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ASSESSMENT OF JAHN PERMEABLE MORTAR SYSTEM IN A HISTORIC BRIDGE ABUTMENT APPLICATION

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16. Abstract

Increasingly, the importance of historic preservation is competing with the requirements to enhance structural capacity of older unique structures. Preservation of the functional and aesthetic qualities limits potential change to meet the expanded needs of the traveling public. The Taftsville Covered Bridge in Woodstock, Vermont was deteriorating at a time the public needed increased capacity. Then in 2011, the tropical storm remnant of Hurricane Irene rendered the bridge impassable. Significant damage to the substructure and superstructure occurred. The bridge required a complete deconstruction and reconstruction to correct deficiencies and enhance capacity. Design and construction techniques focused on retention of the historic presence and value the bridge offered for over a century and a half.

The Taftsville Covered Bridge has been repaired and improved many times over its life. This project continued that trend by restoring one abutment and pier with added strength by the use of Jahn mortar and grout. The existing laid-up stone was repointed with Mortar with minimal addition of new stone where large gaps were located. Once the shell formed by the existing stone and the new mortar set up, a flowable grout was placed within the stones to bond the stones together, thereby strengthening the substructures. The containment of the stones provided increased reliability in addition to strength. The permeability of the Jahn system minimizes damage caused by internal hydrostatic pressures and the effects of chlorides locked within the stone substructures observed in other mortars and grout systems. The feature the Agency hoped to maintain from this was the high permeability of the abutment. This work was conducted in 2012 following significant damage to the Bridge following Tropical Storm Irene.

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Table of Contents

Table of Figures

1. Introduction

Historic bridges throughout Vermont, such as the Taftsville Covered Bridge (Figure 1), are in need of rehabilitation. Emphasis is being put on preserving their distinct historic look while ensuring the safety of the public and longevity of the existing structure. In most cases, the goal with preservation efforts is to retain the original materials and construction to the greatest possible degree. For the Taftsville Covered Bridge, the superstructure required extensive reconstruction to address deficiencies and damage from the flooding of the 2011 Tropical Storm Irene. The rehabilitation work used as much of the original design, timber and construction means and methods as possible to maintain the bridge's historic appearance while providing the enhanced structural capacity required by the traveling public. Only essential enhancements were made, which required new materials and components that were not in the original structure.

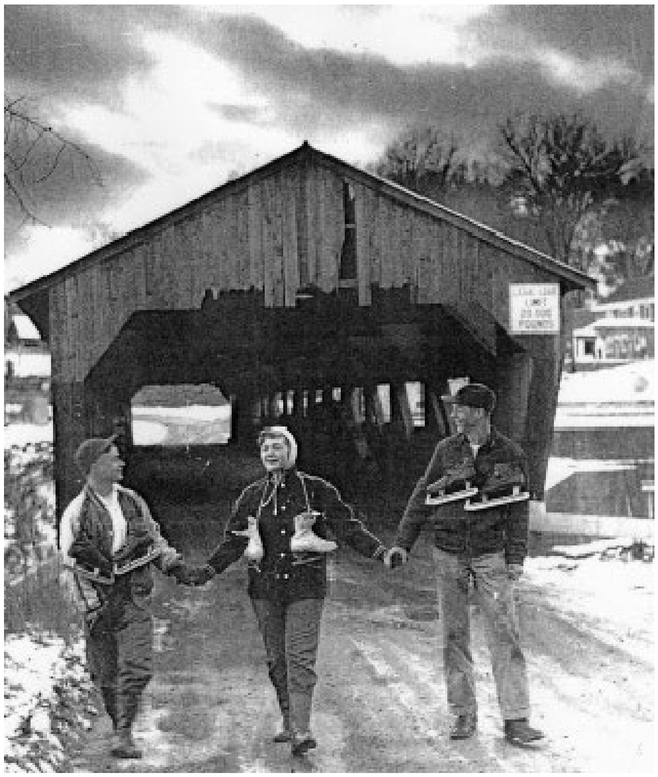

Figure 1: Taftsville Covered Bridge in the 1940's

This study focused on the repair of the substructure. The existing stone and concrete masonry components of the substructure were intact (Figure 2) with the exception of the western abutment. The western abutment was reconstructed with stone-faced reinforced concrete, while the two surviving substructure components were identified for preservation. Typically, this type of preservation is accomplished by removing and replacing the deteriorated mortar with new pointing mortars and grouts to fill in the gaps and void spaces between stones in the wall. During design and construction, it is vital to account for lateral forces that build up behind the wall from rain events, frost penetration and groundwater. In the case of piers and abutments, consideration must also include vertical forces applied by the superstructure's weight and applied live loads. Preservation considerations were centered on maintaining the visual appearance of the surviving pier and abutment. All structural enhancements were hidden from the sight for that reason. The repaired bridge in 2012 can be seen in Figure 3.

