# Best Practices for Constructing Concrete Pavements

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LTRC Concrete Pavements Seminar

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# Learning Objectives

- Recognize the relationship between design assumptions and construction operations.
- Develop a checklist of all critical construction elements and corresponding responsibilities.
- Recognize the most typical construction–related problems and how to avoid them.
- Determine which construction operations have the most influence on ride quality, slab uniformity, premature cracking and other important factors.

# How Do You Define Quality?

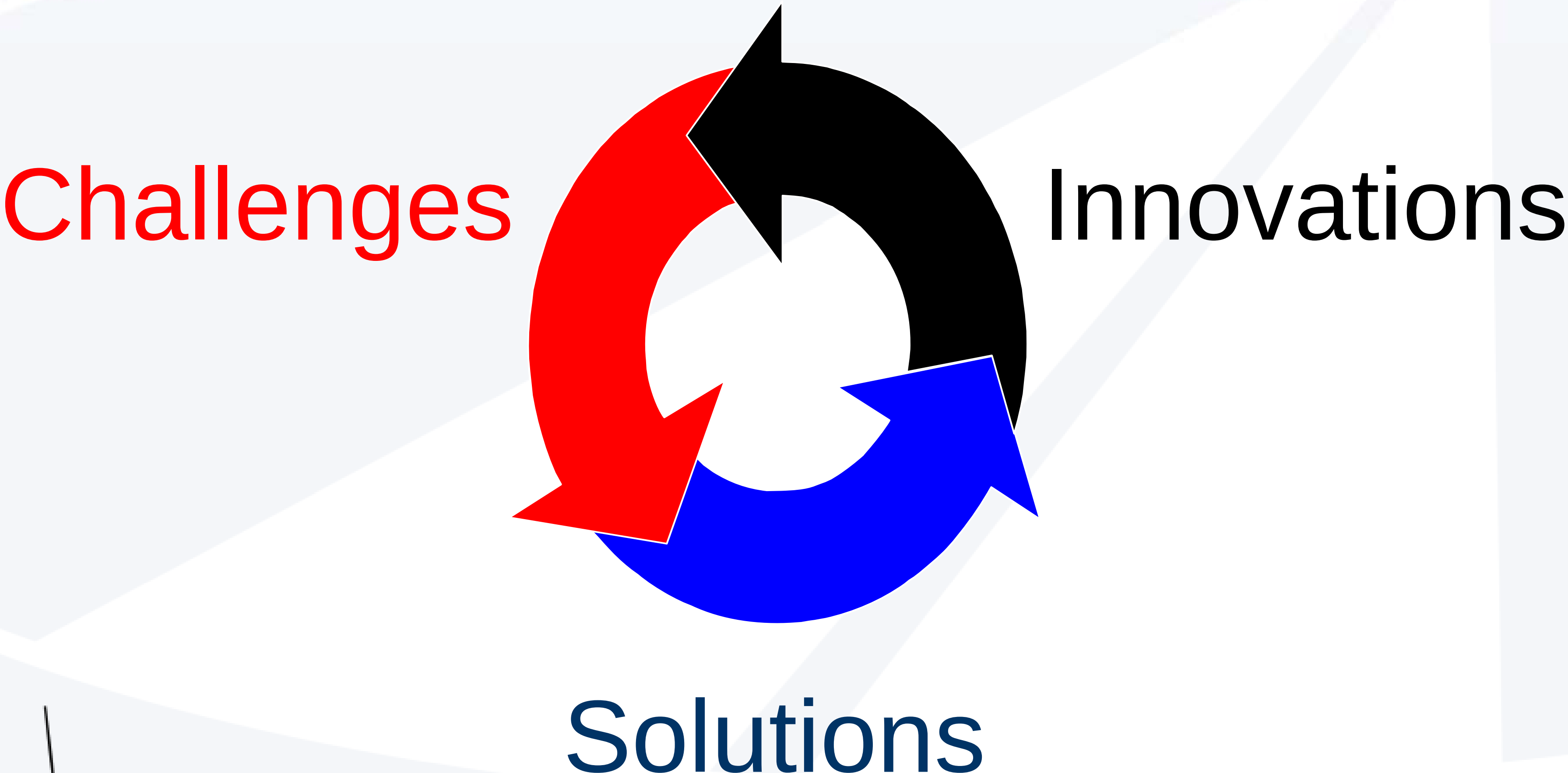
- Depending on your perspective (contractor, owner, user) the following may define quality issues:
  - Inexpensive to build and maintain.
  - Safe, smooth, quiet, environmentally friendly.
  - Constructible.
  - Others?

# Quality Construction Practices

- Concrete pavements play a primary role in satisfying public demands for better roads.
- The best design will fail prematurely if construction is not of adequate quality.
- The number 1 goal in construction is:

Build it equal to or better than called for in the design and specifications!!!

# Cycle of Quality

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# Challenges

- Design and construct concrete pavements with the following characteristics:
  - Long-lasting (minimal maintenance and rehabilitation).
  - Reasonable initial cost.
  - Rapid construction (minimal delays to public).
  - Smooth.
  - Safe.
  - Quiet.
  - Cost effective.
  - Environmentally “friendly.”

# Innovations

- Innovations generally fall into one or more of the following categories:
  - Design (AASHTO Interim Mechanistic-Empirical Pavement Design Guide (M-E PDG)).
  - Materials.
  - Equipment.
  - Processes.

# Solutions

- The means to construct high performance, long life concrete pavements exists today
- A coordinated effort is required to achieve this goal including designers, specification writers, materials producers, contractors, and many others

# Relationship Between Pavement Design and Construction

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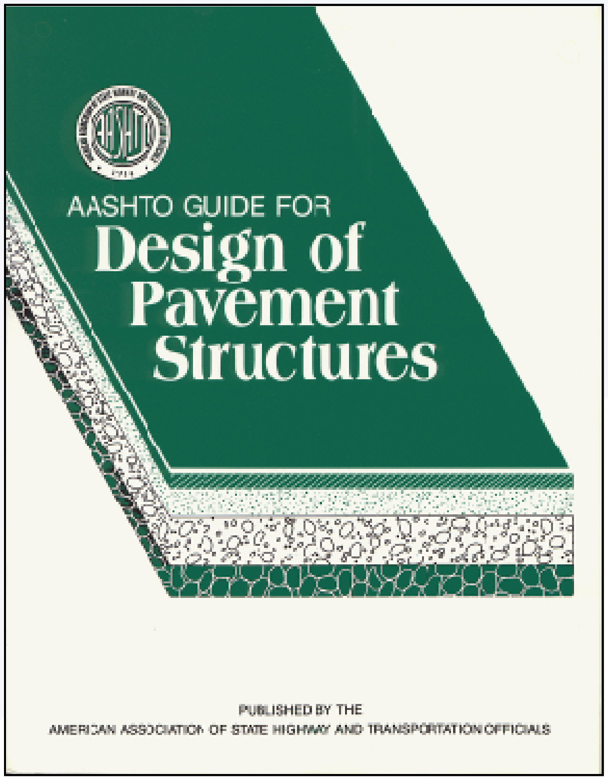
# Objectives of Pavement Design

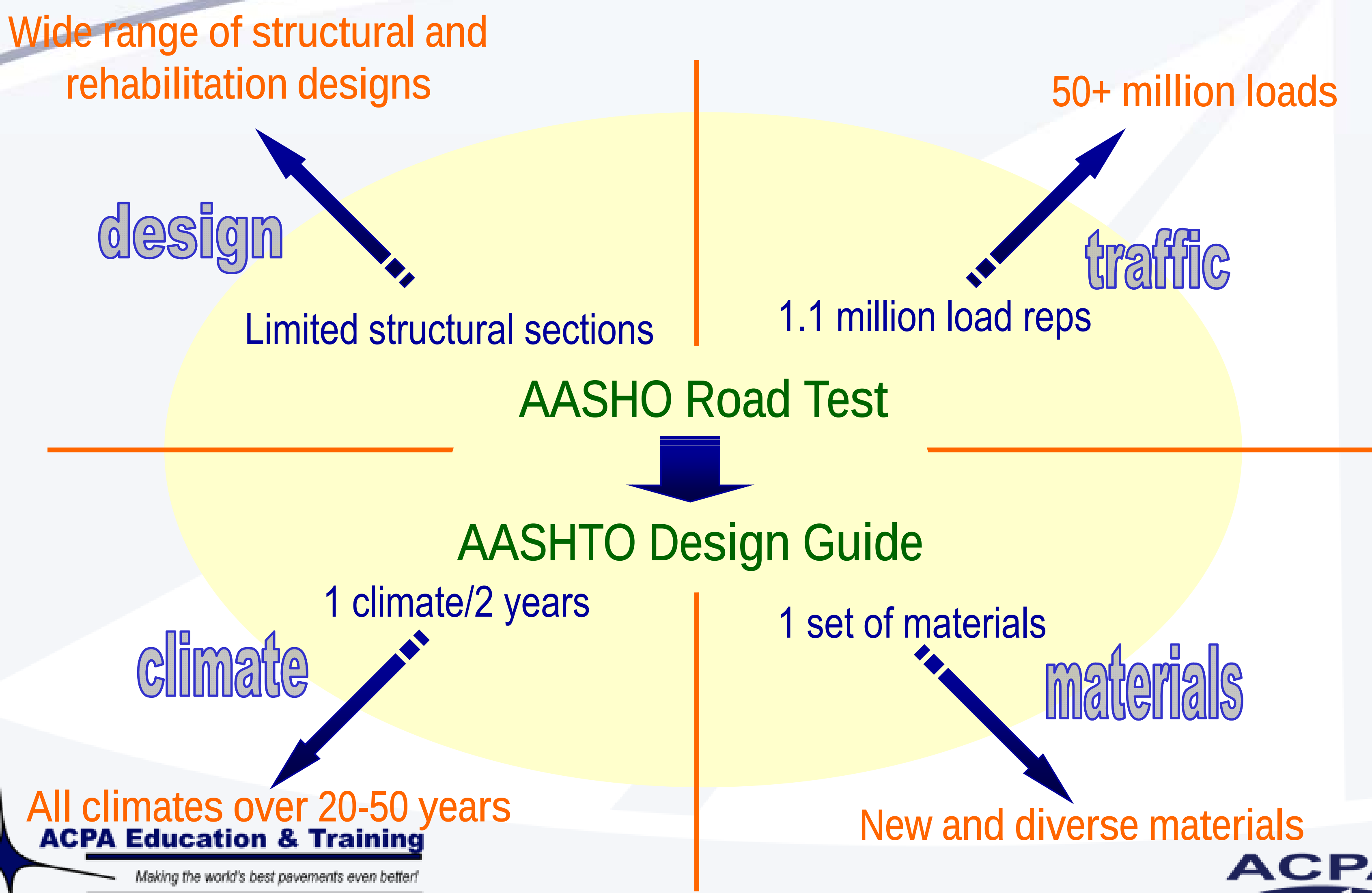
- To provide a surface that is:
  - Strong (structural)
  - Smooth (ride)
  - Safe (friction and drainage)
  - Economical
    - Initial construction cost
    - Recurring maintenance cost

