FDOT Contract Number TWO # BED49 977-03

Methods for Sealing Vertical Cracks on Concrete Structures

Final Report

April 2023

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: volumes greater than 1000 L shall be shown in m^3			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Methods for Sealing Vertical Cracks on Concrete Structures		5. Report Date 6. Performing Organization Code
7. Author(s) Abu Ahmed Sufian and Hyung S. Lee		8. Performing Organization Report No.
9. Performing Organization Name and Address Applied Research Associates, Inc. 100 Trade Centre Dr., Suite 200 Champaign, IL 61820		10. Work Unit No. (TRAIS) 11. Contract or Grant No. BED49 977-03
12. Sponsoring Agency Name and Address Florida Department of Transportation State Materials Office 5007 N.E. 39th Avenue Gainesville, FL 32609		13. Type of Report and Period Covered Draft Final Report June 2022 to April 2023 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The Florida Department of Transportation (FDOT) has had inconsistent success in sealing vertical cracks in concrete structures. This necessitated the investigation of the performance of different sealant types and application methods to address the concern of proper crack sealing in concrete substructures that cannot be routinely investigated. For this purpose, an extensive literature review was conducted. In addition, a targeted evaluation of the most commonly used concrete crack sealant products was conducted based on the information gathered from a survey directed to the state highway agencies within U.S. and Canada. Based on the literature review and survey data analysis, recommendations were developed that can be used as an internal guidance document to update the FDOT Standard Specification 400-21.

17. Key Word			18. Distribution Statement	
Vertical Cracks, Crack Sealing, Crack Sealant Products, FDOT Standard Specification 400-21			No restrictions	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified		21. No. of Pages 44	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

EXECUTIVE SUMMARY

Cracks in concrete structures can occur for a variety of reasons. The nature and extent of cracks also vary with types of structure, exposure condition etc. Cracks can originate in concrete when it is in its plastic state as well as when it reaches the hardened state. Some cracks are superficial and shallow, and hence, only affect the exterior surface. These cracks are generally harmless in nature. Others, however, may lead to significant structural distresses with problems threatening the durability of the structure. Regardless of the cause or extent of the crack, effective and durable repair techniques are absolutely necessary to determine the selection of appropriate repair procedures that take the root causes into account; otherwise, the repair serves as a short-term fix that does not resolve the cause of cracks and not able to efficiently treat the cracks. The main objective of this study is to document the best practices for sealing cracks in concrete structures, especially substructures. Since the substructures cannot be routinely inspected, the existence and extent of the cracks cannot be investigated thoroughly.

FDOT had limited success in sealing vertical cracks in concrete structures, especially on large projects. The agency adopted routing of cracks and filling with epoxy or viscous materials. However, for some deep cracks with narrow widths, the epoxy or viscous sealants do not penetrate deep enough to fill the necessary volume of the crack. Other existing problems include the cracking of the sealant itself, UV aging, and debonding, that allow penetration of water to the inside of the structure and threaten its functional and structural integrity. So, it was necessary to investigate the performance of different sealant types and application methods to address the concern of proper crack sealing in the concrete substructures that cannot be routinely investigated.

In this study, an extensive literature review was conducted. In addition, a targeted evaluation of the most commonly used concrete crack sealant products was conducted based on the information gathered from a survey directed to the state highway agencies within U.S. and Canada. Based on the literature review and survey data analysis, recommendations were developed that can be used as an internal guidance document to update the FDOT Standard Specification 400-21.

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1 INTRODUCTION/BACKGROUND

Cracking in concrete structures can be attributed to a range of causes. The manifestation and severity of cracks are contingent upon the type of structure, environmental conditions, and other factors. Cracks can originate in concrete when it is in its plastic state as well as when it reaches the hardened state. Some cracks are superficial and shallow and only affect the exterior surface. These cracks are generally harmless in nature. Others, however, may lead to significant structural distresses with problems threatening the durability of the structure. Regardless of the cause or extent of the crack, effective and durable repair techniques are absolutely necessary to determine the selection of appropriate repair procedures that take root causes into account; otherwise, the repair serves as a short-term fix that does not resolve the cause of cracks and not able to treat the cracks efficiently. The main objective of this study is to document the best practices for sealing cracks in concrete structures, especially substructures. Since the substructures cannot be routinely inspected, the existence and extent of the cracks cannot be investigated thoroughly.

2 PROBLEM STATEMENT

FDOT had limited success sealing vertical cracks in concrete structures, especially on large projects. The agency adopted routing of cracks and filling with epoxy or viscous materials. However, for some deep cracks with narrow widths, the epoxy or viscous sealants do not penetrate deep enough to fill the necessary volume of the crack. Other existing problems include the cracking of the sealant itself, ultraviolet (UV) radiance-related aging, and debonding, which allow air, water, and contaminants (e.g., chloride ions) penetration to the inside of the structure and threaten its functional and structural integrity. So, it was necessary to investigate the performance of different sealant types and application methods to address the concern of proper crack sealing in concrete structures that cannot be routinely investigated.

3 LITERATURE REVIEW

An extensive literature review was performed to study the state-of-the-practice and state-of-the-art for sealing cracks in concrete structures at the local and global levels. Details on crack sealant types, application methods, type, and extent of associated cracks, as well as the necessary pretreatments for the cracked structures, were documented. The significant findings from the literature search are highlighted in this section of the report.

3.1 Causes of Cracks on Concrete

Cracks in concrete structures develop due to factors either in the pre-construction phase or during construction. Pre-construction is a critical phase of a construction project that takes place before the actual construction begins and usually involves planning and organizing the project, developing a budget and schedule, and identifying specifications and mitigating risks. Different causes of cracks in concrete are summarized in Table 1.

Table 1. Common Causes and Mitigation Techniques of Concrete Cracking (ACI Report 224.1R, 1998)

Stage of Construction	Causes of Cracking	Crack Mitigation Techniques
During Construction	Plastic shrinkage	Prevent rapid moisture loss using fog nozzles, plastic sheeting, windbreaks, and sunshades.
Pre- and During Construction	Settlement cracking	Provide sufficient time between placement of concrete in vertical and horizontal sections, use lowest possible slump, and increase concrete cover.
	Drying shrinkage	Increase aggregate volume, reduce water content, pour concrete from bottom to top in vertical structures.
Pre- and During Construction	Thermal stresses	Reduce maximum internal temperature, delay the onset and rate of concrete cooling, allow movement by using properly designed contraction joints and correct detailing.
Pre-Construction	Chemical reaction	Use low alkali cement, use pozzolans, avoid reactive aggregates, use smaller maximum size aggregate.
Pre and During Construction	Weathering	Decrease water-cement ratio and total water content, use durable aggregate, provide adequate air entrainment and adequate curing prior to exposure to freezing conditions, and allow the structure to dry after curing.

Table 1. Common Causes and Mitigation Techniques of Concrete Cracking (ACI Report 224.1R, 1998) (Cont.)

Stage of Construction	Causes of Cracking	Crack Mitigation Techniques
Pre-Construction	Corrosion of reinforcement	Use low-permeability concrete, stirrups, and adequate cover. Using innovative additives like carbon fiber-reinforced plastic (CFRP), basalt fiber-reinforced plastic (BFRP) and glass fiber-reinforced plastic (GFRP) in the concrete.
Pre-Construction	Construction overloads	Design for load limits during construction.
Pre-Construction	Errors in design and detailing	Conduct proper design, and place rigorous Quality Control/Quality Assurance (QC/QA plan.
Pre-Construction	Steel Reinforcement Spacing	Use small-diameter bars with minimum practical spacing.

3.2 Determination of Location and Extent of Cracks

It is important to know the location and extent of cracks as well as the general condition of the concrete in a structure before selecting a repair technique. Several methods are available for assessing a concrete structure, as shown in Figure 1.

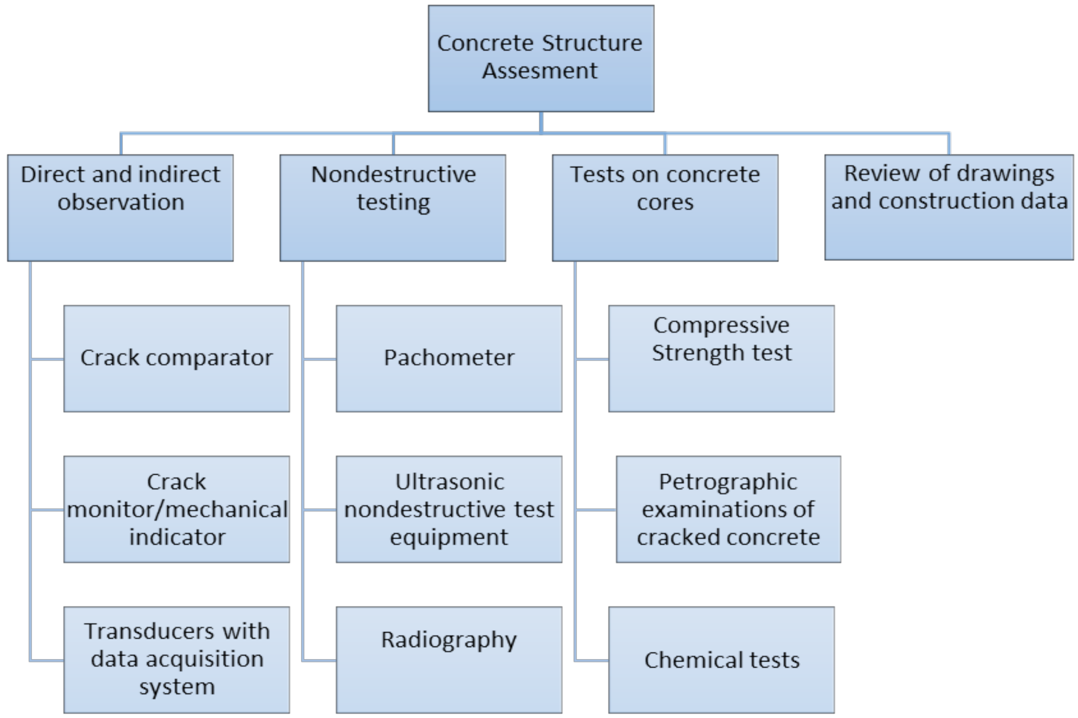

Figure 1. Different Methodologies of Concrete Crack Determination (ACI Report 224.1R, 1998).

3.3 Commonly Used Concrete Crack Sealants

Concrete crack sealants can be broadly divided into two broad types: Silanes and Siloxanes. Silane is an inorganic compound often used in paints, inks, and coatings to improve mechanical strength; and increase adhesion, thermal stability, and crosslinking (The Chemical Company, 2023). On the other hand, siloxanes are silicone-based organic compounds generally used to form chemical compounds with good thermal stability, chemical resistance, tunable refractive index, tunable mechanical properties, and excellent photo-stability (Su et al., 2006). Silane is the most commonly used deck sealant in the United States (US) (Johnson et al., 2009). The characteristics of these two compounds are shown in Figure 2.

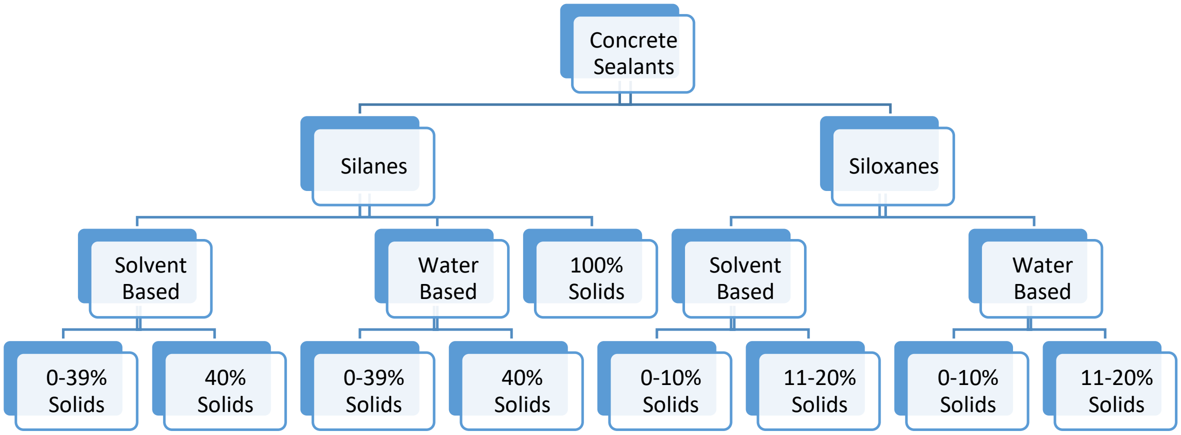

Figure 2. Classification of Deck Sealants (Johnson et al., 2009)

Crack sealants can be primarily categorized into five categories (Johnson et al., 2009):

- Epoxies: Epoxies are made from cyclic ethers called oxacyclopropanes that harden during polymerization. They are organic compounds containing an oxygen atom and a three-membered ring of carbon atoms typically developed by a reaction between biphenol A and Epichlorohydrin. Epoxies are generally known for their high tensile strengths (often four times that of High Molecular Weight Methacrylates); however, many different types are developed with a wide assortment of physical properties. Due to this, epoxies are known for their versatility). Epoxies also typically are more expensive than most other types of crack sealers. Epoxies can also cause minor skin irritation and allergic reactions (Meggers 1998, Johnson et al., 2009).
- Reactive Methyl Methacrylates: Reactive Methyl Methacrylates (MMA) are two-component sealers that have similar characteristics as High Molecular Weight Methacrylates but are much safer to use. MMA is formed from reactive methyl methacrylate catalyzed by a 50% dibenzoyl peroxide powder.
- Methacrylates: Methacrylates (another form of High Molecular Weight Methacrylates) are occasionally used because of their low viscosity and ability to cure at low temperatures. But these sealants are weak against freeze-thaw conditions (Johnson et al., 2009). They are mostly used as deck sealers.
- High Molecular Weight Methacrylates (HMWM): HMWMs are polymers made from methacrylate monomers. During the curing process of the sealer, an initiator is added to create an oxidation/reduction reaction. The monomer then develops into a high molecular weight polymer. When mixing the three-component system (monomer, initiator, and promoter), it has the potential to become violent. For example, if the initiator and promoter are mixed together prior to the monomer resin, it has the ability to explode. Typically, the promoter is mixed with the monomer resin initially to avoid problems. Because of this, reading the mixing instructions for all HMWM sealers are extremely important. HMWM resins are known for their low viscosity and high penetration depths.
- Polyurethanes: Polyurethane resins can also be used to seal cracked bridge decks. The advantages of using a polyurethane resin are the fast-curing time, little odor, and ease of application. Researchers stated that the polyurethane resin also have some drawbacks. The sealer failed to reach a satisfactory depth of penetration at high temperatures. Also, the

sealer had trouble standing up to freeze-thaw effects. Lastly, the sealer was less than satisfactory in sealing wider cracks (Sprinkel 1991, Johnson et al., 2009).

3.4 Different Crack Repair Techniques

After a proper evaluation of the cracked structure, a suitable repair procedure can be determined. In selecting the crack repair method, special consideration should be given to the effects of cracks on the expected durability and performance of the concrete structure and design service life of the repair method itself (Lasa and Antunes, 2022).

In this section of the report, different crack repair methods and materials are presented for various types of structures and crack characteristics with a short description of each.

Localized Crack Repair Techniques

- *Epoxy injection:* This is an effective method of concrete crack repair in buildings, bridges, dams, and other types of concrete structures. Cracks as narrow as 0.002 inches (0.05 mm) can be bonded by the injection of epoxy (ACI Report 224.1R, 1998). Best results are obtained if the crack width does not exceed 0.375 inches (9.5 mm) since the polymerization of the injected material may be affected at larger widths (Lasa and Antunes, 2022).
    - Materials: Epoxy materials used for structural repairs should conform to ASTM C 881 (Type IV).
    - Procedure: Epoxy injection procedures include cleaning the cracks with vacuuming or flushing with water, sealing the surface to keep the epoxy from leaking out before it has gelled, installing the entry and venting ports, mixing the epoxy, injection of epoxy (using hydraulic pumps, paint pressure pots, or air-actuated caulking guns), and finally removing the surface seal.
    - The success of epoxy injection depends on the absence of bond-inhibiting contaminants from the crack plane. Epoxy resins and injection procedures should also be carefully selected (ACI Report 224.1R, 1998).

- *Routing and sealing:* This is primarily for a remedial repair in case structural repair is unnecessary. This method is mostly applicable to relatively flat horizontal surfaces such as floors and pavements. However, routing and sealing can be applied to vertical surfaces (with a non-sag sealant, as for vertical applications, the sealant needs to be at a consistency that will permit application without any appreciable sagging or slumping) as well as on curved surfaces (pipes, piles, and pole). Its service period for wet or high moisture areas exceeds that of the topically applied waterproofing sealers (Lasa and Antunes, 2022).
    - Materials: Sealants used in this technique can be epoxies, urethanes, silicones, polysulfides, asphaltic materials, or polymer mortars.
    - Procedure: The procedure consists of preparing a groove at the surface ranging in depth, typically, from 1/4 to 1 inch (6 to 25 mm). The groove is then cleaned by air blasting, sandblasting, or waterblasting, and dried. A sealant is placed into the clean and dry groove and allowed to cure. Sometimes a bond breaker may be provided at the bottom of the groove to allow the sealant to change shape (ACI Report 224.1R, 1998).

- *Stitching*: This technique is used when tensile strength must be reestablished across major cracks.
  - Materials: Grout, epoxies.
  - Procedure: The stitching procedure consists of drilling holes on both sides of the crack, cleaning the holes, and anchoring the legs of the staples in the holes, with either a non-shrink grout or an epoxy resin-based bonding system.

- *Additional reinforcement:* This is mostly suitable for cracked reinforced concrete bridge girders or when a major portion of a member must be strengthened.
  - Materials: Reinforcing bars and epoxies.
  - Procedure: This can be done with conventional reinforcement and prestressing steel. The conventional method includes sealing the crack, drilling holes that intersect the crack plane at approximately 90 degrees, filling the hole and crack with injected epoxy and placing a reinforcing bar into the drilled hole. While the post-tensioning uses prestressing strands or bars to apply a compressive force.

