Table of Contents

I. INTRODUCTION

This training manual has been prepared to provide guidance and instruction to technicians involved with the construction of Portland Cement Concrete (PCC) pavements. The important tasks involved in this work are explained and good practice procedures are described. Most of the material is targeted for those who have not had experience in PCC paving construction and some of the material is focused on those that have experience in PCC paving and are renewing their PCCP Roadway Certification.

This manual is intended for use in any of three ways:

1. A text for a Certification class
2. A self-training manual
3. A reference to be used in the field

This manual is intended to help the technician learn the various aspects of what is involved in a PCC paving operation and also to become familiar with the duties and responsibilities of the PCC pavement technician.

At the beginning of each section, references are made to the:

- 2012 North Carolina Department of Transportation Standard Specifications with the Specification Article listed
- NCDOT Standard Drawings
- Construction Manual Chapters

These references will enable the technician to refer to those documents for more detailed information.

Different Project Special Provisions may be applicable to different projects being constructed in the same construction season. The project letting date will determine which Specification Article, Standard Drawing, Project Special Provision, or Construction Manual Chapter is applicable.

ACKNOWLEDGEMENTS

The North Carolina Department of Transportation would like to express appreciation to the National Concrete Pavement Technology Center (CP Tech Center) for their permission to use quotations, graphs, illustrations and other literature in the preparation of this manual.

Appreciation is also expressed to Gomaco, CMI, Caterpillar, Ingersoll-Rand, and other equipment manufacturers for the use of their illustrations and information. Use of specific trade names or manufacturers' illustrations does not imply endorsement by the Department. These are used solely because they are considered necessary in meeting the objective of this manual.

The Department also expresses appreciation to the Iowa Department of Transportation, America Concrete Pavement Association, American Concrete Institute, Federal Highway Administration, the Transportation Research Board, and others for the use of their materials in the preparation of this manual.

Special appreciation is expressed to Jim Grove, Bob Steffes, Heath Gieselman, Jeremy McIntyre, Peter Taylor, Bryan Zimmerman, Jim Cable, Dale Harrington, Mike Ayers, Leif G. Wathne, Shannon Sweitzer, Wiley Jones, III and many more for their help and guidance on the subject of PCC Pavement and the preparation of this manual.

MISSION STATEMENT

PCC Pavement Certification Program

The Mission of
The PCC Pavement Certification Program is to continuously improve the overall knowledge and quality of
Portland Cement Concrete Pavement Technicians.

For Technical Assistance:

Nilesh Surti, P. E.
State Pavement Construction Engineer
NCDOT Construction Unit
1 South Wilmington Street
Raleigh, North Carolina 27601
919-707-2403
nsurti@ncdot.gov

Jess S. Earley, PE
Research and Investigations Engineer
NCDOT Materials and Tests Unit
1801 Blue Ridge Road
Raleigh, NC 27607
919-329-4223
jsearley@ncdot.gov

Darrell Lumley
Area Materials Engineer
NCDOT Materials ad Tests Unit
1801 Blue Ridge Road
Raleigh, NC 27607
919-329-4200
dlumley@ncdot.gov

ETHICS

The table listed below indicates the current status of ethics today. Pollster George Barna asked people whether they had complete confidence that leaders from various professions would consistently make job related decisions that are morally appropriate.

Type of Leader	Percent Who Hold the Public's Complete Confidence
Executives of Large Companies	3%
Elected Government Officials	3%
Film and TV Producers, Directors and Writers	3%
News Reporters and Journalists	5%
Small Business Owners	8%
Ministers, Priests, and Clergy	11%
Teachers	14%

Note that even in the most trusted category, only one out of seven people is willing to give complete trust. Ethics is in a terrible state. Unethical choices are being made. In most cases there are three reasons for the choices.

1. We do what is most convenient. In most cases we do what is easy, not what is right.
2. We do what we must to win. Many believe there are two choices, to win by whatever it takes, or to have ethics and lose.
3. We rationalize our choice with relativism. Many people choose to deal with situations by deciding what is right in the moment.

We seem to exist in a state of ethical dilemma, facing undesirable or unpleasant choices relating to a moral principle or practice. In the early 1960's Dr. Joseph Fletcher, dean of St Paul's Cathedral in Cincinnati, Ohio, published a book called Situation Ethics. In his book, Dr. Fletcher noted that love was the only viable standard for determining right from wrong. The interpretation of this was that love could be used to justify anything, including lying, cheating, stealing, and even murder.

Since the 1960's, situational ethics has become the norm for social behavior. After spreading rapidly through the worlds of education, religion, and government, situational ethics has penetrated the business world. The result is ethical chaos.

Ethics is never a business issue or a social issue or a political issue. Ethics is a personal issue. The problem we face today is the same person who cheats on taxes or steals office supplies demands honesty and integrity from the corporation whose stock he buys, the politician he votes for, and the client he deals with in his own business.

Most people want to be ethical. According to the Ethics Resource Center in Washington, DC, companies that are dedicated to doing the right thing, having a written commitment to social responsibility, and acting on it consistently, are more profitable than companies that operate unethically. In the long term, people always lose when they live without ethics.

How do you rate yourself on ethics?

1. I am always ethical.
2. I am mostly ethical.
3. I am somewhat ethical.
4. I am seldom ethical.
5. I am never ethical.

The majority of people place themselves in the first or second category. Most people who place themselves in the second category do so because of personal convenience. The absolute of the first category can be intimidating. Conflict is inconvenient. Practicing discipline is inconvenient. Losing is inconvenient. Paying a high price for success is inconvenient. The problem is that many people believe to be always ethical; they have to be always inconvenienced.

The Josephson Institute of Ethics states: "Ethics is about how we meet the challenge of doing the right thing when that will cost more than we want to pay. There are two aspects of ethics; the first involves the ability to discern right from wrong, good from evil, and propriety from impropriety. The second involves the commitment to do what is right, good, and proper. Ethics entails action, it is not just a topic to mull or debate.

You will be able to use one guideline to govern all your ethical decision making; the Golden Rule. The rule is simple; treat others as you want to be treated.

Companies can benefit from operating under the Golden Rule. For example, Synovus, a Fortune 500 company, experienced tangible and intangible benefits by operating ethically. The tangible benefits were lower turnover, fewer EEOC claims, and a disappearance of harassment issues. Intangible benefits included the growth of people in an environment where they are not suppressed, retention of your best people, and an environment where your young emerging leaders want to stay.

Application of the Golden Rule:

1. Decisions, not conditions, determine your ethics. Ethical people make good choices regardless of circumstances.

2. Wrong decisions leave scars. Every time people make wrong decisions, there is an impact, even if it is not immediately noticed.
3. The more people involved, the greater the pressure for conformity.
4. Inaction is also a decision.

To be trustworthy, a person must be predictable. Using the Golden Rule, you create an ethical predictability in your life.

There are five factors that come into play when ethics are compromised.

1. **Pressure.** According to Linda Trevino, professor of organizational behavior at Penn State's Smeal College of Business Administration, " Ethical breaches are often the result of the corporate culture or pressure from management, pressure that can emerge when a company finds itself unable to live up to financial forecasts or expectations and tries to bend the rules to achieve them." Questions to ask yourself when facing pressure are:
   a. Am I making rash, emotional decisions?
   b. Am I compromising the truth?
   c. Am I taking shortcuts?
   d. Am I keeping my commitments?
   e. Am I bowing to others' opinions?
   f. Am I making promises I can't keep?

2. **Pleasure.** The desire for pleasure will talk us into doing things we will regret afterward. Poet Robert Browning Hamilton writes these words:

   " I walked a mile with Pleasure,

   She chattered all the way,

   But she left me none the wiser,

   For all she had to say,

   I walked a mile with Sorrow,

   And ne'er a word said she;

   But, oh, the things I learned from her

   When Sorrow walked with me!"

a. The first solution to the lure of pleasure is to run from temptation. If you know you are susceptible to a pleasure that would tempt you to cross an ethical line, put yourself out of harm's way.
b. The second solution is to develop discipline.

3. **Power.** The abuse of power leads to ethical compromise. John Maxwell notes in his book, Ethics 101 that power is like a mighty river. As long as it keeps its course, it is a useful thing of beauty. But when the river floods its banks, it brings great destruction.
4. Pride. Each person's pride is in competition with everyone else's pride. Everyone wants to be above the rest. Several years ago, Time magazine noted a decline in ethics in business, politics, law, and medicine. The decline was attributed to pride.
5. Priorities. Anytime you do not know what your priorities are, there is a strong likelihood you will make poor decisions.

Ethical Quiz

QUIZ 1

1. Name the five wealthiest people in the world.
2. Name the last five Heisman trophy winners.
3. Name the last five winners of the Miss America contest.
4. Name ten people who have won the Nobel prize.
5. Name the last half dozen Academy Award winners for best actor and actress.
6. Name the last decade's World Series winners.

QUIZ 2

1. Name three teachers who inspired you to achieve in school.
2. Name three friends who helped you through a difficult time.
3. Name five people who taught you something worthwhile.
4. Name three people who made you feel appreciated and special.
5. Name five people with whom you enjoy spending time.

6. Name half a dozen heroes whose stories have inspired you.

The quizzes above are an indication of focus. When faced with the facts, it is easy to see what the true gold is. The most impactful times we remember are the times when someone used the Midas touch to help others.

There are two basic paths to achievement a person can choose. One is to go for the gold, and the other is to go for the Golden Rule.

People Who Go for the Gold	**People Who Go for the Golden Rule**
Ask, "What can you do for me?"	Ask, "What can I do for you?"
Make convenient decisions.	Make character decisions.
Sacrifice family for finances.	Sacrifice finances for family.
Develop a rationale for their actions.	Develop relationships with their actions.
Possess a "me-first" mind set.	Possess an "others first" mind set.
Count their dollars.	Count their friends.
Base their values on their worth.	Base their worth on their values.

This Ethics presentation is based on the book, Ethics 101, What Every Leader Needs to Know. The books author is John C. Maxwell.

Falsification of Records

It is in the interest of every technician to avoid committing acts of engineering dishonesty and to encourage others from committing such acts. Each act of dishonesty can harm the technician's reputation and thereby the value of the honest work of all technicians.

The success of any Quality Control / Quality Assurance testing program is based on information taught through the various NCDOT Certifications courses, and on the knowledge of the technicians who work very hard and honestly to make their testing and reporting the best possible. The perception that Quality Control / Quality Assurance works is grounded in a culture of honesty and ethical conduct where there is no tolerance of engineering dishonesty.

Maintaining such a culture requires acceptance of certain responsibilities by both the NCDOT and the technician. The purpose of the Application for NCDOT Technician Certification statement is to describe those responsibilities and clearly define the behavior that contributes to engineering dishonesty. These responsibilities are examined and discussed in this chapter.

So, what is falsification of records?

Falsification of Records is defined as the changing or misrepresenting Data or Tests which also can include the Destruction, Alteration, or Falsification of Records.

How can falsification of records occur? It can either be intentional or by a direction of another.

The purpose of PCCP training and certification is to ensure that both QC and QA Technician provide proper documentation, acceptance procedures, and test results.

A technician who is qualified and holds a valid certification (s) for PCCP certification shall perform QA/QC testing or acceptance at a project site. These responsibilities cannot be delegated to non-certified personnel.

What does the North Carolina State Law say:

G.S. Chapter 136.

Roads and Highways.

13.2. Falsifying highway inspection reports.

(a) Any person who knowingly falsifies any inspection report or test report required by the Department of Transportation in connection with the construction of highways shall be guilty of a Class H Felony.

(b) Any person who directs a subordinate under his direct or indirect supervision to falsify an inspection report or test report required by the Department of Transportation in connection with the construction of highways shall be guilty of a Class H Felony.

What is a Class “H” Felony:

- **According to the Attorney General’s Office**
    - **Up to 3 years and 3 months in jail for the first Offense**
    - **Fines set by the Court**
    - **Or Both**

What does the Federal Law Say:

TITLE 18--CRIMES AND CRIMINAL PROCEDURE

PART I--CRIMES

CHAPTER 47--FRAUD AND FALSE STATEMENTS

Sec. 1020. Highway projects

Whoever, being an officer, agent, or employee of the United States, or of any State or Territory, or whoever, whether a person, association, firm, or corporation, knowingly makes any false statement, false representation, or false report as to the character, quality, quantity, or cost of the material used or to be used, or the quantity or quality of the work performed or to be performed, or the costs thereof in connection with the submission of plans, maps, specifications, contracts, or costs of construction of any highway or related project submitted for approval to the Secretary of Transportation; or

Whoever knowingly makes any false statement, false representation, false report, or false claim with respect to the character, quality, quantity, or cost of any work performed or to be performed, or materials furnished or to be furnished, in connection with the construction of any highway or related project approved by the Secretary of Transportation; or Whoever knowingly makes any false statement or false representation as to a material fact in any statement, certificate, or report submitted pursuant to the provisions of the Federal-Aid Road Act approved July 11, 1916 (39 Stat. 355), as amended and supplemented,

Shall be fined or imprisoned not more than three years plus, or both.

Application for NCDOT Technician Certification

When your exam for the PCCP Roadway Certification is presented to you, you will be given a form which is an **Application for NCDOT Technician Certification** which appears below. You will be required to fill it out completely. It states that with certification carries inherent rights and responsibilities.

These rights include being exclusively sanctioned, along with others so certified by the NCDOT, to perform sampling, testing, and reporting of test results for QA, QC, and Assurance programs.

The responsibilities include performing and reporting tests with the accuracy and precision expected of the technician in accordance with the required test procedures.

By signing the application, the technician agrees to strict compliance with all laws, rules, regulations, specifications, industry standards, procedures, policies, and guidance applicable to any work performed under the PCCP certification which includes the NCDOT Field Certification, PCCP Roadway Certification, PCCP Field (Field Laboratory) Certification Batch Plant Certification, and PCCP IRI Certification.

Any determination by the NCDOT of either a willful or negligent violation thereof, including an omission or failure to act, may result in a suspension or revocation of the rights and responsibilities conferred on the Technician upon issuance of the certification, whether or not any erroneous results were obtained.

A negligent violation is defined as an unintentional act or omission in which a Technician fails to exercise due care.

A willful violation is defined as an intentional act or omission.

Revocation or suspension of one certification may cause all certifications held by the Technician to be revoked or suspended as well. Permanent revocation of certifications may result in the technician being ineligible for any future NCDOT Certifications. Further, any suspension or revocation of technician's certification in any other State or jurisdiction may result in the NCDOT taking the same or other action, against technician's certification in North Carolina.

By signing the application for certification the technician also affirms that he/she is aware that both State and Federal laws may govern construction projects in North Carolina, including Title 18, The United States Code, Section 1020, that states, in pertinent part, that anyone making falsifications on Federal-aid projects:

"Shall be fined per the court or imprisoned not more than three years, or both for the first offense."

North Carolina Department of Transportation

APPLICATION FOR NCDOT TECHNICIAN CERTIFICATION

This is to affirm that ___________________________(Technician's Name), hereinafter "Technician," desires to be certified by the NCDOT as a (an) ____(Name of Certification desired.)

By making this Application, Technician acknowledges and agrees that Certification carries inherent rights and responsibilities. The rights include being exclusively sanctioned, along with others so certified by NCDOT, to perform sampling, testing, and reporting of test results for quality acceptance, quality control and assurance programs. The responsibilities include performing and reporting tests with the accuracy and precision expected of the Technician in accordance with the required test procedures.

By signing this Application, Technician agrees to strict compliance with all laws, rules, regulations, specifications, industry standards, procedures, policies, and guidance applicable to any work performed under the Certification. Any determination by the NCDOT of either a willful or negligent violation thereof, including an omission or failure to act, may result in a suspension or revocation of the rights and responsibilities conferred on the Technician upon issuance of the Certification, whether or not any erroneous results were obtained.

A negligent violation is defined as an unintentional act or omission in which Technician fails to exercise due care. A willful violation is defined as an intentional act or omission. Revocation or suspension of one Certification may cause all Certifications held by the Technician to be revoked or suspended as well. Permanent revocation of Certifications may result in Technician being ineligible for any future NCDOT Certifications. Further, any suspension or revocation of Technician's Certification in any other State or jurisdiction may result in the NCDOT taking the same, or other action, against Technician's Certification in North Carolina.

By signing below, Technician also affirms that he/she is aware that both State and Federal laws may govern construction projects in North Carolina, including Title 18, United States Code, Section 1020, that states, in pertinent part, that anyone making falsifications on Federal-aid projects.

"Shall be fined per the court or imprisoned not more than three years, or both for the first offense."

I, __________________________________(Print Name), affirm that I have read and fully understand the foregoing "APPLICATION FOR NCDOT TECHNICIAN CERTIFICATION," and I agree to be bound by these terms.

_____________________________________   _____________________

Technician's Signature   Date

If you Falsify Records:

You will be in trouble but who with will depend on where the funds for the roadway are coming from. What kind of trouble you will be in will also depend on where the funds for the roadway are coming from. Usually if the funds are coming from the US government the USDOT in combination with the FBI would be involved in the investigation (Federal Funds). If the funds are State funds the SBI would be involved with the investigation (NC Funds), and if a municipal funds are used then local law enforcement could become involved.

What are the Penalties?

The state and federal laws both may require time in prison or fines up to $10,000 but there are other things that are lost.

1. The possible loss of employment,
2. The possible loss of certifications,
3. The loss of credibility, and
4. Goes on your records.

With the loss of employment you lose the possible ability to get a pay check. You may be restricted from working on state and federal projects in your chosen career. It may restrict you from working for any other Department of state government, if you desire.

Losing one or more of your certifications restricts you from working on state and federal projects by restricting the work that you can do.

Loss of credibility is hard to reclaim. Once lost you must work extremely hard to convince an employer that you are trustworthy and honest in the information that you are supplying.

When will your troubles start:

If caught you are caught, legal proceedings will start immediately and one or all of your certifications will be revolted

If you were to question someone who has been caught falsifying or other offence they would tell you that the legal proceedings started the day they were caught.

Would Being Dishonest, Just A Little, Be Worth It ?

The advice here is when testing and reporting put down what you get. Do all tests to the best of your ability and report the results of those tests accurately. It is not worth not testing and reporting honestly. Even when being asked or told by a supervisor or subordinate to falsify even a little, the results can be devastating.

If You See Falsification, To Whom Do You Report Violations:

U. S. DOT Office of the Inspector General

Hotline for Fraud, Waste, or Abuse

Phone #: (800) 424 – 9071 or Email : hotline@oig.dot.gov

Mike Holder, P.E.

NCDOT – Chief Engineer

1536 Mail Service Center

Raleigh, N.C. 27699 – 1536

John F. Sullivan, III, P.E.

FHWA – N.C. Division

310 New Bern Avenue – Suite 410

Raleigh, N.C. 27601 - 1418

Process Control Plans

The Standard Specifications state: "Submit a plan detailing the process control procedures and the type and frequency of testing and inspection deemed necessary to produce concrete that meets the requirements of the specifications. Submit this plan at the pre-construction conference."

The ACPA defines quality control and process control as follows:

Quality Control* - *Actions taken by a producer or contractor to provide control over what is being done and what is being provided so that the applicable standards of good practice for the work are followed.

Process Control* - *Those quality assurance actions and considerations necessary to assess production and construction processes so as to control the level of quality being produced in the end product. This includes sampling and testing to monitor the process but usually does not include acceptance sampling and testing.

A good process control plan (PCP) should discuss the basic who, what, where, when, and how of the PCCP processes from the aggregate producers to the completion of the final product. The PCP should comprise two to four pages of detailed information for each major category of the work.

One of the first things to be covered should be the project organization structure. This should include personnel and phone numbers of key personnel, etc. (chain of command) for quick resolution of problems that develop.

The following major categories should be discussed:

- Subgrade Control and Concrete Pavement Preparations
- Concrete Mix Design
- Paving Equipment
- Concrete Plant Operations/Production
- Transportation / Trucks / Delivery
- Paving Operations
    - Slipform Paving Operations
    - Fixed Form Paving
- Spreading and Vibration Operations
- Finishing Operations
- Curing Operations / Protection
- Joint Construction
- Final Traffic Preparation / Acceptance Testing
- Pavement Marking
- Pavement Repairs

Who, What, Where, When, and How?

For each category and phase of the operation, the PCP should answer these questions as they relate to the category and phase:

1. ***Who will be responsible for QC during the operation?***
2. ***What will that person do to ensure contract and Standard Specification compliance?***
3. ***Where will these activities be performed?***
4. ***When will these activities be performed?***
5. ***How will inspections be performed?***

The PCP should minimize any parroting or paraphrasing of requirements in the contract, or Standard Specifications and should avoid simply promising to comply with the contract or Standard Specifications. These kinds of statements and assurances are of essentially no added value. The PCP must go beyond the contract and Standard Specification requirements and address the contractor's organizational process for consistently delivering the requirements.

Records and Documentation

While good documentation is often a reflection of good quality control, documentation is not the same thing as quality control. Documentation should be the minimum necessary to concisely document the adequate function of the process.

Process control testing

List the material to be tested, tests to be conducted, the location of sampling, and the frequency of testing.

Inspection/control procedures

Address each of the following subjects in each phase of construction:

Preparatory phase.
Startup phase.
Production phase.

Description of records

List the records to be maintained and how they will be distributed.

Personnel qualifications (See Article 700-14 and Section 1000)

Document the name, authority, relevant experience, and qualifications of person with overall responsibility for the inspection system.

Document the names, authority, and relevant experience of all personnel directly responsible for inspection and testing.

The items listed above are only to serve as guidelines for the Contractor in the development of a suitable Process Control Plan. The descriptions above show how detailed the Contractor's Process Control Plan should be and what main items should be discussed.

CONCRETE PAVING PROCESS CONTROL PLAN

PRECONSTRUCTION/ PREPAVE

Please indicate whether all contractors and subcontractors involved in the concrete paving process have been invited to discuss the various aspects of the concrete paving operation including subgrade, asphalt, and concrete tolerances and also whether those same individuals have checked the limits of stabilization and asphalt paving including appropriate width to include trackline.

SUBGRADE CONTROL/ CONCRETE PAVEMENT PREPARATIONS

What type of fine grading equipment will be used? Will a stringline be used and what is the frequency of checks for conformity to line, grade, and typical sections? Are there any grade adjustments necessary and have these been brought to the attention of NCDOT project personnel or the Resident Engineer? Are grades approaching structures correct? What type of hauling equipment will be used and has R.E. given approval for hauling on base course? If a stringline is to be used for fine grading, will it remain in place for concrete paving and if so, will it be checked for accuracy frequently during all operations?

CONCRETE MIX DESIGN

Include a copy of the concrete mix design with flexural beam information, maturity curve and information and all admixtures including dosage rates? What will be done in the case that ingredient sources or combinations change (a new mix design is required)?

CONCRETE PLANT OPERATIONS/PRODUCTION

Please list all lab technicians and their certifications. Please list all batch plant operators and their certifications. Will the M&T Form 253P be submitted daily by the batch plant technician to the Roadway technician? What is location of field laboratory relative to plant and stockpiles? Will cement be sampled and submitted to M&T according to specifications? List operations relative to air entraining agents. List the duties and responsibilities of the plant/lab inspector. List the duties of the batch plant inspector. What types of checks are being performed on the plant equipment and what is the frequency of these checks?

Can admixture dispensing equipment, including measuring vials, be monitored visually from the batching trailer or cabin? How often are admixture dispensing systems, weighing systems, and water gauges checked and calibrated? Are stockpiles replenished daily, weekly? Have M&T personnel approved Plant? How often will air and slump be checked? How often will the moistures be check on sand and aggregates?

TRANSPORTATION/TRUCKS/DELIVERY

What type of trucks will be used? List all checks that will be performed on any non-agitating trucks, and agitator trucks (mixing blades, counters, backup alarms, etc.). Will a batch ticket be provided with each truck to the roadway? What information will be included on the batch ticket (date and time of batch, mix design no., weights of constituent materials, mixing water added, ticket no., truck no., etc.)?

PAVING OPERATIONS

Is the Roadway Foreman PCCP Field Technician Certified? List all equipment to be used in slip form paving operations. Has all concrete paving equipment been checked and approved by the Resident Engineer or his representative? List all equipment to be used in fixed form paving operations. Will PADL and / or asphalt base coarse be dampened before placing concrete pavement? How often will vertical and horizontal control on the paver be checked with the roadway technician present? Will a spreader/placer be used to place concrete (specifications call for this to be used)? What type of protection will be provided when paving next to adjacent lanes to prevent infiltration on mortar into joints? Will paving foreman be in charge of coordinating paver speed with the concrete delivery? What will be used to secure dowel baskets and has that method been approved by the Resident Engineer? How will dowel baskets be stored on the project? Has M&T and the Resident Engineer approved baskets?
How will finishing operations be conducted and what equipment will be used? If edge slump occurs how will this be addressed and how will it be taken care of?

How will joint sawing and sealing be done? What type of saws will be used? After initial sawing takes place, how will the initial cuts be kept clean and free from incompressibles (dirt haul, construction equipment, etc.)? What type of sealant will be used and has it been approved? What are the manufacturer's instructions on maximum and minimum air and surface temperature restrictions? How will transverse joints be aligned? How will emergency joints be done (ties bar sizes, etc.)?

CURING OPERATIONS/PROTECTION

How will concrete be cured? What steps will be taken to protect the concrete during the curing period? Will a sufficient supply of polyethylene film be available at the day's operation? Where will it be stored? Indicate how these materials will be used in the curing process. Indicate how newly placed pavement will be protected during cold weather (cold weather plan)? Indicate how newly placed pavement will be protected from rain?

FINAL TRAFFIC PREPARATION/ACCEPTANCE TESTING

Will an IRI vehicle be available each day on the project? Who will operate the IRI vehicle and is he/she be PCCP Profilograph certified? Will the Resident Engineer or his representative be present during the running of the IRI Vehicle? How will raw data from the IRI vehicle be presented to the Resident Engineer after the run is completed(Jump Drive, etc.)? Briefly discuss pavement markings. Will N.C.D.O.T personnel have access to all materials? Have approved curing facilities been provided? What is the core cutting process? When will core holes be patched? Please indicate knowledge of specifications regarding cores and sampling.

TRAFFIC CONTROL AND PROJECT SAFETY

❖ Traffic Control

Traffic control is an important part of safety on a paving project. While the set up and maintenance of traffic control devices is the contractor's responsibility, the inspector should always bring to the attention of the contractor deficiencies which need to be repaired or changed to make the work zone safe for everyone. The inspector should encourage the contractor to make changes or repairs as quickly as possible to minimize the risk of accidents or worse fatalities.

Safety planning is the most important part of a concrete paving project. Evaluation of processes and overall project safety must be identified and the hazards at the paving work site must be identified before a plan can be developed.

Time, materials and costs will rise if proper planning is not done before the work commences. Planning makes the difference between either the success or failure of any paving project and whether there is a profit, or a loss.

Before devising appropriate traffic control, we must first become familiar with the hazards, the fundamental principles of traffic control, and their application. Proper and adequate placement of traffic control devices is the critical responsibility of the contractor who is in charge over the particular roadway where the paving and pavement construction is located. Also the inspector should ensure that the contractor is setting up the traffic control properly. The contractor's responsibility must consist of pre-job planning which includes a written traffic control plan and this plan should be included in the process control plan, which is presented at the pre-construction meeting.

The traffic control plan should include initial and periodic inspection of existing devices and conditions throughout the project for compliance, and the safety of the motorist and the worker. The traffic control plan should be discussed at the pre-construction meeting and be easy to understand, signed, and dated by the contractor and turned in for approval by the Engineer.

❖ Safety

Safety is everyone's job. Inspectors should be attentive to all activities that may pose a safety concern. The contractor is responsible for safety on the project but the inspector should always be on the alert for safety hazards and immediately bring them to the contractor's attention that need to be changed or improved.

The contractor's equipment should be in and kept in good working condition at all times. The equipment should have all safety guards required on the equipment. The inspector does not use the equipment but the inspector will be working in close proximity to the equipment. The safety of the inspectors, as well as the contractor's personnel, depends partially on the safe operating condition of the contractor's equipment.

The spreader belt can be dangerous.

Anytime anyone must walk near the spreader belt they should be very cautious. Some spreaders have warning horns and others do not when the belt is lowered. Trucks are backing up to the belt and cannot see someone that may be standing between the belt and the truck bed. Also, one should never walk under the belt when it is in the upright position. The hydraulics can fail and the belt simple falls without warning.

Spreader belts can be a danger

The condition of the haul roads used by the contractor should be inspected periodically. The contractor has the responsibility for maintaining dust control on the haul roads. A water truck should periodically spray water on the roads to control dust. If dust begins to make visibility difficult for construction vehicles or motorist, the inspector should have the contractor water the haul roads.

