FIBER-REINFORCED POLYMER (FRP) COMPOSITE DOWEL BARS

.... a 15-year durability study

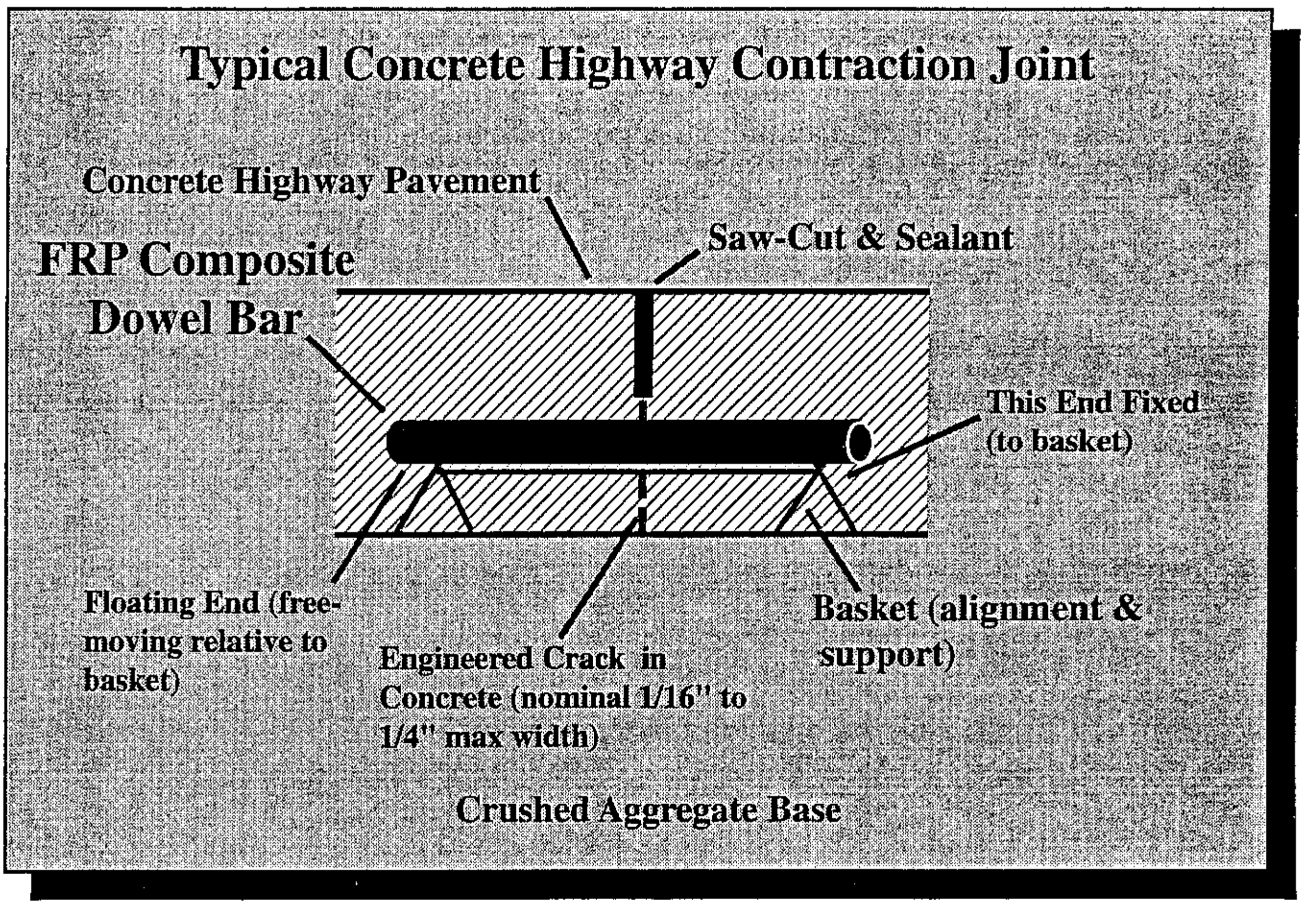

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TABLE OF CONTENTS

Page Number

ABSTRACT

Corrosion of mild steel dowel bars in the contraction joints of concrete highway construction has been characterized as "the primary source of premature concrete pavement failure" by the American Concrete Paving Association (ACPA). Traditional contraction joints use a mild steel dowel bar, typically 1.5 inches diameter by 18 inches in length to transfer environmental and wheel loads across road joints. Bars are welded on one-foot centers to a non-structural "basket" assembly to facilitate alignment before the concrete is poured. Steel dowel bars, whether fusion-bonded epoxy coated or not, corrode as a result of the penetration of chloride containing de-icing salts through the joint sealant system. Corrosion of the steel dowel bar creates exfoliation of the steel surface, causing the steel dowel bar to "lock" in the joint. Locking in turn, induces excessive tensile loads on the surrounding concrete with attendant pulverizing or micro-rubbleizing of the concrete and results in greater movement around the joint. Greater joint movement accelerates the rate of joint failure. ACPA estimates that steel dowel bars can fail in as little as seven to fifteen years depending on design and location, whereas the concrete highway slab itself can easily perform for 35-to-40 years. Therefore, finding a solution to the failure of steel dowel bars is important to all segments of the concrete highway paving community.

In 1983 and 1985, the Ohio Department of Transportation (ODOT) and the Civil Engineering Department at Ohio University installed several alternative dowel bars for long-term durability performance studies in sections of Interstate-77 in Guernsey County and Ohio State Route-7 in Belmont County. The alternative materials that were installed at these test sites included fiber-reinforced polymer (FRP) composites and stainless steel. FRP composite dowel bars were composed of approximately 78% (wt.) E-glass continuous glass fibers and approximately 22% (wt.) vinyl ester thermosetting resin. The cut ends of the composite bars were not treated.

Interest in alternative dowel bars, including FRP composite products, has been growing during the past several years. In 1997, the Market Development Alliance (MDA) organized a new FRP Dowel Bar Team, comprising composites fabricators and material suppliers to help coordinate development of specifications and standards and also to organize and coordinate product demonstrations. HITEC was retained to conduct a preliminary evaluation of FRP composite dowel bars. During the 1998 paving season, four demonstration projects were conducted; two in Ohio and two in Wisconsin. Additionally, in July 1998, under the auspices of ODOT, the Market Development Alliance Dowel Bar Team (DBT) undertook the task of removing and testing the original FRP dowel bars that had been installed in I-77 and SR-7 to determine their durability performance over nearly 15-years of in-pavement service.

After approximately 15 years in the field, the epoxy coating of the steel dowel bars had delaminated and could be peeled away as a thin film shell. Corrosion damage and exfoliation was evident on all mild steel dowel bars that were inspected, but not evident on the stainless steel.

