Initiating Cracks in PCC Pavements

by

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Technology Transfer Concrete Consortium (TTCC) and National Concrete Consortium (NCC)

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Better Performance Through Innovative Designs

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GEE, HOW COULD ANY-BODY BE OPPOSED TO BUILDING MORE ROADS?
EVERY TIME I SEE HIGHWAY CONSTRUC-TION . . .
. . . SOME PROTESTER HAS ALREADY PUT UP A SIGN.
END CONSTRUCTION
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5-6

PCC Pavement

PCC Pavement showing

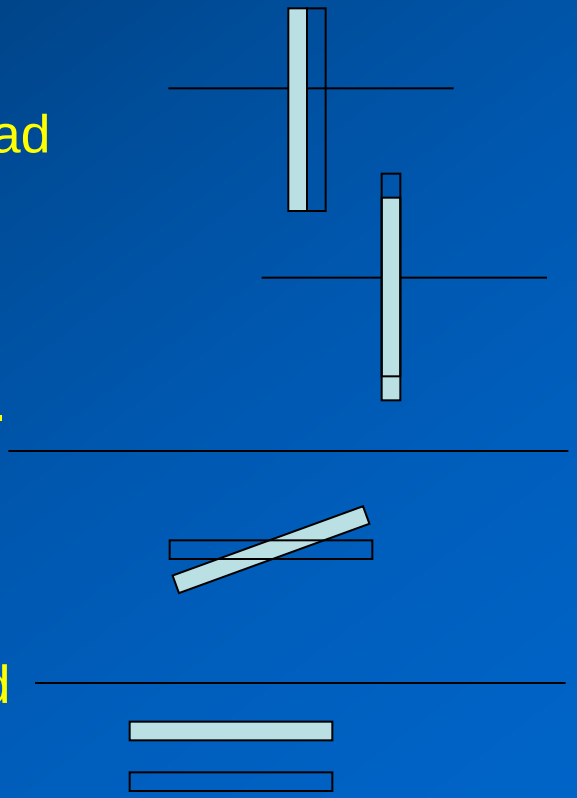
Overall Pavement Thickness

PCC Pavement Surface

Dowel Baskets & Saw Cut Joints on Pavement

Common Malfunction Mechanism In PCC Pavements

- Horizontal translation reduces the effectiveness of the dowel bar and affects load transfer efficiency
- Longitudinal translation causes the bearing stresses to increase resulting in dowel looseness and affect load transfer efficiency.
- Horizontal skew and vertical tilt results in restraining joint movement due to thermal effects.
- Vertical translation may result in spalling and loss of load transfer efficiency



"Guidelines for Dowel Alignment in Concrete Pavement", NCHRP, February 2009

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Controlling Random Cracking

Random cracking in Portland cement concrete pavement is primarily controlled by two important factors:

- concrete shrinkage behavior and restraint condition

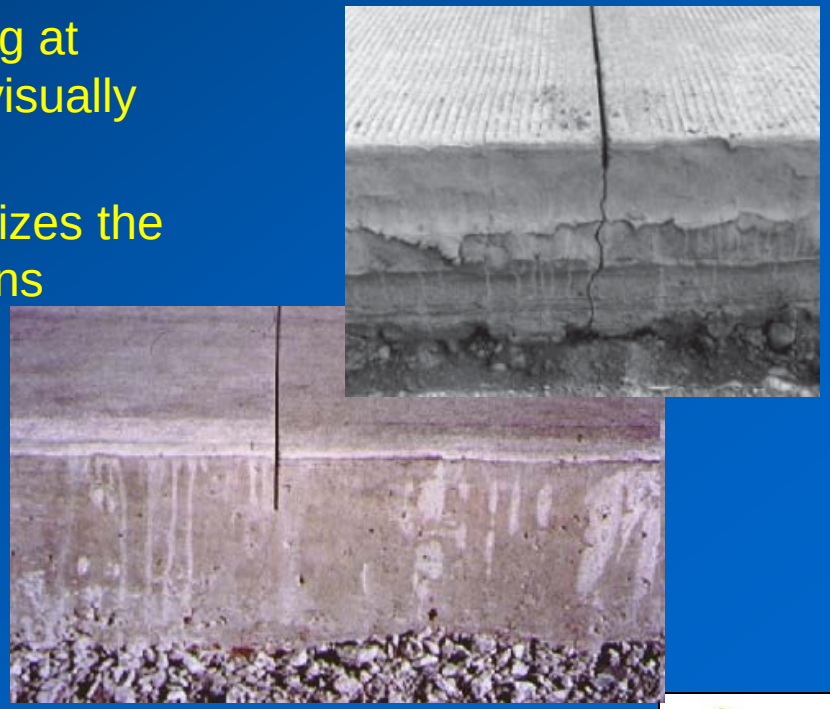
Saw Cutting Joints

Saw cutting joints in concrete pavements create vertical weakening planes in the concrete pavement to induce the cracks along their controlled axis. To controlled cracking in a PCC Pavements, joint sawing procedures are established. In general, the time of joint sawing should consider the following limiting criteria:

- The joint sawing should be performed before stresses develop in the pavement that are large enough to cause cracking.
- The joints must not be sawed until the pavement is strong enough to support the weight of the sawing equipment and operator, and also strong enough to avoid excessive raveling due to the forces introduced by the cutting blade.

