

Elastomeric Concrete Plug Joints: A New Durable Bridge Expansion Joint Design

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<p>16. Abstract:</p> <p>Expansion joints are important components of bridges that accommodate the movements between deck spans that result from thermal loads, traffic loads, and other environmental factors. Experience shows that joints undergo premature deterioration on a regular basis, thus leading to unexpected problems caused by leakage of water and other corrosive chemicals over the components of the superstructure and substructure, thus leading to premature deterioration of those components.</p> <p>Millions of dollars have been spent by the Virginia Department of Transportation (VDOT) over more than 50 years for repairs and replacements of joints. Several types of closed joints have been developed and installed in the past three decades to combat this problem. In addition, jointless details at piers and abutments have been developed and installed in the same time period to eliminate the need for joints. However, the issue persists. VDOT's Structure and Bridge Division has developed a new design for a flexible joint system with bonded and debonded zones. An elastomeric concrete material acts as the load-bearing surface and the component that allows free expansion and contraction. This joint system has been installed in selected pilot bridges on secondary roads for observation. This study evaluated the performance of this joint system and detailed the challenges faced in developing it.</p> <p>The elastomeric concrete plug joint system was successfully implemented in five pilot bridges in Virginia. Short-term performance of the system was satisfactory under Virginia weather conditions. Rutting during the summer months has not been observed even though one of the elastomeric materials had failed in the laboratory testing. Expansion cracking during the winter months was not observed in the first year after installation. It was determined that shore durometer hardness values can be used as a preliminary filter to select elastomeric material with resistance to permanent indentation. Dynamic modulus testing can be used as a measure of the toughness and flexibility of elastomeric concrete material under different temperatures. However, these tests do not give a complete picture of the material properties, so engineering judgment is also necessary in order to make decisions regarding the elastomeric materials. The Virginia Transportation Research Council and VDOT's Structure and Bridge Division should continue to monitor visually the performance of the elastomeric concrete plug joint systems installed during this study and continue to evaluate new elastomeric concrete candidates for the joint system. Further, the Virginia Transportation Research Council and VDOT's Structure and Bridge Division should expand the trials to other VDOT districts for various exposure conditions.</p>					
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ABSTRACT

Expansion joints are important components of bridges that accommodate the movements between deck spans that result from thermal loads, traffic loads, and other environmental factors. Experience shows that joints undergo premature deterioration on a regular basis, thus leading to unexpected problems caused by leakage of water and other corrosive chemicals over the components of the superstructure and substructure, thus leading to premature deterioration of those components.

Millions of dollars have been spent by the Virginia Department of Transportation (VDOT) over more than 50 years for repairs and replacements of joints. Several types of closed joints have been developed and installed in the past three decades to combat this problem. In addition, jointless details at piers and abutments have been developed and installed in the same time period to eliminate the need for joints. However, the issue persists. VDOT's Structure and Bridge Division has developed a new design for a flexible joint system with bonded and debonded zones. An elastomeric concrete material acts as the load-bearing surface and the component that allows free expansion and contraction. This joint system has been installed in selected pilot bridges on secondary roads for observation. This study evaluated the performance of this joint system and detailed the challenges faced in developing it.

The elastomeric concrete plug joint system was successfully implemented in five pilot bridges in Virginia. Short-term performance of the system was satisfactory under Virginia weather conditions. Rutting during the summer months has not been observed even though one of the elastomeric materials had failed in the laboratory testing. Expansion cracking during the winter months was not observed in the first year after installation. It was determined that shore durometer hardness values can be used as a preliminary filter to select elastomeric material with resistance to permanent indentation. Dynamic modulus testing can be used as a measure of the toughness and flexibility of elastomeric concrete material under different temperatures. However, these tests do not give a complete picture of the material properties, so engineering judgment is also necessary in order to make decisions regarding the elastomeric materials. The Virginia Transportation Research Council and VDOT's Structure and Bridge Division should continue to monitor visually the performance of the elastomeric concrete plug joint systems installed during this study and continue to evaluate new elastomeric concrete candidates for the joint system. Further, the Virginia Transportation Research Council and VDOT's Structure and Bridge Division should expand the trials to other VDOT districts for various exposure conditions.

FINAL REPORT

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INTRODUCTION

Throughout the service life of a bridge, concrete components undergo expansion and contraction caused by thermal loads, live loads, inherent concrete properties such as shrinkage and creep,¹⁻⁵ and secondary stresses generated by restraints from abutment foundations and backfill.² The movements can induce stresses large enough to exceed the tensile strength of concrete,⁶ thus leading to cracking.⁵ A concrete deck protects the components of the superstructure and substructure underneath against water, contaminants, deicing salt,⁵ dust, grit, ultraviolet rays, ozone, petroleum derivatives, and so on.⁶ To accommodate movements of the superstructure, bridge spans are typically divided into smaller spans.⁵ Expansion joints are then used between the individual spans to accommodate movements.^{6,7} Thus, expansion joints serve a very important function. When expansion joints fail to function adequately, many underlying bridge components can undergo premature deterioration, largely as a result of being exposed to chloride-contaminated water.⁶ Damage related to failed expansion joints costs agencies, and consequently taxpayers, millions of dollars every year in the United States.^{5,6} The total cost is often far beyond the cost of simply repairing or replacing the joints themselves, since the costs of repairing or replacing the damaged components of the underlying superstructure and substructure are also incurred.³

Joints are basically categorized as open or closed.³ As the names suggest, closed joints are supposed to be sealed and watertight, unlike open joints.³⁻⁵ Based on the degree of movement allowed, joints can be classified as fixed joints or expansion joints; fixed joints allow rotations only about the primary axis of the joint, and expansion joints may allow longitudinal, transverse, and rotational movements.^{4,6}

The earlier designs of expansion joints comprised mostly open joints.⁵ A few examples of open joints are butt joints, sliding plate joints, and finger joints.^{4,5} The open joints allow runoff of water laden with corrosive chemicals from the surface to spill through to the superstructure and substructure elements below. To prevent this, open joints are often paired with a drainage system, such as a trough underneath, to collect the runoff water that carries deicing salts and other contaminants and direct it away from the components of the superstructure and substructure.^{5,6}

Expansion joints require significant maintenance over the service life of a bridge.^{5,7,8} One of the reasons is that expansion joints are located in the most vulnerable position in a bridge deck in terms of exposure to the recurring impact and vibration of live loads and to water and contaminants.⁶ Over time, open joints with drainage systems have failed to function properly because of the accumulation of debris.⁵ Such drainage components require routine cleaning and maintenance to avoid clogging or rupturing of flexible trough components, which presents a burden on agency resources. The otherwise resulting deterioration of the bridge components has shown the importance of watertight joints. This led to the popularity of closed expansion joints.

Several closed expansion joints have been in use in recent decades. Field-molded seals, compression seal joints, strip seal joints, cushion seals, and plug joints are the most commonly used systems.^{4,5} Although closed expansion joints are expected to perform better than open joints, depending on their type, some perform better than others.

- *Field-molded seals*, also known as silicone seals because silicone is the most commonly used material for this type of joint, are constructed by filling silicone in the joint over a compressed backer rod that spans the gap and provides a bottom form.
- *Compression seal joints* are installed by fitting a precompressed elastomeric neoprene section into the gap between spans. Relaxation of the compression restraint allows the seal to expand and push against the faces of the adjacent spans, and a bonding agent may fix the seal in place.
- *Strip seal joints* are neoprene membranes, typically V-shaped, that are mechanically attached to metal angles on both sides of the gap. The metal angles are in turn attached to, or often embedded in, the edge of the concrete deck.
- *Cushion seals* are steel-reinforced neoprene pads that are fitted into recesses made on the edges of both sides of the gap. The pad is fixed using steel anchors embedded into the concrete on both sides.

