COMPOSITES 2006 Convention and Trade Show
American Composites Manufacturers Association
October 18-20, 2006
St. Louis, MO USA

Alternative FRP Dowel Joint Reinforcement

by

Max Porter, Iowa State University, and
James Cable, Iowa State University

Abstract – Alternative FRP Dowel Joint Reinforcement

Alternative materials from the conventional steel dowels have been investigated for joints as reinforcement to carry the shear forces across the opening. Among these alternative materials, fiber reinforced polymer (FRP) has been given considerable attention. FRP is considered a high candidate to replace steel in those areas where corrosion is of concern. The FRP allows for the slip that is needed but provides for a non-corrosive dowel bar. Alternative dowel bars for joints have been undergoing investigation at Iowa State University (ISU). The alternatives include size, shape and material parameter changes from the conventional 1.5-in. diameter, 18-in. long steel dowels currently employed in joints of pavements, bridge approaches and other locations where load transfer is needed but longitudinal movement must be accommodated. In addition to alternative materials that have been investigated, alternative shapes have been tested and placed in field applications in research projects conducted at ISU. Elliptical, hollow, and other shapes have been tested in the Structural Engineering Laboratory. The tests include elemental behavioral parameter tests, and full-scale pavement slabs subjected to up to 10 million cycles of load. This paper will focus on the structural behavior and field applications of these alternative dowel bars and shapes utilized in conventional joints of a small gap. Results of the tests and field applications will be presented.

Introduction

A vast majority of the nation's highways and roads are made of jointed concrete pavement. These joints allow for deformation and movement due to thermal and environmental conditions. Joints may either be longitudinal joints, parallel with traffic, or transverse joints, perpendicular to traffic. Transverse joints are placed at regular intervals creating discontinuities in the pavement and forming a series of slabs. Load transfer within a series of concrete slabs takes place across these joints. An effective load transfer device, therefore, must be present in order to transfer load between adjacent slabs.

For a typical concrete paved road, these joints are assumed to be approximately 1/8-inch gaps between two adjacent slabs. Dowel bars are located at these joints and used to transfer load from one slab to an adjacent slab. After a significant number of vehicles have passed over the joint an oblonging where the dowel bar contacts the concrete can occur. This oblonging creates a void space. This void space is formed due to a stress concentration where the dowel contacts the concrete at the joint face directly above and below the dowel. Over time, the repeated process of traffic traveling over the joint crushes the concrete surrounding the dowel bar and causes a void in the concrete. This void inhibits the dowels ability to effectively transfer load across the joint.

Possible corrosion of the dowel bar can potentially bind or lock the joint. When locking of the joint occurs no thermal expansion is allowed and new cracks parallel to the joint are formed directly behind the dowel bars in the concrete. As temperature decreases, contraction of the concrete will occur resulting in the new cracks becoming wider and a resulting load transfer failure. Once there is no longer load transferred across the joint all the load is then transferred to the subgrade and differential settlement of the adjacent slabs occurs. Differential settlement of the slabs creates a vertical discontinuity at the joints, making vehicle travel uncomfortable, and requires that the slab be repaired or replaced.

A majority of the dowel bars used today for load transfer are epoxy-coated steel. This epoxy coating aids in the reduction of the exposure to corrosive agents. However, many times this coating is nicked or scraped before installation leaving the uncoated steel susceptible to deterioration.

As was mentioned previously, a void around a dowel bar is formed by stress concentrations crushing the concrete directly in contact with the dowel. When a wheel load is applied to the concrete slab the force is supported only by the top or bottom of the dowel bar, not the sides. Since the stress concentration region lays on the top or bottom of the dowel bar, the smaller the dowel the higher the stress concentration. The sides of the dowel bar do not aid in the distribution of the wheel load from the concrete. Therefore, the top and bottom of the dowel bar at the face of the joint is where the stress concentration is located and is directly related to the width and/or shape of the dowel bar. While round dowel bars handle these stress concentrations relatively well, other shapes and materials may provide a better distribution.

