NORTH CAROLINA DEPARTMENT OF TRANSPORTATION
PARTIAL AND FULL DEPTH REPAIR MANUAL

TABLE OF CONTENTS

North Carolina Department of Transportation
Procedure for Repair of Portland Cement Concrete Pavement

Portland Cement Concrete (PCC) pavements are specified for their durability and low maintenance requirements. The long-term performance of the PCC pavement depends greatly on the initial construction practices. That is why is it supremely important that PCC pavements are constructed of quality materials and quality workmanship in accordance with the Specifications. Most of the problems that hinder PCC pavements are the results of flaws in the initial construction or lack of maintenance inspection.

This manual identifies some of the common types of PCC pavement distress, their causes, and describes typical methods and procedures for the repair. When pavement distresses occur the cause of the distress must be corrected at the source of the problem.

Concrete pavements, like other construction materials, expand and contract with moisture and temperature changes and may show early distress after paving has been completed. Distress could occur while the concrete is still in the plastic state or soon after the concrete has hardened. Examples of common early distressed problems are:

1. Shrinkage cracking
2. Spalling
3. Full-depth cracking

When early cracking or distress is observed, the cause of the problem should be identified and appropriate corrective actions taken to reduce the potential for additional cracking or spalling to develop.

SECTION I
COMMON DISTRESSES

Plastic Shrinkage Cracking:

Shrinkage cracking is shallow (1″-4″ deep) closely spaced parallel cracks in the top surface of the concrete slab. When the rate of evaporation is higher than the rate of cumulative bleeding in plastic concrete, shrinkage cracking has the potential to develop. Often shrinkage cracks form perpendicular to the direction of the wind at the time of placement.

Plastic Shrinkage Cracks

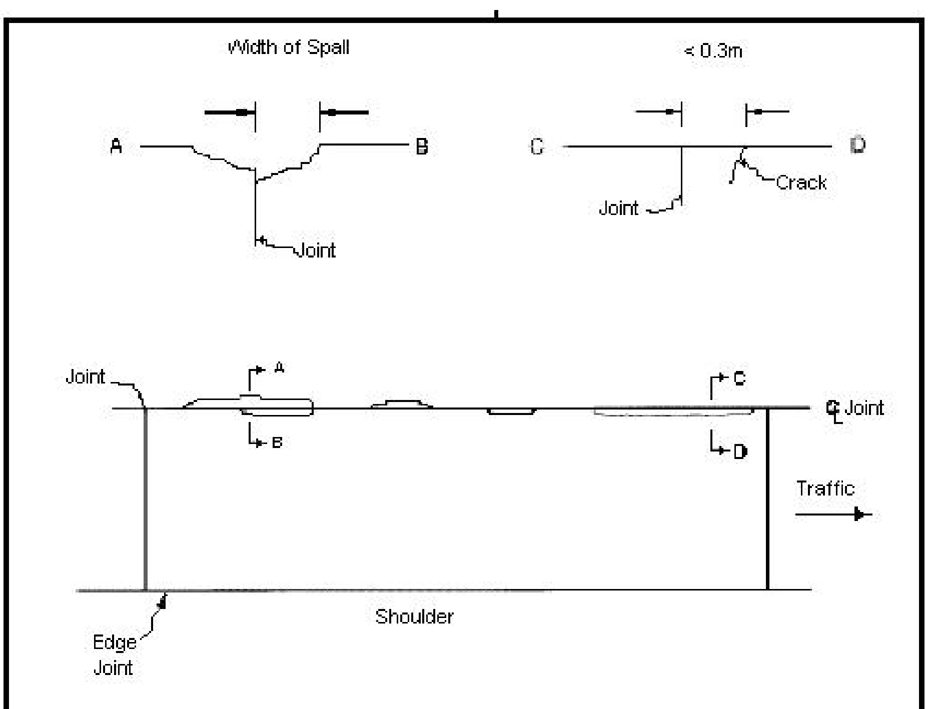
When plastic shrinkage cracks are suspected it is recommended that 4″ cores be taken to determine the depth and severity of the cracking. Depending on the depth of cracking, partial or full-depth replacement is required. If the crack is deeper than 3″ or if extensive cracking is observed, full-depth slab removal and replacement will be required. Both full depth and partial depth procedures are addressed later in this manual.

To reduce the susceptibility to plastic shrinkage cracking, fresh concrete should be protected from environmental conditions such as wind, high temperatures, and low humidity. The internal concrete temperature often plays a part as well. High internal concrete temperature increases the potential for plastic shrinkage cracking. Lowering the internal concrete temperature or applying a curing compound early will reduce the susceptibility to shrinkage cracking.

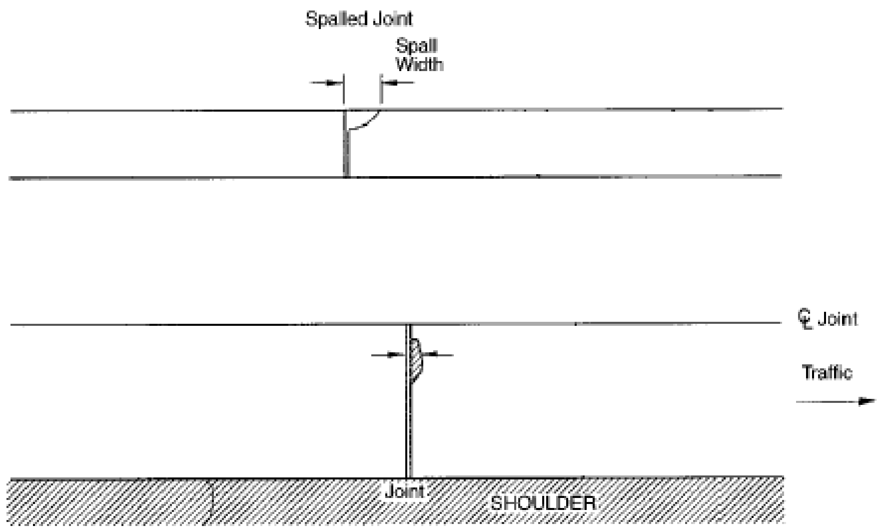
Spalling:

SPALL AT TRANSVERSE JOINT

Spalling is defined as cracking, breaking, chipping, or fraying of slab edges within 0.3 meters from the face of the longitudinal or transverse joint. Spalling or excessive joint raveling may develop as a result of the joint sawing operations, use of the wrong blade size, or poor operation of the sawing equipment, or incompressible material infiltrating into the joint.



LONGITUDINAL SPALLS FOR REPAIR



SPALLED JOINT (CRACKING IN THE SLAB).
SPALLING IS CAUSED BY OBSTRUCTIONS OF THE JOINT CLOSURE DUE TO INCOMPRESSIBLES (SAND, SMALL STONES, FRAGMENTS OF CONCRETE, SLURRY, ETC.) IN THE JOINT, AND SAW CUT TIMING.

Spalling can occur when unsealed joints or cracks fill with incompressible material that prevents movement of the slab due to thermal expansion. Other causes of spalling are poor construction, poor repairs, dowel bar lockup, improperly located dowels, etc.

The Specifications require taping or sealing joints adjacent to new lane construction to prevent material from entering joints and causing joints to spalling. After sawing the joints a good paving practice would be to seal off the newly formed joint to prevent fine material from entering the joint before it is sealed if construction traffic has been allowed on to the new pavement.

Minor joint spalling is typically repaired using a partial depth repair technique discussed in Section II of the manual. Partial-depth repair is typically used to repair spalling at pavement joints. If the spalling is severe and excessive in length, replacement of the affected slab should be considered.

Full Depth Cracking:

Cracks that extend through the entire depth of the slab is defined as full depth cracking. These cracks often begin moving and functioning as a contraction joint without load transfer devices.

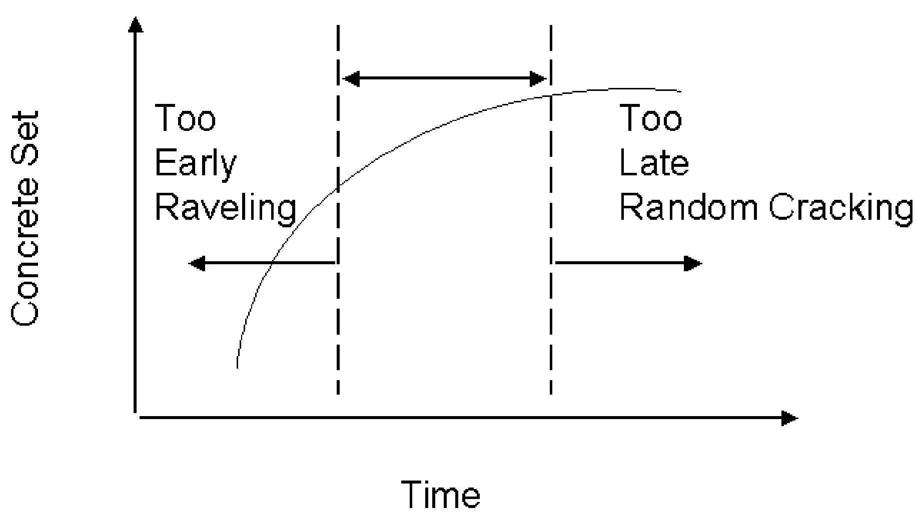
Full depth cracking can be caused by: repeated heavy traffic loads, failure of the doweled joints to function properly, loss of aggregate interlock along the crack face, inadequate joint sawing (saw timing), lack of subgrade support, excessive shrinkage, or the intrusion of incompressible materials in the open cracks.

To prevent full depth cracking saw joints in the sawing window, cure fresh concrete in a timely manner, and properly maintain joints by protecting the joints from the infiltration of incompressible material.

Saw Timing Window:

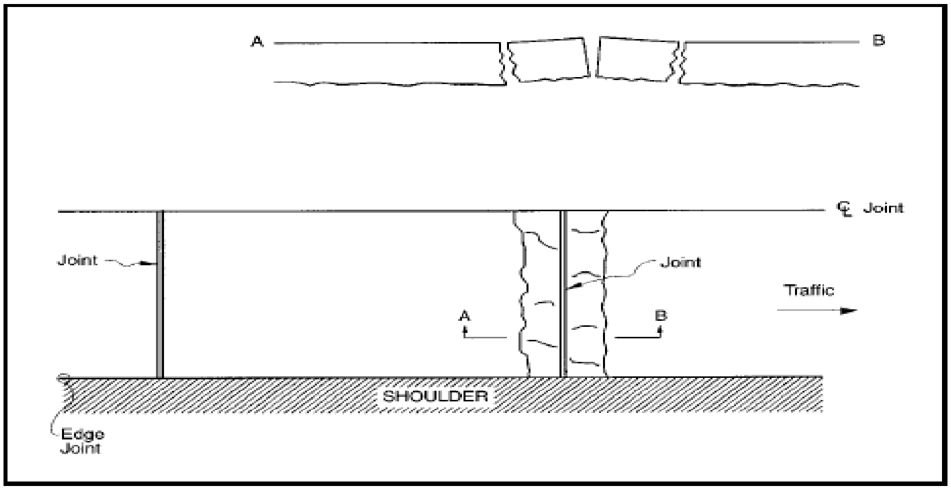
There is an optimum time to saw contraction joints in new concrete pavements as illustrated below by the Saw Timing Window. The window for sawing is a short period after the placement of the concrete pavement when the concrete pavement can be cut to control crack formation (controlled cracking). This timing begins when the strength of the concrete pavement is sufficient to saw without excessive raveling or breaking aggregates free along the surface of the concrete pavement. The sawing window ends when the concrete pavement starts shrinking significantly which is known as dry shrinkage or temperature contraction. When the window ends uncontrolled cracking will occur.

Defining the sawing window in the field can be done by the *scratch test method.* Experienced saw operators and technicians rely on judgement and the scratch test to estimate the time to saw the joints. The test requires scratching the concrete surface with a nail or knife blade, and then examining the depth and how clear the scratch is. In general, if the scratch removes the surface texture it is too early to saw without raveling problems.

