GRIDFORM – Prefabricated FRP panel for rapid bridge deck construction

What is the innovation?

GRIDFORM is a prefabricated Glass Fiber Reinforced Polymer (GFRP) integrated stay-in-place (SIP) and bidirectional, double layer rebar panel for the rapid construction of corrosion-free concrete bridge decks. The lightweight GRIDFORM panel, which weighs only 4.7 psf, is prefabricated in very large units that are limited only by shipping constraints to approximately 50 ft by 8 ft. When the GRIDFORM panel arrives on site it is easily lifted with a single pick of a crane and placed directly on the bridge girders. The GRIDFORM panel is pre-engineered and detailed to enable rapid attachment to the bridge girders and subsequent concrete placement and finishing. The panel is made of off-the-shelf glass/vinylester FRP components that are produced commercially by many US pultrusion companies and the current prototypeells for $26 ft$^{2.}$ The anticipated lifespan of a GRIDFORM bridge deck is 75 to 100 years.

Why is it innovative?

GRIDFORM is innovative because it enables truly accelerated construction of lower-cost bridge decks that have a longer lifespan than traditional decks reinforced using tied-in-place steel rebars built on temporary plywood formwork. The faster construction is due to the prefabricated and pre-engineered geometry of the GRIDFORM panels - inconceivable with conventional materials due to their weight - that typically allow for an entire regular (45 ft wide by 200 ft long) bridge deck formwork and reinforcing system to be placed in a single working day leading to significant labor cost savings. The cast-in-place concrete can then be poured and finished the following day. Since a bottom concrete cover is not required for the FRP bars, the depth of the concrete slab can be reduced by 1 to 2 inches compared with traditional steel reinforced concrete decks, which leads to material cost savings. The GRIDFORM panels produce a completely steel free reinforced concrete bridge deck that is additionally protected on the underside by the FRP SIP panel, which leads to maintenance cost savings.

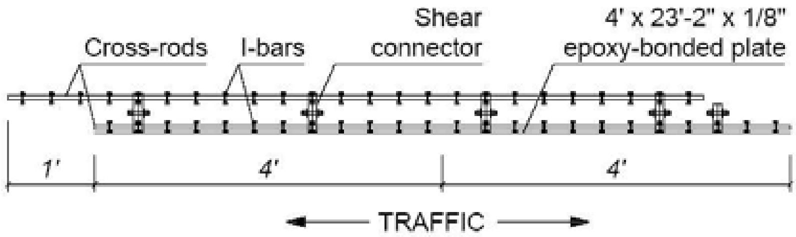
What has the innovation changed or replaced?

