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Research and Development Section
Research Report

ASSESSMENT OF THE “BRIDGE IN A BACKPACK” BRIDGE SYSTEM FROM ADVANCED INFRASTRUCTURE TECHNOLOGIES (AIT)

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December 2014

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STATE OF VERMONT
AGENCY OF TRANSPORTATION

RESEARCH & DEVELOPMENT SECTION

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16. Abstract

The Vermont Agency of Transportation (VTrans) installed a Bridge in a Backpack (BiaB) system, or also referred to as a Rigified FRP Tube Arch (RFTA) Structure on a low volume road in a rural setting. The value of using this system is the potential to use smaller and lighter construction equipment for a restricted delivery location such as forest or farm roads. The BiaB does not require large cranes and there is a potential for in-field fabrication of the tube arch members where large truck delivery is limited. Advantages of the system include good waterway characteristics and suitability for ledge controlled or spread footings. Disadvantages of the system are that few have been constructed and that it has aesthetic limitations.

The construction of the Fairfield BiaB project proceeded smoothly. Generally, site conditions and limited experience with the BiaB led to less than ideal means and methods for construction of the system. During construction, it was noted that several opportunities remain for further expedited construction and cost reduction. Generally, VTrans’ experience with the BiaB showed that the system provides a benefit to the State.

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ABSTRACT

The Vermont Agency of Transportation (VTrans) installed a Bridge in a Backpack (BiaB) system, or also referred to as a Rigified FRP Tube Arch (RFTA) Structure on a low volume road in a rural setting. The value of using this system is the potential to use smaller and lighter construction equipment for a restricted delivery location such as forest or farm roads. The BiaB does not require large cranes and there is a potential for in-field fabrication of the tube arch members where large truck delivery is limited. Advantages of the system include good waterway characteristics and suitability for ledge controlled or spread footings. Disadvantages of the system are that few have been constructed and that it has aesthetic limitations.

The construction of the Fairfield BiaB project proceeded smoothly. Generally, site conditions and limited experience with the BiaB led to less than ideal means and methods for construction of the system. During construction, it was noted that several opportunities remain for further expedited construction and cost reduction. Generally, VTrans’ experience with the BiaB showed that the system provides a benefit to the State. The Research and Development Section recommends the Agency continue to consider the use of the system.

INTRODUCTION

The Vermont Agency of Transportation (VTrans) proposed to construct the Bridge in a Backpack (BiaB) in the town of Fairfield, on Wanzer Road. The BiaB system is a unique structure type that currently lacks a similar competitive alternative. The predominate component of the BiaB are ribbings constructed of fiber reinforced polymer (FRP) tubes made rigid by reinforced concrete. These ribbings are spaced at a regular interval and are configured to arch over the opening. The arched tubes are lightweight and can be carried into place by manual labor, thereby giving its name (see Figure 1). In order to use the BiaB system, VTrans was required to obtain FHWA approval for sole sourcing the Bridge technology. This was initially pursued through the Public Information Finding (PIF) process, which allows state transportation agencies (STA's) to use unique products in the transportation system. The impetus of obtaining this PIF approval from the FHWA was to explore the use of a construction technique that was less equipment-intensive.

Figure 1 FRP tubes can be carried into place by hand labor. (AIT)

The sole source request covered the major structural elements namely, the FRP tubes and panels that are only provided by Advanced Infrastructure Technologies (AIT). Remaining components of the BiaB system could be obtained through competitive bidding and pricing. If proven successful, the Agency could use the BiaB bridge system to save public dollars both in the short and long terms. The system's quick and simple construction process will result in lowering initial costs. The system's durability and inherent resistance to environmental impacts will reduce maintenance costs and extend the overall structural life span. This bridge technology was selected as an AASHTO Technology Implementation Group (TIG) Lead States Team effort. In order to promote and further refine this innovative bridge technology the AASHTO TIG Lead States Team encourages the design and construction of pilot projects throughout the country.

The Public Interest Finding process is a clearly defined mechanism in Title 23 CFR 635.411, as supported by 23 USC 112(a) to allow for propriety products or materials to be used on highway products. Though 23 USC 112(a) requires competitive bidding, the FHWA has provided for an allowance to use propriety products and materials when "the need for a particular product outweighs the need to procure products competitively." (*1*) The Agency chose to incorporate an Experimental Feature (EA) Research study in association with the PIF as a condition of FHWA approval. A five-year monitoring plan is currently underway to evaluate the overall value and initial performance of this technology.

