MPC-609
February 18, 2020

Project Title

Durable Bridges Using Glass Fiber Reinforced Polymer and Hybrid Reinforced Concrete Columns

University

University of Utah

Principal Investigators

Chris P. Pantelides, Ph.D., P.E., S.E
Professor
Dept. of Civil and Environmental Engineering
University of Utah
Phone: (801) 585-3991
Email: c.pantelides@utah.edu
ORCID: 0000-0003-3309-3488

Research Needs

Fiber Reinforced Polymer (FRP) composites have been studied and applied to reinforced concrete (RC) structures that require strengthening or seismic rehabilitation. Structural strengthening and seismic rehabilitation utilize externally bonded FRP laminates as an alternative compared to conventional techniques such as steel plates or section enlargement. Such activities have initiated an increasing trend for overcoming the detrimental effects of steel reinforcement corrosion in RC structures, particularly columns and cap beams in bridges. Capacity degradation of RC components occurs in harsh weather conditions when initially corroded steel reinforcement expands, which causes subsequent strength losses through cracking and spalling of concrete. A high cost of rehabilitation and disruption occurs because of closures, for extending the lifespan of bridges. Experiments prove that externally wrapped carbon FRP layers may reduce corrosion rates, but the corrosion process is not completely prevented, leading to a loss in ultimate axial capacity of columns (Bae and Belabri, 2009; Pantelides et al. 2013).

Glass FRP (GFRP) reinforced concrete columns are investigated in this proposal to resolve these concerns. The proposed merit is replacing steel reinforcement in a concrete column by GFRP longitudinal bars and spirals to utilize the non-corrosive properties of GFRP materials. In addition to corrosive resistance, GFRP bars and spirals perform as well as steel reinforcement in tension. Alkali reaction of GFRP bars is not an issue when guidelines such as the American Concrete Institute ACI 440 (2015) and Canadian Standards Association (2012) are followed. Economical and performance impacts of structures would be enhanced with a proactive alternative of applying corrosion-free reinforcement in new columns experiencing severe exposure to harsh weather, imperfection of construction, as well as time degradation of structural materials. With a relatively new mindset in areas of high seismic activity, bridges are designed to limit residual displacements after large earthquakes. Permanent drift requirements have been changed to no more than 1% by the Japan Road Association in 2002, after the Kobe earthquake, as a new design criterion for the Japanese bridge design standard (Japan Rail Association 2002). One effective solution to this challenge is to use self-centering systems by un-bonded post-tensioning tendons. Based on the advantages of FRP materials, Carbon FRP (CFRP) post-tensioning rods will be used to bring the column back to the original position.

Accelerated Bridge Construction (ABC) has been implemented in bridge construction thanks to significant advantages for commuters in urban areas. Precast columns with post-tensioning systems capable of self-centering after earthquakes will be developed in this research. Rocking damage-resistant end joints made with Polyurethane (PU) will be used in plastic hinge regions to sustain significant deformation/rotation with minimal damage. PU materials are one of the most adaptable plastic-based materials because of their mechanical properties (Nikoukalam and Sideris 2017). The material is versatile and is widely applied in industrial and commercial products because of its ability to be molded into various shapes and sizes.

Research Objectives

The proposal addresses inspection, evaluation, and design of bridges to promote longevity and cost-effective maintenance. The performance of self-centering columns for ABC in high seismic zones will be studied. Four column-to-footing specimens will be tested. The proposed hybrid systems consist of two cast-in-place (CIP) columns: one with two layers of all-GFRP longitudinal bars and spirals, and one with an inner layer of conventional steel longitudinal bars and a GFRP spiral, and an outer layer of longitudinal GFRP bars and spirals. The innermost layer of longitudinal steel bars is effectively protected by the surrounding longitudinal GFRP bars and spirals from corrosion and aging degradation (Pantelides et al. 2013). In addition, two precast post-tensioning columns with PU resilient end joints will be investigated with the same hybrid reinforcement. Galvanized ducts filled with ultra-high-performance concrete (UHPC) will be utilized to connect the precast concrete segments. Large inelastic deformations/rotations will be sustained due to gap opening at the rocking planes without concrete crashing in the plastic hinge regions. Post-tensioning accommodating self-centering is designed with high-strength CFRP tendons.

