Failures: What Can We Learn?

What are Failures?

- A failure is defined as a foundation, structure, component, or facility that doesn’t perform as intended.
- A failure does not have to involve a collapse or catastrophic event.

Some Examples

- Foundation that exhibits excessive differential movement
- Parking lot that ponds water
- Roof that has excessive deflection
- Masonry wall that cracks because of lack of expansion joints
- Basement wall that leaks

Most failures aren't on the evening news

- But they are important to the building owner who has to deal a cracked foundation and walls
- And to the contractor who has to repair his work
- And the engineer who gets sued for faulty design
- And to the attorneys who make a lot of money

Symptom	Cause
Map cracking – occurring anytime from weeks to years	Excessive drying shrinkage


Compare with map-cracking due to ASR where extrusion of joint sealant provides evidence of expansion

Symptom	Cause
Severe spalling of concrete surface	Fire damage (petroleum tanker crashed into bridge pier and ignited)

How do we learn from failures?

- Personal level: can you think of a failure that has taught you a lesson?

- Profession level: Many of the changes in the building codes have come from failures
  - Earthquakes
  - Hurricanes
  - Tornadoes
  - Floods
  - Fires

Case Study: Concrete Runway

- Private runway in the Panhandle to accommodate big jets—100 ft. wide, 6000 ft. long, 11 ½ in. thick.
- Consisted of four 25-ft. lanes. with sawed transverse joints at 15-ft. spacing; dowel bars used at saw cut control joints
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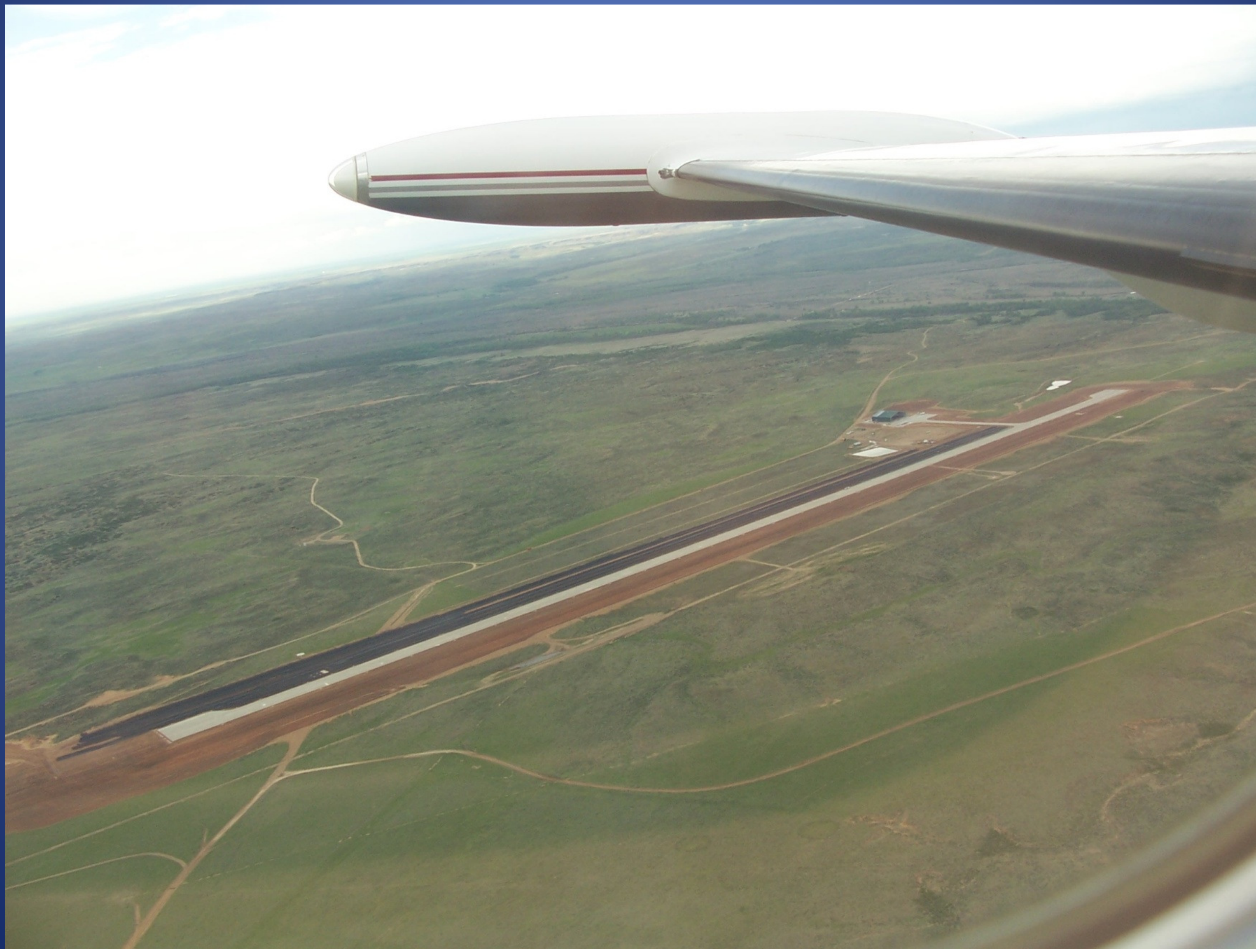
Aerial View of Runway



Pavement showing panels

Nothing like a West Texas sky!

Issues

- Initially, slightly lower strengths than the specified 4200 psi compressive strength was an issue.
- However, it was shown that the use of fly ash and low temperatures during the winter placement had been the cause. The continued strength gain gave the required strength eventually.

Other Issues—from owner's expert's report

- Inadequate air void system
- Surface voids due to clay balls (~1/2 in. diam.), apparently due to "dirty" aggregate
- Lack of testing of aggregates for clay—only two tests were performed by the contractor
- Lack of washing of coarse aggregate—specification required it but contractor didn't wash it.

Clay balls in the surface

Reddish clay made them easily visible

Many were quite small

Clay could easily be chipped out

Siliceous aggregate that contained trace amounts of clay, chert, caliche

Broken cylinder

Are clay balls considered defects?

- ASTM D 5340 defines pop outs as ranging from “approximately 1 to 4 inches in diameter and ½ to 2 inches deep.”
- It goes on to say: “No degrees of severity are defined for pop outs. However, pop outs must be extensive before they are counted as a distress; that is, average pop out density must exceed approximately three pop outs per square yard.”
- These clay balls did not constitute a defect.

- American Concrete Pavement Association in an R&T Update (2004): :   "If the voids are less than 2 inches in diameter, they do not require repair even if they are numerous. The recommendation is similar to the recommendation for pavement with a chert or shale pop out condition." The Update states that clay balls "create a surface defect that is typically not a structural problem, but can detract from the surface appearance. … They 'float' to the surface during vibration because they weigh less than the aggregates and other particles in the surrounding fresh concrete."
- No defect according to ACPA

Void, likely due to paving operation

Owner's expert's conclusion

- The owner's expert performed a comprehensive visual examination, petrographic examination, and other tests and issued a report that was critical of the paving subcontractor because of:
  - Lack of an adequate air entrainment
  - Lack of testing for clay in aggregate
  - Failure to wash aggregate

Lawsuit was filed

- The result was that the general contractor on behalf of the owner sued the paving subcontractor.
- I served as an expert for the paving subcontractor

But wait—there is more!!

- After all the depositions were completed, a different picture came out.
- The owner settled with the paving subcontractor and assigned to him the rights to sue the design engineer.
- The paving subcontractor then filed suit against the original design engineer who had provided plans and specifications.

Four issues against the engineer

- Lack of communication on the part of the engineer with the owner.
  - Owner: “I envisioned a runway ….that would have the quality of a tennis court.”
  - Clearly his expectations were not met by the specifications which made no mention of aesthetics.
  - ASTM C 33 which was cited in spec: “This specification is regarded as adequate to ensure satisfactory materials for most concrete……where aesthetics are important, more restrictive limits may be considered regarding impurities that would stain the concrete.”

- Lack of oversight on part of engineer in preparing the specifications.
  - Inclusion of aggregate class designation in ASTM C 33 of 1N for “negligible weathering regions” when it should have been 4M for “moderate weathering” (error was due to fact that a previously used spec served as the basis for spec).
  - Entrained air was specified to be 4% +/- 1% which was too low for Panhandle.
  - Frequency of testing was not specified.
  - Aesthetics were not included in spec

-Engineer specified a joint sealant that was not resistant to jet fuel.

-Specification made reference to curbs and there were none in this job.

The objective of this complaint was to show that the engineer did not adequately review the specification—allowed a subordinate to prepare it.

As a result of failing to admit his error in the specs when their expert report was released, he allowed blame to be placed on the paving contractor and resulted in the contractor having to expend considerable funds in defending himself

- Engineer was negligent in allowing blame to be placed on paving contractor for not testing the aggregate.
  – subcontractor had contractual responsibility for performing ASTM C 142 for measuring clay and friable particles in aggregate.
  – Deposition testimony was that after work began, engineer verbally relieved contractor of testing requirements but didn’t have the test performed.
  – But expert’s report left the impression that contractor didn’t meet requirements.

- Engineer allowed contractor to be blamed for not washing aggregate.
  - Before paving commenced, there was discussion about whether aggregate should be washed.
  - Paving contractor offered to take it to another location to wash it, but general contractor didn't want to delay paving.
  - Engineer conceded that he allowed paving to proceed without washing.

Result

- The paving contractor had a very strong case.
- When the engineer was called by the plaintiff, he made a very poor witness.
- After my testimony in which I emphasized the four major points listed in previous slides, the defense settled. They had previously offered about $1 million which the paving contractor would not accept, but they added a substantial amount and the case settled.

Lessons Learned

- From the paving subcontractor's view:
  - Get all changes in writing—no need to wash aggregate and no need to test aggregate
- From the engineer's view:
  - Don't rely on an old spec without going over it with a fine-toothed comb.
  - Don't allow the blame to be placed on the contractor when clearly you were the culprit. That is a breach of engineering ethics.

