HITEC Evaluation Plan for

Fiber Reinforced Polymer Composite Dowel Bars

and

Stainless Steel Dowel Bars

Final Version
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Technical Evaluation Panel

Panel Chair:	Robert Schmiedlin, P.E., Wisconsin Department of Transportation
	Peter R. Booth, Nevada Department of Transportation
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	Andrew Gisi, Kansas Department of Transportation
	David Graves, New York Department of Transportation
	Roger Green, Ohio Department of Transportation
	Joseph Hannon, California Department of Transportation
	Roger Larson, Federal Highway Administration
	James Mack, American Concrete Pavement Association
	Vernon Marks, Iowa Department of Transportation
	Max Porter, Iowa State University
	Gary Robson, West Virginia Division of Highways
	Billy C. Wade, Illinois Department of Transportation
HITEC Staff:	David Reynaud, Senior Program Manager
	Michael S. Higgins, Research Engineer
Panel Consultant:	L. G. (Gary) Byrd

ABSTRACT

This plan has been prepared at the request of two Highway Innovative Technology Evaluation Center (HITEC) applicants. It documents a procedure developed to provide an objective evaluation of Fiber Reinforced Polymer (FRP) Composite Dowel Bars and Stainless Steel Dowel Bars.

These products are used to transfer loads across sawed or formed transverse joints from one concrete pavement slab to another. Presently, steel dowel bars with various coatings are used to transfer these loads, but as they age corrosion problems have become evident causing joint problems. The products under consideration in this HITEC evaluation are intended to have similar load transfer characteristics without the corrosion problems. The conventional epoxy-costed mild steel dowel will serve as the control for this study.

The goal of this evaluation is to provide potential users (material, structural, highway, and construction engineers, etc.) with objective design, material, construction, and performance information needed to make an informed assessment of these systems for particular engineering applications.

During execution of this plan existing field installations will be inspected, removed, and tested; laboratory testing will be completed; and new dowel bars will be installed and monitored for a time period of up to five years.

The overall evaluation, including field activity, will take place over a five to six year period.

1.0 INTRODUCTION

1.1 HITEC Mission and Process

The Highway Innovative Technology Evaluation Center was established by the Civil Engineering Research Foundation through a grant from the Federal Highway Administration to encourage and 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.

Applications for evaluation of technologies are screened for suitability by HITEC and, if accepted, Panels are formed to design and monitor the implementation of an evaluation plan to assess the performance of the technology in its highway application. The objective of the evaluation is to provide potential users of an applicant's technology with sufficiently-comprehensive information to permit them to make at least preliminary decisions about including the technology in their programs.

1.2 Alternative Materials for Dowel Bars in Concrete Pavement Joints

The use of steel dowel bars to transfer loads across sawed or formed transverse joints from one concrete pavement slab to another while permitting expansion and contraction movements of the concrete, has been a basic design practice in most U. S. state departments of transportation for many decades.

As the U. S. highway system ages, however, doweled pavement joints have shown many problems. (1) A common problem is the corrosion of the steel dowels which causes the bars to be "frozen" into place in the surrounding concrete, thus "locking" the joint and transferring the slab movement stresses to the concrete where cracking and spalling and eventually joint faulting may occur producing an unsatisfactory serviceability level for the pavement.

To address the corrosion problem, experimentation has been performed in the field and laboratory using various coatings, from asphalt cement to epoxy resins, applied to the steel dowels. Also, alternative materials have been used to manufacture dowels that are corrosion resistant in the concrete matrix. While the resistance to corrosion for some alternative materials has been well documented in laboratory examinations, other performance characteristics affecting service life remain to be fully evaluated, particularly in representative field installations and over meaningful time periods.

With the foregoing common objective, two applicants offering different alternative dowel materials separately requested evaluation but agreed to participate concurrently in a joint program of field installations, laboratory tests, observations and evaluations.

