

Research Record

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Research in Michigan Michigan Universities & MDOT Find New Solutions to Old Problems Through Research

The Michigan Department of Transportation continues to look for new solutions to transportation infrastructure problems through cooperation with some of the leading research facilities in the world—Michigan universities. This cooperation benefits MDOT by drawing on the knowledge of leading researchers in the transportation industry and benefits universities by giving researchers and students real-world problems.

This Research Record looks at six research projects that the MDOT Construction & Technology Division undertook with Michigan universities. The projects help solve common bridge problems using new materials and practices. Three of the projects look at the use of non-metallic composites to strengthen and repair traditional concrete structures. The fourth project looks at stainless steel as a corrosion resistant replacement for epoxy-coated reinforcement. The last two projects look at new methods of girder and deck evaluation that help engineers better understand the real-world performance of concrete and steel structures. MDOT is already using the results of some of this research in field studies and regular construction.

Fiber Non-Metallic Composites in Concrete Structures

Composites combine the beneficial properties of two distinct materials to the benefit of the combined material. For example, the traditional material for making composite reinforced concrete structures is steel. The performance qualities of steel and concrete complement each other well, with steel performing well under tension (pulling) and concrete performing well under compression (pushing). Because steel and concrete also bond well, a structure made of these two materials gains the beneficial properties of both materials, resulting in durable, strong, and tough structures.

In spite of the complementary qualities of steel and concrete, researchers continue to look for other materials that will improve concrete structures. Some of the most promising materials for improv-

ing concrete performance and longevity are non-metallic. Researchers are experimenting with glass, carbon, other natural, and synthetic fibers which augment or replace steel in concrete structures, and some of those materials are already specified for special applications. Many non-metallic materials perform as well or better than steel under tension, yet lack steel's weight and corrosion penalties, simplifying installation and extending service life.

Composite Reinforcing Bars

Michigan State University (MSU) and the Michigan Department of Transportation (MDOT) investigated non-metallic composites to replace metal reinforcing bars in concrete bridge decking. Since the good tensile properties of glass and aramid (e.g. Kevlar and Technora) are well known, researchers investigated the corrosion-resistance and durability of these materials when used in concrete. The results of accelerated aging testing showed that glass fibers could lose significant tensile strength with exposure to high temperatures and alkali solutions. Aramid fiber properties remained relatively stable after the aging tests, so MSU researchers chose these fibers for further research as a reinforcing bar replacement.

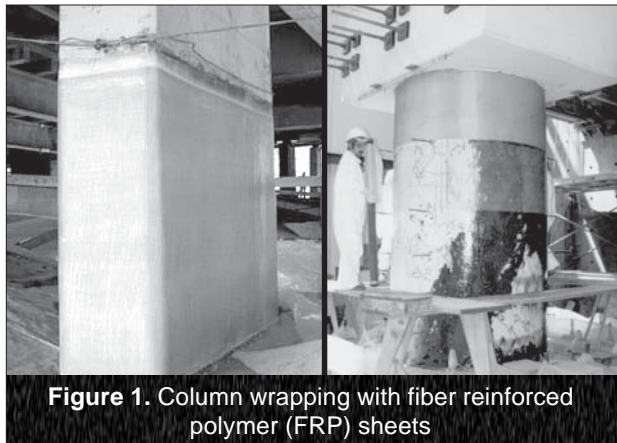
To compare aramid fibers to steel, researchers made similar concrete slabs, one set using aramid bars and the other using steel bars. The commercially-available aramid bars are formed using a polymer resin matrix and are available in deformed, smooth, and sand-coated profiles. The bars were set in concrete in a manner similar to steel bars of similar size and type. Tests were performed to compare the static and fatigue performance on bridge deck slabs as well as flex, bond, tensile, and shear properties of aramid bars compared to steel bars in concrete.

The results of these tests showed that aramid fiber reinforced slabs performed similarly to steel-reinforced slabs. The similar test results support the use of composites as a direct replacement for steel bars, albeit with a greater reinforcement ratio (greater area of bar cross section per concrete

cross section) to compensate for the lower elastic modulus of composites. To verify these laboratory test results, researchers decided to conduct an in-service test of composite-reinforced slabs on a Michigan bridge. The in-field test is underway on a bridge deck over Goodings Creek on M-15 in Tuscola County, Michigan, and MDOT will continue monitoring the bridge to evaluate the long-term performance of composites as a replacement for steel reinforcing bars in reinforced concrete.

