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VERMONT AGENCY OF TRANSPORTATION

Research and Development Section
Research Report

ASSESSMENT OF MECHANICALLY FASTENED FIBER REINFORCED POLYMER (MF-FRP) STRIPS FOR EXTENDING BRIDGE SERVICE LIFE

Report 2015 – 08

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Initial Report 2015 – 08

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Reporting on Work Plan 2013-S-01

STATE OF VERMONT
AGENCY OF TRANSPORTATION

RESEARCH & DEVELOPMENT SECTION

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16. Abstract

The enhancement of load rating concrete structures by the installation of Fiber reinforced polymer strips (FRP) is becoming a preferred short-term action. The addition of supplemental tensile capacity to concrete beams by applying high tensile strength FRP strips to the exterior of concrete structures provides immediate increase in live load capacity.

This study assessed the installation, theory and effectiveness of adding external FRP reinforcement. The assessment of the connections of the FRP strip to the concrete structure warrant further study to determine development strengths and bearing capacity.

Analysis of the system confirmed that it is a cost effective technique to increase load rating for concrete pier cap applications. Supplemental detailing to include improved shear connection at the bolting points may provide an improved in-place performance of the FRP.

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EXECUTIVE SUMMARY

Increasing weight and size of commercial freight loads is stressing infrastructure more than originally planned. In order to accommodate increased loads and maintain or extend service life for bridges, VTrans is examining simple retrofits. Fiber reinforced polymer strips (FRP) are a high strength, lightweight product for structural applications. FRP technologies have matured to provide increased tensile and shear capacity. These features make it a very desirable material to increase the structural capacity of concrete beam structures.

VTrans staff from Structures, Operations and Research joined in a project to install, rate and analyze FRP strip reinforcement of a pier cap that was suitable for retrofitting. The retrofit was accomplished with a minimum of resources. The strips were handled easily by manual labor, installed with hand tools in a period of one day. For installations that are outside of the travelled way, a crew of three persons can complete installation.

The technique involved attaching the FRP strips with a bolted connection. The connection itself is an area that may be improved further by addition of polymer to eliminate slippage the connection. If the detail is improved, even further capacity gains and durability will result.

The capacity increase on the 4-foot by 4-foot pier cap beam was approximately 40%. The capacity increase was limited by the capacity of the fasteners. Further capacity increases may be realized with the redesign of the connection and further analysis of the structural mechanisms to include the cantilever ends of the pier cap. The increased capacity accommodates current loads with less deflection, which is expected to extend service life as well as increase reliability.

In conclusion, retrofitting concrete structural elements with FRP strips is a very effective, simple process that VTrans personnel can be complete at low cost.

William E. Ahearn, P.E.
Research Managing Engineer

TABLE OF CONTENTS

ABSTRACT

The purpose of this study is to examine and evaluate the constructability, overall performance and cost effectiveness of using a retrofit repair method. Structures and Research personnel assessed the existing bridge condition before construction. Ongoing periodic assessment coupled with further analysis identified some opportunities to further the deployment of this technology to document all distresses, construction practices, and visit the sites annually to document any failures.

The enhancement of load rating concrete structures by the installation of Fiber reinforced polymer strips (FRP) is becoming a preferred short-term action. The addition of supplemental tensile capacity to concrete beams by applying high tensile strength FRP strips to the exterior of concrete structures provides immediate increase in live load capacity.

This study assessed the installation, theory and effectiveness of adding external FRP reinforcement. The assessment of the connections of the FRP strip to the concrete structure warrant further study to determine development strengths and bearing capacity.

Analysis of the system confirmed that it is a cost effective technique to increase load rating for concrete pier cap applications. Supplemental detailing to include improved shear connection at the bolting points may provide an improved in-place performance of the FRP.

The existing literature and engineering support documents are providing a protective level of conservatism in the assessment of bolt capacity. In light of field observations regarding eccentricity of load on the bolts, the values cited in the literature appear sound. Supplemental shear development by revised detailing and application of sustained shear adhesives in the bolt placement offer promise for this technology.

INTRODUCTION

Increasingly, Vermont Agency of Transportation (VTrans) is facing funding constraints. The need for implementing new solutions to ensure the safety and security of the Vermont transportation system while at the same time keeping costs to a minimum is pressing upon VTrans officials. Vermont's interstate system is aging. The construction of Vermont's interstate system, which began in the late 1950's, occurred within a short period (largely throughout the 1960's and into the early 1970's.) Many of the bridges on the system are now in need of rehabilitation work within a similar short period. Many bridges have exceeded or will soon exceed 50 years of service life and are starting to show significant wear. Vermont has been facing lean budgets with bridge rehabilitation efforts and this is likely to continue for the near future. To reduce the annual bridge rehabilitation and replacement costs, VTrans will need to adopt new means and methods to prolong the lives of these bridges sufficiently in the short term. This will give VTrans the ability to distribute rehabilitation or replacement costs over a longer period of time. With increasing loads and traffic demands by the traveling public of the Vermont infrastructure, these solutions need to minimize or eliminate inconveniences to schedules, typical routines and the functional freight capacity needs of the public.

Two structures selected for evaluating low-cost life-extending measures was a set of bridges on I-89 in Swanton. Each set of pier caps supporting the bridges, both northbound (98N) and southbound (98S) have been exhibiting significant cracking and concrete spalling along the tensile face of the pier caps between the columns. Without correction, structural capacity is likely to decrease. This is possibly due to the increase in load demand created by increases in traffic volume and vehicular loads or due to loss of confinement on the reinforcing steel. Traditionally, cracking can be repaired with standard patching repair methods; however, the standard concrete repairs would not have increased the flexural capacity of the pier caps. Flexural strengthening would reduce future cracking, provide additional load capacity and limit moisture exposure to the reinforcing bars. Methods include increasing the size of the section or adding tensile reinforcement.