1.3 Products to be Evaluated

1.3.1 Epoxy-Coated Mild Steel Dowels

Epoxy-coated mild steel dowels are the standard of practice for concrete pavement joints for most departments of transportation today. As such, they will be used as the "control" material against which the alternative materials will be evaluated in this experiment. Samples of epoxy-coated mild steel dowels will be tested and included as the control in all laboratory and field tests delineated in the following experiment plan for evaluation of Fiber Reinforced Polymer (FRP) and Stainless Steel dowels.

1.3.2 Fiber Reinforced Polymer (FRP) Composite Dowel Rods

The Composites Institute, New York, New York, made application to HITEC for the evaluation of "*a new generation of FRP composite dowel rods and installation methods for new construction and repair of concrete highways."* The FRP Composites are defined by the Composites Institute as: " A matrix of polymeric material that is reinforced by fibers or other reinforcing material." FRP composite constituents include resins (polymers), fiber reinforcements, fillers, and additives.

The Composites Institute (CI) is the largest division of the Society of the Plastics Industry, Inc.(SPI). The CI trade association is the collective and leading voice of the composites industry, with more than 375 member companies. Formed in 1945, CI continues to be the foremost association supporting the use of composites in construction and civil infrastructure. The Market Development Alliance (MDA) consists of broad-based CI membership representing suppliers, fabricators, processors, and consultants of the composites industry. It acts as the coordinating body for CI's generic pre-competitive market development activities, including development and commercialization of new composites and application for the civil infrastructure. The MDA has focused committees on marine/waterfront piling system, structural shapes, concrete repair, FRP composite bridges, and the newly formed Composite Dowel Bar Team. There are a number of FRP projects underway in fields related to highways and structures, including:

- an Army Pier restoration in Oakland, California
- a cable stayed suspension foot bridge in Perthshire, Scotland
- a repaired I-95 prestressed concrete bridge beam in West Palm Beach, Florida
- polymer concrete parapet panels used on the Pennsylvania Turnpike and Allegheny Bridge, and
- a composite wrap to repair structural columns on FDR Drive in New York City.

The FRP Composite Dowel Bar Project is the newest focus of the MDA with 17 members committed and four or five others expected to participate in its support.

1.3.3 Stainless Steel (ASTM T304) Dowel Bars

An additional application for evaluation was made by the Specialty Steel Industry of North America for the evaluation of *"Stainless Steel (ASTM T304) dowel bars as load transfer devices in concrete highway joints."*

Stainless Steel is a corrosion-resistant material due to the presence of chromium and other alloying elements that create an impenetrable barrier to oxidation. The composition of Stainless Steel can be controlled to provide corrosion resistance in different environments. T304 is designed to resist corroding in high chloride-bearing concretes such as coastal areas or where there is extensive use of de-icing salts during winter snow storms.

Stainless Steel bars can be fabricated as:

- solid bars of full-section Stainless Steel,
- stainless clad bars with a core of mild steel or other material and a bonded Stainless Steel outer layer,
- Stainless Steel hollow pipes, and
- Stainless Steel pipes, filled with concrete or other materials.

While Stainless Steel has been in commercial use since the 1920s, initial costs have deterred its use in highway applications until more recent recognition of the importance of life-cycle costs and extended service life. Current highway projects and field programs reflecting a renewed interest in Stainless Steel include:

- a Michigan DOT bridge deck (built in 1984) using Stainless Steel reinforcing bars for one-half and epoxy-coated steel for the other,
- a New Jersey bridge deck (1984) using stainless-clad reinforcing bars,
- Stainless Steel dowel bars on Maryland Highway 97 in the late 1980s,
- 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.

2.0 SCOPE OF EVALUATION

2.1 Performance Issues

Applications to be considered in the field evaluations include the use of the alternative dowel bars in two types of joints.

2.1.1 Transverse contraction joints in concrete pavements

Pavement joints are constructed in new pavements to accommodate one or more of several movements. While the new concrete is curing, the hydration process causes the pavement mass to contract or shrink and the presence of transverse contraction joints at strategic longitudinal intervals, generally 12 to 20 foot, prevents the development of random cracks in the slab. Cured and mature pavement slabs respond to changes in ambient temperature and radiant heat from the sun by expanding and contracting. These movements are accommodated in part by the doweled joints where at least one end of each of the embedded dowel bars is treated with a debonding agent and is free to slide longitudinally within the concrete.

