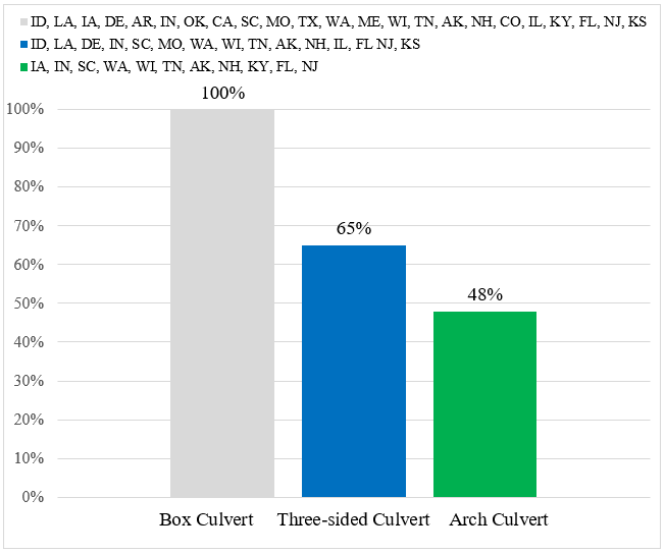
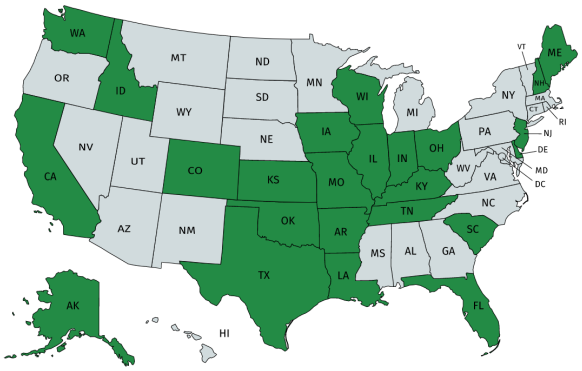
Division of Engineering Research on Call Task #9 - Exterior Protection of Precast Reinforced Concrete Culverts





Prepared by:
Halil Sezen, The Ohio State University
Baris Kasapoglu, The Ohio State University
Kevin White, E.L. Robinson Engineering of Ohio
Shad Sargand, Ohio University

Prepared for:
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Halil Sezen (ORCID No. 0000-0002-0907-5557) **Baris Kasapoglu** (0000-0001-6098-0010) **Kevin White** (0000-0002-2902-2524) **Shad Sargand** (0000-0002-1633-1045)	

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16. Abstract

Application of exterior coatings and membrane waterproofing on precast reinforced concrete box culverts, three-sided flat-topped culverts, and precast reinforced concrete arch and round sections is required by Ohio Department of Transportation (ODOT). Sealing and waterproofing limit the intrusion of ground water through the top of the joint and it protects the top and sides of the concrete surfaces from top-down chloride intrusion, thus extending the service life of the culvert. The intrusion of water through the joint, particularly in low cover applications, can lead to premature degradation of the reinforced concrete. This project investigated the suitability of the current exterior surface preparation of large-span reinforced concrete structures to eliminate water infiltration. Based on survey data from 24 state DOT agencies and precast concrete industry, literature review, and evaluation of ODOT's current waterproofing and joint treatment methods, successful practices are identified and recommended for repair and protection of precast concrete culverts.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

INTRODUCTION

1.1 Background Information and Problem Statement

The application of exterior sealers and waterproofing on precast reinforced concrete box culverts, precast reinforced concrete three-sided flat-topped culverts, precast reinforced concrete arch sections, and precast reinforced concrete round sections is required by Ohio Department of Transportation (ODOT) Construction and Material Specifications (CMS) Item Section 611.

CMS 611.09 specifies the requirements for the application of exterior coatings and membrane waterproofing. This is mainly to protect the exterior coatings and membrane waterproofing from damage during placement of bedding, backfill, and embankment. CMS 611.09 requires application of membrane waterproofing to all surfaces that would be in contact with the backfill (top and sides) according to the membrane waterproofing manufacturer's recommendation.

Sealing and waterproofing limits intrusion of ground water through the top of the joint and it protects the top and sides of the concrete culvert from top-down chloride intrusion thus extending the service life of the culvert. In addition to waterproofing, CMS (Section 611.08) requires additional protective measures dependent upon the type of structure.

For box culverts, the top exterior joint, and bottom and side interior joints are filled with mortar prior to application of the membrane waterproofing.

For three-sided flat-topped culverts, the procedure specified is dependent upon the joint type utilized. If the structure uses keyway type joints, fill the joint with nonshrink mortar; however, if tongue and groove type joints are utilized, then utilize the same procedure as for box culverts. After placement of the grout, per Section 611.08.B.3.b of ODOT CMS (2019), exterior of the joint is covered with a 12 inch wide strip of joint wrap centered on the joint. The required continuous joint wrap should extend from the bottom of the vertical face on one side to the bottom vertical face on the other side. Membrane waterproofing is applied to the precast sections after they are installed.

For concrete arch sections and round sections, a flexible joint sealant is placed within the exterior joint chamfer. According to Section 611.08.B.3.c of ODOT CMS (2019), a continuous joint sealant is needed to extend from the bottom of the vertical face on one side to the bottom vertical face on the other side. All exterior joints are required to be wrapped with a 12 inch wide strip of joint wrap centered on the joint. The continuous length of the joint wrap will extend from the bottom of the vertical face on one side of the structure to the bottom vertical face on the other side. Next, membrane waterproofing is applied, as shown on the plans, to the precast sections after they are installed.

Application of waterproofing membranes and overlapping requirements are provided in Section 512.08 of ODOT CMS (2019). For Type 2 membrane waterproofing, consisting of rubberized asphalt and peel-and-stick waterproofing material, membranes are required to be lapped by at least 1 inch. For Type 3 membrane waterproofing, consisting of primer coat and a waterproofing membrane, the required lap width is at least 3 inches along the edges of the membrane.

The various combinations joint filler, joint wrap, and membrane waterproofing are intended to prevent water infiltration through the joints in the upper and side portions of the precast conduit, and to protect the exterior surfaces of the culvert from environmental degradation. However, in some instances, post installation inspections have found infiltration through some joints.

The intrusion of water through the joint, particularly in low cover applications, can lead to premature degradation of the reinforced concrete. Considering the multi-faceted approach to eliminate water infiltration, identifying and eliminating the causes of this infiltration is of high importance to ODOT. It is important to note that the developed system may be sufficient and that the root cause may be related to poor quality control or quality assurance (QC/QA) procedures during construction.

This project investigates the suitability of the current exterior surface preparation of large-span reinforced concrete structures to ensure the structures are provided with water-tight joints. As outlined below, this project goal was achieved by: 1) conducting a literature review, 2) conducting a survey of other state Departments of Transportation (DOTs), 3) evaluation of ODOT's methodology and practices, and 4) proposing repair methods.

1.2 Objectives

The objectives and associated deliverables of this task order project include:

1. Literature review of what other state DOT's require for joint preparation and waterproofing of precast reinforced concrete box culverts, three-sided flat-topped culverts, precast reinforced concrete arch sections, and precast reinforced concrete round sections.

2. Survey of other state DOT engineers and follow up interviews with engineers from a few selected DOTs to learn about their experiences.

3. Evaluation of the current sealing and waterproofing methods used by ODOT as compared to findings from the literature review and survey results.

4. Proposed repair methods and materials as determined by literature review and consultation with conduit manufacturers.

5. Evaluation of methods or materials that can be used to address leaking joints discovered during post installation inspections.

1.3 Scope of the Study

This research is mainly conducted and led by the Ohio State University (OSU) with significant contributions from the researchers at Ohio University (OU) and E.L. Robinson Engineering of Ohio (ELR).

This project starts with a literature review of existing research studies and practices of other state DOTs that require waterproofing for precast reinforced concrete three-sided flat-topped culverts, precast reinforced concrete arch sections, and precast reinforced concrete round sections (Chapter 2). This is followed by a survey of State DOTs to better understand the waterproofing applications and requirements of state DOTs. A summary of survey results, as well as observations gleaned from discussions with selected few state DOT representatives, are provided in Chapter 3.

Chapter 4 presents requirements and practices of additional states based on documents obtained from an online search. The main focus here was waterproofing outside the joint regions of culverts. ODOT's waterproofing methodology and requirements are evaluated in Chapter 5. This evaluation was done in light of other DOT practices to identify deficiencies or opportunities for improvement. Both material standards and installation procedures are considered. Potential repair methods are presented, and their pros and cons are discussed in Chapter 6. The goal was to identify repair methods to achieve a watertight joint at the top and sides. This chapter also presents an evaluation of methods or materials that can be used to address leaking joints discovered during post installation inspections considering the impact to service life of the culvert.

CHAPTER II

LITERATURE REVIEW AND BACKGROUND INFORMATION

2.1 Literature Review

A literature review was performed, and the published documents related to waterproofing of precast concrete culverts, observed culvert damage, and potential repair methods and practices are summarized herein. Most of the repair related reports were prepared by or for the state DOTs. These reports are summarized in Chapter 6.

Waterproofing has been a critical problem affecting the service life of concrete culvert systems. There are two main locations where waterproofing measures are typically applied: (1) within joints and/or on the exterior face of the joints, and (2) exterior concrete surfaces away from the joints, which typically includes top surface of the three-sided and box culverts. There have been numerous studies investigating the possible causes and effects of water damage. Some methods and recommendations are also proposed in the literature about preventing and repairing the damage.

Precast concrete culvert systems have been used in the United States since the late 1970s. Cook et al. (2002) investigated the performance of precast box culvert systems as part of a research project funded by the Florida Department of Transportation. In their responses to the survey of state agencies on their experiences with the box culverts, many states reported they had poor waterproofing performance at joints (Cook et al., 2002).

As early as the 1960s, some of the state DOTs started to report permeability problems with concrete bridge decks and associated damage (Manning, 1995). Waterproofing membrane products have been applied to protect concrete surfaces against water and moisture. Manning (1995) surveyed U.S. state and Canadian provincial transportation agencies to investigate the use of waterproofing membranes on concrete bridge decks. Figure 2.1 shows usage of the membranes in the United States when a survey was conducted by Russell in 2012. Waterproofing membranes were used by vast majority of European countries and Canadian provinces while approximately 60% of the U.S. states were applying those membranes (Russell, 2012).

One cause of the joint leakage problems identified and reported by the Oregon Department of Transportation was “poor adhesion between the waterproofing membrane and the asphalt-wearing course, and the material properties of the asphalt layer” (Haynes et al., 2019). This rare waterproofing related study involved laboratory experiments at the Oregon State University with a main goal of investigating sealing methods to protect bridge decks. This research and several other field investigations related to waterproofing of concrete bridge decks may not be applicable to culverts when the culvert backfill material exceeds 1 ft.

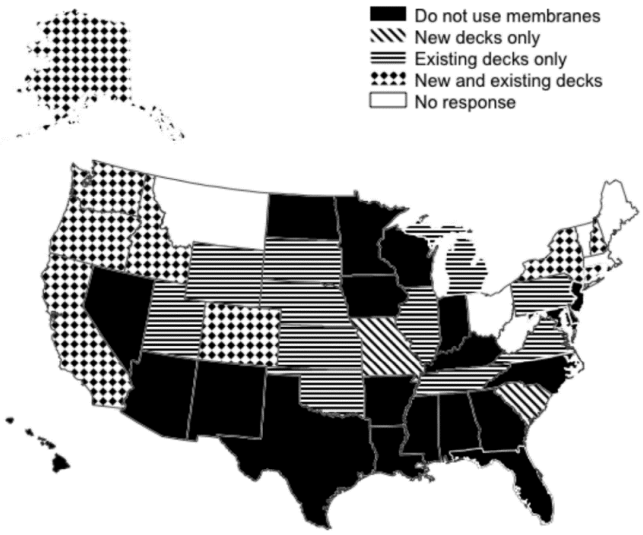


Fig. 2.1 Usage of waterproofing membranes in the US in 2012, as reported by state DOTs in response to the survey conducted by Russell (2012).

Muhammad et al. (2015) reviewed available research studies on waterproofing strategies for concrete. Their taxonomy lists three main approaches to improve the watertightness of concrete: (1) external coating, (2) integral mixing, and (3) external membrane (Figure 2.2). These methods have been applied independently or in combination in different structures following the appropriate standards and specifications. This research also has shown that several state DOTs apply these approaches precast concrete that may include (1) silane or epoxy coating, sometimes at the precast plant, (2) reduce permeability and increase freeze-thaw resistance of concrete by improving the concrete mix, and (3) external geotextile or other types of membranes.

One of the earliest approaches to waterproofing concrete is by applying an external coating. As long ago as 3000 BC, cold-applied coatings made of beeswax, gelatin, and clay were used by Egyptians to seal wooden boats. The use of cold-applied asphalt coatings for waterproofing of roofs and other construction started in the U.S. during the 1930s. The distinct advantage of this method is that it can be applied easily by spraying or brushing the coating material on the concrete surface (Dutton, 1997). The integral mixing method (Figure 2.2) typically involves addition of certain agents, such as polymers, to concrete to reduce permeability. This type of waterproofing is distributed throughout the entire structure. Muhammed et al. (2015) states the advantages of this method concluding that there is no concern regarding sufficient penetration depth. The third method of waterproofing or external membrane shown in Figure 2.2 can include bitumen-based waterproofing membranes such as bitumen-polymer mixes that have gained importance since the 1960s (Cogneau, 1997). The extensive literature review conducted by Muhammed et al. (2015) showed that 60 research studies focused on the external coating method, while eight studies investigated the waterproofing of external membranes, and 18 researchers successfully demonstrated integral mixing by incorporating the additive into the concrete mix.

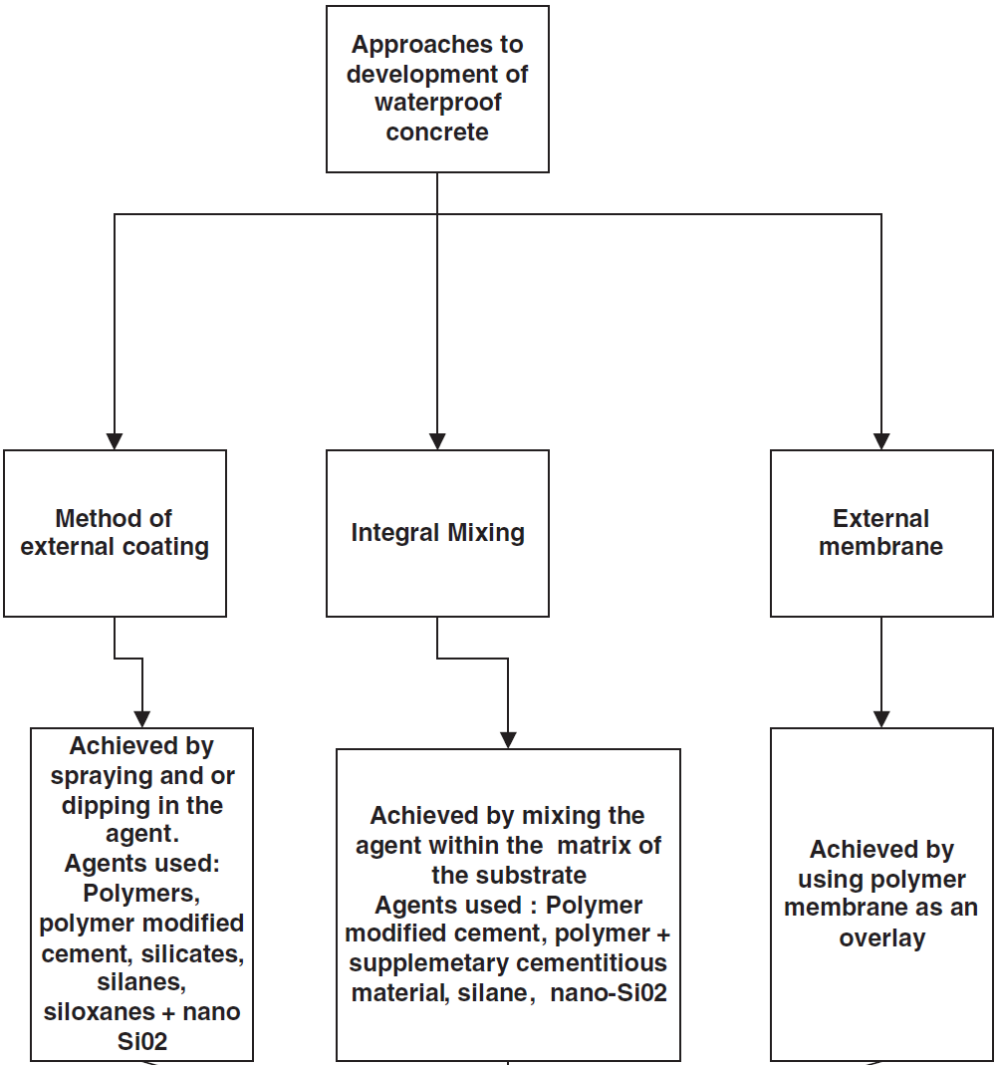


Fig. 2.2 General classification of approaches for the development of waterproof concrete (Muhammad *et al.*, 2015)

There have been some additional concrete waterproofing methods developed and reported in the last two decades. In the early 2000s, spray-applied waterproofing membranes have been introduced (e.g., by ITAtech 2013). Yang et al. (2020) conducted an experimental study on the long-term behavior of the spray-applied acrylate waterproofing membrane materials. Similarly, an experimental investigation of the mechanical properties of polyurethane modified bituminous waterproofing membrane was published by Rupal et al. (2020).