- Find out what your client expects for appearance. He was building a show place on his ranch and was going to bring in high rollers and wanted the runway to look the part.

- For all parties:
  - Wait until all the evidence is in before assigning blame.

One last point…

- The owner hasn't given all his money to Oklahoma State University.

Series of lakes built along creek

Owner's artificial lakes and house

Forensic Manual for Portland Cement Concrete Pavements

Prepared for TxDOT by
David Fowler and Zhanmin Zhang

Introduction

- PCC pavements exhibit many forms of distress.
- Many factors that affect pavement performance including:
  - Environment (moisture and temperature)
  - Sub-base and base including drainage
  - Loading and number of applications
  - Concrete materials, strength, curing
  - Thickness
  - Construction and reinforcement

Possible Failures in PCC Pavements

- Bump
- Corner break
- Crack spalling
- D-cracking
- Faulting
- Joint failure
- Joint sealant extrusion
- Joint separation
- Joint spalling
- Longitudinal cracking
- Loss of skid resistance
- Loss of surface material
- Pumping
- Punchout
- Reactive material distress
- Settlement
- Shrinkage cracks
- Slab shattering
- Transverse crack

Bump

Description:

- An upward vertical movement of the pavement from its original constructed longitudinal profile.
- Usually occurs locally and is a result of climatic factors (freezing water in the subgrade may result in upward movements of the pavement surface).
- Cracking on the surface of the slab may result from bumps.

Field Investigations:

1. A soil boring of the underlying layers can be obtained.

Bump

Measures for Prevention:

1. Providing adequate drainage will reduce moisture content changes of the base materials.
2. Use a stabilized base to control volume changes due to moisture.

Strategies for Repair:

1. Hot-mix patch (to level surface)
2. Cold-mix patch (to level surface)
3. Cold planning
4. Excavation, backfill, and hot-mix patch

Corner Break

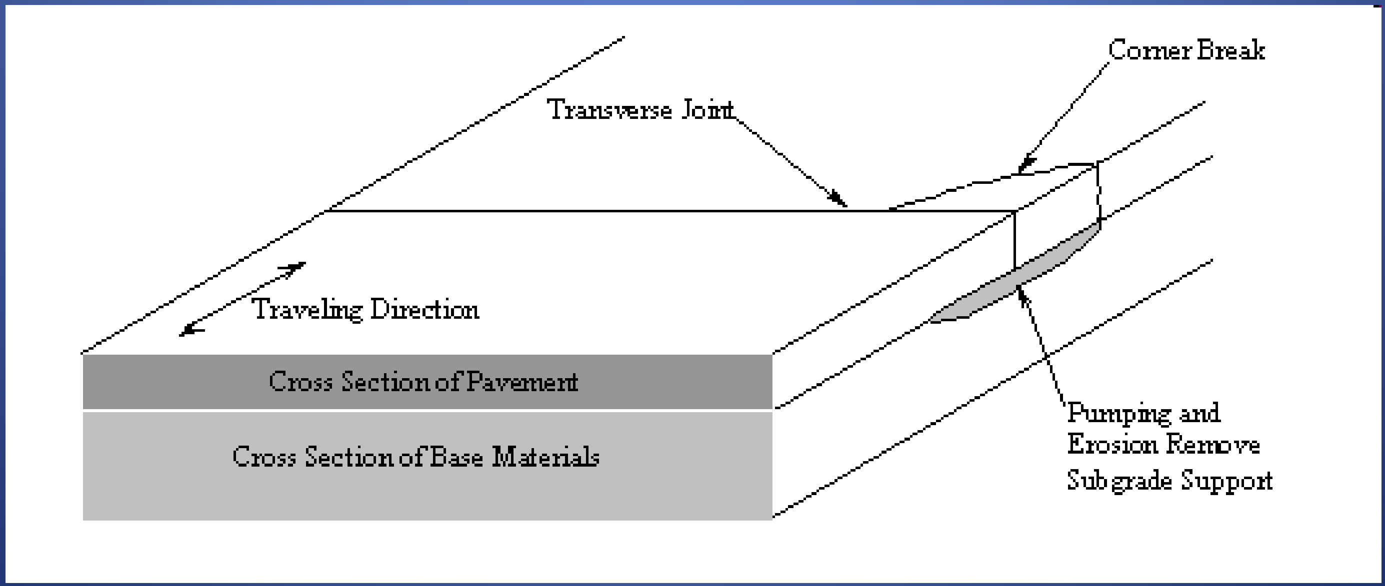
Description:

- A crack that extends from a transverse joint or crack to a longitudinal joint or the pavement edge.
- Each end of the crack should be less than six feet from the corner of the slab.
- If one end of the crack is further than six feet from corner of the slab, the crack should be categorized as a diagonal crack and not a corner break.
- A corner break extends through the thickness of the slab.

Corner Break

Possible Mechanisms:

- A corner break is a result of repeated loading combined with lack of subgrade (can be a result of erosion).
- Poor load transfer across the joint, thermal curling stresses, and moisture warping stresses may also contribute to the formation of a corner break.



Corner Break

Field Investigations:

1. Deflection testing to determine the structural capacity of the base materials.
2. A soil boring of the underlying layers can be obtained.
3. Observe the base materials for evidence of erosion and weathering.

Measures for Prevention:

1. Provide adequate drainage.
2. Frequent inspection and early repair of transverse cracking or joint sealant deterioration may prevent water from reaching the base materials.
3. Use a base materials less susceptible to weathering or erosion.

Strategies for Repair:

1. Slab stabilization
2. Full-depth repair

Cracking Spalling

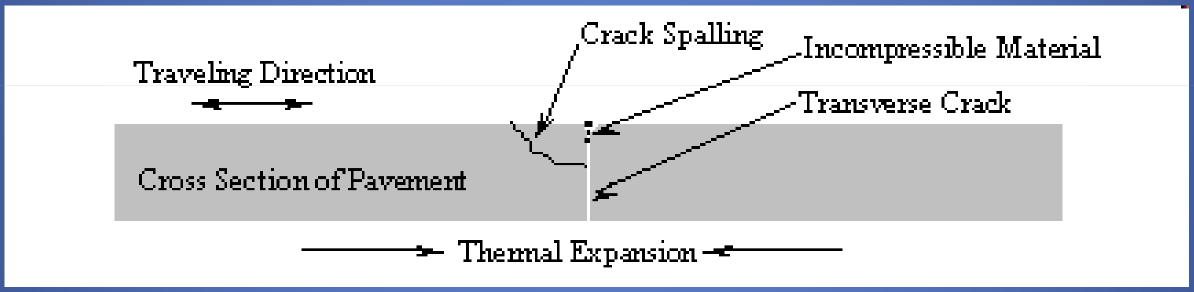
Description:

- Crack spalling is the chipping of the concrete slab at the edges of longitudinal or transverse cracks.
- Crack spalling is due to excessive local pressure at the joint. This pressure may be due to a combination of traffic action, thermal expansion, and/or steel corrosion.
- The spall might progress into pothole.

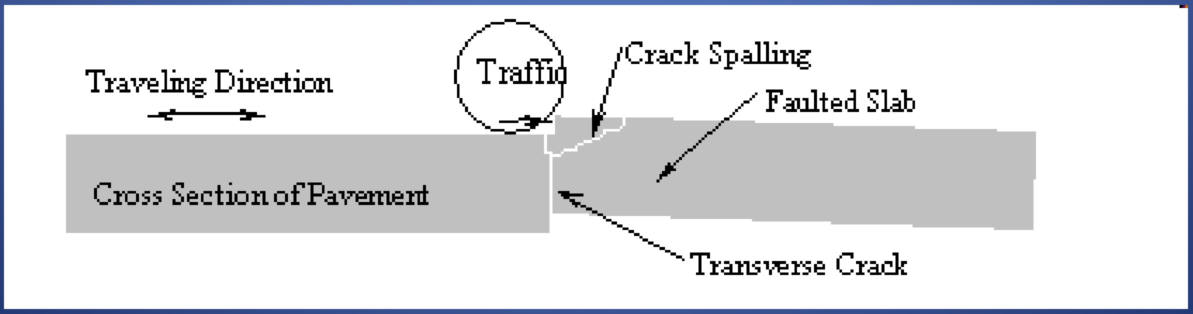
Cracking Spalling

Possible Mechanisms:

- Water entering the slab may corrode the reinforcing steel, resulting in expansive internal pressures and eventually crack spalling.
- The crack may be wide enough to allow incompressible material to enter the crack. The restraint results in at the crack causing spalling.



- If the slab is faulted at the crack, the spalling may be a result of traffic striking the raised edge of the slab.



Cracking Spalling

Field Investigations:

1. A pavement core can be taken through the crack and near the joint to see if the reinforcement is corroded.

Measures for Prevention:

1. Frequent observation of pavement sections can provide early identification of debris in the cracks.
2. Seal the crack as soon as possible after the crack is noticed.
3. Use air-entrained concrete.

