PROJECT DESCRIPTION FOR
PROPOSED REGIONAL POOLED FUNDS STUDY

I. Research Project Title: Construction of Crack-Free Concrete Bridge Decks, Phase II

II. Research Project Statement:

Cracks in concrete bridge decks provide easy access for water and deicing chemicals that shorten the life of the deck. Both materials increase the effects of freeze-thaw damage, while the deicing chemicals lead to higher concentrations of chlorides, and subsequently, corrosion of reinforcing steel. Measurements taken on bridges in Kansas show that dense, high quality concrete can significantly slow the penetration of chlorides to the level of the reinforcing steel. However, measurements taken at cracks show that the chloride content of the concrete can exceed the corrosion threshold at the level of the reinforcing steel by the end of the first winter. The formation of cracks, thus, significantly lowers the effectiveness of other techniques that are used to increase the life of a deck.

Research, some of which dates back nearly 40 years, has addressed the causes of cracking in bridge decks in North America. The research includes three detailed bridge deck surveys carried out by the University of Kansas since 1993. The results of the studies provide specific guidance on modifications in materials and construction techniques that will reduce the amount of cracking in bridge decks: Settlement cracks, transverse deck cracks that form immediately over reinforcing bars, can be reduced with increased cover, decreased bar size, and decreased concrete slump. Shrinkage cracks can be reduced by decreasing the volume of water and cement, and maintaining an air content above 6%. Optimized aggregate gradations can be used to minimize the cement paste constituent of concrete, and workability can be enhanced at reduced paste contents using water reducers and superplasticizers. Increased compressive strength, normally associated with high-performance concrete, often has a negative impact on cracking. During construction, plastic shrinkage cracks increase as the rate of evaporation from the concrete surface increases. Even when plastic shrinkage cracking is not specifically observed, conditions associated with high evaporation rates are also associated with increased total cracking in the completed deck, due to movement of plastic concrete. Techniques such as wind breaks and fogging have had a positive impact on the problem, as has thorough curing of the concrete. The crack surveys by the University of Kansas demonstrate that, in general, cracking increases with increased age. However, concretes cast in different eras exhibit significantly different amounts of cracking – decks in Kansas cast between 1983 and 1987 average less than half the crack density of bridges cast since 1990 suggesting that changes in construction methods and materials have had a major impact Examples include the use of progressively finer portland cement, higher cement paste contents needed to produce pumpable concrete, and increased paste contents at the upper surface of decks that result from increased finishing and the use of "finishing aids."

In spite of this accumulation of knowledge, only a small number of these findings have been used to implement changes in bridge deck design and construction procedures. In specific cases, on-site observations indicate that it is possible to develop nearly crack-free bridge decks, if "best practices" are followed. Even with these few successes, most bridge decks exhibit significant cracking, exposing the reinforcing steel to deicing chemicals and subsequent corrosion and increasing the degree of saturation, which increases the impact of freeze-thaw cycles. The current level of understanding, however, offers strong direction for constructing bridge decks with minimum cracking.

This improved understanding has been put to use during the first phase of this study, in which 20 low-cracking, high- performance concrete (LC-HPC) bridge decks, with an equal number of control decks, are planned for construction. The decks involve the use of low cement and water contents, increased air contents, optimized aggregate gradations that produce pumpable, workable, placeable, finishable concrete with cement contents as low as 535 lb per cubic yard, temperature control during placement, limited finishing, and early curing. Of the twelve decks let in Kansas to date, construction costs for all but the first two have been about the same as those of the control decks (some a little higher and some a little lower). The first four decks (three in Kansas and one in South Dakota) have been completed and exhibit crack densities equal to between zero and 10% of that observed on conventional decks. To date, the study has been successful in identifying low-cracking portland cement concrete mixes. Several additional approaches, however, have been identified that have the potential to increase the benefits of the project, including using mineral admixtures, new sources of aggregate, and new approaches to finishing. These approaches cannot be fully exploited in Phase I. Data indicates that, when coupled with internal curing (provided by fully or partially saturated KsDOT approved limestone with 2 ½ - 3% absorption), using blast furnace slag as a replacement for portland cement can reduce drying shrinkage by an additional 40%. Two other mineral admixtures, fly ash and silica fume (microsilica), are also under investigation, although with less advantageous results. They will continue to be evaluated, however, because of their widespread use and the desire to construct decks with minimum permeability (achieved using silica fume) and environmentally beneficial waste materials (fly ash). The new mixes must be investigated for their shrinkage and freeze-thaw properties, as well as construction qualities, especially the ability to use pumps to place the new mixes. Optimum procedures for concrete placement and fogging will continue to be areas of special emphasis. Finishing techniques have been restricted in the current study. Additional work is necessary to determine if some of the restrictions (principally on the placement and finishing equipment) may be lifted.

III. Research Objectives:

The purpose of this study is to implement the most cost-effective techniques for improving bridge deck life through the reduction of cracking. The work involves cooperation between state departments of transportation, cement companies, contractors, and designers. The following tasks will be used to achieve this objective.