Iowa State University researchers have been actively performing continuous research in the area of dowel bars for pavement slabs since 1991. Interest in this work was generated by the utilization of alternative dowel bar shapes and materials. A significant amount of research was funded by the Iowa Department of Transportation (IDOT) in two fairly significant projects, resulting in several research reports, the most notable of which are Report #TR408 “Investigation of Glass Fiber Composite Dowel Bars For Highway Pavement Slabs”(Porter, et al 2001) [1] and Report#HR343 “Non-Corrosive Tie Reinforcing and Dowel Bars For Highway Pavement Slabs” (Porter, et al 1993) [2] . These reports serve as examples of the work done by Iowa State University for FRP dowel bars. The concepts of alternative materials and shapes were to provide dowel bars that are not subject to the severity of corrosion and stress experienced by the current steel circular dowel bars.

Background and Laboratory Tests

The most common load transfer device currently in use is the epoxy-coated steel dowel. The dowel is usually round with a diameter of 1.25 or 1.5 inches, depending upon the slab thickness. The dowels present two main problems to the lifespan of the joint: corrosion and oblonging within the joint.

Corrosion occurs in the steel bar because of a chloride ion exchange caused by the environment and various salts applied to the roadway during adverse winter weather conditions. The corrosion weakens the dowel by causing a reduction in the effective load bearing area in the steel dowel. The corroded steel will also cause chipping and spalling in the surrounding concrete. The epoxy coating is designed to prevent the chloride from interacting with the steel. However, there are usually flaws in the epoxy coating caused by careless handling, storage, placement, or manufacturing, which in turn causes nicks, pin-holes, and scrapes. Moisture attacks the coating flaws and causes pitted corrosion beneath the surface of the coating [1].

Corrosion also causes the steel dowels to expand and thus freeze or lock the joints, preventing the intended normal slip required of a dowel bar within the joint. The dowel bar must slip to accommodate the expansion and contraction that results from temperature, shrinkage, and moisture changes in the slabs. A locked joint will cause cracking to occur outside of the intended doweled joint, resulting in pavement failure.

Oblonging occurs in the concrete around the dowel due to excessive bearing stresses between the bar and the concrete surface under repeated reversed loadings. The high stresses weaken the concrete and eventually loosen the connection between the dowel and the pavement.

To date, all fiber-reinforced polymer (FRP) dowel bar-related research in the United States has centered on the chemical makeup of materials in the bars and their laboratory strength evaluations. Iowa State University (ISU) has done much of this research [1-11]. Currently, research is underway to evaluate field installations for round dowels. A recent ISU study indicated that elliptical-shaped dowels could offer pavement performance benefits by reducing bearing stresses above and below the dowel [12-14]. This assertion is currently being tested further at ISU under the direction of Dr. Max Porter and Dr. James Cable. A field evaluation of the performance of elliptical-shaped steel and FRP dowels has been performed on Iowa Highway 330 near Melbourne, Iowa, in Marshall County.

References (Porter, et al 1993 (2), and Porter, et al 2001 (1)) provide the results of full-scale tests and analysis. An example of the full-scale test is shown in Fig. 1.

Some of the key results of this laboratory work, which included up to 10 million cycles of load on dowel bars made of FRP, are as follows:

- The results of this research indicated that the elliptical dowel bars behaved as predicted. When comparing the 1-1/2 in. ϕ round epoxy coated steel dowel bars to the large elliptical steel dowel bars, the large elliptical steel dowel bars produce bearing stresses on the concrete that are greatly reduced while the increase in relative deflection is minimal.
- The large elliptical steel dowel bars have an increase in cross-sectional area of nearly 18% but provide a reduction in bearing stress of over 26%. In contrast, the 1-1/2 in. ϕ round epoxy coated steel dowel bars have a 44% increase in cross-sectional area over the smaller 1-1/4 in. ϕ round epoxy coated steel dowel bars yet only provide a 25% reduction in bearing stress.
- The round dowel bars did retain a slight advantage in the stiffness over elliptical dowel bars of a similar cross-sectional area due to their shape. However, this difference in stiffness is insignificant based on the small variance in the deflection of the slabs. The difference in magnitude of the deflections is so small that the dowel bars could be considered as having roughly the same deflection.
- This research has shown that the 1.5 in. ϕ round epoxy coated steel dowel bars have roughly same bearing stress as the medium elliptical dowel steel bars. This occurrence could be beneficial if the load transfer efficiency was determined.
- This research has shown that the 1.5 in. ϕ round epoxy coated steel dowel bars have roughly the same bearing stress as the medium elliptical dowel steel bars. This occurrence could be beneficial if the load transfer efficiency was determined.

