Post Installation Evaluation and Repair of Installed Reinforced Concrete Pipe

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Table of Contents

cont. next pg.

I. POST INSTALLATION EVALUATION AND REPAIR OF INSTALLED REINFORCED CONCRETE PIPE

SCOPE

This document, its references and companion resource materials contain a detailed discussion of the evaluation and repair of newly installed reinforced concrete pipe (RCP). The document was developed for the sole purpose of providing information to allow the reader to properly evaluate post installation inspection data collected from newly installed Reinforced Concrete Pipe (RCP). There are similarities between the inspection and evaluation of older pipelines, however, that is beyond the scope of this document.

The owner of the evaluated pipe system normally places the monetary burden of repair, remediation and/or replacement on the contractor, if new pipe installations are found to have damage. The Matrix and this commentary can be used to provide the evaluation team and the contractor with a reasonable approach to economically evaluate what defects are in need of repair. This document provides good descriptions of basic repair methods that can help guide the contractor and/or owner in selecting and reviewing possible repair methods. Owners benefit with assistance in assessing repairs of pipe systems and by evaluating repair options submitted by contractors. This document should not be directly used to select a specific repair method for a project without the evaluation and guidance from a design professional as the selection of specific repair method is a complicated decision influenced by site specific conditions, budget, availability, and schedule.

Note: many of the evaluation issues and/or repair techniques are not applicable to other drainage piping products.

FOREWORD

Many state transportation departments and municipalities throughout North America and around the world place great emphasis on storm drainage infrastructure. One way this increased emphasis has manifested itself, is through the use of Post Installation Inspection for new pipe installations. As more post installation inspection data is generated and presented to owners, engineers, and inspection professionals, the need to properly and quickly evaluate the issues identified in the inspection documents becomes critical. The decision maker must be trained to differentiate between items that are purely aesthetic from conditions that require remediation to maintain the intended service life for the installed pipe system. Needless repair of minor aesthetic imperfections will lead to unnecessary cost increases. Likewise, failure to remediate a deficiency may lead to unanticipated maintenance and/or replacement.

This document addresses possible issues identified in post installation inspection reports and/or video documents of newly installed RCP. The accompanying RCP Evaluation and Repair Matrix provides evaluation guidance for cracks, spalling, slabbing, and joint integrity. Furthermore, a commentary is provided as an overview of possible remediation and repair techniques. Please note, the repair and remediation procedures outlined are potential options. Each repair or remediation procedure should be carefully reviewed by a professional whose decision is based upon individual site conditions, importance of the facility, defect severity, local availability and design considerations.

BACKGROUND

To best understand and evaluate RCP, one must first understand how RCP and the soil embedment work in concert to accommodate loads, how RCP is designed, and how the finished RCP structural design strength is confirmed prior to installation of critical elements. *The goal is to provide a discussion with references for installed conditions one might see in accurate post installation inspection reports.*

Back to start

This commentary along with review of the reference material will help the user to properly differentiate acceptable aesthetic conditions from conditions that may require remediation.

LOADS

When properly designed and installed, the RCP and soil embedment work together to support the imposed soil column and any live load, fluid load or surcharge load.

Structural Strength Provided by Soil - Depending on the Standard Installation Type, the pipe may be designed to provide the majority of structural strength of the installed system. A SIDD Type IV bedding installation (weakest soils/least compaction required) would require the RCP to carry a large majority of the load, while a SIDD Type I bedding installation (strong granular soils combined with good compaction/consolidation) would allow more of the load to be carried by the soil embedment materials. All SIDD Installation Types are fully defined and discussed in ASTM C 1479[1].

Structural Strength Provided by Pipe - The structural strength of the pipe is provided by manufacturing RCP with two complimentary products; concrete and steel reinforcement. Similar to an engineered concrete beam, RCP utilizes concrete to resist compressive forces and steel reinforcement to resist tensile forces that are present under load, see Figure 1.

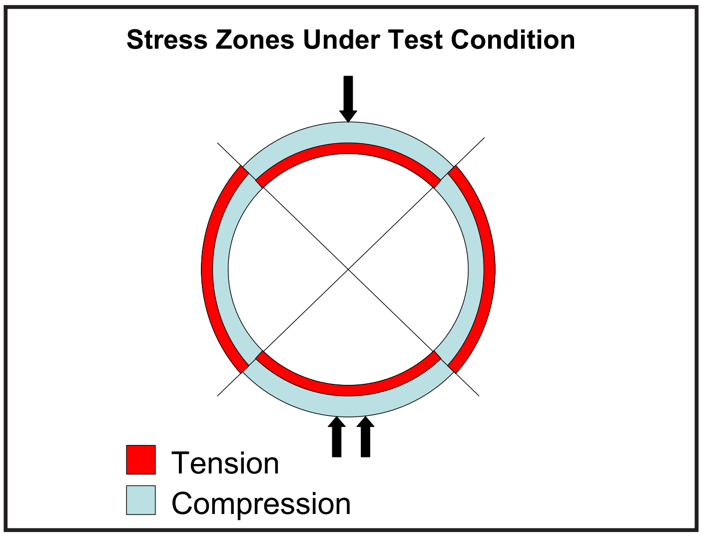


Figure 1: Zones of Tension and Compression in Reinforced Concrete Pipe during Three Edge Bearing Test (field conditions of installed pipe similar.)

The attributes of the steel reinforcement in the pipe wall are under-utilized, unless the pipe wall cracks. As with a concrete beam, the concrete wall of an RCP will crack to transfer tensile loads to the steel reinforcement. The steel reinforcement in the tension areas of the pipe wall is designed to control the crack width and to increase the load carrying capability of the RCP. A properly designed reinforced concrete pipe is expected to crack under service load conditions. Owners, Inspectors and Design Professionals should not be overly concerned when hairline cracks or cracks up to 0.01 inch in width that are visible in collected inspection data. ACPA CP Info “Cracks In Installed Reinforced Concrete Pipe”[2] is a good resource to understand more about significance of cracks in installed RCP.

DESIGN

National Standards (ASTM & AASHTO) allow two methods for designing RCP; the Indirect Design Method and the Direct Design Method. Both methods satisfy service limit states and strength limit states required by AASHTO LRFD Bridge Design Specifications.[3]

Back to start

The Indirect Design Method is the most common design method utilized by design professionals. RCP has been successfully designed utilizing the Indirect Design Method since the early 1900s. The Indirect Design Method correlates the anticipated installed pipe load to a standard Three-Edge-Bearing (3EB) test D-load. ASTM C-76 (AASHTO M 170) provides the required design load (D-Load), steel areas, and concrete strengths for each strength class of pipe.

The Direct Design Method allows the designer to determine the required concrete strength and steel areas for the pipe installation conditions based upon structural analysis. Typically, most engineers utilize the Direct Design Method for designs that are not included in ASTM C-76.

The reader may want to review "Concrete Pipe Design – Direct Design Versus Indirect Design/Strength Tested Pipe"(4) to learn more about application of the Direct and Indirect Design Methods of RCP.

STRUCTURAL CONFIRMATION AND SIGNIFICANCE OF THE 0.01 INCH CRACK

The Indirect Design strength class of RCP is confirmed through the use of Three Edged Bearing (3EB) Testing Method as defined in ASTM specification C497. Figure 1 along with the test apparatus in Figure 2 illustrates the loading points of the 3EB test. Pipe producers use this test on representative samples of finished pipe sections prior to shipment to the job site.

ASTM C-76 sets forth two design loads, $D_{0.01}$ and D_{ULT}, for each strength class of pipe. As the pipe is loaded during the test, small hairline cracks form. This is an indication that the load on the pipe is sufficient to create tensile stresses greater than the tensile strength of the concrete. As the test load increases, the crack width increases and the tensile forces are transferred to the reinforcing steel. The pipe satisfies the $D_{.01}$ strength criteria and AASHTO Service Limit State if the $D_{.01}$ test load is reached before the formation of a crack 0.01" in width and 12 inches long. As the test load approaches D_{ULT}, the reinforcing steel controls the crack width. Professor Spangler's paper on "The Case Against the Ultimate Load Test for Reinforced Concrete Pipe"(5) discusses the use of the D_{ULT} Test and how pipe reacts in the field condition vs 3EB Test Loads.

Figure 2: Three-Edge-Bearing Test Machine

"Some engineers insist that a crack in a concrete pipe in excess of 0.01-inch represents a failure or partial failure situation. Such a conclusion is utterly ridiculous and represents a disservice, not only to the concrete pipe industry, but taxpayers as well". This quote from Professor M.G. Spangler, a well respected authority and early pioneer in the design of concrete pipe, should be taken into consideration when inspecting a project using reinforced concrete pipe. ASTM C 76 further states; *"The 0.01 inch crack is a test criteria for pipe tested in the Three-Edge-Bearing test and is not intended as an indication of over stressed or failed pipe under installed conditions."*

We strongly urge evaluation and design professionals to tour an RCP production facility to see how RCP is produced and witness a 3EB Quality Assurance Strength Test. This type of hands-on experience will greatly help one understand crack development during a RCP test load. It will also help the individual to gain a perspective on the 0.01 inch design crack compared to smaller "hairline" cracks. One will see that a 0.01 inch crack is insignificant in size; that a 0.05 inch width crack (0.05 inch = thickness of a dime) is very small; and a 0.10 inch width crack can develop in a heavily loaded pipe section - capable of handling additional loads. Note that ***AASHTO LRFD Bridge Construction Specification Section 27*** allows acceptance of cracks up to and beyond 0.10 inch (the thickness of two dimes) in reinforced concrete pipe.