- *Plug joints* are typically formed by recessed areas of the deck adjacent to the gap between the spans and filled with a modified asphalt mixture on top of a steel gap plate that spans the gap. A modified elastomeric binder lies underneath the steel gap plate to create a water-resisting layer. This binder is supported by a backer rod below.

The main reasons that closed expansion joints have performed poorly were identified in a survey of state transportation agencies as improper installation, poor maintenance, damage by debris, damage by snowplows, and extreme thermal loads.⁵ A survey was conducted on the performance of closed expansion joints on small movement joints (<2 in, <0.8 mm); those surveyed were the state transportation agency members of the Northeast Bridge Preservation Partnership, which includes Connecticut, Delaware, the District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont.⁹ The survey revealed that the most commonly used joint system in new highway bridge construction was the strip seal joint; for existing structures, the most common replacements were asphalt plug joints, strip seals, and field-molded sealers.⁹ Compression seal joints were the least popular because of frequent failures and maintenance difficulties.

The survey also indicated that joints in new construction lasted between 5 and 15 years and that joints installed as maintenance activities on existing structures lasted between 2 and 10 years.⁹ In another survey of U.S. state agencies and Canadian provinces regarding the performance of joint systems, of the 26 respondents, on average 15 reported joint leakage 0 to 5 years after construction, 10 reported leakage 5 to 10 years after construction, and 1 reported leakage 10 years after construction.⁵

There is a trend toward building jointless, integral bridges to avoid the disadvantages associated with expansion joints.⁷ However, there are restrictions on the maximum span length, skew angle, and curvature that can be designed for a jointless, integral bridge.

A variety of closed expansion joints are currently being developed, which in itself is an indication that existing designs have not been successful in solving the problem.⁵

PURPOSE AND SCOPE

According to element level inspection reports, 6,388 bridges in Virginia had expansion joints as of June 2016. More than 4,000 of these bridges had joints that had at least begun to deteriorate from the element condition states.¹⁰ These expansion joints will soon require significant repairs or replacement. Given that most state transportation agencies have observed that joints typically leak within 10 years after construction, many even within 5 years after construction, repairing or replacing a number of expansion joints in the near future will put a burden on state maintenance funds.

The Virginia Department of Transportation's (VDOT's) Structure and Bridge Division has developed a plan for a flexible expansion joint system for bridge decks. The purpose of this study was to improve and implement this system in Virginia. The system is designed to be water

resistant and durable without the need for meticulous maintenance. The scope of this study included selecting and evaluating materials as candidates for elastomeric concrete; installing the finalized elastomeric concrete plug joint (ECPJ) system in five bridge decks in Virginia; and visually monitoring the installed systems through a winter and a summer.

METHODS

As stated previously, VDOT's Structure and Bridge Division has proposed a new design for expansion joints in existing and new structures. This joint system is a closed expansion joint system that is filled with an elastomeric concrete material and employs a debonded zone in the middle to accommodate movement, as shown in Figure 1. The process behind the development of this design is iterative. The details have been modified several times, as experience dictated a better alternative to the existing framework.

The concrete on both sides of the joint is removed according to the design. The elastomeric concrete material is then allowed to form anchors on both ends of the joint by bonding with the coarsely chipped-out concrete, within either spans or approach slabs. The required dimensions of the anchored portion of the elastomeric concrete depend on the bond strength with the deck concrete. The middle portion of the joint consists of unbonded elastomeric concrete that is continuous from the bonded anchor portion. The unbonded region will accommodate joint movements in the structure. This portion will be prevented from bonding to the concrete by the placement of a metal sheet over the concrete edges and an adhesion-resistant, low friction coefficient material between the plate and elastomeric concrete for free sliding movement.

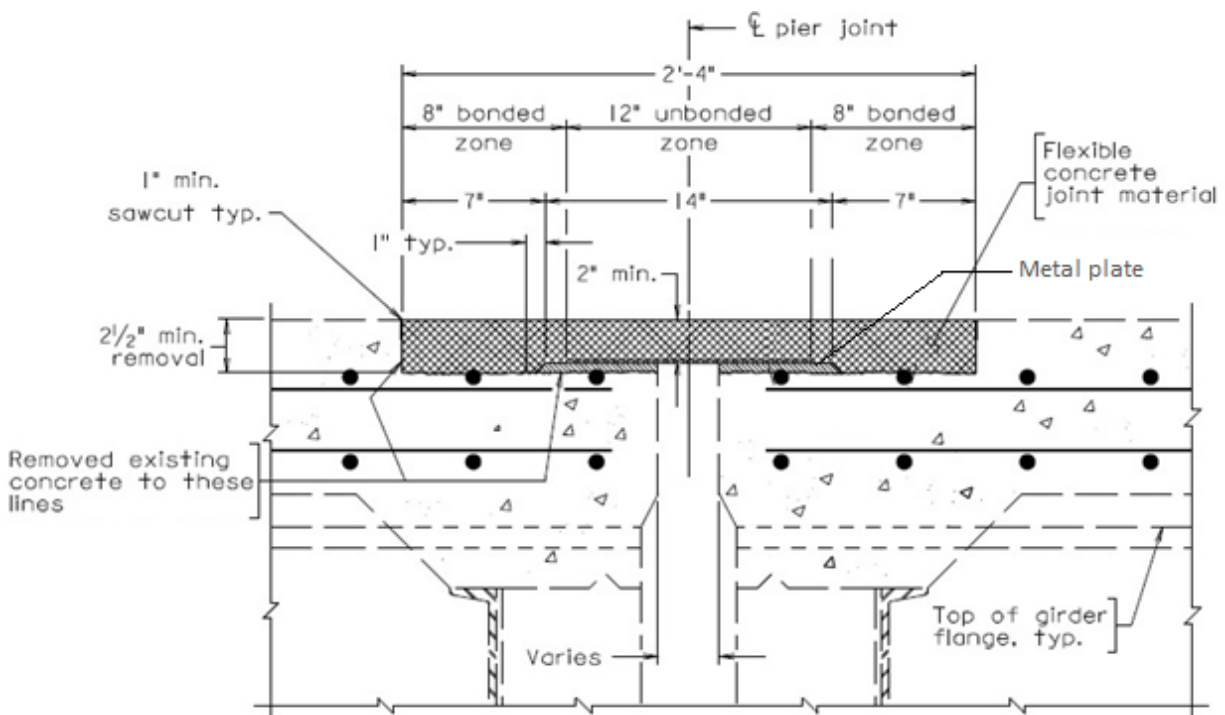


Figure 1. Drawing of Elastomeric Concrete Plug Joint

The metal plate acts as a form for the elastomeric concrete and helps the elastomeric concrete support truck wheel loads as the wheel passes over the expansion gap. The metal plate contained slots for the bolts to allow movement in the earlier versions of the design. However, this detail has been modified in the latest revision. Currently, the metal plate is fixed on only one side of the span and consists of 10-ft-long pieces. Figure 2 shows the built-up area, which provides a smooth surface and helps prevent elastomeric concrete from leaking below the plate during placement while it is setting.

Figure 3 presents the drawings of the details along the parapet walls and curb. It is imperative to have a good sealed joint at this location where water collects.