PROJECT LOCATION AND SUMMARY

The Bridge in a Backpack was installed in Fairfield, Vermont on Wanzer Road (TH-30) at bridge 48 over the Wanzer Brook (See Figure 2). Wanzer Road receives about 200 vehicles daily. The original bridge was constructed in 1919. Figure 3 show that the bridge was very narrow (17.2 ft) and was located at the bottom of a significant sag in the roadway with steep slopes descending to and ascending away from the bridge. The roadway had a significant "S-curved" horizontal alignment through the project site. Figure 4 shows that the bridge had a timber deck on steel girders and spanned a small brook. The project scoping field report suggested that the timber deck comprised of vertically laminated 2x6 boards fastened by nails. The deck appeared to be in good condition. The steel beams were rusted and had supplemental supporting beams, which were added at a later time (see Figure 5). The substructure which carried a fair rating exhibited substantial deterioration. According to the field inspector in 2011, the rating for the substructure required a reduction in rating based on findings at the time. (*2*)

The field investigation found that using a temporary bridge located on either side of the existing structure was not feasible due to the challenges the vertical and horizontal alignments provided. Adequate detours were available within the proximity of the project to provide essential mobility (see appendix). The project scoping report suggested that the location justified an accelerated bridge construction method with a 4-week bridge closure. The challenge with closing the roadway at the bridge site was coordinating with the nearby farms and their access to their fields.

Figure 2 Project Location (Microsoft Bing Maps)

Figure 3 Bridge 48 alignment (VTrans)

Figure 4 Bridge 48 profile (VTrans)

Figure 5 The underside of bridge 48 showing the added beams (VTrans)

The existing substructure consisted of abutments comprising of a concrete cap setting on laid up stonewalls fortified at the base by concrete kneewalls. The abutments were placed on a timber mat (see Figure 6.) The clear span was 25.5 ft., just below the bridge seats and above the kneewalls. The kneewall clear span was 16 ft. Hydraulic engineering recommendations suggested that the kneewalls and timber matting could remain in place. Further recommendations suggested that a concrete wall should be constructed to a height that exceeded the Q25 storm event to keep debris from coming in contact with the FRP tubes and that the FRP arches should span 30 ft. with a radius of 18.75 ft. providing a rise of 7.5 ft. The initial assumption was that integral abutments with steel piles would be used for the substructure. (*3*)

Figure 6 Existing substructure (VTrans)

The United States Geological Survey (USGS) analysis of the bridge suggested moderate scour susceptibility with a greater risk assigned to the up-station abutment (Abutment #1). Though it was felt that at lower flow rates the timber mat would stay in place, higher flow rates increased the chances the timber mat would erode away. (*4*)

Though the existing structure was rated as fair, several factors led to the decision to replace it. The substructure was less reliable than the bridge rating of fair would suggest. The width of the structure and the approach alignments were sub-standard for traffic. The steel beams were rated good; however, the supplemental beams that have been added to shore up the original beams suggests that confidence in the structure was low. (*2*) A prudent measure was taken to replace the entire substructure, remove the timber matting and return the riverbed to a more natural condition.

While closing the bridge accommodated smaller project limits and reduced environmental impacts, the inconvenience to the public could only be addressed by accelerated bridge construction. Though the centerline of the bridge and roadway would essentially be maintained with no correction to the “S curve” alignment, the roadway width would be widened to an 18 ft. traveled way with 2 ft. shoulders. The vertical alignment would be corrected by raising the bottom elevation of the sag by 4 to 5 ft. Using a deck system would have required a longer bridge to keep the substructures to a minimum or would require very tall abutments to maintain the current bridge length of 28 ft. The chosen structure type was to be a buried structure.

PRODUCT DESCRIPTION

The Structures Section chose to replace the existing structure with innovative composite bridge system called “Bridge in a Backpack.” However, the structure is more accurately referred to as a “Rigified FRP Tube Arch (RFTA) Structure.” The RFTA or BiaB system suggests that it lowers construction costs, extends structural lifespan up to 100 years, and is a greener alternative to concrete and steel construction. (*5*) Product literature suggests that the bridge can be constructed in 10 days. The system was developed by the University of Maine’s Advanced Structured and Composites Center in Orono Maine and is distributed and marketed by Advance Infrastructure Technologies also in Orono, Maine.

The RFTA system is referred to as a “Bridge in a Backpack” because the tubes, prior to being stiffened, are flexible polymer fabric socks. These socks can be rolled up, put into a duffel bag and easily transported to the project site. The socks would then be unbundled and inflated into long straight tubes on the ground. The installers would then use bracing to bend the tube into the specified arches. The final step would then be to use a vacuum assisted transfer molding process to infuse the tube with resin. The tube would then be allowed to cure. (*6*) The materials and equipment needed for this task can be loaded into the bed of a typical pickup truck for delivery to the project location. (*7*)

The BiaB system, as stated earlier, comprises primarily of ribbing made up of FRP tubes shaped into arches. A single tube is essentially a composite exoskeleton, which fortifies the concrete within. The tubing provides significant strength, durability and protects the concrete from corrosion. As was with this project, tubes are manufactured in a plant similar to the field application previously mentioned. The resin is allowed to set up in about 30 minutes. (*5*) Each tube acts as external reinforcing and can eliminate the need for internal steel reinforcing which is common with concrete construction. The fabrication of a FRP tube fuses several layers (including carbon fiber) with resin to create the composite material. The exact blend is engineered to optimize the efficiency of the bridge design. The completed FRP tubes are relatively lightweight. Transporting them to a project site will not require special loading permits and when they reach the project site, they can be carried into position by two construction workers as shown earlier in this report. (*9*) The spacing and diameter of the tubes will vary depending span length and results from ongoing research.