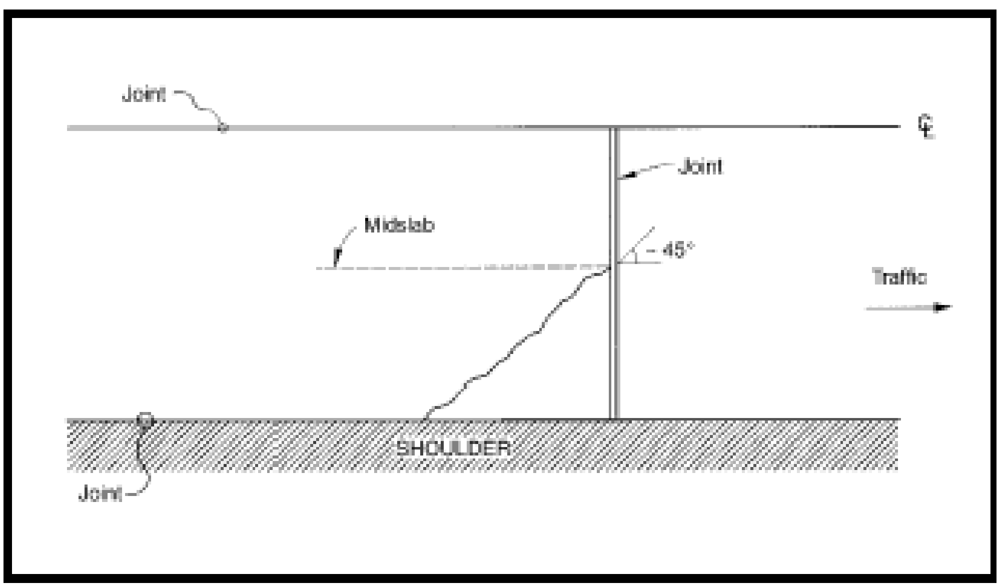


SAW TIMING WINDOW

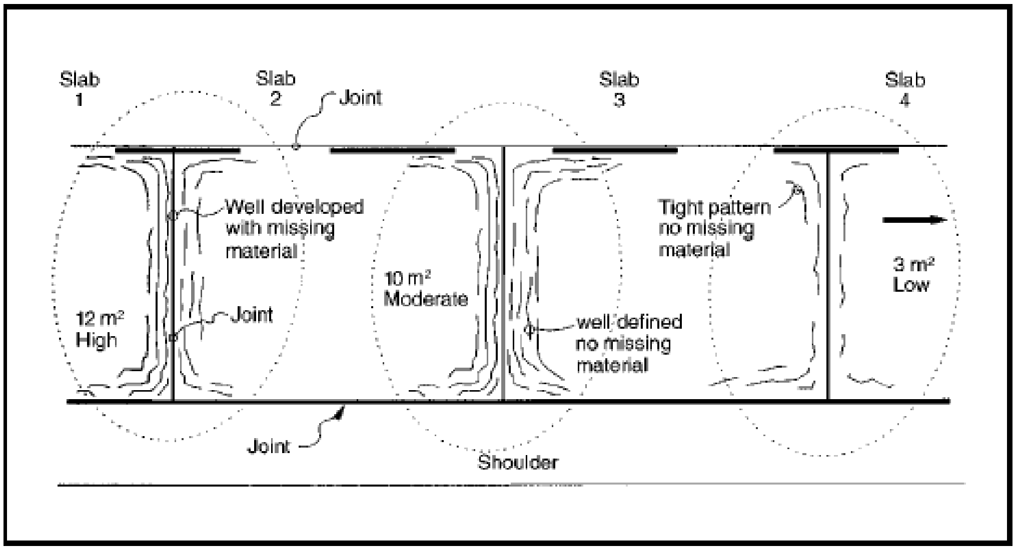
When full depth cracking occurs the only repair option is a full-depth repair method. The full depth repair method is discussed in Section IV of this manual.



CANDIDATE FOR FULL DEPTH REPAIR (BLOW UP)
BLOW UPS ARE CAUSED BY THE BUCKLING AND SHATTERING FROM THERMAL EXPANSION AND USUALLY OCCURS IN HOT WEATHER AT TRANSVERSE JOINTS OR CRACKS WHICH DO NOT ALLOW FOR EXPANSION.



CANDIDATE FOR FULL DEPTH REPAIR (CORNER BREAK)
CAUSED BY THE INTRUSION OF MATERIAL IN THE JOINT AND POOR SAW TIMING.



<u>CANDIDATE FOR FULL DEPTH REPAIR ("D" CRACKING)</u>
<u>CAUSED BY FREEZE-THAW EXPANSION AND OCCUR NEAR TRANSVERSE JOINTS AFTER MANY YEARS OF SERVICE.</u>

SECTION II
PARTIAL DEPTH REPAIR:

The purpose of partial depth repairs is to correct localized areas of concrete pavement distress such as edge spalling. Repair of this type restores rideablility, deters further deterioration of the joint, reduces foreign material damage potential, and provides proper edges so those joints can be effectively resealed.

Below are the procedures for both the Partial Depth and Full Depth repair methods. When the contractor submits his procedure and materials for approval to the Resident Engineer he should have materials that meets the requirements of the enclosed specifications and procedures that are as detailed as shown below.

Spall repair shall be for small areas only. The areas shall be cut square or with a maximum length to width ratio of 1.5:1. If two spalls are less than 12 inches apart they shall be combined. A maximum to two spall repairs per joint (per slab) will be allowed.

PROCEDURE FOR BASIC CONCRETE PAVEMENT SPALL REPAIR (PARTIAL DEPTH REPAIR):

PROCEDURE:

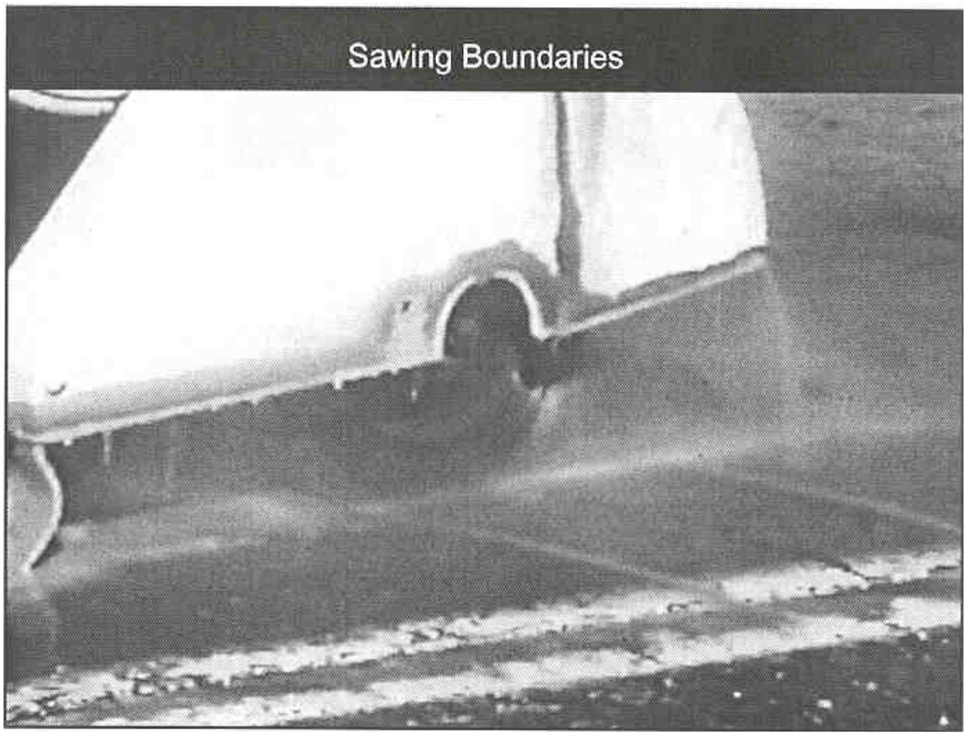
1. Survey the limits of the repair:
   Prior to repairing the spalled area, a survey of the spalled area should be made to determine the limits of unsound or delaminated concrete. Sounding is done by striking the existing concrete surface with a steel rod, chain, or hammer. Delaminating or unsound concrete will produce a dull or hollow thud, while acceptable concrete will produce a sharp metallic ring. The repair boundaries of the repair should be extended beyond the detected unsound area concrete 4". All partial depth repairs should be of rectangular-shape regardless of the location.

   A sketch of the slab showing locations and severity of the spalls should be made. Pictures, if available, should accompany the sketch of the slab. An example of symbols and a sketch are shown in Section V or this manual.

MARKING THE BOUNDARIES OF A PARTIAL DEPTH REPAIR

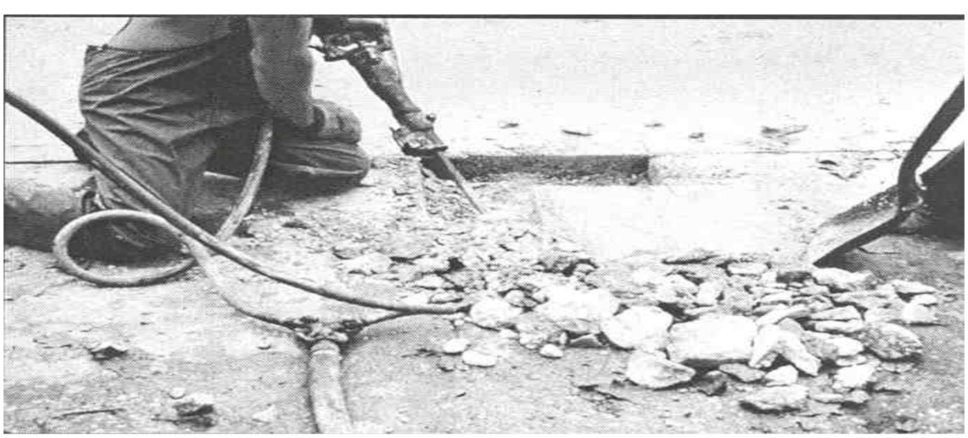
2. Remove the joint or crack sealant adjacent to the repair area.

3. The repair boundaries should be kept rectangular and aligned with the joint pattern to avoid irregular shapes. Irregular shapes may cause cracks to develop in the repair material. Saw cut the parameter of the repair area to a minimum depth of 4". Over saws, or partial depth cuts outside of the repair boundary, can be eliminated by using a core drill in the corners of the repair and then chiseling out the corner of the repair. A saw cut along an existing joint is made by skimming the blade along the joint face to remove sealant residue and leave a clean vertical joint face.



SAWING THE OUTSIDE BOUNDARIES OF A PARTIAL DEPTH REPAIR

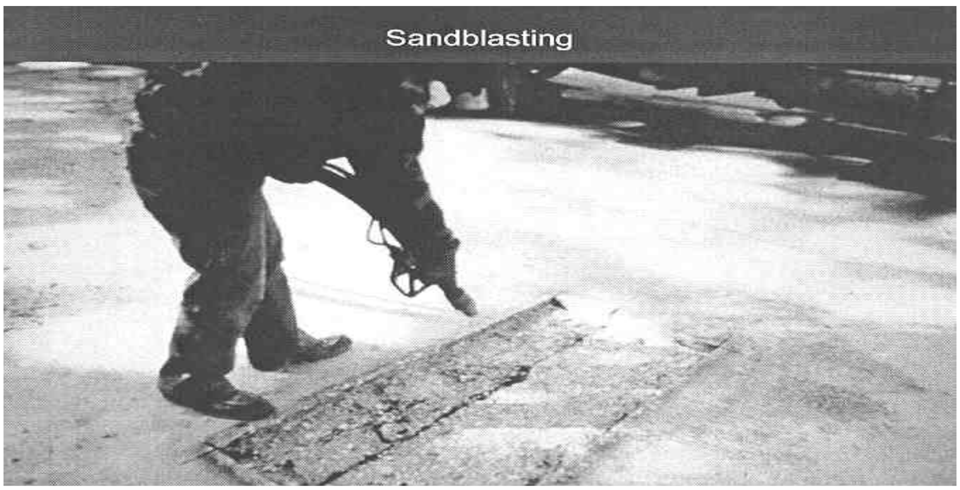
4. Remove all unsound concrete from the affected area to a minimum depth of 4", but do not expose the dowel bars. Be careful not to damage the underlying concrete during the removal process.



