Spring 2013

RESEARCH Showcase

Jet Grouted Piles

Extending Bridge Life with CFRP

Freight Focus of TRB Visit

Spring 2013

The Florida Department of Transportation (FDOT) Research Showcase is published to provide information regarding the benefits of FDOT-funded research.

Managing Editor
Darryll Dockstader

Editor
Vicki Morrison

Writers / Graphic Design
Charles Brown
Vicki Morrison

Printer
Durra-Print

Front Cover
A University of Florida engineering team works under a reaction frame to set up a load cell for full-scale top-down testing of a drilled shaft pile.

Back Cover
Test pile setup in Keystone Heights. The top-down test setup places a jack capable of lifting thousands of tons and a load cell between the reaction frame at the top of the photo and the pile cap at the bottom. The wooden frame suspends devices to measure test pile movement.

Contact
FDOT Research Center
605 Suwannee Street, MS 30
Tallahassee, FL 32399-0450
Phone (850) 414-4615
http://www.dot.state.fl.us/research-center/

In This Issue

In January, the Research Center held its fourth peer exchange, focusing on transportation research implementation and performance analysis. Peer exchanges help to fulfill FHWA eligibility requirements for planning and research funding and give state DOT research, development, and technology program participants a forum to share information about common needs. As an applied research program, FDOT's Research Center supports and promotes the implementation of research activities, from concept development through post-project monitoring. This support has extended to the development of demonstration and pilot projects, such as the jet-grouted piles research featured in this issue.

From light poles to interstate bridges, virtually every transportation structure in Florida is supported on piles or drilled shaft foundations. These foundations depend on resistance, acting at the sides and the tip, offered by soil or rocks in which they are situated. Traditional methods to increase bearing capacity include installing groups of piles/shafts or using post-grouting technology to improve tip resistance. In recent years, researchers at the University of Florida have developed a technology to better install piles—jet grouting—in which grout is injected along the bottom and sides of piles and drilled shafts. The researchers have determined that this technology significantly increases resistance and bearing capacity, thereby reducing construction time and cost associated with building foundations.

Researchers at the University of North Florida, University of Central Florida, and the University of Florida have been testing another time- and cost-savings technology: carbon fiber reinforced polymer (CFRP) wraps used to repair damaged concrete bridges. Research has shown that CFRP's durability, light weight, ease and cost of installation, and high strength- and stiffness-to-weight ratios make it an economically viable alternative to traditional repair systems and materials. Although repairs using CFRP may not extend a bridge's service life indefinitely, research has shown that externally bonded CFRP can provide an economically feasible and effective means to repair, strengthen, and extend the life of aging structures, saving millions of dollars in labor and construction costs.

Read about these technologies and more on the following pages.

Contents

Jet-Grouted Piles—A New Foundation for Florida

Engineering deep foundations, such as driven piles and drilled shafts, is critical to the vast array of transportation structures they support, ranging from bridges and viaducts to high mast and mast arm signs. Driven piles and drilled shafts are by far the most common types of deep foundations, and each has its advantages. In Florida, with its sandy soils, high water tables, and inconsistent rock layers, the technology of driven piles and drilled shafts is critical to supporting the state's transportation infrastructure.

Piles vs. Drilled Shafts

Piles are usually driven into the ground by the repetitive hammering of a pile driver. The ground's resistance to further penetration at the tip of the pile and the friction along its sides give a pile its bearing capacity. Using dynamic pile-driving monitoring, structural engineers can estimate side and tip resistance with fair accuracy. Generally, the deeper the pile is driven, the greater the total side resistance. Pile tip resistance also varies with depth, depending on the soil/rock stiffness and strength. Despite their usefulness, driven piles have drawbacks. An important one in Florida's increasingly urbanized construction environment is the noise and vibration caused by pile driving. They not only can be disruptive to businesses and residential areas, they can damage buildings and infrastructure. A second drawback is that pile driving, if not done properly, can damage the pile itself, resulting in costly delays. Further, piles need to be driven until desired bearing characteristics are achieved, and since the ground is rarely uniform, driving more piles and driving them deeper increases the chance of running into anomalies in the ground strata, which can also increase cost.

A drilled shaft is a foundation created by drilling a hole in the ground to a required depth, often with a large auger, and filling it with concrete. For this reason, the drilled shaft is also referred to as a cast-in-place pile, drilled pier, or drilled caisson. Drilled shafts in Florida are usually installed using either slurry or casings to prevent drilled-hole collapse. The sizes of drilled shafts range from 3.5 to 12 feet in diameter. The largest drilled shafts constructed in Florida were those for the People Mover of the Miami Intermodal Center project, which used 12-foot-diameter drilled shafts with lengths ranging from 80 to 90 feet.

Foundation piles are usually driven into the ground by the repetitive hammering of a pile driver.

Drilled shafts have many advantages. They can be used in multiples or even in a single unit. They can provide very high axial and lateral resistances, and they can be used in a wide range of soil types and in rock. One advantage of drilled shafts that is of special interest to the Florida Department of Transportation (FDOT) is the low noise and vibration of their installation, which makes them suitable for urban construction.