Once the ribbing is in place and anchored into the footings, corrosion resistant FRP corrugated decking is fastened over the top of them. The FRP decking is essentially higher-grade corrugated roofing panels one could purchase at any lumberyard. The decking is fastened using corrosive resistant screws, which will later act as concrete anchors. Though not taken advantage of in the Fairfield project, the panels can be used to shore up and accurately position the tubes, rather than using temporary bracing, thereby eliminating a construction step. At the crest of each tube, a single access hole is drilled with vent holes being drilled at points along the arch of each tube. Self-consolidating expansive concrete is placed through the access holes and allowed flow down the arches. (*9*) The vent holes show where the concrete is during the placement and can allow air to bleed out. The BiaB system was initially designed to allow soil to be placed directly on the decking. Several installs have also included placing a reinforced concrete shell over the decking before placing the roadway materials. A headwall system is attached and the bridge is backfilled. The system components can be seen in Figure 7.

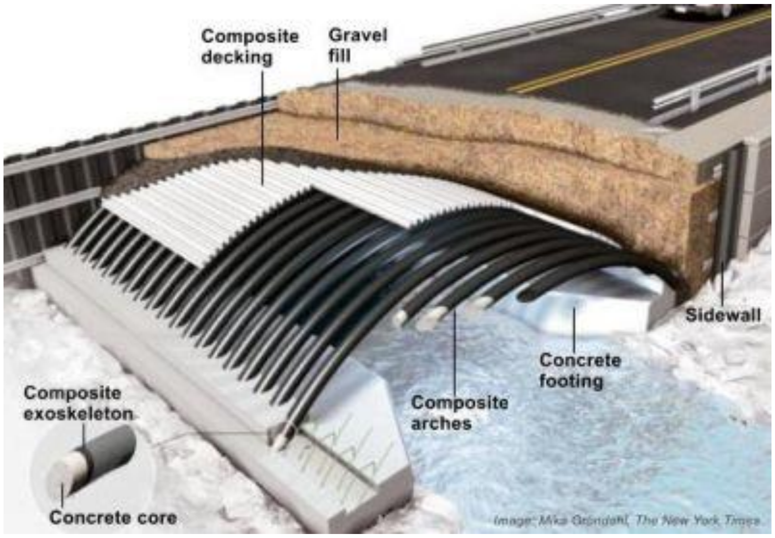

Image: Mika Grondahl, The New York Times

Figure 7 3D rendering of the BiaB (New York Times) (*10*)

The product has been used in 13 locations up to 2012, with the most BiaB systems constructed in Maine. Other BiaB construction locations are in New Hampshire, Massachusetts and Michigan. (*9*) In 2013, an additional system has been constructed in Ellswoth, ME. The system has also been used internationally. The first BiaB system was constructed in Pittsfield, Maine in 2008. This 28 ft. long bridge consisted of 23 1 ft. diameter tubes spaced 2’ on center, which supported the earth and vehicular loads. The bridge headwalls consisted of composite sheet piling and the FRP decking was off the shelf roof decking. Both of these items can be competitively bid because there are multiple suppliers. (*11*) Other headwall systems have been used successfully as well including precast concrete wall systems. Table 1 contains a list of the other BiaB systems that have been constructed.

Table 1 Bridge in a Backpack Construction Locations and Statistics (*12,13,14,15*)

Location	Year Built	Span	Rise	Width	Skew	Number of Arches	Spacing	Tube Diameter
Pittsfield, ME	2008	28’-10”	7’-6”	45’	5°	23	2’-0”	12”
Anson, ME	2009	27’-7”	4”-5”	25’	15°	9	3’-0”	12”
Auburn, ME	2010	38’-0”	9’-6”	38’	15°	13	3’-1”	12”
Bradley, ME	2010	28’-6”	6’-0”	34’	19°	12	2’-11”	12”
Hermon, ME	2010	44’-6”	6’-10”	12’	0°	3	5’-6”	12”
Belfast, ME	2010	47’-7”	11’-0”	45’	0°	16	2’-11”	15”
Caribou, ME	2011	54’-2”	12’-0”	55’	30°	22	2’-8”	15”
Fitchburg, MA	2011	37’-7”	5’-7”	36’	30°	15	2’-6”	12”
Pinkham Grant, NH	2011	23’-8”	6’-0”	26’	0°	6	4’-9”	12”
Huron County, MI[13]	2012	37’-7”	6’-7”	52’	20°	16	3’-6”	12”
Ellsworth, ME[14]	2013	40’-0”	14’-0”	32’	25°	11	5’-6”	12”
Fairfield, VT[15]	2014	36’-2”	7’-6”	38’	20°	9	5’-4”	12”

The fabricator, AIT, provides conceptual and design services for the bridge system, the plant fabrication of composite superstructure elements as well as installation oversight. AIT states that all designs are engineered to exceed AASHTO load standards for single span bridges from 25 ft. to 70 ft. and multi-span designs exceeding 800 ft.

