I. RESEARCH PROJECT TITLE

Evaluating the Time-Dependent and Bond Characteristics of a Lightweight Concrete Mix for Kansas Prestressed Concrete Bridges

II. BACKGROUND

Self-Consolidating Concrete (SCC) has become increasingly popular in the fabrication of precast concrete members in the United States during the past several years. Dr. Robert Peterman has been conducting research with SCC for the past 5 years (funded by both KDOT and the Precast/Prestressed Concrete Institute), particularly with the issues of strand bond, creep, and shrinkage of SCC mixes for pre-tensioned bridge girders.

Because of the successful implementation of SCC in the prestressed concrete industry, several precasters throughout the Unites States have also implemented Lightweight SCC, in which the coarse and fine aggregates are replaced with lightweight aggregates in order to reduce the dead load by as much as 30%. As part of the current PCI Strand Bond Study with SCC, Dr. Peterman tested 9 prestressed beams with a Lightweight SCC cast at Metromont Corporation's facility in Greenville, SC.

All of these beams exhibited excellent structural performance and exceeded the current design code requirements.

In Kansas, many bridges are located in rural areas, thus creating long travel distances for prestressed girders to be delivered to the jobsite. The use of Lightweight SCC would reduce bridge construction costs by providing the following advantages.

- Increased Span-to-depth ratio for a given cross-section
- Smaller foundation requirements
- Reduced crane sizes since members weigh less
- The possibility of shipping more members on a single truck (for small members such as Inverted-T's)

Thus, based on these initial findings, in 2006 KDOT funded the project titled "Development and Implementation of Lightweight Concrete Mixes for KDOT Bridge Applications." This recent work has focused on the evaluation of lightweight concrete mixes utilizing 3 different lightweight aggregate sources, and the results from this laboratory phase have been very positive.

Before lightweight concrete can be implemented in Kansas bridges, however, several critical material properties must be quantified. Specifically, the modulus of elasticity, shrinkage, creep, and bond characteristics of SCC concrete mixes specific to Kansas lightweight aggregates must be determined. Generally, SCC mixes contain lower percentages of coarse aggregate and higher paste volumes than standard concrete mixes having equal strength. Thus, SCC mixes exhibit lower elastic moduli, and higher shrinkage and creep characteristics. The addition of lightweight aggregates in SCC

mixtures will likely reduce the modulus and increase the creep characteristics of the mix. Both of these parameters can vary greatly with changes in mix design, and need to be quantified for the lightweight mixes used in Kansas bridges.
Thus, the next step required to move this technology towards implementation is to verify the ability of the lightweight concrete mixes to be consistently produced by the local precast plants, and to evaluate the time-dependent and bond characteristics of such mixes when produced at precast plants.

III. PROJECT OBJECTIVES

The objectives for the project are listed below.

1. Work with local prestressed concrete producer to develop a lightweight concrete mix for use in Kansas prestressed concrete bridge girders.
2. Determine the material properties of the lightweight mix required for the design of a pretensioned concrete bridge.

IV. WORK PLAN

1. Obtain raw materials used by local prestressing plant (Coarse and Fine Aggregate, Type III cement, and admixtures).
2. Develop light-weight concrete mix in cooperation with the prestressing plant and admixture supplier.
3. Determine Shrinkage, Creep, Elastic Modulus, Modulus of Rupture, and Bond Characteristics for the light-weight concrete mixes using standard testing procedures. Results from the ASTM standard tests for creep and shrinkage on the lightweight specimens will then be compared and correlated to the corresponding values from measurements on the Inverted-T light-weight concrete sections in Work Plan item #4. These results will also be used to investigate the general equations proposed by ACI Committee 209 for predicting creep coefficient (ratio of creep strain to initial elastic strain) and also shrinkage of concrete at any time and applicability of these equations to the light-weight concrete mixes.

Creep: The standard test method (stipulated in ASTM C512) measures the load-induced time dependent compressive strain at selected ages for concrete under an arbitrary set of controlled environmental conditions. Creep coefficients will be determined for both the Standard Prestressed Light-Weight Girder mix and the light-weight SCC mix. The environmental conditions stipulated by ASTM are 73.4 ± 2.0° F with a relative humidity of 50 ± 4% until completion of the test. However, since KSU does not have a large environmental chamber, specimens will be stored inside the KSU laboratory and temperature and relative humidity will be monitored. It is expected that the “indoor” environment, as permitted by the standard, will approximately represent the ASTM value and will be sufficient to directly compare the creep performance of both (standard and SCC) lightweight mixes.