Saw Cutting Joints

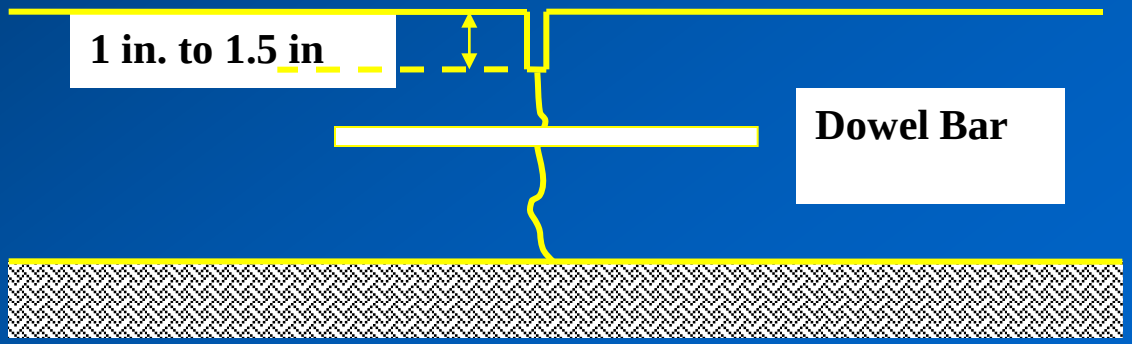
- Saw cutting allows the concrete segments to move and deform freely, lowering the stress build up in the pavement.
- The basic purpose of saw cutting joints is to encourage shrinkage restraint cracking at predetermined locations allowing for visually appealing finish.
- Saw cuts at the “right” location maximizes the load transfer ability when the crack runs through the center of the dowel bar



Types of Saw Cutting

EARLY ENTRY SAW CUTTING

- typically 1 -1.5 in deep
- typically 1 to 2 hrs after
  concrete placement
- utilizes lightweight equipment

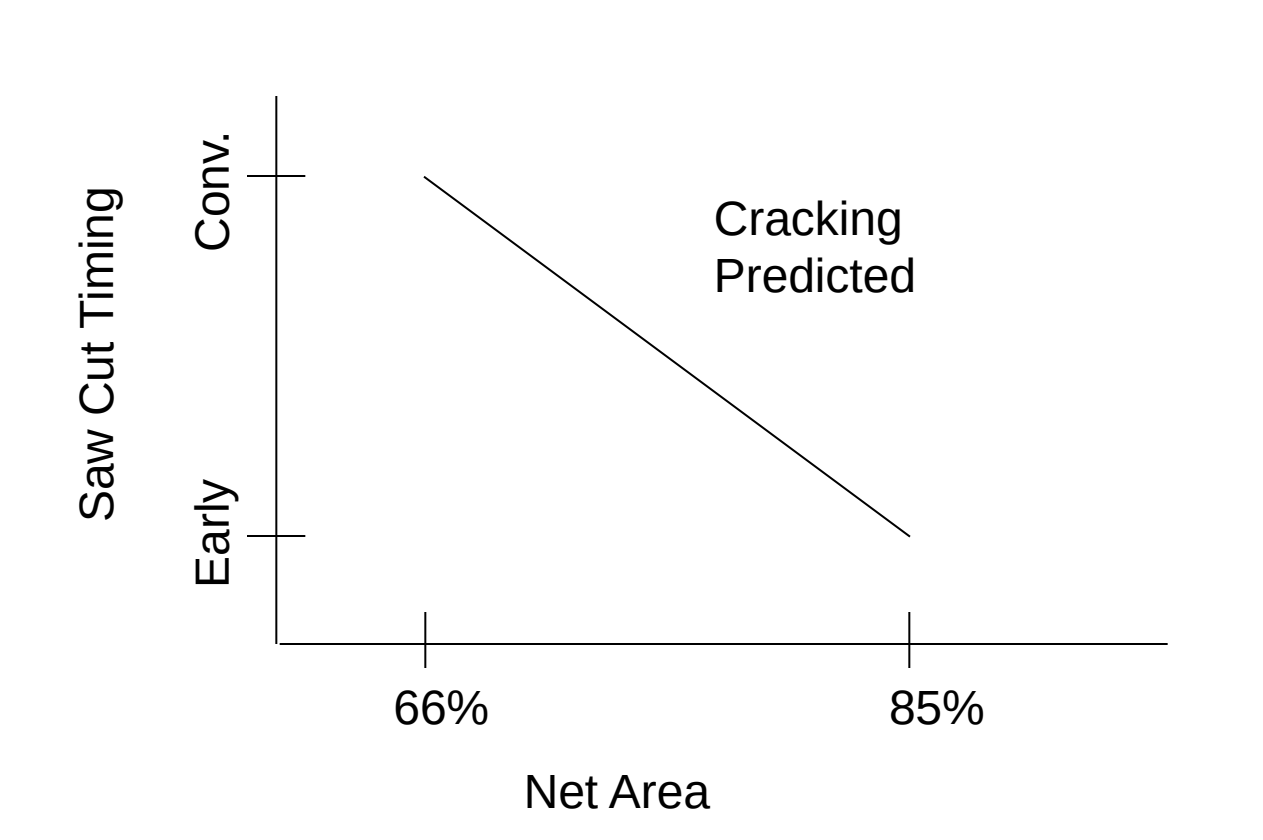


Types of Saw Cutting

CONVENTIONAL SAW CUTTING

- typically ¼d to ⅓d deep
- typically 6 to 12 hrs after concrete placement
- utilizes conventional saw cutting equipment

Predictability of Cracking



Based upon a 10 in. Thick Slab

Concept

Current saw cutting practice adds a weakened plane to the top of the PCC pavement thereby allowing it to crack at the desired location – the weakest link. This happens from the top of the pavement down.

