Concrete Distress – Assessments and Solutions

2017 Municipal Streets Seminar
November 15, 2017
Ames, Iowa

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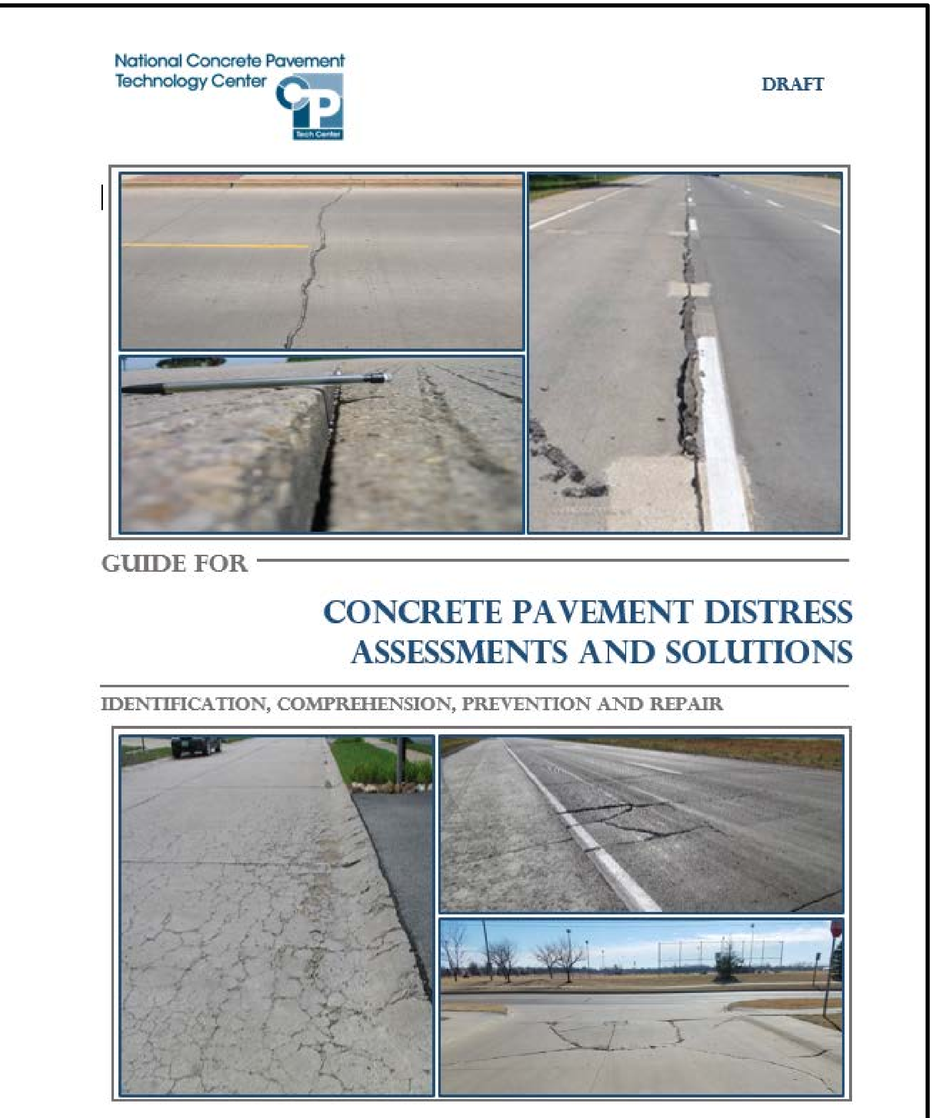
Representing the CP Tech Center

Distress Guide 2017



- Surface Defects
- Surface Delamination
- Material Related Cracks
- Transverse & Diagonal Cracking
- Longitudinal Cracking
- Corner Cracking
- Spalling
- Faulting
- Joint Warping and Curling
- Blowups
- Settlement and Heaves
- Subgrades & Base Support Conditions
- CRCP
- Concrete Overlays, BCOA, BCOC, UBCOA, UBCOC
- Laboratory & Field Testing

Focus:

- Identification
- Causes
- Prevention
- Rehabilitation

Surface Defects

Map Crazing

Plastic Shrinkage Cracking

Scaling

Popouts

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Summary of Causes & Prevention of Surface Defects

		Prevention or Mitigation		
Distress	Causes	Design	Material Selection	Construction
1. Map Cracking (Crazing)	• Overworking/over-finishing of concrete surface • Finishing while bleed water is present on surface • Late or inadequate curing • Batching absorptive aggregates that are on the dry side of SSD	• Design concrete with low permeability • Use moderate slump mixtures (with low w/cm ratio)	• Use blended cements or SCMs to control AAR • Use durable, nonreactive aggregates.	• Do not: – Overwork surface – Spray water on surface during finishing – Finish while bleed water is present. – Sprinkle dry cement on surface to dry bleed water – Begin curing as soon as possible. – Keep stockpiles wet when absorptive aggregates used
2. Plastic Shrinkage Cracking	• Rapid evaporation of moisture from the concrete surface	• Use durable mixtures with low w/cm • Minimize cement	• Reduce aggregate absorption of mix water	• Employ proper hot-weather and cold-weather paving practices, as appropriate • Begin curing as soon as possible

Summary of Causes & Prevention of Surface Defects

		Prevention or Mitigation		
Distress	Causes	Design	Material Selection	Construction
3. Scaling	• Excessive use of deicing salts and freeze-thaw cycles • Use of poor finishing and curing practices • Failure to protect surface of newly placed fresh concrete from rain	• Ensure proper air-void system parameters (adequate air content and spacing factor) in concrete • Use appropriate amounts of SCMs		• Ensure effective curing • Do not: – Overwork surface – Spray water on surface during finishing – Finish while bleed water is present – Sprinkle dry cement on surface to dry bleed water – Protect slab from rain
4. Surface Polishing or Surface Wear	• Use of soft aggregates with poor abrasion resistance • Use of poor surface finishing and curing practices.	• Use concrete mixtures with adequate strength	• Use hard wear-resistant aggregate	• Use proper finishing practices. • Employ effective curing practices

Summary of Causes & Prevention of Surface Defects

		Prevention or Mitigation		
Distress	Causes	Design	Material Selection	Construction
5. Popouts or Mortar Flaking	• Use of unsound or reactive aggregates • Aggregate expansion upon freezing (popout) • Excessive Vibration of concrete	• Use durable mixtures with low w/cm	• Use only sound, nonreactive aggregates that have been tested for undesirable fine particles	• Begin curing as soon as possible. • Use evaporation retarders to minimize moisture loss • Use effective stockpile management practices to minimize contaminants (see ACPA 2004)

Treatment & Repairs

- Penetrating Sealers
  - for surface defects caused by deicing salts
- High Molecular Weight Methacrylate (HMWM)
  - achieves excellent penetration into cracks and can serve to strengthen the concrete by filling the crack and bonding it together
- Void Filling
  - cementitious, epoxy, and proprietary materials have all been used successfully to fill and repair clay ball voids
- Slab Replacement
- Overlay

Material Related Cracks

- Durability cracking, commonly referred to as D-cracking, is a distress associated with the freezing and thawing of critically saturated, susceptible coarse aggregate particles in the concrete

- Alkali-aggregate reaction (AAR) describes a family of chemical reactions between certain susceptible aggregates and the alkali hydroxides in the concrete, which can lead to cracking of the concrete matrix and cracking.