Problems occur when the mild steel dowels corrode. The oxidized surface of the dowel expands and locks the dowel into the surrounding concrete, thus transferring any longitudinal movement stresses to the concrete which fails in tension or shear. The failure process, once begun, is progressive as the cracked concrete admits moisture, the corrosion of the dowels increases, the concrete disintegrates further, and the joint weakens and eventually faults. In current practice, mild steel dowels are usually epoxy coated to prevent or reduce corrosion.

2.1.2 Transverse expansion joints in concrete pavements

Adjacent to structures and at other strategic locations where pressure from adjacent pavement slabs could be highly damaging, expansion joints are constructed with a full-depth formed opening width of up to 7.5 centimeters or 3 inches, filled with a preformed compressible material. The dowels in expansion joints are fitted with hollow caps to provide a recess into which they can slide as the expansion joint closes. The primary functional difference between contraction and expansion joints is the need for the dowel to span a greater space between slabs for load transfer when an expansion joint is open.

The same failure mechanism occurs in expansion joints as in contraction joints. Corroded and locked dowels may transfer compressive stresses to the concrete which may result in crushing or shear failures at the joint or damage to adjacent structures or facilities.

2.1.3 Positioning dowels

Methods used in positioning the dowels in field installations in new concrete pavement construction include the use of wire baskets to position dowel bars or the use of mechanical inserters. Regardless of the placement method, a critical consideration is the accuracy of the dowel position in the joint. The dowel must be aligned horizontally with the centerline of the pavement, vertically with the longitudinal profile of the pavement, at an elevation that is mid-point in the pavement slab thickness, and approximately centered longitudinally on the sawed or formed joint opening. Where pavement joints are skewed rather than perpendicular to the pavement centerline, the positioning of the dowels must remain parallel to the centerline and profile. In any of the alignment requirements, a misaligned dowel can "lock" the joint and transfer stresses to the concrete just as a corroded dowel may do.

Quality control in the construction of joints requires the ability to verify the accuracy of the dowel placement in the finished concrete matrix. Ground penetrating radar (GPR) is the most promising non-destructive technology for this process but its applicability for FRP bars is still unproven and its effectiveness may be diminished in wet, uncured concrete. The use of taggants may be required for the detection of FRP bars by the GPR or by other metal-detecting devices.

2.2 Overview of Evaluation Plan

The evaluation plan is designed to limit the variables to the dowel materials and to limit the materials to a selected few offered by the applicant materials industries.

The dowels from the Composites Institute to be evaluated will be glass-fiber reinforced polymer (FRP), meeting approximately the performance specifications for mild steel dowels except in the bending modulus. Dowels will be approximately 18 inches in length and 1.5 inches minimum diameter.

Dowels from the Specialty Steel Industry of North America, will be T304 Stainless Steel solid or hollow pipe filled with concrete or other materials. Dowels will be approximately 18 inches in length and 1.5 inches in diameter.

Conventional epoxy-coated mild steel dowels will serve as the control for this study.

The Evaluation Plan will consist of three parts as described in the following sections.

2.2.1 Literature Review

Valuable testing work has been done on non-corrosive dowel bars by the Engineering Research Institute at the Iowa State University and by the Federal Highway Administration. Highway structures have been constructed in the U. S., Canada, and overseas using alternative materials for concrete reinforcement and/or for structural members. Experimental projects using non-corrosive dowel bars in concrete pavements have been completed in Illinois, Connecticut, Wisconsin, Ohio and Arkansas. The Ohio Department of Transportation has accepted the FRP dowel bars as an alternative to epoxy coated steel for the repair of doweled joints. The records and reports of these laboratory and field activities and others will be reviewed, synthesized and incorporated in the evaluation report. (See the brief Bibliography at the end of this plan report.)