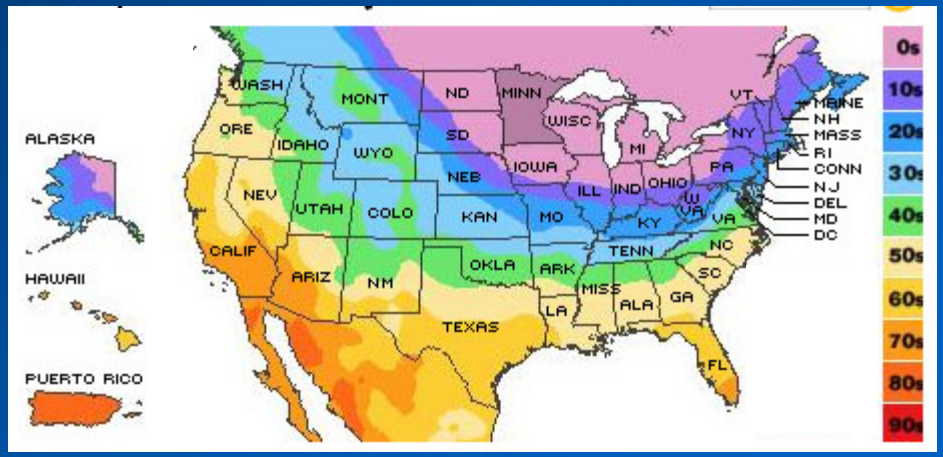
The research capitalizes on the weakest link principle to develop a weakened plane within the PCC pavement.

Factors Affecting Cracking in PCC Pavements

- Ambient Temperature
- Depth of Saw Cut
- Timing of the Saw Cut
- Concrete Mix and Subgrade
- Location of identifying marking

Factors Affecting Cracking in PCC Pavements

- Ambient Temperature – influences strength development in the concrete and optimal time to begin saw cutting
- Depth of Saw Cut
- Timing of the Saw Cut
- Concrete Mix and subgrade
- Location of identifying marking



Factors Affecting Cracking in PCC Pavements

- Ambient Temperature
- Depth of Saw Cut
  - Early age saw cutting 1-1.5 in. deep cut
  - Conventional saw cutting ¼ d or ⅓ d
- Timing of the Saw Cut
- Concrete Mix and subgrade
- Location of identifying marking

Factors Affecting Cracking in PCC Pavements

- Ambient Temperature
- Depth of Saw Cut
- Timing of the Saw Cut
  - Early Age saw cutting – shortly after initial set
  - Conventional: Too early - spalling and raveling along the joint face
  - Conventional: Too late: uncontrolled cracking in some cases
- Concrete Mix and subgrade
- Location of identifying marking

Factors Affecting Cracking in PCC Pavements

- Ambient Temperature
- Depth of Saw Cut
- Timing of the Saw Cut
- Concrete Mix and subgrade
  - Regional variations
- Location of identifying marking

Factors Affecting Cracking in PCC Pavements

- Ambient Temperature
- Depth of Saw Cut
- Timing of the Saw Cut
- Concrete Mix and subgrade
- Location of identifying marking
  - affects the location of the saw cut. Needs to be centered on the dowel bar

Objective of Research

- Develop a means whereby cracking and the location of the crack is predictable - develops across the center of the dowel bar
- Create a weakened plane within the PCC pavement
- Utilize current saw cutting techniques – minimize saw cut depth
- Minimize the effects of an off centered saw cut – Longitudinal Translation
- Increase the predictable behavior in PCC pavements

Goals of Initiator Research

Research has been underway to reduce the effects of the following factors:

- Ambient Temperature
- Depth of Saw Cut (reduce the initial depth)
- Timing of the Saw Cut (increase the window with conventional saw cutting practice and no change with early age saw cutting)
- Concrete Mix and Subgrade
- Location of identifying marking (allow for some longitudinal translation)

Goals of Initiator Research

Research has been underway to reduce the effects of the following factors:

- Ambient Temperature
- Depth of Saw Cut (reduce the initial depth)
- Timing of the Saw Cut (increase the window with conventional saw cutting practice and no change with early age saw cutting)
- Concrete Mix and Subgrade
- Location of identifying marking (allow for some longitudinal translation)
- Increase predictable behavior probability