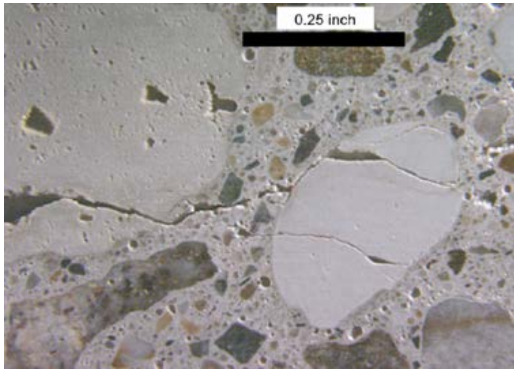
D-Cracking

- Causes:

  Three factors are needed for D-cracking to develop:

  - 1) Concrete contains aggregates susceptible to D-cracking in sufficient quantity and size
  - 2) Concrete is exposed to sufficient moisture, and
  - 3) Concrete is exposed to repeated cycles of freezing and thawing

- Prevention
  - Effective way of preventing D-cracking is to avoid the use of susceptible aggregates



Fractured Aggregate In D-Cracked Pavement


Staining Accompanying D-Cracking at Joints

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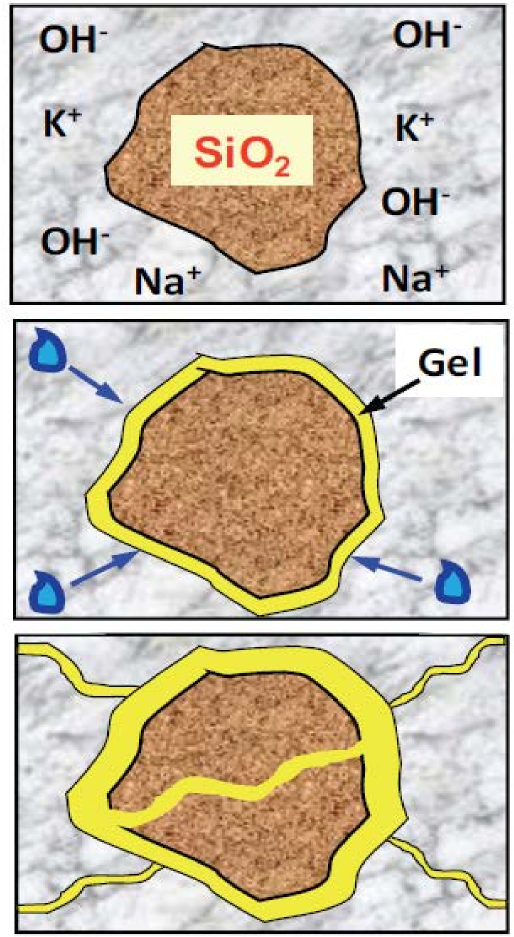
Alkali-Silica Reactivity (ASR)

- ASR is a deleterious reaction between alkalis in the pore solution and reactive silica in aggregate
- Common susceptible aggregates include chert, quartzite, gneiss, and shale, among others



Sequence of ASR Development

Reaction between the alkali hydroxides (Na, K & OH) from the cement and unstable silica, SiO_2, in some types of aggregate.

The reaction produces an alkali-silica gel.

The gel absorbs water from the surrounding paste …

… and expands.

The internal expansion eventually leads to cracking of the surrounding concrete.

Material Related Cracks - Prevention

ASR Prevention

- Use SCMs
- Avoid susceptible aggregates

D-Cracking Prevention

- Use durable aggregates
- Provide adequate drainage

Required Levels of SCMs to Control ASR (Thomas, Fournier, and Folliard 2013) – Distress Guide

Type of SCM	Total Cementitious Materials
Low-calcium fly ash (<8% CaO; typically Class F fly ash)	20 to 30
Moderate-calcium fly ash (8 - 20% CaO; can be Class F or Class C fly ash)	25 to 35
High-calcium fly ash (>20% CaO; typically Class C fly ash)	40 to 60
Silica Fume	8 to 15
Slag Cement	35 to 65

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Material Related Cracks - Treatment and Repairs

Repairs

- Partial-Depth Repair
- Full-Depth Repair/Slab Replacement
- Retrofitted Edge Drains
- Unbonded Concrete Overlay

Maintenance

- Joint Filling/Sealing
- Edge Drain Maintenance
- Topical Treatments

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Longitudinal and Transverse Cracking




Types

- Volumetric changes (concrete) – dry shrinkage/thermal contraction
- Volumetric changes (subgrade) – poor soils/drainage
- Settlement and poor support
- Slab length
- Sawing practices
- Traffic loading (design)
- Sympathy cracks

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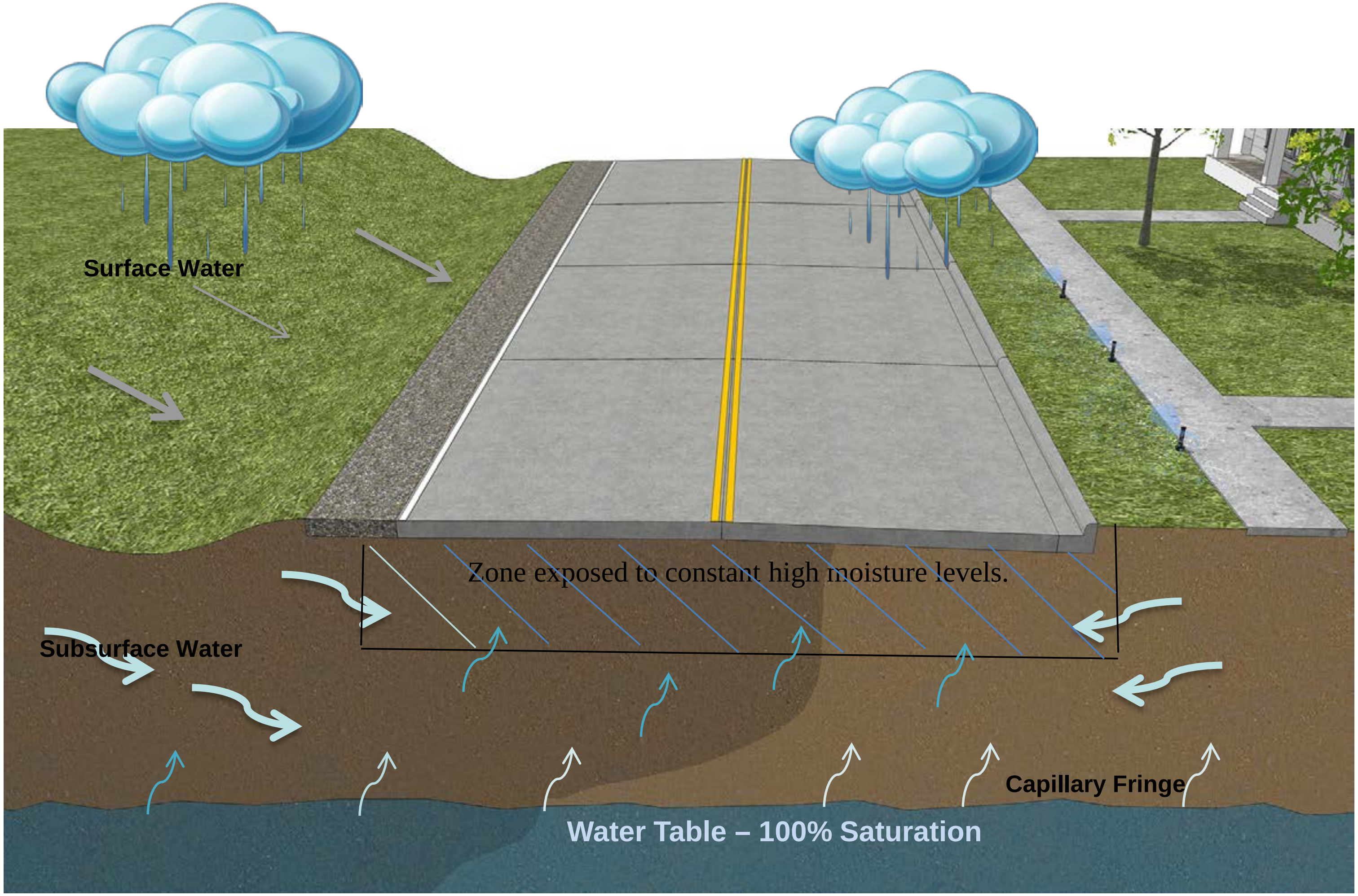
Volumetric Changes in Concrete

1. Dry Shrinkage - Increased risk for drying shrinkage cracking are:
   - High *w/cm* ratio.
   - High cement contents.
   - High-early strength cements.
   - High CTE values of the coarse aggregate.