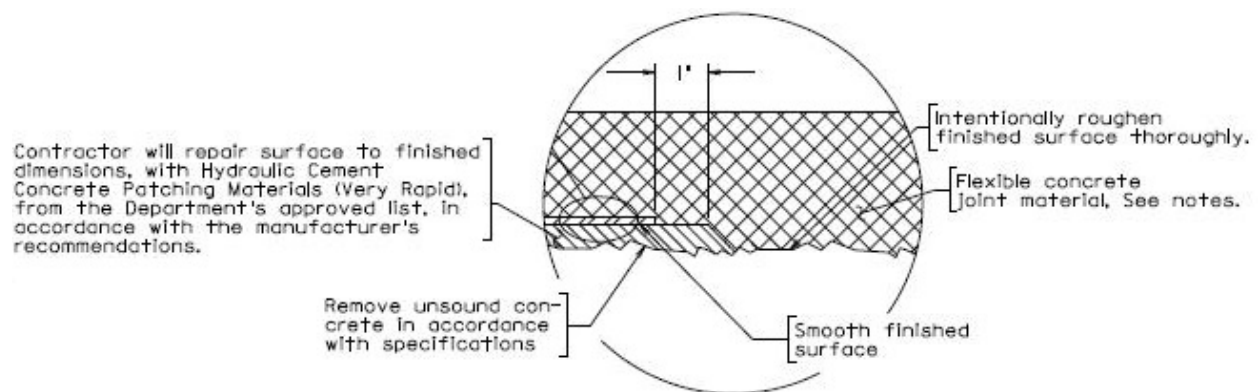


Figure 2. Drawing of Built-up Area

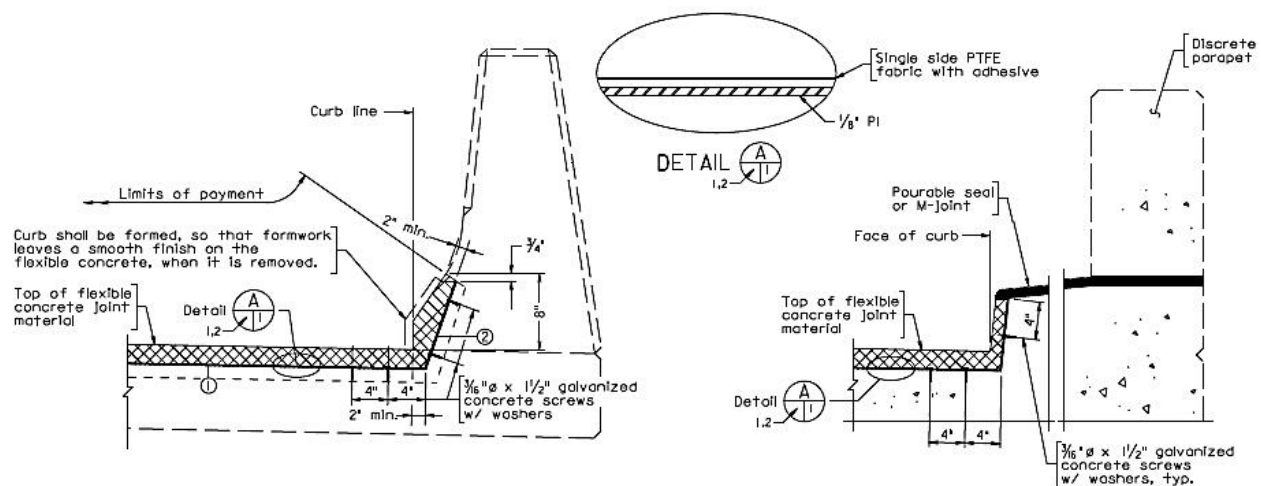


Figure 3. Drawings of Project Details at Parapet

RESULTS AND DISCUSSION

Implementing the ECPJ design involved finding appropriate materials that could reasonably make this joint system function as expected in terms of resistance to water penetration and durability under environmental and traffic loads. The material would also need to be procured and placed at a reasonable cost to ensure financial feasibility for state transportation agencies.

Criteria for Elastomeric Concrete Acceptance

In order to sustain repeated heavy traffic loads, freeze-thaw cycles, and expansion and contraction, the elastomeric concrete must have specific material properties. The following criteria for elastomeric concrete acceptance were developed by VDOT's Structure and Bridge Division through preliminary calculations of superstructure movements for a 100-ft-long (30.48 m) concrete span:

1. Minimum elastic strain (at yield): 10 percent (both compression and tension)
2. Minimum modulus of elasticity (E): 5,000 psi (at temperatures from 0 °F to 120 °F)
3. Minimum compressive strength: Larger of 500 psi or $E/10$
4. Minimum tensile strength: $E/5$ (at all values of E for temperatures from 0 °F to 120 °F)
5. Minimum shear strength: Larger of $E/9$ or 500 psi
6. Minimum bond strength: 250 psi
7. Other requirements:
 - a. The material is able to bond to itself.
 - b. The material has a maximum desirable set time of 6 hours, although longer durations will be considered if other properties are excellent.
 - c. The material will hold a broadcast aggregate in its surface or otherwise meet skid resistance requirements where the skid number = 35.¹¹
8. If the material stress-strain relationship is not linear in the elastic region, as is often the case with synthetic materials, the material may be acceptable as long as the cracks induced by large strains are thin and the material recovers fairly well, as detailed here. The material will undergo loadings of two categories: short-term and sustained.
 - a. The short-term loads (approximate duration up to 5 seconds) will be due to vehicular traffic that will induce strain either through tire pressure or end rotation caused by deflection of the span. There will be in excess of 1 million such loads over the lifetime of the joint, so the strain recovery will need to be almost complete after these loads occur. These strains will usually not exceed 2 percent axial elongation.
 - b. The sustained loads (approximate cycle duration of 1 day or longer) will be due primarily to thermal cycles and will be much fewer in number. The maximum sustained elongation (caused by deck shrinking from warmest allowable

installation temperature to coldest day) represents about 6 to 7 percent strain and will occur only a few times in a year. Smaller sustained strains due to daily thermal cycles will also occur.

- c. If the material is not linear-elastic, the actual stress-strain curve will be created and the ability of the material to sustain the applied strains for the predicted number of cycles will be observed. Hysteresis may also be observed and documented if required.
- d. Shore D hardness values from 30 to 60 or Shore A hardness values from 80 to 100 indicating hard texture are required. The Shore durometer hardness scale indicates the material's resistance to permanent indentation.

With the criteria identified, several manufacturers and suppliers were contacted for information regarding their products. After the material properties were reviewed, six materials were selected. However, after reviewing the material safety data sheets, VDOT safety and compliance officers rejected three of the six materials because of the presence of carcinogens such as isocyanates. Thus, three materials, as listed in Table 1, were selected for pilot installations: Fibrecrete, EPPJ, and TechCrete.

Table 1. Elastomeric Concrete Materials Used in Pilot Installations

Product	Application	Status of Field Performance
Fibrecrete	Hot applied	Under observation
EPPJ	Cold applied	Under observation
TechCrete	Hot applied	Under observation

Debonding Layer

In order to accommodate the movements in the joint, the middle portion of the elastomeric concrete must move independently of the steel gap plate below. If the elastomeric concrete in the debonding zone sticks to the gap plate during expansion or contraction, the top of the concrete will be restrained against movement by the bottom layers of concrete. This will induce cracking and lead to leakage of the joint. Thus, a debonding layer between the elastomeric concrete and the steel gap plate had to be applied. Materials with a low friction coefficient and high heat resistance (stable at 400 °F) that were chemically inert were explored.

