to potentially change the results.

The following variables will be investigated under the ruggedness testing:

1) Strength of mortar cubes at time of test - The strength of the mortar at testing may impact the bond strength, but the current window of 4500-5000 psi is quite small, and the PIs believe that there would be little difference in pullout values within this strength window.

One way to discern if mortar strength has a significant impact on the STSB pullout values is to review the data from the STSB Round Two series of tests that were conducted by Dr. Russell at the University of Oklahoma. These data are summarized in Figure 4. This table was generated using data obtained from pages 10, 11, 67, and 69 of the STSB Round Two Report (Russell and Paulsgrove 1999).

In the OU Series 1 tests, the average mortar strength at the time of testing was about 4220 psi (the actual value was likely less, but earlier mortar strengths are not reported for strand lots 55&56), while the average strength for Series 2 was 5160 psi. Thus, the mortar strength of Series 2 was at least 940 psi greater than for Series 1. However, there appears to be no apparent influence in the corresponding STSB pullout values at 0.10 inches of slip (See Figure 4). In fact the average pullout values for strand series A and C decreased with increasing mortar strength.
Per the RFP stipulation, the pullout strength of the strands will be tested when the mortar cubes reach 4500 psi vs. waiting until the mortar cubes reach 5000 psi to begin testing.

2) Variation in loading rate – the loading rate has been shown to influence the pullout strength in the NCHRP 603 report. Ramirez and Russell (2008) suggested keeping the loading rate below 8,000 lb/min for 0.5 in diameter strand because they felt that when the loading rate was higher, the values were significantly different. Since the test is specified as displacement controlled, it is impossible to control simultaneously the loading in terms of loading rate and displacement rate. The ability of Ramirez and Russell to maintain a lower loading rate while keeping the displacement rate constant can be explained by the inclusion of a neoprene pad between the specimen and the loading frame, as shown in Figure 5. Note, even though this neoprene pad was used by Ramirez and Russell, it is not specified in the STSB procedure. In this case, even though the testing machine may be displacing the strand at a 0.1 in/minute rate compared to the loading frame, the displacement rate of the strand compared to the encasing mortar (which is the displacement that really affects the strand pullout), will vary during the duration of the test because of the neoprene pad deformation. A new loading frame similar to that shown in Figure H2 in the STSB specification will be fabricated that is sufficiently stiff and free to rotate. As part of this task, specimens will be tested at a displacement rate of 0.12 in/min. and 0.08 in/min according to the STSB test procedure (without the neoprene pads).
Figure 5 – Figure 3.3 from NCHRP 603 report showing the placement of a Neoprene pad in between the specimen and loading frame (Ramirez and Russell 2008)

3) **Mortar flow rate** - The concrete fluidity is known to affect strand bond to concrete, as shown by higher transfer lengths in SCC (R. J. Peterman 2007). The mortar flow rate as determined by ASTM C1437 (Figure 6) is specified in the proposed standard to be between 100 and 125. This is a very large flow range which could give very different pullout strengths. Mortar flows of 100 and 125 will be tested.
By using the recommended experimental design from both Table 1 and 2 in ASTM E 1169, the two-way interactions between factors can be tested. The experimental matrix shows 8 different combinations of test factors, which will be repeated twice each to give a total of 16 sets of STSB tests to be performed. By repeating the tests twice as recommended by section 6.7 of ASTM E 1169, an estimate of the error can be made.

**Table 2 - Experimental Matrix for Pullout Strength Testing**

<table>
<thead>
<tr>
<th>Test #</th>
<th>Mortar Cube Strength (psi)</th>
<th>Loading Rate (in/min)</th>
<th>Mortar Flow Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5000</td>
<td>1.2</td>
<td>125</td>
</tr>
<tr>
<td>2</td>
<td>5000</td>
<td>1.2</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>5000</td>
<td>0.8</td>
<td>125</td>
</tr>
<tr>
<td>4</td>
<td>5000</td>
<td>0.8</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>4500</td>
<td>1.2</td>
<td>125</td>
</tr>
<tr>
<td>6</td>
<td>4500</td>
<td>1.2</td>
<td>100</td>
</tr>
<tr>
<td>7</td>
<td>4500</td>
<td>0.8</td>
<td>125</td>
</tr>
<tr>
<td>8</td>
<td>4500</td>
<td>0.8</td>
<td>100</td>
</tr>
</tbody>
</table>

Note: Each of these 8 tests will be performed twice to allow for a measure of the test error.
REPEATABILITY TESTING

After the ruggedness testing is performed, the research team in close cooperation with the Industry Advisory Board will determine if any changes are needed to the STSB standard. If any changes are needed to the STSB specification, the STSB specification will be tested for repeatability in the KSU laboratory. Six (6) identical STSB tests (each test consisting of 6 strand samples) would be conducted in order to establish the repeatability of the STSB procedure. The cost for this repeatability testing is already included in the budget as the PIs deem it to be an essential part of the ruggedness testing program.

TASK 4: INTERLABORATORY IDENTIFICATION AND WEB-BASED TRAINING

Eight laboratories, including KSU, will be identified for an interlaboratory study (ILS) of the STSB test to develop a precision and bias statement. A minimum of eight laboratories will be used based on the recommendation by ASTM E691 (2009) which states that “Under no circumstances should the final statement of precision of a test method be based on acceptable test results for each material from fewer than 6 laboratories. This would require that the ILS begin with 8 or more laboratories in order to allow for attrition.” The potential laboratories will be screened to ensure that each laboratory has adequate testing equipment, curing facilities, and personnel to conduct the STSB test. Currently, there are 6 laboratories committed to participating in the STSB interlaboratory study. These laboratories include: Kansas State University, RJ Peterman & Associates, Inc., the Kansas DOT (confirmed by Josh Welge, Engineer of Tests for KDOT), the Florida DOT (confirmed by Roger Becker), Washington State DOT (confirmed by Roger Becker), and the FHWA laboratory (confirmed by Roger Becker).

