Center for Integration of Composites into Infrastructure

2023 NSF IUCRC CICI- IAB Fall Meeting
TAMU Site Projects' Summaries

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TAMU Site Projects' Summaries

TAMU - 1: Evaluating the Performance of Fiber-Based Concrete Mixes for Various Applications
Program Manager / PI: Dr. Anand J Puppala
Company / Sponsor: Warstone Innovations, LLC

I/UCRC Executive Summary - Project Synopsis		**Date**: November 7th, 2023
Center/Site: Center for the Integration of Composites into Infrastructure (CICI) / TAMU		
Tracking No.:	**Phone:** ( ) -	**E-mail:** anandp@tamu.edu
Center/Site Director: Dr. Anand J Puppala		**Type: Continuing**
Project Leader: Krishneswar Ramineni (Doctoral Student), Akash Ashok Tanshette (Doctoral Student), Nicole Arackal (undergraduate student) and Dr. Anand J Puppala		**Proposed Budget**: $ 30,000

Project Description:
Rising seawater levels and increased frequency of high intensity storms due to climate change is a serious concern for the coastal areas. These factors make coastal areas vulnerable to flooding, coastal erosion, and water pollution causing damage to infrastructure assets and human lives. Traditionally sandbags are used as barriers to control the destructive behavior of flooding and stormwater. These sandbag barriers are typically designed to take the impact, from the hydraulic forces of the storm and the debris flowing in the storm, and protecting physical assets and communities. Preliminary findings from the interactions with the industry indicated that sandbags have some limitations in terms of handling and transportation. Moreover, sandbags deteriorate when they are exposed for prolonged alternate wetting and drying cycles. The limitations of this existing practice offered the need for exploring the application of the matrix of fiber-based concrete mix bags, patented by Warstone Innovations LLC, for various coastal purposes. So, this project currently focuses on evaluating the performance of various fiber-based concrete mix bags as flood barrier materials.

Experimental plan: The preliminary testing includes evaluating the physical and chemical properties of concrete constituents. Based on material properties, fiber-based concrete mix proportions are prepared, and the fiber dosage is optimized considering the physical and durability tests. Wetting and drying studies will be conducted under two different temperatures (40°C and 4°) and also separately by using artificially prepared seawater. Permeability and strength studies will be conducted on fiber based concrete mixes. Expansion tests will be performed to evaluate the expansion behavior of the mixes. For the second phase of testing, a large-scale laboratory box size 3’ x 3’ x 4’ is constructed to evaluate the performance of the fiber-based concrete mix bags in similar conditions mentioned above.

Related work elsewhere: Sand filled bags are used as erosion barriers during flooding. Research studies were performed to optimize the natural fiber dosage in cement-concrete and for structural applications. Not much work was conducted on evaluating the performance of fiber-based concrete mixes as erosion barriers in various conditions. This project focuses on developing a system to use fiber-based concrete mix filled bags as an efficient alternative to sandbags and prevent the damage due to flooding.

How this project is different: There have been many past studies that used natural fibers in concrete to improve mechanical properties like compressive strength and flexural strength. The fiber dosage is limited to a maximum of 10% weight of cement mixture. But this project focuses on developing fiber-based concrete mixture that can contain more than 50% weight of cement mixture to address flooding and erosion issues.

Milestones for the current proposed year: During this year, large scale laboratory box setup will be to study the performance of fiber-based concrete mix bags in various conditions and the final report will be submitted.

Deliverables for the current proposed year: A Final report with findings emphasizing fiber dosage optimization based on small-scale and large-scale Laboratory wetting and drying studies in various conditions will be provided. Hydraulic conductivity, compressive strength and split tensile strength for concrete fiber mixes will also be presented.This work will be presented at Geoenvironmeet 2024 and IECA annual conference 2024

How the project may be transformative and/or benefit society: The research findings of this project will provide an idea about the feasibility of using fiber-based concrete mix bags to reduce the damage caused due to flooding and erosion. This will help in enhancing the resilience of communities, especially located in coastal corridors.
Research areas of expertise needed for project success: Extensive knowledge in concrete technology and different microstructural techniques to understand cement chemistry. Adept knowledge of coastal flooding and erosion. A good understanding of solid and fluid mechanics.
Potential Member Company Benefits: Identify optimum fiber-based concrete mix through a comprehensive laboratory testing plan. Explore various applications of these mixes to address other infrastructure related areas.
Progress to Date: Material properties of concrete constituents were evaluated, and fiber-based concrete mix proportions were identified. Wetting and drying tests using potable water at 20°C and 50 relative humidity (RH)were completed. Wetting and drying studies at different environmental conditions: 40°C, 4°C and using saltwater water are completed. permeability tests and strength tests on fiber based concrete mixes are completed. Large scale wetting and drying studies on geotextile bags filled with optimized fiber based concrete mix and sand are being performed.

Estimated Start Date: 08/01/2021	**Estimated Knowledge Transfer Date**: 12/31/2023

TAMU - 2: Application of Geofoam in Thermal Encapsulation of Foundations
Program Manager / PI: Dr. Anand J Puppala
Company / Sponsor: Thermafoam

I/UCRC Executive Summary - Project Synopsis		**Date**: November 7th, 2023
Center/Site: Center for the Integration of Composites into Infrastructure (CICI) / TAMU		
Tracking No.:	**Phone:** ( ) -	**E-mail:** anandp@tamu.edu
Center/Site Director: Dr. Anand J Puppala		**Type:** Continuing
Project Leader: Hiramani Raj Chimauriya (Doctoral Student), Clay Caldwell (Doctoral Student), Gustavo Hernandez Martin (undergraduate student) and Dr. Anand J Puppala		**Proposed Budget**: $45,000
Project Description: The main objective of the research work in this project is to mitigate temperature fluctuations within dwellings by designing and using thermally insulated and energy efficient novel foundation systems. Temperature fluctuations inside the dwellings typically occur from advection, diffusion and radiation at foundation joints; therefore, an insulation material around dwelling foundation systems would help in reducing these temperature fluctuations. The proposed research plan will explore the use of expanded polystyrene geofoam material as a thermal insulating material for two foundation alternatives or systems to assist the building infrastructure in conserving energy. The proposed research study attempts to identify and optimize the design and construction of foundation insulation systems using geofoam materials, which are cost-effective and provide resilient support. The novelty of the proposed research lies in the use of geofoam for thermally encapsulating residential dwellings, at low additional cost and minimal deviation from the standardized structural and architectural design and construction of residential dwellings.		
Experimental plan: Two different types of insulated foundation systems, viz., (a) Geofoam blocks attached around the periphery of foundation (referred here to as GAF system), and (b) Geofoam slab placed underneath the foundation system (referred here to as GBF system) will be constructed in the laboratory. Temperature sensors will be installed both inside and outside of the structure to monitor the variation in temperature and heat transfer over time. The results will be compared with that of the control prototype to study the effect of thermal encapsulation and energy savings. The cost benefit analysis will also be conducted as a part of this study.		
Related work elsewhere: The insulating properties of EPS Geofoam have been studied earlier in brevity, however, its efficiency to provide thermal insulation to dwelling has not been evaluated in detail.		
How this project is different: The insulating properties of EPS geofoam are known, however, its application for saving energy consumption of dwelling needs to be evaluated. In this study, various sizes and types of EPS Geofoam blocks are being used for encapsulating the foundation of a dwelling prototype and evaluating its performance related to energy transfer.		
Milestones for the current proposed year: During this year, the lab scale studies for the 2-in., 4-in., and 8-in. GAF R-250 geofoams were completed. GAF testing with different R-value geofoams has commenced. Numerical simulations will also be conducted in conjunction with the experiments to model a wider range of scenarios of thermal encapsulation using Geofoam material.		
Deliverables for the current proposed year: Report with preliminary findings of the energy efficiency of the dwelling prototype with Geofoam-encapsulated foundation. The current work will be presented at Geocongress 2024 and TRB annual meeting 2024.		

How the project may be transformative and/or benefit to society: The energy savings from the insulation would allow the owner to recoup the cost of foundation insulation systems quickly. Subsequently, with a large number of dwellings adopting such a foundation system, the lower power consumption costs of each of these dwellings would collectively help in reducing the energy loads on the power grid. Supporting the reduced energy needs of these modified dwellings with other renewable energy sources such as solar energy will achieve net-zero energy status for most dwellings. Apart from the economic benefits of these foundation insulation systems, the foundation systems can also promote the development of sustainable infrastructure, namely green buildings and zero-energy ready homes.	
Research areas of expertise needed for project success: The knowledge of thermodynamics involved in evaluating the energy transfer in homes during warm and cooler climatic conditions and use of cost-effective construction materials and techniques is required for the study.	
Potential Member Company Benefits: The study on thermal encapsulation of the foundation using EPS Geofoam will be able to provide design guidelines for full-scale pilot studies or future construction on thermal insulation of buildings with Geofoam-encapsulated foundation.	
Progress to Date: First set of tests on geofoam insulated footing was performed for geofoam-below-footing (GBF) and geofoam-around-footing (GAF) configurations with an insulation grade of R-250. Numerical modeling of the control test was performed using COMSOL Multiphysics. Testing of GAF configurations using 8-inch R-130 grade geofoam is completed and 2-inch R-130 is ongoing.	
Estimated Start Date: 09/01/2020	**Estimated Knowledge Transfer Date**: 05/31/2024

TAMU - 3: Design and Testing of IFI Geosynthetic Products

Program Manager / PI: Dr. Anand J Puppala

Company / Sponsor: Industrial Fabrics (IFI)

<table>
<tr><td colspan="2">I/UCRC Executive Summary - Project Synopsis</td><td>Date: November 7th, 2023</td></tr>
<tr><td colspan="3">Center/Site: Center for the Integration of Composites into Infrastructure (CICI) / TAMU</td></tr>
<tr><td>Tracking No.:</td><td>Phone: (   )   -</td><td>E-mail: anandp@tamu.edu</td></tr>
<tr><td colspan="2">Center/Site Director: Dr. Anand J Puppala</td><td>Type: Continuing</td></tr>
<tr><td colspan="2">Project Leader: Krishneswar Ramineni (Doctoral Student), Avinash Gonnabathula (Doctoral Student), Godfred Akwaa (Graduate student),and Dr. Anand J Puppala</td><td>Proposed Budget: $245,000</td></tr>
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Project Description: The application of geosynthetic products can provide an effective solution for the earth retaining systems as well as different foundation systems by reinforcing the earth materials. These products include, but not limited to, geocells, geogrids, and laminated geogrid products. The combination of these products has been used in the field for quicker construction and better performance. However, there are no such guidelines available regarding the design of such products. Giroud and Han (2004) provide a design methodology for geogrid reinforced pavement structures. The objective of this study is to expand on those methods by improving the study behind the theories and/or incorporating new concepts and methods of calculations. There are two major objectives in this study:

- Phase 1 Part I: Performing repeated load tests on geosynthetic reinforced 12-inch base layers built on different weak subgrades and then use the test data to calibrate parameters that can be used with Giroud and Han (G&H) designs.
- Phase 1 Part II: Developing various design charts and methods for IFI, Inc Geosynthetic Products based on the results and calibration studies from Part I.
- Phase 1 Part III: Perform non-destructive tests on geosynthetic reinforced base layers built on weaker subgrades and then use the test data to determine the stiffness properties of different pavement layers in the field.
- Phase 2 Part I : Performing repeated load tests on geogrid reinforced 6-inch base layers built on different weak subgrades.
- Phase 2 Part II: Developing various design charts and methods for IFI, Inc Geogrids Products based on the results and calibration studies from Phase 1 Part 1 and phase 2 Part 1

Experimental plan: Physical and engineering soil testing including grain size distribution, standard Proctor test, Atterberg's limit, resilient modulus, shear strength and undrained strength tests, and California Bearing Ratio (CBR) test has been performed on the base material and subgrade soils. Both these materials were selected based on the recommendation by IFI, Inc. For subgrade selection, the subgrades with different CBR values (1 and 3) were prepared by adjusting the moisture content. A large-scale test setup is available at the Center for Infrastructure Renewal (CIR), Texas A&M University, which was designed and constructed to facilitate a wide range of static and repeated load testing to evaluate the behavior and performance of the geosynthetic reinforced soils. The large-scale test setup consists of a steel testing box, loading frame, actuator, along with a data acquisition system. The steel testing box has dimensions of 6 ft x 6 ft x 5 ft (1.83 m × 1.83 m × 1.52 m). In the test box, subgrade layers of select CBR were prepared using selected material at target dry density and moisture content.