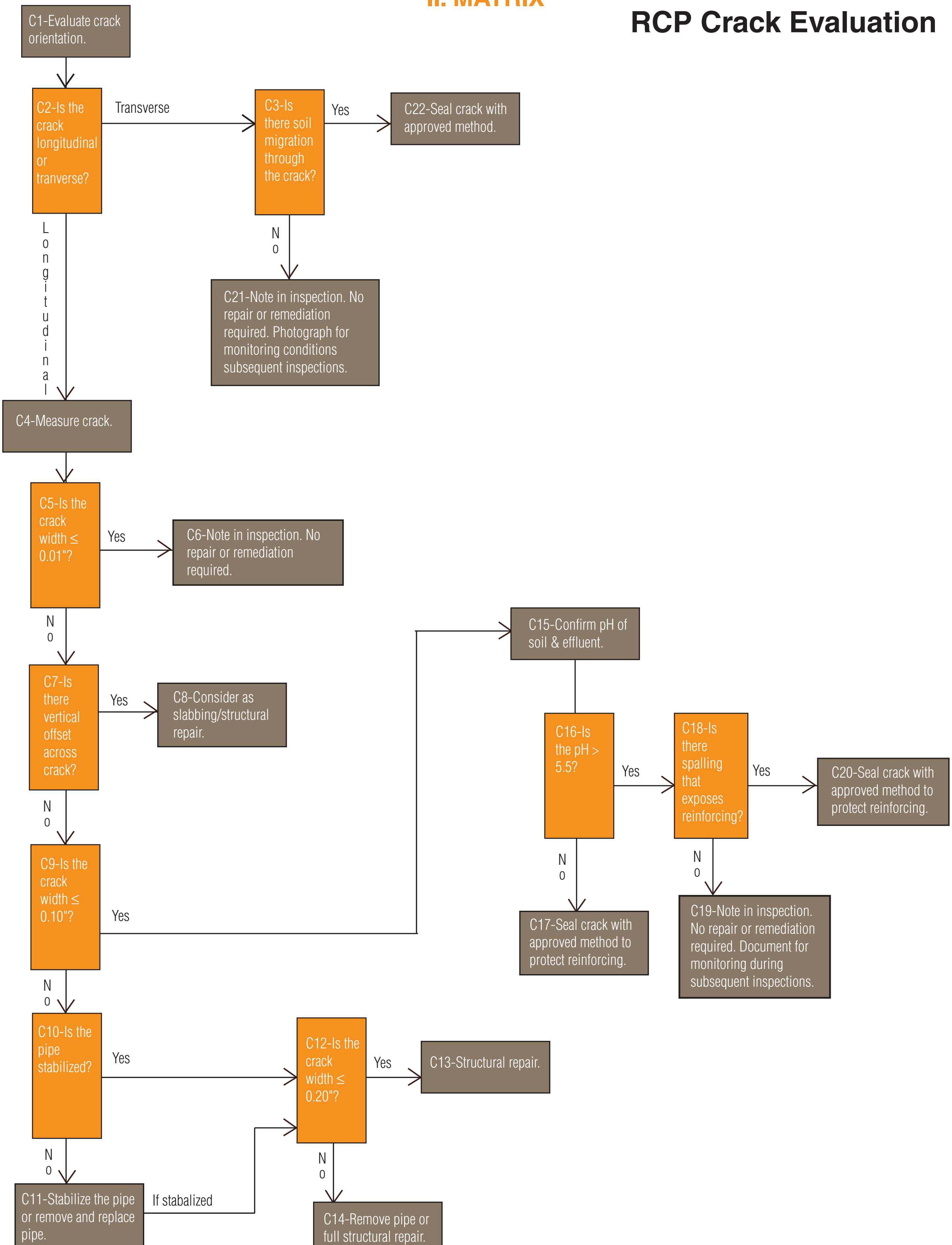
JOINT PERFORMANCE

Pipe joint evaluation considerations are a key component of evaluating the overall performance and acceptability of new RCP installations. The structural and hydraulic performance of the joint affects the stability of the supporting soil embedment around the pipe, the line/grade of the pipeline, integrity of the overlying backfill, pavement structure and compliance to leakage requirements.

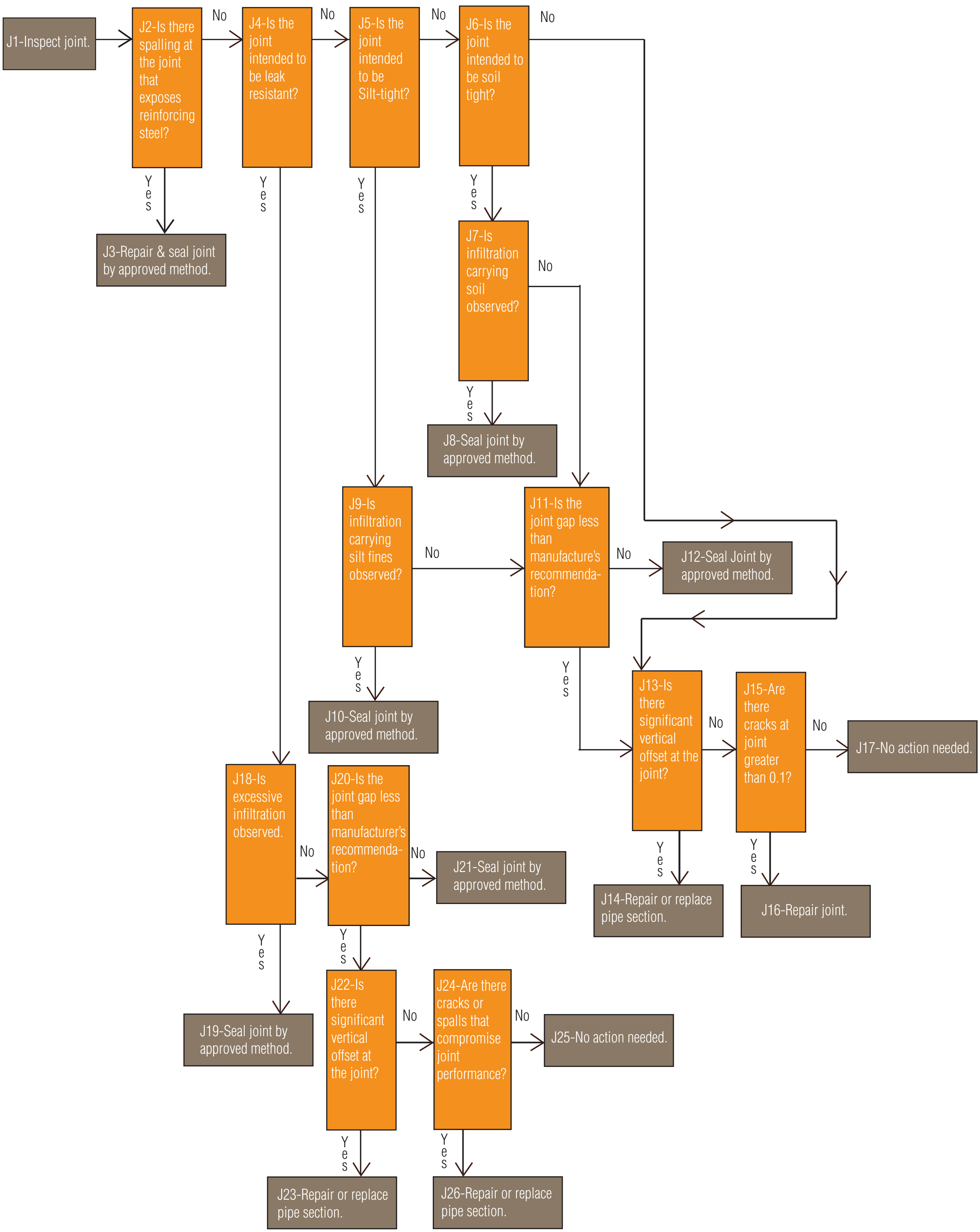
"AASHTO Designation: PP 63-091 Provisional Standard Practice for Pipe Joint Selection for Highway Culvert and Storm Drains[6]" provides transportation professionals with a joint selection and joint performance guidance document. AASHTO clearly identifies and defines several possible joint design performance levels for storm drainage piping. AASHTO worked with the major pipe industries to develop joint design descriptions and testing criteria for: soil tight joints, silt tight joints, leak resistant joints and water tight joints. The joint performance evaluation portion of the Matrix was developed with these key joint performance guidelines in mind.

Several FHWA and AASHTO Documents included in the reference materials of this document address the importance of joint design and field performance. All of the reference background materials are relatively consistent in their approach and identification of the items that should be of concern for the evaluation team for the installed pipe system.

