USE OF PRESTRESSED CONCRETE PANELS
FOR PAVEMENT CONSTRUCTION

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INTRODUCTION

This paper contains a description of the research and developmental work directed by the author for a more effective utilization of the strength of prestressed concrete for highway pavement design and construction. The pavement that evolved from this research work consists of prestressed concrete panels covered with asphaltic concrete. This new concept in pavement design is referred to in this paper as a composite pavement.

The paper contains a brief review of the fundamentals and problems associated with prestressed concrete pavements as an introduction to the systems analysis of the concept for composite pavement design. The systems analysis consists of the design and prefabrication of the panels, a laboratory investigation of the structural components, and the field testing of the composite pavement. This paper also contains suggestions for further uses of this new concept for the construction of other prefabricated pavement structures.

The research described in this paper was sponsored by the South Dakota Department of Highways in cooperation with the Department of Transportation (Bureau of Public Roads). Two reports (1,2) prepared

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for the sponsor contain a complete description of this research and developmental work. A brief report on the first field study was published (3) in the Highway Research Record Number 239.

PROPERTIES AND PROBLEMS ASSOCIATED WITH PRESTRESSED CONCRETE PAVEMENTS

The basic concept of prestressing structural components for a better utilization of the strength properties of two or more materials is not new. However, in recent years this concept has been used very extensively in view of the significant increases in material strengths and the current demands for more efficient and economical structural systems.

In essence the prestressing concept consists of the combination of an elastic material having a high tensile strength (such as steel) with a material having a high compressive strength (such as concrete). By prestressing the steel so that some percentage of the tensile strength counterbalances some percentage of the compressive strength in the concrete, a "preloaded" structure is produced with a high level of resisting moment per unit of deflection. The compressive stress in the concrete is introduced by pretensioning or post-tensioning the steel tendons. After the pretensioning or post-tensioning force is removed from the tendons, the structural system will be reduced in length in proportion to the stress levels and the moduli of elasticity of the two materials (5). However, when prestressing or post-tensioning structural members that remain in place, the reduction in length that is associated with the transfer of prestressing force to the structure is resisted by subgrade friction. The author recognized
the loss of prestressing force to subgrade friction as one of the major deterrents to the use of prestressed concrete for pavement construction.

The research and developmental work described in this paper was directed toward a plant production of panel components for field placement. This approach was considered a rational solution to the problem of losing significant levels of prestressing force to subgrade friction. Field placement of prefabricated panel components also offered a solution to the problem of shrinkage cracks developing in concrete slabs. The following sections contain brief summaries of the significant findings obtained from this study of composite pavement design and construction.

COMPOSITE PAVEMENT DESIGN AND LABORATORY TESTING

The concept of prefabricating structural components for field placement represented a significant departure from conventional pavement construction practices. This systems approach was envisioned primarily to circumvent the problem of losing significant levels of prestressing force to subgrade friction. However, a further study of this construction procedure revealed other advantages as described below:

(a) The elimination of the problem of tensile stresses developing in concrete slabs during hardening and curing (shrinkage cracks).

(b) The availability of quality controls and efficient prestressing operations through the use of a plant operation.

(c) The opportunity to give more continuity to the construction operation in areas confronted with adverse weather conditions.
After establishing a generalization of the structural and economical advantages associated with the use of prefabricated panels, the next problem consisted of the selection of a weather resistant surface course with a high level of flexibility. Asphaltic concrete was selected for this need in view of the material properties and excellent riding characteristics demonstrated by this material. This combination of materials yielded a composite pavement consisting of prestressed concrete panels for the pavement structure and asphaltic concrete for the leveling and riding course. This new type of pavement reflected intermediate levels of flexibility and rigidity as well as other favorable features associated with rigid pavements and flexible pavements.