Joints of precast concrete segments are probably the most critical locations experiencing damage due to infiltration or water leakage in reinforced culvert systems. Gong et al. (2019) proposed a sealant mechanism based on a finite element analysis. They examined 13 road tunnels in Shanghai where ethylene-propylene-diene monomer (EPDM) rubber gaskets were used to seal joints in eleven of the tunnels, which were

constructed in the past 20 years, while epoxy was used for the earliest one, constructed in 1970 (Gong et al., 2019). Lin et al. (2020) linked the leakage at the joints to underground water and earth pressure based on their investigation of the poor performance of waterproofing of a precast concrete utility tunnel. Wu et al. (2019a) performed finite element analysis to evaluate the waterproofing performance of rubber strips at joints and determined that the compressive stress is nonuniformly distributed under different posttensioning reinforcement sectional designs. Wu et al. (2019b) conducted an experimental study to investigate the relationship between compressive stress and water pressure applied on putty-based composite rubber (EPDM rubber strip) used in joints of precast concrete culvert box systems. They found that the waterproofing performance of the sealing rubber strip does not change when the water pressure is less than 17 psi.

2.2 Other Potential Concrete Waterproofing Methods Found in the Literature

Although not directly related to the research conducted in this study, the researchers found publications on general waterproofing of concrete culverts during the literature review. Some of these studies are briefly described here as alternative methods. One such alternative approach is integral mixing method for concrete waterproofing, which involves introducing some agents with the cement in the mix. Commonly used agents are:

- Polymer additives
- Polymer additives and supplementary cementitious materials such as microsilica or silica fume
- Silane
- Nano-$Si0_2$

Muhammad *et al.* (2015) state that "increasing w/c ratio of the concrete mix caused the reduction of water absorption by 98.96% of the treated material compared to the control sample (Vipulanandan & Liu,2004), water penetration depth decreased by 94%. It was further discovered that nano waterproof agents increased the static water contact angle (a measure of hydrophobicity) of the treated sample to 142° (Woo et al.,2008)".

Agents can be classified based on material structure using three size scales: (i) macro, (ii) micro, and (iii) nano materials, as shown in Table 1.1 (Muhammad *et al.*, 2015).

1. Silanes and siloxanes are the two common macro materials used for waterproofing concrete. They reduce water permeability by 89% and 75% respectively (Diamanti, 2013). Another macro material is silicate additive, such as ethyl silicate and sodium silicates. These compounds may reduce water absorption by 98.5% (Toutanji, 2013).

2. Micro materials consist mainly of polymers and their dispersions and emulsions. The reduction of water permeability was reported to be up to 98.96% (Vipulanandan & Liu, 2004).

3. The most common nano materials used for concrete waterproofing are SiO_2, ZnO_2, and nano clay. Static water contact angles were observed as 120°, 130°, and 142° (Zhang et al., 2012; Woo et al., 2008).

Table 1.1: Classification of Agents based on the Material Structure (Muhammad et al., 2015)

S/No	Type of additive	Examples	Effect on the concrete
1	Macro materials	Silanes, siloxanes	Showed to have the ability to resist water absorption by 98% and increase static water contact angle to 164° in the treated sample
		Silicate containing compounds	Reduced water absorption up to 98.5% and showed the lowest chloride penetration depth of 1 mm compared to the control sample
2	Micro materials	Polymers	Reduced water absorption up to 98.96% and decreased chloride penetration depth to 1 mm in the treated sample
3	Nano materials	SiO_2, ZnO_2 and nano clay	Could reduce chloride penetration by 69% and increase static water contact angle to 142°

CHAPTER III

SUMMARY OF RESPONSES AND ANALYSIS OF SURVEY DATA

3.1 Survey of State DOTs about Waterproofing Practices

A questionnaire was sent to representatives of 49 state DOTs on November 16, 2020. A total of 23 responses were received (Figure 3.1). The survey included questions about type of culverts used, waterproofing applications within and outside the joint regions, and potential poor performance of concrete culverts. Through the survey many states provided their installation and/or material specifications or similar documents. All states responding to survey (23) use precast concrete culverts, and 22 of them use waterproofing on joints. Only eight states use waterproofing on top of the culvert between the joints. None of the states reported poor performance due to lack of waterproofing protection.

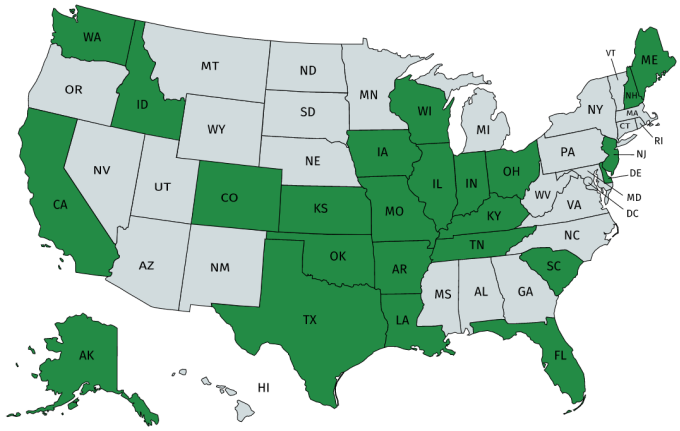


Fig. 3.1 States Which Responded

3.2 Survey Questions

The following questions were asked in the survey. The summary of all responses are included in the Appendix A. The responses are analyzed in the next sections.

1. Does your agency utilize precast concrete culverts? If so, which shape(s) do you use? Box culverts, three-sided culverts, and/or arch culverts?

2. What kind of waterproofing treatment is required for the joints of precast concrete culverts?

3. Please provide details such as material requirements and installation specifications for any waterproofing treatment(s)? Does your agency have construction and/or material specifications or similar documents? If yes, can you email or provide a web link?

4. What type of backfill materials are used around the culvert?

5. Do you waterproof more than the joints? If so, what else is waterproofed and with what material(s)?

6. Are there reports of poor performance of the waterproofing protection identified above?

7. Please explain your experience, what cause(s) were identified, and how were the performance issues were addressed.

8. Were designs, installation procedure, or specifications modified in response to performance issues? In what way(s)?

9. Does your agency have a preferred method of repair to eliminate water infiltration through a joint?

3.3 Which Culvert Shapes are Used?

All states that responded to the survey use box culverts (23), 15 states use three-sided culverts, and 11 states use arch culverts. State names are provided in Figure 3.2. Nine states use box, three-sided and arch culverts, while six states use only box culverts. ODOT utilizes each of the structure types discusses herein.

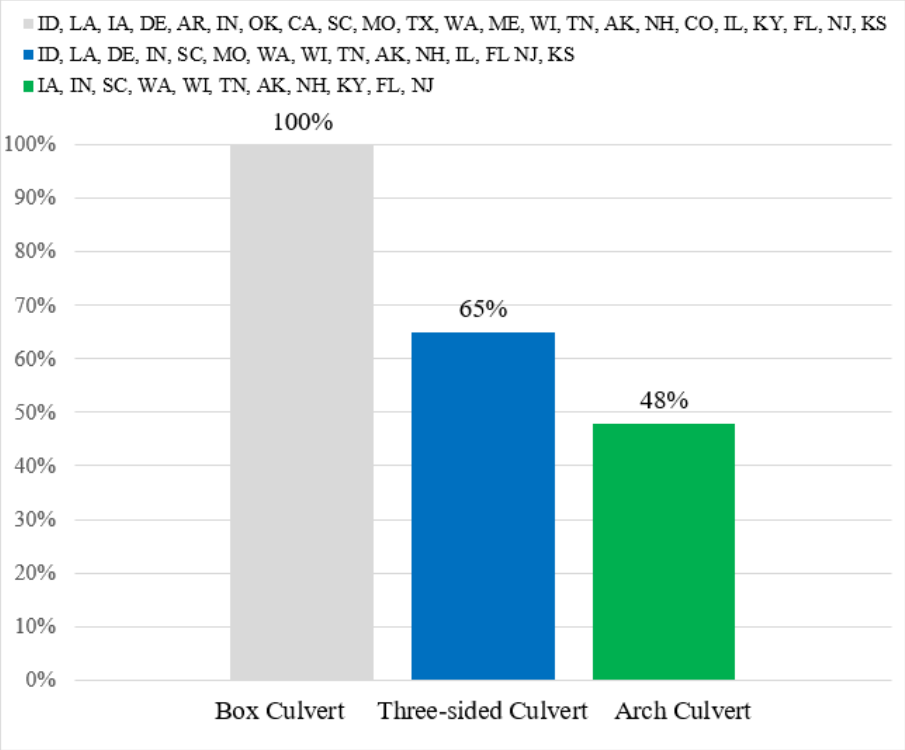


Fig. 3.2 Reported Use of Culvert Shapes

3.4 Culvert Backfill Materials Used

Out of the 23 states, 21 states responded to the question regarding backfill materials. The responses are summarized in Table 3.1. It is interesting to note that New Jersey DOT specifically states that "When coarse aggregate is used, geotextile filter fabric material shall be placed at the interface of the aggregate and the regular roadway materials and/or embankments." ODOT places the responsibility of the selection of proper bedding and backfill material on the material manufacturer and contractor.

Table 3.1: Backfill Materials used by states responding to the survey.

States	Backfill Materials
Alaska	Subbase gravels
Arkansas	Normally the in-situ material that was excavated, although most contractors use the borrow material available on the project.
California	Compacted granular backfill or concrete.
Colorado	Class 1 Structure Backfill Material is required around the top and sides of the box culvert(s). A minimum horizontal thickness of 1.5' is required on the sides of the box culvert and a minimum 1.0' is required on top of the box.
Delaware	Borrow Type C that can be found in Sections 207, 209, and 1001 of https://deldot.gov/Publications/manuals/standard_specifications/pdfs/2020/2020_standard_specifications.pdf?cache=1605620615763
Florida	Begin backfilling only after the Engineers approval. Seal blockouts and holes provided for lifting or joint restraint by plugging using an epoxy mortar or non-shrink grout in accordance with Sections 926 or 934 and properly cure to ensure a sound and watertight plug, prior to backfilling.
Idaho	We usually require 3/4" base material for backfill.
Illinois	Porous granular embankment for a minimum of 2' on each side and in-situ soil for the rest of the backfill.
Indiana	904.05 Structure Backfill: The material shall be of acceptable quality, free from large or frozen lumps, wood, or other extraneous matter. It shall consist of suitable sand, gravel, crushed stone, 350 ACBF, or GBF. Structure backfill shall be in accordance with one of the gradations shown in the table below, or coarse aggregate in accordance with the gradation requirements of 904.03(e). Coarse aggregate shall be crushed stone or ACBF, class D or higher.
Iowa	See Iowa DOT Standard Specifications
Louisiana	Granular or select low plasticity clay
Maine	Granular borrow is typically used around the culverts and must typically meet the requirements for Underwater Backfill (See Standard Specification Section 703.19).

Missouri	Select granular
New Hampshire	2.1.2 Granular backfill (gravel) shall consist of a mixture of stones or rock fragments and particles with 95 to 100 percent passing the 3" sieve and 25 to 70 percent passing the No. 4 sieve.
New Jersey	Two foot thick porous fill, Soil Aggregate I-9, is used on the sides of the culvert. Backfill and compact around the precast culvert is as specified in 203.03 and 505.03.02 of the standard specifications. "Table 203.03.01-1 Placing and Compacting Methods" will determine what method is used per project depending on ground conditions and will dictate what materials are used for backfilling. The NJDOT Standard Specifications permit the use of I-9 or I-15 soil aggregate or coarse aggregate no. 57 as backfill material. When coarse aggregate is used, geotextile filter fabric material shall be placed at the interface of the aggregate and the regular roadway materials and/or embankments.
Oklahoma	Coarse Cover Aggregate, Section 703.06 in our Specifications. The gradation for this mix is shown in Table 703:8
South Carolina	A-1, A-2-4, A-3 soils
Tennessee	Pipe Culverts – Class B Bedding (Use sand or a natural sandy soil, all of which passes a 3/8-inch sieve and not more than 10% passes a No. 200 sieve, or a Type A or Type B aggregate meeting Grading C, D, or E of 903.05.) and unclassified backfill (fine compactable soil) Box Culverts –granular backfill material (Type A, Grading D)
Texas	Compacted backfill free from stones large enough to interfere with compaction and placed in layers no greater than 10" or 8" deep (depending on location) and compacted to density requirements of the roadbed or embankment material. See Item 400.3.3.1 and 400.3.3.2 of TxDOT Specifications available here: ftp://ftp.dot.state.tx.us/pub/txdot-info/des/spec-book-1114.pdf
Washington	Backfill materials are controlled by WSDOT Standard Specification 6-20.3(9). https://wsdot.wa.gov/Publications/Manuals/M41-10.htm
Wisconsin	Typical structure backfill.

3.5 Waterproofing of the Joints

All but one state DOT, Alaska, that responded to the question regarding waterproofing materials mentioned that they use some kind of waterproofing either within the joint (e.g., gasket) or sealants (e.g., geotextile or membrane wrap) on the exterior face of the joints. The responses are summarized in Table 3.2. Three states (California, Oklahoma, and South Carolina) required jointing material such as mortar, rubber gaskets or similar materials between the precast members, but not explicitly on the exterior face of the joints. The minimum specified width of the wrapping material (geotextile membrane, mastic wrap, asphalt coating, or other sealing bands) on the joint varied between 12 inches and 36 inches (by Missouri DOT).

Summary of all data available for most states, e.g., through their web sites are summarized in this chapter and Appendix C. It turns out almost all states that responded to our survey have some kind of waterproofing requirement (Table 3.2), however there are many states with no such requirements (Appendix C).

Table 3.2: Waterproofing materials used in the joints or wrapping materials outside surface of the joints, as reported by the states responding to the questionnaire.

States	Waterproofing between members or on the exterior face of joints
Arkansas	The joint on the top of the box culvert sections must be sealed with one of the waterproofing membranes in Section 815 of our Standard Specifications (see page 828 on the attached link) http://ardot.gov/standard_spec/2014/Division%20800.pdf
California	Cement mortar, rubber gaskets, other resilient materials (i.e. polyvinyl chloride, fiberglass impregnated with epoxy resin)
Colorado	Rubber gaskests meet ASTM C1677. Joint Sealants meet ASTM C990, 6.1 or 6.2 pr AASHTO M 198, 6.1 or 6.2.
Delaware	18" wide mastic wrap centered on the joints. Joints are tongue and groove for box culverts, and we post-tension them once set. Gaskets or compression seals are used for 3-sided frames and arches.
Florida	Depends on whether is a water conveyance or pedestrian access tunnel. 410-11.2 Profile Rubber Gaskets, 410-11.3 Preformed Flexible Joint Sealants, Specification 410 (Box Culverts) and 407 (three-sided culverts) details the requirements. https://www.fdot.gov/programmanagement/Implemented/SpecBooks/default.shtm
Idaho	Precoated Preformed Membrane Sheet Typed D
Illinois	The joints are to be filled with a mastic joint sealer and shall additionally be externally sealed with a 13" wide sealing band. Boxes with 3' and less fill shall have a waterproofing membrane on the top and extend 1' down on the side walls. The mastic and sealing band are per sections 1055 and 1057 of our standard specifications. Link on following page. The membrane is per Guide Bridge Special Provision 81. Link on following page.
Indiana	https://www.in.gov/dot/div/contracts/standards/book/sep19/900-2020.pdf 907.07 Joint Membrane System for Precast Reinforced Concrete Box Structure Sections The Contractor may elect to use an approved self-adhering membrane system in lieu of the detail shown on the plans. Joint membrane systems shall be in accordance with the following requirements. Property Test Method Requirements Thickness ASTM D 3767, Procedure A 59 mil, min.

	Tensile Strength Grab Tensile Strength, ASTM D 4632 650 N, min. Elongation Grab Tensile Strength, ASTM D 4632 20%, min. Bursting Strength Mullen Burst, ASTM D 3786 290 psi, min. Peel Strength ASTM D 903 850 N/m, min. Permeance ASTM E 96, Water Method 1.05 Perm, max. 140 The membrane system shall be supplied in roll widths of at least 12 in. The membrane shall be a composite sheet material composed of a non-woven fabric and a polymer membrane material. The membrane shall be protected by a release paper. Material furnished under this specification shall be covered by a type B certification in accordance with 916.
Iowa	A flexible water tight 1 inch butyl rope gasket is installed on the bottom of the joint and extends 6 inches up the sides of the culvert joint. A 2 foot wide piece of engineering fabric is centered about the joint on the top and sides and is positively attached.
Kansas	Geotextile cover on the joints (1 ft on each side of joint) – Options A and C in the drawing.
Kentucky	Asphalt coating
Louisiana	Preformed / elastomeric
Maine	The requirements for waterproofing of joints is included in MaineDOT's Standard Specification Section 534, Precast Structural Concrete. Following is an excerpt from Section 534, from the 2020 edition of the Standard Specifications (https://www.maine.gov/mdot/contractors/publications/).
Missouri	733.3.2.1.1 All joints between individual box sections shall be sealed with an approved plastic joint compound or a tubular joint seal. Trowel grade compounds shall be applied to both mating surfaces. Rope or tape-type plastic joint compounds and tubular joint seals shall be applied in accordance with the manufacturer's recommendations. Excess compound shall extrude from both the inside and outside of the joint when box sections are assembled. The joint gap between individual box sections shall be uniform for the full perimeter...or 1026.3.7 Joints. If a rubber gasket-type joint is specified, joints shall be Type A rubber gaskets in accordance with AASHTO M 198. The manufacturer shall conduct tests in accordance with AASHTO M 198, Section 8, to demonstrate adequate performance, and shall furnish certification that physical & chemical properties of the gasket are in accordance with this specification.
New Hampshire	Barrier membrane
New Jersey	A water-stop is installed to prevent water from entering vertical joints between the end of a precast culvert and any cast in place sections. A flexible watertight rubber gasket is used between precast sections. Gaskets must be continuous around the circumference of the joints. NJDOT requires a flexible, watertight, neoprene gasket according to ASTM D 1056 at the joint between the

	precast units. Prior to backfilling, a 2 foot wide strip of filter fabric shall be placed over the top and side transverse joints. Prior to backfilling, a 2 foot wide strip of filter fabric shall be placed over the top and side transverse joints.
Oklahoma	If you mean watertight, our specs call for "mortar, cold applied mastic-rubber gaskets, or plastic joint material as shown on the plans." Otherwise, we don't have a specific waterproofing treatment just for the joints.
South Carolina	All joints require joint material, however the joint material does not make the culvert completely waterproof.
Tennessee	Pipe Culverts - TDOT requires rubber ring gaskets meeting ASTM C443 for water tightness. Box Culverts – Butyl Rubber Base (AASHTO M198) or QPL approved Bituminous Plastic or Cement Mortar
Texas	Jointing materials required by TxDOT specifications may be 1) mortar, 2) cold-applied, plastic asphalt sewer joint compound, 3) rubber gaskets, or 4) pre-formed flexible joint sealants. See TxDOT specifications (Item 464.2.7) found here: ftp://ftp.dot.state.tx.us/pub/txdot-info/des/spec-book-1114.pdf
Washington	Because the vast majority of these structures are used to pass streams beneath highways, we are not overly-concerned about small amounts of water leaking into or out of these structures. We are concerned, however, about losing any fill material through the precast segment joints, and so we employ some waterproofing measures at the joint surfaces. We use lap joint details at the connections (tongue-and-groove) between segments. The vertical and horizontal joints between adjacent segments of the precast structures employ both a butyl rubber sealant material between the mating surfaces and a waterproof external sealing band around the outside of the joint, installed before backfilling.
Wisconsin	WisDOT requires mastic in the joints on the bottom and sides of precast box culverts. The top and sides are then covered with a geotextile.