At least 3 creep specimens will be prepared, cured and tested for each load level and concrete mix. The load levels will provide the same compressive stress in the concrete as found at the strand level in typical Inverted-T beams. These specimens will have the same ingredients and mix design as the full-scale specimens on which the shrinkage and creep is measured (refer to Work Plan item #4). As per the ASTM standard, the equipment used for application of the force is arbitrary provided a constant force and uniform stress within the acceptable error limits can be maintained. Figure 1 shows a typical test setup in which springs, a jack, and threaded rods are used to maintain the desired force on the specimens. A similar test setup will be used in this research program.

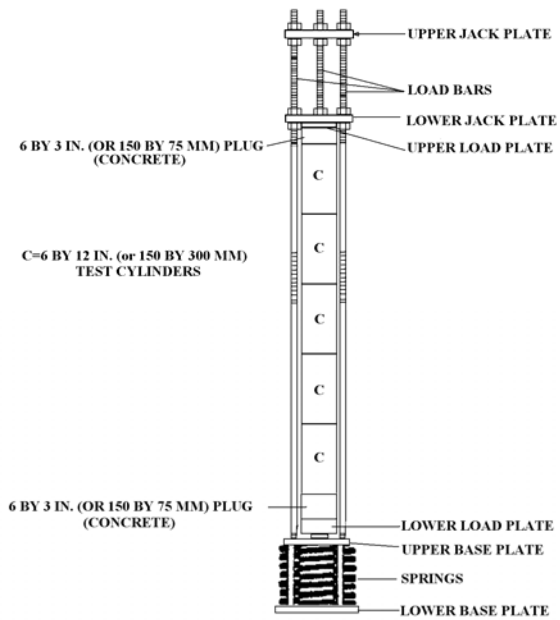

Figure 1- Typical test setup for creep test using springs to maintain the force

<u>Shrinkage</u>: The shrinkage is determined as the deformations that take place in a test specimen free from load after the hardening process has started and compensation is made for deformations originating from the temperature variations in the concrete. Shrinkage during setting and curing will be measured on standard specimens under 2 different environmental conditions. 50% of the specimens will be in an outdoor environmental condition similar to the full-scale light-weight concrete sections on which shrinkage is measured and the conditions for the rest of the specimens will be "indoors." At least 8 specimens will be prepared for this purpose. Based on the ASTM standard, the same specimens previously used for shrinkage, shall be used to measure the coefficient of thermal expansion. Length of the specimen (s) is measured using a comparator along with embedded studs in the specimen, at different temperatures in a process detailed in the standard process.

4. Creep and Shrinkage properties will also be determined for full-scale members prior to designing the actual bridge. To do this, two (2) full-scale prestressed beam segments will be fabricated with the standard lightweight and lightweight SCC mix as shown in Figure 2. For each specimen, measurements of strand end slip, surface

strains, plus internal strains and temperatures (from embedded vibrating-wire gages) will be monitored over a period of 6-9 months.

From measurements of strain vs. time, the combined effects of shrinkage, creep, and temperature will be determined.