RCP Crack Evaluation

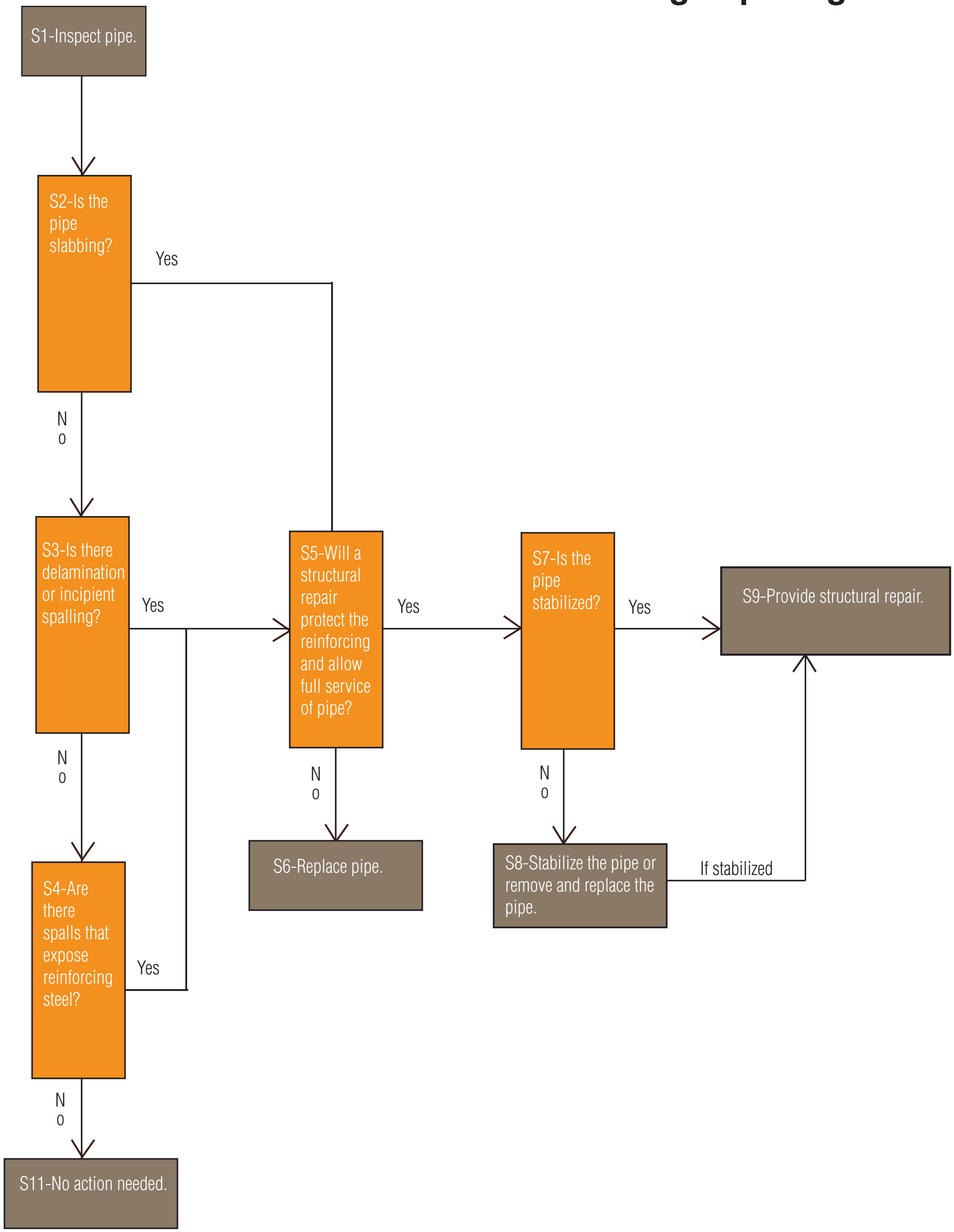


RCP Joint Evaluation



Back to start

RCP Slabbing / Spalling Evaluation



III. CRACK EVALUATION AND REPAIR

C1 (CRACK INSPECTION), C2 (LONGITUDINAL /TRANSVERSE CRACKS)

It is important to understand that the orientation of a crack in the pipe wall will assist in determining the severity and possible cause of the crack. There are excellent references to better understand crack orientation, crack severity, and possible causes of issues that may be found in pipe inspections. The ***AASHTO LRFD Bridge Construction Specification Section 27.6.4 & 5*** contains several brief explanations in the commentary portions of that document about the cause of various crack location or crack patterns. The following is an excerpt from FHWA Culvert Inspection Manual[7] that discusses possible causes of certain crack locations and or patterns one might find in installed RCP:

Longitudinal Cracks--Concrete is strong in compression but weak in tension. Reinforced steel is provided to handle the tensile stresses. Hairline longitudinal cracks in the crown or invert indicate that the steel has accepted part of the load. Cracks less than 0.01 inches in width are minor and only need to be noted in the inspection report. Cracks greater than hairline cracks, or those more than 0.01 inch in width but less than 0.1 inches, should be described in the inspection report and noted as possible candidates for maintenance. Longitudinal cracking in excess of 0.1 inch in width may indicate overloading or poor bedding. If the pipe is placed on hard material and backfill is not adequately compacted around the pipe or under the haunches of the pipe, loads will be concentrated along the bottom of the pipe and may result in flexure or shear cracking, as illustrated in exhibit 108.

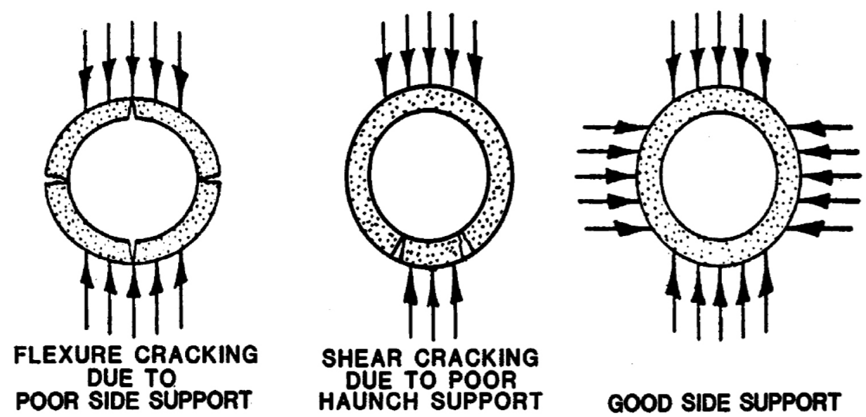


Exhibit 108. Results of poor and good side support, rigid pipe.

Other signs of distress such as differential movement, efflorescence, spalling or rust stains should also be noted. Examples of longitudinal cracking are shown in exhibits 109 and 110. When cracks are wider than 0.1 inch measurements should be taken of fill height and the diameter of the pipe both horizontally and vertically to permit analysis of the original design. Crack measurements and photographs may be useful for monitoring conditions during subsequent inspections.

Back to matrix

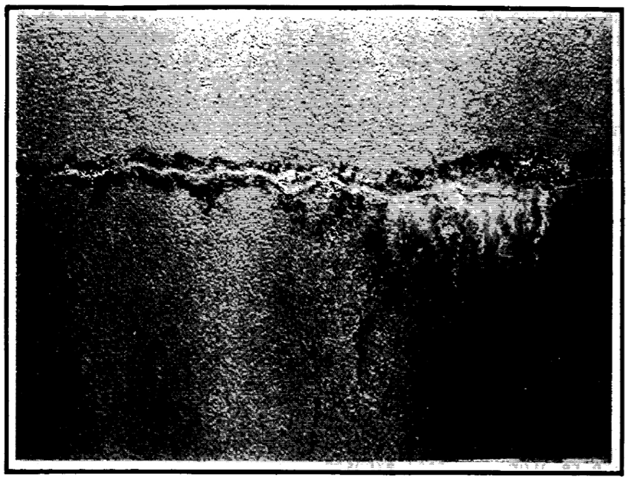


Exhibit 109. Minor longitudinal crack with efflorescence.

d. Transverse Cracks--Transverse or circumferential cracks may also be caused by poor bedding. Cracks can occur across the bottom of the pipe (broken bell) when the pipe is only supported at the ends of each section. This is generally the result of poor installation practices such as not providing indentions (bell holes) in hard foundation material for the ends of bell and spigot-type pipe or not providing a sufficient depth of suitable bedding material. Cracks may occur across the top of pipe (broken back) when settlement occurs and rocks or other areas of hard foundation material near the midpoint of a pipe section are not adequately covered with suitable bedding material. Transverse cracking is illustrated in exhibit 111.

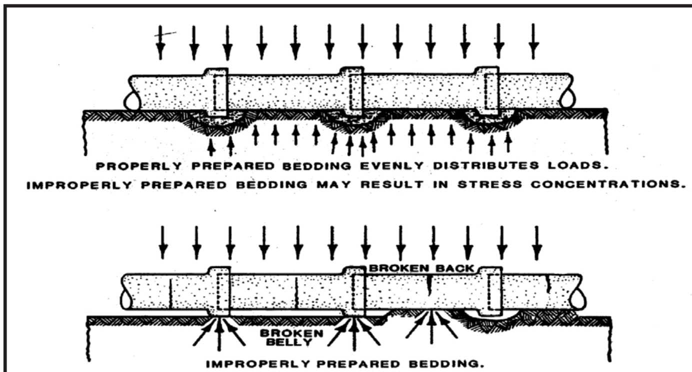


Exhibit 111. Transverse or circumferential cracks.

Back to matrix

Circumferential Crack with minor spalling along crack & circumferential crack with autogeneous healing.

C3 (SOIL MIGRATION W/ TRANSVERSE CRACK)

Circumferential/Transverse cracks can be evaluated similar to a joint integrity evaluation process. If the circumferential crack is not allowing transport of backfill material into the pipe, and the pipe does not have a vertical offset that could impede flow, and the pipe is in a non-corrosive environment, it should only be noted in the inspection report. Under these conditions, no remediation would be required. The severity of a circumferential crack is limited, because this type of crack will not affect the structural load capacity of the RCP pipe wall; it can be viewed similar to just another joint in the system.

The steel reinforcement arrangements utilized in RCP are comprised of longitudinal steel wires running length wise along the pipe and circumferential steel wires which transverse the reinforcement assembly. The longitudinal wires are typically smaller in diameter and spaced further apart as compared to the circumferential reinforcement. The longitudinal reinforcement functions to space the circumferential wires and help hold the reinforcement assembly in shape during the RCP production process. The circumferential steel in the reinforcement arrangement provides the structural component of the assembly. A circumferential crack will transverse across the longitudinal steel. As previously stated, the longitudinal steel reinforcement has a minor role in structural integrity of the pipe wall; therefore circumferential (transverse) cracks are of much less structural concern than longitudinal cracks. Circumferential steel provides the structural component of the completed steel cage.

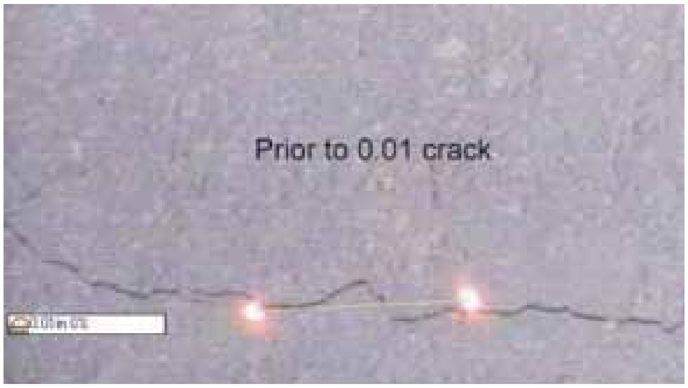
Circumferential steel provides the structural component of the completed steel cage

Repair of a circumferential crack would be warranted if there is soil migration into the pipe, or if there is significant vertical offset that could significantly impede flow. Causes of circumferential cracks are generally related to poor bedding or foundation support. Improper handling and storage of RCP during the construction process can also induce stress to cause cracks in the pipe wall or jointing surfaces. It is important for the installer and inspector to understand proper storage, handling and installation techniques of RCP to limit damage of the product. The ACPA *Installation Manual*[8], and ACPA *Dos and Don'ts*[9] are both good training resources to help installers and inspectors better understand proper installation, storage and handling techniques and guard against issues that can damage RCP.

