| **I/UCRC Executive Summary - Project Synopsis** | | **Date**: May 26, 2021 |
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| **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:** Final |
| **Project Leader:** Greg Lucier, Rudi Seracino | | **Budget**: $100,000 |

**Project Description**: Timber piles and poles often experience damage and decay due to environmental conditions and marine borers, which eventually lead to significant reduction in the effective timber cross section. Various techniques have been used to repair and strengthen damaged piles and poles. A common repair method involves the use of composite materials in the form of a fabric wrap to encapsulate the damaged pile. The purpose of this project is to analyze and test a newly developed strengthening system that incorporates transverse carbon-fiber (CF) straps and longitudinal GFRP bars with a conventional GFRP shell, while introducing an innovative continuity connection to ensure confinement by the CF strap.

**Experimental plan**: The testing plan included small-scale and large scale material and pile/pole specimens. Materials were tested in axial tension, and radial dilation using the ICE test. Larger scale specimens were tested in concentric axial compression and full-scale specimens were tested in flexure.

**Related work elsewhere**: The use of FRP wraps and jackets have been used extensively in the industry as a reliable repair solution for axially loaded timber members. However, current practice does not provide a cost-effective means for including high levels of confinement and the possibility of strengthening existing timber structures to resist higher applied loads. The Warstone SCS system under investigation introduces innovative components that have not been previously used in practice. Design guides do not exist yet for the proposed repair system.

**How this project is different**: This strengthening system involves the use of carbon fiber hoops along the height of the GFRP jacket in combination with a proprietary continuity connection. This system can provide an increased ultimate capacity as compared to conventional strengthening solutions. Further, it eliminates the complexity of applying FRP wraps in the field using traditional wet layup approaches.

**Milestones for the current proposed year**: The experimental program compete. The draft final report needs to be finalized, and papers with design recommendations and guidelines written and submitted.

**Deliverables for the current proposed year**: Final research report. Submission of journal and conference papers.

**How the project may be transformative and/or benefit society**: This project introduces an innovative solution for strengthening or repairing heavily damaged timber piles and poles that suffer from significant loss in ultimate capacity, thus extending the service life and durability of critical infrastructure. The SCS system could be used with concrete piles and columns for cases such as submerged bridge piers. Overall this project studies a system that would reduce repair costs and installation time by avoiding demolition or the need for complex repair techniques.

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| **Research areas of expertise needed for project success:** Understanding the design and behavior of timber piles and poles. The project was laboratory intensive and required significant experimental skill. |
| **Potential Member Company Benefits:** The outcome of this project will provide members with reliable test data on all the components of the system, which will enable the design and manufacture of the system. Further, the data analysis would provide members with an optimum system configuration increasing the efficiency of the system. A new repair and strengthening system that offers benefits over traditional systems should be of great interest to several members. |
| **Progress to Date:** The following has been achieved to date: (1) Testing 12 full scale retrofitted timber piles in flexure and performing a layered structural analysis on the test data. (2) Testing 8 large sale retrofitted timber specimens in axial compression. (3) Construction and testing of 21 GFRP specimens in radial tension using the ICE test. (4) Testing of 20 full-scale CFRP strips in axial tension. (5) Evaluation of 4 different epoxy resins used in the continuity connection. (6) Testing of 5 specimens to determine flexural strengthening capability. (7) Draft final report reviewed, current under revision. |

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| **Start Date**: July 2018 | **Estimated Knowledge Transfer Date**: June 2021 |

| **I/UCRC Executive Summary - Project Synopsis** | **Date**: May 26, 2021 |
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| **Center/Site**: Center for the Integration of Composites into Infrastructure (CICI) / NC State | |
| **Tracking No**.: CICI-14 **Phone :** (919) 515 - 7695 | **E-mail :** rseraci@ncsu.edu |
| **Center/Site Director:** Rudi Seracino | **Type:** Final |
| **Project Leader:** Rudi Seracino, Greg Lucier | **Budget**: $150,000 |