Test results were analyzed and calibrated to determine various parameters for both geocell and Fabgrid (geocomposites) reinforced soils. Test results from the repeated load tests would be used to generate 1/tan α vs log N plots. This information could be used to calibrate the performance of the section as a function of the Aperture Stability Modulus (J) for proposed Fabgrid. Analyses of these results would provide calibration parameters that will be useful for designing reinforced base/subbase systems using IFI geosynthetic products.

Field studies include performing non-destructive tests like Lightweight deflectometer (LWD), Dynamic Cone Penetrometer (DCP) and Variable Energy Dynamic Cone Penetrometer (VE-DCP) tests on different geosynthetic reinforced unpaved field sections. Perform Laboratory tests on base and subgrade materials to develop co-relationship between surface modulus, tip resistance and CBR. Develop a geosynthetic reinforced unpaved section numerical model and validate the model with field data.	
Related work elsewhere: The longevity and performance of the pavement sections on problematic soils including soft and expansive subgrades, has been a major concern for transportation practitioners (Puppala et al. 1996; Puppala and Pedarla 2017). Flexible pavements and unpaved roads constructed on problematic soil suffer from different failures such as cracking, rutting, and depression (George et al. 2019; Khan et al. 2020; Puppala et al. 2017). The reasons for such failure may be attributed to fatigue, temperature changes, moisture ingress and egress, and softening caused by surface layer cracking (Han et al. 2011, Pokharel et al. 2018). The use of geosynthetics as an additional supporting layer to the existing subsoil might help the agencies and organizations to eliminate the distress problems associated with the problematic soils (Giroud and Noiray 1981).	
How this project is different: In the previous studies, researchers used planar geosynthetic products or the combination of two/three different geosynthetic products; however, there is very little information available about the utilization of combined products such as FabGrid. This study focuses on the utilization of different combinations of high-density polyethylene (HDPE) products for different types of foundation systems.	
Milestones for the current proposed year: Completed 12 inch base large scale repeated load testing . Developed the preliminary design equation for geogrid reinforced pavement structures and improvement factors for geosynthetics based on 12-inch base large scale repeated load test results. Completed field testing (LWD, VE-DCP, DCP tests) and small scale laboratory tests . Design charts were developed based on field data and numerical model.	
Deliverables for the current proposed year: Design charts for different IFI products based on field testing. Layer coefficient table for the design of unpaved and paved road based large scale repeated load tests (only 12 inch base sections).	
How the project may be transformative and/or benefit society: This study mainly focuses on the utilization of new combinations of HDPE products (e.g.,Fabgrid and Fabgrid+GeoCell). This study aims to develop design charts for different HDPE products/combinations of HDPE products for different stiffnesses of foundation materials. The outcome of this research will help to ensure the safety and reliability of the geotechnical structures by providing the design charts.	
Research areas of expertise needed for project success: A thorough knowledge in foundation design using geosynthetics reinforcement, pavement engineering and load transfer mechanisms with different combinations of HDPE products.	
Potential Member Company Benefits: Development of design guidelines for foundation systems with different combinations of HDPE materials.	
Progress to Date: Performed material characterization of base and subgrade materials in the laboratory. Performed large-scale repeated load tests for 16 reinforced and 2 unreinforced with 12-inch base sections. Developed the preliminary analytical models to accommodate the stiffer geogrid materials.Developed preliminary design charts for unreinforced and reinforced sections based 12-inch base large scale testing. Developed layer coefficient chart for different IFI products. Performed field studies and developed numerical model for geosynthetic reinforced unpaved section.	
Estimated Start Date: 9/1/2020	**Estimated Knowledge Transfer Date**:03/31/2024

TAMU - 4: Performance of Pavement Sections with Wicking Geosynthetics
Program Manager / PI: Dr. Anand J Puppala
Company / Sponsor: TenCate/Solmax

I/UCRC Executive Summary - Project Synopsis		**Date**: May 8th, 2023
Center/Site: Center for the Integration of Composites into Infrastructure (CICI) / TAMU		
Tracking No.:	**Phone:** ( ) -	**E-mail:** anandp@tamu.edu
Center/Site Director: Dr. Anand J Puppala		**Type:** Continuing
Project Leader: Dr. Nripojyoti Biswas (Post Doc) and Dr. Anand J Puppala, Avinash Gonnabathula (GAR), Krishneswar Ramineni and Gustavo Hernandez Martin (undergraduate student)		**Proposed Budget**: $310,000

Project Description: Expansive soils are found in various regions around the globe. In the US itself, expansive soils cover a vast stretch in western and southwestern states. The seasonal moisture variation leads to a large volume change in these soils causing alternate swelling and shrinkage. As a result, this induces significant surficial distress in the form of heaving and cracking. The Mirafi H2Ri is an innovative geosynthetic product that integrates the features of traditional woven geosynthetics like strength, separation, and puncture resistance to an additional water-wicking capability with the presence of hydrophilic and hygroscopic fibers. These woven geotextiles have the capability to be utilized in various applications including pavement sections, where they can be used as a separation between the base and subgrade while providing drainage through the geotextile.

The main objective of the proposed project is to study the separation and drainage characteristics of woven geotextile Mirafi H2Ri when introduced between base and subgrade layers of the pavement section. Full-scale field implementation of the geotextile on the eastbound FM 1807 in Venus, Texas was constructed. In addition, small-scale laboratory tests in a controlled environment will be performed to understand the moisture movements in subsoil due to the placement of H2Ri. A large scae repeated load pavement tests will be performed using teh geotextile under different moisture conditions of teh subgrade. Additionally, the Life Cycle Analysis (LCA) will be performed and compared with other traditional materials used for the construction of pavement sections. Finally, the benefits of using the H2Ri geosynthetic in pavement sections having high plasticity soils as subgrades will be evaluated and summarized in the final report. Currently additional studies to investigate the performance of RS580i geosynthetics are also considered.

Experimental plan: The study focuses on the installation and monitoring of TenCate Mirafi H2Ri between the subgrade and the base layers on the eastbound FM 1807 in Venus, Texas. Field data for the past year was obtained from two test sections, (i) RAP aggregate as a base layer, and (ii) traditional flex-base aggregate as a base layer and their performance was compared with a control section. Instrumentation such as moisture probes, pressure cells, and Shape Array Accelerometer (SAA-MEMS) were installed for continuous monitoring of the test sections. The influence of variation in moisture, traffic loads on the stresses developed on top of the subgrade layer was measured and evaluated and is expected to continue in the coming years. Furthermore, the wicking action of the TenCate Mirafi H2Ri, when embedded in expansive soil subgrade, is being studied by performing small-scale laboratory tests. Numerical models will be developed and validated against the experimental data obtained from the laboratory and field test sections. LCA will be performed and compared with pavement sections built with conventional construction materials. Additional monitoring will be performed for another year on the test sections. Some studies will be performed on the benefits of RS580i geosynthetics in synchronous with the H2Ri geosynthetics.

Laboratory studies, using large scale pavemnt similator will be performed in the final phase to simulate the pavement performance under flooded conditions.	
Related work elsewhere: The effectiveness of wicking geotextile in reducing soil moisture for roadway application was studied in a laboratory model by Wang et. al. (2017). Zhang et.al. (2014) studied the effect of wicking fabric to prevent the effect of frost boil on Alaskan pavements by performing full-scale field implementation of the woven geosynthetics. The rate of water removal under controlled temperature and humidity using wicking was studied by Guo et.al. (2016).	
How this project is different: In the previous studies, H2Ri geotextile was used to mitigate the effects of frost-heaving. This study primarily focuses on the improvement in the drainage of pavement sections by using H2Ri and its application in high plasticity subgrade soils. In addition to the enhancement of drainage coefficient, H2Ri is a high-strength material that would provide adequate support for the base layer. Similarly, RS580i geotextiles is a high-strength woven fabric whose application could be beneficial for long-term serviceability of pavement sections.	
Milestones for the current proposed year: Performed analyses of the performance of test sections constructed with RS580i and compared the performance with H2Ri sections. Started data collection for robust LCCA analyses of the H2Ri geotextiles.	
Deliverables for the current proposed year: Performance monitoring of field test sections. Develop LCA framework for the wicking geotextiles. Perform large scale repeated load testing to simulate different mositure conditions.	
How the project may be transformative and/or benefit society: This study mainly focuses on the drainage improvement of pavement which will enhance the structural capacity of the pavement system. This new technology will not only increase the drainage coefficient but also enhances overall stiffness which will reduce the required pavement thickness. This project will contribute to enhanced safety to the traveling public and reduced construction costs. It also increases the resiliency and longevity of the pavement systems, thereby contributing to a higher return on investment. Additionally, the use of RAP material can make the pavement structures more sustainable and cost-effective as it will decrease the demand for virgin aggregate.	
Research areas of expertise needed for project success: A thorough knowledge in pavement design using Geosynthetics reinforcement, advanced numerical modeling of H2Ri/RS580i reinforced pavements under static and repeated loadings, sustainability of RAP bases with H2Ri/RS580i in the pavement construction, and the estimation of cost-effectiveness of pavement constructed with RAP material on expansive subgrade soil.	
Potential Member Company Benefits: Development of design and construction guidelines for H2Ri supported pavements with RAP base in areas where the subgrade soil is expansive. Pavement structures will be resilient and will have lesser distress during their service life.	
Progress to Date:. Started comprehensive Life Cycle Analysis (LCA), and the Cradle to Gate + construction boundary condition was identified. Life Cycle Cost Analysis was performed using the market costs with the determined boundary conditions. For the sustainability analysis, the environmental impact factors i.e embodied energy and various categories of emissions were determined for the different sections in the field using OpenLCA software.	
Estimated Start Date: 5/1/2018	**Estimated Knowledge Transfer Date**:07/31/2024

Center for Integration of Composites into Infrastructure

2023 NSF IUCRC CICI- IAB Fall Meeting
University of Miami
Project Summaries

Center for Integration of Composites into Infrastructure

2023 NSF IUCRC CICI- IAB Fall Meeting
University of Miami Projects' Summaries

UM - #1: Using Machine Learning and Artificial Intelligence to implement FRP in infrastructure: Areas of Opportunity

Program Manager / PI: Prof. Antonio Nanni

Company / Sponsor: Altus Group, Arkema, Miller & Long Company, Structural Technologies, Simpson Strong-Tie.