Polytetrafluoroethylene (PTFE), known commercially as Teflon, has among the lowest friction coefficients of commercially available materials. After a variety of PTFE-laden materials were compared, a PTFE-coated glass-fiber fabric was selected. The fabric has adhesive on one side for adhesion to the gap plate.

Spanning Gap Plate

An A36 steel plate 1/8 in (3.2 mm) thick was selected to act as a form during placement of the elastomeric concrete and to assist the elastomeric concrete in resisting wheel loads of vehicles as they crossed over the expansion gap.

Raised Platform

The design requires a raised platform 0.5 in (12.7 mm) high for the width of the debonding zone in the middle of the joint. Because of its relatively short setting time, a Rapid Set cement-aggregate mixture was used to form this platform, which provides a uniform support for the steel plate so as to prevent the elastomeric concrete from leaking under the plate during placement before it sets.

Material Properties

Elastomeric concrete can be classified into two categories based on mixing and placing: hot applied and cold applied. Two hot-applied materials and one cold-applied material were used in this project. However, laboratory testing on one of the hot-applied materials (TechCrete) is not included because the specimens had not been received from the manufacturer.

Hot-applied elastomeric concrete is heated and melted to about 350 °F (177 °C) and poured in the joint. As it cools, the material cures and solidifies. Cold-applied elastomeric concrete consists of two or more parts. These parts are combined at a manufacturer-prescribed ratio and poured in the joint. The mixture cures and solidifies. These materials behave similar to asphalt mixtures at some temperature ranges. Thus, material characterization was conducted using tests applicable for asphalt mixtures, such as rutting resistance and dynamic modulus.

At 76 °F (24 °C), EPPJ rutted to a depth of 1.08 mm (42.5 mil) and Fibrecrete rutted to a depth of 2.73 mm (107.5 mil); the testing was conducted in accordance with Virginia Test Method 110.¹² As shown in Figure 4, at 110 °F, only the hot-applied Fibrecrete failed. However, this was an extreme case of concentrated loading. The confining concrete around the elastomeric material is expected to prevent it from rutting, and the relatively longer time available between the loads is expected to provide recovery in actual traffic conditions.

Figure 5 presents the results of the dynamic modulus testing¹³ of the elastomeric concrete mixtures along with two asphalt mixtures for comparison only. The test was conducted by applying sinusoidal loads at different frequencies and under five temperatures.



Figure 4. Rutting Test Results

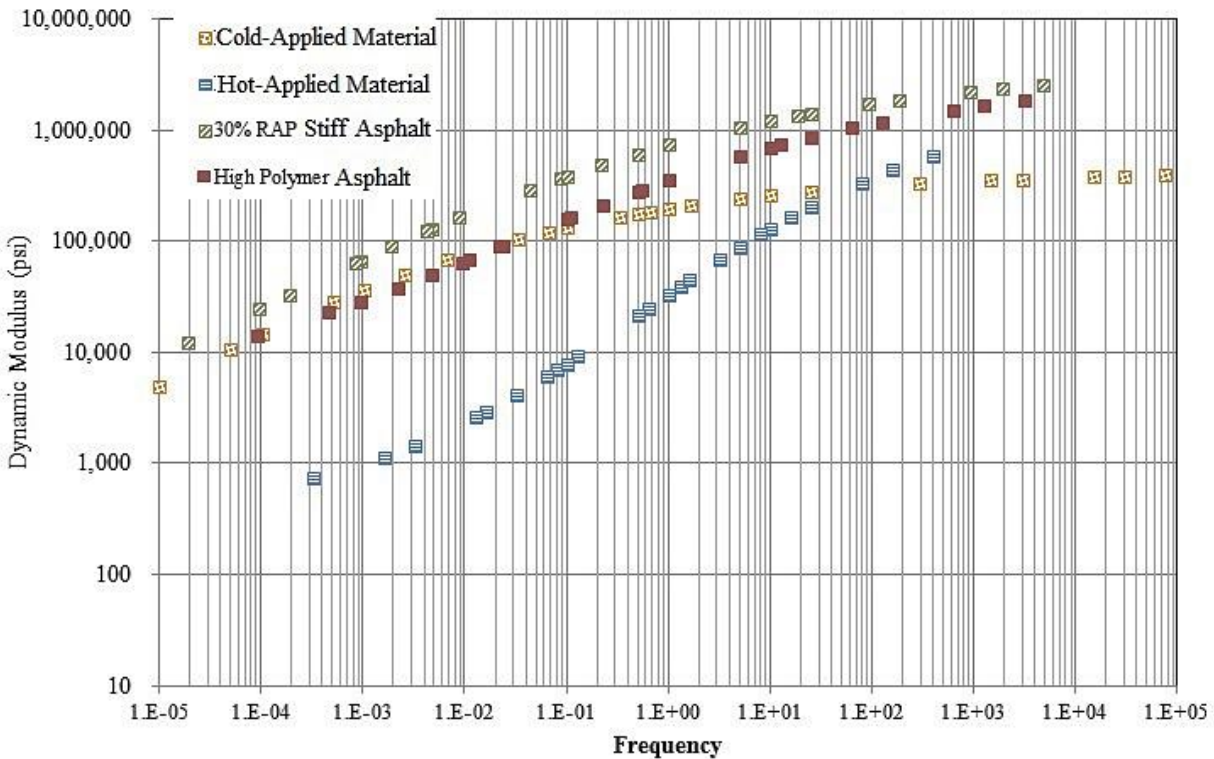


Figure 5. Dynamic Modulus of Elastomeric Concrete Mixtures. RAP = recycled asphalt pavement.

In Figure 5, the modulus values on the left indicate the performance of the materials under low temperatures, and the values on the right represent modulus at high temperatures. The cold-applied material appears to have a significantly higher dynamic modulus than the hot-applied material at low temperatures, whereas the cold-applied material becomes less flexible at high temperatures. The cold-applied material was comparable to a high polymer asphalt mixture at colder temperatures. The asphalt mixture with 30 percent reclaimed asphalt pavement appears to be less flexible than all elastomeric concrete mixtures.

A strong bond with the concrete is important for the design to be successful. Elastomeric concrete was cast between two concrete blocks for the concrete pull bond test. The outside of the blocks was glued to steel discs for grip. The steel discs were pulled away from each other until the elastomeric concrete failed, as shown in Figure 6.

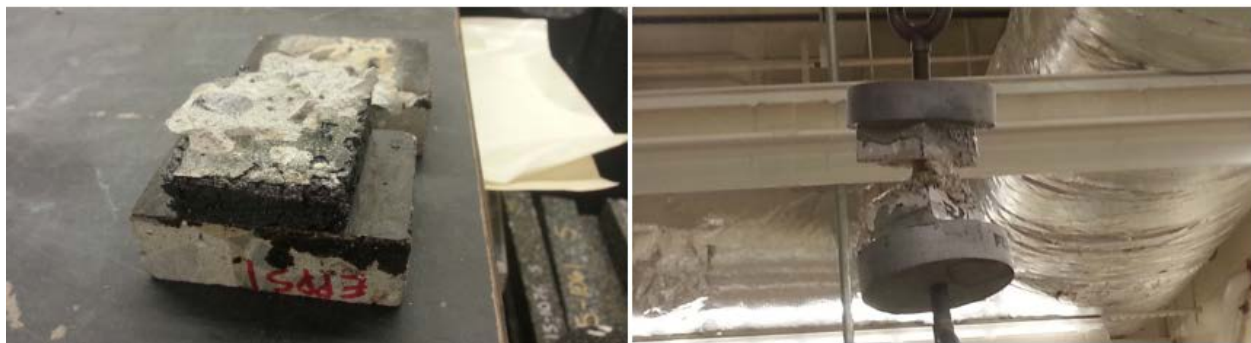


Figure 6. Bond Strength Test

The average bond strength was 234 psi. This was less than the required bond strength of 250 psi from the calculations. However, the concrete blocks were smooth whereas the field concrete will be fashioned to have rough surfaces, which will increase the bond strength. It was noted that the failure was always at the interface between the concrete and elastomeric concrete and not within the elastomeric concrete material. However, this does not guarantee that the elastomeric concrete material will not crack under tension.