1. Develop a detailed plan to construct bridge decks with minimum cracking by incorporating "best practices" dealing with materials, construction procedures, and structural design. This step involves improving techniques in use in Phase I and

meeting with department of transportation personnel from multiple states, as well as other experts, to select the procedures to be used and the bridge types to which they will be applied.

2. Work with state DOTs, designers, contractors, inspectors, and material suppliers to modify designs, specifications, contracting procedures, construction techniques, and materials to obtain decks exhibiting minimal cracking.

3. Select and schedule bridges to be constructed using "best practices," and pre-qualify designers and contractors in application of the techniques. To date, 13 bridges in Kansas, two in South Dakota, one in Minnesota, and one in Missouri have been identified for construction. Three more must be selected for the current study and 20 additional bridges are proposed for Phase II. Researchers from the University of Kansas and state DOT personnel work closely with designers and contractors to achieve the desired results. Pre-qualification of designers and contractors includes the presentation of workshops sponsored by the University of Kansas to help educate and train engineers in implementing the "best-practices" identified in Tasks 1 and 2.

4. Perform detailed crack surveys on the bridge decks six months, one year, two years, and three years after construction. The surveys are beginning within three months of construction, and are performed using techniques developed at the University of Kansas that involve identifying and measuring all cracks visible on the upper surface of the bridge deck. The majority of the early surveys will be done by the University of Kansas. As the project progresses, teams outside of the State of Kansas will be trained in the survey techniques. Three teams in South Dakota have been trained.

5. Correlate the cracking measured in Task 4 with environmental and site conditions, construction techniques, design specifications, and material properties and compare with earlier data. Similar data from participating states, where it exists, is being incorporated in the analysis. Actual costs and future cost estimates will be compared with potential benefits.

6. Document the results of the study. A final report will be prepared and disseminated to participating states regarding the findings of Tasks 1-5.

7. Update the training program developed (and currently being presented) in Phase I to assist the participating states in implementing the findings of the study. The program consists of workshops to be held at the representative state DOT offices. These workshops are individually coordinated with each participating DOT.

A technical committee, structured with one representative from each state providing funds, oversees the project. A meeting has been held each year with very high participation of state representatives along with mineral and chemical admixture company representatives.

IV. Benefits:

State departments of transportation expend significant effort and resources on the construction of durable reinforced concrete bridges and bridge decks. Existing data indicates that specific modifications to construction procedures, materials, and design details will significantly reduce the degree of cracking in bridge decks and, thus, reduce exposure of reinforcing steel to the corrosive effects of deicing chemicals and decrease freeze-thaw damage. Of the two, corrosion is by far the greater problem. The project provides a mechanism for combining ideas from research and practice to develop a comprehensive strategy for the construction of bridge decks. If successful, as demonstrated to date, the result will be a major reduction in bridge deck cracking, an improvement in durability, and an increase in the useful life of bridges. A great deal is known about the factors that affect cracking in bridge decks – the goal of the proposed effort is to implement that knowledge.

V. Budget and Schedule:

Estimated budget: $980,000 matched by an additional $500,000 from the University of Kansas Transportation Research Institute (includes travel costs for state representatives).

Estimated duration: 5 years (start 9/1/07, end 3/1/13).

VI. Project Personnel:

The project will be directed by David Darwin, Ph.D., P.E., Deane E. Ackers Distinguished Professor of Civil Engineering and Director of the Structural Engineering and Materials Laboratory, and JoAnn Browning, Ph.D., P.E., Associate Professor of Civil Engineering at the University of Kansas. Darwin has extensive experience in concrete materials, the causes and control of cracking in concrete decks, and bridge deck evaluation. He has directed three bridge deck evaluation studies for KsDOT. He is an active researcher in both reinforced concrete and steel-concrete composite structures, and is past chairman of American Concrete Institute Committees 224, Cracking, and 408, Bond and Development of Reinforcement, and the American Society of Civil Engineers Committee on Composite Construction. Browning is an expert on reinforced concrete, with experience in field studies of both bridges and engineering materials. Browning has been a member of the team since the beginning of the current project and helps to lead efforts to reduce cracking and corrosion of reinforcement in bridge decks. She is also member of ACI Committee 408, Bond and Development of Reinforcement. Darwin and Browning are also co-directing a long-term study on bridge deck durability with emphasis on selecting cost-effective corrosion protection systems.

Professors Darwin and Browning will be assisted in this study by student researchers in the School of Engineering at the University of Kansas who have the appropriate training in reinforced concrete and composite structures.

Contact: David Darwin, Ph.D., P.E. (daved@ku.edu) or JoAnn Browning, Ph.D., P.E. (jpbrown@ku.edu), Univ. of Kansas, Dept. of Civil, Environ. & Arch. Engrg., 2142 Learned Hall, Lawrence, KS 66045-7609, 785/864-3827, fax: 785/864-5631