Laboratory tests were conducted to measure tensile strength, flexural modulus (stiffness), shear strength, surface appearance and load transfer efficiency of the FRP composite dowel bars. *These tests have shown that the FRP dowel bars were virtually unaffected by approximately 15-years of field service and exposure to the alkali environment of the concrete.* Based on the results of this study, highway engineers can now design and specify FRP composite dowel bars with confidence

FIBER-REINFORCED POLYMER (FRP)
COMPOSITE DOWEL BARS
... A 15 YEAR DURABILITY STUDY

Introduction

Corrosion of mild steel dowel bars in the contraction joints of concrete highway construction has been characterized as "the primary source of premature concrete pavement failure" by the American Concrete Paving Association (ACPA). This premature failure results in millions of dollars per year in unnecessary maintenance. The market share of more durable concrete highways is at less that 8% of total U.S. new highway construction, largely due to the problems of steel dowel bar joint durability. Traditional contraction joints use a mild steel dowel bar, approximately 1.5 inches diameter by 18 inches in length to transfer environmental and wheel loads across road joints on nominal 15-foot intervals along the length of the highway. Bars are welded on one-foot centers to a non-structural "basket" assembly to facilitate alignment before the concrete is poured. Please see the report cover for a detailed sketch of this application.

Figure One
Typical Steel Dowel Bar and Basket Assembly

Steel dowel bars, whether fusion-bonded epoxy coated or not, corrode as a result of the penetration of chloride containing de-icing salts through the joint sealant system. Corrosion of the steel dowel bar creates exfoliation of the steel surface, causing the steel dowel bar to "lock" in the joint. Locking in turn, causes excessive tensile loads on the surrounding concrete with attendant stress concentration on the concrete and greater movement around the joint, which hastens the rate of joint failure. ACPA estimates that steel dowel bars can fail in as little as seven to fifteen years depending on the design and the design and location, whereas the concrete highway slab itself can easily perform for 35-to-40 years. Therefore, finding a solution to the failure of steel dowel bars is important to all segments of the concrete highway paving community.

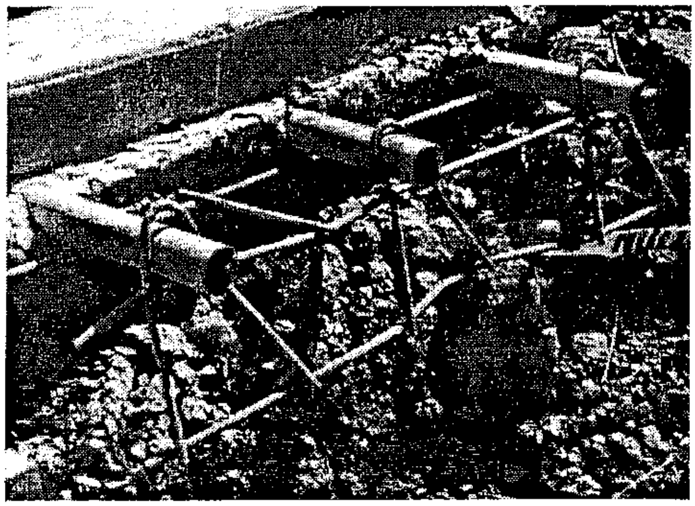

Figure Two
Close-Up of Typical Dowel Bar and Basket in Concrete

The search for more durable dowel bars is not a new undertaking. With the advent of fusion-bonded epoxy coated steel reinforcements, the concrete highway industry believed that it had found a long-term solution to the dowel bar joint durability problem. Unfortunately, the epoxy coated dowel bars demonstrated the same performance problems that are normally associated with surface coatings including voids, holidays, damage, etc. Also, chemical and electrolytric corrosion effects were found to concentrate corrosive mechanisms in the areas of these types of defects, in some cases, leading to more rapid failure than the same steel reinforcements without any epoxy coating.

In 1983 and 1985, the Ohio Department of Transportation (ODOT) and the Civil Engineering Department at Ohio University installed several alternative dowel bars for long-term durability performance studies in sections of Interstate-77 in Guernsey County and State Route-7 in Belmont County. The alternative materials that were installed at these test sites included fiber-reinforced polymer (FRP) composites and stainless steel. FRP composite dowel bars were composed of approximately 78% (wt.) E-glass continuous glass fibers and approximately 22% (wt.) vinyl ester thermosetting resin. The cut ends of the composite bars were not treated.

Interest in alternative dowel bar materials, including FRP composite products, has been growing over the past several years. To address the opportunity for a new product application, the Market Development Alliance organized a new FRP Dowel Bar Team in 1997. This team comprises leading composites fabricators and material suppliers with a mission to help coordinate pre-competitive and generic development of specifications and standards and also to organize product demonstrations.

The Civil Engineering Research Foundation's Highway Innovative Technology Evaluation Center (HITEC) was retained in 1998 to conduct a preliminary evaluation of FRP composite dowel bars. A survey of the 50 state DOT's yielded an amazing 78% response of states with an interest in alternative dowel bar materials. Even more surprising, 13 state DOT volunteering to participate in an evaluation study. Working with the HITEC panel, draft product performance and installation specifications were developed to permit state DOT's to specify and purchase FRP composite dowel bars.

During the 1998 paving season, four demonstration projects were conducted under the auspices of HITEC, including two projects in Ohio and two projects in Wisconsin. Other state DOT's, including Iowa and Illinois, conducted their own non-HITEC demonstrations. In July 1998, in association with ODOT, the MDA Dowel Bar Team undertook the task of removing and testing the original FRP dowel bars that had been installed in I-77 and SR-7 to determine their durability performance over 12-to-15 years of in-pavement service.

Methodology

Site Conditions and Traffic Loading The first research task was to characterize the service conditions at the test site including temperature, weather, application of deicing salts, etc. Falling Weight Deflectometer (FWD) tests were performed by ODOT along with an attempted Ground Penetrating Radar (GPR) survey prior to coring and joint removal. Unfortunately, the Ground Penetrating Radar survey was unsuccessful. In addition, loading cycles were developed based on data obtained by an ODOT survey. For the I-77 site, a traffic counter, and vehicle classification device was employed, and for SR-7, a counting device was used. This portion of the analysis was used to determine dowel alignment, and was also employed in conjunction with the FWD testing. During removal of the two joints, one on I-77, the other SR-7, dowel alignment was observed, and dowels were correctly aligned. Subsequent analysis of the data shows that the I-77 and SR-7 sites were cycled approximately 14,403,046 and 1,103,400 times, respectively, with loads of approximately 18,000 pounds per cycle. Table One below provides the de-icing salt application summary.