Compressive strength and tensile strength testing of the elastomeric concrete materials was attempted. However, the materials yielded readily at the supports, thus disturbing the test procedure. The material strength will be considered using dynamic modulus testing as presented in Figure 5. Beyond the laboratory tests, the samples were observed to undergo elastic deformation under the pressure of a thumb and bounce back within a few seconds. Though not scientifically quantified, this was useful in order to gain a sense of confidence with regard to the material's flexibility and toughness.

Debonding Layer Properties

Several polymeric materials with low friction coefficients were selected, and samples were obtained from manufacturers. Hot asphalt mixture (~350 °F) was poured on top of the thin sheets, and a thick paper was embedded into the hot mixture for grip. The mixture was allowed to cool down. Then, an attempt was made to pull up the paper, as shown in Figure 7. A PTFE fabric sheet successfully allowed the cold asphalt to be removed without any effort. Thus, this material was selected as the debonding layer. An illustration of the debonding layer is shown in Figure 8.



Figure 7. Debonding Layer Test

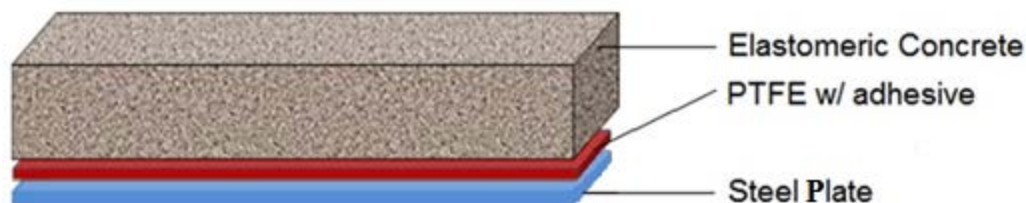


Figure 8. Illustration of Debonding Layer. PTFE = polytetrafluoroethylene.

Selection of Phase I Pilot Bridges

Phase I of the joint installations was limited to five bridges in VDOT's Richmond District; the bridges were on secondary roads with an annual daily traffic under 6,000. Preference was given to bridges with short detours or, if not available, in locations where a flagging operation would allow partial width construction. The intent was to allow the contractor the option to close the bridge or keep a lane open. To date, no bridge has been completely closed during construction. Straight simple-span bridges with minimal skews, no sidewalk or raised medians, and no asphalt overlays were ideal candidates. From a geometric standpoint, bridge selections were kept between 30 to 40 ft in width along the skew and maximum span lengths of 75 ft (22.9 m) for steel superstructures and up to 100 ft (30.48 m) for concrete, with a minimum of four joints.

To ensure the pilot structures would not be scheduled for major rehabilitation or repair in the near future, a general condition rating of 6 or above was required for the superstructure, substructure, and deck,¹⁴ as indicated in Table 2. This would allow adequate time to observe and track the performance of the joints.

Table 2. Selection Criteria for Pilot Bridges

General	
•	Secondary road
•	Low annual daily traffic (<6,000)
•	Easy detour available
•	Minimum of 4 joints
Geometry	
•	30-40 ft (9.1-12.2 m) out-to-out along skew
•	Steel spans around 75 ft (22.9 m) or more (preferred)
•	Concrete spans 100 ft (30.48 m) or more
Condition	
•	Bridge is not a candidate for superstructure/deck replacement or full bridge replacement. General condition rating = 6 or above.
•	Damage/deterioration of elements below joints (e.g., beam ends, diaphragms, bearings) is minimal.
•	Joint type
—	>20 ft in Condition State 2 or 3
—	Strip seal (300)
—	Pourable (301)
—	Compression (302)

Typical deterioration resulting from leaking joints, such as spalled and/or rusted beam ends, diaphragms, and bearings, was required to be minimal in order to assess properly the integrity of the joints. Candidate bridges with either strip seal expansion joints, pourable joints, or compression joints with greater than 20 ft (6.1 m) in Condition State 2 or 3 were targeted as a narrowing guideline. The final selections were made by the VDOT district with consideration of their maintenance management needs, as shown in Figure 9.