- *Drilling and plugging:* This method consists of drilling down the length of the crack and grouting it to form a key. This is frequently used in repairing vertical cracks in retaining walls (ACI Report 224.1R, 1998).
  - Materials: Precast concrete or mortar plugs, grout.
  - Procedure: Drilling (Figure 3) a hole [typically 2 to 3 inches (50 to 75 mm) in diameter], then the drilled hole should be cleaned, made tight, and filled with grout. The key formed due to the grout prevents transverse movements of the sections of concrete adjacent to the crack and reduces heavy leakage through the crack and loss of soil from behind a leaking wall.

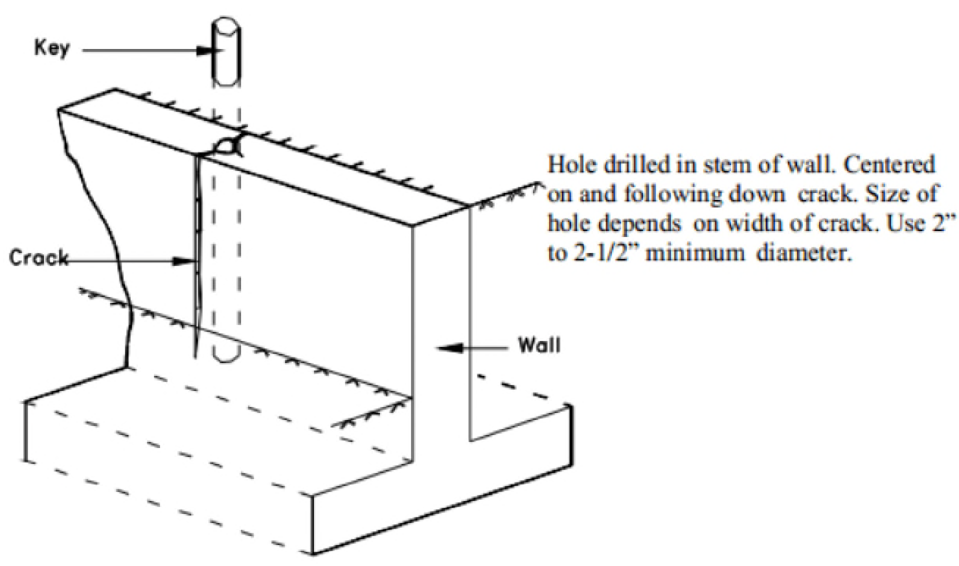

Figure 3.Drilling and Plugging Method (ACI Report 224.1R, 1998)

- *Gravity Filling*: Cracks with surface widths of 0.001 to 0.08 inches (0.03 to 2 mm) can be sealed by gravity filling (Rodler et al., 1989).
    - Materials: Low viscosity monomers and resins, high-molecular- weight methacrylates, urethanes, and some low viscosity epoxies.
    - Procedure: Typical procedure includes cleaning the surface by air blasting and/or waterblasting, then the monomer or resin can be poured onto the surface and spread with brooms, rollers, or squeegees, working the material back and forth over the cracks to obtain maximum filling since the monomer or resin recedes slowly into the cracks.

- *Grouting*: This method is mostly applicable for wide cracks, particularly in gravity dams and thick concrete walls. This is mostly effective in stopping water leaks, but it will not bond the structural cracks. Grouting can be done in two ways – Portland cement grouting and chemical grouting.
    - Materials: Portland cement, urethanes, sodium silicates, and acrylamides.
    - Procedure: The procedure consists of cleaning the concrete along the crack; installing built-up seats (grout nipples) at intervals (Figure 4) aside the crack (to provide a pressure tight connection with the injection apparatus); sealing the crack between the seats with a cement paint, sealant, or grout; flushing the crack to clean it and test the seal; and then grouting the whole area.
    - Chemical grouts can be applied in moist environments and can cover very fine fractures, while cement grouts are easy to apply and offer high strength.

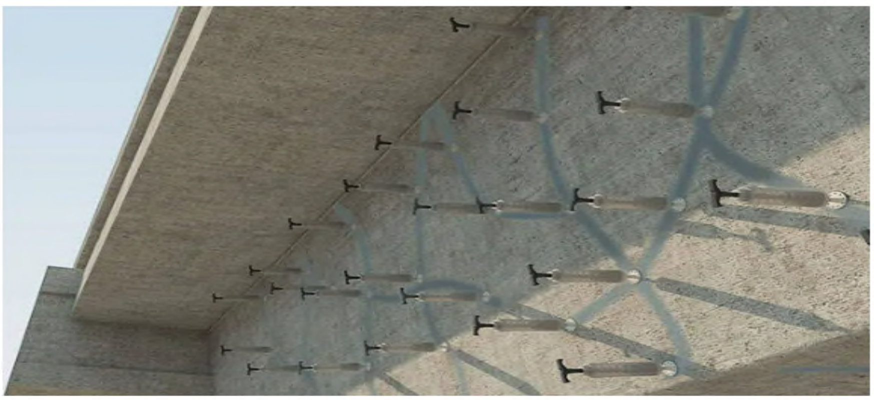

Figure 4. Grouting (Courtesy: Structuralguide)

- *Dry packing*: This method is suitable for repairing dormant cracks.
    - Materials: Cement slurry, dry pack mortar (one part cement, one to three parts sand and small amount of water) latex bonding compound (ASTM C 1059).
    - Procedure: The portion adjacent to the surface should be widened to a slot about 1 inch (25 mm) wide and 1 inch (25 mm) deep, cleaning and drying of the slot, applying a bond coat (cement slurry or equal quantities of cement and fine sand mixed with water), placing dry pack mortar.

- *Crack arrest*: This method is suitable for controlling cracks that formed due to a high temperature differential between the core and surface of the element during construction of massive concrete structures. The process includes blocking the newly initiated crack and spreading the tensile stress over a larger area (U.S. Army Corps of Engineers, 1945).

- Materials: Bond-breaking membrane or grid of steel mat. A semicircular pipe placed over the crack may also be used.
- Procedure: Cleaning the area in the vicinity of the crack, placing the pipe or mat in sections to remain centered on the crack, welding the sections together, cutting holes to install grout pipes, covering the installation with hand-placed concrete so that installed grout pipe can be used for grouting the crack at a later date.

➢ *Polymer impregnation*: This method is not effective for repairing cracks, as polymer can be soaked if there is moisture present in the cracks. But it can offer a more durable, impermeable surface that will resist cracking (Webster et al., 1978).

- Materials: Methyl methacrylate.
- Procedure: Drying the fractured concrete part, temporarily encasing it in a watertight (monomer proof) band of sheet metal, soaking the fractures with monomer, and polymerizing the monomer.

➢ *Overlay and surface treatments*: Very fine surface cracks in structural slabs, pavements, bridge decks and parking structures can be repaired using either a bonded overlay or surface treatment.

- Materials: Urethanes, epoxies, polyesters, and acrylics for surface treatments. polymer (styrene butadiene or acrylic latexes) modified Portland cement mortar or concrete for overlays.
- Procedure: Applying materials in thickness of 0.04 to 2.0 inches (1 to 50 mm) for surface treatments (ACI Report 224.1R, 1998). For overlays the procedure includes cleaning the surface, a bond coat consisting of mortar, or an epoxy adhesive, should be applied immediately before placing the overlay, continuous batching and mixing of polymer-modified concretes, placing, and finishing rapidly, 24-hour moist curing.

➢ *Autogenous healing*: A natural process of crack repair known as “autogenous healing” can occur in concrete in the presence of moisture and the absence of tensile stress (Lauer and Slate, 1956). It aids closing dormant cracks in a moist environment. Saturation of the crack and the adjacent concrete with water during the healing process is essential for developing any substantial strength. Submerging of the cracked section is also desirable. Mostly suitable for non-structural cracks.

The above-mentioned methods are mostly effective for localized crack control. When the intensity and frequency of the cracks are high, it becomes impractical and time-consuming to address each crack separately. In such cases, more global crack sealing approaches are practiced (Lasa and Antunes, 2022). Some of these methods are briefly described below.

Global Crack Repair Techniques

➢ *Flood sealing*: The method includes flooding a large area of the cracked structure with a low viscosity material to seal the cracks. Methacrylate flood coat is most commonly used for this purpose (ACI RAP Bulletin 13, 2010). It is primarily used on new bridge decks or horizontal surfaces but cannot be used on vertical cracks.

- *Structural jacketing*: This method consists of placing a continuous reinforced overlay jacket around the cracked component. It is typically used for repairing large areas for new and older concrete structures.
- *Cathodic protection and prevention*: This method is used mostly when there is a high concern of the structure developing severe corrosion due to the cracks. Appropriate anodes are placed externally to the structure to apply a corrosion prevention current. These systems are typically designed with a minimum service life of 25 years (Lasa and Antunes, 2022).
- *Electrochemical chloride removal*: Also known as electrochemical chloride extraction (ECE). The process includes extracting chloride ions from chloride-contaminated older reinforced concrete structures by applying an electrical current between the embedded steel and an external anode (Sohanghpurwala and Scannell 2011). Once the chlorides are removed, the cracks should be sealed to prevent re-intrusion of the chlorides. Total duration of this application process varies but one study indicated that about 40% of the initial chloride is removed within 7 weeks (Orellan et al., 2007).
- Chemical encapsulation: Encapsulation strategy is widely considered as a versatile and effective strategy for self-healing of concrete (Souradeep and Kua, 2016). It is adopted for buried structure (retaining walls/footings) components when there is concern of a reduction in service life due to cracks or other mechanisms. It consists of injecting a chemical compound into the soil around the structural component that would form a membrane and prevent chlorides or other contaminants from getting close to the concrete. These materials typically include polyurethanes, bituminates, or a modified elastomeric (Lasa and Antunes, 2022).

Table 2. Materials Used in Different Crack Repair Technique

Crack Repair Technique	Materials
Epoxy injection	Epoxy materials conform to ASTM C 881 (Type IV)
Routing and sealing	Epoxies, urethanes, silicones, polysulfides, asphaltic materials, or polymer mortars
Stitching	Grout, epoxies
Additional reinforcement	Reinforcing bars and epoxies
Drilling and plugging	Precast concrete or mortar plugs, grout
Gravity Filling	Low viscosity monomers and resins, High-molecular- weight methacrylates, urethanes, and some low viscosity epoxies
Grouting	Portland cement, urethanes, sodium silicates, and acrylamides
Dry packing	Cement slurry, dry pack mortar
Crack arrest	Bond-breaking membrane, grid of steel mat, semicircular pipe placed over the crack.
Polymer impregnation	Methyl methacrylate
Overlay and surface treatments	Urethanes, epoxies, polyesters, and acrylics for surface treatments. polymer (styrene butadiene or acrylic latexes) modified Portland cement mortar or concrete for overlays
Autogenous healing	Natural process for non-structural cracks
Flood sealing	Low viscosity material like methacrylate flood coat

References: ACI Report 224.1R, 1998; Lasa and Antunes, 2022; Rodler et al., 1989; U.S. Army Corps of Engineers, 1945; Webster et al., 1978; Lauer and Slate, 1956; ACI RAP Bulletin 13, 2010

3.5 Materials Characterization of Concrete Crack Sealants

Different types of concrete crack sealants have distinct characteristics that make them favorable for specific situations and unfavorable for others. Some of these characteristics include volatility, viscosity, initial shrinkage, tensile strength, and tensile elongation (Johnson et al., 2009). Some chemical characteristics of concrete crack sealants are briefly described below:

- **Deck sealants:** As stated before, most concrete deck sealants are based on silicone technology, primarily silanes, and siloxanes. These materials are derivatives of silicone with molecules small enough to penetrate and bond to the concrete, creating a hydrophobic layer in the treated surface. Since they are sealers, not membranes, they do not provide an impenetrable physical barrier. Rather, they reduce water inflow by inducing a chemical repulsion of the concrete to water (Aitken and Litvan, 1989). Silanes and siloxanes are usually supplied as a solution or as a suspension in a solvent.
- **Crack sealants:** Typical crack sealant products can bridge and seal fine cracks by creating a barrier that prevents water and water-borne contaminants from entering the concrete (Pincheira, 2005).

An ideal concrete crack sealer should have the following properties (Johnson et al., 2009):

- Viscosity less than 500 cP (or 25 cP for HMWM sealers),
- Tensile strength more than 1,160 psi (8 MPa), and
- Tensile elongation larger than 10 percent.

Viscosity ranges of typically used crack sealants are provided in Table 3:

Table 3. Viscosity Ranges of Typically Used Crack Sealants (Soltesz, 2010)

Crack Sealant	Viscosity (cP)
Epoxy	40-230
Methyl Methacrylate	5-20
High Molecular Weight Methacrylate	15-35
Urethane	12-16

Performance Testing of Concrete Crack Sealants

There are six primary performance measures for concrete crack sealants. These are listed below with their corresponding standards. (Johnson et al., 2009, Pincheira, 2005):

- Depth of penetration (NCHRP 244 series II, OHD L-40)
- Bond strength (ASTM C 496)
- Chloride content/resistance to corrosion (AASHTO T259/T260 and NCHRP 244 Series II). FDOT uses the Florida Method (FM 5-516).
- Seepage rate (ASTM E514)
- Rapid Chloride Penetration (ASTM C 1202)
- Durability against freeze-thaw and scaling (ASTM C 666 and ASTM C 672)

Quality Control/Quality Assurance (QC/QA) of Concrete Crack Sealants

From the review of different state highway agency (SHA) practices, it was found that many states do not conduct acceptance tests to identify acceptable crack sealing products, and products are typically chosen based on well-known research (Pincheira, 2005). However, some observations were made from different SHA practices:

- 90-day ponding (AASHTO T259) and absorption (ASTM C642) tests are commonly used as acceptance tests (Johnson et al., 2009).
- Depth of penetration and chloride content tests are the most commonly conducted QA/QC tests on bridge decks, but the results are highly variable (Johnson et al., 2009).

3.6 Florida Department of Transportation (FDOT) Practice of Sealing Cracks in Concrete Structures

FDOT Standard Specification section 400-21 provides necessary information and guidelines for determining proper methods for sealing atmospherically exposed, nonstructural cracks on new concrete structures. Based on the inspection of an engineer, cracks are classified as nonstructural (1/2 inch or less deep from the surface of the concrete) or structural cracks (cracks that extend deeper than 1/2 inch). However, a fully or partially underwater crack at any time during its service life will be classified as a structural crack (FDOT SS-400, 2023). Based on the cracking significance and type of structures, repair strategies for cracks are selected per Table 4 and Table 5.

Table 4. FDOT Cracked Concrete Treatment Selection (Concrete Structures Other Than Bridge Decks) (Abbreviations and Footnotes are given below) (FDOT SS-400, 2023)

Table 400-3
DISPOSITION OF CRACKED CONCRETE OTHER THAN BRIDGE DECKS
[see separate Key of Abbreviations and Footnotes for Tables 400-3 and 400-4]

Elev. Range	Crack Width Range (inch) (2) x = crack width	Cracking Significance Range per LOT (1)											
		Isolated Less than 0.005%			Occasional 0.005% to<0.017%			Moderate 0.017% to<0.029%			Severe 0.029% or gtr.		
		Environment Category											
		SA	MA	EA	SA	MA	EA	SA	MA	EA	SA	MA	EA
Elevation: 0 to 6 ft AMHW	x ≤ 0.004	NT	NT	PS (6)	NT	PS (6)	PS (6)	PS (6)	PS (6)				
	0.004< x ≤ 0.008	NT	PS (6)	EI (3)	PS (6)	EI (3)	EI (3)	PS (6)					
	0.008< x ≤ 0.012	NT	PS (6)	EI									
	0.012< x ≤ 0.016	PS (6)				Investigate to Determine Appropriate Repair (4, 5) or Rejection							
	0.016< x ≤ 0.020												
	0.020< x ≤ 0.024										Reject and Replace		
	0.024< x ≤ 0.028												
	x > 0.028												
Elev.: More Than 6 ft to 12 ft AMHW	Crack Width	SA	MA	EA	SA	MA	EA	SA	MA	EA	SA	MA	EA
	x ≤ 0.004	NT	NT	PS (6)	NT	PS (6)	PS (6)	PS (6)	PS (6)	PS (6)	PS (6)		
	0.004< x ≤ 0.008	NT	PS (6)	EI (3)	PS (6)	PS (6)	EI (3)	PS (6)	EI (3)				
	0.008< x ≤ 0.012	NT	PS (6)	EI	EI	EI							
	0.012< x ≤ 0.016	PS (6)	EI	EI	EI								
	0.016< x ≤ 0.020	EI											
	0.020< x ≤ 0.024					Investigate to Determine Appropriate Repair (4, 5) or Rejection					Reject and Replace		
	0.024< x ≤ 0.028												
	x > 0.028												
Elev.: Over Land or More Than	Crack Width	SA	MA	EA	SA	MA	EA	SA	MA	EA	SA	MA	EA
	x ≤ 0.004	NT	NT	NT	NT	PS (6)	PS (6)	PS (6)	PS (6)	PS (6)	PS (6)		
	0.004< x ≤ 0.008	NT	PS (6)	PS (6)	PS (6)	PS (6)	EI (3)	PS (6)	EI (3)	EI (3)	PS (6)		

Table 5. FDOT Cracked Concrete Treatment Selection (Bridge Decks) (Abbreviations and Footnotes are given below) (FDOT SS-400, 2023)

Table 400-4
DISPOSITION OF CRACKED CONCRETE BRIDGE DECKS
[see separate Key of Abbreviations and Footnotes for Tables 400-3 and 400-4]

Elev. Range	Crack Width Range (inch) [2]	Cracking Significance Range per LOT [1]: Isolated less than 0.005%			Occasional 0.005% to<0.017%			Moderate 0.017% to<0.029%			Severe 0.029% or gtr.		
	x = crack width	Environment Category: SA	MA	EA	SA	MA	EA	SA	MA	EA	SA	MA	EA
Elevation: 12 feet or Less AMHW	$x \le 0.004$	NT	NT	NT	NT	NT	NT	NT	NT	NT			
	$0.004 < x \le 0.008$	NT	NT	EI/M	NT	NT	EI/M	EI/M	EI/M	EI/M			
	$0.008 < x \le 0.012$	NT	NT	EI/M	NT	EI/M	EI/M	EI/M	EI/M				
	$0.012 < x \le 0.016$	NT	NT	EI/M	NT	EI/M							
	$0.016 < x \le 0.020$	EI/M	EI/M	EI	EI								
	$0.020 < x \le 0.024$	EI/M	EI	EI		Investigate to Determine Appropriate Repair [4, 5] or Rejection					Reject and Replace		
	$0.024 < x \le 0.028$	EI/M	EI										
	$x > 0.028$												
	Crack Width	SA	MA	EA	SA	MA	EA	SA	MA	EA	SA	MA	EA
Elevation: Over Land or More Than 12 feet AMHW	$x \le 0.004$	NT	NT	NT	NT	NT	NT	NT	NT	NT			
	$0.004 < x \le 0.008$	NT	NT	NT	NT	NT	EI/M	NT	EI/M	EI/M			
	$0.008 < x \le 0.012$	NT	NT	EI/M	NT	NT	EI/M	EI/M	EI/M				
	$0.012 < x \le 0.016$	NT	NT	EI/M	NT	EI/M							
	$0.016 < x \le 0.020$	NT	EI/M	EI	EI/M		Investigate to Determine Appropriate Repair [4, 5] or Rejection						
	$0.020 < x \le 0.024$	NT	EI/M	EI							Reject and Replace		
	$0.024 < x \le 0.028$	NT	EI/M										
	$x > 0.028$												

Key of Abbreviations and Footnotes for Tables 400-3 and 400-4

Type Abbreviation	Abbreviation	Definition
Repair Method	EI	Epoxy Injection
	M	Methacrylate
	NT	No Treatment Required
	PS	Penetrant Sealer
Environment Category	EA	Extremely Aggressive
	MA	Moderately Aggressive
	SA	Slightly Aggressive
Reference Elevation	AMHW	Above Mean High Water

Footnotes

(1) Cracking Significance Range is determined by computing the ratio of Total Cracked Surface Area (TCSA) to Total Surface Area (TSA) per LOT in percent [(TCSA/TSA) x 100] then by identifying the Cracking Significance Range in which that value falls. TCSA is the sum of the surface areas of the individual cracks in the LOT. The surface area of an individual crack is determined by taking width measurements of the crack at 3 representative locations and then computing their average which is then multiplied by the crack length.