The objectives of this project are:

1. Construct and test bridge columns in high seismic regions using longitudinal GFRP bars and GFRP spirals with self-centering in terms of CFRP post-tensioning
2. Develop analytical models for self-centering in terms of post-tensioning of columns in bridges with CFRP corrosion-free tendons
3. Present the results at national conferences and journal publications

Research Methods

The proposed research will evaluate the seismic performance of bridge columns constructed with ABC methods under simulated earthquake loads. The research will be performed by conducting experiments of prototype bridge columns constructed using hybrid reinforcement including steel and GFRP bars and GFRP spirals, post-tensioned CFRP tendons, and PU end joints. Analytical models will be developed for implementing these systems using OpenSees (McKenna et al. 2000). The methods of analysis will include static pushover and nonlinear dynamic analysis under scaled earthquakes.

Expected Outcomes

The proposal will provide an effective approach for constructing new bridge columns using ABC in high seismic zones. The combination of CFRP composite post-tensioning with PU rocking end joints and hybrid reinforcement consisting of conventional steel and GFRP bars and spirals will be investigated. Analytical models will be developed in OpenSees (McKenna et al. 2000) with design recommendations for implementing the proposed research. The expected outcome of the study is bridge columns with low damage after large earthquake events.

Relevance to Strategic Goals

Corrosion-free bridges are desirable in that they improve a transportation system's *good repair*. Seismic resilience of bridges contributes to the *safety* and quick recovery of communities. Successful completion of the proposed project will ensure that this innovative method of constructing bridges will maintain the transportation system's *good repair* while improving seismic *safety* and resilience of the bridge inventory for strong earthquake events. The experiments to be carried out in this project will validate the proposed concept.

The proposal addresses longevity and cost-effective bridge maintenance. Glass Fiber Reinforced Polymer (GFRP) materials do not corrode. This is also the case for hybrid columns made of GFRP and stainless steel bars. The objective of this project is to investigate a practical and innovative method to create new reinforced concrete columns composed of non-corrosive reinforcement which will create a bridge inventory that is more resilient and durable. Three types of columns will be considered: (a) columns reinforced with only GFRP bars, (b) hybrid columns reinforced with stainless steel longitudinal bars with GFRP hoops, or (c) hybrid columns reinforced with a combination of stainless steel and GFRP longitudinal bars with GFRP hoops. The capacity of short and slender columns under loads will be determined through large-scale experiments. Analytical efforts will include development of column interaction diagrams, load-deflection curves, and behavior under cyclic loads." Since the research on hybrid GFRP and stainless steel reinforcement of RC columns has been carried out in another investigation (Wright 2019), the present proposal will address the hybrid reinforcement composed of carbon steel bars and GFRP bars and spirals only.

Education Benefits

At least two university students will be involved in the project. One PhD student will be involved in the experimental and analytical portion of the work. One undergraduate student will be funded from the Office of Undergraduate Research Opportunities program at the University of Utah. The technology transfer activity will involve high school students through an Annual Exploring Engineering Camp, during which small-scale models will be built to show details of the bridge columns. In addition, small-scale models will be constructed by students during a mini-engineering day. The P.I. will make a presentation at the annual UDOT Engineering Conference and at other national conferences including the Annual AASHTO Subcommittee on Bridges and Structures Meetings and the Annual Transportation Research Board Meeting.

Technology Transfer

The main objective of this research is to create an alternative for accelerated construction of bridges in seismic regions using self-centering in terms of post-tensioning of columns of a bridge bent. In addition, the columns will be protected against corrosion. There is a need for developing such innovative technology and the proposal addresses that need. The resulting technology will produce bridges that are seismically resilient, sustainable, economical, and long lasting. If successful, the research should be further developed, through commercialization and practical applications by DOTs. It is expected that coastal areas and areas with severe corrosion problems will benefit the most. Technology transfer of this research will improve efficiency, seismic safety, and cost effectiveness by eliminating corrosion from occurring. The work will be presented at conferences such as the Transportation Research Board Meeting and leading journals such as the Journal of Bridge Engineering, ASCE. In addition, a webinar will be arranged through the Mountain Plains Consortium and a presentation will be made at the Utah Department of Transportation Annual Conference. In addition, technology transfer will occur through workshops, web pages, social media, and seminars.