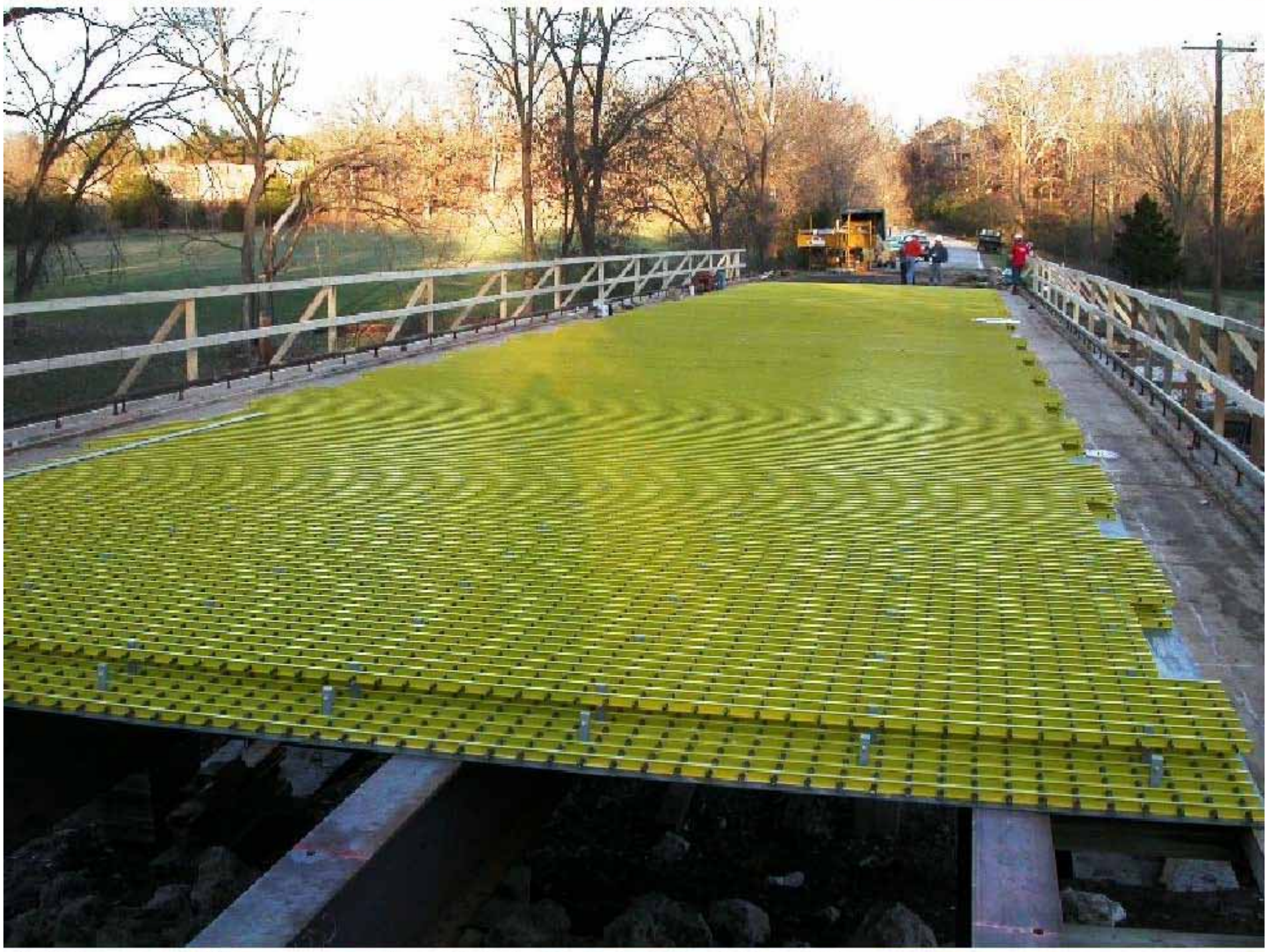
The GRIDFORM panel has changed the way in which concrete bridge decks are constructed. The pre-engineered GRIDFORM panel fundamentally changes the way in which concrete bridge deck construction is viewed. The GRIDFORM panel takes the labor-intensive activities of formwork construction and rebar placement and tying out of the field and into the factory, where precise placement, quality control and labor productivity is enhanced and material waste is less. However, as is necessary for an economical, better-finished, homogenous and contiguous concrete material system it keeps the concrete placement activity in the field.

Where and when did the innovation originate, has it been used, and where is it expected to be used in the future?

The GRIDFORM system is a result of 13 years of research at universities funded primarily by the FHWA. Two bridges have been constructed in Wisconsin on the busy Highway 151 corridor between Madison and Fond-du-Lac using first-generation versions of GRIDFORM. The current third-generation GRIDFORM system was used in November 2005 for the construction of the deck of bridge no. 14802301 in Greene County, Missouri. The old superstructure was replaced due to extensive corrosion-induced degradation of the steel reinforced concrete deck and of the steel girders. The new 144 ft long four-span slab-on-girder bridge, consists of four W24×84 girders spaced at 6 ft and acting non-compositely with a 7 in thick GRIDFORM deck. GRIDFORM can be used for bridge deck construction in any structural system configuration – steel girders, precast concrete girders, composite or non-composite action decks, and for both new deck and bridge deck replacement construction. It is anticipated that the price of the GRIDFORM system will decrease with increased applications.

Contact: Lawrence C. Bank, PhD, PE • University of Wisconsin-Madison • 1218 Engineering Hall Madison, WI 53706-1691 • 608-262-1604 • Fax 608-262-5199 • bank@engr.wisc.edu


Cross-rods
I-bars
Shear connector
4' x 23'-2" x 1/8" epoxy-bonded plate
1'
4'
4'
TRAFFIC



INVESTIGATOR'S SUMMARY[1]

Nomination 2006-24
Investigator: Amir H. Behzadan[2]

Prefabricated GFRP Concrete Bridge Deck Panels (GRIDFORM)

The Innovation

GRIDFORM is a prefabricated Glass Fiber Reinforced Polymer (GFRP) integrated stay-in-place (SIP) and bidirectional, double layer rebar panel for the rapid construction of corrosion-free concrete bridge decks.