(2) Crack Width Range is determined by computing the width of an individual crack as computed in (1) above and then identifying the range in which that individual crack width falls.

(3) When the Engineer determines that a crack in the 0.004 inch to 0.008 inch width range cannot be injected then for Table 400-3 use penetrant sealer unless the surface is horizontal, in which case, use methacrylate if the manufacturer's recommendations allow it to be used and if it can be applied effectively as determined by the Engineer.

(4) (a) Perform epoxy injection of cracks in accordance with Section 411. Seal cracks with penetrant sealer or methacrylate as per Section 413. (b) Use only methacrylate or penetrant sealer that is compatible, according to manufacturer's recommendations, with previously applied materials such as curing compound or paint or remove such materials prior to application.

(5) When possible, prior to final acceptance of the project, seal cracks only after it has been determined that no additional growth will occur.

(6) Methacrylate shall be used on horizontal surfaces in lieu of penetrant sealer if the manufacturer's recommendations allow it to be used and if it can be applied effectively as determined by the Engineer.

(7) Unless directed otherwise by the Engineer, repair cracks in bridge decks only after the grinding and grooving required by 400-15.2.5 is fully complete.

Moreover, based on recent published guidelines by the FDOT State Materials Office (SMO), the following recommendations are suggested when selecting appropriate crack-sealing methods for reinforced concrete structures.

Table 6. Recommended Crack Remediation Practices by FDOT (Lasa and Antunes, 2022)

Crack Widths (inches/mm)	Crack Sealing Method	Materials and Structure Type
<0.005/<0.127	Topical Waterproofing (Figure 5)	Surface coating only. Mostly suitable for vertical fine cracks (Figure 6).
>0.005-0.375/>0.127-9.525	Epoxy Injection	Fluid epoxy type E (Section 926). For horizontal and vertical applications.
>0.005/>0.127	Polyurethane and Rubberized Polymers	Hydrophilic polyurethane, rubberized polymers. Mostly for horizontal surfaces.
>0.005/>0.127	Overlays	Polymer or Portland cement based. For horizontal bridge decks.
>0.002/>0.05	Gravity Seal	Methacrylate: For horizontal bridge decks.
0.002-0.250/0.05-6.35	Routing & Sealing	Fluid epoxy type F (Section 926): Mostly used on vertical surfaces.
>0.002/>0.05	Cathodic Protection/Prevention	Mainly for corrosion prevention. For horizontal and vertical applications.

Figure 5. Waterproofing of Concrete Surface (Courtesy: ANDERSAL)

Figure 6. Waterproofing of a cracked basement wall (Absolutely Dry Basement Waterproofing, Inc, 2023)

3.7 Overview of Practices by State Highway Agencies in the U.S.

California Department of Transportation (Caltrans)

Caltrans outlines and follows a methodical procedure for structural concrete repair and rehabilitation. A summary of the procedural steps is listed below (Caltrans Concrete Technology Manual, 2013):

- Assess the defect and determine its cause,
- Determine the limits of cracks or defective concrete,
- Determine if repairs are required,
- Determine which repair method will be used,
- Remove defective concrete if needed for the repair,
- Place the repair, and
- Cure the repair.

Caltrans treats the critical cracks in concrete structures either as structural cracks or cracks that are indicative of internal stress development. Structural cracks are repaired by filling the crack with a pressure-injected epoxy adhesive. Other repair options are doing nothing, partial replacement with dry-packed mortar, conventional concrete, shotcrete, an overlay, surface treatment with a sealant and total replacement (Caltrans concrete technology manual, 2013). The materials used for these methods are listed in Table 7. Figure 7 represents the various repair techniques used by CalTrans for concrete deterioration including voids and cracks.

Table 7. Different Materials Used by Caltrans for Concrete Crack Repair (Caltrans Concrete Technology Manual, 2013

Material	Purpose
Cementitious Materials: Portland cement mortar or concrete, water activated magnesium phosphate/sulfoaluminate cements.	Patching material for permanent reconstruction of deteriorated concrete. For horizontal and vertical surfaces.
Polymeric Materials: Epoxy, polyester-styrene, and methacrylate.	Bridge repair/rehabilitation work.
Thermoplastic/Thermoset: Mylar, polyvinyl chloride (PVC), acrylonitrile butadiene styrene (ABS), methacrylate, and polyester polymers.	Overlay for bridge decks, fill and rebond cracks as a surface sealant. For horizontal surfaces.
Polyester Concrete	Bridge deck overlays, excellent patching material. For horizontal surfaces.
Urethane Resins	Deck rehabilitation work. For horizontal surfaces.
Epoxy	Crack sealing in vertical walls
Epoxy Mortar	Patching

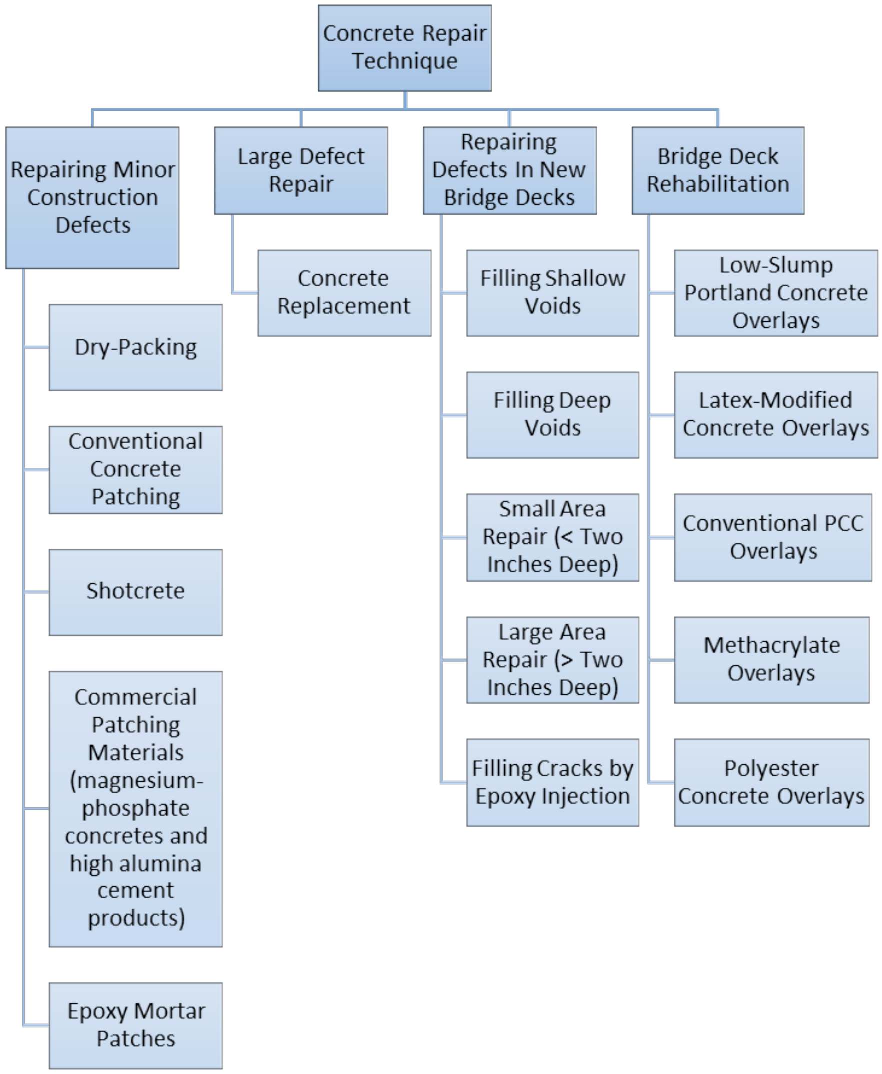

Figure 7. Different Concrete Crack Repair Techniques (CalTrans Concrete Technology Manual, 2013)

Georgia Department of Transportation (GDOT)

According to GDOT Standard Specifications for Construction of Transportation Systems, standard Type V epoxy adhesive is used for sealing cracks at the concrete surface (GDOT, 2021). The process includes cleaning and preparing the concrete surfaces, coring holes that are 1/2 inch (13 mm) in diameter and 3/4 inch (19 mm) to 1 inch (25 mm) in depth, inserting full-depth copper or plastic tubes into cored holes, sealing the circumference of the ports at the surface, and injecting the epoxy at a constant pressure not to exceed 250 psi (GDOT, 2021). For bridge deck repairs, GDOT use patching and overlays.

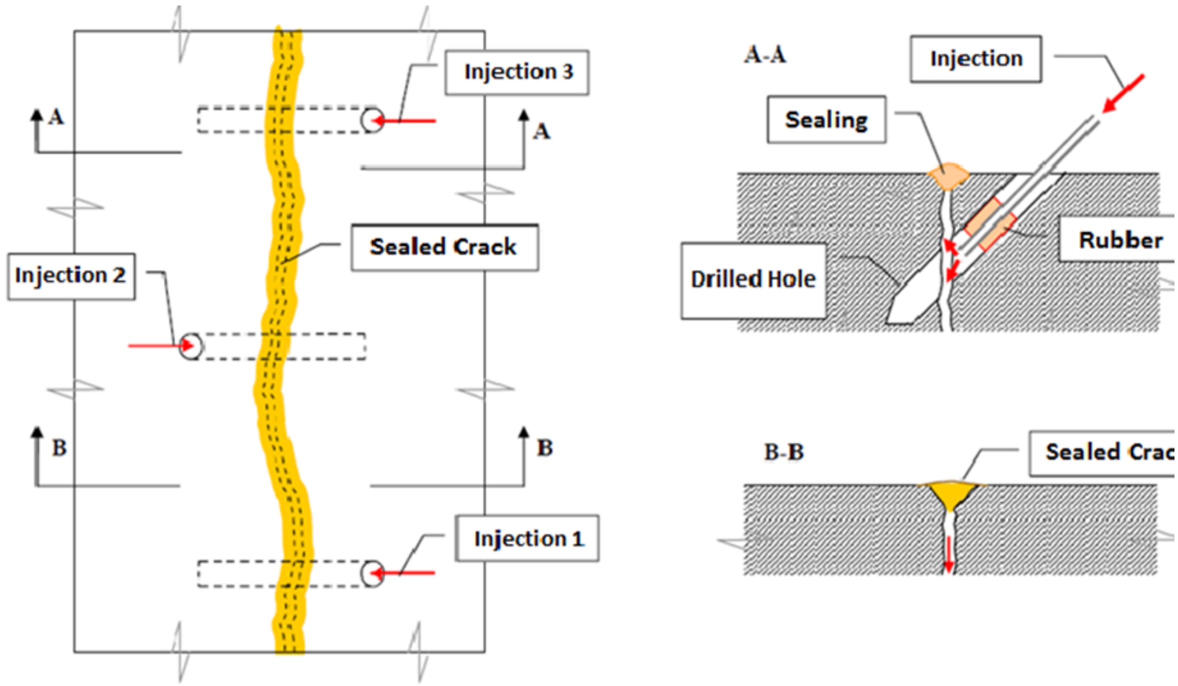

Figure 8. Crack Sealing in Vertical Walls (Araújo, 2016)

Illinois Department of Transportation (IDOT)

IDOT treats cracks in concrete structures in two ways:

- Crack openings less than or equal to 1/2 inch: Inject an epoxy crack-sealing material into the crack. Cracks located in a vertical wall with voided areas behind the wall cannot be effectively sealed by injecting material into the cracks unless the voided area has been filled with material which will prevent the injected crack sealing material from being forced into the voided area (IDOT Structural Services Manual, 2017).
- Cracks with openings greater than 1/2 inch: Should be sealed by removing all loose material along the edges of the crack and then using an expansive cement grout to fill the crack. The presence of large vertical cracks in an unreinforced concrete pier may require the installation of a steel collar (IDOT Structural Services Manual, 2017).

Minnesota Department of Transportation (MnDOT)

The current practice of MnDOT is crack sealing using epoxy injection. The procedure includes surface preparation by air blowing, chasing/detecting cracks using a bottle or pump, or in some cases, a flood seal. Paulco TE-2501 epoxy is the most commonly used product in Minnesota. MnDOT also performed an extensive field study on twelve crack sealant products to evaluate the performance of these sealants through field permeability testing, visual observations, and petrographic examination. The work included the examination of various crack sealant materials (deck sealants were not included) on an in-service bridge over a period of three winters (Oman, 2014). After extensive visual observation, testing, and coring through three winters, the recommended epoxy products which demonstrated the best performance are presented in Table 8.

Table 8. Recommended Epoxy Products by MnDOT

<table>
<tr><th>Product</th><th>Surface Preparation</th><th>Application Method</th><th>Estimated Service Life</th></tr>
<tr><td>TK-2110</td><td rowspan="4">Air Blown</td><td>Flood</td><td rowspan="4">3 to 4+ years*</td></tr>
<tr><td>Paulco TE- 2501</td><td>Bottle</td></tr>
<tr><td>Dural 50 LM</td><td rowspan="2">Flood</td></tr>
<tr><td>EpoXeal GS Structural</td></tr>
</table>

*Service life is reported in (Oman, 2014)

Recommended methyl methacrylates (MMA) products are:

Table 9. Recommended MMA Products by MnDOT

<table>
<tr><th>Product</th><th>Surface Preparation</th><th>Application Method</th><th>Estimated Service Life</th></tr>
<tr><td>KBP 204 P</td><td rowspan="3">Air Blown</td><td rowspan="3">Flood</td><td rowspan="3">3 to 4+ years*</td></tr>
<tr><td>T-70-MX-30</td></tr>
<tr><td>DegaDeck CSP</td></tr>
</table>

*Service life is reported in (Oman, 2014)

Figure 9. Typical Operations During Concrete Crack Sealing – a) blowing surface with air b) sand blasting c) shot blasting d) bottle application e) caulk gun application f) pump application g) flood application h) sand casting on surface (Oman, 2014)

New York Department of Transportation (NYDOT)

NYDOT uses epoxy injection technique for both crack sealing (prevention) and crack repair (restoration).

- Preventive crack sealing: use in contaminated, cracked concrete areas to prevent movement and protect reinforcement.
- Restoration crack sealing: use in uncontaminated cracked concrete areas to restore structural integrity (NYDOT, 1999).

The procedure includes installing injection ports, sealing the crack opening, injecting the crack with epoxy (full depth for restoration work, or as deep as conditions allow for prevention work), and restore the sealed surface to a flush condition in areas visible to the public (NYDOT, 1999).

North Dakota Department of Transportation (NDDOT)

NDDOT evaluated five types of sealers based on eight sets of laboratory tests. These sealers were evaluated for three groups of concrete mixes: normal concrete mix, fly ash concrete mix, and old concrete. The test data was used to determine which sealer/concrete mix combination was the most adequate in improving resistance to the deterioration of concrete properties (Mamaghani et al., 2007). Table 10 describes these different types of sealant names, their properties, and their effectiveness against deterioration.

Table 10. Performance of Different Concrete Sealers (Mamaghani et al., 2007)

Sealant	Chemical and Other Properties	Effectiveness
Tamms Dural 335 (D335)	Solvent free, two components, moisture insensitive, and ultra-low viscosity epoxy sealer.	i) Against water absorption ii) Against freeze-thaw iii) Resistance to chloride ion penetration iv) Can seal cracks up to 0.008 inches (0.2 mm)
DegaDeck Crack Sealer (DCS)	Low viscosity, low surface tension, rapid curing methacrylate reactive resin.	
Star Sealer (SS)	Based on specialty polymers and concrete saturants.	
Radcon Formula #7 (R7)	Biochemically modified silicate solution.	i) Against water absorption
Chem-Trete BSM-40 VOC (CT40)	Isobutyl-trialkoxy silane in an alcohol carrier.	i) Against water absorption

From the study, it was evident that D335 was the best-performing concrete sealer, as it showed less water absorption (ASTM C642-97), better resistance against deicing chemicals (ASTM C672/C 672M-03) and chloride ion penetration (AASHTO T259-02). It can also fill cracks up to 0.008 inches (0.2 mm) in width. Another conclusion was that the fly-ash concrete mix performed best among the concrete mixes.