Work Plan

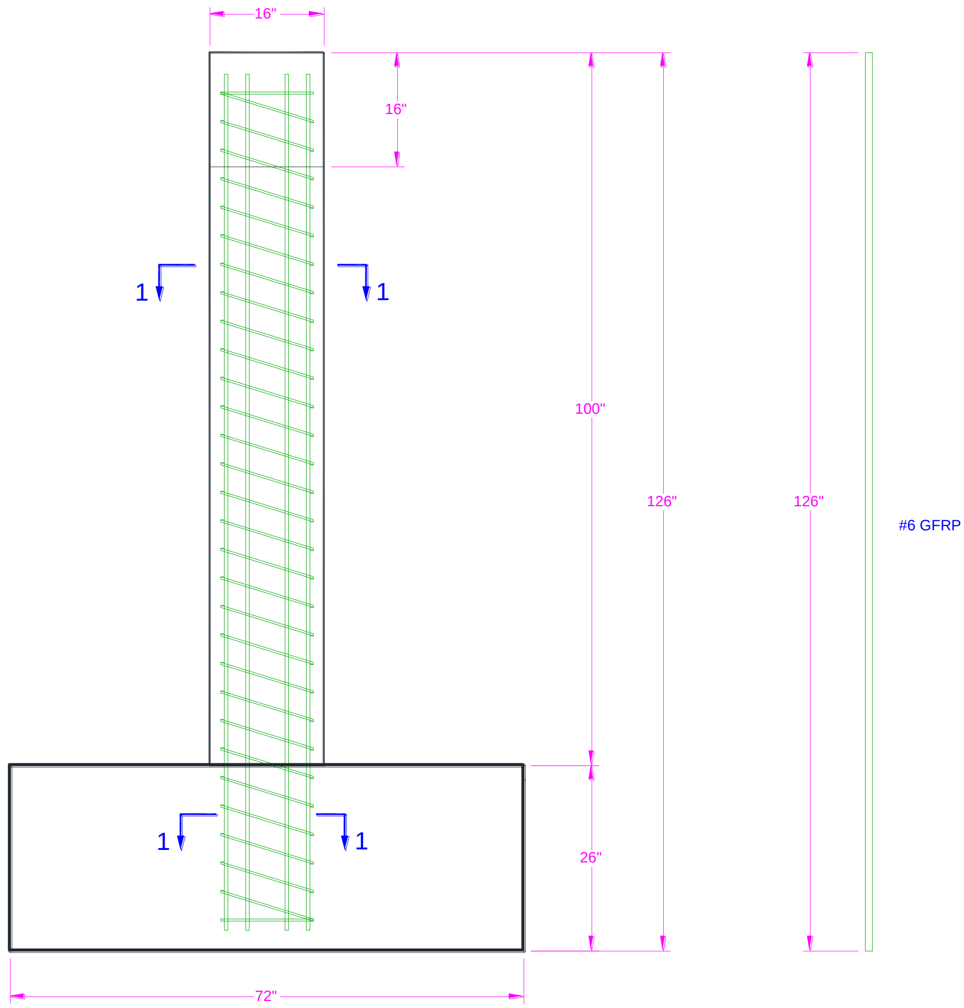
The proposed study will consist of the following tasks:

Task 1. Build four bridge columns – 3 months

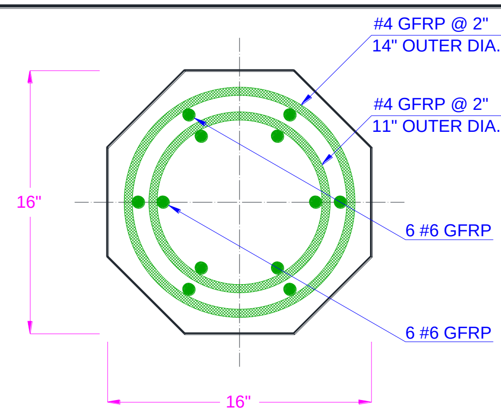
Four bridge columns will be built with two cast-in-place and two precast specimens. Two cast-in-place columns consisting of one with all GFRP reinforcement (Fig. 1a) and one with a hybrid system will be built (Fig. 1b). Two precast concrete columns employing post-tensioning CFRP tendons and PU resilient damage-free end joints will be built: one with all GFRP reinforcement (Fig. 2a) and one with a hybrid system (Fig. 2b). The tests will be carried out at the University of Utah Structures Laboratory. The concrete will have a compressive strength of 8,000 psi and the steel reinforcement will have a tensile yield strength of 60,000 psi; #6 GFRP bars and #4 GFRP spirals will have tensile strengths of 100,000 psi and 110,000 psi, respectively. The columns will be 8 ft-4 in. long with an octagonal cross-section with a 16 in. size. The footings will be 6 ft. long with a 26 in. x 26 in. cross-section. The axial load will be 10% of the axial compression column capacity. The lateral drift history will consist of increasing amplitudes of the predicted column yield drift ratio; two cycles will be employed for each drift ratio step to the east and west (ACI Committee 374, 2013).

Task 2. Perform seismic tests of bridge columns - 6 months

The bridge columns in this research have the overall dimensions shown in Figs. 1 and 2. The reinforcement details for the precast columns include four 3/8 in. post-tensioning (PT) bars located as shown in Fig. 2 that are unbonded. Post-tensioning is achieved by using #3 CFRP rods with a tensile strength of 315,000 psi, anchored in the footing and post-tensioned at the top of the columns. Hybrid reinforcement will be used, with #6 GFRP and #6 conventional steel longitudinal bars. The GFRP spiral consists of #4 diameter GFRP bar at a 2 in. pitch, as shown in Fig. 1 and Fig. 2. There is limited research regarding the seismic performance of GFRP reinforced concrete columns. Recent research by Tavassoli et al. (2015) indicates that columns reinforced with GFRP spirals and GFRP longitudinal bars under quasi-static lateral loads have produced some interesting results; in general, the all-GFRP columns showed a very stable response with large deformability; failure was gradual mainly due to crushing of the core concrete.