Dust can be a hazard especially when it blocks visibility

If the construction is immediately next to traffic a greater degree of awareness to the surrounding is necessary. Anyone who must work near an open lane must always be aware of where they are in relation to the passing traffic. The picture below illustrates what can happen if the float handle was struck by a passing truck or car in an open lane. If the handle was on the upstream side of the finisher's head he would be hurt badly or killed if hit by a passing vehicle.

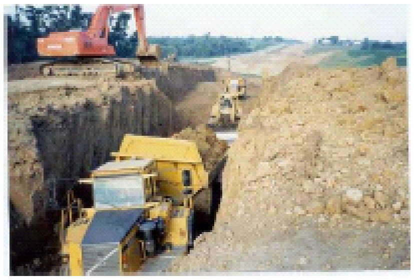
One must be aware of the location of Construction Traffic

A stringline is also a safety hazard. If someone were to trip over a stringline and fall under a passing vehicle he or she would be killed or hurt badly.

Stinglines can be a tripping hazard

An ever-present problem and hazard on construction sites is the parking of vehicles. Everyone would like to have his or her vehicle near him or her on the grade, especially near the end of the day but parking near the work may not be a good place to park. The lead inspector and the contractor superintendent must designate areas, which are good for parking vehicles near the construction activities. Parked vehicles can be an obstruction to the construction activities, construction vehicles, and the traveling public. Sometimes parking on the shoulder of an open roadway is not a good idea. If possible pull down into the ditchline and out of the way of the construction or the traveling public, this could be a temporary solution to parking.

When doing shoulder work often material must be excavated and hauled away. Although it is not the inspector's responsibility to direct the contractor's work, if an unsafe condition becomes evident, the inspector should not let the operation go on without bringing it to the Resident Engineer and contractor's attention and if not corrected immediately, shut down the operation until corrected.



Unsafe conditions need to be reported

When working around or near equipment, doing work such as paving operations, etc., using bulldozers, graders, rollers, or any construction vehicles contact the contractor personnel in charge of the operation and inform them of the place where you will be working. Use proper safety procedures to protect yourself from harm. Be aware of the construction equipment and communicate with the operators and have direct eye contact with them. Remember, it only takes a second for an accident to happen!!!!

If any violations of the specifications or any safety problems are observed, the inspector should immediately notify the Resident Engineer and the contractor. The inspector should also notify the lead inspector in charge of the project as soon as possible of any action taken. Any violations, problems, conversations, or solutions with the contractor or his personnel should be noted in the Inspector's Daily Diary each day.

Strength

The simple definition of strength is a measure of the ability of concrete pavement to resist stresses or forces at a given age.

Strength is a very important property of concrete and is an acceptance criterion for the NCDOT Specifications. Sufficient concrete strength is needed to carry loads on concrete pavements.

Many factors affect strength and must be considered when designing concrete mix designs while other factors must be considered and observed during construction process.

Strength increases with a decreasing water / cement ratio. Strength gain is accelerated at higher temperatures and decelerated at lower temperatures. Strength decreases as air content increases. Strength is measured for acceptance in **compressive strength (compression), and designed in** flexural strength (bending). Early strength can be approximated in the field by using the maturity method (time and temperature) measurements.

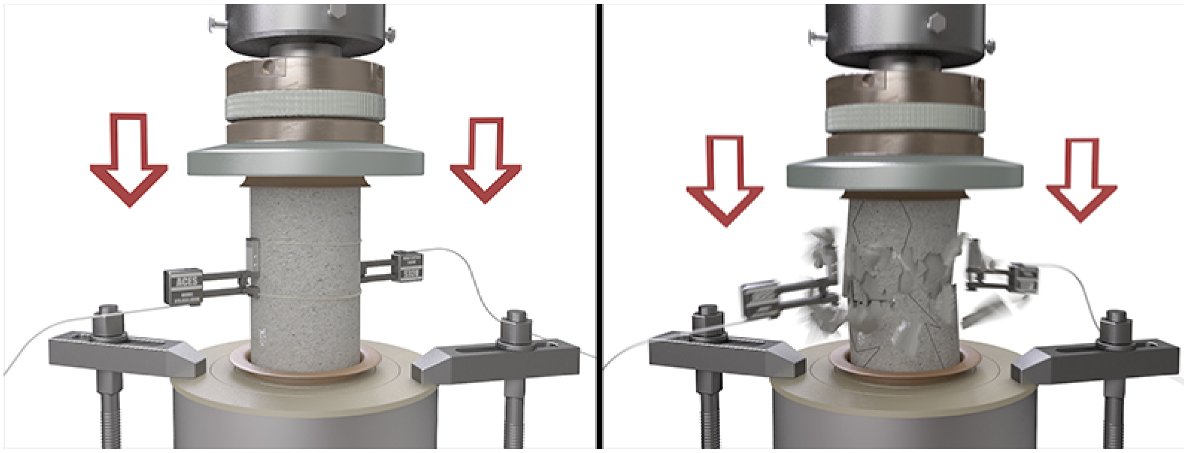
Strength is a typically measured property of concrete and is often used as a basis for accessing concrete quality because strength measurements give a direct indication of the concrete pavement's ability to resist loads and the flexural testing is relatively easy to perform.

Concrete is generally strong in compression, meaning it can resist heavy loads pushing directly down on it. Concrete is much weaker in terms of flexural strength or tension, meaning that concrete is weaker in resisting forces pulling it apart or bending it.

Concrete is 10 to 12 times stronger in compressive (crushing) strength but loads that effect Portland Cement concrete pavements are in flexural strength (bending), which produce compressive forces on one face of the pavement and tensile forces or pulling apart on the other. Most concrete pavement failures are in flexural rather than compressive strength and consequently, the flexural stresses and the flexural strength or modulus of rupture of the concrete is used to design concrete pavements and to determine slab thickness.

Compressive Strength:

The compressive test method measures the behavior of materials subjected to simple axial (crushing) loading. Compressive strength is defined as the measured maximum resistance of a concrete specimen to axial (crushing) load.



Compressive strength is the method, which is used by the North Carolina Department of Transportation to monitor and accept the concrete strengths of PCC pavements. It is measured using an approved cylinder-breaking machine.

The compressive strength required for opening a pavement to permanent traffic is based on compression testing of 6” X 12” cylinders tested using an approved breaking machine and is 4500 psi at 28 days.

The procedure for sampling, making, curing, and testing of flexural test beams is as follows:

Sample the concrete as per ASTM C 172 “Standard Practice for Sampling Freshly Mixed Concrete”, make and cure cylinders per AASHTO T 23 “Making and Curing Concrete Test Specimens in the Field and test cylinders for compressive strength as per AASHTO T 22 “Compressive Strength of Cylindrical Concrete Specimens”.

The test should be plotted and tracked during the project and day to day operations by the contractor to verify his consistency is being met.
The “Compressive Strength of Cylindrical Concrete Specimens” should be checked regularly during the paving operations and should be detailed with the frequencies in the Contractor’s Process Control Plan.

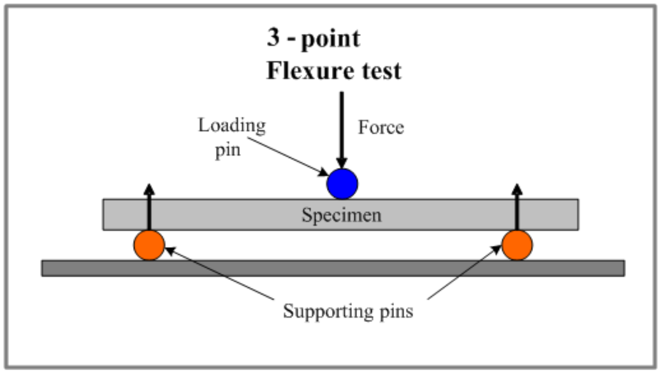
Flexural Strength

If slabs fail within the first few weeks after placement the probable cause is loss of support under the pavement slab, which results in excessive forces on the pavement slab. Another force is fatigue or the concrete’s ability to carry repeated loads. Under fatigue the concrete develops a small crack and after many cycles of loading the crack grows.

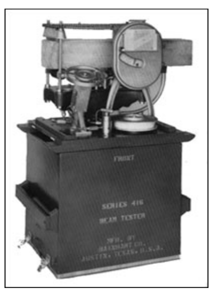
The flexural test method measures the behavior of materials subjected to simple beam loading. Flexural strength is defined as the maximum stress in the outermost fibers.

A flexural test produces tensile stress in the convex side of the specimen and compression stress in the concave side. This creates an area of shear stress along the midline.

In a 3-point test the area of uniform stress is quite small and concentrated under the center loading point.



Flexural strength is the method, which is used by the North Carolina Department of Transportation to **design (**monitor and accept**)** the concrete strengths of PCC pavements. It is measured using a Rainhart beam-breaking machine furnished by the Materials and Tests Unit.



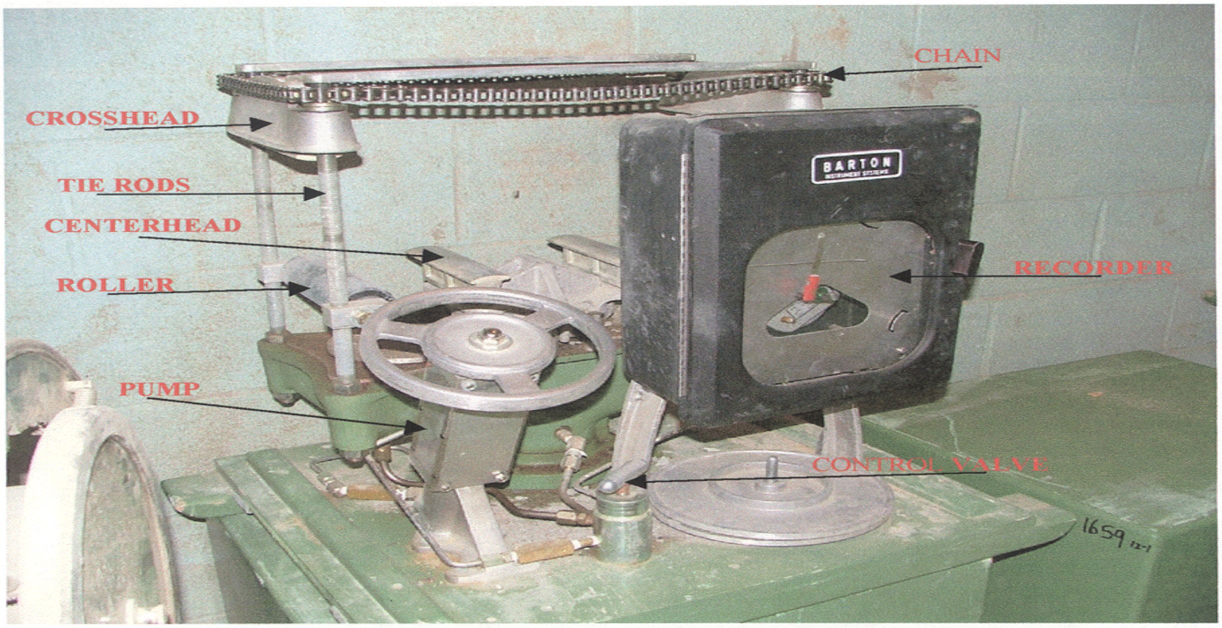
The flexural strength required for opening a pavement to permanent traffic is based on the modulus of rupture of beams tested using simple third point loading and is 650 psi.

The procedure for sampling, making, curing, and testing of flexural test beams is as follows:

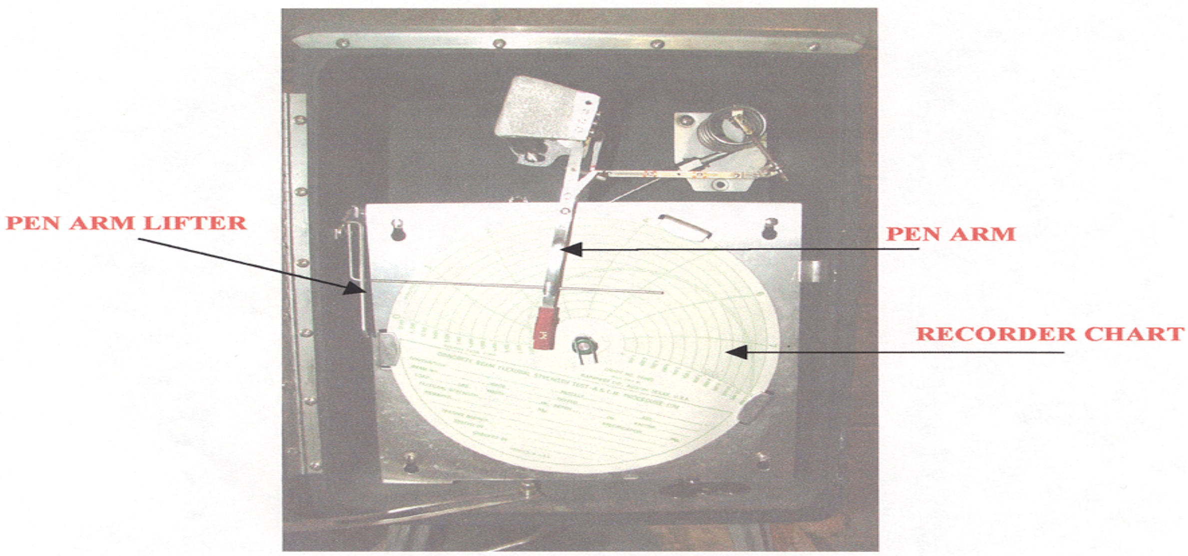
Sample the concrete as per ASTM C 172 “Standard Practice for Sampling Freshly Mixed Concrete”, make and cure flexural test beams per ASTM C 31”Making and Curing Concrete Test Specimens in the Field”, and test for flexural strength per ASTM C 78 “Standard Method of Test for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)”.

This test should be plotted and tracked during the project and day to day operations by the contractor to verify his consistency is being met.

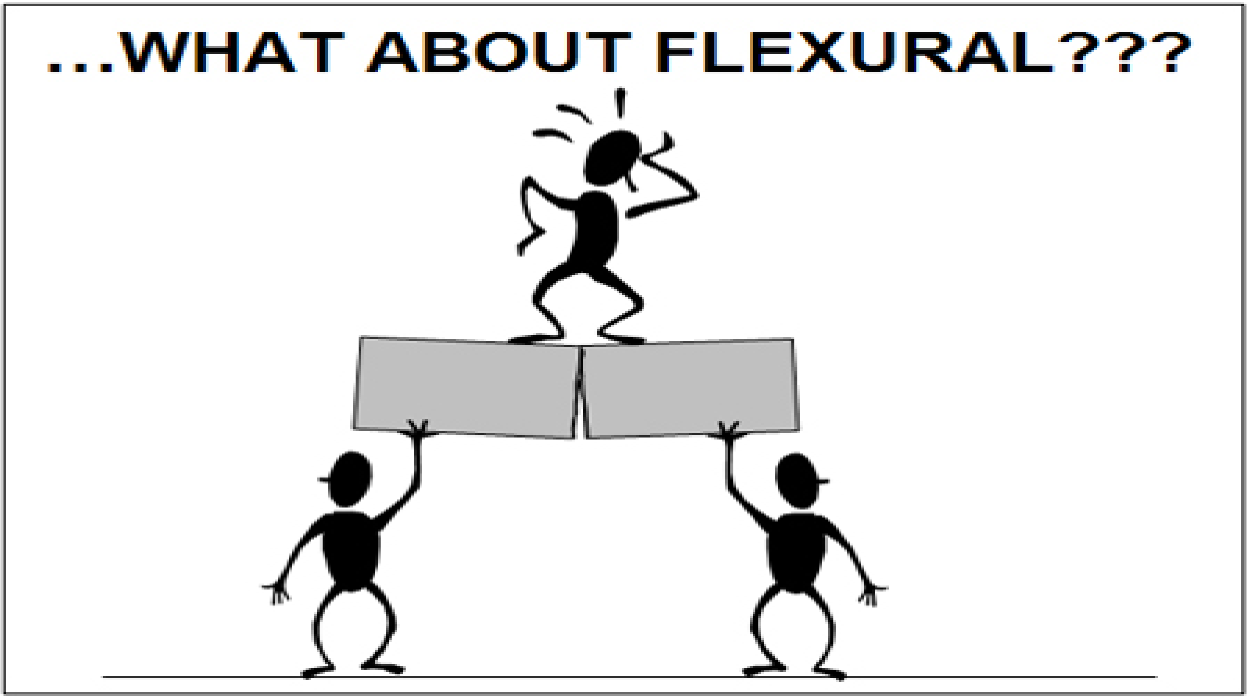
The “Standard Method of Test for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)”should be checked regularly during the paving operations and should be detailed with the frequencies in the Contractor’s Process Control Plan.



Rainhart Beam Breaker Machine



Rainhart Beam Breaker Recorder



Flexural Strength of Concrete is determined using 6” x 6” x 20” Concrete Beams. The length can vary on some types of molds, but the width and depth have to be 6”.

Equipment
Rainhart Beam Breaker (Furnished by the M&T Unit)
Record Charts
Rulers or Calipers

Procedure:

1. Before each series of tests, fully wind the chart drive (12 half turns). Do not over wind the chart drive. If pen is not recording properly, if needed, put on another recorder pin. Do not bent the pin holder. Open control valve by turning it counterclockwise. Allow ram head to come to rest, and then close control valve by turning it clockwise.

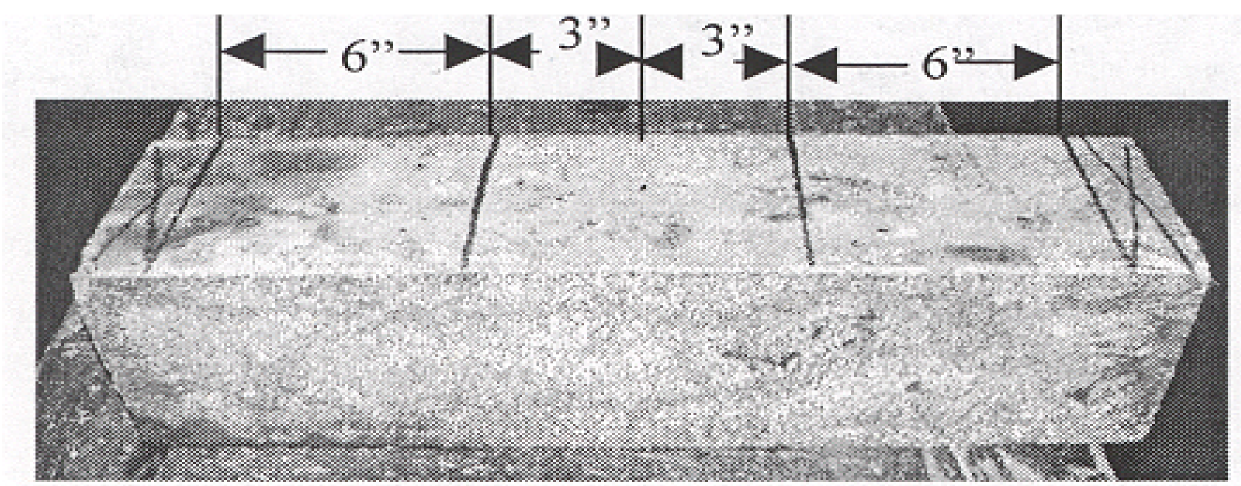
2. Remove test specimen from curing bed. Keep specimen wet with burlap when transferring it from curing bed to beam breaker. Place specimen on its side with respect to its position as molded, brush off sand from sides to be loaded, roll specimen into apparatus, and adjust it so that the section to be tested is centered in relation to four corner posts. Secure beam by tightening four post hand knobs, keeping top castings reasonably level. Record pretest data as desired on recording chart. Open recorder door, raise pen with lifter arm, and center and secure chart on drive hub so that start of loading track is about 1/2" to right of normal pen

position. Using lifter arm, lower pen into free recording position, and close and latch recorder door.

3. Close control valve securely by turning it clockwise. Apply slight load with level-action pump at right. Rotate handwheel of vernier pump at left so that pen records within spiral loading track, reversing rotation immediately when stoppage points are reached. DO NOT FORCE AT STOPPAGE POINTS. After beam breaks or fractures, open control valve by turning it counter-clockwise. Allow ram head to come to rest, and then close control valve by turning it clockwise. Loosen four post hand knobs, remove beam sections, and clear any fragments from ram head or third-point loading assembly.

4. Open recorder door, raise pen with lifter-arm, and remove chart from drive hub. Using lifter-arm, lower pen to about 1/4" above back-up plate. Close and latch recorder door. Record maximum applied load per loading graph apex. Measure average width and average depth of beam at the section of failure to nearest 1/16" and record this on chart. If the fracture occurs in the tension (lower) surface outside the middle third 6" of the span length, measure and record the average distance in tenths of an inch from the fracture to the nearest support.

NOTE: This is a horizontal distance measured along the lower surface of the beam from the fracture to the centerline of the support.



Calculations:

CASE 1:

If the fracture occurs in the middle third of the beam, the Modulus of Rupture (R), or flexural strength, is determined by multiplying the maximum recorded Load (P) in pounds by the applicable factor from the Table. The factor is determined by the average width and depth of the beam measured at the section of failure. A copy of this table of factors is shown on the back of each box of beam breaker charts.

		Beam Width (inches) - (b)										
		5 11/16	5 3/4	5 13/16	5 7/8	5 15/16	6	6 1/16	6 1/8	6 3/16	6 1/4	6 5/16
Beam Depth Inches (d)	5 11/16	0.0978	0.0968	0.0957	0.0947	0.0937	0.0927	0.0918	0.0908	0.0899	0.0890	0.0882
	5 3/4	0.0957	0.0947	0.0937	0.0927	0.0917	0.0907	0.0898	0.0889	0.0880	0.0871	0.0862
	5 13/16	0.0937	0.0927	0.0917	0.0907	0.0897	0.0888	0.0879	0.0870	0.0861	0.0852	0.0844
	5 7/8	0.0917	0.0907	0.0897	0.0888	0.0878	0.0869	0.0860	0.0851	0.0843	0.0834	0.0826
	5 15/16	0.0898	0.0888	0.0878	0.0869	0.0860	0.0851	0.0842	0.0834	0.0825	0.0817	0.0809
	6	0.0879	0.0870	0.0860	0.0851	0.0842	0.0833	0.0825	0.0816	0.0808	0.0800	0.0792
	6 1/16	0.0861	0.0852	0.0843	0.0834	0.0825	0.0816	0.0808	0.0800	0.0792	0.0784	0.0776
	6 1/8	0.0844	0.0834	0.0825	0.0817	0.0808	0.0800	0.0791	0.0783	0.0775	0.0768	0.0760
	6 3/16	0.0827	0.0818	0.0809	0.0800	0.0792	0.0784	0.0776	0.0768	0.0760	0.0752	0.0745
	6 1/4	0.0810	0.0801	0.0793	0.0784	0.0776	0.0768	0.0760	0.0752	0.0745	0.0737	0.0730
	6 5/16	0.0794	0.0786	0.0777	0.0769	0.0761	0.0753	0.0745	0.0738	0.0730	0.0723	0.0716

CASE 2:

If the fracture occurs in the tension surface outside the middle third of the span length by not more than 5%1 of the span length, calculate the Modulus of Rupture (R) as follows:

where,

P is the maximum applied load indicated by the testing machine (lbf)

a is the average distance between line of fracture and the nearest support measured on the tension surface of the beam (in.)

b is the average width of the specimen (in.)

d is the average depth of the specimen (in.)

$$R = \frac{3Pa}{Bd^2}$$

CASE 3:

If the fracture occurs in the tension surface outside the middle third of the span length by more than 5%1 of the span length, discard the results of the test.

1Note: 5% of an 18-inch span length is 0.9 inch (23 mm).

Report:

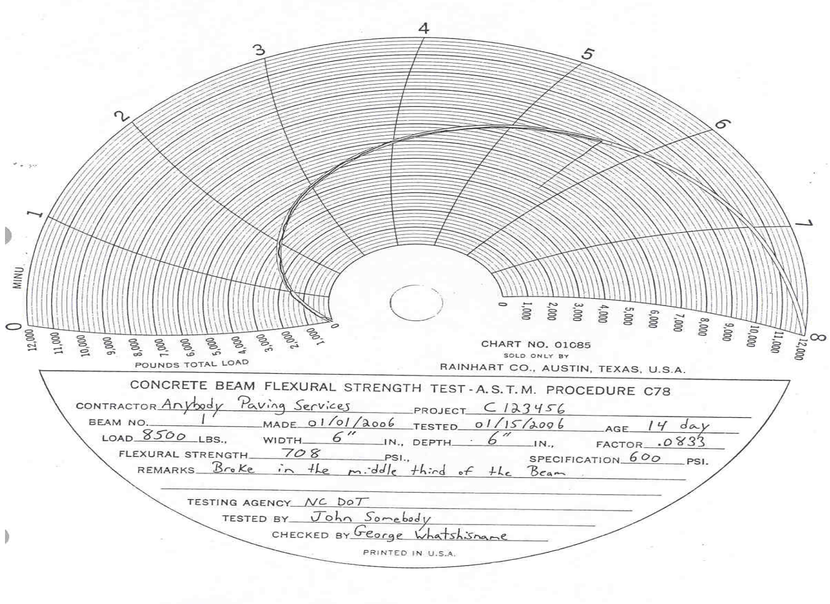
A sample of the recording chart used with the beam breaker is shown in this Manual. All spaces should be completed by the Inspector who tests the beams.

The space for "Remarks" should include the source of aggregates and any other information considered necessary concerning the test, including location of the fracture.

(For example, "Fracture location = middle third," or "Fracture location = 0.5 inch (13 mm) outside middle third.").

After the results have been recorded in the Resident Engineer's records, the charts are to be attached to M&T Report 253 and forwarded to the Materials and Tests Unit.

Sample of a Completed Concrete Beam Flexural Strength Test Form



FLEXURAL BEAM FREQUENCY:

Sample the concrete at the plant from the middle of the batch. Do not obtain the sample from the very first or last part of the batch discharge. Perform the sampling by passing the container through the entire discharge stream or by completely diverting the discharge into the container.

The minimum size sample for strength tests shall be a minimum of 1 ft3 for each set of 2 beams.

Lot Sizes & Frequencies:

For all concrete pavement, including mainline, shoulders, ramps, tapers, intersections, entrances, crossovers, and irregular areas not otherwise defined, produce a lot consisting of 1,333.3 square yards or fraction thereof placed within 28 calendar days. From each lot, make a minimum of one set of two 6” x 6” x 20” beams from a randomly selected batch of concrete. The average flexural strength of the two beams is considered one test.

Cylinder and Beam Sampling for PCCP for Strength-Maturity Relationship (SMR)

CONTRACTOR	NCDOT
MIX DESIGN Develop a maturity curve at mix design Submit with Concrete Mix design	Materials & Tests Concrete section reviews and approves concrete mix design(s)
TRIAL BATCH (after approval of mix, plant and lab) Establish a maturity curve based on approved mix design Produce cylinder and beam samples sufficient to test at 1, 3, 7, 14, and 28 days (3 per day break + 2 instrumented = 17 total cylinders and 17 total beams) Develop a flexural and compressive strength-maturity curve based on TTF	TRIAL BATCH Establish a maturity curve with DOT equipment to verify Contractor's curve Produce cylinder and beam samples sufficient to test at 1, 3, 7, 14, and 28 days (3 per day break + 2 instrumented = 17 total cylinders and 17 total beams) Develop a flexural and compressive strength-maturity curve based on TTF Resident Engineer may allow production of concrete paving to begin if 14-day breaks indicate strength will reach acceptance requirement for flexural and compressive strengths will be obtained at the 28-day breaks on the curve
PRODUCTION SAMPLING First day of production, verify the SMR established from trial batch by making 5 cylinder samples (3 for strength breaks and 2 that are instrumented) The contractor tests three compressive strength samples at the TTF needed to achieve the required estimated strength of 3000 psi (2006 Specs) or 3500 psi (2012 Specs). If, as stated in the Specifications, the verification sample is less than 3000 psi (2006 Specs) or 3500 psi (2012 Specs) compressive, a new maturity curve has to be developed and early traffic is not permitted on the concrete pavement. If the average strength of the three cylinders is greater than 10% of the TTF at the target strength of the curve, a new maturity curve may be developed.	PRODUCTION SAMPLING For the first lot for each mix, make cylinder and beam samples to allow for 1, 3, 7, 14, and 28 day tests. For the 2nd and 3rd lots, make cylinders only for the 14 and 28-day compressive tests except as noted below: ○ For every tenth lot (Lot #10, #20, #30, etc.) obtain cylinder and beam samples to allow for 14 and 28 day tests If there are any occasions where 3 consecutive compressive tests fail to meet the minimum strength (4500 psi) for that mix, then on the next tested lot make cylinder and beam samples sufficient to test at 1,3,7,14,and 28 days. Continue to run both cylinder and beam samples for 14 and 28 day breaks until such time M&T can perform an in-depth review of the in-place concrete and the batching procedures.

