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AGENCY OF TRANSPORTATION

ASSESSMENT OF THE COMPOSITE ARCH BRIDGE

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16. Abstract
The Vermont Agency of Transportation (VTrans) installed a Composite Arch Bridge (CAB) system, known as Bridge-in-A-Backpack^{TM}, 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 CAB 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 footing foundations. Disadvantages of the system are that few have been constructed and that it has aesthetic limitations.

The construction of the Fairfield, VT CAB project proceeded smoothly. Generally, site conditions and limited experience with the CAB 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. Observed performance has shown a stable and well preforming structure, with expected benefits including reduced chloride affects and reduced maintenance through its service life. Generally, VTrans' experience with the CAB showed that the system provides a benefit to the State.

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The Vermont Agency of Transportation (VTrans) installed a Composite Arch Bridge (CAB) system, known as Bridge-in-A-Backpack^{TM}, 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 CAB 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 footing foundations. Disadvantages of the system are that few have been constructed and that it has aesthetic limitations.

The construction of the Fairfield, VT CAB project proceeded smoothly. Generally, site conditions and limited experience with the CAB 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. Observed performance has shown a stable and well preforming structure, with expected benefits including reduced chloride affects and reduced maintenance through its service life. Generally, VTrans' experience with the CAB showed that the system provides a benefit to the State.

Table of Contents

Table of Figures

Table of Tables

1. Introduction

The Vermont Agency of Transportation (VTrans) constructed a Composite Arch Bridge (CAB) in the town of Fairfield, on Wanzer Road. The CAB system is a unique structure type that currently lacks a similar competitive alternative. The predominate component of the CAB 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, a significant difference from conventional bridge materials (see Figure 1). In order to use the CAB system, VTrans received 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 (1)

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 CAB system can be obtained through competitive bidding and pricing. If proven successful, the Agency could use the CAB 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) (now AASHTO Innovation Initiative) Lead States Team effort. In order to promote and further refine this innovative bridge technology the AASHTO TIG Lead States Team encouraged 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 proprietary 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 proprietary products and materials when "the need for a particular product outweighs the need to procure products competitively" (2). 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 was undertaken to evaluate the overall value and initial performance of this technology.

This final report aggregates information from the Work Plan, Construction Report, a Cost Analysis report and includes a summary of the field data collected by research section site visits.

2. Project Location and Summary

The CAB 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 has a significant "S-curve" horizontal alignment through the project site. Figure 4 shows that the previous bridge had a timber deck on steel girders and spanned a small brook. The project scoping field report suggested that the timber deck was 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 condition of the substructure required a reduction in load rating based on findings at the time (3).

A 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 the Appendix). The project scoping report suggested that the location justified an accelerated bridge construction method with a 4-week bridge closure. One challenge with closing the bridge was coordinating with the nearby farms for access to their fields.

Figure 2: Project Location

Figure 3: Bridge alignment

Figure 4: Bridge profile

Figure 5: The underside of bridge showing the added beams

The existing substructure consisted of abutments comprising of a concrete cap on laid stone walls fortified at the base by concrete knee-walls. The abutments were placed on a timber mat to control downcutting (see Figure 6). The clear span was 25.5 ft, just below the bridge seats and above the knee-walls. The knee-wall clear span was 16 ft. Hydraulic engineering recommendations suggested that the knee-walls 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. VTrans Structures design staff, working with AIT came up with a plan for FRP arches with a span of 30 ft, radius of 18.75 ft, which provides a rise of 7.5 ft. The initial assumption was that new integral abutments with steel piles would be used for the substructure.

Figure 6: Existing substructure

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) (4). 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. Through consultation with the Hydraulics and

Environmental sections, it was decided that the entire substructure, including the timber matting would be removed, returning the riverbed to a more natural condition.

Full closure of the bridge accommodated a smaller project limit and reduced environmental impacts, but 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 a buried structure.

3. Product Description

The Structures Section chose to replace the existing structure with the innovative CAB structure called “Bridge-In-A-Backpack™”. The CAB system is advertised for its lower construction costs, extended structural lifespan up to 100 years, and as 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 (AIT) also in Orono, Maine.

