

Alternative Dowel Bars

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ABSTRACT

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. Alternative materials from the conventional steel dowel have been investigated. Among these alternative materials, fiber reinforced polymer (FRP) has been give 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. In addition to alternative materials that have been investigated, alternative shapes have been tested 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 of the dowel bars utilized in conventional joints of a small gap.

Key words: dowel bars—FRP—pavement—reinforcement—slabs

INTRODUCTION

Based upon a research survey conducted at Iowa State University sponsored by the Civil Engineering Research Foundation's (CERF) Highway Innovative Technology Evaluation Center (HITEC), over 18 million dowel bars are sold per year for use in the US highway systems (1). If approximately two-thirds of the US has a potential for corrosion via roadway chemicals, sea salts, or chemical concrete mixtures; then, a potential for an alternative corrosion-free or corrosion resistant dowel bar would affect the sales of about 12 million dowel bars per year. One of the likely candidates for an alternative material to stop the corrosion problem is that of a fiber-reinforced polymer, commonly known as FRP or GFRP.

Dowel bars are subject also to large cycles of fatigue loading as the bars transmit loads from one portion to another of a concrete pavement, bridge, or other structural components. As the continued cycling occurs, the bearing of the contact from the bar on the concrete can cause an "oblonging" of the hole surrounding the bar for a typical circular bar. Thus, a need also exists to reduce the bearing stresses between the dowel bar and the concrete.

The combination of the corrosion and bearing fatigue problems for dowel bars leads to the need to consider alternative shapes and materials for dowel bars. Research has been on-going at ISU on both the alternative shapes and the alternative materials for dowel bars. Several types of structural tests and analyses have been conducted at ISU. This short paper will provide a summary, some results and analyses, and some recommendations based upon the ISU structural work.

PARTIAL SUMMARY OF ISU WORK

The structural laboratory work at ISU has focused on many different potential dowel bars of various shapes and materials. The different types of dowel bars investigated include

- 1.5-in. ϕ standard epoxy coated,
- 1.5-in. ϕ stainless steel,
- 1.5-in. ϕ GFRP,
- 1.875-in. ϕ GFRP,
- 1.5-in. ϕ aluminum,
- 1.957-in. ϕ aluminum,
- 1.714-in. ϕ copper,
- 1.5-in. ϕ copper,
- 1.5-in. ϕ stainless steel,
- 1.5-in. ϕ hollow-filled,
- 1.75-in. ϕ GFRP,

- Aged GFRP,
- Special-sized shaved GFRP,
- Hollow-filled,
- 1.5-in. ϕ plain steel, and
- Several sizes of elliptical shaped

The types of structural laboratory tests conducted include

- full-scale pavement sections subjected to fatigue loading,
- Iosipescu elemental shear (static)
- AASHTO T-253 elemental shear (static and fatigue),
- Pull-out,
- Alkalinity aging, and
- Chemical properties