Table One
De-Icing Salt Application Summary

Data	I-77	SR-7
County Location	Guernsey	Belmont
Lane Miles	228	662
Test Area (Square Feet)	28,892,160	83,888,640
Concrete Pavement Depth	10 inches	10 inches
Concrete Volume (Cu. Ft.)	24,076,800	69,907,200
Duration of Test (Years)	13	14
Salt Applied/Year (Pounds)	5,328,000	3,466,000
Salt Concentration/Year Lbs/ft.^{3}	0.22	0.05
Total Salt Accumulation Lbs/ft.^{3}	2.86	0.70

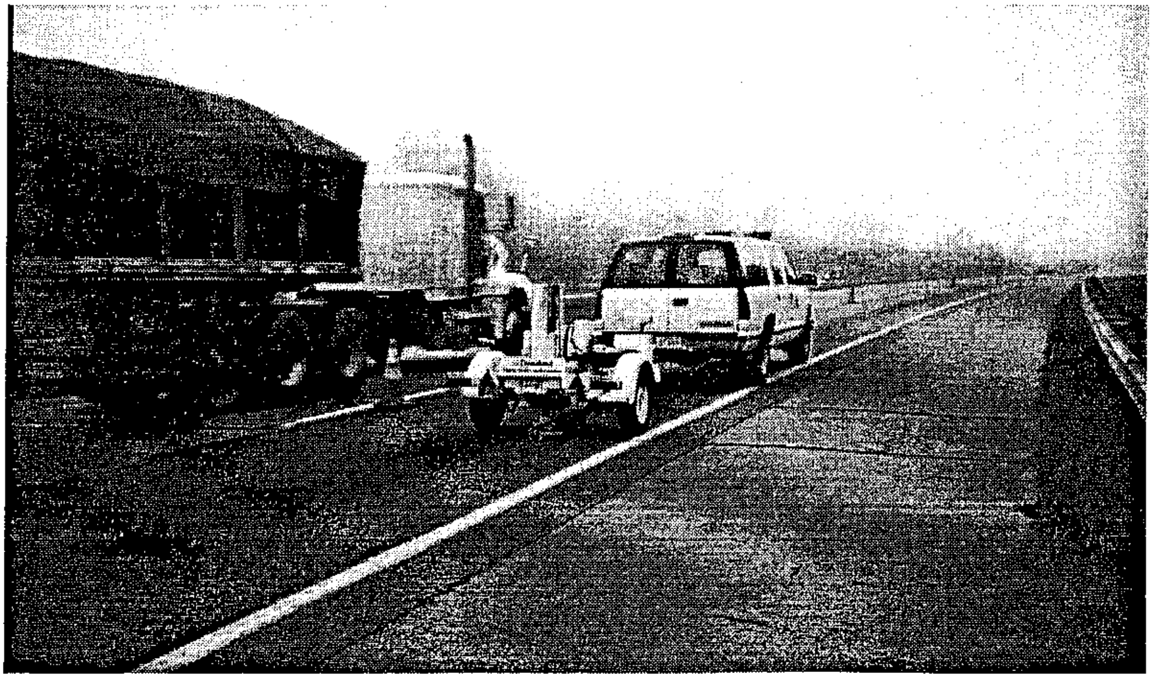

Figure Three
Falling Weight Deflectometer Testing on I-77

Selected dowel bar sets were cored by drilling to remove both the dowel bar and surrounding concrete. Figure Four below shows a cross section core of an FRP composite dowel bar embedded in concrete. Please note the excellent condition of the FRP dowel bar.

Figure Four
FRP Composite Dowel Bar Core from SR-7

In addition to coring, more than a half-dozen full-size joint slabs were cut out of both I-77 and SR-7 test sites in Figure Five below. The excavated joints were then replaced using FRP composite dowel bars at either end of the exposed joint, also as shown below in Figure Six.

Figure Five
Removal of Test Joint Slabs

Field Observations

After approximately 15 years in the field, the epoxy coating of the steel dowel bars had delaminated and could be removed as a thin film shell. There was evidence of corrosion damage and exfoliation, including pitting and necking-down on all steel dowel bars in the test including controls and non-stainless steel test materials. The FRP dowel bars appeared to be unaffected by long-term service; surfaces retained their as-manufactured gloss levels. The end-cuts were hard and dry. Some abrasive wearing down of the dowel bar surface was noted in several joints in which the sub-grade had failed, permitting excessive vertical travel of the joint in response to environmental and wheel loads.

Figure Six
Replacing the Test Slab with
FRP Composite Dowel Bars

Figure Seven
Removal of Dowel Bars from Concrete Slabs

Laboratory Testing

Prior to this report, other studies attempted to characterize the long-term performance of FRP dowel bars by simulating the chemical and operating environment of a concrete highway slab. In these test protocols, after conditioning the FRP materials were subjected to standard industry test methods to determine the performance of the bars in the simulated environment.

The significance of the MDA FRP Composite Dowel Bar durability study is *that the highly durable performance of the FRP materials occurred under actual field conditions for periods up to nearly 15 years.* This real-life, real-time field conditioning was a function of thermal and traffic loading, alkalinity of the concrete, and effects of materials intentionally placed on the pavement such as road de-icing salts, or are inherent in the end-use, such as motor vehicle engine oil, fuel, coolant, incidental spills of various chemicals, etc. These conditions simply can not be duplicated in the laboratory.

Laboratory tests were conducted to measure tensile strength, flexural modulus (stiffness), shear strength, surface appearance, etc. of the FRP composite dowel bars. This testing has shown that the FRP dowel bars were virtually unaffected by approximately 15-years of field service and exposure to the alkali environment of the concrete. Based on the results of this study, highway engineers can now design and specify FRP composite dowel bars with confidence

Test methods used to characterize the controls and field samples were as follows:

Table Two
FRP Composite Test Methods

ASTM D4476 -	Test Method for Flexural Properties of Fiber Reinforced Pultruded Plastic Rods.
CI DBT-3	Recommended FRP Dowel Bar Shear Test Method
ASTM D2584 -	Standard Test Method for Ignition Loss of Cured Reinforced Resins.
Surface Condition	Micrographs.

Only the FRP dowel bars were subjected to full laboratory testing. The steel dowel bars, both stainless and epoxy coated were analyzed from extracted core specimens. Inspection was limited to visual observation of effects of environmental conditions; alkalinity, and chlorides from de-icing salts.

Fortunately, one of the original dowel FRP composite dowel bars was retained by ODOT. This specimen is identified as "*I-77-Control, as received.*" FRP dowel materials from both test sites were produced by the same manufacturer, using the same raw materials (i.e.; vinyl ester resin from Ashland Chemicals and "E-Glass" type continuous fiber glass reinforcement from Owens Corning. Testing per ASTM-D2584 determined that the FRP composite dowel bars comprise approximately 22% vinyl ester resin and 78% "E" type glass reinforcement, by weight.)