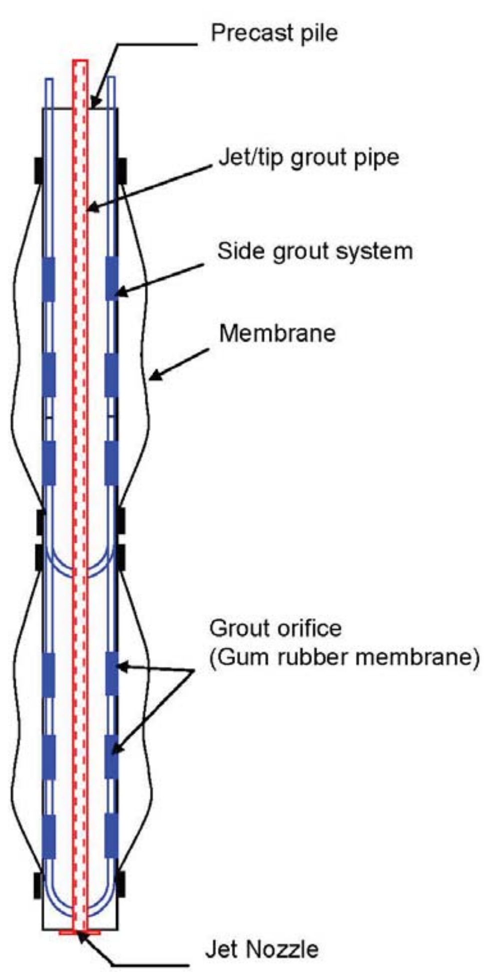
Nevertheless, drilled shafts also have drawbacks, primarily that they have the lowest side resistance of any deep foundation installed in soils. To compensate, Florida structural engineers ensure that drilled shafts are secured or "socketed" in the Florida limestone formation whenever possible. However, constructing shafts long enough to reach the limestone formation is costly. Further, the deeper the drilled-hole excavation required to reach the limestone formation, the higher the risk of drilled-hole wall collapse. These challenges motivated FDOT engineers to search for a method of improving drilled shaft technology.

Drilled Shaft Research

In the late 2000s, researchers under contract with FDOT began studying methods to improve the tip resistance of drilled shafts with post-grouting methods, i.e., injecting grout at the tip of the shafts after installation. Unfortunately, post-grouting at the tip did not improve side resistance, and FDOT sought a new alternative. That alternative, called a jet-grouted pile, currently is being developed and tested at the University of Florida's (UF) Department of Civil and Coastal Engineering. The creative force behind the technology includes Drs. Michael McVay and David Bloomquist, professors at UF, and Mr. Peter Lai, a geotechnical engineer and FDOT project manager (retired). The central innovation of the jet-grouted pile, Lai says, is the way it improves both tip and side resistance. Also, a jet-grouted pile can be designed to specifications and tested in situ, allowing tighter control, thus reducing time, material, and cost.

Preliminary Tests

The jet-grouted pile consists of a precast concrete pile, side grout systems, and a water-jetting system. The first step for installing the pile is setting the pile in the ground using the water-jetting system. Pipes for this procedure are cast into the pile. Once the pile obtains the proper depth, engineers use other cast-in pipes to inject side grout. After the side grout has attained sufficient strength, usually seven to ten days, engineers inject tip grout through the water-jetting pipes.



Left: The anatomy of a jet-grouted pile. Right: An excavated test jet-grouted pile exhibits full bottom and side grout coverage. Due to the side grouting, the tip grout will not flow upward, but is forced to flow both sideways and downward, forming a bulb under the pile and increasing resistance.

Water jetting to aid pile driving and grouting are two proven geotechnical construction techniques; however, they had never been used together for pile installation. Therefore, the method needed development from design through implementation. To test this prototype pile system in a known soil condition, the research team first constructed a special test chamber at UF's Civil and Coastal Engineering Laboratory. The test chamber is a steel-lined casing, 12 feet in diameter and 35 feet deep. It allowed researchers to construct piles full-scale in a uniform, controlled soil/sand mix, with careful placement of multiple sensors to monitor vertical and horizontal stresses in the soil during installation and subsequent grouting. It also allowed researchers to excavate and examine the piles after installation and load testing.

After initial testing, the researchers found that the grout mix and delivery system both required adjustments. Also, test pit trials showed that grout injected without membranes tended to push out away from the pile rather than flowing along its surface, and the grout had poor bonding with the precast pile. The researchers redesigned the grouting system and secured two semi-rigid, high tensile strength membranes to the side of the pile to control the grout flow along the sides, and to prevent grout from mixing with the soil. The revised pile system produced a jet-grouted pile with full side grout coverage and high bonding strength. Load tests revealed a fivefold increase in rotational resistance and quadrupled vertical load capacity, compared to a similar drilled shaft foundation.

Based on these results, the researchers revised the installation process by setting a temporary steel casing a few feet into the ground, aligning the pile with the center of the casing, and pumping high-pressure water from a tanker through the tip of the pile. The pile penetrates the ground by its own weight because of the high-pressure water erosion at the tip and upward flowing water at the sides. Once the pile reaches the desired depth, researchers remove the temporary casing and cap the pile.

Next, the researchers side-grouted the pile, first in the top membrane and then in the lower one. They pumped grout into the top of the pile through the pre-installed grouting system, filling the side membranes and forming cylindrical expansions along the pile shaft. Grouting the upper membrane first not only densifies the eroded soil, it enables higher grouting pressure for the lower side membrane, which increases normal side stress from a minor principal stress to a major one, substantially increasing the side resistance of the pile.