Column Wrapping

Wrapping with non-metallic composites gives engineers a new method of reinforcing damaged concrete structures in the field without costly reconstruction or replacement. In this application, composite wraps do not replace steel, but augment the existing structure to repair or enhance the reinforced concrete structure. The wrapping of fiber reinforced polymers (FRP) is applied in sheets to the surface of concrete structures and held in place with the polymer resin (Figure 1). The wraps can repair or inhibit damage by impact, corrosion, earthquakes, and overloading.



In Michigan, MDOT has wrapped bridge columns damaged by chloride de-icing solutions. The column surface had begun to spall and expose the internal reinforcing bars. With exposure to the elements, the bars corroded more rapidly. To repair the damage, workers cleaned and patched the columns and then applied FRP wraps. The wrapping protects columns from further corrosion by sealing the column surface. Laboratory accelerated corrosion tests showed that FRP wrappings reduced corrosion by 46 to 59 percent.

In addition to corrosion protection and repair, circumferential FRP wrappings significantly improved the compressive strength of columns. In laboratory tests, round columns wrapped with FRPs are 2.3 to 2.6 times stronger, and square columns are 1.4 to 1.5 times stronger than unwrapped columns. Accelerated freeze-thaw and wet-dry tests did not statistically reduce the increased compressive strength, even though the ultimate strain of carbon and glass panels are reduced 28 and 36 percent, respectively, by these tests.

MSU researchers also tested the FRP materials' performance after exposure to temperatures above 100°C and after impact. The FRP resins begin to discolor and char near 150°C and will burn and evaporate above 200°C. Fibers that are not contained in the resin matrix lose their structural integrity; therefore, insulation must protect FRP wraps if they are expected to perform in high-temperature applications. Impact testing showed minor delamination at the point of impact, but impact damage did not significantly affect the wrapped column's performance.

Laboratory evaluations show that FRP materials should perform well in the field. MDOT and MSU will continue to monitor corrosion probe readings and visually inspect the FRP wrappings currently under field tests on Lansing Road under I-96 in Lansing, Michigan. With Michigan's and other states' experiences to support them, engineers can look to FRP wraps as an alternative to expensive reconstruction and replacement.

Beam Reinforcement

University of Michigan (U of M) and MDOT researchers investigated the use of carbon fiber reinforced polymers (CFRP) for repairing beams as an alternative to replacement or external steel reinforcement of concrete beams. As with column wrapping, FRP beam reinforcement can lend strength when applied to the exterior of existing structures.

For this research, U of M researchers experimented with two types of CFRP, a 0.11 mm thick flexible sheet and a 1.2 mm thick stiff plate. Both the flexible and stiff materials are glued to the surfaces of concrete with adhesives, and in the case of the flexible sheets, may be wrapped around beams. A CFRP sheet or strip glued to the bottom of a beam increases the beam's bending capacity, and gluing CFRP to the web (side) increases shear strength. The thick (1.2 mm) sheets are cut into strips and intermittently glued to the side, perpendicular to the beam length, for shear reinforcement, or long strips are glued longitudinally to the bottom of the beam for bending reinforcement (Figure 2).

Researchers tested new beams, pre-loaded and pre-cracked beams, patched beams, and beams with varying levels of concrete cover. Testing showed that CFRP reinforcement significantly strengthened for bending and shear in every case except when reinforcing was applied over patching. Patched beams were more likely to suffer interlaminar debonding between the patch and the original beam concrete.