# AASHTO Pavement Design Guide




- Empirical methodology based on AASHO Road Test in the late 1950's
- Several versions:
  - 1961 (Interim Guide), 1972, 1986, 1993 (Empirical)
  - 1986 Guide highlights need for M-E design
  - 1998 Rigid Supplemental Guide (based on M-E concepts)

# Current AASHTO vs. Current Needs

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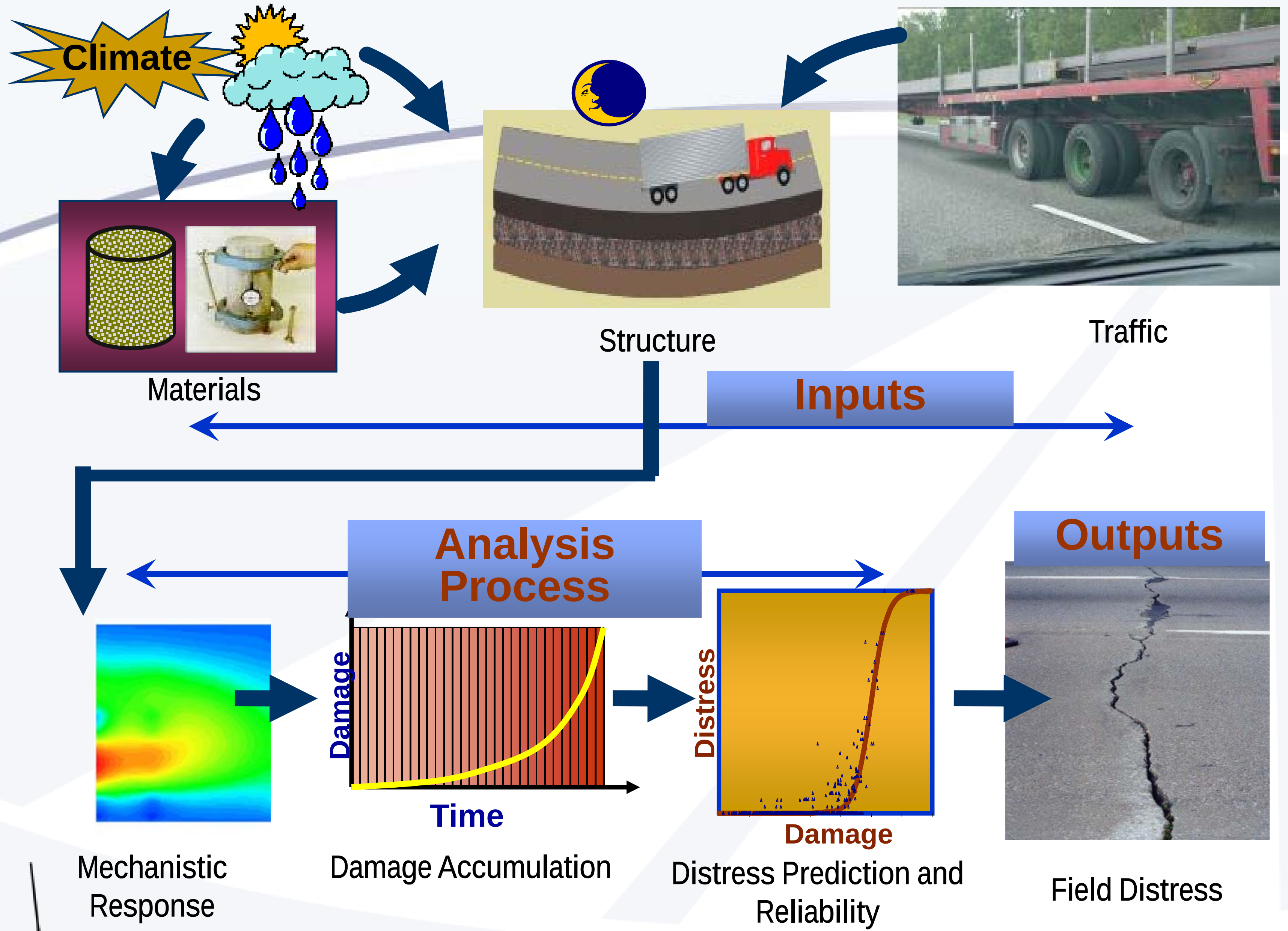
# M-E Design

- *Mechanistically* calculate critical pavement response (i.e., stresses, strains, and deflections) due to:
  - Traffic loading
  - Environmental conditions
- Accumulate damage over time
- *Empirically* relate damage over time to pavement distresses through ***calibrated*** distress models, e.g.:
  - Cracking, Faulting, Roughness in JPCP
  - Punchouts, Crack Width, Roughness in CRCP

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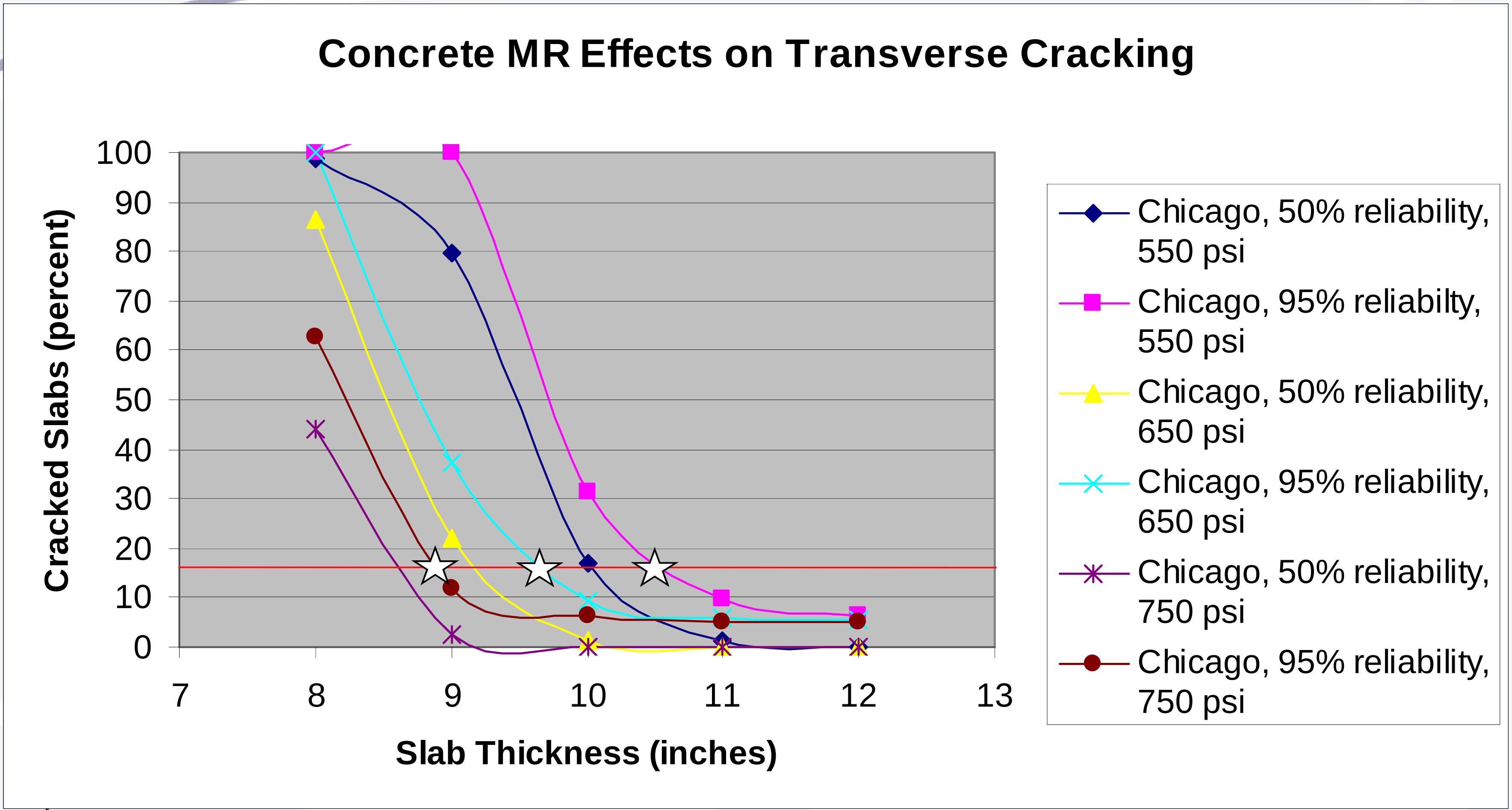
# Current and Future Construction Requirements Controlled by Design?