Subsequently, the researchers pumped grout to the tip of the pile through the water-jetting pipes. Due to the side grouting, the tip grout will not flow upward, but is forced to flow both sideways and downward, forming a bulb under the pile; the grout pressure can be much higher than that of a tip-grouted shaft without side grouting. The researchers found that because they know the amount of grout injected and the grout pressure, they can calculate the carrying capacity of the pile and design foundations more precisely using fewer piles and reducing construction time and cost.

Full-scale Field Testing

Following the preliminary studies, the researchers conducted full-scale testing at a test site near the town of Keystone Heights in Clay County to see how methods developed in the controlled soil/sand mix of the test chamber would translate to Florida soils whose composition varies both vertically and horizontally. The site's soil profile is common in Florida: a few feet of clayey sand over poorly graded sand with silt over poorly graded sand. Soils like this, with the water table near the surface (5'-10') develop low skin friction along a drilled shaft, making improved deep foundation designs even more important.

Four test foundations—two jet-grouted piles and two drilled shafts—were installed for a variety of static and dynamic torsional, lateral, and vertical load tests. Engineers conducted the torsional load tests using a full-scale FDOT mast arm assembly. The pole was mounted on a footing fixed to the top of the jet-grouted pile. During the test, the researchers applied incremental horizontal loads to the arm using the cable of a winch attached to the tip of a crane boom. The other end of the cable was attached to the mast arm at a standoff distance of 35 feet from the pole, which is the geometric center of the standard 78-foot arm. The researchers used the same test setup with regular drilled shaft foundations. Test results showed that the torsion resistances were 2-ft-kip for drilled shaft and 12-ft-kip for jet-grouted pile.

The researchers also performed axial static load tests using an anchored resistance girder method. The testing method consisted of a reaction girder/beam, which is supported and tied down to drilled shafts located at both ends of the girder so that when the jack is activated, the shafts will resist the uplift. In this testing, the system consisted of a pair of girders with a dimension of 40 ft x 2 ft x 8 ft that were supported on and anchored to two 4-ft-diameter x 41-ft-deep drilled shafts. The researchers applied vertical loads with a calibrated hydraulic jack capable of supplying 1,200 tons of vertical force. They conducted tests up to an axial force of 320 kip (160 ton) and stopped when one of the reaction shafts reached its ultimate resistance. At this point, the test pile deviated less than one tenth of an inch, which indicated there was still much reserved resistance.

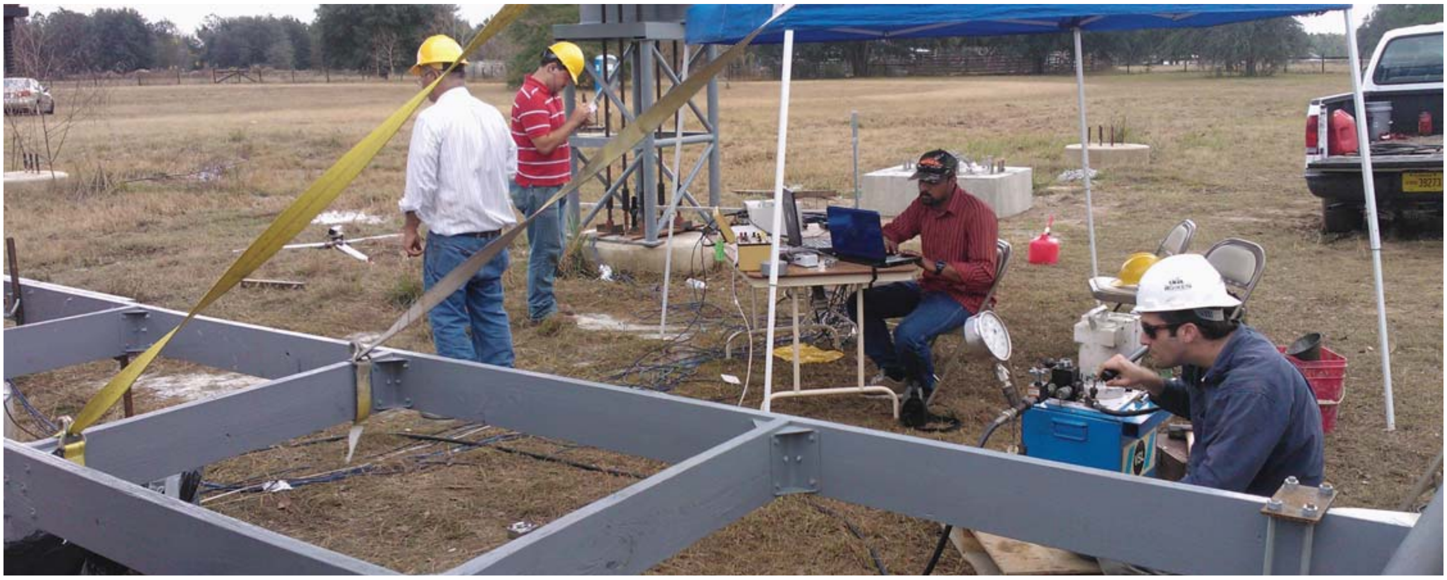
Test field for full-scale testing. In the foreground is the round cap of a drilled shaft foundation, one of several visible in the photo. The square cap to the left is on top of a jet-grouted foundation awaiting testing. The reaction frame at the center top is centered over a drilled shaft foundation, the subject of the full-scale, top-down test. Between the reaction frame and the drilled shaft foundation is a hydraulic jack capable of lifting thousands of tons and a load cell used to convert force into an electrical signal (inset). At the top right of the photo is a mast arm structure used for torsional-lateral stability tests.