CIP COLUMN - ALL GFRP



SECTION 1 - 1

Figure 1a. CIP Column with All GFRP

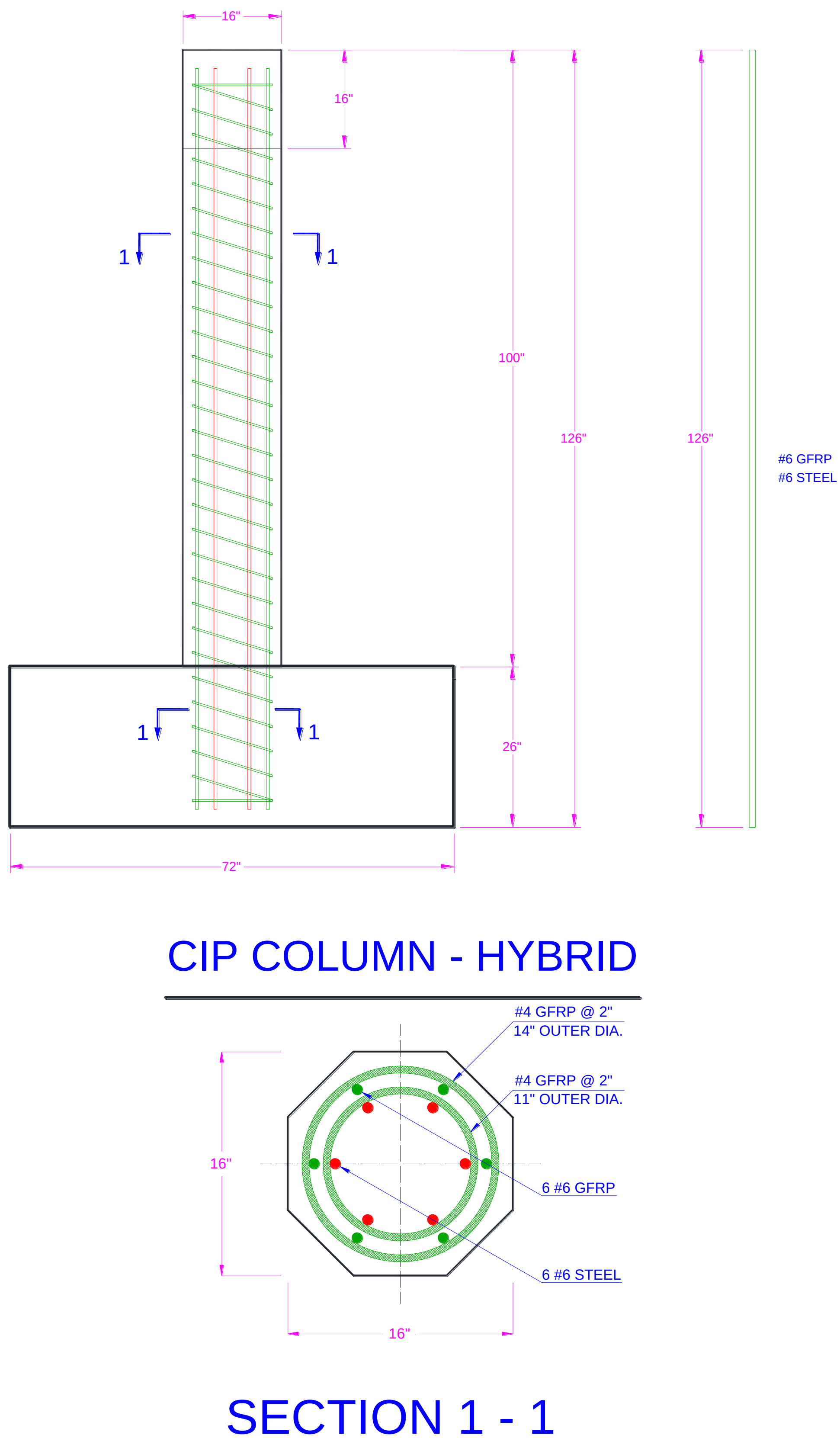


Figure 1b. CIP Column with Hybrid Reinforcement

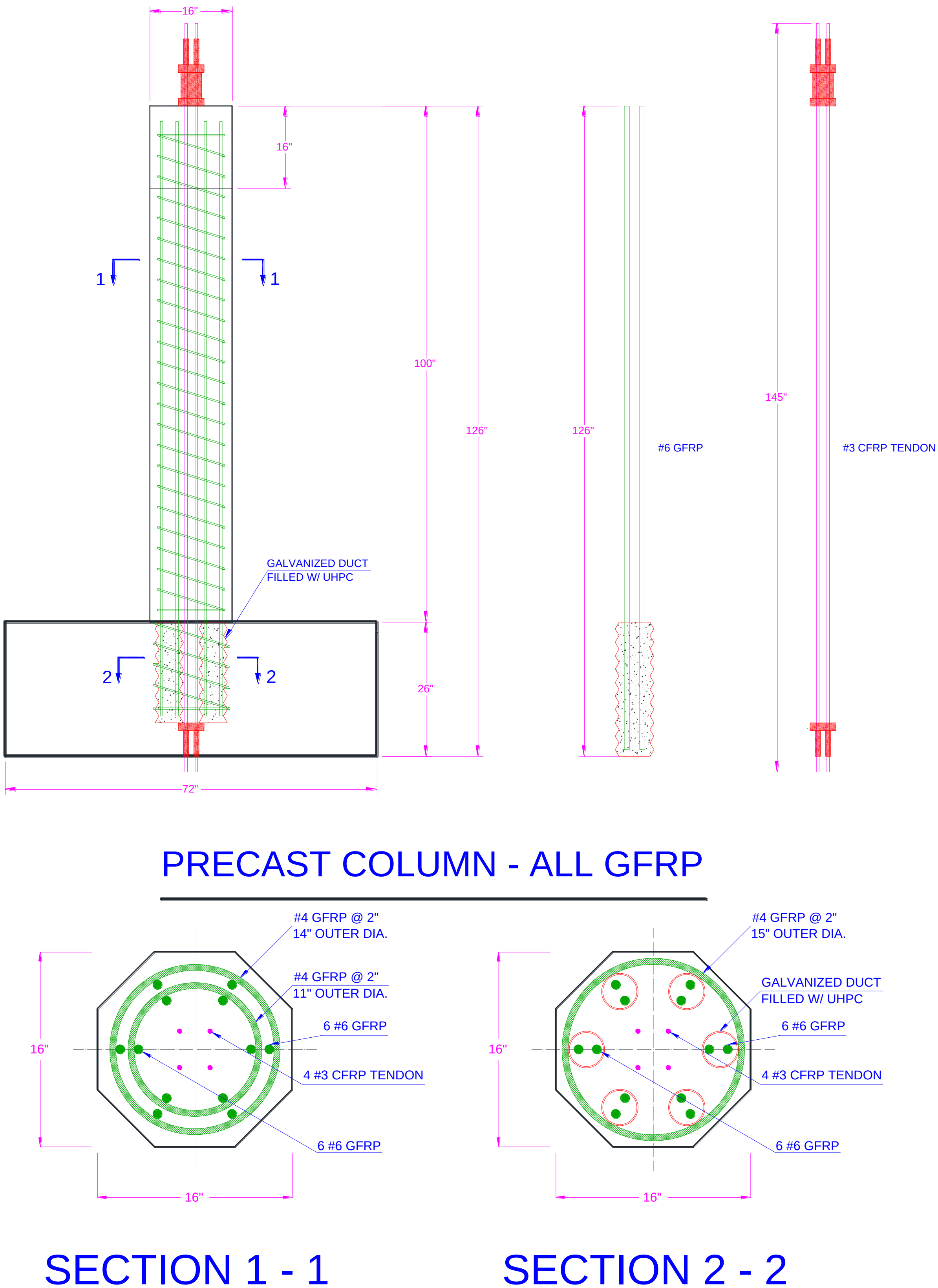


Figure 2a. Precast Column with All GFRP

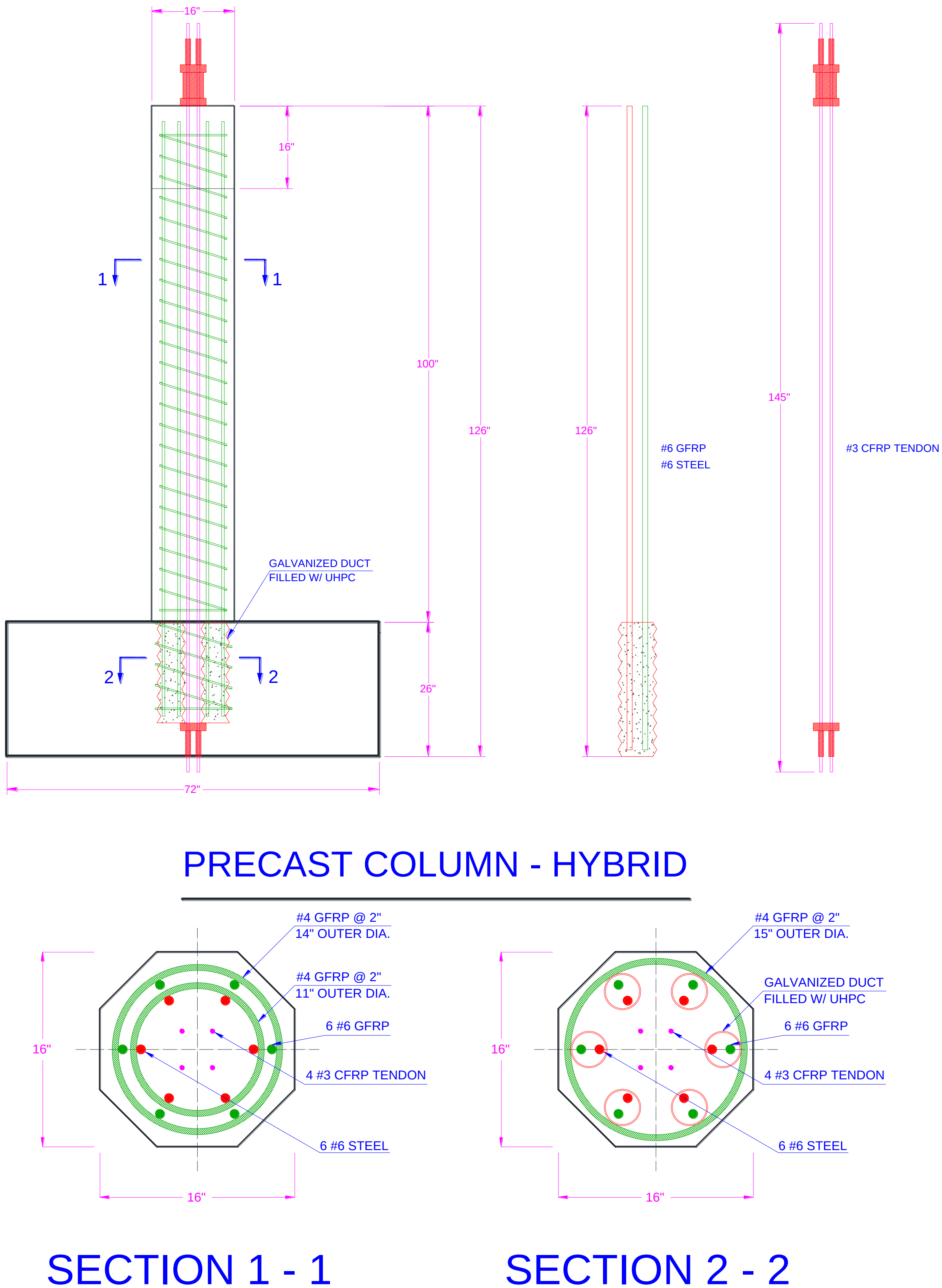


Figure 2b. Precast Column with Hybrid Reinforcement

Task 3. Analysis and seismic design of bridge bent – 3 months
In this task, a numerical model will be created to assist in the development of a design method for implementing the proposed bridge columns. The model will be calibrated with the results of the test presented in Task 2. Two types of analysis will be performed: (1) static cyclic analysis to find the capacity of the system, and (2) nonlinear time-history dynamic analysis to find the level of demand on the bridge columns. This will provide information on capacity-demand relationships for the column alternatives, and will reveal more insight into the overall behavior of the bridge columns under various input ground motions.