The Agency chose to use Fiber Reinforced Polymer (FRP) composites to strengthen these bridges. Using FRP has been seen as a low cost and effective solution that has been gaining interest in recent years (Whittemore & Durfee, 2011). The advantage of FRP composites is that they are light in weight and corrosion resistant. FRP reinforcement has a broad application capability. One technique is using FRP strips applied as surface reinforcement to concrete decks and beams. This method is a rapid, non-invasive and low cost solution for strengthening bridges with very limited interruptions to the traveling public. The life extending measure was chosen for the I-89 bridges with the intent that they would provide added longevity and strength to the structures at the same time providing an excellent low-cost rehabilitation alternative that can be constructed with minimal impact to the traveling public.

PROJECT LOCATION AND SUMMARY

The experimental product was installed in conjunction with Swanton IM089-3(70) on both northbound and southbound bridges, 98N and 98S, located on I-89 at mile marker 123.400 in Swanton, VT (see Figure 1) The bridges carry I-89 over Vermont Route 78, which connects Swanton Village to the Town of Highgate (see Figure 2.) The southbound bridge was constructed in 1964 and the northbound in 1965 as part of the original I-89 construction. In 2009 and 2010 the bridges were cleaned, painted and received drainage maintenance. The southbound bridge received bridge joint repair, a new deck membrane and waterproofing. Over the 50 years of service life for these bridges, the bridge piers have accumulated significant cosmetic deterioration and some structural distress, which has reduced the bridge's capacity as shown in Figure 3. The two bridges were considered ideal candidates for the Agency to prolong the current expected service life and to increase their structural capacity sufficiently to extend the date for future replacement.

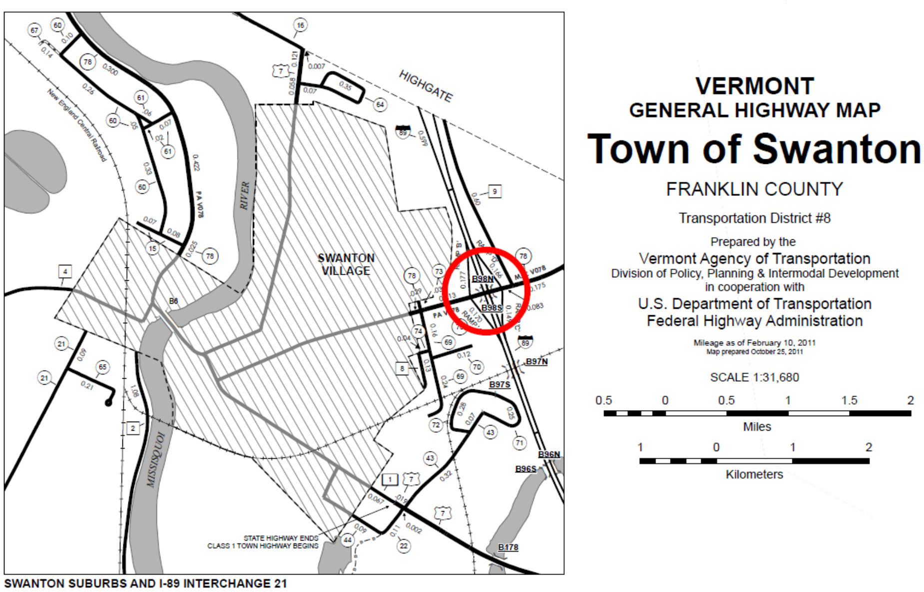


Figure 1 Project location in Swanton, VT (VTrans)

Figure 2 Project site – I-89 Bridge 98 over VT 78 in Swanton (VTrans 2010)

Figure 3   Concrete distress in pier bent (VTrans 2010)

MATERIAL DESCRIPTION

The selected material for this study was SAFSTRIP Fiber Reinforced Strengthening Strip shown in Figure 4. From the product documentation, SAFSTRIP® "*is a pultruded composite strip that improves the strength of an existing structural member when mechanically fastened to the structure. SAFSTRIP® has high bearing and longitudinal properties and is designed to strengthen the flexural capacity on the tension face of concrete girders, slabs and decks. Installation on bridges can occur without any interruption of service.*

SAFSTRIP® is supplied in rolls and may be pre-drilled with holes at the required fastener spacing to receive fasteners. SAFSTRIP® measures 4" wide x 1/8" thick and is shipped in rolls up to 100 ft. long. SAFSTRIP® is designed to be easily field cut by the customer into shorter lengths using standard carpenter tools." (Strongwell Corporation, Structural Reinforcements, 2015)

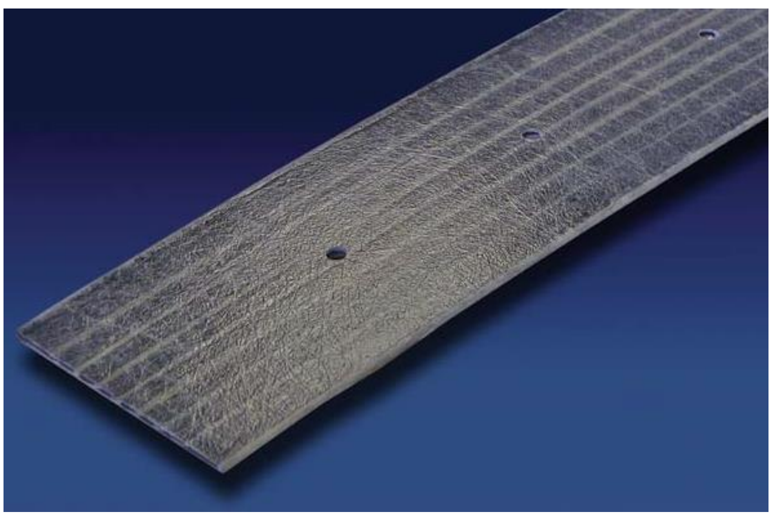


Figure 4 SAFSTRIP Fiber Reinforced Strengthening Strip (Strongwell Corporation, Structural Reinforcements, 2015)