Back to matrix

C4 (CRACK MEASUREMENT)

The evaluation of longitudinal cracks should begin with crack width measurement. Length and width measurement is key to the evaluation of a longitudinal crack in RCP. The information collected about the crack can indicate not only the severity, but also the possible causes of the cracks observed. Longitudinal cracks can be measured with feeler gauges if the pipe is large enough for entry (inspection team must follow all OSHA safety requirements). Longitudinal cracks in smaller diameter pipes can be measured with laser micrometers.



Crack measurement utilizing laser micrometer.

Measurement of crack with feeler gauge.

Example of autogenous healing.

Longitudinal crack width measurement is used to classify a given crack as hairline (crack less than 0.01 inch), design (crack 0.01inch - 0.10 inch) or a stress (crack greater than 0.10 inch). The current ***AASHTO LRFD Bridge Construction Specification Section 27.6.4 & 5***[10] addresses longitudinal cracks in detail, but it is important to understand that the crack width criteria set forth in AASHTO requires evaluation by a pipe or drainage professional for longitudinal crack widths exceeding design crack widths of 0.01 inch.

C5, C9, C12 (CRACK WIDTH)

AASHTO LRFD Bridge Construction Specifications Section 27.6.4 & 27.6.5[10] describes potential longitudinal cracks observed in concrete pipe culverts and a simplified summary is as follows:

C9 (CRACKS < 0.1")

According to AASHTO, evaluation is not needed unless longitudinal crack width is greater than 0.01 inch. The commentary goes on to state that crack widths up to 0.10 inch are generally acceptable if the pipe is in a non-corrosive environment.

From a structural integrity standpoint, crack widths less than 0.10 inch should be considered acceptable if located in a non-corrosive environment as discussed in AASHTO Section 27. Sealing these types of cracks can prove to be difficult - especially in small diameter pipelines that do not permit man entry. Sealing hairline and design cracks is not required unless corrosive conditions exist that can further deteriorate the pipe. Research indicates that hairline and design cracks in the pipe wall often heal themselves through a process known as autogenous healing. Autogenous healing occurs between the crack surfaces of buried pipe. The healing process is a result of a chemical reaction that takes place in the presence of moisture and air. During this process, calcium carbonate (a hard white crystalline substance) forms when moisture and oxygen react with un-hydrated cement in the pipe wall. The healing process results in a monolithic pipe structure that is often stronger. References included at the end of the commentary, provide a more in depth discussion on the topic of autogenous healing of concrete pipe and structures. (See "Autogeonous Healing of Cracks [11] and Healing of Cracks in Lightweight Concrete.[12])

C7 (VERTICAL OFFSET)

It is important to note any significant vertical offset across all cracks. In pipes large enough for man entry, the vertical offset across the crack can be measured by using leaf gauges. In video inspections of smaller pipes, a visual estimation may be the only way to evaluate the vertical offset across a crack.

RCP exhibiting a crack with vertical offset in obvert (Top) of pipe

Concrete slabbing near invert due to radial tension shear.

C8 (SLABBING)

A pipe under structural distress caused by a load that creates high shear stresses in the pipe wall can be identified by offset across the face of the crack. Vertical shear cracks usually are found in the haunch (area between invert and springline) areas of the pipe as opposed to flexural cracks which are usually found at the invert and obvert of the pipe wall. (See Picture on left) If a significant vertical offset is apparent in the video inspection while using no magnification, the offset is most likely large enough to warrant further investigation to determine if future slabbing of the pipe wall is of concern. AASHTO Section C27.6.4 commentary has a good discussion of shear cracks.

C10 (MEASURING STABILIZATION)

Before structural repairs can be made to an installed RCP, it must be determined if the installation has stabilized. As RCP deforms in a slabbing, radial shear, or gross deformation condition, the pipe loses rigidity and approaches a flexible or semi-rigid structure condition. Reinforced concrete pipes under extreme earth loading that is experiencing gross deformation may still be capable of accepting additional load and an "ultimate" load is practically never reached. In this condition, passive soil pressures generate at the sides of the pipe until the pipe and surrounding soils reach a stabilized state. Once the pipe-soil system has stabilized, the system is said to have reached equilibrium; meaning further pipe deformation is prevented due to the counter balancing soil pressure, which develops in response to the horizontal deformation of the pipe against the soil. This equilibrium state can be determined by establishing permanent horizontal and vertical reference points at 12, 3, 6 and 9 o-clock positions throughout the pipe run. The distance between the horizontal and vertical points are then determined with a solid rod micrometer (see picture to right) and recorded.

Measurements should be taken over a three week period to determine if the pipe-soil system has reached equilibrium. If the installed pipe-soil system has reached equilibrium, cracks can be reamed out with air chisel or power grinder, damaged concrete removed and the areas patched with Portland cement grout or epoxy cement grout. Patches of this kind will not add strength to the pipe, but will protect the reinforcing steel from corrosion.

Back to matrix

Soil consolidation continues with time after the final fill is placed over the pipe. Therefore, AASHTO Section 27 requires that an elapsed time of 30 days (4 weeks) pass before conducting Post Installation Inspection and Evaluation of the installed reinforced concrete pipe. When cracks greater than 0.1 inches are found during the inspection, measurements should be taken over the next three week period resulting in a total of 7 weeks to determine if the pipe-soil system has reached equilibrium. If the installed pipe-soil system has reached equilibrium, cracks can be reamed out with air chisel or power grinder, damaged concrete removed and the areas patched with Portland cement grout or epoxy cement grout. Patches of this kind will not add strength to the pipe, but will protect the reinforced steel from corrosion. Should the installed reinforced concrete pipe not reach equilibrium, then some type of structural repair should be made that will not solely rely on structural integrity of the installed pipe. Removal and replacement of the installed pipe or structural slip line are potential final options.

C11 (ACHIEVING STABILIZATION)

Reinforced concrete pipe with multiple cracks in excess of 0.10 inch and determined to have not reached equilibrium may be equalized by drilling holes through the pipe wall at the haunch area and injecting pressure grout between the pipe and the embedment soil. This will effectively increase the lateral pressure along the length of the pipe and improve the bedding condition to such an extent that the supporting pipe strength is made adequate to carry the vertical load without further deformation. Again, the pipe should be monitored as described in the proceeding paragraph. Once the pipe-soil system has reached equilibrium, cracks can be structurally repaired.

C12 (CRACKS >0.1" AND < 0.2")

Cracks larger than 0.10 inch in width are rare and should be structurally evaluated to determine if the pipe is structurally capable of supporting the loads. As discussed above, if the pipe system has reached equilibrium the pipe has proven to have accommodated the load. The cracks should be structurally remediated. Possible remediation actions could include sealing the cracks with structural epoxy type materials placed in the crack plane or Full Barrel repairs such as: Cured in place liners, Fold and Form liners, Epoxy resin Liner, or slip line systems.

C15, C16 (PH)

AASHTO and other resources also utilize pH conditions of the installed pipe environment to identify if a corrosive environment exists for the subject installation. In a corrosive environment, a design or stress crack in the pipe wall could deteriorate further, as the pipe wall material is attacked by the acidic influent or soil conditions. Evaluation of the influent, ground water and soil conditions should be made as outlined in ASTM G51, Standard Test Method for Measuring pH of Soils for Use In Corrosion Testing and ASTM D1293, Standard Test Method for pH of Water. The FHWA Culvert Inspection Manual[(7)] contains the following discussion on corrosive soil and water conditions and should help one evaluate, if test results from samples would indicate pipe is in a corrosive environment:

> *Certain soil and water conditions have been found to have a strong relationship to accelerated culvert deterioration. These conditions are referred to as "aggressive" or "hostile." The most significant conditions of this type are:*
>
> *a. pH Extremes--pH is a measurement of the relative acidity or alkalinity of water. A pH of 7.0 is neutral, values of less than 7.0 are acid, and values of more than 7.0 are alkaline. For culvert purposes, soils or water having a pH of 5.5 or less are strongly acid and those of 8.5 or more are strongly alkaline.*

Back to matrix

California Department of Transportation DIB 83-01[13] "Problem Identification and Associated Repair for Culvert Barrels" 5.1.1.2 CRACKS states the following with respect to crack width and corrosive environment:

> *"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."*

Professor Spangler also noted his opinion on the durability of RCP, "Cracks up to approximately 1/16-inch in width will not permit corrosion except under the most adverse conditions."

C18, (SPALLING)

Spalling may be seen along the edges of cracks. Minor spalling that does not expose the reinforcing steel is no structural concern as long as pipe is in a non-corrosive environment as previously discussed. If spalling along a crack exposes the circumferential steel reinforcement, the spalled area should be repaired. Note; exposed circumferential reinforcing steel should be differentiated between exposed longitudinal steel and/or exposed steel spacers to prevent unnecessary repairs.

Crack exhibiting minor spalling along edge of crack.

C17, C20, C22 (REPAIR METHODS FOR CRACKS IN RCP)

The decision process between the need to seal a crack versus the need to structurally repair a crack has been discussed above in the crack evaluation section of this document.

There are many reasonable repair methods for the various crack conditions. It is challenging to provide guidance as to what repair method is best for a specific defect for a specific project. The list of possible repair methods outlined on the RCP Evaluation and Repair Matrix is consistent with repair methods discussed in detail in FHWA Culvert Repair Practices Manual[14], California Department of Transportation DIB 83-01[13], and Chapter 14 "Culvert Inspection, Material Selection, and Rehabilitation Guideline" of the AASHTO Highway Drainage Manual[15].