Environmental issues will be addressed to determine if there is documentation in the literature or manufacturer's records that the dowels are free from hazardous materials in the manufacturing process or product. Information on the potential for recycling of used bars or by-products of the manufacturing process will be sought also.

2.2.2 Field Installations

The principle thrust of the HITEC evaluation will be in the observation and testing of field installations completed or planned by various state departments of transportation. Construction of new or rehabilitated concrete pavements with joints using alternative materials for dowels has been completed in some participating highway agencies and others are planned for the next construction season. Five states, Illinois, Iowa, Kansas, Ohio, and Wisconsin will participate in these field installations under the FHWA initiative, *TE-30, High Performance Rigid Pavements (HPRP).*

The participating states, in some cases, also may conduct additional experiments with other alternative materials and designs under TE-30, but the HITEC program will be confined to the evaluation of FRP and Stainless Steel dowels installed in standard joint designs using bond-breakers as recommended by the manufacturers providing the dowels.

Initial monitoring of the HITEC test sections will be performed by the highway agency immediately upon completion and curing of the installations and at six month intervals for the first 18 months of service life. Annual monitoring by the highway agency will continue thereafter, for a total period of five years. In addition to pavement condition observations using the Strategic Highway Research Program (SHRP) protocol, load transfer will be measured using falling weight deflectometers (FWD) and verification of dowel positions will be determined using NDT methods such as ground penetrating radar (GPR). If these methods prove to be inadequate, cores may be required to determine dowel bar positions and orientation in the experiment installations.

A second and concurrent part of the field installation program will be the joint condition assessment, deflection testing, and the coring of "old" FRP and Stainless dowels from concrete pavement joint repair installations made in Ohio in 1985 on I-

77 in Guernsey 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.

The third and final part of the field program will be the removal and laboratory evaluation, at the conclusion of the five-year observation period, of sample cores and full-length dowels from the alternative materials dowel joints placed as a part of this experiment.

2.2.3 Laboratory Investigations

On laboratory samples of the dowel bars and laboratory concrete castings, tests will be conducted on dowel fatigue, dowel debonding or pull out stress, dowel durability and load transfer capability using dowel shear tests. The laboratory shall design and propose fatigue testing subject to the approval of the Panel. The 1983 and 1985 Ohio section cores and dowels and those taken from the experiment sections at the end of five years, will be inspected and tested for all forms of degradation and performance as outlined in the following evaluation plan.

3.0 EVALUATION PLAN

3.1 Objectives

The objectives of the evaluation are:

- To assess the constructability, placement verification, environmental qualities and performance capabilities of Fiber Reinforced Polymer dowels and Stainless Steel dowels to perform the load transfer and joint movement requirements in concrete pavement joints for the full service life of the pavement without detrimental corrosion or deterioration; and
- To consider the comparative performance and service-life costs of these alternative materials and epoxy-coated mild steel for use in dowel bars.

3.2 Field Installations

Dowels will be supplied by the applicants for the field and laboratory tests in compliance with the state specifications for dowel dimensions and installation methods in each of the participating state departments of transportation. The sponsoring agencies are encouraged to select project sites so that different types of joints are constructed (i.e. expansion, contraction, and/or repair).

Dowel installations will be designed to meet standard size, positioning, and joint design requirements for epoxy-coated mild steel doweled joints so that the performance data will reflect the alternative dowel materials, not alternative joint designs. Epoxy-coated mild steel doweled joints will also serve as the control for all comparisons.

The field installations to be made in the participating states will include the use of FRP and/or Stainless Steel dowels meeting the minimum dimensions of 18 inches in length and 1.5 inches in diameter. Installations will be by baskets or by inserters as defined by project specifications for joint construction in each state. The planned installations are delineated in *Table 1, Summary of Plan Schedule, Sites, and Tests for Field Program.*

In addition, previous installations of FRP Dowels will be extracted and tested per the testing program described below. At a minimum, the dowels from the Ohio projects shall be removed. Dowels from other previous installations may also be added to the evaluation.

