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| Sponsor | Nominations must be submitted by an AASHTO member DOT willing to help promote the technology | 1. Sponsoring DOT (State): Michigan
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| 1. Name and Title: Mark Chaput, Deputy Director, Bureau of Field Services
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| Organization: Michigan Department of Transportation |
| Street Address: 6333 Lansing Road |
| City: Lansing | State: MI | Zipcode: 48917 |
| E-mail: chaputm@michigan.gov | Phone: 517-322-3331 | Fax:       |
| 3. Is the sponsoring State DOT willing to promote this technology to other states by participating on a Lead States Team supported by the AASHTO Technology Implementation Group? Yes or No: Yes |
| **Technology Description (10 points)** | The term “technology” may include processes, products, techniques, procedures, and practices. | 4. Name of Technology:Carbon Fiber Reinforced Polymer (CFRP) prestressing and post tensioning strand |
| 1. Please describe the technology.

**With respect to the theory on the design, AASHTO provides specifications for design using steel prestressing cables, to impart a pre-compression into the concrete elements, and at service loads, concrete handles compressive stresses, and the strands handle tensile stresses.  If designed properly, theoretically, there is zero tension in the extreme fibers of the concrete at service loads.  At ultimate load, the strands are designed for ductile yield well before the compression failure of the concrete, causing large deflections, and hence, warning to close the bridge.** Steel prestressing materials are the industry standard, but are also subject to corrosion, section loss, and eventual loss of critical prestress force. **CFRP cables behave similar to steel strands at service loads, the concrete handles compression, and the CFRP strands handle the tension.  The main difference is at ultimate load.  Since the CFRP is less ductile that steel, the failure mode is linear, so the CFRP strands are designed to handle larger stresses at ultimate, thus forcing a ductile failure of the concrete.  Ductile failure of concrete seems counter intuitive, however, there are large deflections prior to concrete failure, so there is still warning.****CFRP prestressing and post tensioning materials offer advantages over traditional steel materials, which mainly follow the ASTM A 416, grade 270 low relaxation strand designation. These strands are uncoated, and subject to corrosion, section loss, and eventually loss of prestressing force. CFRP materials are non-corrosive, and in post tensioning applications, offer additional benefits, as the duct does not have to be grouted. Given the recent excessive chloride content of pre-packaged thixotropic grouts, and the intensive grouting procedures and inspection during construction, the ability to eliminate this step in construction is of large benefit.** |
| 6. If appropriate, please attach photographs, diagrams, or other images illustrating the appearance or functionality of the technology. (If electronic, please provide a separate file.) Please list your attachments here.See attached presentation. |
| **State of Development** **(30 points)** | Technologies must be successfully deployed in at least one State DOT. The TIG selection process will favor technologies that have advanced beyond the research stage, at least to the pilot deployment stage, and preferably into routine use. | 1. Briefly describe the history of its development.

Prior to implementation on the MDOT trunkline, Lawrence Technological University, located in Southfield, Michigan conducted exhaustive research on concrete elements reinforced, and pre-tensioning using CFRP materials. Research included designing and testing elements for various limit states and failure modes consistent with AASHTO bridge design specifications. In 1999 the Bridge Street Bridge was built in Southfield, Michigan, which was design and built using all of the LTU research results to date. The beams were prestressed using CFRP prestressing strands, and longitudinally and transversely post tensioning using CFRP post tensioning tendons. The bridge is equipped with strain gages, load cells and deflectometers to actively monitor the performance, and verify design and analysis assumptions. LTU has also published many technical articles and ACI, and PCI journal on results of research, and research implementation.MDOT has been involved with the investigation, development and deployment of CFRP as longitudinal prestressing, and transverse post tensioning in our Bridge Program for a number of years. The first MDOT project in Michigan was completed in 2011 using CFRP transverse post tensioning of adjacent box beams, with several other projects utilizing these materials in subsequent years. MDOT is devoting 2 – 3 bridges per year in the bridge program to using these materials. MDOT has partnered with a local university on a number of research projects confirming the structural properties, analysis, limit states, failure modes and comparisons to traditional materials. Also, at this time we are involved with a number of initiatives at the state and national level in support of moving this technology forward including:* Active membership and participation in the AASHTO Subcommittee on Bridges and Structures technical subcommittee T-6 (composites)
* Participation in NCHRP 12-97, the development of the AASHTO LRFD CFRP prestressing specification
* Lead state for a pooled fund study for the development of a CFRP prestressed decked bulb-T beam, TPF-5 (254)
* Assisting other states such as Maryland, Florida and Virginia on implementation of CFRP prestressed or post tensioned elements.
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| 1. For how long and in approximately how many applications has your State DOT used this technology?