This study centered on permeable grouts and mortars that were used to shore up the pier and abutment. Permeable grouts allow moisture to seep slowly out from within the abutment stonework thereby reducing the risk of increased lateral instability due to hydrostatic pressure buildup. The mortar used must adhere to the stone with the specific strength and stiffness requirements and must have a lower compressive strength and a greater vapor permeability than the masonry abutments. The intent of the rehabilitation project was to treat the surviving dry-laid stone foundation components with a proprietary permeable mortar that fulfilled these functions. Specifically, the grouting system used in this study was the Jahn M110 Historic Pointing Mortar and the Jahn M40 Crack and Void Injection Grout (Cathedral Stone Products, Inc., 2012).

The Vermont Agency of Transportation (VTrans) began this study to examine and evaluate the impacts of the constructability, overall performance and life cycle cost of a permeable mortar and grout system. The materials used in this study were designed by Cathedral Stone Products specifically for the Taftsville covered bridge rehabilitation project.

Figure 2: The Taftsville Covered Bridge in 2006 showing the Pier and Abutment that were preserved

Figure 3: Taftsville covered Bridge after repair in 2012

2. Project Background

2.1. Project Location

Jahn permeable mortar and injectable grout was used on the Taftsville Covered Bridge project, Woodstock BHO1444(52). The bridge is located on Town Highway 2 ("*Covered Bridge Road*") spanning the Ottauquechee River, roughly 105 feet east of its intersection with US 4 in the town of Woodstock (Figure 4).

2.2. Taftsville Covered Bridge History

The historic commemorative plaque placed at the project site explains (Figure 5):

> "*The Taftsville Covered Bridge is a rare example of early vernacular wooden truss covered bridges in the United States. All evidence indicates the builder, a longtime Taftsville resident named Solomon Emmons III, used no existing patented bridge truss design, and that the design and construction techniques are unique. Constructed entirely of local wood and stone in 1836, at a cost of $1800, it is the oldest covered bridge in Windsor County, and is the third oldest bridge in the state. At approximately 189 feet in length at the floor, and 200 feet at the roof, it is the second longest covered bridge in Vermont. On August 28, 2011, Tropical Storm Irene devastated the south abutment, closing the bridge for two years while extensive repairs and renovation efforts were made*."

Figure 4: Project location

Figure 5: New historic plaque at the Taftsville Covered Bridge

Originally built in 1836, the Taftsville Covered Bridge is 198 feet long (along the roofline), 14.8 feet wide, with a single lane (Figure 6). The bridge was built to maintain the connection across the river for the community and businesses established by the Taft brothers with the major nearby throughway NE Route 13, now known as US Route 4. In 1793, a footbridge, which was washed away in 1807, was built at the location. Two other bridges had been built in the same location (one washed out in 1811 and the other in 1828) before the present bridge was constructed. The bridge was first painted red in 1959. On August 28, 1973, the bridge was included in the National Register of Historic Places.