In the absence of design guidelines, it was necessary to use engineering rationale coupled with a program of laboratory testing for the design of the composite pavement structure. Engineering rationale dictated the preliminary selection of a minimum panel thickness of 4 1/2 inches. This was considered the minimum panel thickness that would provide adequate cover for the tendons and the panel rigidity necessary to withstand handling stresses. The level of prestress (approximately 300 psi) recommended by Mellinger (4) was increased to 350 psi for panel construction. After selecting a panel depth and a level of prestress, a modular panel was designed to utilize the load carrying capacity of a four-ton crane. A prestressed concrete panel 6 feet wide, 24 feet long, and 4 1/2 inches thick was found to satisfy the above described requisites. With these dimensions the panels could be placed in a longitudinal or a transverse pattern for the construction of a paved surface 24 feet wide.
The panels were designed to transfer vertical shearing forces to adjacent panels through a grout key. The panel design also included steel panel connectors to further strengthen the panel joint and prevent lateral movement or panel separation. Figure 1 shows the basic design information and the details for the prefabrication of a prestressed concrete panel (interior panel) to be placed in a longitudinal arrangement. The grout key and panel connectors are not required along the outer edge of exterior panels.

The details of the composite pavement structure involving the use of prestressed concrete panels are shown in Figure 2. Primary consideration was given to the longitudinal arrangement of the prestressed panels in view of the simplified construction operations and the promise of a high type riding surface. The use of the longitudinal pattern simplifies the construction of a pavement with cross slope or crown symmetrical about the center line. The alternation of the panel joint between the outside and inside wheel path offers definite promise for high type riding characteristics as well as an improvement in the structural performance of the pavement.

A comprehensive program of laboratory testing was used to establish the structural performance of panels 4 1/2 inches thick and prestressed to a level of 350 psi. This program consisted primarily of the application of repetitive wheel loads to a prototype section of the composite pavement supported on an elastic foundation. One phase of the testing program consisted of the application of longitudinal forces to simulate the effects of expansion and contraction in the pavement structure. The program of laboratory testing was designed to establish data regarding the following structural performance char-
PRESTRESSED IN LONGITUDINAL DIRECTION
WITH 9, SEVEN-STRAND, TENDONS 3/8" DIA. NUMBERRTEN.
5000 psi CONCRETE & 350 psi PRESTRESS.

TOTAL WEIGHT = 4 tons

by HARGETT

FIGURE I. MODULAR PANEL DESIGN FOR PRESTRESSED CONCRETE PAVEMENT
FIGURE 2. ISOMETRIC VIEW OF COMPOSITE PAVEMENT CONSTRUCTION
acteristics:

(a) Structural performance of the composite pavement when subjected to repetitive wheel loads.

(b) Structural performance of the grout keys and steel connectors when subjected to vertical shearing forces (repetitive wheel loads).

(c) Structural performance of grout keys and steel connectors when subjected to longitudinal shearing forces (forces associated with expansion and contraction).

The repetitive load testing consisted primarily of a study of the changes in pavement deflection and the pumping potential of the granular base material. At the beginning of a series of load applications the pavement was deflected 0.020 inches at the center by a 5000 pound wheel load and a 100 psi tire pressure. After 50,000 wheel load applications the pavement deflection decreased to 0.014 inches. The pumping potential of the base material was tested during saturation by the application of more than 5000 wheel load (7500 lb.) applications two feet from the pavement edge. Both testing procedures furnished indices of favorable structural performance. More than 300,000 wheel load applications were applied to the pavement structure during the program of testing without reflecting a significant increase in pavement deflection or any indication of structural failure.

The grout keys and panel connectors were subjected to a shearing force equivalent to a wheel load of 7500 lbs. The panels were supported with timbers along the joint so as to subject the joints to a shearing force equal to the wheel load. The grout keys and panel connectors withstood more than 50 wheel load applications without any indication of structural failure.

The longitudinal force applications provided test data regarding
the stress-strain relationship of grout keys and panel connectors. This testing procedure pointed up the feature of the longitudinal panel assembly whereby some percentage of the temperature stresses will be counterbalanced by opposing stresses in adjacent panels.

FIELD TESTING AND EVALUATION

Two field test sections of composite pavement were sponsored by the South Dakota Department of Highways for a study of construction methods, construction costs, and field performance. The test sections consisted of a 96 foot pilot test section constructed in a driveway and a 1000 foot test section constructed on a mainline highway. These two field test sections are described briefly in the following sub-sections.