The following repair techniques are excerpts from California Department of Transportation DIB 83-01[13]:

Back to matrix

CRACK REPAIR IN CONCRETE PIPE USING A MAXIMUM STRENGTH, NON-SHRINK, PORTLAND CEMENT OR MORTAR (REFER TO INDEX 5.1.1.2) – CAL DIB 83-01(13)
Dimensions of "V" Grind shall be 0.25 inch wide minimum and approximately 0.5 inch deep. 1 inch deep Grinds may damage reinforcement. The Grind shall be cleaned of any grinding dust and surface thoroughly moistened before filling with non- shrink Portland cement or Mortar (e.g. Jet PlugTM by Jet Set California Inc, see Appendix F) to ensure a good bond.
The mortar mix should be mixed to a low-slump consistency with only enough water added to gain a consistency of heavy glazing putty. Allow repair to become firm to touch 6 to 10 minutes after installation. Then shave to grade with a trowel edge. Do not overwork.

If the new patch is not under water, a curing agent shall be used to cover the new patch plus 1 inch on either side of the new patch immediately after patch is firm. It should be noted that when longitudinal cracks are found at the crown of the pipe, usually the invert of the pipe is also cracked.

Crack repair method for Cracks in RCP from "FHWA Culvert Repair Practices Manual.

APPENDIX B-25: PROCEDURES FOR REPAIRING CRACKS IN CONCRETE

APPLICATIONS
The following discussion applies to the repair of cracks in Portland cement concrete.

COMMENTS
The procedures and materials that should be used for repairing cracks in Portland cement concrete will frequently depend upon the cause of the crack, its location, and the environment surrounding it. Shrinkage cracks may be quite narrow and shallow and have little influence on the structural behavior, whereas wider and deeper cracks may have been caused by structural loading and may signify more serious effects on structural load carrying capacity. Both types of cracks may have an influence on long term durability of the structure.

With regard to procedures for repairing cracks in concrete culverts, there is always an overall requirement that cracks be clean and preferably dry before they are repaired. Obviously, it may be difficult to meet both of these criteria for cracks in culverts. The cracks will generally be old by the time they are found, and if they are wide enough, they may be full of sand or dirt. In addition, they may be continuously wet from water from either the inside or the outside of the culvert. Thus, generally some work will be needed to prepare the crack for the repair material.

There is a choice of materials that may be used to repair cracks. The materials generally may be categorized as either flexible crack fillers or rigid materials that are more permanent that may create a structural repair. The latter group includes both Portland cement-based mortar and structural adhesives including epoxy systems that may be filled with aggregate or a powder or unfilled.

The general opinion of many practitioners is that cracks that are moving because of movement in the structure should be repaired with a flexible sealing-type material, *whereas stationary cracks may be filled with a rigid material. This is not an absolute rule, but it does highlight the need to determine whether the crack is moving. For most concrete culverts it may be assumed that the crack is moving, especially since there is a close relationship between soil pressures and the resistance (and strength) of a concrete culvert; and the soil pressures that may have caused cracking will continue to be exerted on the culvert. Under some situations the condition may have stabilized. Thus, there is a rationale that the structure is probably still moving and it should be filled with a flexible material. However, there is also another principle in soil-structure behavior that if conditions are allowed to continue they will be come worse, as the soil pressures will continue to deform the structure until collapse occurs. From that standpoint it may be best to try to strengthen or stabilize the structure so that it can resist the increasing soil pressures, in this case by effecting a structural repair on the more serious cracks. This will require filling the cracks with a rigid material. If tensile, flexure of shear forces will occur it may be necessary to use a structural adhesive. Some of these materials may be installed in wet or submerged cracks.*

PROCEDURES

1. Installation of a Flexible Sealant

The following is a general procedure for filling a crack with a flexible sealant. The manufacturers of such sealants will have more specific recommendations for their particular materials if the highway agency has not established such procedures.

a. Clean the surface of the concrete.
b. Route a groove into the surface of the crack, so that it will serve as a reservoir for the sealant.
c. Clean concrete dust and debris out of the crack by sand-blasting, air-water jet, or both.
d. Fill the crack with the sealant by pressure injection or troweling. If troweling is to be done a bond breaker should be first applied to the surface of the concrete on both sides of the crack so that the sealant will not have a wide width at the top of the crack.
e. Scrape excess sealant off the concrete surface, so that the surface will be smooth. (For some types of cracks it may be desirable to trowel a shallow depression in the surface of the sealant.)

2. Installation of a Portland Cement Mortar or Grout

Wide cracks may be repaired by filling with Portland cement grout, as follows:

a. Clean the surface of the concrete.
b. Install built-up seats and grout nipples at intervals along and astride the crack to provide a pressure tight contact with the injection apparatus.
c. Seal the crack between the grout nipples, with a cement paint, sealant, or grout.
d. Flush the crack to clean it and to test the seal.
e. Grout the crack. The grout mixture may contain cement and water or cement plus sand plus water, depending on the width of the crack. However, the water-cement ratio should be kept as low as possible to provide maximum strength and low shrinkage. The grout may include a water reducer or other admixtures to improve the properties of the grout.

3. Repair by Injection of Epoxy Adhesive

The following is from guidelines of the Pennsylvania DOT.

Back to matrix

Equipment

a. Type – The equipment used to meter and mix the two injection adhesive components and inject the mixed adhesive into the crack shall be portable, positive displacement type pumps with interlock to provide positive ratio control of exact proportions of the tow components at the nozzle. The pumps shall be electric or air powered and shall provide in-line metering and mixing.

b. Discharge Pressure – The injection equipment shall have automatic pressure control capable of discharging the mixed adhesive at any preset pressure up to 200 psi plus/minus 5 psi an shall be equipped with a manual pressure control override.

c. Ratio Tolerance – The equipment shall have capability of maintaining the volume ratio for the injection adhesive prescribed by the manufacturer of the adhesive with a tolerance of plus or minus 5 percent by volume at any discharge pressure up to 200 psi.

d. Automatic Shut-Off Control – The injection equipment shall be equipped with sensors on both the component A and B reservoirs that will automatically stop the machine when only one component is being pumped to the mixing head.

Preparation

a. Surfaces adjacent to cracks or other areas of application shall be cleaned of dirt, dust, grease, oil efflorescence or other foreign matter detrimental to bond of epoxy injection surface seal system. Acids and corrosives shall not be permitted for cleaning.

b. Entry ports shall be provided along the crack at intervals of not less than the thickness of the concrete at that location.

c. Surface seal material shall be applied to the face of the crack between the entry ports. For through cracks, surface seal shall be applied to both faces, if possible.

d. Enough time for the surface seal material to gain adequate strength shall pass before proceeding with the injection.

Epoxy Injection

a. Injection of epoxy adhesive shall begin at lower entry port and continue until there is an appearance of epoxy adhesive at the next entry port adjacent to the entry port being pumped.

b. When epoxy adhesive travel is indicated by appearance at the next adjacent port, injection shall be discontinued on the entry port being pumped, and epoxy injection shall be transferred to the next adjacent port where epoxy adhesive appeared.

c. Perform epoxy adhesive injection continuously until cracks are completely filled.

d. If port to port travel of epoxy adhesive is not indicated, the work shall immediately be stopped and the engineer notified.

Finishing

a. When cracks are completely filled, epoxy adhesive shall be cured for sufficient time to allow removal of surface seal without any draining or runback of epoxy material from cracks.

b. Surface seal material and injection adhesive runs or spills shall be removed from concrete surfaces.

c. The face of the crack shall be finished flush to the adjacent concrete showing no indentations or protrusions caused by the placement of entry ports.

Back to matrix

IV. JOINT EVALUATION

J1 (JOINT INSPECTION)

Evaluation of the joints for installed concrete pipe requires both visual interpretations of inspection data, as well as actual measurements to determine severity of some items of note in the joint inspection process. Whether inspection is manual or by video, the entire circumference of every joint should be inspected.

The Matrix and subsequent commentary on Joint integrity follows the guidelines set forth in ***AASHTO PP 63-09 "Standard Practice for Pipe Joint Selection for Highway Culvert and Storm Drains***[(6)]. AASHTO PP63-09 provides transportation designers with joint selection criteria and joint performance requirements for several different performance levels for each of the major pipe types including RCP.

J2, J3 (SPALLING)

During handling and installation it is possible to damage joint surfaces. Minor spalled areas of the joint surface do not need repair, unless steel reinforcement is exposed or the broken area is allowing transport of fine soil to migrate into the storm system.

J4 (LEAK RESISTANCE)

Leak resistance - Leak resistance refers to a system that is not completely (100 percent) watertight, but allows some defined allowable rate of water leakage into or out of the system.

Leak-resistant joint - a joint which limits water leakage at a maximum rate of 200 gallons/inch-diameter/mile/day for the pipeline system for the project specified head or pressure.

J5 (SILT TIGHTNESS)

Silt-tightness - refers to a pipe system's resistance of fine soil migration through the openings of the joint.

Silt-tight joints - a joint that is resistant to infiltration of particles that are smaller than particles passing the No. 200 sieve. Silt-tight joints provide protection against infiltration of backfill material containing a high percentage of fines, and typically utilize some type of filtering or sealing component, such as an elastomeric rubber seal or geotextile.

J6 (SOIL TIGHTNESS)

Soil tightness - refers to a pipe system's resistance of course grained soil migration through the openings of the joint.

Soiltight joint - a joint that is resistant to infiltration of particles larger than those retained on the No. 200 sieve. Soiltight joints provide protection against infiltration of backfill material containing high percentage of coarse grain soils, and are influenced by the size of the opening (maximum dimension normal to the direction that the soil may infiltrate) and the length of the channel (length of the path along which the soil may infiltrate).

J7, J9 (INFILTRATION)

When the water table is higher than the invert of the pipe, water may seep into the culvert or pipelines during low flows. Infiltration can also occur during flood events if gravity flow systems become pressure flow and cause suction from pressure differentials in inlet control culverts.

Back to matrix

Infiltration can cause settlement and misalignment problems if it carries fine-grained soil particles from the surrounding backfill (Soil Migration). In such cases, measures should be taken to seal the joints.