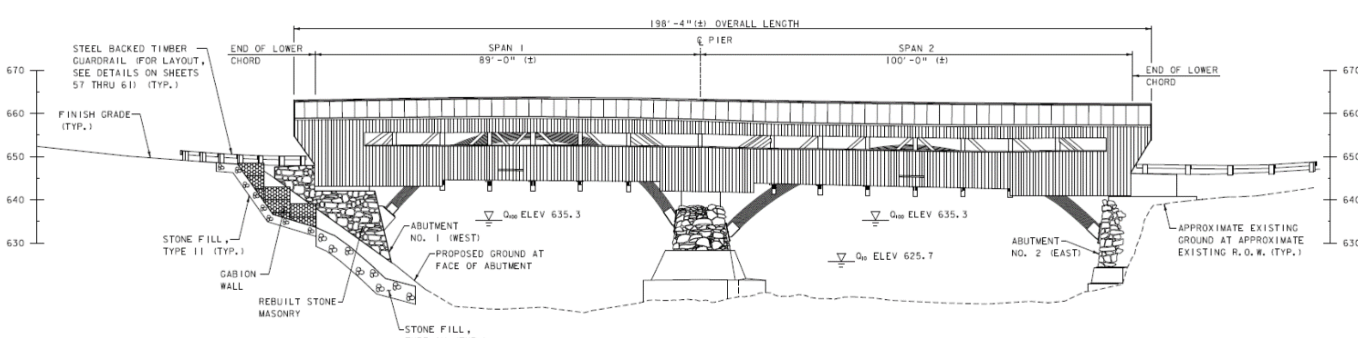

Figure 6: Profile of the Taftsville Covered Bridge

The covered bridge comprises of two spans; 89 feet and 100 feet, and is rated to carry 8 tons. Its design is roughly along the lines of a long Multiple Kingpost Truss with semi-independent arches (Figure 7). The United States National Park Service suggests its significance is because the "*Taftsville Bridge is a rare survivor of the early craftsman tradition of wooden truss bridge building. It shows no influence from any of the patented bridge truss designs, but the builder may have been aware of the Swiss tradition from published literature of the time*" (Christianson, 2006).

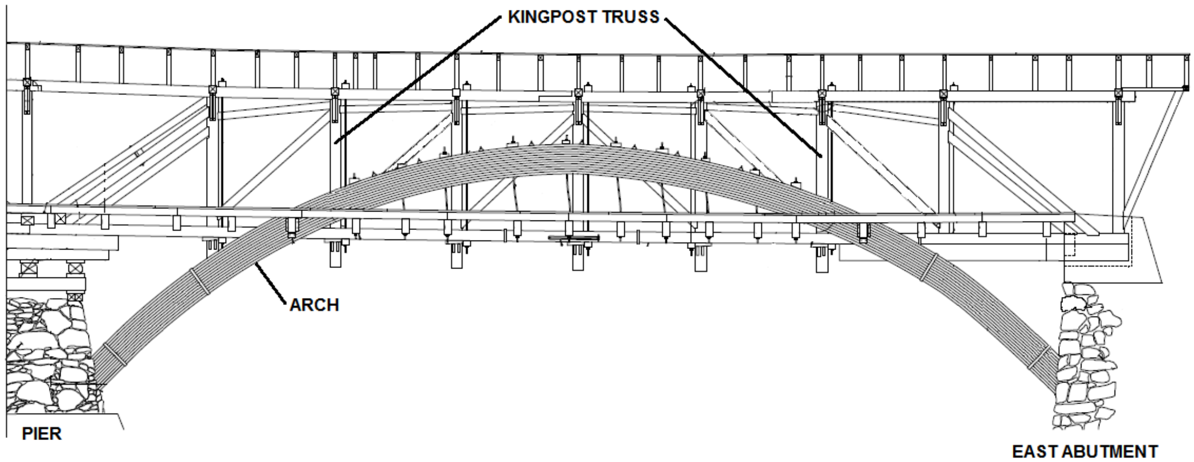

Figure 7: Configuration of the eastern span showing arches

The bridge was rehabilitated in 1869 when it was raised 3 feet and rehabilitated once again in 1910 (Christianson, 2006). It is suspected that the laminated timber arches were added in 1914 to accommodate load-rating requirements set by the Vermont Highway Department in 1913. A little later, the windows were opened along the sides of the bridge (Christianson, 2006) (Figure 8). In 1952, the bridge underwent extensive reconstruction activities by Miller Construction. According to the scope of the project, Woodstock SA 5, "*the project contemplates the squaring, aligning, raising the trusses one foot, installing new concrete foundation pads and backwalls at abutments, replace of all defective truss members, adjustment of arches and arch bases, installing new steel braces at top chord, repairing of the top chord lateral system, a complete new floor system, and plank guard rail at bridge ends. Also, such repairs to end overhangs, siding, etc. as is necessary for a complete and satisfactory job*." Repairs to the abutment included new concrete caps being built on each abutment and short wingwalls at each corner of the bridge superstructure. Minor maintenance work was done in the 1980's with the addition of distribution beams and in 1993 where repairs to the roofing and tie beams were made.