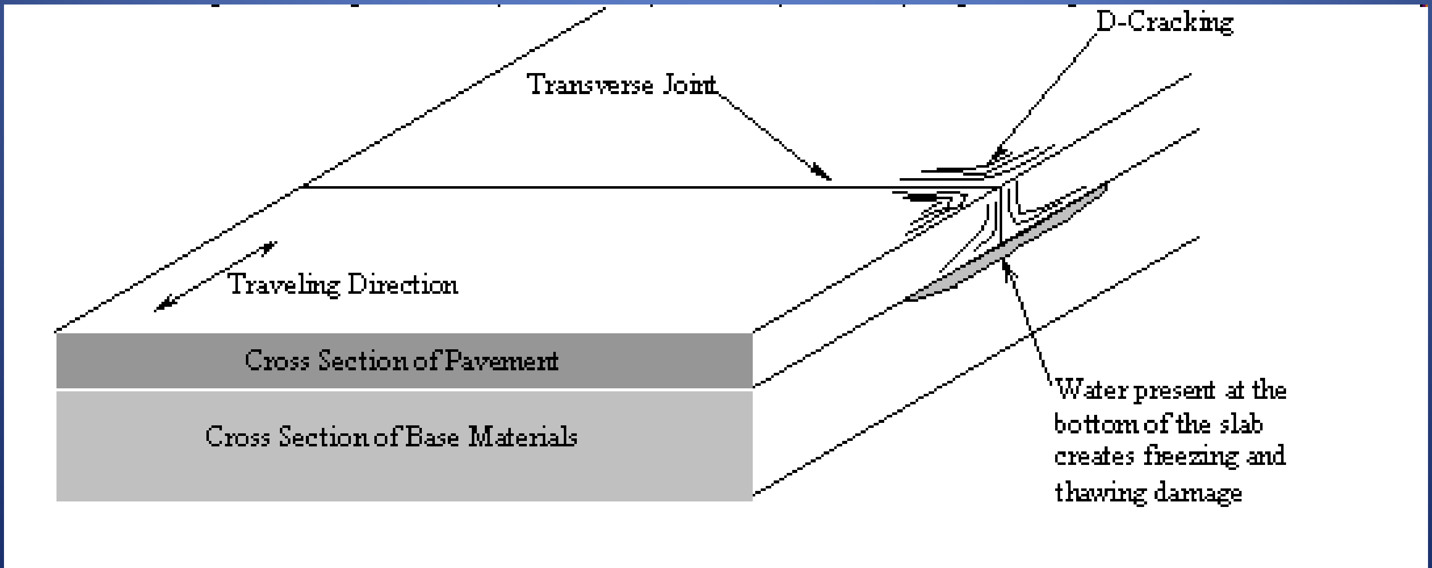
Strategies for Repair:

1. Clean and seal cracks
2. Clean crack and hot-mix patch
3. Saw and reseal
4. Partial-depth repair
5. Full-depth repair

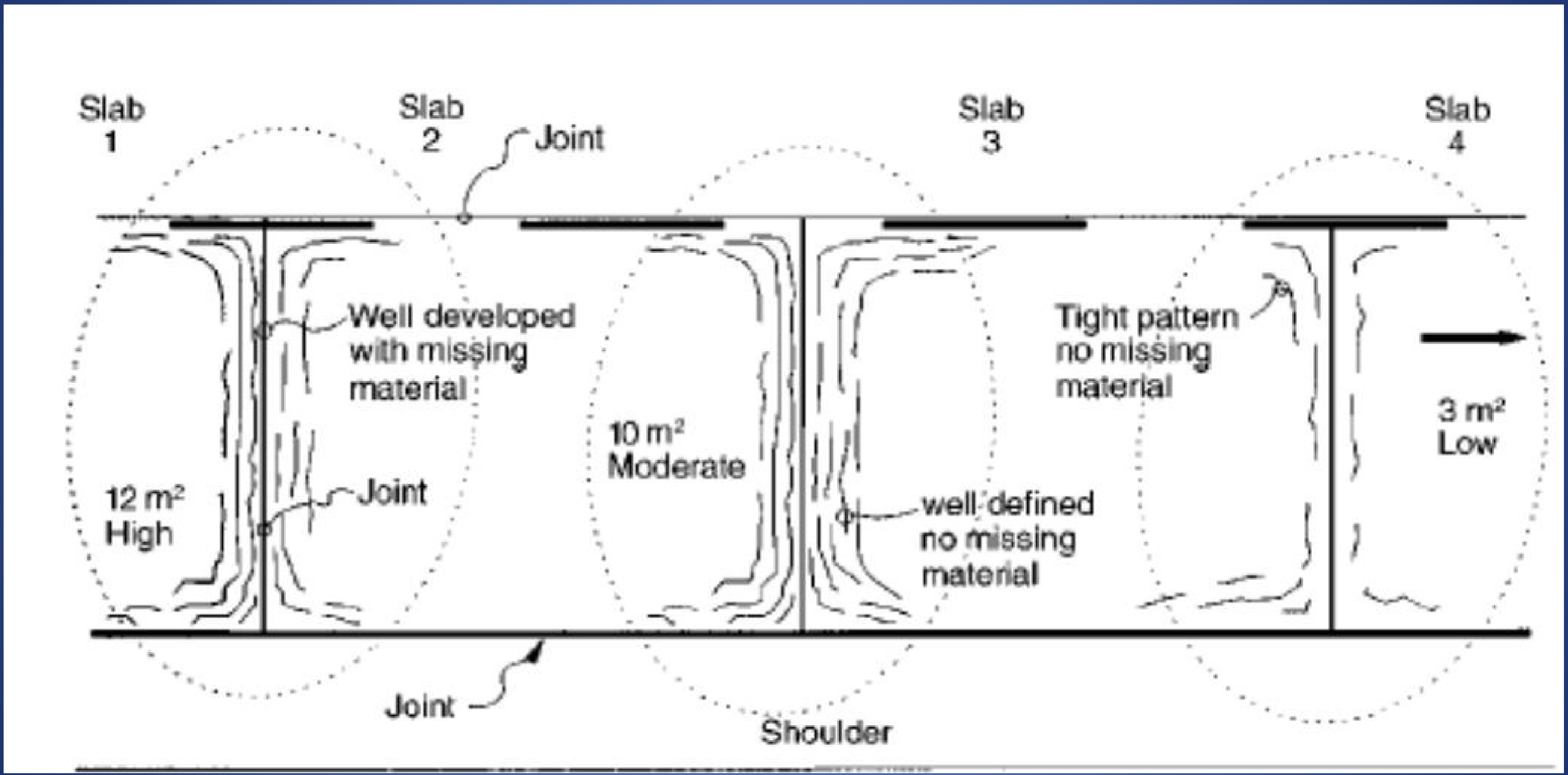
D-Cracking

Description:

- D-cracking is a series of closely spaced cracks that curve around a slab corner. The cracking will parallel the transverse joint and curve around to parallel the longitudinal joint.
- As water reaches the base materials, the bottom of the slab tends to be saturated. Freezing and thawing cycles will deteriorate the saturated aggregate near the bottom of the slab. The deterioration starts at the bottom of the slab and eventually progresses to the surface of the pavement.



D-Cracking Patterns



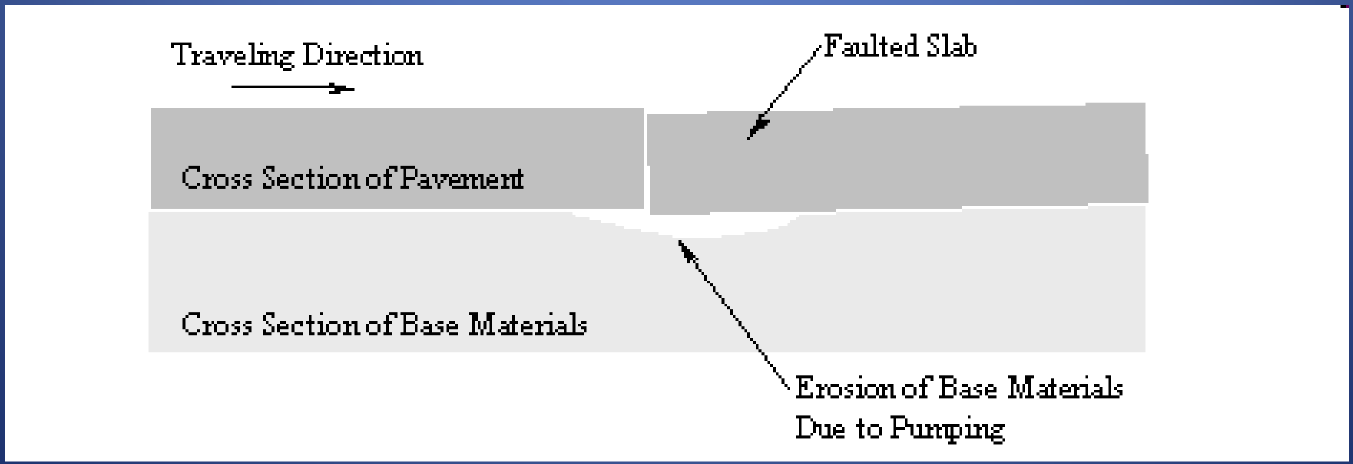
D-Cracking

D-Cracking

Faulting

Description:

- Faulting is the differential vertical displacement of the slab edge across a transverse joint or crack. The difference in elevation results in a step deformation.
- Faulting may be the final result of pumping.
- The pavement may settle due to lack of subgrade support. Erosion of the base materials may leave large voids beneath the rigid pavement and the pavement may settle into these voids.
- Inadequate load transfer across the joint will often accelerate faulting.



Faulting

Faulting

Field Investigations:

1. Deflection testing (Dynaflect, FWD, etc.) can be used to determine if the load transfer across the joint is adequate.
2. GPR may be used to find voids beneath joints and cracks.
3. A pachometer can be used to locate load transfer devices across the joint.
4. A concrete core can be taken through the load transfer device to determine if they have seized.
5. A soil boring of the underlying layers can be obtained.
6. Observe the base materials below the fault for evidence of erosion and weathering.

Faulting

Measures for Prevention:

1. Providing adequate drainage will reduce the amount of moisture coming in contact with the base materials.
2. Frequent inspection of the joint for joint sealant extrusion may prevent water infiltration into the joint.
3. Repairing the joint or crack once pumping is observed may prevent faulting.
4. Provide consistent and proper compaction of the subgrade during construction.
5. Provide load transfer devices for all joints. Also, make sure the dowels are properly installed to that load transfer is adequate.