Other laboratory tests included thermal and moisture loading, alkalinity of the concrete, effects of road de-icing salts (including residual alkalinity), mechanical and physical testing (including tensile strength, flexural modulus, shear, and observation of the surface condition of the FRP dowel bar via photomicrographs). The test results are summarized below.

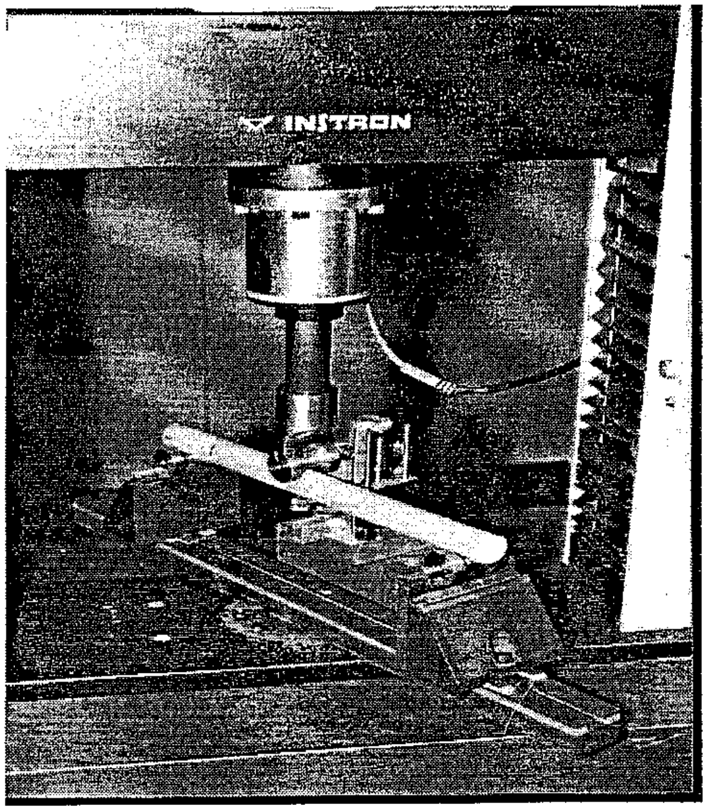

Figure Eight
Testing for Flexural Modulus per ASTM D4476-97

Flexural Modulus (Stiffness) The flexural modulus of each of the dowel bar samples was determined in accordance with Flexural Modulus (ASTM D4476-97), with some modifications to the procedure. These modifications involved the use of a full-round test specimen instead of one with a semi-circular cross section. The intention of the full-round profile was to provide a comparative modulus (stiffness) of the dowel bars without destroying the specimens which were required for other tests. The other modification for this test was the utilization of a shorter support span than is called for in the ASTM procedure. This was required due to the shortness of the specimens that were embedded in the concrete. Specimens were placed on the support arbors as described the in the ASTM test method, using the maximum support span available for each specimen. Tests were conducted with a constant crosshead speed of 0.05 inches per minute (ipm). All specimens were loaded to 200 pounds and then unloaded. Modulus values were calculated using Instron Series IX software with the segment modulus determined between 40% and 80% of the maximum load. The reader should be reminded that these modulus measurements are based on a non-standard test protocol and are, therefore, provided for comparative purposes only.

Table Three
Flexural Modulus per ASTM D4476-97

Sample Identification	Number of Specimens	Diameter (inches)	Modulus Psi X 10^6
I-77 Control*	1	1.00	3.73
State Route 7	4	1.25	5.30
I-77-4AW	1	1.00	4.38
I-77-4LW	1	1.00	5.06
I-77-5AW	1	1.00	4.60
I-77-5LW	1	1.00	5.53
I-77-6AW	1	1.00	5.22
I-77-6LW	1	1.00	6.68

* Note: this is un-installed dowel bar control.

A further comment on the flexural modulus data is in order. Flexural modulus is calculated on the basis of the relationship between the applied load and the cross sectional area. Each of the removed dowel bars had slightly reduced cross sectional area as a result of abrasion at the joint face. This means that while the apparent modulus increased, the actual performance was within testing nominal limits between the un-installed control and the field-tested dowel bars. Essentially, the data shows that the bars were unaffected by long-term service in the field.

Shear Strength Testing The shear strength of each of the FRP composite dowel bars was determined according to the specifications and test method outlined in the test method developed by the MDA FRP Dowel Bar Team in their test method, MDA DBT-3, *"Recommended FRP Dowel Bar Shear Test Method."* The loading fixture designated by this test procedure was provided by RJD Industries.

A total of four (4) tests were conducted on the SR-7 materials with two shear strength measurements determined from the ends of the test dowel bars, and two determined at the center portion of the dowel bars. A total of eighteen (18) shear tests were performed on the I-77 materials. A portion of each test was conducted on the ends of the specimens and a portion conducted on the center section of the specimens.

Falling Weight Deflectometer (DWT) As shown in Figure Three on page seven, ODOT conducted extensive tests on joint load transfer efficiency using a mobile Falling Weight Deflectometer. DWT testing conducted in 1984, 1988 and 1998 showed that the FRP composite dowel bars were equal to, or greater than, steel dowel bars in load transfer efficiency. There were also indications that some of the steel dowel bar controls had bent under load, whereas the lower modulus FRP composite dowel bars recovered without damage and did not subject the surrounding concrete to excessive concentrated compressive loads.

Table Four
Shear Summary Comparison (Test Method MDA DBT-3)

Sample Identification	Location	Number of Specimens	Shear Stress Psi X 10^3
I-77 Control*	End	1	25.7
State Route 7	End	2	20.7
	Center	2	19.4
I-77-4AW	End	2	26.3
	Center	1	17.3
I-77-4LW	End	2	21.8
	Center	1	20.4
I-77-5AW	End	2	21.5
	Center	1	13.5
I-77-5LW	End	2	16.0
	Center	1	12.2
I-77-6AW	End	2	23.6
	Center	1	15.3
I-77-6LW	End	2	20.7
	Center	1	19.1

** Note: this is the un-installed dowel bar control.

Again, the reader should be aware that the shear values determined at the center sections of the I-77 FRP dowel bars are based on an assumed 1-inch diameter cross-section. Due to mechanical degradation (wear), the actual cross-section was somewhat less than the diameter specified. This causes the calculated strength values above to be understated. Actual shear strength, based on cross-sectional area, would be higher than the values listed. It is estimated that the degradation in some cases may have sufficient to reduce the cross-sectional area in some severely failed joints by as much as one-third, with a corresponding underestimation of the actual shear stresses.

Reinforcement Content Test Protocol (ASTM D-2584) Glass fiber reinforcement (non-volatile content) measurements were conducted on two portions of each sample, in accordance with ASTM D2584. Specimens were cut from the submitted dowel bars, weighed, placed in a crucible and ignited in a muffle furnace at approximately 1,050 °F, burning off the organic resin matrix and leaving only the inorganic glass fiber reinforcement. Specimens were then removed from the oven, cooled in a dessicator and re-weighed to determine the weight loss and resultant reinforcement content. The average glass content was very uniform, ranging from 77.9% to 78.4% by weight.