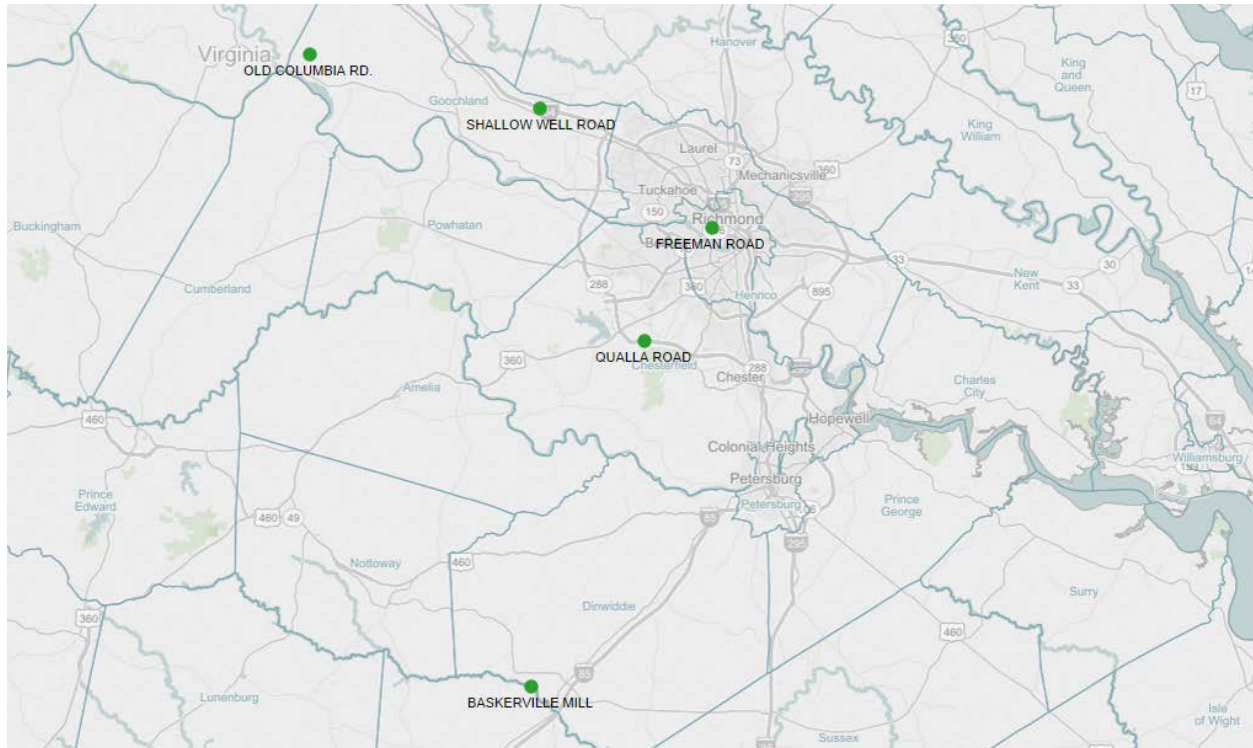


Figure 9. Map Showing Locations of Phase I Pilot Bridges

Installation

In existing structures, the concrete on both sides of the gap must be formed in accordance with the design drawing in Figure 1. This is done by saw cutting the perimeter to a depth of 1 in and removing the required depth using jackhammers, for a minimum total depth of 2.5 in (63.5 mm). The unbonded zone in the middle of the joint necessitates the steel plate to be placed on a flat surface. The elastomeric concrete in the unbonded zone needs to be a minimum of 2 in (50.4 mm) thick. If the overall depth of the removal does not meet the specifications, the thickness of the elastomeric concrete will be reduced, which increases the stress in the cross section. Figure 10 shows an image of the prepared surface of the joint. The surface of the chipped concrete is quite rough, which is a benefit in terms of increased bond between substrate concrete and elastomeric concrete. The figure shows the old slotted metal plate detail.

A raised flat surface is formed for the width of the unbonded zone by using a mixture of packaged Rapid Set cement (Quikrete Fastset DOT Mix) with fine aggregates. Then, a steel plate $\frac{1}{4}$ in thick is placed on the concrete and bolted in place using concrete screws, as shown in Figure 11a.



Figure 10. Preparation of Joint

As shown in Figure 11b, the prepared surface of the joint is cleaned with compressed air. The next step is to desiccate the surface with a blow torch, as shown in Figure 11c. This removes the moisture in the joint, thus increasing the bond between the concrete and elastomeric concrete. The last step before pouring the elastomeric concrete is coating the concrete surface with a primer to enhance the bond, as shown in Figure 11d. This may or may not be required, depending on the type of elastomeric concrete material used.

The debonding layer, a PTFE-coated fabric with an adhesive side, goes on top of the steel gap plate, as shown in Figure 12.

Once the debonding layer is applied, hot-applied or cold-applied elastomeric concrete is prepared for the pouring (Figure 13). Adequate safety measures must be taken to avoid exposure to heat or fumes if applicable.

At the parapet, the ECPJ is extended to a height of about 8 in (203.2 mm) above the deck level to direct the runoff water away from the joint. This is performed by removing a sufficient quantity of concrete from the parapet base. Then, formwork is erected with an opening in the top so as to pour elastomeric concrete material into the mold. Figure 14 shows a finished elastomeric concrete surface on the parapet.

An added advantage of the ECPJ system is that the construction can be completed lane by lane. This allows traffic control as individual lane closures in place of complete bridge closure, which reduces the impact of the construction and the user costs. Figure 15 shows live traffic on a bridge with just one lane of ECPJ already constructed. Figure 16 shows the completed joint across the full deck.



Figure 11. ECPJ Installation Sequence: (a) Bolting Steel Plate; (b) Cleaning With Compressed Air; (c) Placing Debonding Layer and Heating to Remove Moisture; and (d) Applying Primer. ECPJ = elastomeric concrete plug joint.



Figure 12. Debonding Material: *Left:* PTFE-Coated Fabric Roll; *Right:* Installation of Debonding Layer. PTFE = polytetrafluoroethylene.



Figure 13. Preparing to Pour Hot-Applied Elastomeric Concrete



Figure 14. ECPJ Formed on Parapet Stem. ECPJ = elastomeric concrete plug joint.



Figure 15. Live Traffic on Lane With New Joint Installation



Figure 16. Bridge Deck With ECPJ System. ECPJ = elastomeric concrete plug joint.

Challenges and Solutions

There are some potential challenges and concerns regarding the short-term and long-term performance of the ECPJ system that are being monitored.

Performance during winter:

- Snow removal with snowplows may damage the joint.
- The contraction caused by freezing temperatures in the elastomeric concrete and the joint expansion induced by the contraction of the deck may induce cracking.

Performance during summer:

- High summer heat will expand the elastomeric concrete material; there will be contraction induced in the joint by the expansion of the concrete deck. This may cause the elastomeric concrete to rise above the deck concrete level. This in turn can combine with the effects of softening caused by heat and result in rutting.

The effects of freezing and heat were taken into account in the design of this joint system. The Shore durometer values were used to classify the material's resistance against rutting. The adequate flexibility and inherent cohesion of the materials resist crack formation. Periodic observations through the first winter and the first summer since construction revealed nearly inert behavior with regard to freezing and heat. No water leakage, or evidence thereof, was observed, which indicates good performance to date.

Some unexpected challenges were encountered during the construction phase of the ECPJ. Solutions to these challenges have been developed to improve the design.

- *Anchoring slope.* In the original design, a thicker platform below the debonding layer was required. However, the construction of the platform using Rapid Set cement mortar was found to be difficult and time-consuming. The calculations showed that a thicker platform was not necessary for the bond strength with concrete. Thus, the design was modified to have a thin platform for the debonding zone, as shown in Figure 17.

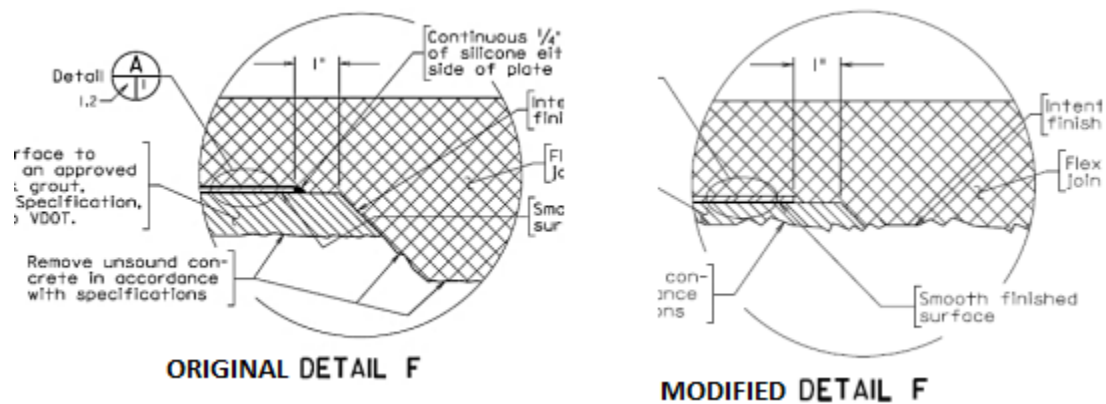


Figure 17. Anchoring Slope Modification

- *Parapet turn-up.* Turn-up at the parapet has been simplified for easy installation without having to waste time in removing concrete at angles (see Figure 18). One of the concerns with widening of the concrete removal is the settlement of the aggregates.