A 4 hour webinar will be developed and delivered to the laboratories involved in the ILS. The mortar mixing procedures and proportions (if any requirements are needed) will be refined during the ruggedness testing and will be fully explained in the webinar. Procedures for handling the specimens when shipped, cement and sand selection and processing, curing, and vibration techniques to use will be described. It is anticipated that the webinar will be developed using suitable software, such as for example a GOTO meeting.

TASK 5: MATERIAL DISTRIBUTION FOR ILS STUDY

Strand specimens will be cut and shipped in protected containers to prevent corrosion of the strands during shipping. The strand shipped will be labeled strand A, B, and C in order to protect the confidentiality of the source.

TASK 6: ILS STUDY PARTICIPATION AND DATA COLLECTION

Dr. Riding and Dr. Peterman will travel to each laboratory participating in the ILS for 2-3 days. It will be expected that the laboratory perform trial batches before the ILS testing. The first day will be used to check the laboratory mixtures, laboratory readiness, witness and film the mortar mixing, specimen fabrication and curing. The PIs will bring a load cell and LVDT to all participating laboratories to ensure that their load frames and LVDT are calibrated and functioning properly. During the second day, the team will film and monitor the strand pullout tests performed to ensure that the test is
adequately performed. This will allow the team to determine the likely cause of any major differences found in the tested values for one laboratory. Data from the test results will be collected from each laboratory at the conclusion of the testing and before the researchers leave the laboratory.

The ILS test data collected in Task 6 will be analyzed to determine the single operator precision and multi-laboratory precision needed for the Standard Test Method. The results will be prepared according to ASTM 670-03 and submitted to the Industry Advisory Committee.

**TASK 7: STRAND TESTING USING METHODS OUTLINED IN NCHRP REPORT 621**

The three strands will be tested using the NCHRP 621 Quality Control tests recommended in NCHRP Report 621. Although more candidate tests were tested by Osborn et al. in that study, four test methods were recommended for use as shown in Table 3 and will be performed by WJE. Samples from the three strand sources used in the round robin testing will be sent to John Lawler at WJE for testing. As confirmed through conversations with John Lawler, WJE had agreed to commit a total of $10,000 of labor to conduct and report results for these tests. An additional $5,000 is budgeted (as requested by WJE) to cover other direct costs associated with this testing. A report will be prepared and delivered to the Industry Advisory Council that compares the results from the NCHRP Report 621 quality control tests with the STSB pullout test.

**Table 3 - Strand Surface Characteristics Test Methods Recommended by NCHRP Report 621 (Osborn, Lawler and Connolly 2008)**

<table>
<thead>
<tr>
<th>Test Method</th>
<th>Recommended Quality Control Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight Loss On Ignition (LOI) of Strand</td>
<td>I</td>
</tr>
<tr>
<td>Contact Angle Measurement of Water Droplet on a Strand Surface</td>
<td>I</td>
</tr>
<tr>
<td>Change in Corrosion Potential of Strand</td>
<td>I</td>
</tr>
<tr>
<td>Organic Residue Extraction with FTIR Analysis</td>
<td>II</td>
</tr>
</tbody>
</table>

**TASK 8: DRAFT REPORT**

The PIs will keep in close contact with the Industry Advisory Committee and will schedule meetings during the same time period as the PCI conventions. A draft report will be written and delivered to the Industry Advisory Council that summarizes the work performed in Tasks 1-7, and will include conclusions that can be drawn from the testing performed about the ruggedness, repeatability and reproducibility of the Standard Test Method for the Bond of Prestressing Strands. The section of the report on the interlaboratory study will be formatted according to ASTM E 691-09 Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method and ASTM C 670-03 Preparing Precision and Bias Statements for Test Methods for Construction Materials.
Phase II: Relationship between STSB Value and Transfer Lengths from Standard Flexural Beam Tests

Task 9: Sensitivity Analysis Calculations

A sensitivity analysis will be performed numerically to determine the impact of transfer length and development length on the capacity of 8”-thick hollow-core for 11 to 32’ spans, for 12” thick hollow-core for 20 to 40’ spans, for 24 inch deep double tees for 30 to 60’ spans, and for 32” deep double tees for 44 to 80’ spans. Both normal-weight and sand-lightweight concrete will be considered in the analysis. These calculations will be performed using software developed at Kansas State University and verified by comparison with commercial software at High Concrete Structures, Inc. (Please see attached letter of support from High Concrete).

The sensitivity analysis will be used to establish the basis for recommended confidence interval targeted in the analysis of the STSB data. The tolerance interval for which a percentage of the STSB results would be below is calculated using Equation 1:

\[ TL_L = F_m - (K \cdot V \cdot F_m) \]  \hspace{1cm} \text{Equation 1}

Where \( TL_L \) is the lower limit for the confidence level, \( F_m \) is the sample mean, \( V \) is the coefficient of variation, and \( K \) is the characteristic value for determining the confidence at a given fractal. The confidence level is how certain you are that your sample set is representative of the overall population of test results, and the fractal is the percent of values that you wish to be below the lower tolerance limit. For example, a 90% confidence level of 5% fractal would mean that you are 90% confident that 19 out of 20 STSB test values would be above \( TL_L \).

\( K \) is dependent on both the percent confidence level chosen, the percent fractal chosen, and the number of tests in the dataset. This is important because more tests mean that a smaller factor of safety is needed to have the same confidence that your dataset is representative of the overall data population. Table 4 shows the \( K \) values for 90% confidence of having either the 5% or 10% fractal, showing the penalty that is paid for a higher STSB threshold value for a lower fractal level. If, by analyses, the sensitivity of the overall member capacity is deemed to be marginally sensitive to increases in transfer and development length, then a 90% confidence level for a 10% fractal will be used for determining the STSB threshold value (refer to Task 10 description). Note, ACI Committee 214 has chosen to use a 10% fractal for estimating the in-situ concrete strength from field cores (ACI 214.4 2010).

