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Demonstration and Field Evaluation of Alternative Portland Cement Concrete Pavement Reinforcement Materials

Construction Report

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REPORT

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Disclaimer

"The opinions, findings, and conclusions expressed in this publication are those of the author and not necessarily those of the Iowa Department of Transportation nor the United States Department of Transportation, Federal Highway Administration."

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ACKNOWLEDGEMENTS

This project is the combined effort of Iowa State University and the Iowa Department of Transportation. The researchers would like to acknowledge the Iowa DOT's Office of Materials Special Investigations Unit, ERES Consultants and RUST Engineering for contributing their time and effort in collecting and analyzing raw field data.

This research would not be possible without the cooperation of the Flynn Construction Co. and their staff. This is another example of how the construction industry benefits from cooperative research efforts.

ABSTRACT

The function of dowel bars is the transfer of a load across the transverse joint from one pavement slab to the adjoining slab. In the past, these transfer mechanisms have been made of steel. However, pavement damage such as loss of bonding, deterioration, hollowing, cracking and spalling start to occur when the dowels begin to corrode. A significant amount of research has been done to evaluate alternative types of materials for use in the reinforcement of concrete pavements. Initial findings have indicated that stainless steel and fiber composite materials possess properties, such as flexural strength and corrosion resistance, that are equivalent to the Department of Transportation specifications for standard steel, 1 ½ inch diameter dowel bars.

Several factors affect the load transfer of dowels; these include diameter, alignment, grouting, bonding, spacing, corrosion resistance, joint spacing, slab thickness and dowel embedment length. This research is directed at the analysis of load transfer based on material type and dowel spacing. Specifically, this research is directed at analyzing the load transfer characteristics of: (a) 8-inch verses 12-inch spacing, and (b) alternative dowel material compared to epoxy coated steel dowels, will also be analyzed.

This report documents the installation of the test sections, placed in 1997. Dowel material type and location are identified. Construction observations and limitations with each dowel material are shown.

INTRODUCTION

Dowel bars are used as transfer mechanisms to assist in the prevention of damage to roads and highways caused by pumping and faulting at the slab-joint interface. Specifically, the function of dowel bars is to transfer a load across the transverse joint from one pavement slab onto the adjoining slab [3]. The most commonly accepted material used to make the dowel bars is steel. However, an increasingly severe problem associated with the use of steel dowel bars is the significant amount of pavement damage that occurs when the steel starts to corrode. Because the dowels span the contraction joints, they are susceptible to corrosion from the environment and the salt used for ice control. Once corrosion in the joint begins the function of the dowel to act as an efficient transfer mechanism is reduced. Dowel corrosion causes the dowel bar to fail or freeze, which can result in joint faulting, spalling and cracking.

Research has been done to develop a protective coating that can be used to cover the steel dowel bars and prevent corrosion. Various coatings developed from materials such as asphalt cement and epoxy resins have been evaluated using laboratory procedures and full scale field applications under normal operating conditions. Results of these tests have shown that protective coatings can significantly affect the bond strength of the reinforcing material. In addition, testing results have indicated that the protective coating can cause more damage then it can prevent. If the dowel bar is not completely covered, corrosion of the steel will result. An uncovered area the size of a pinhole can corrode at a faster rate then if the whole dowel bar was not covered. Careless storing, handling or placement of the dowels in the concrete can damage or nick the protective coating resulting in corrosion of the dowel bar.

Although protective coatings are a logical solution used to prevent corrosion of steel dowels, limited research results are available that describe performance characteristics of the protective coating. This information is important due to the relationship between the performance characteristics of the protective coating and the service life of the pavement. In addition, as previously mentioned, available research results have indicated problems, other then corrosion, that can reduce the steel dowel's ability to function as an efficient load transfer mechanism. As a result of these findings or lack there of, new methods and materials that can prevent and eliminate pavement damage due to corrosion of the steel dowels need to be investigated.

The use of alternative materials, such as fiber composite and stainless steel, as reinforcement in pavements and structures is rapidly becoming a subject matter of extensive testing and research. The goal of this research is to evaluate field performance of and provide recommendations on design, materials, construction practices and performance characteristics of stainless steel and fiber composite dowel bars. Using this information material, highway, construction and structural engineers will be able to make decisions regarding the use of stainless steel and fiber composite materials in projects involving rehabilitation, repair and new construction of pavements and structures.