3.6 Waterproofing Outside Joint Regions

The responses received from eight states are copied in Table 3.3 regarding their waterproofing practices on the exterior face of the culverts outside their joint regions. These responses are summarized and evaluated in the next sections along with specifications of other states that did not respond to this survey.

Table 3.3: Waterproofing outside joint regions of precast components

States	Waterproofing between members or on the exterior face of joints
Colorado	If the fill height on the box culvert is less than 2 feet over the top of the box, a waterproofing membrane or 30 mil thick geomembrane is

	required for the top of the top slab and 18 inches down along the tops of the exterior walls.
Delaware	Silane sealer applied to all exposed surfaces. Lapped waterproof membrane for top slab and 1' down sides if hot mix placed directly on slab. If stone or fill on top of culvert, no membrane needed. (Silane Sealer. Section 1045)
Idaho	The top slab of the culvert is waterproofed with a Type D.
Illinois	The entire top for fills of 3' and less as previously noted.
Maine	Prior to final installation of box sections, each joint is typically internally sealed with a mastic product, such as ConSeal CS-102. This work is not specified in our contracts; however, it is directed by most of our precast fabricators. The material that is used on the face of the joints, lifting points, and dowel holes is a material from the QPL, under the Concrete & Bridge section, under Rapid Setting Concrete Patching Materials. Most of our Contractors use the Silpro product line. The 12-inch joint wrap that is placed on the horizontal and vertical joints on the exterior of the structures is from the QPL, from the Standard System section of the Waterproofing Membrane list. Most of our Contractors use Chase Corp. Royston 10AN Easy Pave. Some boxes, arches, and three-sided frames have been specified to have the top covered in its entirety with a waterproofing membrane, typically in shallow backfill and at road grade scenarios. In these cases, a High Performance - Torch Applied membrane is specified from the same QPL section.
New Hampshire	Culverts with fill less than 5 feet over the top slab: the entire top slab shall be covered with barrier membrane with protection board and extend 1 foot down culvert wall
New Jersey	Precast reinforced concrete culvert units shall be given one coat of an epoxy waterproofing seal coat on the exterior of the roof slab. This coating shall be provided at the precasting plant. In addition, any top slab hand hole pockets or lifting holes, which are grouted in the field, shall receive one coat of epoxy waterproofing seal coat after the grout has properly cured. Also, the top slab will have 2 inch draw from center to both sides to form a slight slope in transverse direction. For concrete waterproofing, use epoxy-resin that conforms to ASTM C 881, Type 7, Grade 1, 2, or 3, Class D, E, or F, and is listed on the QPL. Ensure that the color is gray to match the color of the adjacent concrete.
Tennessee	Section 605 of TDOT specification provides details and requirements of Waterproofing. • Provides qualified products for Joint Waterproofing • Procedures 23 are the evaluation procedures • Products 23 is a list of qualified products for Concrete Waterproofing https://www.tn.gov/tdot/tdot-construction-division/transportation-construction-division-

	resources/transportation-construction-2015-standard-specifications.html https://www.tn.gov/tdot/materials-and-tests/research---product-evaluation-and-qualified-products-list.html

3.7 Interviews with Engineers from Selected State DOTs

Based on the survey results, mainly based on the responses provided in Table 3.3, the research team contacted several state DOTs. Interviews were conducted with Arkansas, Delaware and Maine engineers in December 2020 and early January 2021. The interviews were very beneficial to understand the reasons behind certain requirements, challenges and practical solutions implemented by these states. More specifically, effectiveness of various membrane and concrete materials and different procedures were discussed.

The interviews with the Arkansas, Delaware and Maine DOT engineers showed and confirmed that, in general:
1) Standard culvert joints including gaskets, mastic sealers and mortar inside perform well. Both membrane and bitumen-based materials are effective on top.
2) Joint wrap on the exterior face is effective, especially in shallow culverts.
3) Stainless steel (or galvanized and epoxy coated) bars or fiber reinforced polymer bars are considered or used in decks, especially in corrosive environments.
4) Low-permeability concrete or use of silica fume or corrosion inhibitors in concrete can help in potentially corrosive environments. Higher air content can also improve freeze-thaw resistance and durability of concrete.

Some of these strategies learned during the interviews with engineers from these three state DOTS are included in Chapter 5 considering the survey responses and specific requirements of other state DOTs.

3.8 Interview with Maine Department of Transportation

In the interview, engineers from the Maine Department of Transportation stated that torch applied waterproofing membrane is used to cover entire top of the box culvert if there is less than 18 inches gravel fill. It is brought down the sides of the box ½ ft to 1 ft. This is the same membrane used for bridges. 3 ft wide membrane sheets are used with 4-6 inches overlap on adjacent sheets as specified by manufacturer. It is applied to the primed surface after cleaning the concrete surface and letting the surface dry. A gasket is used in each joint.

Stainless or galvanized steel rebars are used to reduce the risk of corrosion. Epoxy spray sealer can be applied on concrete. The amount of sealer varies based on the environmental conditions. If the environment has more salt, more sealer is used.

The low-permeability concrete mix used for culverts differs from the concrete used for bridges. The reinforcement in concrete on bridge decks is stainless steel or a combination of glass fiber reinforced polymer bars with stainless steel bands.

In conclusion, three main strategies are used by Maine Department of Transportation for waterproofing. These involve using the following:

- More corrosion resistant steel rebar, e.g., stainless or galvanized bar,
- Torch applied waterproofing membrane or epoxy spray sealer on the surface of concrete, and
- Concrete with low permeability or corrosion resistance.

3.9 Analysis of Survey Data

The concrete joint waterproofing measures used by the state DOTs responding to the survey are shown in Figure 3.3. Nine states use gaskets (CA, DE, FL, IA, MO, NJ, OK, TN, TX), three states use Portland cement mortar (CA, ME, TN), mastic joint sealer (IL, OK, WI), three states use geotextiles (KS, ME, WI), and two states use asphalt coating (KY, TX).

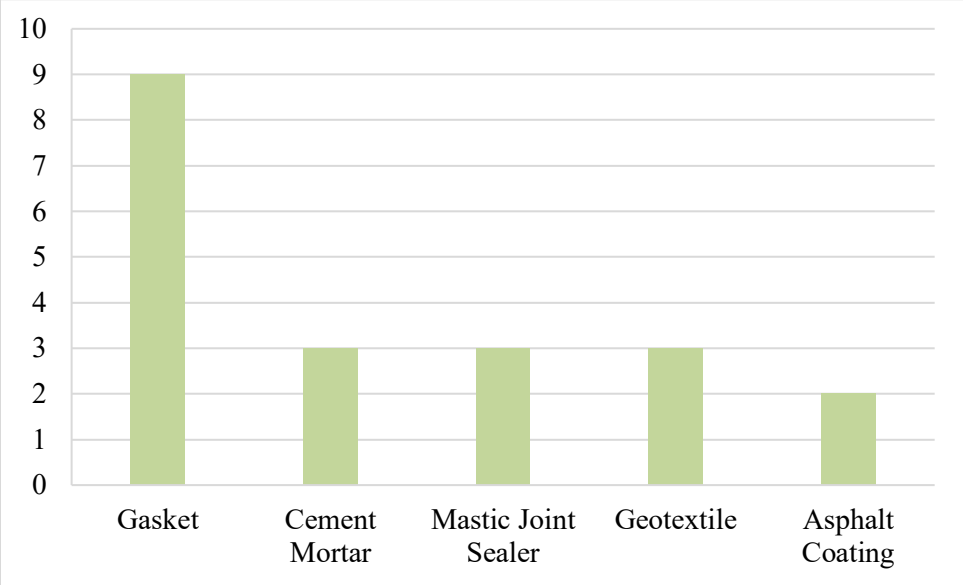


Fig. 3.3 Common Waterproofing Materials Used on Joints

Eleven states use waterproofing membranes on concrete surfaces outside joint locations, as shown in Figure 3.4.

- Five states use a sheet system that can be self-adhesive, rubberized asphalt membrane, or geomembrane (ID, CO, IL, ND and UT).
- Four states use sealers that can be applied by spray, brush, or roller (DE, NJ, PA and NH)
- Three states use hot applied modified bitumen material (ME, TN and NH).

It should be noted that New Hampshire DOT uses two different waterproofing options: (1) rolled sealer, and (2) heat welded bitumen material.

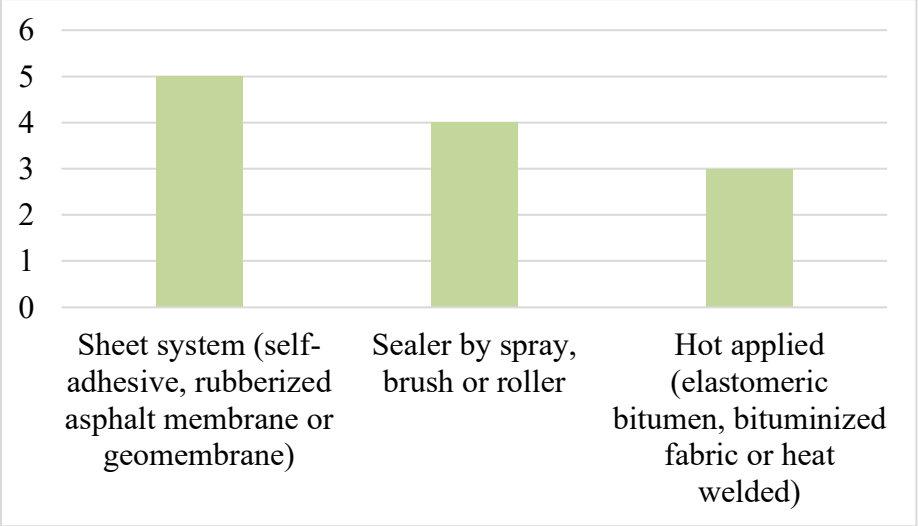


Fig. 3.4 Variation of Preferred Waterproofing Treatments by States Surveyed

CHAPTER IV

CULVERT WATERPROOFING PRACTICES AND REQUIREMENTS OF ALL 50 STATE DOT'S

The standards and specifications of all the state DOTs, including 26 states which did not respond to the survey, were obtained by the research team (Appendix B). In addition, the research team contacted National Precast Concrete Association (NCPA) and received information on any special waterproofing requirements by each state. The information provided by NCPA is included in Appendix C. The combination of state DOT documents obtained by the research team and by NCPA showed that in addition to nine states responded to survey (Table 3.3), only three states (North Dakota, Pennsylvania, Tennessee, and Utah) appear to use waterproofing on the exterior of the precast elements outside the joint regions. Out of these twelve states, Arkansas focuses mainly on joints and near wingwalls.

The next sections summarize the practices and highlight the basic requirements of the twelve states in alphabetical order. Based on the specifications and survey responses, these are the only states with some requirements for waterproofing on the exterior face of culverts away from the joints between the precast members.

4.1 Colorado Department of Transportation

The response survey states that "*if the fill height on the box culvert is less than 2 feet over the top of the box, a waterproofing membrane or 30 mil thick geomembrane is required for the top of the top slab and 18 inches down along the tops of the exterior walls*". This is illustrated in Figure 4.1.

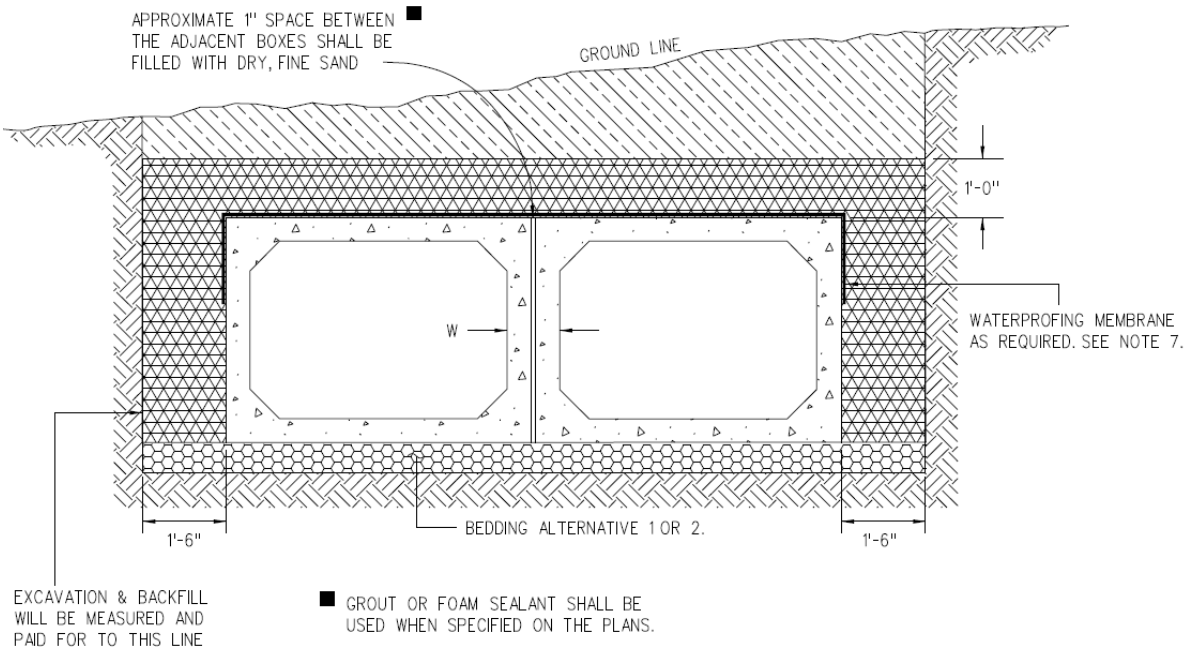


Fig. 4.1 Waterproofing of Box Culverts in Colorado DOT Standard Specification (2019)

Property	Thickness			Test Method
	0.25 mm (10 mil)	0.51 mm (20 mil)	0.76 mm (30 mil)	
Thickness, % Tolerance	±7	±5	±5	ASTM D1593
Tensile Strength, kN/m (lbs./in.) width	3.50 (20)	8.75 (50)	12.25 (70)	ASTM D882, Method B
Modulus @ 100% Elongation, kN/m (lbs./in.)	1.58 (9)	3.50 (20)	5.25 (30)	ASTM D882, Method B
Ultimate Elongation, %	350	350	350	ASTM D882, Method A
Tear Resistance: N (lbs)	18 (3.2)	29 (6.5)	38 (8.5)	ASTM D1004
Low Temperature Impact, °C (°F)	-23 (-13)	-26 (-15)	-29 (-20)	ASTM D1790
Volatile loss, % max.	1.5	0.9	0.7	ASTM D1203, Method A
Pinholes, No. /8 m^2 (No. Per 10 sq. Yds.) max.	1	1	1	
Bonded Seam Strength, % of tensile strength	80	80	80	

Fig. 4.2 Requirements for Waterproofing Geomembranes (Colorado DOT Standard Specification, 2019)

According to the section 712 miscellaneous of Colorado Standard Specifications for Road and Bridge Construction 2019, the lining of geomembrane shall consist of virgin polyvinyl chloride (PVC) resins, plasticizers, stabilizers, and other necessary materials that, when compounded, shall meet or exceed the physical requirements for the thickness provided in Figure 4.2. provided in the:
https://www.codot.gov/business/designsupport/cdot-construction-specifications/2019-construction-specifications/2019-specs-book/2019-standard-specifications

4.2 Delaware Department of Transportation

The response to the survey question was: "*silane sealer applied to all exposed surfaces. Lapped waterproof membrane for top slab and 1' down sides if hot mix placed directly on slab. If stone or fill on top of culvert, no membrane needed*".

According to the section 612.3.3 "Precast Concrete Elements" of the Delaware Standard Specifications for Road and Bridge Construction 2020, "*silane sealer is applied in accordance with Section 1045.3 to the top of each unit plus 2 feet down each side and to all headwalls, end faces, and exposed faces in accordance with Section 613*". The sections of 612, 613 and 1045 are provided in:
https://deldot.gov/Publications/manuals/standard_specifications/pdfs/2020/2020_standard_specifications.pdf?cache=1610076619596

4.3 Idaho Department of Transportation

The survey response was "t*he top slab of the culvert is waterproofed. This is done with a Type D waterproofing membrane*". The Type D precoated preformed membrane sheet system is described as "*prefabricated sheets that are self-adhesive or require a separate bonding agent*" under section 511 – concrete waterproofing systems in the Idaho DOT 2018 Standard Specifications for Highway Construction.
https://apps.itd.idaho.gov/Apps/manuals/SpecBook/SpecBook18.pdf

There are four different Type D products specified in the standard under the section 511. These are described as:

- **Product A:** This cold-applied, self-adhering tape is effective as a temporary patching material and also offers excellent bonding for repair of the substrate prior to a complete asphalt overlay.
- **Product B:** This a is self-adhesive paving membrane geotextile designed to protect pavements from moisture damage by providing a stress absorbing interlayer to decrease the development of cracking over time.
- **Product C:** This is designed for use prior to an asphalt overlay. When placed on joints and cracks of pavement, it will waterproof and also reduce the extent and severity of reflective cracking. When installed, it acts as a waterproofing membrane, protecting reinforcing steel in the deck from corrosion.
- **Product D:** This is an effective waterproofing membrane that is a minimum thickness of 0.065 inch and is composed of a layer of self-adhesive polymer modified asphalt waterproofing adhesive (with a release liner) bonded to a non-woven polypropylene reinforcing fabric.