<table>
<thead>
<tr>
<th>Number of Samples in Dataset</th>
<th>90% confidence on 5% fractal</th>
<th>90% confidence on 10% fractal</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>3.96</td>
<td>3.19</td>
</tr>
<tr>
<td>6</td>
<td>3.09</td>
<td>2.49</td>
</tr>
<tr>
<td>8</td>
<td>2.76</td>
<td>2.22</td>
</tr>
<tr>
<td>10</td>
<td>2.57</td>
<td>2.06</td>
</tr>
<tr>
<td>15</td>
<td>2.33</td>
<td>1.87</td>
</tr>
<tr>
<td>20</td>
<td>2.21</td>
<td>1.78</td>
</tr>
</tbody>
</table>
However, if these analyses show that the overall member capacity is highly sensitive to slight variations in the transfer and development length, then a higher (5% fractal) threshold should be applied. The procedure used by Committee 214 is that “first, a lower bound estimate on the average in-place strength is determined from core data. Then the 10% fractal of the in-place strength, which is equivalent to the specified strength is obtained (ACI 214.4 2010).”

A similar procedure will be used by the PIs to establish the threshold criteria for the STSB test. First, an upper-bound estimate of the average transfer length and development length data will be obtained from the beam tests in Task 10. Next, these data will be compared to the lower confidence limit for the STSB values determined through Round Robin testing, with the threshold (either 5% or 10% fractal based on sensitivity analysis) then determined as described in Task 10. Since the round robin testing will have eight labs (at least 6 after attrition), the K value used for establishing the STSB threshold could range from 2.22 to 3.09, depending on the number of successful labs and the fractal chosen. The determination as to what an acceptable margin of safety should be for increased transfer and development lengths against a bond failure is subjective. For this reason, the PIs will make a recommendation to the Industry Advisory Board as to whether the 5% or 10% fractal should be used, with the final decision made by the Industry Advisory Board.

**Research Team Philosophy**

The reported transfer lengths associated with a prestressing tendon can be highly variable, and are largest for members with sudden release of prestress force. The PI’s believe that, for a given combination of strand and concrete, a significant component of this variability comes from the inherent difficulty and human error associated with the measurement process (both end-slip measurements and by surface strain measurement using a de-mountable mechanical (DEMEC) gage).

Since the measurement of strand end-slip for flame-cut members is much more difficult and prone to human error than for saw-cut members, it is proposed that the de-tensioning method used for the 6 ½” x 12” specimens in Phase 2 be by saw-cutting rather than flame cutting. This is consistent with the method of sudden release used historically (Logan 1997). In addition to inferring the transfer length from strand end-slip measurements, transfer lengths will be obtained by use of a laser-speckle measuring device (previously developed and validated at Kansas State University). Use of the laser-speckle device will allow for a rapid, unbiased determination of the transfer length.

While transfer lengths can vary significantly for individual strands within a single member (R. J. Peterman 2007), the average transfer length of members with multiple strands will not vary to the same degree. The PI’s believe that there is inherently a higher degree of risk associated with bond variations in members with only a few strands that is currently not considered in the design of prestressed concrete members. Therefore, when evaluating the data and projecting its potential significance to the design of hollow-core members and double-Ts, the philosophy of the research team will be to consider both the individual strand performance as well as the average performance of multiple-strand combinations.
For example, the 6 1/2” X 12” single-strand beams will produce 20 transfer length measurements for each of the three strand groups (10 members with 2 ends each). These transfer length values can then be compared with the ACI recommended values of \((f_{se}/3)\times d_b\) (for partially-developed strand) or 50 \(d_b\) for shear. However, when the team statistically analyzes these results, greater emphasis will be placed on the probability of the average from several consecutive transfer length values falling below the ACI value, rather than the probability of a single value falling below. This is what is meant by establishing an “upper-bound estimate of the average transfer length.” The PI’s believe that this is the most rational way to accommodate outliers in the transfer length data, which often occur and cannot be simply dismissed.

**Task 10: 6 ½” X 12” Rectangular Beam Specimens**

The PIs have chosen to cast the flexural beams at Stresscon in Colorado Springs, CO using the same low-slump concrete mixture that was used in several previous research projects (refer to letter of commitment from Stresscon). The mix will contain 658 lbs cement/\(\text{yd}^3\) and a crushed granite coarse aggregate (Logan 1997). Note, previous work (R. J. Peterman 2007)(Burgueño and Haq 2007) has shown that the bond of pretensioned members can be extremely sensitive to changes in concrete consistency and aggregate source. By casting the beams at Stresscon with the previously-used standard low-slump mix (without superplasticizers), the research team will ensure that the correlation with beam testing will be consistent with previous studies.

All ends of the test beams will be de-tensioned by saw-cutting. To enable this, additional 4-ft-long concrete “dummy” blocks will cast at each end of the line of test beams.

Ten (10) standard 6.5” by 12 inch beams, approximately 18 feet in length, will be cast and tested for each of the three (3) strands selected in Task 2. These will be used to determine both the transfer length and development length of the beams, and to obtain a direct comparison with STSB tests. Because each beam end will be tested, this gives a total of 60 beam load tests to be conducted, 20 with each strand source.

The thirty beams will be cast in three consecutive casting days using two strand lines on a single 100’ bed, as shown in Figure 7. The specimen quantity selection for testing is based on both statistics and cost. Strictly speaking, testing more beams will always improve the analysis performed; however there is a diminishing return for each additional specimen tested, while the costs for running each additional test remain the same (Hawkins and Ramirez 2010).

The per beam additional cost is very small for this study because the beams will be cast and tested at Stresscon with most of the costs for making and testing the beams coming from making the forms and mobilization costs (refer to attached quotation from Stresscon for 16 vs. 30 beams). The most economical way for Stresscon to cast the beams is five beams per line, meaning that the most economical way to fabricate the beams is by multiples of 5. For this study, the PIs believe that this optimum value of statistical benefit occurs at 10 beams per strand, or 20 total tests per strand. Although the PIs plan to use the average values for establishing the STSB threshold, the impact of outliers on the average will be reduced by the use of a larger sample size. Since this decision involves
both technical and cost issues, the number of beams tested per strand can be adjusted up or down by 20% (from 8-12 beams per strand) with a per beam cost listed in the budget.