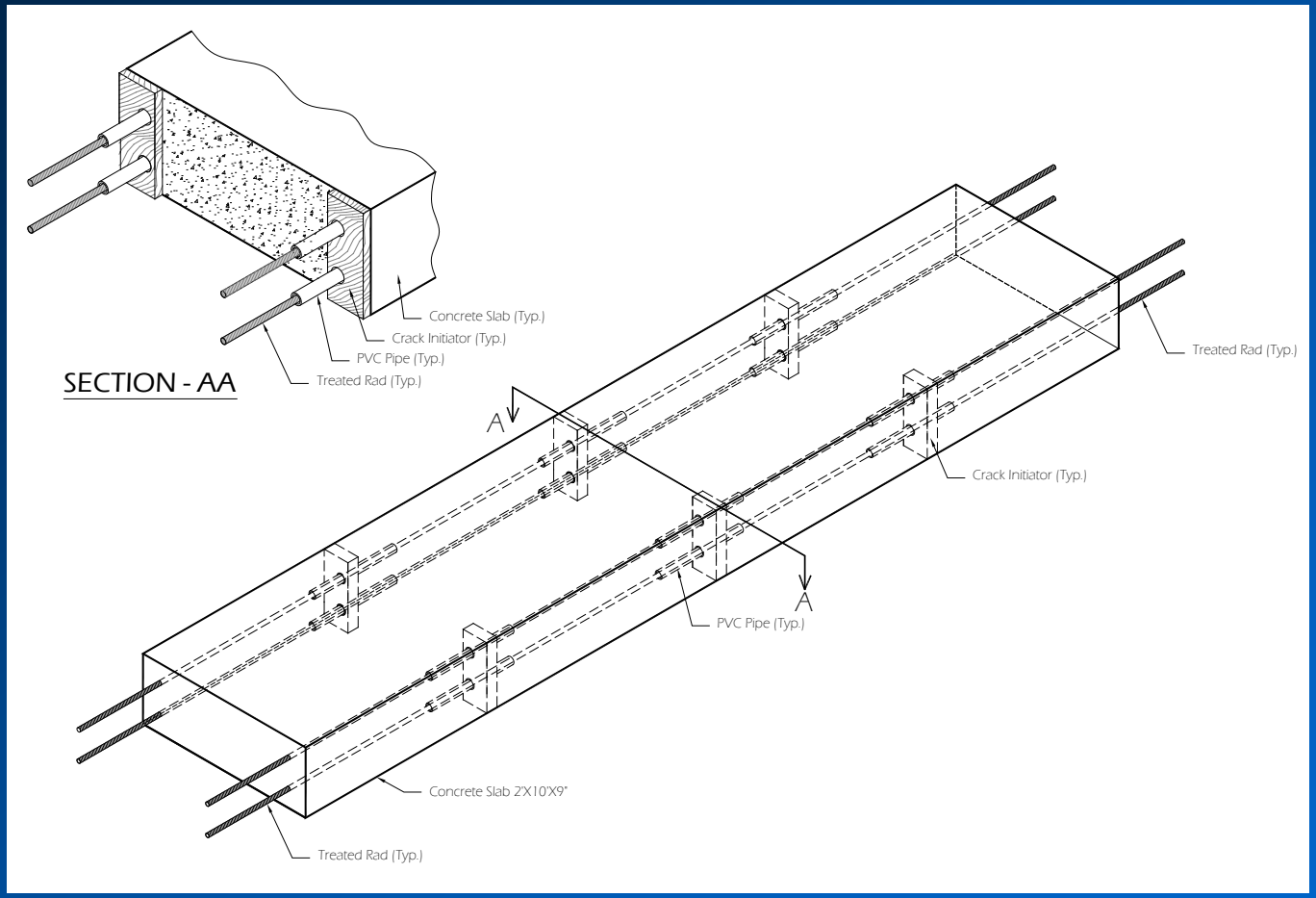
Research Emphasis

In order to minimize the effects of timing, location, depth of the saw cut and predictable behavior, research looked into introducing cracking initiators and the following factors:

- different initiator shape factors
- different initiator surface areas
- location of initiators
- surface reduction
- critical surface area