4.4 Illinois Department of Transportation

The responder states that "*boxes with 3' and less fill shall have a waterproofing membrane on the top and extend 1' down on the side walls. The mastic and sealing band are per sections 1055 and 1057 of our standard specifications. The membrane is per Guide Bridge Special Provision 81. The entire top for fills of 3' and less as previously noted*" http://www.idot.illinois.gov/Assets/uploads/files/Doing-Business/Manuals-Guides-&-Handbooks/Highways/Construction/Standard-Specifications/Standard%20Specifications%20for%20Road%20and%20Bridge%20Construction%202016.pdf

The drawing of membrane waterproofing for precast box culverts in Guide Bridge Special Provision 81 is provided in Figure 4.3. According to the Guide Bridge Special Provision 81, the materials used in the waterproofing system must consist of the following:

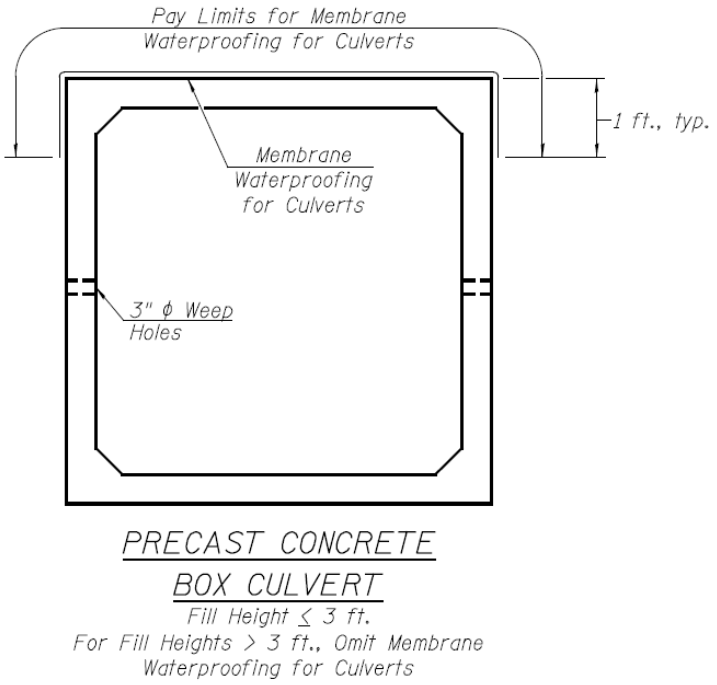


Fig. 4.3 Membrane Waterproofing for Precast Box Culverts as Specified in Illinois Guide Bridge Special Provision 81

- Cold-applied, self-adhering rubberized asphalt/polyethylene membrane sheet with the properties shown in Figure 4.4.
- Ancillary Materials: Adhesives, Conditioners, Primers, Mastic, Two-Part Liquid Membranes, and Sealing Tapes as required by the manufacturer of the membrane and film for use with the respective membrane waterproofing system. https://www.idot.illinois.gov/Assets/uploads/files/Doing-Business/Manuals-Guides-&-Handbooks/Highways/Bridges/Bridge-Special-Provisions/GBSP81.pdf

Physical Properties	
Thickness ASTM D 1777 or D 3767	60 mils (1.500 mm) min.
Width	36 inches (914 mm) min.
Tensile Strength, Film ASTM D 882	5000 lb./in^2 (34.5 MPa) min.
Pliability [180° bend over 1" inch (25 mm) mandrel @ -20 °F (-29 °C)] ASTM D 146 (Modified) or D1970	No Effect
Puncture Resistance-Membrane ASTM E 154	40 lb. (178 N) min.
Permeability (Perms) ASTM E 96, Method B	0.1 max.
Water Absorption (% by Weight) ASTM D 570	0.2 max.
Peel Strength ASTM D 903	9 lb./in (1576 N/m) min.

Fig. 4.4 Physical Properties of Waterproofing Membrane Sheet in Illinois Guide Bridge Special Provision 81

4.5 Maine Department of Transportation

Maine DOT's response to the survey was: "*some boxes, arches, and three-sided frames have been specified to have the top covered in its entirety with a waterproofing membrane, typically in shallow backfill (less than 18 in. gravel fill) and at road grade scenarios. In these cases, a High Performance - Torch Applied membrane is specified from waterproofing membranes section of the Qualified Products List (QPL)*" https://www.maine.gov/mdot/research/products

There are two different products for High Performance - Torch Applied membrane in the QPL, describe as follows:

- **Product A:** Waterproofing membrane made up of a non-woven polyester reinforcement and elastomeric bitumen (SBS modified bitumen). The top face is covered with colored granular, the under face is covered with a thermofusible plastic film. The product A is torch applied.
- **Product B:** Non-woven polyester reinforcing mat that is coated and impregnated with Modiflex SBS modified bitumen to a thickness of approximately 4.5 mm (177 mils).

The hot asphalt overlay should be between 290 - 320°F (143 – 160 °C) at the time of application.

4.6 New Hampshire Department of Transportation

The responder states that "*culverts with fill of 5 feet or more over the top slab: a 2 feet strip of barrier membrane with protection board shall be applied to all joints in the top slab and extend 1 foot down culvert wall. Culverts with fill less than 5 feet over the top slab: the entire top slab shall be covered with barrier membrane with protection board and extend 1 foot down culvert wall*".

However, this information has not been detected in the New Hampshire Standard Specifications for Road and Bridge Construction 2016 – https://www.nh.gov/dot/org/projectdevelopment/highwaydesign/specifications/documents/2016NHDOTSpecBook.pdf

There are two barrier membranes: (1) "Peel and Stick" and (2) "Heat Welded" in the standard specifications; however, it is not clear which barrier membrane is required for precast culvert systems.

- Peel and Stick: Shall consist of adhesive primer, preformed waterproofing membrane sheet and mastic all as one system as included on the Qualified Products List.
- Heat Welded: Shall consist of an approved prefabricated reinforcement of synthetic non-woven material, thoroughly impregnated and coated with SBS modified bitumen as included on the Qualified Products List.

https://www.nh.gov/dot/org/projectdevelopment/materials/research/documents/qpl.pdf

4.7 New Jersey Department of Transportation

The responder states that "*if earth fill above culvert is less than 2 feet, the top mat of reinforcement, and ties, in the top slab must have corrosion protection. Roof slabs are coated with an epoxy waterproofing seal coat provided at the precast plant. Lifting holes are grouted in the field and then epoxy coated after grout cures*".

According to the subheading Epoxy Waterproofing under the Section 504 – Structural Concrete in the New Jersey Standard Specifications for Road and Bridge Construction, "epoxy-resin conforms to ASTM C 881, Type 7, Grade 1, 2, or 3, Class D, E, or F, and is listed on the QPL."
https://www.state.nj.us/transportation/eng/specs/2019/pdf/StandSpecRoadBridge2019_20201009.pdf

There are four different products for epoxy waterproofing which are listed in qualified products list (QPL): http://www.state.nj.us/transportation/eng/materials/qualified . The descriptions of those products are as follows:

- **Product A:** Provides a stress-relieved coating for concrete, masonry, and steel surfaces. It provides a high build chemical, abrasion, and water resistant, tile-like coating. The properties of the product are provided in Figure 4.5.

NVM	100%
Mixing Ratio	1:1 by volume
Viscosity (AST M D-1084)	13,000-14,000 cps.
Shelf Life	1 year min.
Pot Life	45-55 min.
Tack Free	4-5 hours
Initial Cure	8 hours
Final Cure	7 days
Dry Film Thickness (ASTM D-1005)	1st Coat 8 mils
	2nd Coat 8 mils

Fig. 4.1 Properties of New Jersey DOT Product A

- **Product B:** A high-build, protective, solvent-free, colored epoxy coating which can be applied using high-quality roller, brush or spray. Two coats are recommended.
- **Product C:** A high-solids, two-component, moisture-tolerant, high-build protective coating designed to protect steel, concrete and wood. It can be brush, roller or spray applied.
- **Product D:** A 2-component, 100% solids, moisture-tolerant, epoxy resin binder. It conforms to the current ASTM C-881, Type III, Grade-2, Class-C and AASHTO M-235 specifications.

4.8 North Dakota Department of Transportation

Waterproof membrane and joint requirements are defined by the North Dakota Department of Transportation Standards Specifications for Road and Bridge Construction 2019, under Section 606 "Precast Reinforced Concrete Box (PRCB) Culverts" as follows:

Joints:
- Provide watertight joints on the floor, on the exterior walls, and roof using a preformed mastic meeting ASTM C 990.
- Use a waterproof membrane that is a minimum of 24 inches wide.
- Lap waterproof membrane joints a minimum of 2.5 inches. Seal the joints and exposed edges with a joint sealing mastic.

Waterproof membrane:
- Provide self-adhesive black polyethylene membrane that meets the following requirements:
- Has a sheeting thickness of 0.004 inches.
- Has a rubberized asphalt coating of 0.056 inches.

https://www.dot.nd.gov/divisions/environmental/docs/supspecs/fullsupplementalspecswith10012019.pdf)

4.9 Pennsylvania Department of Transportation

Under the subheading "Protective Coating" in Section 1085 "Precast Reinforced Concrete Box Culvert" in the Pennsylvania Department of Transportation Specifications 2020, the following is provided: "*If indicated, apply two spray coats of coal tar epoxy, conforming to the requirements of SSPC-PS 16-82, to the top of the box and exposed end faces and to the entire height of the outside walls.*"
http://www.dot.state.pa.us/public/PubsForms/Publications/Pub_408/408_2020/408_2020_1/408_2020_1.pdf

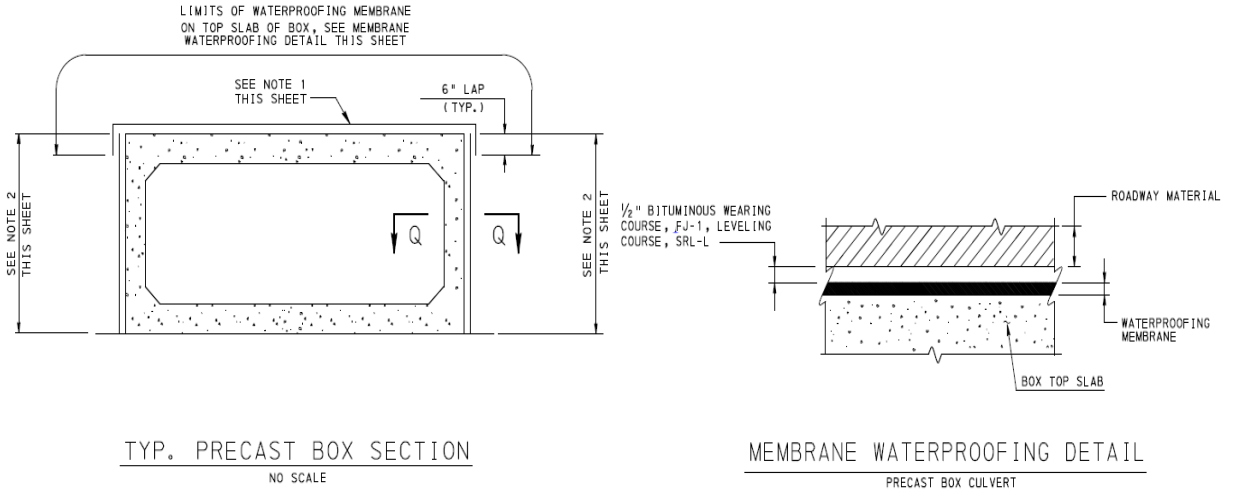
Under the subheading "Waterproofing" in the same section in the specifications, it is stated that: "*Apply waterproofing as specified in Section 680.3 and as shown on the Standard Drawings. Submit a plan to the Department to correct exterior joints that exceed 1/2 inch difference across two adjacent box segments. Ensure waterproofing membrane will have full support and contact across the joint after correction and prior to membrane installation*". The minimum requirements for preformed membrane sheet are shown in Figure 4.6.

It is noted in the drawing of precast reinforced concrete box culvert that "*provide approved waterproofing membrane for the entire top width and length of the box and 2'-0" width ± along the side joints for fills 2'-0". for fills 2'-0" provide 2'-0" width ± on the top and side joints*". The drawing is provided in Figure 4.7.
https://www.paconstructors.org/wp-content/uploads/2016/07/bc788m-4.75mm-change-on-Pg.-10-of-12.pdf

It is also required to use a gasket around the perimeter of each joint. To summarize, gasket material is used on each joint, with 2 ft width on the top and side joints, and two spray coats of coal tar epoxy are required for waterproofing of precast concrete culvert systems.

Preformed Membrane Sheets		For Bridge Deck Surfaces		For Surfaces Other Than Bridge Decks	
Property	**Test**	**Rubberized Asphalt Type**	**Modified Asphalt Type**	**Rubberized Asphalt Type**	**Modified Asphalt Type**
Tensile Strength, lbs/in (minimum)[1][3]	ASTM D882 [2]	50	40	20	20
% Elongation at Break, (min) [3][4]	ASTM D882 [2]	15	10	25	25
		7[7]			
Pliability	ASTM D146 [5]	No cracks	No cracks	No cracks	No cracks
Thickness, mils (minimum)[6]	ASTM D1000	Polyethylene Film Backed—60 Fabric Reinforced Backed—65	70	60	60
Softening Point, F (minimum)	ASTM D36	190	210	190	210

Fig. 4.6 Adhesive-Backed Preformed Membrane Sheet Minimum Requirements (PDOT Standard and Specifications, Section 680.2)



NOTES:

1. PROVIDE APPROVED WATERPROOFING MEMBRANE FOR THE ENTIRE TOP WIDTH AND LENGTH OF THE BOX AND 2'-0" WIDTH ± ALONG THE SIDE JOINTS FOR FILLS ≤ 2'-0". FOR FILLS > 2'-0" PROVIDE 2'-0" WIDTH ± ON THE TOP AND SIDE JOINTS.
2. LIMITS OF WATERPROOFING AT SIDE OF PRECAST BOX SECTION JOINTS 2'-0" WIDTH ± . PLACE THIS BEFORE THE TOP SLAB WATERPROOFING.

Fig. 4.7 Waterproofing Membrane Requirements in PennDOT Standard and Specifications (Drawing BC-788M)

4.10 Tennessee Department of Transportation

The responder states that "*section 605 of Tennessee Department of Transportation specification provides details and requirements of waterproofing. Section 906 provides material requirements. Provides qualified products for Joint Waterproofing. Procedures 23 are the evaluation procedures. Products 23 is a list of qualified products for Concrete Waterproofing*". The list of Products 23 with its procedure descriptions, Sections 605 and 906, are provided in:
https://www.tn.gov/content/dam/tn/tdot/construction/old_web_page/TDOT_2015_Spec_Book_FINAL_pdf.pdf

According to Section 605, waterproofing on concrete shall consist of a primer applied cold, followed by four applications of asphalt sealer applied hot, and three layers of bituminized fabric or saturated fabric. However, waterproofing on culverts is not described specifically in the Tennessee Standard Specifications for Road and Bridge Construction (2015).

4.11 Utah Department of Transportation

According to the Section 02645 "Precast Concrete Box and Three-sided Culvert Structures" and Section 07105 "Waterproofing Membrane" in the Utah Standard Specifications for Road and Bridge Construction (2020), joint sealant, joint wrap, and waterproofing membrane are required for waterproofing of precast concrete box and three-sided culvert systems.
https://drive.google.com/drive/folders/1bHZnAA5CdqvTPBy1ot8lQHwUbGr2Zkka

As a joint sealant for box culverts, flexible butyl rubber material with a minimum cross-section of ¾ x 1½ inches is used in accordance with ASTM C 990. There are two types of joint sealant offered by ASTM C 990 as follow:

- Bitumen Sealants: Bitumen sealants shall comply with the following composition and physical requirements shown in Figure 4.8.

Hydrocarbon Blends, % by weight	50 min
Ash-Inert Mineral Matter, % by weight	25 min
Volatile Matter, % by weight	3 max
Specific Gravity at 77°F	1.15 to 1.40
Ductility at 77°F, cm	5 min
Flash Point, C.O.C.	350°F min
Fire Point, C.O.C.	375°F min
Softening Point	320°F min
Compression Index at 77°F, lbf/in^3	100 max
Compression Index at 32°F, lbf/in^3	350 max
Cone Penetration at 77°F, 150 g, 5 s, dmm	50 to 120
Cone Penetration at 32°F, 150 g, 5 s, dmm	15 min
Chemical Resistance	No deterioration, no cracking, no swelling

Fig. 4.8 Physical Requirements of Bitumen Sealants

- Butyl Rubber Sealant: Butyl rubber sealant (elastomeric polymer shall be butyl rubber only) shall comply with the following composition and physical requirements shown in Figure 4.9).

Butyl Rubber (hydrocarbon blends), % by weight	50 min
Ash-Inert Mineral Matter, % by weight	30 min
Volatile Matter, % by weight	3 max
Specific Gravity at 77°F	1.15 to 1.40
Ductility at 77°F, cm	5.0 min
Flash Point, C.O.C.	350°F min
Fire Point, C.O.C.	375°F min
Compression Index at 77°F, lbf/in.^{3}	100 max
at 32°F, lbf/in.^{3}	200 max
Cone Penetration at 77°F, dmm	50 to 120
at 32°F, dmm	30 min
Chemical Resistance	No deterioration, no cracking, no swelling

Fig. 4.9 Physical Requirements of Butyl Rubber Sealant

As a joint wrap, a minimum width of 2 ft centered on the joint is used in accordance with ASTM C 877. There are three types of joint wraps offered by ASTM C 877 as follows:

- Type I: Rubber and Mastic Bands.
- Type II: Plastic Film and Mesh Reinforced Mastic Bands.
- Type III: Chemically Bonded Adhesive Butyl Bands.