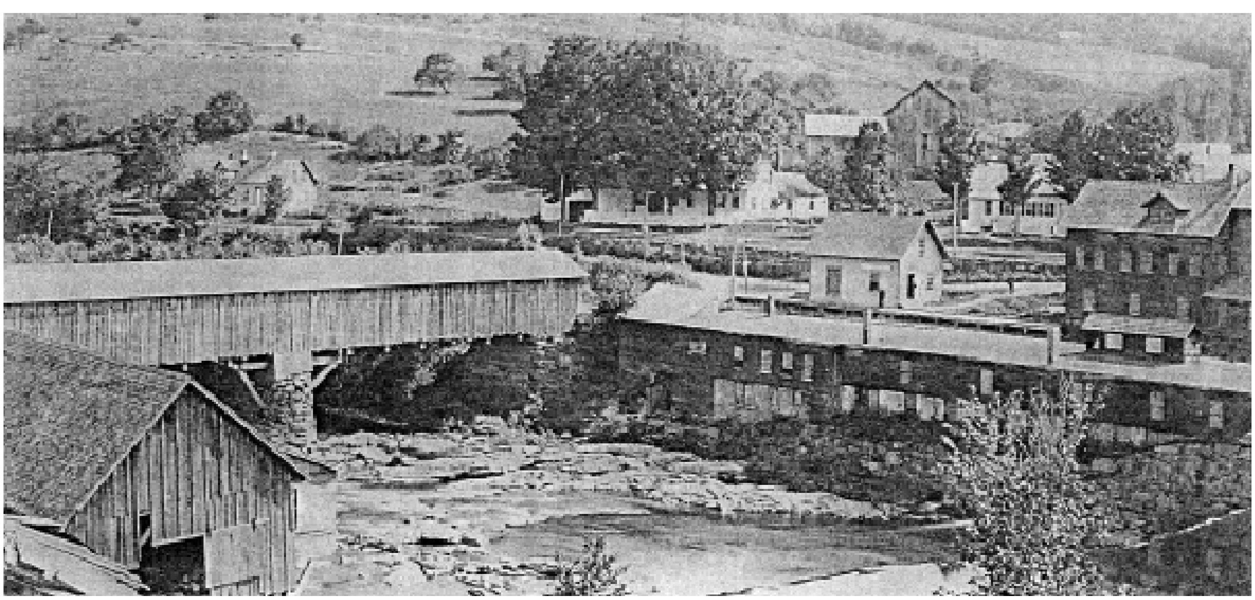

Figure 8: The Taftsville Bridge in the mid 1910's with laminated arches, but before the windows were opened

On August 28, 2011, Tropical Storm Irene caused significant damage to the crossing. The western abutment was undermined and partially collapsed (Figure 9), causing damage to the timber structure of both spans of the bridge. Though the bridge remained standing, the western abutment continued to break apart in the months after the storm. That winter, the western span was removed except for the arches (Figure 10). The timber was carefully removed, labeled and stockpiled at the town garage for later use in the rehabilitation project. For nearly two years, the surviving components of the structure lay dormant. In late 2012, construction began on the bridge and on September 7, 2013 the bridge was reopened after extensive $2.5 million reconstruction was completed.

Figure 9: Western abutment partially collapsed

Figure 10: Western span dismantled leaving only the arches

2.3. Bridge Condition

Before the extreme weather event, the 2010 Inspection summary notes indicated, "*The structure is in need of full rehabilitation due to a heavy sag in* [the eastern] *span, twisted arches in both span areas, significant horizontal sweep of both spans towards the downstream channel and overall racking of the structure towards the downstream channel*". At the time, the structure was rated stable for scour. The summary from the 2008 inspection references the abutments and piers, and states "[the western] *Abutment upstream wing and stem are quite unstable. The pier is somewhat unstable on the upstream side.*" Average annual daily traffic (AADT) at the location of this bridge was 1500 vehicles as of the 2008 reporting.

According to McFarland Johnson, the engineering firm hired to design and specify the rehabilitation work for the covered bridge, the dry-laid stone abutments and pier have flaws and weaknesses. The pier comprises of dry-laid stone down to the riverbed. The pier and abutments have a concrete skirt encasing the stone pier placed after the original construction, which can be seen in Figure 10.