REMOVING THE UNSOUND CONCRETE

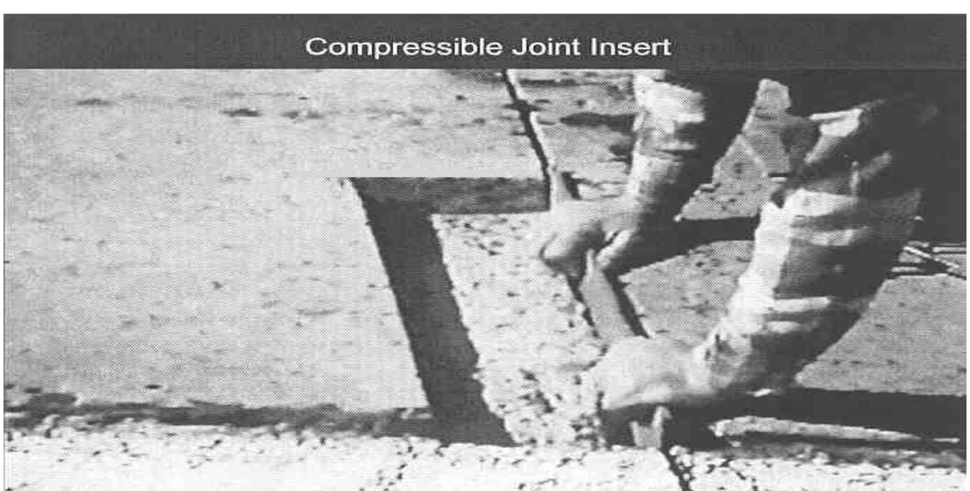
5. Sound test the newly exposed concrete to ensure all of the delaminating or unsound concrete has been removed. With a hammer to remove any fractured rock.

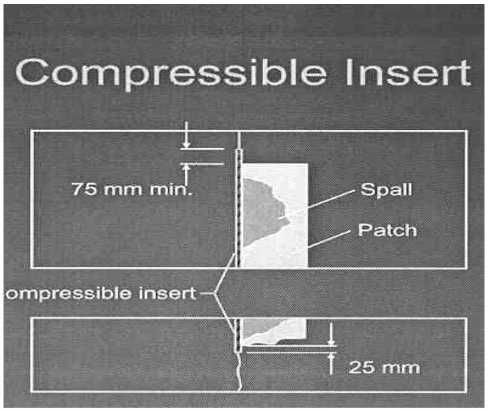
6. Thoroughly clean the repair area; remove any dust, loose aggregate, etc. from the repair area. Prior to patching, the exposed vertical faces and bottom of the repair area should be sandblasted to remove all loose particles, oil, dirt, dust, asphaltic concrete, rust, and other contaminates. After sandblasting, blow out area with an air lance connected to an air compressor to remove sandblast sand, etc. Check the area for contaminates prior to patching the area. Any contamination on the repair surface will reduce the bond between the new patch material and the existing concrete pavement.

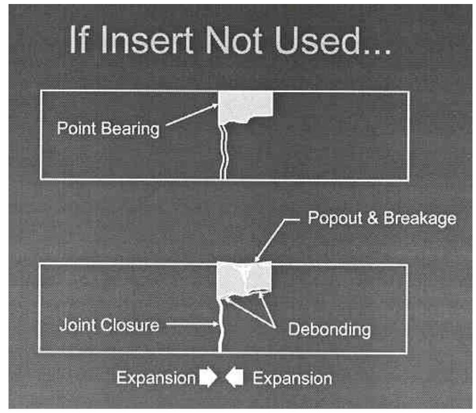


SANDBLASTING THE REPAIR AREA

7. To prevent the repair material from flowing into the adjacent joints, use caulk in the saw cuts and adjacent joints. When placing a partial depth patch adjacent to any joint, there must be no bond between the repair patch and the face of the adjacent concrete joint. A compressible insert such as Styrofoam, asphalt-impregnated fiberboard, or plastic joint inserts should be set to form the joint area prior to placing the patch material. The new joint should be no less than the same width as the existing joint or crack. Failure to reestablish the joint as described can result in a repair failure.







USE OF COMPRESSIBLE INSERTS AND PROBLEMS CAUSED IF INSERTS ARE NOT USED

8. Saturate the repair area with water and/or ice mixture (for air temperature greater than 80°F.) if required by the manufacturer's product instructions.

9. Remove all excess water from the repair area with air to achieve a Saturated Surface Dry (SSD) condition.

10. Apply a bonding agent with a scrubbing effort to thoroughly coat the patch surface and fill the voids.

11. Place repair material in accordance with the manufacturer's recommendations. Materials for Partial depth repairs are discussed in Section III of this manual.

PLACING REPAIR MATERIAL WITH COMPRESSIBLES IN JOINT LOCATION

12. Strike off patch flush or higher than the existing roadway surface. If patch is raised, grinding to a smooth surface will be required, however, patch material which is not flush with the pavement will have to be removed and replaced.

13. Protect the repair material from direct sunlight and/or freezing temperatures during curing. Allow the repair material to cure per the manufacturer's recommendations.

14. Saw and Reseal joints in accordance with Article 700-12 of the NCDOT Standard Specifications.

SECTION III
PARTIAL DEPTH REPAIR MATERIAL

Material for small repairs such as corner breaks should have the following specifications:

% water by weight			**7.9 – 8.0**
Flow @ 5 drops			**100**
Setting time (ASTM C 266 @ 72°F **Initial:** **Final:**			 **14 to 75 minutes** **20 to 90 minutes**
Compressive Strength, psi (ASTM C 109) **2 hours** **24 hours** **7 days** **28 days**			**70°F** **1500** **4500** **8000** **9000**
	1 day psi	**7 days psi**	**28 days psi**
Flexural Strength (ASTM C 348)	**580-850**	**880-1000**	**1100-1150**
Splitting Tensile (ASTM C 496)	**550-850**	**1100-1200**	**1250-1300**
Slant Shear Bond (ASTM C 882)	**1800-2500**	**2900-3000**	**3100-3360**
Direct Shear Bond (Michigan DOT)	**150-200**	**350-390**	**375-450**
Direct Tensile Bond (ChemRex, Inc. Method	**100-150**	**170-190**	**290-300**
Modulus of Elasticity (psi X 10^6)	**3.8**		**4.7-5.1**
Abrasion resistance, inches of wear (ASTM C 779A, 28 day, air cured sample) **30 minutes** **60 minutes**			 **0.0110 inches** **0.0260 inches**
Freeze/thaw resistance (ASTM C 666 A)		**Retain 98.3-98.5% of original dynamic modulus**	
Rapid Chloride Permeability[2] (AASHTO – T277/ASTM C 1202			**960-990 coulombs (very low)**
Scaling resistance (ASTM C 672) **25 cycles** **50 cycles**		**Weight Loss lb./ft^2** **$CaCl_2$ 0.003** **$CaCl_2$ 0.005**	 **NaCl 0.067** **NaCl 0.084**

[1]Typical Results from air cured samples.

[2]Typical results from 3 days moist cured and 39 days air cured samples.

15. Elastomeric Concrete should be used for transverse joints because of wheel traffic concerns. Provide material that complies with the following requirements at 14 days.

Performance Data (Elastomeric Concrete - Transverse Joints Repair)

Concrete Properties	Test Method	Minimum Requirement
Bond Strength to Concrete, psi	ASTM D 638	450
Brittleness by Impact, ft-lb.	Ball Drop	7
Compressive Strength, psi	ASTM D 695	2800
Binder Properties (with aggregate)	**Test Method**	**Minimum Requirement**
Tensile Strength, psi	ASTM D 638	800
Ultimate Elongation	ASTM D 638	150%
Tear Resistance, lb/in	ASTM D 624	90

In addition to the requirements above, use elastomeric concrete that also resists water, chemical, UV, and ozone exposure and withstands extreme temperature (freeze-thaw) changes.

Furnish a manufacture's certification verifying that the materials satisfy the above requirements. If requested, provide samples of elastomeric concrete to the Engineer to independently verify conformance with the above requirements.

A manufacture's representative should be present on-site during the installation of the elastomeric concrete until the crew has a comfort level working with this material.

SECTION IV
FULL DEPTH CONCRETE PAVEMENT REPAIR:

Localized full-depth cracking may result from one or more of the following:

1. Late transverse joint sawing or insufficient depth of sawing.
2. Misaligned dowel bars.
3. Excessive curling and/or warping
4. Rapid surface cooling.
5. Early age loading by construction equipment
6. Excessive drying shrinkage.
7. Excessive base friction restraint

Full-depth cracking that appears within 30 days is usually the result of poor construction practices. The important items to consider for full-depth cracking include:

1. Panels in pavement areas with full depth cracking that extends the full width or length of the slab panels should be replaced.

2. Full depth cracking in pavement areas that extends less than one-third the width or length of the slab should be treated as a full width crack.

3. Full depth corner cracking in pavement areas must be repaired by full panel replacement.

4. Use of partial panel replacement in critical pavement areas on new pavement is not recommended.

5. Proper procedures need to be followed for slab removal and replacement. The procedures must include the following:

    a. Slab removal without damaging adjacent sound slabs or the base.
        - Use of double saw cut method along slab perimeter.
        - No heavy impact loading to break slab into small pieces.
        - Saw cut panel into smaller segments and lift out.
    b. The base must be inspected for damage and corrected prior to concrete placement.
    c. Use of approved concrete mixture for machine and hand placement operations
    d. Use of vibration to consolidate the concrete.
    e. Use of proper techniques to finish, texture, and cure replacement slab.

Types of distress that occur in rigid pavements which may justify full-depth repair include:

- Corner break
- Durability ("D") cracking
- Patch deterioration
- Shattered slab (A slab broken into four or more pieces with some or all cracks of medium and high severity.
- Joint or crack spalling (if spalling is one-half the slab thickness or deeper)

Many rigid pavements are also subject to spalling and faulting at intermediate cracks. This deterioration may be caused by repeated heavy traffic loads, failure of doweled joints to function properly, and/or the intrusion of incompressible materials in open cracks (hauling on new pavement with initially cut joints).
The following procedure should be used for full depth repair:

PROCEDURES FOR BASIC FULL DEPTH CONCRETE PAVEMENT REPAIR:

1. Define Repair Boundary Area:

Each distressed area should be examined and the repair boundaries marked on the slab. A detailed survey, with sketch and photos, should be made to identify the required repair area. An example of symbols and a sketch are shown in Section V of this manual. Guidelines for locating repair boundaries are provided below.

- All full depth repairs should be full lane width.
- The minimum recommended repair length is 6 ft (1.8 m). The Standard Specifications require that 6 feet is a minimum length when load transfer is provided.
- On multilane pavements, if a distressed area exists in adjacent lanes, align repair boundaries to avoid small offsets and to maintain continuity.

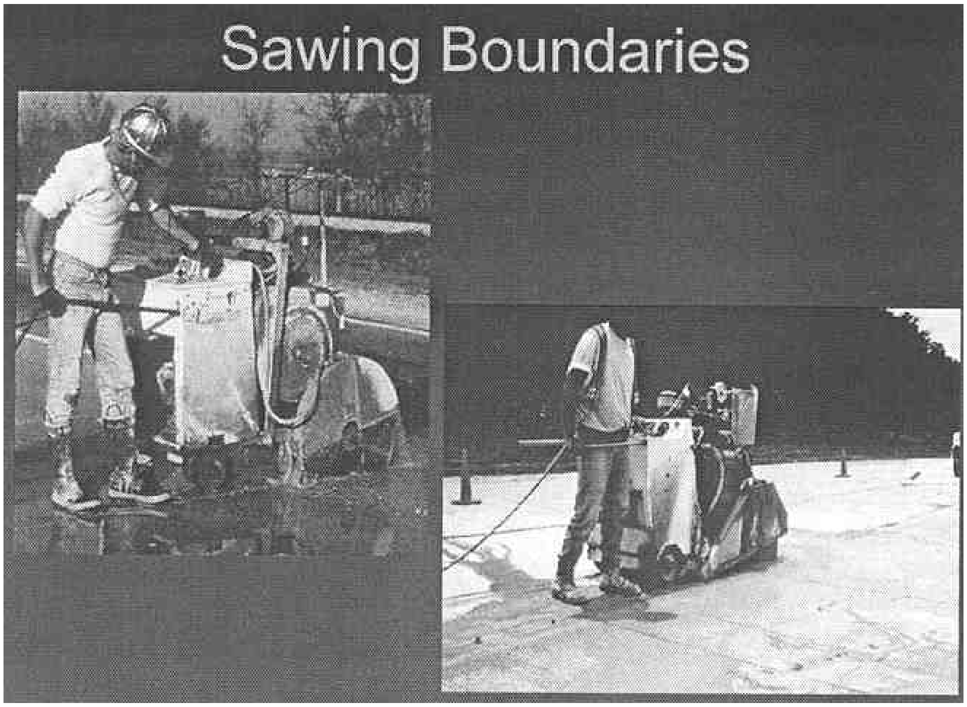
DEFINING THE REPAIR LIMITS

2. Saw Existing Concrete:

Isolate the repair area from adjacent concrete and shoulder materials using full depth saw cuts.