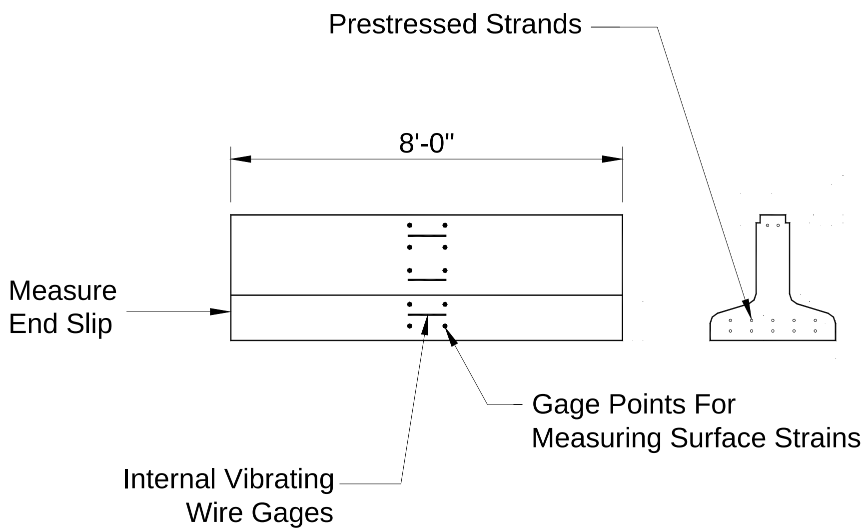

Figure 2- Prestressed Sections with light-weight concrete for evaluation of shrinkage & creep properties.

In order to separate the effects of creep and shrinkage; two (2) identical sections will be fabricated with un-tensioned bonded strands using both the lightweight and lightweight SCC mixes (See Figure 3). Measurements of strain will also be recorded for these beams, but the differential strains over time) will be caused by shrinkage only (after correcting for temperature effects).

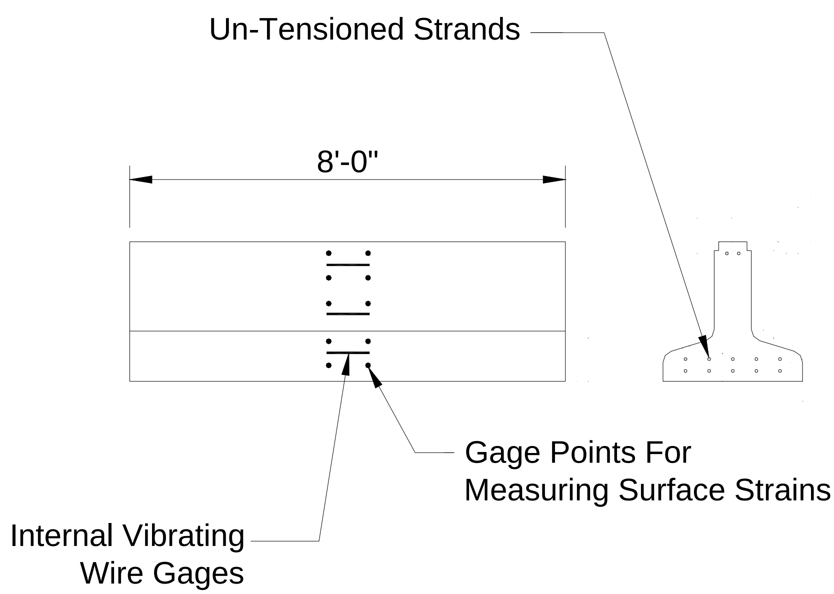

Figure 3- Un-stressed Sections with light-weight concrete used to isolate shrinkage and creep effects.

Using the information from the specimens above, the time-dependent length changes due to creep, shrinkage, and thermal expansion can be isolated. After several months of data collection, the expected total shortening and loss of prestress force may be reasonably estimated. Note that based on the current time-dependent models, approximately 60% of the time-dependent effects are expected to occur during the first 3 months.

5. Verify that the current development length equations may be used for the Kansas beams with lightweight concrete through load testing of both single-strand specimens and three multiple-strand specimens. All specimens in this study will be manufactured from the same reel of strand. The strand will be "pre-qualified" for bond capability using the so-called "Moustafa Procedure."

   The single-strand specimens (8 total) will be used to evaluate the standard development length of both the light-weight and light-weight SCC girders. The multiple-strand beams (Figure 4 c) will each contain five strands at 2-inch spacing, and have a "T"-shape in order to induce high stains in the prestressed tendons (larger than 3%) at nominal moment capacity. A total of four (4) multiple-strand beams will be tested.