Stainless steel materials have been used in the commercial industry since the 1920's. However, due to the increase in cost when compared to other materials, the construction industry has been reluctant to use stainless steel extensively. Applications for the use of fiber composite materials are most commonly found in the aerospace and aeronautics industries. Parts of space shuttles, fighters and bombers are manufactured using fiber composite materials. Similar to stainless steel materials, the use of fiber composites in the construction industry is very limited. Manufacturers feel that the biggest barrier to the use of fiber composite materials is the limited amount of knowledge that engineers and contractors have about their properties. Although some research has been done to determine the properties of fiber composite, a significant amount of research is still needed.

Projects which currently involve research and testing of fiber composite materials as an alternative material for reinforcement include (1):

- Army Pier restoration in Oakland, California
- Cable stayed suspension foot bridge in Perthshire, Scotland
- I-95 prestressed concrete bridge beam repairs in West Palm Beach, Florida
- Polymer concrete parapet panels used on the Pennsylvania Turnpike and Allegheny Bridge and
- Composite wrap repairs of structural columns on FDR Drive in New York City.

Existing highway and structural projects that currently involve research and testing of stainless steel as an alternative reinforcement material include (1):

- Michigan DOT bridge deck (built in 1984) containing stainless steel reinforcing bars for one-half and epoxy coated steel for the other,
- New Jersey bridge deck (1984) containing stainless clad reinforcing bars,
- Stainless steel dowel bars in Maryland Highway 97 in the late 1980's,
- Adoption of stainless steel specifications for concrete reinforcing bars by the British Standards institute, and
- Stainless steel reinforcing projects planned by the Oregon DOT, the New Jersey Turnpike Authority, and the Ontario Ministry of Transport.

Characteristic properties that make stainless steel and fiber composites good candidates for an alternative reinforcement material include resistance to corrosion, durability, high tensile strength and in the case of the fiber composite material, ease of handling, flexibility and light weight. Attributes that have made the construction industry apprehensive to the use of stainless steel and fiber composite materials as an alternative reinforcement material include an increase in cost, low modulus of elasticity, low shear strength, low abrasion and in some instances problems with long term durability. Although these weaknesses are more characteristic of the fiber composite materials, the increase in cost is a definite disadvantage in the use of stainless steel as an alternative reinforcement material.

This research is directed at evaluating the deflection basins of fiber composite and stainless steel dowels to estimate load transfer capabilities. Various dowel materials, diameters and spacings were used and compared to the characteristics of the standard steel coated, 1-½ inch diameter dowel bars placed at 12-inch spacings.

The fabrication of dowels using fiber composite and stainless steel materials is different from that of standard coated steel dowels. Dowel bars made from fiber composite materials are "a matrix of polymeric material that is reinforced by fibers or other reinforcing material." Other elements needed to fabricate fiber composite dowels include resins (polymers), fiber reinforcements, fillers and additives. Stainless steel dowels can be manufactured as (1) solid bars of full section stainless steel, (2) stainless clad bars with a core of mild steel or other material and a bonded stainless steel outer layer, (3) stainless steel hollow pipes and (4) stainless steel pipes filled with concrete or other materials. This research is evaluating the performance of the solid stainless steel bars. Although the materials combined to fabricate dowels using alternative materials differ slightly from those of the standard coated steel bars, all materials meet the requirements described in Iowa Department of Transportation (Iowa DOT) specification #4151, Steel Reinforcement.

RESEARCH OBJECTIVES

This research uses "in-service" field applications to demonstrate the performance of fiber composite, epoxy coated steel and stainless steel dowels in highway pavements. Problems associated with the installation and use of each type of dowel in one continuous pavement section. The specific goal of this research is the comparative study of highway joints reinforced with fiber composite dowel bars and tie bars to the behavior of conventional steel and stainless steel bars under the same design criteria and field conditions. Accomplishing this goal will require the completion of the following tasks:

Task I: Field Installation and Data Collection
Task II: Data Analysis
Task III: Report Development

Terminology

While conducting research and writing the construction and other additional reports, it may be necessary to clearly define several key terms. These terms are related to the testing and analysis of this research.

- Deflection Basin – Curve formed by deflection responses, to the application of a known load, at known locations away from the load. The following independent variables define the deflection basin (1) d_o the maximum deflection under the center of the falling weight deflectometer load plate and (2) the cross sectional "area" of the [2].
- Dense liquid foundation – Force-deflection relationship is characterized by an elastic spring.