Strategies for Repair:

1. Milling or grinding
2. Saw and reseal joint or crack
3. Hot-mix patch
4. Full-depth repair

Joint Failure

Description:

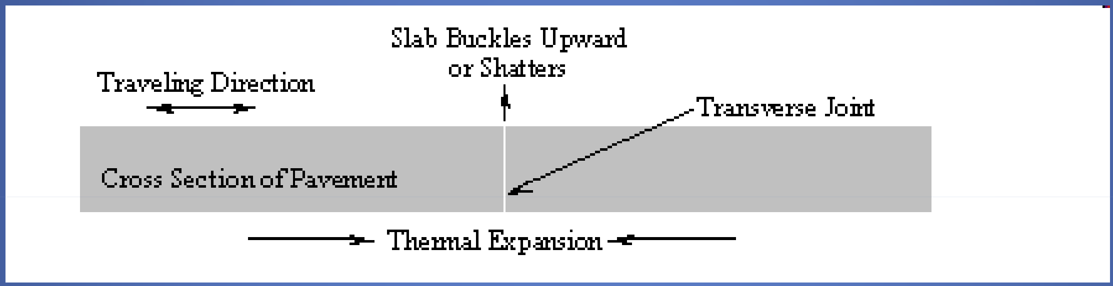
- Joint failure can be separated into buckling (or blowup) and shattering. Joint buckling is the upward displacement of the slab edge at the transverse joint. Joint shattering is the crushing of the concrete near a slab edge at the transverse joint.

Localized Joint Failure

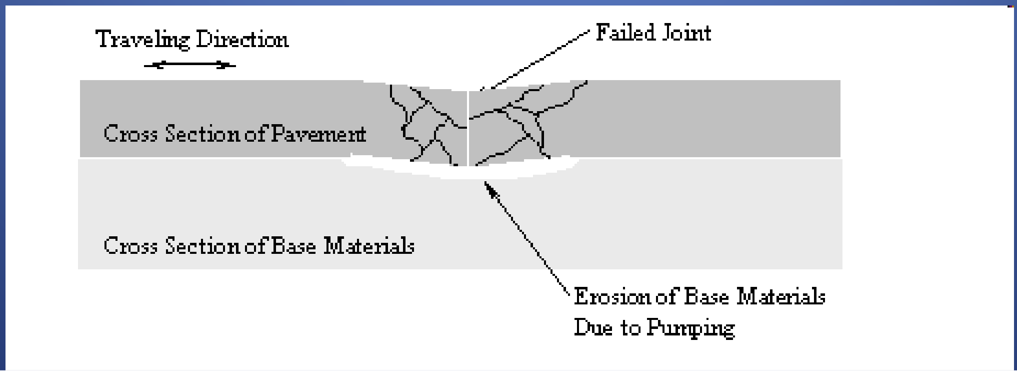
Joint Failure

Possible Mechanisms:

- Insufficient joint width or incompressible material in the joint can restrain the slab during expansion. Seized dowel bars can result in excessive compressive stresses at the joint during thermal expansion.



- Creeping slabs can cause compressive stresses at the joint high enough to result in joint failure.
- Lack of subgrade support due to pumping may cause high deflections at the slab edges.



Joint Failure

Field Investigations:

1. Deflection testing (Dynaflect, FWD, etc.) can be used to determine if the load transfer across the joint is adequate.
2. GPR may be used to find voids beneath joints and cracks.
3. A pachometer can be used to locate load transfer devices across the joint.
4. A concrete core can be taken through the load transfer device to determine if they have seized.
5. A soil boring of the underlying layers can be obtained.
6. Observe the base materials below the joint for evidence of erosion and weathering.

Joint Failure

Measures for Prevention:

1. Frequent observation of joints can provide early identification of:
   – Joint sealant loss or deterioration
   – Debris in the joint
   – Joint spalling
   – Creeping slabs
   – Pumping
2. Provide better quality control for dowel placement during construction
3. Clean joints before performing an asphalt overlay

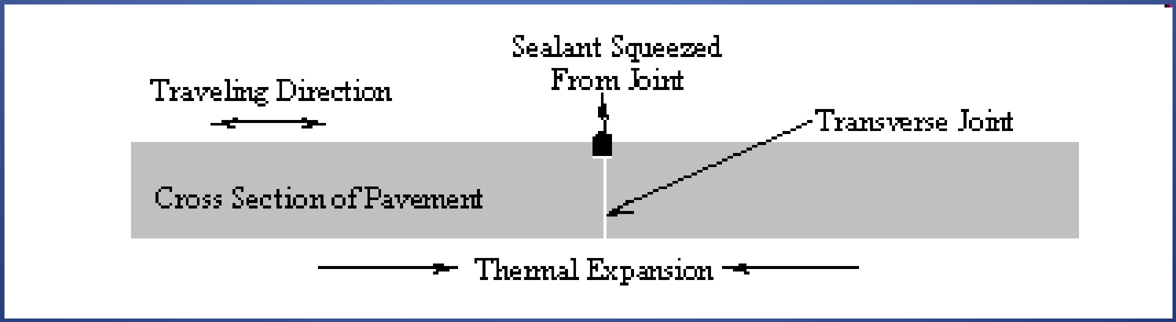
Strategies for Repair:

1. Joint excavation and hot-mix patch
2. Full-depth repair

Joint Sealant Extrusion

Description & Possible Mechanism:

- Joint sealant extrusion occurs when the joint sealant is squeezed from the joint. Extrusion may occur on longitudinal joints, but it is most common on transverse joints.
- A poor quality sealant may experience deterioration such as adhesive failure, cohesive failure, or abnormal aging. Joint sealant deterioration may result in extrusion.
- Improper joint construction such as inadequate shape of the sealing groove, too much sealant in the joint, failure to clean joint before sealing, or inadequate joint spacing may result in joint sealant extrusion.
- Once the joint sealant extrusion has initiated, traffic action may continue to pull the sealant from the joint.



Joint Sealant Extrusion

Joint Sealant Extrusion

Field Investigations:

1. A knife blade may be pushed down along the joint face and then twisted. Effortless penetration indicates lack of adhesion between the joint sealant and the face of the joint.
2. Compare the actual joint width with the specified width.
3. Measure the joint spacing to determine if the joints are spaced too far apart.

Measures for Prevention:

1. Frequent observation of joints to identify early stages of joint sealant extrusion
2. Provide better quality control during joint construction to ensure:
   - Proper width
   - Adequate spacing
3. Improve the quality of the joint sealant

Strategies for Repair:

- Clean joint and reseal

Joint Separation

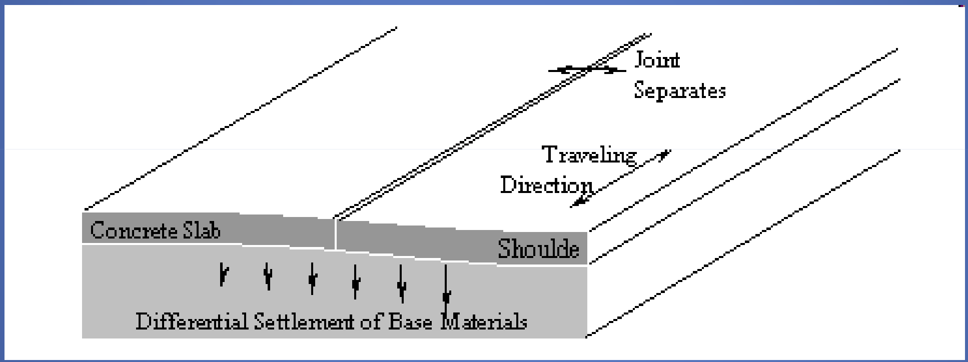
Description:

- Joint separation is the lateral slippage of slabs resulting in the widening of a longitudinal joint. Joint separation usually occurs between the traffic lane and the shoulder.
- Lane separation is not considered serious unless water can easily infiltrate into the joint. The infiltration of water may cause additional damage or movement.

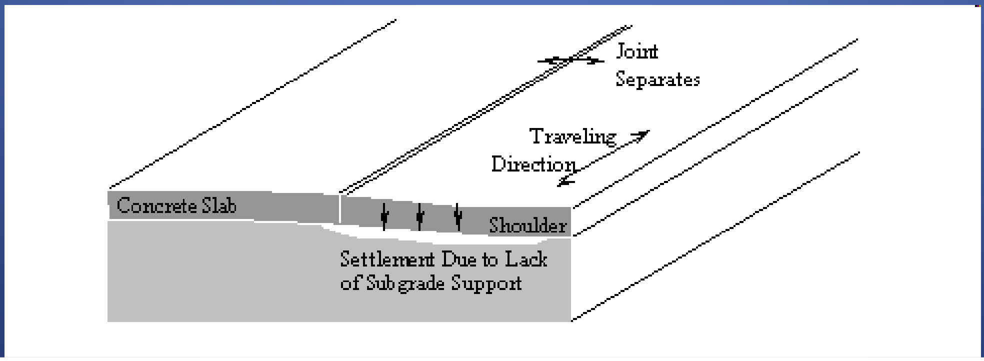
Joint Separation

Possible Mechanisms:

- Joint separation may be caused by differential settlement between the traffic lane and the shoulder. The differential settlement may be due to lack of a stabilized shoulder.



- The infiltration of water into the joint may erode the underlying layers. The erosion may result shoulder settlement.



Joint Separation

Field Investigations:

1. Deflection testing (Dynaflect, FWD, etc.) can be used to locate voids beneath the shoulder.
2. Deflection testing to estimate the structural capacity of the base materials.
3. GPR may be used to estimate void locations.
4. A soil boring of the underlying layers can be obtained.

Measures for Prevention:

1. Frequent observation of longitudinal joints can provide early identification of joint separation. If the separation is noticed early, damage or movement due to water infiltration may be prevented.
2. Use a stabilized base underneath the shoulder.
3. Provide consistent and proper compaction of soils during construction.