Left: Engineers conduct the torsional load tests using a full-scale FDOT mast arm assembly. The pole was mounted on a footing fixed to the top of a jet-grouted pile. During the test, researchers applied incremental horizontal loads to the mast arm using the cable of a winch attached to the tip of a crane boom.

Bottom: During an axial static load test, engineers increase hydraulic pressure to a preassigned level and monitor load cell response. The wooden frame (foreground) suspends devices to measure test pile movement.

Based on an engineering analysis, the researchers determined that a pile similar to the test pile without side grouting would only resist about 80 tons. Testing at the Keystone Heights site will continue into the summer of 2013 and, in addition to their work on jet-grouted piles, the researchers will use the results to improve grouted drilled shafts.

Florida-type soils occur in many coastal zones, so the knowledge gained through the research has potential applications in many locations of the nation and around the world. Commercial use of the technology will also produce feedback pointing to new research directions. McVay points out that work on improving support foundations never stops. "Improvements can always be made that yield a more effective foundation at lower cost," says McVay. "The quest for more cost-effective foundations is continual, and there is always room for improvement." ⬣



Extending Bridge Life with Carbon Fiber Reinforced Polymers (CFRP)

The American Association of State Highway Transportation Officials' (AASHTO) 6th edition of *A Policy on Geometric Design of Highways and Streets* provides that the minimum vertical clearance to structures passing over freeways should be at least 16 feet above the entire roadway width. However, not all bridges meet these height requirements because either they were constructed before the standards were issued or pavement overlays raised the height of the roadway, effectively reducing the clearance height. In highly developed urban areas where attaining the 16-foot clearance is not practical, AASHTO provides that a minimum clearance of 14 feet may be used if there is an alternative freeway facility with the minimum 16-foot clearance.

In Florida, any vehicle over 13′6″ is considered overheight and requires a permit issued by the Office of Commercial Vehicle Enforcement with the Department of Highway Safety and Motor Vehicles (DHSMV) to travel on any Florida road. When drivers of overheight vehicles receive a permit, they are provided information on how to get to the desired destination on roads with sufficient vertical clearance.

FDOT places low-clearance warning signs in advance of every bridge or structure with a minimum vertical clearance of 14′6″ and with a history of over-height vehicle hits. In addition, low clearance warning signs are placed on every bridge with a minimum clearance of 13′6″ or less. Nevertheless, vehicle collisions with bridges still occur. They can result in prestressed steel reinforcement damage, girder misalignment, steel yielding, connection failure, reinforcement exposure, and cracking. Vehicle impacts can even lead to structural collapse. When impacts occur, bridges are closed while structural engineers determine if the integrity of the bridge has been compromised and whether it should be subject to load restrictions until emergency repairs are complete.

In many instances, bridges damaged by impacts can be repaired to meet or even exceed load-carrying specifications. Repair is much more cost effective than replacement, and traditional repair methods include steel plate bonding, section enlargement, external post tensioning, and beam replacement. These installation methods are effective but can be cumbersome and inefficient, and the materials can be susceptible to corrosion.

In the 1980s, transportation engineers in several European countries and Japan began investigating various applications of fiber-reinforced polymer (FRP) to repair concrete structures. They recognized that FRP's durability, light weight, ease and cost of installation, minimal site constraints, and high strength- and stiffness-to-weight ratios could make it an economically viable alternative to traditional repair systems and materials. Since then, transportation agencies worldwide have embraced the use of FRP to repair damaged structures, rehabilitate deteriorating infrastructure, and strengthen or upgrade the load-carrying capacity of bridges. In many cases, FRP provides an effective means to upgrade deficient infrastructure, saving millions of dollars in replacement costs.

FRP refers to plastic and polymer materials that are reinforced with structural fiber such as fiberglass (GFRP), carbon fiber (CFRP), or aramid fiber

Left: Damage similar to this occurred to the Chaffee Road Bridge in Jacksonville in 2001 when it was struck by an over-height vehicle.

Right: A bridge with impact damage repaired with CFRP wraps.

(AFRP). The fibers generally occupy 30-70 percent of the matrix volume of the composites. The fibers can be chopped, woven, stitched, and/or braided. The fibers provide strength and stiffness to the composite and generally carry most of the applied loads. The matrix acts to bond and protect the fibers and to provide for transfer of stress from fiber to fiber through shear stresses.


Above: A technician applies CFRP wraps to a bridge girder.

State DOTs began using FRP to repair damaged bridges in the mid 1990s. One of the first applications of FRP in Florida to repair a bridge girder occurred in July 2001, when two over-height construction vehicles struck and severely damaged the Chaffee Road Bridge over the eastbound lane of I-10 in Jacksonville. Built in 1960, the prestressed concrete bridge had an original clearance height of 15'6". The collision damaged two girders and resulted in concrete cracking, section loss, and broken prestressing strands. FDOT District 2 structural engineers placed a load restriction on the bridge until they could determine how severely the structural integrity of the span was compromised.

Closing the bridge to replace the damaged girders was not desirable due to heavy traffic demand. Based on research and experience with similar projects, FDOT District 2 determined that repairing the bridge components with CFRP was the most feasible option.

SDR Engineering Consultants, Inc., performed the repairs by removing the damaged concrete and making other repairs; restoring the girders to their original shape using high-quality concrete capable of achieving full material strength within 24 hours of application; applying an adhesive epoxy to the side and bottom concrete surfaces of the damaged girders with paint rollers; and wrapping each girder with sheets of CFRP. The application of the CFRP took approximately eight hours to complete with minimal disruption to traffic. The damaged girders were restored to their original strength and the bridge was returned to full service within a week of impact.