Full depth sawing will physically separate the repair area from sound concrete, eliminate damage at the bottom of the slab, provide necessary room for removal without damaging the surrounding materials, and leave smooth vertical faces for dowel bar placement. An air hammer shall not be used to outline the repair area.

Sawing operations should not proceed removal and repair operations by more than two days because the full depth cuts eliminate any load transfer. Not having effective load transfer could cause the repair area to begin pumping or punch into the subbase, causing subgrade damage.



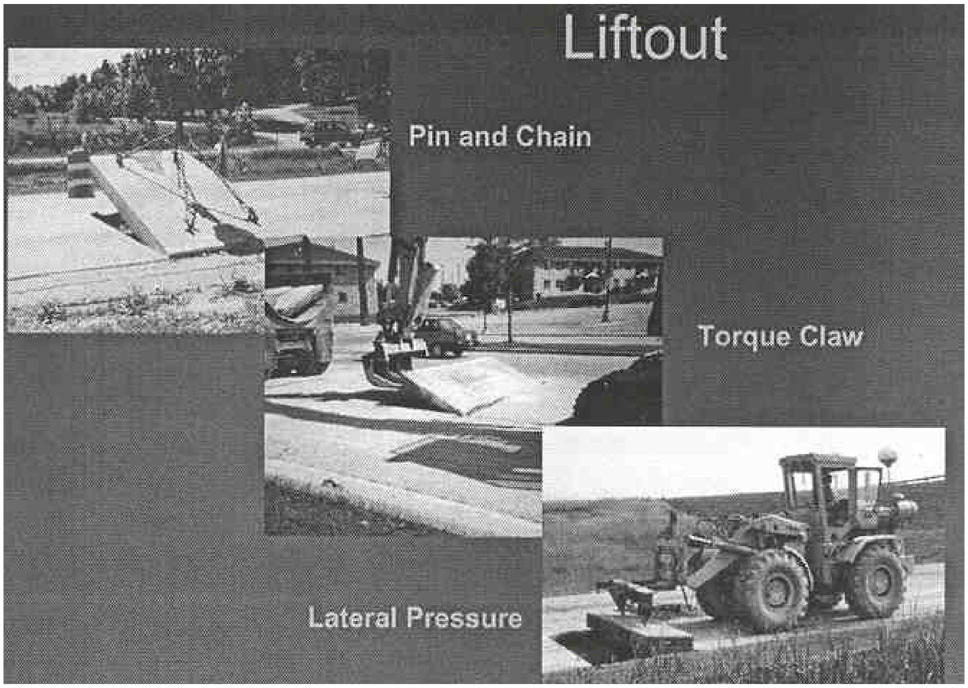
SAWING THE REPAIR LIMITS

3. Remove the deficient concrete slab:
Procedures that are used for removal must not spall or crack the adjacent concrete edges or unnecessarily disturb the base coarse. Two basic methods are used to remove concrete pavement, the lift-out method and the breakup method.

- Whenever possible, the lift-out method is preferable to remove the deteriorated concrete. The lift-out method is typically accomplished by using a crane or front-end loader to remove the damaged concrete from the repair area. After sawing the area full depth around the perimeter of the repair, multiple holes are drilled into the concrete slab and lift pins are inserted. Chains are then attached to the crane or front end loader to lift the damaged concrete slab out vertically.

  This operation should be closely monitored to make sure that no damage occurs to outside edges adjacent to the repair area. If damage to the adjacent concrete occurs, the repair area will have to be expanded.

  The lift-out method usually does not disturb the underlying subbase.



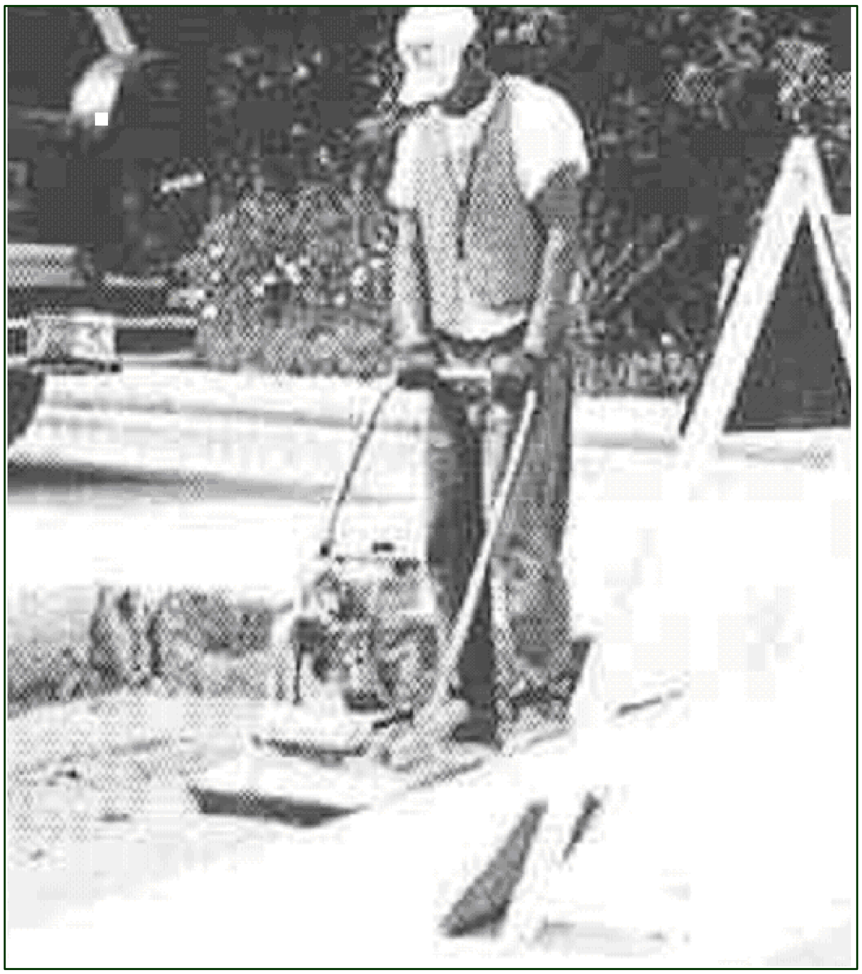
THE LIFTOUT METHOD

THE SAW CUTS FOR THE LIFTOUT METHOD

- The breakup and cleanout method is typically accomplished by using a pavement breaker and removing the broken pieces of concrete with a backhoe. This method will disturb the underlying base layer. The breakup and cleanout method can damage the adjacent slabs if proper sawing procedures of the area are not followed. When the outside of the repair area has been sawed with the full depth saw method additional saw cuts should be made approximately 1.5 to 2.0 feet inside the outside perimeter of the repair area. The breaking up the slab should start in the center of the repair area and work ouward. Once the center piece has been removed, a backhoe can easily lift out and remove the smaller pieces without damaging the outside edges of the repair area.

4. Prepare the Base layer:

After cleaning out the concrete from the repair area, repair any damage to the base coarse. If any damage to the underlying base is found, the base layer must be replaced with material that conforms to the Standard Specifications.

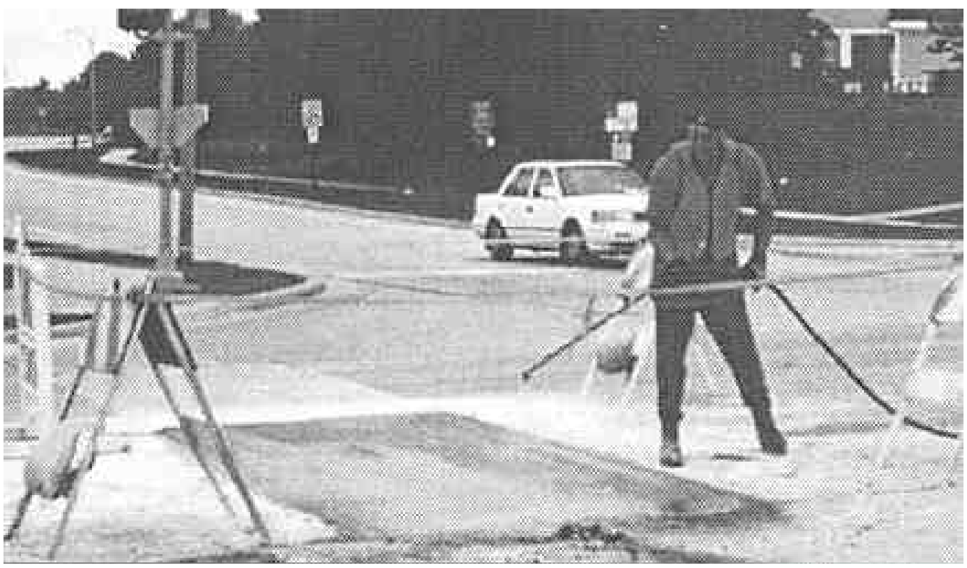


REPAIRING THE BASE LAYER

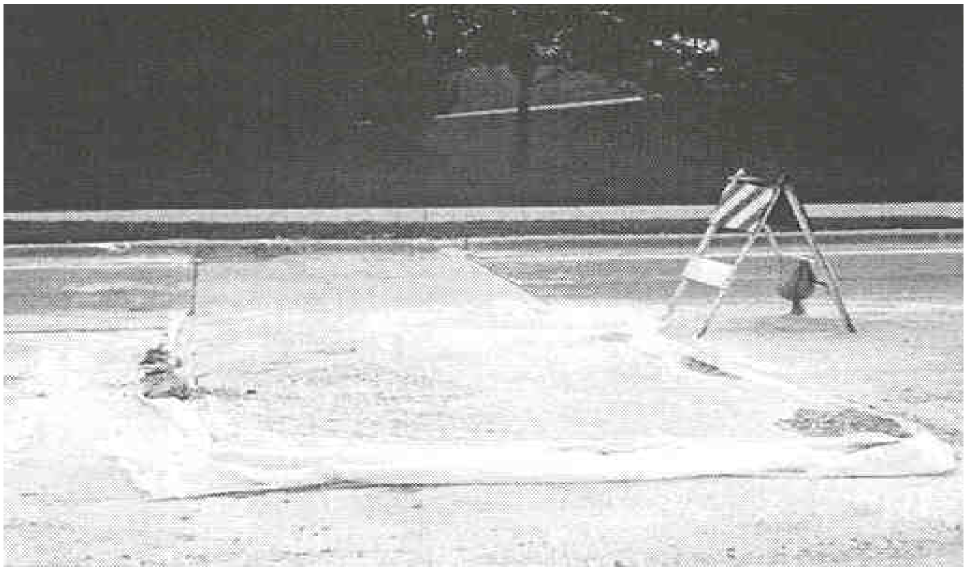
5. Provide Load Transfer:
Reestablishing load transfer across the transverse joints is the most critical factor affecting full-depth repair performance. Tie-bars should be drilled and epoxied into the adjacent concrete along the longitudinal joint. Dowel baskets should be installed at contraction joints, to provide adequate joint functionality. Tie bars of the same size as the dowel bars should be drilled and expoxyed along a transverse joint where there is not a regular contraction joint.

6. Sandblast and Clean Surfaces:
Sandblast and clean all surfaces and use an approved Portland Cement concrete pavement mix design for hand placement. The Portland Cement concrete used to fill the area shall be finished, cured, and jointed per the appropriate Standard Specifications.

7. Place and Finish Concrete:
Patched area should be protected from direct sunlight during curing and/or freezing temperatures.