I/UCRC Executive Summary - Project Synopsis		**Date**: December 7, 2023
Center/Site: Center for the Integration of Composites into Infrastructure (CICI) / UM		
Tracking No.: UM01	**Phone:** (305) 284 -6150	**E-mail:** fdecaso@miami.edu
Center/Site Director: Antonio Nanni (PI), and Francisco De Caso (Co-PI)		**Type:** Continuing
Project Leader: Nima Khodadadi		**Proposed Budget**: $50,000.00

Project Description:

The implementation of Machine Learning (ML) and Artificial Intelligence (AI) in the design and use of FRP in infrastructure can provide several areas of opportunity, such as:

a) Design optimization: ML and AI can be used to optimize the design of FRP materials for specific infrastructure applications. By analyzing data on material properties, environmental factors, and load conditions, ML algorithms can generate optimal designs that minimize material usage, reduce weight, and improve performance.
b) Predictive maintenance: AI can be used to develop predictive maintenance models that can anticipate the need for repairs or replacement of FRP structures. These models can be trained on data from previous inspections and maintenance activities, as well as real-time sensor data, to predict when maintenance is needed and optimize maintenance schedules.
c) Quality control: ML algorithms can be used to analyze data from manufacturing processes to identify defects, optimize production parameters, and improve quality control. This can lead to more consistent and reliable FRP materials, reducing the risk of failure in infrastructure applications.
d) Life-cycle assessment: ML and AI can be used to perform life-cycle assessments of FRP materials, evaluating their environmental impact and comparing them to traditional construction materials. This can help inform decision-making around the use of FRP in infrastructure projects and support the development of sustainable infrastructure solutions.

Experimental plan:

Here is an experimental plan for using Machine Learning and Artificial Intelligence to implement FRP in infrastructure:

1) Data collection: Collect data on FRP materials, their properties, and their performance in infrastructure applications. This can include data from previous projects, laboratory experiments, and field tests. Data should also be collected on environmental factors and load conditions.
2) Data preprocessing: Preprocess the data to ensure that it is clean, consistent, and ready for use in ML and AI algorithms. This may involve data cleaning, normalization, and feature engineering.
3) ML and AI algorithm selection: Choose appropriate ML and AI algorithms based on the specific area of opportunity being addressed. For example, regression algorithms may be used for design optimization, while classification algorithms may be used for quality control.
4) Algorithm training and testing: Train the selected algorithms on the preprocessed data and test their performance on validation data. This will help ensure that the algorithms are accurate and effective.
5) Implementation and evaluation: Implement the trained algorithms in real-world infrastructure applications and evaluate their performance. This may involve monitoring the behavior of FRP structures using sensors, analyzing data on material usage and performance, and comparing the results to traditional construction materials.
6) Optimization and refinement: Use feedback from the implementation and evaluation to optimize and refine the ML and AI algorithms. This may involve adjusting parameters, modifying features, or selecting different algorithms altogether.
   Scaling and dissemination: Once the ML and AI algorithms have been optimized and refined, scale up their implementation to other infrastructure projects and disseminate the results through academic publications, conference presentations, and industry reports.

This experimental plan can be adapted and customized based on the specific area of opportunity being addressed and the available data and resources.

Related work elsewhere: There have been several studies and projects that have explored the use of Machine Learning (ML) and Artificial Intelligence (AI) to implement Fiber Reinforced Polymer (FRP) in infrastructure. Here are some examples of related work in this area: Researchers have used ML algorithms such as neural networks and genetic algorithms to optimize the design of FRP materials for specific infrastructure applications. For example, one study used a genetic algorithm to optimize the design of FRP-reinforced concrete beams, achieving significant reductions in material usage while maintaining structural performance. Researchers have used AI to develop predictive maintenance models that can anticipate the need for repairs or replacement of FRP structures. For example, one study used a Bayesian network to predict the remaining service life of FRP-reinforced concrete columns based on their environmental exposure and load history. ML algorithms have been used to analyze data from manufacturing processes to identify defects, optimize production parameters, and improve quality control. For example, one study used a support vector machine to classify defects in FRP materials, achieving high accuracy rates and reducing the need for manual inspection. Researchers have used ML and AI to perform life-cycle assessments of FRP materials, evaluating their environmental impact and comparing them to traditional construction materials. For instance, one study used a decision tree algorithm to assess the environmental impact of FRP-reinforced concrete beams, finding that they had lower environmental impact than traditional steel-reinforced beams.
How this project is different: Metaheuristic algorithms are optimization algorithms that can be used in combination with Machine Learning (ML) to gain more accuracy in the implementation of Fiber Reinforced Polymer (FRP) materials in infrastructure. By using metaheuristic algorithms in combination with ML, it is possible to gain more accuracy in the implementation of FRP materials in infrastructure, leading to improved performance, reduced costs, and increased sustainability.
Milestones for the current proposed year: Pulishing and finishing two hot topic project based on FRP and AI.
Deliverables for the current proposed year: A detailed plan for collecting data on FRP materials, their properties, and their performance in infrastructure applications. This plan should include the data sources, data types, and data collection methods. A report detailing the ML and AI algorithms selected for use in the project, based on the specific area of opportunity being addressed.
How the project may be transformative and/or benefit society: The implementation of Machine Learning and Artificial Intelligence in Fiber Reinforced Polymer (FRP) infrastructure has the potential to be transformative and benefit society in several ways: Improved infrastructure performance: ML and AI algorithms can optimize the design and use of FRP materials in infrastructure, leading to improved performance, durability, and safety. This can result in longer-lasting infrastructure and reduced maintenance and repair costs. Sustainability: ML and AI can be used to perform life-cycle assessments of FRP materials, evaluating their environmental impact and comparing them to traditional construction materials. This can help inform decision-making around the use of FRP in infrastructure projects and support the development of sustainable infrastructure solutions. Increased safety: ML and AI can be used for structural health monitoring and predictive maintenance, providing early warnings of potential failures and enabling timely repairs or replacements. This can improve safety for people and property in the vicinity of the infrastructure. Economic benefits: The use of FRP materials in infrastructure can result in significant economic benefits, such as reduced maintenance and repair costs, improved structural performance, and increased durability. ML and AI algorithms can further enhance these benefits by optimizing the design and use of FRP materials. Advancement of technology: The implementation of ML and AI in FRP infrastructure represents a significant advancement in technology, which can have far-reaching impacts on other industries and fields. The development of these technologies can also spur further innovation and research in the field of infrastructure engineering.
Research areas of expertise needed for project success: The project requires a strong foundation in data science, including data collection, data preprocessing, and data analysis. This includes knowledge of statistical analysis, machine learning algorithms, and data visualization. Expertise in optimization algorithms is essential for optimizing the design and use of FRP materials in infrastructure.

Potential Member Company Benefits:

Member companies involved in the project can benefit from improved competitiveness, cost savings, innovation, collaboration, and sustainability, leading to long-term success and growth in the field of infrastructure engineering.

Progress to Date:

We published three papers and we already submitted four papers and attend ACI confrenece with two presenattions.

Published:

1. The mountain Gazelle Optimizer for truss strcutures optimization
2. Optimizing Truss Structures Using Composite Materials under Natural Frequency Constraints with a New Hybrid Algorithm Based on Cuckoo Search and Stochastic Paint Optimizer (CSSPO)
3. A comparison performance analysis of eight meta-heuristic algorithms for optimal design of truss structures with static constraints

Submitted:

4. Data-Driven PSO-CatBoost Machine Learning Model to Predict the Compressive Strength of CFRP-Confined Circular Concrete Specimens
5. Predicting the flexural strength of 3D printed fiber-reinforced concrete (3DP-FRC) using efficient training of artificial neural networks with the meta-heuristic algorithm
6. Modeling the compressive strength of geopolymer recycled aggregate concrete using ensemble machine learning
7. Fiber-Reinforced Polymer (FRP) in Concrete: A Comprehensive Survey

Estimated Start Date: 11/2022	**Estimated Knowledge Transfer Date**: 11/2024

UM - #2 - Composites for Infrastructure Applications: Areas for improvement in the 440.11 Code
Part A: Effect of Stirrup Confinement on the Bond Strength of GFRP-RC Beams
Program Manager / PI: Dr. Antonio Nanni
Company / Sponsor: TUF-N-LITE LLC, Owens Coring Infrastructure, Galen, Basalt Engineering LLC, Miller & Long Company LLC

Executive Summary - Project Synopsis		**Date**: December 7, 2023
Center/Site: Center for the Integration of Composites into Infrastructure (CICI) / UM		
Tracking No.: UM02-A	**Phone:** (305) 284 -6150	**E-mail:** fdecaso@miami.edu
Center/Site Director: Antonio Nanni (PI), and Francisco De Caso (Co-PI)		**Type:** Continuing
Project Leader: Part A: Zahid Hussain		**Proposed Budget**: $50,000
Project Description: The current provisions for development length in the ACI 440.11 Building Code disregard the confinement effect provided by GFRP stirrups on bond strength of longitudinal bars and require splice lengths that pose implementation challenges. Given the significant improvement in GFRP material properties, this project investigates the bond strength of sand-coated GFRP bars and proposes a new factor to include the effect of stirrup confinement on the bond strength provisions.		
Experimental plan: The experimental program involved 16 full-scale GFRP-reinforced concrete (RC) beams, consisting of two repetitions for every configuration, subjected to a four-point loading. The test parameters comprised lap splice lengths and spacing of stirrups in the lap-spliced zone. Out of 16 GFRP-RC beams, two beams were reinforced with 2-M16 (No.5) continuous bars and six with varying lap splice lengths (i.e., 40-, 60-, and 80-bar diameters (db)) without confining stirrups. To evaluate the effect of confining stirrups, eight beams were reinforced with 2-M16 (No.5) lap-spliced longitudinal bars (i.e., 40-, and 60-db) and M13 (No. 4) stirrups spaced at 100 mm (4 in.) and 200 mm (8 in.) center-to-center.		
Related work elsewhere: Most of the available literature dedicated to evaluating the effect of stirrup confinement utilized ribbed GFRP bars and steel stirrups.		
How this project is different: The present project focuses solely on the new generation of bars with sand-coated surface treatment. Additionally, the effect of stirrup confinement is achieved through GFRP stirrups rather than steel stirrups, as traditionally done in the literature.		
Milestones for the current proposed year: During this year, the data obtained from the tests of the 16 beams reinforced with GFRP bars with and without stirrups was analyzed. Based on the data a new factor for sand coated bars is proposed to include the effect of stirrup confinement on the bond strength.		
Deliverables for the current proposed year: We are currently submitting our first article on the effect of stirrup confinement on the bond strength followed by another article that will focus on updates to ACI 440.11 development length equation.		
How the project may be transformative and/or benefit society: The expected success of this project will form a basis to propose a more representative equation for development length. The results obtained, can be made available to the public via research papers and conference presentations to make the topic open for further research if needed. Ultimately, ACI Committee 440 will have the opportunity to update the 440.11-22 provisions related to development length; thus, making the GFRP technology more economically viable and as important improve its constructability.		
Research areas of expertise needed for project success: Design and analysis of reinforced concrete structures, knowledge of standards and codes. Strength factors and reliability indexes. Bond stress mechanisms.		
Potential Member Company Benefits: Any improvements in the current Code equation will be a critical development for practitioners interested in GFRP reinforcement as it will make the design and construction of a building a more doable opportunity.		
Progress to Date: All experimental work has been completed to date.		
Estimated Start Date: 12/2021	**Estimated Knowledge Transfer Date**: 01/2024	