Rubberized asphalt membrane (self-adhesive surface protected by special release paper) shall be applied to the top slab and side walls of concrete box culverts and three-sided structures for the full length of the structures. Mechanical properties of the membrane are provided in Figure 4.10.

Mechanical Properties		
Property	**Value**	**Method**
Thickness, inch, minimum	0.065	
Permeance-Perms, grains/sq ft·hr·inhg	0.10	ASTM E 96, Method B
Tensile Strength, psi	50	ASTM D 882, modified for 1 inch opening
Elongation, percent	75	ASTM D 882, modified for 1 inch opening
Puncture Resistance (Mesh), lb	200	ASTM E 154
Pliability, at -15 degrees F	No cracks in mesh or rubberized asphalt when bent 180 degrees over a ¼ inch mandrel	ASTM D 146

Fig. 4.10 Mechanical Properties of the Rubberized Asphalt Membrane (UDOT Standard Specifications, Section 07105)

CHAPTER V

REPAIR METHODS

5.1 Introduction

In this section, the most common repair methods for precast reinforced concrete culvert systems are provided. Caltrans (2014), Maine (Hartley, 2014), Minnesota (Wagener & Leagjeld, 2014) and Wisconsin DOTs (2020) provide best practices and guidance to repair and rehabilitate concrete culverts.

5.2 Types and Sources of Culvert Damage and Potential Solutions

Joint repair methods can be categorized based on the source and extent of the damage observed in the field. In this section, the most common types of observed problems leading to damage in and around the joints are provided.

5.2.1 Misalignment

Potential issues related to construction or the supporting soil may cause misalignment of the precast members and joint damage e.g., due to uneven settlement under the culvert. If there is a continuing settlement, joint repair should not be applied until the soil reaches stabilization. Reconstruction might be the best option or the only option in some cases. If leaking joints and undermining lead to misalignment, the cause of undermining should be determined first. It may be caused by piping, water exfiltration, or infiltration of backfill material. A combination of sealing joints of the culverts and grouting the external voids with chemical grouting or other joint repair techniques described in Section 5.3 (Caltrans, 2014) may be sufficient to stop leakage and structural stabilization.

5.2.2 Exfiltration

If soils are not erosive, minor leakage might be negligible. If exfiltration leads to piping, measures are needed for sealing culvert joints, and making them watertight in addition to grouting for filling voids in the soil behind the joint. The techniques for infiltration problem described in Section 5.3 can also be used to stop exfiltration (Caltrans, 2014).

5.2.3 Infiltration

If infiltration problem takes away fine-grained soil from the surrounding backfill, it might result in settlement and misalignment problems. One of the measures for sealing joints is using an internal joint sealing system in conjunction with pressure grouting to fill voids in the soil behind the joint. Infiltration can also be stopped by applying internal grouting and some of the available lining techniques. Internal grouting can be used to stop infiltration at deteriorated joints. In many cases, for culvert repair, Portland cement based grout is adequate and cheaper than epoxy, foam or chemical grout, which

are usually needed to resist high fluid pressure (Wagener & Leagjeld, 2014; and Caltrans, 2014).

5.2.4 Cracked and Separated Joints

Cracked joints may be considered a minor problem if no other problems are found, such as misalignment, and cracks are not open or spalling. The source of cracking in or around joints needs to be determined. Likely sources of joint separation include improper installation, undermining, or uneven settlement of fill. If undermining is detected, it is necessary to determine whether the undermining is caused by piping, water exfiltration, or infiltration of backfill material. After the cause of the problem is determined, measures can be taken as specified in the previous sections (Wagener & Leagjeld, 2014; and Caltrans, 2014). A Crack less than 0.01 inch wide can be considered a minor problem, but if the crack is larger than 0.1 inch in width, it may be a signal for a serious problem (Caltrans, 2014).

5.2.4.1 Longitudinal and Transverse Cracks

Longitudinal cracking larger than 0.1 inch in width may be due to the overloading or poor bedding. For such cases, cement-based mortar and structural adhesives including epoxy systems can be used. Transverse cracking may be a result of poor bedding and/or poor installation. Repair options discussed in Section 5.3 can be applied.

5.2.5 Spalling, Corrosion, Slabbing and Other Damage

Spalls often take place along the edges of cracks if overloading or poor support leads to cracks rather than tension cracks. Mortar should be applied after cleaning around the spall if overloading is the cause of cracks. If the cracking results from post construction loading, the precast member should be replaced by another or the loading must be reduced.

If corrosion of the steel bars causes concrete spalling, it is required to determine where the corrosive material comes from. If the corrosive material comes from the interior only, the deteriorated concrete cover can be removed, and a mortar patch can be applied. Coatings and full-length slipping can be applied if the environment is acidic. If the corrosion results from both interior and exterior environment, mortar patch should be applied as described for the interior and monitoring the culvert is required to determine the level of degradation in the future. If the spalls are due to the debris, around the spalled area should be cleaned and a mortar patch should be applied in case there is no other damage (Caltrans, 2014).

Slabbing refers to a failure of concrete resulting from straightening of the reinforcement cage. It might occur when the strength of the reinforced concrete member is inadequate under high backfills and/or inadequate depth of bedding on a rock foundation. Also, it may occur due to the poor consolidation or backfill conditions with a high water table. According to Caltrans (2014), for such cases, damaged area,

chip back and sandblast steel can be cleaned to remove the rust, and a mortar patch can be applied. If the slabbing results from post construction loading, either precast component can be replaced, or the loading must be reduced.

5.3 Repair Methods

Recommended methods for the repair and rehabilitation of the damaged or leaking joints are provided in this section. These potential methods are mostly based on the guidance provided in Caltrans (2014) and Wagener & Leagjeld (2014).

5.3.1 Chemical Grouting

Chemical grouting is the most common method used for sealing of leaking joints. The long-term service life of chemical grouting is not well known (Caltrans, 2014). Chemical grouting including insulating spray foam and gel materials is generally a non-structural solution to provide water tightness. Therefore, chemical grouting is inappropriate for structural damage such as longitudinal cracks or crushed pipes. For such cases, epoxy- or mortar-based grouting or repair sleeves (structural) in combination with chemical grouting (non-structural) can be applied.

The two main types of chemical grouting materials are polyurethane foams and gels. Polyurethane foams can be formed in place as a gasket and their service life do not depend on moisture. Therefore, they can be used in locations with wet-dry cycles. In general, foam grouts are difficult to install and more expensive. The most common types of gel grouts are acrylamide, acrylic, acrylate, and urethane. The service life of the non-urethane gels is moisture dependent, and it is not appropriate for locations with wet-dry cycles. On the other hand, urethane gel, which is different from acrylate or acrylamide gels, may be used in locations with wet-dry cycles. Acrylamide base gel is more toxic during installation (Caltrans, 2014).

5.3.2 Internal Joint Sealing Systems

According to Caltrans (2014) for the sealing of leaking joints, if the groundwater pressure is low and internal head pressure does not exceed 20 ft above the invert at any point, EPDM rubber pipe joint sealing system including an EDPM rubber membrane, backing plates, spacers, shims, clips, and set screws can be used. Additionally, supplemental grouting might be used to fill any voids in the soil behind the joint, if needed.

Any joint gaps are filled with epoxy or cement mortar and on each side of the joint where the seating surface band location of the seal is are located and rendered flush with the surrounding joint surface. The steel expansion ring may be covered with concrete, shotcrete, or other authorized material (Caltrans, 2014). Depending on the material used, the range of application for internal joint seals varies widely.

Internal mechanical pipe joint seals should not be used if the gap or physical separation is larger than 2 in. for tongue and groove joints. Also, this method may not be an option where the joint offset exceeds 1/2 in. for pipes with certain geometric characteristics. Another method for sealing joints is using a jacked-in-place PVC repair sleeve which ranges from 36 inches to 100 inches in diameter combined with O-rings and annular space chemical or cementitious grouting (Caltrans, 2014). Other stainless steel or metal grouting sleeves, bands or plates may be applied on the inside face of the joint after it is filled with grout material.

5.3.3 Compaction Grouting and Stabilization of Backfill Material

Compaction grouting can be applied to the loosened background material surrounding the culvert due to ground loss. The goal is to compact and make the soil denser. It must be performed carefully not to damage the culvert or heave the road surface during the operation (Wagener and Leagjeld, 2014). Pressure grouting operation or controlled injection has the goal of both stabilization of existing surrounding backfill as well as filling outside voids with new material.

Slabjacking can be used to realign pavement sections that are settled because of a ground loss around an existing culvert. Holes are drilled through the pavement section and cementitious based material is placed to fill voids and provide support for the section (Wagener and Leagjeld, 2014).

5.3.4 Sprayed Coatings and Linings

Sprayed coatings and linings can be used to repair and rehabilitate interior concrete surface that may be damaged or may have limited corrosion. After cleaning the deteriorated or spalled off areas, typically in early stages of damage, pressurized spraying of mortar/concrete onto culvert wall surface can be applied by centrifuge type gun. Trenchless robotic applicators are available for pressurized spraying, especially for smaller culverts. There are different commercially available spray-on liners, or spray-on treatments, such as gunite lining or shotcrete.

For lighter and more uniform deterioration, sandblasting may be an option to remove the corrosion related or similar damage and then recoating/painting the interior surface of the wall can be completed.

5.4 Invert and Crown Repairs/Strengthening

Paving or lining be applied to deteriorated inverts in precast concrete culverts to restore them. As the invert needs to be dry at the time of paving or lining process, the repair/strengthening can be scheduled in summer or flows should be diverted. Typically, reinforced concrete is used to repair or replace the entire deteriorated invert section of the culvert. Fiber reinforced polymer or similar materials can also be used for the lining of the concrete invert.

Precast concrete culverts may be damaged in their crown section because of the depth of cover being too shallow. Cracking, spalling and distortion may occur in the crown area. For many cases, replacement might be needed (Caltrans, 2014).

5.5 Sample Joint Repair Method

Figs. 5.1 and 5.2 show a joint repair method that combines both structural repair (mortar inside joint) and non-structural repair materials (resin-based material outside joint). SikaTop 123 is a polymer modified, fast setting Portland cement-based mortar that fills the interior face of the joint. Cementitious material has the strength to resist potential abrasion and pressure that may be applied to the joint.

As shown in Fig. 5.2, the precast member is drilled from inside on the spigot side and then the water activated polyurethane resin (blue colored Avanti AV 202) is injected to the joint and outside face to mainly prevent joint leaking. A rubber gasket in the middle separates the cementitious grout and polyurethane resin grout. In this repair technique, the combination of gasket and the two grout materials on each side of the joint should provide sufficient strength and water tightness.

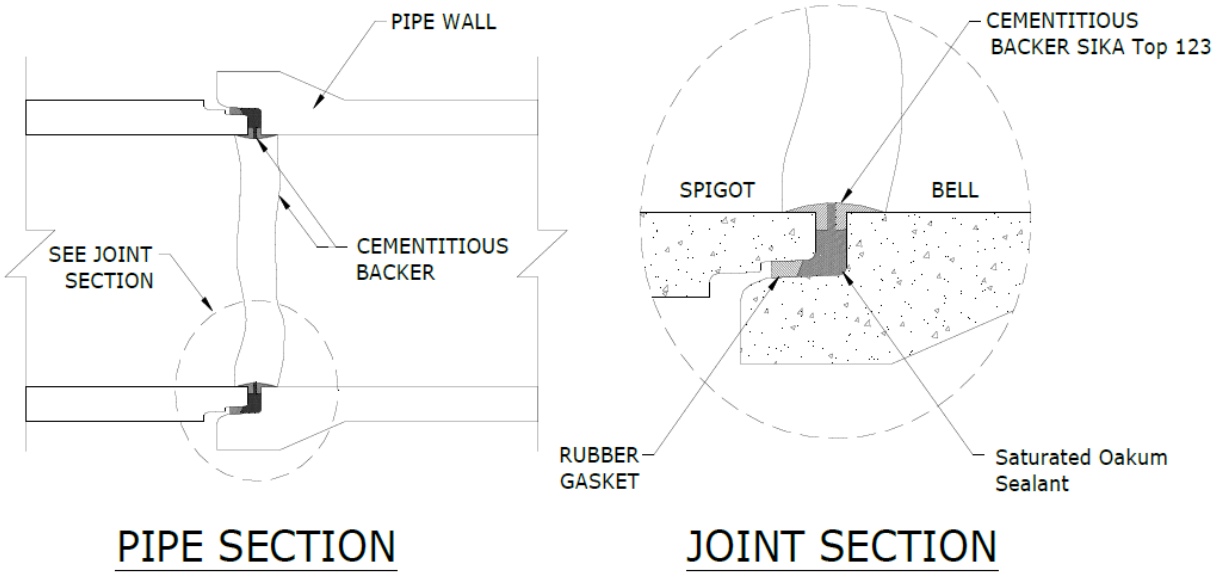


Fig. 5.1 Recommended Culvert Joint Repair Method.

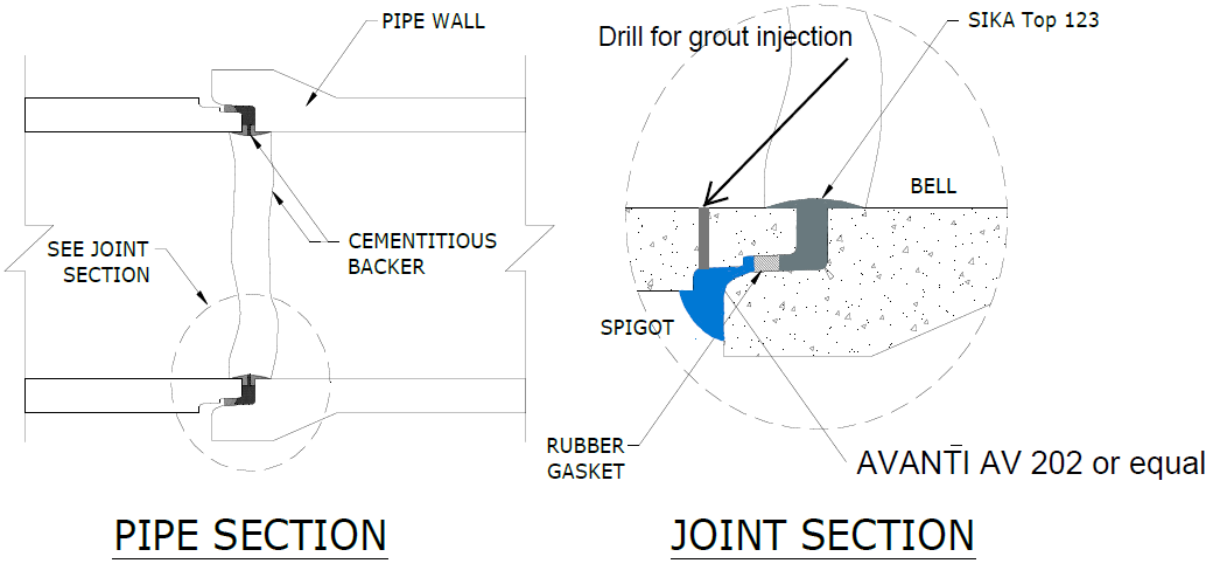


Fig. 5.2 Culvert Repair Approach Recommended by a Company in Ohio.

5.6 Summary and Recommended Repair Methods

One of the objectives of this research was to understand the reasons behind culvert joint infiltration and identify appropriate methods to reduce or prevent infiltration. The recommended repair methods may limit joint infiltration. However, such measures do not address the overall performance of the waterproofing system and may lead to chloride capture and the eventual penetration of chlorides into the structural concrete.

The selection of the method to repair the damaged culvert depends on several factors. First, the source of the damage or deterioration needs to be determined. The damage may be related to materials used, construction, structural loading, or combination of these. It is also possible that one problem may trigger seemingly unrelated damage. For example, misalignment or joint separation tied to poor construction practices may lead to joint leaking and trigger material damage or cause additional stresses near the joint regions at the end of the precast components.

Material related culvert damage or joint leakage may be tied to low quality concrete or low quality waterproofing materials. Silane or similar type of sealing of exterior of entire precast components at the precast plant can be an effective approach remedy potential long term deterioration.

Construction related culvert damage may be caused by uneven settlement of the precast pieces, typically leading to damage in the joint regions. Improper seating of joints may be a result of improper backfilling, and heavy construction equipment

unevenly loading the culvert during the backfilling and/or pavement construction. This type of damage should typically be reflected early, say in the form of cracking or joint leakage, rather than widespread corrosion or spalling of concrete.

Culvert damage may also be caused by structural loading, which includes live (traffic) and dead (backfill and pavement weight) loads. Culvert may be subjected to unevenly distributed heavy traffic loading, for example the joint in the median may be unloaded while the rest of the culvert may be always heavily loaded during rush hour. Similarly, dead load may be increased due to expectedly heavier backfill or pavement materials.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Based on the literature review, survey, follow up interviews, and research meetings, the research team offers the following preliminary recommendations.

1. Consider using joint wrap on box culverts, under the membrane waterproofing.

Out of the eleven state DOTs that have some waterproofing requirements for concrete culvert surfaces away from joints (Chapter 5):

- Maine, North Dakota, and Pennsylvania DOTs explicitly require both joint wrap first and complete waterproofing over that.
- Delaware, Illinois, New Jersey and Utah possibly use both, but there is no explicit requirement in their specifications.
- It is not clear if joint wrap is required under the membrane in the other states.

It appears that ODOT is only having an issue with box culvert joints, and this is the only structure utilized by ODOT that does not utilize joint wrap.