SAFSTRIP® was developed by a joint effort by the University of Wisconsin and the Army Corps of Engineers. The intent was to create a "*long polymer bandage*" for troops to use to repair or reinforce bridges to carry a 113-ton military tank transport vehicle. The desire was to keep important transportation routes open during wartime. Though the use of similar strips had been in use for over a decade prior to the development of the FRP strips used in this study, they had to be glued in place. This required a significant amount of prep-work in good weather to obtain a surface where the glue could be applied and cured for a good bond. The strips in this study were developed to be fastened to "*crumbly, cracked and pockmarked undersides of a decades-old concrete bridge*" in any weather. (Bank, 2005)

Earlier strips were largely made of longitudinal fibers, which would split when punctured or when in bearing against a fastener. FRP strips such as the SAFSTRIP® product comprises of carbon fibers, glass fibers and glass mats. The glass mats are tightly woven, thereby preventing splitting of the strip when punctured or in bearing on a fastener. The load is adequately transferred through the strip bearing onto the fastener. (Bank, 2005)

The use of FRP strips similar to the SAFSTRIP® product has been effective in repairing and strengthening prestressed concrete bridge structures. An increasing number of State Transportation Agencies have accepted the use of FRP strips for this purpose. The strips, when applied to an external face of a concrete beam, have shown to be able to increase its flexure and shear capacities. The benefits of using FRP strips are that they are lightweight, easy to install manually and they provide a tremendous tensile strength. These features allow for an expedited installation with lightweight equipment, thereby reducing construction costs and impacts to the traveling public. (Zureik, 2010)

INSTALLATION

On Friday, May 16, 2014, Research personnel were present to observe the initial install of the FRP strips on the project site. The linear per-foot linear cost of installing the FRP strips was $125 with a total cost of $31,500. The install began on the northerly pier of the southbound lanes of I-89. The Contractor placed four FRP strips on the work platform. Each was predrilled with an alternating bolt pattern. The FRP Strips and the predrilled pattern can be seen in Figure 5.

Prior to the install, the Contractor had experimented with alternative fasteners to those specified by the FRP supplier for ease and speed of installation. The first alternative was a Hilti powder actuated fastener with a 0.158-inch diameter and a 1¾" length. This fastener is driven into concrete by the force generated from a Powers 0.27 caliber blank fired from a concrete nail gun (See Figure 6). This alternative had a moderate amount of success in new concrete; however, in older concrete, the force of the nail being shot into the concrete caused the concrete around the fastener to burst (See Figure 7).

Figure 5 FRP Strips to be installed (VTrans 2014)

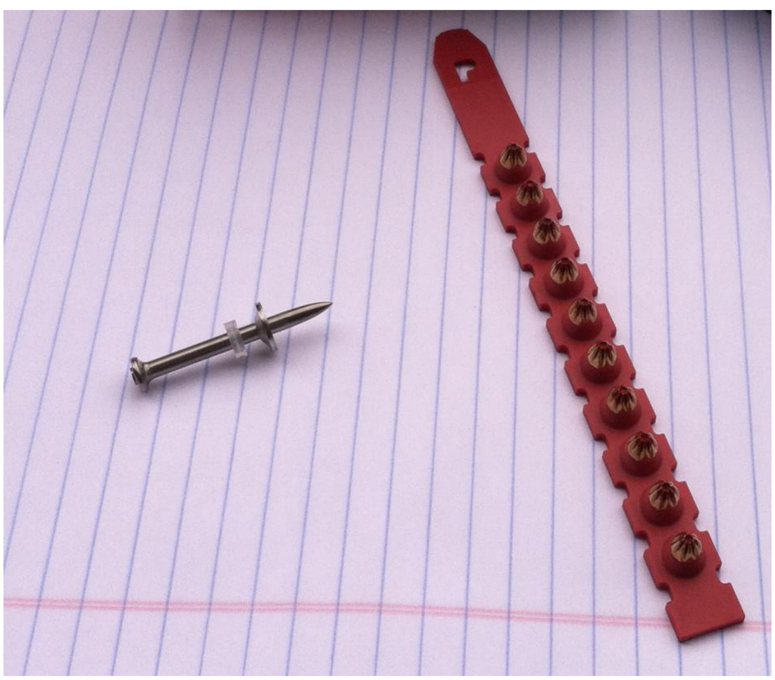


Figure 6 Hilti 0.158 inch x 1¾" Powder Actuated Fastener (VTrans 2014)

Figure 7 Powder Actuated Faster Caused Concrete to Burst (VTrans 2014)

The next alternative tried was the Perma Seal coated Tapper Plus® Concrete Screw (See Figure 8). The screws required a ¼" hole to be drilled in the concrete face. The screw was then inserted with the threads digging into the wall of the hole for a tight fit. The coating also acts as a lubricant to make insertion easier. Though this option seemed to work well for installation, the screw was standard steel with a protective coating that has a high risk of being scraped off during installation. With the application being subjected to potential chlorides from nearby roadway spray; it was felt that this would not be a good long-term solution. An alternative to the Tapper Plus® would be a similar product made with stainless steel. The use of the Tapper Plus® Concrete Screw requires a hole to be pre-drilled, similar to the specified swedge bolt.

The Contractor used the fastener specified, which was a ⅜-inch Power-Stud™ stainless steel swedge bolt (See Figure 9). Installation required a ⅜-inch hole to be drilled in the concrete. To match the holes in the FRP strip and in the concrete beam exactly, the installation required the strip to be placed and held in position. Using the predrilled holes in the FRP strip as a template, the Installer would drill a hole into the concrete. The swedge bolts were tapped into the holes with a hammer. The anchoring collar was lodged in the hole by friction. Once properly seated, a ratcheting socket wrench was used on the nut to pull the bolt out of the hole. The swedge bolt had a cone shaped wedge at its end. As the bolt was pulled out, the wedge pressed the lodged anchoring collar made of softer metal into the wall of the drilled hole, thereby fastening the bolt to the concrete beam. The installer then torqued the bolt to 28 ft-lbs or 3 to 5 turns past finger tight. (Powers Fasteners, 2011). Figure 10 shows the sequence. Figure 11 shows a completed pattern of bolts. Figure 12 shows the completed installation on one pier.

