Center for Transportation Research
The University of Texas at Austin

Project Summary Report 1852-S

Prestressed Structural Lightweight Concrete Beams

Authors: J. A. Heffington, R. T. Kolozs, G. S. Sylva III, D. B. Thatcher, J. E. Breen, and N. H. Burns

December 2001

PROJECT SUMMARY REPORT

Summary: High Performance Lightweight Concrete Prestressed Girders and Panels

A significant portion of the load carried by prestressed concrete bridge girders is the self-weight of the girders and deck. If all or part of the girder and deck can be made using lightweight concrete, there is a potential for economic savings since the self-weight could be reduced by as much as 15-20%. This project was undertaken to explore the advantages and disadvantages of using high performance lightweight concrete (HPLC) pre-tensioned bridge girders and deck panels.

With normalweight concrete, high strength or high performance is ordinarily defined as concrete with strengths ranging from 8000 to 12,000 psi. In lightweight concrete, high performance may more often refer to strengths greater than or equal to 6000 psi. The higher strength is achieved through a mix design with a low water/cement ratio and admixtures. The possible material savings must be balanced against the higher cost of the HPLC, and will vary depending on the specific job conditions.

An additional possible application of HPLC is in precast pretensioned deck panels. These panels comprise approximately half the thickness of the deck. They are positioned on top of the girders, spanning the spaces between them. The panels act as formwork. They are left in place when the rest of the deck is placed on top of them to form a composite system. This eliminates the difficulty and cost of getting underneath the bridge in order to remove typical wooden or metal formwork. The precast prestressed panel serves as a stay-in-place form to support cast-in-place concrete. Lightweight concrete panels could reduce overall bridge dead load.

The overall objective of the research was to determine whether high performance lightweight concrete is a feasible material for use in Texas highway bridges. The main objective of the early portion of the project was to determine whether high-strength high-performance lightweight concrete mix designs could be developed with f'_c = 6000 psi and f'_c = 8000 psi for use in prestressed concrete girders. The equilibrium unit weight desired was to be less than 125 pounds per cubic foot (pcf).

The intermediate portion of the project focused on structural factors including transfer and development length of prestressing strand in lightweight concrete, flexural testing of lightweight prestressed concrete beams, the use of lightweight prestressed deck panels, and the manufacture of the beams and the deck panels. This phase included full scale testing of AASHTO Type I (Texas Type "A") precast pretensioned prestressed concrete beams with composite slabs.

The final phase was an economic and analytical study of practical bridge applications.

What We Did...

The initial portion of the project investigated mix designs for usable high-strength lightweight concrete mixes for possible use in pretensioned bridge girders. Two distinct concrete mixes were developed. One was intended to have a 28-day strength of 6000 psi while the other was intended to have a 28-day strength of 8000 psi. (Subsequent results indicated that the 8000 psi design was impractical and the upper strength was re-rated as 7500 psi.) Both also were intended to have a strength of at least 3500 psi at one day of age to expedite release of prestress in precast plants.

To obtain these two mixes, an extensive laboratory mixing and testing program was carried out. Thirty-five mixes were designed and fabricated. For each of the mixes, mechanical behavior and workability was determined. From these mixes, two mix designs were chosen that combined the best mechanical performance with adequate workability performance.

Using each mix, one highly congested 20-foot long and two normal 40-foot long beams were plant cast. The 20-foot long beams represented the highest degree of congestion that might reasonably be expected.

After the forms were removed and the transfer length testing was performed, the beams were brought to Austin for testing the development length and flexural capacity of the beams. A group of prestressed lightweight concrete panels were cast by a local fabricator. Transfer length tests were performed there.

Extensive comparative analyses of a typical bridge span using AASHTO Type IV bridge girders and decks made from various combinations of normal weight and lightweight concrete were performed using the TxDOT prestressed girder design program, PSTRS14. Three different composite deck combinations were used in the analyses.

Finally, an economic and constructability analysis was carried out. Several Texas precast concrete product manufacturers supplied premium costs for lightweight concrete and beam manufacture. These studies assessed the economic practicality of using high performance lightweight concrete.

What We Found...

The mix design phase of the project was moderately successful. A highly dependable 6000 psi mix was attained. Mix design is included in Report 1852-1. The 6000 psi mix was controlled by the 1-day strength requirement. 4000 psi at 1 day was achieved with 7.15 sacks of Type III cement with 25% replacement of fly ash. The 28-day strength of the concrete averaged 7200 psi in the laboratory and 7800 psi in the field. The fresh unit weight of the concrete was 127 pounds per cubic foot (pcf), which later decreased to 118 pcf at equilibrium conditions. This concrete mix provided about 30 minutes of working time under room temperature and average humidity conditions. The concrete placed well at the precast plant.

The desired 8000 psi was attained in the laboratory, but field studies indicated that 7500 psi was a more practical maximum. Mix design is included in Report 1852-1.

To reach 8000 psi at 28 days, 10.5 sacks of cementitious material were required. The 1-day strength was 5500 psi, easily surpassing the 1-day strength requirement. The 28-day strength of this mix in the laboratory was 8600 psi but in the field was probably only 7500 psi, and the 180-day strength of this mix in the field was 7900 psi. The fresh unit weight of the concrete was 129 pcf, dropping to 122 pcf at equilibrium conditions. The concrete was somewhat difficult to work in the laboratory. At room temperature and humidity conditions, this concrete gives only about 20 minutes of workability. At the precast plant, the workers had trouble placing the concrete. However, as shown in Figure 1, the final product was very satisfactory in appearance.

