Florida Department of Transportation

RESEARCH SHOWCASE

Halls River Bridge

Homosassa Springs, FL

Research Contract: BDV30 706-01

Corrosion is a constant concern for bridge design and maintenance in Florida. Due to the aggressive environments in Florida, bridge maintenance costs can become excessive, leading the Florida Department of Transportation (FDOT) to research new technology and designs that can reduce bridge life-cycle costs. FAMU-FSU College of Engineering and the University of Miami College of Engineering teamed up to monitor the fabrication, construction, and installation of the experimental technology being implemented on Halls River Bridge in Homosassa Springs, Florida.

Marked for replacement from significant deterioration and functional deficiency, Halls River Bridge was the best candidate to implement corrosion-free structural elements as part of FDOT's Invitation-for-Innovation initiative focusing on FRP structural application development. From the carbon fiber composite cable (CFCC) prestressed concrete piles to the glass fiber-reinforced polymer (GFRP) traffic railings, every component of the new bridge design includes a composite element. The West Halls River Bridge replacement project was the first bridge in Florida to use hybrid composite beams (HCB), and should lead to decreased construction time and increased life-cycle of future bridge projects. Monitoring the bridge replacement also allowed FDOT to determine the viability of using this technology for future projects.

Composite elements on Halls River Bridge, shown in *Figure 1*, include:

- CFCC prestressed concrete piles
- GFRP reinforced pile caps
- Hybrid Composite Beams
- CFCC prestressed and GFRP reinforced sheet piles
  - GFRP reinforced sheet pile caps
  - GFRP reinforced bridge deck
  - GFRP reinforced traffic railings

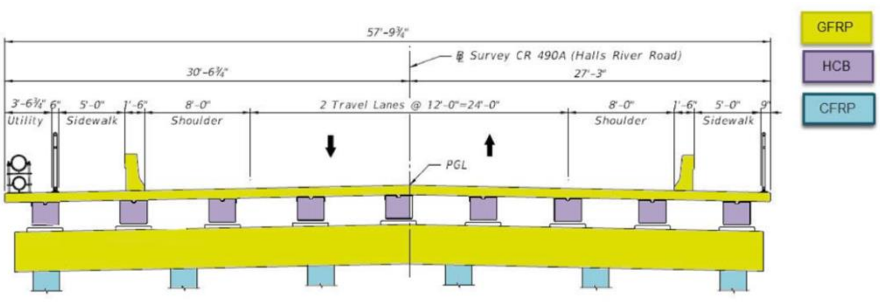

Figure 1: Completed structure indicating composite elements

Halls River Bridge was also associated with the Infravation-SEACON project coordinated by the University of Miami College of Engineering. SEACON or *"Sustainable Concrete using Seawater, Salt-Contaminated Aggregates, and Non-corrosive Reinforcement"* was a collaboration between USA and European Union participants to research and implement near-market materials and processes to improve highway infrastructure. The elements of Halls River bridge specifically related to the SEACON research were the bulkhead caps, retaining walls, and the traffic railings.

Through the combined effort of FAMU-FSU College of Engineering, the University of Miami, and FDOT the materials, fabrication processes, and construction of Halls River Bridge were monitored and evaluated. The main areas of research included the evaluation of sustainable concrete using seawater, recycled chloride-contaminated aggregates, and embedded composite (FRP) reinforcement, the monitoring of prestressed structural member fabrication and HCB fabrication, and the monitoring of composite elements construction practices.

Evaluation of sustainable concrete using seawater, recycled chloride-contaminated aggregates, and embedded composite reinforcement

Concrete Mixtures

The bulkhead caps of Halls River Bridge were cast with "Green-" concrete (similar to SEACRETE ™), which has identical mixture proportions to conventional concrete used in other elements of the bridge (Class IV) but fresh water was replaced by seawater. A retarder was used to offset the accelerating effect of seawater due to its high chloride content. Fresh properties of the Green- and conventional concrete are reported in Table 1. As it can be seen in *Figure 2*, Green-seawater concrete has higher early age strength than conventional concrete.