2. Thermal Contraction Cracking
   - Temperatures can play a critical role, such that elevated ambient temperatures can induce an early set to the concrete that leads to significant contraction (and potentially cracking) later when it cools.
   - sudden change in ambient temperatures.
   - paving reaches a higher peak temperature than concrete that is placed later in the day; this is because the peak heat of hydration of the concrete (which typically occurs about 4 to 8 hours after paving) coincides with the hottest part of the summer day

Volumetric Changes in Subgrade

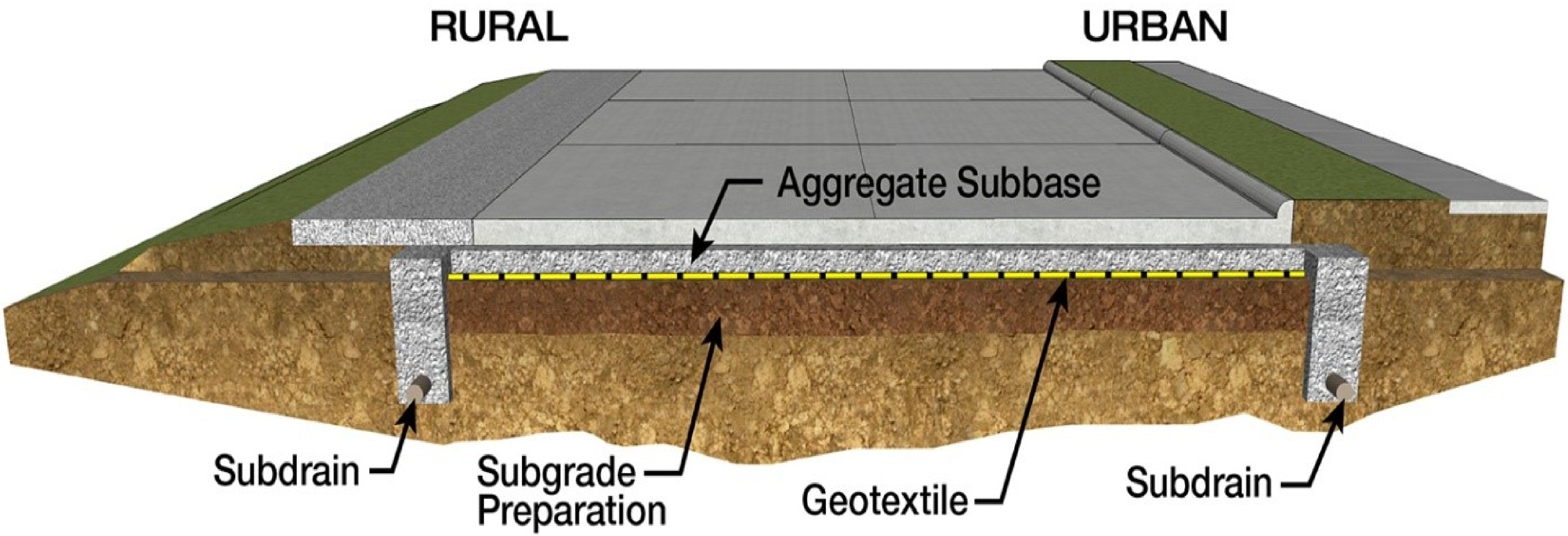


Different Soils; Uniform Support; Drainage Characteristics

Subgrade Treatment Based on Subgrade Conditions

No	Subgrade Conditions	Treatment
1	• Varying types of soil • Meets M & D tests • Passes proof roll test	• Disc and mechanically blend soils (8 in. lifts to 2 ft. depth) for subgrade • Compact to 95% standard proctor
2	• Uniformly wet soils • Does not pass proof rolling or density test	• Dry subgrade by disking • If drying weather is not available or soils are too wet, utilize quick lime, cement or fly ash
3	• Expansive or unsuitable soils	• Chemically stabilize soil with cement (changes the PL and LL to acceptable levels. • Remove unsuitable soils and replace with select material

Controlled Drainage System



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Longitudinal and Transverse Cracking – Causes and Prevention

Causes	Prevention
• Excessive slab length	Follow guidelines, saw to adequate depth
• Late sawing	Maximize sawing window, increase labor/equip forces
• Inadequate saw depth	Check blades, saw to T/3 on transverse joints
• Traffic loading	Use proper thickness, keep construction traffic away from edges

Cracking Treatment and Repairs

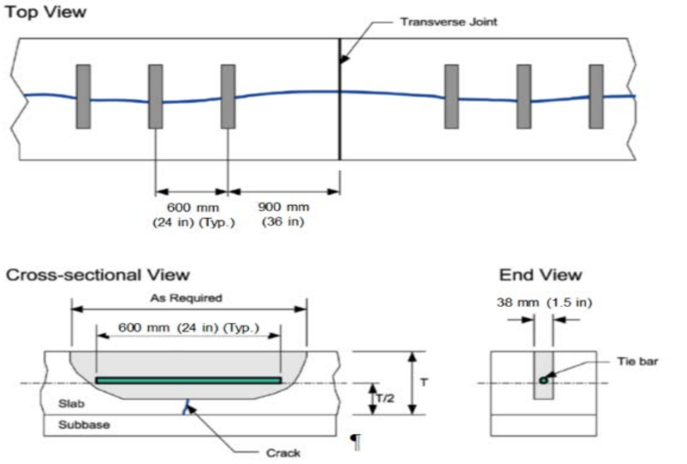
Repairs

- Full-depth repair
- Cross-stitching/Slot stitching (longitudinal cracking)
- Crack sealing/Filling (if not working crack)
- Diamond grinding

Maintenance

- Crack sealing

Slot Stitching



Appendix 9-6 Iowa DOT Construction Manual

Curling and Warping

- Concrete slabs undergo non-uniform volumetric changes due to temperature and moisture gradients.
- A gradient is the variation that occurs in temperature and/or moisture from the bottom of the concrete slab to the top.
- The slab is normally colder on the top than the bottom from late at night through mid-morning, resulting in a negative temperature gradient.