CONSTRUCTION

The BiaB in Fairfield was constructed by A. L. St. Onge Contractor, Inc. from Montgomery, VT in the 2014 construction season. The low bid price for the VTrans project, Fairfield BRO 1448(38), was $983,841.00. Adding contingencies and construction engineering costs brought the total construction costs up to $1,129,817.15. Construction began in May of 2014 with a contract end date of October 3, 2014. Construction completed on September 30, 2014.

Several of the BiaB systems installed prior to the Fairfield project used simple block foundations. Due to hydraulic and substructure requirements, VTrans used a more typical footing-abutment construction. Removal of the entire structure, excavating the timber mat and the necessary excavation of the footing began on May 28, 2014. On June 24, the contractor began work constructing the substructures with setting the formwork for the northerly abutment. To construct the substructure, the contractor chose to use a medium duty crane with a boom reach adequate for both abutments. On July 9, stone fill and backfill were placed behind the northerly abutment. By August 18, the contractor had completed all substructure work and began to prepare the site for constructing the superstructure. (*16*)

Construction of the superstructure began on August 20, with the setting of the first arch (see Figure 8.) The only superstructure steel reinforcing were anchors inserted in each end of the FRP tubes (see Figure 9.) FRP tube were placed using the medium duty crane. The contractor chose to use the crane due to the rough terrain for the safety of the construction workers and to prevent potential damage to the tubes. Within a week, the tubes were set and the decking was installed (see Figure 10.) In the next week, final concrete placement in the abutments, effectively anchoring the tubes in place, was completed. Grouting within the tubes followed. As mentioned earlier, self-consolidating concrete (SCC) with expansive admixtures included to ensure the concrete expanded into and adhered to the FRP tubed during the concrete cure, was used. (*17*) SCC was chosen due to its ability to flow within and adhere to the walls of a form without segregation of the aggregate from the concrete matrix. SCC also does not require vibration. The desired slump of the SCC is 24 to 30 inches. Once the SCC was placed, no loads, other than light foot traffic was allowed on the structure for 48 hours. (*18*) According to AIT, it took only 22 crew hours from the beginning of setting the first tube to completing the final placement of the SCC within all the tubes.

Figure 8 Installation of the first tube (VTrans)

Figure 9 Anchorage reinforcement of the tubes (VTrans)

Figure 10 All tubes in place with decking being installed (AP) (*18*)

Initially VTrans designed a concrete shell over the specified FRP panels. In a Value Engineering determination, a more heavy-duty FRP panel called the ATLAS FRP Panel was chosen to replace the lighter duty panels and the concrete shell. All engineering and production of estimates and design details were absorbed by AIT. AIT provided 25 full width 42-foot long ATLAS FRP composite panels. These panels were determined to be capable of withstanding the expected design loads. The change in design provided an overall savings of $31,510.00 and expected to shorten the system construction time by up to a week. The concrete shell item, which comprised of 4,800 pounds of reinforcing steel and over 20 cubic yards of concrete, was eliminated from the project as was 1,700 square feet of torch-applied waterproofing, as it was no longer necessary. Though the more durable ATLAS panels were more expensive than the lighter gauge panels, the elimination of labor and materials costs from the reduction of reinforcing steel, concrete and the membrane provided the overall savings.

On both sides of the arch, fascia mounted headwalls made out of 3” x 24” Composolite building panels by Strongwell were installed to provide the support for a Mechanically Stabilized Earth or MSE structure. Figure 11 shows the MSE panel design detail used in construction. The panels were anchored to the arch by means of 2” wide sections of a 7x4x⅜ hot-dipped galvanized steel angle connected to the outer arches by the means of stainless steel anchoring rods. Once the headwalls were in place, a low slump grout was applied to seal the joint between the headwall and the arch. At this point, the superstructure was ready to receive final fill and roadway grade materials.