Load testing showed that both CFRP sheets and plates are effective strength reinforcement for both bending and shear. In this study, ultimate load capacity increased nearly linearly with the strengthening level of CFRP sheets: Increasing the strength or number of individual reinforcing sheets predictably increased the strength of a beam. Testing also showed that ultimate deflection and ductility decreased for CFRP reinforced beams, but after

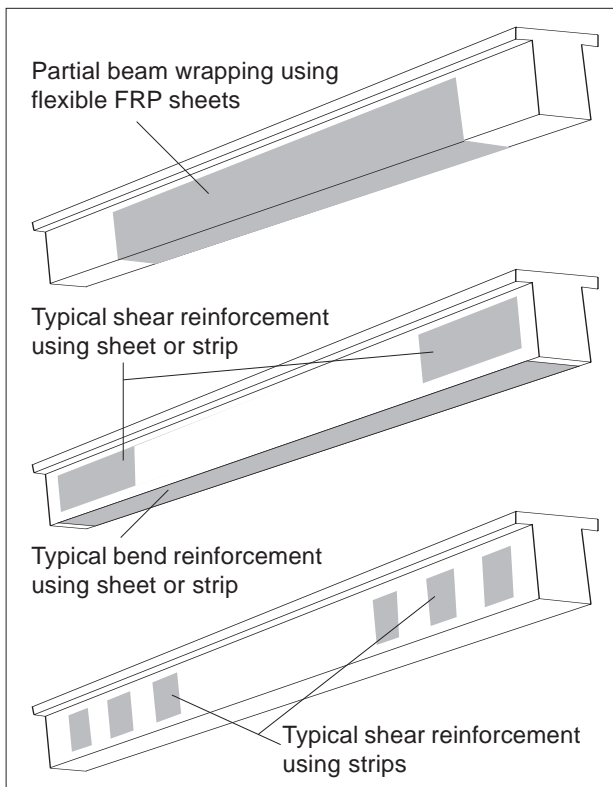


Figure 2. Typical glued FRP beam reinforcement for bend and shear

CFRP delamination or failure (Figure 3), the beams maintained a minimum load capacity and ductility similar to control beams without CFRP reinforcement.

To determine the effects of the environment on the CFRP reinforcement, researchers conducted shear and bend tests after 100, 200, and 300 freeze-thaw cycles. In addition, beams were subjected to cyclical loading and testing while cooled to -29°C . In both the environment and the cooling experiments, the CFRP reinforcement behaved predictably and without significant reductions in reinforcing performance.

This research showed that gluing CFRP sheets to beams is an effective field-applied reinforcement that increases the ultimate loading capacity of concrete

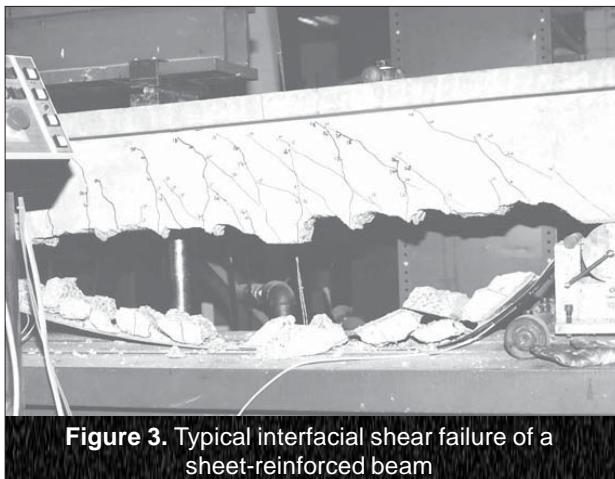


Figure 3. Typical interfacial shear failure of a sheet-reinforced beam

beams, even when those beams have been damaged. Both the flexible sheets and the stiff plates strengthened beams similarly, allowing engineers a choice of material and application based on installation needs.

Corrosion Resistant Metals for Reinforcing Concrete

In spite of the promise the exotic materials mentioned above may show, the advantages of steel as reinforcement for concrete—toughness, predictability, and a hundred years of experience—are good reasons to continue its use in construction today. To overcome the problem of corrosion and extend the life of steel-reinforced structures, engineers have already used stainless and stainless-clad bar as a direct replacement for black or epoxy-coated reinforcing bar. As with non-metallic reinforcement, researchers suspected that stainless steel might not bond to concrete as well as black bar, so researchers at Michigan Technological University (MTU) sought differences between black bar bonding and stainless bar bonding in concrete.

The MTU research showed that same size stainless and black reinforcing bar bonded similarly in concrete. The researchers therefore concluded that stainless can be used as a direct replacement for black bar where added corrosion resistance is required. Furthermore, stainless bar does not require the added bonding length that other corrosion resistant bars such as epoxy-coated bar require.