UM - #2 - Composites for Infrastructure Applications: Areas for improvement in the 440.11 Code
Part B: Re-assesement of Two-way Shear Equation in ACI 440.11 Code
Program Manager / PI: Dr. Antonio Nanni
Company / Sponsor: TUF-N-LITE LLC, Owens Coring Infrastructure, Galen, Basalt Engineering LLC, Miller & Long Company LLC

Executive Summary - Project Synopsis		**Date**: December 7, 2023
Center/Site: Center for the Integration of Composites into Infrastructure (CICI) / UM		
Tracking No.: UM02-B	**Phone:** (305) 284 -6150	**E-mail:** fdecaso@miami.edu
Center/Site Director: Antonio Nanni (PI), and Francisco De Caso (Co-PI)		**Type:** Continuing
Project Leader: Part B: Zahid Hussain		**Proposed Budget**: $50,000
Project Description: The two-way shear equation in ACI 440.11 Building Code was developed two decades ago and poses implementation challenges. The equation was developed and verified based on the literature available before 2003 and utilized fiber-reinforced polymer (FRP) bars that are no longer used in construction projects. The FRP bars available in the marketplace today have better physio-mechanical properties and improvements are particularly present in glass FRP (GFRP), the only allowed type of FRP reinforcement in the ACI Code. Therefore, there exists a need to reassess the two-way shear equation to provide reasonable means for the design of GFRP-reinforced concrete (RC) members. This study aims to revisit the two-way shear equation in ACI 440.11 based on research carried out over the last two decades.		
Related work elsewhere: This study utilizes a database of 51 GFRP-RC slabs available in the literature.		
How this project is different: It is observed that using the code provisions for two-way shear poses implementation challenges. Therefore, this project focuses on the re-assessment of two-way shear equation that was developed two-decasdes ago. The modified model for predicting two-way shear equation provides reasonable and safe punching shear capacity estimates. Adopting the modified model will help avoid unnecessary material costs and limitations to the applicability of the shear equation in the code.		
Milestones for the current proposed year: Based on the analysis of literature a new equation is proposed for predicting the punching shear capacity of slabs.		
Deliverables for the current proposed year: Based on the analysis of literature a new equation is proposed and the manuscript is submitted for possible publication.		
How the project may be transformative and/or benefit society: It has been observed that utilizing the current code equation in ACI 440.11 poses implementation challenges. Using the current code equation for the design of GFRP-RC footings results in dimensions that are difficult to implement, particularly in areas with high water table. Therefore, a new proposed model may help avoiding un-nessary material costs and associated limitations to the applicability of design.		
Research areas of expertise needed for project success: Design and analysis of reinforced concrete structures, knowledge of standards and codes.		
Potential Member Company Benefits: Any improvements in the current Code equation will be a critical development for practitioners interested in GFRP reinforcement as it will make the design and construction of a building a more doable opportunity.		
Progress to Date: Based on the analysis a manuscirpt is submitted for possible publication with proposed model		
Estimated Start Date: 08/2023	**Estimated Knowledge Transfer Date**: 11/2024	

UM - #3: Solutions for the Implementation of Composites Through Experimental Testing and Design

Part A: Slab-on-Ground & Push-off test

Program Manager / PI: Dr. Antonio Nanni

Company / Sponsor: TUF-N-LITE LLC, Owens Corning Infrastructure, Galen, Basalt Engineering LLC, Miller & Long Company LLC

Executive Summary - Project Synopsis		**Date**: December 7, 2023
Center/Site: Center for the Integration of Composites into Infrastructure (CICI) / UM		
Tracking No.: UM03-A	**Phone:** (305) 284-6150	**E-mail:** fdecaso@miami.edu
Center/Site Director: UM/Antonio Nanni (PI), and Francisco De Caso (Co-PI)		**Type:** Continuing
Project Leader: Hossein Roghani and Camilo Vega		**Proposed Budget**: $150,000

Project Description:

The aim of this project is to address FRP design related issues with testing. The type of issues are barriers that limit the implementation of FRP composite. The project is looking at three aspects that currently represent a knowledge gap related to FRP reinforcements: i) using FRP as secondary reinforcement in non-structural Slab-on-Ground, ii) shear load transfer between two separate concrete elements (concrete cold joint) and iii) Compressive behavior of GFRP bars (detailed as Part B).

With regards to Part A, the first part of the project aims to develop experimental evidence to prove efficiency of FRP as secondary reinforcement, establish a feasible equivalency between FRP and Steel for practical applications. The project aims to then evaluate and validate the findings by deploying the findings in field applications to assess the practical in-situ performance with actual construction projects, in addition to experimental program and field implementation a guideline will be provided for the use of FRP mesh in concrete applications.

In the second part, the project aims to investigate the contribution of GFRP to the mechanism of shear transfer by using push-off tests on concrete specimens reinforced. Thus, the project intends to propose the

Experimental plan:

The plan is to evaluate different parameters that affect concrete plastic shrinkage in terms of the concrete reinforcement and determine reproducible conditions for testing and evaluation of FRP bar or mesh spacing, and then evaluate field applications.

Regarding the second part of the project, the purpose of the experimental work to be conducted on push-off specimens is to determine the contribution of GFRP bars to interface shear resistance. Such contribution will be made apparent by comparison with results from plain concrete (no reinforcement across the shear plane). Additional insight will be obtained by comparing the contribution of GFRP to that of steel. Finally, the new set of specimens with a cold joint at the shear interface will indicate if there is a difference in terms of GFRP performance in post-cracking behavior.

Related work elsewhere:

To date, there is no single document in the open literature that provides a concise introduction to the use of non-metallic FRP composite mesh for concrete reinforcement, documenting not only material specifications and design approach, but also constructability and serviceability features, while addressing the challenges and opportunities FRP mesh can offer. By providing a path that features the process leading to qualification (listing of relevant material specifications) and design approaches, this guideline will provide the reader to develop an understanding to implement FRP composite mesh as concrete reinforcement, resulting in a significant impact.

Related to the second project, most of the research related to interface shear transfer has utilized steel bars as Reinforcement, while GFRP Reinforcement as a shear transfer mechanism has received very little attention experimentally or analytically. For this reason, the inclusion of FRP to provide shear resistance across a given plane is an important topic for this project, especially because bridge elements frequently use precast concrete girders with a composite cast-in-place concrete deck, which are connected across an interface that must resist shear.

How this project is different:

In the first project the team is conducting comprehensive research on the use of FRP as secondary reinforcement through experiments. Moreover, a guideline will be provided at the end that will go beyond the

technical specifications and available literature, extending to field implementation. The team considers this to be of critical value to the document being proposed, due to the constructability benefits FRP composite can potentially offer. To this end the team will plan to identify field case studies in order to address the full value chain of the FRP composite mesh in concrete. The evidenced based data will differentiate and add value to the proposed guideline.
As for the second part of this project, a very comprehensive experimental campaign is being carried out in relation to the contribution of GFRP reinforcement to the resistance of the shear transfer mechanism in concrete structures. An important number of test specimens have been constructed to evaluate different variables to make contributions to the current design guidelines.

Milestones for the current proposed year:
Establishing a comprehensive guideline on the use of FRP meshes by documenting all materials generated until the end of the study. Regarding the second project, results of the specimens tested show that GFRP reinforcement contributes significantly to the interface shear strength with ultimate strength values higher than the results from specimens without reinforcement. GFRP reinforcement makes a significant contribution to the interface shear once the ultimate strength is reached, allowing the specimen to deform at a slightly lower level of load and preventing sudden failure.

Deliverables for the current proposed year:
Regarding the first project the deliverables will be a journal publication on the experimental program (this paper is under preparation). Additionally, a conference paper that described the use of GFRP meshes in a Slab-on-Ground was already submitted to FRPRCS-15 and accepted for publication. The final deliverable will be a comprehensive guideline document that will provide the reader with the necessary information to develop an understanding to implement FRP composite mesh as concrete reinforcement. Additionally, the document will contain recommendations based on the findings.
As for the second project, preliminary results were presented at the fib 2023 symposium in Turkey. Another paper already accepted, and which will be part of an ACI Special Publication will be presented at the next FRPRCS-16. Finally, a technical paper with the final experimental results is being prepared and will be presented in a Journal at the end of November.

How the project may be transformative and/or benefit society:
This project will generate and contribute to enhance the necessary technical information to develop robust building code compliance specifications and a standard test method for plastic shrinkage evaluation and shear load transfer at cold joints.
Regarding the second project, only a few design specifications include provisions for the calculation of the interface shear transfer design strength when using GFRP as the reinforcement. Therefore, experimental data are required to allow development and validation of the design approach for GFRP reinforcement as interface shear transfer reinforcement. This data can be used to demonstrate the effectiveness of proposed design provisions and to increase the degree of reliability.

Research areas of expertise needed for project success:
Design of experiments, civil engineering, material science, laboratory tests, structural engineering, data analysis. Propel integration of composite rebar into infrastructure by validating the non-structural applications.

Potential Member Company Benefits:
The study on interface shear transfer using GFRP as a reinforcement will be able to propose modifications to the AASHTO GFRP guide specifications for the design of prestressed concrete girders using GFRP auxiliary (non-prestressed) reinforcement and develop guidelines for the design of prestressed concrete girders using GFRP auxiliary reinforcement including design examples and training materials to demonstrate the application of the proposed AASHTO GFRP guide specifications modifications and guidelines. The project also pretends to propose the inclusion of GFRP reinforcement to the shear interface resistance in the ACI 440 design code.

Progress to Date:
Regarding the first project, the lab-based experimentation is already complete, and two field projects utilizing FRP meshes, and bars have also been completed. The ultimate objective is to create guidelines for the application of FRP composite mesh in concrete.
Regarding the second project, two-thirds of the experimental program of push-off tests have been carried out. The results for the GFRP-reinforced specimens are clearly well below the estimate given by the AASHTO GFRP guide spec, confirming its overestimation and the need to make modifications.

Estimated Start Date: 12/2021	**Estimated Knowledge Transfer Date**: 11/2024

UM - #3: Solutions for the Implementation of Composites Through Experimental Testing and Design
Part B: Compressive behavior of GFRP bars
Program Manager / PI: Dr. Antonio Nanni
Company / Sponsor: TUF-N-LITE LLC, Owens Corning Infrastructure, Galen, Basalt Engineering LLC, Miller & Long Company LLC

Executive Summary - Project Synopsis		**Date**: December 7, 2023
Center/Site: Center for the Integration of Composites into Infrastructure (CICI) / UM		
Tracking No.: UM03-B	**Phone:** (305) 284 -6150	**E-mail:** nanni@miami.edu
Center/Site Director: Dr. Antonio Nanni		**Type:** Finished
Project Leader: Amin Mirdarsoltany		**Proposed Budget**: $50,000

Project Description:
This research project aims to provide a simple test setup to determine FRP bars' compressive strength and elastic modulus, ensuring that the load is applied at the center of the coupon. 3D-printed plugs made of Polylactic Acid (PLA) and Thermoplastic Polyurethane (TPU) filament are used to fill the gap between the FRP samples and the centering steel fixture.