The CAB system is referred to as a “Bridge-In-A-Backpack” because the tubes, prior to being stiffened, are flexible polymer fabric socks, and can be rolled up and transported in duffel bag from the manufacture to the curing facility. The socks would then be unbundled and inflated into long arches around a brace, and then impregnated with resin and allowed to cure into their arch shape (6). The cured tubes are then brought to site and put into place.

The CAB 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. Each tube acts as external reinforcing and can eliminate the need for internal steel reinforcing which is common with concrete construction. The fabrication of an 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, making transportation and placement cheaper and easier. 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 construction workers as shown earlier in this report, or with an excavator for ease of placement (5). The spacing and diameter of the tubes will vary depending span length and results from ongoing design 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 (5). Vent holes can show where the concrete is during the placement and can allow air to bleed out. The CAB 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.

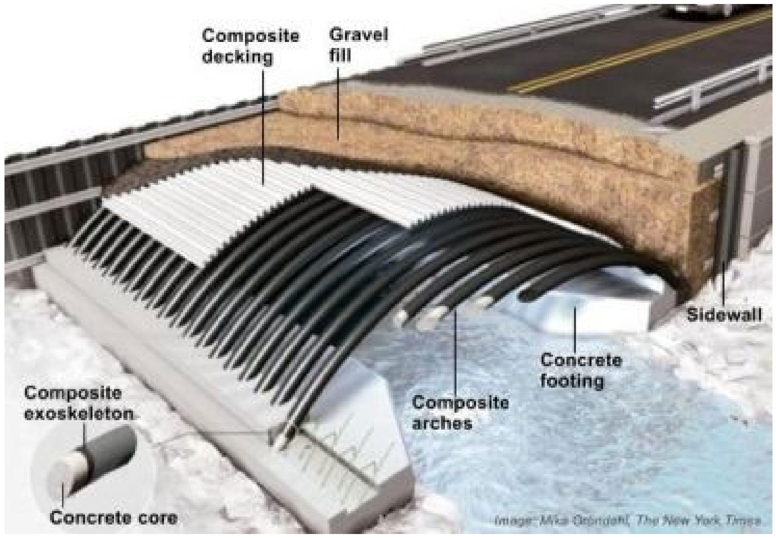

Figure 7: 3D rendering of the CAB (5)

The product was used in 13 locations up to 2012, with most CAB systems constructed in Maine. Other CAB construction locations are in New Hampshire, Massachusetts and Michigan (1). The system has also been used internationally. The first CAB system was constructed in Pittsfield, Maine in 2008. This 28 ft long bridge consisted of 23, 1 ft diameter tubes spaced 2 ft on center. 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. Other headwall systems have been used successfully as well including precast concrete wall systems. Table 1 contains a list of several of the other CAB systems that have been constructed between 2008-1014.

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.

Table 1: CAB Construction Locations and Statistics (1, 7, 8, 9, 10)

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, MI13	2012	37'-7"	6'-7"	52'	20°	16	3'-6"	12"
Ellsworth, ME14	2013	40'-0"	14'-0"	32'	25°	11	5'-6"	12"
Fairfield, VT15	2014	36'-2"	7'-6"	38'	20°	9	5'-4"	12"

4. Construction

The CAB 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 was completed on September 30, 2014.

Several of the CAB 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.

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 a 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, grouting was done with self-consolidating concrete (SCC) with expansive admixtures included, to ensure the concrete expanded into and adhered to the FRP tubes during the concrete cure. 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. 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

Figure 9: Anchorage reinforcement of the tubes

Figure 10: All tubes in place with decking being installed

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 (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.