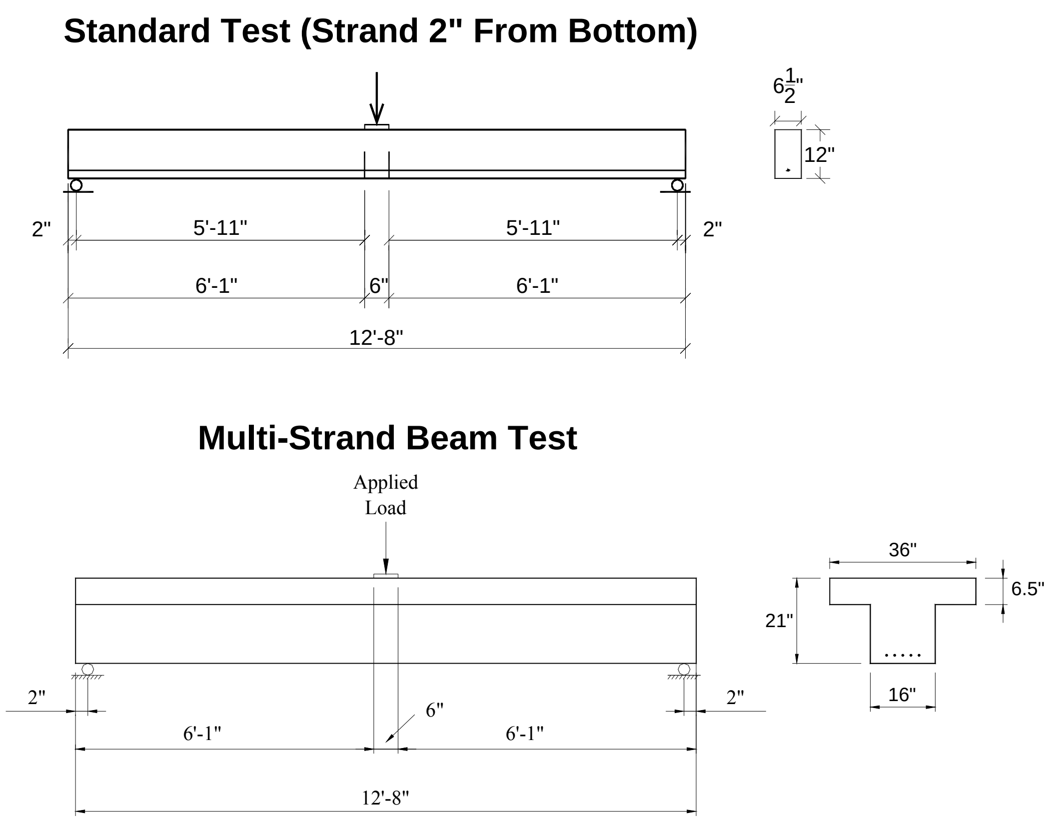

Figure 4- Development-Length Specimens a) Single Strand and, b) Multiple-Strand Effect.

V. IMPLEMENTATION

Following the successful completion of this project, the final step towards wide-spread implementation of the results, will be to construct and monitor a bridge utilizing light-weight concrete. This will be performed under a future research proposal where the PIs will perform the following tasks:

1. Assist with the design of a multiple-span bridge, with one end-span containing Light-Weight SCC in all of the prestressed concrete girders, and other spans containing standard light-weight concrete.
2. Construct the bridge with instrumentation embedded in the lightweight SCC girders, the companion girders with standard lightweight concrete, and the cast-in-place lightweight concrete deck

Task name	Year 1				Year 2			
	Q 1	Q 2	Q 3	Q 4	Q 1	Q 2	Q 3	Q 4
Obtain Raw Material								
Literature Review								
Develop Light-Weight Mixes								
Prepare Creep & Shrinkage Apparatus								
Cast Small Creep & Shrinkage Specimens								
Monitor Creep and Shrinkage Specimens								
Cast Development Length Specimens								
Cast Full-Scale Creep & Shrinkage Specimens								
Test Development Length Specimens								
Prepare/Submit the Report								

Figure 8. Project Time Line

VI. STAFF AND FACILITIES AVAILABLE

Robert J. Peterman

Dr. Peterman is a licensed professional engineer who has more than 15 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 performance in Columbus, Ohio.

In 1993, Dr. Peterman returned to Purdue University to work on his Ph.D. His doctoral thesis, titled "Behavior and Durability of Multi-Span Bridges with Full-Span Prestressed Concrete Form Panels" resulted in three publications in the PCI and ACI Materials Journals. As a Post-Doctoral Research Associate at Purdue University, Dr. Peterman investigated the bond performance of pretensioned strands in semi-lightweight concrete. This work led to the paper titled "Influence of Flexure-Shear Cracking on Strand Development Length in Prestressed Concrete Members" which was published in the September/October 2000 issue of the PCI Journal.