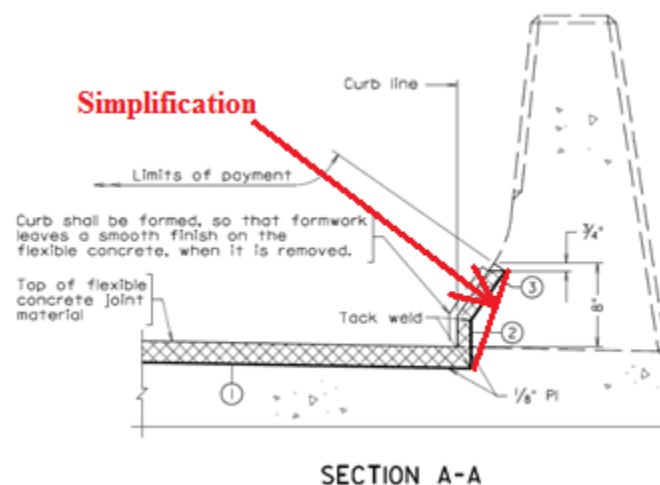


Figure 18. Simplification of Parapet Turn-up

- *Abutment obstacles.* Sometimes the drawings and plans of a structure would not match with the actual field conditions, such as absence of the approach slab or lack of reinforcement in the backwall. These were dealt with in the field by digging deeper into the approach side and filling with elastomeric concrete material to form a hook for bonding, as shown in Figures 19 and 20.



Figure 19. Formation of Elastomeric Concrete Hook

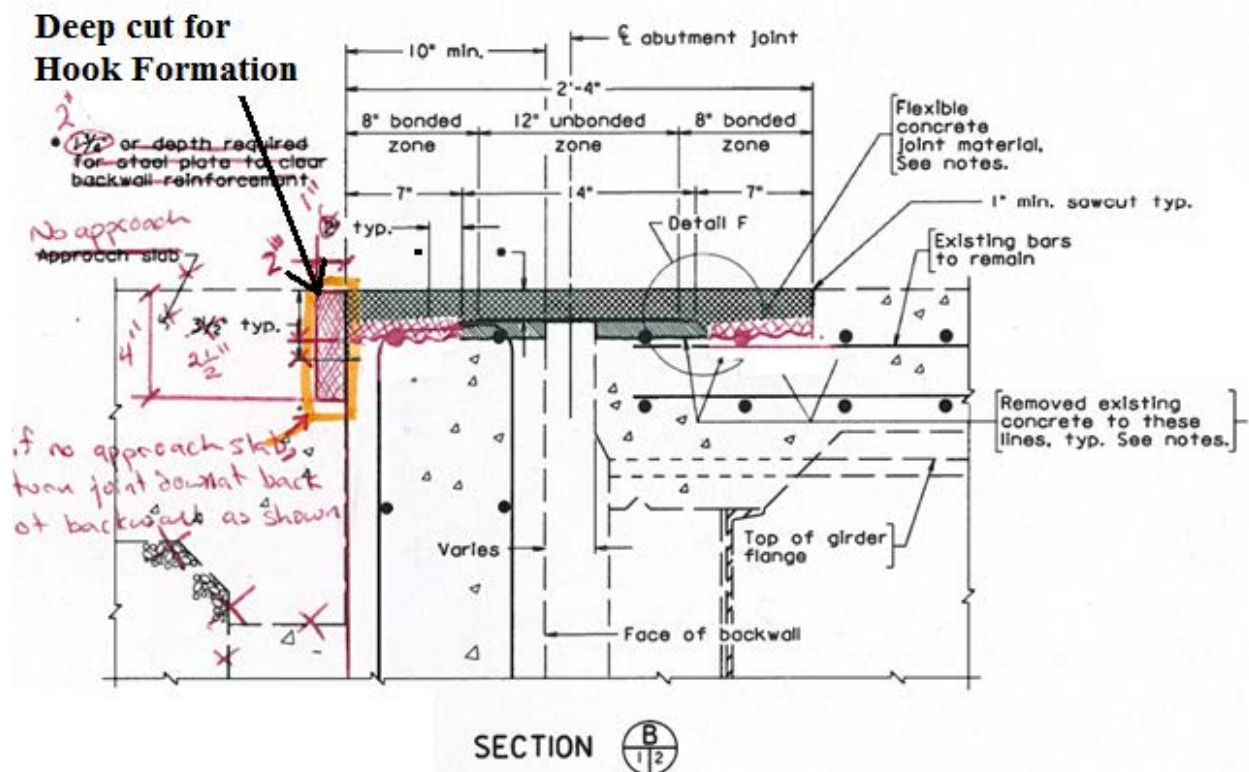


Figure 20. Backwall Detail for Elastomeric Concrete Hook

- *Varying cover depths of pier reinforcing bar (rebar).* When the concrete cover over the rebar was found to be too low, as shown in Figure 21, the top rebar was removed. When the concrete cover was found to be too deep, a rebar was added in the ECPJ. Current joint detail does not need the removal of existing rebar or the insertion of new rebar in the joint, since rebar neither contributes nor disrupts the functioning of the ECPJ, because of the different thermal expansion properties.



Figure 21. Low Concrete Cover Over Pier Reinforcing Bar

- *Equipment for hot ECPJ pours.* The equipment for melting the hot-applied elastomeric concrete, as shown in Figure 22, did not have the required volume to allow installing the joints one after the other. The material had to be melted for close to 3 hours before a new joint could be poured. Multiple kilns will be required for a bridge with a high traffic volume or where the lane closure is limited.
- *Steel plate bowing.* The steel plate placed on the platform below the debonding layer may bow up during the pouring of the hot material. To prevent this, the design has included a 1/8- to 1/4-in gap at the ends to allow movement.
- *Rebar bowing.* A rebar had bowed up during the pouring of the hot material (see Figure 23). The rebar was removed by cutting to prevent interference with traffic. In the future, the transverse rebar may have to be tied down or removed to avoid this problem.



Figure 22. Equipment for Hot Pours



Figure 23. Bowing of Transverse Reinforcing Bar

Field Instrumentation

An attempt at measuring the movements in the ECPJ was made. Chase of the University of Virginia developed a new technique with available modern printed circuits to measure movements. This method works on the basis of the varying electrical resistance because of the movable knob that mechanically extends the circuit during expansion and retracts during contraction where the sensor is illustrated in Figure 24.

This movement-measuring system has been under an iterative process of modification through experience. The current setup of the instrumentation is shown in Figure 25. At this stage, little valid data have been collected for analyzing the expansion joint. In Phase II, the researchers expect to collect meaningful data on the movement of the ECPJ system.