EstimatingIn-PlaceStrengthforOpeningtoConstructionTrafficorHeavyEquipment

1. After the Strength - Maturity Relationship curve and a target TTF has been established for a given concrete mix design field measurements of maturity and strength from maturity can be performed for that mix.

2. Field measurements involve placing maturity sensors in the pavement within the last 100' of each day's production by the Contractor's personnel and periodically monitoring the subsequent strength gain via the TTF of the concrete using the sensors.

3. The TTF will be read by both the Contractor and Engineer's representative and compared to the Target TTF from the Strength Maturity Relationship curve. If the TTF is equal to or greater than the Target TTF then the pavement can accept construction traffic or heavy equipment.

4. The following steps outline the procedures for estimating in-place compressive strength based on TTF established by the most recent Maturity curve:

   i. The Contractor will insert a minimum of two temperature probes or sensors using two maturity meters randomly placed within the last 100 feet (30 m) of each day's production.
   ii. The Contractor will embed the thermocouples in the fresh concrete at the mid-depth of the concrete slab at least 2.5 feet (0.8 m) from the edge of the pavement. Thermocouples should not be located near tie bars or dowel bar assemblies.
   iii. As soon as practical and while the concrete is still plastic the Contractor will insert the thermocouple and activate the maturity meter(s). Do not disconnect the maturity meters unless automatic probes are being used until the required maturity values are achieved. Data collection must be uninterrupted.
   iv. The Contractor will read the maturity meter daily in the presents of the Engineer or his representative. The contractor and RE personnel will record maturity data on a permanent data sheet. The data sheet shall show the required flexural strength and TTF.
   v. When the maturity value is equal to or greater than the required strength for the concrete mix, as determined by the strength-maturity relationship, record the maturity value. Remove the meter and clip thermocouple wires at the concrete surface. Maturity meters should be read in the presents of the Engineer or his representative.

Transporting Equipment:

There are three primary types of concrete transporting vehicles for transporting concrete to the project site: 1.) Dump Trucks (Non-Agitating Trucks), 2.) Agitator Trucks, and 3.) Ready Mix Trucks (Transit Mixer Trucks).

Dump Trucks:

Dump trucks are the truck of choice by the majority of Contractors to transport Portland Cement Concrete from the Batch Plant to the roadway on concrete pavement projects. They are cheap and versatile to use. Dump trucks are quick loading and unloading

Dump trucks can be used for delivering many things, but for concrete paving the dump truck beds used for delivering Portland Cement Concrete to a concrete paving project, must have bodies which are smooth, watertight, metal containers with rounded internal corners. The dump truck must also be equipped with vibrators and gates to discharge the concrete without segregation or damage to the mix.

Dump trucks do have disadvantages such as a limited elapse time, limited flexibility during discharge, and limited overhead clearance.

Dump trucks, according to the 2012 Standard Specifications, are limited to a 60-minute elapse time limit. The elapse time is defined as the period from first contact between the mixing water and cement until the entire operation of placing up to micro surfacing, including any corrective measures, if necessary, has been completed. This limit is imposed on dump trucks because no mixing is preformed within the truck bed.

If extra time is needed with a dump truck a mix conformity test can be done to see if extra time can be added to the elapse time. The mix conformity test is clarified in the test procedure in ASTM C 94 Annex. Seven tests are required in the test procedure and six of the tests have to pass the parameters explained in the procedure.

Another limitation is dump trucks cannot discharge part of a load. Discharging a part of a load or placing the concrete at other locations other than the back of the dump truck is extremely difficult. When using dump trucks with spreaders / placers the spotter must be very careful and not unload the truck on the belt or in the hopper too quickly. This can overload the belt or hopper and slow the operation down. The vibrator which is required for dump trucks should be used when emptying the end of the load.

The last limitation of a dump truck is the flexibility around obstacles. Getting under bridges and under powerlines can be a problem. The spotters when dumping dump trucks must be extremely vigilant not to get too high and strike a bridge or tear down a powerline.

Agitator Trucks:

Agitator trucks are not used as much as dump trucks or Ready Mix trucks. They are called agitator trucks because they have paddles inside the truck box. The paddles continually turn or agitate in the box of the truck when in transit. Even though the paddles continually turn (agitate) they do not mix the concrete and therefore do not get added elapse time. These trucks are a dump truck for all practical purposes. If extra time is needed with an agitator truck a mix conformity test can be done to see if extra time can be added to the elapse time. The mix conformity test is clarified in the test procedure in ASTM C 94 Annex. Seven tests are required in the test procedure and six of the tests have to pass the parameters explained in the procedure.

One advantage of an agitator truck is its ability to direct its discharge to a particular area such as an irregular area or hand pours.

One disadvantage of the agitator truck is it is limited in its use to concrete delivery only.

Another disadvantage is a reduction in speed of loading and unloading. The unloading is difficult because the discharge shoot is similar in size to a Ready Mix truck discharge and as with a dump truck getting under bridges and under powerlines can be a problem. The spotters when dumping an agitator trucks must be extremely vigilant not to get too high and strike a bridge or tear down a power line.

The last disadvantage is when loading an agitator truck the truck, because of it shape, must be in the correct location below the mixer so as not to empty part of the load on the ground.

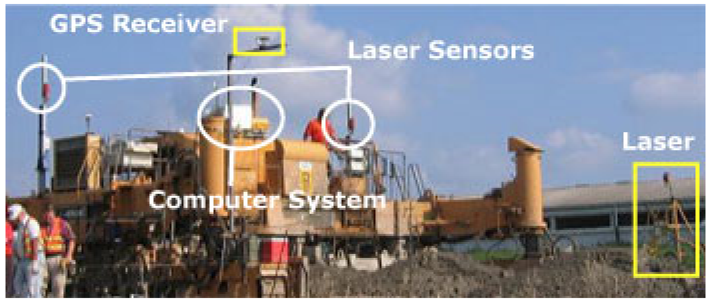
Ready Mix (Transit Mix) Trucks:

Ready mix trucks can be used as delivery vehicles when they are charged from a central batch plant or in some cases they can be used to mix the concrete. Ready mix trucks are normally used when the requirement is for a lower volume paving or for longer elapse times, such as urban paving. When used in higher volume paving, Ready mix trucks are used as delivery vehicles with the mixing done at the central batch plant.

Some advantages of the Ready Mix truck are the extended elapse times and no overhead clearance problems. The extended elapse time would be set per **Table 1000-2** and could be from 30 minutes up to 2 hours and 15 minutes depending on the air or concrete temperatures whichever is higher.

Some disadvantages are the reduction in the ease and speed of both charging and discharging the concrete and the limited usage of a ready mix truck.

Subgrades and Bases



Several companies have developed stringless equipment control and guidance systems using technologies such as robotic total stations and GPS with laser positioning. These stringless technologies have been successfully implemented on construction earthmoving and grading projects.

Stringless GPS control can successfully guide the slip-form paver and adequately control the concrete yield quantity, pavement depth, and surface elevations.

The GPS receiver location on the grading equipment and slip-form paver is critical to coordination with the 3D design program and proper machine control. Grading and paving equipment hydraulic controls and computer software must be modified to allow for uniform changes in elevation as the equipment moves forward to meet profile specification requirements. GPS control can provide a reasonably smooth riding pavement from the grading to the concrete surface. However, additional software development is required to uniformly produce surface profiles smooth enough to meet NCDOT specification requirements.

Stringless paving eliminates the need for string lines. This carries many advantages such as avoiding project delays caused by time-intensive staking of the string lines, reduces contractors' move in and move out times, have shorter construction periods that disrupt traffic, reduces labor costs for placing and removing string lines, increases the amount of traffic access along the roadway, especially in areas where the shoulders are limited, reduces the need to set string lines in hazardous areas, experiences greater working access to the slip-form paver and surrounding area, eliminates the need for string-line sensors on the grading and paving equipment, and decreases the overall width of grading and paving machines by eliminating need for stringline sensors making it easier and faster to cross bridges and other tight spots.

In the language of pavement design, the word **base** refers to the lift of asphalt material, the drainage layer, placed directly beneath the concrete pavement**.** Any selected asphalt course, the surface, which is placed beneath the drainage layer, is referred to as the **subbase.** The earth grade at the bottom of the pavement structure, modified by a special treatment, is referred to as the **subgrade.**

The subgrade is the top surface of the roadway embankment and is located underneath the base courses. It is the thickest layer in the roadway. Subgrades can be lime or cement treated.

All the underlying courses, regardless of the placement methods, shall be built to acceptable specified tolerances and provide the working platform necessary to enhance the quality of the finished product, minimize the loss of concrete, eliminate short core penalties, and contribute to the smoothness of the concrete pavement.

In Division 5, Subgrade, Bases, and Shoulders, of the Standard Specifications state that the work covered includes preparing, grading, shaping, and compacting the stabilized roadbed to a condition suitable for placement of subgrade, subbase, drainage layer, concrete pavement and shoulders.

The roadway should be shaped to conform to the lines, grades, and typical sections shown on the plans.

Article 700-4 States: Prepare the subgrade and base beneath Portland cement concrete pavement in accordance with the applicable sections of these Specifications and with a grading tolerance of ± 1/4" from the established grade on mainline lanes and a grading tolerance of ± 1/2" in all other areas. **Use approved automatically controlled grading and paving equipment to produce final subgrade and base surfaces meeting the lines, grades and cross sections required by the plans or as directed.** When in the judgment of the Engineer the use of such equipment is impractical, this requirement will be waived.

Provide and maintain ditches and drains as may be necessary to satisfactory drain the subgrade. Where previously approved subgrade is damaged by natural causes, by hauling equipment, or by other traffic, restore the subgrade to the required lines, grades, and typical sections and to the required density at no additional cost to the Department.

Placing and Consolidation Equipment:

There is two pieces of equipment that moves the concrete from the point of discharge of the truck, places it on the grade, and constructs it into a finished pavement.

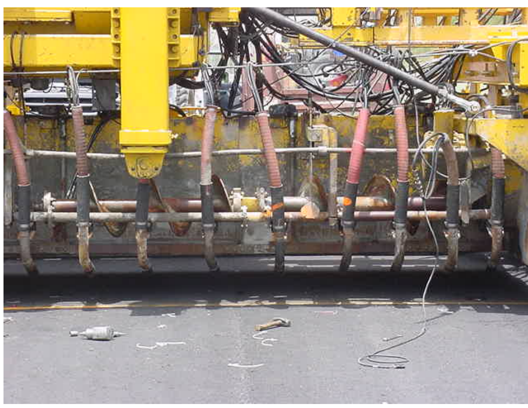
Placer / Spreader:

The belt placer is the first piece and serves a number of functions. The first function is that it takes the concrete from the truck and conveys the concrete to the grade in front of the paver, allowing the truck to unload from the side of the roadbed or in some cases on the grade. The belts then deposit the concrete in the middle of the grade just in front of the paver or spreader. When a placer is used as a spreader it utilizes a stringline and is set a fraction higher than the paver so as to give the paver a constant head of material. This function spreads the concrete uniformly across the width of the paver. This function also provides a more uniform flow of concrete into the paver thereby resulting in a smoother ride. The 2012 Standard Specifications specify the use of a mechanical spreader, which is independent of the paver.

Paver:

The paver and/or finishing machine is the most important part of the paving train. It forms the concrete into the proper width, elevation and depth. The paver consolidates the concrete with machine mounted vibrators. It has tie bar insertion capability and sometimes dowel bars are inserted into the fresh concrete as a part of the paver function.

The paver has three major parts: augers, vibrators, and pan. The augers move the concrete back and forth in front of the paver to maintain a proper head. The proper head means that an equal amount of concrete is distributed in front of the paver. This also ensures that there are no piles of concrete in front of the paver thereby making the paver ride up on a mound of concrete and create a bump.




Next are the vibrators which liquefy and consolidate the concrete which is being forced through the paver. Proper setting of the frequency of each vibrator is a very important and vital step when it comes to the paving operation.

According to the 2012 NCDOT Standard Specifications the Contractor should furnish an electronic monitoring device, displaying the operating frequency of each individual vibrator on the paving equipment. This equipment should record the time, station, location, paver track speed and operating frequency of each individual vibrator after every 25 feet or after each 5 minute time interval has elapsed. A report showing all the above information should be supplied to the Engineer daily for the first three days and weekly thereafter.

Over vibration can damage the air entertainment system in the concrete and segregate the aggregate within the concrete.

Under vibration can cause voids to be created within the concrete and reduce both the concrete's strength and durability.

The last component of a paver is the pan. It strikes off the concrete to the proper line and grade, and smooths the surface. There are a number of adjustment devices attached to the pan in order to make changes in the crown or change the superelevation.

Some contractors attach finishing devices such as oscillating floats, “V” Floats, or Tube Floats in order to finish the concrete as it exits the paving pan.

Finishing:

Finishing tools are used on the surface of the pavement immediately after it comes out from the pan of the paver. Finishing closes the surface of the plastic concrete and removes bumps and imperfections in the surface.

Common types of finishing devices that are attached to the paver are the tube float, “V” float and the Oscillating float. Not all contractors use these but some feel they aid in obtaining a smooth ride.

The tube float consists of rotating tubes, which immediately follow the pan or could be mounted on a separate device. It brings some mortar to the surface to fill in the imperfections on the surface.

The “V” float is suspended behind the paver and floats the entire surface as it passes.

The oscillating screed brings mortar to the surface. If the amount of mortar is not excessive, it is not a problem and simply aids in closing the surface. If excessive mortar is present, either too much water is being added to the burlap or water needs to be removed from the mix. The oscillating screed works back and forth across the pavement while it oscillates on a short forward to backward stroke.

Hand finishing tools include straightedges, and bull floats. Pavement should be first checked with straightedges to remove any bumps and then finished with bull floats. The pavement is finished further with a macro and micro texture.

Texturing

Texturing consist of two types: **micro texture** and **macro texture**. Both are accomplished in the paving operation but normally done with two different pieces of equipment.

Micro texture

Micro texture is the roughened surface created by the dragging of wet burlap or astro turf along the fresh concrete surface. Often a bridge is attached and pulled along, using cables attached behind the paver. Pushing this bridge along by hand should be discouraged. Pushing the bridge by hand results in the bridge “crabbing” along and leaving a wavy texture pattern.

Such a pattern, although not addressed in the specifications, is very noticeable to the driver and conveys a message of poor workmanship.

Macro texture

Macro texture is the grooving pattern scored into the fresh concrete through a process normally referred to as tining. The machine, which has a rake containing many wire teeth spaced in a random pattern made of spring steel, is controlled by a stringline and is used to construct transverse grooves and is usually called the tining machine. North Carolina allows transverse tining.

The texturing is done transversely. The contractor must be consistent with the texturing along any section of roadway. This should be discussed with the contractor prior to the start of paving operations.

The Contractor is encouraged to construct the grooves as shallow as practical within the Specification limits. Shallow texture reduces pavement noise but still provides adequate friction.

Curing

Curing is a critical final step in the paving operation. This is completed with a machine commonly known as a cure cart. It has a holding tank to hold the curing compound and a spray bar with nozzles to apply the cure to the surface of the pavement, including the edges, in a uniform application. Sometimes the curing operation and the tining operation are combined on one machine. This has advantage for the contractor by minimizing the amount of equipment needed but has the drawback of interfering with one operation if a malfunction occurs with the other operation.

Sawing

Saws are used to cut the joints in concrete pavements. They are commonly grouped into two categories: Early entry dry cut saws and conventional saws.

Early entry dry cut saws

Early entry dry cut saws are used by the contractor to cut the initial transverse and longitudinal joints. They make a cut four inches deep. Sawing must begin as soon as possible after the concrete is placed, often within about three to four hours. The saws used by many contractors in North Carolina use an up-cut design. This produces a clean joint with very little dust.

Conventional Saws

Conventional saws are much heavier and more powerful than Early entry dry cut saws. The contractor if allowed to use a conventional saw for cutting the "initial cut" would have to wait to begin sawing until the concrete had gained more strength than the point at which sawing could begin with Early entry dry cut saws. The saw depth is the major difference in the approach to sawing with early entry dry cut saws or conventional saws. Conventional saws would have to make an initial cut that is 0.3 T + ¼" in depth if used for this operation. Conventional saws are used to cut the "final" or "reservoir" cut.

Conventional saws can be of two types: dry saws and wet saws. Wet saws use water to cool the saw blade during the sawing operation. These saws use diamond blades. Dry sawing does not require water and utilizes either diamond or carbarendum blades. A disadvantage of dry sawing is the dust that is created, which can especially be a problem in urban areas or when wind carries the dust across open lanes of traffic.

Span Saws

Span saws are heavy-duty saws used for high production on large projects. They are capable of spanning the full width of a pavement and sawing joints much more quickly than conventional saws. They are very similar to conventional saws in that the contractor must wait to begin sawing until the concrete has gained sufficient strength to allow the weight of the equipment without damaging the slab. North Carolina and other states do not allow heavy span saws, which are supported on new pavement, to be used.

Sealing

The joint sealing operation will follow the joint sawing and includes a number of steps. The type of joint being sealed and the type of saw that was used will determine what operation will be required.

The joint must be cleaned. A high-pressure water blast must be used if the joints were sawn with a wet saw. An air blast must be used to clean the joint if a dry saw was used. A conventional air compressor is commonly used for this work.

A backer rod may is required. A suitable tool must be used which will insert the rod to the proper depth.

Silicone sealant when applied on concrete pavement projects is applied with a truck or trailer with a tank to hold the sealant and a pressure application system with a nozzle made for the purpose of sealing concrete roadway joints. Some hand tools are required to put the correct shape on the top of the sealant and to achieve the correct depth from the top of the joint.

Cold Weather Protection

Article 700-8

Article 700-8 dictates the type of protection needed for concrete paving. It is necessary for the grade inspector to obtain the projected low temperatures to assure the paving is being protected adequately. An easy way to obtain this information is from a local radio station.

At times the contractor will use a weather service to obtain this information also. Normally these temperatures will be the overnight temperatures. Article 700-8 dictates the concrete and air temperatures required for the contractor to be allowed to pave. The grade inspector will need to actually carry several thermometers and take the air and concrete temperatures to be sure the contractor is in compliance with the specification. The problem with using the current air temperatures from a radio station is the station may be a fair distance away from the project and there could be a difference in temperatures between the two locations. Another problem is the station is probably in town where the temperatures are normally warmer than what they are on a rural paving project.

It is necessary for the inspector to record these temperatures and the time they were taken. If any action is taken such as not allowing the contractor to start or having them shut down, this should also be documented in the inspector's diary.

Hot Weather Protection

Article 700-8

When the anticipated daily high temperature is above 80°F, place the concrete at the coolest temperature practical. Control concrete temperatures to assure proper placing, consolidation, finishing, curing, and to prevent plastic shrinkage cracking.

Rain

Article 700-8

When rain appears imminent, stop all paving operations, and have all available personnel protect the surface of the unhardened concrete. Failure to properly protect the concrete pavement may constitute cause for removal and replacement of the damaged pavement, at no cost to the Department.

JOINT CONSTRUCTION

Saw Cuts

Article : 700-11

Road Standard Drawings: 700.01

Earlier in the manual, the types of saws were discussed. The NCDOT Standard Drawings 700.01 has types of transverse and longitudinal contraction joints detailed and NCDOT Standard Specification 700-11 details each of the types of saws used. All joints will be sawed in a single cutting operation. Each joint shall be sawn true to line and dimension. Joint sawing will begin as soon as the concrete has hardened enough to permit sawing without raveling or moving of aggregate.

The inspector should check a minimum of 20% of the width and depth of the saw cuts made. A worksheet to document those checks is included in the Appendix. Documentation should be made in the Inspector’s Daily Diary.

The inspector should check the location of sawcuts. The location of transverse contraction joint baskets should be properly marked so the sawcuts can be placed directly over the middle of the basket.

If the contractor does not want to saw completely through the edge of the new pavement on the first pass of sawing the Engineer may give permission as to the method of stopping the saw cut before it reaches the edge of the pavement. Sawing completely through the edge of the concrete edge in the time required or as allowed will be required. This method could prevent spalls or “blow outs” from happening with lightweight early cut saws at the edge of the slab as the saw comes out the pavement. If allowed by the Engineer, pull up of the saw just before the edge of the slab.

Again, sawing through the edge of the pavement will be required either in the required time or as allowed by the Engineer. Random inspection of the joint location for conformance to the dowel reference markers and depth will be required.

Light early saws

The light early entry saw is used for cutting the initial saw cut. The start of the sawing window is much earlier than when the larger conventional saws were used. Often, sawing can begin within about 3 hours of placement of the concrete, depending on weather conditions and concrete mix temperature.

The light early entry saw offers many advantages compared to the conventional saws. There is very little dust because the saw cut is made when the concrete is very green and there is a lot of moisture still in the swarf. Normally the swarf is left in a small pile next to the joint. The swarf remaining should be blown away as soon as possible to keep the swarf from infiltrating back into the sawn joint and to clean up in preparation for the use of the profilograph.

Also, this type of saw is smaller than conventional saws so it is less powerful, but much quieter. This is particularly helpful when in an urban environment.

Note the specifications do specify the use light early entry saw to be used to cut both initial transverse and longitudinal contraction joints to the specified depth and width.

Joints must be sawed before uncontrolled cracking takes place. Sawing operations will be continuous, regardless of weather or daylight conditions. If sawing in darkness refer to Articles 105-14 "Night Work" and 1413 "Portable Construction Lighting" in the Standard Specifications. Adequate artificial lighting should be provided when performing sawing activities at night.

When random transverse cracks occur, it is required that the pavement be repaired. The PCCP Repair Manual provides guidance for repair of random cracking. The inspector needs to work with the contractor to insure that joints in irregular areas are sawn properly. Project plans may show the location of these joints. Be careful not to have saw joints intersect at a "T" corner. Often these will lead to a random crack as shown below.

If bridges with skews are anticipated please plan the joints between expansion joints near the bridges but please contact the NCDOT Construction Unit, Pavement Construction Engineer, with the layout. If joints near bridges are not planned correctly cracking could occur.

Conventional saws

Conventional saws will be used for cutting the reservoir cuts. The sawing is normally done with a gang of diamond blades and can be done as a dry process or wet sawing may be used.

Dowel Bars

Dowel Bars are defined as smooth plain round steel bars conforming to the requirements of AASHTO M 31, Grade 60.

A dowel bar provides a mechanical connection between two slabs without restricting the horizontal joint movement, known as contraction and expansion, but allows the slabs to share the load of a car or truck from slab to slab known as load transfer.

Load transfer is the distribution of a load, typically a wheel load, across a joint. Without dowel bars the slabs would not share the load and each slab would flex repeatedly and eventually cause faulting, pumping, or cracking of the slabs.

Verification of Dowel Bar Alignment (Magnetic Imaging Device)

In Article 700-11(G) “Verification of Dowel Bar Alignment” the specifications require the use either properly secured dowel baskets or a dowel bar inserter, provided the ability to correctly locate and align the dowels at the joints is demonstrated.

The contractor is to provide a calibrated magnetic imaging device that will document the dowel bar location and alignment. The contractor will utilize this device as a part of his process control and make any necessary adjustments to ensure the dowels are placed in the correct location.

The contractor will scan at least 25% percent of the joints in the initial placement or 1.0 mile of pavement, whichever is greater, at random intervals throughout the pavement each time the paving train is mobilized.

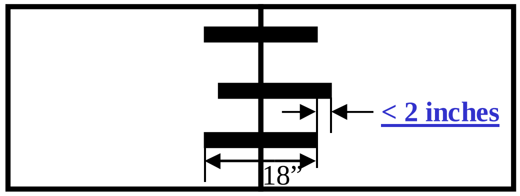
He will scan all joints in this initial section if the dowel bars exhibit side shift, horizontal displacement, vertical displacement, horizontal misalignment, or vertical misalignment, above the allowable tolerances defined below. In addition, he will continue scanning 25% of the joints until it is established that the dowel bar inserter or secured dowel basket assemblies are consistently being placed at the correct location (meeting the tolerances defined below). Once the engineer determines that consistency is established, the contractor may reduce the percentage of scanned joints to 10%. At any time, inconsistency in the placement of the dowel bars become evident, additional scanning may be required up to 100% of the joints.

If the consistency of the proper dowel bar alignment cannot be established within a reasonable time frame, the Engineer will have the option of suspending the paving operation.

The contractor will provide a report of the scanned joints. This report should include the station and lane of the joint scanned, as well as the horizontal location, depth, horizontal and vertical misalignment, and lateral displacement or side shift of each dowel bar in the joint. The joint score described below should also be provided in the report.

Side shift is defined as the position of the center of the dowel bar in relation to the sawed joint. The maximum allowable side shift is 2 inches

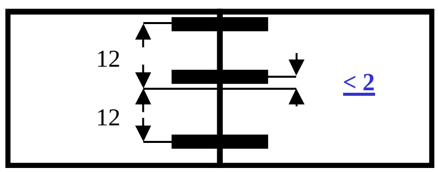
Side Shift
less than 2 inches



Horizontal displacement is defined as difference in the actual dowel bar location from its theoretical position as detailed in the standard details. The maximum allowable horizontal displacement is 2 inches.

Horizontal displacement

— less than 2 inches

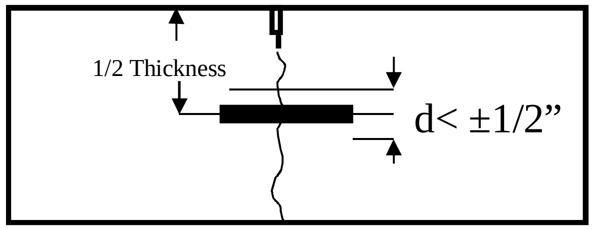


Plan

Vertical displacement (depth) is the difference in the actual dowel bar location from the theoretical midpoint of the slab. The maximum allowable vertical displacement depth is 1/2 inch.

Vertical Displacement

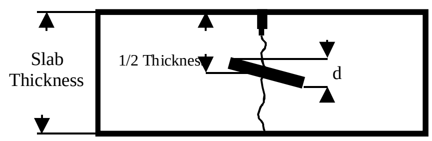
Less than ½” from mid point of the slab



Profile View

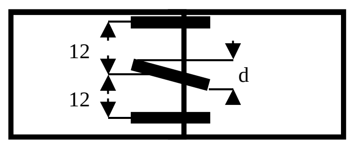
Dowel bar misalignment is defined as the difference in position of the dowel bar ends with respect to each other. Vertical misalignment is measured in the vertical axis whereas horizontal misalignment is measured in the horizontal axis.

Vertical Misalignment



Profile View

Horizontal Misalignment



Plan

Determining a joint score for each joint scanned as below:

Joint Score = Σ(# of bars * Misalignment Category)+1

Example: A joint has 12 bars. 10 are aligned correctly. 1 bar is misaligned 16mm, and 1 bar is misaligned 22mm.

Joint Score = **Σ {(10*0) + (1 * 2) + (1 * 4)} + 1**

Joint Score = 7

The joint score is a measure of combined effects of horizontal and vertical misalignment. The joint score is determined by summing the product of the weight (shown in the table below) and the number of bars in each misalignment category and adding 1. The vertical and horizontal dowel misalignment should be evaluated and the greater misalignment shall be utilized in determining the joint score.

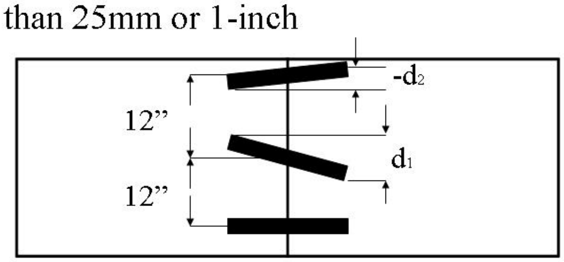
Misalignment Category, mm	**Weight**
0 <= d <= 15	0
15< d <= 20	2
20< d <= 25	4
25 < d <= 38	5
38 <= d	10

Where d is the individual dowel bar misalignment.

A joint that has a joint score of 10 or greater will be considered locked.

Identify any scanned joints where the opposing horizontal or vertical misalignment of any two bars within the joint exceeds 1 inch. This situation will be considered a locked joint.

Evaluate joints for opposing skew (Cross-Stitching)
- less than 25mm or 1-inch



Opposing Skew = $d_1-(-d_2) < 25mm$

When a locked joint as defined above is discovered, scan the two joints immediately adjacent to the locked joint. If either of the adjacent joints are deemed to be locked, provide a written proposal to address the dowel misalignment for each locked joint. No corrective action should be performed without written approval.

Any and all corrective action necessitated by improper joint alignment shall be at no cost to the Department.