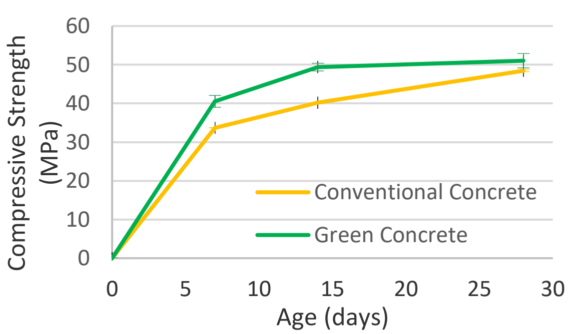

Figure 2: Early age compressive strength of Green and conventional concretes

Table 1: Fresh Concrete Properties

Mixture type	Slump (mm)	Density (kg/m^3)	Air content (%)	Concrete temperature (°C)
Conventional Concrete	100	2277.8	2.1	36.6
Green Concrete	82.5	2269.8	2.0	35.0

Green-RAP concrete in which Recycled Asphalt Pavement (RAP) partially replaces the total aggregate, will be used in a gravity wall of Halls River Bridge. Since RAP has a wide range of particle size, with the nominal maximum aggregate size of 13 mm, it was treated as both coarse and fine aggregate.

Green-RCA concrete using Recycled Concrete Aggregate (RCA), with the nominal maximum aggregate size of 1-inch, will also be used as partial replacement for the coarse aggregate in a gravity wall. The fresh and hardened properties of the RAP and RCA concrete are shown in *Table 2*, and *Figure 3*, respectively. Higher air content was measured for RAP concrete compared to RCA concrete, although the same amount of air entraining admixture was used for both mixtures; more research is needed to pinpoint the cause of this difference.

Table 2: Fresh properties of RAP and RCA concrete

Mixture type	Slump (mm)	Density (kg/m^3)	Air content (%)	Concrete temperature (°C)
RAP Concrete	114	2212.0	4.8	26
RCA Concrete	190	2218.5	2.8	26

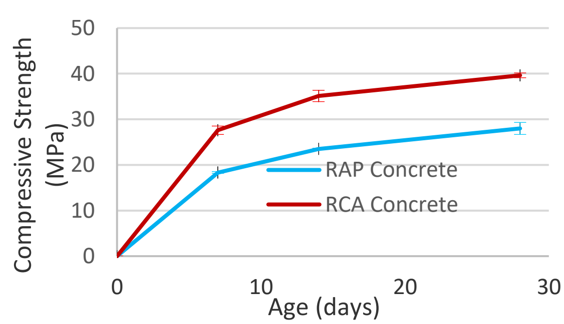

Figure 3: Early-age compressive strength of the RAP and RCA concretes

In order to increase the visibility, traffic railings will be cast with two other Green concrete mixtures using 100% white cement and a blend of 60% slag and Portland cement. Their fresh and hardened concrete properties are shown in Table 3, and *Figure 4*, respectively. Higher early age strength but comparable 28-day compressive strengths were observed for Green-seawater concrete and Green-60% slag concrete compared to conventional and 100% white cement concrete, respectively, which was expected. However, RCA concrete maintained its superior performance compared to RAP concrete even after 28 days. This was also expected due to the higher strength of RCA in comparison to RAP aggregate.

Table 3: Fresh properties of 60% slag and 100% white cement concretes

Mixture type	**Slump (mm)**	**Density (kg/m^3)**	**Air content (%)**	**Concrete temperature (°C)**
60% slag concrete	95.0	2289.0	1.5	35
100% white cement concrete	63.5	2276.5	2.3	35

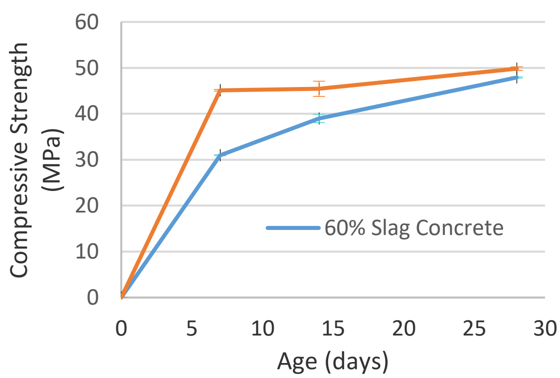

Figure 4: Early-age compressive strength of 60% slag and 100% white cement concretes

Monitoring

Test blocks from different elements of the Halls River Bridge were cast in order to monitor the performance and validate the lab results. Test blocks from the bulkhead cap are attached to the wall cap on both sides of the bridge. Seawater was used as mixing water for these elements reinforced with three different types of composite bars made of glass, basalt and carbon fibers (i.e., GFRP, BFRP and CFRP). Test blocks will be extracted every six months to examine the state of both concrete and embedded FRP bars. *Figure 5* shows the configuration of the bulkhead cap test blocks.