- Dowel bar spacing is a method to distribute load to the dowel bars. The smaller the spacing of the dowel bars the smaller the load on the dowel bars. A decrease in pavement thickness will lower the number of bars available for load transfer and a smaller spacing may be required.
- The 1.5-in. diameter GFRP dowels spaced at 12 in. on center were inadequate in transferring load.
- The 1.5-in. diameter GFRP dowels spaced at 6 in. on center were effective in transferring load over the design life of the pavement.
- The current design guideline for steel dowels cannot be applied to GFRP dowels.
- The 1.75-in. FC dowels spaced at 8 in. performed at least as well as 1.5-in. steel dowels at 12 in. for transferring static loads across the joint in the full-scale pavement test specimens. The performance of the 1.75-in. FC dowels spaced at 12 in. was similar to that of the 1.5-in. steel dowels spaced at 12 in. with any difference being attributed to dowel diameter.
- The load transfer efficiency of 1.75-in. FC dowels spaced at 8 in. for a full-scale pavement slab was nearly constant (approximately 44.5% load transfer) through two million applied load cycles with a maximum of 9,000 pounds.
- The load transfer efficiency of 1.5-in. steel dowels spaced at 12 in. for a full-scale pavement slab decreased (approximately from 43.5% to 41.0% load transfer) over the first two million cycles.
- The load transfer efficiency of 1.75-in. FC dowels spaced at 12 in. for a full-scale pavement slab decreased from an initial value of approximately 44% to a final value of approximately 41% after 10 million cycles.
- A theory has been used to analyze the dowel behavior based upon the deflections shown in Fig. 2.

Field Applications – Examples

The objective of the field research was to evaluate the load transfer capabilities of elliptical-shaped FRP dowels and basket assemblies across pavement joints (shown in Fig. 3). The intent of this work was to estimate the performance of the individual dowel configurations in terms of stiffness, durability, modulus of dowel support, and deflection predictions. The following comparisons were made after analyzing field data from Iowa Highway 330 (15):

- Performance of elliptical FRP dowels versus that of conventional 1.5-inch diameter circular epoxy-coated steel dowels
- Performance of FRP versus conventional steel dowels with respect to long-term resistance to corrosion
- Effect of an elliptical versus circular shape in reducing the bearing contact stress between the concrete and the dowel bar.
- The field tests consisted of the following procedures to monitor the pavement's performance:
- Falling weight deflectometer (FWD)
- Strain gage analysis under two conditions:
    - Load application with a standard Department of Transportation dump truck (crawl truck)
    - Load application with FWD
- Joint faulting measurement
- Joint widening measurement
- Visual distress survey

Placement of the dowel bars occurred in the northbound lanes at thirty joint locations beginning at Station 1371+09 and ending at Station 1372+83. The spacing between each joint is 19.69 feet (6 m) and all joints were constructed perpendicular to the edge of the concrete pavement. Spacing of the dowel bars within each joint was varied, with three different dimensions of 10, 12, and 15 inches (254, 305, and 381 mm).

Specially built elliptical dowel bar basket assemblies were used to install the dowel bars in this portion of the project in order to elevate the center of the bars 5 inches (127 mm) from the subgrade, placing them in the center of the 10-inch (254-mm) slab pavement. Fig. 3.3 shows a photo of a typical dowel bar basket assembly. Conventional welding methods for attaching the dowel bars to the baskets, as used with steel dowel bars, could not be used with the FRP material. Therefore, plastic ties and epoxy were used to attach the FRP dowel bars to the baskets. Special care was taken to ensure that the epoxy was strong enough to hold the bars in place during concrete placement, yet brittle enough to crack and allow the bars to move in the longitudinal direction after the concrete had cured.