![Beam fabrication layout and casting schedule](image_url)

**Figure 7 - Beam fabrication layout and casting schedule**

The transfer lengths of the strands will be determined from both strand end-slip measurements and from surface strain measurements and by using a laser-speckle imaging (LSI) device. Mast’s strand slip theory will be used to calculate the development length from the measured end slip before loading. The 95% average maximum strain (95% AMS) method will be used to determine the transfer length from surface strain measurements. Note, the LSI device is a rapid, non-contact strain measuring instrument that was developed at Kansas State University and is fully functional. This device was recently used to measure transfer lengths at the CXT Concrete Tie plant in Grand Island, NE and was also demonstrated to Ken Baur of High Concrete Structures, Inc. in Manhattan, KS in March 2011.

Companion strength cylinders will be cast on site and match cured during the first 16 hours. Cylinders will be tested for compressive strength and splitting tensile strength at the time of release, at 7 days, and 28 days after casting.

It is expected that the strands will be de-tensioned 12-16 hours after casting, when the concrete compressive strength reaches 4000 psi, which is consistent with previous studies. The flexural testing will be performed on the concrete at approximately 28 days after casting. The beams will be load
tested at the Stresscon plant in Colorado Springs, CO as previously done by Logan (Logan 1997). Testing at the plant will allow for much more consistency in the concrete strengths of all specimens, and much greater efficiency as testing of all 30 beams can be accomplished in one week. Kansas State University personnel will take a hydraulic loading cylinder to Stresscon that is instrumented with a pressure transducer, load cell, and cable potentiometer in order to obtain analog outputs of load and stroke which will be captured by a Keithley Model 2700 data acquisition system. A similar instrumentation plan was used previously by Dr. Peterman to obtain force and stroke data during Large Block Pullout Testing at Stresscon. In addition, LVDT’s will be used to measure the mid-span deflection and possible strand end-slip during testing.

If a strand is obtained with a STSB value between 10500 and 12000 pounds, then one end of the flexural beam will tested with an embedment length equal to 80% of the development length calculated using Mast’s strand slip theory ($L_d$), and the other end tested at 100% $L_d$ as calculated using Mast’s strand slip theory. However, if the STSB value for the strand is above 12,000 pounds, then both ends will be tested at 80% of the development as calculated using Mast’s strand slip theory as shown in Figure 8. The strand stress at nominal capacity for the partially-developed members will be calculated from the moment at failure, and used to establish a tri-linear graph as depicted in Figure 9. The 90% confidence level for the STSB values, as determined from the ILS study, will then be used in calculating the STSB threshold acceptance value (Figure 10).

![Figure 8 – Beam testing layout](image_url)

Since the current ACI code expressions for transfer and development length were based on mean values (Hawkins and Ramirez 2010), the PI’s propose that a similar philosophy be used to establish the
STSB threshold value in this study. However, the PIs plan to additionally consider upper-bound estimates of the average transfer length.

During the analysis phase, the establishment of the tri-linear curves in Figure 9 will be done using several different techniques. First, the data will be plotted through the average points for transfer length and development length, as shown in Figure 9. Additionally, the data will be analyzed by considering the effect for multiple strand combinations. This will be done by using the probability density function for a beam with multiple pre-tensioned strands, as calculated from the single-strand beam transfer length values. Under this scenario, a higher confidence would be used for this probability density function, which would then provide a higher level of safety while taking into account the averaging effect that occurs in members with multiple strands.

Figure 9 – Plot of the transfer length and beam capacity test results for the case when average values are used from single strand beam tests.
Figure 10 – Hypothetical 90% confidence Pullout Strength from STSB test to a) % calculated transfer length and b) % calculated development length

Figure 10 illustrates the approach that the PI’s will use to establish the STSB threshold value. Once values for transfer length and development length for the three strands are determined, these values will be plotted, along with the upper-bound 90% confidence STSB value. The fractal value used (10% or 5%) will depend on the results from the sensitivity analysis.

A hypothetical example of this approach follows. If data from 6 labs in the ILS study are valid as shown, having a mean value of 13.27 kips and a coefficient of variation of 4.04%, then the value plotted for that strand on the horizontal axis in Figure 10 would be 14.53 kips (based on a 90% confidence of the 10% fractal). Note, if all 8 data points are valid, then the K value (from Table 4) would be 2.22 instead of 2.49.

<table>
<thead>
<tr>
<th>STSB Value (kips)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab 1</td>
</tr>
<tr>
<td>Lab 2</td>
</tr>
<tr>
<td>Lab 3</td>
</tr>
<tr>
<td>Lab 4</td>
</tr>
<tr>
<td>Lab 5</td>
</tr>
<tr>
<td>Lab 6</td>
</tr>
</tbody>
</table>

Mean = \(13.20\)
St. Dev = 0.53
COV = 0.0404

90% Confidence (10% Fractal) Pullout Strength = \(13.20 + (2.49 \times 0.0404 \times 13.20) = 14.53\)
In this way, two different threshold values will be obtained, one for transfer length and one for
development length, with the higher (more conservative) value recommended for final acceptance.

**TASK 11: DRAFT REPORT WITH STSB ACCEPTANCE CRITERIA RECOMMENDATIONS**

A draft report will be prepared that summarizes the sensitivity analysis and beam transfer length tests
conducted in Tasks 9 and 10. Recommendations for an appropriate threshold acceptance criteria based
on the sensitivity analysis, testing performed according to the proposed Standard Test Method for the
Bond of Prestressing Strands, and the transfer length beams tested and their resulting load-deflection
response and failure mode. The recommendation for the STSB threshold acceptance value will be
based on the procedure described in Figure 10.
Phase III: Comparison of Bond Testing to Peterman Beam Test Results

TASK 12: PETERMAN BEAM TEST PROGRAM

Three prestressed concrete beams will be made for each strand type tested in Phase II to compare the Peterman beam test results to that of the standard flexural beam testing conducted in Task 10 and the STSB testing. Standard 8” by 6” beams 11’6” in length will be made by Stresscon using the three different strands (R. J. Peterman 2009). The beams will be shipped to the R.J. Peterman & Associates, Inc. laboratory for testing in a controlled environment, make instrumentation during loading easier, and allow for loading until failure (Figure 11).