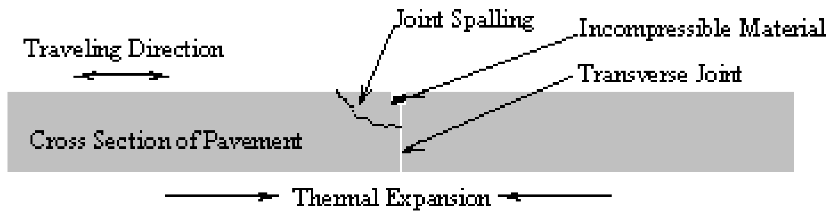
Strategies for Repair:

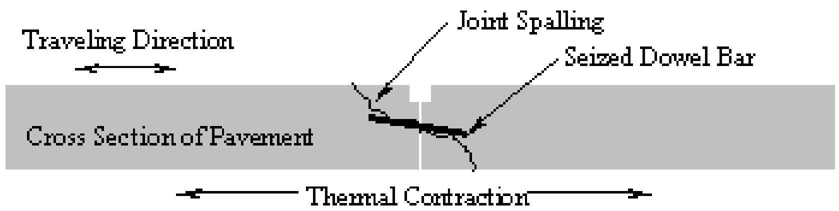
1. Clean joint and reseal
2. Clean joint and hot-mix patch

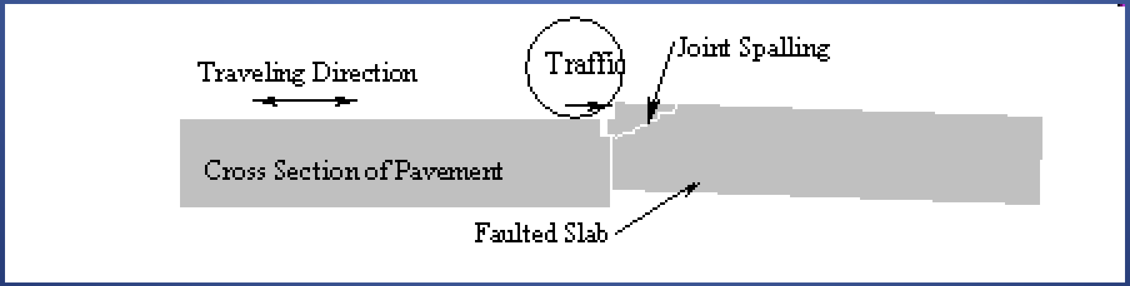
Joint Spalling

Description:

- Joint spalling is the chipping of the concrete slab at the longitudinal or transverse edges. The spalling may occur along the whole length or a portion of the length of the joint
- Joint spalling is due to excessive local pressure that is due to a combination of traffic action, joint-sealant extrusion, thermal expansion, steel corrosion, and/or slab curling.







Joint Spalling

Field Investigations:

1. A pavement core can be taken through the joint and near the joint.
2. Observe the core to see if the dowel bars were placed correctly and are lubricated properly.
3. Observe the core to see if the dowel bars or reinforcement is corroded.
4. A deflection test (Dynaflect, FWD, etc.) can be performed to determine if the load is properly transferred across the joint.

Joint Spalling

Measures for Prevention:

1. Frequent observation of joints can provide early identification of:
   – Joint sealant loss or deterioration
   – Debris in the joint
2. Reseal the joint as soon as joint sealant deterioration is noticed
3. Provide better quality control for dowel placement during construction
4. Improve the mix design or construction techniques for the concrete
5. Use air-entrained concrete.

Strategies for Repair:

1. Clean joint and reseal
2. Clean joint and hot-mix patch
3. Joint saw and reseal
4. Partial-depth repair
5. Full-depth repair

Longitudinal Cracking

Description:

- Longitudinal cracks are cracks that follow a course approximately parallel to the centerline of the pavement. These cracks are generally straight but they may curve slightly back and forth across the length of the pavement.

Longitudinal Cracking

Possible Mechanisms:

1. Longitudinal cracking may be caused by improper joint construction.
2. The loss of the joint sealant may allow incompressible material to enter the transverse joint. The material in the transverse joint creates restraint and will prevent the slab from expanding.
3. Swelling soils may result in an upward movement of the pavement.
4. The loss of foundation support may initiate a longitudinal crack.
5. Warping and curling stresses may initiate a longitudinal crack. Temperature differentials may cause the edges of the slab to curl upwards.

Longitudinal Cracking

Field Investigations:

1. A soil boring of the underlying layers can be obtained.
2. Deflection testing can be used to determine the structural capacity of the base materials.
3. Determine the proper spacing of longitudinal joints and compare with the actual spacing.

Measures for Prevention:

1. Provide proper construction procedures of longitudinal joints:
2. Frequent observation of joints can provide early identification of joint sealant loss, deterioration, or debris in the joint
3. Reseal the joint as soon as joint sealant deterioration is noticed
4. Provide adequate drainage
5. Use a stabilized base
6. Provide consistent and proper compaction of the subgrade during construction.

Strategies for Repair:

1. Clean and reseal crack

Loss of Skid Resistance

Description:

- Loss of skid resistance occurs when the surface of the pavement becomes polished, or slippery. Polishing is the shining of the coarse aggregates located at the surface of the pavement.

Loss of Skid Resistance

Possible Mechanisms:

1. Traffic passing over the pavement may result in polishing of fine aggregates at the surface. This mechanism can be easily recognized if the polishing is occurring primarily in the wheel paths (wheel track wear). As polishing progresses the loss of skid resistance increases.

Field Investigations:

1. The skid resistance can be measured and compared to previous measurements to determine if there has been a reduction in the skid resistance

Measures for Prevention:

1. Use fine aggregate that is less susceptible to polishing

Strategies for Repair:

1. Diamond grinding/grooving
2. Hot-mix patch/asphalt or concrete overlay

Loss of Surface Material

Description:

- Scaling is the progressive peeling or flaking of the rigid pavement surface. Scaling may occur anywhere on the pavement surface, but the affected areas are located randomly (spotty) across the pavement.
- Raveling is the loss of fine aggregates from the pavement surface. Raveling is continuous over the pavement surface and is usually the worst in the wheel paths.
- An aggregate pop out is the removal of coarse aggregate particles from the surface. Potholes are bowl shaped holes of various sizes in the pavement surface and can also be classified as loss of surface material.

Loss of Surface Material

Loss of Surface Material

Possible Mechanisms:

1. Poor construction technique and/or poor quality control of materials may result in a local inclusion of soft/dirty aggregate, clay, silt, non-homogeneous mortar, or poorly consolidated concrete.
2. Excessively wet mixes may cause water to flow the surface during finishing. This will weaken the surface of the pavement.
3. Overfinishing of the pavement may also cause laitance of the surface, and the concrete at the surface is likely to have a lower strength.
4. If the reinforcing steel is placed too close to the surface, the lack of cover may cause the surface material to spall off.
5. Traffic abrasion may cause the surface material to deteriorate.
6. Chains or studded tires may result in wheel-track wear. In addition, localized impact loadings and car accidents may initiate a spall.
7. Fires, due to a car accident, for example, will heat the concrete and the resulting expansion may cause pop-outs and spalling.

Loss of Surface Material

Field Investigations:

1. A pavement core can be taken to determine the depth of reinforcing steel.
2. Visual inspection of the core can reveal inadequate consolidation and air voids near the surface.

Measures for Prevention:

1. Provide better quality control for material properties
2. Improve construction techniques such as steel placement and finishing

Strategies for Repair:

1. Diamond grinding/grooving
2. AC overlay/hot-mix patch
3. Bonded concrete overlay

Pumping

Description:

- Pumping is the expulsion of water and silts, sands, or clays from joints or cracks when load is applied to the pavement. If water enters the joint or crack it may erode the underlying layers of the pavement.

Possible Mechanisms:

1. Pumping results when water is allowed to enter the joint or crack. The movement of the water, when load is applied, will erode the base materials. The use of base materials that are susceptible to weathering will also promote pumping

Pumping

Pumping—see staining

Pumping

Field Investigations:

1. A soil boring of the underlying layers can be obtained.

Measures for Prevention:

1. Providing adequate drainage will reduce the amount of moisture coming in contact with the base materials.
2. Frequent inspection of the joint for joint sealant extrusion may prevent water infiltration into the joint.
3. Use a stabilized base or other base materials less susceptible to weathering or erosion.

Strategies for Repair:

1. Retrofit edge drains
2. Saw and reseal joint or crack
3. Full-depth repair
4. Slab stabilization

Punchout

Description:

- A punchout is a full-depth block of pavement, formed at the edge, when one short longitudinal crack forms between two existing transverse cracks. The existing cracks are closely spaced, usually less than four feet apart. The punchout is often rectangular, but some may appear in other shapes. Punchouts are most common in continuously reinforced concrete pavements.

Punchout—note two transverse cracks and longitudinal crack

Punchout

Possible Mechanisms:

1. A punchout initiates with two closely spaced transverse cracks. The cracks extend through the thickness of the pavement and permit the flow of water to the base materials. The water washes the base materials away by pumping and erosion. With some of the base support removed, a cantilever is created between the transverse cracks. Heavy load applications will connect the transverse cracks with a short longitudinal crack. The punchout progresses with spalling of the cracks, rupturing of the reinforcing steel, and eventually settlement of the punchout below the original surface of the pavement.

Punchout

Field Investigations:

1. Deflection testing to determine the structural capacity of the base materials.
2. A soil boring of the underlying layers can be obtained.
3. Observe the base materials below the punchout for evidence of erosion and weathering.