As the material used for printing plugs is much softer than steel materials, it results in minimizing confinement compared to directly inserting samples to steel tubes. This research investigates two GFRP bar types, coupon length-to-diameter ratios of 2 and 4, two 3D-printed plug materials, two inner diameters of the plugs, and cutting surface quality.

Experimental plan:
In this study, two different types of GFRP, named G1 and G2, all having a nominal diameter of 12.7 mm (0.5 in.), were selected to be evaluated under uniaxial compression. In addition to considering bars from different manufacturers, two different length-to-diameter ratios were assessed The bars' physical and mechanical characteristics were considered per the test methods listed in ASTM D7957 and FDOT 932-3.

Related work elsewhere:
While the tensile performance of FRP bars has been investigated comprehensively, only a limited number of research projects have evaluated their behavior under compression due to the lack of a standard test method. In recent years, some attempts have been made to develop a test method to determine the compressive behavior of the FRP bars. According to the current literature, there are divergencies between the results of the compressive behavior of FRP bars, ranging from compressive strength and compressive modulus of elasticity to ultimate compressive strain and stress-strain curve, and this is mainly due to the need for a standard test.

Due to inconclusiveness in the available literature, the contribution of FRP bars to the capacity of concrete columns reinforced with FRP is neglected, and ACI 440.11-22 states that "*The area of GFRP reinforcement in compression shall be treated as having the same strength and stiffness as the concrete in the surrounding compression zone*." The *AASHTO LRFD Bridge Design Guide Specifications for GFRP-Reinforced Concrete* have a more conservative statement that ignores the compressive strength of GFRP reinforcements in design calculations. The test setups in the previous research projects show that preparing samples for compression testing is complicated. The provided test method tried to propose a simple test method to obtain the compressive behavior of FRP bars.

How this project is different:
The lack of a proper test method to determine the compressive behavior of FRP bars is one of the reasons preventing their consideration in the design of compressive members. The overarching goal of this paper is to provide a test setup to measure the compressive strength and compressive elastic modulus of GFRP bars in order to eventually pave the way for the inclusion of these characteristics in ASTM D7957.

Milestones for the current proposed year:
The project is finished. The published paper is available through the following link: Evaluating GFRP bars under axial compression and quantifying load-damage correlation - ScienceDirect

How the project may be transformative and/or benefit society: The results of this project show the contribution of FRP bars under compressive loads. By considering their compressive behavior in the design of compressive members, such as columns, the design would be more optimal and result in saving up costs in projects. The results of this study will help to determine the k_b factor for each type of FRP bar based on their surface treatment.
Research areas of expertise needed for project success: Extensive knowledge in mechanical behavior of FRP bars and working with some special apparatus like micro-computed tomography.
Potential Member Company Benefits: The results will benefit all companies that fabricate FRP bars for the construction industry.
Progress to Date: The project is completed

Estimated Start Date: 10/2022	**Estimated Knowledge Transfer Date**: 11/2023

UM - #4: Propelling the use of FRP Composites with Meaningful Standards and Guidelines
Part A: Guide for Field Inspection
Program Manager / PI: Dr. Antonio Nanni
Company / Sponsor: Structural Techologies, Simpson Strong-Tie, Quakewrap, Fisher, and Co-sponsoring by Federal Highway Administration (FHWA)

Executive Summary - Project Synopsis		**Date**: December 7, 2023
Center/Site: Center for the Integration of Composites into Infrastructure (CICI) / UM		
Tracking No.: UM04-A	**Phone:** ( ) -	**E-mail:** nanni@miami.edu
Center/Site Director: Dr. Antonio Nanni		**Type:** Continuing
Project Leader: Jesus Ortiz		**Proposed Budget**: $50,000

Project Description: The main objective of this project is to develop the framework of a unified guide for inspection and condition assessment of in-service FRP reinforced/strengthened concrete (FRP-RSC) bridge elements. The guide applies to both FRP reinforced structures (FRP internal application) and FRP strengthened structures (FRP external application) and conforms with National Bridge Inspection Standard (NBIS). emphasis is put on the application of available NDT methods for detection of internal FRP reinforcement and/or developing new methods to accomplish this challenging task. The findings were verified through design and fabrication of small-scale test specimens, and laboratory testing.

Experimental plan: The research work is divided into two phases. The first phase aimed to gather information about the most suitable NDT methods for damage detection in FRP-RSC elements. In the second phase, an experimental approach was taken, with a focus on three different objectives. First, it was sought to determine whether existing NDT methods such as GPR (Ground Penetrating Radar) and PAU (Phase Array Ultrasonic) testing could detect internal FRP reinforcement. This involved the construction of small-scale concrete slabs with various types of rebar, including steel, glass, carbon, and basalt. Secondly, selected damages were intentionally introduced into the FRP rebars, and their locations inside the concrete slab were determined. Finally, damages in the externally applied FRP system were created. In total, 12 slab specimens were tested, targeting various parameters, such as the type of FRP, rebar diameter, rebar direction, rebar defects, concrete defects, and more. Two of the panels had a depth of 5 inches, while the remaining ten specimens were 7 inches deep.

Related work elsewhere: There are research studies focused on damage detection in both internal and external FRP. The available NDT methods have been assessed to determine their feasibility in detecting various types of damage in these elements.

How this project is different: Numerous research studies have focused on the inspection of FRP-RSC elements. However, they tend to target specific parameters, such as the type of reinforcement/strengthening, the NDT method, or the defect. This literature review was compiled and studied to assess the most promising NDT methods for addressing specific types of damage. Once they were selected, an experimental campaign was carried out to assess them.

Milestones for the current proposed year: During the current year, the first phase involved identifying and classifying damages in FRP-RSC elements, complemented by a comprehensive literature review on damages. Following this, an experimental phase assessed selected Non-Destructive Testing (NDT) methods using small-scale slabs. Once the outcomes of the experimental phase are obtained, the deliverables will include a selection of methods tailored for specific damages and defects.

Deliverables for the current proposed year: We have already published three journal papers and currently working on three proposed articles based on the data obtained from the literature review and tests. We also hope to attend conventions and conferences where we can share the results. Furthermore, a Guide for Field Inspection of In-service FRP Reinforced/Strengthened Concrete Bridge Elements will be published.

How the project may be transformative and/or benefit society: The research outcomes offer inspectors insights to choose efficient on-site NDT techniques, with potential time and cost savings. The Guide for Field Inspection of In-service FRP Reinforced/Strengthened Concrete Bridge Elements will serve as a basis for future inspections guidelines.

Research areas of expertise needed for project success: Design and analysis of reinforced/strengthened concrete structures, knowledge of standards and codes. NDT methods. Inspection of concrete elements.

Potential Member Company Benefits: The results of this research, along with the inspection guide that will be published, will serve to instill greater confidence in project owners regarding the material. Having a document that facilitates the inspection of these elements is crucial. Additionally, NDT manufacturers can see in FRP composites a potential investment field for ongoing research and optimization of their products for this specific material.	
Progress to Date: All experimental work has been completed to date.	
Estimated Start Date: 07/2022	**Estimated Knowledge Transfer Date**: 11/2024

UM – #4: Propelling the use of FRP Composites with Meaningful Standards and Guidelines
Part B: Design and Selection of FRP pultruded elements
Program Manager / PI: Dr. Francisco De Caso
Company / Sponsor: Creative Pultrusions with Co funding by NEx An ACI Center of Excellence for Nonmetallic Building Materials

Executive Summary - Project Synopsis		**Date**: December 7, 2023
Center/Site: Center for the Integration of Composites into Infrastructure (CICI) / UM		
Tracking No.: UM04-B	**Phone**: (305) 284-6150	**E-mail:** fdecaso@miami.edu
Center/Site Director: Dr. Francisco De Caso		**Type:** Completed
Project Leaders: Ehsan Harati and Alvaro Ruiz Emparanza		**Proposed Budget:** $25,000

Project Description:
The project aims to to develop design and selection guidelines for non-metallic (NM) pultruded structures and will cover the following topics:

- Define different pultruded components and applications
- Step by step demonstration of how and where to use pultruded components
- Outline common applications and benefits
- Provide information on material specifications
- Provide guidelines for product qualification and testing
- Design guideline in jointing methods

There is no single document in the open literature that provides a concise introduction to the use of NM pultruded shapes while addressing the challenges and opportunities they offer. By being made aware of the process leading to qualification and the listing of relevant material specifications and design standards, the reader will develop an understanding of what needs to be done in order implement this technology including segments of the construction market beyond that of buildings.

Related work elsewhere:
To date, there is no single document in the open literature that provides a concise introduction to the use of non-metallic FRP pultruded elements, documenting not only material specifications and design approach but also constructability and serviceability features while addressing the challenges and opportunities FRP mesh can offer.

How this project is different:
The research team has the primary objective of providing the sponsoring agency, NEx, with a comprehensive report that in a clear, exhaustive, and yet succinct way offers an overview on the topic of design and selection guidelines for NM pultruded structures. At the same time it will address barriers faced bu industry meanufactures to improve the implementation of NM into building applications. Moreover, this report will not be restricted to technical specifications adopted in the US but will include a review of those recently developed in Europe following the philosophy and approach of the Eurocodes

Milestones for the current proposed year:
1- Data gathering and contact manufacturers.
2- Literature review and document development.
3- Document finalization and review.

How the project may be transformative and/or benefit society:
The report will address pultruded components are used in a variety of applications that affect society, including those that support:
1. Construction, including window, door, and frame profiles and reinforcements for residential and commercial applications, pipe and electrical supports, roll-up door panels, field erected, and factory built cooling towers applications.
2. Utility poles cross arms, and line markers, electrical lines, wastewater and water treatment components, non-conductive ladder rails, and fiber optic cables are all examples of utilities.
3. Bridge components, corrosion-resistant guardrails, antenna housing, railway crossing arms, and highway sound barriers are all examples of infrastructure.