MATURITY

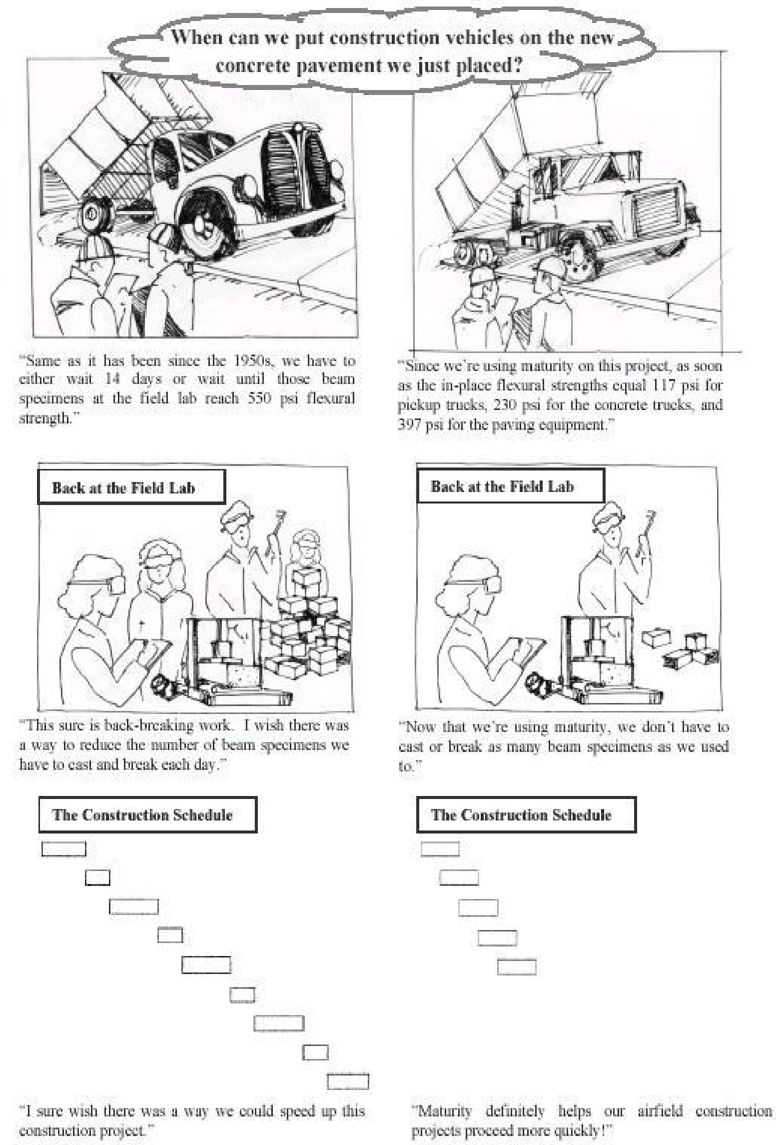


Figure 1.1 – Benefits of using Maturity to Make Meaningful Open-to-Traffic Decisions

Using Maturity Testing for Airfield Concrete Pavement Construction and Repair, Report IPRF-01-G-002-03-6, March 06

Introduction to the Maturity Method:

When properly implemented, the maturity method is a powerful tool for estimating in-place strength. It can expedite construction and improve the quality of construction and repair projects. Maturity is well suited for use in Portland Cement Concrete. It can be used on concrete pavements, bridges, etc..

Maturity testing is a reliable technique for the continuous monitoring of strength gain. There are several advantages over the traditional making and breaking of beams testing. The most important advantage being the opening to construction traffic earlier, therefore, continuing construction of other lanes, shoulder, etc..

In the past, when using the traditional method of opening, a NCDOT Technician would make a set of beams and cured the beams for 28 days. The Contractor's technician would make more sets of beams for early breaks. At a time chosen by the Contractor the NCDOT Technician would break the Contractor's beams in order to find out if the strength of a pavement was adequate for opening to construction traffic.

The maturity method is a non-destructive technique for estimating the strength of Portland Cement Concrete in the field. The technique does not require as much traditional field-testing and is more representative of in-place conditions. The test beams in the laboratory do not reflect changing conditions, which are occurring on the in - place slab in the field in the curing process. The strength being determined in the laboratory is the strength of the specimen in the bath and is not representing the in - place concrete or the conditions that it is being exposed to.

History and Overview of the Maturity Method:

The maturity method for measuring concrete strength was demonstrated in Europe as early as 1949 (Nurse 1949). It made its way to the US after some tragic accidents occurred in 1973 and 1978.

In 1973 in Fairfax County, Virginia a building collapsed during construction killing 14 and injuring 34. The NBS (National Bureau of Standards) was asked to investigate by OSHA (Occupational Safety and Health Administration). The NBS investigators traced the accident back to a four day old floor slab which had been subjected to an average ambient temperature of only 44 degrees as the most likely cause of the accident (Carino and Lew, 2001). This accident was explained as temperature-dependency affecting the concrete strength gain. In other words, If the average ambient temperature is low then strength gain would be slower.

Temperature-dependency affecting the concrete strength gain also caused a similar accident during the construction of a cooling tower at the nuclear power plant located at Willow Island, West Virginia in 1978. In this accident a scaffold collapsed causing 51 workers to be killed. The combination of these two accidents caused the NBS to examine other alternatives to estimate in-place strength. As a result of the examination of other alternatives for estimating concrete strength the NBS determined that the maturity method was a viable means for estimating the strength of concrete subject to various curing temperatures. This led to the establishment of ASTM C 1074 for estimating concrete strength by the maturity method.

As a part of the SHRP (Strategic Highway Research Program) in the mid 1990's, the FHWA (Federal Highway Administration) recommended the maturity method as an available technology for estimating in-place concrete strength development in highway structures.

Opening to Construction Traffic:

On projects using the 2012 Standard Specifications, the maturity method is required for opening to construction traffic. Slipform paving will benefit tremendously by the use of the maturity method for opening to construction traffic sooner.

The magnitude of the benefit of using the maturity method for opening to construction traffic is directly tied to the timetable of the project. In general the size and type of the project play a role in terms of the benefits derived from the use of the maturity method.

Benefits of Maturity:

Since hydration increases over time, and the rate of the increase is dependent on temperature, it should be possible to estimate the degree of hydration by tracking time and temperature. "Maturity" is the term used to describe this concept. Most maturity measures are expressed as a function of the product of curing time and temperature.

For example, the *Nurse-Saul expression* that is also required per the 2006 Specification is:

$$\mathbf{M = \sum_{0}^{t} (T - T_0)\, \Delta T}$$

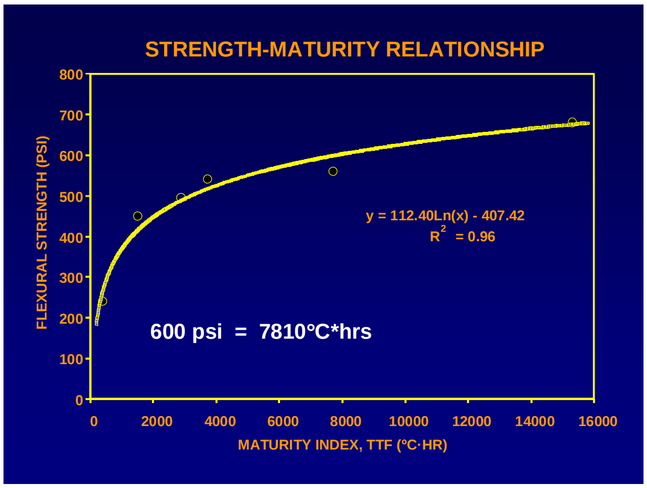
where: **M** = **maturity (usually in °C-hours or °C-days)**

t = **Time interval being considered**

Δt = **Time interval**

T = **Average temperature of the PCC during the time interval, Δt, being considered**

T_0 = **datum temperature – the temperature below which PCC shows no strength gain with time (-10°C is most commonly used)**



Example of a Strength - Maturity Relationship

Strength vs. Maturity

Maturity is linked to PCC strength gain by laboratory testing prior to the PCC placement. A non-destructive maturity measurement can then be used to estimate strength and avoid destructive strength tests during construction. ASTM C 1074 defines the maturity method as "...a technique for estimating concrete strength that is based on the theory that samples of a given concrete mixture attain equal strengths if they attain equal values of maturity index (TTF)." The maturity method is useful because it can provide strength estimates of the in-place PCC pavement subject to the actual outside temperatures rather than relying solely on controlled laboratory tests. The Maturity method identifies the earliest possible opening time for construction traffic, allows for a determination of the optimum time to saw joints, facilitates fast track paving applications, requires fewer specimens to be fabricated and tested, and improves public relations by reducing closure time for construction.

Limitations of Maturity:

There are also a number of significant limitations when using maturity to estimate strength:

1. ***The maturity method requires the establishment of a strength-maturity relationship in the laboratory prior to any field measurements.*** Because different concrete mixes mature at different rates, maturity meters are typically calibrated to actual flexural strength using laboratory test beams. Thus, any change in mix proportions from the laboratory concrete mix design used for the strength-maturity relationship curve will require a new curve to be established.
2. ***Other characteristics affecting PCC strength.*** Items such as moisture content, Portland cement chemical composition and fineness, and construction practices (e.g., consolidation, finishing, and air content) are not accounted for.
3. ***Maturity only accounts for ambient temperature.*** In large concrete volumes, the heat of hydration contributes significantly to the PCC mass temperature, and

thus, strength gain. In typical PCC pavements that are relatively thin, this heat is quickly lost to the environment and can be ignored.

4. ***Maturity functions are not accurate at low maturities.*** This is probably because the point at which time should be measured from is poorly defined. Probably, the best time is not the time of mixing or casting, but rather the time that the PCC actually begins to gain strength.

5. ***Maturity does correlate well with strength when there are large temperature variations during curing.*** Typically, a low initial curing temperature followed by a high temperature will lead to higher strengths, while the opposite (high followed by low) leads to lower strengths (Mindess and Young, 1981).

In summation, the maturity method is not a physical law, but rather a convenient way to estimate strength gain. In PCC pavement applications, maturity meters can be used to estimate the appropriate time for form removal, joint cutting or opening a pavement to construction traffic, but should not be entirely substituted for basic laboratory strength tests.

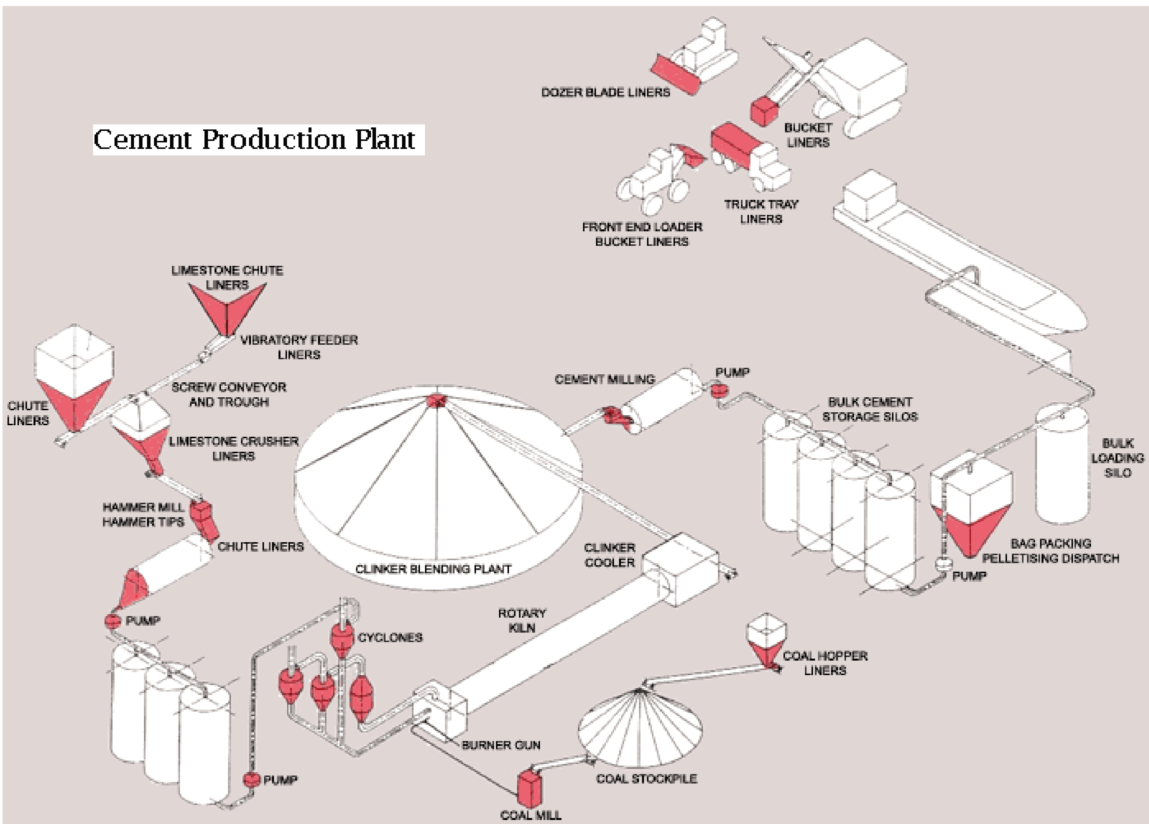
Maturity Meter

Measuring Maturity

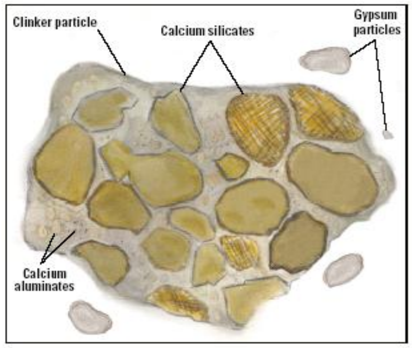
Note: CONCRETE MATURITY METHODS SHOULD NEVER BE RELIED UPON FOR FINAL ACCEPTANCE. FLEXURAL TEST BEAMS SHALL BE USED FOR FINAL ACCEPTANCE.

THE BASIS FOR MATURITY:

To understand the maturity method we must first understand the make up of Portland Cement that is the glue of the concrete. Portland Cement is produced from several items such as Limestone, and a 'cement rock' such as clay or shale. These are quarried and delivered to the cement production plant.



These rocks contain lime (CaCO3), silica (SiO2), alumina (Al2O3) and ferrous oxide (Fe2O3) - the raw materials of cement manufacture. To form a consistent product, it is essential that the same mixture of minerals be used each and every time. For this reason the exact composition of the limestone and clay or other materials is determined at this point, and other ingredients added if necessary. The rock is also ground into fine particles to increase the efficiency of the reaction. The raw materials are then dried, heated and fed into a rotating kiln. Here the raw materials react at very high temperatures to form 3CaO•SiO2 (tricalcium silicate), 2CaO•SiO2 (dicalcium silicate), 3CaO•Al2O3 (tricalcium aluminate) and 4CaO•Al2O3•Fe2O3 (tetracalcium alumino-ferrate).

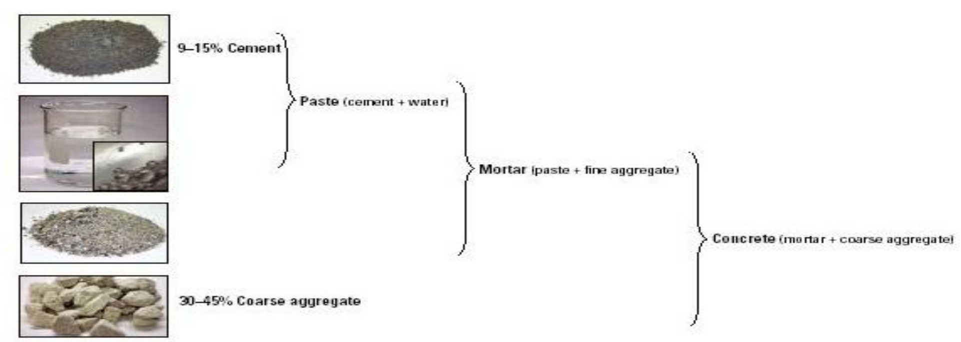


Composition of portland cement

The 'clinker' that has now been produced will behave just like cement, but it is in particles up to 1.2 inches in diameter. These are ground down to a fine powder to turn the clinker into useful cement. Gypsum is then added as a set retarder to slow down the hydration process.

Portland Cement Concrete:

Concrete contains several constituents that are illustrated below:

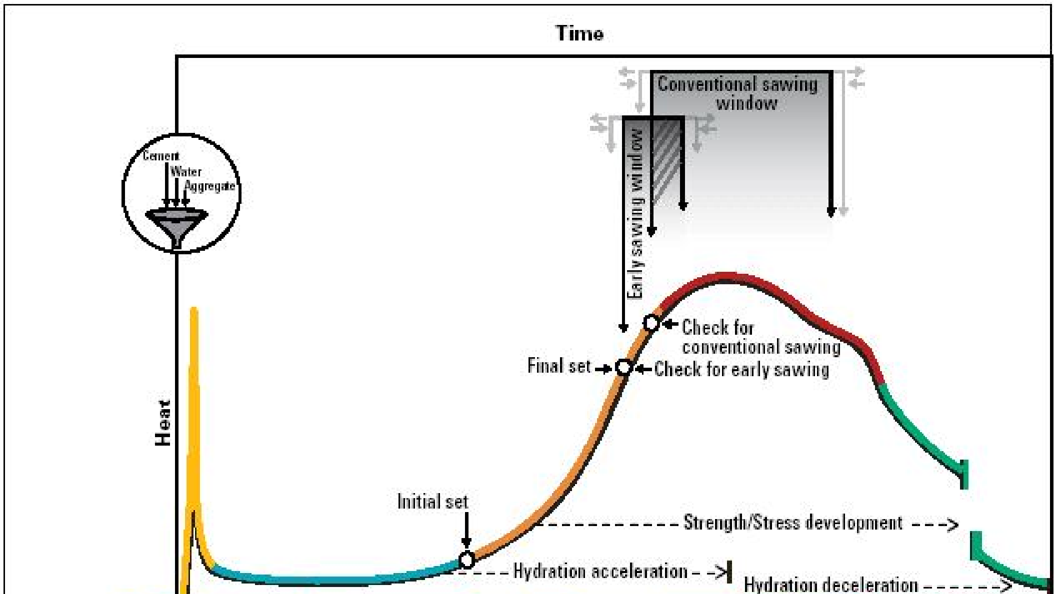


Concrete is basically a mixture of cement, water/air, and aggregates (percentages are by volume). (PCA)

Concrete gains strength gradually over time as a result of multiple exothermic chemical reactions between the mixing water and the various cementious (cement) and pozzolanic (flyash, etc.) materials in the mix. Over time, various chemical and physical reactions take place, allowing hydration to take place. The cementious materials combine with the water to produce hardened concrete.

For a specific concrete mixture, strength at any age is related to the combined degree of hydration of the cementious materials in the mix. The degree of hydration of the cementious materials is measured indirectly by measuring a property, such as strength, of the concrete as a whole.

The rate of hydration occurs is greatly dependent upon the temperature and whereas the individual hydration reactions are exothermic, one indirect method of determining the degree of hydration is by measuring heat generation. Also because the rate of hydration is temperature dependent, the rate of strength development for a given concrete mixture will be a function of the internal concrete temperature. The strength of the concrete depends on its time-temperature history assuming that sufficient moisture is present to feed the hydration reaction. Insufficient moisture within the concrete will cause the hydration reactions and the simultaneous strength development to cease thus emphasizing the importance of timely and adequate application of curing compound.



	Stage 1 Mixing	Stage 2 Dormancy	Stage 3 Hardening	Stage 4 Cooling	Stage 5 Densification
	Lasts about 15 minutes	Lasts about 2–4 hours	Lasts about 2–4 hours		Continues for years
Characteristics of concrete mixture	High heat is generated immediately, followed by rapid cooling.	Mixture is plastic, workable, and not generating significant heat.	• Hydration generates significant heat. • Mixture sets, begins to harden, and gains strength. • Stress begins developing in the concrete.	Stress development will exceed strength development if stress is not relieved.	Slab continues to become stronger and less permeable.
What engineers, supervisors, and workers must do to ensure durable pavement	Ensure adequate mixing.	Transport, place, and finish the concrete while plastic and workable.	• Begin curing as soon as possible. • Thoroughly apply curing compound.	Saw joints to relieve stress and control cracking.	• Insulate the slab if the air temperature is expected to cool rapidly and significantly. • Protect curing compound as long as possible.

Concrete characteristics, and implications for workers, during stages of hydration

FHWA Publication #HIF-07-004

Calculating Maturity:

In 1987, the ASTM (American Society for Testing and Materials) published a standard practice for determining the strength of concrete using maturity method (ASTM C 1074). This practice requires a calibration procedure to establish the unique strength – maturity relationship for a given concrete mix. The resulting strength – maturity relationship can then be used in conjunction with field maturity values to determine in – place strength. The Nurse – Saul Function assumes the chemical reaction rate in concrete increases linearly with temperature.

In 1949, R. W. Nurse proposed a method to estimate the strength gain of concrete based on a linear equation relating to the hydration rate and temperature. In 1951, A. G. A. Saul linked R. W. Nurse's maturity function to compressive strength in what he called the law of gain of strength with maturity:

> Concrete of the same mix at the same maturity (calculated in Temperature - Time) has approximately the same strength whatever combination of temperature and time go to make up that maturity.

The equation below combines the work of Nurse and Saul and is known as the Nurse – Saul Function:

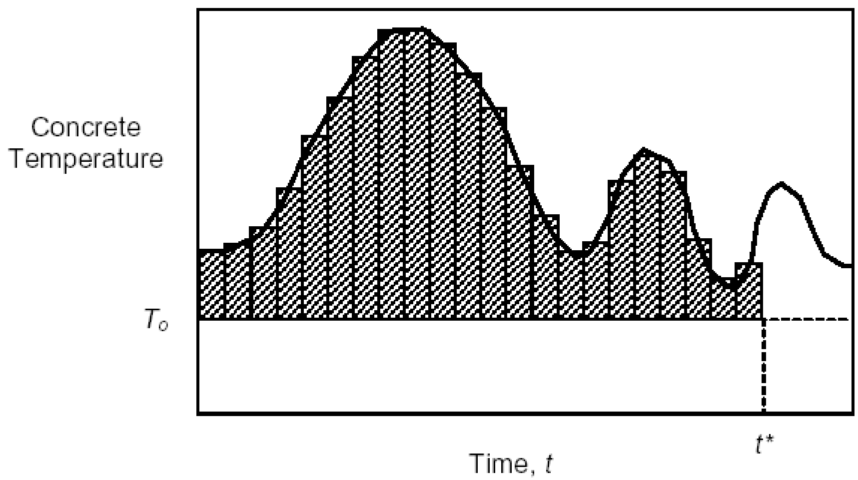
The Nurse-Saul Maturity Function:

$$M = \sum_{0}^{t} (T - T_0)\, \Delta T$$

where:

M	**=**	**Maturity (usually in °C-hours or °C-days)**
t	**=**	**time interval being considered**
Δt	**=**	**time interval**
T	**=**	**Average temperature of the PCC during the time interval, Δt, being considered**
T_0	**=**	**datum temperature - the temperature below which PCC shows no strength gain with time (-10°C is most commonly used)**

The index that is computed by the equation above is known by different terms, such as the maturity index, the temperature – time factor (TTF), or just simply maturity of the concrete. From this point the index will be referred to at the temperature – time factor or TTF. The equation above is based on the assumption that the initial rate of strength gain is a linear function of temperature (Carino 1984, 1991). The effect of the equation above is that the TTF for the in – place concrete is the area under the curve down to the datum temperature when internal concrete temperature is plotted versus time with the temperature along the y – axis and time along the x – axis. This is graphically shown below:



Throughout this section, maturity will be referenced in metric units of ºC – hours. The rationale for using metric is:

1. ºC is the standard practice throughout much of the P.C.C. paving industry.

2. The use of different units, such as ºF – hours, can lead to significant and dangerous errors if the units are inadvertently switched between laboratory calibration and the field measurements.

3. Since the units of "temperature times time" have no real physical meaning other than the area on a time - temperature chart, conversion to another system of units provide no substantial benefit.

Datum Temperature:

The explanation of datum temperature is “the temperature for a given concrete mix below which all hydration reactions cease.” When the temperature of concrete falls below the datum temperature, no additional strength gain occurs and, therefore, the Nurse - Saul Function equation, records no net gain in maturity. While other datum temperatures have been proposed, the following is recommended:

- Use a -10º C datum temperature, and

- Cure standard laboratory maturity calibration specimens (Beams) in accordance with ASTM C 31(initial cure for 24 to 48 hours at between 60ºF and 80ºF, Final Cure in a Lime water storage tank at 73ºF ± 3ºF for the remainder of the curing period) Note: Drying of the surface of the beam shall be prevented between the removal from water storage and completion of testing.

The Nurse – Saul equation for calculating concrete maturity relies upon a “datum temperature” as the basis for the maturity calculations.

Maturity Equipment:

The 2006 Standard Specifications state:

700-13 USE OF NEW PAVEMENT OR SHOULDER

Traffic or other heavy equipment will not be allowed on the concrete pavement or shoulder until the estimated compressive strength of the concrete using the maturity method has exceeded 3,500 psi, unless otherwise permitted.

Estimate the compressive strength of concrete pavement in accordance with ASTM C1074 unless otherwise specified.

Furnish thermocouples or thermistors and digital data logging maturity meters that automatically compute and display the maturity index in terms of a temperature-time factor (TTF). The maturity meters must be capable of storing at least 28 days worth of data and exporting data into an Excel® spreadsheet. Submit the proposed equipment to the Engineer for approval.

When establishing a strength-maturity relationship, perform compressive tests at ages 1, 3, 7, 14 and 28 days in accordance with AASHTO T22.

Use the TTF maturity function to compute the maturity index from the measured temperature history of the concrete. Set the datum temperature at -10^{0}C to calculate the TTF in Equation 1 of ASTM C1074.

Establish and submit a strength-maturity relationship in conjunction with each concrete pavement mix design. Determine the TTF corresponding to the strength-maturity relationship at 3,500 psi, TTF. Any changes to plant operations, material sources or mix proportions will affect the strength-maturity relationship. If any changes occur during production, develop a new strength-maturity relationship unless otherwise directed.

Verify the strength-maturity relationship during the first day's production. Use the TTF developed at mix design TTF to verify the production strength-maturity relationship. Verify the strength-maturity relationship at least every 10 calendar days or when production is suspended for more than 10 days. If the verification sample's compressive strength when tested at TTF is less than 3,500 psi, immediately suspend early opening of traffic on pavement that has not obtained TTF until a new strength-maturity relationship is developed.

No permanent traffic will be allowed on the pavement until construction of the joints, including all sawing, sealing and curing that is required, has been completed.

Take particular care to protect the exposed pavement edges and ends.

Maturity measurement equipment has evolved from simple manual systems to complex electronic systems to advanced micro-electronic systems. A variety of equipment currently exists, providing varying degrees of accuracy, automation, security, and data integrity.

The standard specifications call for equipment with certain capabilities. The equipment can be any make but shall automatically compute and display the maturity index in terms of a temperature-time factor. The maturity meter must be capable of storing a minimum of 28 days worth of data and exporting data into an excel spreadsheet. Use the temperature-time factor maturity function to compute the maturity index from the measured temperature history of the concrete. (Set the datum temperature at 10°C to calculate the temperature-time factor in Equation 1 of ASTM C 1074.)

Submit the equipment chosen to the Resident Engineer for approval.

In general, a concrete maturity system consist of the following components:

- Temperature sensors,
- Electronic data storage,
- A means of calculation, and
- A user interface.

The combination of these various system components into complete systems determines the overall functionality, costs, and relative benefits of each system. The following discusses six different configurations of maturity systems and discusses the relative merits and limitations of each.

- **Temperature Sensors:**

There are two different temperature sensors typically used in maturity measurement equipment – thermocouples and themistors. Whichever type of temperature sensor is used it must conform to ASTM C 1074 standard practice, which states that the temperature recording device shall be accurate to within ±1º.

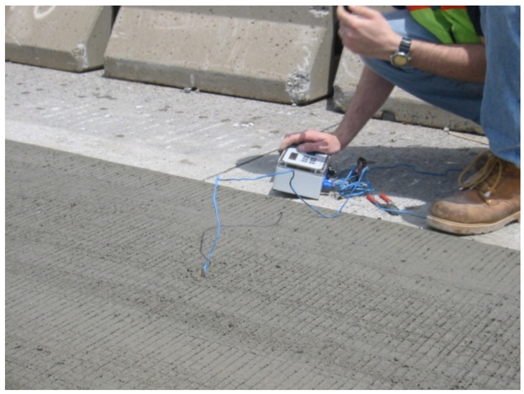
A thermocouple is composed of two dissimilar metal wires welded together at one end referred to as the "hot" junction. These wires are connected to an electrical circuit at the other end referred to as the "cold" or reference junction. The wires produce a voltage difference whenever the temperature of the hot junction is different from the temperature of the reference junction. The voltage corresponds merely to the temperature differential between the hot and cold junctions. To determine the actual temperature of the hot junction, a second temperature-measuring device, typically a thermistor must be used to determine the actual temperature at the cold junction. The cold junction temperature measurement is then used in conjunction with the temperature differential measured by the thermocouple to determine the actual temperature at the hot junction.