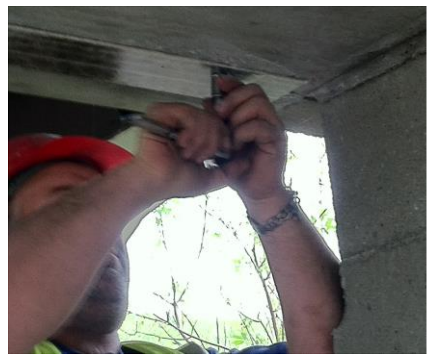
Figure 8 ¼" Tapper Plus® Coated Steel Concrete Screw (VTrans 2014)

Figure 9 Chosen fastener - a ⅜-inch Swedge Bolt (VTrans 2014)

Hold in Place

Drill

Tap in Swedge Bolt



Set Anchor with ratcheting socket wrench

Figure 10 Sequence of Installing FRP Strips (VTrans 2014)

Figure 11 Completed Pattern of Bolts (VTrans 2014)

Figure 12 Completed FRP Installation (VTrans 2014)

OBSERVATIONS AND ANALYSIS

The first problem encountered was in stabilizing the FRP strip while drilling. The space that the installers were working within was moderately cramped. When the drill started, the FRP strip jerked, which took it out of alignment. The installers tried using “two-by-four” wood studs to wedge the strip in place, which worked well. The Installer eventually bolted the strip in place every 18 inches or so, then went back to bolt the rest of the pattern. The idea of having an adhesive to adhere the strip in place was suggested by the installer. The adhesive could be applied by the fabricator with a peel-off cover to protect it before placement. It was felt that the adhesive would also seal the strip against the concrete surface to prevent roadway spray from permeating in between the two materials.

To bolt the strip to the concrete, the installer drilled ⅜” holes through the FRP strip and into the concrete to accommodate bumps on the anchoring collar (See Figure 13). This allowed for the proper setting of the anchor bolts into the concrete. However, this created a hole slightly larger than the shank of the swedge bolt. It is essential to know if the bolting pattern was designed as a bearing connection rather than a friction connection. If the deflection of the horizontal concrete pier bent where the FRP strip would go into tension, then the strip would slide to the extent of the gap. This being the case, small deflections may never engage the FRP strip, thereby never realizing the full benefit of the enhancement.

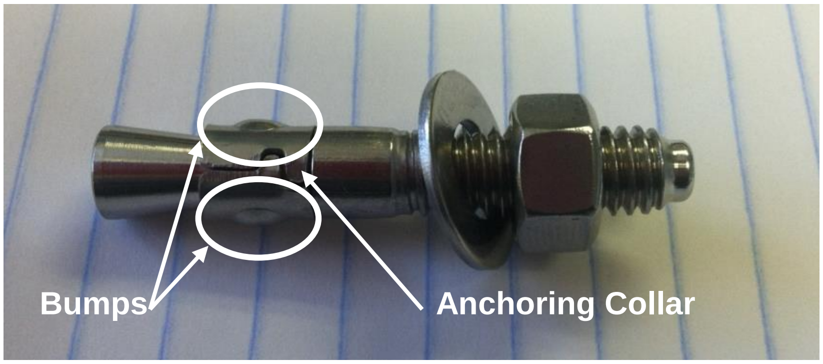


Figure 13 Swedge Bolt Features (VTrans 2014)

It is unknown what the friction coefficient between an FRP strip and concrete is. However, some observations of the two materials would suggest that little resistive force would be gained to stop slippage when compared with bearing with the 28 ft-lb torque. First, the FRP strip is very smooth and the concrete surface is rough. During the installation, it was observed that the strip would bridge over imperfections in the concrete surface and in so doing would not fully bear on the concrete. The coefficient of friction of concrete to steel is 0.45 and concrete to Teflon is 0.10. (Agboatwala) One could assume that the friction coefficient between concrete and the FRP strip could be somewhere in between. The maximum tensile force that can be obtained from the anchor bolts used is 480 lbs. (Powers Fasteners, 2011) At best, assuming full bearing at each bolt, the maximum resistant force that can be obtained is 220 lbs or less at each bolt location.

New Hampshire Department of Transportation (NHDOT) used similar FRP strips for a low-cost rehabilitation project on a small bridge in Gilford, NH. Of the assumptions NHDOT made, two specific assumptions should be considered in using FRP strips to prolong the life of a bridge. First, "*the tensile capacity in the FRP is transferred via friction but ultimately via bearing on the high strength wedged anchor bolts. Slip will begin to occur with subsequent engagement of the FRP in a progressive fashion, more and more bolts becoming engaged at higher stress levels.*" The second assumption is the "*capacity of the section is determined by the lesser of the bearing capacity of the bolts on the FRP verses the tensile capacity of the FRP net section.*" (Whittemore & Durfee, 2011)

Each anchor bolt has shear strength of 890 lbs. when anchored in 2,000-psi concrete or 940 lbs. when anchored in 4,000 psi concrete (Powers Fasteners, 2011). The FRP strip has a tensile strength of 92.9 ksi (Strongwell Corporation, SAFSTRIP, Fiber Reinforced Strengthening Strip, 2008). For exterior exposure, the maximum tensile strength is reduced by 85% to 79 ksi. (ACI Committee 440, 2002) The holes drilled in the strip are ⅜-inch holes (see Figure 14 and Figure 16). With the cross section of the strips measuring 4-inch by ⅛-inch, and the bolt pattern shown in Figure 14 the effective area of the strip was 0.453 in^2, which provides for strength of 35.8 kips per strip. To restrain 35.8 kips it would take 41 bolts on either end of the strip. The installed number of bolts per strip was 82. Considering the bolts within the midspan of the strip would likely never become engaged in bearing when the pier bent deflects, one could surmise that there are not enough bolts to resist the maximum strength of the FRP strip. For this installation, the resistance provided by the bolts is the controlling factor and not the resistance provided by the strips.