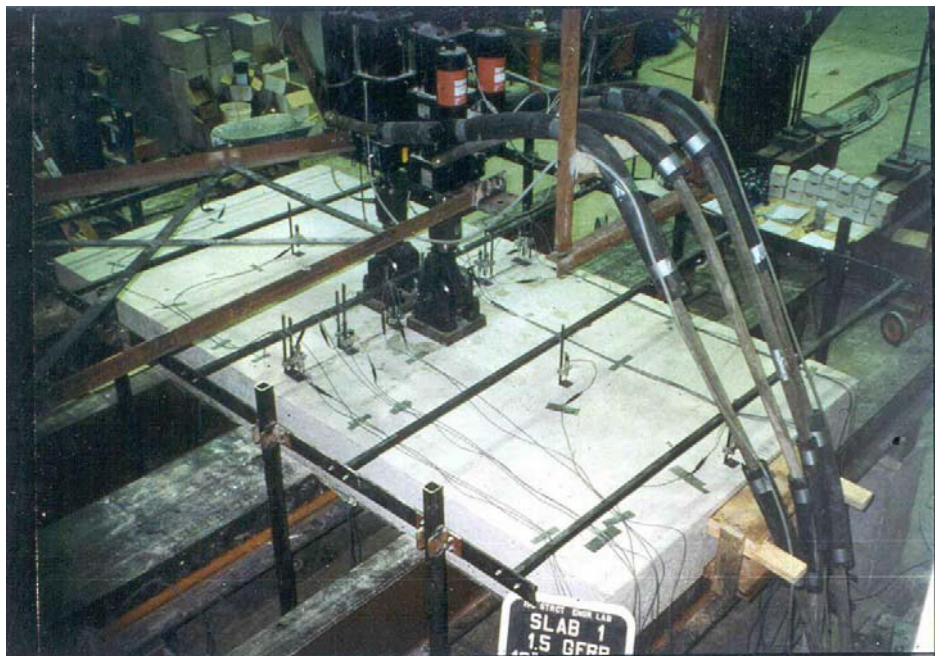


FIGURE 1. Full-Scale Test of Pavement Slab Containing Dowel Bars

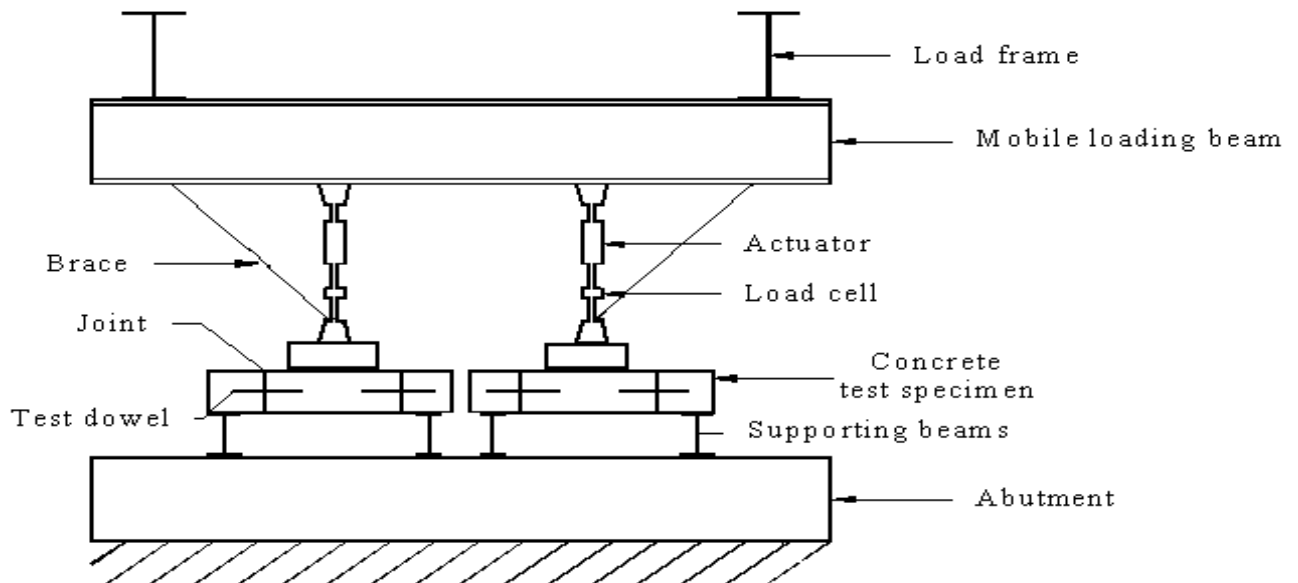
All of the above-mentioned tests were conducted in the Structural Engineering Laboratory at ISU. The full-scale test is shown in Figure 1. The AASHTO test is shown in Figure 2. Since the FRP was a special idea of the author, a significant number of tests have focused on this application.

The latest work has focused on elliptically-shaped dowels. The elliptical shape has been used for steel and GFRP dowels for laboratory testing and in recent field applications. The field projects currently underway are directed by Dr. James Cable and the author. This paper, however, is focused only on the structural laboratory applications.

Most of the laboratory tests have been supported by the IDOT, the IHRB, and the various manufacturers of the alternative dowel bars and given in References (2-6). Some of the significant results of the GFRP dowels have been summarized in the Papers (7-9) and in a newsletter Article (10).

ANALYSIS

The analysis of the alternative dowel bars has included several aspects, most important of which is a straight forward means of determining a mathematical means of strength and deflection of the dowels across a pavement joint. The following equations have been derived to give a relation of the deflection of the pavement joint as shown in Figure 3.



Side elevation view

FIGURE 2. AASHTO Elemental Tests

The deflection at the face of the joint, Δ , was determined by Equation 1. The equation for shear deflection, δ , is shown in Equation 2 and was obtained from Young (11).

$$\Delta = 2y_0 + z \left(\frac{dy_0}{dx} \right) + \delta + \frac{Pz^3}{12EI} \quad (1)$$

where,

$$\delta = \frac{\lambda Pz}{AG} \quad (2)$$

The modulus of dowel support, K_o , along with the bar properties are related as shown in Equations 3.

$$y_o = \frac{P}{4\beta^3 EI} (2 + \beta z) \quad (3)$$

where,

$$\beta = \sqrt[4]{\frac{K_o b}{4EI}} = \text{relative stiffness of the dowel bar encased in concrete (in}^{-1}\text{)}$$

By inputting various values of K_o into Equation 3, a K_o versus y_o graph can be created. Since Equation 2.9 is dependant on the bar shape and material properties, a K_o versus y_o graph must be created for each dowel bar of a different shape and/or material. Shown in Figure 4 is a sample K_o versus y_o graph for a 1.5-in. ϕ round epoxy coated steel dowel bar.