Thermocouple – based systems require two separate temperature – measurement devices. The overall temperature accuracy of the system must be assessed, not just the stated accuracy of the individual components. For this reason each spool of thermocouple wire should be calibrated for the specific instrument channel to which it will be connected to obtain precise and unbiased temperature reading.

Thermistors are temperature – sensitive resistors. With themistors, the impedance of the resistor changes as its temperature changes. To measure the actual temperature of the thermistor, its resistance is measured and then converted to temperature using a pre – established resistance – to – temperature conversion curve. The manufacturer of the thermistor typically performs this conversion calibration. As such, unlike thermocouple – based temperature systems relying upon themistors do not typically require any additional temperature calibration to meet their stated accuracy levels.

- **Electronic Data Storage:**

In addition to type of sensor, maturity systems can be classified into two groups related to how they store temperature or maturity data.



Those systems that store the data externally and

those systems that store the data within the concrete.

The primary difference between the two types involves the security and protection of the devices and their stored data. The systems that store data externally tend to be more susceptible to theft, vandalism, sabotage, weather, construction vehicles, and other job-site hazards that frequently result in lost of the recorded data, equipment, or both. The systems that store the data within the concrete are more secure but are still susceptible to loss of recorded data as a result of battery power of the internal unit, wires being covered up, wires damaged, etc.. Other units which are internal recorders such as the one shown above have the capability of wireless connections that are very good unless the recording unit is lost.

When choosing equipment the following issues should be considered with respect to data storage:

- Data integrity,
- Accessibility,
- Ease of retrieval,
- Time required to access the data,
- Time interval between stored maturity values,
- The extent of which additional project, location, or mix specified data can be stored alongside the maturity data.

Means of Calculation:

The means of calculation for maturity systems can be broken down into two categories:

- Automated, and
- Manual

Most of the modern maturity systems that would be approved by the Resident Engineer are the fully automated type systems.

The automated calculation systems can be subdivided into two groups:

- Automated
  - ❖ Those that calculate maturity outside the concrete and
  - ❖ Those that calculate maturity inside the concrete.

Some automated devices perform calculations using both Nurse-Saul and Arrhenius maturity function but by NCDOT Standard Specifications only the Nurse-Saul Maturity function is necessary. Some devices can only calculate using one of the maturity equations. Some systems allow user input of the datum temperature while others are preset with a fixed value that cannot be changed by the user.

For the systems that store temperature date within the concrete but perform the maturity calculations outside of the concrete, a delay of several seconds, or even minutes may be encountered as the user waits for the temperature data to upload from the data storage device and for the handheld reader to perform the required maturity calculations. The length of the delay depends on the amount of data to be downloaded and the data download rate.

Those systems that calculate the maturity directly from inside the concrete slab can provide instantaneous calculations of the current maturity value.

Those systems that calculate maturity externally via a continuous one to one wired connection also provide an instantaneous readout of the current maturity value.

Instantaneous maturity readings can also be obtained from wireless systems that have adequate range to remain continuous connected to the reader or the base station.

User Interface:

There are four user interfaces:

❖ Handwritten

- Permanently – attached external displays
- Handheld readers
- Desktop computers

Handwritten sheets are typically only used when the maturity calculations are performed manually. “Permanent – attached” external displays are only available on systems that remain continuously connected to the embedded sensor. Handheld readers are those that can be connected at will to an infinite number of embedded sensors and most systems at some point also provide the ability to view the data on a desktop computer using an excel type worksheet. The ease with which the data can be transferred from the electronic data-storage device, either external or internal, to the desktop computer varies with the configuration of the system and the ease with which it communicates.

Using Concrete Maturity on P. C. C. Pavement Projects:

Implementation of concrete maturity on P.C.C. Pavement projects will be most effective when introduced as soon as possible preferably at or before the project pre – construction meeting. This pre-planning should show in the process control plan that has to be submitted at this meeting. First and foremost, the Contractor and his personnel, the Resident Engineer and his personnel, and other testing personnel all must have a good working knowledge, and understanding of P.C.C. paving and the maturity method and an appreciation for the maturity method’s limitations and potential sources for error. This being the case, a considerable amount of education and familiarization with the maturity method may be required. The maturity method necessitates significant up-front planning and testing prior to the field implementation. Proper time and attention must be given to these requirements during this planning stage. Maturity is most beneficial when it is included as part of the initial project plan, actively incorporated into the initial construction schedule, and made an integral part of the contractor's quality control program.

Measuring Compressive/Flexural Strength Using the Maturity Method:

Originally in 1987, ASTM developed its standard practice for using concrete maturity to determine in-place strength the method was only applied to the determination of concrete compressive strength. In 2004, ASTM C 1074 was revised to include the application of concrete maturity for determining in-place flexural strength in conjunction with ASTM C 78, Flexural Strength of Concrete Using Simple Beam with Third-Point Loading.

Determining in-place compressive & flexural strength using the concrete maturity method involves a three-step process. The first step is necessary before any in-place strength measurements can be obtained. Step 1 sets the stage by enabling accurate, real-time, in-place flexural strength measurements and in Step 3 provide a framework for a robust QA and QC mechanism to quickly catch undesirable changes to the concrete and to help ensure the veracity of the anytime, real-time flexural strength from maturity measurements.

Step #1. **Develop a compressive/flexural strength–maturity relationship:**

Due to the mix-specific nature of the maturity method, a laboratory calibration must be performed for each mix design to establish each unique strength – maturity relationship.

Step #2. **Estimate in–place compressive strength:**

Using the Strength – Maturity relationships established for each mix design, anytime, real – time field measurements of in – place compressive strength can be performed using in – place maturity measurements in conjunction with the strength – maturity relationship for the mix as established in Step #2.

Step #3. **Verify the compressive/flexural strength–maturity relationship:**

Best practices dictates that the contractor should daily verify that the concrete and ingredients being incorporated into the project is representative of the concrete used to establish the strength – maturity relationship. In addition, this mix-verification process will quickly identify any adverse changes that might occur with the batching procedures or the raw materials

Validation testing is necessary to verify the strength-maturity relationship during the first day's production. Utilize the temperature-time factor developed at mix design (TTF) to verify the production strength-maturity relationship. Verify the (compressive/flexural) strength-maturity relationship at a minimum of every 10-calendar days or when production is suspended for more than 10 days. If the verification sample's strength when tested at TTF is less than 550 psi and/or 3500 psi immediately suspend early opening of traffic on pavement that has not obtained TTF until a new strength-maturity relationship is developed.

NCDOT personnel will verify at least 10% of all verification testing that the contractor had completed.

The purpose of the validation testing is to determine whether subtle yet significant changes in the raw materials or the batching process may have occurred. **NOTE: If any changes occur during production, develop a new strength-maturity relationship unless otherwise directed.**

Step #1 - Laboratory "Calibration" Phase and / or
Developing a Compressive/Flexural Strength–Maturity Relationship:

(The Nurse–Saul "temperature–time factor (TTF)" maturity index shall be used in this test method.)

The calibration or development of a compressive/flexural strength – maturity relationship for each specific mix design is normally conducted in a laboratory setting. The concrete used for the calibration batch(es) can be produced either in the laboratory or in the field at the batch plant (This would require that the batch plant to be set up on site.). Irrespective of how the concrete is batched, the calibration specimens should be cured under controlled temperature and humidity conditions as specified in ASTM C 31.

Equipment:

The following equipment may be required for maturity testing:

1. Commercial battery powered four-channel maturity meters that automatically compute and display the maturity index in terms of a temperature–time factor, or both a temperature–time factor and equivalent age. (Note: Before using any maturity meter, check to be sure the datum temperature is set to -10°C.)

   A. Batteries in maturity meters are to be adequately charged prior to use.
   B. The same brand and type of maturity meter shall be used in the field as those used to develop and verify the flexural strength–maturity relationship.
   C. A minimum of one maturity meter shall be provided for each thermocouple location. The Engineer may allow the use of a multi-channel meter when several thermocouples are in close proximity.
   D. Meters shall be protected from excessive moisture, theft, and the LCD display protected from direct sunlight.
   E. Thermocouple wire shall be greater than or equal to 20 awg.

Precaution: When the concrete temperature is below 50°F (10°C), maturity strength development will cause over extended TTF values. Development of flexural strength-maturity relationship should be performed on concrete with temperatures above 50°F (10°C).

A certified lab annually shall calibrate maturity meters to ensure proper temperature sensing. The maturity meter should be checked periodically against a certified thermometer or other calibrated meter to ensure accurate temperature measurement.

2. 6" X 6" X 20" Beam molds & 6"X12" Cylinder molds
3. Shovels (square point), rubber hammers or equivalent, wood floats
4. Hydraulic testing machine – M&T Furnished and Calibrated
5. Maturity meters
6. Hand held thermometer
7. Type T thermocouple wire (20 awg Minimum)
8. Connectors
9. Certified Rainhart Beam Breaker & Compression Cylinder Machine
10. Handtools

Calibration of Meters:

Verify the calibration of maturity meters prior to use on the project and annually thereafter by placing a thermocouple in a controlled temperature water bath. Compare the indicated result with the known temperature of a water bath. At least three temperatures are recommended to calibrate the maturity meter (examples: 50°F, 70°F, 115°F (10°C, 20°C, and 45°C). The meter shall be accurate to within ±2°F (1°C).

Developing a Compressive/Flexural Strength–Maturity Relationship:

The following steps outline the procedures for developing a Compressive/Flexural Strength – Maturity relationship:

Establish a flexural strength-maturity relationship for each proposed concrete pavement mix design by following the steps outlined below. The materials and proportions detailed in the concrete pavement mix design shall be the same as those to be used on the project. The minimum size of each batch shall be approximately 4 cubic yards (3 cubic meters).

1 - Prepare a minimum of 17 cylinders and beams according to "ASTM C31 Making and Curing Concrete Test Specimens in the Field". Additional specimens should be cast to avoid having to repeat the procedure.

2 – Test each batch of fresh concrete (ASTM C 172) for concrete placement temperature (ASTM C 1064), slump (ASTM C 143), and air content using the Unit weight method (ASTM C 138).

3 – Instrument thermocouples in at least two of each type of specimens using two separate maturity meters. Insert thermocouples in the center of each third along the beam and in the center of the cylinder. Insert the thermocouple to the middle of the beam's and cylinder's depth. Connect the thermocouples to maturity meters and do not disconnect meters unless able. Data collection must be uninterrupted.

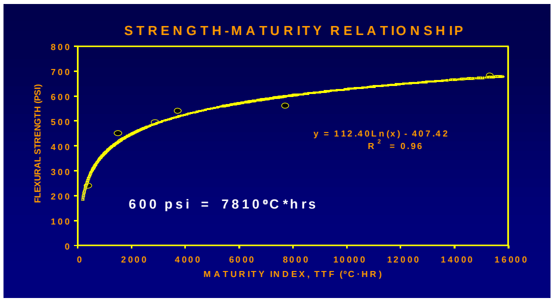
4 – Cure the specimens in accordance with ASTM C 31.

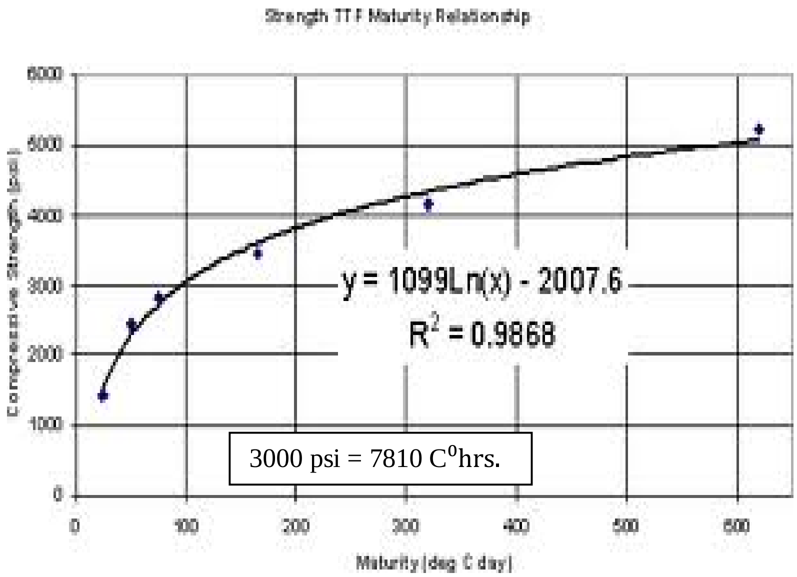
5 – Perform compressive and flexural testing in accordance with ASTM C 78 at ages 1, 3, 7, 14 and 28 days. Addition specimens and test ages may be evaluated at the discretion of the Engineer. Test three specimens of each type and at each age and compute the average compressive and flexural strengths*. **The specimens with thermocouples should not be used.*** If a specimen is defective such as not square or damaged during handling, it should be discarded. If an individual compressive and flexural test beam is greater than 15% outside the average of each type of the three test specimens, the specimen shall be considered defective and must be discarded. When two of the three test specimens are defective, either a new batch must be evaluated or additional acceptable beams and cylinders tested.

6 – Record the individual and average compressive and flexural strength and maturity values on a permanent data sheet (Maturity – 1: Record Log to Develop Flexural Strength–Maturity Relationship).

7 – Plot the average compressive and flexural strengths as a function of the average maturity values, with data points shown. Calculate a logarithmic best-fit curve through the data points using a computer spreadsheet program such as Microsoft Excel. Record the equation of the curve as well as R^2 value. The resulting curve is the compressive/flexural strength–maturity relationship to be used for estimating the strength of the concrete mixture placed in the field. The spreadsheet allows the Engineer to develop the corresponding maturity equation that defines the compressive/flexural strength–maturity relationship and an R^2 value to fit the compressive/flexural strength–maturity relationship. The R^2 value indicates the reliability of the compressive/flexural strength–maturity relationship. Expected results should produce a R^2 value of no less that 0.90. Examine for data for outliers, incorrect cylinder and beam break readings, or incorrect maturity meter readings if the R^2 value is less than 0.90.

8 – Distribute the compressive/ flexural strength–maturity relationship with the corresponding data to the Contractor, Resident Engineer, Pavement Construction Section, and the Materials and Tests Unit.





Example: Strength Maturity Relationship Using both Compressive and Flexural Strengths

Step #2 - Estimating In – Place Strength:

After the Strength – Maturity Relationship curve and a target TTF has been established for a given concrete mix design field measurements of maturity and strength – from – maturity can be performed for that mix. Field measurements involve placing maturity sensors within the pavement within the last 100’ of each day’s production and periodically monitoring the subsequent strength gain via the TTF of the concrete using the sensors. The TTF will be read and compared to the Target TTF from the Strength Maturity Relationship curve. If the TTF is equal to or greater than the Target TTF then the pavement can accept construction traffic.

Verify batching operations while placing Portland Cement Concrete pavement Concrete being placed shall be in accordance with the approved mix design. A Certified Portland Cement Concrete Pavement Technician should confirm the batching operation is in compliance and complete the Maturity – 4: Inspector's Batch Plant Checklist worksheet.

The following steps outline the procedures for estimating in-place flexural strength:

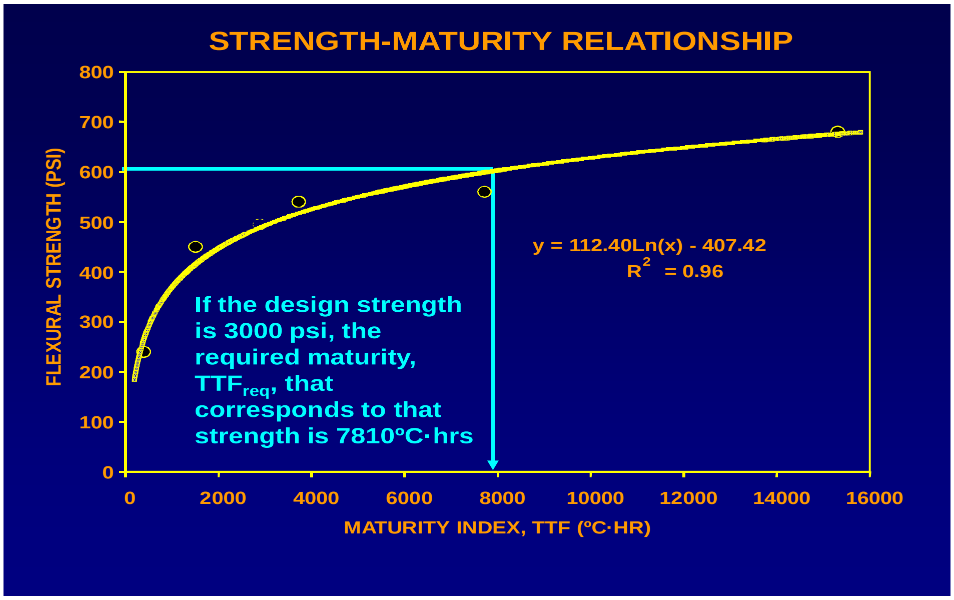
1 – Insert a minimum of two temperature probes or sensors using two maturity meters randomly placed within the last 100 feet (30 m) of each day's production.

2 – Embed the thermocouples in the fresh concrete at the mid-depth of the concrete slab at least 2.5 feet (0.8 m) from the edge of the pavement. Thermocouples should not be located near tie bars or dowel bar assemblies.

3 – As soon as practical and while the concrete is still plastic insert the thermocouple wires into and activate the maturity meter(s). Do not disconnect the maturity meters unless wireless until the required maturity values are achieved. Data collection must be uninterrupted.

4 – Read the maturity meter daily in the presents of the Engineer or his representative. Record maturity data on a permanent data sheet. The data sheet shall show the required flexural strength and TTF (Maturity – 2: Record log for Field Maturity Data).

5 – When the maturity value is equal to or greater than the required compressive strength for the concrete mix, as determined by the compressive strength–maturity relationship, record the maturity value. Remove the meter and clip thermocouple wires at the concrete surface. Maturity meters should be read in the presents of the Engineer or his representative.



Example of In – Place Strength – Maturity Relationship

<u>Step #3 - Verifying the Compressive/Flexual Strength – Maturity Relationship:</u>

The following steps outline the procedures for verifying the Compressive/Flexural Strength-Maturity relationship:

Due to the mix specific nature of the maturity method, variations in mix proportions and in sources or types of concrete making materials must be limited to those tolerable by batching variability in standard practice.

The Contractor will verify the strength-maturity relationship during the first day's production. Utilize the temperature-time factor developed at mix design (TTF) to verify the production strength-maturity relationship. The Contractor will verify the strength-maturity relationship at a minimum of every 10 calendar days or when production is suspended for more than 10 days.

The Engineer or his representative will verify the Contractors data once per each 10 verification tests or every 10% of verification testing completed.

1 – Make a minimum of five test beams and cylinders in accordance with ASTM C 31

2 – Test each batch of fresh concrete (ASTM C 172) for concrete placement temperature (ASTM C 1064), slump (ASTM C 143), and air content using the Unit weight method (ASTM C 138).

3 – Instrument thermocouples in two specimen of each type at the center of each third along the beam. Insert the thermocouple to the middle of the beam's depth and the middle of the cylinder depth. Connect the thermocouples to the maturity meter. Do not disconnect the maturity meter unless wireless as data collection must be uninterrupted.

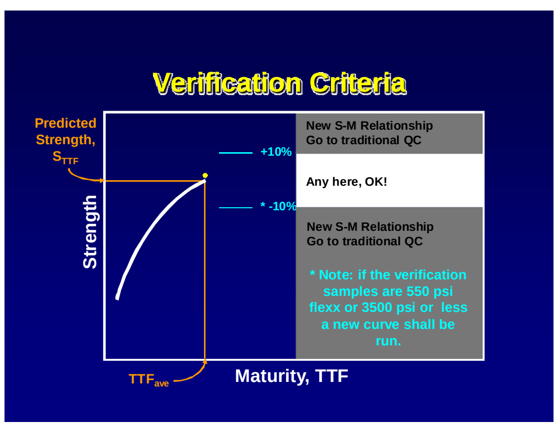
4 – Cure the specimens in accordance with ASTM C 31.

5 – Perform compress and flexural strength tests as described in ASTM C 78. For Portland Cement Concrete pavements, if the average of the three validation beams and cylinders is within 10% of the original curve at the TTF_i, the original curve shall be considered validated. If the average value of the three validation beams and cylinders is less than 10% of the original curve at the TTF_i, a new maturity curve shall be developed. If the average value of the three validation beams and cylinders is greater than 10% of the original maturity curve at the TTF, a new maturity curve may be developed. If the verification sample's strength when tested at TTF is less than 550 psi flexural and/or 3500 psi compressive, immediately suspend early opening of traffic on pavement that has not obtained TTF until a new strength-maturity relationship is developed. (Maturity – 3:Record Log to Verify Strength – Maturity Relationship).

If the test results indicate a new curve must be developed, this should be done in a timely manner.

6 – Factors for requiring a new compressive/flexural strength–maturity curve. Changes in material sources, proportions, and mixing equipment all effect the maturity value of a given Portland Cement Concrete pavement mixture. If the water/cement ratio of the production concrete exceeds the water/cement ratio of the concrete by more than 0.02, a new curve shall be developed. Therefore, development of a new maturity curve is generally required for any changes in the Portland Cement Concrete pavement mixture.

Development of a new maturity curve due to material source or production changes in a Portland Cement Concrete pavement mix may be waived by use of the validation procedure. If the average strength is greater than the original curve at the TTF the validation beams were tested, a new curve will not be required. A new curve will be required if the average strength is less than the original curve at TTF the validation beams were tested.



Example of Verification of Strength – Maturity Relationship

Example Calculations:

Figuring TTF for Maturity by Hand-

Flexural Strength:

					T	M
Reading					**TTF**	**Sum of TTF**
Number	**Date**	**Time**	**Temperature (C)**	**Age**	**(C - hrs)**	**(C - hrs)**
1	5/5/1998	8:00A	28	0	0	0
2	5/6/1998	8:00A	27	24	900	900
3	5/6/1998	8:00P	26	36	438	1338
4	5/7/1998	8:00A	25	48		
5	5/7/1998	8:00P	20	60		
6	5/8/1998	8:00A	18	72		

The Nurse-Saul Maturity Function:

$$M = \sum (T - T_0)\, \Delta t$$

where:	**M**	**=**	**Maturity (usually in °C-hours or °C-days)**
	Δt	**=**	**time interval**
	T	**=**	**Average temperature of the PCC during the time interval, Δt, being considered**
	T_0	**=**	**datum temperature - the temperature below which PCC shows no strength gain with time (-10°C is most commonly used)**

Figure each of the TTF's above using the Nurse – Saul Equation above.

Line 2

First find all the given information:

T = Average temperature of the PCC during the time interval

= (27 ºC + 27 ºC) /2

= 27.5 ºC

T_0 = datum temperature - the temperature below which PCC shows no strength gain with time (-10°C is most commonly used)

= - 10 ºC

Δt= time interval

= 24 hrs. – 0 hrs. = 24 hours

Assemble the equation: M (TTF) = ∑ (27.5 + 10) 24 = 900 C – hrs.

Now add this to the previous TTF = 0 + 900 = 900 C – hrs.

Figure the next TTF:

Line 3

T = Average temperature of the PCC during the time interval

= (27 ºC + 26 ºC) /2

= 26.5 ºC

T_0 = datum temperature - the temperature below which PCC shows no strength gain with time (-10°C is most commonly used)

= - 10 ºC

Δt= time interval

= 36 hrs. – 24 hrs. = 12 hours

Assemble the equation: M (TTF) = ∑ (26.5 + 10) 12 = 438 C – hrs.

Now add this to the previous TTF = 900 + 438 = 1338 C – hrs.

Let complete the TTF's above:

Line 4

T = Average temperature of the PCC during the time interval

= (26 ºC + 25 ºC) /2

= 25.5 ºC

T_0 = datum temperature - the temperature below which PCC shows no strength gain with time (-10°C is most commonly used)

= - 10 ºC

Δt= time interval

= 48 hrs. – 36 hrs. = 12 hours

Assemble the equation: M (TTF) = ∑ (25.5 + 10) 12 = 426 C – hrs.

Now add this to the previous TTF = 1338 + 426 = 1764 C – hrs.

Line 5

T = Average temperature of the PCC during the time interval

= (25 ºC + 20 ºC) /2

= 22.5 ºC

T_0 = datum temperature - the temperature below which PCC shows no strength gain with time (-10°C is most commonly used)

= - 10 ºC

Δt= time interval

= 60 hrs. – 48 hrs. = 12 hours

Assemble the equation: M (TTF) = ∑ (22.5 + 10) 12 = 390 C – hrs.

Now add this to the previous TTF = 1764 + 390 = 2154 C – hrs.

Line 6

T = Average temperature of the PCC during the time interval

= (20 ºC + 18 ºC) /2

= 19 ºC

T_0 = datum temperature - the temperature below which PCC shows no strength gain with time (-10°C is most commonly used)

= - 10 ºC

Δt= time interval

= 72 hrs. – 60 hrs. = 12 hours

Assemble the equation: M (TTF) = ∑ (19 + 10) 12 = 348 C – hrs.

Now add this to the previous TTF = 2154 + 348 = 2502 C – hrs.

Establish a Strength – Maturity Relationship with the information given below:

Specimen #	Specimen Strength (PSI)	Average Stength (PSI)	Maturity Elasped time (hh:mm)	Specimen Maturity (C - hrs)	Concrete Temperture	Avg. Maturity (C - hrs.)	Avg. Temp.
Bm # 1	300			1499	23		
Bm # 2	300	300.0	24	1501	23	1500	23
Bm #3	300			1501	23		
Bm # 4	440			2240	24		
Bm # 5	460	450.0	72	2281	23	2250	23.7
Bm #6	450			2230	24		
Bm # 7	576			4499	23		
Bm # 8	578	575.0	120	4512	24	4500	23.3
Bm #9	571			4490	23		
Bm # 10	595			7510	24		
Bm # 11	610	600.0	168	7485	24	7500	24.0
Bm #12	595			7505	24		
Bm # 13	640			11275	24		
Bm # 14	605	625.0	336	11202	23	11250	23.7
Bm #15	630			11272	24		
Bm # 16	700			23300	23		
Bm # 17	703	700.0	672	23200	23	23250	23.0
Bm #18	697			23250	23		

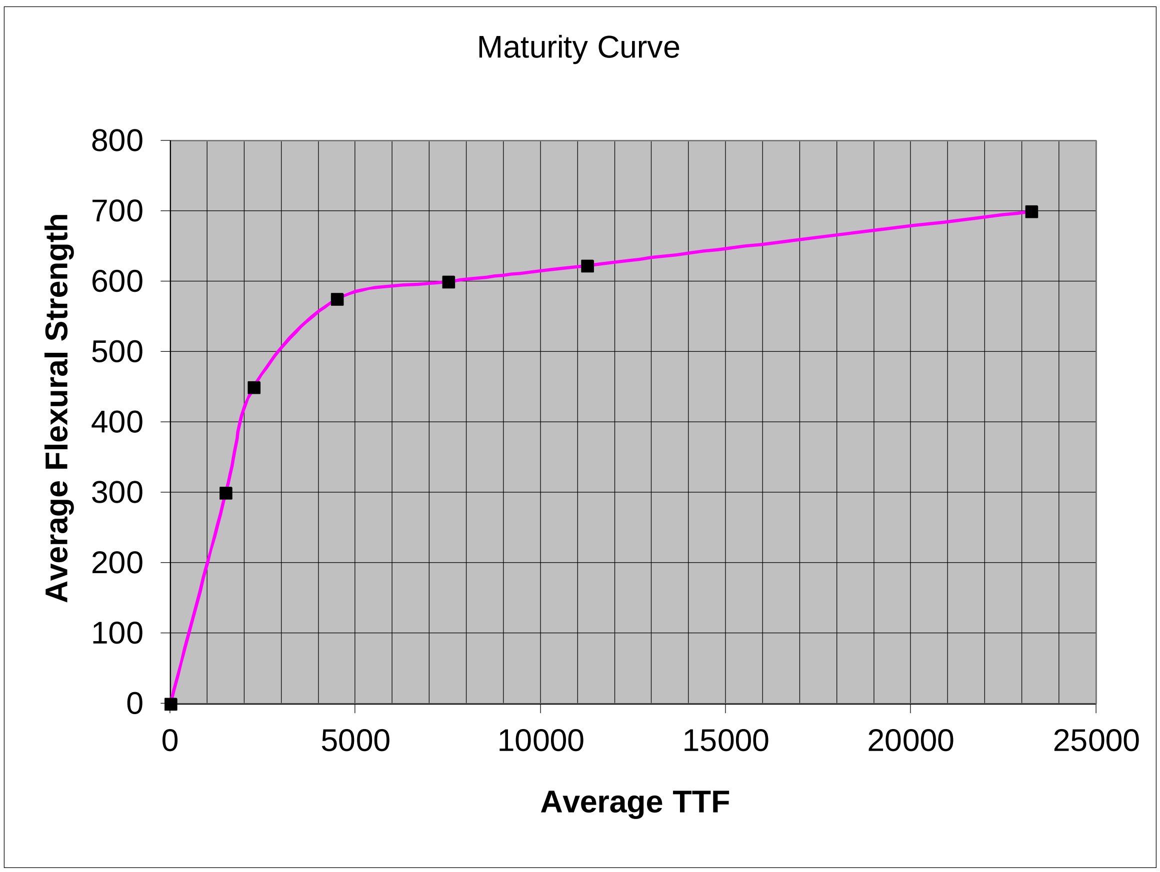
The first information which we need to set up a Strength – Maturity Relationship is the Average Strengths and the Average TTF's.