- Dynamic loading – Loading conditions that represent a situation where the load applied is in constant motion.
- Geophones – Deflection sensors on the falling weight deflectometer that record the pavement's response to being loaded with a known mass.
- Modulus of elasticity (E) – The ratio of stress to strain in the elastic range of a stress-strain curve. $E = f/\varepsilon$, where f = stress and ε = strain
- Load transfer – The ratio of the strain on the unloaded side of the joint to the total strain (sum of the strain on the loaded and unloaded sides) expressed as a percentage.
- Measured joint efficiency – The ratio of deflections of the unloaded slabs to the loaded slabs.
- Modulus of sub-grade (k-value) – The ratio of the pressure of a loaded plate (10 psi) to the deflection of the plate. $k = p/\Delta$, where p = the load on the plate and Δ = the deflection of the plate.
- Non-destructive testing – Testing that results in no major disruption of the pavement. Non-destructive testing usually involves techniques used for "surface measurement deflection or curvature combined with small core drilling to obtain thickness and samples of underlying material for laboratory testing." [3, p. 110]
- Static loading – Loading conditions that represent a situation where the load applied is at rest or moving with a constant velocity in a straight line.

PROJECTS

Through a grant from the Federal Highway Administration, the Civil Engineering Research Foundation organized the Highway Innovative Technology Evaluation Center

(HITEC). The purpose of HITEC is "to expedite the introduction of new innovative technologies to the highway program particularly from the private sector and the entrepreneur who might not otherwise seek to penetrate the diverse and difficult highway market." [5, p.1]

HITEC has provided a significant amount of support and research opportunities in the areas of stainless steel and fiber composite materials. On May 8, 1998, HITEC presented an evaluation plan for fiber reinforced polymer composite dowel bars and stainless steel dowel bars. The evaluation plan consisted of three parts:

1. Literature Review
2. Field Installations
3. Laboratory Investigations

The literature review consisted of reviewing research conducted by the Engineering Research Institute at Iowa State University and by the Federal Highway Administration. The results of this literature review provided documents that contain information on the research of highway facilities that use alternative materials for reinforcement and/or structural members. In the U.S, the states of Illinois, Connecticut, Ohio and Arkansas have all constructed highway projects that involve the use of alternative reinforcement. [5]

HITEC contacted the DOTs at Illinois, Iowa, Kansas and Ohio to study the performance of field installations that contain alternative material for reinforcement. The field installations could be new construction or rehabilitation of concrete pavements containing joints that use alternative materials for dowels. The research is funded by the FHWA under the project, TE-30, High Performance Rigid Pavements (HPRP).

The actions of HITEC are limited to the evaluation of the fiber composite and stainless steel dowels "installed in standard joints designs using bond breakers as recommended by the manufacturers providing the dowels."[5, p. 6] The highway agencies performing the research will monitor the pavement directly after construction is completed and at six month periods for the first eighteen months of service life. The test site will then be monitored annually for five years after which sample cores and full length dowels will be removed and evaluated. Conclusions and recommendations will then be made regarding the performance of the materials used for reinforcement.

Monitoring of the test site will consist of (1) assessing the pavement condition using the procedures outlined in the Strategic Highway Research Program Manual (SHRP), (2) measuring load transfer using falling weight deflectometer testing and (3) determination of dowel location using NDT methods such as ground penetrating radar (GPR). Evaluation will also be made regarding the joint condition along with deflection testing and "coring of "old" FRP and Stainless dowels from concrete pavement joint repair installations made in Ohio in 1985 on I-77 in Guernesy County, and FRP dowels installed in 1983 in Ohio on State Route 7 in Belmont County. Cores and full-length dowels to be cut from the Ohio pavements will be used in the laboratory investigations."[5, p. 7] The cores and dowels that are removed from the preceding sections will be inspected and tested for any type of degradation and desired performance characteristics. Additional laboratory investigation will consist of testing dowel bar samples of each material type and concrete castings to evaluate dowel fatigue, dowel debonding or pull out stress, dowel durability and load transfer using dowel shear tests.

Each state that is currently evaluating the performance of alternative materials for reinforcement in concrete pavements was asked to provide a documented summary of preliminary progress/results of the test sites was available. Although it is too soon for any results to be confirmed, construction reports are available from the states of Wisconsin and Illinois. The states of Kansas and Ohio don't have any available documentation on the progress of their test sites. A review of the construction reports from Wisconsin and Illinois revealed no significant differences in construction, alterations made to construction procedures or problems encountered during construction.

RESEARCH

A significant amount of research involving stainless steel and fiber composite materials has been conducted at Iowa State University. Most of this research has involved laboratory investigations of engineering properties such as tensile strength and modulus of elasticity of the fiber composite and stainless steel materials.