Oregon Department of Transportation (ODOT)

ODOT seals each crack separately if cracks are 10 feet (3 m) apart or more. If the cracks are numerous or are less than 10 feet (3 m) apart, they seal the entire area. The agency uses three types of concrete crack sealers (ODOT Standard Specifications, 2021):

- Low modulus concrete crack sealer: Mostly used in deck sealing and resurfacing. These crack sealers are more flexible and thus perform much better in conditions where mechanical or thermal movement is likely. Because a majority of treated cracks are on concrete bridges and parking decks, a low modulus of elasticity resin is optimal. This type of resin will seal and heal the crack, bind the crack back together, and yet allow a certain amount of movement so as to prevent re-cracking (Euclid Chemical, 2018).
- High modulus concrete crack sealer: These are mostly used to seal routed crack surfaces on non-moving cracks (Crown Polymers, 2016).

- Water repellent concrete sealer: These are usually silane, siloxane, or a silane/siloxane blend. They soak into the crack and coat the sides to provide a water-repellent barrier, but they do not heal the concrete (Euclid Chemical, 2018).

Based on the nature of the repair work and extent of the crack, ODOT select one of these three techniques.

Texas Department of Transportation (TxDOT)

For crack repairing of concrete structures, TxDOT uses three methodologies:

- Pressure-Injected Epoxy: TxDOT uses pressure-injected ASTM C 881 Type IX low-viscosity epoxy resin into concrete cracks to restore the structural integrity of damaged members or to prevent water and chloride infiltration. Although it depends on the epoxy resin material, cracks as narrow as 0.002 inches (0.05 mm) can be injected with epoxy resin. However, it is often difficult to effectively fill cracks that are narrower than 0.005 inches (0.127 mm). The agency guideline is to use a crack gauge to get accurate readings on crack widths.
  - Materials: The epoxy resin should conform to ASTM C 881 Type IV, Grade 1 standard. This epoxy has two liquid components that are combined automatically during the pressure injection process (TxDOT Concrete Repair Manual, 2021).
  - Procedure: The procedure includes preparation and cleaning of the surface, mixing the epoxy resin, inserting injection ports, pressure-injecting the epoxy resin into the crack through the ports, maintaining adequate pressure until resin emerges from the adjacent port; once the resin appears in an adjacent port, remove the injection nozzle, seal the port, and begin injecting in the adjacent port.

- Gravity-Fed Sealant: TxDOT uses Type IV low-viscosity, gravity-fed sealant to fill cracks to help prevent water and chloride infiltration into concrete. Cracks with widths as narrow as 0.004 inches (0.1 mm) can be filled using gravity-fed material.
  - Materials: TxDOT Type IV low-viscosity, gravity-fed sealant.
  - Procedure: The procedure includes surface preparation and cleaning, mixing each component according to the manufacturer's requirements, using a low-speed electric drill, and pouring sealant directly on cracks within the treatment area.

- Surface Sealing: TxDOT seals cracks to prevent infiltration of water, chlorides, and other contaminants. This method is only effective for sealing the cracks at the outer surface of the concrete. There are two ways:
  - Rout-and-Seal Cracks: Effective against water infiltration in cracks. The method includes creating a V-shaped groove about 3/8 inch (9.65 mm) deep, cleaning, and filling the groove using a preapproved Class 4 low-modulus silicone or Type V adhesive.
  - Surface Sealing: This method simply involves applying an adhesive directly over the crack to prevent infiltration of water, chlorides, and other contaminants. The material typically used is a preapproved ASTM Type VIII or Type X epoxy.

Virginia Department of Transportation (VDOT)

VDOT usually follows eight basic steps for repair and preservation of hydraulic cement concrete structure (HCC):

- Defining the repair problem,
- Locating deteriorated concrete,
- Removing deteriorated concrete,
- Preparing concrete surfaces,
- Patching,
- Crack repairs,
- Hydraulic cement concrete overlays, and
- Epoxy overlays, membranes, and sealers.

The agency uses three methods for concrete crack repair (VDOT, 2022):

- Gravity Fill Polymer: This is the most economical way to seal pattern cracks. Cracks must be at least 0.008 inches (0.2 mm) in width for the sealer to penetrate and fill the crack. Mostly suitable for bridge decks, but very low viscosity polymers can deeply penetrate the concrete cracks and is suitable for sealing vertical cracks.
    - Materials: High molecular weight methacrylate (HWWM), epoxy and urethane.

- Route and Seal: This method is used for sealing individual cracks. The process includes routing cracks with a crack-chasing device and filling with epoxy. It is time-consuming and more expensive than gravity fill but faster and lower cost than pressure injection. This procedure works the best for flat horizontal surfaces but can also be used on vertical and curved surfaces when a non-sag sealant is employed (ACI Report 224.1R, 1998).

- Pressure Injection of Epoxy: This is the most expensive crack-sealing method among the three. The process includes applying a paste of epoxy to seal the top and bottom of the crack, installing injection ports at a spacing equal to the depth of injection, injecting low-viscosity epoxy in the crack at the port with lowest elevation, keep injecting until epoxy comes out of the adjacent port and all the ports are filled. This is the most effective method for sealing critical cracks and restoring the strength of cracked concrete.

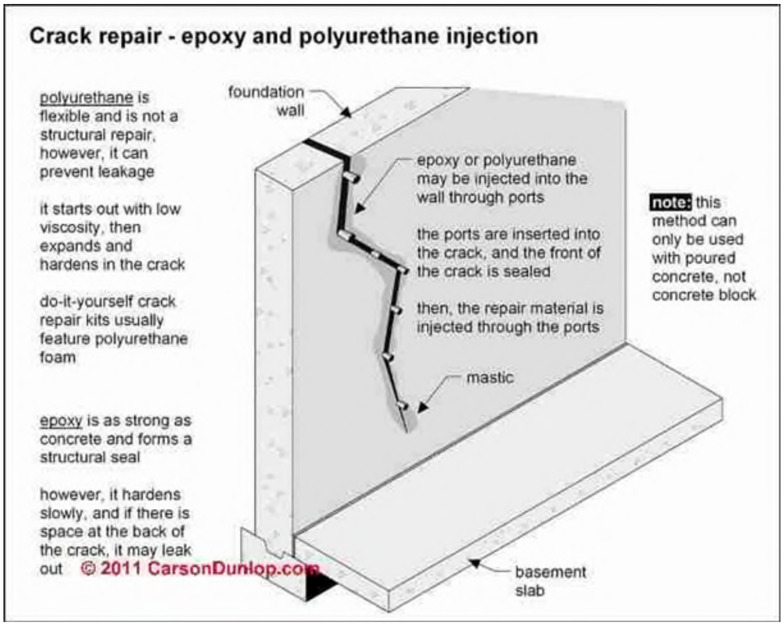

Figure 10. Repair of Concrete Crack in a Vertical Wall (Courtesy: Carson Dunlop)

Wisconsin Department of Transportation (WisDOT)

WisDOT evaluated thirteen deck and ten crack sealants under laboratory conditions that simulated the exposure to deicing salts and freeze-thaw cycles encountered in practice. The study found that the performance of crack sealants depended on the crack width considered. The tests performed on deck sealants were resistance to chloride ion intrusion and against freeze-thaw cycles (AASHTO T 259 and AASHTO T 260). For the crack sealants, the tests performed were the ability of the sealants to penetrate and fill cracks and the bond strength test. Of the thirteen deck sealants studied, two products, Sonneborn Penetrating Sealer 40 VOC and Hydrozo Silane 40 VOC, performed best. Of the ten crack sealants tested in this study, Sikadur 55 SLV showed excellent performance in sealing hairline, narrow, and medium cracks (Pincheira and Dorshorst, 2005).

It was discovered from the literature review that most of the SHAs do not follow any specific criteria for repairing cracks, especially vertical cracks in concrete structures. All the repair works are warranted and performed as a part of routine maintenance works of concrete structures. It has also been found that except in California, North Dakota, and South Dakota, no other SHAs perform any quality control/quality assurance (QC/QA) test to check the quality of concrete crack sealing work. Crack sealing practices of different state highway agencies (SHA) are summarized in Appendix A of this white paper.

3.8 Crack Sealing Best Practices by International Highway Agencies

This section describes innovative crack sealing practices from various countries.

European Practice

European countries repair concrete cracks according to European Standard UNI EN 1504. Cracks are filled with sealant to protect against penetration risk or to ensure structural strengthening. European agencies use two products- Epojet and Epojet LV for concrete crack sealing, and these are formulated with a reactive polymer binder. The following considerations are made while selecting sealants for crack filling:

- Thickness of cracks,
- Moisture level of the crack,
- Minimum and maximum application temperature, and
- Movement of the cracks.

Based on the above-mentioned considerations, a crack sealant method and product are selected so that the following objectives can be achieved from the repair work:

- Protection against ingress
- Moisture control
- Increase in physical resistance
- Resistance to chemicals
- Increasing resistivity

European standard also has provisions for several performance tests to quantify the performance of a particular crack sealant. These are listed in Table 11.

Table 11. Characteristics and Performance Requirements of Injected Sealant Products for Filling of Cracks (European Standard, 2005)

	Performance characteristics	Test method	Repair principle			Requirement
			1	4	4	
			Repair method			
			1.5	4.5	4.6	
BASIC CHARACTERISTICS	Adhesion by tensile bond (H, P)	EN 12618-2	●	●	●	- > 2 N/mm^2 (H) - > 0,6 N/mm2 (for injection products for filling voids and interstices only) - Cohesive failure in the substrate (P)
	Adhesion by inclined shear strength (HP)	EN 12618-3	Δ	Δ	Δ	Monolitic failure
	Volumetric shrinkage (P)	EN 12617-2	●	●	●	< 3%
	Bleeding (H)	EN 445/3.3	●	●	●	Bleeding < 1% of the initial volume after 3 hours
	Variation in volume (H)	EN 445/3.4	●	●	●	- 1% < variation in volume < 5% of the initial volume
	Glass transition temperature (P)	EN 12614	Δ	Δ	Δ	> 40 °C
	Chloride content (H)	EN 196-21	Δ	Δ	Δ	< 0,2%
REACTIVITY CHARACTERISTICS	Injectability into dry medium (H, P)*	EN 1771 EN 12618-2	●	●	●	Injectability class: - high: < 4 minutes for 0.1 mm cracks - minimum: < 8 minutes for 0.2 and 0.3 mm cracks Degree of crack filling > 90% Indirect tension: > 7 N/mm^2 (P) – > 3 N/mm^2 (H)
	Viscosity (P)	EN ISO 3219	●	●	●	Declared value
	Time to efflux (H)	EN 14117	●	●	●	Declared value
REACTIVITY CHARACTERISTICS	Workability time (H, P)	EN ISO 9514	●	●	●	Declared value
	Tensile strength development of polymers (P)	EN 1543	●	●	●	Tensile strength > 3 N/mm2 within 72 hours at the minimum application temperature or within 10 hours at the minimum application temperature for daily movements of more than 10% for the larger cracks or 0.03 mm (the lowest value)
	Setting time (H)	EN 196-3	●	●	●	Declared value
DURABILITY	Adhesion by tensile bond strength after thermal and wet drying cycles (H, P)	EN 12618-2	●	●	●	Reduction of tensile strength less than 30% of initial values (H) Cohesive failure in the substrate (P)
	Compatibility with concrete (H, P)	EN 12618-2	●	●	●	Reduction of tensile strength less than 30% of initial values (H) Cohesive failure in the substrate (P)

Canadian Concrete Crack Sealing Experiment with Shotcrete

A study in Canada had extensive success with concrete repair using site-batched latex-modified dry-mix shotcrete. Shotcrete is commonly used for vertical and overhead repairs. Including latex admixtures provided improved tensile and bond strength properties, reduced permeability, and improved durability, especially against corrosion. Around 5% (by volume) of latex solids were used in the mix design. The process included manual removal of deteriorated concrete, heavy sandblasting to remove rust, replacement of all heavily corroded reinforcing bars, placement of galvanized wire mesh where removal depth is more than 1.6 inches (40 mm), forming, shotcreting in two layers, troweling and float finishing, wet-burlap curing, light sandblasting of wet-cured shotcrete surfaces, and finally the application of two coats of acrylic curing or sealing compound. The repair was found to be very effective, and the bridges were in good condition even after 23 years of service. Data from the study suggested that this repair method can provide a service life of up to 35 years (Carter and Wong, 2006).

Brazilian Metakaolin-based geopolymer cement as a Concrete Crack Filler

Brazilian researchers used geopolymer cement to repair cracks in concrete specimens (Frasson et al., 2020). Cubic concrete test specimens were produced, and mechanical performance and fracture mode were observed. The results were compared with the common practice of applying the epoxy. The geopolymer cement paste used to repair cracks consisted of metakaolin from kaolin calcination at 1,472ºF (800ºC) and a solution activator produced by dissolving sodium hydroxide (NaOH) in sodium silicate Na2SiO3 with 63% water. The repair method consisted of drying, cleaning, and gravity-filling the cracks until the materials overflowed and the excess was removed. The results showed that it is possible to use geopolymer cement as a filler material for both horizontal and vertical cracks with improved experimental compressive strength in cracked specimens. The study presented a new potential for applying geopolymer cements, considering their satisfactory cohesion properties and adhesion, and they are competitive with the recovery materials available on the market (Frasson et al., 2020).

Indian invention of sealant using waste material

A study in India used aquaculture waste-derived material as a renewable feedstock for producing a sealant for healing micro-cracks in concrete (Kannan et al., 2022). The material is a composite of graphene-oxide and chitosan, and it was named Eco-Nanoseal. This nanofibrous film-forming composite can quickly solidify in the concrete environment without any external polymerizing agent. It can quickly form a solid plug and strong bonding with the concrete surface. It is also proven to be hydraulically stable and has an excellent ability to plug microcracks in concrete. It is non-toxic, affordable, and can chemically bind with the concrete surface under ambient conditions. This waste-derived sealant, with less embodied energy and enhanced properties, is believed to significantly reduce the structure's cost and environmental impact during its life cycle.

Malaysian practice of waterproofing concrete

Nawi and Munaaim (2017) explored different causes of waterproofing failures in concrete buildings and structures and proposed remedial waterproofing solutions. They identified different types of cracks in buildings that can lead to water penetration (Figure 11).

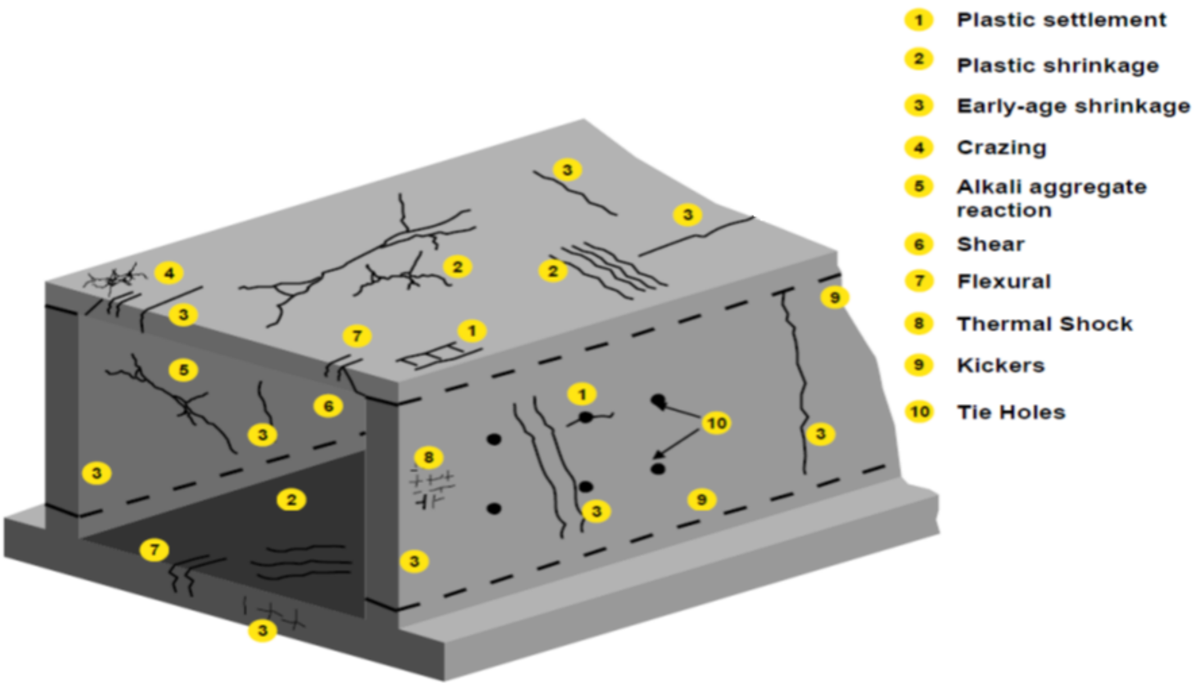

Figure 11. Types of Cracks in Concrete Structure Which Will Lead to Water Penetration (Mydin et al., 2017)

According to this study, cracks are to be filled by epoxy injection to seal and restore the cracks and restore substrates to a safe condition before the waterproofing application can be used. Waterproofing can be done in different ways, such as cementitious waterproofing, liquid-applied membranes, and sheet-based waterproofing membrane. The study concluded that the sheet membrane is the most durable and flexible waterproofing system. Sheet membrane waterproofing includes thermoset and thermoplastic materials. Thermoset membranes may be vulcanized or non-vulcanized materials and preformed rubberized sheets. A sheet waterproofing membrane is usually applied by heat or attached with an adhesive. A fully adhered system prevents water intrusion under the membrane and is less vulnerable to leaks caused by seam failures than other systems. It often comes in a roll where the asphaltic product is modified and bonded to a high-strength fabric of polyester or fiberglass. Sheet membrane has the advantage of allowing protection board placement and backfilling operations to begin immediately after application. Additionally, sheet membranes have elongation properties which make them suitable to protect a structure against any type of stress caused by the weather and normal structural expansion and contraction of a structure.

4 METHODOLOGIES

The whole study was comprised of two main tasks- a detailed literature review that investigated the state of the practice and state of the art on the subject of sealing cracks in concrete structures at the local and global levels; and a targeted evaluation of selected crack sealant products through market evaluation and questionnaire survey. The research team reviewed academic journal publications and conference proceedings, research reports, case studies, articles from professional journals, webinars and posted videos, and specifications of other state DOTs, local highway agencies, and international highway agencies to gather information and data on the various types of crack sealants, application methods, and necessary pretreatments of the cracked structures. Section 4 of this white paper presents findings from this literature search.

