South Carolina
Department of Transportation

U.S. Department of Transportation
Federal Highway Administration

SUMMARY REPORT

Report Number **FHWA-SC-13-04a**
August 2014

South Carolina
Department of Transportation
955 Park Street
P.O. Box 191
Columbia, SC 29202

Development of High-Strength/High Performance Concrete/Grout Mixtures for Application in Shear Keys in Precast Bridges

EXECUTIVE SUMMARY

Introduction

In recent years, short span bridges in South Carolina have been designed and constructed using precast hollow core slab elements. However, concerns arising from cracking in the deck have triggered a renewed interest in finding alternate designs. Based on a recent SCDOT study, NEXT-D bridge system was identified as a potential solution for the South Carolina precast bridge needs. One aspect of this technology that requires *in-situ* construction is the construction of shear key joints. Shear key is used to transfer both lateral and vertical forces through the joint and to prevent relative vertical displacements between the deck elements at the joints. The structural integrity and the durability of concrete used in the shear key is vital to the successful performance of a bridge constructed using precast concrete components. Previous investigation on two potential shear key materials -Quikrete® Non-shrink Precision Grout (Quikrete NSP grout) with PVA fiber reinforcement and Lafarge DUCTAL® with either steel microfibers or PVA microfibers indicated that Quikrete® NSP grout with PVA microfibers did not perform adequately, while the steel fibers used in DUCTAL did not meet standard procurement policies, even though it exhibited superior performance. These difficulties with existing shear key material options required that an alternative solution be developed using local materials and a non-propriety mix design

.

Experimental Methodology

In this investigation, a customized ultra-high performance concrete (UHPC) mixture using readily available local materials was developed and evaluated. The experimental program in this research study was divided into two phases. In the first phase, a *preliminary investigation* was conducted to identify suitable materials for UHPC along with appropriate mixing and testing procedures to characterize specific properties. Based on this information, a range of mixture proportions that would yield adequate mechanical and durability properties were developed. In the second phase, a *detailed investigation* that was focused on selected UHPC mixtures was conducted. For comparing the performance of UHPC developed in this study with a commercially available material, limited tests were conducted on Quikrete Non-Shrink Precision grout with steel fibers.

Results

Results from the preliminary studies showed that UHPC mixtures containing Type III portland cement with conventional siliceous (quartz) river sand, low-carbon silica fume (white silica fume), a powdered polycarboxylate ester-based high-range water-reducer, steel microfibers and shrinkage-reducing admixture showed promise in meeting the desired needs for shear key application. It was also observed that Quikrete NSP grout underperformed in all aspects compared to the UHPC produced using local materials. Based on the preliminary findings, a series of four UHPC mixtures were developed that had the potential to meet both fresh and hardened properties required. The four mixtures were designed in such a way to study the individual and the additive effects of silica fume, steel microfibers, and shrinkage reducing admixture on various properties of UHPC. Findings from these studies showed that a high quality self-consolidating UHPC mixture (UHPC 4 in the report) can be produced using locally available cementitious and aggregate materials and normal mixing, placing and curing practices that can achieve a 28-day compressive strength of 158.7 MPa (23,000 psi), elastic modulus of 50.1 GPa (7.26 x 10^6 psi) with superior bond and flexural strength and negligible chloride permeability. Moderate level of shrinkage was observed.

The behavior of shear key prepared with UHPC was studied in the precast slab/shear key specimen using both static and a fatigue loading. In these tests, 13 mm (0.5 in.) steel reinforcing bars protruding from the outside edge of the precast panels into the shear key were designed to have two types of configurations: - a U-bar configuration and a straight bar configuration. The profile at the interface of the panel and the shear key was the same for both types of rebar configuration, however, the use of 125 mm (5 in.) straight rebar configuration resulted in a shear key width that was only 140 mm (5.5 in.) wide at the top and bottom compared to a width of 200 mm (8 in.) with U-bar configuration. The reduction of UHPC required for the narrower shear key for straight bar configuration was over 25%. The results from the static tests (both configurations of reinforcing steel) indicated the compressive strength, bond strength of the UHPC to the reinforcing steel and bond of the UHPC to the precast concrete at the interface was more than adequate to cause the failure mode of the test specimens to be related to the development of flexural and shear cracks in the precast concrete panels. Fatigue resistance was also investigated by subjecting each specimen to at least 5 x 10^6 cycles of service level stress prior to conducting a static ramp to failure. The fatigue loading created little, if any, distress (formation of cracks in precast, shear key or interface) or reduction in the overall bending stiffness of the specimens after the application of the 5 x 10^6 cycles of load. The post-fatigue behavior of the specimens under the static ultimate loading was very similar to the specimens not subjected to the fatigue loading.

Conclusions and Recommendations

A high-quality UHPC was developed in this study using locally available materials and normal mixing, placing and curing practices, with a unit cost that is significantly lower than some commercially available UHPC options. Based on this research, the UHPC produced using local materials was found to be a viable and an economical solution for meeting the shear key needs of NEXT-D bridge design. One important conclusion from the precast slab/shear key specimen tests was that a 125 mm (5 in.) straight bar configuration of reinforcement into the shear key produces more than adequate length of development of the reinforcement and effectively allows the shear key to transfer bending moment across the joint and control the formation and opening of cracks at the interface. Protruding straight bars will be much easier for precasters to design the formwork for the casting of the modified NEXT-D pieces than the U bars.

Prasada Rao Rangaraju, Ph.D., P.E., Associate Professor, Glenn Department of Civil Engineering, Clemson University, Clemson, SC, 29634-0911, P: (864) 656-1241; F: (864) 656-2670; Email: prangar@clemson.edu.
Zhengqi Li, Harish, K.V., and Schiff, S. Glenn Department of Civil Engineering, Clemson University