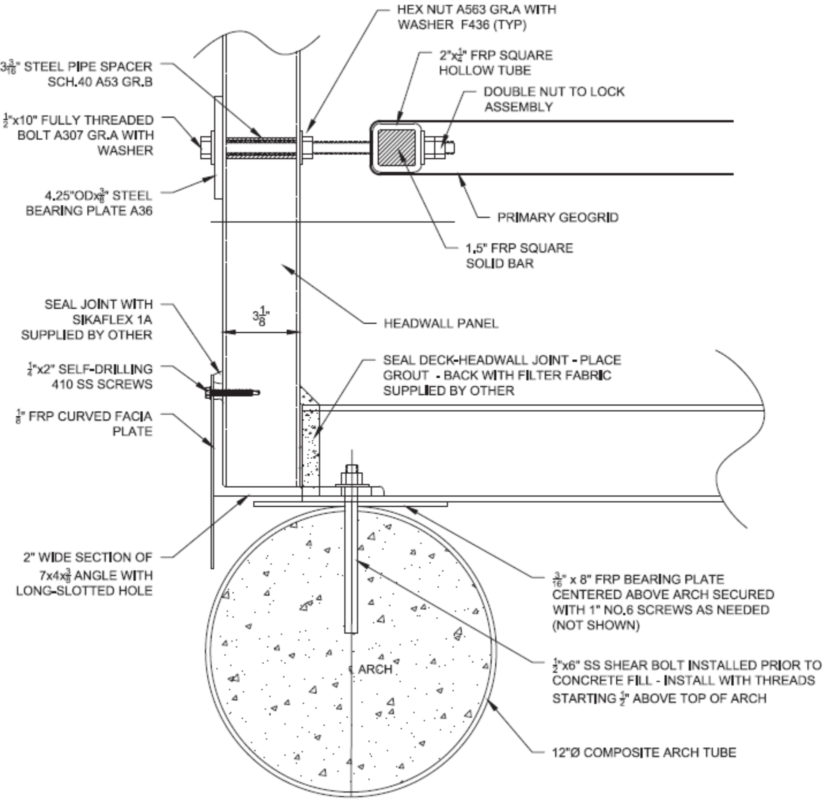

Figure 11 Cross section of the MSE headwalls connection to the arch system (ATI)

The headwalls are intended to contain the highway grade using a mechanism called Mechanically Stabilized Earth or MSE. MSE uses geogrids, which are rigid high strength synthetic polymer sheets, either woven or are manufactured in a grid configuration, that are bolted or otherwise attached to vertical panels, which then extend into the supported soil, in lifts, for the purpose of holding the panel in place. "The layered system of strips forms a reinforced mass which is sufficiently stable to provide structural support." (*19*) For the headwall panels, geogrid reinforcement was attached to the panels at vertical intervals in horizontal planes, which extended from the headwall into the highway gravel towards the centerline of the roadway with compacted gravel holding it in place (see Figure 12.) Figure 13 shows the final bolting pattern where the geotextile was attached to the headwall.

Figure 12 Applying subbase material over geotextile layers (ATI)

In September, the final effort involved constructing wingwalls from precast MSE panels, final grading of Wanzer Road, including constructing stone reinforced drainage and then the installation of specified safety features. Figure 13 and Figure 14 show the completed project.

Figure 13 Completed Bridge in a Backpack (VTrans)

Figure 14 Completed project (VTrans)

PERFORMANCE AND OBSERVATIONS

The stated benefits of Bridge in a Backpack system were rapid and simplified construction, reduced life-cycle costs, increased bridge design life and a decreased carbon footprint of bridge construction. (*9*) At this phase of this research, it is not practical to examine the life span of the bridge. The oldest BiaB system has been in service since 2008 or 6 years at the writing of this report. Typically, bridges that have been in service this long do not exhibit any observable changes to assist in forecasting longevity.

Any assessment on lifespan and life-cycle costs would be speculative; however, a few observations made by the fabricator warrant mentioning. The exposed components of the bridge are comprised of UV resistant materials. The primary structural components, namely the FRP tubes, are shielded by the structure itself from UV rays and ice melting chemicals. Where the BiaB is different from any other structure type is that the only exposed concrete is in the abutments. All concrete in the superstructure is contained within the FRP tubes; therefore, protected from any corrosive substance. "If you think of it, there's really nothing in our system that can corrode or degrade," Tim Kenerson, a design engineer with AIT, said. (*18*) A side benefit to this containment is that the concrete is allowed to cure in an ideal environment, without requiring additional labor maintaining the concrete's moisture level.

Most concrete elements in bridge superstructures deteriorate due to steel reinforcing bars corroding over time. The BiaB is absent of any reinforcing in the primary supporting members, which should eliminate the risk of similar deterioration. The final performance enhancement of the BiaB is that it is an arch. Stone arches have been in use since before the founding of the Roman Empire with many of those arches remaining in service as roadway bridges or in aqueducts. A properly design and constructed arch will be in constant axial compression throughout its length. The expansive additives in the self-consolidating concrete will put the material in constant compression laterally by the containment of the tube wall. With these mechanisms and defenses in place, it is safe to project that a BiaB will last longer and require much less maintenance than conventional deck systems or buried exposed concrete.

An assessment of construction speed and simplification for the Fairfield project will require consideration to the project site compared to other BiaB that have been constructed. Most of the prior BiaB projects have occurred on relatively level terrain and on straight roadway alignments with relatively slow moving creeks. Bridge 48 over the Wanzer Brook had several impediments that made construction difficult. The two primary impediments, which required a longer construction period, were the requirements of a typical substructure and a modified vertical alignment of the roadway. To assess the construction performance of the Fairfield project requires looking specifically at the construction of the superstructure.

Construction of the superstructure began on August 20 and was essentially complete in just over two weeks. The Value Engineered change of using the ATLAS FRP Panels further enhanced the construction speed by eliminating the need to place the concrete shell. Any abutment-deck system for this length would require both forming a concrete deck and placing reinforcing steel, which would require more than a month, or placement of precast or prestressed concrete elements. Using precast or prestressed concrete elements have proven to allow construction within this period; however, precast or prestressed concrete elements provide a much higher degree of complexity and cost. To construct a prestressed box beam or voided slab bridge deck quickly, a concrete deck overlay will need to be omitted. In these cases, the bridge deck will require a membrane and a pavement topping. Precast arches can be constructed within this period; however, depending on the bridge skew, this alternative starts to become very complex with irregularly shaped components. Both precast arches and prestressed beams require heavy cranes to place and heavy hardware for installation.