2. Consider a wider membrane width to reduce the number of laps. Also consider specifically requiring a minimum width of overlap with adjacent sheets.

ODOT Item membrane waterproofing Type 2 (Item 711.25) and Type 3 (Item 711.29) have a minimum width of 36 inches. When available, 48 inch wide wrap can/should be used to reduce the number of overlap joints required. Different states specify joint wrap width varying between 12 inches and 36 inches (e.g., Missouri).

The lap widths specified by state DOTs vary from 1 inch to 6 inches. A few states give a range, e.g., Maine DOT specifies 4-6 inches and New Hampshire requires 3-6 inches. Given that greater lap width would likely reduce raveling or de-bonding, ODOT should consider using the upper range of overlap, at least 4 inches.

3. While there is no specific evidence indicating construction equipment is directly related to waterproofing sheet performance, common sense would indicate that a less disturbed waterproofing sheet would tend to perform better. Therefore, consider a change in specifications to prohibit construction equipment on the waterproofed concrete, other than as necessary for the placement of backfill material.

4. Consider using a heat bonded sheet type. The heat bonding may be superior to the Type 2 (peel-and-stick type) and Type 3 membrane materials currently used by ODOT (Section 512.08 of ODOT CMS, 2019).

5. Consider the use of plant-applied sealers, e.g., silane sealers, in combination with field-applied joint wrap. Maine DOT require silane sealers applied at the precast plant for culverts with anticipated high salt exposure. Also, the quality control will be better if waterproofing can be done at the precast plant. In New Jersey, top slabs are coated with an epoxy waterproofing sealant at the precast plant.

6. No state DOTs reported issues with their existing culverts and their repair methods. Caltrans, Maine, Minnesota and Wisconsin DOTs have general culvert repair and rehabilitation guidance and best practices as presented in Chapter 5.

7. The selection of the method to repair the damaged culvert depends on several factors that may be related to materials used, construction or structural loading, or combination of them. A joint repair method recommended as shown in Figs. 5.1 and 5.2, which should restore both strength and prevent joint leakage.

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APPENDIX A. SURVEY SUMMARY

States	Shape	Backfill Materials	Waterproofing for joints	Waterproofing more than joints	Material requirements and installation
Alaska	Box, Three-sided, Arch	Subbase gravels	No, the tongue and groove mechanical joint without sealant.	NO	See the standard: http://www.dot.state.ak.us/stwddes/dcsspecs/index.shtml
Arkansas	Box	Excavated insituor borrowed material	Top box culvert joint must be sealed with approved waterproofing membranes	Wingwall to box vertical and the top joints.	See the standard: https://www.arkansashighways.com/standard_spec/2014/2014SpecBook.pdf
California	Box	Compacted granular backfill or concrete	Cement mortar, rubber gaskets, other resilient materials (i.e. polyvinyl chloride, fiberglass impregnated with epoxy resin)	NO	See the standard specifications: https://dot.ca.gov/-/media/dot-media/programs/design/documents/f00203402018stdspecsa11y.pdf
Colorado	Box	Class 1 Structure Backfill Material.	Rubber gaskests and Joint sealants	A waterproofing membrane or 30 mil thick geomembrane for the top and 18 in. down sides if the fill < 2 ft.	See the standard specifications: https://www.codot.gov/business/designsupport/cdot-construction-specifications/2019-construction-specifications/2019-specs-book/2019-standard-specifications
Delaware	Box, Three-sided, Arch	Borrow Type C	Gaskets or compression seals for 3-sided frames and arches.18" wide mastic wrap centered on the joints.	Silane sealer for all exposed surfaces. Lapped waterproof membrane for top and 1' down sides if hot mix placed directly on slab.	See Bridge Design Manual showing details and Standard Construction Specifications: https://deldot.gov/Publications/manuals/standard_specifications/pdfs/2020/2020_standard_specifications.pdf?cache=1610076619596
Florida	Box, Three-sided, Arch	Select soil/sand back fill per Specification 125	Profile rubber gaskets or preformed joint sealants. A 2-feet wide wrap Type D-3 geotextile filter fabric wirh overlap of 24 in.	NO	See the standard specifications: https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/programmanagement/implemented/specbooks/january2021/1-21ebook.pdf?sfvrsn=1c62cb58_2

Idaho	Box Three-sided	3/4" base material	Precoated Preformed Membrane Sheet Typed D	Type D waterproofing for the top.	See the standard: https://apps.itd.idaho.gov/Apps/manuals/SpecBook/SpecBook18.pdf
Illinois	Box, Three-sided	A min. 2' porous granular embankment for each side and in-situ soil for the rest of the backfill.	Mastic joint sealer and 13" wide sealing band. A waterproofing membrane on the top and 1' down sides if the fill < 3'.	The entire top for fills of 3' and less as previously noted.	See the standard: http://www.idot.illinois.gov/Assets/uploads/files/Doing-Business/Manuals-Guides-&-Handbooks/Highways/Construction/Standard-Specifications/Standard%20Specifications%20for%20Road%20and%20Bridge%20Construction%202016.pdf
Indiana	Box, Three-sided, Arch	Suitable sand, gravel, crushed stone, 350 ACBF, or GBF.	A 12 in. wide non-woven fabric and a polymer self-adhering membrane.	NO	See the standard: https://www.in.gov/dot/div/contracts/standards/book/sep19/2020%20INDOT%20Standard%20Specifications.pdf
Iowa	Box, Arch	See Iowa DOT Standard Specifications	A 1 in. butyl rope gasket for the bottom of the joint and extends 6 in. up the sides. A 2 ft. wide engineering fabric for joints on the top and sides.	NO	IDOT Standard Specifications Article 4196.01, B, 3: http://publications.iowa.gov/17478/1/IADOT_Standard_Specifications_Highway_Bridge_Construction_Series_2012.pdf
Kansas	Box, Three-sided	UNANSWERED	Geotextile cover 1 ft on each side of joint	NO, based on drawing sent	See the Standard Specifications : https://www.ksdot.org/burconsmain/specprov/specifications.asp
Kentucky	Box and Arch culverts	UNANSWERED	Asphalt coating	NO	See the standard: https://transportation.ky.gov/Construction/Standard%20amd%20Supplemental%20Specifications/Complete%20KYTC%20Standard%20Specifications%20-%202019.pdf
Louisiana	Box, three-sided	Granular or select low plasticity clay	preformed / elastomeric	NO	AASHTO/ASTM specifications for bedding, alignment

Maine	Box	Granular borrow	A minimum 12 in. wide wrap extended one foot from the top down the sides. A non-woven geotextile for the back of joints.	A High Performance - Torch Applied membrane is specified from te same QPL section.	the Standard Specifications: https://www.maine.gov/mdot/contractors/publications/standardspec/docs/2020/2020%20Standard%20Specification.pdf
Missouri	Box, Three-sided	select granular	A Type A rubber gaskets (AASHTO M 198)	NO	See the standard: https://www.modot.org/sites/default/files/documents/2020%20Missouri%20Standard%20Specific%20-%20MHTC%20%28Jan%202021%29.pdf
New Hampshire	Box, Three-sided, Arch	Granular backfill (gravel).	barrier membrane	A barrier membrane with protection board for the top and extend 1 foot down culvert wall if the fill < 5 ft.	See the standard: https://www.nh.gov/dot/org/projectdevelopment/highwaydesign/specifications/documents/2016NHDOTSpecBook.pdf
New Jersey	Box, Three-sided, Arch	I-9 or I-15 soil aggregate or coarse aggregate no. 57 for backfill material and I-9 is for the sides.	A water-stop and a flexible continuous watertight rubber gasket for joints. A 2 ft. wide filter fabric strip for the top and side joints.	An epoxy waterproofing seal coat on the top if the fill < 2 ft.	Epoxy Waterproofing specification section 912.02.02 Performed Joint Filler specification 914.01 2019 NJDOT Standard Specifications link: https://www.state.nj.us/transportation/eng/specs/2019/pdf/StandSpecRoadBridge2019_20201009.pdf
Oklahoma	Box	Coarse cover aggregate, section 703.06 in the Specifications.	Mortar, cold applied mastic-rubber gaskets, or plastic joint material	NO	See the standard: https://www.odot.org/c_manuals/cmanual/con_cm_ch-500.pdf
South Carolina	Box, Three-sided, Arch	A-1, A-2-4, A-3 soils	All joints require joint material, however the joint material does not make the culvert completely waterproof.	NO	See the standard: https://www.scdot.org/business/pdf/2007_full_specbook.pdf

Tennessee	Box, Three-sided, Arch	Pipe Culverts – Class B Bedding and unclassified backfill (fine compactable soil)	A rubber ring gaskets (ASTM C443) and a butyl rubber base (AASHTO M198) or QPL approved Bituminous Plastic or Cement Mortar	Products 23 is a list of qualified products for Concrete Waterproofing (QPL)	See the standard: https://www.tn.gov/tdot/materials-and-tests/research---product-evaluation-and-qualified-products-list.html (Section 906)
Texas	Box	400.3.3.1 and 400.3.3.2 of TxDOT Specifications	One of the followings: (1) mortar, (2) cold-applied, plastic asphalt sewer joint compound, (3) rubber gaskets, or (4) pre-formed flexible joint sealants.	NO	See the TxDOT specifications: ftp://ftp.dot.state.tx.us/pub/txdot-info/des/spec-book-1114.pdf
Washington	Box, Three-sided, Arch	WSDOT Standard Specification 6-20.3(9).	Both a butyl rubber sealant for the vertical and horizontal joints and a external sealing band. A lap joint details at the connections (tongue-and-groove) between segments.	NO	See the specifications: https://wsdot.wa.gov/Publications/Manuals/M41-10.htm
Wisconsin	Box, Three-sided, Arch	Typical structure backfill	Mastic in the joints on the bottom and sides of precast box culverts. a geotextile for the top and sides.	NO	See the WisDOT specifications: https://wisconsindot.gov/Pages/doing-bus/eng-consultants/cnslt-rsrces/rdwy/cmm.aspx

APPENDIX B. ONLINE STATE DOT SPECIFICATIONS

Alaska:
Standard Specifications:
http://www.dot.state.ak.us/stwddes/dcsspecs/index.shtml

Arkansas:
Standard Specifications:
https://www.arkansashighways.com/standard_spec/2014/2014SpecBook.pdf

California:
Standard Specifications:
https://dot.ca.gov/-/media/dot-media/programs/design/documents/f00203402018stdspecsa11y.pdf

Colorado:
Standard Specifications:
https://www.codot.gov/business/designsupport/cdot-construction-specifications/2019-construction-specifications/2019-specs-book/2019-standard-specifications

Delaware:
Standard Specifications:
https://deldot.gov/Publications/manuals/standard_specifications/pdfs/2020/2020_standard_specifications.pdf?cache=1605558533310

Bridge Design Manual:
https://deldot.gov/Publications/manuals/standard_specifications/pdfs/2020/2020_standard_specifications.pdf?cache=1610076619596

Florida:
Standard Specifications:
https://fdotwww.blob.core.windows.net/sitefinity/docs/defaultsource/programmanagement/implemented/specbooks/january2021/1-21ebook.pdf?sfvrsn=1c62cb58_2

Provided in the survey question:
https://www.fdot.gov/programmanagement/Implemented/SpecBooks/default.shtm

Illinois:
Standard Specifications:
http://www.idot.illinois.gov/Assets/uploads/files/Doing-Business/Manuals-Guides-&-Handbooks/Highways/Construction/Standard-Specifications/Standard%20Specifications%20for%20Road%20and%20Bridge%20Construction%202016.pdf

Illinois Construction Manual:
http://idot.illinois.gov/Assets/uploads/files/Doing-Business/Manuals-Guides-&-Handbooks/Highways/Construction/Construction-Manual/Construction%20Manual.pdf

Illinois Culvert Manual:
http://www.idot.illinois.gov/Assets/uploads/files/Doing-Business/Manuals-Guides-&-Handbooks/Highways/Bridges/Design/Culvert%20Manual%202016.pdf

Provided in the survey question:
http://www.idot.illinois.gov/doing-business/procurements/engineering-architectural-professional-services/Consultants-Resources/guide-bridge-special-provisions

http://www.idot.illinois.gov/doing-business/procurements/engineering-architectural-professional-services/Consultants-Resources/index

Indiana:
Standard Specifications:
https://www.in.gov/dot/div/contracts/standards/book/sep19/2020%20INDOT%20Standard%20Specifications.pdf

Provided in the survey question:
https://www.in.gov/dot/div/contracts/standards/book/sep19/900-2020.pdf

Iowa:
Standard Specifications:
http://publications.iowa.gov/17478/1/IADOT_Standard_Specifications_Highway_Bridge_Construction_Series_2012.pdf

Kansas:
Standard Specifications:
https://www.ksdot.org/burconsmain/specprov/specifications.asp

Section 735 Precast Reinforced Concrete Box:
https://www.ksdot.org/Assets/wwwksdotorg/bureaus/burConsMain/specprov/2015/735.pdf

Kentucky:
Standard Specifications:
https://transportation.ky.gov/Construction/Standard%20amd%20Supplemental%20Specifications/Complete%20KYTC%20Standard%20Specifications%20-%202019.pdf

Maine:
Standard Specifications:
https://www.maine.gov/mdot/contractors/publications/standardspec/docs/2020/2020%20Standard%20Specification.pdf

Qualified Products List (QPL):
https://www.maine.gov/mdot/research/products

Provided in the survey question:
https://www.maine.gov/mdot/contractors/publications/

Missouri:
Standard Specifications:
https://www.modot.org/sites/default/files/documents/2020%20Missouri%20Standard%20Specific%20-%20MHTC%20%28Jan%202021%29.pdf

Provided in the survey question:
https://www.modot.org/missouri-standard-specifications-highway-construction

New Jersey:
Standard Specifications:
https://www.state.nj.us/transportation/eng/specs/2019/pdf/StandSpecRoadBridge2019_20201009.pdf

Oklahoma:
Standard Specifications, materials and testing:
https://www.odot.org/cnstrctengr.htm

Chapter 500 – Structures: Standard Specifications:
https://www.odot.org/c_manuals/cmanual/con_cm_ch-500.pdf

South Carolina:
Standard Specifications:
https://www.scdot.org/business/pdf/2007_full_specbook.pdf

Tennessee:
Standard Specifications:
https://www.tn.gov/content/dam/tn/tdot/construction/old_web_page/TDOT_2015_Spec_Book_FINAL_pdf.pdf

Provided in the survey question:
https://www.tn.gov/tdot/tdot-construction-division/transportation-construction-division-resources/transportation-construction-2015-standard-specifications.html
https://www.tn.gov/tdot/materials-and-tests/research---product-evaluation-and-qualified-products-list.html

Texas:
Standard Specifications:
https://www.txdot.gov/business/resources/txdot-specifications.html

Washington:
Standard Specifications:
https://www.wsdot.wa.gov/publications/manuals/fulltext/M41-10/SS.pdf

Wisconsin:
Standard Specifications:
https://wisconsindot.gov/Pages/doing-bus/eng-consultants/cnsltrsrces/rdwy/cmm.aspx

Chapter 500 – Structures:
https://wisconsindot.gov/rdwy/stndspec/ss-05-00.pdf

APPENDIX C. INFORMATION PROVIDED BY PRECAST CONCRETE INDUSTRY

State DOT	Special Waterproofing Specified/Required	Web page location for pertinent documents.
Alabama	No special requirement; Cold joints for cast-in-place culverts, wing walls, etc. have to be water-tight. Precast joints just required to be soil-tight.	
Alaska	Alaska is vague at best when even using box or 3 sided. Couldn't find a reference at all to either only precast bridge member joints	
Arizona	No special waterproofing requirements found in spec or stds. Construction Manual section 1011 Joint Materials: Joints include waterstop, joint sealant [hot poured], joint sealant [cold application], bridge deck joint seals (neoprene), preformed expansion joint filler, bituminous joint filler, non-bituminous joint filler, cellular plastic joint filler, and silicone joint sealant.	https://azdot.gov/sites/default/files/construction-manual/CMChapter_10_Section_1011.pdf
Arkansas	No, but waterproofing membrane applied at joints, per standard drawing BPC-1, General Notes	https://www.arkansashighways.com/roadway_design_division/usunits/34-pbc-1.pdf
California	No, joint wrap required. See 2018 Standard Plans and Specifications, Section "65-2.02F Joints" as stated below is standard specification designation. If you download the standard plans from that same page and look at page A62G, it makes note of an external sealing band to be used under two different conditions. This is really the only reference to a wrap and typically deals with minimal earth cover. Aside from that, none of my contacts with Caltrans are familiar with a waterproofing spec for box culverts either.	https://dot.ca.gov/-/media/dot-media/programs/design/documents/2018-std-plns-for-web-a11y.pdf
Colorado	Yes, for box culverts with fill heights less than 2 feet a rubber membrane or 30ml thick geomembrane shall be provided for the top slab and 18 inches down the side. See standard M-603-1 note 7.	https://www.codot.gov/business/designsupport/2019-and-2012-m-standards/2019-m-standards-plans/2019-m-standards-plan-

		sheets/m-603-3-precast-concrete-box-culvert/m-603-3-precast-concrete-box-culvert
Connecticut	Yes, when box culvert is 0-2' cover. See Bridge Design Manual (BDM) section 13.1.3.10 Membrane Waterproofing Requirements, woven glass fabric material	https://portal.ct.gov/-/media/DOT/documents/dpublications/bridge/CTDOT-Bridge-Design-Manual.pdf
Delaware	No, only 9" wide joint wrap, email	
Florida	No, waterproofing requirements. Box culvert joints to be soil tight, unless special purpose such as pedestrian tunnels, etc. the joint to have waterproof joint wrap system. 3-sided bridge structures require waterproof joint wraps per ASTM C877. See 2002 Report BC354 RPWO#47-part 1 Evaluation of Precast Box Culvert Systems (history review)	https://www.fdot.gov/docs/default-source/roadway/ppmmanual/2016/Volume1/Chap33.pdf
Georgia	No, standard mastic sealant material or preformed rope sealant, use come-along	http://www.dot.ga.gov/PartnerSmart/Business/Source/specs/ss513.pdf
Hawaii	No requirements found in spec or standards search, not much information on precast box culvert in general. May not be fabricated on the islands	
Idaho	Yes Idaho does have a more in depth requirement for joint wrap. Section 578.03 General 12" joint wrap, "Wrap the outside face of the joint continuously from the bottom of one wall, up and over the top slab, and down the opposite wall with a single length of wrap. The Engineer will not allow splices in joint wrap. If required by the manufacturer to produce a watertight joint, fill joint gaps with non-shrink grout" & "Apply a waterproof membrane (Type A or D) as specified in 511 to the top slab of all buried culverts regardless of the fill depth. A waterproof membrane is not required when there is no fill on the top slab."	https://apps.itd.idaho.gov/Apps/manuals/SpecBook/SpecBook18.pdf
Illinois	Yes, "membrane waterproofing" for precast similar to cast-in-place. See Culvert Manual, page 2-11:	http://www.idot.illinois.gov/Assets/uploads/files/Doing-Business/Manuals-Guides-&-