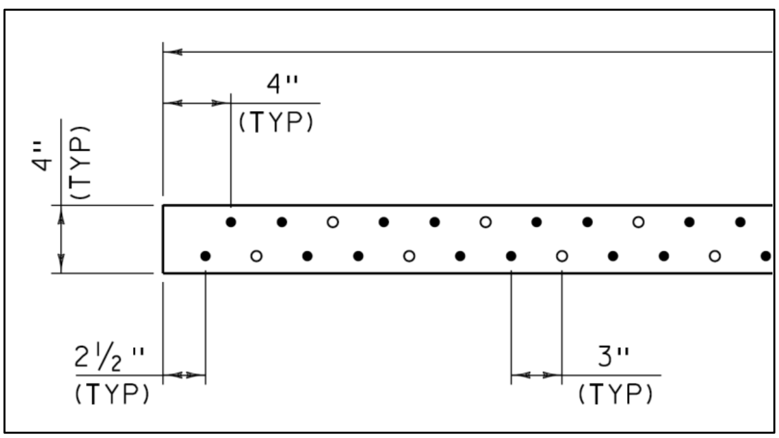


Figure 14 Hole pattern. Holes were drilled in the dark circles (VTrans 2012)

Based on the shear and moment characteristics of the beam, displacements are amplified at the ends of the span, but most notably outside the inflection points of the moment diagram. Assuming only 25% of the installed bolts on either end become engaged during an extreme event, the increased flexural capacity of the concrete pier bent would be determined by about 20 bolts resisting on each end of the strip. Twenty bolts provide a maximum resistance of 17.8 kips, or 39.3 ksi resistive tensile stress within the FRP strip. Due to the designed geometry shown in Figure 14, the FRP strips will only provide 42.3% of their maximum capacity.

The original design of the structure in 1963 assumed a concrete strength of 3 ksi and a reinforcing steel strength of 40 ksi. The design was for a 48-inch by 48-inch rectangular reinforced concrete section. With tensile steel comprising of four #5 bars and five #6 bars contained within #4 bar stirrups with a 2-inch clear distance to the face of concrete beam (Figure 15), the nominal moment capacity was calculated to be 704 ft-kips.

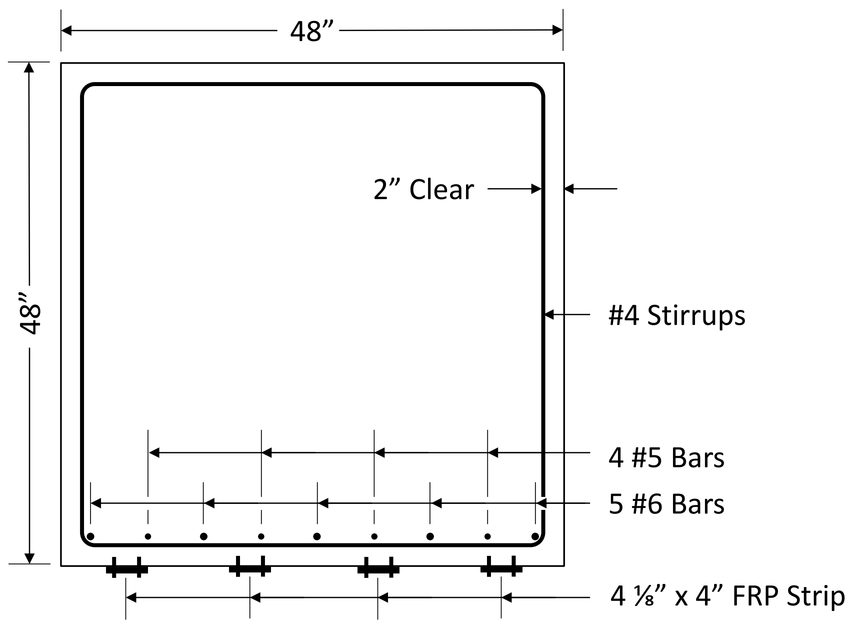


Figure 15 Pier Bent Section

Placing 4 FRP strips at the bottom face of the section effectively added 71.2 kips of tensile resistance at the bottom face of the bent. This translated to a modified nominal moment capacity of 978.4 ft-kips or an increase of capacity by almost 39%.

As Figure 17 shows, there is an approximate $^{1}/_{32}$” gap between the anchor bolt and the FRP strip. From observations made during the installation, this was mostly consistent throughout. In order to realize the increased capacity, the FRP strip will need to come into bearing with the bolts. In this application, one can assume that as the structure is loaded beyond the original capacity the deflection will cause the strip to pull inward from both ends, engaging one bolt at a time in succession. This allows the capacity of the concrete bent to increase as it is loaded, thereby providing a safety net and preventing the bent from cracking.

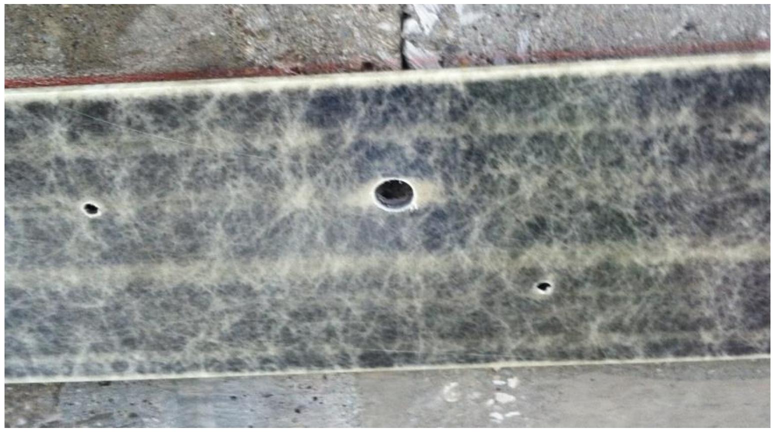


Figure 16 Drilled holes in FRP strip and concrete were ⅜-inch (VTrans 2014)

Figure 17 Swedge Bolt Anchored (VTrans 2014)

SUMMARY AND RECOMMENDATIONS

The system as installed suggests that it will provide the benefits that were anticipated and desired. The structural capacity of the pier bents has been enhanced by applying the FRP strips, thereby extending the service life of the bridge. In addition, the cost to increase the capacity was very low when compared to a reconstruction. Finally, installing the enhancement allowed for full traffic flow on VT 78. Using FRP strips to increase the capacity of a concrete beam, effectively met the objectives to extend the life of a bridge in need of rehabilitation in a cost-effective way without affecting the traveling public.