- The M-E PDG has many construction–related variables including the following:
  - Concrete strength and uniformity.
  - Coefficient of thermal expansion of the concrete.
  - Curing type and effectiveness (curling and warping).
  - Joint spacing.
  - Load transfer.
  - Subbase type and overall support conditions.
  - Others.

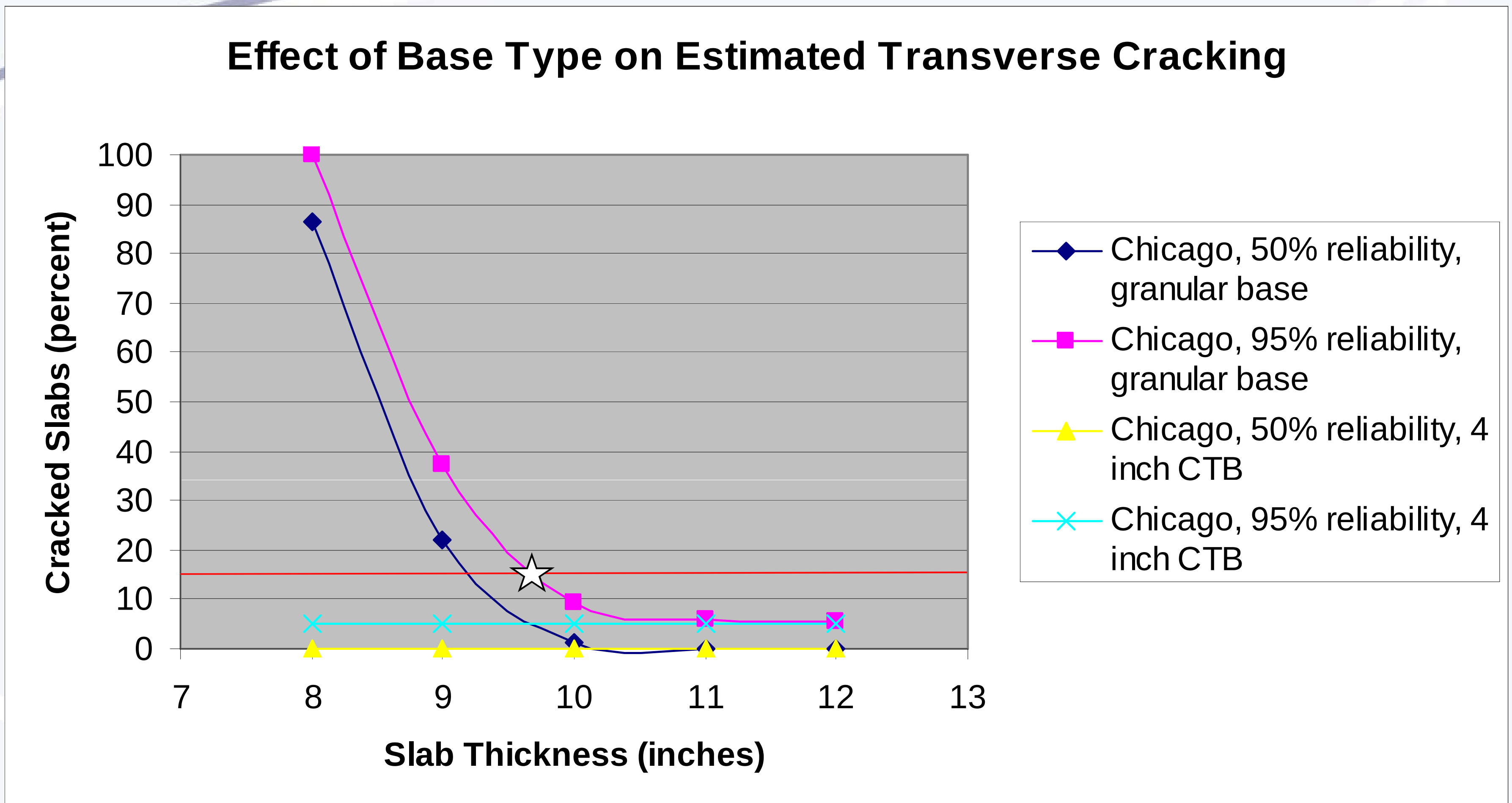
# Inputs

- Site-related inputs (these cannot be altered economically)
  - Traffic—ESALs or load spectra
  - Subgrade—engineering properties, strength, modulus
  - Climate—precipitation, temperature
- Design-related inputs (the designer has control over these properties)
  - Structural section—thicknesses, layer types
  - Paving materials—strength, modulus

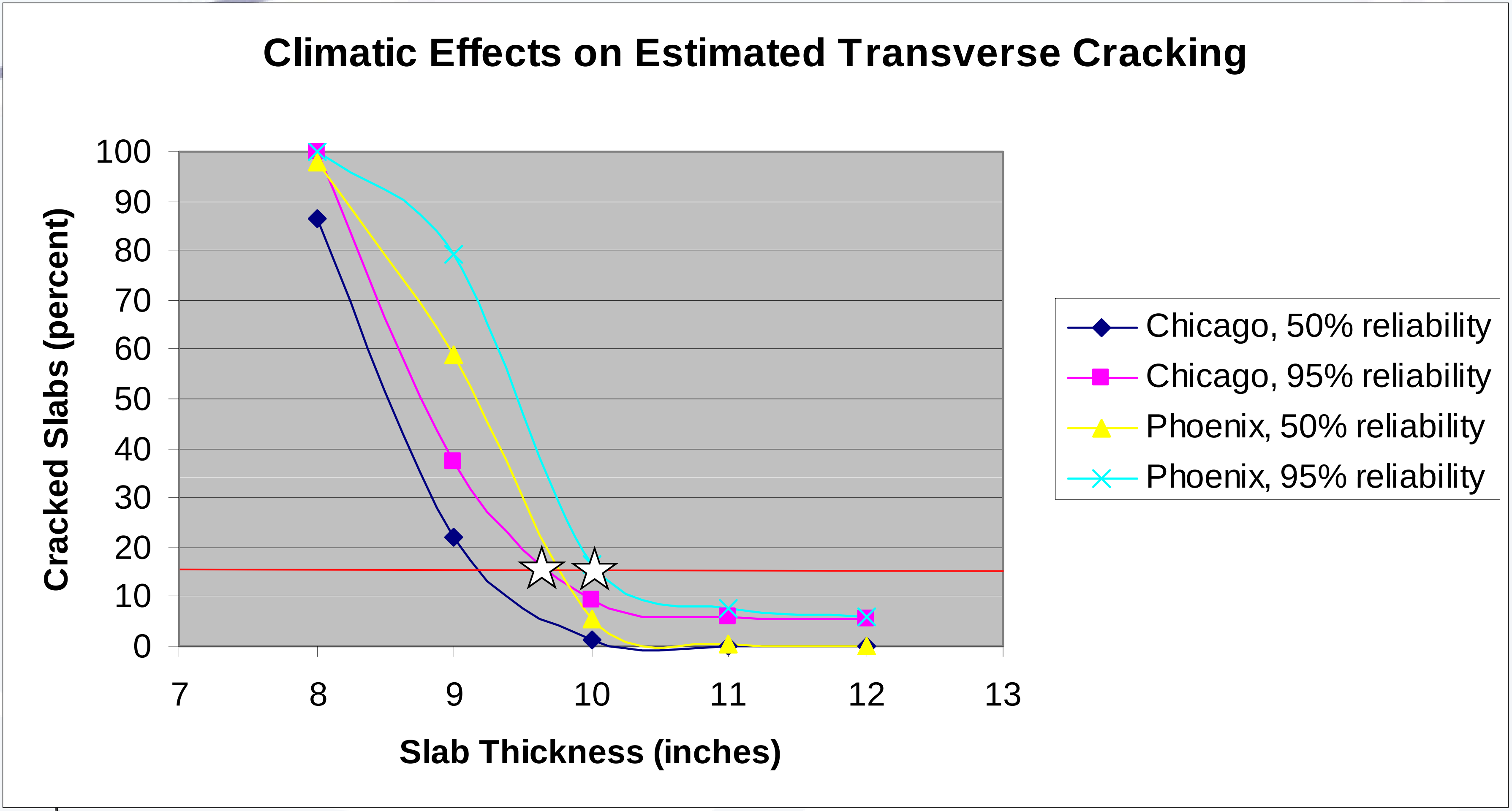
# Concrete Strength, Cracking



# Base Type, Cracking



# Climatic Effects, Cracking

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# What Isn't Covered in Design?

- Probably the single most important aspect of long-term pavement performance isn't even listed as a design input.

Concrete Durability

- How can we address durability and what needs to be measured?