From observations by Agency employees, the construction of the superstructure did meet the fabricator's documentation. Though the contractor chose to use the available crane to lift and place the FRP tubes, their weight was low enough to be carried manually. The installation was simple and could be done mostly by hand labor with lightweight materials and light hand equipment. The advantage of the BiaB system is that the tube arches can be placed in line with the roadway. The decking is placed in line with the bridge skew. Any trimming of the decking can be done with a hand-held reciprocating saw. It should be understood; however, the claim that a bridge could be built in 10 days is only for the core superstructure. The elements beyond the completed arch seem to take as much time as with any conventional construction.

With regards to the BiaB resulting in a smaller carbon footprint during construction, a BiaB does seem to have fewer environmental impacts when compared to conventional construction. First, the system uses much less concrete and a significant reduction in reinforcing steel usage. The largest environmental concern with concrete production is that it consumes a significant amount of energy, which in turns releases a significant amount of CO_2 into the atmosphere. Reinforcing steel requires a similar high amount of energy to fuel the high temperature smelting process. The resulting release of CO2 comes from both the heating and smelting processes. Further, the reduced usage of heavy equipment put fewer emissions into the air. For the Fairfield project, the use of the medium-duty crane to place the lightweight FRP tube did not require the same fuel consumption as is necessary for concrete and steel elements. The carbon footprint was further reduced by using the ATLAS FRP panels through the elimination of reinforcing steel, concrete and eliminating the need to apply a membrane via torches. Though specific carbon savings were not estimated, it can be assumed from observing how the Fairfield bridge was built that there was a significant reduction in carbon emissions when compared to conventional bridge deck systems.

Performance Monitoring

The Agency chose to conduct a five-year monitor program of the BiaB as part of the public information finding for the BiaB. Areas to be monitored are as follows:

1. The fascia tubes will be visually observed for any UV effects. This will comprise of taking photos over the five-year period to detect any change in the surface.
2. The tubes will be observed for possible oxidation.
3. After flooding events, any damage to the bridge will be documented.

4. Measurements of tubes 4, 5 and 6 will be taken to detect any creeping of the arches (see Figure 15.)

COST ANALYSIS

The low bid price to construct the Fairfield BiaB project was $983,841.00. With the Value Engineered alternative, the price was reduced by $31,510.00, for a project cost of $952,331.00. The cost breakdown of the project is in Table 2. As can be seen from Table 3, the Fairfield BiaB was comparably priced with other BiaB system constructed over the last six years. The cost breakdown shows that the BiaB is still costly. AIT documentation suggests that the BiaB will have higher material costs when comparison to other more common bridge types. The cost savings come from lower labor, transportation and installation costs. This was evident during construction. Additional cost savings come from lower maintenance costs over the life of the bridge. Experience with the Pittsfield, ME BiaB over the last six years is showing that maintenance is unnecessary.