J8, J10, J12, J16, J18, J19 (JOINT SEALING)

If joint is allowing fine particle migration, the joint should be sealed.

DIB 83-01 - 5.1 Problem Identification and Associated Repair for Culvert Barrels(13)

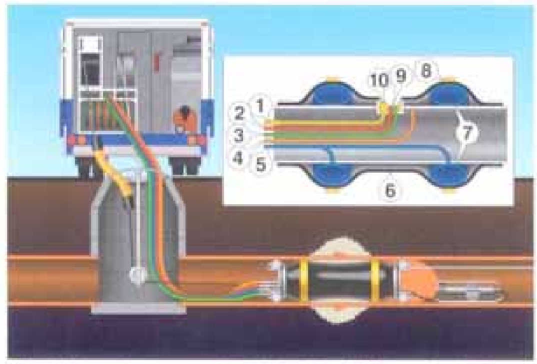
"Internal grouting, internal joint seals, or some of the lining methods such as sliplining, or lining with CIPP will stop infiltration. In general, for culvert repair work, Portland cement based grout, with and without special admixtures, is usually adequate and much less expensive than the foaming and chemical grouts that are used to resist high external and internal fluid pressures. Internal grouting can be specifically designed to stop infiltration at deteriorated, continuously leaking or open joints. See FHWA Culvert Repair Practices Manual Volume 1, pages 5-37, 6-11, 6-14, and Volume 2, Appendices B-30 and B-26 for procedures on grouting voids and sealing culvert joints. Also see Index 11.1.1.

Internal Chemical Grouted Joint

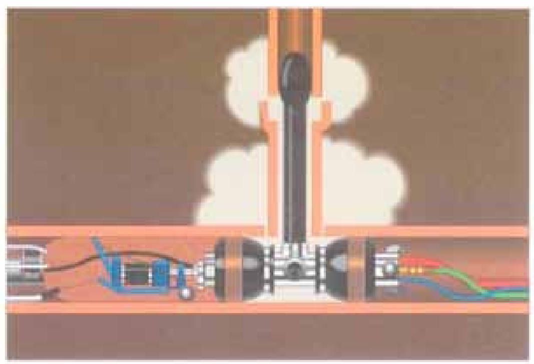
Chemical grouting is the most commonly used method for sealing leaking joints in structurally sound, sewer pipes that are under the groundwater table. Chemical grouting will not provide structural repair. However, other methods such as using repair sleeves in combination with chemical grouting are appropriate for structural repairs (see discussion towards end of this section). Attempting to utilize chemical grout to seal joints that are not leaking or have no physical infiltration of ground-water during the sealing process has produced questionable results. Some types of chemical grouts have failed in arid regions where the grout has dried up during periods of low groundwater and in coastal regions where the ground is subject to tidal fluctuations. The long-term service life for chemical grouting is unknown. One study concluded the life expectancy for chemically grouted joints was no more than 15 years, other

Back to matrix

references indicate a 20 year service life, and it is known to last even longer in other applications such as sealing tunnels and dams.
In non-human (small diameter) entry pipes, grouting is generally accomplished using a sealing packer and a closed circuit television (CCTV) camera. The sealing packer and CCTV camera are pulled through the pipe with cables. Concurrently, air or water testing equipment is used to test the joint and determine the effectiveness of the sealing.



Modern injection packers are very sophisticated, consisting of: (1) Pressure Sensing Line, (2) Chemical "A" Line, (3) Chemical "B" and Air Pressure Line, (4) Sleeve Air Line, (5) End Seal Air Line, (6) Sleeve, (7) End Seal Elements, (8) Sealing Pads, (9) Chemical Injection Ports, (10) Pressure Sensor Element.



New injection packers can seal lateral connections and the first few feet of service lines with chemical grout quickly and cost-effectively.

In pipes with large enough for human entry, pressure grouting is accomplished using manually placed inflatable pipe grout sealing rings or predrilled injection holes and a hand-held probe (see figure below):

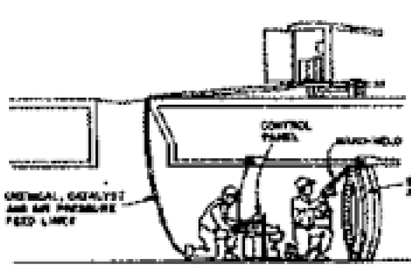


FIGURE 4.4. Typical arrangement for sealing large diameter pipe with grouting rings.

Illustration of gel grout penetrating outside the pipe joint

Back to matrix

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. The mixture cures to an impermeable condition around the joint area.

The service life of the non-urethane type gels discussed below is moisture-dependent, and therefore these types should not be considered for use in locations with wet-dry cycles. Urethane gel however, is different from the acrylamide, or acrylate gels in that water is the catalyst and they may be used in locations with wet-dry cycles to form either an elastomeric collar within the pipe joint as well as filling the voids in the soil outside the joint.

The most commonly used gel grouts are of the acrylamide, acrylic, acrylate and urethane base types. Acrylamide base gel is significantly more toxic in its pre-gelled form than the others but grout toxicities are of concern only during handling and placement or installation and EPA has now withdrawn a long standing proposal that sought to ban the use of acrylamide grouts. Due to its very low viscosity, acrylamide has long been the material of choice to repair underground structures in the sanitary sewer industry. The non-toxic urethane base gels are EPA approved for potable water pipelines because they use water as the catalyst rather than other chemicals. Because of soil and moisture variability, formulating the correct mixture is largely dependent on trial and error on a case-by-case basis, and is difficult to accurately specify in design.

If the pipe is round and large enough for human entry and the external hydraulic head pressure is low, it may be possible to use an internal steel expansion ring gasket joint sealing system in conjunction with pressure grouting to fill voids in the soil behind the joint. See FHWA Culvert Repair Practices Manual Volume 2, pages B-111 to B-116. If corrosion and abrasion protection is needed, it may be necessary to cover the steel expansion ring with shotcrete or cement mortar; however, rings are available in stainless steel for enhanced corrosion protection."

Back to matrix

J11, J20 (JOINT GAP)

All producers have joint designs for their products that meet the required performance criteria as outlined in the technical specifications or design guidelines. Soil tight joints may consist of a joint with butyl mastic joint material, a silt tight joint may include a rubber gasket, or a butyl mastic joint material and may in some cases be combined with an exterior joint wrap and a leak resistant joint normally requires a joint design that utilizes a rubber gasket. Each manufacturer may also produce pipe with a slightly different concrete joint configuration on their pipe when compared to another pipe manufacturer. Actual joint geometry and tolerances should be provided by the manufacturer to determine acceptable joint tolerances to meet the required joint performance criteria set by the owner/project specifications. Note; even properly installed joints can appear to not be fully homed when inspected with CCTV inspection equipment, because of the lack of perspective and measurement. The pipe manufacturer should always be consulted when evaluating acceptable joint gaps.

J13, J22 (VERTICAL OFFSETS/MISALIGNMENT)

Significant vertical offset or severe misalignment at the joint may indicate the presence of serious problems in the embedment soils. If progressive settlement is present, joint repair should not be performed until a solution to stabilize the surrounding soil has been found. If the vertical offset or misalignment is a result of leaking joints and soil migration, a determination should be made whether the migration is due to water exfiltration or infiltration of the soil material. A combination of grouting the external voids and sealing the culvert joints may be warranted using chemical grouting or other joint repair methods. **CCTV inspection equipment may amplify acceptable alignment such that it appears to be misaligned at the joint sections.** Depending on the manufacturing process, RCP may be produced with a slight internal taper which could naturally create a joint offset. ASTM C76 sections 9.1 & 12.1 give some guidance on how much this natural offset could be. RCP produced within the maximum allowable manufacturing tolerances could have a natural offset that ranges from ¼” on 12” diameter, varying linearly up to 3/8” on 24” diameter, and continuing to over ½” for pipes larger than 48” diameter. Joint designs also allow for movement or minor adjustment in the field for line and grade. These minor misalignments should not be of concern and are taken into account when using the recommended hydraulic design criteria for concrete pipe systems.

Back to matrix

J15, J24 (CRACKS)

A cracked joint, while not ideal, may provide the intended performance. If no other problems are evident, such as misalignment and the cracks are not open (less than 0.10 inch in width) or spalling, cracked joints may be considered a minor issue to be noted in inspection report. 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 the other. Embankment slippage may also cause separations to occur. An attempt should be made to determine whether the separations are caused by improper installation, soil migration along the length of the pipe, or uneven settlement of fill. If soil migration is determined, an attempt should be made to determine whether the migration is due to ground water, water exfiltration, or infiltration of backfill material.

Repair of large cracks can be made in a similar fashion to those methods discussed in crack repair portion of this document. Internal joint seals or joint repair methods, discussed in joint infiltration repair section, could also be considered.

Crack near joint of RCP.

Small crack near joint.

V. SPALLING AND SLABBING EVALUATION

S1 (INSPECTION)

During the inspection of the pipe, there may be noticeable vertical offset combined with some spalling along longitudinal cracks in the haunch areas of the pipe. These could be signs of structural distress and should be carefully investigated. They may be likely candidates for some type of repair or remediation.

S2, S3 (SLABBING & SPALLING)

Spalls are fractures of the concrete parallel, or inclined to the surface of the concrete. Spalls are caused by excessive shear forces, or may be caused by corrosion of the reinforcing steel in areas where it does not have sufficient cover.

Crack exhibiting minor spalling along edge of crack.

Slabbing can be a radial failure of the concrete due to excessive deflection, and may be difficult to distinguish from spall fractures. In slabbing, the concrete cover over the reinforcement is forced away from the reinforcement as the pipe deflects and the reinforcement steel straightens out. This is a serious structural problem normally identified as radial tension shear and is caused by overloading, usually under very high fills. Sections which have experienced extreme slabbing should be repaired or replaced.

Crack with vertical offset – early indication of possible radial tension shear in pipe wall.

Interior view of RCP with cracks in haunch area with vertical offset. Early sign of possible slabbing and radial tension shear forces present in wall of pipe.