Information to be recorded for each field installation project will include the following:

3.2.1 Design data

- Location: route and milepost or section.
- New construction, or rehabilitation.
- Design traffic: ESALS
- Roadway location: tangent, curve, grade, cut/fill.
- Type of joint: contraction, expansion.

- Joint design: position, spacing, sealant used (if any).
- Dowel: size, material (manufacturer's specifications), debonding agent.
- Dowel basket or insertion details and specifications.
- Pavement design: sugrade soil, subbase, base, slab thickness, mix design, reinforcement.

3.2.2 Construction Data

- Manufacturer of dowels.
- Date and weather conditions during construction.
- As-built pavement, joint design, and concrete strength data.
- Base and subbase classifications and conditions
- Materials, equipment, and labor costs for the joint(s) construction (if available).
- Observations regarding the constructability, ease of handling, quality control, and other dowel-related factors.
- Dowel placement verification using Ground Penetrating Radar (GPR) or other method to determine dowels positions in constructed joints.

3.2.3 Performance Data

Immediately before opening to traffic, at six-month intervals over the first 18 months, and annually for the remainder of the 5-year period:

- FWD measurements of load transfer.
- Faulting measurements.
- Joint condition (spalling, cracking, crushing, etc.,) observations using the SHRP protocol
- Joint sealant condition.
- Pavement roughness (Mays Number, IRI, or other, but preferably IRI)

3.2.4 Operations Data, Annual

- Weather data: temperature range, freeze-thaw cycles.
- Traffic data and axle loading estimates developed and accumulated throughout the observation period.
- Joint sealing practices, materials and cleaning-resealing frequency.
- Snow and ice control practices, salt and abrasive applications and frequency during observation period.

3.3 Laboratory Evaluations

A series of tests and analyses, listed in *Table 2*, *Test Specifications for FRP and Stainless Steel Dowels*, will be performed in one or more laboratories (selected by HITEC with the advice of the Panel) to supplement the field investigations and to permit accelerated loadings and exposure through simulations of field conditions. Three types of laboratory information will be used in the evaluation:

1) Laboratory samples and castings of fabricated specimens using new, original tests,
2) Cores and full length dowels of each material type taken from the field test sites and subjected to laboratory examination and performance testing,
3) Manufacturer's and other accredited laboratory tests and analyses of dowel bar physical properties, and manufacturer's certification that dowel materials, manufacturing processes, and products meet all current Federal environmental requirements.

3.3.1 Laboratory Tests

The following tests will be performed in selected laboratories using the FRP dowels and the Stainless Steel dowels supplied by the manufacturers.

Where accredited laboratories have already performed the specified tests on sample dowels that meet the same identical specification as the dowels provided for field installations, the HITEC Panel may waive the repetition of those tests and incorporate the already available test data in the evaluation.

In any event, the dowels tested in the laboratory for this evaluation must be identical to those provided for the field evaluation program. In general, the laboratory portion of the evaluation plan includes the following items:

- Physical property test data (to be furnished by applicants),
- Durability test data,
- Fatigue testing to simulate repeated truck loading,
- Elemental isopescu shear strength test,
- Debonding and pullout tests,
- Limited durability tests of full-length cut outs of: (a) previously-installed dowel bars (Ohio), and (b) the five-year experimental joints, and
- Correlation of laboratory specimens with field measurements and behavior.

Each of the laboratory tests are shown in Table 2 and described in the following sections.

3.3.1.1 Physical Property Tests

The material properties of modulus of elasticity, tensile strength, coefficient of thermal expansion, porosity and elongation characteristics should be determined by the Applicants for the alternative material dowels (in accredited laboratories) and reported to the Evaluation Panel for each type of dowel bar to be evaluated in the field and laboratory program.

3.3.1.2 Elemental Isopescu Shear Strength Tests

Elemental tests will be used to determine the shear strengths of the dowel bars of the alternative materials. These tests use full-size dowel bars embedded in blocks of concrete and subjected to pure shear isolated from moments and other forces.