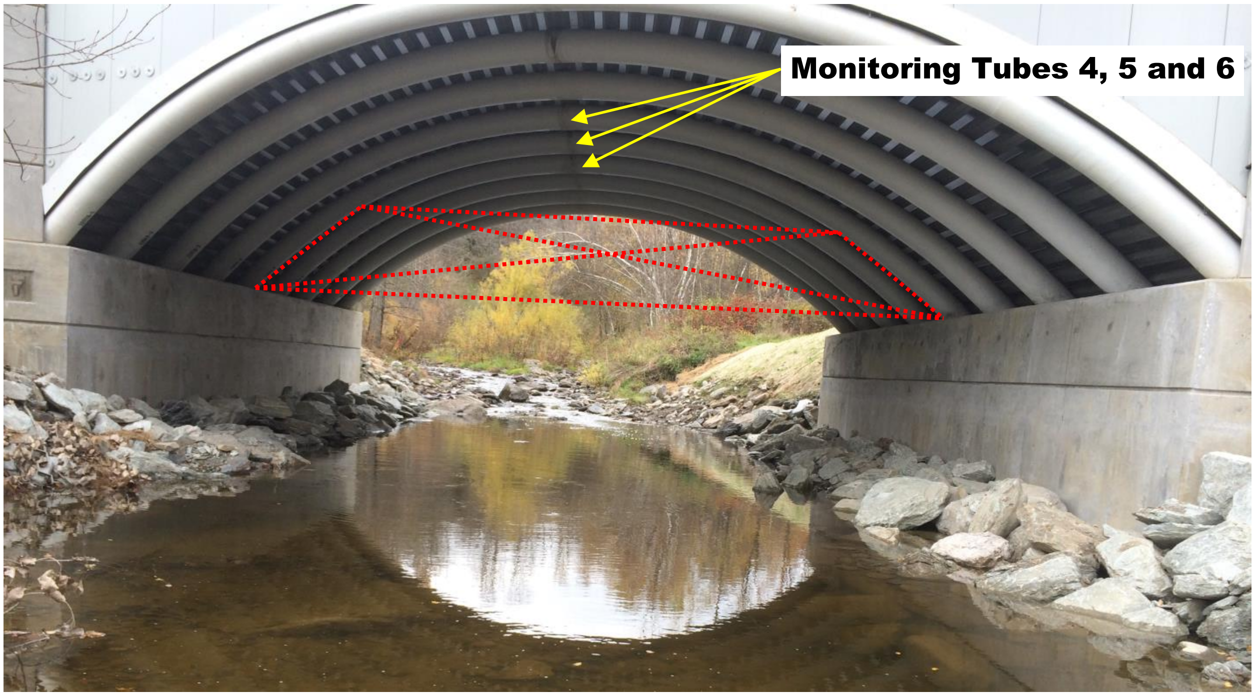

Figure 15 Measurements to be taken to detect a shape change due to creep (VTrans)

Table 2 Cost breakdown of project

Component	Cost
Erosion Control	$27,870.00
Roadway	$180,910.00
Bridge	$727,551.00
C&E Items	$16,000.00
Total	**$952,331.00**

Table 3 Comparative costs

Location	Year Built	Bid Price*	Span	Rise	Width
Pittsfield, ME	2008	$615,365.00‡	28’-10”	7’-6”	45’
Auburn, ME	2010	$832,784.00	38’-0”	9’-6”	38’
Bradley, ME	2010	$888,096.00	28’-6”	6’-0”	34’
Belfast, ME	2010	$951,575.00	47’-7”	11’-0”	45’
Huron County, MI[13]	2012	$1,167,181.00	37’-7”	6’-7”	52’
Ellsworth, ME[14]	2013	$229,275.00†	40’-0”	14’-0”	32’
Fairfield, VT[15]	2014	$952,331.00	36’-2”	7’-6”	38’

* 2014 Inflation adjusted dollars (*20*)
‡ Final cost
† Composite arch superstructure only.

The bridge costs can be further broken down as shown in Table 4. The cost for excavation would be similar for more commonly used substructure types, such as spread or pile footings, with the exception of an integral abutment substructure. Substructure costs would be higher with common superstructures, which would require higher abutment walls. More commonly used deck systems for this span length would be at par with the BiaB. Square foot costs of similarly sized bridge projects range from $382 to $707 in total construction costs using historic cost data from VTrans’ Structures Section. In Table 5, one can see that most BiaB installation costs fell within this range and the Fairfield project cost was at the top of the range. Historic bridge specific costs relating to similarly sized bridges ranged from $172 to $298. Table 6 shows that the bridge-only costs for Ellsworth, ME and the Fairfield project both fell within this range.

Table 4 Breakdown of bridge costs

Component	Cost
Excavation	$184,760.00
Substructure	$258,536.00
Superstructure (arch)	$284,254.00
Total	**$727,551.00**

Table 5 Square foot cost of BiaB systems (total costs)

Location	Square Foot Cost*
Pittsfield, ME	$474.27
Auburn, ME	$576.72
Bradley, ME	$916.51
Belfast, ME	$444.40
Huron County, MI[13]	$597.23
Fairfield, VT[15]	$692.94
Average Sq. ft. Cost	$617.01
* 2014 Inflation adjusted dollars (*20*)	

Table 6 Square foot cost of BiaB systems (Bridge costs only)

Location	Square Foot Cost*
Ellsworth, ME[14]	$179.12
Fairfield, VT[15]	$206.83
Average Sq. ft. Cost	$192.98
* 2014 Inflation adjusted dollars (*20*)	

SUMMARY AND RECOMMENDATIONS

The use of the Bridge in a Backpack system was fueled by VTrans' drive to find new ways to construct bridges faster. This effort began in response to the damage to Vermont's highways and bridges caused by recent storms including the Tropical Storm Irene in 2011. "We did it so much in Irene, it transformed our willingness to do it far more," said Vermont Deputy Transportation Secretary Sue Minter in response to accelerated construction practices. (*18*)

VTrans found that the stated benefits of the BiaB system have a sound basis. The bridge system was able to be constructed rapidly with ease and simplicity. Observations made during construction suggest that more rapid and less expensive means and methods for constructing a BiaB remain available with the use of more efficient construction sequencing, lighter equipment and materials delivery. If such improvements were made to the process of constructing the BiaB system, towns would be able to construct the system using crews and maintenance equipment commonly used by the towns. The structure will provide reduced life-cycle costs because it will experience an increased bridge design life. Wayne Symonds, the Structures Program Manager stated that the BiaB is expected to last at least 100 years with little maintenance, where most steel structures last about 75 years and require routine maintenance. (*18*)

Though it is difficult to quantify with precision, the BiaB system can reduce the impact of carbon emissions thereby decreased the carbon footprint of bridge construction due to reduced energy demands for superstructure and substructure materials. The costs of the system seem to be at par with other bridge construction alternatives. At the writing of this report, there are about 15 BiaB systems constructed in the United States with others constructed internationally. This means the cost of the materials and construction is higher than it would be when the system matures. With greater use of the system and increased construction experience, the costs associated with the BiaB will likely decrease.