Theory - Modulus of Dowel Support

The deflection of a dowel bar within pavement can be modeled using Timoshenko's model of a beam on an elastic foundation [16], as shown in Equation 1:

$$-ky = EI\frac{d^4y}{dx^4} \qquad \textbf{(1)}$$

Where,

k = Modulus of foundation (psi)
y = Vertical dowel deflection (in)
E = Young's modulus for dowel (psi)
I = Moment of inertia for dowel (psi)

The general solution of Timoshenko's differential equation is as follows in Equation 2.

$$y = e^{\beta x}\left(A\cos\beta x + B\sin\beta x\right) + e^{-\beta x}\left(C\cos\beta x + D\sin\beta x\right) \qquad \textbf{(2)}$$

Where,

β = Relative stiffness of beam on foundation $= \sqrt[4]{\dfrac{k}{4EI}}$

When applying appropriate boundary conditions to Equation 2, the constants A, B, C, and D can be obtained. In the case of a semi-infinite beam with a point load, P, and moment, M_0, Timoshenko's equation becomes the following:

$$y = \frac{e^{-\beta x}}{2\beta^3 EI}\left[P\cos\beta x - \beta M_0\left(\cos\beta x - \sin\beta x\right)\right] \qquad \textbf{(3)}$$

Equation 3 was applied by Friberg [17] to evaluate a dowel with semi-infinite length and an elastic base. In order to calculate the deflection at the face, Equation 3 is applicable by setting x=0. Equation 3 then becomes the following:

$$y_0 = \frac{P_t}{4\beta^3 EI}\left(2 + \beta z\right) \qquad \textbf{(4)}$$

and

$$\beta = \sqrt[4]{\frac{k_0 b}{4EI}} \qquad \textbf{(5)}$$

Where,

k_0 = Modulus of dowel support (pci)
b = Dowel bar width (in.)
P_t = Load carried by dowel (lbs)
z = Joint width (in.)

Equations 4 and 5 can be solved by calculating a y_0 value from the data, solving for β using Equation 4, and finally obtaining k_0 from Equation 5.

The deflection of the dowel at the face of the joint can be calculated using the relative displacement between slabs and the joint width. A diagram of the interaction between the two slabs is shown in Fig. 2.

According to the above figure, the relative deflection, Δ, is dependent on four main components:

- Deflection at each joint face, y_0
- Deflection due to the slope of the dowel, $\dfrac{z dy_0}{dx}$
- Moment deflection, $\dfrac{Pz^3}{12EI}$
- Shear deflection, δ

The relative deflection, Δ, can be calculated by using Equation 6:

$$\Delta = 2y_0 + z\frac{dy_0}{dx} + \frac{Pz^3}{12EI} + \delta \qquad \textbf{(6)}$$

Where,

δ = Shear deflection= $\dfrac{\lambda P z}{AG}$
P = Load carried by dowel (lbs)
A= Cross-sectional area of dowel (in.^{2})
λ = *Form Factor* = 10/9 (assumed) for elliptical dowels
G= Shear modulus (psi)

For this work, the joint widths are very narrow, roughly 0.125 inches. Due to the small differential displacement and joint width, both moment deflection and slope deflection were neglected. The authors assumed that the numbers would be insignificant due to the total deflection calculation. The following equation was used to calculate y_0 after making the appropriate changes to Equation 7:

$$y_0 = \frac{\left(\Delta - \delta\right)}{2} \qquad \textbf{(7)}$$

Laboratory Tests

Tests were performed at ISU in the structures laboratory located in Town Engineering Building. The tests are a part of ongoing research to investigate the current AASHTO T253-76 [18] testing method for dowel bars. The test specimens were constructed using concrete and various dowel shapes. Steel and glass fiber reinforced polymer (GFRP) dowels were tested. Each specimen consisted of three concrete blocks connected with two dowel bars (see Figs. 4-5). The fiber percentage for FRP dowels was approximately 50% by volume (varied from dowel bar to dowel bar type).

Summary of Performance

The vertical dowel deflections, y_0, calculated at the center of each joint in the FRP dowel sections for 10-inch, 12-inch, and 15-inch spacing from FWD testing averaged values less than 1 mil (0.0254 mm). Results obtained from strain gage data also displayed y_0 values of less than 1 mil (0.0254 mm). Additionally, the relative deflections associated with the FWD testing were less than 2 mils (0.0508 mm). Faulting data, representing the effects of repeated loading, subgrade conditions, and weather over time, give maximum displacements across the joint of 0.067 inches (1.7 mm) and an average of 0.020 inches (0.508 mm). These small deflections show that the FRP dowels at each spacing provide adequate load transfer across the joints. Furthermore, the deflections are of magnitudes small enough to provide adequate rider comfort as vehicles traverse the joints.