Back to matrix

S4 (EXPOSED REINFORCING)

If the spalling occurs along crack planes, or if the pipe is exhibiting slabbing, it is important to remove all delaminated and/or loose concrete from above the steel. If the pipe is stabilized and equilibrium has been achieved, the exposed reinforcement can be cleaned and protected, so pipe can maintain an appropriate service life and be repaired in a way to maintain long-term structural strength.

Concrete slabbing near invert due to radial tension shear.

S5 (STRUCTURAL REPAIR)

Even though slabbing is a structural issue that requires proper attention, in many cases it can be remediated in a way to reestablish adequate structural integrity. If repaired properly, the pipe can provide the anticipated service life.

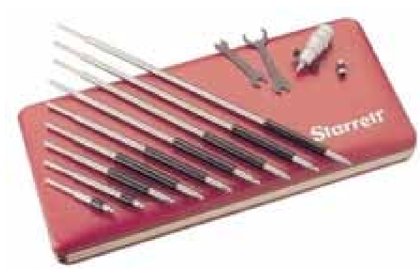
S6 (REPLACEMENT)

If the pipe wall has experienced excessive deformation to the point the pipe cannot be stabilized, the pipe may need to be replaced.

S7 (MEASURING STABILIZATION)

As the RCP deforms in a slabbing, radial shear, or gross deformation condition, the pipe loses rigidity and approaches a flexible or semi-rigid structure condition. Reinforced concrete pipe under extreme earth loading that is experiencing gross deformation may still be capable of accepting additional load and an “ultimate” load is practically never reached. In this condition, passive soil pressures generate at the sides of the pipe until the pipe and surrounding soils reach a stabilized state. Once the pipe-soil system has stabilized, the system is said to have reached equilibrium; meaning further pipe deformation is prevented due to the counter balancing soil pressure, which develops in response to the horizontal deformation of the pipe against the soil. This equilibrium state can be determined by establishing permanent horizontal and vertical reference points at 12, 3, 6 and 9 o’clock positions throughout the pipe run. The distance between the horizontal and vertical points are then determined with a solid rod inside micrometer, and recorded.

Measurements should be repeated weekly over a three week period to determine if the pipe-soil system has reached equilibrium. If the installed pipe-soil system has reached equilibrium, cracks can be reamed out with air chisel or power grinder, damaged concrete removed and the areas can be repaired to protect the steel reinforcement from corrosion and re-establish the invert flow line.



Soil consolidation continues with time after the final fill is placed over the pipe. Therefore, AASHTO Section 27 requires that an elapsed time of 30 days (4 weeks) pass before conducting Post Installation Inspection and Evaluation of the installed reinforced concrete pipe. When delamination or spalling is

Back to matrix

found during the inspection, measurements should be repeated weekly over a three week period resulting in a total of 7 weeks to determine if the pipe-soil system has reached equilibrium. If the installed pipe-soil system has reached equilibrium, cracks can be reamed out with an air chisel or power grinder, damaged concrete removed, and the areas can be repaired to protect the steel reinforcement from corrosion and re-establish invert flow line.

S8 (ACHIEVING STABILIZATION)

Reinforced concrete pipe with more extensive slabbing that have not reached the equilibrium state can be stabilized by drilling holes through the pipe wall at the haunch area and injecting pressure grout between the pipe and the embedment soil. This will effectively increase the lateral pressure along the length of the pipe and improve the bedding condition to such an extent that the supporting pipe strength is made adequate to carry the vertical load without further deformation. Again, the pipe should be monitored as described in the proceeding paragraph. Once the pipe-soil system has reach equilibrium, the loose slabs of concrete may be removed and a protective cover applied over the steel as in the proceeding paragraph.

S9 (STRUCTURAL REPAIR)

Structural repair for slabbing can include High Strength Portland Cement Grout, or more exotic repairs for severely spalled and deformed pipelines such as Epoxy Resin Mortar Applied Liners, Fold and Form Liner systems, or Slip line of entire line (all of which have been discussed in other areas of this document).

It is challenging to provide guidance as to what repair method is best for a specific defect on a specific project. Selection of a repair method is based upon many variables that include cost, availability, access, pipe size, and job schedule. It should also be noted that new materials or application methods are also consistently being developed by the repair industry. The list of possible repair methods outlined on the RCP Evaluation and Repair Matrix for the various conditions are consistent with repair methods discussed in detail in FHWA Culvert Repair Practices Manual[14], California Department of Transportation DIB 83-01[13], and Chapter 14 "Culvert Inspection, Material Selection, and Rehabilitation Guideline" of the AASHTO Highway Drainage Guidelines.[13]

Spall Repair – FHWA Culvert Repair Practices Manual[]
"Spalling is generally the result of corrosion of reinforcing bars that initially causes horizontal (or in plane) cracking of the concrete and then subsequent delamination and spalling of the surface concrete off of the reinforcing bars. Information on concrete patching is provided in appendix B-28.

Slabbing Repairs

The terms slabbing, shear slabbing, and slab shear refer to a problem of radial failure of the concrete over the inner layer of reinforcement, due to excessive deflection and straightening of the reinforcing cage. The deformation causes radial tension and diagonal shear tension in the concrete that splits the concrete at the level of the interior layer of reinforcement. It is characterized by large slabs of concrete "peeling" away from the reinforcement. Slabbing is a serious problem that may occur under high fills with reinforced concrete pipe of inadequate D-load strength and/or on inadequately deep bedding on a rock foundation. Slabbing is a phenomenon that occasionally occurs during installation of precast concrete culverts as well as the result of bad soil conditions and a high water table. The corrective action that should be undertaken will depend upon the amount of bending and distortion that has taken place in the concrete section and the likelihood that additional movement and slabbing will occur.

Back to matrix

If it is determined that the cause of the slabbing has been corrected (during construction) or that additional distortion and slabbing is unlikely, then the corrective action is rather simple and straightforward. If this is the case, and it may be determined that the culvert is structurally stable, then the primary concern is protection of the inner (and exposed) layer of steel reinforcing against corrosion. Information on procedures for patching concrete is provided in appendix B-28.

APPENDIX B-28. PROCEDURES FOR PATCHING CONCRETE

APPLICATIONS

The following procedure may be used to patch spalled, delaminated and broken area of Portland cement concrete.

COMMENTS

Although there are many materials that may be used for patching concrete, the overriding principle for such repairs is that it be done carefully and with good workmanship. The cracked, spalled, or otherwise deteriorated area to be repaired must be properly prepared, good materials must be used, and the work must be properly protected until the materials have gained sufficient strength and other physical properties to withstand the expected environmental and loading conditions. The alternative to this produces a patch that will not endure and the patching work will be a total waste of time and money. Moreover, loss of the patch may create worsening or additional problems that will certainly require even more time, material, and funding to correct. Depending upon the site conditions, even well prepared and installed patches may not last very long, and it should be an established practice to periodically inspect critical patches to ensure that the structure is performing adequately.

The material that normally provides the most permanent patch for Portland cement concrete is Portland cement concrete. The closer the physical properties of the patch are to the existing material, the better. It is important to minimize shrinkage of the patching material. This may be done by using a low water/cement ratio material. A water reducing admixture may also be used. Inclusion of a latex additive to the concrete or mortar will also reduce the amount of water required for workability and also reduce the permeability of the patch material. Other performance-proven additives can be used to reduce setting time and to increase strength.

Proper curing is important for all concrete work and especially important for patching. Thin patches present a particularly difficult problem because they dry out quickly. The existing concrete will tend to absorb the moisture in the patching material. If exposed to the sun or wind, moisture is lost even more rapidly. If possible, patches should be covered with moist burlap.

The following provides some guidance for patching Portland cement concrete.

2. Remove delaminated and/or broken concrete from the distressed area. For some areas or structures it may be desirable to make a ¾ inch deep sawcut around the area to be patched. For delaminated and spalled areas, the edge of the repair should be extended 12 to 18 inches into good concrete to be ensured that all cracked concrete is removed. Deteriorated concrete may be removed with power-driven hand tools. If used, pneumatic hammers should not be heavier than a nominal 30 pounds.

A 15 pound chipping hammer may be useful, particularly around reinforcing bars. Care must be taken to not apply heavy vibrations to reinforcing bars, to prevent breaking bond with the concrete.

3. The repair area should then be air – or sand-blast cleaned to remove all dust and debris. Do not use water to clean the area.

4. Apply a cement or cement-latex grout or an epoxy resin to the sides and bottom of the area to be repaired.

5. Place the patching material in the distressed area, in accordance with State, ACI or the manufacturer's guidelines. The material should be placed before the bonding layer (step 4) begins to set up. The patch material should then be struck off, finished, and edged as required.

6. The patch area should then be covered with wet burlap or a moisture barrier and allowed to cure with disturbance.

RESOURCE COMMITMENT = 1:	*5*	*4*	*3*	*2*	*1*
	Heavy		*Medium*		*Low*

COST RELATIVE TO REPLACEMENT = 1:	*5*	*4*	*3*	*2*	*1*
	High		*Medium*		*Low*

B-122

GENERAL CULVERT BARREL REHABILITATION

The preceding discussion has addressed specific types of distress or damage, and techniques for repairing them have been presented. When the extent or type of distress severely limits the structural strength or the functional adequacy of an existing culvert barrel and it cannot be effectively repaired, other procedures should be considered to restore the structural strength and the serviceability of the culvert. The following discussion presents techniques that may be considered.

The viability of these techniques will depend upon site-specific conditions, the cost of materials and labor, and the type and extent of the inadequacy.

Most of the following techniques for restoring the structural strength and serviceability of culverts also reduce the internal cross sectional area of the culvert, which may accordingly reduce the hydraulic capacity of the culvert. The actual reduction in hydraulic capacity will depend upon many factors; including the size, type and condition of the existing culvert as well as upon details of the corrective action. Decisions regarding the corrective action, and justification for downsizing, must be done as the result of analysis of site-specific conditions by a hydraulic engineer.