Specifications

# Specifications

- Specifications are used to control critical elements of projects.
- All specifications act to assign risk.
  - Method specifications assign risk to the owner.
  - End result specifications assign risk to the contractor.
- Alternative types of specifications are being used on an ever increasing number of projects:
  - Performance based specifications, design/build, warranties and others

# Concrete Materials and Mix Considerations

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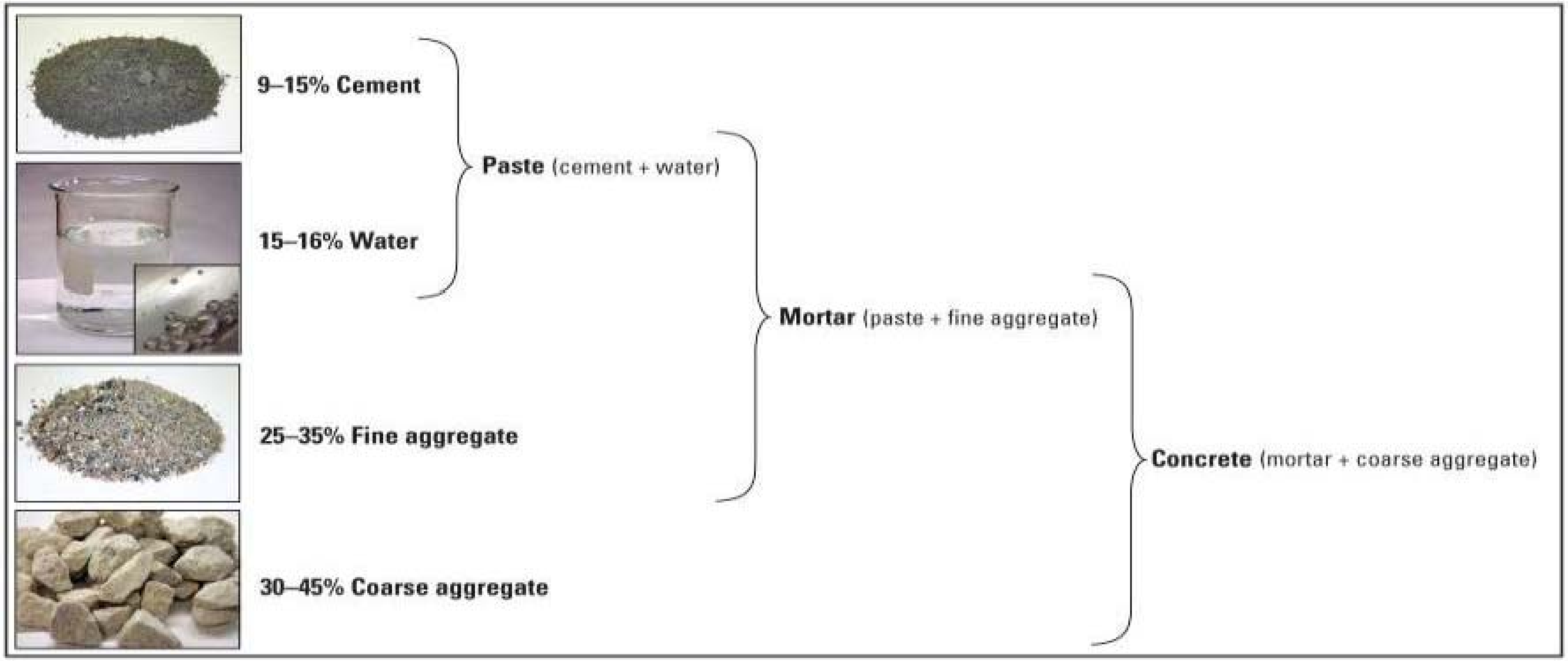
# Concrete Materials




Don't forget about chemical admixtures and SCM's

# Concrete Properties

- The key construction element is UNIFORMITY.
- For most projects, uniformity can only be controlled at the time of batching.
- The following factors are the most important:
  - Workability (slump is NOT a very good indicator).
  - Setting time and rate of strength gain.
  - 28-day strength (or what the specification requires).

# Typical Cement Composition

| Phases | Amount, % | Property |
|---|---|---|
| $C_3S$ | 50 – 55 | Early strength<br>Heat |
| $C_2S$ | 20 – 25 | Later strength |
| $C_3A$ | 5 – 12 | Heat<br>Sulfate resistance |
| $C_4AF$ | ~ 8 | Color |
| $C\bar{S}H_2$ | ~ 5 | Setting<br>Strength/shrinkage<br>Admixture performance |

# Chemical Admixtures

- The most typical admixture types for paving applications are listed below.  Changing the concrete mix and components may change requirements .
  - Air entraining admixtures (AEA).
  - Water reducers.
  - Set-modifying admixtures.

# Aggregates

- Aggregates comprise the majority of the volume of a concrete mix.
- Aggregate properties have a strong influence on the following concrete properties:
  - Durability.
  - Workability.
  - Strength.
  - Dimensional changes in concrete.
  - Many others.

# Aggregates in Concrete

- The physical properties of aggregates (natural or manufactured) have a strong effect on the properties of fresh and hardened concrete:
  - Gradation.
  - Surface texture.
  - Particle shape.
  - Absorption.
  - Durability.

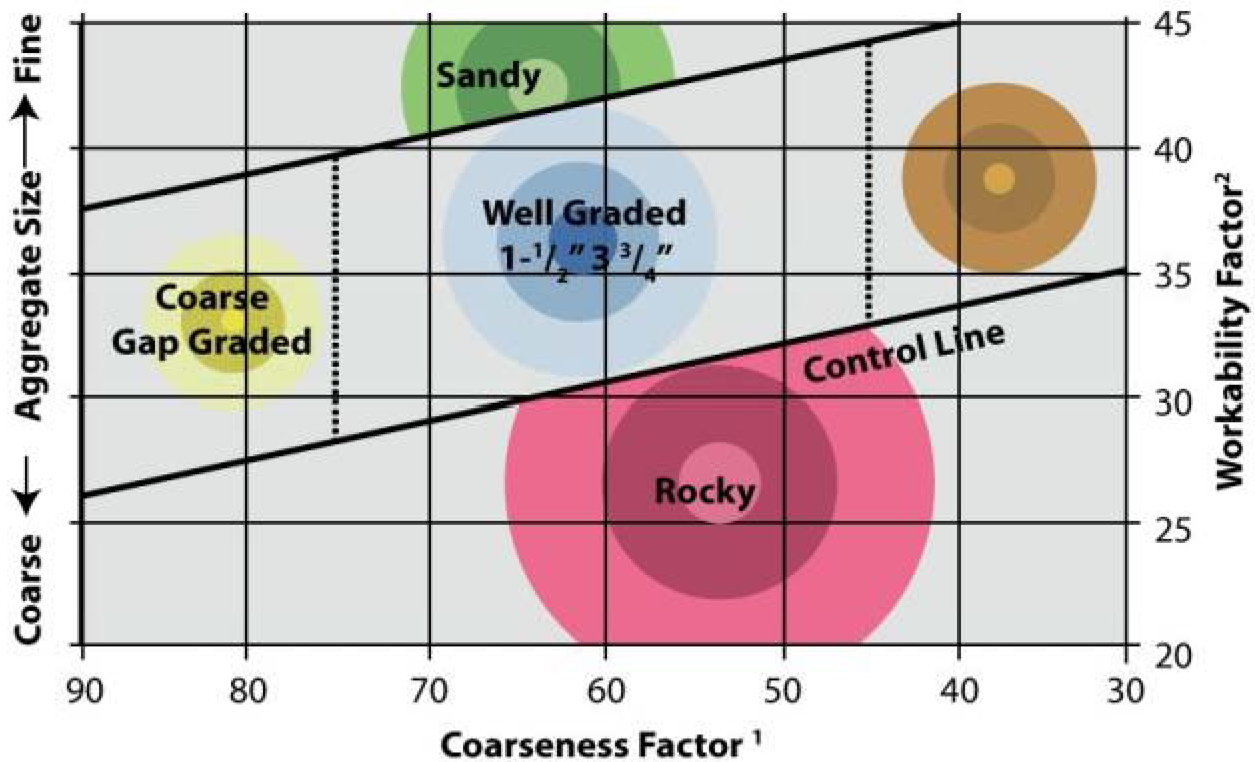
# Aggregate Gradation (cont.)

- The maximum aggregate size used for paving is usually 1½ inches or less.
- Well-graded aggregates are desirable:
  - Maximize aggregate packing.
  - Minimize cement content (economical).
  - More workable.
  - Less drying shrinkage.

# Aggregate Gradation (cont.)

- Combined grading is used to obtain the maximum aggregate density with the materials at hand.
- Combined grading may use 2 or more aggregate stockpiles (bins)
- Overall material specifications generally represent the total or combined grading, although individual aggregate specifications may apply.

# Shilstone Coarseness Chart




**Notes:**

1. *Coarseness Factor* = $\frac{\text{\% Retained Above 3/8" (9.5mm) Sieve}}{\text{\% Retained Above \#8 Sieve}} \times 100$

2. *Workability Factor* = *% Passing #8 Sieve*

# Field Testing Plan

- The 3 categories of testing include:
  - Prior to production.
  - Mix design evaluation.
  - Mixer uniformity test.
- These procedures are suggested when a new mix is being evaluated, regardless of project size.

# Adjusting Properties

- Subject to the results of the trial batches, adjustments to the mix are likely
- The most typical mix proportion adjustments include:
  - Workability
  - Stiffening/setting
  - Bleeding
  - Air void system
  - Unit weight
  - Others

# Final Thoughts on Materials

- The stockpiles at either the ready mix plant or the batch plant need to be constantly checked. If the project requires the Contractor to provide the QC, then the control charts should be maintained continuously.
- Admixtures – check the compatibility with the cement, fly ash or slag.

# Subgrades and Subbases

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# Subgrades and Subbases

- Roadbed (subgrade and subbase) design is key to long-term performance and smoothness of concrete pavements.
  - Terminology
  - Design Principles
  - Subgrades
  - Subbases

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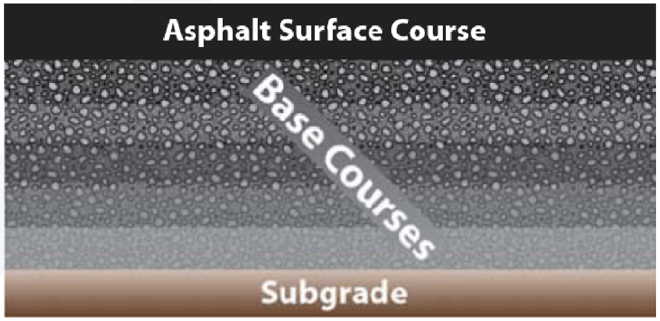
# Terminology

- A **concrete pavement** structure typically consists of a concrete surface and **subbase(s)** placed upon a prepared **subgrade.**
- A "**base**" is part of an **asphalt pavement** structure, while a **subbase** is an optional element of a concrete pavement structure.