Overall, this study has shown that FRP dowel bars performed adequately, as demonstrated by this field application of over 700 FRP dowel bars in Iowa Highway 330. The overall small measured deflections demonstrated that the FRP dowel bars provided adequate load transfer across all of the joints. These deflections were small enough to provide adequate rider comfort for vehicles crossing joints containing FRP dowel bars. Faulting and joint opening measurements were similar and demonstrated that the joints were operating properly.

Acknowledgements

The research studies summarized in this paper were conducted at Iowa State University in the Civil, Construction and Environmental Engineering Department. Funds were made available by the Iowa Department of Transportation, the Iowa Highway Research Board, and the Federal Highway Administration. The authors thank various material suppliers, including Hughes Brothers, American Highway Technology, and others. A big thanks goes to the numerous undergraduate and graduate students who have worked on the various studies. Acknowledgement and thanks go to Douglas Wood, who supplied laboratory and field technical testing support from the Structural Engineering Laboratory.

References

1. Porter, M.L., R.J. Guinn, Jr., A.L. Lundy, Dustin D. Davis, and John G. Rohner. 2001. *Investigation of Glass Fiber Composite Dowel Bars for Highway Pavement Slabs: Final Report*. Iowa Highway Research Board Project TR-408. Ames, Iowa: Iowa State University, Engineering Research Institute.
2. Porter, M.L., B.W. Hughes, K.P. Viswanath, and B.A. Barnes. 1993. *Non-Corrosive Tie Reinforcing and Dowel Bars for Highway Pavement Slabs: Progress Report*. Iowa Highway Research Board Project HR-343. Ames, Iowa: Iowa State University, Department of Civil and Construction Engineering.
3. Porter, M.L., E.A. Lorenz, K.P. Viswanath, B.A. Barnes, and M. Albertson. 1992. *Thermoset Composite Concrete Reinforcement: Final Report—Part II*. Project HR-325. Ames, Iowa: Iowa State University, Engineering Research Institute.
4. Hughes, B.W., and M.L. Porter. 1996. Experimental Evaluation of Non-Metallic Dowel Bars in Highway Pavements. *Proceedings of Fiber Composites in Infrastructure*. Edited by H. Saadatmanesh and M.R. Ehsani. First International Conference on Composites in the Infrastructure (ICCI96), January 1996.
5. Porter, M. L., Bradley W. Hughes, and Bruce A. Barnes. 1996. Fiber Composite Dowels in Highway Pavements. *Proceedings of the Semi Sesquicentennial Transportation Conference*. Ames, Iowa: Iowa Department of Transportation and Iowa State University.
6. Porter, Max L. 1999. FRP Dowel Bars. *Proceedings of the 1999 International Composites Expo*. Harrison, NY: Composite Institute.
7. Porter, M.L., and R.L. Braun. 1997. *Preliminary Assessment of the Potential Use of Alternative Materials for Concrete Highway Pavement Joints: Final Report*. Highway Innovative Technology Evaluation Center (HITEC) Report. Ames, Iowa: Iowa State University, Department of Civil and Construction Engineering.
8. Porter, M.L., and D.D. Davis. 1999. Glass Fiber Reinforced Polymer Dowel Bars for Transverse Pavement Joints. *Proceedings of the FRP Symposium*. Baltimore, MD: ACI Fall Convention.
9. McConnel, Vicki. 1999. FRP Reinforcement Durability and FRP Dowel Bars. *Transportation Composites Newsletter*.
10. Porter, M.L., and R.J. Guinn. 2002. *Assessment of Highway Pavement Slab Dowel Bar Research: Final Report*. Iowa Highway Research Board Project HR-1080. Ames, Iowa: Iowa State University, Center for Transportation Research and Education.
11. Cable, James K., L. Edgar, and J. Williams. 2003. *Field Evaluation of Elliptical Steel Dowel Performance.* Construction Report. Ames, Iowa: Iowa State University, Center for Portland Cement Concrete Pavement Technology.
12. Porter, M.L., E.A. Lorenz, R.J. Guinn, and A.L. Lundy. 2004. *Solutions for Structural Dowel Bar Alternatives.* Draft. Ames, Iowa: Iowa State University, Center for Transportation Research and Education, Center for Portland Cement Concrete Pavement Technology, and American Highway Technology.
13. Cable, J.K., M.L. Porter, J. Hoffman, L.L. Rold, L.E. Edgar. 2003. *Demonstration and Field Evaluation of Alternative Portland Cement Concrete Pavement Reinforcement Material.* HR-1069. Ames, Iowa: Iowa State University, Highway Division of the Iowa Department of Transportation, Iowa Highway Research Board, and Federal Highway Administration Demonstration Projects Program.
14. Porter, M.L., R.J. Guinn, Jr., and A.L. Lundy. 2001. *Dowel Bar Optimization—Phases I and II: Final Report*. American Highway Technology Report. Ames, Iowa: Iowa State University, Center for Portland Cement Concrete Pavement Technology.
15. Porter, Max; Cable, James; Harrington, John; Pierson, Nathan; Post, Anthony. June 2005. "Field Evaluation of Elliptical Fiber Reinforced Polymer Dowel Performance", Report to FHWA, Center for Portland Cement Concrete Pavement Technology.
16. Timoshenko, S., and J.M. Lessels. 1925. *Applied Elasticity*. Pennsylvania: Westinghouse Technical Night School Press.