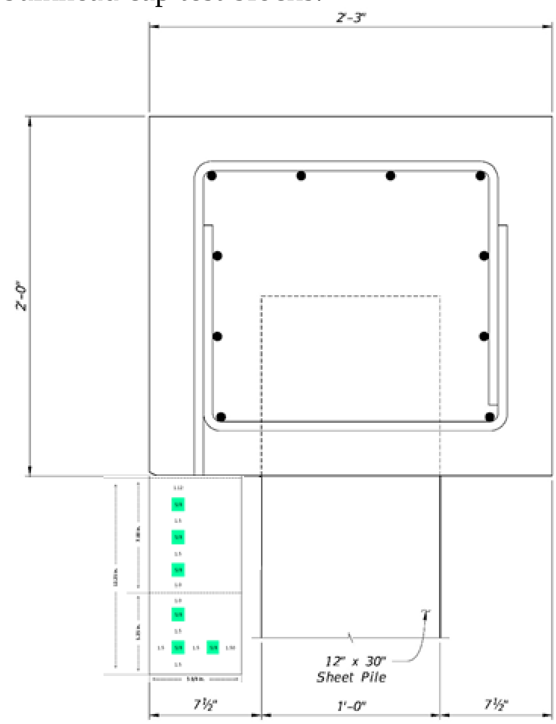

Figure 5: Configuration of the bulkhead cap test blocks (1 in = 25.4 mm)

The test blocks from the Green-RAP and Green-RCA gravity walls will be cast separately at the time of the construction. Although gravity walls will be cast with conventional RAP and RCA concrete mixtures, half of the test blocks will be cast with SEACRETE-RCA and SEACRETE-RAP concrete which have identical mix design except the mixing water which is seawater. Similarly, to the test blocks of the bulkhead cap, these test blocks will be reinforced with GFRP, BFRP, and CFRP providing the opportunity to monitor their performance when combining seawater and chloride-contaminated recycled aggregates. The configuration of the gravity wall test blocks is shown in *Figure 6*.

Identical formwork will also be filled with the two concrete types used for the traffic railings made with white cement and a blend of slag and Portland cement, traffic railings made with white cement and a blend of slag and Portland cement, respectively. These test blocks will only be reinforced with GFRP bars.

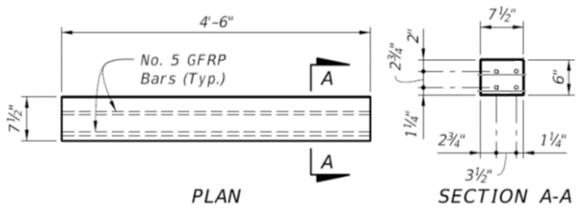

Figure 6: Configuration of the gravity wall test blocks (1 in. = 25.4 mm; 1 ft = 204.8 mm)

INFRASTRUCTURE

Monitoring Structural Element Fabrication

The main objective of Halls River Bridge construction is corrosion resistance against the extremely aggressive environment of Halls River, thus carbon fiber composite cables (CFCC) and spirals and glass fiber reinforced polymer (GFRP) stirrups were used in place of standard steel in the pre-stressed components. Due to the use of new materials in the sheet piles and bearing piles for Halls River Bridge, fabrication of the pre-stressed elements was monitored.

CFCC Prestressed Piles and Sheet Piles

Gate Precast Company in Jacksonville, FL fabricated the sheet piles and bearing piles where the fiber reinforced polymer cables, spirals, and stirrups were supplied by Tokyo Rope.

Principal differences between stressing CFCC strands and traditional steel strands is the use of plywood headers, CFCC-steel couplers, and plastic-coated ties. Plywood headers are required when using CFCC instead of standard steel headers due to the non-malleable characteristics of CFCC; shown in Figures 7 & 8 are the standard steel header and the plywood headers. CFCC strands are pulled from a spool and fed through the headers; the light weight of CFCC allows for one worker to pull the strand as other workers ensure the CFCC is correctly passing through the headers and GFRP stirrups, while in traditional fabrication practices multiple workers and equipment are required to pull the steel strands the length of the bed.

Figure 7-8: Standard steel headers (top) and plywood headers (bottom)

After the CFCC strands were pulled, the coupler between the CFCC strand and steel strand was installed; *Figure 9-10* display the CFCC-steel coupler setup and installation.