The lightweight GRIDFORM panel, which weighs only 4.7 pounds per square feet, is prefabricated in very large units that are limited only by shipping constraints to approximately 50 ft by 8 ft. When the GRIDFORM panel arrives on site it is easily lifted with a single pick of a crane and placed directly on the bridge girders. The GRIDFORM panel is pre-engineered and detailed to enable rapid attachment to the bridge girders and subsequent concrete placement and finishing. The panel is made of off-the-shelf glass/vinylester FRP components that are produced commercially by many US pultrusion companies and the current prototypeells for 26 dollars per square feet. The anticipated lifespan of a GRIDFORM bridge deck is 75 to 100 years.

The main structural advantages that distinguish this innovation from other existing technologies in concrete bridge construction can be classified as follows:

(1) Strength and stiffness during construction – the GFRP panels are developed in compliance to performance specifications that limit the level of stress and deformation under several vertical and lateral loading, in-plane racking, and overlapping conditions.

(2) Static and fatigue strength – The entire design and fabrication process is being conducted in accordance to ACI 440.1R-06 to comply with AASHTO LRFD (1998) and Standard Specifications (2002).

(3) Enhanced durability – to date, the results of extensive research have demonstrated the superior durability of internal FRP reinforcement for concrete when compared to steel rebars. The corrosion resistance of FRP composites represents a critical advantage for bridge decks, which are highly susceptible to deterioration due to chloride (deicing salts) penetration. This translates into a reduction in bridge maintenance operations, thereby supporting a more efficient bridge management, and prioritization of limited funds.

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[1] September 15, 2006
[2] Ph.D. Student of Civil Engineering, University of Michigan, Ann Arbor, Michigan 48109.

In addition to the structural characteristics guaranteed by FRP reinforced concrete (RC) decks, the key features of the solution presented herein are:

(1) Easier and faster installation – the elimination of labor-intensive and time-consuming field operations (formwork setting between the girders, and tying of rebars) by means of large-size prefabricated FRP panels lifted with a single pick of a crane, translates into over 70% reduction in construction time from reinforcement installation to deck casting and finishing, as well as into significantly improved working conditions.

(2) Higher Productivity – the rate of concrete placement is increased by 50% compared to traditional steel reinforced decks with similar dimensions.

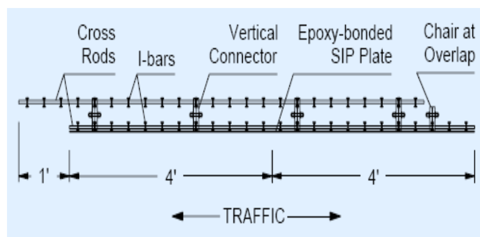
(3) Reduced Labor Cost – the reduced need of manpower, faster and easier field operations, and higher productivity translate into over 75% reduction in deck construction labor cost.

(4) Improved safety – the use of very lightweight FRP panels, easy to handle and placed with no need of formwork (as opposed to heavy partial-depth precast prestressed panels commonly used), and the design of the reinforcing profiles to facilitate walking over the top mat, result in improved safety in the work area.

Detailing of FRP SIP Panels

The panel details and deck construction solutions were devised with the main objective of improving constructability, taking advantage of valuable inputs from contractors and practitioners.

Full continuity of the main reinforcement elements is preserved by adopting a panel width that replicates that of the bridge deck. An acceptable degree of continuity in the secondary reinforcement is also ensured by the panel-to-panel overlap connection, as allowed by the 1 ft. offset between the top and bottom layers.

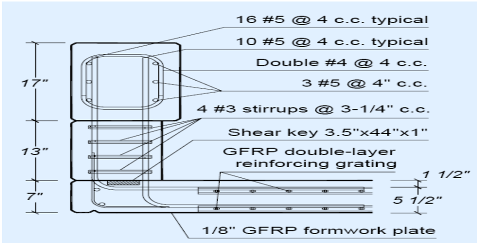


The end panels are designed to accommodate the expansion joints, and can be easily adjusted on-site due to the ease of saw-cutting the FRP components.