IMPLEMENTATION STRATEGY

In the future, AIT will be using the term, "Composite Arch Bridge System (CABS)" rather than "Bridge in a Backpack" for this bridge system. The Research and Development Section recommends that the BiaB system or CABS continue to be used for future bridge projects in the state. Where the Fairfield project used typical substructure construction and had to overcome a challenging terrain for construction, it is recommended that the BiaB system (or CABS) be demonstrated in a project location that requires limited construction equipment access and environmental sensitivity. This bridge type would be ideal for remote locations where heavy equipment cannot reach. Enhancing the State's experience in using this system under the stated benefits will provide the greatest return of investment of this finding.

Refinements to the BiaB/CABS are currently focused on improved connection details and aesthetics treatments. Precast concrete panels and stone-faced walls are now available along with integrating Geosynthetic Reinforced Soil (GRS) blocks such as the Redi-Block and Redi-Scapes products. Though the BiaB/CABS have mostly been used as a cost-effective utilitarian structure, the Agency should consider aesthetic treatments where the natural or cultural settings of certain sites demand.

APPENDIX

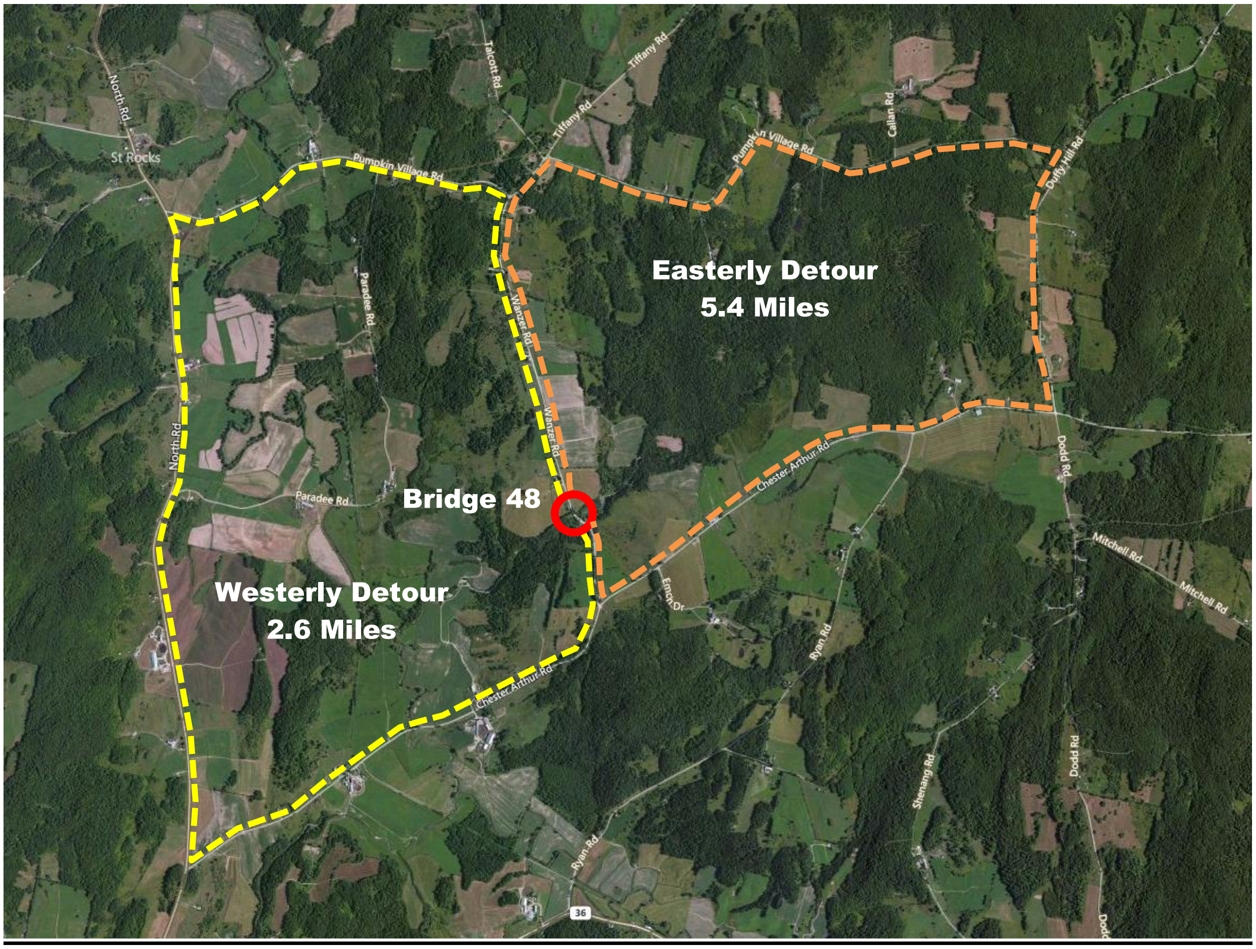

Figure 16 Detour Options

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