To enhance the performance of the system, it is recommended that the gap between the anchor bolt and the FRP strip be filled sufficiently with a stiff enough material to engage a bearing connection at the onset of deflection. This will provide the maximum structural capacity of the beam throughout the loading cycle. Bolts within the midspan may not be necessary. To ensure contact and to aid in application, it is recommended that an adhesive be used to adhere the strips in place before bolting.

APPENDIX A

The following Capacity Calculations are based on the AASHTO Standard Specifications. The initial check was to determine if the FRP Strips would be the controlling factor of the enhancement. With the assumption that the midspan bolts would never become engaged in bearing, the outer 20 bolts were assumed to carry the tensile load from the FRP strip. The calculations then transforms the FRP strips into steel. With the additional reinforcement, the increase of capacity is calculated. With these calculations, it was shown that the FRP strip increased by 39%.

Capacity Check for FRP Strips - Swanton I89 Bridges over US Rte 7

Assumptions

Class B Concrete with strength less than 3,000 psi Power-Stud is rated with either 2,000 psi or 4,000 psi and higher for the 3/8 swedge bolt. Using the values provided for 2,000 psi.

Initially this evaluation is assuming a bearing connection.

Bolt Shear Ultimate Capacity

$$v_b = 890lb$$

FRP Strip Axial Tension Capacity from Documentation

$f_{frp} = 92.902ksi$ — Tensile strength of FRP strip

$C_e = .85$ — Coeficient for Exterior exposure ACI 440.2

$f_{frp'} = f_{frp}\ C_e = 78.967\ ksi$ — Adjusted Tensile strength for Ce

$t_{frp} = \frac{1}{8}in = 0.125\ in$ — Thickness of Strip

$b_{frp} = 4in$ — Width of Strip

$A_{frp} = t_{frp}\ b_{frp} = 0.500\ in^2$ — Gross area of strip

$s = 3in$ — Bolt spacing horizontal

$g = 2in$ — Bolt spacing vertical

$\phi_b = \frac{3}{8}in = 0.375\ in$ — Diameter of Bolt

$\phi_h = \phi_b = 0.375\ in$ — Diameter of Hole

$A_h = \phi_h\ t_{frp} = 0.047\ in^2$ — Area of Hole

$A_{e1} = A_{frp} - A_h = 0.453\ in^2$ — Effective area straight line

$A_{e2} = A_{frp} - 2\ A_h + \left(\frac{s^2}{4\ g}\right) t_{frp} = 0.547\ in^2$ — Effective area through diag's

$A_{frp'} = min(A_{e1}, A_{e2}) = 0.453\ in^2$ Effective area of FRP strip

$T_{frp} = A_{frp'}\ f_{frp'} = 35.782\ kip$ Axial Tensile Capacity

Number of bolts to resist maximum capacity of strip

$n = \dfrac{T_{frp}}{v_b} = 40.204$ $n = 41$ $n_{tot} = 82$

Total number of bolts =82
Need 41 to resist either side

Need 41 bolts on either end to resist maximum tension

A total of 82 bolts were installed throughout the FRP strip. 41 bolts are half of the bolts installed. This essentially means the strip will never achieve maximum tensile capacity. The bolts within the midspan of the abutment cap will not experience any bearing. As the Abutment Cap deflects, the strips will pull inward from the midspan. It is expected that the outer bolts will be enganged in bearing. For simplicity, 25% of the bolts will be assumed to be engaged in bearing.

$n_b = .25\ n_{tot} = 20.500$ $n_b = 20$ Will use 20 bolts at each end

$P = n_b\ v_b = 17.800\ kip$ Total resisting force from 20 bolts

Maximum Stress expected in FRP strip

$f_{frp'} = \dfrac{P}{A_{frp'}} = 39.283\ ksi$ $capacity = \dfrac{f_{frp'}}{f_{frp}} = 0.423$ Only using 42.3% of capacity of the strips.

Cross section of the Abutment cap is essentially a 48 x 48 inch beam with 5 #6 bars and 4 #5 bars contained within stirrups of #4 bar with a 2" concrete clearance, the Nominal Capacity of the beam is:

$b = 48in$ Width of Beam

$h = 48in$ Height of Beam

$f_{c'} = 3.000ksi$ Concrete Strength

$f_y = 40.000ksi$ Reinforing Strength

$A_s = 4.76in^2$ Area of Reinforcing 4~#5 and 5~#6

$\beta_1 = .85$

Ratio of depth of equivalent compressive zone to depth from fiber of maximum compresive strain to the neutral axis

$$\rho_b = \frac{.85\ \beta_1\ f_{c'}}{f_y}\left(\frac{87000psi}{87000psi + f_y}\right) = 0.03712$$

The Balanced Reinforcement Ratio

$$\rho = \frac{A_s}{b\ h} = 0.002$$

Ratio of reinforcement provided

$$\rho_{max} = .75\ \rho_b = 0.028$$

Maximum Ratio

$$a = \frac{A_s\ f_y}{.85\ f_{c'}\ \ b} = 1.556\ in$$

Depth of Equivalent rectanglar compressive block

Depth to center of Reinforcing

$$d = h - 2in - \frac{1}{2}in - \frac{1}{2}\left(\frac{6}{8}in\right) = 45.125\ in$$

$$M_n = \left[A_s\ f_y\ d\left(1 - .6\ \frac{\rho\ f_y}{f_{c'}}\right)\right] = 704.1\ ft\ \ kip$$