Glass FRP strips with 1/8 in. thickness are to be inserted between the bottom-layer cross-rods and the form to cover the butt joints between adjacent form plates, thus preventing leaking of concrete during the casting operations.

Each SIP unit can be anchored to the top flanges of steel I-girders by means of stainless steel threaded bolts and FRP washers.

However, in case composite action is required between deck and girders, automatic welded shear studs can be accommodated in holes pre-drilled in the form plates. Mounting of the very lightweight (about 35 lb.), prefabricated FRP rail post cages at the correct spacing is facilitated by the presence pockets cut out in the double-layer grating.



Application of the Innovation: 5-Day Installation

The GRIDFORM system is a result of 13 years of research at universities funded primarily by the FHWA. In brief, here is the development process of the innovation:

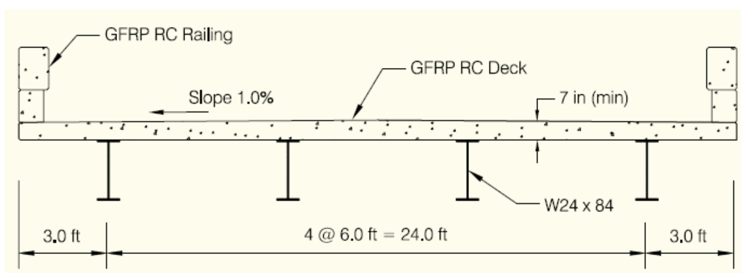
- Strongwell began developing the GRIDFORM™ system with the University of Wisconsin in 2001.
- First generation of the GRIDFORM™ system was installed on a bridge in Waupun, Wisconsin, in 2003.
- Second generation of the GRIDFORM™ system was installed on a vehicular bridge near Fond du Lac, Wisconsin, by the Wisconsin Department of Transportation in 2004.
- The Fond du Lac research project compared two bridges: one constructed using the GRIDFORM™ system and another constructed with conventional steel rebar reinforcement.
- Third generation of the GRIDFORM™ system was installed on a vehicular bridge in Greene County, Missouri, in 2005. A 1/8" thick FRP plate was integrated into the system and bonded to the bottom layer of grating to create the stay-in-place concrete form (below).

As a successful example, the application of GRIDFORM technology in the construction of the new bridge no. 14802301 is described in more details.

Project Summary: Construction of Bridge no. 14802301

The current third generation GRIDFORM system was used in November 2005 for the construction of the deck of bridge no. 14802301 in Greene County, Missouri. The County opted for the replacement of the 73-year old posted bridge due to the severe deterioration of the concrete deck, safety appurtenances, and steel girders that reduced the load rating from the original 10 ton to only 4.3 ton, forcing the owner to impose vehicle weight restrictions. Snapshots of the concrete deck and steel girders and also the safety appurtenance of the old bridge are shown below:

The new bridge, designed by Great River Engineering of Springfield, Missouri, has the same total length of 144 ft. of the old structure, and consists of four symmetric spans, the exterior ones with a length of 37 feet, and the interior ones of 35 feet. The 7" thick RC deck sits on four W24x84 rolled steel girders spaced at 6 feet o/c and running continuously along the bridge two-span half-length portions, with a closed expansion joint at the central support the out-to-out deck and clear roadway width is 24 feet.



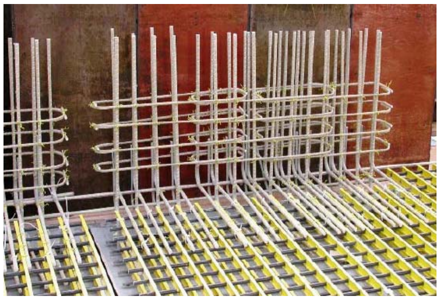
The field implementation project was developed in a joint effort between academia, government, and industry parties, including:

- University of Missouri-Rolla (UMR)
- University of Wisconsin-Madison
- Green County Highway Department (general contract and bridge owner)
- Great River Engineering (engineer of record)
- Hartman Construction (contractor)
- Master Contractors LLC (FRP rail cages contractor)
- Strongwell Corp. (SIP panel manufacturer)
- Hughes Brothers Inc. (GFRP rebars manufacturer)
- Missouri Department of Transportation (MoDOT).