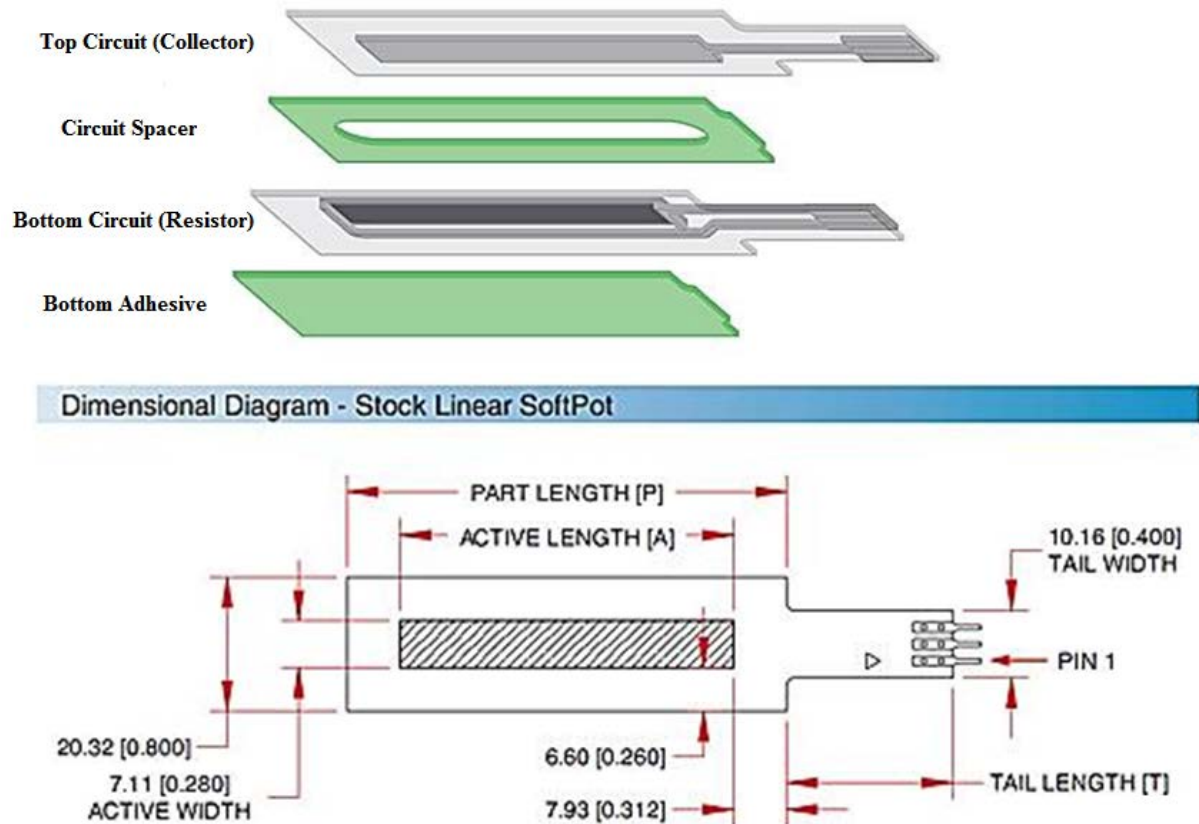


Figure 24. Illustration of Sensor

Pilot Phase II

Preliminary Report

Phase II of this pilot testing expanded the program to four additional districts in accordance with criteria similar to those for Phase I. Pending successful installation on the secondary road candidates, a fourth and final bridge for each district was selected on a primary route with low annual daily traffic for joint installation. Figure 26 shows the locations of the Phase II bridges.



Figure 25. Field Setup of Instrumentation

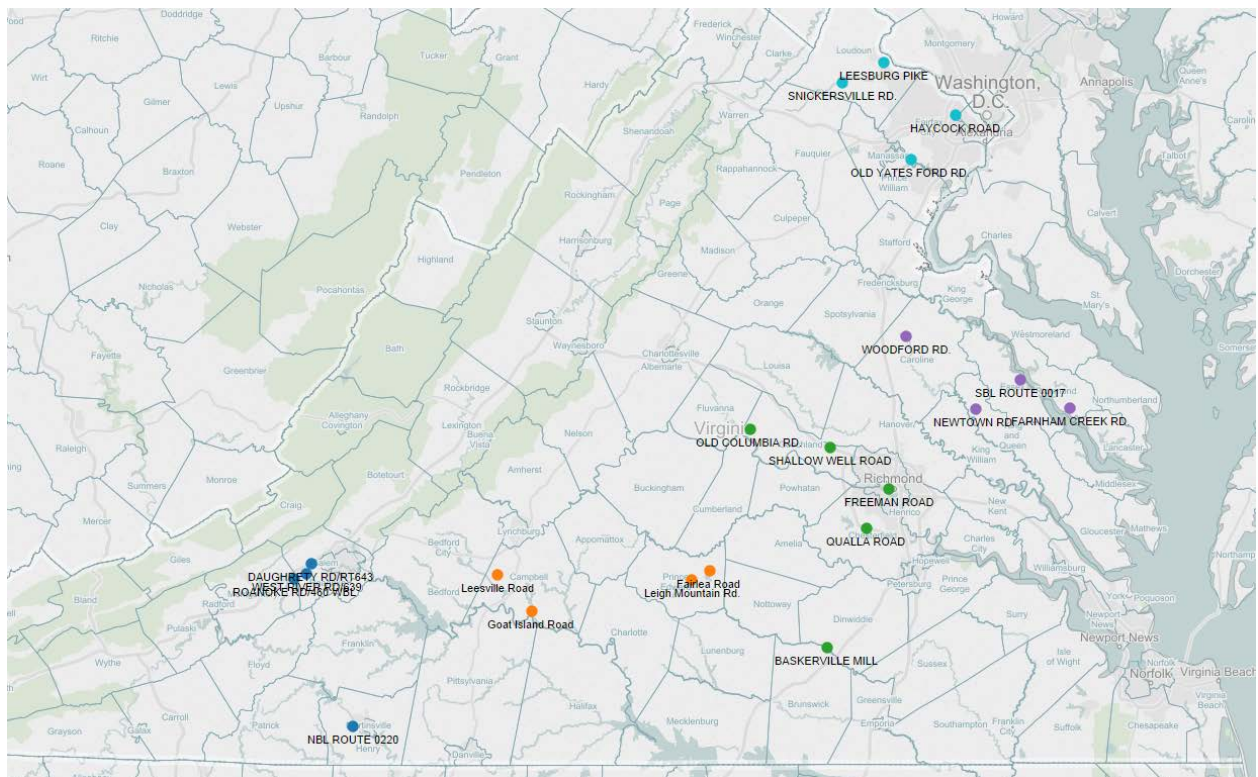


Figure 26. Map Showing Locations of Phase II Pilot Bridges

CONCLUSIONS

- *Shore durometer hardness values can be used as a preliminary filter to select material with toughness against permanent indentation.*
- *Dynamic modulus testing (AASHTO TP 79-15¹³) can be used as a measure of the toughness and flexibility of elastomeric concrete material under different temperatures. However, these tests do not give a complete picture of the material properties, so engineering judgment is also necessary in order to make decisions regarding the elastomeric materials.*
- *Short-term performance of the elastomeric concrete plug joint system was satisfactory under weather conditions in Virginia. Rutting during the summer months was not observed even though Fibrecrete failed in the laboratory testing (Virginia Test Method 110¹²). Expansion cracking during the winter months was not observed during the first year after installation in five bridge decks.*

RECOMMENDATIONS

1. *The Virginia Transportation Research Council (VTRC) and VDOT's Structure and Bridge Division should continue to monitor visually the performance of the ECPJ systems installed during this study and continue to evaluate new elastomeric concrete candidates for the joint system.*
2. *VTRC and VDOT's Structure and Bridge Division should expand the ECPJ trials to other districts for various exposure conditions.*

IMPLEMENTATION AND BENEFITS

Implementation

With regard to Recommendation 1, VTRC will work with VDOT's Structure and Bridge Division and VDOT district bridge maintenance personnel to monitor the performance of joints for a period of at least 5 years.

With regard to Recommendation 2, VTRC and VDOT's Structure and Bridge Division are working with three districts to install additional ECPJ systems in their bridge decks as a part of the Phase II pilot. This implementation phase is expected to be complete by the end of December 2018.

Benefits

As per Recommendation 1, the performance of ECPJ sections in terms of being watertight and adequately flexible can be ascertained. Problems arising through the life of the

ECPJ sections can be identified, and the joint system can be improved overall for enhanced durability.

As per Recommendation 2, the performance of the ECPJ sections can be monitored under various exposure conditions such as precipitation, snowfall, traffic volume, deicing salt use, and other conditions.

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