The flooding eventually undermined the western abutment at the downstream end. The abutment fractured, resulting in the downstream western arch to pull out of the stone socket securing it in place (Figure 11). In turn, the western span twisted, causing damage at connections throughout both spans. The covered bridge was scheduled for a nearly $3 million National Covered Bridge rehabilitation project that was scheduled to begin in September 2012. Much of the work that was planned for that project was incorporated in the project resulting from the storm activities.

Figure 11: Downstream western arch dislodged from abutment

3. Material Description

The materials used in this project that were included in the testing are:

- Jahn M110 Pointing Mortar
- Jahn M40 Injection Grout

The material used in this study required some up-front compatibility testing. According to Cathedral Stone Products, the stone in the restoration project must be tested first for compression, porosity, and properties of expansion and contraction, and the grout will then be developed accordingly.

Training is recommended and in some cases, required for applying the Jahn grouting system as well as other Jahn products supplied by Cathedral Stone Products. Training is offered on a regular basis at the company headquarters in Hanover, Maryland. Training includes hands on repair of limestone, sandstone, terra cotta and brick materials. The company provides the training to stone or brick masons, craftspeople, specifiers, preservation professionals and contractors who wish to achieve long lasting results and provide the best possible finish for projects they are awarded. Formal training was not required for the products used in this study.

3.1. Jahn M110 Pointing Mortar

The Jahn M110 Pointing Mortar is used predominately on restoration of historic structures. According to product literature, "*These single-component, cementitious, mineral based pointing mortars are specifically formulated for the restoration of mortar joints in all types of masonry*." The mortar does not contain latex or other acrylic bonding agents or additives. It has been formulated to be compatible with historic masonry. The reported features of the product are: (Cathedral Stone Products, Inc., 2012)

- The mortar is unaffected by the corrosive properties of salts
- The mortar is free of shrinkage
- Placement can be accomplished in a single lift. There is no need to apply the grout in several lifts
- Product variation is controlled in the factory therefore prevents field chemistry change from occurring
- The mortar comes in several standard formulas as well as allowing for custom formulation for specific projects
- The customer can specify specific color requirements
- Formulated as a single component – Only needs water
- Free of Latex and Acrylic bonding agents, thereby allowing salts, water vapor and liquid water to leach out to the surface, ultimately preventing failure caused by salt expansion and effects of the freeze/thaw cycles

The mortar requires a clean surface for best results. Any dust, dirt, grease, laitance and/or any other coating or foreign substance must be removed. Any of these contaminates may prevent proper adhesion between the mortar and the stones. All surfaces in the joints that will be in contact with the mortar should have a final rinse with clean water. The ambient temperature range for application should be between 40°F to 90°F. The minimum thickness of the applied mortar is ½ inches.

Being attentive on the mixing of water into the powder is essential. Conditions such as temperature and humidity as well as the chosen formulation of the mortar can affect the amount of water that is necessary. Typically, the mixing ratio is 1-part water to about 4 to 5 parts powder. Higher ambient temperatures require more water. Excessive water can negatively affect the color of the grout repair. The stonemason can mix the product by hand until the mortar is thoroughly consistent. Prior to application, all surfaces must be moistened using clean water. The stonemason must be mindful of any surface drying out before the mortar is placed. The stonemason must keep the surface moisten by misting after application for curing for at least a 72 hour period. Misting should begin within 30 to 60 minutes for hot dry conditions or longer (several hours) for cooler and damp conditions and should continue several times a day.

3.2. Jahn M40 Injection Grout

The Jahn M40 Crack Injection Grout is used for crack repair and filling voids. Cracks widths between 3/16 to 9/16 inches or wider may be repaired by the means of low pressure or gravity fed equipment. The injection grout is formulated in the same manner as the pointing mortar. The features of the grouting product are: (Cathedral Stone Products, Inc., 2012)

- Formulated as a single component – Only needs water
- Provides compatible physical properties of the substrate its being applied to, so both the substrate and the grout reacts similarly to environmental conditions

- Free of Latex and Acrylic bonding agents, thereby allowing salts, water vapor and liquid water to leach out to the surface, ultimately preventing failure caused by salt expansion and effects of the freeze/thaw cycles
- Strong bonding properties
- Product variation is controlled in the factory therefore prevents field chemistry change from occurring
- Low viscosity ensuring deep and thorough penetration
- Simplified manual or mechanical application
- Water based formula allowing for safe and easy cleanup

The requirements for the grout are similar to those for the pointing mortar. First, the surfaces the product will be applied on needs to be cleaned in the same manner as the mortar. Mixing the product requires a little more attention. The ratio of water to powder is 1-part water to 2-2.5 parts powder. The grout can be mixed by hand, though it may be best to use a slow speed drill (400 to 600 RPM) with a Jiffler-type mixing paddle (Figure 12). Mixing should not be less than 3 minutes. Like the mortar, the ambient temperatures should be between 40° F and 90° F.