Concrete Pavement Structure



Asphalt Pavement Structure

# Terminology

- Why the difference in terminology?
  - **Pressures** imposed on a **base** (under asphalt) are dramatically **different** than those imposed on a **subbase** (under concrete) due to differences in moduli (stiffness) of the surface layer.
  - Material requirements for a subbase may be relaxed when compared to a base.

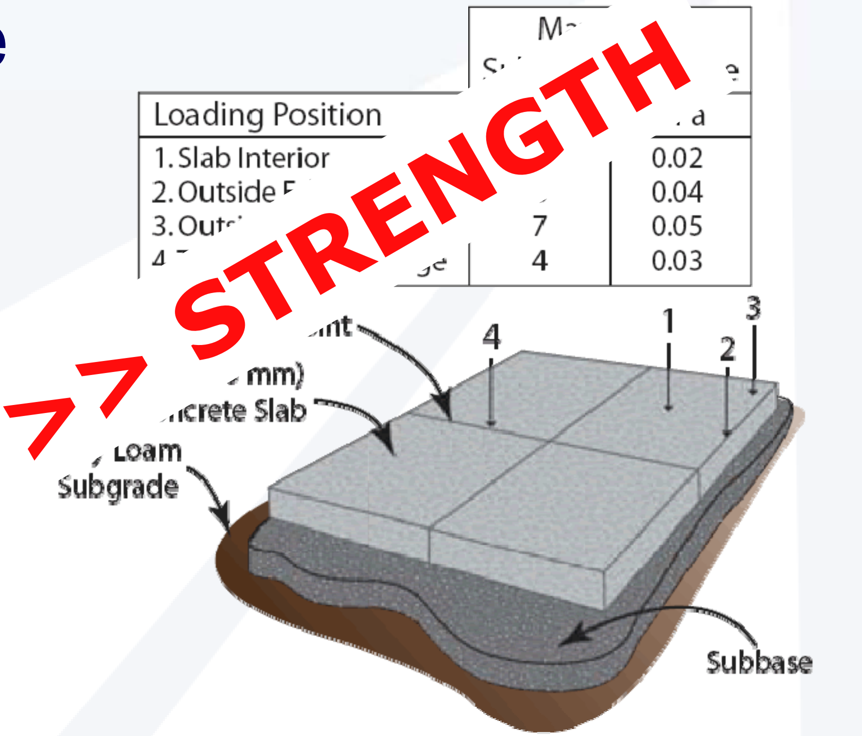
# Design Principles

- Roadbeds for a concrete pavement structure should:
  - Be free from abrupt changes in character of the materials (should be uniform and constructed of a material that will provide requisite stability over the life of the pavement)
  - Resist erosion
  - Be engineered to control subgrade soil expansion and frost heave.
- Above all other design concerns, **uniformity is of utmost importance.**

# Design Principles

- Because of the rigid nature of concrete pavements, loads are distributed over relatively large areas, greatly reducing stresse[illegible] on the subgrade/s[illegible] thus, concret[illegible]ents do not [illegible]ly require e[illegible]ally strong fou[illegible]dation support.

**UNIFORMITY >> STRENGTH**




A 12,000 lb (5,400 kg) load is placed on a 12 in. (380 mm) plate. This yields a pressure of 106 psi (0.73 MPa) on the pavement surface and the resultant subgrade pressures listed above.

# Design Principles

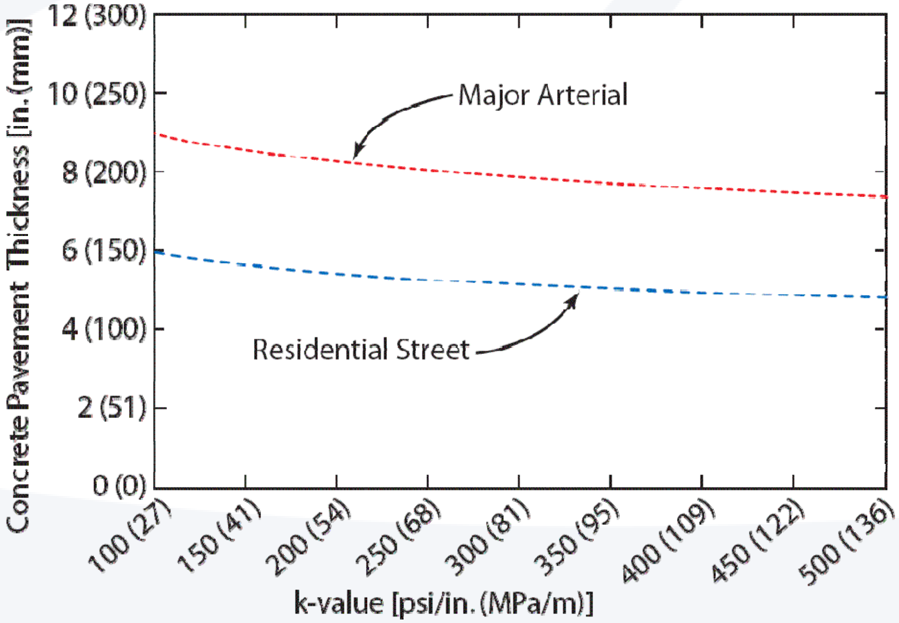
- Subgrade/subbase design is engineering:
  - The pavement design engineer should consider all subgrade/subbase types (stabilized or unstabilized) and available materials (recycled or virgin) for each pavement design; there is no standard recommended subgrade/subbase combination for any concrete pavement.
- Subgrade/subbase selection/engineering is the designer's option!

# Subgrades

- Means to control wet soils:
  - Enhancement – removing excessive moisture by providing drainage via trenches or toe drain; compacting the subgrade using heavy equipment; or adjusting the moisture content through chemical modification
  - Reinforcement/Separation – removing excessive moisture by using a geosynthetic
  - Substitution – removing excessive soils and replacing with select borrow material or, alternatively, covering up excessive soils with a suitable material

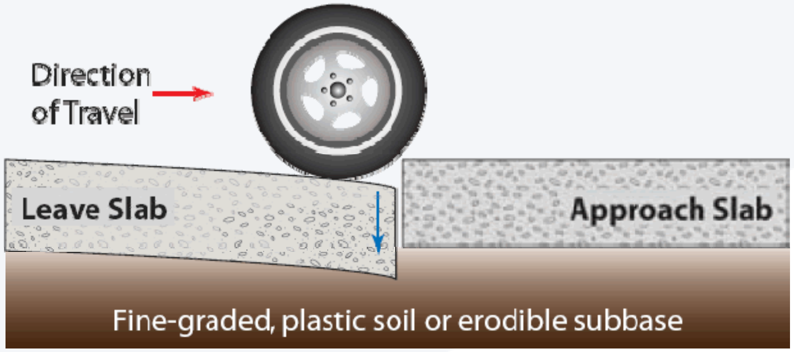
# Subbases

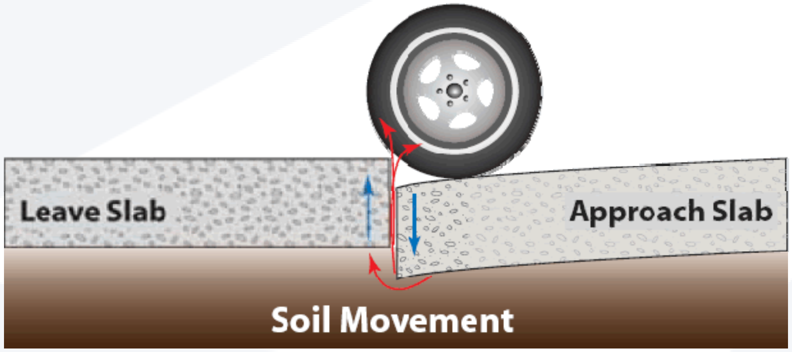
- Concrete pavement design thickness is relatively insensitive to support stiffness (modulus of subgrade reaction), so it is improper engineering to make a subgrade/subbase stronger or thicker in an attempt to decrease concrete pavement thickness…



# Subbases

- Pumping of concrete pavements




# Subbases

- For pumping of a subbase to occur, several conditions must exist:
  - The pavement must have undoweled joints or joints with poor load transfer
  - Water must be present
  - The roadway must have fast moving, heavy loads
  - The subgrade must be a fine-grained material or the subbase must be an erodible material
- Eliminating one or more of these casual factors should mitigate pumping.

# Subbases

- Do you need a subbase?
  - Pavements that are expected to carry 200 trucks or fewer per day (or less than 1,000,000 18-kip (80 kN) ESAL's over the course of the service life of the pavement) do not typically require a subbase to prevent pumping.
  - A subgrade soil that is naturally free draining typically will not pump.
  - Subgrade soils with less than 45% passing a No. 200 (75 μm) sieve and with a PI of 6 or less are adequate for moderate volumes of heavy truck traffic without the use of a subbase layer.

# Subbases

- Subbase Types:
  - Unstabilized (granular) - 4 in. (100 mm) min. thickness
  - Stabilized
    - Cement-Stabilized
      - Cement-Treated (CTB) - 4 in. (100 mm) min. thickness
      - Lean Concrete (LCB) - 4 in. (100 mm) min. thickness
    - Asphalt-Stabilized (ATB) - 2 in. (50 mm) min. thickness
- With any subbase type, it is possible to utilize waste material (i.e., recycled concrete) as aggregate.