Photo Micrographic Inspection Samples were inspected visually with an optical light microscope. Close inspection of the surfaces revealed that the surfaces remained glossy and unaffected. After sanding off approximately 25µm, the rod ends appeared solid and glossy. At this depth, the resin was smooth and intact, indicating that the chemicals from the concrete have not penetrated or degraded the FRP composite dowel bar.

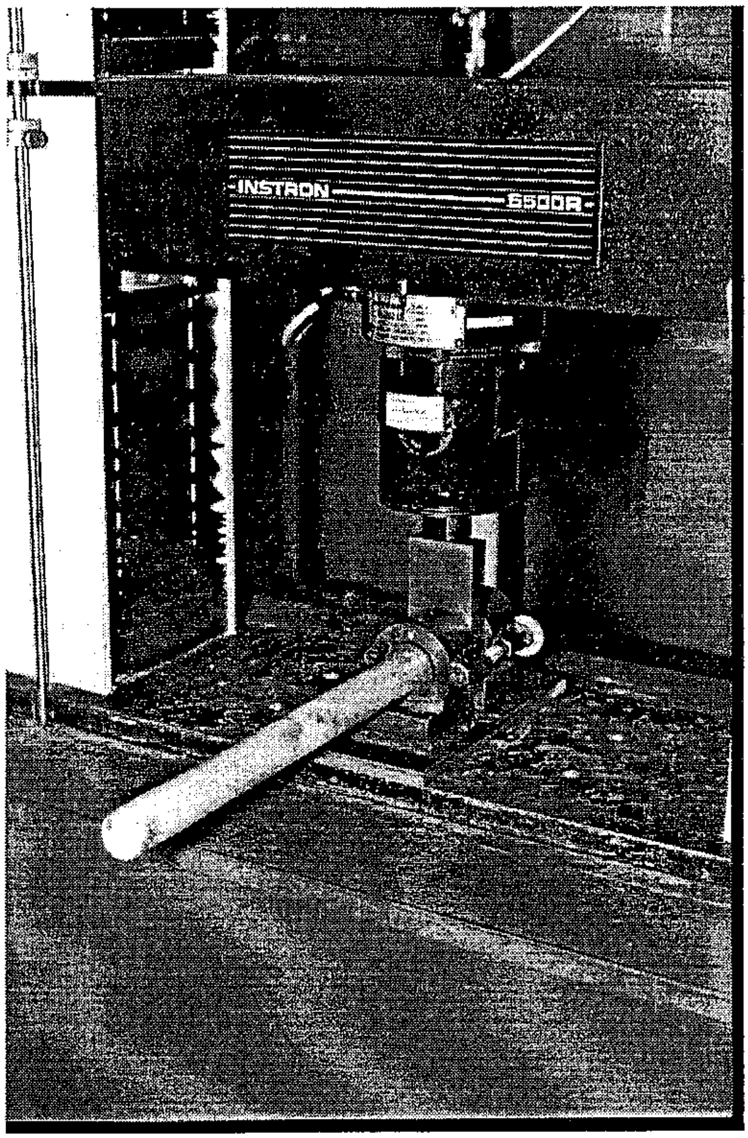

Figure Nine
Shear Testing per MDA DBT-3

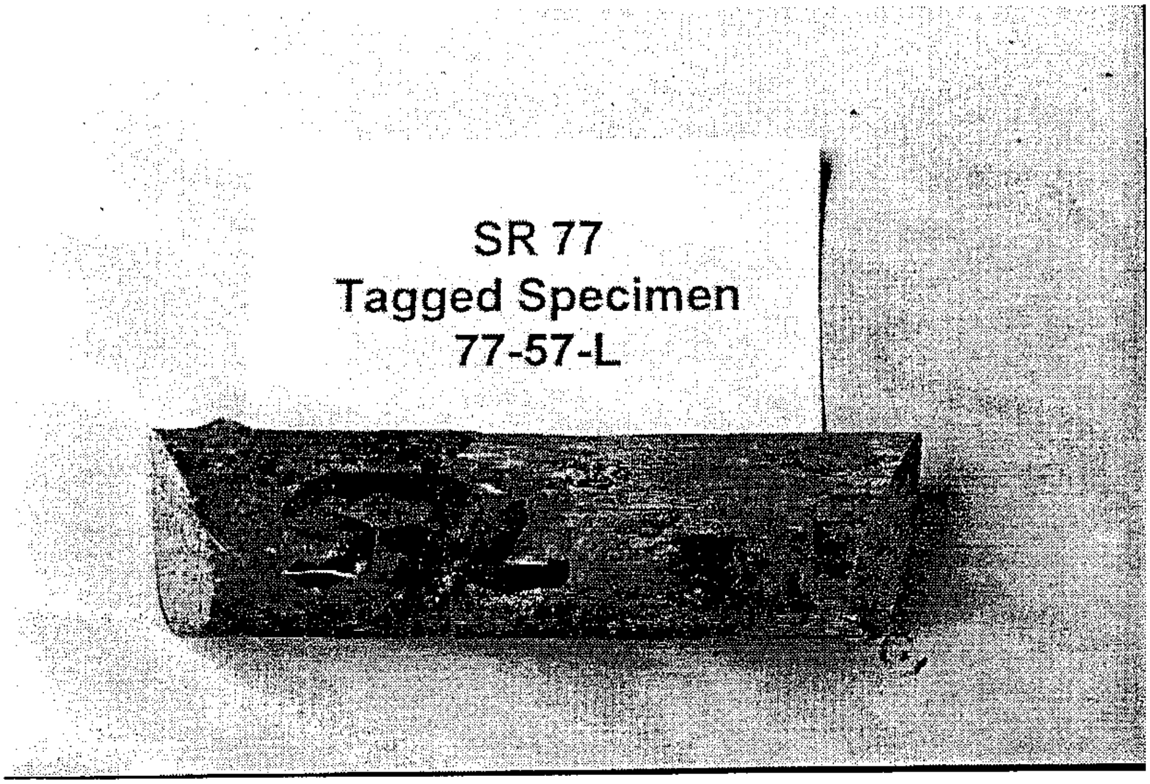

Figure Ten
Closeup of FRP Composite Dowel Bar Sample

Conclusions

After nearly 15 years of in-service performance on heavily traveled roads, in the high pH alkaline environment of concrete, and in an area requiring extensive use of de-icing salts, the FRP composite dowel bars showed no sign of deterioration, other than mechanical erosion caused by excessive joint movement. The load transfer efficiency of FRP composite dowel bars was equal to, or greater than, steel dowel bars.