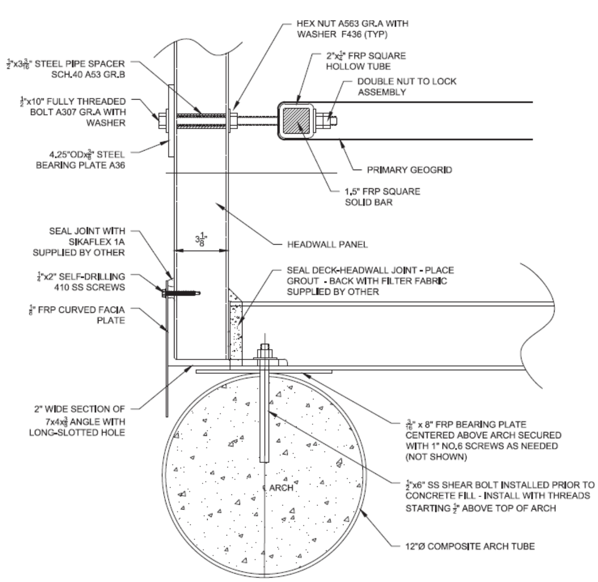

Figure 11: Cross section of the MSE headwalls connection to the arch system (5)

The headwalls are intended to contain the highway grade using 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. 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. 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 12: Applying subbase material over geotextile layers (1)

Figure 13: Completed CAB

Figure 14: Completed project

5. Performance and Observations

The stated benefits of CAB system were rapid and simplified construction, reduced life-cycle costs, increased design life and a decreased carbon footprint of bridge construction. (8) At this phase of the project, it is not practical to examine the life span of the bridge. The oldest CAB system has been in service since 2008. Typically, bridges that have only 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 CAB 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. 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 CAB is absent of any reinforcing in the primary supporting members, which should eliminate the risk of similar deterioration. The final performance enhancement of the CAB 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 designed 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 CAB 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 of the project site compared to other CAB that have been constructed. Most of the prior CAB 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 CAB 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.

5.1. Performance Monitoring

The Agency chose to conduct a five-year monitor program of the CAB as part of the public information finding for the CAB.

Observation included measurement of arches 4, 5, and 6 for any deflection or creep (Figure 15), visual inspection of the head walls, and visual inspection of the tubes to detect any oxidation, damage, or UV effects.

A final site visit to the CAB project was conducted on July 16th, 2018. The weather was sunny with high temperatures and the stream bed was dry. Initially, the overall appearance and basic geometry of the bridge was evaluated. The bridge appeared to be in good condition and no points of impacts or damage were detected. Overall, the bridge appeared to be performing as expected, with little change since the last research inspection in 2015.

One area of close observation identified in 2015 was the headwall, which were noted to be bulging and bowing from lateral earth pressures. The western headwall is bowing throughout its entire length in a smooth curve, while the eastern headwall is showing shoving in some areas and not others. The westerly headwall appears to have a maximum deviation of 4 inches from straight. Bowing of the westerly headwalls can be seen in Figure 16. These deflections have been stable since 2015, with no increased spread detected in 2018.

Measurements were taken on arches four, five and six, which are located at the center of the structure. In October of 2014, marks were placed on the arches. One mark was located about one inch above the abutment and another mark was placed where a straight 7.5 foot line intersects the arch, from the first mark. The measurements were taken between the two upper marks, the diagonals from the upper marks to the lower marks and between the lower marks. The 7.5 diagonal measurements were checked. A diagram of the measurement patterns can be seen in Figure 16. Table 2 shows the measurements taken over three site visits spanning from 2014 to 2018.

The overall measurements averaged about 0.5 inch different from the measurements taken in 2014, well within the capacity of the arches to redistribute loads without harm. These observations show that overall, the arches are performing well, with little deflection or creep.