Repairing the bridge cost approximately $20,000 and allowed it to remain in service. Due to the bridge's age and history of vehicle impacts, FDOT replaced it in 2012.

In 2010, the St. Lucie West Boulevard bridge over I-95 was severely damaged when a trailer full of used tires caught fire while parked under the bridge. The heat caused the concrete beams to crack and spall, and required FDOT structural engineers to close the bridge to traffic until repairs could be made. FDOT District 4 authorized emergency repair of the beams using CFRP. Total cost of the work, including maintenance of traffic on I-95 and St. Lucie West Boulevard, cleaning, preparation, engineering services, CFRP application, and load rating cost $400,000. The bridge was repaired and reopened to traffic within a week. FDOT estimates replacing the beams would have taken five times as long and cost twice as much.

When the Chaffee Road Bridge was impacted in July 2001, FDOT had limited experience using with FRP products to strengthen and/or repair concrete structures. Within months of the incident, the University of Florida was contracted to study various CFRP systems available to repair impact-damaged bridge girders.

A technician works on wet layup application of CFRP fabric laminate on a prestressed concrete girder at the Marcus H. Ansley Structures Research Center as part of FDOT research project BDK82 977-03.

In the study, CFRP Repair of Impact-Damaged Bridge Girders (BC354-55), Dr. Trey Hamilton and his research team tested six Type II AASHTO girders to evaluate the post-repair behavior and capacity of different FRP repair methods. They also tested a method to inspect the FRP composites before, during, and after the load tests using infrared thermography (IRT) to determine if the systems bonded properly to the concrete surfaces. Two girders served as control specimens, one without damage and one with simulated impact damage. The remaining four girders were subjected to simulated impact damage and repaired with different FRP systems. The researchers loaded all test girders to failure to determine moment and shear capacities, and deformation and ductility behavior.

The load tests demonstrated that all of the tested FRP systems can be used to restore a significant portion of the moment capacity that may be lost due to vehicle impact. Researchers found, however, that FRP system performance is dependent on proper detailing at the termination points of the composite on the tension face to prevent the FRP wraps from debonding. The research provided FDOT with valuable information about the performance of various FRP products.

A roll of CFRP.

During this project, researchers also learned that IRT is a potentially powerful tool for identifying unbonded areas in FRP systems and for detecting near-surface defects. However, they found that as the thickness of the FRP system increases, detecting unbonded areas at the FRP/concrete interface becomes increasingly difficult. Researchers concluded that IRT methods can be used successfully to detect application defects on single-layer systems and in detecting near-surface delamination in multi-layer systems.

In 2010, Dr. Adel ElSafty and Dr. Mike Jackson at the University of North Florida conducted a study to develop a method to assess the degree of damage to bridge girders after collisions and to correlate the assessment with repair options (Repair of Damaged Bridge Girders with Carbon Fiber Reinforced Polymer Laminates, BDK82 977-03). They damaged test concrete girders and cut some of the prestressing strands to mimic impact damage observed in the field. They tested repair configurations of CFRP laminates based on longitudinal strips and U-wrapping on full-scale (40-ft) and half-scale (20-ft) prestressed concrete girders. Then they designed repair systems to restore original flexural capacity.

The researchers tested the repaired girders under fatigue loading for two million cycles to simulate traffic conditions. They found during fatigue testing of the half-scale beams that crack opening and propagation could be restrained by covering the damaged section with transverse and longitudinal CFRP strips.

The study suggested the optimum repair configuration: longitudinal CFRP laminate applied to the girder soffit along with U-wrapping anchored with a longitudinal CFRP strip at the top ends of U-wraps. This

Concrete bridge structures require maintenance and repair over their lifetime. In addition to repairing damage from vehicle impacts, CFRP can also be used to repair girders and beams that deteriorate from exposure to environmental conditions, such as salt water.

Left: A deteriorated girder located in Indian River County, Florida, before repair.

Right: A deteriorated girder repaired with CFRP and painted to protect it from environmental conditions.

configuration restored and increased girders' load-carrying capacity. The researchers found that evenly spaced transverse U-wraps provided an efficient configuration to mitigate debonding. The research resulted in a comprehensive design procedure for the application of CFRP laminates to collision-damaged bridge girders.

Bridges are designed for a service life of 75 years, but they require maintenance and repair over their lifetime. They can deteriorate and become structurally deficient due to increased service loads, settling, age, and constant exposure to environmental conditions. The U.S. Department of Transportation determined in 2008 that of the 600,000 bridges in the Federal Highway Administration's (FHWA) inventory, 72,868 (12.1%) are "structurally deficient." Of Florida's 11,982 bridges, 262 (2.18%) are classified as structurally deficient.

Although repairs may not extend a bridge's service life indefinitely, research has shown that externally bonded FRP can provide an economically feasible and effective means to repair, strengthen, and extend the life of aging structures. Unfortunately, little information exists regarding the long-term durability of this type of retrofit technology.