Project Cost

Total Project Costs:	$178,218
MPC Funds Requested:	$ 74,173
Matching Funds:	$104,045
Source of Matching Funds:	Owens Corning and Corebrace LLC, financial and in-kind support

References

American Concrete Institute (ACI) Committee 374. (2013). "Guide for Testing Reinforced Concrete Structural Elements Under Slowly Applied Simulated Seismic Loads." *ACI 374*, Farmington Hills, MI.

American Concrete Institute (ACI) Committee 440. (2015). "Guide for the design and construction of structural concrete reinforced with FRP bars." *ACI 440.1R-15*, Farmington Hills, MI.

Bae, S. W., and Belarbi, A. (2009). "Effects of corrosion of steel reinforcement on RC columns wrapped with FRP sheets." *J. Perform. Constr. Fac.*, 23(1), 20–31.

Canadian Standards Association (2012). "Design and construction of building structures with fibre-reinforced polymers." S806-12, Standards Council of Canada, Ottawa, Canada.

Japan Road Association (2002). "Design Specifications of Highway Bridges. Part V: Seismic Design." Japan.

McKenna, F., Fenves, G., and Scott, M. (2000). "Open System for Earthquake Engineering Simulation (OpenSees)." *Univ. of California, Berkeley, CA. (http://opensees.berkeley.edu)*.

Nikoukalam, M.T., and Sideris, P. (2017). "Resilient Bridge Rocking Columns with Polyurethane Damage-Resistant End Segments and Replaceable Energy-Dissipating Links." *J. Bridge Eng.*, 22(10): 04017064.

Pantelides, C.P., Gibbons, M.E., and Reaveley, L.D. (2013). "Axial load behavior of concrete columns confined with GFRP spirals." J. Composites for Construction, ASCE, 17(3), 305-313.

Tavassoli, A., Liu, J., and Sheikh, S. (2015). "Glass fiber-reinforced polymer-reinforced circular columns under simulated seismic loads." ACI Structural J., 112(1), 103–114.

Wright, J.W. 2019. “A comparison of corrosion resistant reinforcement in a highly corrosive environment.” MSc thesis, Dpeartment of Civil and Environmental Engineering, University of Utah, Salt Lake City, Utah, 121 pages.