The strands will be released at 4000 psi by saw-cutting. The end-slip will be measured after release, after 7 days, and before loading after 28 days. The end slip will be measured during loading using an LVDT. The loading will be accomplished using the same test setup that was used during the PCI SCC study on strand bond (Peterman 2007). After the required 24 hour hold period at 85% M_n, and the 10 minute hold period at 100% M_n, the beams will additionally be loaded to failure to determine the ultimate capacity and failure mode for comparison to the testing performed in Tasks 6 and Tasks 10. A comparison of the transfer lengths found using the Peterman Beam Test to the STSB test results, similar to what is done for the standard beam tests, will be performed in order to confirm the pullout strength threshold value determined in Task 10.

Figure 11 The Peterman Beam tests will be conducted by RJ Peterman & Associates, Inc. using the same loading apparatus that was used previously by Dr. Peterman during the PCI SCC study.

TASK 13: DRAFT REPORT ON PETERMAN BEAM TEST PROGRAM
A draft report will be prepared and submitted to the Industry Advisory Committee that compares the findings of Task 11, with a recommendation about a threshold acceptance value for the Standard Test Method for the Bond of Prestressing Strands for reliable performance. Any differences in threshold values determined under Tasks 10 and 12 will be discussed.

**Task 14: Final Report**

A final report containing the reports developed in Tasks 8, 11, 13 and updated after comments from the Industry Advisory Committee will be prepared and submitted to the Industry Advisory Committee and to PCI.

**Task 15: Summary Paper**

A summary paper of the projects key findings will be developed and submitted to the PCI Journal for publication, with a focus on suggestions for product acceptance.
<table>
<thead>
<tr>
<th>Entity</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stresscon</td>
<td>Fabricate Beams for Phase II and II, Provide frame, hydraulics and space for Phase II testing</td>
</tr>
<tr>
<td>High Concrete Structures, Inc.</td>
<td>Work with K-State to perform sensitivity analysis in Task 10 that reflects industry standards, provide sand</td>
</tr>
<tr>
<td>Kansas Dept. of Transportation</td>
<td>Participate in round robin testing</td>
</tr>
<tr>
<td>American Spring Wire</td>
<td>Provide strand</td>
</tr>
<tr>
<td>Bekaert Canada Ltd.</td>
<td>Provide strand</td>
</tr>
<tr>
<td>Insteel</td>
<td>Provide strand</td>
</tr>
<tr>
<td>Nucor/ NISTRAND</td>
<td>Provide strand</td>
</tr>
<tr>
<td>Strand Tech Martin, INC.</td>
<td>Provide strand</td>
</tr>
<tr>
<td>Sumiden Wire Products Corporation</td>
<td>Provide strand</td>
</tr>
<tr>
<td>WJE</td>
<td>Test strands using methods developed in NCHRP 621</td>
</tr>
</tbody>
</table>
**Budget**

The revised budget is shown in the following table:

<table>
<thead>
<tr>
<th>Phase</th>
<th>Group of work</th>
<th>Cost by PCI</th>
<th>Contribution by KSU &amp; KSUTC*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1</td>
<td>Tasks 1-8 (without optional tasks)</td>
<td>$204,840</td>
<td>$71,850</td>
</tr>
<tr>
<td>Phase 2</td>
<td>Tasks 9-11</td>
<td>$64,821</td>
<td>$34,570</td>
</tr>
<tr>
<td></td>
<td>Note, the per beam cost in Task 11 (plus 6 beams or minus 15 beams) = $400</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase 3</td>
<td>Tasks 12-13</td>
<td>$25,869</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tasks 14-15</td>
<td>No additional cost if any of the phases are funded</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Totals:</strong></td>
<td><strong>$295,530</strong></td>
<td><strong>$106,420</strong></td>
</tr>
</tbody>
</table>

*Note, the cost of this study will be considerably reduced (by approximately 26%) by contributions from the Kansas State University Civil Engineering Department (through faculty release time for Dr. Riding and Dr. Peterman to work on this project) and by the KSU University Transportation Center (through graduate student support for one year).*
PROPOSED TIMELINE

The research leadership is made up of leading experts in all of the technical areas relevant to this project. The team consists of an expert in precast concrete structures and strand bond (Bob Peterman), a concrete materials expert (Kyle Riding), and a statistician (Leigh Murray). Ryan Benteman, the KSU civil engineering research technologist, will assist in the specimen fabrication and testing. Two graduate students and one undergraduate student in civil engineering will work on this project.

Figure 12 - Proposed timeline

STAFF & RELATED EXPERIENCE
The research leadership is made up of leading experts in all of the technical areas relevant to this project. The team consists of an expert in precast concrete structures and strand bond (Bob Peterman), a concrete materials expert (Kyle Riding), and a statistician (Leigh Murray). Ryan Benteman, the KSU civil engineering research technologist, will assist in the specimen fabrication and testing. Two graduate students and one undergraduate student in civil engineering will work on this project.
Qualifications of Robert J. Peterman, Ph.D., P.E.

Dr. Peterman is a licensed professional engineer with more than 20 years of experience in the design and investigation of prestressed concrete structures. After receiving his Master’s degree in Civil Engineering from Purdue University, Dr. Peterman worked as a design engineer for American Precast Concrete, Inc. (Indianapolis, IN) for 3 ½ years. During this time, he was responsible for the design, inspection, and retrofit of numerous prestressed concrete structures. In 1991, Dr. Peterman was lead investigator of a prestressed concrete structure that had substandard strand bond in Columbus, Ohio.

In 1993, Dr. Peterman returned to Purdue University to work on his Ph.D. under Dr. Julio Ramirez. As a Post-Doctoral Research Associate at Purdue University, Dr. Peterman investigated the bond performance of pretensioned strands in semi-lightweight concrete.