Strategies for Repair:

1. Slab stabilization
2. Full-depth repair

Reactive Aggregate Distress

Description:

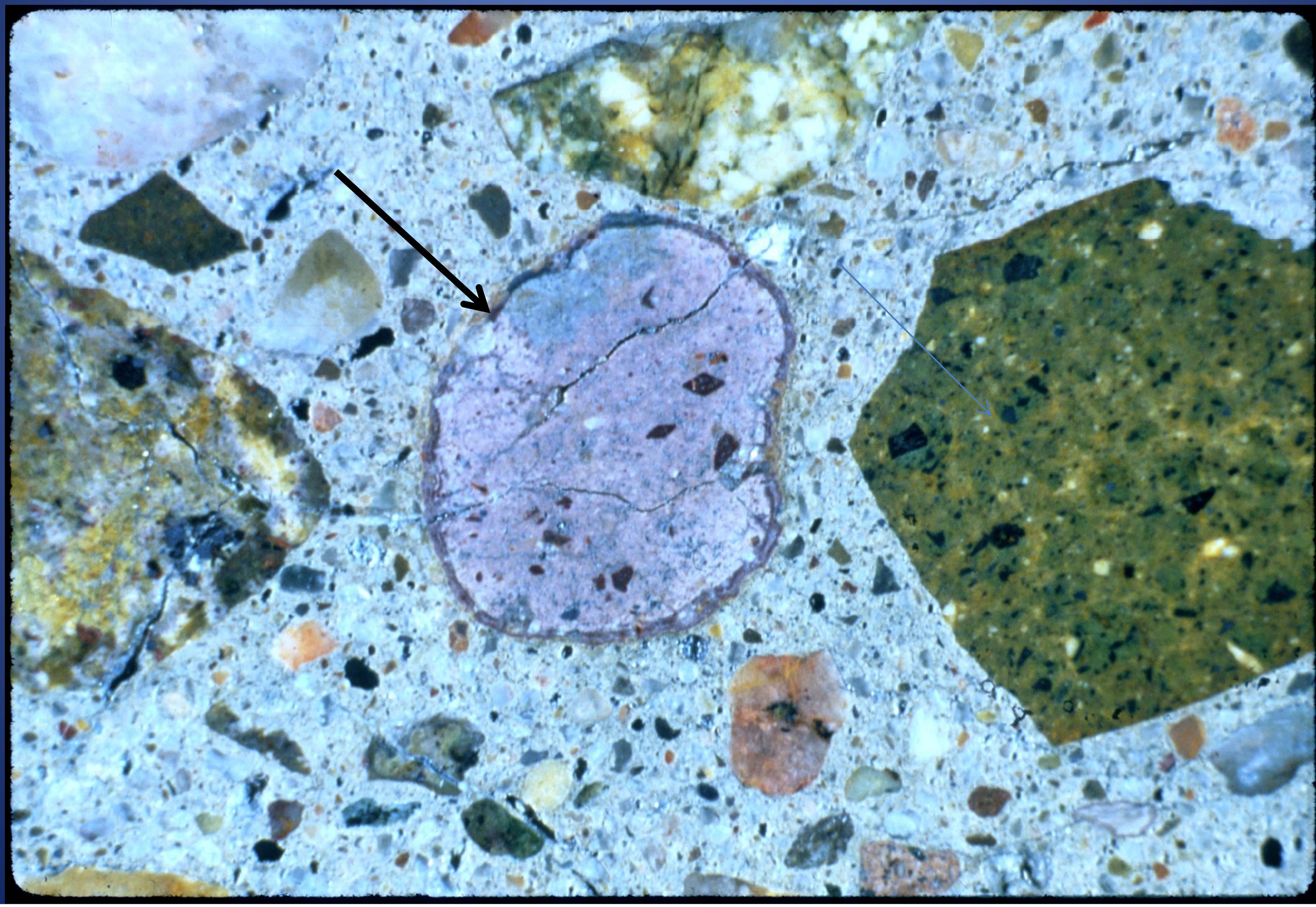
- Fine, closely spaced cracks are a result of reactive aggregates. These cracks can form as longitudinal cracks or map cracks. As the reaction progresses, spalling of these cracks may occur.
- Cracking and spalling will usually initiate at a joint or a crack and progress to the rest of the slab over time. Cracks due to reactive aggregates are usually deeper than normal map cracking.

Possible Mechanisms:

1. Alkali-silica reaction occurs when aggregates that contain certain forms of silica react with the alkalis in the cement paste. This reaction, which aided by a warm, moist environment, will produce a gel-like material. The gel expands when it absorbs water. The expansion of the gel may result in cracking of the hardened concrete.

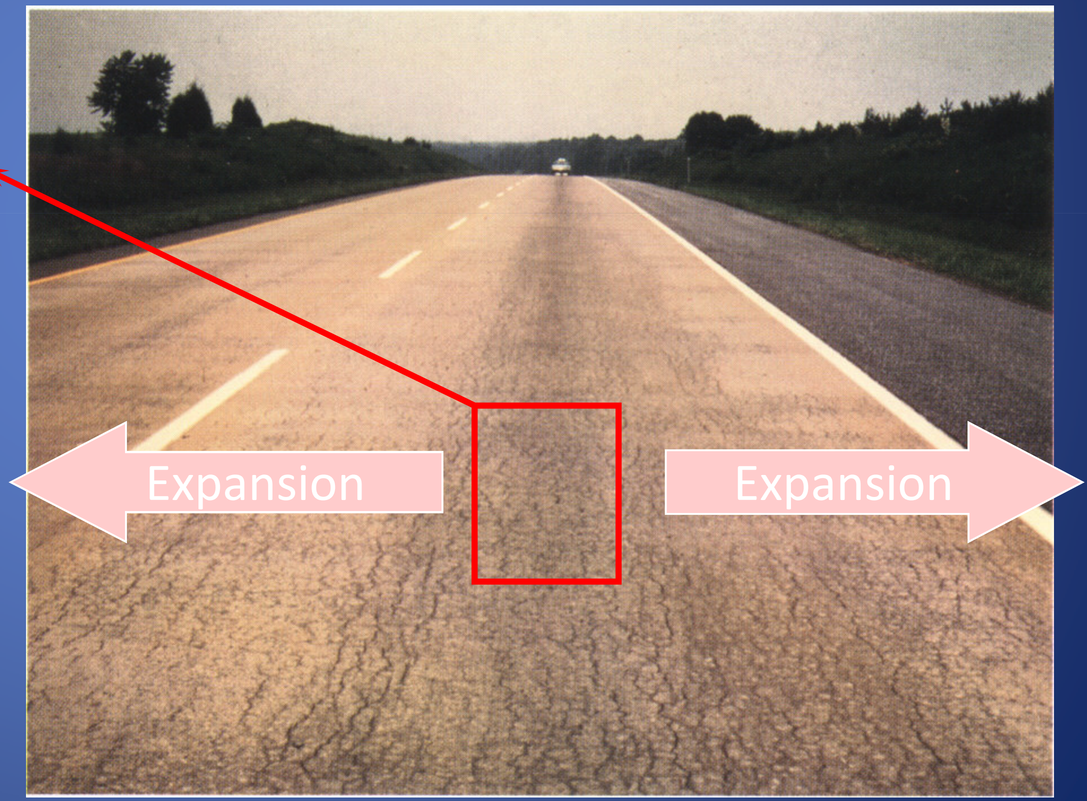
Reactive Aggregate Distress--ASR

Note ASR gel around aggregate



ASR Crack Orientation

As ASR advances in pavements the joints close and continued expansion in the longitudinal direction is restrained. Consequently, expansion continues in the transverse and vertical directions, which results in increased cracking in the longitudinal direction.



SHRP-C-315

Reactive Aggregate Distress

Field Investigations:

1. A concrete core can be taken through a crack. Cracks due to reactive aggregates are usually deeper than normal map cracking.

Measures for Prevention:

1. Use non-reactive aggregates in the concrete.
2. Use blended cements in the concrete.
3. Use pozzolans known to reduce alkali-aggregate expansion.
4. Use chemical admixtures known to reduce alkali-aggregate expansion (e.g: lithium)

Strategies for Repair:

1. Clean and seal cracks
2. Concrete slab reconstruction

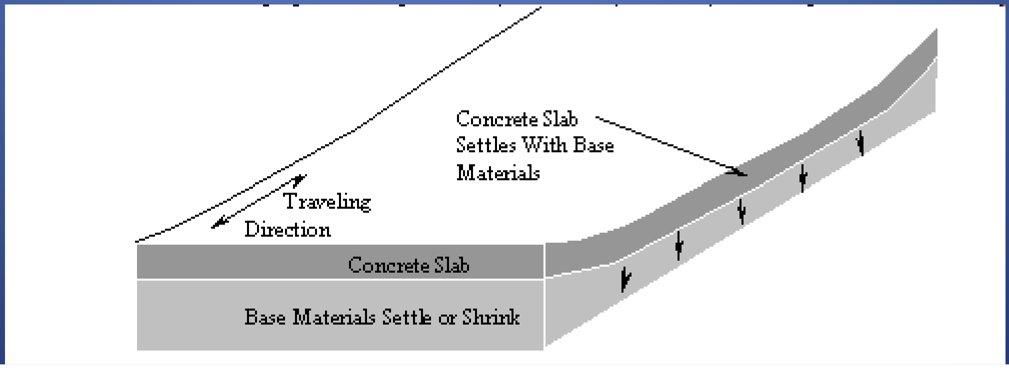
Settlement

Description:

- Settlement is the downward vertical movement of the pavement from its original constructed longitudinal profile. The settled pavement elevation will be lower than the elevation of the surrounding pavement. The gentle longitudinal slopes created by settlement may result in slab cracking, an increase in roughness, or the ponding of water.