Michael Albertson lead the laboratory investigation of fiber composite and stainless steel dowels in 1992. The objective of Albertson's research was to explain the factors that contribute to the behavior of fiber composite and stainless steel dowels. These factors include "material behavior topics such as shear strength of fibercomposites, bearing strength of concrete and shear cone strength of concrete."[2, p 7]

Results of Albertson's research indicated much higher deflections for the fiber composite dowels at the face of the joint compared to the deflections of the stainless steel dowels. The fiber composite dowel deflections averaged 0.113 inch at 10,000 pounds compared to 0.0075 inch deflection of the stainless steel dowels. At 4,500 pounds the fiber composite dowels deflected 0.059 inch compared to 0.0034 inch deflection of the stainless steel dowels at the same load. Values of static deflection for each material type were under 0.13 inch at 4,500 pounds, which is the recommended maximum allowable value set by FHWA.

Kent Fish was performing research on fiber composite dowels during the same time as Albertson. Fish had three objectives which included [3, p 4]: (1) determination of *the feasibility of FCR as reinforcement for concrete structures,* (2) formulatation of *an expression for the development length of both three-eigths inch and on-half-inch diameter fiber composite reinforcement rods and* (3) development of a *the test procedure and test apparatus for FCR reinfocement concrete.* In addition the engineering properties of tensile strength and modulus of elasticity of fiber composite dowels were determined.

Testing 127 beams, which were reinforced with fiber composite dowels, indicated that "conventional reinforced concrete analysis techniques could be utilized for FCR-reinforced beams."[3, p 121] The results of Fish's research are summarized in table 1.

Advantages	**Disadvantages**
• High tensile strength • High corrosion resistance • Lightweight, therefore easily shipped and handled • Creates fewer concrete splitting problems • FCR does not generate magnetic field	• Low modulus of elasticity • Long development length • Brittle tensile failure • Low compressive strength • Low dowel shear strength

TABLE 1. Advantages and Disadvantages of Fiber Composite Reinforcement

Eric Lorenz continued the research by analyzing the accelerated aging process of fiber composite dowels and bars. Lorenz's objectives included determining [8, p 2]: (1) *shear behavior and strength of FC dowel bars without aging,* (2) *shear behavior and strength of FC dowel bars with aging, and* (3) *potential aging effects on bond of FC reinforcing bars.* Results of Lorenz's research revealed the fiber composite materials resistance to accelerated aging effects particularly in corrosive environments.

Research performed in 1995 by Jacob Mehus investigated long term durability of fiber composite reinforcement for concrete. The objectives that Mehus established included[9, p 4]: (1) evaluation of *the structural behavior and tensile strength of unaged commercially available FRP rebars and prestressing tendons,* (2) evaluation of *the structural behavior and tensile strength of commercially available FRP rebars and prestressing tendons directly exposed to an accelerated aging solution,* (3) determination of *the potential effect of corrosion or simulated aging on FRP rebars under constant load, and* (4) investigation of *the potential effect of corrosion or simulated aging action on prestress losses in concrete beams reinforced with FRP prestressing tendons.*

Results of Mehus' research indicated lower ultimate tensile strengths then expected for the unaged fiber composite dowels. The lower values of tensile strength were verified by experiments performed at the University of Wyoming and the results of flexural testing conducted at Iowa State University. The tensile strength values for aged fiber composite dowels was reduced up to 50% when compared to the tensile strength of the unaged dowels. The tensile strength values were not influenced by the effects of sustained loading, however the maximum strain capacity was slightly reduced.

During the same time that Mehus was conducting his research, Kasi Viswanath was performing laboratory and field evaluation of fiber composite dowel and tie bars for static and fatigue performances in highway pavement slabs. The specific objectives of Viswanath's research include [13, p 5]: (1) comparison of the *static and fatigue behaviors of FC dowels to those of steel dowels when used as load transferring devices across transverse joints of highway pavement slabs, and* (2) *study the bond characteristics of FC bars for potential use as tie rods across the longitudinal joints of highway pavement slabs.*

Results of Viswanath indicated that the joints reinforced with fiber composite dowels performed as well as those reinforced with standard steel dowels. In fact, the fiber composite dowels which were spaced 8 inches on center had smaller deflections then standard steel dowels spaced at 12 inches on center.

TEST SITE

As stated previously the objective of this research is to compare highway joints reinforced with fiber composite dowel bars and tie bars to the behavior of conventional steel and stainless steel bars under the same design criteria and field conditions. Full scale field applications under normal operating conditions were used to fulfill this objective. Evaluation of the performance of the fiber composite and stainless steel dowels is a five year study being performed through a combined effort by Iowa State University (ISU) and the Iowa DOT. A thorough comparison of the alternative materials used for reinforcement is best achieved over the service life of the pavement. Because the service life of a pavement can extend over 20 years or more, continuous evaluation is needed to best determine the advantages and disadvantages of the alternative materials.