**Project Description**: The objective is to develop a temporary retrofit solution intended to improve the operating load rating and extend the service life of deteriorated prestressed concrete bridge superstructures until such time that it may be scheduled for major rehabilitation or replacement. The retrofit must be sufficiently durable, easy to install, inspect and maintain, and be applicable to a range of common prestressed concrete bridge beams. In addition to the technical design details, the proposed retrofit must be competitive in the context of a cost-benefit analysis. It is proposed to develop an external prestressed mechanically fastened (MF) system using pultruded FRP plates with transverse splitting resistance provided by randomly oriented glass fibers on the perimeter of the carbon plate core. In this approach, the prestressed MF-FRP plate will restore the prestress lost due to deterioration of the existing beam such that existing flexural cracks will be closed and the cracking moment re-established to provide the required operating load rating which is a common reason why such bridges are load posted, or closed.

**Experimental plan**: The major experimental tasks include the following: (1) Small-scale material and fastener tests which incorporate Digital Image Correlation to quantify capacity of bolted plates with holes and optimize bolt pattern. The load condition in the FRP plates considered in this project is longitudinal tension for applications on the tension face of prestressed beams (e.g. cored slabs). (2) Development of a simple technique for prestressing the MF-FRP in the field. (3) Sustained load testing of a bolted MF-FRP connection. (4) Fatigue testing of the optimized MF-FRP anchor pattern. Load cycles between the prestress and the operating live load levels will be examined to determine the complete failure envelope of the MF-FRP connection. (5) Full-scale testing of the proposed prestressed MF-FRP system on representative prestressed beams taken from in-service bridge superstructures in need of repair. (6) Apply the proposed prestressed MF-FRP system on in-service bridges as the retrofit solution and conduct long-term monitoring of the repair system. All material-scale and full-scale tests are conducted with a sufficient sample size to generate results which are statistically significant at the 90% confidence level, or greater.

**Related work elsewhere**: Previous research has been published on the use of MF-FRP at other institutions, but to the best of the PIs knowledge the system has never been used in the application proposed in this project. At least one manufacturer commercially produces an FRP plate suitable for this application however, other manufacturers of pultruded FRP would be able to produce similar products should the market increase with the introduction of new applications.

**How this project is different**: Existing techniques of adhesively bonding FRP systems to the external surface of prestressed concrete beams are efficient to increase flexural capacity of the section. However, they do not effectively address a primary issue faced by state DOTs when load rating bridges that have deteriorated to the extent that the prestress force is reduced and the cracking moment is not sufficient under operating and/or inventory load conditions. In addition, many state DOTs are resistant to use adhesively bonded FRP systems due to concerns relating to QA/QC and long-term inspection and monitoring

of the critical bonded interface. The proposed system of prestressing a mechanically fastened FRP plate is a viable alternative to effectively address many of the common concerns and issues faced by state DOTs. The outcomes of this project would create new markets for an existing FRP system that is not widely adopted in practice, while at the same time addressing many practical design and implementation concerns of state DOTs.

**Milestones for the current proposed year**: The milestones for this final phase of the project are: finish testing the remaining sustained load specimens to quantify the residual capacity; complete the full-scale testing on C-channel beams, including a set of tests in shear simulating observed deterioration near the supports of in-service beams; finalize the analytical model to predict the full beam behavior at any given load; and conduct long-term monitoring on the repaired in-service bridges, to extent possible.

**Deliverables for the current proposed year**: The deliverables will include: completing the testing and analysis of the full-scale tests developing a layered section analysis program to predicting the behavior of PS members strengthened with MF-FRP; submit the final project report; continue to apply the system to in-service bridges in need of repair, as appropriate; complete dissertation and submit conference and journal manuscripts for review.

**How the project may be transformative and/or benefit society**: State DOTs are lacking reliable and implementable solutions to address a common problem associated with deteriorating prestressed concrete bridges, which is an insufficient operational load rating due to loss of prestress. The number of bridges in many states is such that it may take several years before a bridge may be scheduled for major rehabilitation or replacement, and during this period of time it is common to load-post (or close) bridges due to the lack of simple and cost-effective means of extending the service life. In rural areas, where many such bridges exist, detours due to load-posting or closure can add significant travel distance and time with compounding direct and indirect costs to society. In some cases, load-postings prevent the crossing of school buses or emergency service vehicles leading to significant inconvenience and potential hazards to isolated communities.