Nominal Moment Capacity

$$d_{frp} = h + \frac{1}{2}\left(t_{frp}\right) = 48.063\ in$$

Depth to center of FRP strips

$$n_{frp} = \frac{f_{frp'}}{f_y} = 0.982$$

Ratio of FRP engaged to reinforcing steel

$$A_{frpt} = A_{frp'}\ n_{frp}\ 4 = 1.78\ in^2$$

Effective Area of 4 FRP strips transformed into reinforcing steel.

$$d_{eff} = \frac{A_s\ d + A_{frpt}\ d_{frp}}{A_s + A_{frpt}} = 45.925\ in$$

Effective depth to centroid of the reinforcing and transformed frp

$$A_{eff} = A_s + A_{frpt} = 6.54\ in^2$$

Area of Reinforcing and transformed FRP

$$\rho_{frp} = \frac{A_{eff}}{b\ h} = 0.003$$

Ratio of reinforcement provided

$$a_{frp} = \frac{A_{eff}\ f_y}{.85\ f_{c'}\ \ b} = 2.137\ in$$

Depth of Equivalent rectanglar compressive block

$$M_{nfrp} = \left[A_{eff}\ f_y\ d_{eff}\left(1 - .6\ \frac{\rho_{frp}\ f_y}{f_{c'}}\right)\right] = 978.4\ ft\ \ kip$$

Nominal Moment Capacity of section with FRP strips

$$Improvement = \frac{M_{nfrp}}{M_n} = 1.39$$

FRP strips provide a 39% improvement to the moment capacity of the beam.

$$P_{tot} = P\ 4 = 71.2\ kip$$

Total Tensile reisitance added by FRP

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Approved Date
3/21/13
Planning & Programming Engineer
Federal Highway Administration

Prepared By: George Colgrove
Date: February 14, 2013

STATE OF VERMONT
AGENCY OF TRANSPORTATION
MATERIALS AND RESEARCH SECTION

WORK PLAN FOR RESEARCH INVESTIGATION
Assessment of Fiber Reinforced Polymer (FRP) Strips for Bridge Rehabilitation
Work Plan No. 2013-S-1

INTRODUCTION:

Increasingly, Vermont is facing serious budget constraints as are many states as well as the federal government. The need for implementing new solutions to ensure the safety and security of the VT transportation system, at the same time keeping costs to a minimum is pressing upon VTrans officials. Such solutions will need to provide the minimum acceptable means of preserving the current state of public transportation structures. Vermont's interstate system is aging. Many bridges are passing or have passed their 50th year anniversary of their construction and are starting to show their wear. Since the early construction of Vermont's interstate system fell within a short time frame, many of these bridges are now requiring necessary rehabilitation within the same time frame of each other. Vermont has been facing lean budgets with bridge rehabilitation and this is likely to continue for the near future. VTrans will need to find ways to prolong the lives of these bridges while spreading out the rehabilitation projects to a greater number of years. The Structures section is looking for low-cost rehabilitation alternatives to prolong the lives of these bridges.

With the increasing demand by the traveling public for the use of our infrastructure in both structural and traffic capacities, these solutions also need to address minimizing any inconvenience to schedules, typical routines and carrying-weight needs. Two structures under consideration for evaluating low-cost rehabilitation alternatives are the north and southbound I-89 bridges in Swanton. Each set of pier caps on I-89 bridges 98 North and South are showing signs of cracking and spalling concrete along the tension face of the pier caps between the columns indicating a lack of flexural strength, possibly due to the increase in load demand likely created by an increase in traffic volume and vehicular loads. The cracking could be repaired with standard patching repair methods. However the standard concrete repairs would not address the lack of flexural capacity of the pier caps. Flexural strengthening could prevent future cracking and exposure to moisture which would prevent additional spalling concrete and corrosion to the reinforcing bars. All of the flexural strengthening methods work by increasing the section or adding tensile reinforcement to the structure in question.

The rehabilitation method required for these bridges will need to provide added longevity and strength to the structures at the same time providing an excellent low-cost rehabilitation alternative that can be constructed with minimal impact to the traveling public.

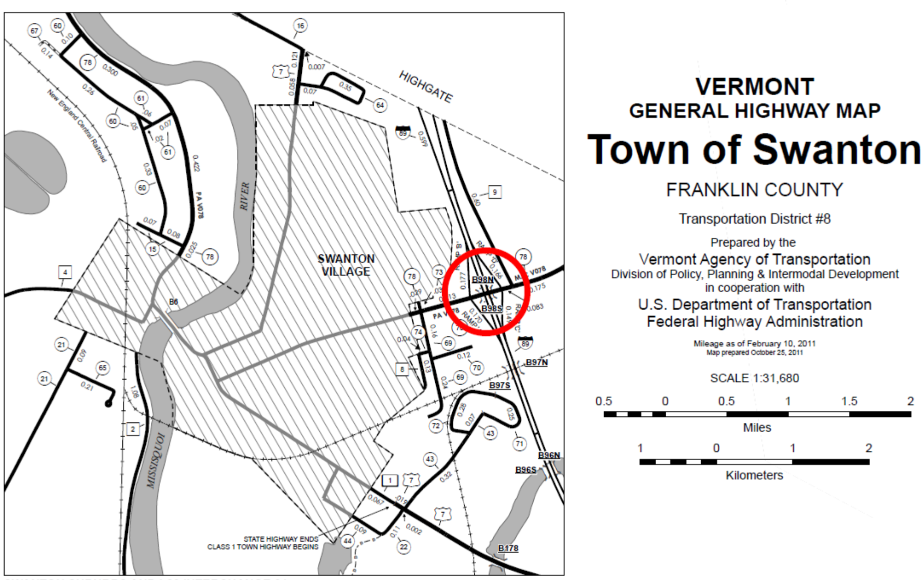
Using Fiber Reinforced Polymer (FRP) composites for rehabilitating and strengthening these bridges is being considered. Using FRP has been seen as a low cost and effective solution that has been gaining interest in recent years. The advantage of FRP composites is that they are light in weight and corrosion resistant. FRP reinforcement has a broad application capability. One technique is using FRP strips applied as surface reinforcement to concrete decks and beams. This method is a rapid, non-invasive and low cost solution for strengthening bridges with very limited interruptions to the traveling public.