The deterioration of the epoxy-coated steel material was well documented. This failure of the epoxy coating and resulting corrosion can lead to premature failure of the concrete highway joint.

Copies of the following new MDA FRP Dowel Bar Team product specifications for FRP composite dowel bars can be found in the Appendix:

- **MDA DBT-1:** ***"FRP Dowel Bar (Solid) Properties"***
- **MDA DBT-2:** ***"Recommended Dowel Bar Durability Test Protocol"***
- **MDA DBT-3:** ***"Recommended FRP Dowel Bar Shear Test Method"***

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ACI 325.9R – Guide For Construction of Concrete Pavements and Concrete Bases.

ASTM A615 (AASHTO M 31) – Specification for Deformed and Plain Bars for Concrete Reinforcement

ASTM A616 (AASHTO M42) – Specification for Axle-Steel Deformed and Plain Bars for Concrete Reinforcement.

ASTM A775 (AASHTO M284)– Specification for Epoxy Coated Reinforcing Steel Bars.

ASTM D2584 - Standard Test Method for Ignition Loss of Cured Reinforced Resins.

ASTM D3916 - Test Method for Tensile Properties Glass-Fiber-Reinforced Plastic Rod.

ASTM D4065 - Standard Practice for Determining and Reporting Dynamic Properties of Plastics.

ASTM D4476 - Test Method for Flexural Properties of Fiber Reinforced Pultruded Plastic Rods.

ASTM D695 - Test Method for Compressive Properties of Rigid Plastics.

MDA DBT-1 (1998) – FRP Dowel Bar (Solid) Properties

MDA DBT-2 – Recommended FRP Dowel Bar Durability Test Protocol

MDA DBT-3 (1998) – Recommended FRP Dowel Bar Shear Test Method.

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- Ashland Chemical Co., Dublin, OH
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- Highway Innovative Technology Evaluation Center (HITEC), Washington, D.C.
- ISORCA, Inc., Granville, OH 43023
- Owens Corning Technical Center, Granville, OH
- Ohio Department of Transportation, Columbus, OH
- Ohio University, Athens, OH
- RJD Industries, Inc., Laguna Hills, CA

DBT – 1

FRP Dowel Bar (Solid) Properties

PROPERTY	TEST METHOD	VALUE
Tensile Strength(1)	ASTM D638/D3916	70 Ksi (min)
Flexural Stength (2)	ASTM D790	70 Ksi (min)
Tensile Modulus(3)	ASTM D638	5 Msi (min)
Flexural Modulus(4)	ASTM D790	5 Msi (min)
Shear Strength	DBT-3(5)	16 Ksi (min)
Coefficient of Thermal Expansion		
Longitudinal	ASTM D696	3.0×10^{-6} in/in/^{0}F (typical)
Transverse	ASTMD3386	1.0×10^{-6} in/in/^{0}F (typical)
Pullout	AASHTO T253	1,000 lb. (max.)
Durability	DBT-2(6)	Minimum retention of shear and flexural strengths

(1) Tensile stress x cross sectional area. For 1.5 inch diameter Minimum tensile stress = 70,000 psi

(2) Flexural stress x cross sectional area

(3) Modulus of elasticity x cross sectional area. Modulus of elasticity = $5.5 \times 10^{(6)}$ psi

(4) Modulus of elasticity x moment of inertia. For 1.5 inch diameter, Moment of inertia = 0.249 in.^{4}

(5) Guideline provided by the SPI Composites Institute Market Development Alliance's Dowel Bar Team for shear strength test method

(6) Guideline provided by the SPI Composites Institute Market Development Alliance's Dowel Bar Team for test protocol

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DBT – 2

Recommended FRP Dowel Bar Durability Test Protocol

composites institute

MDA

MARKET DEVELOPMENT ALLIANCE

TITLE

Method of empirically determining the long-term performance of composite dowel bars used for shear transfer at joints in concrete highway pavements.

OBJECTIVE

Develop data in 180 or less days to prove that a composite reinforcing dowel bar product being tested can be used to provide satisfactory service over the pavement's life with minimal maintenance. The method assumes that shear and flexural forces are the dominant forces acting on the dowels during its entire service life.

SCOPE

Conduct shear strength and flexural modulus tests on composite dowel bars at prescribed time intervals after exposure to an environment of concrete extract (high pH) and elevated temperature. The concrete extract is used to condition the dowel bar in an environment similar to that anticipated in use. The elevated temperature(s) is used to accelerate the aging of the samples to allow long-term performance to be inferred from short-term data. The test protocol reflects the methods offered by Devalapura, et al. [1] and ASTM C581 [2].

SAMPLE FABRICATION/DETAILS

Samples are to be taken from a standard dowel bar production. For a given lot, 19 samples of 18 in. are to be provided. Two test specimens of 9 in. long will be cut from each sample. Specimens are to be sequentially numbered to allow randomization of testing. 3 specimens are tested for initial properties determination (as received) at room temperature. 9 additional specimens are to be tested as received three at each elevated temperatures. The remaining samples are to be used for conditions of combined environment and elevated temperature. Reinforcement(s), resin system(s), construction details, composition, date of production, and processing parameters are to be provided for each test lot.. DMA tests are to be conducted for each test lot to assess degree of cure through initial and second scan Tg measurements.

Each sample is to be clearly labeled with identifying markings and then weighed. Each sample is to have length and diameter thoroughly characterized and measured.

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Alliance of the
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CONDITIONING OF SAMPLES

Conditioning of samples include the combination of environmental exposure and application of an elevated temperature. The environmental exposure, both temperature and aqueous media, will influence the time to failure. The temperature is the acceleration factor. Each group of specimens is to be placed in cement extract environment and placed at three pre selected temperatures, 90°F, 120°F, and 160°F. Cement extract solution is prepared by mixing commercially available Portland Cement Type III with tap water. pH is measured at the beginning of the test and maintained throughout the test. Specimens are immersed in the solution in closed containers and placed in three constant temperature ovens. Once the specimens/solution reaches the prescribed temperature, the conditioning time is to start.

Samples will be kept in the conditioning environment with exposure times of 60 and 180 days designed to provide sufficient data for master curve based on the work of Proctor [3] who correlated accelerated aging from temperature to real-time exposure using the principle of time/temperature superposition.

TESTING OF SPECIMENS

Samples are to be removed from the conditioning oven, towel dried, weighed, and observed for changes in appearance. Three specimens per temperature will be tested in shear and flexure at the conditioning temperatures following ASTM D 4255/D 4255M for shear and ASTM D 4476 for flexural properties. Hence a total of 9 specimens for shear and flexural strength are tested at two time intervals of 60 and 180 days. Care should be taken to minimize evaporation losses during the test.

The primary output of this testing will be the shear and flexural strength retentions for a given length of time under an elevated temperature in an environment. A complete description of the environment and specimen must be documented. Post conditioning tests include strength and modulus values and any physical degradation if present.