Currently a Professor of Civil Engineering at Kansas State University (KSU), Dr. Peterman has been the Principle investigator on seven projects involving the determining of bond characteristics of pretensioned strands under static and cyclic loading conditions. He is president of RJ Peterman & Associates, Inc. which routinely performs strand and wire bond pullout tests (including the STSB).

Research Honors and Awards Related to Strand Bond:
- 2008 “George D. Nasser Award” (presented by the Precast/Prestressed Concrete Institute (PCI) for the paper published in the PCI Journal that is “most worthy of special commendation for its merit on the design, research, production or construction of precast/prestressed concrete structures” for authors who are 40 years or under.
- 2007 “Charles C. Zollman Award” (presented by the Precast/Prestressed Concrete Institute (PCI) for the “best State-of-the-Art precast and prestressed concrete paper appearing in the PCI Journal during a single year”)

Related Publications:

1. Larson, K., Zhao, W., Peterman, R., Beck, T., Wu, J., “Development of a Laser-Speckle Imaging Device to Determine the Transfer Length in Pretensioned Concrete Members,” Accepted for publication in the PCI Journal (Winter 2010).
Qualifications of Kyle A. Riding, Ph.D., P.E.

Education

Brigham Young University
B.S. Civil & Environmental Engineering 2002

The University of Texas at Austin
M.S.E. Civil Engineering 2004
Ph.D. Civil Engineering 2007

During his graduate studies at the University of Texas at Austin, Dr. Riding worked as a graduate research assistant on developing tools to help prevent mass concrete cracking at the Concrete Durability Center. This work received a Top Research Innovations and Findings Award from the Texas Department of Transportation in 2005. There, he gained experience in designing and conducting experimental work. He also gained experience with field instrumentation of large concrete structures and bridge decks.

After graduation from the University of Texas at Austin, he worked for one year as a scientific collaborator at the Construction Materials Laboratory (LMC) at the Swiss Federal Institute of Technology at Lausanne. There, he worked on determining the mechanism of cement early age strength enhancement by chemical admixtures. He gained experience there in working with industrial partners on a very tight schedule in a very diverse work environment.

Dr. Riding joined the KSU faculty as an Assistant Professor in 2008, and has experience in both concrete materials and structural research. He is a member of the American Concrete Institute and the American Society of Civil Engineers and a licensed professional civil engineer in Nebraska. He is very active in the American Concrete Institute as a voting member of Committee 231: Properties of Concrete at Early Ages and an associate member of Committee 201: Durability of Concrete. He has also been selected to be the 2011 recipient of the ACI Wason Medal for Materials Research.

Select publications include:


Leigh W. Murray

Current Position (2007-present): Professor, Department of Statistics

Responsibilities: Teaching appointment (approximately 50%):
Teach graduate Statistics classes in the Statistics
Advise Statistics graduate students.
Statistical consulting appointment (approximately 50%):
Provide statistical consulting to the university research community
through the K-State Statistical Consulting Lab.

Previous positions: 1984-2007: Asst Prof, Assoc. Prof and Professor, Experimental Statistics &
University Statistics Center, NMSU, with a 50/50 appointment in teaching/statistical consulting; 1979-
1984: Asst Prof, Dept of Mathematical Sciences, NDSU.

Education: Ph.D. in Statistics, Virginia Polytechnic Institute and State University, 1981
M. Applied Statistics, Louisiana State University, 1976
B.A. in Anthropology, Rice University, 1972

Honors and awards:
Gamma Sigma Delta Distinguished Award for Graduate Teaching and Advisement,
1996.
CBAE Award for Outstanding Performance in Scholarly Research, Senior Faculty, 1999
2000.
Dennis W. Darnall Faculty Achievement Award, 2001
Grant from the Spanish government to offer a seminar and do collaborative research
with Faculty, Dept of Psychology, University of Jaime I, Castellon, Spain, Dec
2003.
NMSU College of Agriculture and Home Economics Team Award, April 2006 (with J.
Schroeder, S. Thomas and I. Ray)

Publications: Have authored or co-authored over 90 refereed publications since 1983, both in statistics
journals and in other subject journals through my university statistical consulting.

Statistical consulting through the Statistical Consulting Lab: Consult with approximately 30-75
researchers (faculty, staff and students) at KSU yearly and supervise masters and Ph.D. statistics
students who staff the Statistical Consulting Lab. Primary areas of consulting: Agriculture, Biology and
Vet Medicine.

Grants: Co-P.I. or collaborator for grants in Agriculture and Education, totaling over $800,000.

Graduate Student Advising: Research advisor for over 20 statistics masters students; member of
over 30 statistics masters committees; member of over 50 completed doctoral committees and over
110 completed masters committees in non-statistics disciplines.
FACILITIES
Pullout strength testing will be conducted under the supervision of the KSU civil engineering faculty at the KSU structural mechanics laboratory. The civil engineering department technician, Ryan Bente man is factory trained in MTS controls and operation and will be available to assist in this project.

The Fiedler Hall Structural Mechanics Laboratory at KSU contains a 400-kip universal test machine (UTM), two MTS fatigue-rated load frames, and four smaller mechanical load frames. Figure 15a shows the 70,000 lb capacity MTS load frame, while Figure 15b shows the 50,000 lb capacity MTS load frame, both of which would be adequate for the pullout strength testing. This laboratory is served by an MTS Flextest digital servo-control capable of controlling four simultaneous stations. An MTS 30 gpm hydraulic power supply was installed in February 2003 at the Fiedler Hall Structural Mechanics Laboratory. Three 200-channel Megadac data acquisition systems, three Keithley data acquisition systems, and a Vishay Micro-Measurements System 7000 data acquisition system are available for this project. Eight Vishay signal conditioners are available for use with LVDT. The LVDTs used in the STSB testing will be measured directly using the MTS system. Space is available for storing cement and three spools of strand at the Structural Mechanics Laboratory. KSU and the PIs have a long history of prestressed concrete research which required storing prestressed strand for long periods of time. KSU has one steel cage available for storing steel strand. Additional strand cages will be made using KSU’s excellent welding facilities and equipment. Dehumidifiers will be placed in the Structural Mechanics Laboratory to ensure that the humidity in the lab remains low to prevent strand corrosion. Bulk sand storage bins for the STSB testing are available at the Civil Infrastructure Systems Laboratory for storing the large quantity of sand needed for this study.
While Kansas State University has facilities and load frames capable of making and testing the prestressed concrete beams, the PIs believe that casting the beams at Stresscon will ensure that the concrete mixture used is one that has been used in previous research. It will then be fastest and most cost effective to test the beams at the Stresscon facility, and will minimize the difference in concrete strengths between tests.