4. Pultruded items are also used in a variety of verticals, including: Components of refrigeration; plate armor; disinfecting blades; trays for cables; arrestors that are static; handles for tools; struts made of cored tubing; fencing; decks; and, guardrails and handrails. The motor vehicle, railway, and aerospace manufacturing verticals, as well as the industrial, construction, electrical, chemical, and civil engineer sectors, all rely significantly on pultrusion for specialty-made parts that are robust and lightweigh. In the report, a detailed description will be provided of the ASTM standards related to qualification, specification, and testing of FRP pultruded shapes. the research team will consider provisions and intent of ASCE-SEI 74, "Load and Resistance Factor Design (LRFD) for Pultruded Fiber Reinforced Polymer (FRP) Structures." Publication is imminent. This standard is intended for use in the design of new buildings and other structures constructed of pultruded FRP composite structural shapes, connections, and prefabricated building products. This standard does not cover tendons and cables, and makes no reference to bridges. The research team will go beyond the building applications and study the recently developed guide titled: "Design of fibre-polymer composite structures," CEN/TS 19101. This Technical Specification was prepared by Technical Committee CEN/TC 250 "Structural Euro-codes," which is responsible for all Structural Eurocodes and has been assigned responsibility for structural and geotechnical design matters by CEN. Because of the international nature of NEx, it would be a shortcoming if only a US specification were to be considered. In fact, CEN/TS 1901 for the design of fiber-polymer composite structures, prepared in line with the Eurocodes, is intended for use by designers, clients, manufacturers, constructors, relevant authorities, educators, software developers, and committees drafting standards for related product, testing and execution standards. This Technical Specification gives a general basis for the design of composite structures composed of (i) composite members, or (ii) combinations of composite members and members of other materials (hybrid-composite structures), and (iii) the joints between these members. Finally, CEN/TS 1901 contains Annex E (informative) which covers bridge details. .
Research areas of expertise needed for project success: Civil engineering, material science, and scientific writing.
Potential Member Company Benefits: This project has the potential to be advantageous for all manufacturers of FRP who currently produce pultruded shapes, or have pultrusion capacity to expand to alternativive pultruded elements. The suggested comprehensive guideline is crucial in addressing the knowledge and practice gap among all stakeholders who can benefit from using FRP composite pultruded elements.
Progress to Date: Project is completed.
Estimated Start Date: 01/2023 — **Estimated Knowledge Transfer Date:** 12/2023

UM – #4: Propelling the use of FRP Composites with Meaningful Standards and Guidelines
Part C: Guideline for FRP Composite Mesh in Concrete
Program Manager / PI: Dr. Francisco De Caso
Company / Sponsor: TUF-N-LITE LLC, Owens Corning Infrastructure, Galen, Basalt Engineering LLC, Miller & Long Company LLC, co funding by NEx An ACI Center of Excellence for Nonmetallic Building Materials

<table>
<tr><td colspan="2">Executive Summary - Project Synopsis</td><td>Date: December 7, 2023</td></tr>
<tr><td colspan="3">Center/Site: Center for the Integration of Composites into Infrastructure (CICI) / UM</td></tr>
<tr><td>Tracking No.:</td><td>Phone: (   )   -</td><td>E-mail:</td></tr>
<tr><td colspan="2">Center/Site Director: Dr. Antonio Nanni and Dr. Francisco De Caso</td><td>Type: Continuing</td></tr>
<tr><td colspan="2">Project Leader: Hossein Roghani and Alvaro Ruiz Emparanza</td><td>Proposed Budget: $50,000</td></tr>
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Project Description:
The objective of this project is to develop a guideline for FRP composite mesh in concrete. This guideline is a comprehensive document that, in a clear, exhaustive, and yet succinct way, offers an overview of the use and implementation of FRP composite mesh for use as reinforcement in concrete. This document goes beyond the technical specifications and available literature, extending to applications, constructability, and field case studies in order to address the full value chain of the FRP composite mesh in concrete.
This guideline covers the following topics:

- Define applications for the use of FRP composite mesh in concrete;
- Step-by-step field demonstration of how to construct with FRP composite mesh;
- Outline the benefits of the use of FRP composite mesh as concrete reinforcement;
- Identify relevant FRP mesh classifications and material specifications;
- Review and provide guidelines for FRP mesh qualification and testing;
- Review and identify design approaches for FRP composite mesh reinforcement.

This guideline is intended to provide designers, users, and specifiers with a state-of-the-art and -practice overview of the use of FRP composite mesh in concrete structures that extend beyond buildings, looking at the material properties (to include glass, carbon, and basalt FRP meshes), construction and implementation, specification needs, and design approaches.

Experimental plan:
The purpose of this study is to establish a guideline for the utilization of FRP mesh without any experiments being scheduled.

Related work elsewhere:
To date, there is no single document in the open literature that provides a concise introduction to the use of non-metallic FRP composite mesh for concrete reinforcement, documenting not only material specifications and design approach but also constructability and serviceability features while addressing the challenges and opportunities FRP mesh can offer.

How this project is different:
By providing a path that features the process leading to qualification (listing of relevant material specifications) and design approaches, this guideline provides the reader with an understanding of how to implement FRP composite mesh as concrete reinforcement, resulting in a significant impact.

- Develop a comprehensive, concise document for NEx, offering an extensive overview of FRP composite mesh for concrete reinforcement.
- Explore the applications, practical implementation, and constructability of FRP composite mesh beyond technical specifications, encompassing the entire value chain.
- Incorporate real-world case studies to demonstrate the effectiveness and performance of FRP composite mesh in diverse construction scenarios.

• Provide NEx with a resource that goes beyond available literature, equipping them with a holistic understanding of FRP composite mesh's potential and benefits in concrete reinforcement.	
Milestones for the current proposed year: 4- Data gathering and contact manufacturers. 5- Literature review and document development. 6- Document finalization and review.	
Deliverables for the current proposed year: The final document will be submitted to ACI NEx by the end of January.	
How the project may be transformative and/or benefit society: The realization of the potential economic advantages of deploying FRP materials is not apparent to the different stakeholders, especially in the use of FRP composite mesh. Therefore, the impact of a comprehensive guideline as proposed is of high importance to address the knowledge- and practice-gap that exists across all stakeholders that can benefit from implementing FRP composite mesh as a default secondary reinforcement solution in concrete construction.	
Research areas of expertise needed for project success: Civil engineering, material science, and scientific writing.	
Potential Member Company Benefits: This project has the potential to be advantageous for all manufacturers of FRP who produce mesh or grid. The suggested comprehensive guideline is crucial in addressing the knowledge and practice gap among all stakeholders who can benefit from using FRP composite mesh as the secondary reinforcement solution in concrete construction.	
Progress to Date: The document is almost completed, and we are currently conducting internal reviews. It will be submitted to ACI NEx by the end of January.	
Estimated Start Date: 6/2023	**Estimated Knowledge Transfer Date:** 11/2024

I/UCRC Executive Summary - Project Synopsis		Date: December 05, 2023
Title: Enhancing Load Capacity of FRP Pedestrian Bridges		
Tracking No.: WVU-9	**Phone:** (304) 293-9985	**E-mail:** p.vijay@mail.wvu.edu
Center/Site Director: WVU-CFC/Hota GangaRao		**Type: Continuing**
Project Leader: P.V.Vijay		**Proposed Budget**: ~$120K (add on exists)

Project Description: The glass fiber reinforced polymer (GFRP) composite pedestrian truss bridge was constructed using individual truss elements in tension and compression in addition to using deck and diaphragm (cross members) elements. The Pratt truss dimensions are 7/10 feet in width and 50 feet in length. Steel bolts were used to connect all the members including connections in this study.

Experimental plan: The FRP bridges were tested for H5, equestrian, 100 psf UDL, transverse, and vibration loading, as applicable. The instrumentation to measure strains, deflections and accelerations consisted of strain gages, LVDTs (Linear Variable Differential Transducers), dial gages, load cells, accelerometers, and loading pistons/jack system. While conducting load tests, the data were collected using Vishay data acquisition systems. Both strain gages and LVDTs were positioned in the mid-span and end-span members of the bridge system where maximum stresses and displacements were expected. Accelerometers were positioned both along the longitudinal and transverse directions for evaluating vibration response.

Related work elsewhere: WVU-CFC has previously designed, developed, evaluated, field-implemented, and monitored various FRP-bridge and FRP-deck systems.

How this project is different: Similar FRP pedestrian bridge system design with such assembly configuration can be modularly scaled up or down to different spans doesn’t exist.

Milestones for the current proposed year: The work involved laboratory construction and testing for the applicable loads for both FRP and wood deck systems. This work and analyses are completed.

Deliverables for the current proposed year: The work will extend to scaled up spans of 50’.

How the project may be transformative and/or benefit society: The proposed pedestrian bridge system can be scaled to different larger or shorter span lengths, with similar modular configurations and joining schemes. This will lead to the use of FRP pedestrian bridges in an economical and durable manner and help different clients located in urban and rural settings comprising of market-centers, golf-courses, and park areas.

Research areas of expertise needed for project success: Advanced understanding of FRP pedestrian bridge component responses to applied UDL, lateral (wind) load, and vehicular load (H5) and vibrations loads. Field experience with FRP composite manufacturing and testing. Previous experience with developing engineering guidelines and specifications.

Potential Member Company Benefits: Upon completion of the project, CICI members will have access to FRP response under the applied bridge loads. This benefits the society with durable FRP pedestrian bridge systems for different spans under various urban and rural settings.

Progress to Date: Project started in January 2022. We have completed the testing of FRP pedestrian bridge with 8.5’ and 10’ wide decks with 70’ span. We have also tested the single and two span bridges. The results are provided to BRP Inc.

Estimated Start Date: 01/01/2022	**Estimated Knowledge Transfer Date**: 02/2024

I/UCRC Executive Summary - Project Synopsis		**Date**: December 1, 2023
Title: Design Optimization of FRP Composite Jacketing for Tank Cars under Impact and Fire: Simulation		
Tracking No.: **WVU-10**	**Phone :** (304) 293-5742	**E-mail :** eduardo.sosa@mail.wvu.edu
Center/Site Director: WVU-CFC/Hota GangaRao		**Type: Continuing**
Project Task Leader: Eduardo M. Sosa, Task 4		**Proposed Budget**: $211,714

Project Description: Rail tank cars are commonly used to transport hazardous materials, including crude oil, petroleum products, and ethanol. Unfortunately, these tank cars can be prone to puncture and impact failures, particularly when encountering sharp objects like rails during derailments. To address this issue, industry, and government are working to improve the safety and efficiency of rail transportation. Recently, new regulations from the US Department of Transportation have required enhanced performance standards for rail cars, which has led to the need to retrofit older tank cars. However, retrofitting with heavier materials to meet these standards may reduce carrying capacity and increase shipping costs, potentially compromising the economic viability of using tank cars for hazardous material transportation. The CFC-WVU has spent over two years developing a multi-functional FRP composite jacket to address this challenge. This lightweight material can provide the same strength as traditional tank car materials while reducing retrofitting time and transportation costs. By using this innovative material, it may be possible to retrofit older tank cars and bring them up to new performance standards without sacrificing their economic viability as a transportation mode for hazardous materials.

Simulation plan: Finite Element Simulations of the FRP composite jacket follow a multiscale approach. The different structural components are simulated at micro, meso, and macro scales to determine homogenized material properties that feed into the different simulation scales. An explicit solution algorithm in Simulia/Abaqus is implemented to simulate low-velocity impacts representative of experimental and field conditions. Simulation results are validated with experimental results obtained previously as part of the broader project.

Related work elsewhere: WVU-CFC has previously manufactured and tested multifunctional multilayer FRP structures with enhanced thermomechanical properties including fire resistance.

How this project is different: Finite element simulations of FRP stitched jackets at the multiscale level are not standard and provide a valuable prediction tool for testing the design space as well as for anticipation and evaluation of performance.

Milestones for the current proposed year: The second-year work involves the development of a multi-scale modeling approach for flat and curved FRP jacket subjected to impact loads.

Deliverables for the current proposed year: A working simulation model validated by experimental results obtained during the manufacturing and testing phase of the project.

How the project may be transformative and/or benefit society: WVU-CFC has developed a multifunctional jacket for tank cars that offers superior performance over traditional materials. It has high strength and stiffness, excellent puncture resistance, and energy absorption capabilities. The material also offers longer survival time under fire and can reduce both the cost and time of retrofitting. It can be mass-produced in just two days, speeding up the overall retrofitting capacity.