The tests provide a means of determining the shear strength of the dowel. In addition, the tests provide a means of determining the informal contact modulus properties for a more theoretical determination of the force distribution along the dowel length. Three tests of each alternative material should be performed.

3.3.1.3 Debonding and Pullout Tests

Since dowel bars are not designed to be subjected to axial forces and are designed to slip in the pavement joints, the dowels must not bond with the concrete in the joint. Pull-out (debonding) tests with and without bond breakers are needed to show that the alternative material dowel bars pull out freely from the concrete. The surface roughness, dowel bar materials, and the concrete material properties should be varied for tests through the range of conditions expected in highway pavement joints. A standard pullout test is indicated in Table 2. However, the test configuration or size of specimen should be large enough so as to not allow the resisting load to be located close to the zone of influence of the pullout (bond) forces of the dowel bar. Three tests of each material and parameter should be performed.

3.3.1.4 Durability Tests

Durability tests are needed for each selected alternative material dowel bar and previously installed dowel bars. Since corrosion is a potential problem of mild steel dowel bars, the alternative materials should be investigated for possible degradation due to corrosive environments.

Potential deleterious environmental conditions may cause different reactions for different alternative materials. Corrosive chloride ions and acids may affect Stainless Steel, where high alkalinity moisture conditions may affect FRP materials. Each of these potential degrading conditions needs to be tested in the laboratory using the Owens Corning test protocol described in the Appendix. The tests should include submersed specimens in a bath, followed by shear strength tests to measure any potential decline of the dowel bars performance. Three specimens should be tested for each selected environmental condition for each alternative material.

3.3.1.5 Testing of Previously-Installed Dowel Bars

Full-length dowels for each material cut out of the 1980s installations in Ohio sections and the five-year-old experiment sections installed under the HITEC program should be subjected to the durability tests. Other installations as deemed appropriate may also be removed. Dowel bars that were installed in Ohio in 1985-86 and at the end of five years in each of the cooperating states, dowel bars on the experiment sections will be removed following pavement condition surveys by coring three sections of each alternative dowel material for observation and limited durability tests. In addition, three full-length dowels of each alternative material will be cut out. The departments of transportation will perform the coring. Cutting out the full-length dowels will be arranged by HITEC in coordination with the departments. The dowels will be subjected to flexural bend strength tests and compared to original (new) dowel strength values. The dowels will be observed for signs of deterioration due to the loads and environment. Also, durability tests will be performed.

4.0 REPORTING

4.1 Laboratory-Field Coordination

The field and laboratory data will be recorded by the participating state agencies (under FHWA TE-30) and selected laboratories (under HITEC contracts) and collected by a HITEC representative on a quarterly basis for further analysis by the Evaluation Panel and publication as warranted.

The HITEC effort is intended to augment and compliment the individual state evaluation projects and the FHWA initiative, while striving to establish consistency in data collection and reporting systems wherever possible.

In order to provide meaningful correlation of the field and laboratory tests described in the foregoing sections, a coordination consultant will be retained by HITEC to represent the Panel and work with the participating agencies and laboratories by visiting each of the laboratories and field test sites, obtaining samples of the products used in each of the sites, coordinating the testing of the field and lab samples, assembling the tabulation of data, assisting the Panel in performing independent analyses of the laboratory and field test results, and participating in the preparation of reports of the results obtained from the laboratory and field determinations.

4.2 Reports

A quaterly progress report will be issued to update all parties involved until the completion of the HITEC evaluation.

A stand-alone report will be published by HITEC at the conclusion of the initial 18 month observation period and a final complete report will be published following the end of a five year monitoring period. The 18 month report will cover:

- Experiment design and construction data
- Dowel placement verification
- Field construction observations
- Initial load transfer performance
- Initial joint condition observations
- All completed laboratory analyses.

The five year complete report will cover:

- An executive summary of the 18 month report
- Joint condition and dowel performance data for the full five year period
- All laboratory test results and analyses
- An analysis of potential life cycle costs for the alternative dowel materials, as compared to epoxy-coated mild steel dowels.

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