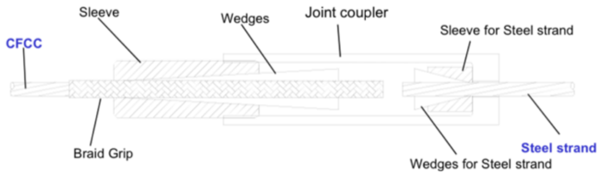

Figure 9: CFCC-Steel coupler setup (Tokyo Rope)

Figure 10: CFCC-Steel coupler installation

Epoxy coated wire and plastic ties, shown in *Figure 11*, were used to stabilize the GFRP stirrups and bars. The epoxy coated wire (copper colored ties) was twisted by hand and cut using wire cutters while the plastic ties (yellow ties) were dispensed from an automatic tie gun.

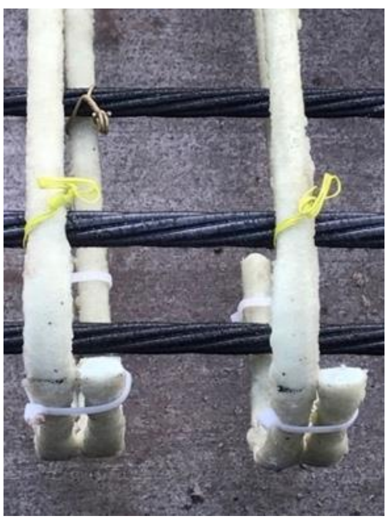

Figure 11: Epoxy and plastic-coated ties

Hybrid Composite Beams

Another experimental aspect of the bridge is the use of HCBs which incorporates the advantages of a concrete compression arch, resin encased galvanized tension reinforcement, and an FRP outer shell.

During transportation and erection, before casting of the concrete compression arch, the HCB is one-tenth of the weight of a comparative span precast/prestressed concrete beam and one-fifth the weight of a typical steel beam for the same span. The HCB has three main components: the shell, compression arch, and tension reinforcement.

The HCBs for Halls River Bridge were manufactured at Kenway Corporation in Augusta, Maine. The following layers were placed in the shell form: blue release film (surface Veil); CFM (continuous flow media); a 24-oz fiberglass layer; and 102-oz fiberglass layers. Two (2) layers of 102-oz fiberglass were used on the bottom of the shell, and one layer was used on the top and sides of the shell. The shell fabrication process is shown in *Figures 12-14*.

An orange plastic inner vacuum bag was placed over the foam arch to prevent resin from filling the concrete arch. The resin was infused through the beam shell in a closed process. After resin infusion, the release film layers were removed from the beam shell and the 4-inch foam channel along the shell centerline was cut-out using a reciprocating saw.

The FRP lids were composed of three layers of 102-oz quadraxial fiberglass and infused with resin in an open infusion process using a 25 to 30-inch mercury vacuum. Approximately 200-lbs of resin was required for the infusion of two fiberglass lids. The shell and lid resin infusion process are shown in *Figure 15-17*. The lids were then moved to a cutting area where holes were cut for shear connectors, concrete filling ports, vibrator holes, and lifting loop holes.

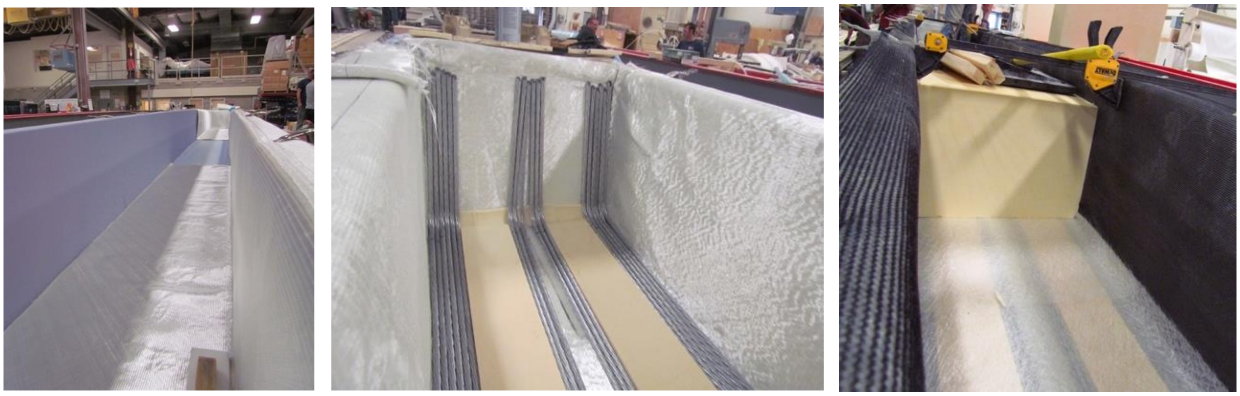

Figure 12-13: HCB fabrication process. From left to right the figures display the fiberglass layers, the steel reinforcement and resin flow piping, and the foam layers of the beam.