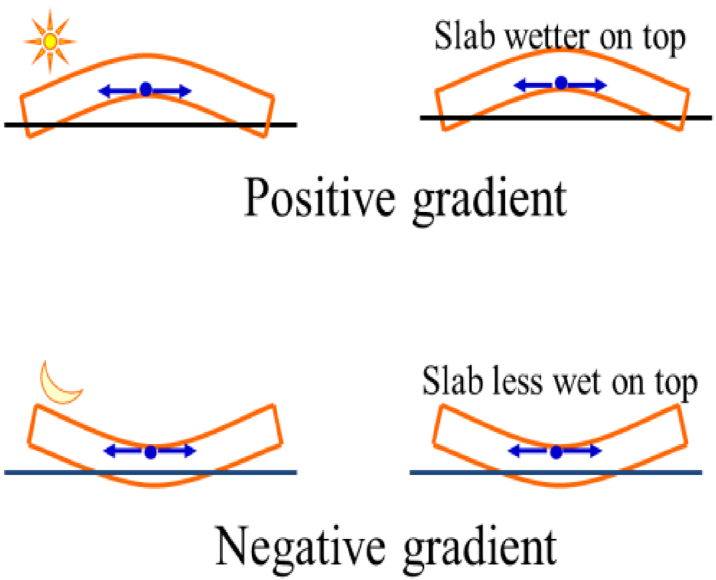


Illustration of Curvature due to Temperature Curling and Moisture Warinig

Curling and Warping

- Jointed concrete pavements can experience upward and downward curvature on a daily basis due to changing temperature gradients (curling) and over time develop upward curvature due to moisture gradients (warping).

- Long-term moisture gradients are almost always negative, with the top of the slab being drier than the bottom; this results in upward warping from the shrinkage that develops in the slab surface as it dries.

Causes – Curling

- Greatest impact on the development of temperature curling is the concrete's coefficient of thermal expansion (CTE).
- As the volume of concrete is predominately aggregate, the aggregate (particularly the coarse aggregate) has a large influence on CTE.
- Limestone aggregates produce concrete with the lowest CTE values.
- Rapid Temperature Changes

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Causes – Warping

- Capillary pores have a large influence on concrete strength and permeability. They have a large influence on the volumetric change that concrete undergoes with changes in moisture. As concrete dries, the pores begin to empty, starting with the largest pores first. In such small pores, as they transition from being full to partially-filled with water.

- In smaller gel pores, the surface tension of the water increases as does the stress pulling the pore walls inward. The result is concrete shrinks as it dries, thus the need for joints to accommodate the shrinkage.

- As dry concrete is re-wetted, the opposite occurs. Empty or partially empty capillary pores take up water, the smallest pores first, until full.

- Concrete slabs that undergo cycles of wetting and drying at the surface but remain largely saturated on the bottom will develop upward curvature that will continue to increase for years to come.

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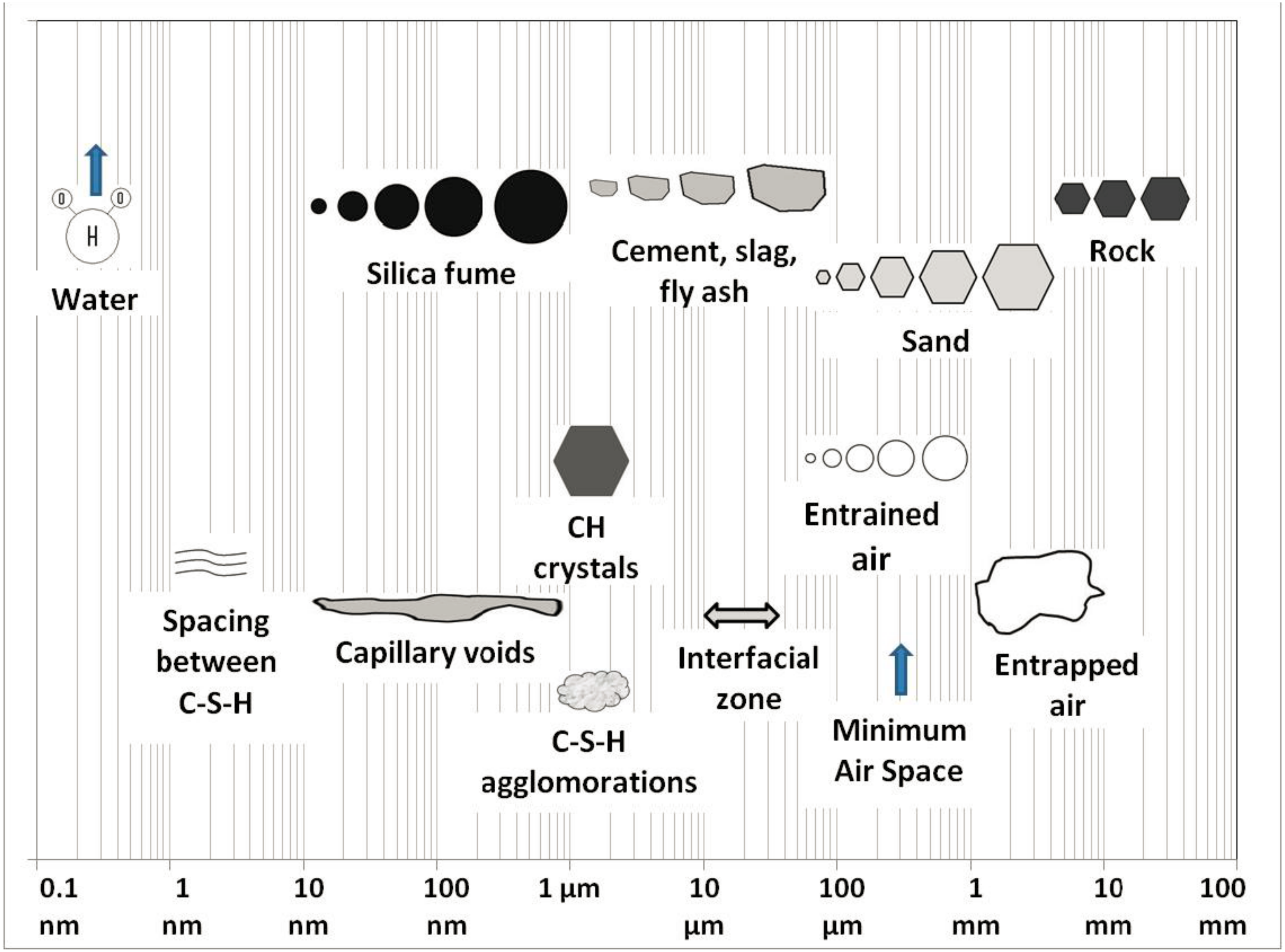
Sizes of Concrete Components