The loading application at Stresscon can be performed using the same approach as the one used in a previous study (Logan 1997). A load cell will be placed between the ram and the point of application on the beam. KSU has 50,000 and 200,000 lb capacity load cells available to bring to the beam load testing at Stresscon. The Vishay Micro-Measurements System 7000 will be used to measure the end slip, beam deflections, and force applied during the beam load testing at Stresscon. A Laser-Speckle Imaging (LSI) device is available for transfer length measurement evaluation. The laser speckle system can rapidly be attached to the beam to take readings, as shown in Figure 16.
Standard concrete and mortar mixing, vibrating, finishing, and curing equipment is available. Standard fresh concrete test equipment such as slump cones, air content meters, and cylinders are also available. A vibrating table, a 7/8 inch immersion vibrator, aggregate sieve shakers, and specific gravity water baths are available for this project. The concrete and mortar mixing lab contains a 76.5 ft$^2$ moist room connected to an American Cube Mold Moisture Room Control System meeting ASTM C 511 that can be used for curing the STSB specimens. Eight cube mold sets are available for making a total of 24 mortar cubes according to ASTM C 109 are available for use in this study. A new Forney 250-kip concrete compression testing machine was acquired and installed in 2009 at Fiedler Hall at KSU which can be used for testing mortar cubes.
REFERENCES

ACI 201.2R. "Guide to Durable Concrete." American Concrete Institute, Farmington Hills, Michigan, 2008, 49 pp.
APPENDIX A: LETTERS OF SUPPORT/COMMITMENT
April 26, 2011

Robert W. Stokes, Ph.D.
2118 Fiedler Hall
Manhattan, KS 66506

Roger Becker, P.E., S.E.
Managing Director, Research & Development
Precast/Prestressed Concrete Institute
200 West Adams Street Suite 2100
Chicago, IL 60606

Dear Mr. Becker:

I am writing to confirm the Kansas State University Transportation Center’s support of the proposal for Acceptance Criteria for Prestressing Strand in Pretensioned Applications by Dr. Riding, Dr. Peterman, and Dr. Murray. The Kansas State University Transportation Center understands the importance of this work and is willing to demonstrate this by providing $20,000 to support a graduate student working on this project. These funds will be available for the period May 31, 2011 – June 1, 2012, contingent upon approval of the K-State UTC’s FY2012 budget request. Please let me know if you have any questions about this support.

Sincerely,

Robert W. Stokes
Professor
Director, Kansas State University Transportation Center
Bob,

As we spoke earlier today these are the costs associated with the beam production and testing to be performed in late 2012 or early 2013.

OPTION #1  30 beams

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<th>Description</th>
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<tr>
<td>Forming &amp; Casting</td>
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<td>Testing Setup &amp; Teardown</td>
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<td><strong>Total</strong></td>
<td><strong>$28,800.00</strong></td>
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OPTION #2  16 beams

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<th>Description</th>
<th>Cost</th>
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<tr>
<td>Testing Setup &amp; Teardown</td>
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<td><strong>Total</strong></td>
<td><strong>$24,933.00</strong></td>
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Additional 9 beams

<table>
<thead>
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</tr>
</thead>
<tbody>
<tr>
<td>Forming &amp; Casting</td>
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</tr>
<tr>
<td>Shipping</td>
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</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$7,993.00</strong></td>
</tr>
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</table>

Very Truly Yours,

STRESSCON CORPORATION
Robert Kolinski
Quality Control Director

cc: Dave Bourgault
March 22, 2011

Dr. Robert J. Peterman, Ph.D., P.E.
Professor of Civil Engineering
Kansas State University
Manhattan, Kansas

Subject: Research Project:

Dear Dr. Peterman:

I am writing to affirm that High Concrete Structures, Inc. is in support of your research to investigate the effect of different types of sand in the calibration of the NASP test program. We are willing to ship a selection of sands used in our structural mixes to Kansas State University at our expense.

In addition, our engineering team will work with you to assess the effect of excessive transfer and development lengths on the design strength of typical hollow-core and double-T members.

Please contact me if I can be of further assistance in support of this important research.

Sincerely,

Kenneth Baur, P.E., FPCI
Director of Research and Development
High Concrete Structures
March 31, 2011

Kansas State University
Department of Civil Engineering

Thank you for the opportunity to submit a quotation to conduct STSB Pullout Tests and “Peterman Beam” Tests as part of the proposed work titled “Determination of Acceptance Criteria for Prestressing Strand In Pretensioned Applications.”

The cost to conduct and report the results for STSB according to the procedures identified in the NCHRP 603 Report pullout tests would be $2020 for the first group of 6 samples and $715 for each additional group of 6 included in the test series (and supplied at the same time). Thus, the cost for 18 tests would be $2020 + (2 x $715) = $3,450.

Additionally, the cost to conduct “Peterman Beam” tests on 9 pretensioned beams using the same loading apparatus as that used in the original PCI SCC Study (by Dr. Peterman) would be $12,600. These tests will be conducted according to the procedure outlined in the PCI Journal Article titled “A Simple Quality Assurance Test for Strand Bond.” During each test, values of load, mid-span deflection, and the strand end-slip at each end will be recorded. Furthermore, all beams will be loaded until failure occurs (although not required by the test protocol) and data collected throughout the entire loading process.