Although the cost of stainless bar used in this research is eight to 24 times that of black bar, large scale projects can bring the cost down considerably. FHWA standards expect black bar decks to last nine to 25 years, whereas stainless reinforced decks may last 75-100 years. With an expected lifespan of stainless reinforced concrete decks of at least 75 years, MDOT hopes to save on the overall structure life-cycle costs and reduce traffic stoppages due to construction and repair. More precise savings estimates can be determined after further analysis and testing. Additional cost savings are possible by designating stainless for target applications such as low-cover decks and pier caps, significantly reducing maintenance on those portions of a bridge prone to corrosion damage (S. Kahl, personal communication, 11 October 2002).

Verifying Load Distribution for Steel Girder Bridges

When deciding how to select and implement the materials mentioned above, researchers rely on previously established standards, environmental conditions, structure condition, traffic loads, and the physical properties of materials used to build or repair a structure. Frequently, engineers verify existing standards and materials by re-examining structures after time, corrosion, and higher loads have had their effects on a structure. For this study, University of Michigan (U of M) and MDOT researchers sought to verify girder distribution factors on steel girder bridges.

University of Michigan researchers performed field testing and finite element analysis of six Michigan bridges with spans from 10.6 to 42.6 meters. The researchers loaded the bridges using two eleven axle trucks weighing 666 kN and 652 kN each (near the maximum legal load of 685kN for two-unit, eleven axle trucks) and measured the actual strain on instrumented girders. The trucks moved at a crawl to determine static loads, and at 40 km/h to determine dynamic loads. Measurements were taken for both one truck and two trucks side-by-side moving across the center and sides of each lane. This testing showed how load distribution could be affected by truck location on the bridge and during simultaneous loading in more than one lane. Engineers also surveyed traffic to determine the frequency of single and side-by-side loading.

After collecting data in the field, the researchers performed finite element (FEM) analysis to simulate loads on simply supported, hinged, and partially fixed beams. The FEM partially-fixed results correlated very closely with actual field data, confirming the accuracy of assumed support conditions.

Load testing using heavy trucks therefore confirms AASHTO LRFD (1998) code-specified values for girder distribution factors on steel girder bridges. This testing also showed that dynamic load factors of 0.10 for two-lane loading and 0.20 for single-lane loading are valid when using heavy trucks.

Efficient Evaluation of Bridge Decks

Although the actual load testing described above is an excellent means of structural evaluation, it is impractical for evaluation of every structure and does not give researchers the data on the cause of deterioration or expected performance into the future. To accurately and efficiently evaluate bridge deck condition and future performance, MDOT and U of M researchers looked at how and where damage occurred on typical concrete bridge decks. MDOT and U of M published a new bridge deck evaluation guide based on this research to help guide inspectors.

Deck evaluation relies primarily on visual inspection, but inspectors may also use hammers and chain drags to detect areas of delamination, submit core samples for laboratory analysis, or use electronic equipment to

evaluate corrosion and delamination. Inspectors look for cracking, scaling, spalling, corroding reinforcement, chloride contamination, delamination, potholes, crushed concrete, and deep cracks. The research found the most commonly damaged locations include,

- Areas exposed to traffic,
- Areas exposed to drainage,
- Bearing and shear areas close to supports,
- Tops of slabs over beams,
- Bottoms of slabs between beams,
- Slab tops and bottoms in negative moment regions,
- Stay-in-place forms, expansion joints, and
- At acute corners of skewed bridge decks.

This research also showed that high average daily truck traffic accelerated most types of deterioration.

U of M's resulting *Michigan Deck Evaluation Guide* contains a Bridge Deck Repair Matrix (developed by MDOT) to help engineers decide which repairs to undertake based on current deck conditions. An engineer can evaluate the condition state of a deck top and underside, look-up the rating in the matrix, and find a suggested action. The matrix also indicates the anticipated improvement in condition state that the suggested action will bring. The improved condition state correlates to a corresponding service life expectation and subsequent evaluation schedule. This research and *Guide* should help engineers systematically evaluate and repair concrete bridge decks to maximize longevity while minimizing costs and closures.

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