Protect the Repair From Rapid Evaporation

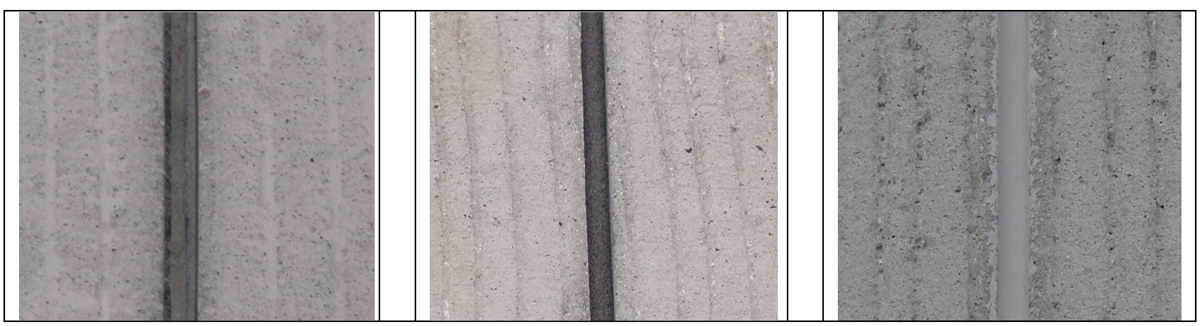


Protect and Cure the Repair

8. Cure and Insulate Concrete:

9. Saw and Seal Joints

Saw the joint to full depth within 7 to 12 hours.Reseal joints in accordance with Article 700-12 of the NCDOT Standard Specifications.



Pictures of joints left to right: Cleaned joint, Backer Rod in Joint, Completed joint

CRCP

The table below provides a summary of the CRCP distresses and severity levels that can be successfully remedied using full-depth repairs. Punchouts are the most common structural distress on CRCP that are addressed with full-depth repairs.

Candidate CRCP distresses addressed by full-depth repairs (Hoerner et al. 2001).

Distress Type	Severity Levels That Require Full-Depth Repair
Punchout	Low, Medium, High
Deteriorated Transverse Cracks[1]	Medium, High
Longitudinal Cracking	Medium, High
Blowup	Low, Medium, High
Construction Joint Distress	Medium, High
Localized Distress	Medium[2], High
D-Cracking (at cracks) [3]	High
Deterioration Adjacent to Existing Repair	Medium[2], High
Deterioration of Existing Repair	Medium[2], High

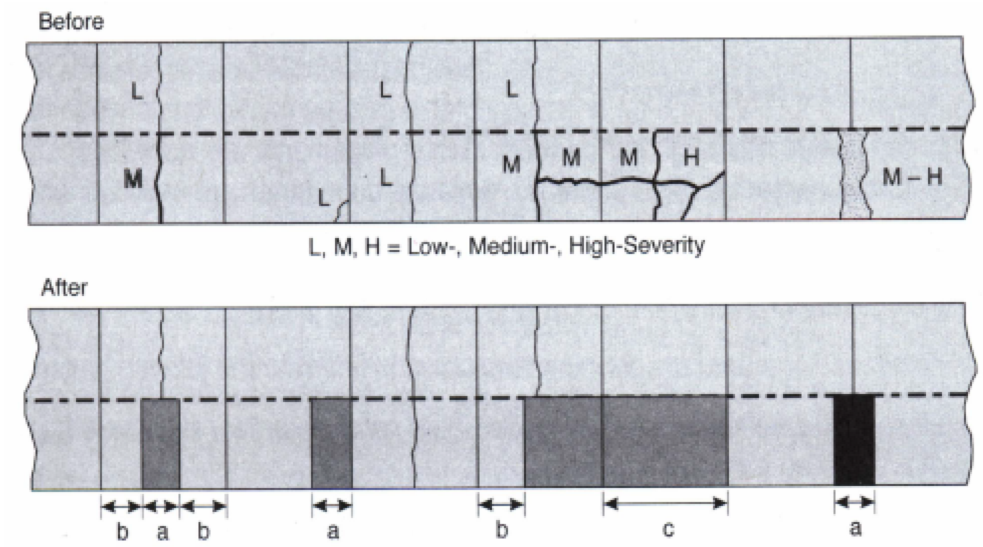
[1] Typically associated with ruptured steel.
[2] Partial-depth repairs can be used if the deterioration is limited to the upper one-third of the pavement slab.
[3] If the pavement has a severe material problem (such as D-cracking or reactive aggregate), full-depth repairs may only
provide temporary relief from roughness caused by spalling. Continued deterioration of the original pavement is likely
to result in redevelopment of spalling and roughness.
NOTE: Highways with low traffic volumes may not require repair at the recommended severity level.

Although full-depth repairs can be designed and constructed to provide good long-term results, the performance of full-depth repairs is very much dependent on best practices and the use of sound designs and best practices. Most problems found can be traced back to insufficient design, poor construction practice, or the placement of these repairs on pavements that are too deteriorated.

If properly designed and constructed, full-depth repairs can restore the pavement to "like new" condition in a near-permanent manner, but selection is very important to obtain the preferred results. Important points to consider in selecting this repair technique include the following:

- If the existing pavement is structurally deficient, and nearing the end of its pavement life, a structural overlay may be needed to prevent continued cracking of the original pavement.
- If the existing pavement has severe material problems such as D-cracking or reactive aggregate, full-depth repairs may only provide short-term relief from roughness caused by spalling and continued deterioration of the existing pavement is likely and result in regeneration of spalling and roughness.
- Additional joints introduced by full-depth repairs add to the pavement roughness so diamond grinding should be considered after the repairs are made to produce a smooth-riding long lasting surface.

Selecting Repair Locations and Boundaries



NOTES
a – Minimum length is 1. 8 m (6 ft).
b – Check distance between patches and nearby joints
c – Replace the entire slab it there are multiple intersecting cracks

The types of CRCP distresses that can be addressed through full-depth repairs are identified in table above.

Sizing the Repair

As illustrated in the figure below, subsurface deterioration accompanying structural distresses of CRCP can be quite extensive. Subbase deterioration is particularly prevalent near punchouts and wherever there is settlement or faulting along the longitudinal lane joint. The results of coring and deflection studies provide information on the extent of deterioration beneath the slab surface, and such studies are recommended on projects of any magnitude.

Guidelines for the determination of repair boundaries for CRCP are given below:

- A minimum repair length of 6 ft. is recommended if the reinforcing steel is tied; 4 ft. if the steel is mechanically connected or welded.
- The repair boundaries should not be closer than 18 in. to adjacent non-deteriorated cracks; however, if cracks are very closely spaced, it may be necessary to place the repair as close as 6 in. to an existing tight transverse crack.
- Full-lane-width repairs are generally recommended, although half-lane widths 6 ft. may be used when all distress are contained within that width

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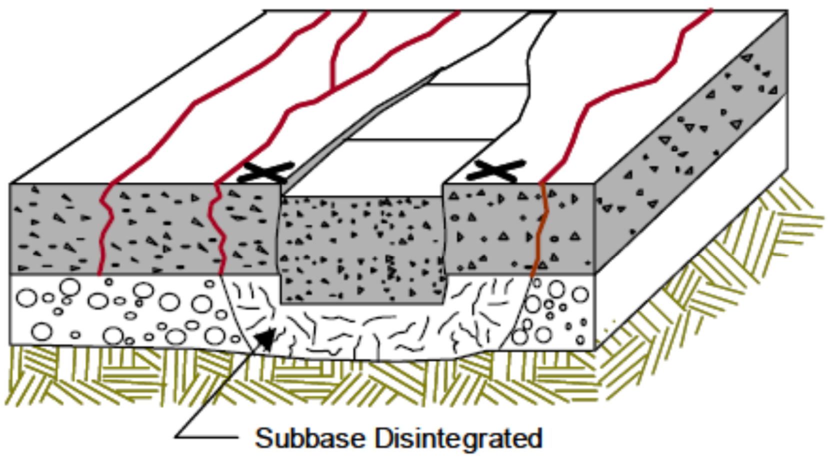
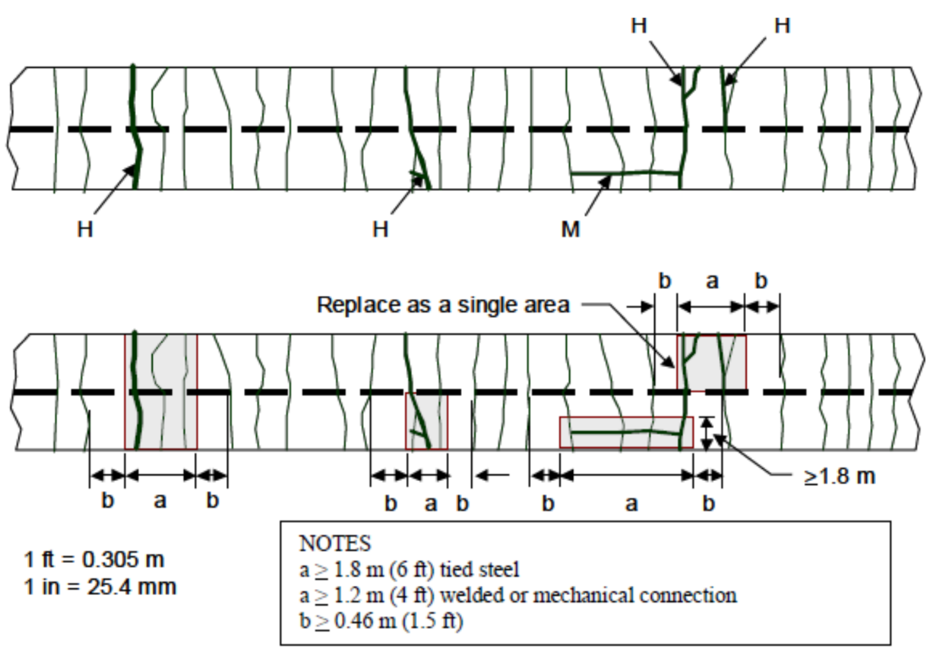


Considerable Pumping and Excess Water

These criteria are illustrated below provide adequate lap length and removal, and to minimize repair rocking, pumping, and breakup. The figure below illustrates these construction recommendations.



Multiple-Lane Repair Considerations

If a distress such as a wide crack with ruptured steel occurs across all lanes, special considerations are necessary because of the potential for:

- Blowups in the adjacent lane.
- Crushing of the new repair during the first few hours of curing by the expanding CRCP.
- Cracking of the repair during the first night as the existing CRCP contracts.

In order to minimize these problems, it may be necessary to place the concrete in the afternoon or evening to avoid being crushed by the expanding CRCP slab. In addition, it is recommended that the lane with the lowest truck traffic be repaired first.

Very High Early Strength Concrete Mix Design Preparation (If called for by the Contract or as approved by the Engineer)

Submit mix designs for Very High Early Strength Concrete for Concrete Pavement Repair in terms of saturated surface dry weights on M & T Form 312U for acceptance at least 30 days before proposed use.

Use a mix sufficient to obtain at least a flexural strength of 400 psi at 4 hours. Entrain 5 % ± 1.5% air in the freshly mixed concrete. Produce the mix with a maximum slump of 1.5" for placement by a fully mechanized paving train and a maximum slump of 3" for hand placement.

Use cement, fine aggregate, coarse aggregate, admixtures and, optionally, pozzolan as shown on the Department's approved list.

Submit 4 hour flexural strength results of at least 6 beams made and tested in accordance with AASHTO T126 and T97 with M & T Form 312U. In addition, submit 4 hour compressive strength results of at least six 4" by 8" or 6" by 12" cylinders and maturity test results of the mix. With permission of the Engineer, compressive strength testing and maturity testing may be used in lieu of or concurrent with flexural strength testing to determine the acceptability of the concrete in the field.

Design and produce the mix in accordance with BASF Chemical Company's 4 x 4 Concrete system or a comparable proprietary system. The timing of the addition of hydration control admixtures is critical to the performance of this concrete; therefore, an admixture representative shall be present on the job when Very High Early Strength Concrete is batched.