The bridge "redecking" operations took **only five days** to complete, instead of the two to three weeks normally required for similar steel reinforced decks with open-post railings built by the contractor. The construction phases are shown below:

Day 1: All of the 18 deck panels were set in place and anchored to the steel girders by six workers in a total of six hours.

Day 2: The prefabricated rail post cages were inserted into the cut-out pockets in the SIP panels; the deck details were formed in a traditional manner using plywood, including expansion joints, chamfers, and drip edges; the finishing machine was finally set.



Day 3: The deck was cast and finished in a total of two and a half hours. The roadway crown was formed using the deck finishing machine, which avoided impractical cambering of the FRP panels, and time consuming preparation of haunches.

Day 4: The prefabricated top longitudinal rail cages were mounted, and the open-post railing formed. Since the temperature was below the minimum required by the County to proceed with casting, the operation was delayed.

Day 5: Casting of the railing was completed.

Background of the Innovation

I established contact with several people who were the main contributors to the project. All of them agreed upon the fact that being involved in the GRIDFORM project provided them with a unique opportunity to find innovative solutions to some of the main bridge construction issues which have been once considered as drawbacks of conventional methods of concrete bridge construction. In summary, those issues can be outlined as follows:

- Moving away form the concept of "forming-laying bars-casting-removing forms" which in fact adds to the construction time and cost.
- Minimizing chances of error in bar placement and inspection by prefabricating the panels as opposed to on-site bar placement. This way, a major part of the work can be considered as an industrial process.
- Developing a corrosion resistant material as opposed to conventional steel rebars. Many road districts have eliminated placing salt on bridge decks in winter because of the damage salt can cause to a typically steel reinforced concrete deck. Since salt will not harm the GFRP deck panels, it can be placed on the bridge deck during inclement weather without fear of causing long term damaging effects to the bridge. This will allow traffic to safely cross the bridge when icing is a problem.
- Safer work conditions as a direct result of prefabricating the panels and reduced level of labor work on site.

In order to achieve these goals, the main challenges faced by both the R&D team and the contractors on site were:

- Detailing of the system
- Coordination among the several parties involved in the project
- Deflection control of the system during concrete placement and due to construction loads

The product has been already commercialized. The main funding and supporting parties of the GRIDFORM project were:

- FHWA Innovative Bridge Research and Construction (IBRC)

- USDOT
- NSF Industry-University Cooperative Research Center

Responsibility for the Innovation

Based on the available background of the GRIDFORM innovation, the following persons are found to be responsible for the innovation and must be recognized by CIF as such, should this innovation receive a NOVA award:

- Lawrence Bank from Civil and Environmental Engineering Department at the University of Wisconsin-Madison
- Antonio Nanni from Civil, Architectural, and Environmental Engineering Department at the University of Miami
- Bruce Nelson from Strongwell Corp.

Opinions of Persons Contacted

A list of reference persons contacted, along with a short summary, is included in this report in the section titled "Selected Interview Summaries". In short, all the persons that I was able to establish contact with, had positive remarks about the innovation and were enthusiastic in providing information on how the innovation improved their operations.

Investigator's Comments

As a former project engineer of a France-based consulting engineering company (SETEC Batiment) in construction of the concrete structure of a 55 story residential skyscraper, I have personally experienced the difficulties of conventional concrete construction methods specially rebar alignment and overlapping, maintaining concrete covering on top and bottom faces of rebar planes during concrete placement, and form stripping in tight corners after concrete hardening; not mentioning the amount of rebar waste as a result of bad on-site measurements and installation.

GRIDFORM (although might not be the only solution) seems to be a very promising and effective solution to most of the problems in the field of concrete construction. The bright side of this project is that it has been already proven to be applicable in field since several projects have used it and almost all the involved people agree upon the fact that GRIDFORM has provided them with a robust, cost and time effective solution to their construction project.

The innovation, however, needs to be fully standardized by related institutions before it can be mass produced. However, this can be potentially achieved during the course of this project as the product is applied in a more variety of real world concrete constructions.

During past years, I have dealt with a number of other "innovative" projects in my field of experience. Most of the so called "innovations" establish newly invented methods to do a conventional task with the expense of deploying more complex devices and as a result ending up with a more expensive way of doing the same job. Whereas, the **integration of design, fabrication, and const and time saving** is a unique feature of the GRIDFORM project which will eventually lead to more approval ratings from designers and contractors and pave the road to achieving a standard product in near future. Although it might be true that in short term, the initial costs of GRIDFORM fabrication and installation are higher than those of the conventional methods, looking at the potential long term perspective of the project which includes longer life cycle, less maintenance costs, and several other factors, one may realize the incredible possible savings in project cost and time using this newly developed technology.