Task 2 of this study was targeted evaluation of crack sealant products which was initially planned to be conducted through three surveys, each targeting one of the three major stakeholders: suppliers, contractors, and DOTs. Different survey questions were prepared for DOTs, material suppliers, and contractors. The DOT survey was sent by an American Association of State Highway and Transportation Officials (AASHTO) liaison on behalf of the Florida Department of Transportation (FDOT). The other two surveys were sent by ARA research team via e-mail or by contacting the company/supplier through their messaging system on their website. However, no responses were received from the material suppliers and contractors. Several attempts were made to contact contractors and material suppliers via phone and e-mails, but no conclusive information could be obtained. So, the targeted evaluation of crack sealant products was performed based on the information and data obtained from the survey results obtained from the state highway agencies in the U.S. and Canada.

Based on the information gathered from the Task 1 report and Task 2 survey, a database of commonly used crack sealant products and a matrix that relates a product and its application method to the type of cracks and associated structures was created and presented in Appendix B and C of this white paper.

In this white paper, a summary of the research finding will be presented in the form of recommendations, which will help FDOT to update their Standard Specification 400 (concrete structures) and will also serve as a guidance document stipulating the best practice in the procedures for sealing vertical cracks in concrete structures.

5 FINDINGS FROM THE TARGETED EVALUATION OF CRACK SEALANTS

As a part of the targeted evaluation of the crack sealant products, eight questions were included in the survey for the U.S. state highway agencies and provincial transportation ministries of Canada. The information obtained from this survey is presented in this section. Appendixes D and E of this report include the survey form and the collected responses (in a tabular format).

5.1 Number of Respondents

The survey was sent to 50 U.S. state highway agencies and 10 Canadian provincial transportation ministries. Figure 12 shows the breakdown of the number of responses received. As shown in the figure, a total of 13 responses were received from State DOTs, and another response was received from a Canadian province. The low response rate is also an indication that many SHAs in the US do not have specific specifications for sealing cracks in concrete structures, especially on vertical or sloped structures.

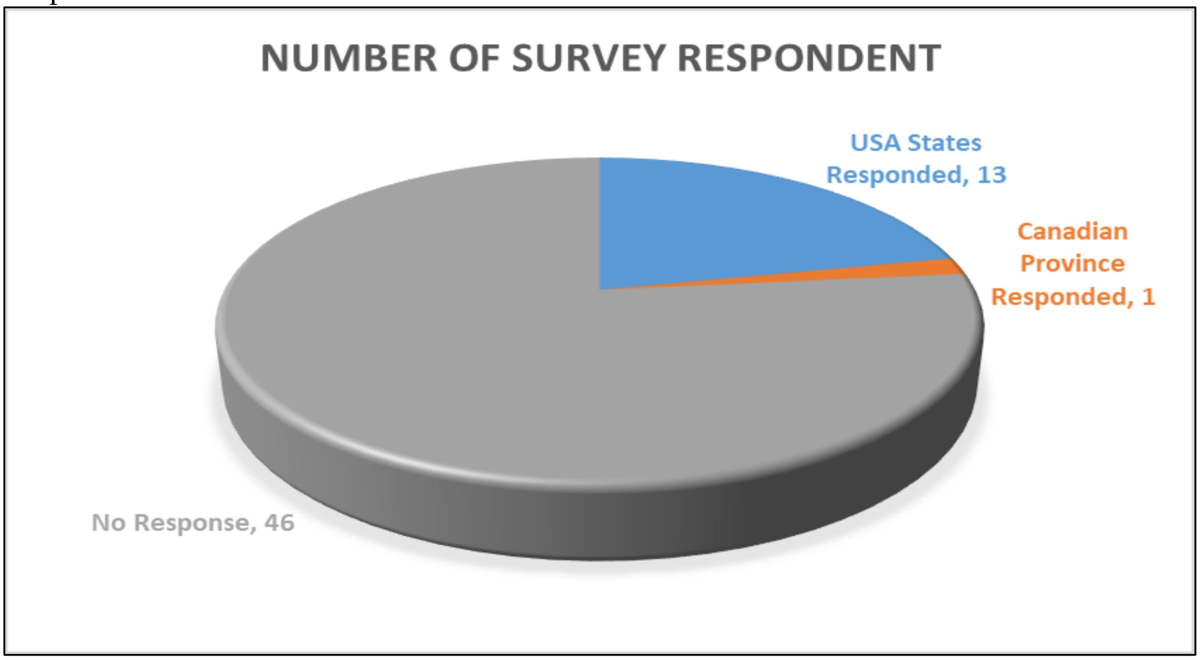

Figure 12. Response Rate form the Survey Conducted on Highway Agencies

5.2 Current Agency Practice of Crack Sealing

One of the primary focuses of the agency survey was to investigate if the routine monitoring and sealing cracks on vertical/sloped concrete structures were part of their current practice. Figure 13 summarizes the received responses. As seen from the figure, the majority of the respondents (i.e., 86 percent) indicated that they have provisions for monitoring and sealing cracks on concrete structures in their specifications.

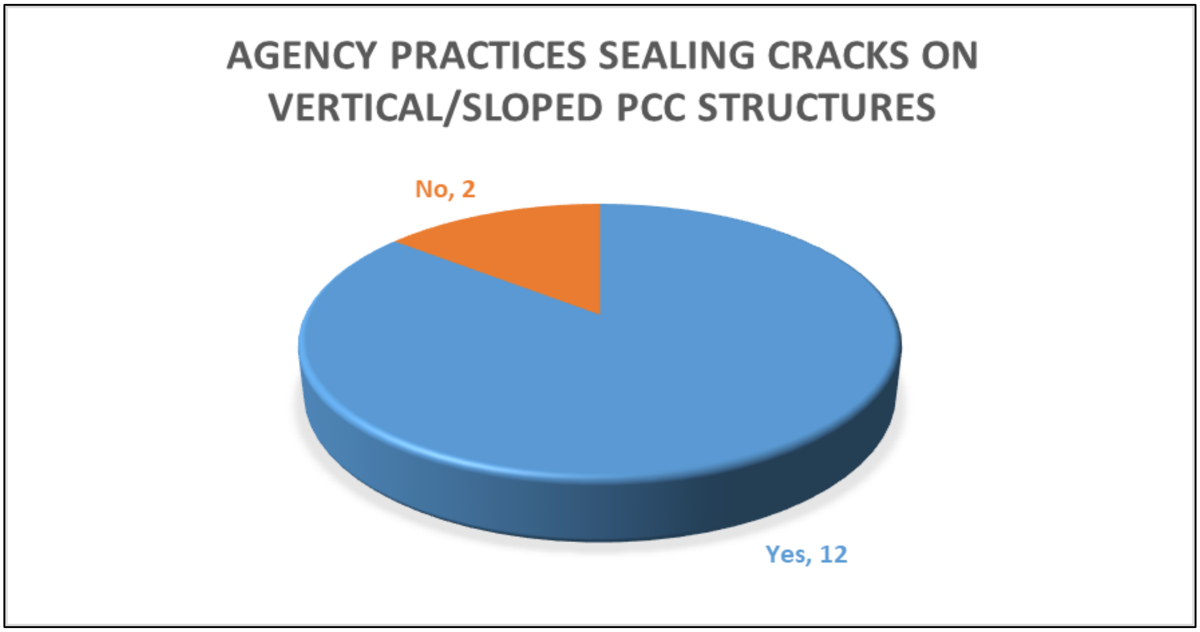

Figure 13. Crack Sealing Practice of Participating Agencies

5.3 Commonly Used Materials for Crack Sealing

Participants of the survey were also asked about the materials they commonly used for concrete crack sealing. The results are shown in Figure 14, indicating that most highway agencies (86 percent) use epoxy as the primary crack-sealing material. Other commonly used materials include High Molecular Weight Methacrylate (HMWM) (43 percent), Polyurethane/Rubberized Polymers (29 percent), and Penetrant Sealers (29 percent). As FDOT adopts routing of cracks and filling with epoxy or viscous materials, epoxy crack sealants can be a reliable material of sealing cracks in vertical/sloped structure.

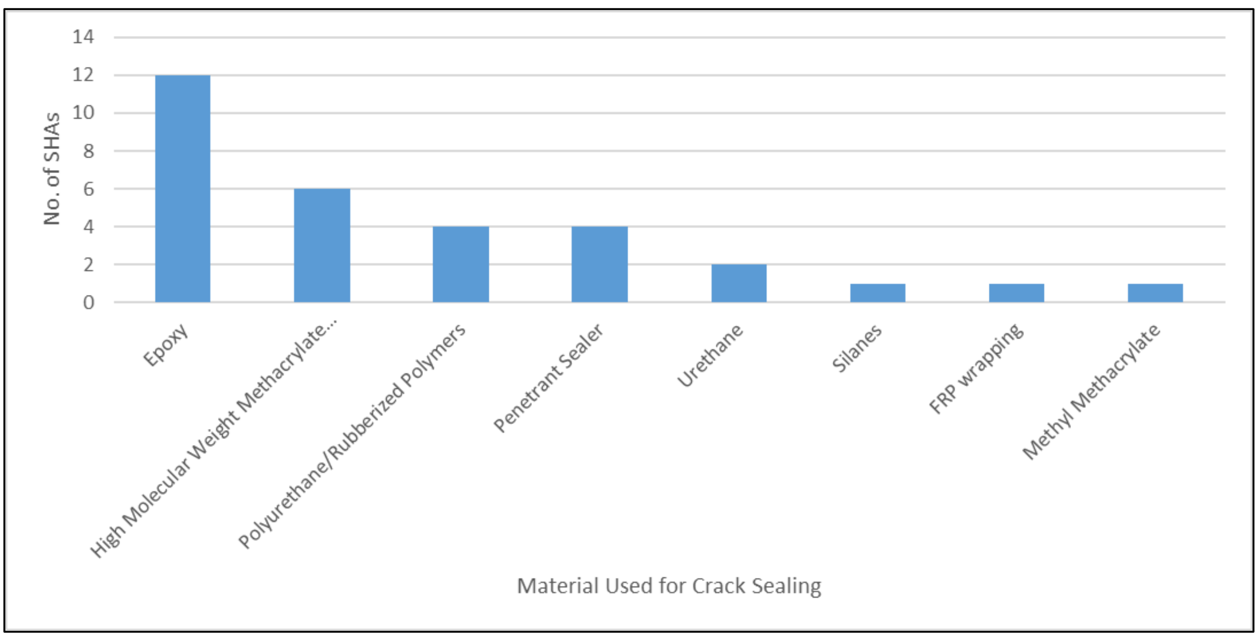

Figure 14. Commonly Used Materials for Crack Sealing

5.4 Commonly Used Crack Sealing Techniques

Participant DOTs was also asked about the most commonly used crack-sealing techniques they practice. Epoxy injection (79 percent) is the most common technique of concrete crack sealing used by highway agencies. Gravity seal and overlays (both 50 percent) are the other two techniques mostly used by highway agencies (Figure 15). Routing & sealing is also used by some highway agencies (36 percent). This also indicates that epoxy injection can be an effective technique for sealing cracks in vertical structures.

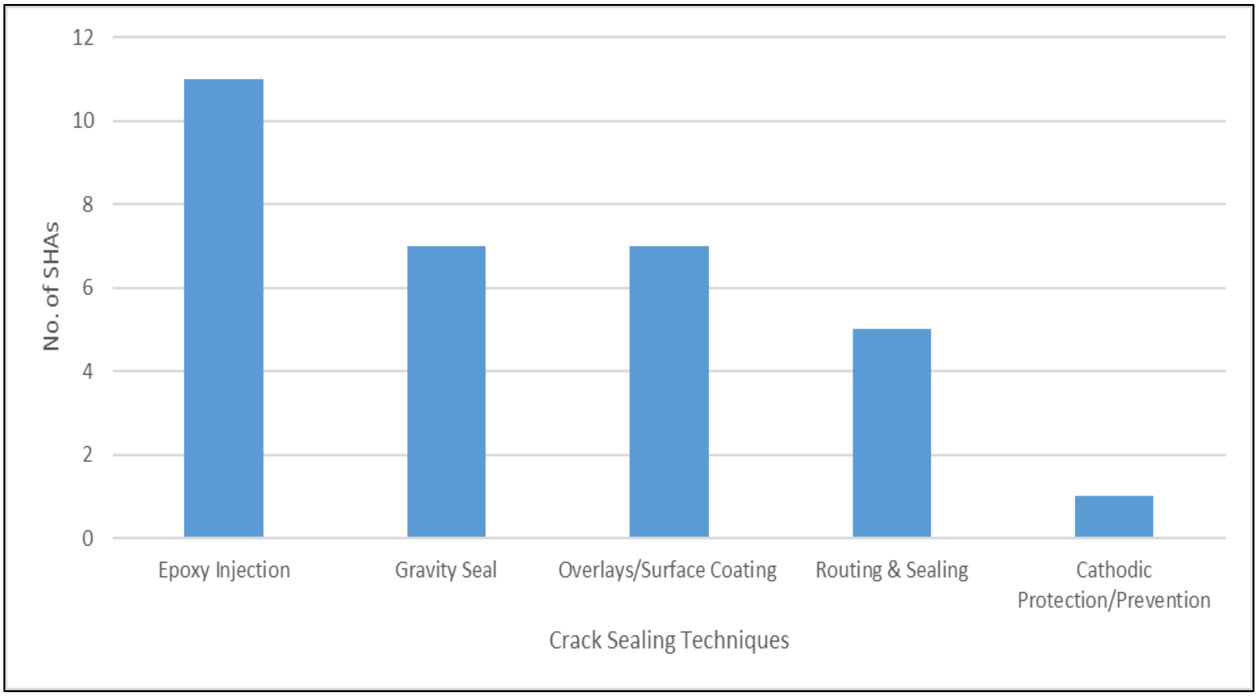

Figure 15. Commonly Used Crack Sealing Techniques

5.5 Service Life of Crack Sealants

The highway agencies were also asked about the service life of different crack sealant treatments they apply on concrete structures. Most of the agencies stated that they do not have any specific way of measuring the performance of the crack sealant with time after the repair job. Due to the lack of historical data, the survey respondents provided the expected (or anticipated) service life of crack sealant products based on their experience. According to the information derived from this survey, epoxy injection is the most reliable concrete crack sealing technique, with an expected service life of 10 to 20 years. Some DOTs believe the service life could be extended up to 40 years. HMWM is believed to be effective for 5 to 10 years after application. Penetrant sealers are anticipated to have a service life of 2 to 5 years. However, the survey respondents also emphasized that the expected service life of a particular treatment depends significantly on the type of treatment, workmanship, and exposure condition.

6 RECOMMENDATIONS

The agencies participating in the survey were also asked to provide a list of approved concrete crack-sealing products. In total, the research team collected 63 crack sealant products from the data and brochures provided by the respondents. Furthermore, the research team gathered the technical and safety data sheets from the respective product websites. The gathered information was used to develop an extensive product database, including the product type and application methods, besides the chemical and physical properties of the sealant materials.

From this extensive crack sealant product database, the ones that can be used in repairing cracks in vertical/sloped structures and can be included in the FDOT standard specifications 400-21 are sorted in the Table 12. The six crack sealants are also ranked based on their physical properties in Table 13.

Table 12. Recommended Crack Sealant Products and Techniques for Repairing Vertical Cracks

Product	Chemical Composition	Repair Technique	Crack Width, inch (mm)	Type of structure
SikaFix® HH LV	hydrophobic polyurethane	Epoxy Injection	Not available	Tunnels, dams, pipe intrusions, wastewater tanks, sewers, manholes
Euclid Chemical AQUASEAL MV, LV & Gel	Two-part, 100% solids epoxy systems	Epoxy Injection	Not available	Underwater structures like piers and piles. Also used for grouting pile jackets and underwater pressure injection
Euclid Chemical EUCOPOXY	Adhesive resin	Epoxy Injection	Not available	Marine structures, retaining walls, other vertical and overhead applications
Kaufman Products Inc SurePoxy LM Gel	Epoxy gel	Epoxy Injection	Not available	Overhead and vertical structural concrete repairs
TK Products TK-290	solvent-based formulation	Penetrant Sealer	up to ¼ inch (6.35 mm)	Marine piers and pilings
Simpsons Strong -Tie CI-GV	Epoxy gel	Epoxy Injection	3/32” – ¼” (2.4–6 mm)	Vertical crack sealing, underwater pressure-injection applications

Table 13. Important Physical Properties of the Recommended Crack Sealant Products

Product	Viscosity (cps)	Gel Time/Pot Life (minutes)	Tensile Strength (psi)	Compressive Strength (psi)	Bond Strength (psi)	Tensile Elongation (%)
Euclid Chemical EUCOPOXY	220	26	9,000	up to 22,000	3,800	3.50
Simpsons Strong -Tie CI-GV		8-55	-	up to 12,400	Up to 3,850	-
Euclid Chemical AQUASEAL MV, LV & Gel	1000 to 7000	40-60	3000-6500	7000 to 9000		1-12
Kaufman Products Inc SurePoxy LM Gel	-	30-40	5,200	4,200	up to 3,780	5-10
SikaFix® HH LV	25	1-12	29	-	-	-
TK Products TK-290	-	-	-	-	-	-

Table 13 lists important physical properties, including viscosity, gel time, pot life, tensile and compressive strengths, bond strength, and tensile elongation. FDOT may consider these properties while selecting crack sealant products for sealing vertical cracks.

QC/QA tests can be a good indicator of how selected crack sealant products will perform in the service life of the repair. Some recommended performance testing for FDOT to consider are shown in Table 14.

Table 14. Recommended Crack Sealant Performance Tests

Performance Test	Standard	Test Indicator
Depth of penetration	NCHRP 244 series II/ OHD L-40	Average depth of sealant penetration into Portland cement concrete structure
Bond strength	ASTM C 496	Splitting tensile strength
Chloride content/resistance to corrosion	AASHTO T259/T260/ NCHRP 244 Series II/ FM 5-516	Total chloride content
Seepage rate	ASTM E514	Water penetration and leakage
Rapid Chloride Penetration	ASTM C 1202	Chloride permeability
Viscosity	ASTM D2196/ASTM D2556/ASTM D2393/ASTM D-1638	Apparent viscosity
Tensile Strength	ASTM D638	Tensile property of crack sealants
Tensile Elongation	ASTM D638/ ASTM D412	Tensile property of crack sealants
Compressive Strength	ASTM D-695/ASTM C109/AASHTO T 106	Compressive properties of crack sealants

Since the researchers explored that most of the SHAs do not have any specific criteria of selecting crack sealing technique or product based on crack width and material suppliers or producers do not typically outline these in their guideline, it is recommended that FDOT use the following guidelines in Table 15 as a general guidance for updating the standard specification 400, which was generated from a previous study conducted by the agency. The table is modified to include the crack sealing treatment which are only applicable for vertical cracks.