# Subbases

- Regardless of subbase type, the best results are obtained by:
  - Selecting materials that prevent pumping
  - Selecting materials that will not contribute to excessive deflections and will remain stable over time
  - Treating the subbase surface (if necessary) to prevent bond to the concrete pavement
  - Specifying material gradation that will ensure a reasonably consistent (and uniform) subbase across an individual project
  - Building the subbase to grade controls that foster a consistent concrete pavement thickness and smoothness

# Unstabilized Subbases

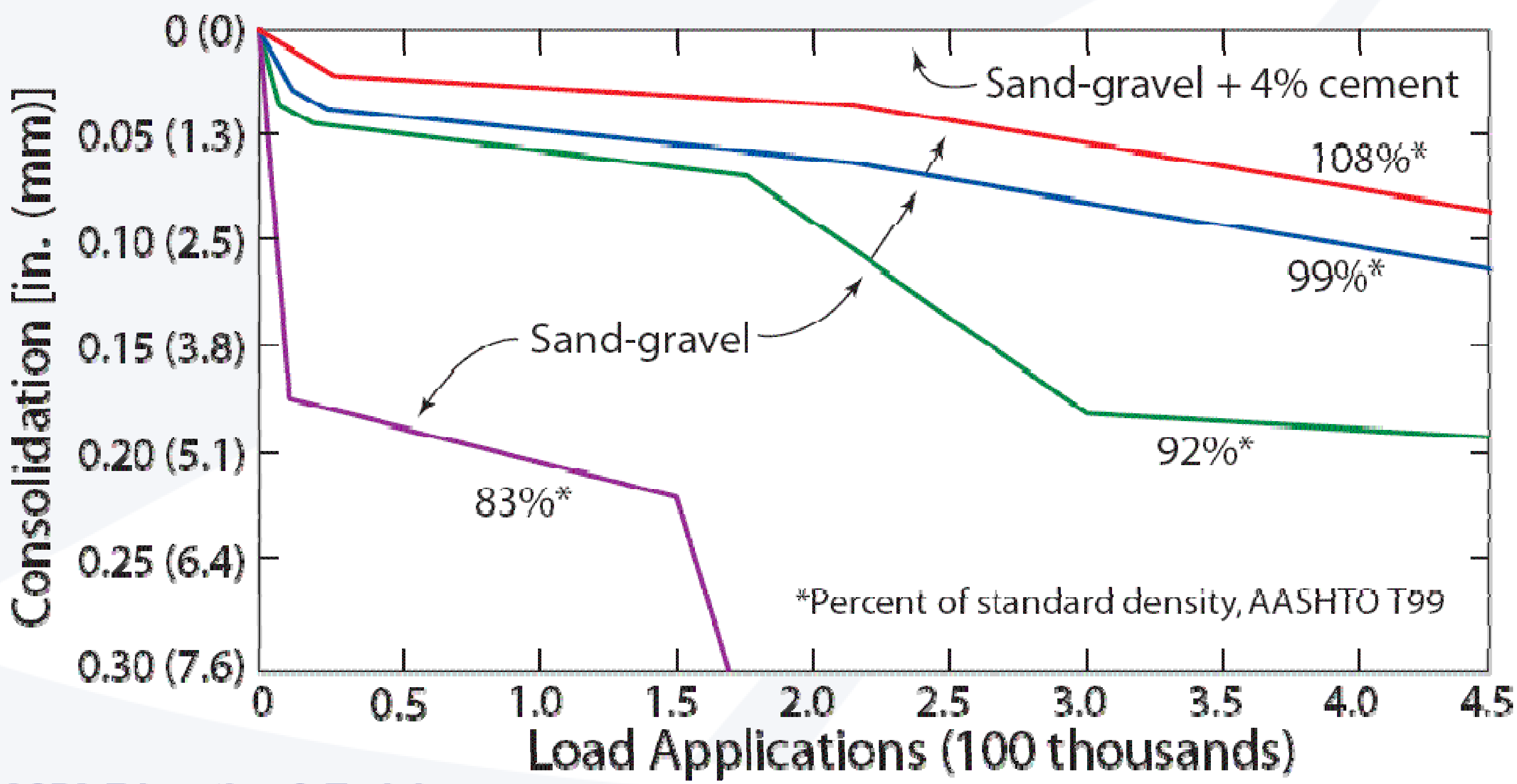
- Unstabilized subbases must have:
  - A 4 in. (100 mm) min. thickness
  - A maximum particle size of no more than 1/3 the subbase thickness
  - Less than 15 percent passing the No. 200 (75 µm) sieve
  - An in-place density of 95 percent according to AASHTO T99
  - A Plasticity Index (PI) of 6 or less
  - A Liquid Limit (LL) of 25 or less
  - A L.A. abrasion resistance of 50% or less
  - A grade tolerance of ± ½ in. (± 12 mm) by a 10 ft (3 m) straightedge
  - A target permeability of about 150 ft/day (45 m/day), but no more than 350 ft/day (107 m/day) in laboratory tests (free-draining, NOT PERMEABLE)
- Of these, limiting the percent of fines passing the No. 200 (75 µm) sieve is of utmost importance to creating a long-lasting unstabilized subbase that will prevent pumping.

# Unstabilized Subbases

- Typical job control tolerances from the target gradation for unstabilized subbases are:
  - ±10% for materials 1 in. (25 mm) and larger.
  - ±8% for materials between 1 in. and No. 4 (25 mm and 4.75 mm).
  - ±5% for materials No. 4 (4.75 mm) and smaller.
- The finished tolerance of the unstabilized subbase should be ±1/2 in. (± 12 mm) of the design profile grade.

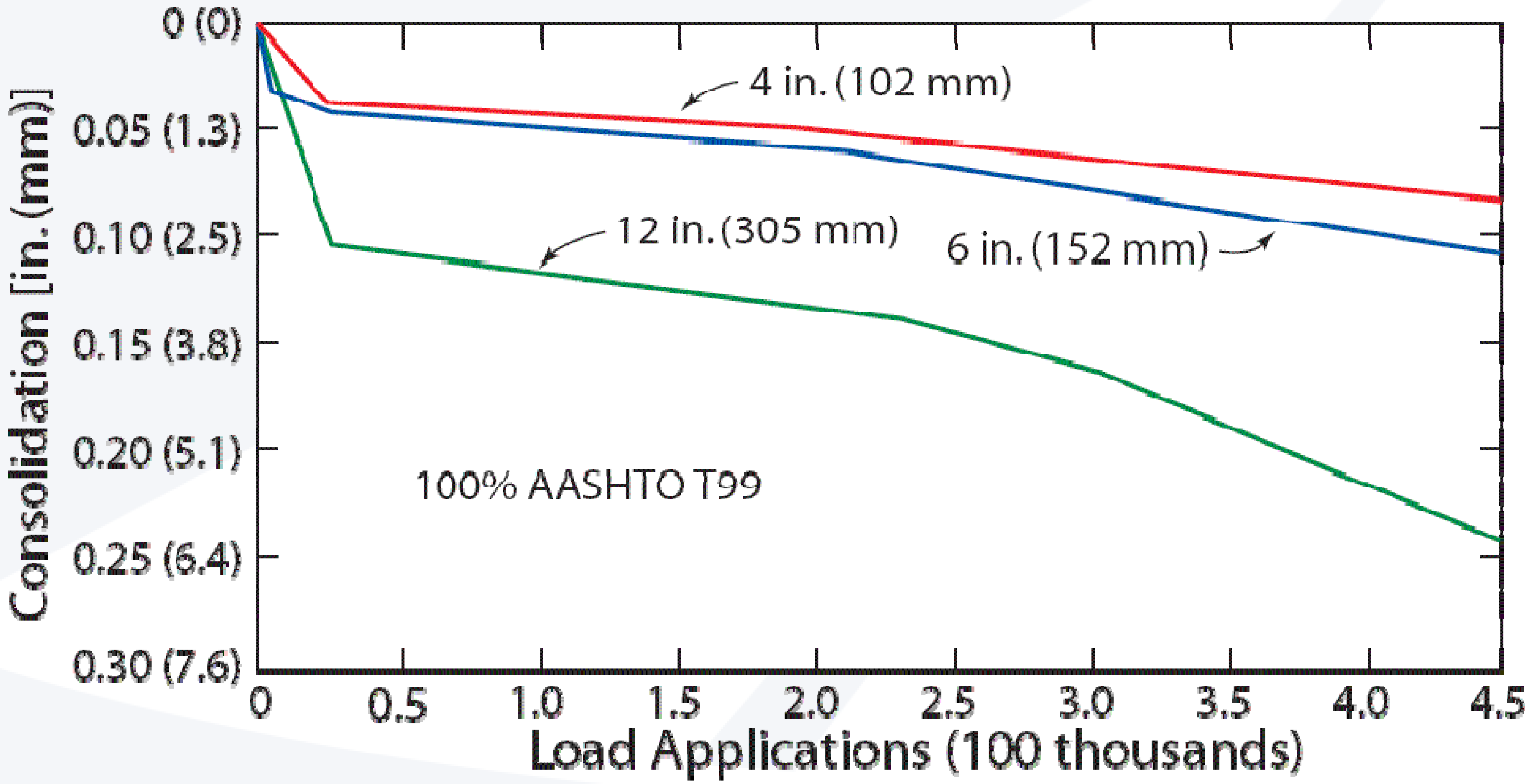
# Unstabilized Subbases

- Be sure to consolidate to spec!



# Unstabilized Subbases

- And at the proper thickness!