As a professor of Civil Engineering at Kansas State University, Dr. Peterman has been the Principle investigator on eight projects related to the design, evaluation, and retrofit of prestressed concrete members. Five of these projects have involved the determination of bond characteristics of pretensioned strands under static and cyclic loading conditions. As a result of his current work, Dr. Peterman was asked to present his findings at a special meeting of the PCI Technical Activities Committee (TAC) Strand Bond Task Force in Chicago, IL, and was an invited speaker at the PCI TAC sponsored session at the recent PCI Annual Convention in Nashville, TN.

Dr. Peterman has been an author or co-author of more than 20 technical publications in structural engineering, including ten journal publications. He currently serves as the Secretary of PCI Prestressing Steel Committee, a member of the PCI Bridge Committee, TRB Committee on Durability of Concrete (A2E01) and Kansas Composite Bridge Committee; and a Friend of the TRB Committee on Concrete Bridges (A2C03).

Asad Esmaeily

Dr. Esmaeily received his Ph.D. degree in Civil/Structural Engineering, M.S. degree in Electrical Engineering and also M.S. degree in Structural Engineering from the University of Southern California (USC, Los Angeles), in 2001, 2000, and 1998 respectively. He has more than 13 years of experience in his areas of specialty including structural engineering in general and seismic performance of reinforced concrete structures, high strength concrete, material models and analytical methods for reinforced concrete structures in particular. He is especially interested in various types of high performance concrete and experimental and analytical research on their material properties and structural performance. He has conducted a number of experimental and analytical researches on high strength concrete structural components and also seismic performance of bridge piers subjected to various loading patterns.

As an assistant and associate professor of structural engineering at KSU, Dr. Esmaeily has been involved in a number of projects funded by Kansas Department of Transportation, including post-tensioning prestressed inverted-T bridge systems, exploring the advantages and disadvantages of various short-span bridge systems for the state of Kansas, study of the thermal effects o the integral bridge systems, and developing computer applications serving as design tools for KDOT. He has also been a co-PI on projects such as investigating the time-dependent properties of Self Consolidating Concrete, funded by state as well as federal departments of transportation.

Dr. Esmaeily has more than 15 technical journal publications and more than 30 technical papers and reports including his 320 page report on seismic behavior of reinforced concrete bridge columns published by the Pacific Earthquake Engineering Research Center (PEER).

He is a member of the ACI_ASCE committee 441 (reinforced concrete columns) and also a member and the vice-chair of the ASCE EAI (Experimental Analysis and Instrumentation Committee).

Other Personnel
In addition to the principal investigator, work will be conducted by qualified graduate students, undergraduate students, and technicians at Kansas State University.

Facilities
Kansas State University has all of the facilities necessary for the successful completion of the proposed research. The Civil Infrastructure Systems Laboratory (CISL), located only 3 miles from Kansas State University, consists of a 4500 sq. ft. high bay area that is used to test full-scale specimens. The state-of-the-art laboratory, which was completed in 1996, utilizes two MTS hydraulic pumps and 2 controllers to apply cycling loading, 2 data acquisition systems, as well as numerous hydraulic rams and load cells. In addition, a self-reacting test frame was installed at the west end of this facility in May 2000. The frame is capable of testing members up to 51 ft in length and has a capacity of 500 kips.

VII. REPORTS/DELIVERABLES

An interim report will be prepared and submitted after the completion of Task 5. The interim report will describe the research findings from Tasks 1 through 5, and contain recommendations for the design of the actual bridge. These recommendations will include proposed design values for shrinkage, creep, elastic modulus, and development length to be used in the design, along with other pertinent findings.

At the conclusion of the project, a camera-ready final report will be submitted, along with an electronic copy in MS Word format. The final report will document the continued monitoring of the time-dependent specimens, as well as the instrumentation and initial data obtained from the bridge. In addition, the report will include recommendations for the continued use of SCC in KDOT prestressed concrete girders as well as suggested inspection/ quality control measures (unique to SCC) that should be implemented at the prestressed plant to ensure a consistent product.