Table 15. Recommended Vertical Crack Sealing Practice Based on Crack Width (Lasa and Antunes, 2022)

Crack Widths (inches/mm)	Crack Sealing Method	Materials and Structure Type
<0.005/<0.127	Topical Waterproofing	Surface coating only. Mostly suitable for vertical fine cracks.
>0.005-0.375/>0.127-9.525	Epoxy Injection	Fluid epoxy type E (Section 926). For horizontal and vertical.
0.002-0.250/0.05-6.35	Routing & Sealing	Fluid epoxy type F (Section 926): Mostly used on vertical surfaces.
>0.002/>0.05	Cathodic Protection/Prevention	Mainly for corrosion prevention. For horizontal and vertical.

In the current crack sealing practice of FDOT (Standard Specifications 400-21, 2023), there are provisions for cracking significance (Isolated, Occasional, Moderate, and Severe) and environmental exposure conditions (Extremely Aggressive, Moderately Aggressive, and Slightly Aggressive) while selecting a particular treatment. Since the research team did not find much evidence of how these two criteria will change depending on the change of orientation of cracks from horizontal to vertical, it is recommended that the agency should stick to current specification while selecting treatment based on cracking significance and environmental exposure condition.

Service life of the crack sealant depends on the types of material, extent of the cracks and exposure condition. The amount of contamination inside the cracks is critical to determine how to extend the service life of a crack sealing method. For older structures, the maximum time to seal cracks can be estimated by comparing the level of contamination in relation to the time of exposure which is typically the age of the structure since most non-structural cracks develop during or shortly after construction. When cracks are addressed on older structures, if the maximum time to seal the cracks has been exceeded, corrosion control methods should be used to reach the expected remaining service life of the structure. For cracks in new structures, the maximum allowable time to seal the cracks is more difficult to predict since the rate of contamination depends on the depth of the crack in relation to the reinforcement cover, the width of the crack, the internal physical properties of the crack, and the contaminant (chloride) intrusion mechanism (Lasa and Antunes, 2022). Based on the findings from this study, estimated service life of different crack sealing techniques and time limit to seal cracks is provided in the table below:

Table 16. Estimated Service Life and Allowable Time Limit to Seal Cracks (Lasa and Antunes, 2022)

Crack Widths (inches/mm)	Crack Sealing Method	Expected Service Life (Years)	Time Limit to Seal (Weeks)
<0.005/<0.127	Topical Waterproofing	5 or less	Direct Exposure- 5-12 Indirect Exposure: 12-30
>0.005-0.375/>0.127-9.525	Epoxy Injection	Severe condition: 7-10 Mild Condition: 20-40	Direct Exposure- 2-6 Indirect Exposure: 4-26
0.002-0.250/0.05-6.35	Routing & Sealing	10-20	Direct Exposure- 2-12 Indirect Exposure: 4-30
>0.002/>0.05	Cathodic Protection/Prevention	Severe condition: 10-20 Mild Condition: 20-40	Direct Exposure- 2-5 Indirect Exposure: 6-15

Based on the criteria of crack widths, environmental exposure, and allowable time limit to seal; Table 16 can be used as a general guideline for selecting crack sealing method. FDOT can update their standard specification 400 based on these guidelines.

Based on the findings of this study and the above discussions, the recommendations to update FDOT Standard Specification Section 400-21 so that it incorporates guidelines and procedures for sealing vertical cracks in concrete structures are summarized below:

1) Epoxy injection is the most widely used technique for sealing vertical cracks. However, the viscosity of the crack sealant will be an important parameter as low viscosity crack sealant material will ensure penetration of sealant deep enough to fill the necessary volume of the crack.
2) The research team generated an extensive database of crack sealant materials from the survey data and literature review conducted on 24 state highway agencies. From this database, six crack sealant products are initially recommended and presented in Tables 2 and 3 of this white paper. This can be a very good starting point of updating Standard Specifications 400-21. Laboratory and field verification are recommended down the road.
3) Performance tests can be a very reliable way of measuring quality of crack sealing work. The research team recommended some performance measuring tests in Table 4 that can be a valuable addition as QC/QA of Standard Specifications 400-21.
4) FDOT's State Materials Office developed an internal guideline of selecting crack sealant based on the width of crack. The research team modified it to make it applicable to vertical cracks (Table 5).
5) Since there is lack of data, current cracking significance and environmental exposure condition parameters in Standard Specifications 400-21 can be used while updating the specification to incorporate vertical cracks on concrete structures.

7 CONCLUSIONS

Current crack sealing practice by FDOT includes only horizontal and slightly sloped surfaces. In this white paper, recommendations are made to update FDOT Standard Specifications 400-21 to incorporate vertical cracks in concrete structures. An extensive literature review and a targeted evaluation of the most commonly used concrete crack sealant products was conducted based on the information gathered from a survey. Crack sealing products and techniques that can be effective in mitigating cracks in vertical and sloped structures are suggested along with some internal guidelines to update the Standard Specifications 400-21. Focused study on the recommended crack sealant technique and products along with laboratory and field verifications is also recommended.

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9 APPENDICES

9.1 Appendix A. State Practice of Concrete Crack Sealing (Pincheira and Dorshorst, 2005; Johnson et al., 2009, Mamaghani et al., 2007)

State	Crack Sealing Material	Application Procedure	DOT criterion to begin surface crack repair	Approved Sealant Products	Estimated Service Life (years)	QC/QA Test
California	HMWM, epoxy	Flooding	No specific criteria	Kwikbond Polymers, Sika Pronto 19	Kwikbond Polymers - 35 years*	Coring, Depth of penetration
Colorado	Silane	Manufacturer's recommendations	No specific criteria			None
Idaho	HMWM and low modulus epoxy		Cracks larger than 0.02 in. (0.5 mm)	Unitex, Transpo, Sika		None
Illinois	siloxane, epoxy	Flooding, Pressure injection	No specific criteria	TK-290 and TK-9000	siloxane : 7-10 years	None
Indiana	Epoxy deck sealants, latex modified overlays	Flooding	None			None
Kansas	Epoxy, Methacrylates	Flooding	No specific criteria	Unitex Bridge Seal		None
Maryland	Methacrylate, epoxy, silane				silane : 7-10 years	
Michigan	Epoxy			Unitex Bridge Seal, Tamms Dural 335, E-Bond 120		None
Minnesota	Silane, resin epoxy, Linseed oil	Spraying, Pressure injection	cracks larger than 0.03 in. (0.76 mm)	PaulCo TE-2501, Accuflex, PENSEAL 244 40%	All products- 3 to 4+ years	None
Mississipi	Methacrylate, epoxy		No specific criteria	KlereSeal		None
Missouri	HMWM, Linseed oil, reactive silicates	Flooding	No specific criteria	Star Macro Deck, Pavon INDeck	Star Macro Deck – 3+ years*	None
Montana	HMWM, silane	Spraying, flooding	No specific criteria		silane : 7-10 years	None
Nebraska	Polymer based sealants	Flooding	No specific criteria	Sika Pronto 19 TF, STAR Macro-Deck	Star Macro Deck – 3+ years*	None
North Carolina	Two-coat epoxy overlay with silica					None

State	Crack Sealing Material	Application Procedure	DOT criterion to begin surface crack repair	Approved Sealant Products	Estimated Service Life (years)	QC/QA Test
North Dakota	Penetrating sealant	Spraying	No specific criteria			Absorption (ASTM C- 642) and chloride ion penetration test (AASHTO T-259)
Oklahoma	Silane, epoxy	Crack filling, flooding	No specific criteria	SSI Deck Seal, SSI ReDeck	siloxane : 7-10 years	None
South Dakota	Silane	Flooding, spray	No specific criteria	Chem-Trete BSM40, Unitex Bridge Seal	siloxane : 7-10 years	Core testing, water beading tests
Texas	Epoxy			Sikadur 55 SLV		

9.2 Appendix B. Sealant Product Database Based on Product Type, Application Method, Type of Crack and Associated Structures

Company	Product Name	Chemical Composition	Repair Method	Application /Usage	Crack Width in. (mm)	Crack Orientation	Mixing Procedure	Application Procedure
Evonik Industries	Protectosil Degadeck CSS	methyl methacrylate (MMA)	M	Concrete bridge decks, parking garage, pedestrian walkway	up to 1/8″ (3mm)	Horizontal concrete surface		
Kwik Bond Polymers	KBP 204 & KBP 204 P SEAL	HMWM	M	Healer/sealer penetrant for road and bridge surfaces	Not Specified	Horizontal concrete surface	4 gallons of KBP 204 P SEAL+12 oz Cumyne Hydro Peroxide+0 to 16 oz of Z Cure Accelerator based on temp.	Prepare surface, use a squeegee, roller, broom, etc. to distribute the material uniformly. approximately 10 to 20 minutes after initial placement, broadcast a
Transpo Industries	T-70-10	HMWM	M	fills and bonds cracks, and seals pores in existing concrete including roadways, bridges, Parking Garages, Industrial Floors, Precast Concrete Elements, Premature Cracking in New Concrete, Aircraft Runways and Hangers.	Not Specified	Horizontal concrete surface	Sealate® resin+Cobalt Napthenate+CHP	Prepare Surface, applied manually with a broom and squeegee or by using spray equipment, Broadcast Sand.
	T-70 MX-30		M		Not Specified	Horizontal and Vertical concrete surface		
	T-78	methyl methacrylate resin system	M		Not Specified	Horizontal concrete surface	T-78 MMA+powder hardener	
	T-523	Epoxy Resin	PS	Bridges, parking garages, horizontal decks, patios, driveways and other structures exposed to foot and tire traffic. To protect sound concrete against water absorption and chloride-ion intrusion on both interior and exterior above grade surfaces. gravity filling of free cracks, reconsolidating	Not Specified	Horizontal concrete surface	Part A Resin+Part B Hardener (2:1 by volume) +Admixture. Mix thoroughly for a minimum of three minutes using a low-speed drill (600 rpm) and a mixing paddle.	Flood coating, distribute the material evenly with a squeegee, roller or a broom on textured surfaces.

Company	Product Name	Chemical Composition	Repair Method	Application /Usage	Crack Width in. (mm)	Crack Orientation	Mixing Procedure	Application Procedure
Sika	SikaFix® HH+	hydrophobic polyurethane foam grout	EI	Fill joints or cracks in concrete structures that exhibit some movement, Fill voids such as rock fissures, crushed fault or gravel layers, May be used in applications with high pressure water flow, Curtain wall grouting below grade structures.	Not Specified	Horizontal and Vertical concrete surface	SikaFix® HH++ 2.5-5% SikaFix Accelerator	Drill 5/8" diameter holes along the side of the crack at a 45-degree angle, install injection packers in the holes and tighten (6-36 inches apart), flush the drilled holes with water to remove debris and drill dust, Begin the injection of the grout at the lowest packer installed on a vertical crack or at the first packer flushed for a horizontal crack.
	SikaFix® HH LV	hydrophobic polyurethane	EI	Sealing leaks through concrete cracks and joints, Defective concrete (cracked and honeycombed), Limestone (tunnels, dams), Pipe intrusions,	Not Specified	Vertical	SikaFix® HH LV+ 2.5-5% SikaFix Accelerator	
	Sikadur®-22 Lo-Mod	epoxy resin binder	EI	skid-resistant broadcast overlay. Use also as the binder resin for epoxy mortar and concrete for patching and overlays.	Not Specified	Horizontal concrete surface	Proportion equal parts by volume of Component 'A' and 'B' into clean pail. Mix thoroughly for 3 min. with Sika paddle on low-speed (400–600 rpm) drill until uniformly blended.	Prime the prepared substrate with Sikadur®-22 Lo-Mod. While primer is still tacky, spread mixed Sikadur®-22 Lo-Mod with a 3/16 in. notched squeegee. When material levels, broadcast the oven-dried aggregate slowly allowing it to settle in the
	Sikadur 55 SLV	modified epoxy resin	EI	cracked concrete, interior slabs and exterior above-grade slabs, elevated horizontal decks, parking garages and other structures exposed to foot	0.002" (0.05 mm)	Horizontal concrete surface	Sikadur 55 SLV modified epoxy resin+viscosity control agents and accelerators (2: 1 by Volume).	Ponding or inject through ports.
	Sikadur® 52	epoxy adhesive	EI	gravity feed or pressure injection of cracks in structural concrete, masonry, wood. Seal interior slabs and exterior above grade slabs from water, chlorides and mild chemical attack and to	Not Specified	Horizontal concrete surface	Proportion 1 part Component 'B' to 2 parts Component 'A' by volume into a clean pail. Mix thoroughly for 3 minutes with Sika Paddle on low-speed (400-600 rpm) drill until uniformly blended.	Gravity feed, Pressure Injection and spreading using a using a roller or squeegee.
	SikaPronto®-19 4K	HMWM	M	Used on above grade concrete and mortar, Seals surface of concrete from water and chlorides.	Not Specified	Horizontal concrete surface	Part 'A' Resin+Part 'B' Norox® MEKP-9+Part 'C' Duroct Cobalt 6%.	applied to horizontal surfaces by roller, squeegee, or broom.

Company	Product Name	Chemical Composition	Repair Method	Application /Usage	Crack Width in. (mm)	Crack Orientation	Mixing Procedure	Application Procedure
Dayton Superior	ProAnchor Elite	epoxy gel adhesive	EI	seal cracks and set injection ports prior to injection grouting.	Not Specified	Horizontal and Vertical concrete surface	equal volumes of Part A and Part B for 3 minutes with a low-speed drill.	Drill hole in concrete using a rotary percussion power drill, blow out hole using oil-free compressed air at a minimum of 70 psi with a nozzle, Insert a cleaning brush for the proper drill hole diameter, dispense material through the mixing nozzle in a continuous bead until a
	Sure Inject™ J56	epoxy adhesive	EI	pressure injection and gravity feed crack repair in concrete and masonry. Sure Inject J56 can also be used to seal interior slabs and exterior above-grade slabs.	Not Specified	Horizontal concrete surface	Premix each component separately then mix two parts by volume of Part A with one part by volume of Part B for three minutes with a low speed (< 450 rpm) drill using a jiffy mixer or paddle.	prepare the surfaces, drill injection ports, The injection ports should be spaced from 8 in. to 36 in. apart depending on the crack width and the thickness of the member to be injected, the crack should be sealed at the
	Pro-Poxy™ Type III DOT	epoxy urethane binder and adhesive	EI	used primary for bonding skid-resistant overlays and high friction surfaces to bridges and elevated slabs and as a low modulus binder for epoxy mortars where thermal change is a consideration. Material can also be used to seal	Not Specified	Horizontal concrete surface	Premix each component then place 1 part by volume of Component A and 1 part by volume of component B into a clean pail and mix for three minutes with a low-speed drill using a Jiffy mixer or paddle until uniformly blended.	Hand mixing and application, mechanical mixing, and application.
	Sure Anchor J50	high modulus epoxy gel adhesive	EI	Sure Anchor J50 is ideal for anchoring bolts, dowels and reinforcing steel in concrete. It is also ideal for vertical and horizontal structural bonding and patching. Sure Anchor J50 may be used to seal cracks and set injection ports prior	Not Specified	Horizontal and Vertical concrete surface	1 part A to 1 part B by volume.	Placing with a manual gun or injecting through ports.