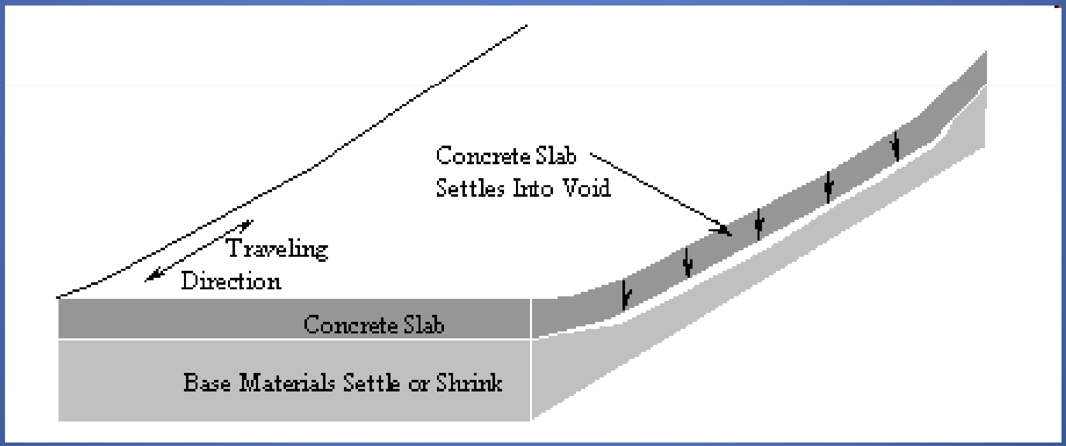
Possible Mechanisms:

1. The settlement may be due to differential settlement of the base or subgrade. Large moisture content changes may cause a portion of the base or subgrade to settle. This differential settlement will cause a depression in the surface of the rigid pavement.



Settlement

2. The pavement may settle due to lack of subgrade support. Erosion of the base materials may leave large voids beneath the rigid pavement and the pavement may settle into these voids.



3. Improper compaction during construction may also leave voids or reduce subgrade stability.

Settlement

Field Investigations:

1. Deflection testing (Dynaflect, FWD, etc.) can be used to locate voids beneath the slab.
2. Deflection testing to estimate the structural capacity of the base materials.
3. GPR may be used to estimate void locations.
4. A soil boring of the underlying layers can be obtained.

Measures for Prevention:

1. Providing adequate drainage will reduce moisture content changes of the base materials.
2. Use a stabilized base underneath the shoulder.
3. Provide consistent and proper compaction of the subgrade during construction.

Strategies for Repair:

1. Asphalt leveling course

Shrinkage Cracking

Description:

- Shrinkage cracks are hairline cracks that often occur on the surface of freshly mixed concrete.
- The pattern of shrinkage cracks is random with cracks oriented in all directions.
- Shrinkage cracks are shallow and rarely penetrate the full depth of the slab.
- The cracking occurs during plastic shrinkage and may take place during finishing or soon after it is placed.

Plastic Shrinkage Cracking

Possible Mechanisms:

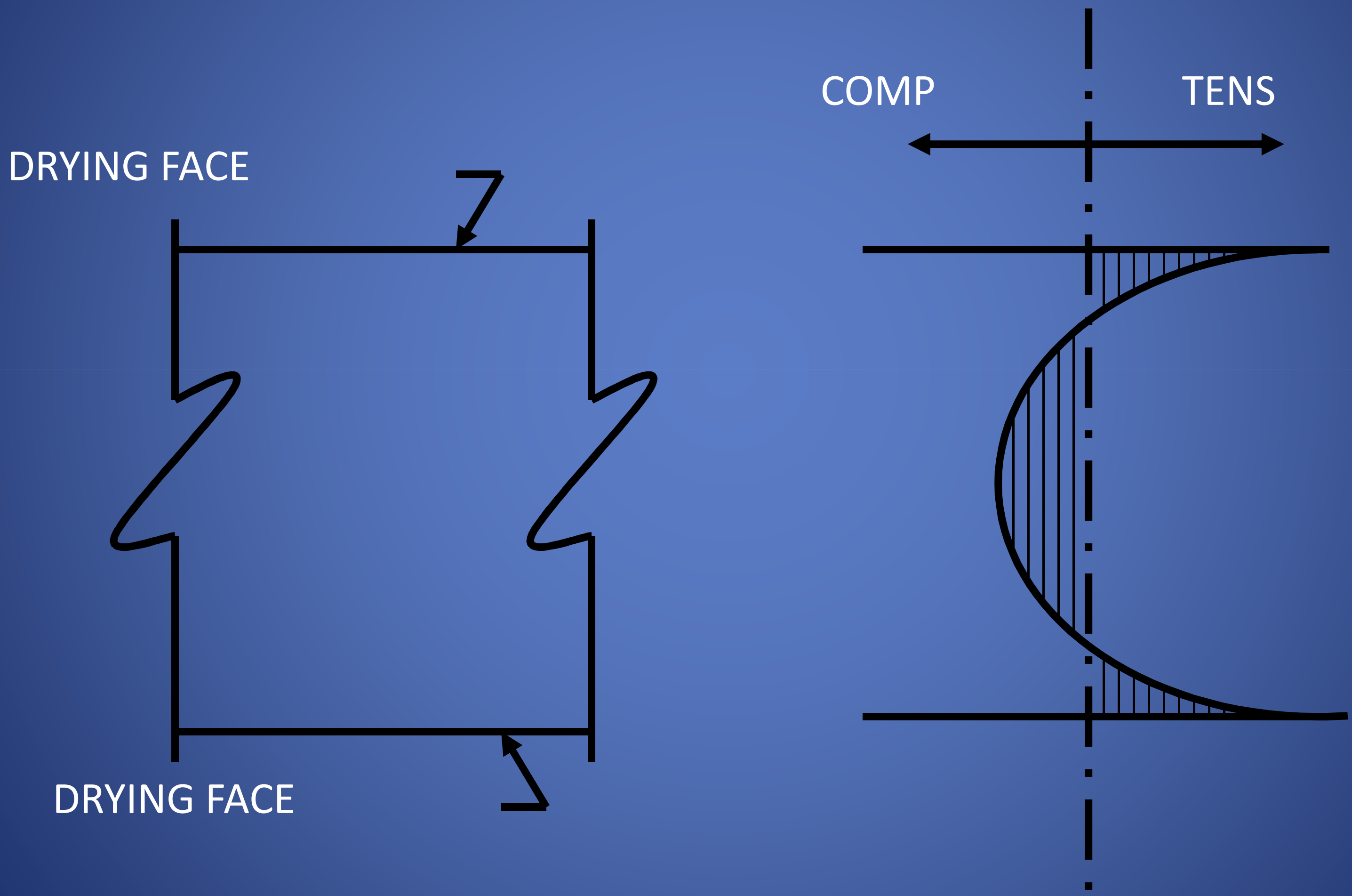
Shrinkage cracks occur when moisture evaporates too quickly from the surface of the freshly placed concrete. When water evaporates from the surface faster then it can appear at the surface during the bleeding process, drying shrinkage tensile stresses are created. Since the strength of the fresh concrete mix is lower than the design strength, these tensile stresses causes cracking.