Answers:

Answers for TTF for Maturity by Hand

					T	M
Reading					TTF	Sum of TTF
Number	Date	Time	Temperature (C)	Age	(C - hrs)	(C - hrs)
1	5/5/1998	8:00A	28	0	0	0
2	5/6/1998	8:00A	27	24	900	900
3	5/6/1998	8:00P	26	36	438	1338
4	5/7/1998	8:00A	25	48	426	1764
5	5/7/1998	8:00P	20	60	390	2154
6	5/8/1998	8:00A	18	72	348	2502

Answer for Maturity Curve:



Strength – Maturity Relationship

References:

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.

Sealing Joints and Post Construction Checks

Before any portion of the pavement is opened to the Contractor's construction forces, the sawn pavement joints must be protected from incompressibles infiltrating into the newly sawn joints. Before any portion of the pavement is opened to general traffic expansion, transverse and longitudinal joints will be sealed.

The joint or reservoir opening will be sawn and prepared to the designated dimensions and cleaned. Joint sealer, meeting requirements of Articles 700-12 and 1028 will be used to seal sawn joints in PCC pavement, shoulders, medians, crossovers, and side road pavement unless otherwise specified.

Within approximately three hours after the joint has been wet sawed, the residue will be flushed away with a high-pressure water blast. Within three hours after the joint has been dry sawn, the residue will be blown from the joint.

Sand blasting will be required on all joints using the proper equipment.

Immediately prior to the installation of the backer rod and sealant, the joint will be cleaned with an air blast of at least 90 psi as required by the Standard Specifications and using proper equipment. The backer rod will be of the proper size and type and will be installed dry, with a suitable tool.

Joint sealer will be prepared and installed in the joint to the proper level. The transverse joint should be filled uniformly across the entire width of pavement. After sealing, excess sealer will be removed from the pavement surface. Check your Standard Drawings before performing this operation.

Joint sealer can be placed only when the pavement and surrounding air temperature is 45 degrees F or higher.

Sealing will be done only when the joint surfaces are dry by manual and visual inspection. If necessary, have a Silicone Sealant Representative present during the sealing operations.

The inspector should check that all joints are cleaned sufficiently and the backer rod is approved and installed properly. An approved joint sealer must be used and installed in the joint at the proper elevation.

A worksheet to document these checks is included in the Appendix. Documentation should be made in the Inspector's Daily Diary.

Texture

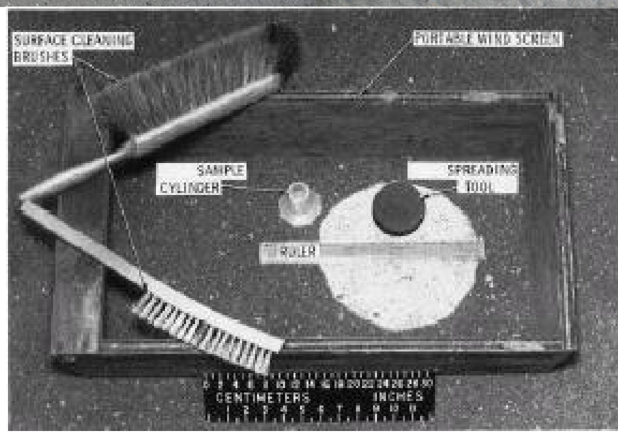
Article: 710-6

Once the pavement has hardened, checks of the depth can be made to determine compliance with Article 710-6 describes the procedure required to check the depth of the texture. A worksheet to document these checks is included in the Appendix.

The depth of the texture is important. The grooves are constructed to break the plain surface and thereby prevent hydroplaning. But, the grooves can create a noise problem.

In order to minimize the noise from the pavement surface, the tine depths shall be as shallow as possible within the specifications. This will insure safety but minimize any objectionable noise.

The apparatus needed to perform ASTM E 965, "Test Method for Measuring Pavement Macrotexture Depth Using a Sand Volumetric Technique" is as follows:



- Container for Glass Spheres
- Sample cylinder (35mm film container)
- Ruler
- Spreading Tool (Hockey Puck)
- Surface Cleaning Brushes (Wire Brush, Soft Bristle Brush)
- Small Straightedge (small spatula)
- Portable Wind Screen

Procedure:

Begin by selecting four randomly selected test areas in each lot (same stations as strength, and thickness cores). Note: The same technician should perform all the testing.

1. Inspect the test area to be measured. Test area must be a dry homogeneous area that contains no unique, localized features such as cracks or joints.

2. Thoroughly clean the surface with the stiff wire brush to remove any residue and then with the soft bristle brush remove any of the residue, debris, or loosely bonded aggregate particles from the test surface.
3. Position the portable wind screen around the test area.
4. Fill the small sample cylinder of known volume with the glass spheres and gently tap the base of the cylinder several times on a rigid surface. Add more material to fill the cylinder to the top and level with a straightedge. If a set of laboratory scales are available, determine the mass of material in the cylinder and use this mass of material sample for each measurement.
5. Pour the measured volume or weight of material onto the cleaned test surface within the area protected by the portable wind screen.
6. Carefully spread the glass spheres into a circular patch with the spreading tool (hockey puck), rubber side down, filling the surface voids flush with the aggregate particle tips.
7. Measure and record the diameter of the circular area covered by the glass spheres at a minimum of four equally spaced locations, such as 0˚- 180˚, 45˚ - 225˚, 90˚ - 270˚, 135˚ - 315˚, around the circumference.
8. Compute and record the average diameter of the circle.

Calculation:

- Cylinder Volume:
    - Calculate the internal volume of the sample container as follows:

$$V = \frac{\Pi d^2 h}{4}$$

Where:

V = internal cylinder volume, in^3, (mm^3)

d = internal cylinder diameter, in. (mm), and

h = cylinder height, in. (mm).

- $MATX_d$ or Average Macro Texture Depth
  - Calculate the average macro texture depth as follows:

$$MATX_d = \frac{4V}{\Pi D^2}$$

Where:

$MATX_d$ = Mean texture depth of pavement macrotexture, in. (mm).

V = sample volume, in^3, (mm^3), and

D = average diameter of the test area covered by the glass spheres, in. (mm).

An example of one test area location for calculating the mean texture depth of the pavement macrotexture is below:

Volume of glass spheres, V: ___________mm^3

Dia. 1: _______mm Dia. 2: _______mm Dia. 3: _______mm Dia. 4: _______mm

Average Diameter, $D_{avg.}$: [ ] mm

Avg. Macro Texture Depth, $MATX_d$: ___________mm

Thickness Coring

Article: 700.15 (F), 710-9, 710-10(B)

Cores shall be taken from PCC pavement to determine pavement thickness, and the amount of payment the Contractor will receive. The Department will identify the limits of each section and the random location of each core. The Inspector will witness core drilling, take immediate possession of the cores, and deliver the cores to the Materials and Tests Laboratory with a

HiCAMS Number and Card.

The cores will be located as follows:

Locating Cores

The Inspector will first assign all cores a random location. Core locations should be consistent and selected at random using the random number chart in the PCCP manual.

The locations will then be marked on the road. These should be placed as accurately as possible to insure the proper location.

The inspector and contractor should check to insure there is not a dowel bar or tie bar in the pavement in that location. If so, the inspector shall approve the moving of the core location slightly in order to miss the obstruction.

The Inspector will also go along with the Contractor while they are cutting the cores. This is to verify that they cut them at the right locations and are marked with the proper identifying marks.

The Inspector will take possession of the cores, mark the cores, put them into the HiCAMS system, and deliver them to the Materials and Tests laboratory for measurement.

Deficient Thickness Areas

When the measurement of the core from a lot is not deficient more than 0.2" from the plan thickness, full payment will be made. When such measurement is deficient by more than 0.2" from the plan thickness, take 2 additional cores at random within the lot and determine the average of the 3 cores.

In determining the average thickness of the pavement, the Engineer will use all 3 core measurements with the exception that measurements which are in excess of the plan thickness by more than 0.2" will be considered as the plan thickness plus 0.2" and measurements which are deficient of the plan thickness by more than 1.0" will be considered as the plan thickness minus 1.0 inch. Measurements which are less than the plan thickness by more than 1.0" will not be included in the average. If the average measurement of these 3 cores is not deficient more than 0.2" from the plan thickness, full payment will be made. If the average measurement of the 3 cores is deficient more than 0.2" but not more than 1.0" from the plan thickness, an adjusted unit price in accordance with Subarticle 710-10(B) will be paid for the lot represented.

When the measurement of any core is less than the plan thickness by more than 1.0", the actual thickness of the pavement in this area will be determined by taking additional cores at not less than 10 foot intervals parallel to the center line in each direction from the affected location until in each direction a core is found which is not deficient by more than 1.0 inch. Exploratory cores for deficient thickness will not be used in averages for adjusted unit price. Patch all core holes within 72 hours of taking the core, using a Department approved nonshrink grout compatible with the pavement concrete. Areas found deficient in thickness by more than 1.0" will be removed full lane width and replaced with concrete of the thickness shown on the plans. Any full width repairs to the concrete pavement must be performed in accordance with the *North Carolina Department of Transportation Partial and Full Depth Repair Manual* and not be less than 1/2 of the panel length (7.5 feet).

Reporting

The HiCAMS system will produce a report that will be available to the Engineer. The Engineer will be required to put in the required thickness into HiCAMS. The Engineer will then be required to initiate PARS if necessary. If help is needed with PARS please contact the Construction Unit.

IRI (International Roughness Index)

PAVEMENT SMOOTHNESS

Pavement smoothness is an important consideration for several reasons. Studies have indicated that the prime factor that influences the user's opinion of a road is longitudinal roughness. Rough riding pavements generate complaints from motorists by providing uncomfortable rides, damaging vehicles, reducing travel speeds, and accelerating the wear of the pavement structure itself. Many believe that pavement roughness is an indicator of overall quality of workmanship by the Contractor. It is generally believed that if the Contractor provides a very smooth pavement, there is greater likelihood that good quality workmanship has been provided throughout the many steps of roadway construction that span the spectrum from subgrade preparation to rolling of the final surface layer. There is also a growing belief among pavement engineers that smooth pavements not only provide a higher level of service but also last longer than otherwise equivalent but initially rougher pavements. Because of these considerations, specifications have been developed in an effort to achieve smoother pavements. In the specifications, incentives and disincentives are provided, depending on the initial level of smoothness achieved during construction.

Roughness experienced by a roadway traveler is a function of pavement profile, vehicle speed, and various vehicle parameters, including tire and suspension characteristics. A variation in any of these factors can make a road profile appear either smooth or rough. From a passenger's viewpoint, roughness can be defined as an undesirable combination of road profile, vehicle parameters, and speed.

Pavement smoothness is adversely affected by a lack of uniformity in the paving operations, improper aggregate gradations, variation in the mix, variation in paver speed, improper operation of trucks, poor joint-construction practices, segregation and improper finishing.

Stopping the paver can cause roughness in the pavement. Every time the paver stops, there is a possibility of the pan leaving a mark on the surface of the concrete. If the screed settles into the surface of the pavement, it causes the automatic sensor to act as if the paver has traveled into a depression. As the paver starts off, the pan automatics lay a thicker mat. This continues until the sensor recognizes the excessive thickness and decreases the slope of the screed. Then a dip is developed until the screed levels out, approximately 30 feet from where the paver stopped.

Rough pavements also result from changes in amounts of material introduced in front of the paver. If there is not enough material in front of the paver, the pan will drop. If there is too much material in front of the pan, it will rise. A uniform head of mix should be maintained at all times in front of the paver.

Profile Testing

The importance of constructing a project to the plan profile and grade for driver safety and producing a smooth pavement which meets or exceeds the testing tolerances cannot be overemphasized. Deviations from the acceptable tolerances can result in expensive corrective actions and/or significant price adjustments. The methods of profile testing utilized by NCDOT to determine specification compliance are as follows:

Article 710-7 of the Specifications requires that the finished pavement surface is tested using an Inertial Profiler. The Contractor shall furnish an inertial profiler equipped with line laser technology to measure pavement smoothness. The Specification applies to the final surface of the pavement; however, the Contractor should not wait until the final layer before using IRI for quality control purposes.


Details on the Inertial Profiler using IRI (International Roughness Index)

The International Roughness Index (IRI) is the roughness index obtained from measured longitudinal road profiles. It is calculated using a quarter-car vehicle math model, whose response is accumulated to yield a roughness index with units of slope (in/mi, m/km, etc.). IRI has become the road roughness index most commonly used worldwide for evaluating and managing road systems.

Inertial profilers measure the pavement surface profile using a distance measurement transducer, noncontact vertical displacement transducer (which NCDOT requires line laser technology), an accelerometer, and a computer. The distance measurement transducer operates similarly to a car's odometer, but is more precise. The noncontact vertical transducer measures the distance from the device and the pavement surface at selected intervals. The accelerometer determines the inclination of the profiler as it ascends and descends hills and corrects for any movement of the vertical displacement transducer relative to the ground caused by the suspension. The computer collects and records all the data from the devices and uses it to calculate the IRI index to describe the ride quality of the pavement.

The system, the operator, and the testing requirements for inertial profilers is covered in several standards from AASHTO and ASTM: AASHTO M328, ASTM E1926, AASHTO R56, and AASHTO R57, and are referenced in the NCDOT Standard Specifications.

The equipment should be configured per the manufacturer's recommendations and to record actual elevation of the pavement surface. The profiler's internal IRI calculation mode should not be used. The software is required to produce electronic inertial road profiles in a format compatible with the latest version of FHWA's ProVAL (Profile Viewing and Analysis software). Contractor shall provide raw data to the Engineer after each run. The profile data shall be filtered with a cutoff wavelength of 300 feet. The interval at which relative profile elevations are reported can be approximately 2".

FHWA's ProVAL software will be used to analyze the raw data. Contact the Pavement Construction Section for assistance with the ProVAL software and training, if necessary. The Contractor shall also submit a formal report with the details as required in the specification. Pay adjustments will be based on MRI values, which is the average of the IRI values for the left and right wheel path for every 0.10-mile section. See Construction Manual for step-by-step checklist for Contractor and Department responsibilities.

The Final Surface Testing will apply to all projects when two or more layers of new asphalt pavement are to be constructed, the speed limit of the facility is 45 mph or greater, and the project length is one mile or greater. Divisions may also require it on select projects.

When Final Surface Testing is not required, there will be a Special Provision in those contracts that states "Final surface testing is not required on this project."

Inertial Profiler

Use an Inertial Profiler to measure the longitudinal pavement profile for construction quality control and smoothness acceptance. Use a profiler with line laser technology as single-point laser technology will not be allowed. Produce International Roughness Index (IRI) and Mean Roughness Index (MRI) values for measuring smoothness. Use testing and recording software to produce electronic inertial road profiles in a format compatible with the latest version of FHWA's ProVAL (Profile Viewing and Analysis) software.

The Inertial Profiler shall be calibrated and verified in accordance with the most current version of AASHTO M 328. Provide certification documentation that the profiler meets AASHTO M 328 to the Engineer before the first day the Inertial Profiler is used on the project.

Configure the profiler to record the actual elevation of the pavement surface. Do not use the profiler's internal IRI calculation mode. The profile data shall be filtered with a cutoff wavelength of 300 ft. The interval at which relative profile elevations are reported shall be 1".

Provide IRI data in accordance with most current version of ASTM E1926. Utilize personnel trained to record and evaluate IRI data.

Provide a competent operator, trained in the operation of the Inertial Profiler. Operation of the Inertial Profiling system shall conform to AASHTO R 57.

Provide the user selected Inertial Profiler settings to the Engineer for the project records. Certification of the Inertial Profiling system shall conform to AASHTO R 56.

Remove all objects and foreign material on the pavement surface prior to longitudinal pavement profile testing.

Operate the profiler at any speed as per the manufacturer's recommendations, however, the speed must be constant to within ± 3 mph of the intended speed and any required acceleration should be as gradual as possible. For example, if the intended speed were 30 mph, the acceptable range of speed for testing would be 27 to 33 mph.

Operate the Inertial Profiler in the direction of the final traffic pattern. Collect IRI data from both wheel paths during the same run. It is permissible to collect data one wheel path at a time if each wheel path is tested and evaluated separately. A wheel path is defined as the 3 foot from the edge of the travel lane. MRI values are the average of the IRI values from both wheel paths. When using an inertial profiler that collects a single trace per pass, take care to ensure that the measurements from each trace in a travel lane start and stop at the same longitudinal locations. Unless otherwise specified, multiple runs are not necessary for data collection.

Operate the automatic triggering method at all times unless impractical. A tape stripe or traffic cone wrapped with reflective material may be used to alert the profiler's automatic triggering sensor to begin data collection. The profiler shall reach the intended operating speed before entering the test section. The runup and runout distances should be sufficient to obtain the intended operating speed and to slow down after testing is completed.

Divide the pavement surface for the project into sections which represent a continuous placement (i.e. the start of the project to bridge, intersection to intersection). Terminate a section 50 ft before a bridge approach, railroad track, or similar interruption. (Separate into 0.10-mile sections).

The evaluation of the profiles will be performed on a section basis. A section is 0.10 mile of a single pavement lane. For any section, which is less than 0.10 mile in length, the applicable pay adjustment incentive will be prorated on the basis of the actual length.

Mark the limits of structures and other special areas to be excluded from testing using the profiler's event identifier such that the exact locations can be extracted from the profile data file during processing.

Unless otherwise authorized by the Engineer, perform all smoothness testing in the presence of the Engineer. Perform smoothness tests on the finished surface of the completed project or at the completion of a major stage of construction as approved by the Engineer. Coordinate with and receive authorization from the Engineer before starting smoothness testing. Perform smoothness tests within 7 days after receiving authorization. Any testing performed without the Engineer's presence, unless otherwise authorized, may be ordered retested at the Contractor's expense.

After testing, transfer the profile data from the profiler portable computer's hard drive to a write once storage media (DVD-R, CD-R or Flash Drive) or electronic media approved by the Engineer. Label the disk or electronic media with the Project number, Route, file number, date, and termini of the profile data. Submit the electronic data on the approved media to the Engineer immediately after testing and this media may not be returned to the Contractor.

Submit documentation and electronic data of the evaluation for each section to the Engineer within 10 days after completion of the smoothness testing. Submit the electronic files compatible with ProVAL and the evaluation in tabular form with each 0.10 mile segment occupying a row. Include each row with the beginning and ending station for the section, the length of the section, the original IRI values from each wheel path, and the MRI value for the section. Each continuous run for a section will occupy a separate table and each table will have a header that includes the following: the project contract number, county, the roadway number or designation, a lane designation, the JMF used for the final lift, the dates of the smoothness runs, and the beginning and ending station of the continuous run. Summarize each table at the bottom.

Traffic control and all associated activities included in the pavement smoothness testing of the pavement surface will be the responsibility of the Contractor.

Acceptance for New Construction

IRI and MRI numbers recorded in inches per mile will be established for each 0.10-mile section for each travel lane of the surface course designated by the contract.

TABLE 610-7 MRI PRICE ADJUSTMENT PER 0.10-MILE SECTION	
MRI after Completion (Inches Per Mile)	**Price Adjustment Per Lane (0.10-Mile Section)**
45.0 and Under	$200.00
45.1-55.0	PA = 600 –(10 * MRI)
55.1-70.0	Acceptable (No Pay Adjustment)
70.1-90.0	PA = 650 –(10 * MRI)
Over 90.1	Corrective Action Required

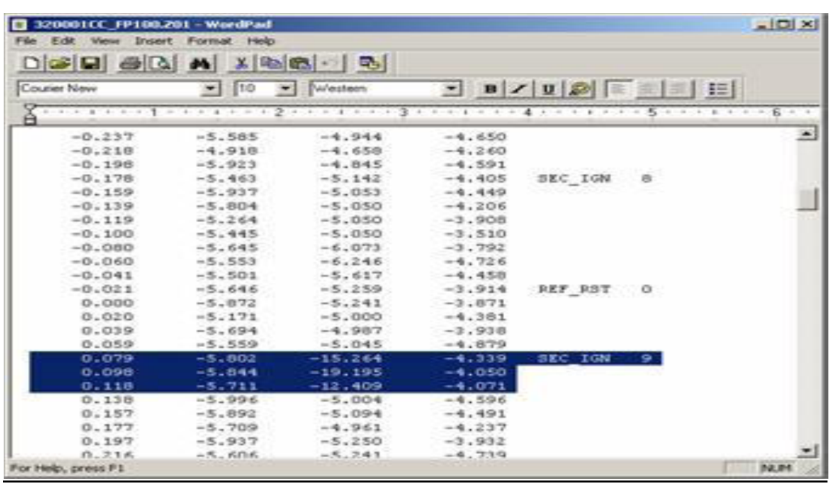
Areas excluded from testing by the profiler will be tested using a 10-foot straightedge in accordance with Article 710-7.

Table 710-1 provides the acceptance quality rating scale of pavement based on the final rideability determination.

This price adjustment will apply to each 0.10-mile section based on the Mean Roughness Index (MRI), the average IRI values from both wheel paths.

When corrections to the pavement surface are required, the Engineer shall approve the Contractor's method of correction. Methods of correction shall be milling and inlay, remove and replace, or other methods approved by the Engineer. To produce a uniform cross section, the Engineer may require correction to the adjoining traffic lanes or shoulders. Corrections to the pavement surface, the adjoining traffic lanes and shoulders will be at no cost to the Department.

Where corrections are made after the initial smoothness testing, the pavement will be retested by the Contractor to verify that corrections have produced the acceptable ride surface. No incentives will be provided for sections on which corrective actions have been required. The Contractor will have one opportunity to perform corrective action(s).



-0.237	-5.585	-4.944	-4.650		
-0.218	-4.918	-4.658	-4.260		
-0.198	-5.923	-4.845	-4.591		
-0.178	-5.463	-5.142	-4.405	SEC_IGN	8
-0.159	-5.937	-5.053	-4.449		
-0.139	-5.804	-5.050	-4.206		
-0.119	-5.264	-5.050	-3.908		
-0.100	-5.445	-5.050	-3.510		
-0.080	-5.645	-6.073	-3.792		
-0.060	-5.553	-6.246	-4.726		
-0.041	-5.501	-5.617	-4.458		
-0.021	-5.646	-5.259	-3.914	REF_RST	0
0.000	-5.872	-5.241	-3.871		
0.020	-5.171	-5.000	-4.381		
0.039	-5.694	-4.987	-3.938		
0.059	-5.559	-5.045	-4.879		
0.079	-5.802	-15.264	-4.339	SEC_IGN	9
0.098	-5.844	-19.195	-4.050		
0.118	-5.711	-12.409	-4.071		
0.138	-5.996	-5.004	-4.596		
0.157	-5.892	-5.094	-4.491		
0.177	-5.709	-4.961	-4.237		
0.197	-5.937	-5.250	-3.932		

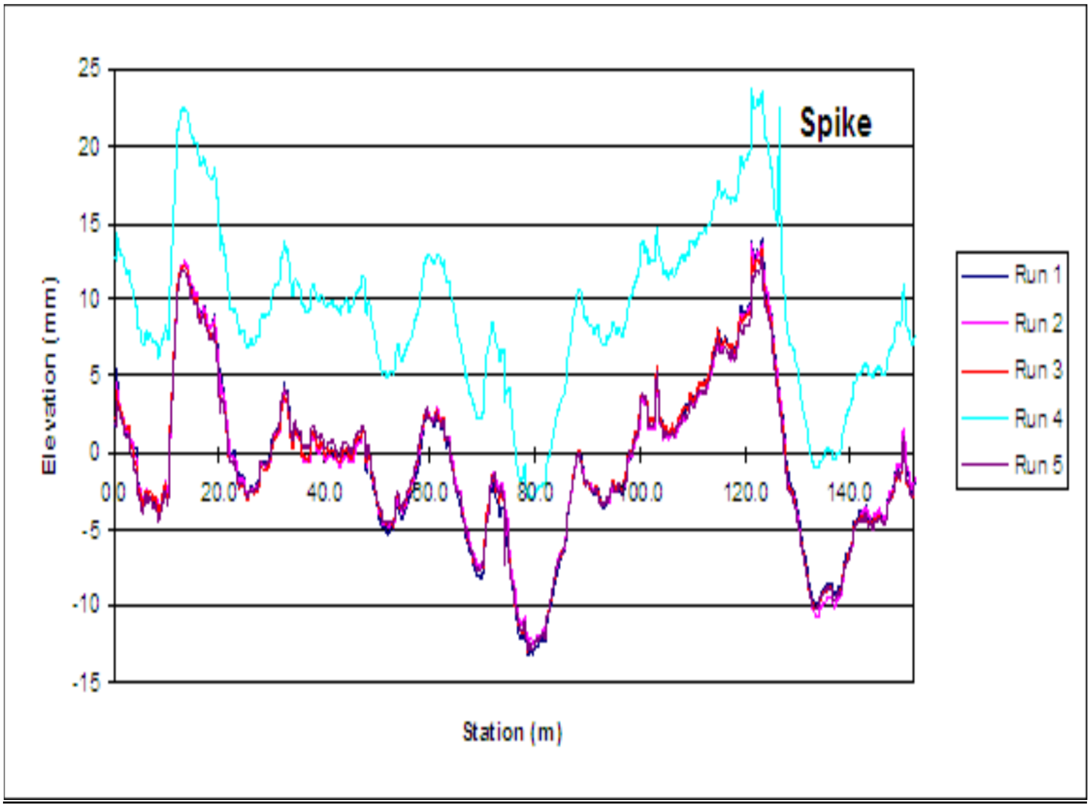
Localized Roughness

Areas of localized roughness shall be identified through the "Smoothness Assurance Module" provided in the ProVAL software. Use the "Smoothness Assurance Module" to optimize repair strategies by analyzing the measurements from profiles collected using inertial profilers. The ride quality threshold for localized roughness shall be 125 in/mile at the continuous short interval of 25 ft. Submit a continuous roughness report to identify sections outside the threshold and identify all localized roughness, with the signature of the Operator included with the submitted IRI trace and electronic files.

The Department will require that corrective action be taken regardless of final IRI. Re-profile the corrected area to ensure that the corrective action was successful. If the corrective action is not successful, the Department will assess a penalty, or require additional corrective action.

Corrective work for localized roughness shall be approved by the Engineer before performing the work and shall consist of either replacing the area by milling and inlaying or other methods approved by the Engineer. Any corrective action performed shall not reduce the integrity or durability of the pavement that is to remain in place. Milling and inlay or any corrective actions shall meet the specifications requirements for ride quality over the entire length of the correction. Notify the Engineer 5 days prior to commencement of the corrective action.

Localized roughness correction work shall be for the entire traffic lane width. Pavement cross slope shall be maintained through corrective areas.