Company	Product Name	Chemical Composition	Repair Method	Application /Usage	Crack Width in. (mm)	Crack Orientation	Mixing Procedure	Application Procedure
	Pro-Flex™	Epoxy Joint Filler	EI	fill joints in industrial floors exposed to hard wheeled traffic. Pro-Flex is useful for contraction/construction joints that are cut or formed. Pro-Flex may	Not Specified	Horizontal concrete surface	Premix each component separately, then mix one volume of Part A and one volume of Part B for three minutes with a low speed (<450 rpm) drill using a Jiffy mixer or paddle.	With a caulking gun or poured into the joint from a suitable container.
	Pro-Poxy™ 100	Epoxy Injection Resin	EI	pressure injection and gravity feed crack repair in concrete, also be used to seal interior slabs and	1/8 in. to 1/4 in. (3.2 mm to 6.4 mm)	Horizontal concrete surface	2:1 mix ratio of 2 Parts A to 1 Part B by volume.	Pressure injection or placing manually.
Mapei	Epojet LV	epoxy injection resin	EI	Use on interior/exterior horizontal, overhead and vertical surfaces, use for pressure-injecting cracks in structural concrete, masonry and wood, Use to repair cracks in horizontal concrete and masonry by gravity feed, Use to restore and seal horizontal concrete slabs, and to improve their wearability, Use to repair delaminated surfaces, Use as an epoxy resin binder for epoxy mortar	Less than 1/4" (6 mm)	Horizontal and vertical	Part A (2 U.S. gals. [7.57 L]) and Part B (1 U.S. gal. [3.79 L]) into a separate, clean mixing container. Mix with a low-speed drill (at 400 to 600 rpm) and Jiffy mixer until blended uniformly.	Place injection ports, Space apart the ports no less than the thickness of the structure being repaired, Application using dual cartridge or kit.
Krytex Products	EPOXY-SCEL-80	two-component epoxy resin	EI	Injection of fine cracks, filing cracks by gravity, Sealing of porous surfaces, Adhesive for concrete and other materials, Hardening of porous surfaces.	Not Specified	Horizontal and vertical	Stir part A and part B separately. Then mix 2 parts A with 1 part B at low speed for a 3-minute period or you may use some equipment made for two components which include a static mixer at	Pour, apply with a roller or inject with an injection pump, according to the use.
Euclid Chemical	AQUASEAL MV	two-part, 100% solids epoxy systems	EI	specifically designed for underwater applications on concrete or masonry surfaces. These products are suitable for applications in both fresh	Not Specified	Underwater Vertical Application	Premix Part A (Base) and Part B (Hardener) individually. Then combine Part A and Part B 1:1 by volume in a clean container. Mix thoroughly	The mixed AQUASEAL system should be transported underwater after mixing. Agitation while underwater must be minimized. Apply a thin

Company	Product Name	Chemical Composition	Repair Method	Application /Usage	Crack Width in. (mm)	Crack Orientation	Mixing Procedure	Application Procedure
	AQUASEAL LV		EI	low viscosity version that can be mixed with aggregate to form a mortar for repair or can also be used "neat'' for crack repair using	Not Specified	Underwater Vertical Application	with a slow speed motor and "Jiffy'' Mixer.	coat of AQUASEAL MV as a primer, by brush or gloved hand working and scrubbing the coating into the pores of the substrate in order to displace the water. Follow with a regular heavy coat of AQUASEAL MV applied
	AQUASEAL GEL			Underwater application.	Not Specified	Underwater Vertical Application		
	DURAL 50 LM	acrylated epoxy resin formulation	EI	Bridge decks, Parking decks, Consolidation of porous and dusting surfaces, reduces water absorption, Reduces chloride penetration, Pressure injection, Gravity feed hairline cracks, Re-bonding of delaminated concrete	Not Specified	Horizontal and vertical	Mix DURAL 50 LM using a low-speed drill and a mixing paddle. Pre-mix Part A and Part B separately for approximately 1 minute each. Combine Part A and Part B in a 2:1 ratio by volume, then mix thoroughly for 3 to 5	Pour or pump properly mixed DURAL 50 LM onto the properly prepared surface in a wave form and spread uniformly with a squeegee or a short nap roller to fill voids, cracks, and porous areas. Allow epoxy to penetrate into the surface, re-applying to
	DURAL 335	epoxy penetrating healer-sealer	EI	Bridge decks, Airport runways, Roadways, Parking garage decks and rapcore-bonding of delaminated concrete toppings.	Not Specified	Horizontal and vertical	Mix DURAL 335 using a low-speed drill and a mixing paddle. Pre-mix Part A and Part B separately for approximately 1 minute each. Combine Part A and Part B in a 4:1 ratio by	Pour or pump properly mixed DURAL 335 onto the properly prepared surface in a wave form and spread uniformly with a squeegee or a short nap roller to fill voids, cracks, and porous areas.
	DURALCRETE LV	epoxy resin adhesive and binder	EI	Crack repair.	Not Specified	Horizontal and vertical	Premix Part A and B with a slow speed motor and "Jiffy" mixer. Pour two parts by volume of Part A and one part by volume of Part B into a clean, dry container and mechanically mix for 3 to	Apply by brush, roller, spatula, or trowel.
	DURALCRETE MV		EI		Not Specified	Horizontal and vertical	Premix Part A and B with a slow speed motor and "Jiffy" mixer. Pour one part by volume of Part A and one part by volume of Part B into a clean, dry container and mechanically mix for 3 to	
	DURALCRETE Gel		EI		Not Specified	Horizontal and vertical		

Company	Product Name	Chemical Composition	Repair Method	Application /Usage	Crack Width in. (mm)	Crack Orientation	Mixing Procedure	Application Procedure
	EUCOPOXY	Adhesive resin	EI	Permanent bonding of structural damage, Parking structures, Bridge structures, Marine structures, Retaining walls, Earthquake	Not Specified	Vertical and overhead applications	Mix parts A and B (resin & hardener) for 2 minutes using a drill and mixing prop.	After mixing, pour or squeegee epoxy into cracks and allow to seep in. Continue to apply material until crack is full.
	REZ-SEAL	acrylic polymer curing and sealing compound	PS	Industrial floor slabs, Parking garages, Exterior pavements, Walls and columns, Dry shake floors, Concrete toppings.	Not Specified	Horizontal and vertical	REZ-SEAL requires no pre-blending prior to use.	Apply at the recommended coverage rate using an industrial, solvent-resistant pump-up sprayer with a high-solids nozzle and a short-nap, solvent-resistant
TK Products	TK-290	solvent-based formulation	PS	Concrete & Cementitious Surfaces, Pavers / Brick / Clay Brick, Travertine, Limestone, Slate, All Light Commercial, Ramps, Parking Structures, Marine Piers & Pilings, Multi-Family Housing, Theme & Water Parks, Healthcare & Educational,	up to 1/4 inch (6.35 mm)	vertical and horizontal	The material is ready for use and requires no mixing.	Apply by roller or spray equipment in a uniform manner and in sufficient quantity to completely wet out the substrate with a minimum of 2-inch run down.
TK Products	TK-2110	Epoxy Sealer	PS	Suitable for exterior use on new or existing horizontal concrete bridge decks and parking structures.	up to .004 inches (0.1 mm)	Horizontal	Mixing ratio for the two components in 4:1 by volume. Components “A” and “B” are supplied in separate, premeasured containers and should be mixed individually using a power mechanical mixer. The two components should then be combined together by pouring the entire contents of component “B” into	Once mixed, immediately pour the entire contents of the epoxy onto the surface and begin to distribute by evenly spreading with a squeegee or roller.
TK Products	TK-9000	Epoxy Resin	PS	Suitable for interior or exterior application to concrete bridge decks and concrete floors. May also be used as an excellent anchor for setting bolts during machinery installation.	Not Specified	Horizontal	Stir parts A and B separately before mixing together. Mix equal parts A and B by volume. Kits are supplied pre-measured, itis advised that kits not be split. Mix well with a paddle-type mechanical mixer for 3 minutes until mixture is	TK-EPOXY CRACK FILLER may be poured directly from the container into the crack and spread with a putty knife, grouting tool, baster, or brush.

Company	Product Name	Chemical Composition	Repair Method	Application /Usage	Crack Width in. (mm)	Crack Orientation	Mixing Procedure	Application Procedure
Texcote	XL 70® BRIDGE COTE® W/SILANE	Silane	PS	protection and beautification of bridges and above-grade exterior surfaces, such as concrete walls, columns, spandrels, median	Not Specified	Horizontal and vertical	ready to use concrete protective coating.	A one-coat application at 50 sf/gallon develops a 15-mil dry film thick-ness.
Viking Paints, Inc.	PAULCO TE-2501 FAST SET	high solids epoxy	EI	permanent water proofing to concrete membrane and resistance against most acids, alkalis, salt, and other chemicals.	Not Specified	Horizontal	The machine automatically mixes components (A&B) at the tip – put 5-Gal Part A {Red} into the canister: put 5 Gal Part B {Green} into the B container: turn on the machine and make sure the colors disappear and a new light tan color is	put the tip of the mixing tube into the crack and fill the crack.
	PAULCO TE-2501 STANDARD	EPOXY CRACK FILLER	EI	crack filler for concrete bridge decks and other flat decks. Paulco TE-2501 prevents water and salt intrusion into the cracks and prevents further degradation of the concrete, provides resistance against most acids, alkalis, salt, and	Not Specified	Horizontal	TE-2501 Standard is a two-component product, mixed equally (one to one parts by volume). The material should be mixed in small amounts to extend the pot life. Combine Part A with Part B into one container and mix mechanically for	Can be applied by mixing in a bottle and hand applied, or with a manual two component/static mixing equipment.
Master Builders	MasterSeal® 630	methyl methacrylate	M	Exterior Concrete, Bridge decks, Parking structures.	Not Specified	Horizontal	MasterSeal 630 must be mixed with the appropriate amount of MasterSeal 918FS just prior to	MasterSeal 630 is applied as a flood coat in a gravity-fed process by broom or roller.
Adhesive Technology	CRACKBOND ® SLV-302	epoxy	R & S	fine to very fine cracks, structural crack repair in concrete, mortar repair, patching, and overlay of interior surfaces, Sealer for interior slabs and exterior above-ground slabs, decks, patios, driveways, parking garages and other structures, Primer for industrial coatings, Shear fracture repairs on interior and exterior concrete slabs, Bonding agent for fresh to hardened concrete and	0.0025 in. to 0.125 in. (0.06 mm to 3.2 mm)	Horizontal	Thoroughly stir each component separately before mixing them together. Mix only the amount of material that can be used before the working time expires. Proportion parts by volume into a clean pail at the exact and propermix ratio for that product. (For CRACKBOND SLV-302 use 2 parts by volume of component “A” and 1 part by volume of component “B”).Mix thoroughly with a low speed drill (400 –	cut a groove to open up the crack using an abrasive or diamond blade to a width of 1/8 in. (3.2 mm) and minimum depth of 3/8 in. (9.5 mm). Use wire brush to abrade and then blow out the crack to remove all dust, dirt, grease, wax, oil or any other con-taminants. Pour or inject CRACKBOND SLV-302 into the crack and its self-leveling ability will fill the entire area.

Company	Product Name	Chemical Composition	Repair Method	Application /Usage	Crack Width in. (mm)	Crack Orientation	Mixing Procedure	Application Procedure
	CRACKBOND ® 2100 MV	epoxy adhesives	R & S	Bonding hardened concrete to hardened concrete, Bonding fresh concrete to hardened concrete and steel, coating and sealing interior or exterior slabs, durable, chemical resistant industrial coating and adhesive, mortar repair for concrete and spalls, gravity feed	Not Specified	Horizontal	Pour the total contents of Part B (Hardener) into the Part A pail (Resin) OR proportion equal parts by volume of both Part A and Part B into a clean pail. Be sure that the components are mixed at an exact 1:1 ratio by volume. Mix thoroughly with a low-speed drill (400 – 600 rpm) with a Jiffy Mixer or	cut a V shaped groove to open up the crack using an abrasive or diamond blade. Use wire brush to abrade and then blow out the crack to remove all dust, dirt, grease, wax, oil or any other contaminants. Pour or dispense the CRACKBOND 2100 MV or 2100 MV-LPL into the crack and fill the entire
	CRACKBOND ® 2100 MV LPL	epoxy adhesives	R & S		Not Specified	Horizontal		
	CRACKBOND ® LR-321	epoxy resin	R & S	Crack filling, mortar repair, bonding agent.	1/8 in. to >1/4 in. (3.2 mm to 6.4 mm)	Horizontal	Proportion parts by volume into a clean pail at the exact and proper mix ratio - 2 parts by volume of component A and 1 part by volume of component B.	cut a groove to open up the crack using an abrasive or diamond blade to a width of 1/8 in. (3.2 mm and minimum depth of 3/8 in. (9.5 mm). Use a wire brush to abrade and then blow out the crack to remove all dust, dirt, grease, wax, oil or any other contaminants. Pour or inject CRACKBOND into the crack and its self-
	CRACKBOND ® EPOTHANE T3	epoxy urethane			Not Specified	Horizontal		
	CRACKBOND ® V120 LO-MOD	epoxy healer/sealer penetrant	PS	seal micro cracks in bridge and parking structure decks and as an overlay for high friction	Not Specified	Horizontal	Easy to mix - 2:1 ratio.	
	CRACKBOND ® V65 HI-MOD	epoxy coating	PS	Seals concrete surface, structurally repair micro-cracks in concrete surfaces, Seals in dry and damp environments, parking garage decks, horizontal elevated roadways and bridge	Not Specified	Horizontal	Use 3 parts by volume of component A and 1 part by volume of component B Mix thoroughly with a low-speed drill (400 – 600 rpm) using a mix paddle attachment (e.g., Jiffy Mixer).	immediately pour all the material generously onto the horizontal surface. Spread within 15 minutes when substrate temperature is 75 °F (24 °C).
	CRACKBOND ® V200 HI-MOD	epoxy healer/sealer deck penetrant	PS		Not Specified	Horizontal		

Company	Product Name	Chemical Composition	Repair Method	Application /Usage	Crack Width in. (mm)	Crack Orientation	Mixing Procedure	Application Procedure
E-Chem, LLC	EP50-OVERLAY	polymer overlay resin	PS	bonding skid-resistant overlays to bridges, elevated slabs and PCCP. In addition to High Friction Surface Treatments, it is also excellent as a binder in epoxy mortars used for patching concrete.	Not Specified	Horizontal	Mechanically mix Component A with Component B 1:1 by volume with Jiffy type mixer and low-speed variable drill at 300 rpm for 3 to 4 minutes,	Apply neat EP50-OVERLAY by notched squeegee at the specified rate. Broadcast select aggregate to refusal.
	EPX50-OVERLAY	epoxy urethane co-polymer overlay resin	PS		Not Specified	Horizontal	Mechanically mix Component A with Component B 1:1 by volume with Jiffy type mixer and low-speed variable drill at 300 rpm	Apply neat EPX50-OVERLAY by 3/16” to 1/4” notched squeegee at the specified rate. Broadcast select aggregate to refusal.
	EP75-SEAL	epoxy healer/sealer	PS	Crack sealing on Bridge decks, Parking decks, Concrete floors, Roadways, Airport runways/taxiways, Columns & beams in splash zones,	Not Specified	Horizontal	Mechanically mix Component A with Component B 1:1 by volume with Jiffy type mixer and low-speed variable drill at 300 rpm for a minimum of 3	Apply neat EP75-SEAL by pouring or spraying on the surface. Distribute material evenly with a squeegee, roller or broom, maintaining a liquid head over cracks until refusal.
	EP100-SEAL	epoxy healer/sealer	PS	Bridge decks, Parking decks, Concrete floors, Roadways, Airport runways/taxiways, Columns & beams in splash zones, Consolidation of porous & dusting surfaces, Primer or pre-treatment	Not Specified	Horizontal	Mechanically mix Component A with Component B 2:1 by volume with Jiffy type mixer and low-speed variable drill at 300 rpm for a minimum of 3 minutes.	Apply neat EP100-SEAL by pouring or spraying on the surface. Distribute material evenly with a squeegee, roller, or broom, maintaining a liquid head over cracks until refusal.
	EP-SLV	epoxy adhesive	EI	crack repair in concrete and masonry. EP-SLV can also be used to heal and seal concrete slabs.	Not Specified	Horizontal	Mix equal volumes of Component A and Component B for 3 minutes with a low-speed drill (300 rpm), jiffy mixer	first prepare the surfaces adjacent to the cracks to expose clean, sound concrete. The injection ports should be spaced from 8” to 36” apart,

Company	Product Name	Chemical Composition	Repair Method	Application /Usage	Crack Width in. (mm)	Crack Orientation	Mixing Procedure	Application Procedure
Simpsons Strong -Tie	CI-GV	Epoxy Gel	EI	structural repairs, pick-proof sealant, underwater pressure-injection applications, seals the crack from moisture, protecting rebar in the concrete from corrosion.	3/32" – 1/4" (2.4–6 mm)	vertical and horizontal	Proportion components at a 2A:1B ratio by volume in a clean pail or use calibrated mixing equipment. Mix thoroughly with a low-speed (300–600 rpm) drill and mixing paddle for 2–3 minutes.	With all ports open, begin injecting CI-GV at the lowest port and work your way up. For horizontal applications, choose one end of the affected site and work your way to the other end. Begin pumping CI-GV into the first port to establish flow. If the next port shows material, close
	CI-LPL	epoxy	EI	structural repairs, underwater pressure-	1/64"–1/4" (0.4–6 mm)	Horizontal	Proportion components at a 2A:1B ratio by volume in a clean pail or use calibrated mixing equipment. Mix thoroughly with a low-speed (300–600 rpm) drill and mixing paddle for 2–3 minutes.	Slowly pour or dispense epoxy into the crack/reservoir.
	CI-LV	epoxy	EI	structural repairs, underwater pressure-injection applications,	up to 1/4" (6 mm)	Horizontal		
	CI-LV FS	epoxy	EI	structural repairs, repair mortar, bonding agent.	1/64"–1/4" (0.4–6 mm)	Horizontal		
	CI-SLV	epoxy	EI	structural repairs, underwater pressure-	up to 1/4" (6 mm)	Horizontal		
Pecora Corporation	KlereSeal® 9100-S	silane penetrating clear sealer	PS	protect parking decks, garages, ramps, roads, bridges, airport runways, stadiums, buildings, major concrete structures such as dams, bulkheads, etc., house foundations, pools and decks, precast and prestressed concrete products, brick and stone	up to 1/4" (6 mm)	Horizontal		The recommended application equipment is a low pressure, airless-type sprayer. Apply KlereSeal® 9100-S until the solution runs or stands.
E-BOND EPOXIES, INC.	E-BOND 550 HI-MOD	epoxy resin system	EI	epoxy mortar for patching spalls on DRY or DAMP Interior surfaces. It is excellent for pressure injection and gravity feeding cracks in both dry & damp concrete. It may also be used for bolt grouting.	<1/4"	Horizontal	Pre-mix each component separately. Place in a clean container, 2 parts by volume of Component A (Resin) and then add 1 part of Component B (Hardener). Container should have a flat wall and flat bottom. Stir and mix until material is thoroughly blended. Mixing should be completed after 2 minutes	pressure injection or placing manually by gravity.