To help engineers better predict the service life of a repair using CFRP, in 2004 FDOT contracted a study, Thermo-Mechanical Durability of CFRP-Strengthened Reinforced Concrete Beams (BD550-06), with the University of Central Florida to research the durability of three different CFRP resin matrix systems — two epoxy and one polyurethane. Led by Dr. Kevin Mackie, the research team investigated the properties of the CFRP materials applied to reinforced concrete beams as they change with temperature to determine whether the systems could be used as a permanent (50+ years) or short-term (up to 10 years) solution. Researchers strengthened 12 reinforced concrete beams with the systems and subjected them to two million loading cycles and/or one year of thermal/humidity cycling. The beams were conditioned mechanically and/or environmentally to simulate long-term exposure to a Florida-like service environment.

While the research indicated that CFRP bonded externally is a suitable repair method for short-term rehabilitation efforts, the results proved inconclusive regarding the feasibility of externally bonded CFRP as a long-term or permanent strengthening option. FDOT anticipates conducting additional research on repair durability using 15- to 20-year-old beams, located at the Marcus H. Ansley Structures Research Center in Tallahassee, that have been bonded with CFRP and are exposed to weather.

A project currently under contract with the University of Florida, Highly Accelerated Lifetime for Externally Applied Bond Critical Fiber Reinforced Polymer (FRP) Infrastructure Materials (BDK75 977-45), is investigating the durability for CFRP composites under accelerated degradation conditions including elevated temperature, stress levels, and concentrations of corrosive media. The research team, led by Dr. Eliot Douglas, is studying the effects of water and temperature on the CFRP-concrete interface. The team also will gather information on UV exposure, oxidation, and chemical degradation of the epoxy resins to predict long-term performance of FRP composites used to strengthen and extend the life of existing bridges.

The future of CFRP bridge components continues to improve and evolve as the materials evolve. Research has proven that using CFRP for bridge repairs provides structures maintenance engineers with a reliable method for returning damaged bridges to unrestricted service faster and with less expense than any other repair method. ⬣

Meet the Project Manager

Sam Fallaha, P.E., FDOT Assistant State Structures Design Engineer

Sam Fallaha has managed research projects involving structural load testing at FDOT's Marcus H. Ansley Structures Research Center since 2010 and has been FDOT's Assistant State Structures Design Engineer since 2008. Developing methods to make bridges safer and more cost effective through research is his specialty.

One of Fallaha's recent projects involved developing lightweight solid decks for movable bridges as an alternative to steel grid decks. Most movable bridge decks are made of lightweight open-grid steel that can withstand American Association of State Highway Transportation Officials (AASHTO) load and resistance factor design (LRFD) specifications. However, steel grid decks are less skid resistant than solid decks and become less so over time due to wear. Other drawbacks include costly maintenance, high noise levels, poor ride comfort, and susceptibility to vibrations.

In 2009, Fallaha worked with a team of researchers at Florida International University (FIU) and the University of Central Florida (UCF) to study alternative types of decks using fiber-reinforced polymer (FRP), aluminum, high-strength steel, and ultra-high-performance concrete (UHPC). The researchers found that decks made with FRP, aluminum, and UHPC are possible alternatives to steel grid decks because they meet LRFD specifications and promise increased service life, improved safety, and reduced maintenance. Fallaha anticipates that FDOT will implement alternative lightweight decks on Florida's movable bridges in the near future.

Fallaha has several ongoing research projects. One evaluates the breakaway performance of FRP, metallic, and hybrid signpost connection systems. Researchers with the University of Florida (UF) Department of Civil and Coastal Engineering are using the pendulum apparatus located at the Marcus H. Ansley Structures Research Center to test the systems. The goal of the project is to develop safer and more cost-effective signpost and breakaway connections.

In another project, Fallaha is managing the completion of a vessel-collision impact modeling project that will incorporate barge impact data obtained from several previous research projects into the FB-MultiPier software program. The software, developed by FDOT engineers and UF researchers, enables bridge design engineers to model and analyze bridges subject to potential barge impacts and other loads, and to design safe, efficient, and more cost-effective piers and structures.

Fallaha is most enthusiastic about recent research to develop concrete piles reinforced with carbon fiber composite cables (CFCC). A disadvantage of traditional steel prestressing strands and reinforcing bars in concrete piles is that the steel strands may corrode and the concrete spall if water penetrates the piles, requiring costly repairs or early pile replacement. Repairing piles damaged by corrosion is a considerable economic burden to FDOT considering the number of bridges in Florida.

Fallaha and researchers at the Florida A&M University/Florida State University (FAMU-FSU) College of Engineering have completed preliminary studies on the feasibility of CFCC in concrete piles and will begin testing their structural integrity this year. Although the initial cost of piles with CFCC is about three times greater than traditional steel reinforced concrete piles, Fallaha believes the ability to extend the service life of bridge piers will more than offset the additional cost. "This new technology has tremendous potential and could save Florida taxpayers millions of dollars in construction and replacement costs of bridges built in wet environments," says Fallaha.

Fallaha is optimistic his research will benefit FDOT in numerous ways. "My research has focused on developing implementable solutions to problems that will result in an immediate improvement to processes and procedures," Fallaha says. "Although my research has been quite challenging, it is extremely rewarding to see it pay off." ⬣

Meet the Principal Investigator

Michelle Rambo-Roddenberry, Ph.D., P.E., Associate Professor, FAMU-FSU College of Engineering

FDOT maintenance engineers use load ratings to issue overweight load permits. The calculation excludes barriers from the design and load rating structural analyses because barriers are designed to withstand impact from vehicle collisions and not designed to contribute to bridge strength. When intact and undamaged, barriers on bridges do, in fact, serve as fully functional structural members, contributing to deck or girder strength. In addition, a barrier and its joints can affect the results of FDOT bridge load tests.