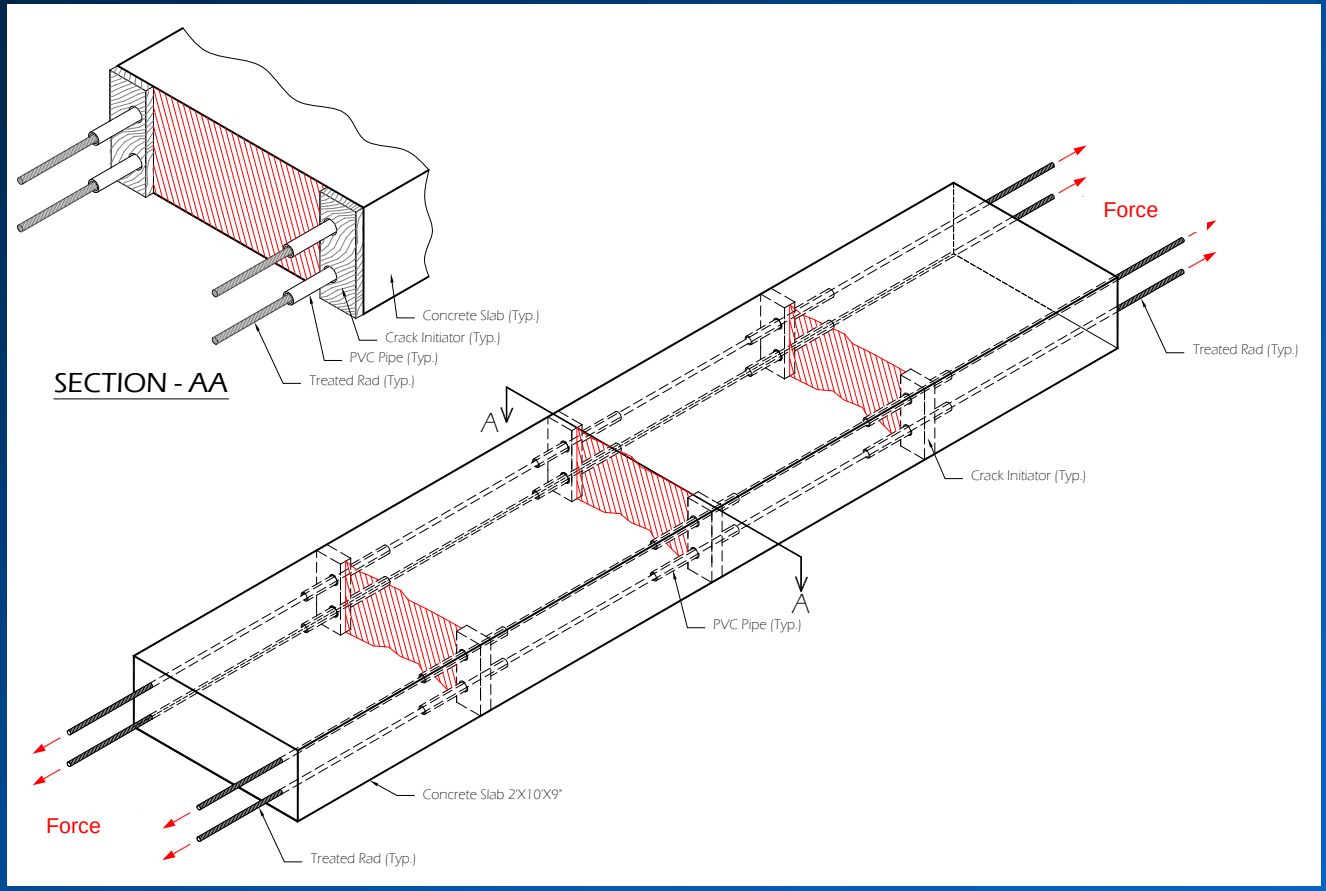
Construction of Test Slabs

Schematic of Test Slabs

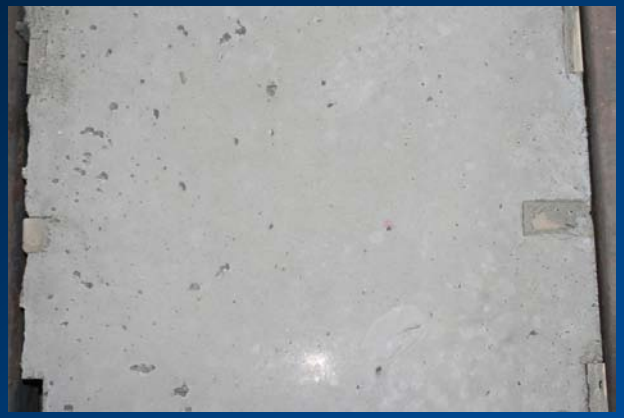


Tensioning of Test Slabs

Schematic of Test Slabs Cracked



Controlled Cracked



Uncracked Slab

Cracked Slab

NCPTC 2009 study*

- 1/3 depth saw cut
  - Average Cracking time: 0.2 to 2.2 days
  - Strain in concrete at the crack time: 6.6 με -206.6 με
- 1/4 depth saw cut
  - Average Cracking time: 0.2 to 6.5 days
  - Strain in concrete at the crack time: 23.5 με -189.7 με
- Early Age saw cut
  - Average Cracking time: 1.4 to 24.1 days
  - Strain in concrete at the crack time: 22.8 με -259.2 με

- *National Concrete Pavement Technology Center, Center for Transportation Research and Education, Iowa State University Crack Development in Ternary Mix Concrete Utilizing Various Saw Depths, February 2009*

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Calculated Strain in Concrete Test Slabs

- Pmax = 50K
- Diameter of Steel Rod = ¾ in.
- Stress(steel) = 37.5 ksi
- Strain(steel) = 1,300 με
- Ratio: $\varepsilon_{steel}/\varepsilon_{concrete}$
- Calculated $\varepsilon_{concrete}$ = 130 - 161με
- Uncracked at 120 days

Summary of Testing Results

Shape of Initiator	Number Tested	Results	Comments
"V" Shape – covering approx 60% of CSA – ¼ in. to 1.5 in. thickness	60 Slabs	Crack at initiator, 0.001 in. pretty straight	Cracking very predictable
Square/circular shape initiator – covering approx. 30 -40% of CSA, ¼ in. to 1.5 in. thickness	60 Slabs	Crack at initiator – 0.001 to 0.01 in. cracking at surface	Cracking controlled. 3/8 in. thickness yield highly predictable results
Rectangular shape with rounded edges initiator – covering 10 - 20% of CSA, ¼ in. to 3/8 in. thickness	200+ Slabs	Crack at initiator – 0.001 in. cracking at surface	Cracking controlled ¼ to 3/8 in. thickness yield highly predictable results – up to 120 days after placement

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Initiator Shape Factors

Different crack initiator shape factors

- Initial versions were utilized using a “V” shape factor, maximizing the area of separation around the “simulated” dowel bar
- Testing has allowed revision of the shape factor to efficiently and effectively maximize the influence of the separation to allow for a controlled cracking – end result – circular, square and rectangular.
- Research also noted that the shape of the initiator affects the predictable behavior of the crack and is key in reducing the variability associated with cracking pattern.
- Surface area of the initiator ranged initially from 60%/ln section down to 16.5 %/ln section (conventional saw cutting reduces cross sectional area by 25% to 33%, early entry saw cutting reduces cross sectional area by 12%)
- Thickness of the initiator – affects cracking predictability

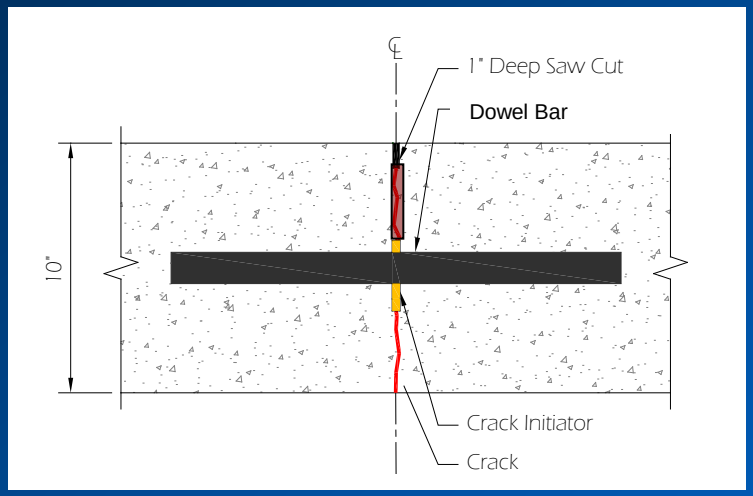
Pavement Critical Stressing Area

Critical Stressing Area

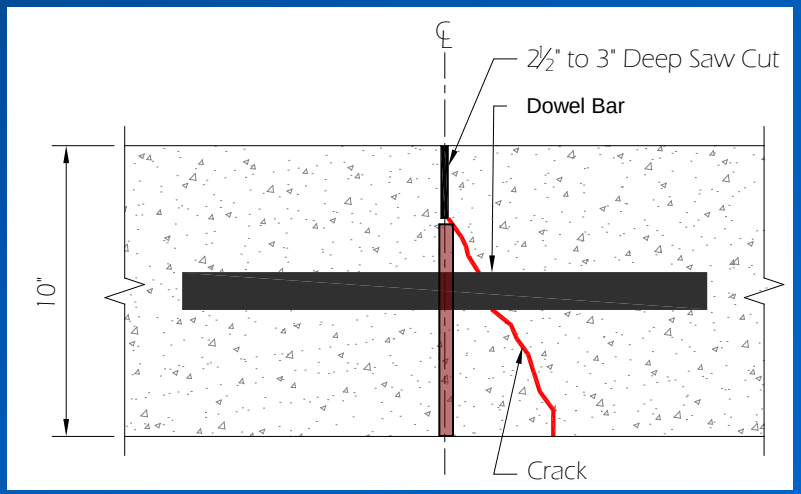
- Critical Stressing Area is the remaining concrete section. In a 10 in slab, the critical stressing area is reduced by 30%