Pilot Field Test: The pilot field study of construction methods, construction costs, and field performance was used first for reasons of economy. The pilot test consisted of a 96 foot prototype test section of composite pavement as described in Figure 2. This test section was constructed in a driveway (driveway and parking area at South Dakota Department of Highways building east of Brookings, South Dakota) during September 1966. The panels as described in Figure 1 were prefabricated and laid in a longitudinal pattern by Gage Brother Concrete Products Company of Sioux Falls, South Dakota. The foundation for the panels consisted of a sand bedding course 1 1/2 inches thick and a granular base course 8 inches thick. Figures 3 and 4 show the field placement of the 4 ton prestressed panels on the prepared foundation. After "seating" the panels with a limited number of wheel loads, the tongue and fork connectors were tightened and the
grout keys were filled with a high strength grout. Figure 5 shows a tongue and fork connector and the grout key opening between adjacent panels. After the grouted key ways cured, the interconnected panel assembly was covered with a bituminous surface course approximately 1 1/2 inches thick.

There were no construction problems revealed by the pilot field test. The construction cost amounted to $14.45 per square yard. Benkelman beam deflections, plate bearing tests, and measurements of expansion and contraction were used for an evaluation of the structural performance of the composite pavement structure. The test data obtained from the above described test procedures reflected favorable structural performance. One of the most significant indices of superior structural performance was reflected in the pavement deflections obtained from a 46,000 lb. plate load. These pavement deflections reflected the effectiveness of the pavement by distributing the effects of the 46,000 pound plate load over the entire width of the pavement (24 ft. pavement). After obtaining favorable results from the pilot test, the South Dakota Department of Highways approved a proposal prepared by the author for the construction of a 1000 ft. test section of composite pavement on a mainline highway.

Field Test on a Mainline Highway: A 1000 ft. test section of composite pavement was constructed on U. S. 14 Bypass north of Brookings, South Dakota, during the summer of 1968 for a further study of pavement performance under typical highway conditions. This field study included an investigation of use of prestressed panels in longitudinal and transverse arrangements as shown in Figure 6. The original design was modified by increasing the level of prestress to 400 psi and abandoning the use of the tongue and fork connectors. The modified panel connectors
FIGURE 6. TEST SECTIONS ON MAINLINE HIGHWAY
consisted of reinforcing bars cast in the panels for field welding.

The prestressed panels were produced by Gage Brothers Concrete Products Company of Sioux Falls, South Dakota. The test section was constructed by Western Contractors of Sioux City, Iowa. The panels were placed at an approximate rate of one per five minutes without encountering any special construction problems. This field test was also designed to furnish additional information regarding construction methods, construction costs, and field performance. Benkleman beam deflections, plate bearing tests, and precise measurements of the length and profile of the pavement are to be used for an evaluation of field performance. A preliminary report on the above tests should be available during this year (1969).

SUGGESTIONS FOR FURTHER APPLICATIONS OF COMPOSITE PAVEMENT CONSTRUCTION

This new concept for the construction of a prefabricated pavement with a high strength and a high level of flexibility offers definite promise for a variety of paving needs. The author considers the use of composite pavement construction of definite promise for the following needs:

1. An economical method for the strengthening of our existing airport pavements.
2. A high strength weather resistant material suitable for bridge deck construction.
3. Structural components suitable for rapid repairs on existing bridge decks.
4. A high strength pavement for truck terminals and truck-rail terminals (piggy back areas).
5. For the construction of helicopter pads for military installations and service areas.
6. For the construction of a temporary pavement for overland movements of heavy industrial or military equipment.
7. For the construction of city streets, alleys, and parking lots that can not be taken out of service for long construction periods.
Most of the above described needs originate in and around large metropolitan areas that have access to prestressing plants. It is believed that the practicality of a further use of prefabricated structural components is unquestioned in view of the quality of the product and the simplification of labor problems.
APPENDIX - REFERENCES