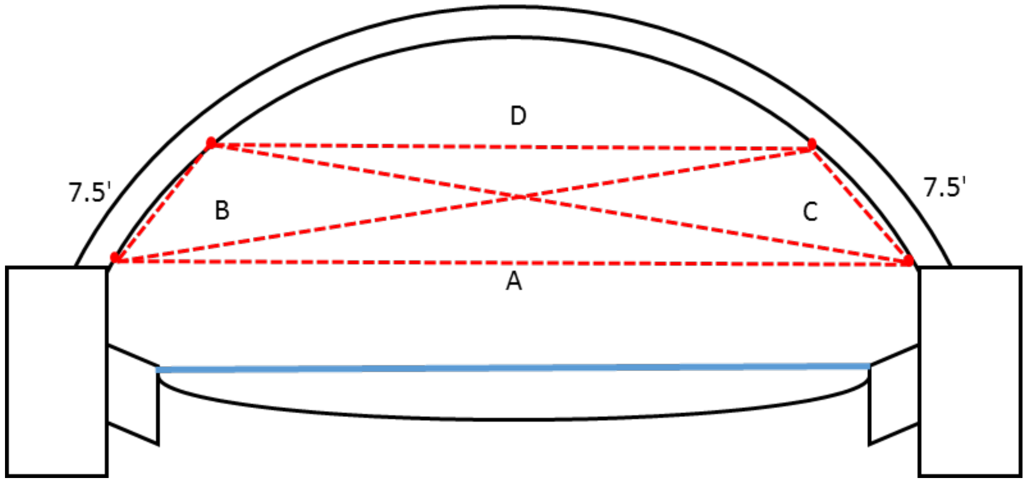

Figure 15: Diagram of Measurements Taken

Figure 16: Bowing on Western Headwall

Table 2: Arch Measurements (ft)

	Original 2014 distances	2015 change from original	2018 change from original
Arch 4			
A	34.58	+0.02	-0.04
B	28.78	+0.05	-0.01
C	28.91	-0.06	-0.08
D	22.47	+0.01	+0.08
Arch 5			
A	34.58	+0.03	+0.03
B	28.78	+0.02	-0.02
C	28.85	-0.04	-0.05
D	22.44	-0.03	-0.03
Arch 6			
A	34.6	-0.02	+0.02
B	28.85	+0.01	-0.04
C	28.91	-0.07	-0.07
D	22.47	-0.03	+0.02

6. Cost Analysis

The low bid price to construct the Fairfield CAB 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 3. As can be seen from Table 4, the Fairfield CAB was comparably priced with other CAB system constructed over the last six years. The cost breakdown shows that the CAB is still costly. AIT documentation suggests that the CAB 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.

Table 3: 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 4: 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, MI13	2012	$1,167,181.00	37’-7”	6’-7”	52’
Ellsworth, ME14	2013	$229,275.00†	40’-0”	14’-0”	32’
Fairfield, VT15	2014	$952,331.00	36’-2”	7’-6”	38’

* 2014 Inflation adjusted dollars (11)

‡ Final cost

† Composite arch superstructure only.

The bridge costs can be further broken down as shown in Table 5. 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 CAB. 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 6, one can see that most CAB 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 a square foot. Table 7 shows that the bridge-only costs for Ellsworth, ME and the Fairfield project both fell within this range.

Table 5: Breakdown of bridge costs

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

Table 6: Square foot cost of CAB 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, MI13	$597.23
Fairfield, VT15	$692.94
Average Sq. ft Cost	$617.01
* 2014 Inflation adjusted dollars (11)	

Table 7: Square foot cost of CAB systems (Bridge costs only)

Location	Square Foot Cost*
Ellsworth, ME14	$179.12
Fairfield, VT15	$206.83
Average Sq. ft Cost	$192.98
* 2014 Inflation adjusted dollars (11)	

7. Summary and Recommendations

The use of the CAB system was fueled by VTrans' searches to find new ways to construct bridges faster. These efforts began in response to the damage to Vermont's highways and bridges caused by storms including the Tropical Storm Irene in 2011.

VTrans found that the stated benefits of the CAB system have a sound basis. The bridge system was constructed rapidly with ease and simplicity. Observations made during construction suggest that more rapid and less expensive means and methods for constructing a CAB 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 CAB 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. CAB is expected to last at least 100 years with little maintenance, where most steel structures last about 75 years and require routine maintenance.

Observations from site visits show very little movement or deflection in the arches, and minor deflection in the headwalls that have remained stable for the last 3 years. No damage or abrasion has been observed to the tubes or composite decking.