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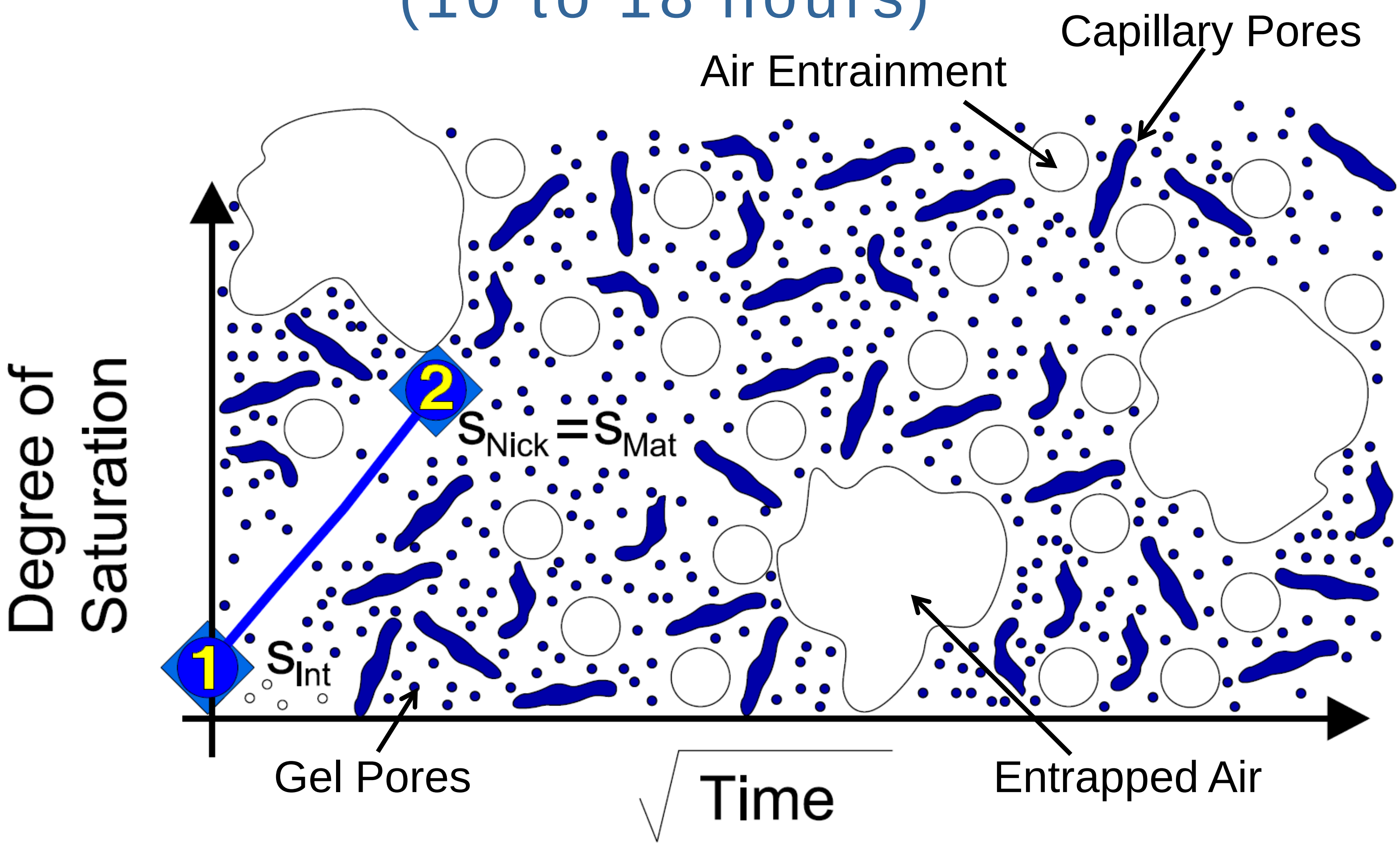
Filling of Smallest Pores
-Gel and Capillary Pores-
(10 to 18 hours)



Weiss 2014

Curling & Warping

		Prevention or Mitigation		
Distress	**Causes**	**Design**	**Material Selection**	**Construction**
Slab Curling	• Temperature gradient in slab induces slab curvature and stress • High CTE aggreg. • contribute to higher levels of curvature and stress	• Accommodate curling in design through proper joint spacing, load transfer, and base restraint	• When possible, use coarse aggregate with a low CTE	• White pigmented curing compound can help surface cool. • Risk of early-age cracking from curling can be reduced by not paving prior to a major temperature fluctuation (i.e. cold front)
Slab Warping	• Moisture gradient in slab induces slab curvature and stress • Arid climates, poor drainage, and concrete mixtures susceptible to shrinkage will contribute to higher levels of curvature and stress	• Accommodate warping in design through proper joints spacing, load transfer, and base restraint • Ensure that the pavement is free draining and does not trap water beneath	• Use concrete mixtures with lower potential for drying shrinkage (e.g. lower paste content)	• Minimize evaporation from the concrete surface at an early age; white pigmented curing compounds can help • Paving during high temperatures can be a contributing factor; employ hot-weather concreting techniques

Blowups

- Blowups often occur in the heat of the day as expansion results in a buildup of pressure that can be dramatically released as the pavement thrusts upwards and/or shatters.

Blowup in Jointed Concrete Pavement

Blowup in Jointed Concrete Pavement

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Blowups- Concrete Material Factors

- Under most circumstance, the volume of the concrete is never greater than the day it is placed. There are exceptions, however, that sometimes lead to blowups.
- Material factors that can lead to expansion beyond the original concrete volume include moisture and/or temperature effects and expansive reactions.
- As dry concrete is re-wetted empty or partially empty capillary pores take up water, the smallest pores first, until full and the menisci disappear. The pore walls rebound, but not to the same degree as where they started.

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Volumetric Expansion Due to Moisture and/or Temperature Effects

- The coefficient of thermal expansion (CTE) defines how a material changes in length with a change in temperature.
- It has been observed that thermal length change is often complicit in the occurrence of blowups, with increasing frequency as temperatures increases.
- Blowups is further increased if the heatwave is accompanied by a significant precipitation which results in saturation and further expansion of the concrete.

Blowups Treatment & Repairs

Blowups are caused by multiple factors that often combine to create excessive compressive stress in the slab

- **Treatment of Incompressible Materials**
  - Incompressible material in joints can only be treated by cleaning the joints and resealing them. Procedures for joint resealing can be found in Smith and Harrington (2014).
- **Repair**
  - The most common repair strategy is to construct a full-depth repair.

Spalling

Freeze thaw damage

Saturated joint backer rod damage

Saturated joint with unsound aggregate

Incompressible joint damage

Deflection spalling from heavy vertical loads

Early saw joint raveling

Chloride penetration

Dowel bar misalignment

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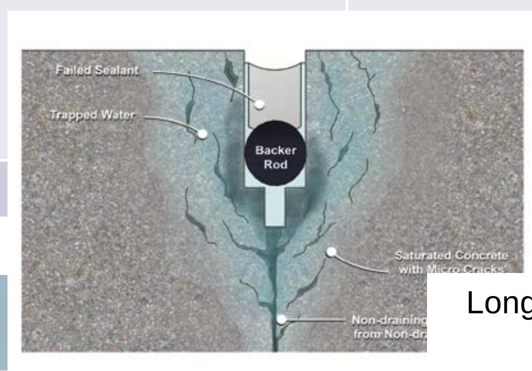
Spalling - Causes

Distress	Category	Description
Spalling (Material or Chemical)	Magnesium & Calcium Chlorides	Deicing chemicals react with Calcium Hydroxide (CH) causing flaking of hardened paste
	Freeze Thaw Damage	Damage to the paste of the concrete from: • Poor air entrainment system • Saturated concrete joints/cracks • Chemical breakdown of the concrete from deicing salts such as calcium and magnesium chloride (Calcium Oxychlorides)
	Thermal Expansion	High coefficient of thermal expansion (CTE) of the aggregate results in higher compressive stresses at the joint or crack.
Spalling (Physical)	Infiltration	Infiltration of incompressibles into poorly sealed or unsealed joints.



Longitudinal Freeze Damage From Backer Rod

Spalling – Deicers

- The formation of Calcium Silicate Hydrate (C-S-H) and Calcium Hydroxide (CH) are the two principal ingredients that mesh into a solid mass forming concrete pavement.
- Magnesium and calcium chloride will react with CH with water at between 32ºF and 122ºF, depending on the salt concentration.