The test site was constructed in September 1997 by Flynn Construction. Two lanes of concrete pavement, in one direction, were constructed with separate test sections containing fiber composite and stainless steel dowels. A control test section that contains standard epoxy coated steel dowels is also being evaluated.

This research is a combined effort of the Iowa Department of Transportation and Iowa State University. The test site location is in the southeast corner of Des Moines as a part of the US 65 bypass. The test site consists of 2,432 feet of continuous pavement made up of four different test sections. Two sections incorporating fiber composite dowels and one section incorporating stainless steel dowels were constructed. A control section containing the standard epoxy coated bars was also constructed. The location, material and dowel bar characteristics of each test section is shown in table 2.

TABLE 2. Stationing, Spacing and Dowel Bar Characteristics.

Begin Station	End Station	Material	Diameter, in.	Spacing, in.
620+03	624+43	FC (Hughes Bros.)	1 7/8	8
624+63	628+80	FC (Hughes Bros.)	1 7/8	12
629+00	630+00	FC (RJD)	1 ½	8
630+20	631+00	FC (RJD)	1 ½	12
631+20	633+42	Stainless Steel	1 ½	8
633+82	639+38	Stainless Steel	1 ½	12
639+58	644+35	Coated Steel	1 ½	12

As indicated in table 1, the fiber composite and stainless steel sections are further divided into two subsections. One subsection contains dowels spaced at 8 inches on center and the other segment contains dowels spaced at 12 inches on center. This was done to support previous research that indicated similar performance of dowels with equal diameters under laboratory conditions.

Three companies that manufacture fiber composite dowel bars expressed an interest in providing materials for this research. In addition, these companies agreed to provide tie bars to install across the longitudinal centerline joint of the test section. Hughes Brothers and RJD were the manufacturers selected because of the ease and speed at which they could provide the dowel bars. A similar procedure was used to determine the manufacturer of the stainless steel dowels. The dowels were provided at no cost to this research project for the installation into the test section.

All alternative materials used to fabricate the dowels meet the Iowa DOT specifications for flexure, shear and moment that are required by DOT specification #4151, Steel Reinforcement. Alternative dowel diameters were determined from laboratory testing and experimental research performed by the manufacturers. All alternative dowel diameters provide the same structural characteristics for load caring capacity at the current Iowa DOT standard of 1 ½-inch diameter.

EXPERIMENTAL DESIGN AND CONSTRUCTION

Experimental Design

The construction of the test site was completed in accordance with the Iowa DOT 1992 Standard Specifications for Highway and Bridge Construction series of 1992 plus current supplemental specifications and special provisions. Research staff from ISU and the Iowa DOT were on the project site to monitor and record the location of dowels in each segment and the construction procedures used by the contractor to install the dowel bars. ISU staff in conjunction with staff from the Iowa DOT, Flynn Construction, the dowel bar manufacturers and ground penetrating radar subcontractor developed the techniques used to determine the location of the dowels in the hardened concrete. Location and placement of the transverse and longitudinal dowels before paving is described in the remainder of this section.

Dowels are placed transversely across the pavement to transfer load between adjoining slabs. Generally, the diameter of the dowels used in the pavement is approximately one-eighth of the pavement thickness and 12 or 18-inches long. For a pavement that is 12-

inches thick, the diameter of the dowel used is 1-½ inches. Steel dowel "baskets" are commonly used to hold the dowels in place at the mid-depth location of the pavement. Each dowel is spot welded to a brace loop on one end (alternating ends) to prevent movement and hold the dowels at the correct height location. Spot welding one end of the dowel not only holds it in place but also ensures that one end of the dowel is tied it into the concrete. This allows the pavement slab to move independently and contract or expand in the longitudinal direction due to changes in the environment, such as temperature or moisture. Figure 1 shows the location of a transverse dowel in the pavement.

Tie bars were placed across the longitudinal joint in the pavement to tie adjoining lanes together so that the joint will be tightly closed and ensure load transfer across the joint. The standard diameter of each tie bar is ½-inch with a length of 36-inches. The spacing of the tie bars is approximately 30-inches. The paver mechanically inserted the tie bars at mid-depth of the pavement.