Selecting Repair Materials

The repair material should be selected based on the available lane closure time. The current state of the art in concrete pavement repair is such that virtually any opening time requirement can be met (from 4 hours to 24 hours or more), using either conventional portland cement concrete (PCC) or 4 X 4 High Early Strength Concrete. However, high early-setting mixes generally have higher costs and special handling requirements. A good rule of thumb in selecting the material for concrete pavement repair projects is to use the least exotic and/or most conventional materials that will meet the opening requirements.

Repairs

The most widely used repair materials for full-depth repairs are conventional PCC mixtures. Typical full depth repair operations utilize concrete mixes containing five to seven bags of cement (Type I, and sometimes Type III) per yd3 6.5 to 8.5 bags/yd3, and an accelerator to permit opening in 1 to 3 days. Type III cement, high cement factors 7 to 9.5 bags/yd3, and chemical accelerators are required for opening in 4 to 6 hours.

Local climatic conditions are an important factor in selecting a repair material. During hot, sunny, summer days solar radiation can significantly raise the temperature at the slab surface. When the ambient temperature is in excess of 90 ºF, it may be very difficult to place some of the very fast-setting materials because they harden so quickly. Although a set retarder can be used with some of these materials to provide longer working times, a better solution may be to use a slower-setting mix.

For high early strength concrete, the early strength gain is typically achieved by reducing the water to cement ratio (w/c), increasing the cement content, and by adding a chemical accelerator. High range water reducers are also typically added to reduce the amount of water required without a loss in workability. Because these early strength mixes typically contain higher cement contents and multiple admixtures, it is not uncommon for them to experience increased shrinkage, altered microstructure, and unexpected interactions. Guidelines are available that summarize the state of practice for high early strength concrete repairs, including the identification of material properties impacting high early strength concrete performance, the selection of materials and mixture design properties for high early strength concrete, and the identification of performance-related tests of fresh and hardened concrete.

Table below provides examples of high-early-strength mix designs and approximate opening times (ACPA 1994). Laboratory testing of proposed repair materials (using the aggregates that will be used in the project mix) must be conducted to ensure that the opening requirements are met. To ensure adequate durability of hardened concrete, the concrete mix should have between 4.5 and 7.5 percent entrained air, depending on the maximum coarse aggregate size and the climate (ACPA 1995). The slump should be between 50 and 100 mm (2 to 4 in) for overall workability and finishability. Temperature during installation and curing should also be closely monitored as adverse temperature conditions during installation have been linked to premature failures.

Mix Component	Type I (GADOT)	Type III (Fast Track I)	Type III (Fast Track II)	RSPC	RSC
Cement, (kg/m^3)	447	381	441	363	386
Flyash, (kg/m^3)	–	43	48	–	–
Course Aggregate, (kg/m^3)	1067	828	776	1011	1070
Fine Aggregate, (kg/m^3)	612	808	774	832	595
w/c Ratio	0.40	0.40 to 0.48	0.40 to 0.48	0.41	0.45
Water Reducer	–	yes	yes	–	–
Air Entraining Agent	As needed to obtain air content of 6 $\pm$ 2 percent.				
$CaCl_2$ % wt. cement	1.0	–	–	–	–
Opening time	4 hr	24-72 hr	12-24 hr	4 hr	4-6 hr

1 kg/m^3 = 1.69 lb/yd^3

Repairs

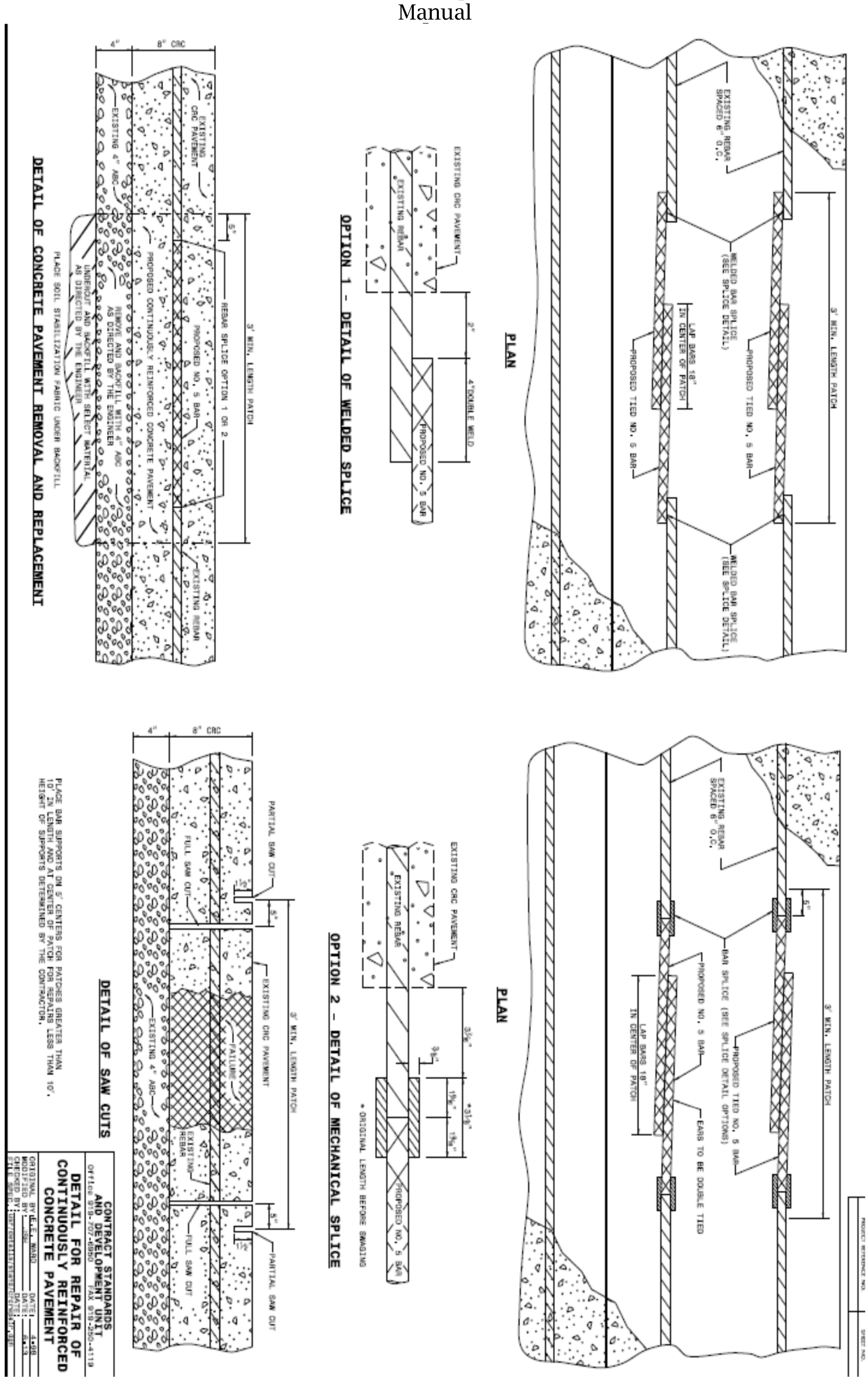
Precast panels have been used in some areas where very short work windows are available. In some cases, a cracked or damaged slab has been replaced with a precast panel in as little as 4 hours. If using precast panels, the dimensions (thickness, width, and length) of the pavement slabs in the repair areas must be clearly defined. Because the use of precast panels is a highly specialized technique that is relatively new, it will not be discussed in detail in this document. Several recent papers and reports are available that document the early experience with this technique (Mathis 2001; Merritt and Tyson 2001; Buch, Lane, and Kazmierowski 2006; Hossain, Ozyildirim, and Tate 2006).

Restoring Reinforcing Steel in CRCP

On CRCP, it is important to maintain the continuity of reinforcement through the full-depth repair. The new reinforcing steel installed in the repair area should match the original in grade, quality, and number. The new bars should be cut so that their ends are at least 5 in. from the joint faces, and either tied, mechanically connected, or welded to the existing reinforcement. In placing the bars, chairs or other means of support should be provided to prevent the steel from being permanently bent down during placement of the concrete. Moreover, a minimum of 3.5-in. cover and/or the cover of the existing bars should be provided over the reinforcing steel.

Depending on the type of splice used, different overlap lengths are required to allow the splice to develop the full bar strength. For all connection types, a 6-in. clearance is required between the end of the lap and the existing pavement. The recommended lap lengths are as follows:

- Tied splice. Tied splices should be lapped 18 in. for No. 5 Rebar
- Welded splice. A 0.25-in. continuous weld should be made 4 in. long on both sides. To avoid potential buckling of bars on hot days, the reinforcement must be lapped at the center of the repair as illustrated in the Detail for Repair of CRCP. This allows movement of the CRCP ends without damaging the steel. Although this procedure has been used successfully, some problems have resulted from poor workmanship.
- Mechanical connection. These have a minimum lap length as illustrated in the Detail for Repair of CRCP.

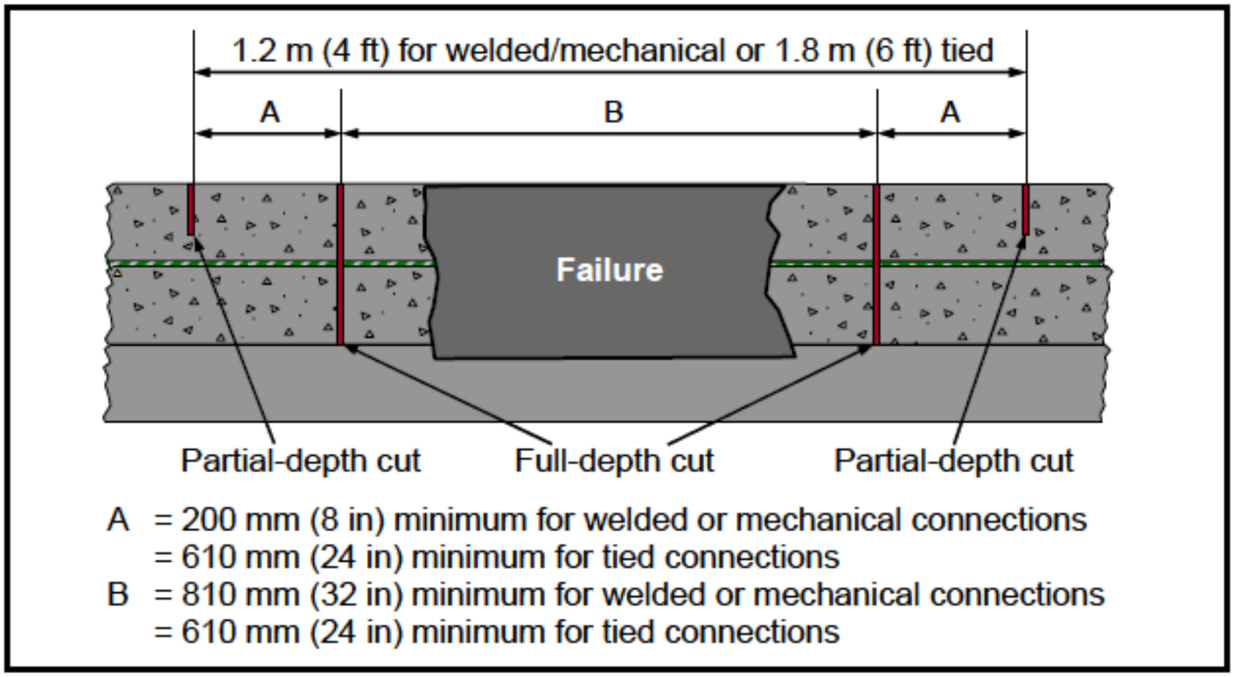

PLAN
OPTION 1 - DETAIL OF WELDED SPLICE
DETAIL OF CONCRETE PAVEMENT REMOVAL AND REPLACEMENT
OPTION 2 - DETAIL OF MECHANICAL SPLICE
DETAIL OF SAW CUTS
CONTRACT STANDARDS AND DEVELOPMENT UNIT
DETAIL FOR REPAIR OF CONTINUOUSLY REINFORCED CONCRETE PAVEMENT

Early Opening to Traffic
A review of NCDOT state highway practices states 3,000 lbf/in^2 compressive strength, 400 lb.f/in^2 flexural strength (third point loading) for the opening of full-depth repairs. However, an opening flexural strength of 450 lbf/in^2 (third-point loading) may be more appropriate if heavy edge loading is anticipated.