The first bridge built in Michigan was done by a local agency in 1999. Since then, MDOT has built several highway bridges using the materials as outlined below:* **Bridge Street Bridge over the Rouge River, Southfield, MI**

This bridge is a prestressed double-T beam structure, containing CFRP longitudinal prestressing, transverse and longitudinal post- tensioning, beam mild reinforcement, and deck and barrier reinforcement. This structure was constructed in 1999 and included gages (strain gages on CFRP strands, load cells for post tensioning strands, and deflection gages on select beams) and data collection equipment. * **Pembroke Avenue over M-39, Detroit, MI**

This bridge is a prestressed side-by-side box beam structure, containing CFRP transverse post tensioning and deck reinforcement. This structure was constructed in 2011 and included gages (strain gages on the deck reinforcement, load cells for the post tensioning strands, and deflection gages on select beams) and data collection equipment that has been transmitting date since 2011. * **M-50 over NSRR, Jackson, MI**

This bridge is a prestressed side-by-side box beam structure, containing CFRP transverse post tensioning. The structure was constructed in 2012, and included load cells on the transverse post tensioning strands, and the data is manually downloaded by MDOT staff on a regular basis.* **M-102 EB and WB over Plum Creek, Detroit, MI**

These two bridges are prestressed spread box beam structures, containing CFRP prestressing strands, beam mild reinforcement, and deck reinforcement. The EB structure was completed in November 2013, with the WB structure expected to be complete by June 2014. Strain gages will be installed on select prestressing strands and deck reinforcement bars, along with deflection gages on select beams. Upon completion of the bridge, data collection will begin.* **I-94 EB and WB over Lapeer Road, Port Huron, MI**

These two bridges are prestressed side-by-side box beam structure containing CFRP transverse post tensioning. This project was let late in 2013, with the EB bridge to be constructed in 2014, and the WB structure to be constructed in 2015MDOT selects projects based on compatibility with market ready CFRP applications such as transverse post tensioning and longitudinal prestressing. Projects are also selected based on significant traffic impacts, and the benefits of durable materials with an expected longer service life between rehabilitation projects.  |
| 1. What additional development is necessary to enable routine deployment of the technology?

The development of AASHTO LRFD CFRP design specifications are required for this technology to be nationally accepted, and all states to consider implementation of this technology. This is currently being worked on as part of a research project in Michigan for the development of design specifications and standards, and NCHRP 12-97, which is the AASHT LRFD design specification development.AASHTO currently has design specifications for strengthening of structures using CFRP, and design of concrete filled fiber tube composite arch structures, so there is acceptance of using the materials for the right applications. The only existing design code available in the United States is ACI 440.4R-04 – Prestressing Concrete Structures with FRP tendons. There are also several design codes used outside of the United States, including Canadian, Japanese, and European codes. The NCHRP 12-97 project is to develop these AASHTO standards, and MDOT staff is on the panel. |
| 1. Have other organizations used this technology? Yes or No:       If so, please list organization names and contacts.
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| Organization | Name | Phone | E-mail |
| Maine DOT | Wayne Funkhauser Jr. | 207-624-3491 | Wayne.frankhauser.jr@maine.gov |
| Maryland DOT |       |       |       |
| Virginia DOT |       |       |       |
| Florida DOT |       |       |       |
| **Potential Payoff****(30 points)** | Payoff is defined as the combination of broad applicability and significant benefit or advantage over other currently available technologies. | 1. How does the technology meet customer or stakeholder needs in your State DOT or other organizations that have used it?

The need for a non-corrosive alternative to traditional prestressing and post tensioning materials. Also, since the post tensioning tendon ducts do not have to be grouted, construction operations are simplified and future repairs of damaged elements can be accomplished simply by de-tensioning the tendons, replacing the element, then re-tensioning. |
| 1. What type and scale of benefits has your DOT realized from using this technology? Include cost savings, safety improvements, transportation efficiency or effectiveness, environmental benefits, or any other advantages over other existing technologies.