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

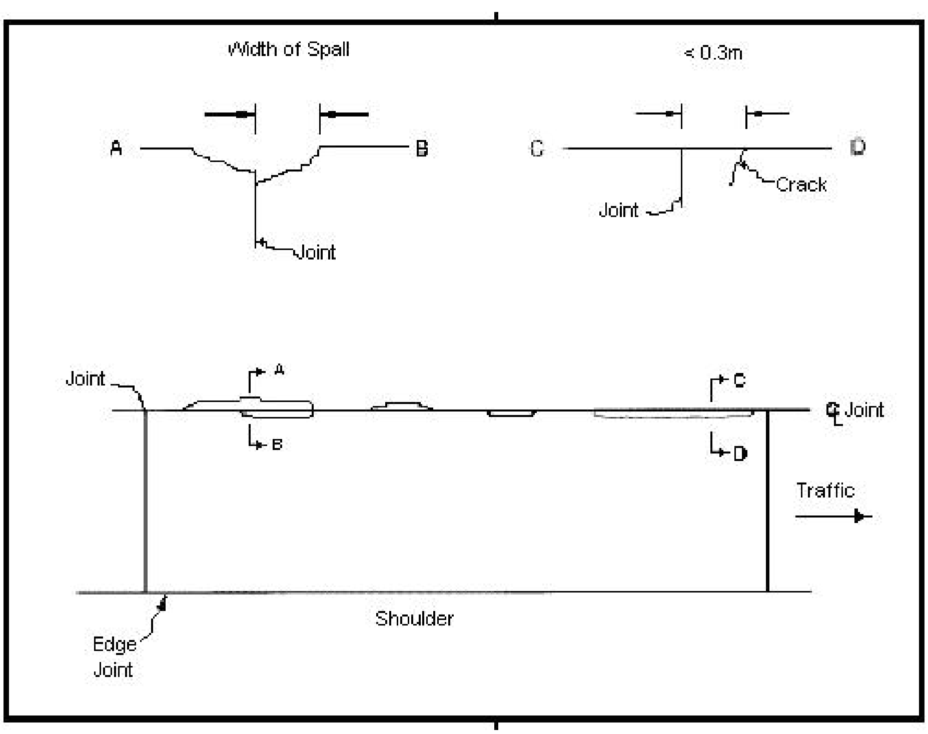
When plastic shrinkage cracks are suspected it is recommended that 4″ cores be taken to determine the depth and severity of the cracking. Depending on the depth of cracking, partial or full-depth replacement is required. If the crack is deeper than 3″ or if extensive cracking is observed, full-depth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

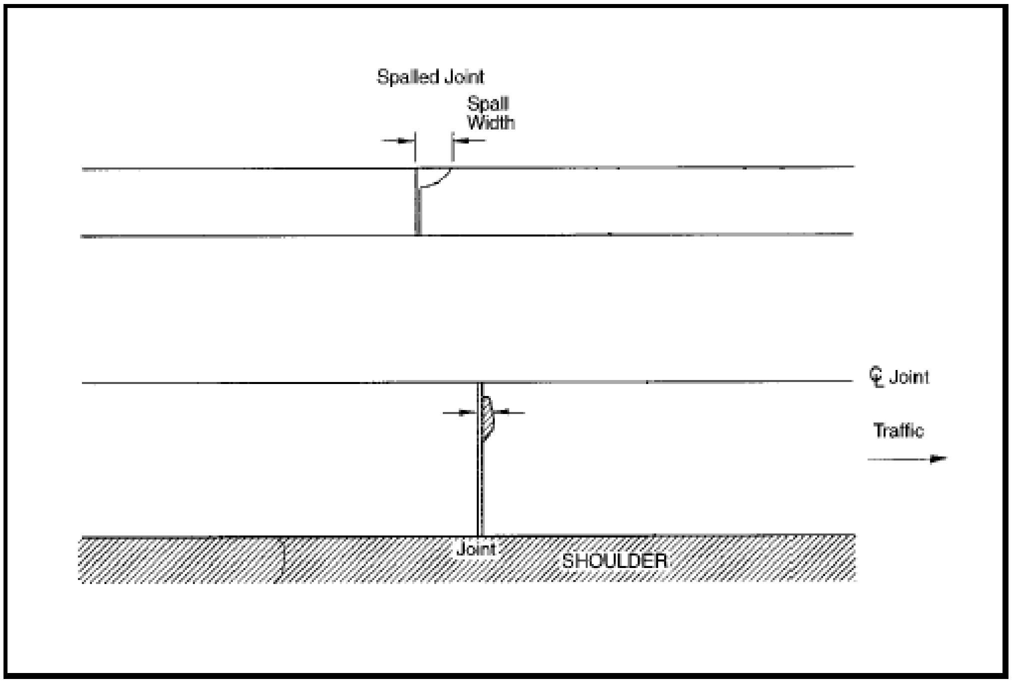
Spalling:

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.

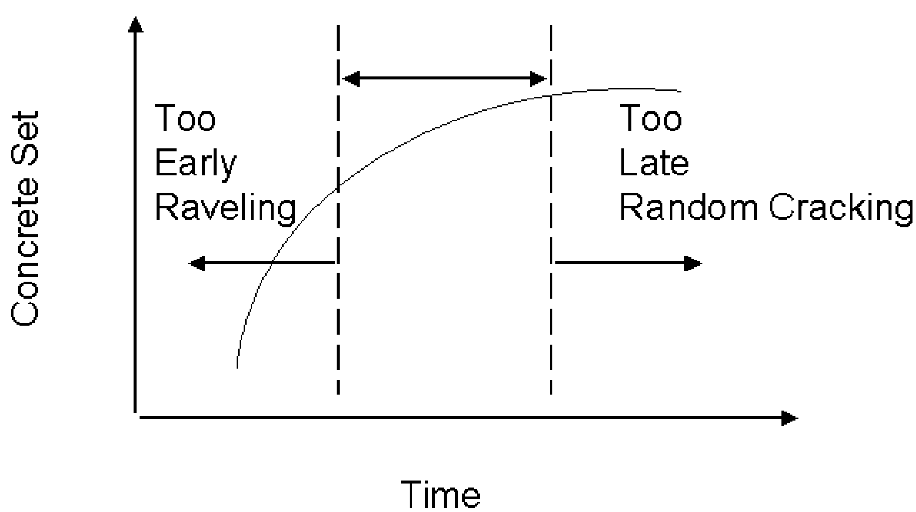
Full depth cracking can be caused by: repeated heavy traffic loads, failure of the doweled joints to function properly, loss of aggregate interlock along the crack face, inadequate joint sawing (saw timing), lack of subgrade support, excessive shrinkage, or the intrusion of incompressible materials in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

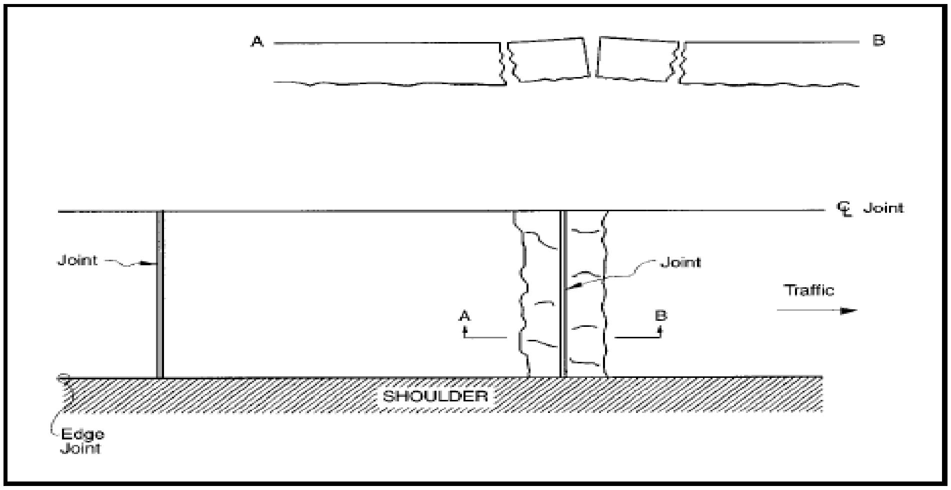
There is an optimum time to saw contraction joints in new concrete pavements as illustrated below by the Saw Timing Window. The window for sawing is a short period after the placement of the concrete pavement when the concrete pavement can be cut to control crack formation (controlled cracking). This 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.

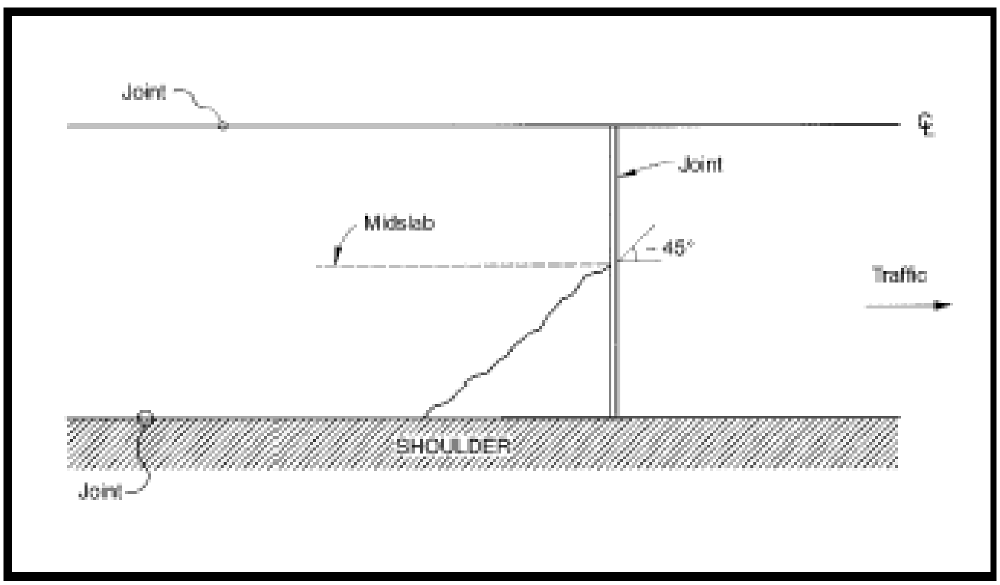


SAW TIMING WINDOW

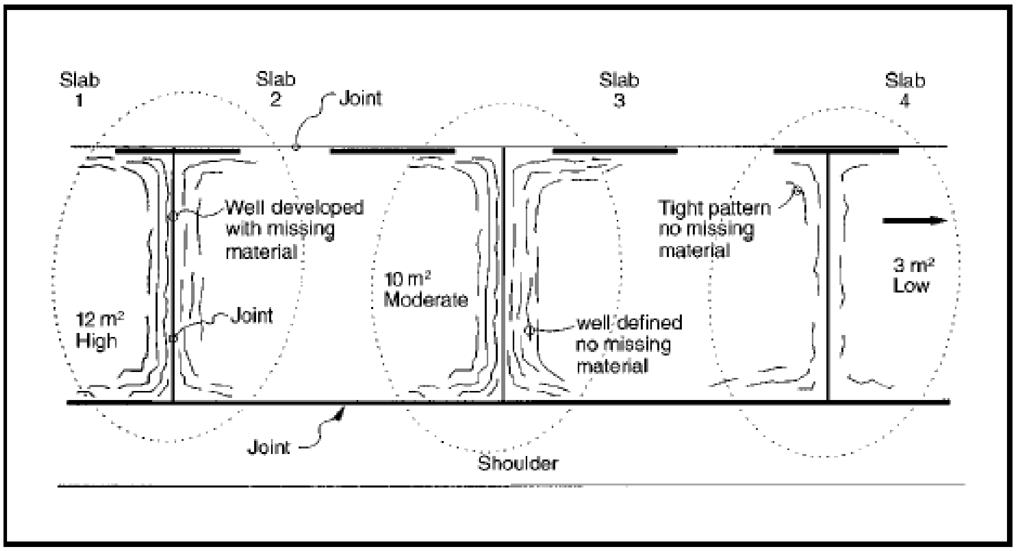
When full depth cracking occurs the only repair option is a full-depth repair method. The full depth repair method is discussed in Section IV of this manual.



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.



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

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:

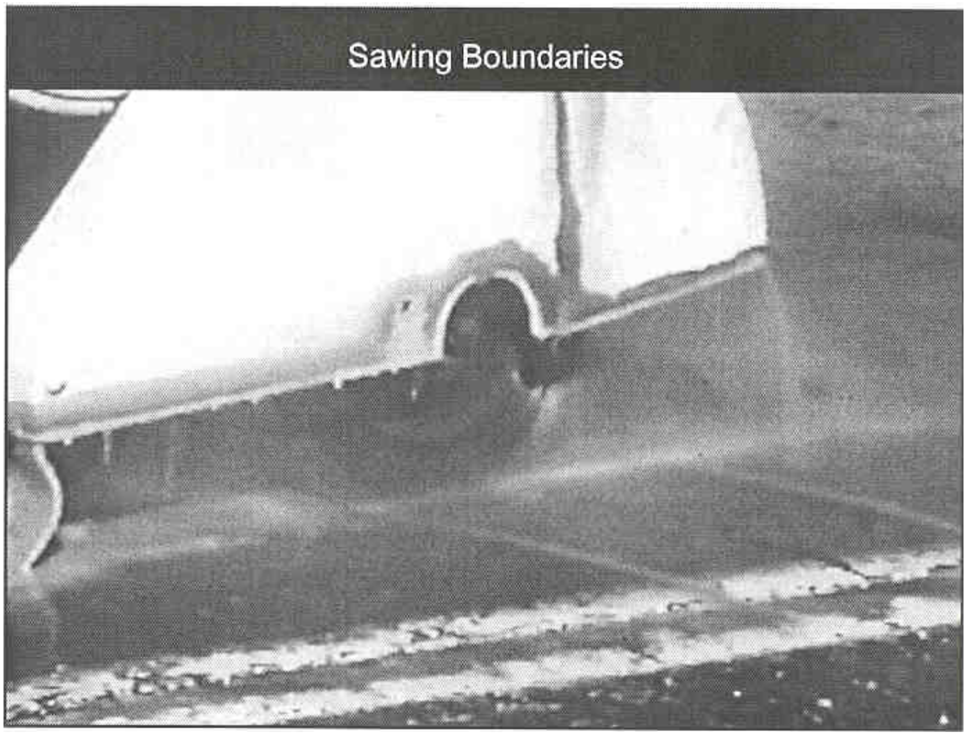
1. Survey the limits of the repair:
   Prior to repairing the spalled area, a survey of the spalled area should be made to determine the limits of unsound or delaminated concrete. Sounding is done by striking the existing concrete surface with a steel rod, chain, or hammer. Delaminating or unsound concrete 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

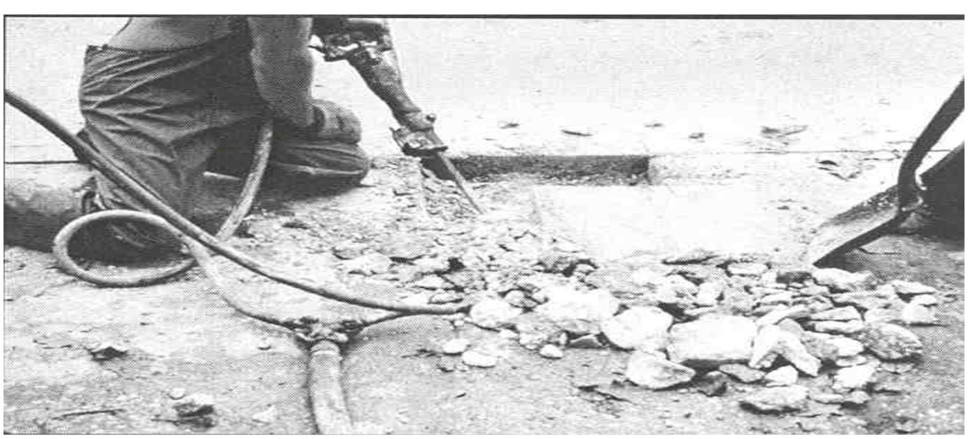
2. Remove the joint or crack sealant adjacent to the repair area.

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.



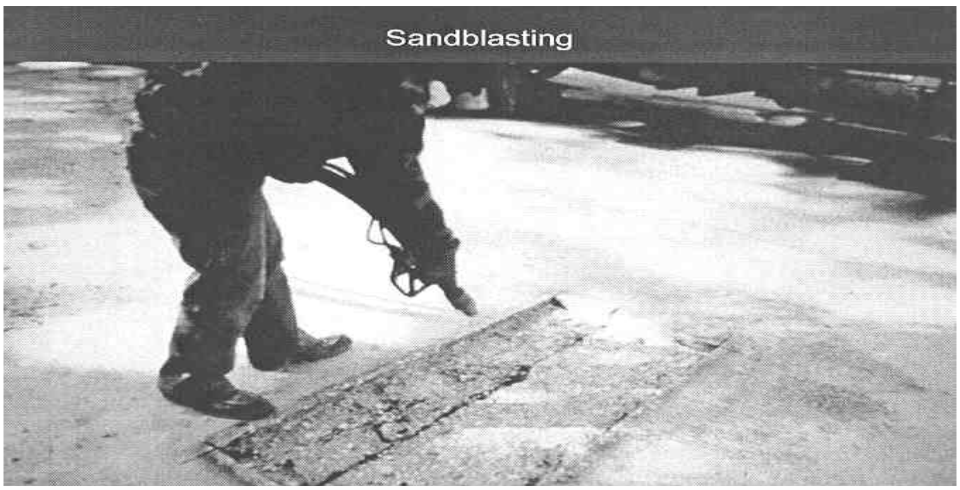
SAWING THE OUTSIDE BOUNDARIES OF A PARTIAL DEPTH REPAIR

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.



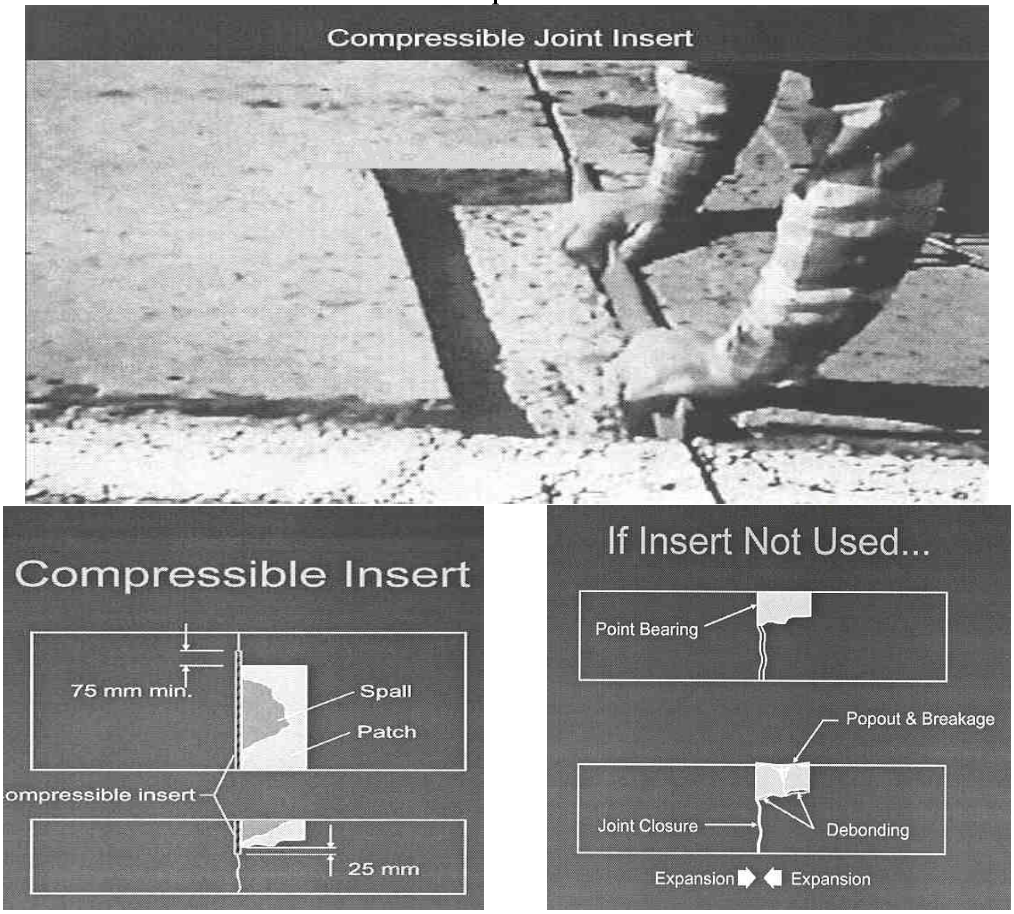
5. Sound test the newly exposed concrete to ensure all of the delaminating or unsound concrete has been removed. With a hammer to remove any fractured rock.

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:			**14 to 75 minutes**
Final:			**20 to 90 minutes**
Compressive Strength, psi (ASTM C 109)			**70°F**
2 hours			**1500**
24 hours			**4500**
7 days			**8000**
28 days			**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			**0.0110 inches**
60 minutes			**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)		**Weight Loss lb./ft^2**	
25 cycles		**$CaCl_2$ 0.003**	**NaCl 0.067**
50 cycles		**$CaCl_2$ 0.005**	**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.

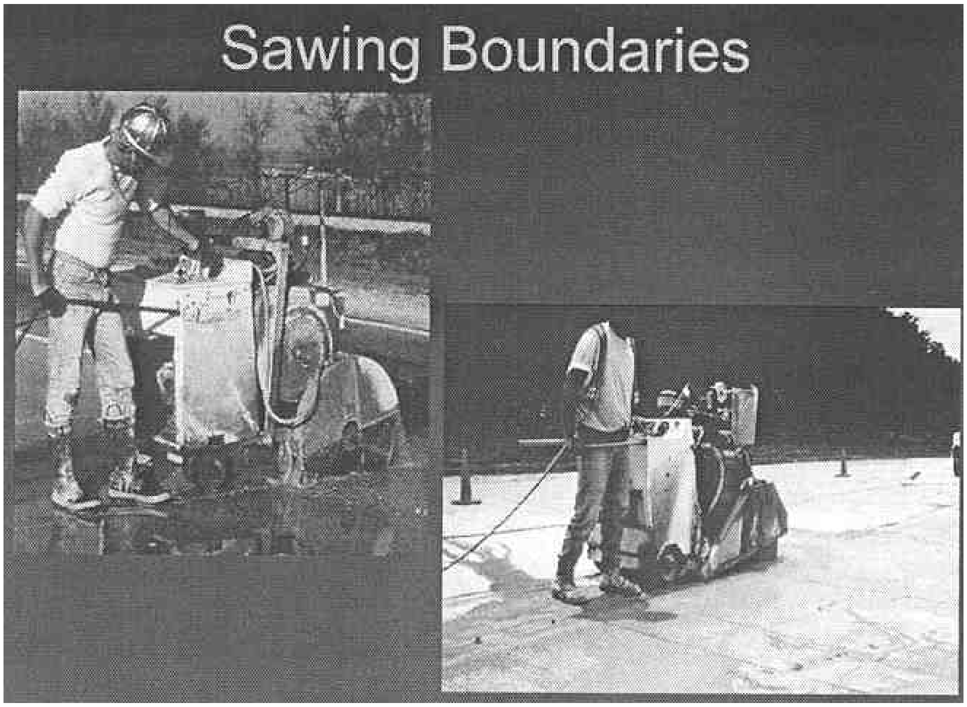
DEFINING THE REPAIR LIMITS

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.



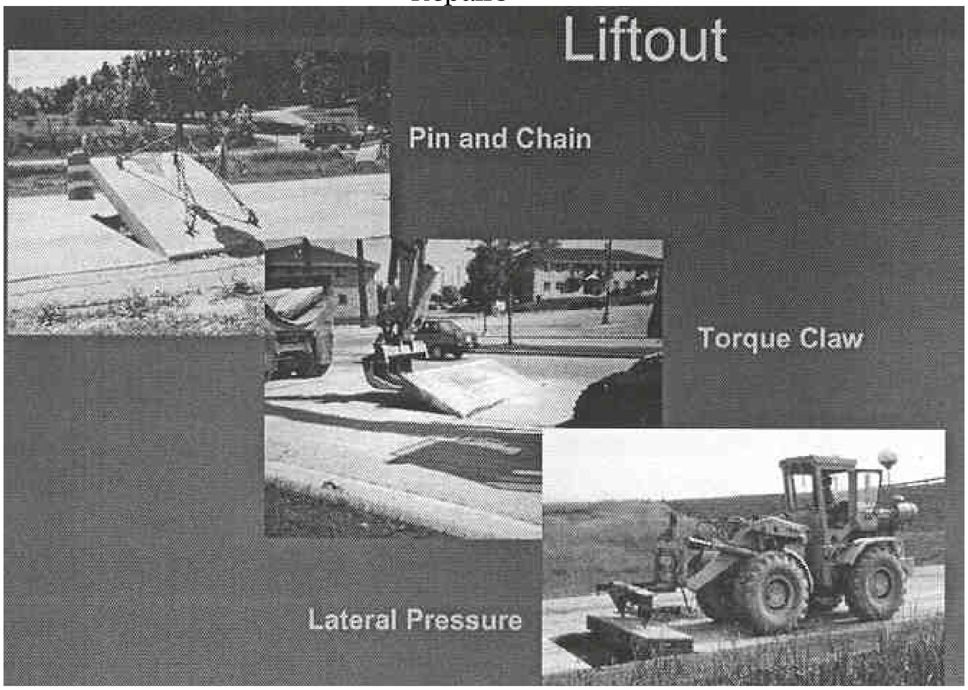
SAWING THE REPAIR LIMITS

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

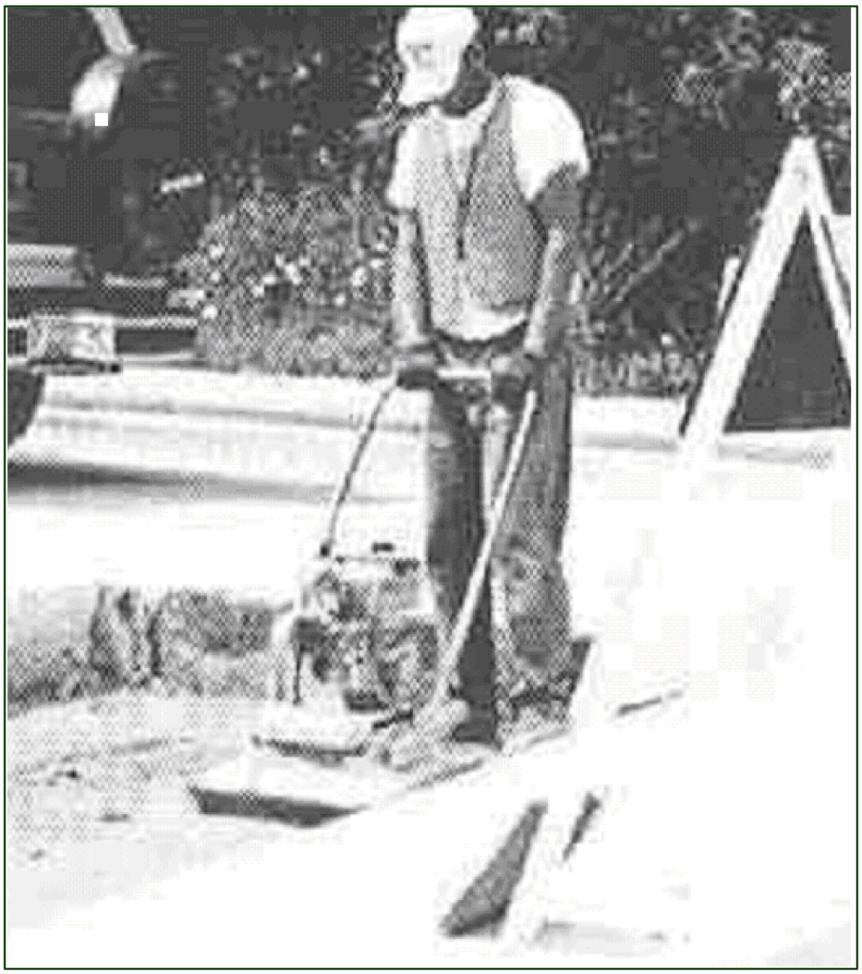
THE SAW CUTS FOR THE LIFTOUT METHOD

- 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.