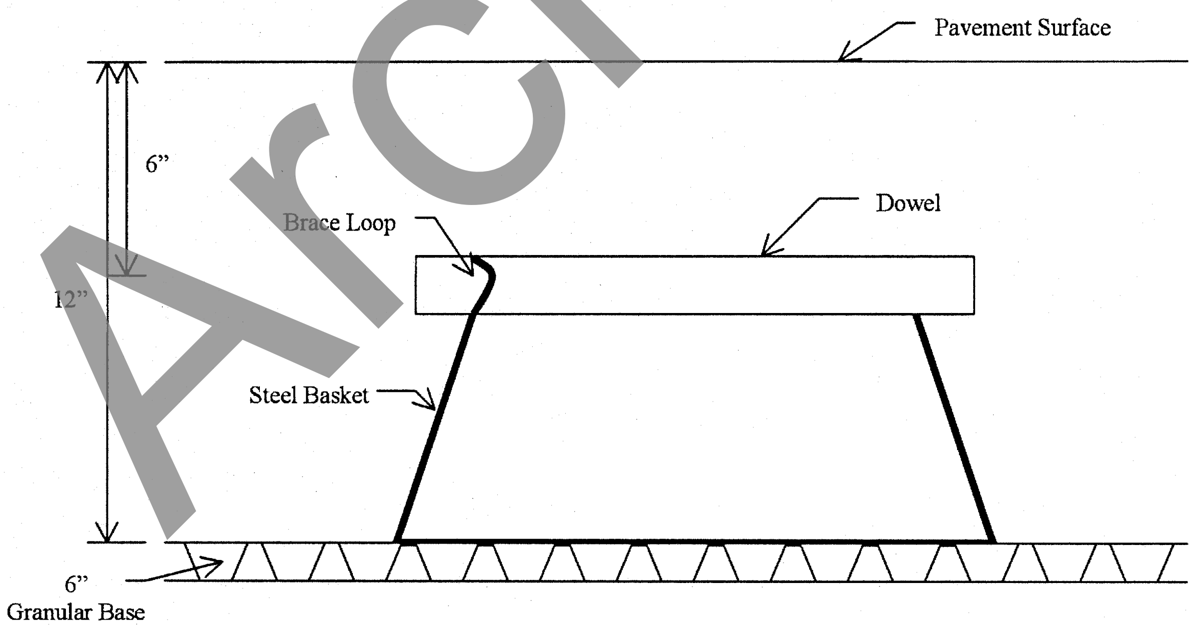

FIGURE 1. Location of a transverse dowel in the concrete pavement.

After paving has been completed, a longitudinal saw cut is made along the center of the pavement slab and a transverse saw cut is made over the top of the dowels. As a concrete pavement cures, it shrinks causing the pavement to crack. The purpose of the saw cut is to control where cracking will occur. In general the depth of a transverse saw cut is ¼ of the slab thickness with a spacing, in feet, that is not to exceed twice the slab thickness, in inches. The test section for this research includes a transverse saw cut that is 4-inches deep at 20 feet longitudinal spacing. Transverse joints were skewed to the centerline of the pavement at 6:1 right ahead to improve joint performance and extend the life of the pavement. The joint is skewed to ensure that only one wheel load crosses the joint at a time. The timing of the saw cut is important to the formation of cracks at the desired location. The transverse and longitudinal joints in the test section were formed and sealed similarly to the joints in the remaining pavement sections. Figure 2 shows the joint design of the test section.