MDOT is strategically selecting bridges for use of CFRP prestressing and transverse post tensioning applications based on anticipated life cycle cost benefits, and the future impacts to mobility. Since the implementation of this technology is relatively new, cost savings have yet to be quantified, but it is anticipated that concrete elements prestressed or post tensioned with CFRP materials will have a longer life cycle than concrete elements containing traditional steel prestressing materials. MDOT is currently using these materials in bridges with the philosophy of progressing towards achieving a 100 year service life bridges.Efficiencies have been realized during construction by eliminating the need to grout post tensioning ducts. The installation of transverse post tensioning tendons can be done by a few workers, and tensioning of the CFRP tendons is done quicker than tensioning of steel tendons. |
| 1. Please describe the potential extent of implementation in terms of geography, organization type (including other branches of government and private industry) and size, or other relevant factors. How broadly might the technology be deployed?

Deployment of CFRP materials for prestressing and post tensioning applications is intended for all transportation agencies. With the development of the AASHTO specifications, these materials can be deployed as broadly as the current steel prestressing strands are deployed.Local agencies build more side-by-side box beam bridges than any other structure type due to economic feasibility. CFRP prestressing strands can easily replace the steel prestressing strands for a longer lasting bridge.Private industry has used CFRP materials more broadly than the transportation industry. CFRP materials are used for plane air frames, automobile parts, military applications, etc. The materials are widely used throughout many industries due to their light weight to strength ratio.Although the non-corrosive nature of the material is beneficial to snow belt and maritime regions, there are a number of other benefits that would be advantageous in extending the service life of all bridges, including coastal regions with salt spray from the ocean. |
| **Market Readiness (30 points)** | The TIG selection process will favor technologies that can be adopted with a reasonable amount of effort and cost, commensurate with the payoff potential. | 1. What actions would another organization need to take to adopt this technology?

Other organizations would need to consider formal adoption of the AASHTO LRFD design specifications when complete, and train their bridge design staff or consultants to be somewhat comfortable with the materials, and understand the differences between designing prestressing or post tensioning with CFRP versus steel. AASHTO LRFD design specifications, when complete will address the potential design concerns. Until those are available, refined analysis is recommended to ensure all material stresses are within AASHTO allowables.MDOT has and will continue assist other agencies with material details and specifications development, and passing on best practices from experience on past projects. |
| 1. What is the estimated cost, effort, and length of time required to deploy the technology in another organization?

No larger an effort than is required to design a bridge, and put together plans and specifications. Additional effort may be required for refined analysis, and performing the necessary background investigation on material behavior and failure modes. Depending on the application, this may add 3+ months during the design phase of a project. |
| 1. What resources—such as technical specifications, training materials, and user guides—are already available to assist deployment?
* Research reports conducted in Michigan on the design and analysis of CFRP prestressed or post tensioned elements
* Material specifications, design calculations and plans developed by MDOT
* ACI 440.4R-04: Prestressing Concrete Structures with FRP Tendons
* CAN/CSA-S806-02: Design and Construction of Building Components with Fibre Reinforced Polymers (Canadian Code)
* CAN/CSA-S6-06: Canadian Highway Bridge Design Code
* Design Manual No. 5: Prestressing Concrete Structures with FRP’s (Canadian Bridge Code)
* Concrete Engineering Series 23: Recommendation for Design and Construction of Concrete Structures Using Continuous Fiber Reinforced Materials (Japanese Society of Civil Engineers)
* Building Research Institute: Design Guidelines for FRP Prestressed Concrete Members, FRP Reinforced (Japanese Ministry of Construction)
* Bulletin No. 40: FRP Reinforcement in Reinforced Concrete Structures (European Code)
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| 1. What organizations currently supply and provide technical support for the technology?

Lawrence Technological UniversityThe American Concrete Institute (ACI)Canadian Ministry of TransportationJapanese Society of Civil EngineersAASHTO – for various other applications |
| 1. Please describe any legal, environmental, social, intellectual property, or other barriers that might affect ease of implementation.

None, all research and implementation of these materials thus far has been in the public domain. |
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