		Handbooks/Highways/Bridges/Design/Culvert%20Manual%202017.pdf
Indiana	Yes, in addition to joint sealing requirements, see 907.07 Joint Membrane for Precast Reinforced Concrete Box Structures , 3-Sided Structure joint sealing section 723.14 Joints- 1.5" sealant and C877 wrap.	https://www.in.gov/dot/div/contracts/standards/usp/USPINDEX.pdf
	Indiana requires a full waterproofing membrane in addition to the joint sealing requirements. INDOT spec book	https://www.in.gov/dot/div/contracts/standards/book/sep19/2020%20INDOT%20Standard%20Specifications.pdf
Iowa	No requirement for precast box culvert waterproofing. Joints are sealed with mastic sealant and top 3 sides are wrapped with 2' wide geotextile. See Box Culvert General Notes & Quantities	https://iowadot.gov/bridge/standards/english/EnglishPrecastCulverts.pdf
Kansas	Yes, see spec section 735 & 736 "Use an approved "non-coal tar" bridge backwall protection system to cover the middle 1/3 of the top of precast arch culverts, the complete top slab of precast rigid frame culverts and the uppermost 12 inches of the outside walls. Indicate on the shop drawings the limits of the bridge backwall protection system."	http://www.ksdot.org/Assets/wwwksdotorg/bureaus/burConsMain/specprov/2015/736.pdf
Kentucky	No special waterproofing	
Louisiana	No, standard mastic sealant material or preformed rope sealant	
Maine	Yes, see spec section 534.20 Installation of Precast Units - "Completely fill the exterior face of joints between precast units with a material from the Department QPL and cover with a minimum 12 inch wide joint wrap. Additionally, for box culverts and three-sided frames, cover the entire top surface with waterproofing membrane; waterproofing membrane shall extend one foot from the top down the sides of the unit	
Maryland	Yes, in addition to joint sealing requirements	
Massachusetts	No special coating	

Michigan	No special waterproofing, but requires "watertight" joint system comprised of joint rope sealant per C990 and 12" wide external sealing band per C877 and 24" wide geotextile over that. See Culvert Manual (draft), page 225	https://www.michigan.gov/documents/mdot/MDOT_2020_Spec_Book_DRAFT_July_2020_697214_7.pdf
Minnesota	Page 165, section 2412.3 B – specifies use of a sealant on the bottom section and a geotextile material on the top and sides. There is language that allows for requirement of a watertight sealant if required by the contract, but it's not standard. No mention of any other sealers for the top of the box culvert.	http://www.dot.state.mn.us/pre-letting/spec/2014/2014-Std-Spec-for-Construction.pdf
Mississippi	No precast box or 3-sided waterproofing. DOT 2017 Standard Specifications Section 713.02.4 – Waterproofing Admixture; used for cast in place bridge decks and bridge deck toppings.	
Missouri	No, specification or details do not show any references to waterproofing. Transverse joint detail section 751.8.3.1 Joints, shows 3' wide geotextile wrap, and mention to waterproof joint is necessary when box culvert is used as pedestrian underpass. Most information is related to CIP box culverts	https://epg.modot.org/index.php/751.8_LRFD_Concrete_Box_Culverts#751.8.3.1_Joints
Montana	No requirements found in spec or standards search, not much information on precast box culvert in general.	
Nebraska	I could not find any reference to waterproofing precast box culvert or 3-side structures.	
Nevada	No special waterproofing stated relating to culverts, see section 707 Joint Material	https://www.nevadadot.com/home/showpublisheddocument?id=6916
New Hampshire	Yes, see section 529 Special Provision Precast Concrete Components, Item 529.002XX Precast Box Culvert (Bridge), paragraph 3.11.5 Barrier4 Membrane with Protetcion Board- 0 to 5' cover full membrane top slab down 1 foot, 5' greater cover 2 foot strip of membrane on all joints stop slab down 1'	
New Jersey	Yes, requires waterproofing coating, see secton 29.5.18 Precast reinforced concrete culvert units shall be given one coat of an epoxy waterproofing seal coat on the exterior of the roof slab. This coating shall be provided at the precasting plant. In addition, any top slab hand hole pockets or lifting holes, which are grouted	https://www.state.nj.us/transportation/eng/documents/BSDM/pdf/2016DesignManualforBridgesandStructures20180604.pdf

	in the field, shall receive one coat of epoxy waterproofing seal coat after the grout has properly cured.	
	912.02.03 Asphalt Waterproofing For use below ground level, use an asphalt waterproofing conforming to ASTM D 449, Type I. For use above ground level, use an asphalt waterproofing conforming to ASTM D 449, Type II or III. Use a primer conforming to ASTM D41.	https://www.state.nj.us/transportation/eng/specs/2019/pdf/StandSpecRoadBridge2019_20201009.pdf
New Mexico	Yes, New Mexico requires a membrane on top slab & end wall locations. Drawing # is 511-66-5/6 and the membrane spec is 511.2.10.	https://www.dot.state.nm.us/content/dam/nmdot/Plans_Specs_Estimates/2014_Standard_Drawings.pdf
New York	No, however requires 2' wide waterproof joint wrap per membrane standard. See detail sheet EB16-037, Spec Section 717 Concrete Protective Coatings, 717-02 Waterproofing Membranes	
North Carolina	No requirements found in spec or standards search, email only	
North Dakota	No, however requires 2' wide waterproof joint wrap per membrane standard. See specification 606, 606.04 Construction Requirements E. Installaton, 3. Joints page 274.	https://www.dot.nd.gov/divisions/environmental/docs/supspecs/2020%20Standard%20Specifications%20for%20Road%20and%20Bridge%20Construction.pdf
Ohio	Yes, 611.08 – Joining conduit – Section B, number 3 – looks like mortar of top and sides and then cover with a membrane waterproofing, “for any exterior joint not covered by membrane waterproofing”. 611.09 – Exterior Coatings – “Apply the membrane waterproofing to all surfaces that will be in contact with the backfill (top and sides)” Seems like conflicting message since it sounds like surfaces are supposed to be waterproofed, but 611.08 says, for surfaces not covered by a membrane waterproofing… Not sure how to interpret this exactly. Maybe it varies by the project?	http://www.dot.state.oh.us/Divisions/ConstructionMgt/OnlineDocs/Specifications/2019CMS/2019_CMS_10162018%20Final%20to%20Printer.pdf

Oklahoma	No, found no drawing specs at all for any membranes. Oklahoma references everything back to the AASHTO specs M259 or M273 . See section 508 Concrete Culverts, 726.01 Drainage Conduits, Rigid Conduits	https://www.odot.org/c_manuals/specbook/oe_ss_2009.pdf
Oregon	Not as general provision - Oregon as a rule do not require a exterior waterproofing and is based on the project requirements. If they do require it then it will refer you to the standard specifications and more than likely address it in depth in the special provisions. Have had to only do it once and it wasn't for a DOT project.	
Pennsylvania	[note: spec and detail sheet on file, need to condense for spreadsheet]	
Rhode Island	No requirements found in spec or standards search, not much information on precast box culvert in general.	
South Carolina	No requirements, email only	
South Dakota	No requirements found in spec or standards search.	
Tennessee	No waterproofing required for box culverts per detail sheet STD-17-28 Precast Box Culvert Details. T&G joints filled with grot or sealant material. Spec Section 605 describes Waterproofing, but appears to be for bridge decks, etc.	https://www.tn.gov/content/dam/tn/tdot/roadway-design/documents/standard_drawings/structure_standard_drawings/current/lrfd-box-culverts/STD1729_000000.pdf
Texas	No waterproofing required for box culverts per detail sheet STD-17-28 Precast Box Culvert Details. T&G joints filled with grot or sealant material. Spec Section 605 describes Waterproofing, but appears to be for bridge decks, etc.	
Utah	No, requires joint sealant and 2' wide joint wrap on exterior per spec section 02645	https://www.udot.utah.gov/main/uconowner.gf?n=7589704633248211
Vermont	Yes, if the culvert top is in the road subgrade, otherwise no	

Virginia	Nothing for box culverts. Waterproofing is shown for box beam, bridge decks, I-beams. See section 213, 416, 429	https://www.virginiadot.org/business/resources/const/VDOT_2016_RB_Specs.pdf
Washington	Washington like Oregon as a rule do not require a exterior waterproofing and is based on the project requirements. If they do require it then it will refer you to the standard specifications and more than likely address it in depth in the special provisions. See Washington State DOT spec sectin 6-20.3(8)A Precast Concrete Structures 2021 Standard Spec M41-10 pat 6-422.	
West Virginia	Section 619 – Waterproofing (requires membrane waterproofing consisting of a primer, two layers of fabric, and three mopping's of hot bituminous material. See section 620 3-sided arch requirements, box culverts section 714.23 do not address it.	https://transportation.wv.gov/highways/contractadmin/specifications/Documents/2010%20Standard%20Specifications%20Roads%20and%20Bridges/Complete%20Publications/2010StandardRoadsnBridges.pdf
Wisconsin	Box Culverts- drawing shows requirement of an 18" wide rubberized membrane to be applied across the top and sides of all joints. For 3-Sided structures-- mention of a 3' wide strip of geotextile material attached to precast bridge units prior to backfill.	https://wisconsindot.gov/dtsdManuals/strct/manuals/bridge/std3603.pdf
Wyoming	No requirements found in spec or standards search.	

APPENDIX D. MONTHLY MEETING PRESENTATIONS

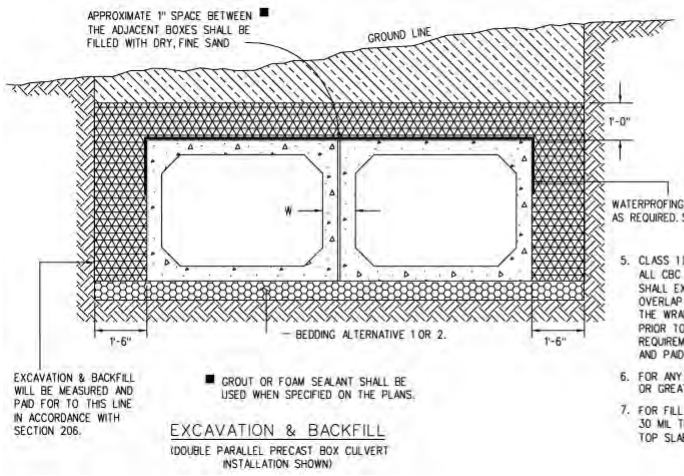
Summary of State DOT Waterproofing Requirements Beyond Joint Regions (Based on Survey Data)

ODOT Project Meeting

December 18, 2020

Waterproofing more than joints

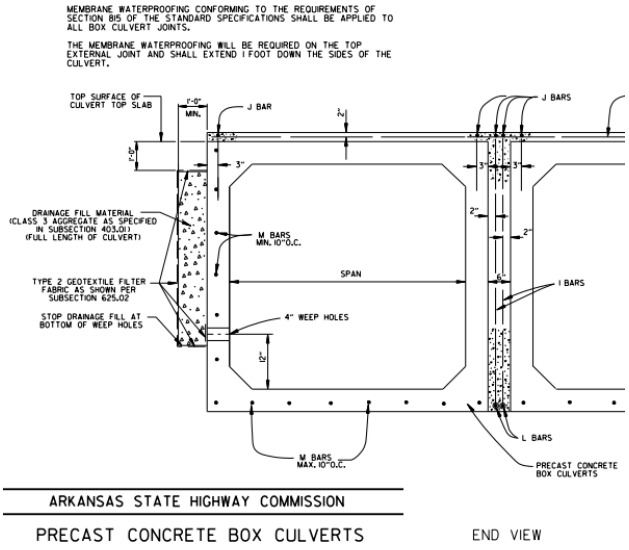
Colorado Department of Transportation



5. CLASS 1 DRAINAGE GEOTEXTILE SHALL BE COMPLETELY WRAPPED AROUND ALL CBC JOINTS WHICH DO NOT HAVE RUBBER GASKETS. THE GEOTEXTILE SHALL EXTEND A MINIMUM OF 1 FT. ON EACH SIDE OF JOINTS AND SHALL OVERLAP AND BE SECURELY ATTACHED FOR AT LEAST 1 FT. AT ITS ENDS. THE WRAP SHALL BE A SMOOTH FIT (NOT LOOSE OR STRETCHED) JUST PRIOR TO BACKFILL. THE GEOTEXTILE MATERIAL SHALL MEET THE APPLICABLE REQUIREMENTS OF SECTION 420. COST FOR GEOTEXTILE WILL NOT BE MEASURED AND PAID FOR SEPARATELY, BUT SHALL BE INCLUDED IN THE WORK.
6. FOR ANY CULVERT SPAN OR COMBINATION OF SPANS FOR MULTIPLE BOXES 20 FEET OR GREATER, A FOUNDATION INVESTIGATION AND REPORT ARE REQUIRED.
7. FOR FILL HEIGHTS LESS THAN 2 FEET, A WATERPROOFING MEMBRANE OR 30 MIL THICK GEOMEMBRANE SHALL BE PROVIDED FOR THE TOP OF THE TOP SLAB AND 18 INCHES DOWN ALONG THE TOPS OF THE EXTERIOR WALLS

Waterproofing more than joints

Arkansas Department of Transportation



3

Waterproofing more than joints

Maine Department of Transportation

- Some boxes, arches, and three-sided frames have been specified to have the top covered in its entirety with a waterproofing membrane, typically in shallow backfill and at road grade scenarios.
- In these cases, a High Performance - Torch Applied membrane is specified from waterproofing membranes section of the QPL (https://www.maine.gov/mdot/research/products).

High Performance - Torch Applied					
Soprema Roofing and Waterproofing					www.soprema.us
REF	96-014	**Product Name**	Sopralene Flam Antirock Membrane	**Recertification Due**	10/31/2023
Description		Waterproofing membrane made up of a non-woven polyester reinforcement and elastomeric bitumen (SBS modified bitumen). The top face is covered with colored granular, the under face is covered with a thermofusible plastic film. Sopralene Flam Antirock is torch applied.			
Other Information		The hot asphalt overlay should be between 290 - 320°F at the time of application.			
IKO					www.iko.com
REF	00-056	**Product Name**	Armour Bridge Membrane	**Recertification Due**	10/31/2023
Description		Non-woven polyester reinforcing mat that is coated and impregnated with Modiflex SBS modified bitumen to a thickness of approximately 4.5 mm (177mils).			
Other Information		The hot asphalt overlay should be between 290 - 320°F at the time of application.			

4

Waterproofing more than joints

Delaware Department of Transportation

- Silane sealer applied to all exposed surfaces. Lapped waterproof membrane for top slab and 1-ft down sides if hot mix placed directly on slab. If stone or fill on top of culvert, no membrane needed.

- 2020 Standard Specification of Delaware DOT
  - 612.3.3 Precast Concrete Elements:
    - 11. Apply silane sealer in accordance with Section 1045.3 to the top of each unit plus 2 feet down each side and to all headwalls, end faces, and exposed faces in accordance with Section 613.

5-Gal. SX5000 DOT Approved Solvent Based Silane Siloxane Penetrating Concrete...
★★★★½ 221
$224.75

5

Waterproofing more than joints

Tennessee Department of Transportation

- Products 23 is a list of qualified products for Concrete Waterproofing (https://www.tn.gov/content/dam/tn/tdot/hq-materials-tests/qpl/QPL_23.pdf).

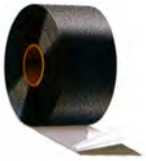
Product Category:	23 - Concrete Waterproofing	
Section:		
Material:	QPL.23.003 - Non-Penetrating Coal Tar Epoxy Sealers	
89900149 - Carboline		
	Trade Name	**Evaluation #**
	Bitumastic 300-M Coal Tar Epoxy	96029
	--	
	Bitumastic 301	96030
	--	
89901310 - INSL-X		
	Trade Name	**Evaluation #**
	Corotech Coal Tar Epoxy	12059
	--	
89900944 - TNEMEC Co Inc		
	Trade Name	**Evaluation #**
	Series 46-143 TNEME-Tar	93046

3

6

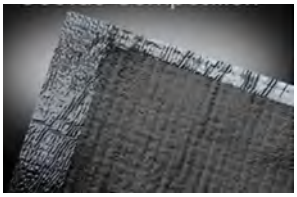
Waterproofing more than joints

Idaho Department of Transportation



- The top slab of the culvert is waterproofed. This is done with a Type D waterproofing membrane.
- Type D Precoated, Preformed Membrane Sheet System. Prefabricated sheets that are self-adhesive or require a separate bonding agent.

1. Tapecoat M860
2. Phillips Petrotac
3. Polyguard nw-75
4. PavePrep GeoTac



Waterproofing of Concrete Culverts

January 13, 2021

1

1. 23 state DOT's responded to our survey
2. We found and evaluated culvert related requirements/specifications of all states
3. National Precast Concrete Association provided information for almost all states

- For conflicting information, follow 2 → 1→ 3
- No research found on complete top surface waterproofing; some limited research on culvert joint wrap effectiveness; and research available on overall improvement through better steel and concrete materials.