DATA TREATMENT

(a) Shear Strength

The shear failure strengths of samples subjected to the conditioning environments shall be obtained for each exposure time and temperature. Data will be normalized using the values for the unconditioned specimens at the same exposure time. This figure will then be plotted against the theoretical real life exposure time. Eventually, when all the series of temperature levels have been completed, this will yield a family of curves showing the lifetime at different temperatures levels that can be expected under the conditions of alkaline environment as shown in Fig. 1. These values are then shifted using shift factors related to each temperature such that a master curve of strength retention versus log-time at room temperature is developed, see Fig. 2.

(b) Flexural Modulus

Elastic modulus data with time is to be treated as similar to shear strength data in the preceding section.

WEIGHT MEASUREMENTS

The initial and final weight s for each sample shall be plotted against time and will yield data reflecting the effect of the conditioning treatment. Data may also indicate any dissolution effects caused by the accelerating environment(s).

SUBSEQUENT TESTING

The failure surfaces of the tested samples shall be examined for evidence of environmental degradation effects and photomicrographic records obtained.

REPORTING

Each test series will be conducted with one environment and three elevated temperatures. Each series is to have specimen construction, composition, constitutive materials and manufacturing procedure comprehensively described. The results are to be reported for each test series in tabulated summary of numerical data, plots of data on a semi-log plot of log time to percent initial shear strength and flexural modulus retention (see Fig. 2), and a thorough description of the failures for each specimen with a representative microphotograph as needed. Weight change data may also be plotted against log time as additional information to assess the effectiveness of conditioning.

A flow chart showing the proposed protocol for evaluating long-term durability of dowel bar is enclosed for convenience in Fig. 3. [Owens Corning to provide at a later date]

REFERENCES

1. Devalapura, R.K., Gauchel, J.V., Greenwood, M.E., Hankin, A, and Humphrey, T.J., 'Long-Term Durability of Glass-Fiber reinforced Polymer Composites in Alkaline Environments,' Proceedings of the Third International Symposium on Non-Metallic (FRP) Reinforcement for Concrete Structures, Sapporo, Japan, October 1997.
2. Standard Practice for Determining Chemical Resistance of Thermosetting Resins Used in Glass-Fiber-Reinforced Structures Intended for Liquid Service, ASTM C 581 - 94, American Society for Testing and Materials, Philadelphia, Pennsylvania, 1994
3. Proctor, B.A., "The Long-Term Behavior of Glassfiber Reinforced Composites," Pilkington Brothers Place, Lancashire, England.
4. Standard Guide for Testing In-plane Shear Properties of Composite Laminates, ASTM D 4255/D 4255M - 83, American Society for Testing and Materials, Philadelphia, Pennsylvania, 1994.
5. Standard Test Method for Apparent Horizontal Shear Strength of Pultruded Reinforced Plastic Rods By the Short-Beam method, ASTM D 4475 - 96, American Society for Testing and Materials, Philadelphia, Pennsylvania, 1996.
6. Standard Test Method for Flexural Properties of Fiber Reinforced Pultruded Plastic Rods, ASTM D 4476 - 85, American Society for Testing and Materials, Philadelphia, Pennsylvania, 1990.

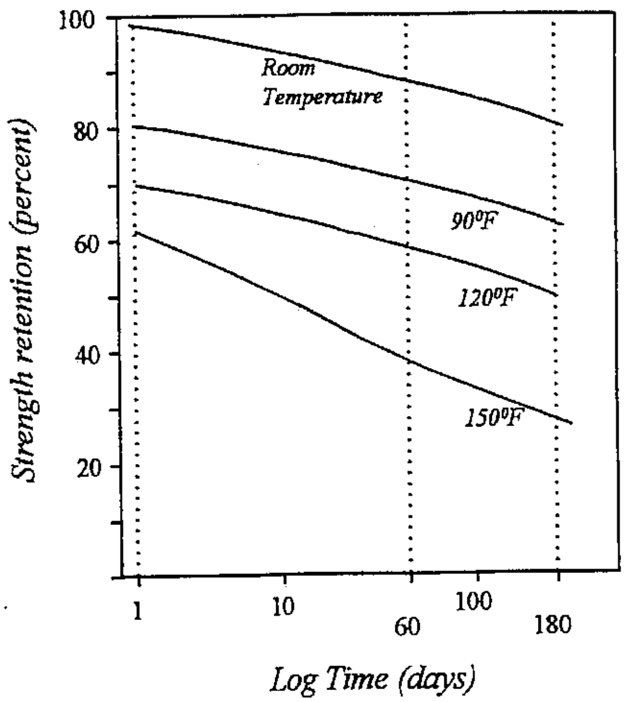

Fig. 1 Semi-log plot of strength retention versus time

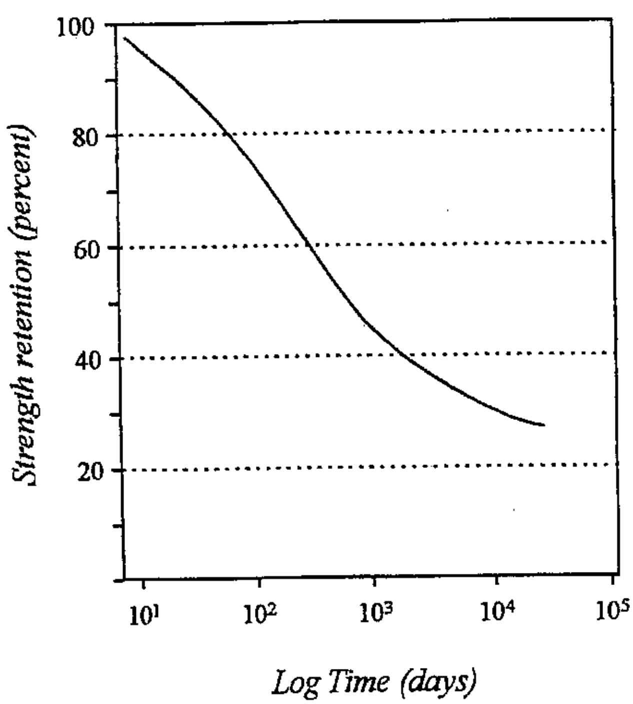

Fig. 2 Master curve for long term durability of dowel bar

DBT – 3

Recommended FRP Dowel Bar Shear Test Method

composites institute

MDA
MARKET DEVELOPMENT ALLIANCE

1. SCOPE

1.1 This test method covers the determination of the apparent shear strength, normal To the longitudinal axis of parallel fiber reinforced pultruded plastics.