CONSTRUCTION
The construction and installation of full-depth repairs involves the following steps:
1. Concrete sawing.
2. Concrete removal.
3. Repair area preparation.
4. Restoration of reinforcing steel in CRCP.
5. Concrete placement and finishing.
6. Curing.
7. Diamond grinding (optional).

For CRCP, two sets of saw cuts are required to provide a rough joint face at repair boundaries. To ensure good repair performance, the joint faces must be rough and vertical, and all underlying deteriorated material must be removed and replaced with concrete. The rough joint faces and continuity of reinforcement (reestablished during repair, keeping the joints tightly closed) provide the load transfer across the repair joints through aggregate interlock.

The rough joint faces are obtained by first making a partial-depth cut around the perimeter of the repair area, to a depth of about one-fourth to one-third of the slab thickness, as shown in the figure below (FHWA 1985). The partial-depth saw cuts should be located at least 18 in. from the nearest tight transverse crack. They should not cross an existing crack, and adequate room should be left for the required lap distance and center area. If any of the steel reinforcement is cut, the length of the repair must be increased by the lap length required.



After the partial-depth cuts, two full-depth saw cuts are then made at a specified distance in from the partial-depth cuts as shown in the figure above. This distance depends on the method of lapping used to connect reinforcement. The recommended distance is 24 in. for tied laps, and 8 in. for mechanical connections or welded laps. This distance may be reduced depending on the required lap length.

Step 2: Concrete Removal

Jointed Concrete Pavements

Two methods have been used to remove deteriorated concrete from the repair area:

- Breakup and Cleanout Method. After the boundary cuts have been made, the concrete to be removed is broken up using a jackhammer, drop hammer, or hydraulic ram, and then removed using a backhoe and hand tools. To prevent damage to adjacent concrete, large drop hammers should not be allowed, and large jackhammers must not be allowed near a sawed joint (FHWA 1985; ACPA 1995). Breakup should begin at the center of the repair area and not at the saw cuts.
- Lift-Out Method. After the boundary cuts have been made, lift pins are placed in drilled holes in the distressed slab and hooked with chains to a front-end loader or other equipment capable of vertically lifting the distressed slab. The concrete is then lifted out in one or more pieces (FHWA 1985; ACPA 1995).

Advantages and disadvantages of each removal method are listed in table below. The lift-out method is generally recommended in order to minimize disturbance to the base, which is critical to good performance. This method generally provides the best results and the highest production rates for the same or lower cost, and with the least disturbance to the base (FHWA 1985).

Regardless of the method and equipment used, it is very important to avoid damaging the adjacent concrete slab and existing subbase. In either case, the specifications should state that if the contractor spalls the existing concrete during removal, a new saw cut must be made outside of the sawed area and additional concrete removed at the contractor's expense.

Method	Advantages	Disadvantages
Breakup and Cleanout	Pavement breakers can efficiently break up the concrete, and a backhoe equipped with a bucket with teeth can rapidly remove the broken concrete and load it onto trucks.	This method usually greatly disturbs the subbase/subgrade, requiring either replacement of subbase material or filling with concrete. It also has some potential to damage the adjacent slab.
Liftout	This method generally does not disturb the subbase and does not damage the adjacent slab. It generally permits more rapid removal than the breakup and cleanout method.	Disposal of large pieces of concrete may pose a problem. Large pieces must be lifted out with lifting pins and heavy lifting equipment, or sawn into smaller pieces and lifted out with a front-end loader.

The procedure for removing concrete from the center section (between the inner full-depth saw cuts) of the repair area is the same as for JCP. The deteriorated concrete must be carefully removed to avoid damaging the reinforcement and to prevent spalling concrete at the bottom of the joint (beneath the saw cut). This can be accomplished by using jackhammers, prying bars, picks, and other hand tools.

Separating the surrounding concrete from the reinforcing steel must be done without nicking, bending, or damaging the steel in any way. The use of a drop hammer or hydro-hammer should not be allowed in the lap area because this equipment typically damages the reinforcement or causes serious spalling beneath the partial-depth saw joint.

After the concrete has been removed, the reinforcement should be inspected for damage. Any bent bars must be carefully straightened. Bent reinforcement in the repair area will eventually result in spalling of the repair because of the large stresses carried by the reinforcement. If more than 10 percent of the bars are seriously damaged or corroded, or if three or more adjacent bars are broken, the ends of the repair should be extended another lap distance.

Step 3: Repair Area Preparation

All subbase and subgrade materials that have been disturbed or that are loose should be removed and replaced either with similar material or with concrete. If excessive moisture is present in the repair area, it should be dried out before placing new material. Placement of a lateral drain may be necessary where there is standing water. A trench must be cut through the shoulder and a lateral pipe or open-graded crushed stone placed.
It is very difficult to adequately compact granular material in a confined repair area. Hand vibrators generally do not produce adequate compaction to prevent settlement of the repair. Consequently, replacing the damaged portion of a disturbed subbase with concrete is often the best alternative.

When the repair length is less than 15 ft., a bondbreaker board is typically placed along the length of the longitudinal joint to isolate it from the adjacent slab. If the repair is longer than 15 ft., tiebars are typically installed in the face of the longitudinal joint (ACPA 2006).

Restoring Reinforcing Steel in CRCP

As mentioned previously, the continuity of reinforcement must be maintained through full-depth repairs.
The splicing of the reinforcement bars should be conducted using the detailed design information presented in the *Design and Materials Considerations* section.

On CRCP repairs, it may be necessary to restrict the time of placing concrete to late in the afternoon, depending on the climatic and pavement conditions. On some projects where concrete has been placed in the mornings, expansion of the adjacent slab in the afternoon has resulted in crushing of the repair concrete. This is especially true when the failure extends across all lanes.

Step 6: Curing

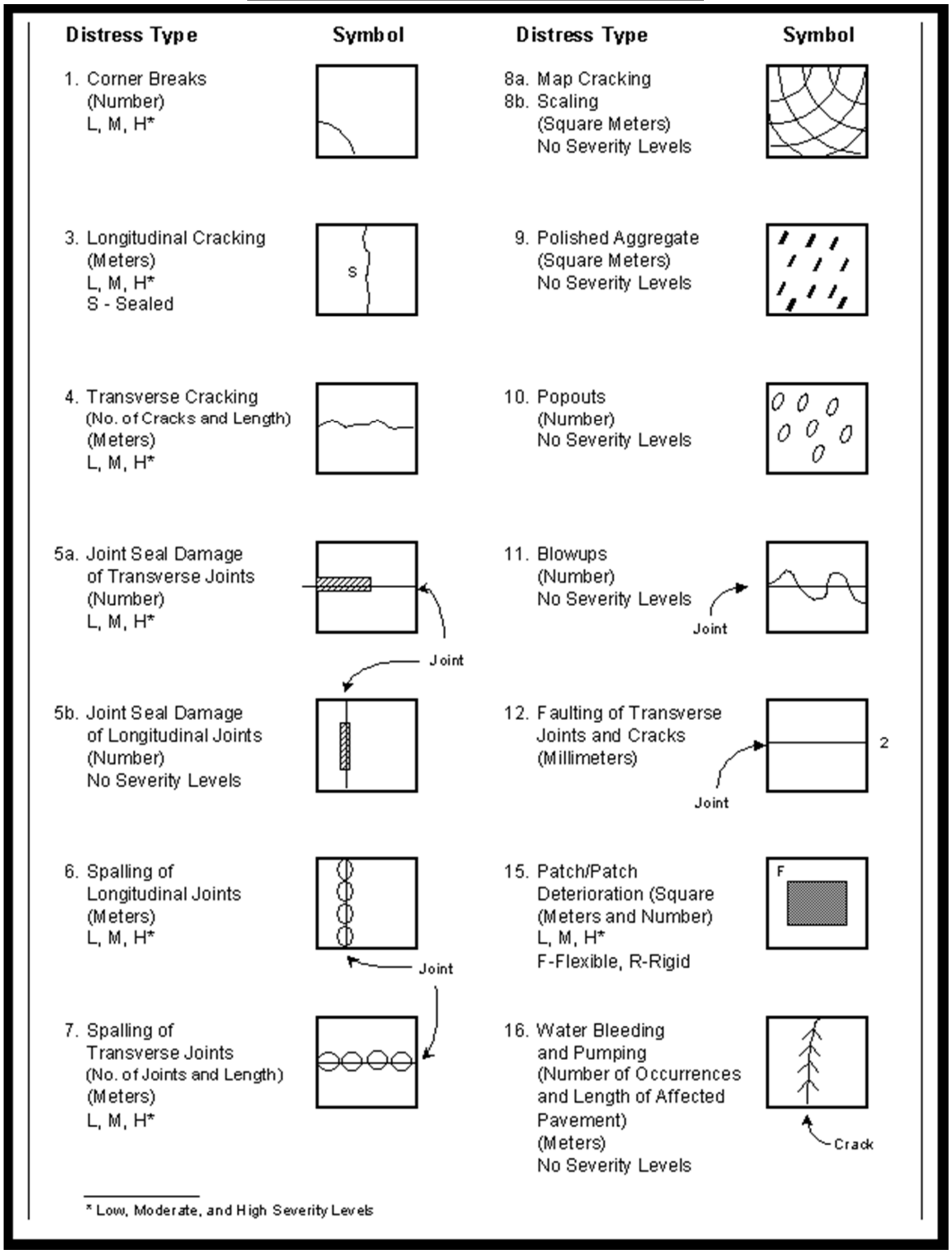
Moisture retention and temperature during the curing period are critical to the ultimate strength of the concrete. Proper curing is even more important when using set accelerating admixtures. Therefore, as soon as the bleed water has disappeared from the surface of the concrete (typically within ½ hour of concrete placement), the approved curing procedure should commence to prevent moisture loss from the pavement (ACPA 2006). Typical curing methods include wet burlap, impervious paper, pigmented curing membranes (compounds), and polyethylene sheeting. In general, a normal application of the pigmented curing compound (typically 4.9 m^2/liter [200 ft^2/gal]) gives the best results.

On projects with very early opening time requirements (4 to 6 hours), it may be necessary to use insulation blankets to obtain the required strength within the available time. The insulation blankets promote rapid strength gain by keeping the internal temperature of the concrete high, thus accelerating the rate of hydration. In general, insulation blankets are not needed on hot summer days. The use of insulation blankets during cold periods requires special care. The insulation blanket should not be removed when there is a large difference between the concrete and air temperatures, because rapid cooling of the pavement surface following the removal of the insulation blanket can cause cracking of the repair slabs.