Figure 15-17: HCB resin infusion process. From left to right the figures display the lid infusion setup, the channel being cut into the top of the HCB, and the shell resin infusion setup.

The wrapped beams were shipped from Kenway Corporation in Augusta, ME to CDS Manufacturing in Gretna, FL where the shear reinforcement was installed and the beams were filled with self-consolidating concrete. The shear connectors were rotated approximately 90 degrees into place under the two (2) galvanized strands in the shell. After ensuring proper placement, the shear connectors were tied to temporary rebar to stabilize them during arch casting.

If the concrete was not flowing properly, a rubber tipped vibrator was inserted into pre-cut holes along the lid centerline to aid in concrete flow. Each beam required approximately 1.3 cubic yards of concrete to fill the compression arch. The filling of the compression arch is shown in *Figures 18-20*.

Figures 18-20: HCB compression arch filling process. From left to right the figures display the rubber tipped vibrator, filling of arch using concrete hopper, and tying of shear connectors.

Composite Element Construction Practices

The use of FRP is expected to be extremely durable due to the inherit corrosion resistance of the materials used. Among the many advantages of FRPs, on site experience values one particular property of FRP over carbon-steel: light weight. Using a material that weights almost 4 times less than typical reinforcement, allows significant energy savings not only during transportation, but also during construction process by requiring less workforce while increasing production. Loading, unloading, sequencing, storage and lifting activities can be handled with lighter equipment than that required for carbon-steel construction. Of course, contractors on site should be properly trained and communicate installation procedures with the FRP manufacturer prior to installation.

Once delivered on site, FRP material shipments were inspected and acceptance was reviewed. Also, particular attention was taken to identify parts with eventual defects, since FRP components can be damaged post production, during transportation or during installation.

While in outdoor storage, FRP bars were placed on firm and level surfaces and adequately covered with black plastic fabrics, in order to protect the bars (in particular the epoxy layer that keeps the fibers together) from UV light over-exposure. Over-exposure can cause degradation and strength-loss of the material. During construction two composite elements required additional evaluation and design due to unexpected soil conditions: CFCC prestressed splice piles and CFCC prestressed sheet piles.

CFCC Prestressed Pile Splicing

Given the particular soil conditions on site, pile splicing was required during construction. Three 66-foot piles in bent 2, needed six 18”x18” CFCC splice piles. The connectors were made using No. 10 stainless steel bars at the precast plant and then connected on-site by epoxy (two-part Pilgrim EM CBC IV Epoxy) bonded dowels and driven to bearing.

Figure 21-25: Construction of CFCC prestressed splice piles. From left to right the figures display the splice piles, the lifting of the piles, and the epoxy dowelled splice connection.

Prior to epoxying the piles surface for the splice connection, an on-site plywood form was assembled, nailed and secured to the pile head using metal flashing. On the top of the pile, 5 nuts were liquid-nailed in order to provide a gap for epoxy to flow evenly inside the holes. Using an air compressor, the holes in the pile head were cleared of any dust. Approximately seven gallons of epoxy were poured into each splice connection. The male splice was then lowered on top of the female and fit, ensuring proper placement of the stainless-steel bars; displayed in *Figures 21-25* is the construction of the splice piles.

This innovative pile splice configuration avoided the use of traditional materials such as carbon-steel that are more susceptible to corrosion, and thus maintained the durability characteristics of the original design. Tests and design revisions are ongoing, to incorporate CFCC dowel connectors (instead of stainless-steel bars) in future similar design scenarios.

Sheet Piles Re-design

The concrete sheet pile retaining wall includes use of GFRP reinforcing bars along with CFRP prestressing strands. The reinforcing in the bulkhead cap also utilized GFRP reinforcing, allowing the entire wall to be designed without steel. High strength concrete was also used with Class V Special Concrete (6 ksi) in the fabrication of the precast sheet pile while Class IV Concrete (5.5 ksi) was used in the Cast-In-Place sections.