In 2007, FDOT contracted with Michelle Rambo-Roddenberry, Ph.D., P.E., Associate Professor, FAMU-FSU College of Engineering, to study the effect barriers have on live load distribution. Rambo-Roddenberry and her research team conducted load tests on a segmental bridge in the Florida Keys using 3-D finite element analysis models. Her research found that some bridges may be able to carry more load if the barrier's structural contribution is considered in the transverse analysis. Her research resulted in changes to FDOT design standards concerning the location along bridges at which to place barrier joints. The research also gives engineers a tool to determine when to use barriers to benefit the load rating. These findings have the potential to save both FDOT and haulers time and money for the permitting and transportation of oversized loads.

"After measuring the performance of a full-scale in-service bridge by load testing it, and being able to make good predictions with analyses, I was hooked on bridge testing and evaluation," says Rambo-Roddenberry. "The research infused me with a desire to be able to see and understand the details that affect a bridge's performance and service life."

Rambo-Roddenberry currently is conducting research to develop a tool that FDOT engineers can use to evaluate segmental box girder bridges quickly and more accurately than the current method. The tool will allow maintenance engineers to analyze permit vehicles for transverse bending effects on the slabs of concrete segmental box girder bridges and give them a better estimate of the ability of a bridge to carry an overweight vehicle.

Recently, Rambo-Roddenberry and her research team worked on a failure theory for concrete. They tested several concrete cylinders and cubes in compression, captured data from strain gauges, and used high-speed video to see how cracks began and propagated in the test specimens. They found that when bearing plates were used to apply compression force, the specimen strengths were consistently higher than when low-friction plates were used. The cracking pattern also differed. The testing and analysis demonstrated the limitations of standard concrete cylinder testing used traditionally to measure compressive strength.

In another recent project, she and her research team investigated standards for prefabricated/precast bridge elements and systems (PBES) and evaluated them for possible use in Florida. Prefabricating bridge elements off-site and transporting them for assembly on-site has the potential to yield substantial cost savings by reducing the overall project delivery time and increasing work zone safety. FDOT structural engineers are currently evaluating the research findings.

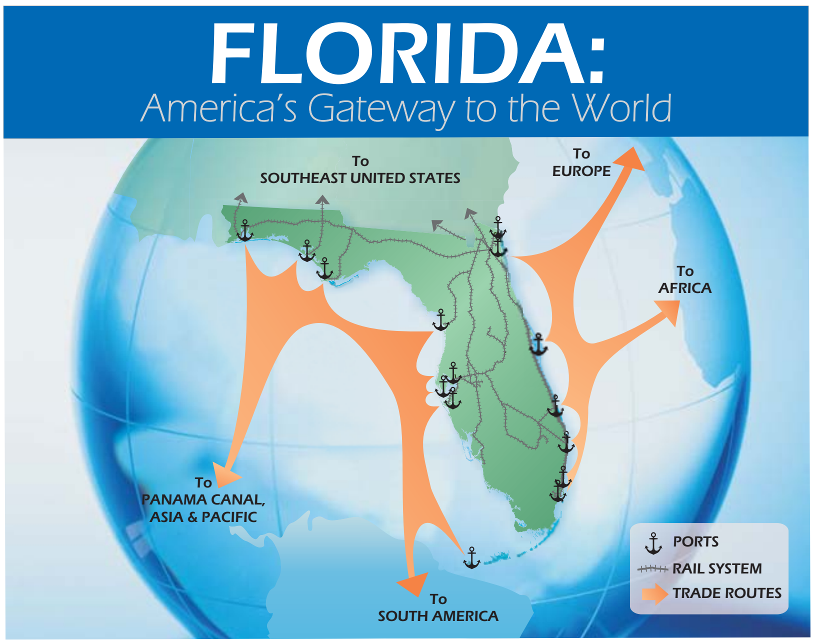
Rambo-Roddenberry is working with Sam Fallaha, P.E., FDOT Assistant State Structures Design Engineer (see page 12), to determine the suitability of using carbon fiber composite cables (CFCC) as a substitute for conventional prestressing steel strands in concrete piles for FDOT bridge construction projects. The project holds great potential to extend the life expectancy and reduce maintenance costs of prestressed concrete piles used in saltwater environments.

"FDOT's investment in research demonstrates its commitment to Florida's citizens to have a safe and reliable infrastructure well into the future," says Rambo-Roddenberry. "I receive great satisfaction working to improve Florida's transportation system through innovation and applied research." ⬣

Freight Focus of TRB Visit

Transportation Research Board (TRB) representatives visit state DOTs annually as part of the State Partnership Visits Program. The visits enhance the partnership between TRB and state DOTs and provide TRB staff opportunity to understand the issues and activities of state DOTs so that TRB may deliver the best service to them.

In December 2012, Dr. William Rogers, Senior Program Officer and representative for TRB's National Cooperative Freight Research Program (NCFRP), and Mr. Scott Brotemarkle, Marine/Intermodal Freight Specialist, met with managers in FDOT's newly created Office of Freight, Logistics, and Passenger Operations (FLP) and other FDOT staff to discuss freight trends and issues facing Florida. Dr. Rogers provided an overview of NCFRP research.