SELECTED INTERVIEW SUMMARIES

James (Jay) W. Carter, III, P.E., S.E.
Alfred Benesch & Company
4633 Washington Road
Kenosha, WI 53144
Phone: 262-652-6677
Fax: 262-652-6922

I have used a variation of this product on USH 151 south of Fond du Lac, Wisconsin. My project did not have an SIP form and therefore was conventionally formed and stripped after concrete hardening. This product was chosen to increase bridge deck durability (by removing corrosion-susceptible steel from the bridge deck), and decrease construction time (by reducing reinforcement installation time).

Initial material cost is higher than existing technology, but labor cost is reduced. Total life cycle cost is reduced due to assumed increase in bridge deck durability (The above-mentioned project was built next to a "twin" bridge of same geometry and traffic intensity. Both bridges will be monitored to verify durability over time for this innovative product against existing technology.

Data I received for the subject project given below compares these twin bridges. As can be seen, innovative bridge deck cost is large compared with existing bridge deck. However, labor and equipment usage are substantively reduced:

Item	Existing*	Innovative*
Bridge Deck Cost	$83,447	$185,089
Deck Sq. Ft. Cost	$11.54	$31.33
Bridge Deck Labor Hours	239	111
Bridge Deck Equipment Hours	32	21.5

* Costs are from awarded as-bid results, not actual costs (I believe awarded as-bid results incorporate a significant amount of risk by the contractor in using this innovative technology).

Because of non-ductile, prefabricated nature of this technology, the ability for field change alterations is reduced. Attention must be paid before installation to ensure fabrication meets field conditions. Owners that would use this product must overcome their natural resistance to use new technologies, in order to realize competitive costing with existing technologies. SIP forms, for instance, are not used by some DOT's due to the possibility that the forms will trap water permeating through the concrete. These problems are mitigated, however, by eliminating corrosion susceptible reinforcement from the deck.

I would definitely use this product again, due to its increased durability and ease of installation.

Finn K. Hubbard, P.E.
State Bridge Engineer
Wisconsin Department of Transportation
Phone: 608-266-8489
Cell: 608-516-3563
Fax: 608-261-6277

This has been an interesting project. We have applied this product to a couple more bridge decks. We continue to work with the application of this technology to get a better understanding of the material strength and installation cost. Our interest is fueled by not having to worry about corrosion issues in the FRP reinforced deck.

We have not seen any cost savings in the short run with this product. If the FRP last as long as we expect it to we will see long term savings by not having to redeck the bridge. The FRP deck system installs very quickly with fewer laborers so I would say we save 3 days time on the construction for an average two span grade separation bridge. The material is light and easy to handle compared to steel reinforcing.

The biggest disadvantage at this time is the initial costs. In the low bid world we live in, the life cycle cost is not always considered to the fullest. Day one costs often override the long-term unfortunately.

We will be using some form of FRP in future bridge decks. This may be of grid form as this project was or of FRP bar form potentially. Five years form now, I think what was an experiment today will be our normal way of doing business. I think this product has great potential.

Patty Lemongelli, P.E.
Organization Results
Missouri Department of Transportation
P.O. Box 270
Jefferson City Missouri 65102
Phone: 573 526-4328
Fax: 573-526-4337

MoDOT has not applied this specific product on any project to date. However, we have maintained and supported an interest in FPR technologies and feel that they offer structural and performance capabilities and advantages over some traditional materials (e.g. corrosive susceptible steel reinforcement).

Since MoDOT has not directly applied this product, I can not provide the specific statistics noted. However, we are interested in the FRP "steel-free" related technologies and recognize the potential savings in terms of time (construction time savings and ease of handling) and costs (while upfront costs can be initially higher, we anticipate less maintenance and lower life-cycle costs).

While I cannot speak on the product itself, in general the potential disadvantages we recognize at this time of FRP technologies include the increased initial cost, lack of formally accepted design guidelines (AASHTO approved), and lack of long-term performance data.

Under the right circumstances and if the funding were available, we would be interested to use this product in our future projects.