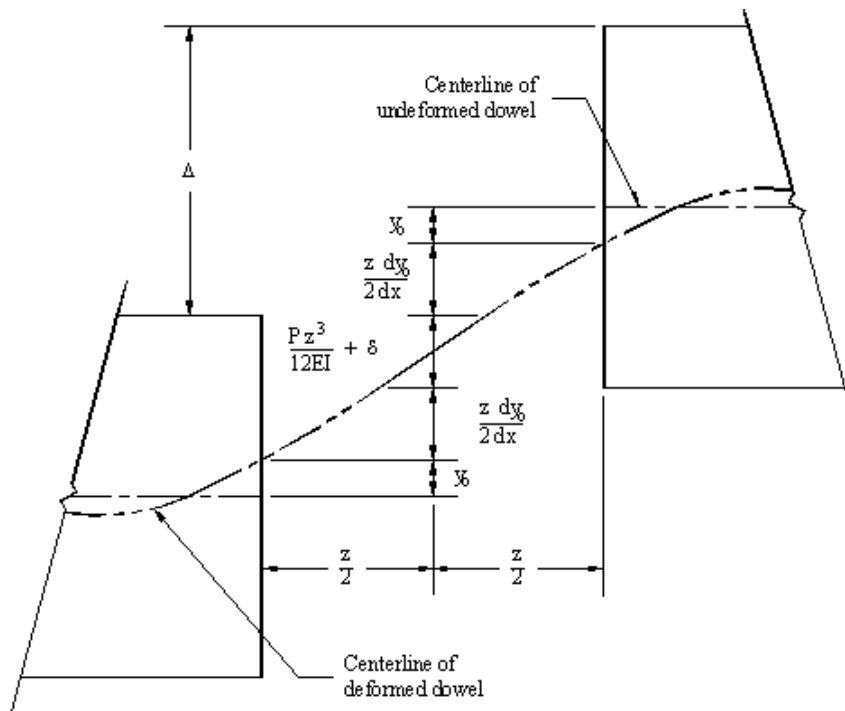


FIGURE 3. Deflection Relationships Across a Joint of Width Z.

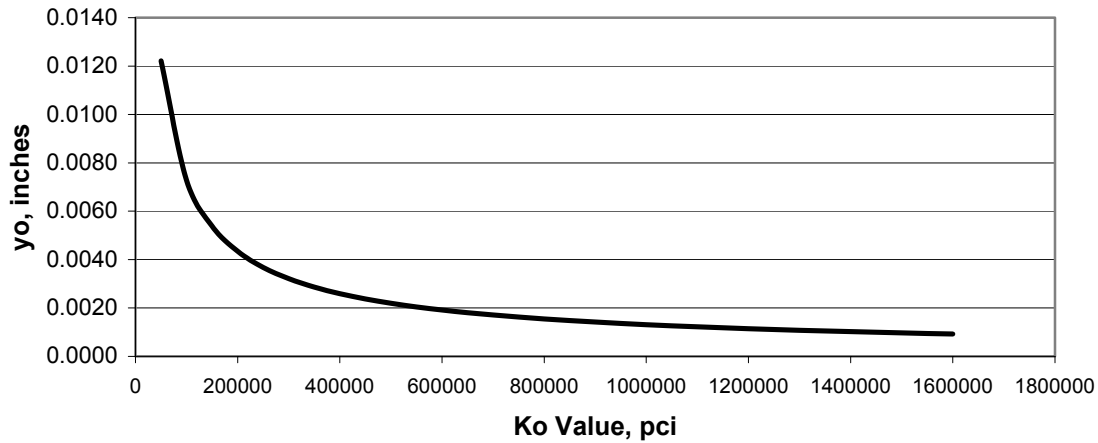


FIGURE 4. Relationship of Modulus of Dowel Support vs. Deflection for a 1.5” Steel Dowel Bar

Using the modulus of dowel support and the deflection at the face of the joint the concrete bearing stress can be calculated, as shown by Equation 4.

$$\sigma_o = K_o y_o = \frac{K_o P}{4\beta^3 EI} (2 + \beta z) \quad (4)$$

where in the above equations

E = modulus of elasticity of the beam (psi)

I = moment of inertia of the beam (in.⁴)

K_o = modulus of dowel support (pci)

B = dowel bar width (in.)

E = modulus of elasticity of the dowel bar (psi)

I = moment of inertia of the dowel bar (in.⁴)

P = load transferred through the dowel (lbs)

z = joint width (in.)

λ = form factor, equal to 10/9 for solid circular section

A = cross-sectional area of the dowel bar (in.²)

G = shear modulus (psi)

BRIEF RESULTS AND CONCLUSIONS OF SOME LABORATORY TESTS

The AASHTO tests were conducted after the Iosipescu tests of elemental specimens subjected to direct shear. During the sequence of conducting the AASHTO tests (Figure 2), several items were found to be wrong with that test procedure. Thus, recommendations are being put forth for work to be done to correct the deficiencies, such as possible rotation, uneven bearing, changes in load distribution, and issues of shear and moment across the interface joint. Also, issues w.r.t. the joint width, z, need to be addressed in a revised test procedure. Some of the highlights from the Reports (2,3,4, and 5) 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 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.

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