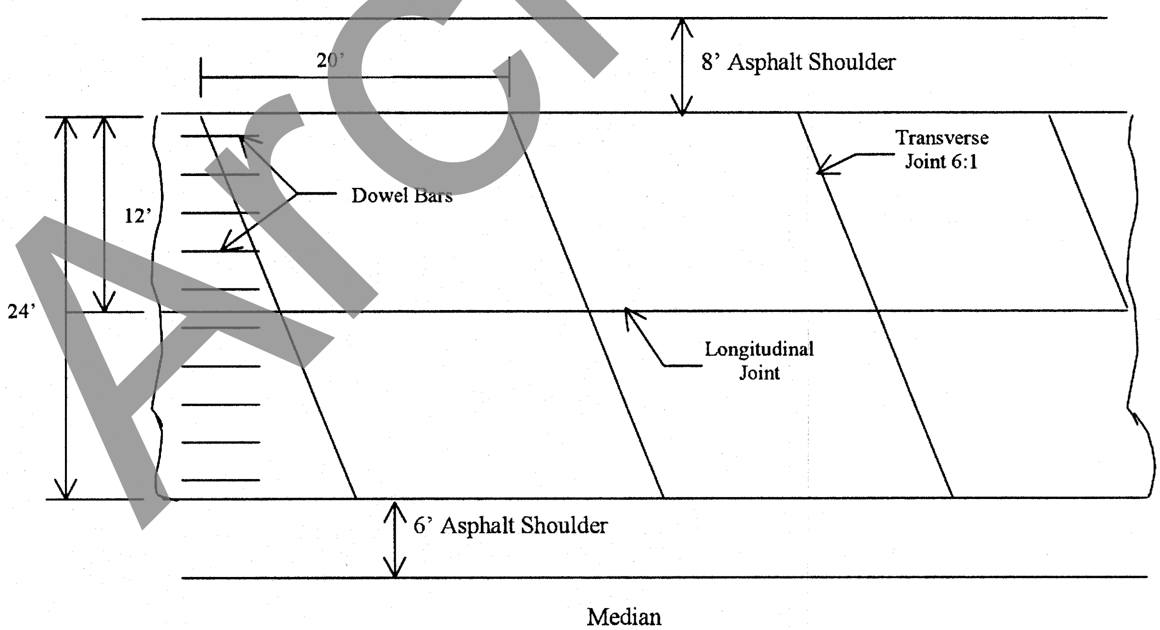

FIGURE 2. Joint design of test section.

Paved asphalt shoulders were constructed at the inside (median) and outside edges of the pavement. The inside shoulder is 6' wide with a 4% slope away from the roadway. The outside shoulder is 8' wide with a 4% slope away from the roadway. The minimum required thickness of the asphalt shoulders was 8". Figure 3 shows the dimensions and locations of the paved shoulders. An aggregate fillet with a 6:1 slope was constructed beyond the asphalt shoulders. Longitudinal subdrains were placed under the outside shoulder, adjacent to the driving lane, to drain water away from under the roadway.

Alterations Made to Construction Procedures

During shipment of the steel baskets with the dowels, the bars were shrink wrapped to minimize loss. The use of shrink wrap limited bar loss to ± 10%. The steel baskets that held the fiber composite dowels were easy to handle even though many dowels were loose in the basket as a result of not being adequately secured tied on each end during shipment. Placement of the stainless steel dowels was more difficult and required three to five people to handle them. Future use of stainless steel dowels will require "x" braces welded to the basket to prevent side sway and collapse during handling.

Minor alterations were made in the mounting technique used to secure the fiber composite and stainless steel dowels in the baskets. Due to problems associated with the heat caused by spot welding the dowels to the baskets, a new method of securing the dowels in place was used. The basket transverse brace wires could not be cut due to the lack of stability of the baskets, and plastic zip ties were "x" tied around each brace loop and end of the dowel to hold them in place. Excess tie length was cut or turned down to avoid potential problems associated with protrusion of the concrete surface and difficulty in finishing.

Two other minor alterations were made in addition to the changes made to the mounting technique of the dowels onto the baskets. One of these alterations involved greasing the stainless steel dowels with Phillips 66 grease to avoid potential bonding with the concrete. Bonding of the stainless steel dowels with the concrete could prevent longitudinal movement of the reinforcement and obstruct load transfer from one slab to the next.

The second change was the attachment of a nail to the bottom of 32 Hughes Brothers and 40 Marshall fiber composite center line bars. This was done as a precautionary measure to increase the possibility that the bars could be located for future monitoring by devices such as a metal detector or ground penetrating radar. With the exception of these alterations, procedures used during construction of the test sections were similar to those used to construct the remaining pavement sections in the construction project.

Problems in Construction

Few problems were encountered during construction of the test site. As paving began, concern was expressed that due to the lack of stability of the baskets, the weight of the concrete would crush the dowels and move them out of alignment. Although this happened twice (at station 629+03 and station 636+60) it was deamed not enough to cause loss of load transfer between the slabs by the research investigator.

Most of the problems that occurred were a result of the use of the fiber composite tie bars. During or after completion of the placement of the tie bars, they had a tendency to "float" up to or come through the top of the pavement surface. The cause of this problem may be attributed to: (1) the automatic tie bar inserter on the paver malfunctioning due to the slightly smaller diameter of these tie bars compared to the standard tie bars or (2) as a result of the lighter weight of the fiber composite centerline tie bars, the roll of the concrete could easily move the tie bar longitudinally in the slab and bring it through the surface. To correct this problem, laborers hand pushed the tie bar back into the pavement, at approximately mid-depth. Insertion of these bars was halted on this project and epoxy coated steel tie bars were used on the remainder of the section after multiple bars surfaced in succession.

During construction of the test site at station 631+42, a basket got caught on the belt placer and started to move out of alignment. To correct this problem, laborers cut the basket free from the belt placer, realigned the basket and continued paving. No other significant obstacles were encountered.

Testing Frequency and Methods

Deflection testing is being performed twice a year at predetermined locations for five years after construction with a Dynatest Falling Weight Deflectometer (FWD). The operation of the FWD is performed by ERES Consultants, Inc. on each of the joints within each test segment in both lanes. Within each test segment three joints and three midpanel locations per lane are tested. Testing is conducted in the outside wheelpath, two feet from the outer edge of the driving lane. Testing is performed in March or April, to represent a wet (weak) foundation condition and August or September, to represent a relatively dry (strong) foundation condition. All testing is performed when the pavement temperature is below 50 degrees Fahrenheit (approximate air temperature of 70 degrees).