17. Friberg, B.F. 1940. Design of Dowels in Transverse Joints of Concrete Pavements. *Transactions, American Society of Civil Engineers*. 105.2081.

18. American Association of State Highway and Transportation Officials (AASHTO). 1993. *AASHTO Guide for Design of Pavement Structures*. Washington, D.C.: AASHTO.

Figures:

Figure — 1. Full-scale test of pavement slab containing dowel bars. [1]

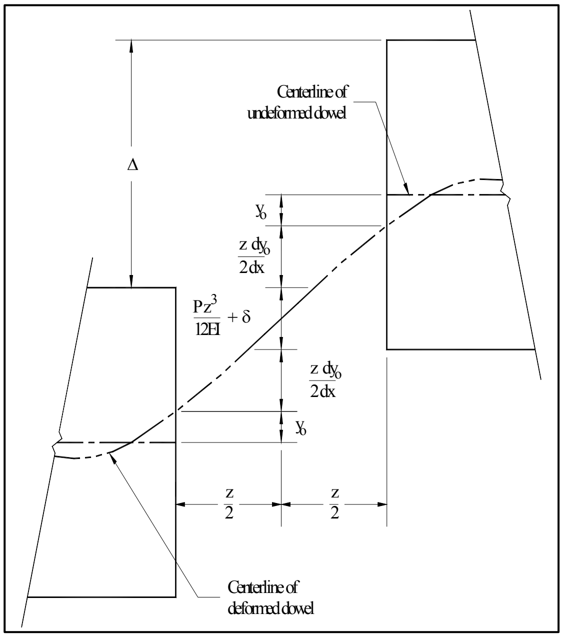

Figure — 2. Relative deflection between slab sections

Figure — 3. Dowel bar basket assembly (bars at 10-inch spacing) [15]

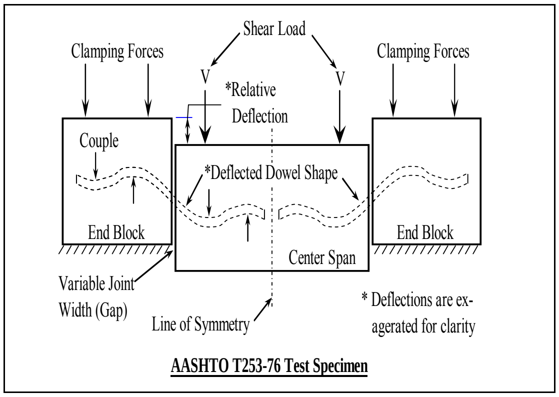

Figure — 4. AASHTO T253-76 test diagram [12, 18]

Figure — 5. Load test frame [15]

Max Porter and James Cable:

Max Porter is a Professor of Civil Engineering in the Civil, Construction and Environmental Engineering Department at Iowa State University in Ames, Iowa 50011.

James Cable is an Associate Professor of Civil Engineering in the Civil, Construction and Environmental Engineering Department at Iowa State University in Ames, Iowa 50011.