Current standard of practice is to

- reduce the overall area by 1 in. deep or ¼ d or 1/3 d.
- difficult to predict overall cracking behavior – affected by slab restrained conditions



With Initiator

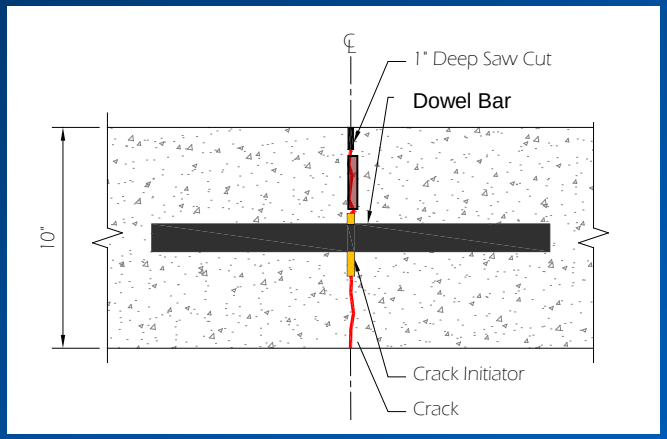


Conv. Saw Cutting

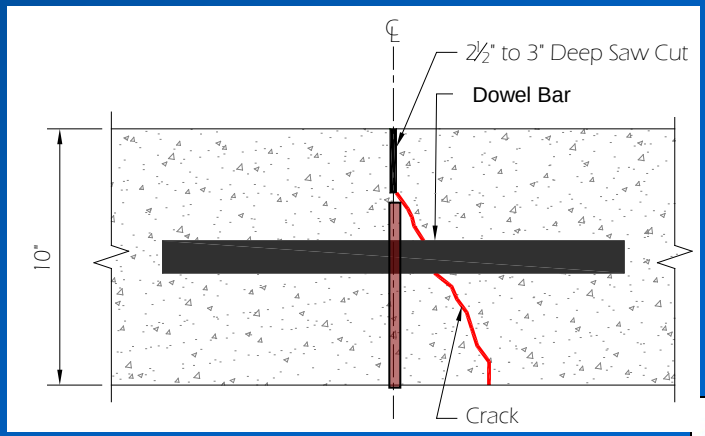
Pavement Critical Stressing Area

Critical Surface Area

- Governing area is typically the shortest distance within the weakened zone
- Initiators reduces the critical surface area to the area between the bottom of the saw cut and the top of the initiator, as oppose to the bottom of the saw cut to the bottom of the slab
- Initiator influences the cracking behavior – making it more predictable



With Initiator



Conv. Saw Cutting

Location of Initiator

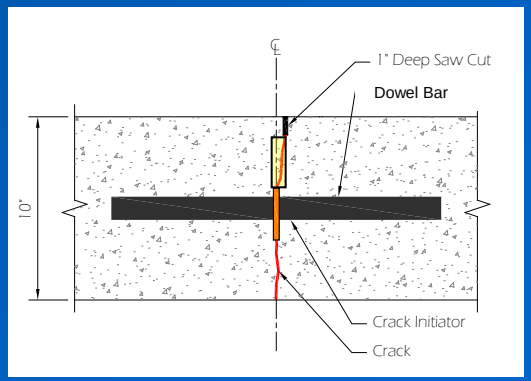
Location of initiators

Bottom of the test slabs

- reduction in critical stressing area, minimum effects noted.
- Alignment of slab reduction saw cut and initiator is critical
- Overall size had to be greater.

Middle of the test slabs

- reduction in critical stressing area. The location provides a break within the slab, thereby minimizing the critical stressing area factor.
- greater effect on crack behavior prediction
- alignment of saw cut and initiator is minimized
- critical section is between the top of the initiator and the bottom of the surface separation



Overall Pavement Surface Reduction

Surface Reduction at the Top

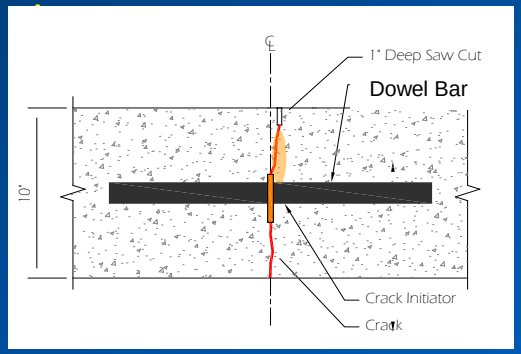
- Separation at the top of the slabs, in line with the initiator, were made with different depths – with the shallowest being 1/8 in. deep.
- Crack formation was noted at the bottom of the separation. Initiator increases the influence of the reduced surface, with the area between the bottom of the reduced surface and the top of the initiator being the governing factor
- A 1 in. deep saw cut would be more than sufficient to include the cracking propagation attributes in the PCC pavement

Timing

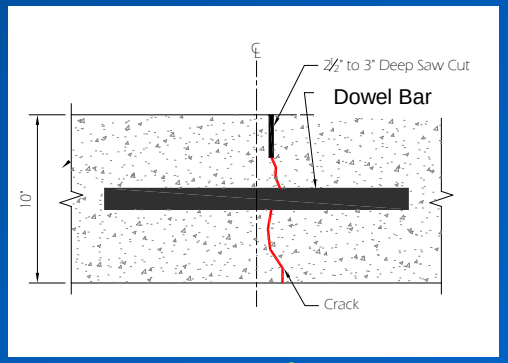
- Slabs have been stored up to 120 days after placement and tensioned to obtain crack at the predicted location
- Slabs cracked only at the initiators
- Slabs cracked when the strain in the concrete reached 130 to 160 με