Company	Product Name	Chemical Composition	Repair Metho d	Application /Usage	Crack Width in. (mm)	Crack Orientation	Mixing Procedure	Application Procedure
ChemMaster s, Inc	DURAGUARD 401-30E RESIN	HMWM PENETRATING SEALER	PS	Provides long term protection for concrete surfaces against water and chloride penetration, penetrates to protect concrete from abrasion,	0.001-0.125	Horizontal and vertical	Part A Resin+Part B Promoter	After mixing, immediately pour all the Duraguard 401-30E onto the prepared concrete. Spread with a serrated squeegee
Kaufman Products Inc.	SurePoxy LM Gel	epoxy gel	EI	bonding irregularly shaped structural materials, to seal cracks for injection grouting, as a pickproof sealant around windows, and bonding parking bumpers or barriers to concrete or	Not Specified	vertical	The volumetric ratio of SurePoxy LM Gel is 2:1 (A: B). To mix, proportion 2 parts A and 1 part B into a clean pail. Mix thoroughly for 5 minutes with paddle on low speed (400-600 rpm) drill until	Place the prepared mortar in void, working the material into the prepared substrate, filling the cavity. Strike off level.
	SurePoxy VLM	epoxy resin system	PS	stress-relieved binder in abrasion and chemical resistant mortars on concrete or steel. It is also useful as a skid resistant overlay for concrete bridges, parking decks and roadways. It is resistant to water and	Not Specified	Horizontal	The volumetric ratio of SurePoxy VLM is 1:1 (A: B). To mix, proportion 1 part A and 1 part B into a clean pail. Mix thoroughly with paddle on low speed (400-600 rpm) drill until blend is uniform in color.	Apply first coat to properly prepare surfaces at coverage rate below using a squeegee. Immediately follow with a light roller pass to eliminate puddles and achieve a uniform film.
DEWALT	PE1000+®	adhesive	EI	Cracked and uncracked	Not Specified	Horizontal		
	PURE50+™	adhesive	EI	Cracked and uncracked concrete conditions as well as seismic and wind	Not Specified	Horizontal		

9.3 Appendix C. Sealant Product Database Based on Physical Properties

Company	Product Name	Usage/Service Temperature (°C)	Viscosity (ASTM D2196/ASTM D2556/ASTM D2393/ASTM D-1638)	Gel Time/Pot Life (AASHTO T237/ASTM C 881) (minutes)	Cure Time (hour) (ASTM D1640/ASTM D2377/AASHTO T237/Californian Test Method 551)	Tensile Strength (ASTM D638) (psi)	Compressive Strength (ASTM D-695/ASTM C109/AASHTO T 106) (psi)	Bond Strength (ASTM C881/ASTM C882/ASTM C1583/Californian Test Method 551) (psi)	Shear Strength (ASTM D-732)	Adhesion (ASTM C-882/ASTM D7234) (psi)	Tensile Elongation (ASTM D638) (ASTM D-412) %
Evonik Industries	Protectosil Degadeck CSS				2						
Kwik Bond Polymers	KBP 204 & KBP 204 P SEAL		< 25		1.5-3	>2000	>3000			>2500	
Transpo Industries	T-70-10		15 – 25	35 – 40	4-7 hr @70°F	1,600		>2000			3-5%
	T-70 MX-30		10 – 25	50 – 60	6-8 hr @70°F	>1,100		>2000			30%
	T-78		<5-10	15 – 20	30 – 40 min	8,100 psi		2200			5%
	T-523		<100	20-30	1.5	2500-5000		2000-3500			30-80 %
Sika	SikaFix® HH+	82 °C max	25	1-3		29					44%
	SikaFix® HH LV	82 °C max	25	1-12		29					44%
	Sikadur®-22 Lo-Mod		Approximately 2,000	30		5,700	up to 9,500		3,000		> 30 %
	Sikadur 55 SLV		105	20	2-11	7,100	up to 12,000		5,800		10%
	Sikadur® 52		200	30	2.5-8	7,900	up to 10,400	2,200	4,300		
	SikaPronto®-19 4K	43 °C max	< 25	20-40		4,500	up to 12600	1,700			
Hilti	CC412-1						7252				
Dayton Superior	ProAnchor Elite			2-14	minimum 2	6,780	up to 14,500	up to 3,150			1
	Sure Inject™ J56		518	21	max 168	7,168	12,385	4233			2.30%
	Pro-Poxy™ Type III DOT		1,500	minimum 15		>3,000	minimum 5,000	>250			minimum 30.0%
	Sure Anchor J50			40		7992	10,500		3190	4395	2.60%
	Pro-Flex™	(-1° to 82°C)		15	8-48	700	2500				71%
	Pro-Poxy™ 100		500	27		7,230	10,150	2950			4.4
Mapei	Epojet LV		170	60		5,900	12,720	2,980			2.40%
Krytex Products	EPOXY-SCEL-80		80	30	7-8	7978	10152			2176	10.90%

Company	Product Name	Usage/Service Temperature (°C)	Viscosity (ASTM D2196/ASTM D2556/ASTM D2393/ASTM D-1638)	Gel Time/Pot Life (AASHTO T237/ASTM C 881) (minutes)	Cure Time (hour) (ASTM D1640/ASTM D2377/AASHTO T237/Californian Test Method 551)	Tensile Strength (ASTM D638) (psi)	Compressive Strength (ASTM D-695/ASTM C109/AASHTO T 106) (psi)	Bond Strength (ASTM C881/ASTM C882/ASTM C1583/Californian Test Method 551) (psi)	Shear Strength (ASTM D-732)	Adhesion (ASTM C-882/ASTM D7234) (psi)	Tensile Elongation (ASTM D638) (ASTM D-412) %
Euclid Chemical	AQUASEAL MV	13	5000 to 7000	60		3000	7000 to 8000				1-5
	AQUASEAL LV	13	1000 to 1500	40		6500	8000 to 9000				6-12
	AQUASEAL GEL	13		60			7000 to 8000				
	DURAL 50 LM	10 °C - 32 °C	120	90	3-5	880		> 1,500 psi			50%
	DURAL 335		80 to 120	70-90/20-25		7,500 to 8,500 psi	11,000 to 11,500 psi /9,500 to	up to 2,300			1 to 5%
	DURALCRETE LV	4 and up	400	40-45		> 7,000	> 10,000	> 2,015			2.3 to 2.5
	DURALCRETE MV		4500	30							
	DURALCRETE Gel		80,000 - 200,000	30							
	EUCOPOXY	21	220	26		9,000	up to 22,000	3,800			3.50%
	REZ-SEAL	4-32			< 1						
TK Products	TK-290										
	TK-2110		124	35	3-11						
	TK-9000		<450	25-30	4		15,000				20%-30%
Texcote	XL 70® BRIDGE COTE® W/SILANE	7.2-37.8			48						
Viking Paints, Inc.	PAULCO TE-2501 FAST SET		391-550	4-8			830	600			30
	PAULCO TE-2501 STANDARD		215-265	25-35	3-6		830	360			57
Master Builders	MasterSeal® 630	5-40	5-15			7,775	12,800				5
Adhesive Technology	CRACKBOND® SLV-302	10 °C to 38 °C	195	11.5	24	6,707	10,180	up to 1750			15.5
	CRACKBOND® 2100 MV	4 °C to 38 °C	17,000	37-199	7 hr 10 min	2,430	11,340	3020			1
	CRACKBOND® 2100 MV LPL		3,980-6,440	53-105	3-6	up to 6000	up to 12,580	up to 3450			1.3-3

Company	Product Name	Usage/Service Temperature (°C)	Viscosity (ASTM D2196/ASTM D2556/ASTM D2393/AST	Gel Time/Pot Life (AASHTO T237/ASTM C 881) (minutes)	Cure Time (hour) (ASTM D1640/ASTM D2377/AASHTO T237/Californian Test Method 551)	Tensile Strength (ASTM D638) (psi)	Compressive Strength (ASTM D-695/ASTM C109/AASHTO T 106) (psi)	Bond Strength (ASTM C881/ASTM C882/ASTM C1583/Californian Test Method 551) (psi)	Shear Strength (ASTM D-732)	Adhesion (ASTM C-882/ASTM D7234) (psi)	Tensile Elongation (ASTM D638) (ASTM D-412)
	CRACKBOND ® LR-321	10 °C to 38 °C	500	27/19		7,230		up to 2,950			4.4
	CRACKBOND ® EPOTHANE	16 °C to 35 °C									
	CRACKBOND ® V120 LO-	16 °C to 35 °C	120		4						
	CRACKBOND ® V65 HI-MOD	4 °C to 41 °C	65	25-238	5	up to 9,860	up to 11,620	up to 2,950			3.3-4.6
	CRACKBOND ® V200 HI-	16 °C to 35 °C	200		6						
E-Chem, LLC	EP50-OVERLAY		1200-1800	15-25	1-6	2,500-3,000		2,000-2,500			40-50%
E-Chem, LLC	EPX50-OVERLAY		1,800-3,500	18-23		3,200-3,900		3,500-4,500			45-60%
E-Chem, LLC	EP75-SEAL		<40	50-70	2.5-8	3,000-3,200	5,000-5,500	1500-2200			35-45%
E-Chem, LLC	EP100-SEAL				3.5-8						
E-Chem, LLC	EP-SLV		120-170	30	4.5-10	7500-	>10,000	>1500			3-6%
Simpsons Strong -Tie	CI-GV			8-55			up to 12,400	up to 3,850		1,100	
Simpsons Strong -Tie	CI-LPL	21	750-3600	40-420/20-	3-16	up to	up to 12,000	up to 3,000		1,250	2.52-3.21
Simpsons Strong -Tie	CI-LV		350-1500	45-400/10-	3-6	up to	up to 12,150	up to 3,450		1,100	2.2-3.2
Simpsons Strong -Tie	CI-LV FS		600-2000	12-55/10-	1.75-4	up to	up to 15,200	up to 4,000		1,100	1.06-1.91
Simpsons Strong -Tie	CI-SLV		150	6-100	4-9	7,500	up to 14,200	up to 3,600		1100	2.14
Pecora Corporation	KlereSeal® 9100-S										
E-BOND EPOXIES, INC.	E-BOND 550 HI-MOD		300-500	25-30	3-18	7500	up to 11,500	up to 3,000			3.5 – 5%
ChemMasters, Inc	DURAGUARD 401-30E RESIN	4 °C to 49 °C	<14-20	15-25	6	1,600-1,800	9,800	>1,500			10-30%
Kaufman Products Inc.	SurePoxy LM			30-40	168 max	5,200	4,200	up to 3,780			5-10
Kaufman Products Inc.	SurePoxy VLM		3100-3500	32	4-168	3,000 min	up to 7,500	2000			30-40%
	PE1000+®										

Company	Product Name	Usage/Service Temperature (°C)	Viscosity (ASTM D2196/ASTM D2556/ASTM D2393/AST	Gel Time/Pot Life (AASHTO T237/ASTM C 881) (minutes)	Cure Time (hour) (ASTM D1640/ASTM D2377/AASHTO T237/Californian Test Method 551)	Tensile Strength (ASTM D638) (psi)	Compressive Strength (ASTM D-695/ASTM C109/AASHTO T 106) (psi)	Bond Strength (ASTM C881/ASTM C882/ASTM C1583/Californian Test Method 551) (psi)	Shear Strength (ASTM D-732)	Adhesion (ASTM C-882/ASTM D7234) (psi)	Tensile Elongation (ASTM D638) (ASTM D-412)
DEWALT	PURE50+™										

9.4 Appendix D. Survey Questionnaire

Materials and Methods for Sealing Vertical Cracks on Concrete Structures

A brief survey on crack sealing repair jobs on vertical/sloped surfaces of Portland Cement Concrete (PCC) infrastructure elements

* Required

1. State Highway Agency: *

2. Indicate your job title, contact information, and role within the Agency. *

3. Is it within the Agency's common practice to use sealants for cracks on vertical/sloped PCC infrastructure elements (retaining walls, piles, foundations, bridge piers, etc.)?

Check only one box.

☐Yes ☐No

4. Which of the material type(s) below do you commonly use for crack sealing? Check all that apply.

☐Epoxy

☐Methyl Methacrylate

☐High Molecular Weight Methacrylate (HMWM)

☐Urethane

☐Polyurethane/Rubberized Polymers

☐Penetrant Sealer

Other:

5. What techniques do you commonly use in the application of crack sealants? Check all that apply.

☐Epoxy Injection

☐Routing & Sealing

☐Gravity Seal

☐Overlays/Surface Coating

☐Cathodic Protection/Prevention

☐Chemical encapsulation

Other:

6. List some of the most commonly used products and suppliers for your crack sealing repair jobs

7. From your experience, what is the expected service life of an applied sealant?

8. Provide a link to the standards and specifications that can be of benefit to this topic

9.5 Appendix E Summary of Survey Responses

No.	Agency	job title	contact information	Agency practices sealing cracks on vertical/sloped PCC structures?	Commonly used material for crack sealing	Commonly used crack sealing techniques	Commonly used crack sealing products	Expected Service Life	Provided a link to the standards and specifications
1	Alaska Department of Transportation and Public Facilities (DOT&PF)	State Quality Assurance Engineer	Richard Giessel, richard.giessel@alaska.gov (907) 269-6244	Yes	Epoxy	Epoxy Injection, Gravity Seal	SuperLowViscosity-Sikadur 55 SLV	Very long service life from epoxy injection and gravity fill	Yes
2	Florida Department of Transportation (FDOT)	Lab Manager – Corrosion	Ron Simmons, ronald.simmons@dot.state.fl.us 352-955-6691	Yes (Specifications focus primarily on horizontal)	Epoxy, High Molecular Weight Methacrylate (HMWM), Penetrant Sealer	Epoxy Injection, Routing & Sealing, Gravity Seal, Overlays/Surface Coating	Sealate T70 Duraguard 401-30E Sikadur® 22 Lo-Mod FS E-Chem EP50 \ EP75; EPX50	penetrant sealers - 2 to 3 years Epoxy Injection - 15 to 20 years HMWM -	Yes
3	Idaho Transportation Department (ITD)	Bridge Staff Engineer		Yes	Epoxy, High Molecular Weight Methacrylate (HMWM)	Epoxy Injection, Overlays/Surface Coating	Any Product that meets spec	5-10 years for epoxy/HMWM overlays, examples of 15+ years	Yes
4	Kansas Department of Transportation (KDOT)	Asst Bureau Chief, Construction and Materials		NO					NO
5	Kentucky Transportation Cabinet (KYTC)	Transportation Engineer Technician III		NO	Epoxy	Epoxy Injection	Epoxy Resin Systems meeting ASTM C881 and AASHTO M200 requirements	Do not have historical experience	Yes

No.	Agency	job title	contact information	Agency practices sealing cracks on vertical/sloped PCC structures?	Commonly used material for crack sealing	Commonly used crack sealing techniques	Commonly used crack sealing products	Expected Service Life	Provided a link to the standards and specifications
6	Minnesota Department of Transportation (MnDOT)	State Bridge Engineer	Ed Lutgen Edward.lutgen@state.mn.us	Yes (eveyr 5 years for bridge concrete barriers) special surface finish to all visible vertical/overhead concrete surfaces at the time of construction	Epoxy	Routing & Sealing Gravity Seal	TexCote XL 70 Bridge Cote w/Silane Paulco TE-2501 Clear Dural 50 LM TK-9000 and TK-2110 MasterSeal 630 (formerly Degadeck Crack Sealer Plus) T-78 KPP 204 P	Many years depending on exposure	Yes
7	Missouri Department of Transportation (MoDOT)	Construction and Materials Liaison Engineer	John Donahue John.donahue@modot.mo.gov (573) 526-4334	Yes	Epoxy, Methyl Methacrylate,High Molecular Weight Methacrylate (HMWM),Polyurethane/Rubberized Polymers	In accordance with manufacturer recommendations	Evonik - Protectosil DegaDeck CSS Kwik Bond Polymers - HMWM Transpo-Industries, Inc - Sealate T-70-10,	Probably 5-10 Years	Yes
8	Nebraska Department of Transportation (NDOT)	Bridge Mgmt. Engineer	Mike Vigil; mike.vigil@nebraska.gov	Yes (not standalone)	Epoxy	Epoxy Injection,Routing & Sealing	Sika, Hilti, Dayton Superior	10-20 years, depends on workmanship and exposure	Yes
9	Nevada Department of Transportation (NDOT)	Concrete Operations	Joe Barreres 775-888-7139 jbarreres@dot.nv.gov	Yes	Epoxy, High Molecular Weight Methacrylate (HMWM), Polyurethane/Rubberized Polymers	Epoxy Injection, Routing & Sealing, Gravity Seal, Overlays/Surface Coating	CRACKBOND V65 HI-MOD EP100-SEAL HM EP-SLV Dural 335 Sikadur 55 SLV CI-GV, CI-LPL, CI-LV, CI-LV	up to 40 years	Yes

No.	Agency	job title	contact information	Agency practices sealing cracks on vertical/sloped PCC structures?	Commonly used material for crack sealing	Commonly used crack sealing techniques	Commonly used crack sealing products	Expected Service Life	Provided a link to the standards and specifications
10	Oregon Department of Transportation (ODOT)	Structural Materials Engineer	David Dobson, David.dobson@odot.oregon.gov	Yes	Epoxy, High Molecular Weight Methacrylate (HMWM), Penetrant Sealer, Silanes	Epoxy Injection, Gravity Seal, Overlays/Surface Coating, Cathodic Protection/Prevention	Pro-Poxy 100	10 years (Bridge deck); Depends on type and exposure condition	Yes
11	South Carolina Department of Transportatio	Structural Materials Engineer		Yes	Epoxy	Epoxy Injection, Gravity Seal, Overlays/Surface Coating	case by case basis	Assumes these products last quite a while	Yes
12	Utah Department of Transportation (UDOT)	Structures Project Engineer for Preservation	Preservation Engineer, 385-226-4499	Yes	High Molecular Weight Methacrylate (HMWM), Urethane, Polyurethane/Rubberized Polymers,Penetrant Sealer, FRP wrapping	Epoxy Injection (only on girders), Overlays/Surface Coating	Sika products	Epoxy/thin bonded polymer - 10 years; HMWM, polyurethane and penetrating sealer - 5 Years	Yes
13	Virginia Department of Transportation (VDOT)	Senior Research Scientist Assistant State Bridge Engineer	Michael M. Sprinkel, P.E. Phone: (434) 293-1941 Email: Michael.Sprinkel@VDOT.Virginia.gov Adam Matteo, PE	Yes	Epoxy, Urethane	Epoxy Injection, Routing & Sealing, Gravity Seal, Overlays/Surface Coating, Cathodic Protection/Prevention	Euclid Chemical Co., Duralcrete EP 4 LV E-Bond Epoxies, 550 EP-4LV Modified Euclid Chemical Co., Aquaseal Gel EP-6	epoxy overlays -15 to 20 years Crack injection -20 years on substructure and superstructure, 5 to 10 years on decks Gravity polymers - 2 to 5 years on	Yes

No.	Agency	job title	contact information	Agency practices sealing cracks on vertical/sloped PCC structures?	Commonly used material for crack sealing	Commonly used crack sealing techniques	Commonly used crack sealing products	Expected Service Life	Provided a link to the standards and specifications
14	Ministry of transportation of Quebec	Concrete Materials Engineer	Nadia Pouliot, engineer Nadia.Pouliot@transports.gouv.qc.ca	Yes. Cracks with opening greater than 0.8 mm and up to 6 mm are treated with epoxy. Cracks with openings greater than 6 mm are treated with cement grout.	Epoxy, Polyurethane/Rubberized Polymers, Penetrant Sealer	Epoxy Injection, Gravity Seal	• Epojet LV, de Mapei inc.; • Époxy-Scel-80, de chez Krytex inc.; • Époxy-Scel-300, de chez Krytex inc.; • Eucopoxy Injection Resin, de chez Euclid inc.; • Seal Rez EP 0127, de chez Ambex inc.; • Sikadur 52, de chez Sika Canada inc.	10 to 20 years is an average	Yes (ASTM)