The FWD is a trailer mounted machine that uses non-destructive test methods to measure the response of a pavement section to an impulse loading device that exerts a dynamic force similar in magnitude to that produced by a moving vehicle tire load. The tow vehicle is equipped with a computerized system that records and processes load/deflection data and other miscellaneous field data. The deflection data recorded by the FWD is used to determine the variances in load transfer and the shape of the deflection basins formed by each load transfer device and testing section. Maximum and minimum deflections can be used to estimate the expected life of each joint type and the joint maintenance that could be expected with each material.

The FWD test is performed by dropping a weight from a known height onto a circular "load" plate. The diameter of the load plate is 5.91 in. and is resting on the pavement surface Typically the loading duration lasts 0.03 seconds and produces a peak force of 9,000 lbf. However, the duration of the load impulse and magnitude of the maximum load can be varied based on the drop height and buffer configuration.

Cables are connected to geophones placed at distances of 12 (d_{12}), 36 (d_{36}), 48 (d_{48}), 60 (d_{60}) and 72 (d_{72}) inches from the center of the load plate (d_o). The geophones measure the deflection data, at known distances from the load plate, to describe the deflection curve (bowl).

At each joint and midpanel tested, three test drops were performed using target loads of 9,000, 12,000 and 16,000 lbf. Multiple load drops were performed with the intent of averaging the results to obtain more accurate information on the pavement's characteristics, specifically the pavement moduli. The variability between drops at a single point is not as significant an issue in the project level evaluation as the variability in pavement moduli along the length of the project. Performing multiple load drops does not significantly increase the time required for data collection and analysis [4]. FWD testing procedures follow those recommended by the Federal Highway Administration.

Testing will be performed across transverse joint within each dowel type section to determine dowel bar depth location and tie bar depth location will be conducted in areas outside the outer wheelpath. Ground penetrating radar will be used to locate the bars in three dowel basket assemblies (each lane) and 50 feet of centerline joint within each test area (bar type and spacing combination). A minimum of ten to twelve cores will be obtained by the Iowa DOT to calibrate the radar activities. Ground penetrating radar will assist in detecting the dowel location in term of depth and orientation relative to the transverse and centerline joints. In addition, the use of ground penetrating radar is an effort to look at other alternative and more cost effective methods to detect dowels and tie bars in hardened concrete. A nail that is attached to the bottom of the dowels and tie rods will allow current metal detectors and non-destructive testing equipment to identify the location and alignment of the fiber composite bars.

Joint faulting will be measured using an electronic Georgia Digital Faultmeter. The Faultmeter has a digital readout that indicates positive or negative faulting in millimeters. The display freezes the measurement so the operator can remove the Faultmeter from the roadway and record the faulting at a safe distance from traffic. "The legs of the base of the Faultmeter are set on the slab in the direction of the traffic on the "leave side" of the joint. The measuring probe contacts the slab on the approach. Movement of this probe is transmitted to a Linear Variance Displacement Transducer (LVDT) to measure joint faulting. The joint must be centered between the guidelines shown on the side of the meter. Any slab which is lower on the leave side of the joint will register as a positive faulting number. If the slab leaving the joint is higher , the meter gives a negative reading." [15, p. 144.] Measuring joint faulting using the Georgia Faultmeter is quick and easy, taking less then 30 seconds to complete and record a measurement for each joint.

The Whittemore gage will be used to measure joint opening. During construction of the test section PK nails were placed along ten consecutive joints in each dowel type and spacing. Measurement of the joint openings using the Whittemore gage were made at the time that FWD measurements were recorded.

A visual distress survey will also be conducted to record any joint or slab deterioration that might affect the transverse joint load transfer. Performing a visual distress survey aids in identifying changes in joint openings, cracking or spalling adjacent to the transverse or longitudinal joints that is associated with lack or presence of bar pullout or load transfer. The visual distress survey is performed by ISU staff in accordance with the distress types, extent and severity described in the Strategic Highway Research Program (SHRP) pavement distress manual.

After monitoring the test section for five years, staff from ISU and the Iowa DOT will conduct coring in each test segment to determine bar condition. Coring will be performed in the outer lane and at centerline only in each test segment. Three cores will be collected to represent each manufacturer's materials used in the dowels and the same number will be collected to represent the tie bars. Laboratory testing of the cores will not only indicate the extent of deterioration that has occurred to the dowels, but it will also denote the amount of bonding present or lack there of.

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