Surface Reduction Alignment

- Current standard practice of saw cutting does not have adequate controls to always predict the crack path – especially in longitudinal translation cases.
- With regularly spaced initiators and with the weakest link principal, the crack will occur at the weakest link, shortest possible distance.
- If the reduction in area within a slab is not immediately at the center of the initiator, the crack will originate from the reduction in area within the slab and will run along side of the initiator
- Crack in concrete is influenced by the reduction in the overall cross sectional area
- With initiators in place, the initiator influences the overall pattern of the crack above the dowel bar. Without the initiator, the crack path is unpredictable.
- Restrain conditions can affect the crack propagation below the dowel



With Initiator



Saw Cutting

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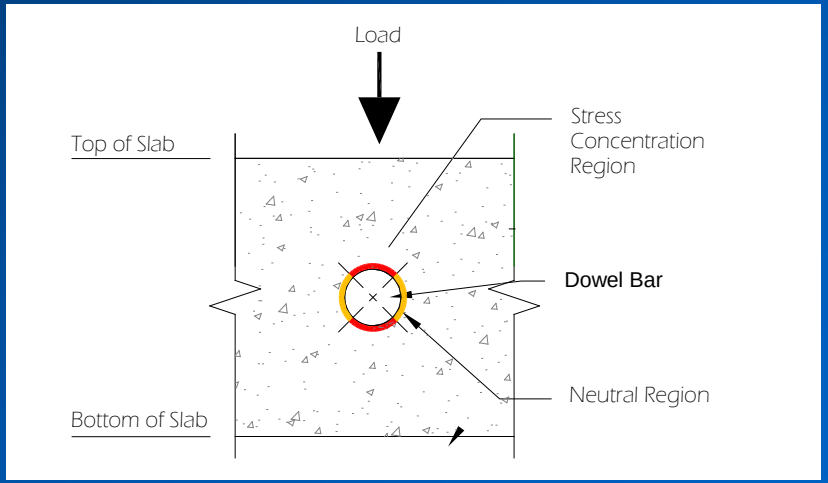
Stresses Concentration on Dowel Bar

- Stresses on dowel bar are highest at the top and bottom of the dowel bar
- Sides of the dowel bar do not aid in shear stress distribution from the concrete
- Smaller diameter bars result in higher stress concentration on the top and bottom of the dowel bar[1]



1. Center for Transportation Research and Education, “Dowel Bar Optimization: Phase I and II, Final Report” Oct. 2001

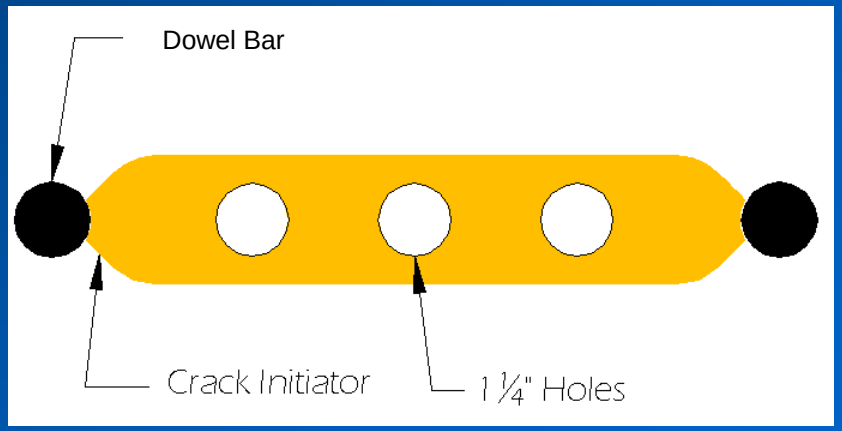
Design of Initiator

Design Considerations

- Shape Factor
- Size of Initiator
- Location of Initiator
- Easy to install on dowel bar
- Steady
- Smooth
- Overall shape factor and weight affecting transportation of baskets
- Number of Initiator Needed – based on overall surface reduction

Design of Initiator

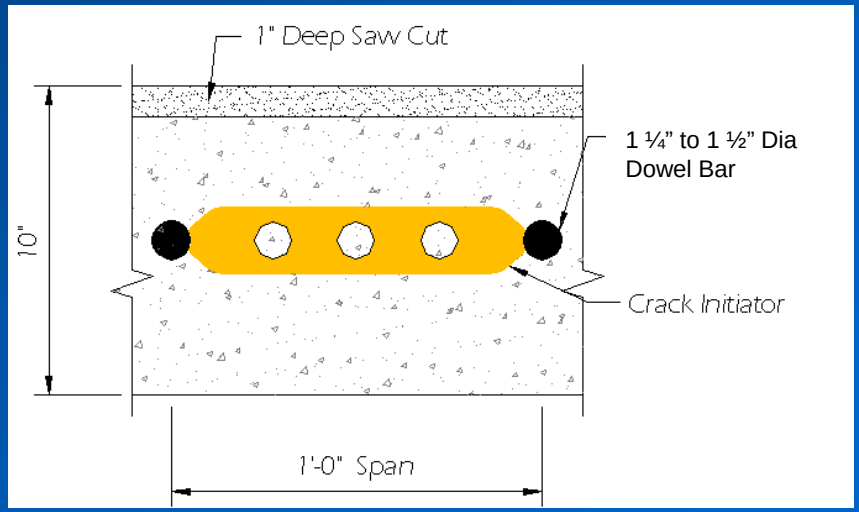
- Designed to be welded to the dowel bar
- Initiator is designed not to influence the stacking of the dowel bar
- Gaps in the initiator to reduce weight
- Welded at neutral stress zone on the dowel bar
- Rounded edges
- Smooth face