Research areas of expertise needed for project success: Advanced understanding of finite element simulation of composite materials comprised of multi-materials stitched and able to dissipate specified energy levels when subjected to impact.

Potential Member Company Benefits: Upon completion of the project, CICI members will have access to FRP jacketing systems for safer HM transportation. This benefits rail service and the society with less accidents and disasters, eliminating or reducing amount of property damages and even loss of lives.

Progress to Date: Project has just started on 09/30/2020 and it is scheduled to finish on 3/30/2024. Simulations include multiple results to study composite behavior under static and dynamic puncture loads.

Estimated Start Date: 09/30/20	**Estimated Knowledge Transfer Date**: 6/30/24

I/UCRC Executive Summary - Project Synopsis	**Date**: Dec 6, 2023

Title: Responses of FRP Utility Poles under Wildfires

Tracking No.: **WVU-11**	**Phone :** (304) 293-9986	**E-mail :** Hota.Gangarao@mail.wvu.edu
Center/Site Director: WVU-CFC/Hota GangaRao		**Type:** Ongoing
Project Leader: Ray Liang		**Proposed Budget**: $75,000

Project Description: Structural damage of utility poles can occur due to wildfires, causing disruption of power delivery depending on the severity of the damage. FRP composite poles have been receiving keen attention from utility companies due to their inherent advantages (high specific strength and stiffness, corrosion resistance, non-conductive, low self-weight, longer time to ignition, lower flame spread index, and others) over wood, steel and concrete poles, especially for mountainous terrain. However, frequent wildfires pose a threat to these FRP composite poles without fire protection mechanisms, since they are combustible. To better understand the performance of composite poles when exposed to wildfire related thermal stresses, research must be performed to quantify the property changes that occur in the material during wildfire exposure. Suitable test methods must be defined, and test parameters must be determined based on the characteristics of forest and wildfire exposure. Additional requirement in pole fire resistance through design and material modifications may be needed with the use of different materials, installation techniques, or other protection methods.

Experimental plan: Conduct literature review from available publications and test reports; Provide in-depth understanding of the fire behavior of FRP composites; Highlight the relevance and performance implications to utility poles exposed to wildfires from fire studies of non-pole structures. Based on the above findings, test methods including flame test around 1000C for up to 3 minutes are to be developed to understand the comparative effects on the mechanical properties of the various FRP composite utility structure materials when subjected to elevated temperatures, leading to model to predict the residual strength and stiffness of FRP pole materials after wildfires.

More specifically, the scope of the work includes the following: (1) Develop fire test methodology exposing utility structures to extreme conditions at 1000°C for 1 minute, 2 minutes and 3 minutes respectively, (2) Conduct fire exposure testing on composite pole and crossarm samples with and without coating and other protective methods, (3) Conduct mechanical testing under bending (pole and crossarm samples) and short beam shear (pole samples only) with specimens subjected to fire exposure conditions as defined a priori; and (4) Analyze mechanical property data to develop predictive models for the residual strength and stiffness at various time and temperature exposures and evaluated the effectiveness of fire protection methods.

Related work elsewhere: WVU-CFC has previously conducted several fire tests on the FRP composite structures developed by WVU-CFC in collaboration with national fire test labs.

How this project is different: This is first time to study fire performance of FRP composites with a focus on wildfires. Fire is a primary keyword to be studied. In other previous studies, fire performance is only a side variable with mechanical properties being the focus.

Milestones for the current proposed year: Several fire protection methods are evaluated and the findings are significant. Delivery of quality tech report

Deliverables for the current proposed year: Report to present the mechanical property data under bending (pole and crossarm samples) and short beam shear (pole samples only) with and without fire protection enhancements.

How the project may be transformative and/or benefit society: People generally believe FRP composites are combustible. This study would convince the public that FRP composites are generally able to sustain from wildfires, thus prompting wider use of FRP poles and ease public's fire concern.

Research areas of expertise needed for project success: Advanced understanding of FRP composite materials in terms of selection of constituents, design, manufacturing, testing and evaluation including fire performance, modelling, field implementation, NDE, rehabilitation schemes, especially various fire test standards and methods.	
Potential Member Company Benefits: FRP utility poles, especially with use of intumescent coatings, are able to survive from general wildfires. This conclusion will help utility industries to use FRP poles with confidence. FRP wraps readily available can be used to retrofit the post-fire utility poles, if needed. This will further release potential concerns from utility industries.	
Progress to Date: The scoped tasks were completed on schedule and Year 3 final report was submitted to industry sponsor on Oct 10 2023.	
Estimated Start Date: 4/1/2020	**Estimated Knowledge Transfer Date**: 12/30/2023

I/UCRC Executive Summary - Project Synopsis		Date: December 05, 2023
Title: Responses of Composite Structural Components and Systems		
Tracking No.: WVU-12	**Phone:** (304) 293-9986	**E-mail:** hota.gangarao@mail.wvu.edu
Center/Site Director: WVU-CFC/Hota GangaRao		**Type: Continuing**
Project Leader: Hota GangaRao		**Proposed Budget**: $20K (add on exists)

Project Description: To evaluate the structural integrity of carbon fiber poles and composite structures like platforms under actual loading conditions. The focus will be on assessing their load-bearing capabilities, analyzing the initiation and progression of failure modes within these composite components, and examining the influence of connections and joints, particularly the impact of torque levels and fixed conditions, on the stability of fiber-reinforced polymer systems.

Experimental plan: In the experiment designed to evaluate the load-bearing capacity and structural integrity of carbon fiber poles, the poles are inserted into steel sleeves and secured to a load floor, and platform will be fixed on the floor, mimicking typical field installations. Load is applied using a cable system connected to a load cell, with deflection measured under load. The platform experiment includes variations such as different structural configurations and torque levels, and tests on platforms of varying sizes.

Related work elsewhere: WVU-CFC has previously tested and evaluated FRP structures and components

How this project is different: All samples in this study were subjected to real-world loading conditions like wind.

Milestones for the current proposed year: The testing has been done and doing analysis work

Deliverables for the current proposed year: Two reports have been delivered to sponsor as requested

How the project may be transformative and/or benefit society The study illustrates the combined failure, flexure, and breakdown of Fiber-Reinforced Polymer (FRP) structures, along with multiple recommendations to enhance their strength, such as the reinforcement of bolt connections.

Research areas of expertise needed for project success: in-depth knowledge of the behavior of Fiber-Reinforced Polymer (FRP) composites under compressive and bending forces. Extensive practical experience in the manufacturing and testing of FRP composites in real-world scenarios. Proven track record in formulating and establishing engineering standards and specifications for FRP composites, along with a strong foundation in applied research and design principles in this field. Demonstrated ability to apply theoretical concepts to practical applications in FRP composite engineering, ensuring adherence to industry standards and enhancing product performance.

Potential Member Company Benefits:. CICI members will benefit from the suggestions and guidelines on FRP composite poles and platform by the WVU-CFC.

Progress to Date: Project has started on 09/01/2023. We have finished all tested and will deliver results and analysis to industrial partners.

Estimated Start Date: 09/01/2023	**Estimated Knowledge Transfer Date**: 12/2023

I/UCRC Executive Summary - Project Synopsis			**Date**: December 7, 2023
Center/Site: Center for the Integration of Composites into Infrastructure (CICI) / NC State			
Tracking No.: CICI-13	**Phone :** (919) 515 - 7695	**E-mail :** rseraci@ncsu.edu	
Center/Site Director: Rudi Seracino		**Type:** Continuing	
Project Leader: Gregory Lucier (with Proestos and Seracino)		**Budget**: $100,000	

Project Description: A dapped end is a common detail in precast concrete structures, especially those that utilize prestressed double-tees bearing on ledges or corbels. Dapped ends allow for a reduced floor thickness, and thus, reduce the floor-to-floor height. Current practice for the design of dapped ends in thin-stemmed members was recently revised by the Precast Prestressed Concrete Institute. Aspects of this new approach still need to be refined, particularly with regards to the topics of deep beams, shallow daps/notches, and lightweight concrete. In addition, work studying repairs of dapped end beams is very limited, tests are few, and guidelines for repair are sparse. This is particularly true for thin-stemmed dapped end members repaired with composites. This project aims to study details of dapped end design and repair within the context of the new recommendations.

Experimental plan: The experimental plan for the broad project is to instrument and test each end of twelve dapped-end beams, for a total of twenty-four tests. Key parameters of interest include lightweight concrete, deep beams, shallow notches, and repair techniques. An analytical study will be pursued in parallel which will include three-dimensional non-linear finite element analyses. Selected test specimens will then be repaired to strengthen the end region.

Related work elsewhere: Previous research on dapped end beams was recently published by Klein and Botros. Tests of dapped end beams have been conducted at NCSU for commercial clients over the past several years, including repairs of some dapped ends. These projects were for specific issues in industry and are not currently published. Existing literature does not address several key aspects of repair and design.

How this project is different: This project aims to fill in the gaps of current design and repair guidelines for dapped-end thin-stemmed members. Double tees in the precast industry continue to grow larger in response to market demands for longer spans and larger loads. Factors such as shallow notches and lightweight concrete are also common in combination with these large members. Repair and strengthening of these types of members is sometimes needed, and current guidelines are not sufficient for determining the best path forward with regards to repair. Additionally, previous tests did not focus on repairing members in-situ, where space limitations may prevent access to the ends of the members. This project aims to address this.

Milestones for the current proposed year: The milestones for the current year are to finalize a report and papers documenting the 12 primary specimens. Then, design repairs for some remaining deficient specimens, apply them, and test to failure.

Deliverables for the current proposed year: Deliverables will include a test report to primary sponsor PCI, and planned papers. The repair pilot test conducted in September went well, so additional specimens can be strengthened and tested.

How the project may be transformative and/or benefit society: Accurate and reliable methodologies for design and repair are required to have safe, efficient structures, and to obtain the longest practical service lives from those structures. In addition, dapped ends are most often used with precast structures that are fabricated off-site. Off-site fabrication helps to reduce construction waste, speed up project delivery times, improve jobsite safety, and reduce the impact of a jobsite on surrounding areas since fewer activities are taking place on the site.

Research areas of expertise needed for project success:

- Behavior and design of prestressed concrete members in flexure and shear
- Behavior and design of bonded CFRP repair systems, including anchored systems
- Construction and production expertise to ensure proposed details are practical

Potential Member Company Benefits: The outcomes of this research will likely enhance the understanding of dapped end beams and of the repair of dapped end beams. Recommendations are expected that will clarify the design of daps with unique features such as shallow notches and lightweight concrete. Detailed knowledge of these situations will benefit companies that design, produce, operate, or repair such structures. It is also likely that the work will expand the market for FRP repair technologies, as it will hopefully provide new options for repairing damaged or otherwise insufficient dapped ends. Currently, dapped ends are most commonly repaired by bonding and/or bolting steel plates to the webs, which is effective, but expensive and heavy.

Progress to Date: A review of the literature is completed as it relates to the design of thin-stemmed dapped end members. The calibration and validation of finite-element modelling is complete, with the modelling techniques extended to include parameters such as lightweight concrete, notches, and strand bond. Additionally, the test matrix has been developed, approved, and mostly executed. To date, 23 tests on 12 beams have been completed. The DIC data have been post-processed and preliminary results have been analyzed. A pilot repair test has been completed and will form the basis of the strengthening techniques that will be pursued further in this research. Using DIC data, it was determined that the magnitude of shear straining undergone by the GFRP plate during testing would suggest composite action between the concrete and the plate, highlighting the viability of the use of GFRP plate as a nib strengthening material.