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Spalling – Deicers (Calcium Oxychloride)

- This reaction results in the formation of calcium oxychloride which results in flaking (expansion) of the hardened paste causing significant damage particularly in joints.
- Oxychloride expansion can be 3 times greater than freeze-thaw expansion.
- The use of SCM's (fly ash, slag, and silica fume) will reduce formation of calcium oxychlorides by tying up CH
- Use of sealers has also shown the potential to limit interaction between salts and CH

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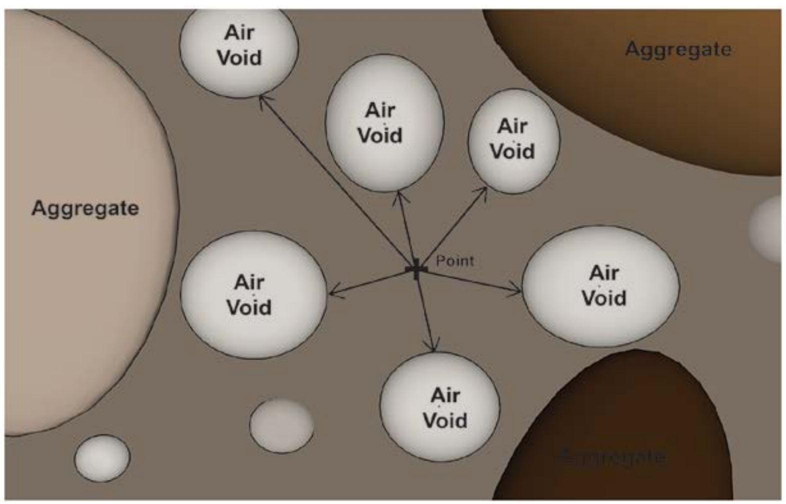
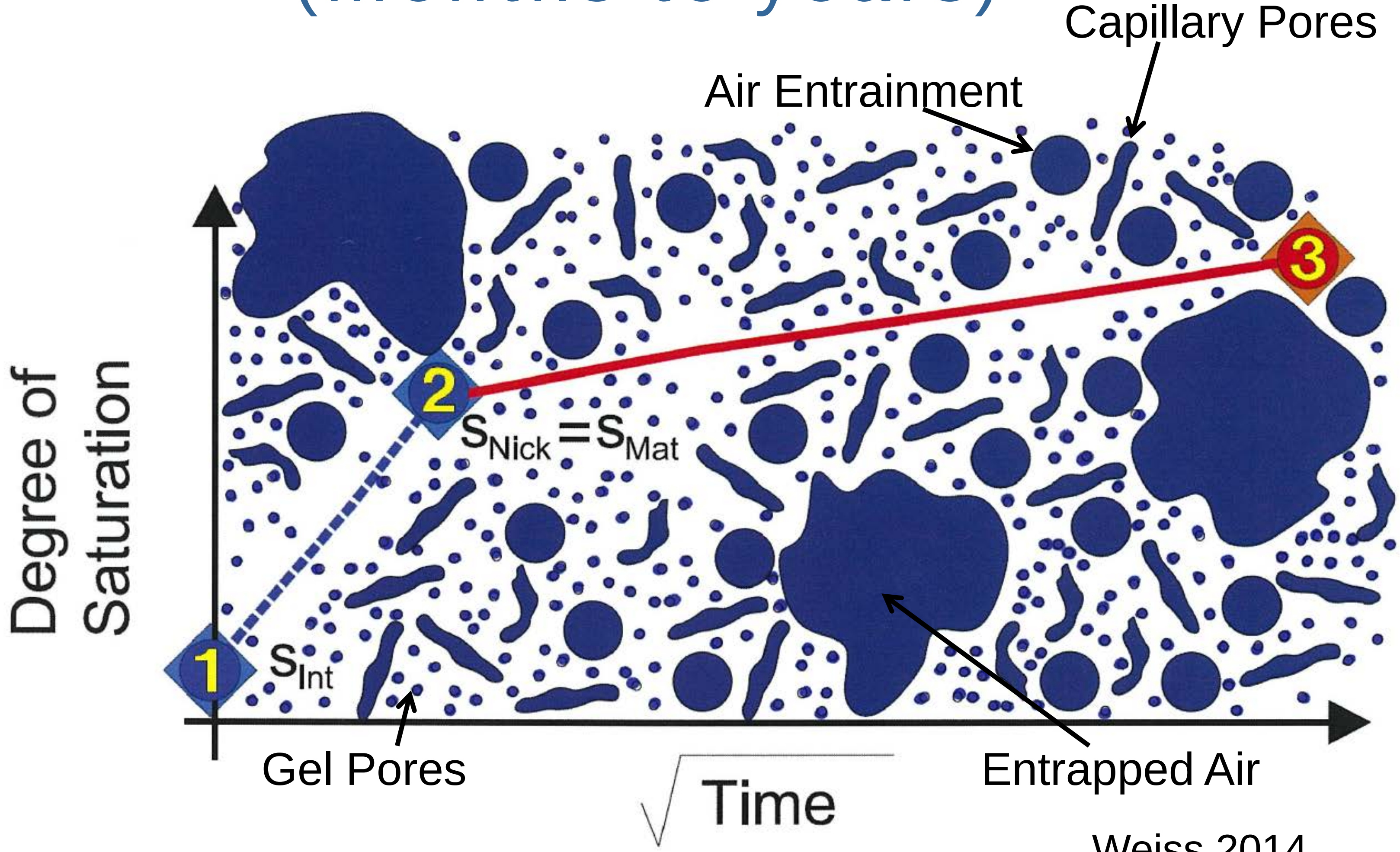
Spalling – Saturation & Poor Air

- Saturation
- Marginal aggregate soundness
- Poor air void system
  - Spacing ≤ 0.008 in.



Shadowing

Second- Filling of Larger Pores -Entrained and Entrapped Air- (months to years)