1.2 *This standard does not purport to address all of the safety concerns, if any, Associated with its use. It is the responsibility of the user of this standard to establish Appropriate safety and health practices and determine the applicability of regulatory limitationsprior to use.*

2. REFERENCED DOCUMENTS

2.1 ASTM Standards
D2344 Test Method for Apparent Interlaminar Shear Strength of Parallel Fiber Composites by Short-Beam Method
D4255 Guide for Testing In-Plane Shear Properties of Composite Laminates

3. SUMMARY OF TEST METHOD

3.1 The apparent shear strength normal to longitudinal axis parallel fiber reinforced pultruded plastics are determined by applying shear loads on the specimen using a fixture consisting of gate moving normal to the longitudinal axis of parallel fiber reinforced pultruded plastics, one adjustable static member which restrains the portion of the specimen not being subjected to the shear loads, and another static member as a stop for the specimen, and guide for the shear gate.

4. SIGNIFICANCE AND USE

4.1 Previous test methods for parallel fiber reinforced pultruded plastics have Determined interlaminar shear strengths between the fiber reinforcement and resin matrix.

5. SUMMARY OF METHODS

5.1 The test fixture is to be designed either to accept multiple cylindrical rod diameters, or a single cylindrical rod diameter. See Figure 1 for multiple cylindrical rod diameters.

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5.2 The body of the fixture may be machined from mild steel stock. Inserts, preferably made from alloy steel tubes used in the manufacture of the cylindrical rod, or machined from alloy steel to a tolerance of +.002" - .000" of the cylindrical rod specimen, are to be inserted in the static, restraining portion of the fixture and the moveable gate.

NOTE: The insert placed in the moveable gate must be the width of the gate, +/- .002".

5.3 The specimen to be tested is inserted through the test fixture adjustable static fixture member, through the moverable gate, abutting the static stop fixture member. A lithium based lubricant is to be applied to the abutting surface of the moveable gate and adjoining static fixture members.

5.4 The test fixture/cylindrical rod assembly is to be placed in a universal testing maching, so that the head of the machine rests on the fixture moveable gate.

5.5 The test fixture/cylindrical rod assembly is to be loaded until the specimen shear occurs.

5.6 Record maximum load at specimen shear.

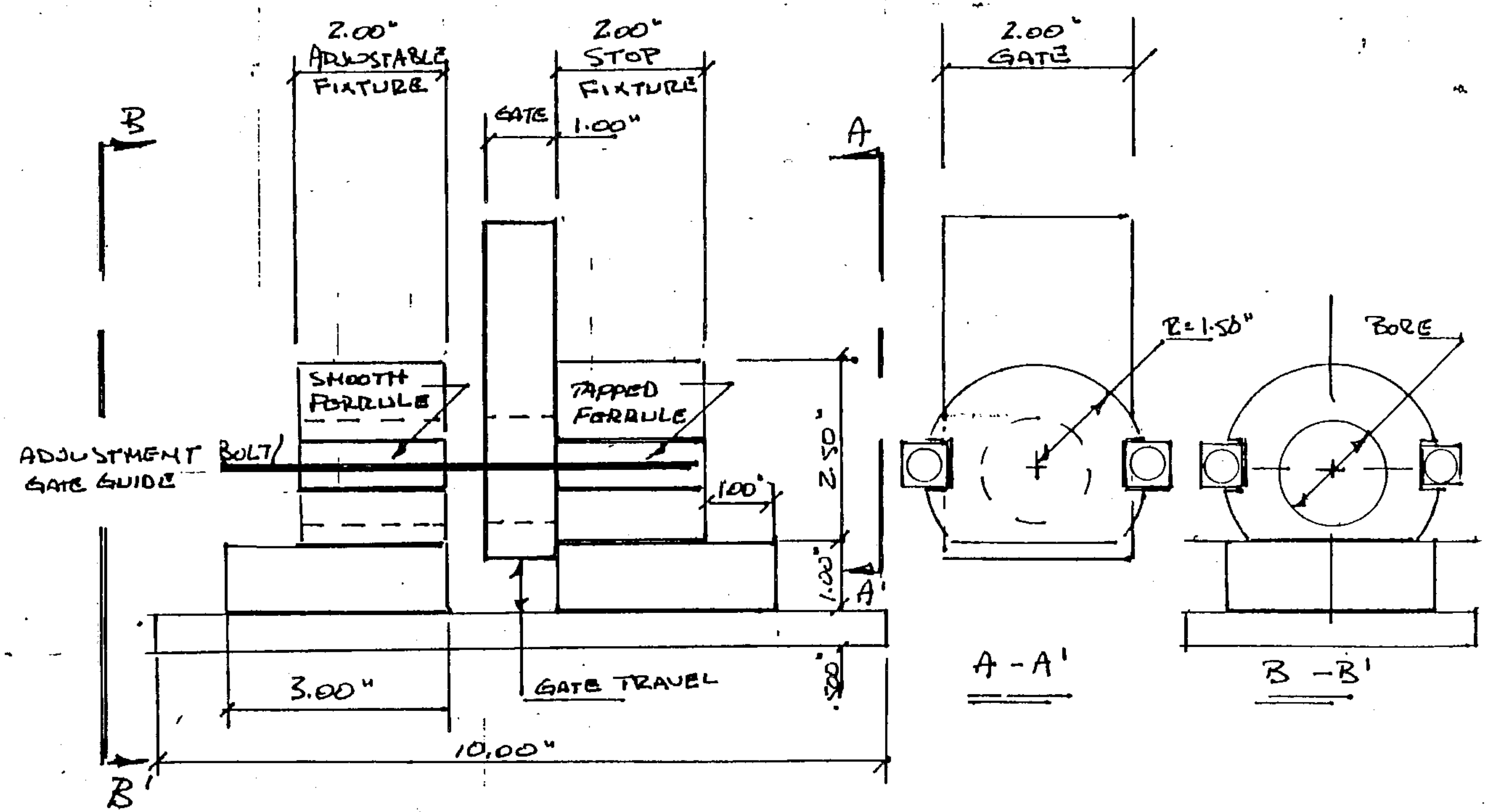
TEST SPECIMENS

6.1 At least five specimens shall be cut from the cylindrical rod specimen of interest. Specimen length shall be a minimum of the length of the adjustable static gate, plus the width of the moveable gate.

7.0 REPORT

7.1 The report shall include the following:

7.1.1 Complete identification of the material tested, including type, source, manufacturer's code numbers, principal dimensions, etc.
7.1.2 Dimensions of test specimens
7.1.3 Number of speciment tested
7.1.4 Speed of testing
7.1.5 Shear strength: average value and percent coefficient of variation
7.1.6 Date of test.



NOTE: 1. BORE = ROD INSERT Ø
2. BORE "ADJUSTABLE FIXTURE ONLY

RJD INDUSTRIES INC.
ROD SHEAR FIXTURE
BY: JPM DATE: 2/10/98
SCALE: 0/0 SK-01