PLACING LOAD TRANSFER DEVICE

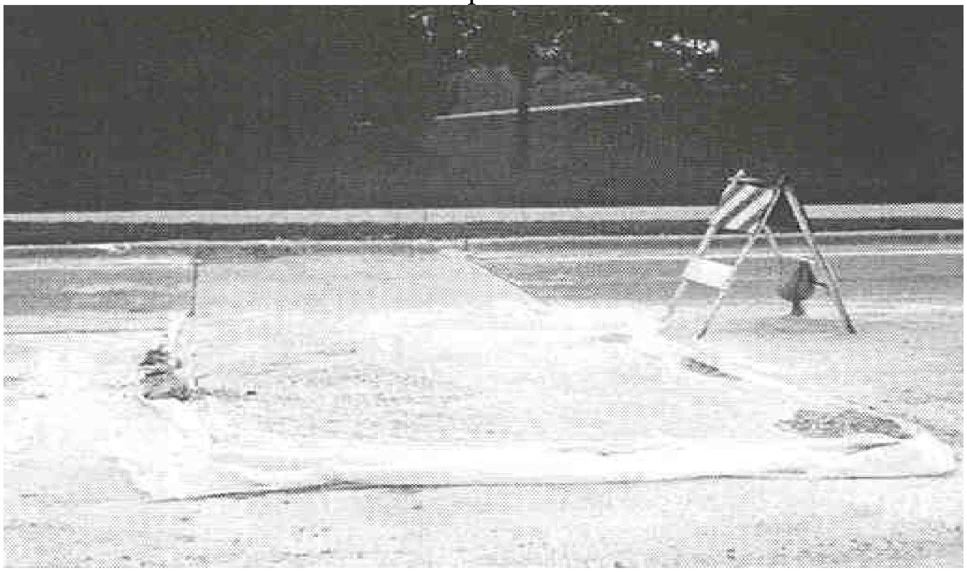
6. Sandblast and Clean Surfaces:

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

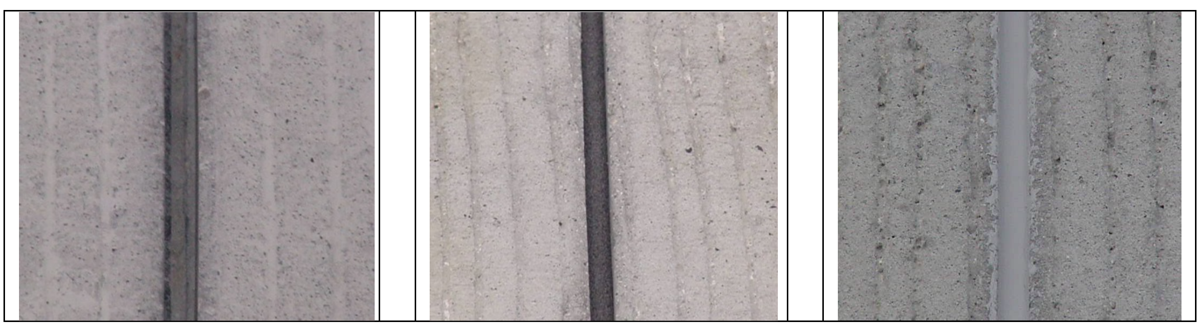


Protect and Cure the Repair

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.

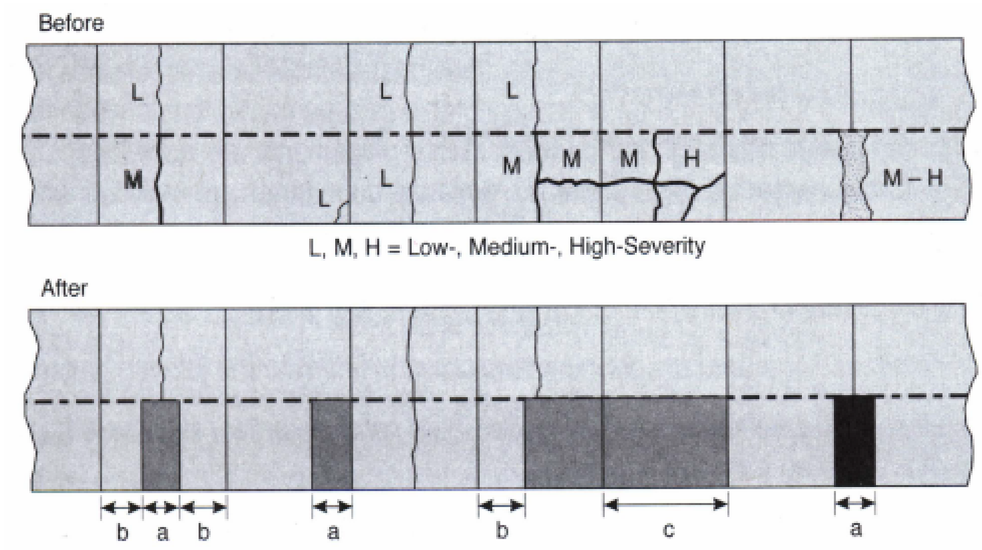
Although full-depth repairs can be designed and constructed to provide good long-term results, the performance of full-depth repairs is very much dependent on best practices and the use of sound designs and best practices. Most problems found can be traced back to insufficient design, poor construction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

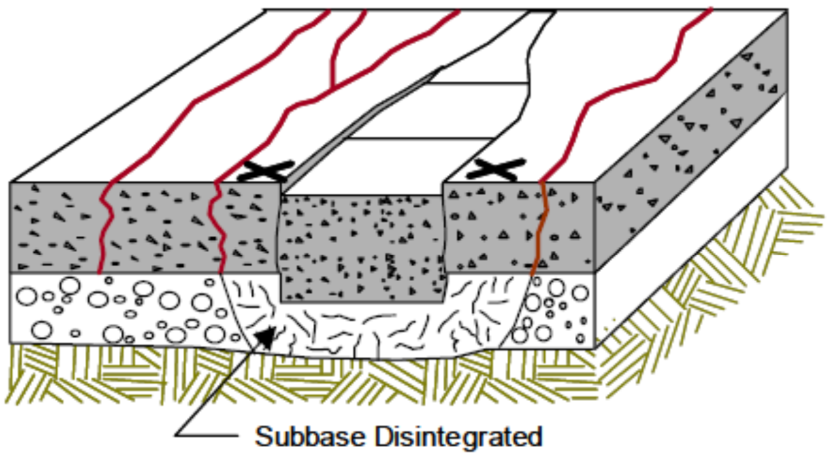
As illustrated in the figure below, subsurface deterioration accompanying structural distresses of CRCP can be quite extensive. Subbase deterioration is particularly prevalent near punchouts and wherever there is settlement or faulting along the longitudinal lane joint. The results of coring and deflection 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

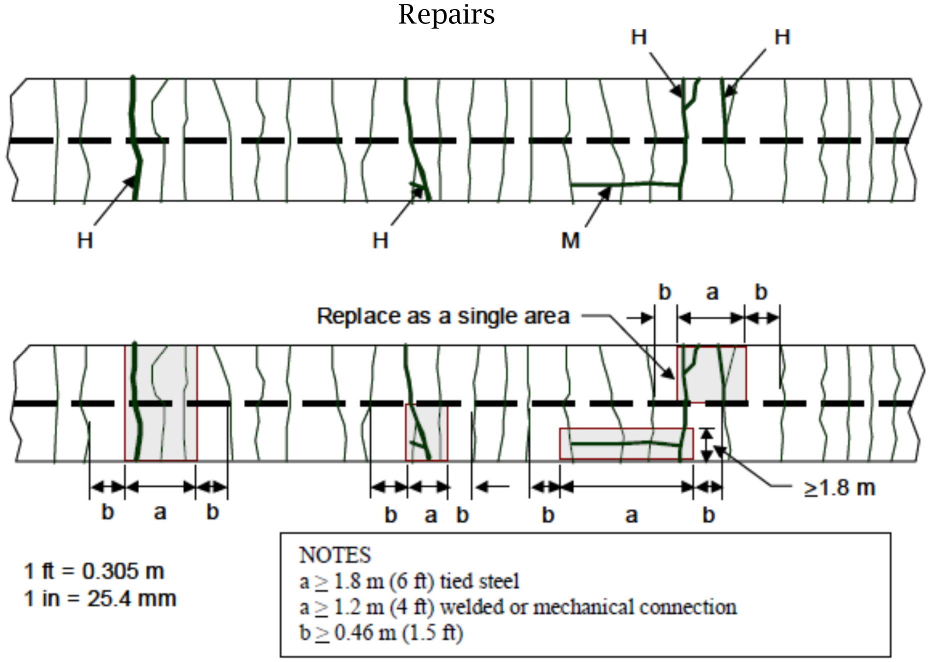
necessary to place the repair as close as 6 in. to an existing tight transverse crack.

- Full-lane-width repairs are generally recommended, although half-lane widths 6 ft. may be used when all distress are contained within that width
- 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 a half-lane width 6 ft. may be used when all distress is contained within that width.



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.

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 yd^3 6.5 to 8.5 bags/yd^3, and an accelerator to permit opening in 1 to 3 days. Type III cement, high cement factors 7 to 9.5 bags/yd^3, 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

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).

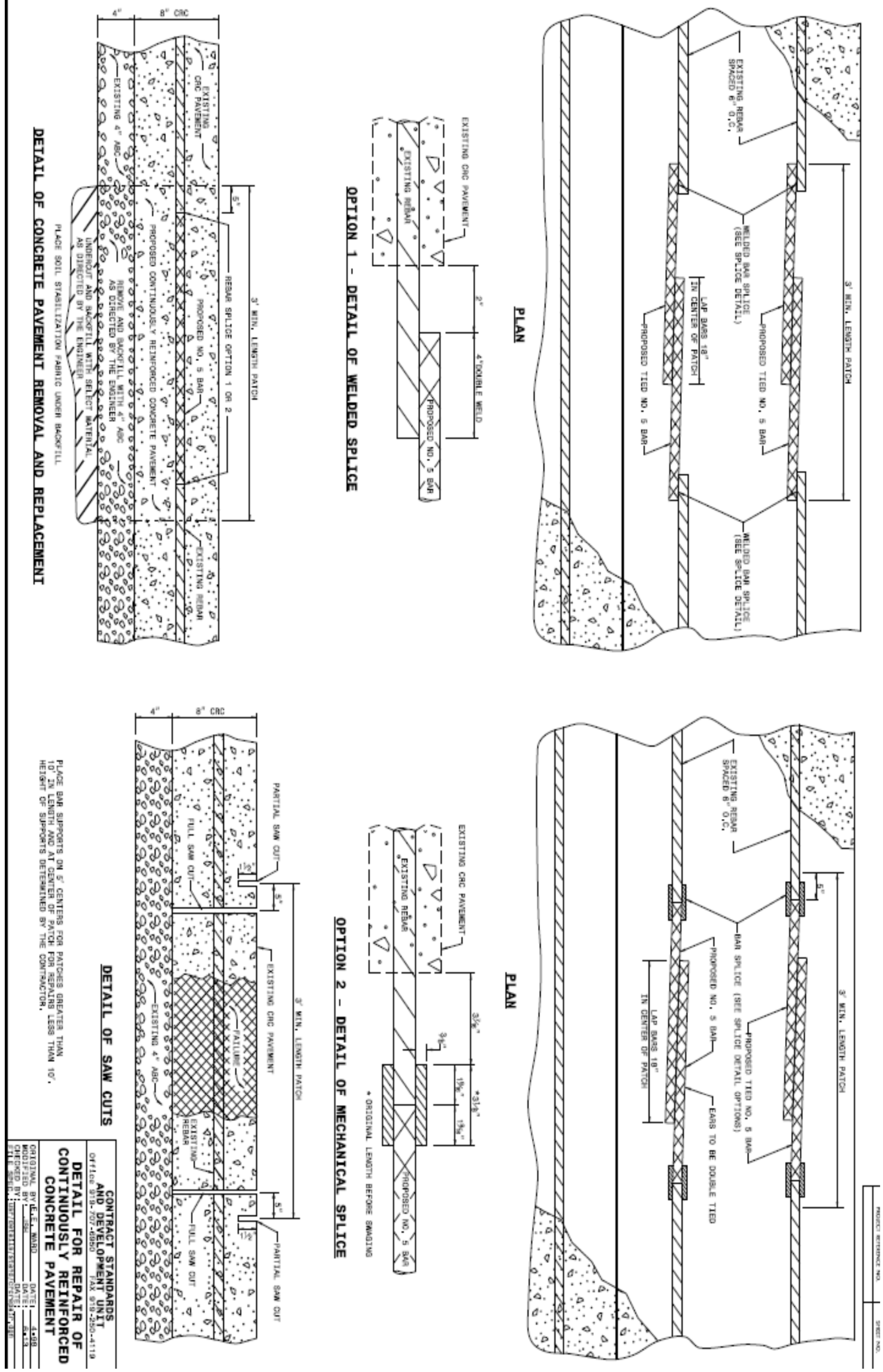
Restoring Reinforcing Steel in CRCP

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.

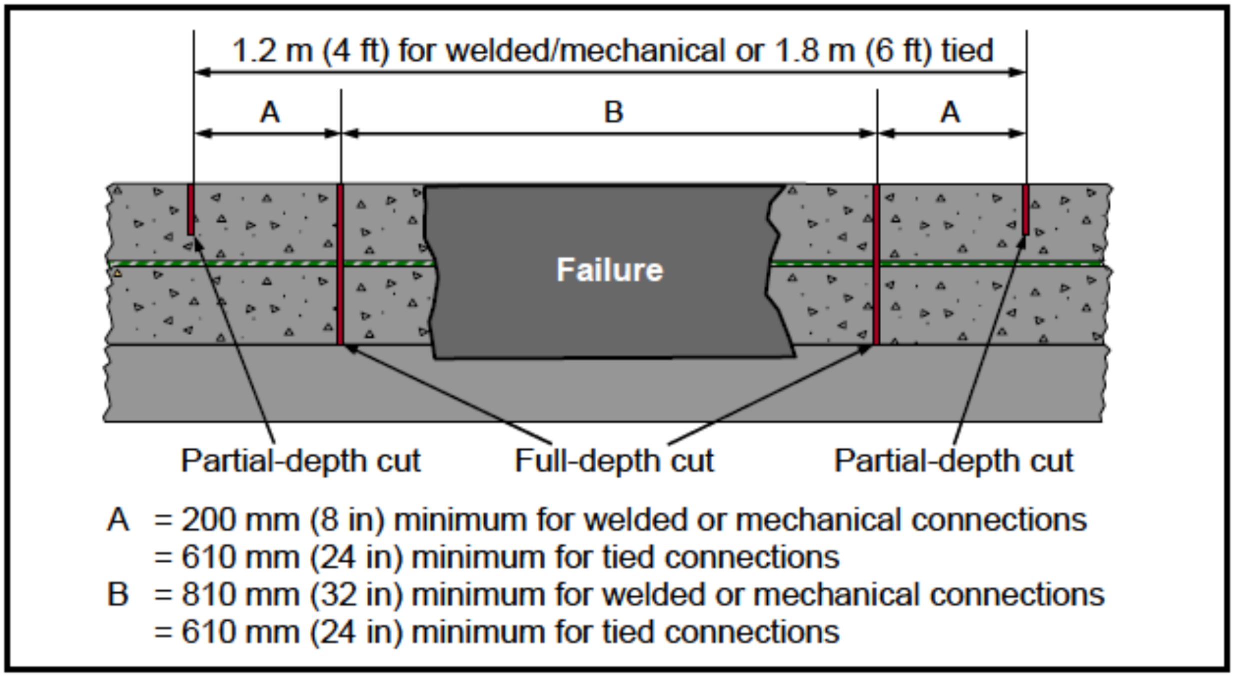

PLAN
EXISTING REBAR SPACED 6" O.C.
WELDED BAR SPLICE (SEE SPLICE DETAIL)
3' MIN. LENGTH PATCH
PROPOSED TIED NO. 5 BAR
LAP BARS 18" IN CENTER OF PATCH
PROPOSED TIED NO. 5 BAR
OPTION 1 - DETAIL OF WELDED SPLICE
EXISTING CRC PAVEMENT
EXISTING REBAR
2"
4" DOUBLE WELD
PROPOSED NO. 5 BAR
DETAIL OF CONCRETE PAVEMENT REMOVAL AND REPLACEMENT
4"
8" CRC
EXISTING CRC PAVEMENT
EXISTING 4" ABC
6"
3' MIN. LENGTH PATCH
REBAR SPLICE OPTION 1 OR 2
PROPOSED NO. 5 BAR
PROPOSED CONTINUOUSLY REINFORCED CONCRETE PAVEMENT
REMOVE AND BACKFILL WITH 4" ABC AS DIRECTED BY THE ENGINEER
UNDERCUT AND BACKFILL WITH SELECT MATERIAL AS DIRECTED BY THE ENGINEER
PLACE SOIL STABILIZATION FABRIC UNDER BACKFILL
EXISTING REBAR
PLAN
EXISTING REBAR SPACED 6" O.C.
6"
BAR SPLICE (SEE SPLICE DETAIL OPTIONS)
3' MIN. LENGTH PATCH
PROPOSED NO. 5 BAR
PROPOSED TIED NO. 5 BAR
LAP BARS 18" IN CENTER OF PATCH
EARS TO BE DOUBLE TIED
OPTION 2 - DETAIL OF MECHANICAL SPLICE
EXISTING CRC PAVEMENT
EXISTING REBAR
3½"
3/8"
*3⅛"
1⁹⁄₁₆"
1⁹⁄₁₆"
PROPOSED NO. 5 BAR
* ORIGINAL LENGTH BEFORE SWAGING
DETAIL OF SAW CUTS
4"
8" CRC
PARTIAL SAW CUT
1½"
6"
FULL SAW CUT
EXISTING CRC PAVEMENT
3' MIN. LENGTH PATCH
FAILURE
EXISTING 4" ABC
EXISTING REBAR
6"
1½"
FULL SAW CUT
PARTIAL SAW CUT
PLACE BAR SUPPORTS ON 5' CENTERS FOR PATCHES GREATER THAN 10' IN LENGTH AND AT CENTER OF PATCH FOR REPAIRS LESS THAN 10'. HEIGHT OF SUPPORTS DETERMINED BY THE CONTRACTOR.
CONTRACT STANDARDS AND DEVELOPMENT UNIT
Office 919-707-6950 FAX 919-250-4119
DETAIL FOR REPAIR OF CONTINUOUSLY REINFORCED CONCRETE PAVEMENT
ORIGINAL BY: L.E. WARD
MODIFIED BY:
CHECKED BY:
DATE: 4-98
PROJECT REFERENCE NO.
SHEET NO.

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

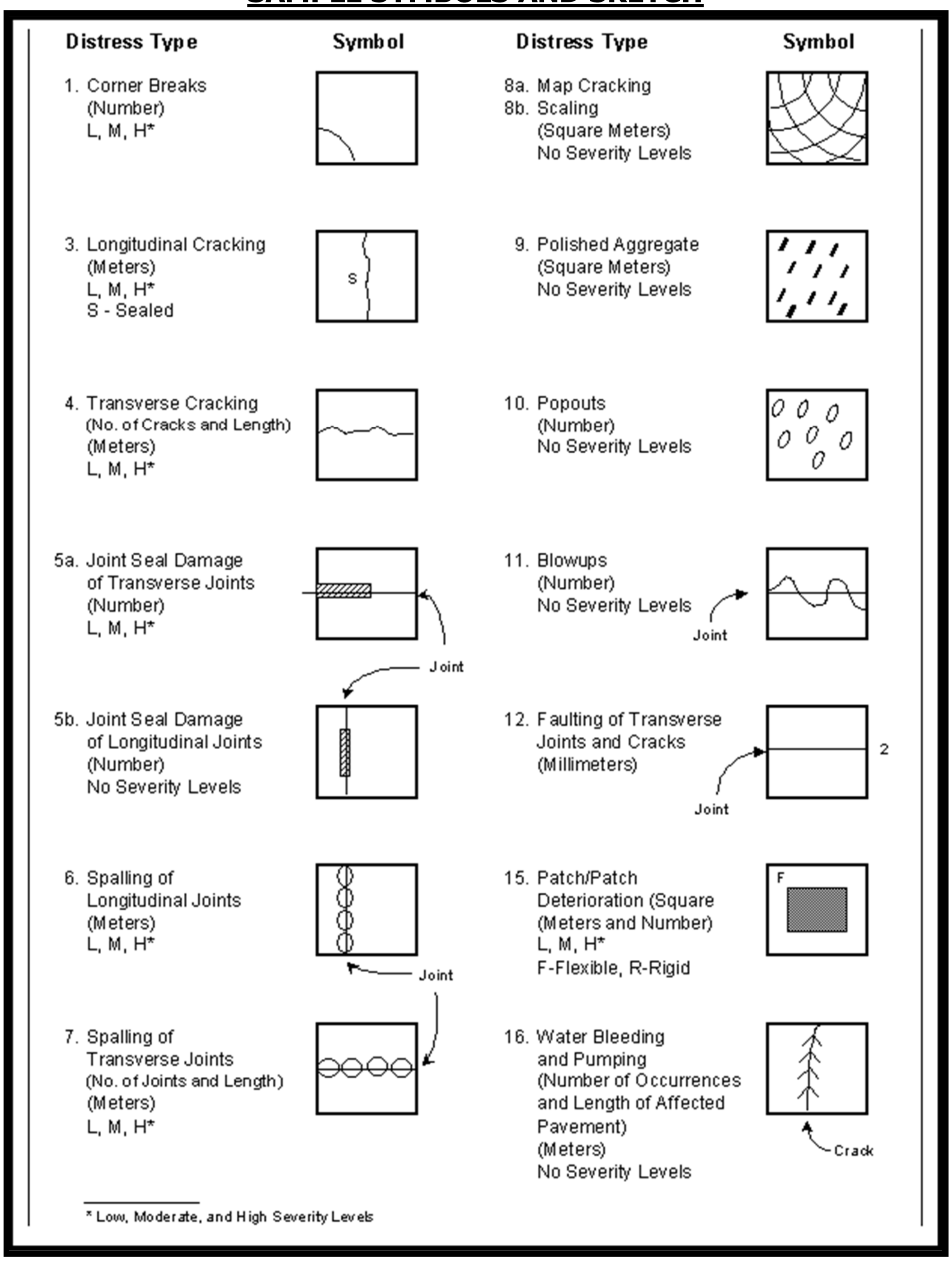
Moisture retention and temperature during the curing period are critical to the ultimate strength of the concrete. Proper curing is even more important when using set accelerating admixtures. Therefore, as soon as the bleed water has disappeared from the surface of the concrete (typically within ½ hour 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.

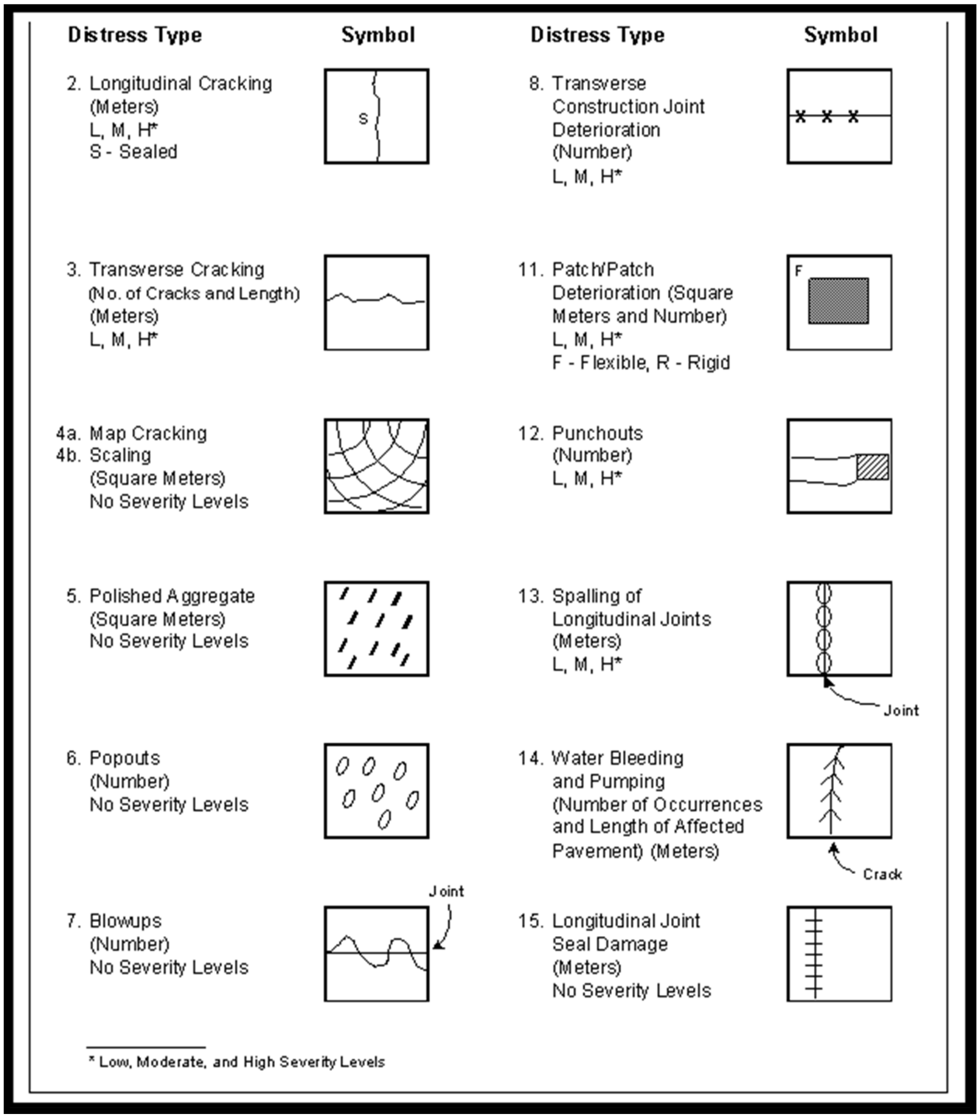
Step 7: Diamond Grinding (Optional)

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.

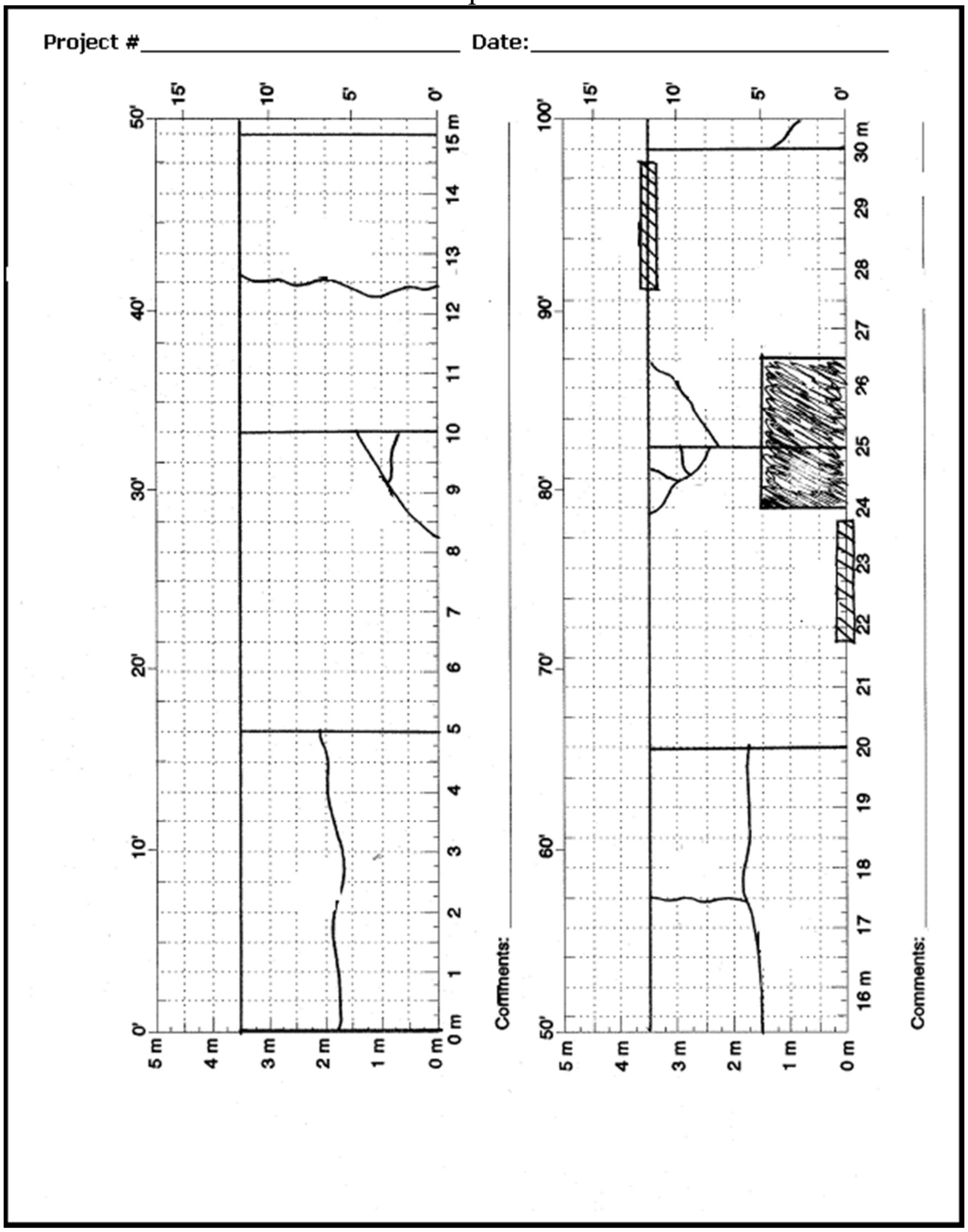
SECTION V
SAMPLE SYMBOLS AND SKETCH



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