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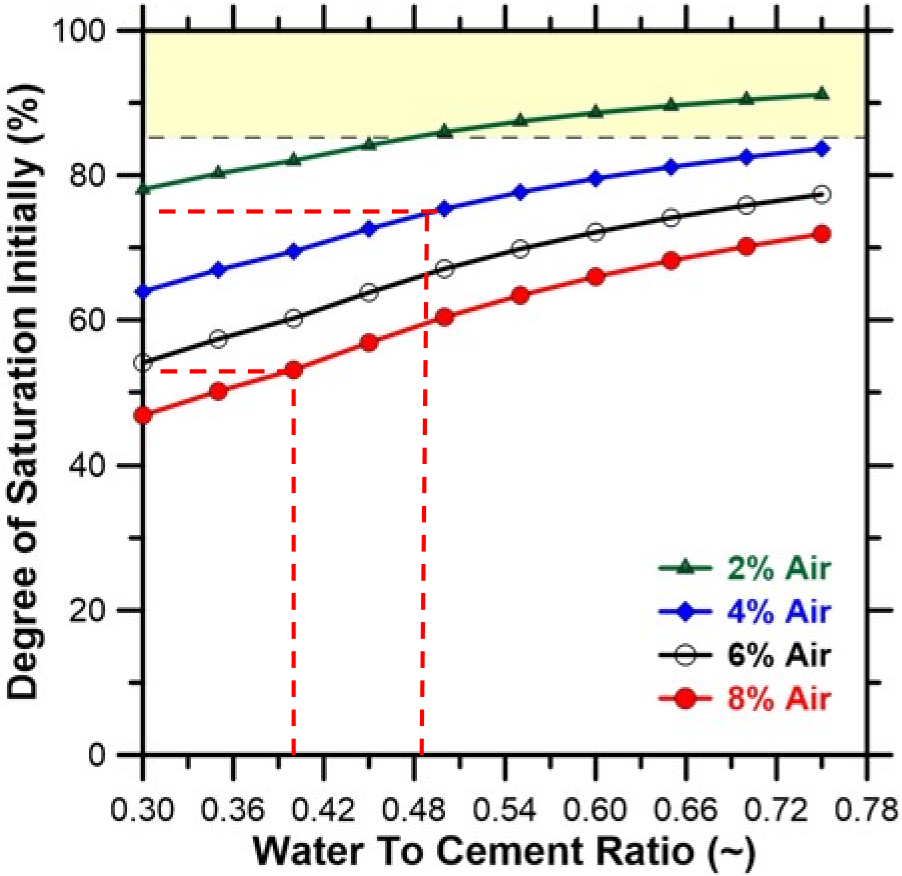
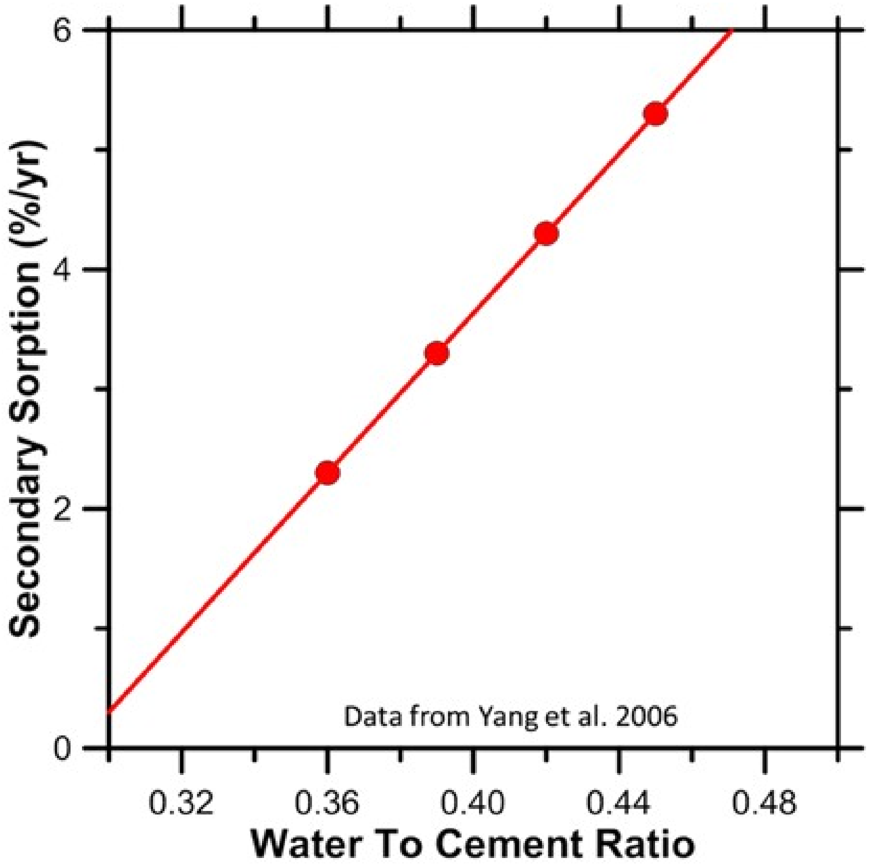
Critical Saturation Rates





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Spalling – Summary of Prevention

- Prevent saturation
- Reduce concrete permeability (Use fly ash to tie up CH)
- Ensure adequate air entrainment

Image of a Super Air Meter (SAM)
(Photo credit Tyler Ley)

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Spalling - Treatment and Repairs

Repairs

- Partial-Depth Repair
- Full-Depth Repair/Slab Replacement
- Retrofitted Edge Drains
- Unbonded Concrete Overlay

Maintenance

- Winter maintenance
- Maintaining sealed joints
- Maintaining sub-drain systems

Settlement and Heaves




Causes
- Inadequate base compaction
- Consolidation of support layers under traffic
- Subgrade soil movement
- Loss of support (contamination of base layers)
- Frost heave
- Expansive soils

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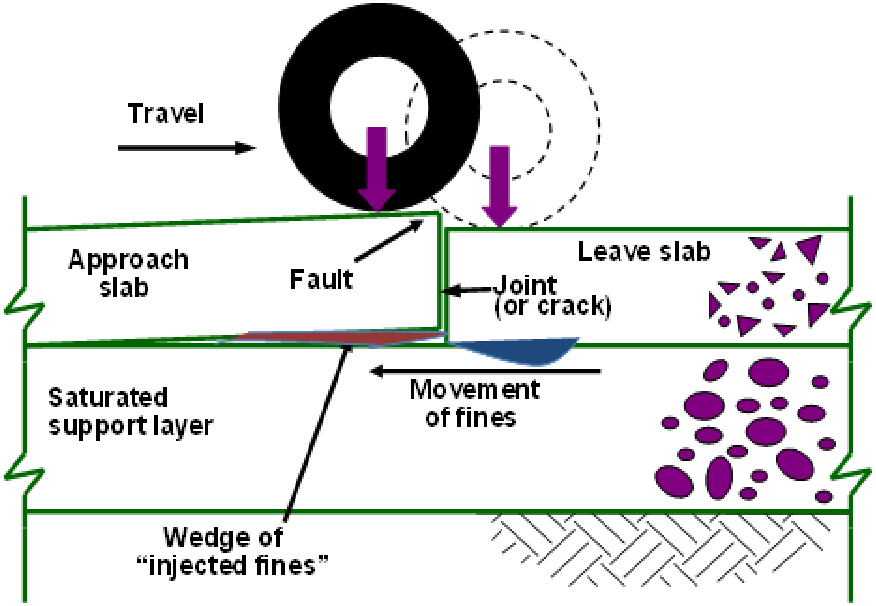
Settlement and Heaves Prevention

Causes	Design	Material Selection	Construction	Preventive Maintenance
Poor consolidation	Characterize soil based on engineering properties	Limit % fines to 10% (passing #200 sieve)	Proper compaction	Routine joint sealing Periodic maintenance of drainage system including cleanout of outlets
Volume changes in soil	Compaction specification based on optimum M & D	Uniform soil, blend, granular subbase or chemical treatment	Uniform soil, blend, granular subbase or chemical treatment	
Excessive moisture	Provide drainage Consider chemical stabilization	Use drainable subbase	Dry soils Compact at optimum M & D	

Faulting


Travel
Approach slab
Fault
Joint (or crack)
Leave slab
Saturated support layer
Movement of fines
Wedge of "injected fines"

Faulting - Causes

Distress	Item	Description
Faulting (Physical)	Load Transfer Loss	Failure of aggregate interlock or mechanical devices that transfer load across pavement joints and cracks
	Pumping	Longitudinal and transverse cracks and unsealed joints which allow water intrusion and lead to future faulting including loss of load transfer
	Loss of Seal Integrity	Portal for intrusion of water into the grade
Faulting (Material or Chemical)	Poor Aggregate Soundness	Poor quality coarse aggregate leads to early loss of load transfer due to low shear capacity Aggregate particles deteriorate resulting in loss of support

Faulting - Treatment and Repairs

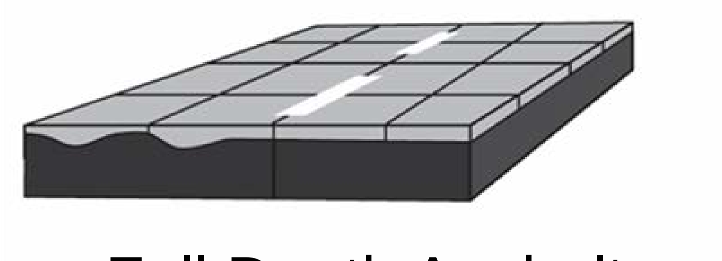
Repairs

- Dowel Bar Retrofit
- Bonded Concrete Overlay (if faulting is less than less than 3/8" faulting or Unbonded Concrete Overlay for 3/8" to 5/8")