Figure 12: A Jiffler Type mixer for a hand-held power drill

The steps involved in placing the injection grout are similar to the mortar. The surfaces need to be moistened. This may include flushing the interior voids with clean water. Ports are inserted into the masonry at specified elevations in a downward angle and sealed with pointing mortar. The grout is injected through these ports until the grout starts running freely out of the other ports at the same height. Cleanup with a hand sponge should occur immediately with clean water before the grout has time to set. After a day or two, any sealants used to contain the grout should be removed.

4. Construction

On Monday October 1, 2012, Alpine Construction of Schuylerville, New York, broke ground for the rehabilitation work on the covered bridge. The subcontractor chosen to work on the stone pointing was P&P Landscaping. The first phase of the pier repairs was to reset stones on the upstream side, or the pier nose, that were dislodged from flooding and debris from past weather events.

Alpine constructed an enclosure around the pier (Figure 13) and on February 5, 2013, the stonemasons began initial application of the Jahn Pointing Mortar on the western face of the pier. The purpose of this initial activity was for testing and training on how to prepare the dry-laid stone for the mortar, mix the mortar to the right consistency and apply to it. Cathedral Stone Products was onsite to oversee the testing and to train the stonemasons. The contractor provided heat in the enclosure to bring the atmospheric and stone temperatures up to the specified level for stone pointing and grouting. Initial observations indicated that the mortar mix had to be adjusted initially to obtain the consistency required for pointing stones.

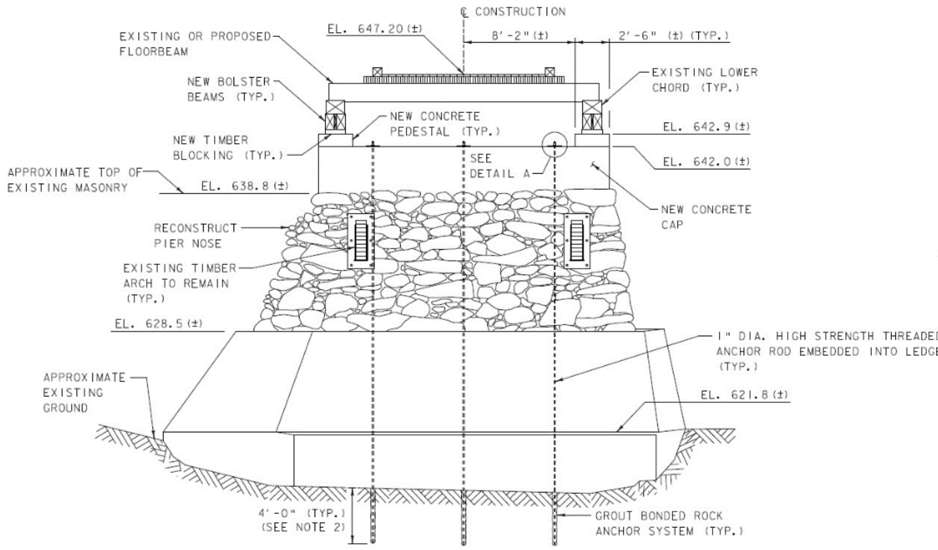

Figure 13: Details of the Bridge Pier

Cathedral Stone Products commented in a Historic Covered Bridge Committee Meeting held on October 8, 2009 that pointing some stones may be difficult. When completed, the pointing should not be visible. Stones would be inserted deeply enough to prevent shifting but also to allow for moisture and salts to leach outward. The stonemasons would need to use care in pointing stones in these areas. There were areas on the abutment and pier where the gaps were large, which resulted in inserted stones being visible.