Start Date: July 2020	**Estimated Knowledge Transfer Date**: May 2024

I/UCRC Executive Summary - Project Synopsis		Date: Dec 7, 2023
Center/Site: Center for the Integration of Composites into Infrastructure (CICI) / NC State		
Tracking No.: CICI-14	Phone : (919) 513-7322	E-mail : gwlucier@ncsu.edu
Center/Site Director: Rudi Seracino		Type: Continuing
Project Leader: Gregory Lucier (with DeCaso @ UM)		Budget: $50,000

Project Description: A precast concrete sandwich panel is typically comprised of a rigid foam core with a layer of concrete on each face. A wythe connector bridges the insulating core and joins the concrete wythes structurally. Traditionally, solid zones of concrete or steel ties have been used as wythe connections, however, these methods are thermally inefficient. The thermal bridging created is significant, and more thermally efficient wythe ties are needed. Enter a wide variety of proprietary FRP wythe connectors on the market. Carbon fiber grid is one option for wythe connection in precast concrete sandwich wall panels that is both thermally and structurally efficient. The system has been tested extensively under static and cyclic loads. It has not been tested as extensively for creep deformation over time.

Experimental plan: The experimental plan was developed to allow loading several small wall panels with full-scale cross-sections for long durations. Standard "push specimens" were produced, including control specimens tested prior to loading, with additional control specimens to be tested after 1 year in storage. Experimental specimens will be tested to failure after 1 year under various levels of sustained loading applied at selected percentages of the ultimate loads sustained by the control samples (25%, 35%, and 45% of ultimate). A total of 21 specimens are planned with 13 of those subjected to sustained loads. 8 of the specimens will be controls, tested without sustained loading.

Related work elsewhere: Previous research on CFRP wythe connections is extensive and the system is in widespread use. However, creep behavior has not been specifically studied, and existing design methods make very conservative assumptions with regards to creep.

How this project is different: This project aims to fill in the gaps of current design guidelines for CFRP grid wythe connectors. Panels have not been loaded in creep, so conservative design methods are currently required.

Milestones for the current proposed year: Since the last update, creep testing remains underway with over 6 months of data now collected. Load will be held in place for the remainder of 12 months with routine measurements of wythe slip are being taken on all 13 loaded panels.

Deliverables for the current proposed year: The deliverables will include measuring ongoing wythe slip and plotting that slip vs. time over 12 months. Activities for the coming year include removing the sustained load in December 2023 and testing all panels to failure in January 2024 after creep loading is completed.

How the project may be transformative and/or benefit society: Accurate and reliable methodologies for design of precast concrete wall panels enable the safest and most efficient structures possible. Safety and efficiency are often at odds with one another, and getting the balance between the two correct is important to protect human life and to promote the most efficient use of resources possible. If current conservative assumptions with regards to creep can be relaxed through rigorous and reliable study, then panels can become more efficient while maintaining the same necessary levels of structural safety.

Research areas of expertise needed for project success:

- Behavior and design of prestressed concrete wall panels
- Understanding of laboratory test methods and measurement methods that are robust and reliable for a 12 month experiment
- Understanding of building codes and design requirements, including those by PCI, ACI, and ICC.

Potential Member Company Benefits: The outcomes of this research will likely enhance the understanding of precast concrete sandwich panels and in particular, those designed with CFRP connections. It is possible that some findings may apply more broadly to FRP structures in general. Detailed knowledge of these structures will benefit companies that design, produce, operate, and/or repair such structures.

Progress to Date: All specimens continue to undergo creep testing. Control samples have been tested and long term controls are in position next to the creep specimens.

Start Date: April 2021	**Estimated Knowledge Transfer Date**: January 2024

I/UCRC Executive Summary - Project Synopsis			Date: December 7, 2023
Center/Site: Center for the Integration of Composites into Infrastructure (CICI) / NC State			
Tracking No.: CICI-15	Phone : (919) 515 - 7695		E-mail : rseraci@ncsu.edu
Center/Site Director: Rudi Seracino			Type: Continuing
Project Leader: Rudi Seracino (with Giorgio Proestos)			Budget: $50,000

Project Description: Reinforced concrete deep beams are defined by their small shear span-to-depth ratios and are referred to as disturbed regions or "D-Regions". For example, bridge pier or pile caps are often classified as deep beams. The response of deep beams is governed by strut action, rather than beam action. This strut action is characterized by direct compression fields that connect the loading and supporting elements. If these members are designed using traditional sectional analysis methods, it can result in the structure being overly conservative. AASHTO LRFD allows the use of strut-and-tie procedures for the design of these members. Strut-and-tie methods take advantage of the direct strut action that occurs in deep beams and is not accounted for in sectional methods. This means that designs can be more efficient, require smaller depths or require less longitudinal or transverse reinforcement. Several aspects of the AASHTO LRFD strut-and-tie procedures rely on the implicit assumption that traditional steel reinforcement will be used in the design. For example, strut-and-tie methods are nominally considered to be lower-bound plasticity methods. This relies on the assumption that the members will respond plastically and is the basis for the code provisions requiring designs include minimum distributed reinforcement. While this minimum reinforcement requirement does not ensure plasticity, the assumption is that the reinforcement will allow for some redistribution and ensure that the designs using the strut-and-tie method are safe. For situations where internal fiber reinforced polymers (FRP) are used in place of traditional steel reinforcement, research is needed to confirm that designs that are determined from the strut-and-tie method perform adequately. Another example where this implicit assumption arises, is in the determination of the nodal limits and strut capacities. In ACI 318 and AASHTO LRFD, these limits are empirically based and rely on experiments that utilize steel reinforcement. In the Canadian CSA A23.3 design code, the strut-and-tie procedures explicitly calculate the strut capacities based on the straining of the longitudinal reinforcement. This is more consistent with the general shear design method for slender members as it accounts for the stiffness and loading condition of the members. Part of the proposed research is to investigate the nodal stress limits and strut capacities to assess if existing strut-and-tie provisions are appropriate for the reinforcement quantities, stiffnesses, and strain conditions of typical deep beams designed using FRP.

Experimental plan: Multiple years will be required to achieve the overall goals of this research program. Additional funding will be required to complete the full program. Hence, this first year of the proposed research program aims to design, manufacture, and test 5 full-scale (or near full-scale) deep beams. This builds on 5 deep beams recently tested at NCSU with internal steel reinforcement, which will serve as a control data set for direct comparison purposes. The deep beams will be 16 ft long and 3.6 ft deep and reinforced with varying glass FRP bars. It is expected that at least one deep beam will be reinforced with carbon FRP bars. A key feature of the test program will be the use of high-resolution full field of view digital image correlation (DIC) to measure the entire deformation field throughout loading.

Related work elsewhere: The works by Andermatt and Lubell (2013), El-Sayed et al. (2012), Farghaly and Benmokrane (2013), Mohammad et al. (2017) and Omeman et al. (2008) experimentally investigate the response of deep beams that utilize FRP reinforcement. These studies indicate significant variability in different strut-and-tie modelling approaches when applied to FRP reinforced structures. In some cases, design procedures have given unconservative estimates of shear strength for members that utilize internal FRP.

Andermatt, M. F., Lubell, A. S. (2013). "Behavior of Concrete Deep Beams Reinforced with Internal Fiber-Reinforced Polymer—Experimental Study," ACI Structural Journal, V. 110, No. 4, Jul.-Aug. pp. 585-594.

El-Sayed A.K., El-Salakawy E.F., Benmokrane B. (2012). "Shear strength of fibre-reinforced polymer reinforced concrete deep beams without web reinforcement," Canadian Journal of Civil Engineering, 39:546–55.

Farghaly A.S., Benmokrane B. (2013). "Shear Behavior of FRP-Reinforced Concrete Deep Beams without Web Reinforcement," Journal of Composites for Construction, 17:040130151–40130210.

Mohamed, K., Farghaly, A.S., Benmokrane, B. (2017). "Effect of vertical and horizontal web reinforcement on the strength and deformation of concrete deep beams reinforced with GFRP bars," Journal of Structural Engineering, 143:0401707901–401707914.

Omeman Z., Nehdi M., El-Chabib H. (2008). "Experimental study on shear behavior of carbon fiber-reinforced polymer reinforced concrete short beams without web reinforcement," Canadian Journal of Civil Engineering, 35:1–10.

How this project is different: At NCSU there has recently been a significant research campaign to better understand the response of deep beams reinforced with conventional steel reinforcement, with high-strength steel reinforcement and with headed steel reinforcement. The experimental campaign has involved the testing to failure full-scale (or near full-scale) deep beams measuring 16 ft long by 3.6 ft deep. A significant aspect of the ongoing research is the use of a full field of view digital image correlation (DIC) system to measure the entire deformation field throughout loading. This system uses a speckle pattern painted on the surface of the member to measure the displacements across the entire surface with a resolution on the strain of $0.25x10^{-3}$ (and even better for smaller specimens). This full field of view DIC data is being used to directly compare design assumptions and model predictions with what the structures experience throughout loading. The DIC system also accurately measures crack widths throughout loading and can therefore be used to comment on expected cracks widths at service loads and at very high loads. While DIC systems are becoming more common, the results being obtained at NCSU at such high resolutions over such a large area are helping provide novel insight into the behavior of concrete structures in ways that was previously not possible. It is expected that the use of these techniques will help provide great insight into the response of deep concrete structures that utilize internal FRP reinforcement in the longitudinal and transverse directions.

Milestones for the current proposed year: Summarizing the results from the experimental work in a final report. More beams will be constructed and tested (beyond the scope of this funding)

Deliverables for the current proposed year: The deliverables will include a comprehensive final report documenting the design, manufacture, and testing of the deep beam specimens. An analysis of the data will presented, and to the extent possible, design recommendations may be proposed.

How the project may be transformative and/or benefit society: ACI 440.1R-06 on the use of FRP in the design of concrete members and the 2018 AASHTO Design Guide Specifications for GFRP–Reinforced Concrete provide limited guidance on the design of internal FRP reinforced disturbed regions. Thus, research is needed in this area to be able to safely and efficiently design FRP reinforced deep concrete beams, such as bridge pier caps.

Research areas of expertise needed for project success:

- Ability to design, manufacture and test full-scale reinforced concrete members
- State-of-the-art instrumentation
- Understanding of the behavior of disturbed regions in deep beams

Potential Member Company Benefits: The outcomes of the experimental campaign proposed for this one-year project will provided much needed data to understand the behavior of disturbed regions in deep beams reinforced with glass or carbon FRP bars. The data and improved understanding will enable to development of design recommendations that can be implemented in ACI and AASHTO design guides and codes. The codification of the strut-and-tie technique for FRP reinforced concrete members will have the tendency to increase the use of FRP bars as internal reinforcement in new concrete construction.

Progress to Date: Four beams were constructed and tested to failure. Data was collected using DIC and Optotrak LEDs for each test. The data is in the process of being analyzed. The experimental data has been used to revise the finite element model and strut-and-tie models.

Start Date: July 2022	**Estimated Knowledge Transfer Date**: June 2024