Overall, the performance of the nominal 8000 psi concrete was somewhat disappointing. The performance in the field was not adequate for 8000 psi concrete. It would be acceptable for a nominal 7500 psi mix.

The structural test phase of the project was very successful. It was determined that the ACI and AASHTO code expressions for transfer length (50 d_b) are a conservative estimate of the transfer length for ½ in. strands in normalweight concrete (37 d_b), but underestimate the transfer length for ½ in. strands in lightweight concrete (70 d_b). The transfer length at transfer of the prestressing force for 3/8-in. strands in the lightweight concrete deck panels in this study was 43 d_b, about 10% longer than for normalweight concrete panels. Clearly, the modulus of elasticity is an important factor in determining the transfer length for both normalweight and lightweight concrete. The actual development length for ½ in strands in all girders was less than 60 in. The AASHTO/ACI development length equation is conservative for both normalweight and lightweight concrete girders. The ultimate moment capacity developed by the lightweight concrete girders and the load-deflection curves for those girders were virtually identical to those for the normalweight concrete girders. The full AASHTO ultimate moment capacity of the girders was developed with a substantial reserve.

The comparative analysis study of this project was quite successful and showed many unexpected results. It was determined that higher prestress losses and lower allowable tensile stresses dramatically reduced the efficiency of the lightweight concrete girders. Elastic shortening was determined to be the key prestress loss variable in lightweight concrete. While lightweight girders using 7500 psi concrete had no problem satisfying allowable stress criteria and could be used for the standard TxDOT bridge section (110 feet span and 8.5 feet beam spacing) used in the analysis, lightweight concrete girders using 6000 psi concrete mix design could not satisfy allowable stress criteria at release. Hence, the maximum span length that could be achieved would be less than 110 feet. Lightweight concrete panels, contingent upon verification of allowable tensile stresses under fluid deck concrete dead load capacity, could be implemented and could potentially produce savings in shipping and handling costs as well as reduction of dead load transmitted to the girders and substructure. Use of the standard TxDOT design program PSTRS14 showed that revisions were required to make it fully functional for the design of lightweight concrete beams.

The economic studies showed that the premium cost of lightweight concrete ranged from $6/cy to $30/cy, with the average of all premium costs equal to $18.50/cy. Comparisons of normalweight concrete and lightweight concrete bridge girders shipped approximately 40 miles revealed 10 to 15% higher unit cost for the lightweight girders.

Details of the complete testing program, comparative analyses, and an economic factors study are provided in Report 1852-1 (Structural Lightweight Concrete Prestressed Girders and Panels) and Report 1852-2 (Feasibility of Utilizing High Performance Lightweight Concrete in Pretensioned Bridge Girders and Panels).

The Researchers Recommend...

The research team recommends that the use of lightweight concrete precast deck panels be immediately considered as an alternate to normalweight concrete precast deck panels. A check should be made of the standard panels to determine in which lengths the allowable tensile stress under fluid deck concrete dead load governs. Panel ranges that are sensitive to the tensile stress limits could be required to be normalweight concrete or higher prestress levels could be specified.

Pretensioned lightweight concrete girders can be used in applications where economic analysis and/or construction limitations such as crane capacity make them desirable. It is necessary to check their shear capacity for the longer transfer length noted and the reduced tensile strength of the lightweight concrete. These should not be severe limits but may require some additional shear reinforcement.

The increased losses due to elastic shortening which reduce the economic savings with lightweight concrete *pretensioned* applications are not a factor in post-tensioned applications. Lightweight concrete should be examined for possible application in post-tensioned bridges.

Figure 1 Finish of Girder with 8000 psi Concrete Mix

For More Details...

Research Supervisors: John E. Breen, P.E., (512) 471-4578, jbreen@mail.utexas.edu
Ned H. Burns, P.E., (512) 471-7298, nedburns@mail.utexas.edu

TxDOT Project Director: Tom Rummel, P.E., (512) 416-2254, trummel@dot.state.tx.us

The research is documented in the following reports:

Research Report 1852-1, *Structural Lightweight Concrete Prestressed Girders and Panels*, September 2001.
Research Report 1852-2, *Feasibility of Utilizing High-Performance Lightweight Concrete in Pretensioned Bridge Girders and Panels*, January 2002.

To obtain copies of the above reports, contact the Center for Transportation Research, The University of Texas at Austin, (512) 232-3126, ctrlib@uts.cc.utexas.edu.

TxDOT Implementation Status
February 2002

The results of this project gave TxDOT the basic tools (concrete batch designs and modifications to design processes) needed to design prestressed beams using lightweight concrete, should that prove necessary. It also demonstrated that fabrication of typical beams should be fairly straightforward using lightweight concrete, and those beams should behave satisfactorily under typical loading conditions. The research did, however, show that the use of this material, for a number of reasons, would probably not be useful in most prestressed beam applications except in rare circumstances.

The use of lightweight concrete deck panels will not be implemented at this time, due to unresolved questions regarding economics and design constraints due to tensile stress limits for deck panel applications. Further work in this area is being contemplated to resolve these issues.

The research did provide useful results for implementation in certain specific instances for post-tensioned lightweight concrete structural elements on a case by case basis, although not as a standard process. The necessary information was developed for designers to utilize this option should conditions warrant.

For more information, please contact Mr. Tom Yarbrough, P.E., RTI Research Engineer at (512) 465-7685 or email at tyarbro@dot.state.tx.us.

Your Involvement Is Welcome!

Disclaimer

Center for Transportation Research
The University of Texas at Austin

The University of Texas at Austin
Center for Transportion Research
3208 Red River, Suite #200
Austin, TX 78705-2650