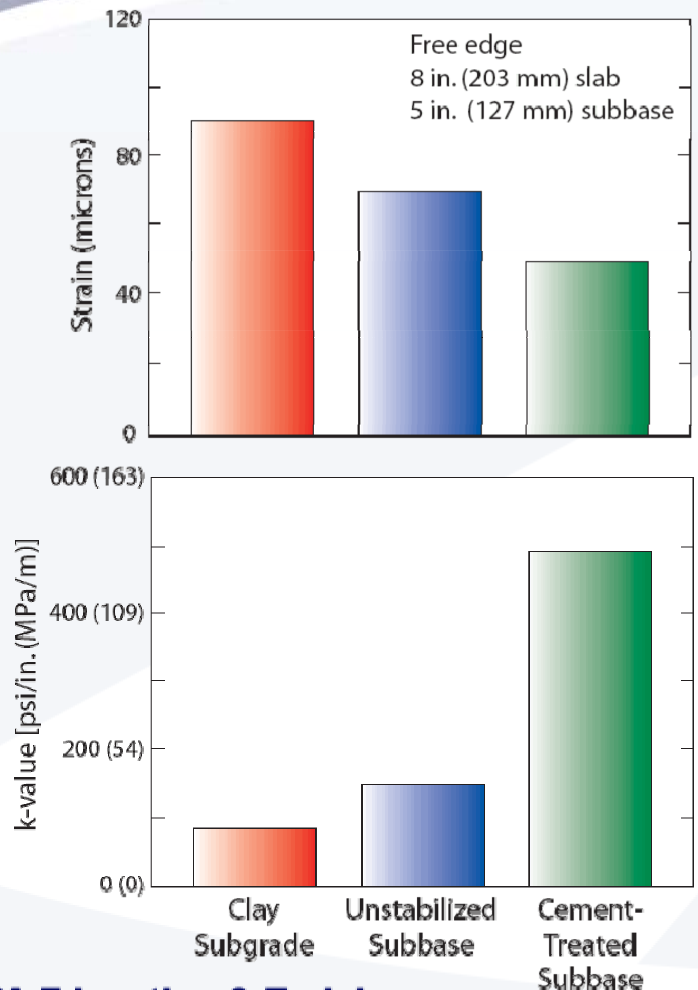
# Stabilized Subbases

- Stabilized subbases generally refer to subbase materials that are bound by either cement or asphalt.
- The higher degree of support offered by a stabilized subbase will not alter the required concrete pavement slab thickness appreciably, but it will add pumping resistance and increase the overall strength of the pavement structure, spreading loads over larger areas and reducing strains.

# Stabilized Subbases

| Erosion Potential | Material Types |
|---|---|
| Extremely resistant | Lean concrete with 7-8% cement.<br>Asphalt-treated subbase with 6% asphalt or greater. |
| Resistant | Cement-treated subbase with 5% cement. |
| Resistant under certain conditions | Cement-treated subbase with 3-5% cement.<br>Asphalt-treated subbase with about 3% asphalt. |
| Fairly erodible | Cement-treated subbase with less than 3% cement.<br>Unstabilized granular subbase. |
| Very erodible | Contaminated untreated granular materials.<br>Unstabilized fine subbase. |

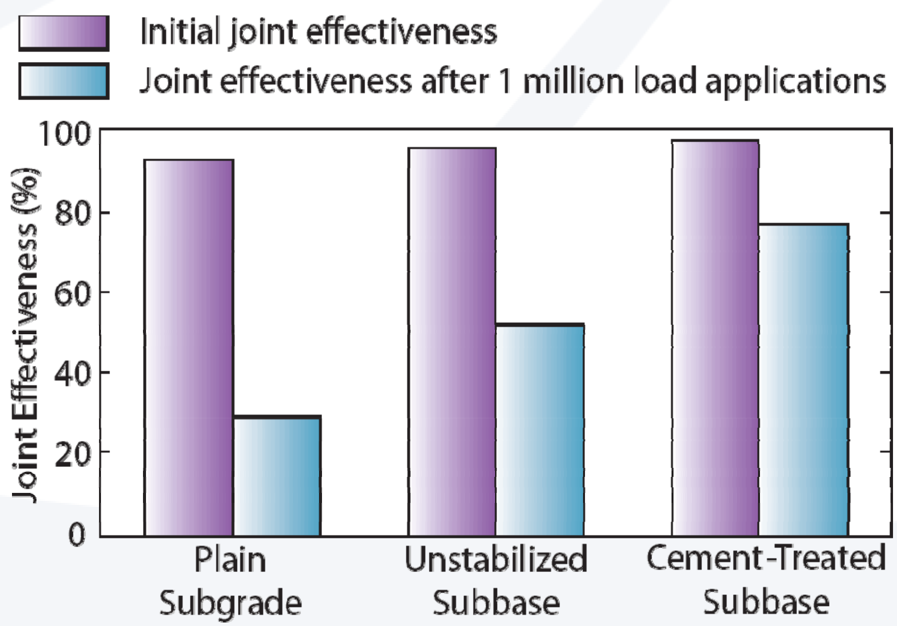
# Stabilized Subbases




- Although increased foundation stiffness via increased strength is beneficial from an applied loads point-of-view, it could potentially have a negative impact on environmentally induced stresses and strains.

# Stabilized Subbases

- On a cement-treated subbase, the loss of support occurs at a much slower rate.  In this study it stabilized around one-half million load applications; even after 1 million loads, joint effectiveness remains at a level of almost 80 percent.



# Stabilized Subbases

- Other benefits of stabilized subbases:
  - An excellent, stable all-weather construction platform
  - Bound subbase surfaces drain water quickly
  - Aid in improving the final pavement smoothness
  - Minimize post-construction subbase consolidation
  - Minimize intrusion of hard granular particles into the bottom of pavement joints
  - Provide an erosion resistant subbase
  - Permit greater use of local materials

# Alternative Subbase Materials

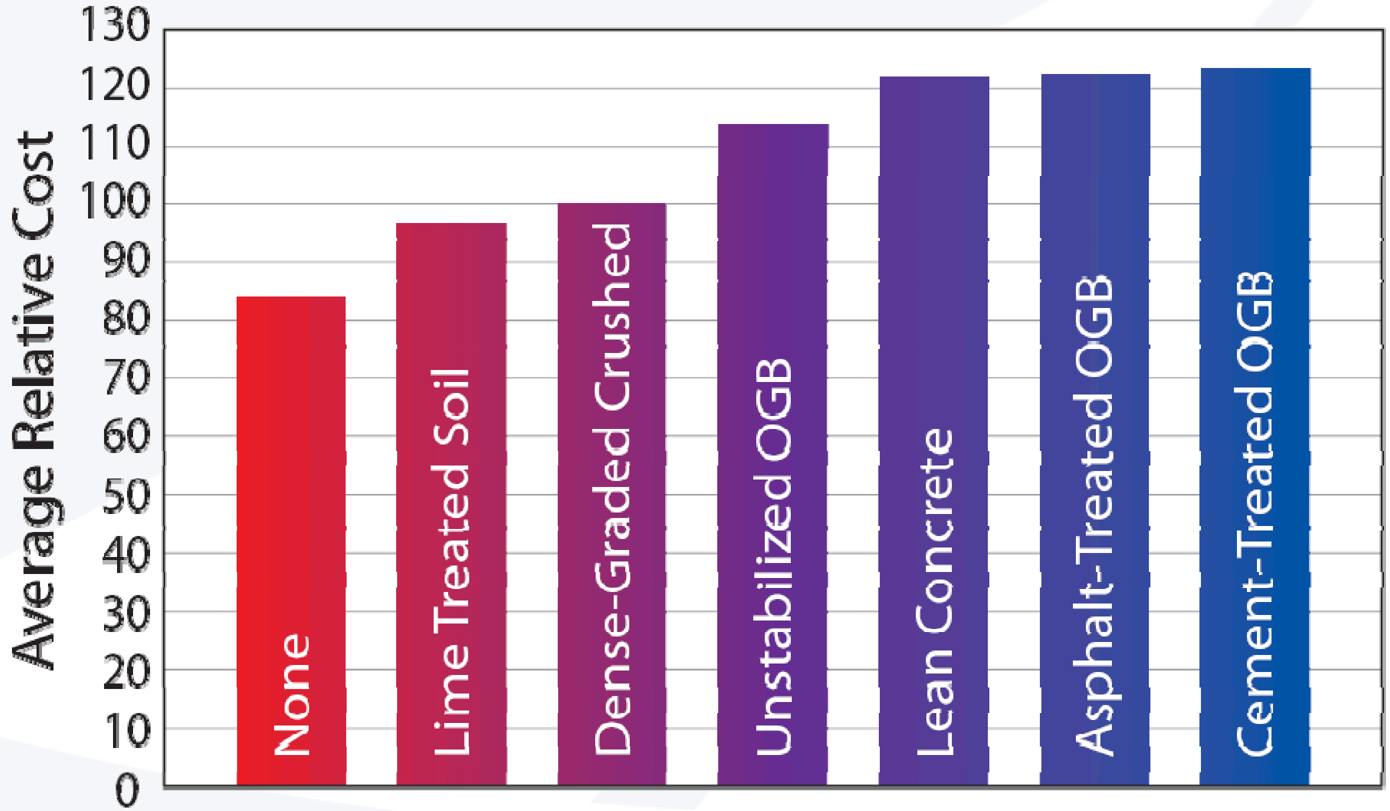
- Recycled concrete and other alternative subbase materials should be considered for inclusion in a subbase for their positive economic and environmental benefits, as well as resource conservation.
- Benefits of using alternative subbase materials:
  - Performance
  - Economics
  - Resource conservation
  - Environmental considerations

# Permeable Subbases

- Permeable subbases (subbases with a permeability of 350 ft/day (107 m/day) or greater in laboratory tests) have had a problematic history in the field.
- The reasons include:
  - Instability as a construction platform
  - Loss of support caused from aggregate breakdown
  - Early age cracking caused from penetration of concrete mortar into the subbase voids during paving
  - Intrusion of fines from underlying layers into the permeable subbase voids
  - Loss of support caused from infiltration of the subgrade into the subbase
  - Cost effectiveness
  - Various other overall field performance problems

# Permeable Subbases

- Cost effectiveness:



# Permeable Subbases

- Thus, permeable subbases are no longer recommended for concrete pavement structures.
- Free-draining subbases (subbases with a permeability between 50 and 150 ft/day (15 and 46 m/day) in laboratory tests) and daylighted subbases are a reasonable alternatives to rapidly draining permeable subbases.