**Research areas of expertise needed for project success:** Understanding of behavior and design of prestressed concrete flexural members (in bending and shear). Understanding of behavior and design of mechanically fastened composite material plates that are similar to external unbonded prestressing strands. Understanding of bridge inspection and maintenance procedures and construction capabilities within the context of the proposed solution.

**Potential Member Company Benefits:** The outcomes of this research will create new applications and markets for pultruded MF-FRP plate systems. The new research published will contribute to the body of knowledge on MF-FRP systems which are just now starting to be integrated in national design guides, including ACI 440. Hence, the outcomes will facilitate further adoption of FRP-strengthening systems into the US and International marketplace.

**Progress to Date:** The sustained load specimens were extracted after 30 months of conditioning and tested to determine the residual capacity. A working prestressing method has been developed by means of a turnbuckle system. C-channel beams and cored slabs have been tested with the retrofit. Development of the analytical modelling. The long-term monitoring of in-service MF-FRP retrofitted system installed on a deteriorated PC bridge is ongoing. The retrofitted system remains in good condition after being in-service for

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| more than six months. Additional C-channel beams were tested in shear to understand the behavior of shear deterioration. | |
| **Start Date**: August 2017 | **Estimated Knowledge Transfer Date**: June 2021 |

| **I/UCRC Executive Summary - Project Synopsis** | **Date**: May 26, 2021 |
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**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 |
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| **Center/Site Director:** Rudi Seracino | **Type:** Continuing |
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| **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 is under development for this project. It will include testing full-scale dapped end beams with thin stems to failure in the laboratory. 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.

**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.

**Milestones for the current proposed year**: The milestones for the current year are to finalize the design and test the thin-stemmed dapped end test specimens. At the conclusion of testing, the repair of dapped end members will be investigated utilizing the previously tested specimens.

**Deliverables for the current proposed year**: The deliverables will include interim reports documenting the results of the tested specimens, which ideally will produce at least two different failure modes (shear in the nib, shear in the full section). Additionally, CFRP repairs will be proposed 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 also complete, with the modelling techniques extended to include parameters such as lightweight concrete, notches, and strand bond. Additionally, the test matrix has been developed and approved. The test setup is nearly finalized, along with the design of the first four specimens. Pending approval of the research committee, this design will be submitted to industry partners to begin production. The goal is to conduct a reasonable number of tests before the end of the summer term.

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| **Start Date**: July 2020 | **Estimated Knowledge Transfer Date**: June 2022 |

| **I/UCRC Executive Summary - Project Synopsis** | | **Date**: May 26, 2021 |
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| **Center/Site**: Center for the Integration of Composites into Infrastructure (CICI) / NC State | | |
| **Tracking No.**: CICI-16 | **Phone :** (919) 513-7322 | **E-mail :** gwlucier@ncsu.edu |
| **Center/Site Director:** Rudi Seracino | | **Type:** New |
| **Project Leader:** Gregory Lucier (with De Caso @ 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 has been developed for this new project to allow for loading several small wall panels with full-scale cross-sections for long durations. Standard “push specimens” will be used and will be tested prior to loading (control specimens) and after sustained loading for 1 year. Various levels of sustained loading will be applied at selected at 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**: In the next 12 months, it is planned to fabricate test setups, load the control panels, and then load the sustained load panels. As creep specimens will remain loaded for 12 months, it is likely that creep test results will still be ongoing at the end of the current year.

**Deliverables for the current proposed year**: The deliverables will include interim reports documenting the research plan, specimen designs, and test setup designs. In addition, test results on the initial control specimens are expected early in the program so that those results can be used to load the creep specimens to the right load levels (creep loads based on selected percentages of ultimate as determined by the control specimens).

**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:** The project officially kicked off with design and production of test specimens in April of 2021.

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| **Start Date**: January 2021 (actual in April) | **Estimated Knowledge Transfer Date**: July 2022 |