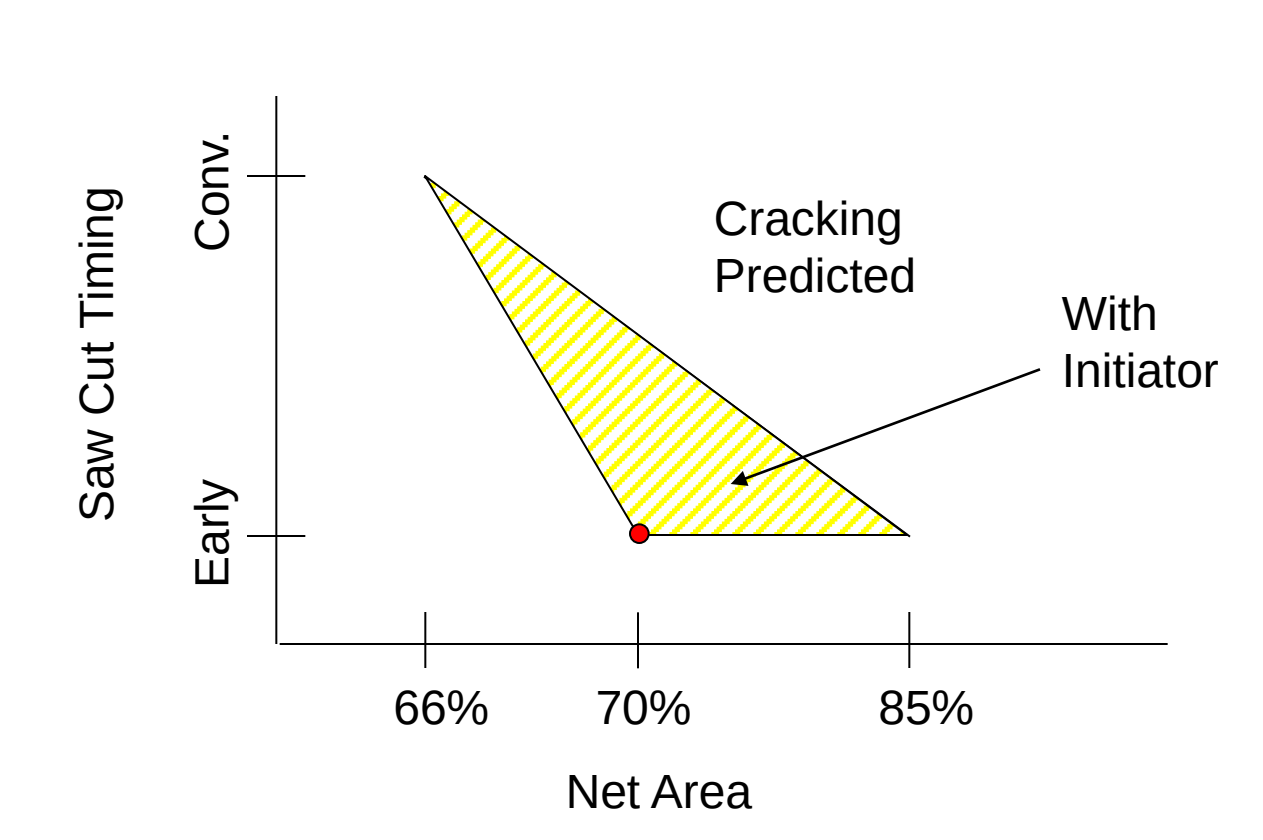
Design of Initiator

- Thickness: ¼ in. to ⅜ in. thick
- Number of Initiators: between dowel bars
- Recommended Surface Reduction: 1 in.
- Depth of Initiator:

Slab Depth	Initiator Thickness	Depth of Initiators
Up to 10 in.	¼ in.	2 in.
> 10 in.	¼ in. to ⅜ in. thick	2.5 in.



Predictability of Cracking With Initiator



Based upon a 10 in. Thick Slab

SUMMARY

- Increase cracking predictability.
- In order to influence the cracking formation, a small separation at the top of the PCC pavement is needed. The depth of separation can be minimized to an inch or less to allow for a visually pleasing appearance
- Utilizes current saw cutting methods
- Location of the initiator – inline with the dowel bar maximizes the influence on the location of the crack
- The initiator influences the behavior of the crack – predictable cracking behavior
- Overall thickness of separation can be 1/4 to 3/8 inch wide – slab depth dependant
- The initiator provides a discontinuity within the PCC pavement.
- The initiator reduces the critical stressing area to form the crack – area above the initiator
- The ability to control cracking characteristics. The precise location (longitudinal translation approx 1 in.) of the saw cut becomes a little less critical.
- May influence the saw cutting window
- Provide savings through better performance of the pavement slab

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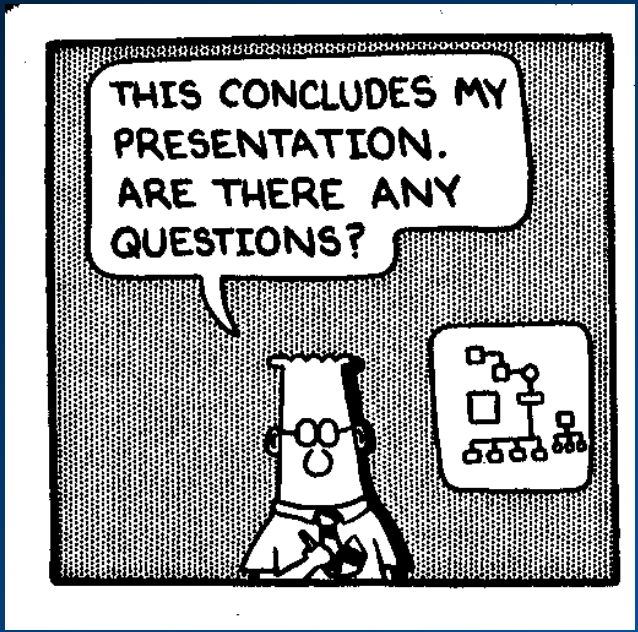

QUESTIONS?

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