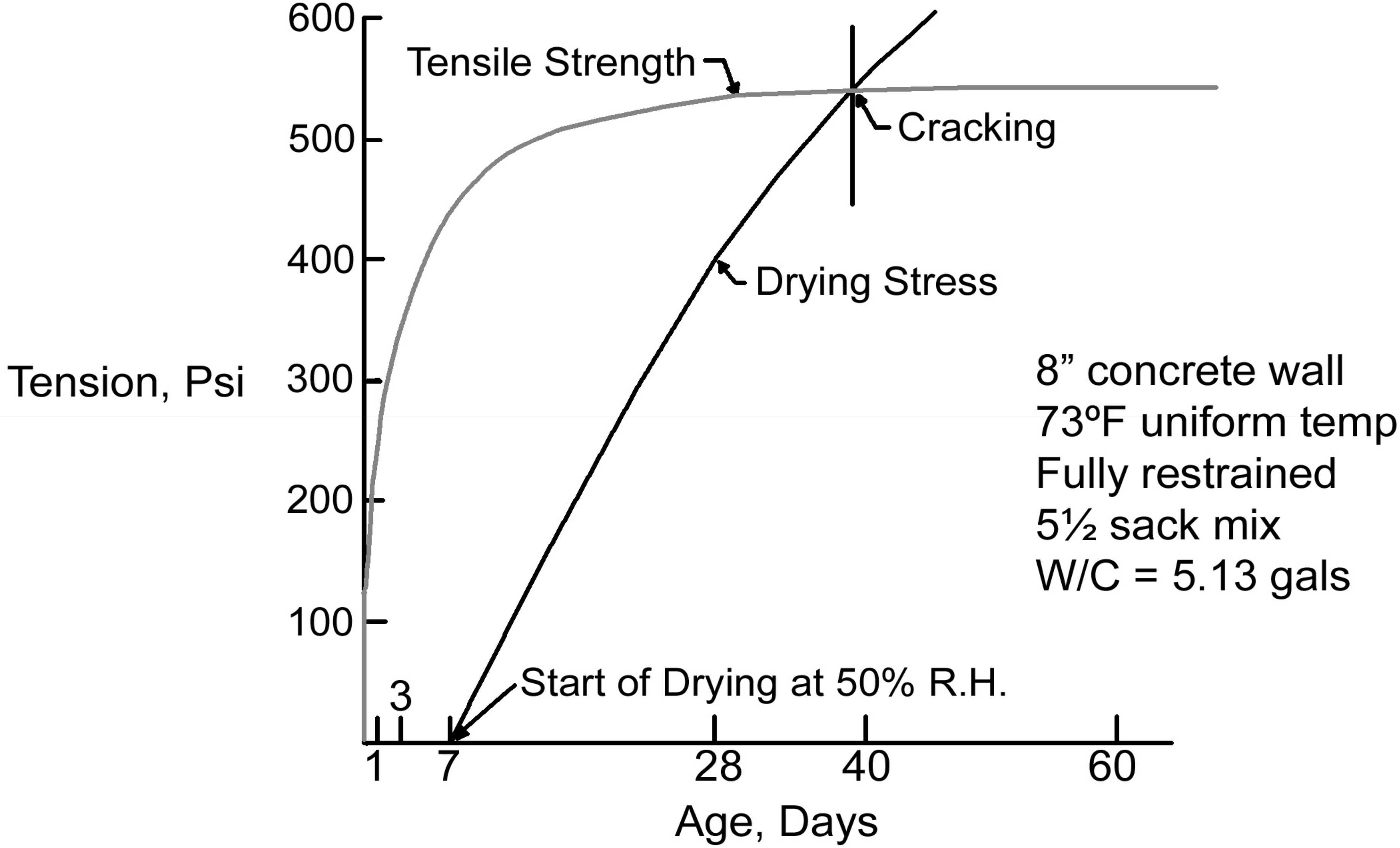
Drying Shrinkage Cracking

Drying Shrinkage Mechanism

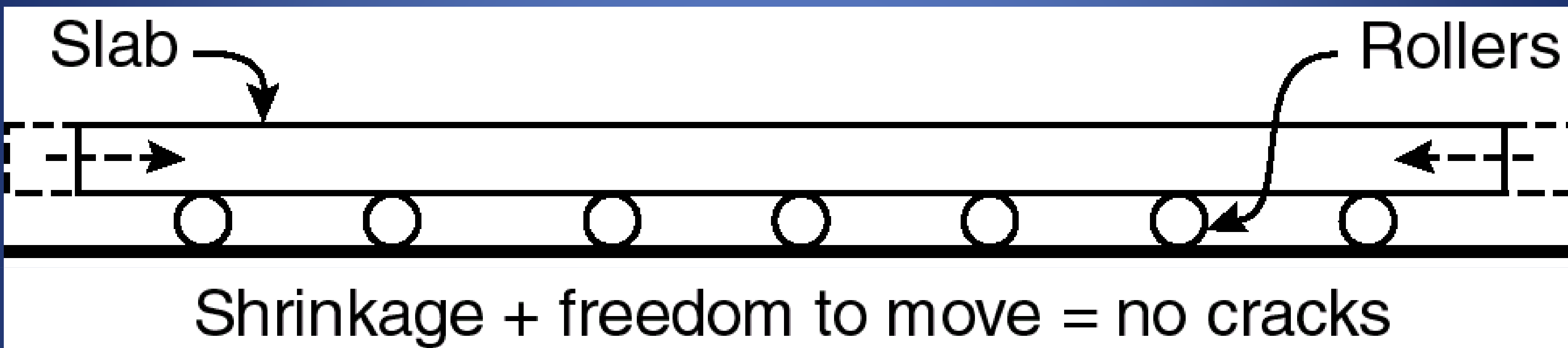
- As moisture continues to be lost due to evaporation after concrete sets, there is a continued reduction in volume, greatest at the surface of the pavement. If the stress due to shrinkage exceeds the concrete strength, the concrete cracks.
- The more restraint due to continuity of the pavement or friction on the bottom, the greater the probablilty of cracking.

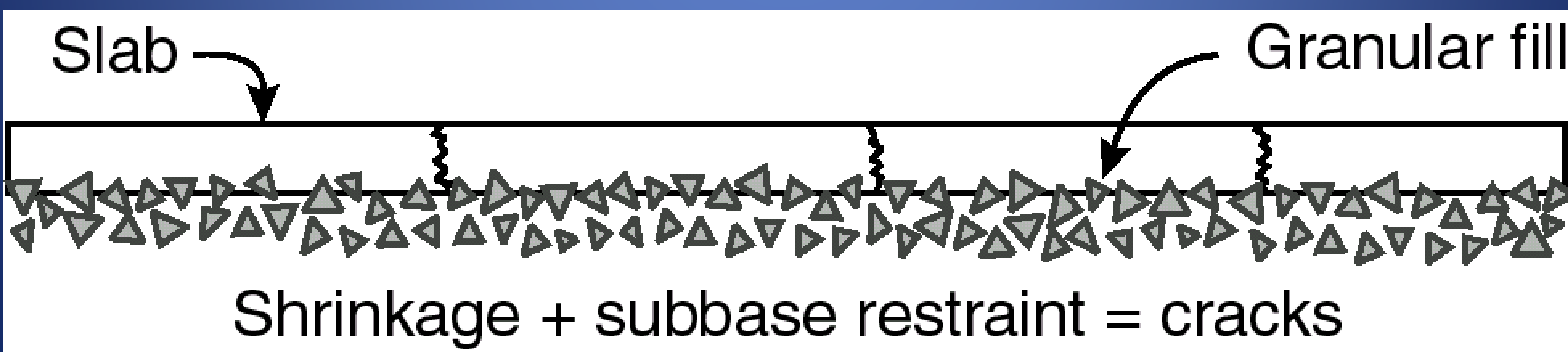
Theoretical Shrinkage Stresses




600
500
400
300
200
100
Tension, Psi
Tensile Strength
Cracking
Drying Stress
8” concrete wall
73ºF uniform temp
Fully restrained
5½ sack mix
W/C = 5.13 gals
Start of Drying at 50% R.H.
3
1
7
28
40
60
Age, Days

Restraint and Cracking





Shrinkage Cracking

Measures for Prevention:

1. Moisten the subgrade and forms before the concrete is poured.
2. Moisten the concrete aggregates that are too dry before adding them to the mix.
3. Provide a barrier to protect the new concrete pavement from the wind.
4. Provide a barrier to protect the new concrete from the heat of the sun.
5. Protect the concrete after finishing to reduce the rate of evaporation:
   - Fog spray or curing compound
   - Wet burlap or curing paper
6. Reduce the time between placing the concrete and the beginning of curing.
7. Shrinkage reducing admixtures may be used.

Strategies for Repair:

1. Refinish the surface (if cracks appear during finishing)
2. Crack seal

Slab Shattering

Description:

- Shattered slabs are formed when a series of cracks intersect to divide the slab into four or more pieces.
- Although the pieces still remain in their original position, they may settle below the original elevation of the pavement. Also, the intersecting cracks are usually accompanied by severe spalling.

Slab Shattering

Possible Mechanisms:

1. Slab shattering is mainly due to lack of subgrade support. The base materials may settle, contain voids, or may be susceptible to erosion, resulting in loss of support. Overloading the concrete slab will create excessive bending stresses where the slab has no support. The result is severe cracking, spalling, and settlement.

Field Investigations:

1. Deflection testing to determine the structural capacity of the base materials.
2. A soil boring of the underlying layers can be obtained.
3. Observe the base materials below the shattered slab for evidence of erosion and weathering.

Slab Shattering

Measures for Prevention:

1. Providing adequate drainage will reduce the amount of moisture coming in contact with the base materials.
2. Prevent overloading of the pavement if possible.
3. Use a stabilized base or other base materials less susceptible to weathering, erosion and settlement.

Strategies for Repair:

1. Full-depth repair
2. Complete slab reconstruction

Transverse Cracking

Description:

- Transverse cracks are cracks that follow a course approximately at right angles to the centerline of the pavement. Transverse cracks are generally straight. A meandering crack wanders back and forth across the traffic lane, usually at a joint.

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Transverse/Longitudinal Cracking

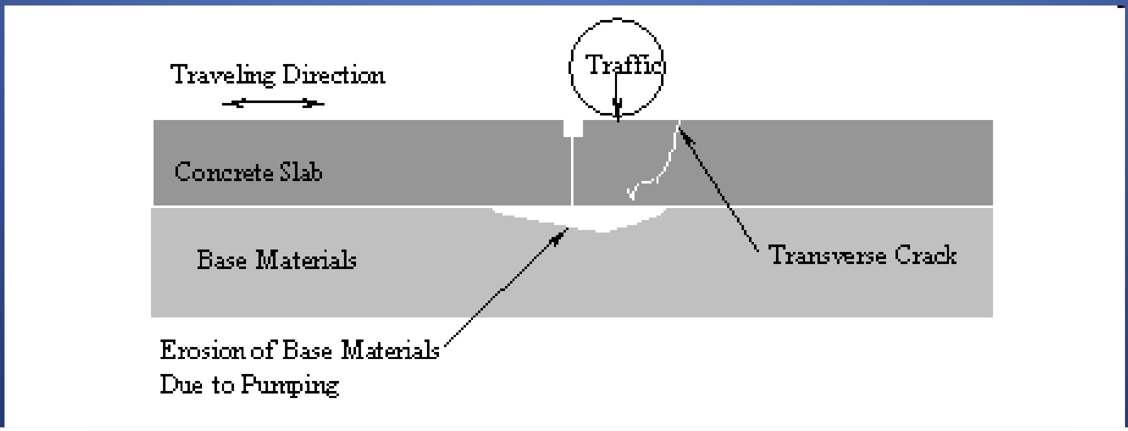
Possible Mechanisms:

1. Transverse and meandering cracking may be caused by improper joint construction.
2. Improper design, construction, or materials of the pavement may result in the formation of transverse cracks.
3. Swelling soils may result in an upward movement of the pavement.
4. The loss of foundation support may initiate a transverse or meandering crack.
5. Warping and curling stresses may initiate a transverse crack

Transverse Cracking

Field Investigations:

1. A soil boring of the underlying layers can be obtained.
2. Deflection testing (Dynaflect, FWD, etc.) can be used to determine the structural capacity of the base materials.
3. Deflection testing (Dynaflect, FWD, etc.) can be used to determine the adequacy of load transfer across the joint.
4. A core can be taken through the concrete slab and the thickness can be determined.
5. A cover meter can be used to determine the quantity and location of reinforcing steel.
6. Determine the proper spacing of transverse joints and compare with the actual spacing.



Transverse Cracking

Measures for Prevention:

1. Provide proper construction procedures of transverse joints:
   - Limit the length between transverse joints
   - Provide adequate depth for the transverse joint
   - Do not saw the transverse joints too late
   - Ensure that the dowel bars are not seized
2. Provide proper design, construction, and materials for the concrete slab:
3. Provide adequate drainage to reduce moisture content changes of the base materials
4. Use a stabilized base
5. Provide consistent and proper compaction of the subgrade during construction.

Strategies for Repair:

1. Clean and reseal crack

Summary

- There are many causes of distress in concrete pavements.
- Before repairs are made it is essential that the cause of the distress be understood.
- Repairs made early may provide a long-term solution at a relatively low cost—delays in repair may result in very expensive and time consuming repairs.