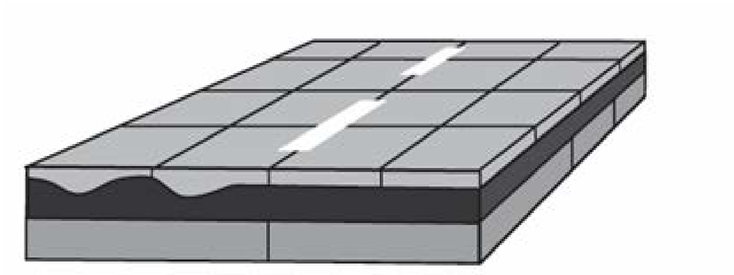
Maintenance

- Diamond Grinding

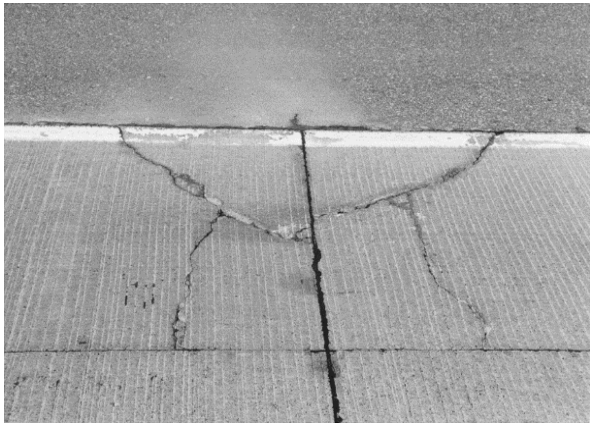
Bonded Concrete Over Asphalt
BCOA



Over Full Depth Asphalt



Over Composites



Corner Cracks

Longitudinal Cracks

Blowup Crack

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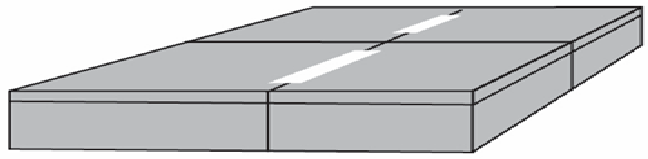
Bonded Concrete Over Concrete
BCOC



Multiple Cracks

Longitudinal Cracks

Reflective Cracks

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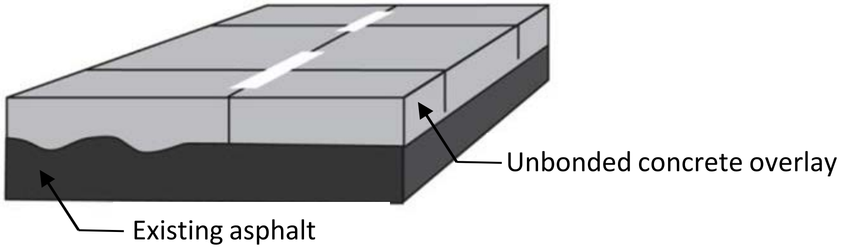
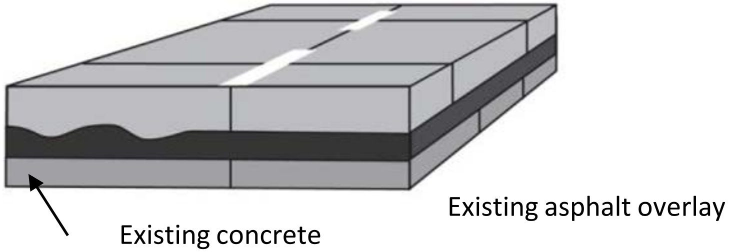
Unbonded Concrete Over Asphalt UBCOA



Over Full Depth Asphalt



Over Composites

Longitudinal Cracks

Transverse Crack

Faulting

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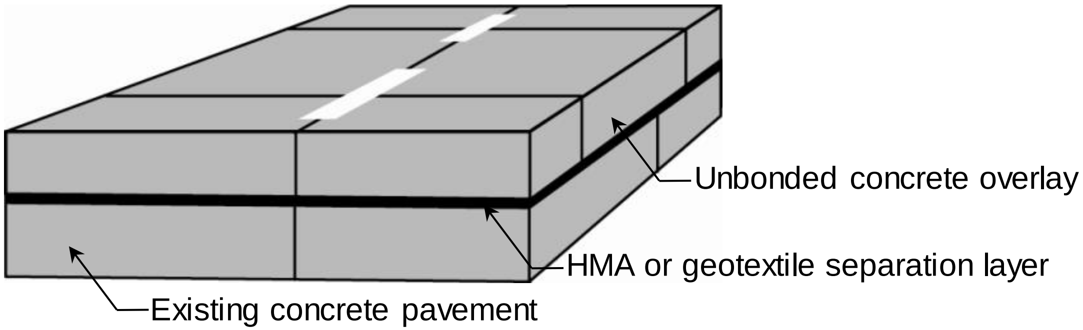
Unbonded Concrete Over Concrete UBCOC



Longitudinal Cracks

Reflective Crack

Faulting

Summary of Overlay Distresses

		Prevention or Mitigation		
Distress	Causes	Design	Material Selection	Construction
1. Longitudinal cracking in tied shoulders and widened sections	• Differential movement (heaving) of materials underlying shoulders and/or widened sections UBCOA • Tie-bar placed at the bottom of the concrete slab • Poor subbase drainage of widening or shoulder	• Tie-bar placed at neutral axis if possible • Utilize structural fibers in lieu of tie-bars • Provide for drainable subbase under shoulder	• Maximum tie-bar size of #4	• Chair or insert bars to specified tolerances • QC checks to confirm tie-bar location behind the paver • Saw all contraction joints to a depth of T/3 except for BCOC which is full depth
2. Longitudinal cracking in wheelpath	• Inadequate slab thickness • Debonding for BCOA & BCOC due to curl/warp or deteriorated existing pavement • Improper slab dimensions • Inadequate load transfer	• Adequate overlay thickness • Appropriate slab dimensions • Load transfer devices when thickness is greater than 7” • Avoid placing longitudinal joints in the wheelpath	• Structural fibers may increase load transfer in thin overlays • Existing HMA Asphalt should be	• Control the temperature and moisture of the HMA at time of paving • Adequate curing • Sawcut longitudinal joints to T/3 • Limit construction traffic on remaining HMA to prevent damage • Provide clean existing pavement

Summary of Overlay Distress

		Prevention or Mitigation		
Distress	Causes	Design		Construction
3. Transverse cracking	• Reflective cracking of underlying thermal cracks	• Set profile grade to assure adequate thickness of existing HMA asphalt remains after milling		• Securely anchor baskets • Adjust anchoring for non-uniform conditions • Do not cut shipping wires on the baskets • Sawcut transverse joints to T/3 except for BCOC which are full depth
4. Blowups	• Undeployed joints non-uniform subbase friction • Incompressibles in the joints • Expansion due to heavy rain, excessive heat or both	• Appropriate slab dimensions for the design thickness • Specify sealing joints to prevent incompressibles from filing the joints • A full-depth transvers sawcut for BCOC • Ensure that the underlying pavement is ell drained		• Saw cut joints to T/3 except for BCOC which are full depth • Seal all joints

THANK YOU!

National Concrete Pavement Technology Center