Authorized by the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) of 2005, NCFRP is an industry driven applied research program that develops near-term practical solutions to improve the efficiency, reliability, safety, and security of the nation's freight transportation system. Managed by TRB and sponsored by the Research and Innovative Technology Administration (RITA) of the U.S. Department of Transportation (USDOT), the program is provided guidance by an oversight committee comprising a representative cross-section of private- and public-sector freight stakeholders, including shippers, carriers, USDOT, other federal agencies, state DOTs, local governments, nonprofit entities, and academia.

America's freight transportation system makes critical contributions to the nation's economy, security, and quality of life. It is a complex, decentralized, and dynamic network of private and public entities, involving all modes of transportation—trucking, rail, waterways, air, and pipelines. As the demand for freight transportation service has increased, fueled by growth in international trade, congestion points in the system have exposed inadequacies of current infrastructure and operations. NCFRP has found that strategic operational and investment decisions by governments at all levels will be necessary to maintain freight system performance, requiring research-based technical guidance.

Recognizing the significant role freight mobility plays in Florida's economy, FDOT established the Office of Freight, Logistics, and Passenger Operations (FLP) in early 2012, advancing Governor Rick Scott's initiative to transform Florida's economy by becoming a global hub for trade, logistics, and export-oriented manufacturing activities. The FLP Office works to better connect, develop, and implement a freight planning process that will maximize the use of existing facilities, while integrating and coordinating privately and publicly owned aviation, spaceports, public transit, seaports, waterways, rail, and motor carrier resources. FLP serves as a coordination point for FDOT's modal offices (rail, seaport, aviation, public transit) and district freight coordinators in undertaking key initiatives in support of Florida's enabling freight-focused legislation.

During the TRB visit, FDOT staff provided an overview of several ongoing FDOT-funded research studies, including work by the University of Central Florida (UCF) to develop a system to read license plates of commercial vehicles using solar-powered cameras mounted on overhead assemblies to trace freight movement; the University of South Florida (USF) to identify freight planning application potential using American Transportation Research Institute (ATRI) truck global positioning systems data; and the Florida International University (FIU) to investigate the adequacy of truck parking space capacity at interstate rest areas and the extent of illegal parking.

FDOT staff also identified potential research needs areas including rail grade crossing safety, clearing ramps, and headways; alternative fuel and methods to assess fuel taxes; and seaport performance measures to assess return on investment resulting from job creation, congestion mitigation, and trade growth.

In February 2012, the FDOT Research Center and FLP hosted a freight round-table meeting that included FDOT and FHWA staff, and members from Florida universities with expertise in freight research. Attendees identified current and emerging freight-related issues facing FDOT and ways to improve freight movement. The meeting provided a valuable opportunity for identifying expertise resources and fostering collaboration between the transportation agencies and state universities.

In March 2013, FLP sponsored a highly successful freight site visit tour across central and south Florida. The tour was given to the Federal Highway Administration (FHWA) and highlighted transportation facilities and capacity expansion projects, beginning with the Miami Intermodal Center, where multiple modes of travel come together in one grand hub. The tour also included the Miami International Airport (MIA) to examine the flower import and airplane maintenance industries; Port Miami and Port Everglades to highlight connection improvements to the road and rail network, and cruise passenger enhancements; a ride along the Florida East Coast Railway; and the Kennedy Space Center to view enhancements designed to welcome private enterprises into the space launching arena.

Florida's freight future is bright. With an ideal geographical location for foreign trade, paired with research initiatives at both federal and state levels to meet freight mobility challenges, the state is primed to become a global hub for trade logistics and export activities.

For more information, contact Juan Flores, Administrator, FDOT Office of Freight, Logistics, and Passenger Operations, juan.flores@dot.state.fl.us, 850-414-5244. ⬣

For More Information

Carbon Fiber Reinforced Polymer (CFRP)

BDK82 977-03, The Repair of Damaged Bridge Girders with CFRP Laminates
Rodney Chamberlain, Project Manager
Adel ElSafty, Principal Investigator

BDK75 977-45, Highly Accelerated Lifetime for Externally Applied Bond Critical Fiber Reinforced Polymer (FRP) Infrastructure Materials
Harvey DeFord, Project Manager
Elliot Douglas, Principal Investigator

BD550-06, Thermo-Mechanical Durability of CFRP-Strengthened Reinforced Concrete Beams
Marc Ansley, Project Manager
Lei Zhoa, Principal Investigator

BC354-55, CFRP Repair of Impact-Damaged Bridge Girders
Marc Ansley, Project Manager
H. R. Hamilton, Principal Investigator

Jet-Grouted Piles

BDK75 977-07, Group Efficiencies of Grout-Tipped Drilled Shafts and Jet-Grouted Piles
Peter Lai, Project Manager
Michael McVay, Principal Investigator

BDK75 977-41, Field Testing of Jet-Grouted Piles and Drilled Shafts
Peter Lai, Project Manager
Michael McVay, Principal Investigator

BD545-31, Prestressed Concrete Pile Installation Utilizing Jetting and Pressure Grouting
Peter Lai, Project Manager
Michael McVay, Principal Investigator

Freight Mobility

BDK80 977-14, Commercial Motor Vehicle Parking Trends at Rest Areas and Weigh Stations
Paul Clark, Project Manager
M. Emre Bayraktar, Principal Investigator

BDK85 977-20, Using Truck Fleet Data in Combination with Other Data Sources for Freight Modeling and Planning
Vidya Mysore, Project Manager
Abdul Pinjari, Principal Investigator

Overview of the Freight Mobility and Trade Plan:
www.freightmovesflorida.com/freight-mobility-and-trade-plan/video