The stonemason used a narrow pointed mason's trowel to pry out small loose stones and debris from the dry-laid stone joints. Using a brush or their hands, the stonemason would remove dust and dirt from within the joints. The crew had access to an air compressor, which they used to clean fines out of the joints. It was determined that a power washer would be the best option to conduct the final cleaning of the stones. Where there were gaps, the stonemason would size up a stone provided on the rigging, and fit it into the opening, carefully matching the shape of the stone to the shape of the gap. In places, several stones were required. Smaller stones were worked deep into the larger gaps (Figure 14). The stones for this work came from the collapsed western abutment that was being excavated. The larger stones were broken apart to make smaller stones for chinking.

Figure 14: Up-close view of stone pointing and mortar work

Once the stone pointing and cleaning was complete, the stonemasons would mix a portion of the Jahn Pointing Mortar. The grout was given a blackish color to give the appearance of a void, to simulate the open joints of dry-laid stone. When cured, the color would become more of a dark gray. The stonemasons would work the mortar deep into the stone joints.

Repeated application would continue until the mortar either could no longer be worked into the joint or the stonemason felt the joints were sealed. The mortar was then worked into a smooth concave surface using a joint filler tool allowing the original stones to protrude out to maintain their original appearance.

With the experience level adequate for the job, the mortaring process continued on the pier on all faces. Since the work was being accomplished in February, the stones and surroundings in the enclosure needed to be warm enough to meet the specifications of a 50°F minimum. This was done by indirectly heated air blowing into the enclosure. By February 22, the stone pointing was complete. On February 26, the enclosures were made ready to begin pointing stones on the eastern abutment (Figure 15). This work was done directly below the superstructure. The stonemasons began pointing on February 28. By March 1, the pointing was complete with the exception of the bottom two feet, as that was outside the heated enclosure. This would be completed later in May.

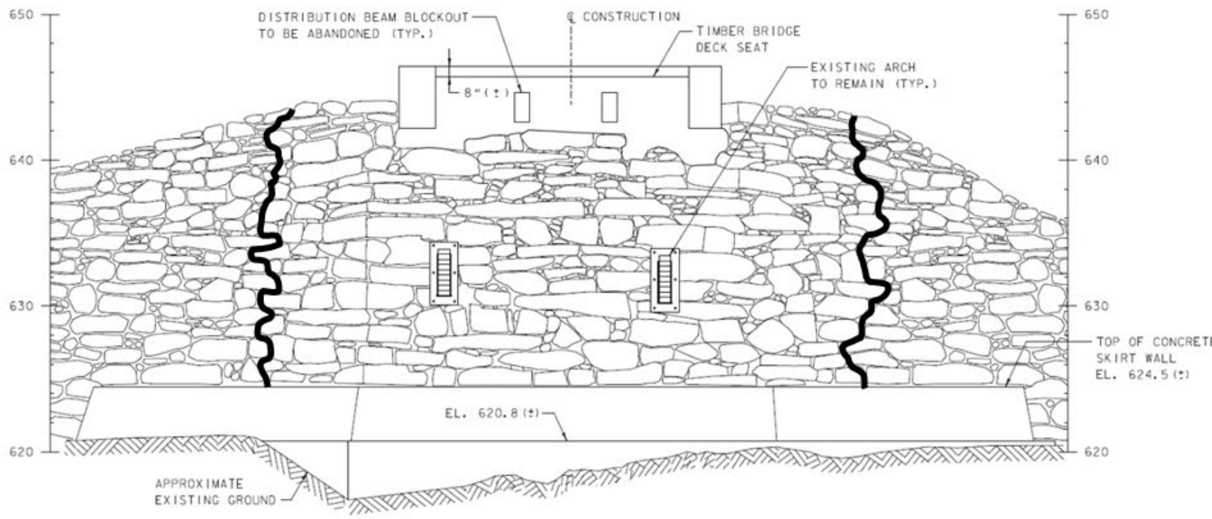

Figure 15: Details of the Eastern Abutment (dark lines shows extent of pointing)

On April 17, the contractor began grouting the interior voids of the pier. The sealed dry-laid stones from the pointing efforts were used as a form to keep the injected grout in place. During the stone pointing, the stonemasons inserted weep tubes in the stone joints. As with applying the pointing grout, the interior of the stones needed to be cleaned to ensure a bond was made between the grout and the internal stones. The interior of the pier was flushed with water. During the flushing process, small particles dusting the interior stones were washed off. These particles traveled with the flowing water, ultimately filling in the small voids within the previously applied mortar. The Jahn M40 MAX BLACK consolidating grout was then prepared and injected into the pier interior to be filled from the bottom up through injection ports. The grout was placed in this style in two lifts. With the initial fluid properties of the grout, remaining leaks in the dry-laid stone and applied mortar were filled. Once the grout cured, the entire pier became one structural unit.