The costs of the system seem to be at par with other bridge construction alternatives. As of 2018, there have been 23 CAB systems constructed. This small number means the cost of the materials and construction is higher than it will be when the system matures. With greater use of the system and increased construction experience, the costs associated with a CAB will likely decrease.

8. References

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9. Appendix

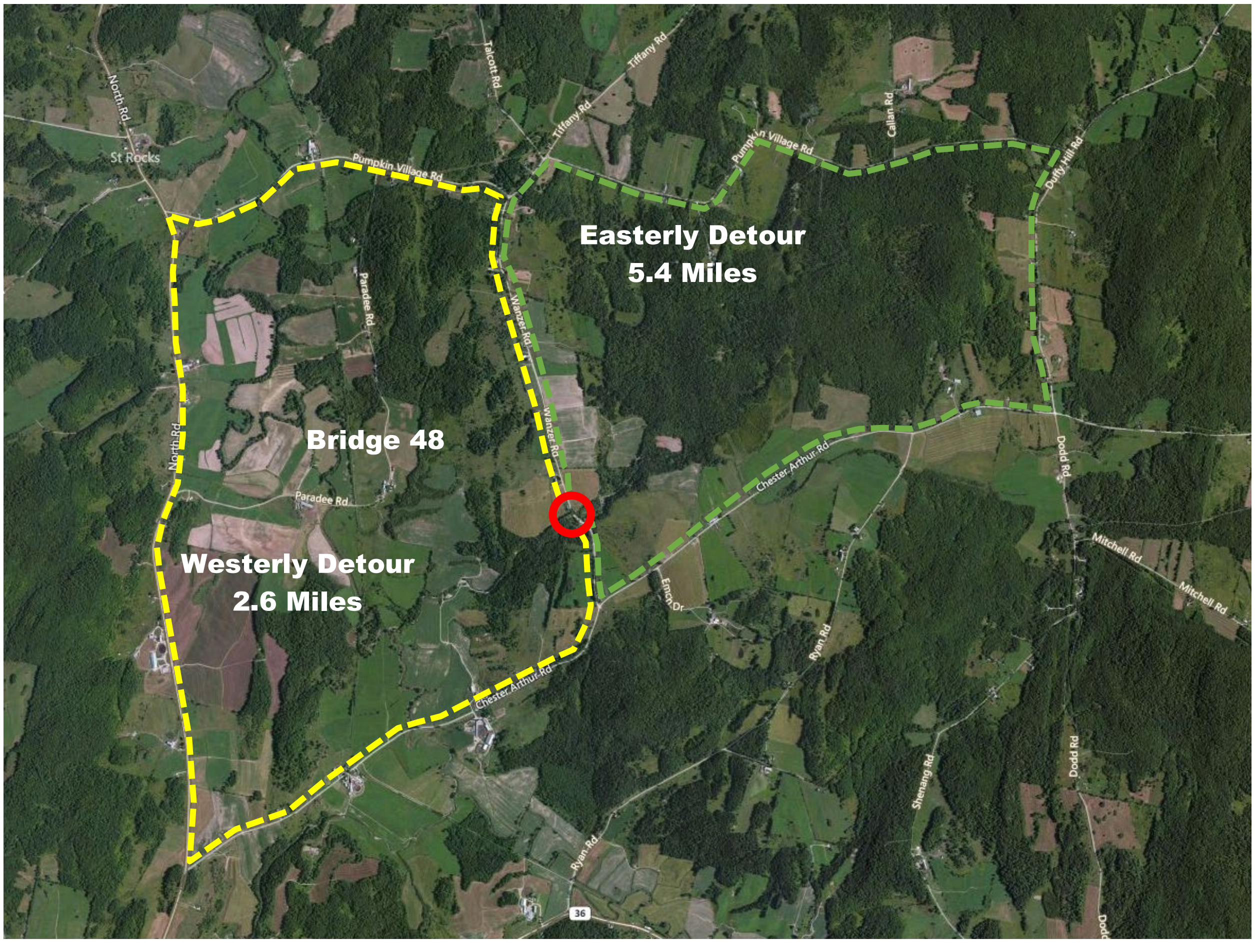

Figure 17: Detour Options