OBJECTIVE:

The purpose of this study is to examine and evaluate the constructability, overall performance and cost effectiveness of using this repair method. Structures and Research personnel will assess the existing bridge condition prior to construction to document all distresses, construction practices, and visit the sites annually to document any failures.

PROPOSED LOCATION:

The proposed project location is bridge 98, north and south bound on I-89 at mile marker 123.4m in Swanton, VT. The pier caps have structural distress that has reduced the bridge's capacity. The bridges received maintenance recently. The Agency would like to prolong the current life and capacity of the bridges and extend the date the structure will have to eventually be replaced. The rehabilitation project is Swanton IM089-3(70).

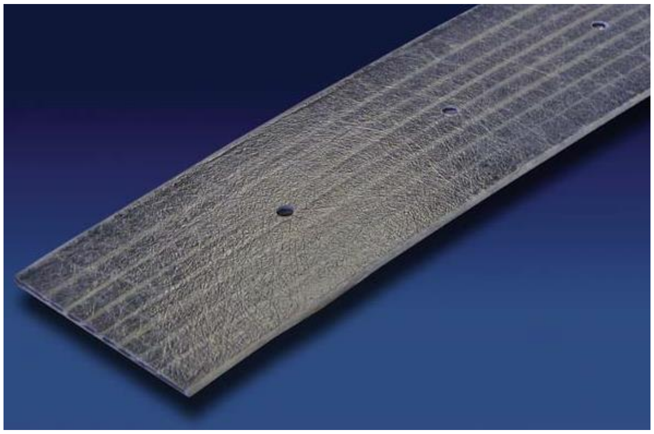


SWANTON SUBURBS AND I-89 INTERCHANGE 21

MATERIAL:

The selected material for this study will be SAFSTRIP Fiber Reinforced Strengthening Strip. From the product documentation, SAFSTRIP® "*is a pultruded composite strip that improves the strength of an existing structural member when mechanically fastened to the structure. SAFSTRIP® has high bearing and longitudinal properties and is designed to strengthen the flexural capacity on the tension face of concrete girders, slabs and decks. Installation on bridges can occur without any interruption of service.*

SAFSTRIP® is supplied in rolls and may be pre-drilled with holes at the required fastener spacing to receive fasteners. SAFSTRIP® measures 4" wide x 1/8" thick and is shipped in rolls up to 100 ft. long. SAFSTRIP® is designed to be easily field cut by the customer into shorter lengths using standard carpenter tools."



SURVEILLANCE AND TESTING:

Temporary Strain Gages will be installed on the underside face of the piers prior to the concrete repair. Measurements will be taken on the structure to provide a baseline of the current performance of the pier caps. After the concrete surfaces have been repaired, a more permanent set of strain gages will be installed. Measurements will be taken before and after the FRP strands are placed to isolate the effectiveness of the FRP strands by themselves, by eliminating the positive effects the concrete repair will have on its own.

1. **Test Sites:**
   The test sites will be the four mid-span piers of both bridges.

2. **Construction:**
   The FRP Strips will be installed according to the plans by affixing the strips to the pier using a bolt pattern.

3. **Deflection measurements:**
   a. First measurements will be taken prior to construction to obtain a baseline performance of the current structure.

b. Second measurements will be taken after the concrete repairs are made, to provide a baseline to isolate the effectiveness of the FRP Strips.
c. Third measurements will be taken after the strips have been installed. This set of measurements will be used to demonstrate the effectiveness of the FRP strips by themselves.
d. Final measurements will be taken a year after strips have been in use to help determine if there are long term concerns of the performance of the FRP stripes.
e. If concerns arise as to the long term performance of the FRP Strips, additional measurements may be made in subsequent years to address these concerns.

4. **<u>Site Visits:</u>**
   Members from Structures and Research will periodically visit the two bridges to make observations as to the condition of the FRP Strip installation. These observations will be used to determine if additional measurements will need to be made after the measurements in 3(d) above.

<u>COST:</u>

Material, labor, and equipment costs incurred will be paid for by project funds while rehabilitation construction work is underway. All additional costs that occur after construction, including site visits, future analysis and report preparation and publication will be paid for by the task entitled, "Evaluation of Experimental Features." The costs may include paying for the sensors and the purchase or rental of the necessary equipment used to acquire the data for this research. As an alternative the State may acquire the services of a consultant to install and collect the readings using their equipment.

Total project costs will be $64,100.00

1. Cost of installing the FRP strips: $12,600.00.
2. Cost of gages and sensors: $10,400.00.
3. Other Labor and contracting costs: $41,100.00

Annual breakdown of costs:

2013	$48,800.00
2014	$7,500.00
2015	$1,000.00
2016	$1,000.00
2017	$1,100.00
2018	$4,700.00

The funding for the research project will be $15,000 from Research Experimental Features Funds and $49,000.00 from Project funding.

STUDY DURATION:

The project will be under evaluation with measurements being taken for up to 12 months after the construction is complete. Additional observations will be made with optional measurements being taken if concerns about the effectiveness of the installation arise. In no case will this project extend beyond five years after the construction is complete.

REPORTS:

Structures and Research will produce a joint initial report that covers the bidding, contracting and installation of the FRP Strips and the initial testing apparatus. The initial report will include the pitfalls and perceived benefits of working with the FRP Strips.

A final report will be published once the 12 month evaluation is complete. This report will extend from the initial report and add the observations made in the 12 month period and will cover the capacity the pier caps gained in using the alternative rehabilitation method. The final report will also include an implementation strategy that will cover where the Agency should go upon the success or failure of this evaluation.

If observations that continue past 12 months reveal concerns, additional funding will be sought to fund additional measurements of the structural integrity of the pier caps. A revised report will be delivered that will cover the concerns and findings with a strategy to remedy the discovered problems.

Reviewed by: ________________________________

William Ahearn, P.E.
Materials and Research Engineer
Date:

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