As construction progressed, a thick rock-like soil was encountered when driving the CFCC prestressed sheet piles. The unexpected soil conditions required a tie-back sheet pile wall design, modifying the sheet pile structure from a cantilevered to an anchored design. The new design re-implemented part of the sheet piles cut-offs as deadmen anchors, as shown in *Figures 26-28*. In fact, the sheet piles were re-designed to accomplish a shorter elevation and allow for an easier installation through the rock layers. The deadmen anchors carry the load of the seawall through stainless steel tie-rods, embedded in a 4-inch perforated pipe (for drainage reasons).

Figures 26-28: CFCC prestressed sheet pile wall tie-back design. From left to right, the figures display the sheet pile wall with GFRP pile cap, installed stainless steel tie-rods in perforated pipe, and formed cast-in-place concrete deadmen anchor blocks.

INNOVATION+ INFRASTRUCTURE = INFRAVATION *(cont.)*

Conclusions

Through the monitoring process a few key items discovered are the

- Higher early age strength of Green concrete compared to conventional concrete
- Small learning curve associated with use of CFCC instead of traditional steel in prestressed members
- Adaptability of CFCC members during construction

This innovative design and implementation of new materials and construction practices would not be possible without the combined effort and support of FDOT and Astaldi Construction Corporation.

Meet the research team

Michelle Gartman, MS

Michelle is a PhD Candidate in structural engineering at the FAMU-FSU College of Engineering working under the supervision of Dr. Michelle Roddenberry. Her main research interests are bridge construction, civil engineering composite materials, and the applications of FRP in transportation infrastructure. Michelle is currently working on the inspection and monitoring of fabrication and construction for Halls River Bridge Replacement demonstration project.

Michelle Rambo-Roddenberry, PhD, PE
Associate Dean for Undergraduate Affairs
FAMU-FSU College of Engineering

Rambo-Roddenberry, Associate Professor, received her bachelor's and master's degrees in civil engineering from Florida State University and her Ph.D. from Virginia Tech. Before joining the university in 2006, she was a bridge engineer for seven years. She teaches structural engineering, including Concrete Design, Bridge Engineering, and Prestressed Concrete. Her research is primarily on prestressed concrete bridges, including analysis, design, construction, testing, and load rating. Her major service activities are with NCEES, the Order of the Engineer, FES, and the Florida Board of Professional Engineers – for which she has served as a board member since 2012.

Thomas Cadenazzi, PhD

Thomas received his Ph.D. form the University of Miami in Dec. 2019 and was deployed to the Halls River Bridge project site as a research assistant during the first construction stage. He obtained his Master's Degree in Civil Engineering from Polytechnic of Milan (Italy) in 2016. Between January and August 2016, Thomas studied (on a Polimi scholarship) at the University of Miami - College of Engineering under the lead of Dr. Antonio Nanni, where he worked as a researcher of composite materials for structural applications, and completed his Master's Thesis, "Study of an experimental anchor system – "staple anchors" – for externally bonded CFRP laminates used for the consolidation and retrofitting of reinforced concrete structures, through an innovative double shear test method.

Morteza Khatibmasjedi, PhD

Morteza Khatibmasjedi received his Ph.D from the University of Miami in 2018, with a Master's Degree from Oklahoma State University in 2014 and Bachelor's Degree from Islamic Azad University in 2012. He had more than 10 years of experience in the fields of structural and concrete materials engineering. During his doctoral program he worked on the Infravation Project called SEACON (Sustainable Concrete using Seawater, Salt-Contaminated Aggregates, and Non-Corrosive Reinforcement). SEACON demonstrated the safe utilization of seawater, salt-contaminated aggregates (natural or recycled), cement without chloride limits and byproducts such as cement kiln dust for a sustainable concrete production, when combined with non-corrosive reinforcement (i.e., FRP and stainless steel) to construct durable and economical concrete infrastructures.

Antonio Nanni, PhD, PE
Inaugural Senior Scholar
Professor and Chair
Department of Civil, Architectural & Environmental Engineering

Nanni, a structural engineer, is interested in construction materials and their structural performance and field application, including monitoring and renewal, with a focus on the sustainability of buildings and civil infrastructure. During the past 30+ years, Nanni has studied concrete and advanced composite-based systems as the principal investigator on a number of projects sponsored by federal and state agencies and private industry. Nanni is the editor-in-chief of the *Journal of Materials in Civil Engineering* (American Society of Civil Engineers) and serves on the editorial board of other technical journals. He has advised more than 60 graduate students pursuing master's and doctoral degrees in the field, published more than 220 papers in refereed journals, published more than 350 papers in conference proceedings and co-authored two books.