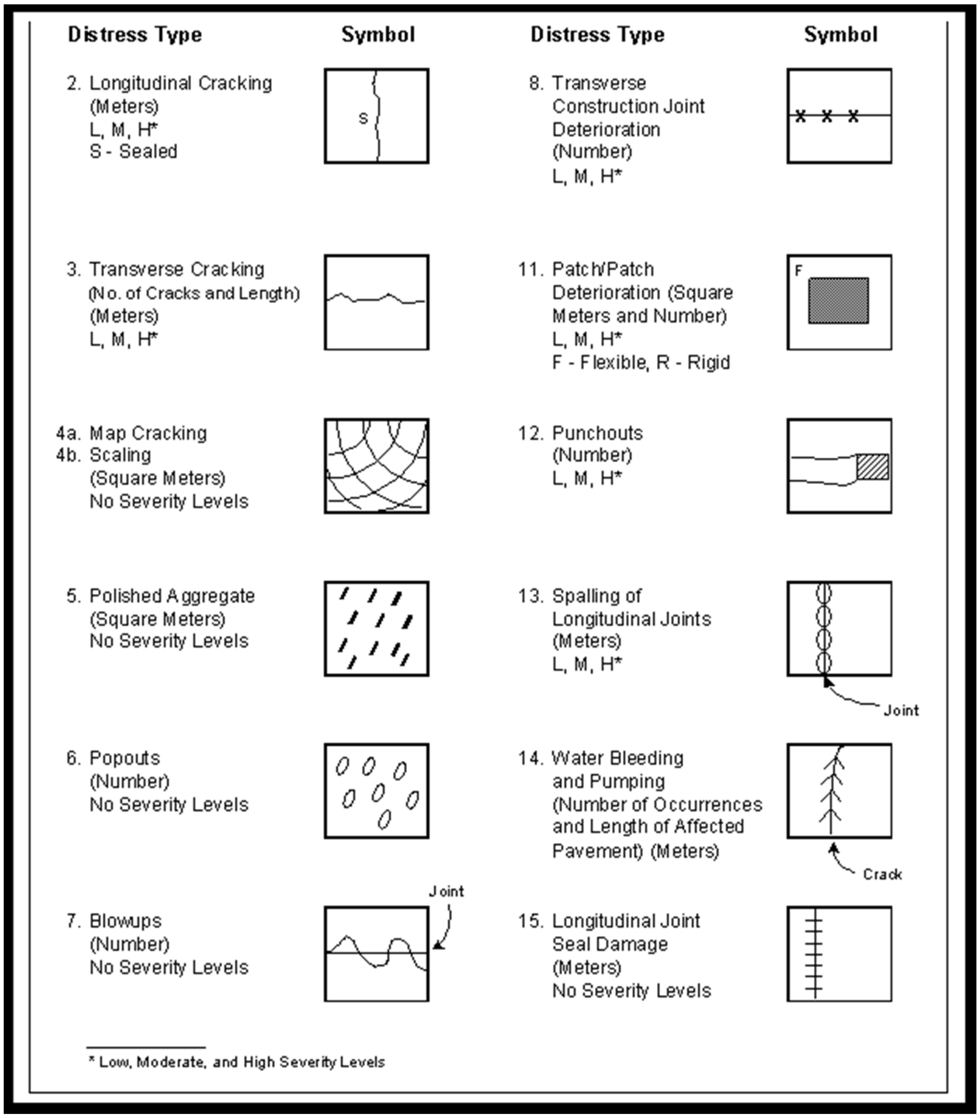
Step 7: Diamond Grinding (Optional)

Rehabilitation techniques such as full-depth repairs may result in increased roughness if not finished properly. In particular, differences in elevation between the repair areas and the existing pavement can create an uncomfortable ride. Restoration of a smooth ride may also be an issue when using precast panels. If needed, the best method to blend repairs into a concrete pavement is with diamond grinding.
The smooth surface results in improved rideability of the construction project.

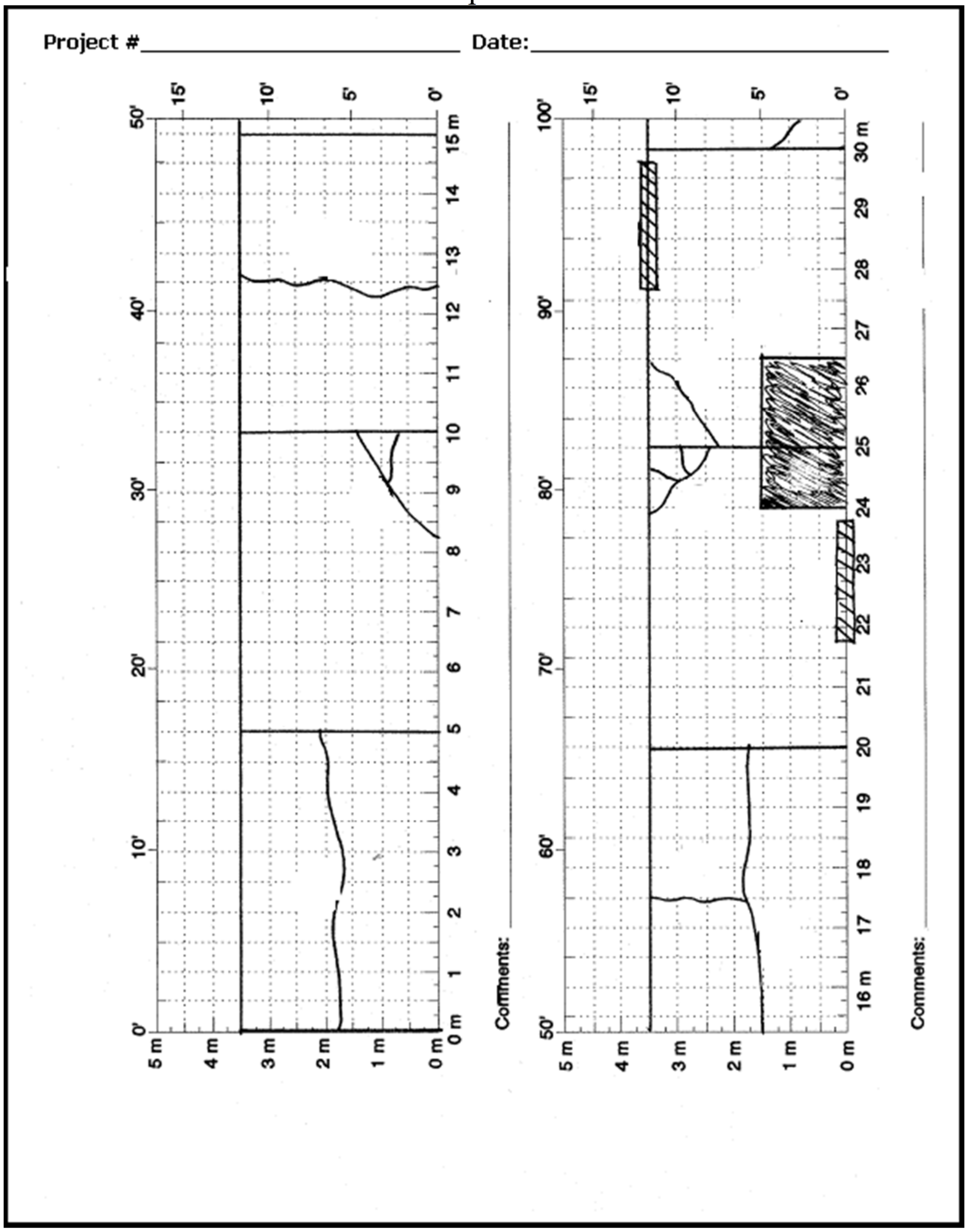
SECTION V
SAMPLE SYMBOLS AND SKETCH



Example-Symbols for Repair Sketch



Example-Symbols for Repair Sketch



Example-Sample Sketch (Should have notes and pictures)

SECTION VI
REFERENCES

References: Guidelines for Partial and Full Depth Repair, TB003, American Concrete Pavement Association, Arlington Heights, IL., 1989

"A Concrete Pavement Owner's Manual, Concrete Pavement Maintance and Repair" ppt., Steve Waalkes, Director or Engineering and Rehabilitation, American Concrete Pavement Association, Arlington Heights, IL.,

"Full Depth Patching of Concrete Pavement, Pavement Rehabilitation Manual, Federal Highway Administration, Washington, D.C., Rev. October 1990

"Repair of Airfield Pavement Surfaces, Rigid Pavement Systems", United States Air Force Guide Specification, USAF-2520, February 1994

"Rigid Pavements for Airfields", TM5-822-9, United States Airforce, August 1988

"Best Practices for Airport Portland Cement Concrete Pavement Construction", JP007P, American Concrete Pavement Association, Arlington Heights, IL. April 2003

"Concrete Pavement Rehabilitation" ppt., Tim Smith, Director – Transportation & Public Works, Cement Association of Canada, April 10, 2001

"Distress Identification Manual for the Long-Term Pavement Performance Program", FHWA-RD-03-081, June 2003

Concrete Pavement Rehabilitation, Guide to Full-Depth Repairs", FHWA, August 2003

References:

Dr. Michael E. Ayers, Joseph G. McDaniel, and Shreenath P. Rao, (2000). Construction of Portland Cement Concrete Pavements, AASHTO/FHWA/Industry Joint Training.

Iowa Department of Transportation, Highway Division, Construction Office (2007). Portland Cement Concrete Paving Field Inspection Manual 2007, Technical Training and Certification Program.

Cement and Concrete Association. Joints. 1 Jan. 2007. 14 Aug. 2007 <http://www.cca.org.nz/construction/joints.htm#>.

Iowa State University (November 2004) Concrete Paving Workforce Reference Number 3, Concrete Pavement Joint Sawing, Cleaning, and Sealing. Center for Portland Cement Concrete Pavement Technology, ISU, Ames.

Federal Highway Administration. Chapter 6, Joint Sealing, Portland Cement Concrete Pavements, FHWA-IF-03-003. 25 Mar. 2003. 1 Au. 2007 <http://www.fhwa.dot.gov/pavement/pub_details.cfm?id=45>.

Federal Highway Administration. TechBrief: Early-Entry Sawing of Portland Cement Concrete Pavements, FHWA-IF-07-031. June 2007. 1 Aug. 2007 <http://www.fhwa.dot.gov/pavement/concrete/pubs/07031/07031.pdf>.

American Association of State Highway and Transportation Officials (AASHTO). (2000). *Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Twentieth Edition*. American Association of State Highway and Transportation Officials. Washington, D.C.

American Concrete Pavement Association (ACPA). (1995). *Construction of Portland Cement Concrete Pavements.* National Highway Institute Course No. 13133. AASHTO/FHWA/Industry joint training. Federal Highway Administration, Department of Transportation. Washington, D.C.

American Concrete Pavement Association (ACPA). (2001b). *Thin Bonded Concrete Overlays of Asphalt Pavement*. Web page on the American Concrete Pavement Association's web site. http://www.pavement.com/techserv/USutw2.html. Accessed 14 February 2002.

American Society for Testing and Materials (ASTM). (2001). *Annual Book of ASTM Standards, Section four: Construction*. vol. 4.03. American Society for Testing and Materials. West Conshohocken, PA.

Brock, J.D. and Skinner, T. (no date given). *Longitudinal Joints, Problems and Solutions*. ASTEC technical paper T-130. ASTEC Industries, Inc. Chatanooga, TN.

Federal Highway Administration (FHWA). (1999). *Concrete Pavement Design Details & Construction Practices*. Course No. 131060. CD-ROM course companion including technical digest, instructor's guide, participants workbook and visual aids. Federal Highway Administration. Washington, D.C.

Federal Highway Administration (FHWA). (1990a). *Concrete Pavement Joints*. Technical Advisory 5040.30. Federal Highway Administration. Washington, D.C.

National Ready Mixed Concrete Association (NRMCA). (no date given). NRMCA web site, *Concrete Basics* home page. National Ready Mixed Concrete Association. Silver Spring, MD. http://www.nrmca.org. Accessed 11 February 2002.

Pavement Consulting Services. (December 1989). *Guidelines and Methodologies for the Rehabilitation of Rigid Pavements using HMA Overlays*. Pavement Consulting Services, Draft Report to the National Asphalt Pavement Association.

Portland Cement Association (PCA). (1988). *Design and Control of Concrete Mixtures*. Portland Cement Association. Skokie, IL.

Texas Department of Transportation (TxDOT). (2002). *Implementation of TxDOT Concrete Maturity Method, Testing Procedures and Related Specifications*. TxDOT workshop PowerPoint slide presentation obtained at the February 2002 State Pavement Technology Consortium meeting. Austin, TX.

Transportation Research Board (TRB). (1999). Glossary of Highway Quality Assurance Terms. Transportation Research Circular, No. E-C010. Transportation Research Board, National Research Council. Washington, D.C.

Washington State Department Of Transportation (WSDOT). (2000). Standard Specifications for Road, Bridge, and Municipal Construction. Publication M 41-10. Washington State Department of Transportation. Olympia, WA.

Carino, N.J., "The Maturity Method: Theory and Application," *ASTM Journal of Cement, Concrete, and Aggregates* CCAGDP, Vol. 6, No.2, Winter 1984, pp. 61-73.

Malhotra, V.M. and Carino, N.J., Eds., *Handbook on Nondestructive Testing of Concrete*, CRC Press, Boca Raton, FL, 1991, 343 pp.

Muench, Steve T., Joe P. Mahoney, and Linda M. Pierce. Chapter 7, Construction. 25 2002. 25 Aug. 2007 <http://training.ce.washington.edu/WSDOT/.htm>.

Taylor, Peter C., Steven H. Kosmatka, and Gerald F. Voigt. Integrated Materials and Construction Practices for Concrete Pavement: A State of the Practice Manual. Washington, D.C.: Federal Highway Administration, 2006.