The final work on the pier was placing a new 3-foot high reinforced concrete cap (Figure 16) for the midspan of the bridge span to rest on and to distribute the vertical loads from the bridge into the pier. The cap was affixed to the stone pier by 28 anchor rods that were drilled and grouted into the stone. Six shafts in a 3-by-2 grid were drilled through the concrete cap and on through the grouted stone mass ending 4 feet into the existing riverbed ledge below the pier. 1-inch diameter high-strength threaded steel anchor rods were inserted into the shafts and embedded into the ledge using grout. The rods were bolted and tightened to a specified tension. Grout was then placed in the shaft. The tensioned rods provide bending resistance caused by lateral forces applied to the pier.

Figure 16: Completed pier showing the concrete cap and abutment

5. Performance and Observations

Research and Development has visited the project site once a year since the project was completed until 2017. In a discussion with the CEO of Cathedral Stone Products, Denis Rude, he said that as the salts leach out of the interior of the pier and abutment, a white powder like substance would appear on the surface of the grout. This powder would eventually blow off the surface with wind or be washed of by rain. There were concerns that the repairs to the pier and abutment would cause an efflorescence to form in places. The use of the Jahn products was intended to prevent such efflorescence from forming. Under observations from 2013-2017, the white powdery substance has been observed forming; however, it is not accumulating (Figure 17). There seems to be a consistent light dusting in places. Overall, the grout appears to be functioning as expected.

Figure 17: Up-close view of white powdery residue on mortar (2017)

Figure 18 shows the overall view of the Southern wall of the west abutment and a close-up view of a powdery residue (most likely chlorides) leaching out of the mortar of the Southern wall of the west abutment. The observed residue stains consisted of two different colors, yellow/orange and white/gray. The yellow/orange stains might be indicating that the mortar is drawing out other minerals besides chlorides or that iron elements are deteriorating within the abutment.

Figure 18: Southern Abutment and closeup of mortar leachate (2017)

Another purpose of using the Jahn products was to strengthen the dry-laid stone pier and abutment to preserve the overall historic appearance of the bridge. Concerns were that the mortar would be obvious from a distance. Observations at various distances from the substructure units gave an appearance of dark joints between stone (Figure 19). The mortar and pointed stones were virtually invisible to the eye from afar. Even up close, the dark grey color of the mortar has aged in a way that it is not obvious in most places on each substructure unit. Places where the mortar is visible are where there were large gaps in the dry-laid stone (Figure 19).

Figure 19: Pier after Construction in 2014

6. Summary

The Taftsville Covered Bridge has survived 177 years of floods, changing load requirements and risk of replacement when significant work was required to maintain an important crossing. The covered bridge has changed over time: by gaining laminated timber arches and windows; by having its footings reinforced with concrete skirting; by receiving a new roof and deck as well as benefitting from new supporting beams. The history of the bridge reflects how it has adapted to the needs of the time. Yet in each of its phases, the bridge has kept its pristine look, which has survived the ages. In 2011, its fate was left to a Tropical Storm, and was found standing in the days following the flood. As with each phase of the bridge's development, new technologies were used to give the covered bridge new strength and new life. The bridge now has within its stone foundations, an advanced mortar and grout system that will guard it against the internal mechanism of hydrostatic pressures, and expansion due to salt buildup. The mortar and grout systems provide added strength and durability to the foundations.

The performance of the Jahn Permeable Mortar System is supported by the visual inspection and photographic evidence gathered during site visits following construction until 2017. The study surpassed its initial (no less than 3 years) study duration detailed in the approved FHWA Work Plan. The field visit documentation suggests that the Jahn Permeable Mortar System performs as expected and detailed by the manufacturer. The Jahn mortar system blends well into the surrounding abutment stonework taking on an aged, less noticeable, more natural look. The mortar also seems to regulate salt and moisture content within the abutments, as advertised and evident by the leeching of chlorides from within the mortar. Results from this study will be given to the VTrans Structures Section and the Historic Bridge Advisory Group for consideration on future bridge designs.

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