Please let us know if you are awarded the proposal and would like to proceed with the testing. This price will be held for 60 days.
March 29, 2011

Kyle A. Riding, Ph.D., P.E.
Department of Civil Engineering
Kansas State University
2118 Fiedler Hall
Manhattan, KS  66506

Dear Dr. Riding:

Materials and Research endorses developing a precision and bias statement for determining steel strand bond strength in prestressed concrete members using pullout tests. As such, Materials and Research is willing to support your Precast/Prestressed Concrete Institute Project by participating in the round robin testing.

Sincerely,

Richard E. Kreider Jr., P.E.
Chief, Bureau of Materials and Research

Joshua A. Welge, P.E.
Engineer of Tests
Hello Bob:

ASW will participate in the PCI study. We can supply you initial individual samples and a test pak of 3000 feet. There will be no charge for these samples.

Contact me if you have any questions.

Regards;
Mike Caranna
Technical Services Manager
American Spring Wire Corp.
To: PCI Research Advisory and Selection Committee

From: Bekaert Canada Ltd

Re: Strand source request by Kansas State University

We have been contacted by Dr. Robert Peterman at Kansas State University (KSU) about a research proposal that KSU will be submitting to PCI for Round Robin Pullout Testing. If KSU is successful in obtaining the research grant from PCI, then we agree to do the following.

1) We will cut and ship (24) 3-ft-long samples to Kansas State University. The samples will be cut from a single larger coil of strand (at least 3000-ft-long).
2) We will maintain the larger coil of strand until KSU conducts the initial testing to determine which strand sources they will include in the round robin testing and structural beam testing portions of the study.
3) If our strand source is selected as one to be used in the study, then we will ship at least 3000 ft of strand from the larger coil to KSU.

We agree to furnish these materials to KSU at a total cost of $1,500.

Signed,
To: PCI Research Advisory and Selection Committee  
From: Insteel  
Re: Strand source request by Kansas State University

We have been contacted by Dr. Robert Peteman at Kansas State University (KSU) about a research proposal that KSU will be submitting to PCI for the project titled “Acceptance Criteria for Prestressing Strand in Pretensioned Applications.” If KSU is successful in obtaining the research grant from PCI, then we agree to do the following:

1) We will cut and ship (24) 3-ft-long samples to Kansas State University. The samples will be cut from a single larger coil of strand (at least 3000-ft-long).
2) We will maintain the larger coil of strand until KSU conducts the initial testing to determine which strand sources they will include in the round robin testing and structural beam testing portions of the study.
3) If our strand source is selected as one to be used in the study, then we will ship at least 3000 ft of strand from the larger coil to KSU.

We agree to furnish these materials to KSU at a total cost of $1500.

Signed,

[Signature]
Title:
March 29, 2011

Robert (Bob) Peterman
Peterman & Associates
3016 Jeanie Lane
Manhattan, KS 66502

To whom it may concern,

NuStrand has agreed to provide strand samples to Peterman & Associates for strand bond tests as part of the PCI round-robin testing program. All tests are to be in compliance with the Standard Test for Strand Bond as developed by the NASPA group and Dr. Bruce Russell.

The agreed total quantity of strand to be provided by NuStrand shall not exceed a maximum of 4,000 linear feet. The strand samples provided by NuStrand will all be from a single production lot of 1/2” 270 ksi, low relaxation, domestic material manufactured at our RettCo Steel facility in Newnan, GA. All strand provided will comply with the most current revision of ASTM A416. A physical test and certification for the strand will be provided with the material.

Nucor/NUSTRAND is proud and thankful for the opportunity to support the prestressed concrete industry’s efforts to insure a brighter future for the industry and its suppliers.

Best Regards,

Ronald Mann
PC Strand Marketing Manager
Nucor/NUSTRAND
Cell Number: (904) 305-0757
Email: Ronald.Mann@Nucor.com

*All statements or agreements in this quotation are contingent upon accidents, labor disputes, acts of God, delays in transportation and any cause unavoidable or beyond our control.
To: PCI Research Advisory and Selection Committee

From: Strand Tech Martin, INC.

Re: Strand source request by Kansas State University

We have been contacted by Dr. Robert Peterman at Kansas State University (KSU) about a research proposal that KSU will be submitting to PCI for the project titled “Acceptance Criteria for Prestressing Strand in Pretensioned Applications.” If KSU is successful in obtaining the research grant from PCI, then we agree to do the following.

1) We will cut and ship (24) 3-ft-long samples to Kansas State University. The samples will be cut from a single larger coil of strand (at least 3000-ft-long).
2) We will maintain the larger coil of strand until KSU conducts the initial testing to determine which strand sources they will include in the round robin testing and structural beam testing portions of the study.
3) If our strand source is selected as one to be used in the study, then we will ship at least 3000 ft of strand from the larger coil to KSU.

We agree to furnish these materials to KSU at a total cost of $2500.00.

Signed,

Jan Holcomb

Jan Holcomb
Title: Sales Rep.,
STRAND TECH MARTIN, INC.
To: PCI Research Advisory and Selection Committee  
From: Sumiden Wire Products Corporation  

Re: Strand source request by Kansas State University  

We have been contacted by Dr. Robert Peterman at Kansas State University (KSU) about a research proposal that KSU will be submitting to PCI for the project titled “Acceptance Criteria for Prestressing Strand in Pretensioned Applications.” If KSU is successful in obtaining the research grant from PCI, then we agree to do the following.

1) We will cut and ship (24) 3-ft-long samples to Kansas State University. The samples will be cut from a single larger coil of strand (at least 3000-ft-long).
2) We will maintain the larger coil of strand until KSU conducts the initial testing to determine which strand sources they will include in the round robin testing and structural beam testing portions of the study.
3) If our strand source is selected as one to be used in the study, then we will ship at least 3000 ft of strand from the larger coil to KSU.

We agree to furnish these materials to KSU at a total cost of $0.

Signed,  

Jon Cornelius  
General Manager  
PC Strand Division  
Sumiden Wire Products Corporation