Current hydrology design and analysis practices may show that older culverts are oversized, and in fact, could be downsized without adversely affecting existing upstream conditions. By flood routing a hydrograph through a culvert system designed for only the flood peak, it is frequently possible to justify downsizing of an existing culvert, provided that there is some temporary storage caused by roadway embankments. It may also be helpful to note that modern culverts are almost always constructed with headwalls, endwalls and wingwalls, but that many older (and some

Back to matrix

modern) culverts are not constructed with these features. Thus, under certain hydraulic related, site-specific, circumstances replacement of an older style culvert inlet with an improved inlet can dramatically increase the capacity of the culvert or justify downsizing the culvert barrel.(4)(5)

Flood hazard related problems due to culvert downsizing or inadequate capacity might be solved with upstream detention or retention ponds. Another possibility is for the hydraulics engineer to consider risk analysis that may permit justification of a lower flood design frequency.

Sliplining

One of the more effective ways to restore a culvert to a functional condition is by sliplining, which is the process of lining the culvert with either conventional or new types of prefabricated culvert products. In a sense, almost any type of culvert can be sliplined with almost any kind of culvert material. The proper selection of the most appropriate material will depend upon many factors, including:

- *Type, kind and size of the existing culvert;*
- *Structural and functional (hydraulic) conditions and adequacy of the existing culvert;*
- *Site-specific conditions*

Urban or rural location

Flat or mountainous terrain

Amount and velocity of water passing through the culvert at the time of the work;

- *Effluent characteristics;*
- *Design life requirements;*
- *Service life assigned;*
- *Economic factors including the cost of materials, labor and equipment; and*
- *Expected maintenance.*

Depending on the materials and techniques used for the sliplining, it may be possible to restore the structural strength of deteriorated culverts and to minimize the loss in hydraulic capacity. It may also be possible to eliminate the influence of environmental conditions that led to the deterioration of the existing culvert, such as the effects of acid mine runoff or caustic water, by selecting a lining or interior coating material that is resistant to such conditions. Although the lining process may reduce the internal cross-sectional area of the existing culvert, some plastic, precast concrete and lined corrugated metal pipe have a lower Manning's roughness coefficient than that of the existing culvert.

Procedures - There are a wide variety of individual techniques that may be used to slipline a culvert, that depend upon the above factors as well as the contractor's knowledge and experience with this type of work and the equipment that must, or can, be used for the work. The following steps are normally required for the sliplining process:

Divert and/or control water passing through the culvert.

Clean and make any repairs in the existing culvert that may be necessary prior to sliplining. Repair embankment as well by identifying voids and grouting behind and culvert.

Construct a guideway on the invert of the culvert, to facilitate the sliplining of sections into the existing culvert.

Install segments of the liner in the culvert, by sliplining, and connect them together.

Grout or seal the space between the liner and the existing culvert.

Perform a check to ensure complete grouting of annular space after sliplining.

As necessary, complete the project by constructing or modifying head- and wing-walls on the ends of the culvert.
There are many technical details that must be worked out for the actual construction project, including: (1) how the liner sections will be moved into place in front of the culvert, (2) how the sections will be slid into the culvert, and (3) if and how structural interaction will be established between the liner and the existing culvert.
Although there are some procedures that are relatively simple and straightforward, others are much more complex. In some cases it may be possible to stipulate standard construction procedures while at other times the procedures should be left open for contractor innovation, which may permit a contractor to use special equipment or techniques that may reduce the cost of the work.
More detailed information on the sliplining process and techniques that have been used are provided in appendix B-39 and B-40 on sliplining and grouting sliplined culverts.

Inversion Lining

Inversion lining is a process by which a culvert is lined with a resin-impregnated polyester felt tube that provides a continuous lining of the existing culvert. The felt liner is impregnated with thermosetting polyester resin and the interior surface is coated with a layer of polyurethane provide corrosion and abrasion resistance and some reduction in roughness for increased hydraulic efficiency. The thermosetting resin is cured in place by the heating and recirculation of the water that is used in the inversion of the polyester felt tube. The continuous lining eliminates problems due to both exfiltration and infiltration of water that may have been passing through the walls and joints of the existing culvert. Depending on the thickness of the liner and the type of resin used, some structural strength may be provided to enhance the strength of the existing culvert.
The process may be used with all types of culvert materials including the following: brick, concrete, corrugated metal, stone masonry, terra cotta, and timber. It provides a close fitting liner for all shapes including: round, oval, trapezoidal, elliptical and arched in sizes from 6 inches to over 72 inches. A particular advantage of this type of liner is that it will bridge all joints and irregularities in the interior surface of the existing culvert. Because of its initial flexibility, the liner will conform to barrels that are longitudinally curved or sections that are displaced, with open joints between them.
The liner is custom-made to the exact diameter, thickness, and length of the culvert to be lined. The liner may be pre-impregnated with the thermosetting polyester and polyurethane resins and shipped to the jobsite in a refrigerated truck or it may be impregnated at the jobsite. The latter method is frequently used when the culvert is long and over 48 inches in diameter, because of the weight of the resin-saturated liner and difficulty in handling it in the uncured state. Precautions must be exercised that the impregnated liner is kept cold until the culvert is properly prepared and the lining operation can proceed without stop.
Consideration should be given to the requirement for sufficient water to invert the liner and to completely fill the culvert. If the culvert is in a municipal area it may be filled with water from a fire hydrant. In rural areas it may be necessary to truck water to the site."

Back to matrix

VI. CONCLUSION

This document is for the sole purpose of assisting design professionals and project owners in the evaluation of concerns, and possible repairs for newly installed reinforced concrete pipe (RCP). While addressing possible issues that may occur while evaluating post installation inspection of RCP, the reference materials cited contain much more detailed information than what is presented within this document. Decision makers are encouraged to review the complete list of reference material to make a more fully informed decision based upon actual site conditions and design considerations of each individual project.

VII. REFERENCE AND SUPPORT DOCUMENTS FOR RCP EVALUATION AND REPAIR MATRIX

Note: Some documents are copyright protected therefore only links are provided to allow purchase/view from user.

1. ASTM C1479 - 10 Standard Practice for Installation of Precast Concrete Sewer, Storm Drain, and Culvert Pipe Using Standard Installations http://www.astm.org/Standards/C1479.htm
2. ACPA CP Info "Cracks In Installed Reinforced Concrete Pipe" http://www.concrete-pipe.org/pdf/2007-09-CP-Info-Cracks-in-installed-Reinforced-Concrete-pipe.pdf
3. AASHTO LRFD Bridge Design Specifications, Customary U.S. Units, 5th Edition, 2010 Interim Revisions https://bookstore.transportation.org/item_details.aspx?id=1615
4. Concrete Pipe Design Direct Design versus Indirect Design/Strength Tested Pipe (Available thru The American Concrete Pipe Association)
5. The Case Against the Ultimate Load Test RCP By M.G. Spangler (Available thru The American Concrete Pipe Association)
6. AASHTO PP-63-09 "Standard Practice for Joint Selection"
7. FHWA Culvert Inspection Manual http://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=31&id=57
8. Concrete Pipe Installation Guide http://www.concrete-pipe.org/installation.htm
9. Concrete Pipe Installation Procedures – Do's and Don'ts http://www.concrete-pipe.org/installation.htm
10. AASHTO LRFD Bridge Construction Specification - Section 27
11. Autogenous Healing of Cracks 1999 by Carlos Edvardsen ACI Materials Journal Technical Paper
12. Healing of Cracks in Lightweight Concrete 1989 by Avi Mor, et al American Society for Testing and Materials
13. Design Information Bulletin (DIB) #83-01-5.1 Problem Identification and Associated Repair for Culvert Barrels http://www.dot.ca.gov/hq/oppd/dib/dib83-01-5.htm
    CADOT DIB #83 Appendix http://www.dot.ca.gov/hq/oppd/dib/dib83-01-12.htm
14. FHWA Culvert Repair Practices Manual Vol.1 http://isddc.dot.gov/OLPFiles/FHWA/010551.pdf
    FHWA Culvert Repair Practices Manual Vol. 2 http://www.linkpipe.com/PDF/Pages_from_010550.pdf
15. AASHTO Highway Drainage Guidelines 4th Edition – Copyright 2007 https://bookstore.transportation.org/item_details.aspx?ID=1012

ADDITIONAL READING AND RESOURCES:

Crack Evaluation:

ACPA Buried Facts –"Culvert Inspection"
http://www.concrete-pipe.org/buried_facts/culvert_insp.pdf

OCPA RCP Pipe Info Book, see Significance of Cracking
http://www.ocpa.com/_resources/OCPA_PipeInfoBook.pdf

ACPA CP Info "Significance of Cracks in Concrete Pipe"
http://www.concrete-pipe.org/cpinfo/Significance%20Of%20Cracks%20In%20Concrete%20Pipe.pdf

"Effects of Cracks in Reinforced Concrete Sanitary Sewer Pipe"
http://www.concrete-pipe.org/cpinfo/Effects%20Of%20Cracks%20In%20Reinforced%20Concrete%20Sanitary%20Sewer%20Pipe.pdf

"Effects of Cracks in Reinforced Concrete Culvert Pipe"
http://www.concrete-pipe.org/cpinfo/Effects%20Of%20Cracks%20In%20Reinforced%20Concrete%20Culvert%20Pipe.pdf

RCP Durability:
"Precast Concrete Pipe Durability"
http://www.concrete-pipe.org/cpinfo/Precast%20Concrete%20Pipe%20Durability.pdf
"Culvert Durability Study"
http://www.concrete-pipe.org/buried_facts/culvert_dura.pdf

PIPE Repair:
Free Trial of TAG-R Trenchless Rehabilitation Decision Software – Available @ Louisiana Tech University Trenchless Technology Center – Purchase TAG-R @ NASSCO.com
http://www.tagronline.com/login.asp

http://www.concrete.org/general/RAP-1.pdf
http://www.concrete.org/general/RAP-2.pdf
http://www.concrete.org/general/RAP-3.pdf
http://www.concrete.org/general/RAP-4.pdf
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http://www.concrete.org/general/RAP-11.pdf