2

Summary of data from state DOTs

- 18 states have no waterproofing requirement (or no information available)
- 16 states have joint wrap/membrane requirements
  - 12 inch wide (Idaho, Illinois-13", Maine, Michigan, Indiana)
  - 18 inch wide (Wisconsin, Delaware)
  - 24 inch wide (New Hampshire, Iowa, New York, Utah, Kansas, Florida, North Dakota, Pennsylvania)
  - 36 inch wide (Missouri)
- 15 states apply waterproofing on joints (gasket, mortar etc.) but no wrap
- 8-11 states require waterproofing outside joint region

3

Summary of data from state DOT's

- States requiring waterproofing outside joint region
  - Maine: membrane when cover < 18 in.
  - Colorado: rubber membrane when cover < 2 ft
  - Connecticut: woven glass fabric when cover = 0-2 ft
  - New Jersey: epoxy waterproofing seal coat when cover < 2 ft
  - Pennsylvania: adhesive-backed membrane when cover < 2 ft (??)
  - Illinois: membrane when cover < 3 ft
  - New Hampshire: membrane when cover < 5 ft (per response)
  - Idaho: waterproof membrane for all cover depths
  - Indiana: full waterproofing membrane

4

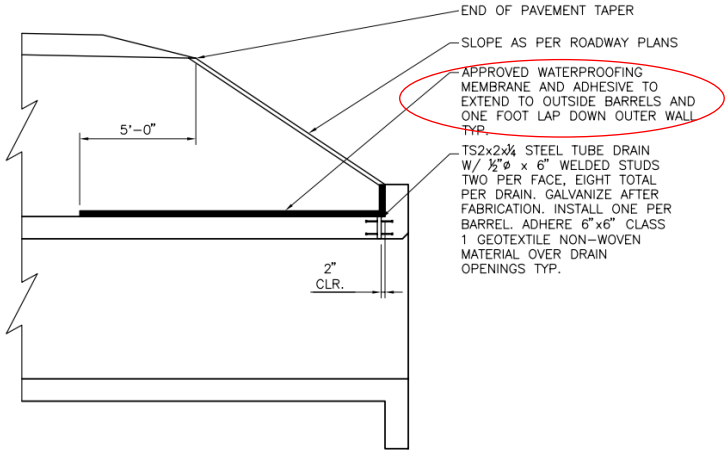
Unique waterproofing requirements outside joint regions

- Two unique cases
  - Kansas: middle 1/3 of the arch culverts with non-coal tar for fill heights ≤ 3 ft.
  - Pennsylvania: apply two spray coats of coal tar epoxy to the top of the box and exposed end faces and to the entire height of the outside walls
  - New Mexico: membrane near end wall locations

5

Is the issue close to the end of the culvert?

New Mexico Department of Transportation



TOP SLAB MEMBRANE AND HEADWALL DRAIN DETAIL

6

Unique waterproofing requirements outside joint regions – Kansas DOT

- For fill heights ≤ 3 ft:
  - Use epoxy coated reinforcing steel and air entrained concrete
  - Use a distribution slab meeting the requirements of KDOT BR031
  - Use "non-coal tar" bridge backwall protection system to cover the middle 1/3 of the top of precast arch culverts, the complete top slab of precast rigid frame culverts and the uppermost 2 in. of outside walls.
  - Indicate on the shop drawings the limits of the bridge backwall protection system.

7

Phone interview with Maine DOT personnel

Not much new information from phone interviews with Delaware and Arkansas DOTs

- In standard precast concrete culverts, grout (inside) and mastic is used in joints
- For shallow culverts (<18 in.) membrane is required on entire top surface.
- In critical locations (e.g., tidal waves):
  - silane sealer on entire surface is used at the precast plant
  - stainless steel rebar (or galvanized or FRP bars) in all decks
  - low-permeability concrete (e.g., with silica fume)
  - corrosion inhibitors are used
  - 6-9% air content in concrete

8

ODOT's joint wrap/membrane requirements

611.08 B-3 and B-4

a. For joints in precast reinforced concrete box culverts (706.05), fill the top exterior joint gap and the bottom and side interior joint gap with mortar. Next, for any exterior joint not covered by membrane waterproofing, cover the exterior joint with a 9 inch (225 mm) wide strip of joint wrap in accordance with the manufacturer's recommendation. Center the joint wrap on the joint.

b. For precast reinforced concrete 3-sided flat topped culverts (706.051), fill the top keyway joint with nonshrink mortar. If the side or leg joints are tongue and groove types, fill the joints as described above for concrete box culverts. If the side or leg joints are keyway types, fill with nonshrink mortar. Prepare, place, and cure the nonshrink mortar according to the nonshrink mortar manufacturer's recommendations. Wet all surfaces of the keyway joint, but do not allow free standing water in the joint. Next, cover the exterior joint with a 12 inch (300 mm) wide strip of joint wrap. Center the joint wrap on the joint. Use a continuous length of joint wrap sufficient to extend from the bottom of the vertical face on one side to the bottom vertical face on the other side. Apply membrane waterproofing to the precast sections after they are installed.

c. For precast reinforced concrete arch sections and precast reinforced concrete round sections (706.052 and 706.053), install a 7/8 x 1 3/8 inch (24 x 34 mm) preformed flexible joint sealant (706.14) along the outside joint chamfer. Use a continuous length of joint sealant sufficient to extend from the bottom of the vertical face on one side to the bottom vertical face on the other side. Before installing the joint sealant, prime the joint chamfer with a primer according to the joint sealant manufacturer's recommendations. For 706.052 and 706.053, cover all exterior joints with a 12 inch (300 mm) wide strip of joint wrap centered on the joint. Use a continuous length of joint wrap sufficient to extend from the bottom of the vertical face on one side of the structure to the bottom vertical face on the other side. Next, apply all waterproofing as shown on the plans. Apply membrane waterproofing to the precast sections after they are installed.

4. For precast reinforced concrete box culverts, precast reinforced concrete 3-sided flat topped culverts, precast reinforced concrete arch sections, and precast reinforced concrete round sections (706.05, 706.051, 706.052, and 706.053), apply an approved epoxy-urethane sealer per the plans to all top surfaces not covered by membrane waterproofing. Extend sealer 1 foot (0.3 m) below the backfill on all sides of the culvert sections including the joint.

9

ODOT's waterproofing requirements (outside joint regions)

611.09

611.09 Exterior Coatings and Membrane Waterproofing. Apply exterior coatings and membrane waterproofing as specified below. Protect the exterior coatings and membrane waterproofing from damage during placing of the bedding, backfill, and embankment.

A. For 611.08.B.3. concrete conduit, clean the surfaces before placing the membrane waterproofing. Apply membrane waterproofing as specified. Apply the membrane waterproofing to all surfaces that

10

Points of discussion

- ODOT's joint waterproofing requirements are more detailed than most states (can be uniform, say all 12 or 18 in.)
- ODOT is one of few states with waterproofing requirements outside joint regions and no backfill depth requirement (like Indiana and Idaho)
- Is ODOT interested in improving concrete or steel bars used in culverts? Is cost justified?
  - low permeability, larger air content, corrosion inhibitors, …
  - stainless steel, …
  - sealing culvert pieces at the precast plant

11

Summary and Recommendations Chapter in the Final Report

February 10, 2021

1

1) Consider using joint wrap on box culverts (on the exterior joint face) below the membrane waterproofing.

Out of the eleven state DOTs that have some waterproofing requirements for concrete culvert surfaces away from joints:

- Maine, North Dakota, and Pennsylvania DOTs explicitly require both joint wrap first and complete waterproofing over that.
- Delaware, Illinois, New Jersey and Utah possibly use both, but there is no explicit requirement in their specifications.
- It is not clear if joint wrap is required under the membrane in the other states.

2

2) Consider a wider membrane width to reduce the number of laps.

Also consider specifically requiring a minimum width of overlap with adjacent sheets.

- ODOT Item membrane waterproofing Type 2 (Item 711.25) and Type 3 (Item 711.29) have a minimum width of 36 in. When available, 48 in. wrap can/should be used to reduce the number of overlap joints required. Different states specify joint wrap width varying between 12 in. and 36 in. (e.g., Missouri).
- The lap widths specified by state DOTs vary from 2 in. to 6 in. A few states give a range, e.g., Maine DOT specifies 4-6 in. and New Hampshire requires 3-6 in. Given that greater lap width likely provides more protection, ODOT should consider using the upper range of overlap, at least 4 in.

3

3) While there is no specific evidence indicating construction equipment is directly related to waterproofing sheet performance, common sense would indicate that a less disturbed waterproofing sheet would tend to perform better. Therefore, consider a change in specifications to prohibit construction equipment on the waterproofed concrete, other than as necessary for the placement of backfill material. QA/QC?

4) Consider using a heat bonded sheet type. The heat bonding may be superior to the adhesive sheet currently used.

4

5) Consider the use of plant-applied sealers in combination with field-applied joint wrap.

6) Maine DOT require silane sealers applied at the precast plant for culverts with anticipated high salt exposure. Also, the quality control will be better if waterproofing can be done at the precast plant. In New Jersey, top slabs are coated with an epoxy waterproofing sealant at the precast plant.

7) No state DOTs reported issues with their existing culverts and their repair methods. Caltrans, Maine, Minnesota and Wisconsin DOTs have general culvert repair and rehabilitation guidance and best practices as presented in Chapter 6.

5

Potential Concrete Culvert Repair and Rehabilitation Methods

February 10, 2021

6

Possible Causes of Deterioration (Minnesota DOT, 2014)

Table 2.2 Key Culvert Observations

All Culverts	• Horizontal and vertical deflections of pipe • Size and location of voids visible through separated joints and holes in the culvert • Sounding the culvert interior with a hammer to listen for 'hollow' sounding areas indicating voids outside the culvert • Width of separated or deflected joints • Misalignment of pipe joints • Camber (bend) or settlement of pipe alignment
Rigid Pipe Culverts	• Crack size, location, length and extent of reinforcement corrosion. Corrosion typically occurs in crack widths exceeding 0.02", especially in the presence of chlorides • Depth of invert erosion. If reinforcement is exposed, amount of section loss • Sound walls and invert to locate areas of delaminating concrete due to slabbing (radial tension failure) or corrosion of reinforcement

7

Culvert Deterioration (Minnesota DOT, 2014)

Table 2.3 Likely Causes of Culvert Deterioration

Observed condition	Likely cause
Invert and crown cracking width in excess of 0.10" in RCP culverts	• Dead and live loading on culvert exceeding culvert design capacity • Increased loading on culvert due to increased soil or groundwater elevations
Slabbing (slabs of concrete "peeling" away from the sides of the pipe and a straightening of the reinforcement due to excessive deflection or shear cracks) in RCP culverts	• Dead and live loading on culvert exceeding culvert design capacity • Increased loading on culvert due to increased soil or groundwater elevations • Improper bedding of culvert
Joint separation and infiltration of soil	• Improperly seating of joint during installation • Movement of pipe due to slope erosion, freeze-thaw or settlement • Movement of pipe due to excessive deflection or structural deterioration • Buoyancy of culvert with insufficient cover

8

Bonnie Peterson, HydInfra Coordinator
Minnesota Department of Transportation
APWX Mpls 2016

Porous weeping patches
indicate bad concrete material

The pipe photo shows water trickling down the inside wall through perforations or honeycombing.
D7 MN Highway 22, 2014

Concrete pipe fails most often when
Joint Separation and Piping causes Road Void

HydInfra data shows about 7% of MnDOT's concrete pipes have separated joints

9

Minnesota DOT

Joint Repair in large Concrete culvert

10

Caltrans (2014):

DESIGN INFORMATION BULLETIN NO. 83 - 04
CALTRANS SUPPLEMENT TO FHWA CULVERT REPAIR PRACTICES MANUAL

e) Evaluate the culvert barrel for joint integrity, soil loss, alignment, cracks (concrete pipe - check location and crack width) and structural integrity:

11

Caltrans:

5.1.1.1.3 Infiltration

Infiltration can cause settlement and misalignment problems if it carries fine-grained soil particles from the surrounding backfill. See Index 5.1.2.3, Soil Migration. In such cases, measures should be taken to seal the joints to make them watertight. It may be possible to use an internal steel expansion ring gasket joint sealing system (see Index 5.1.1.1.3.2) in conjunction with pressure grouting to fill voids in the soil behind the joint. Internal grouting or some of the lining methods described in Index 6.1.3 such as sliplining, or lining with CIPP will also stop infiltration. In general, for culvert repair work, Portland

78 in. RCP with Misalignment Failed 36" RCP

12

Chemical Grouting (Caltrans)

5.1.1.1.3.1 Chemical Grouting

Internal Chemical Grouted Joint (RCP)

Chemical grouting is a commonly used method for sealing leaking joints in structurally sound, sewer pipes that are under the groundwater table. It will not provide structural repair, and it is inappropriate for longitudinal or circumferential cracks, broken or crushed pipes. However, other methods such as using repair sleeves in combination with chemical grouting are appropriate for such repairs (see discussion towards end of this

13

Chemical Grouting (Caltrans)

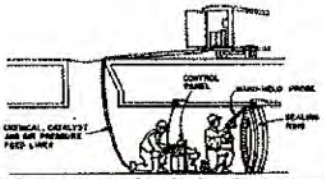


FIGURE 4.4. Typical arrangement for sealing large diameter pipe with grouting rings.

Illustration of Gel Grout Penetrating Outside the Pipe Joint

The two basic groups of chemical grouting materials are gels and polyurethane foams. Polyurethane foam grout forms in place as a gasket and cures to a hard consistency but retains a rubber-like flexibility. The seal takes place in the joint and there is only minimum penetration outside the pipe. The service life of polyurethane foam is not moisture-dependent and therefore it can be considered for use in locations with wet-dry cycles. Gel grouts penetrate outside the pipe and infiltrate the soil surrounding the joint.

14

Cracked and Separated Joints (Caltrans)

RCP Examples With Joint Separation, Missing Seal and Backfill Loss

Refer to the previous discussion under *misalignment, exfiltration and infiltration* for joint

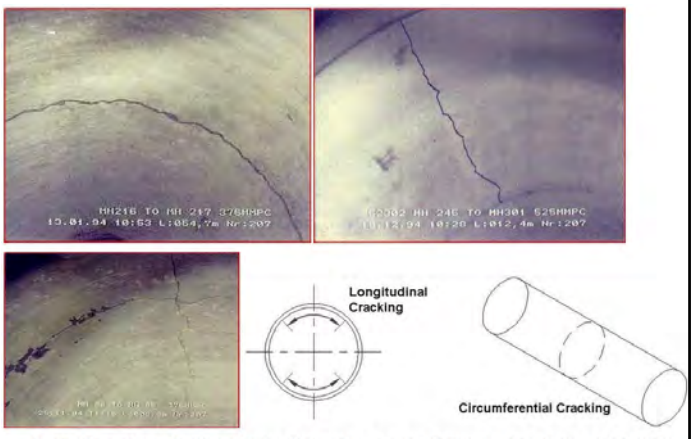
5.1.1.1.4 Cracked and Separated Joints

Cracked joints are more than likely not watertight even if gaskets were used. However, if no other problems are evident, such as misalignment, and the cracks are not open or spalling, they may be considered a minor problem to only be noted in inspection. Severe joint cracks are similar in significance to separated joints. Separated joints are often found when severe misalignment is found. In fact either problem may cause or aggravate

15

Cracked Joints (Caltrans)

- Flexible crack fillers
- Portland cement-based mortar or epoxy injection for structural repair
- Sleeve+chemical grouting
- Mortar patch (spalling)



Typical Locations for Longitudinal Cracking can be Found in the Crown and Invert.

5.1.1.2 Cracks

For culverts that have been newly installed and backfilled, cracks should not exceed 0.01 inch in width in severely corrosive environments (pH of 5.6 or less, water containing vegetal or animal wastes, seawater, or other water with high concentration of chlorides). Conversely, for culverts installed in a non-corrosive environment (neutral pH close to 7, low concentrations of salt, vegetal or animal wastes), cracks of up to 0.1 inch in width of the installed pipe are acceptable if they are not excessive in number.

16

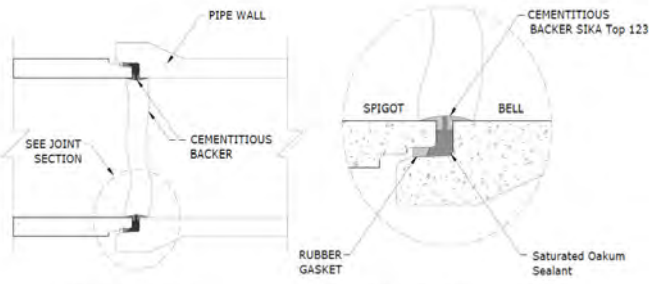
Potential Source of Damage/leaking

- Material related (unlikely in this case)
  - Low quality concrete
  - Low quality waterproofing material
- Construction related (likely in this case)
  - Improper seating of joint
  - Improper backfilling
  - Heavy construction equipment on one side of the joint – during pavement or backfilling process
- Structural loading related (possible)
  - Heavier (unequal) traffic or live load on one side of the joint
  - Heavier backfill and/or pavement materials

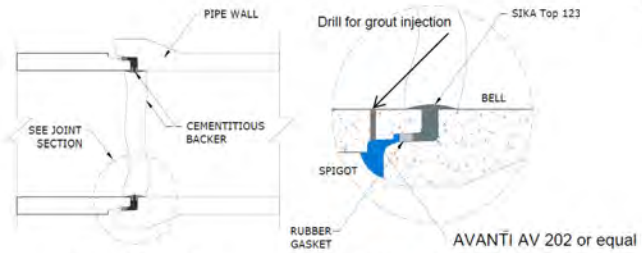
17

Recommendation by a Local Company

- Polymer modified, fast setting, Portland cement-based mortar (SikaTop 123)
- Water activated polyurethane injection resin (Avanti AV 202) to prevent joint leaking.



PIPE SECTION JOINT SECTION



PIPE SECTION JOINT SECTION

18