# Construction Operations

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# Pre-Construction Meeting

- Provide the owner with the required information,
  - Names & contact information for key project and emergency personnel.
  - Erosion and environmental control plan.
  - Proposed schedule.
  - Materials & subcontractor list.
  - Quality control plan.
- Propose any traffic control plans.
- Confirm the owners expectations – materials, specifications and quality.

# Factors Influencing Quality

- Equipment selection and set-up.
- Grade control (stringline or form setting operations).
- Subgrade and subbase preparation.
- Concrete production and delivery.
- Slipform paver or fixed form equipment operation.
- Dowel bar and tie bar placement.
- Finishing and texturing.
- Curing.
- Sawing operations.

# Equipment Selection

- Equipment selection is typically at the contractor’s discretion.
- The selection will be based on what is available, project size and location, specifications governing the project and so on.
- The quality of the job depends equally on the equipment selected and the skill level of the crew.

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# Slipform Equipment Setup

- Prior to paving, the contractor must check that the paver and all other elements of the paving train are working correctly . Setup is specific to a particular manufacturer and model.
- General paver considerations (abbrieviated list):
  - String line the pan.
  - Check the side-forms, depth, keyways, cleanliness.
  - Check the vibrators.
  - Check the width of the pan.
  - Check the over-build.
  - Check if the kit is tight.
  - Check the sensors are working and are set at the correct sensitivity.
  - Check the tie-bar spacing is correct on the placer.

# Grade Control - Stringline

- Set stringline to the proper elevation based on survey hubs.
- Use suitable material.
- Maintain stringline.
- Use 2 stringlines.
- Common set-up preferred.
- Check, check, and check again!!!

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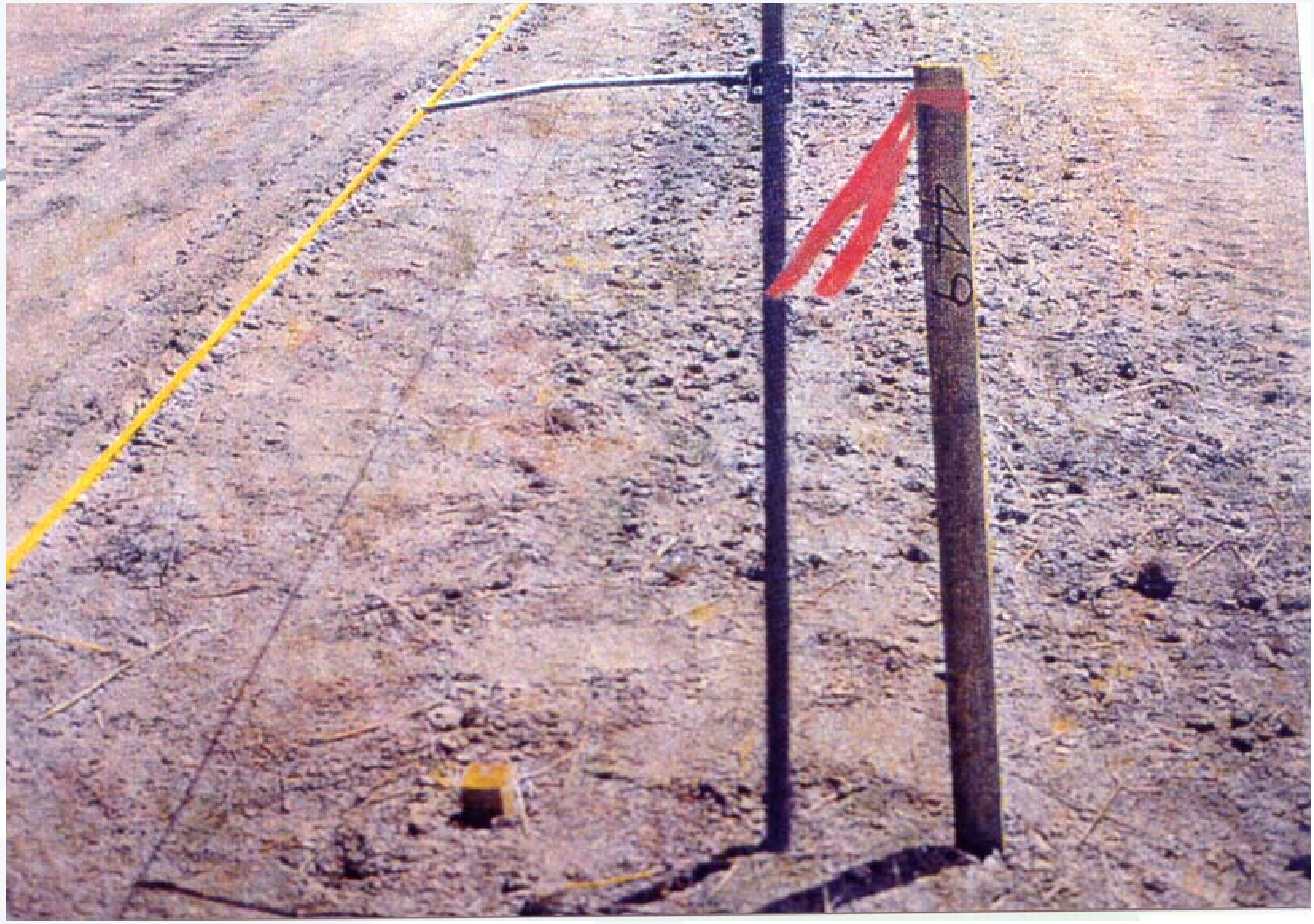
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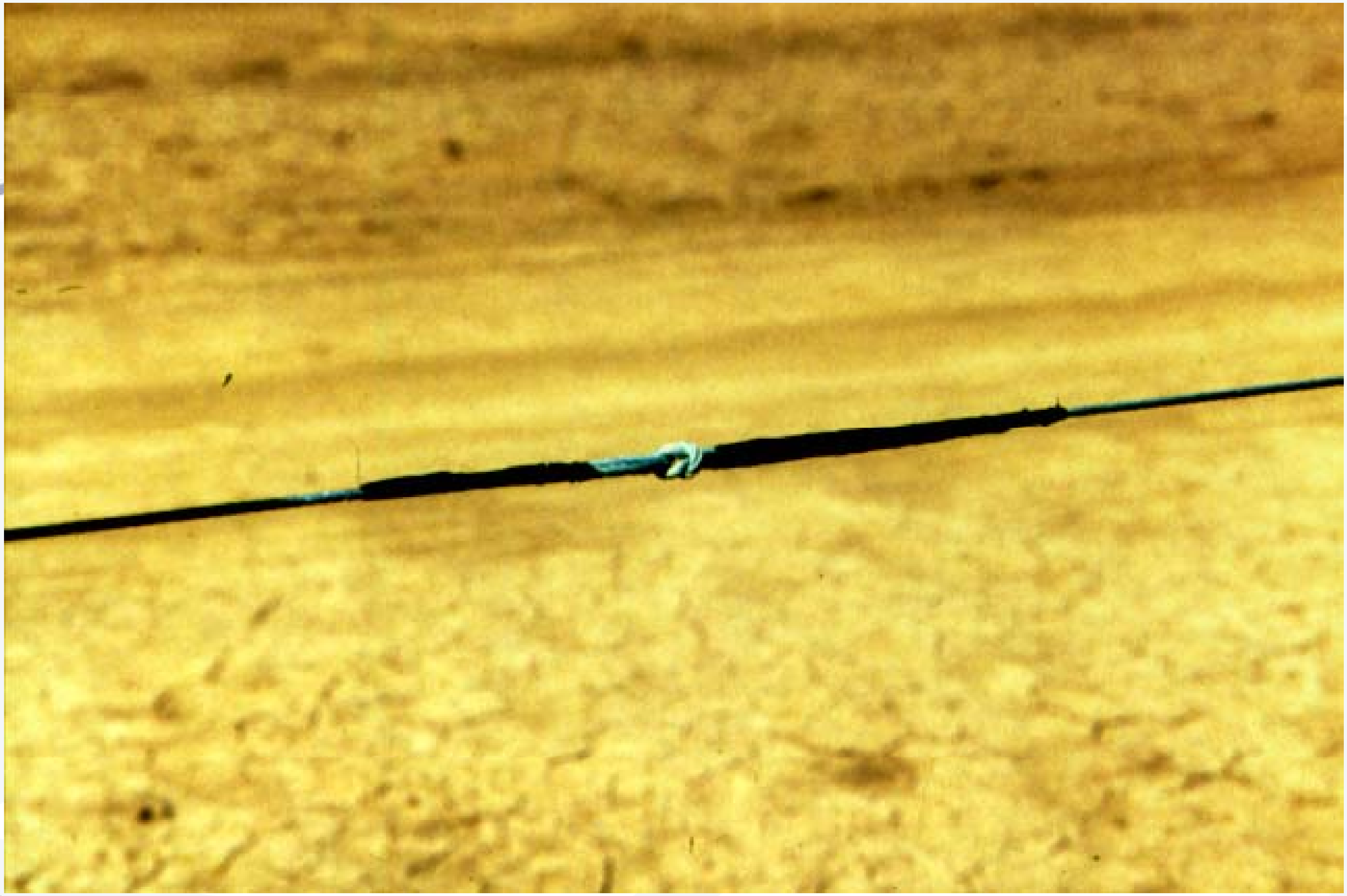

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# Grade Control - Forms

There are many options available in setting forms

The overriding considerations are:

- Match the form type to the placing equipment.
- Follow the established line and grade.
- Place the form on a firm foundation.
- Align the forms properly.

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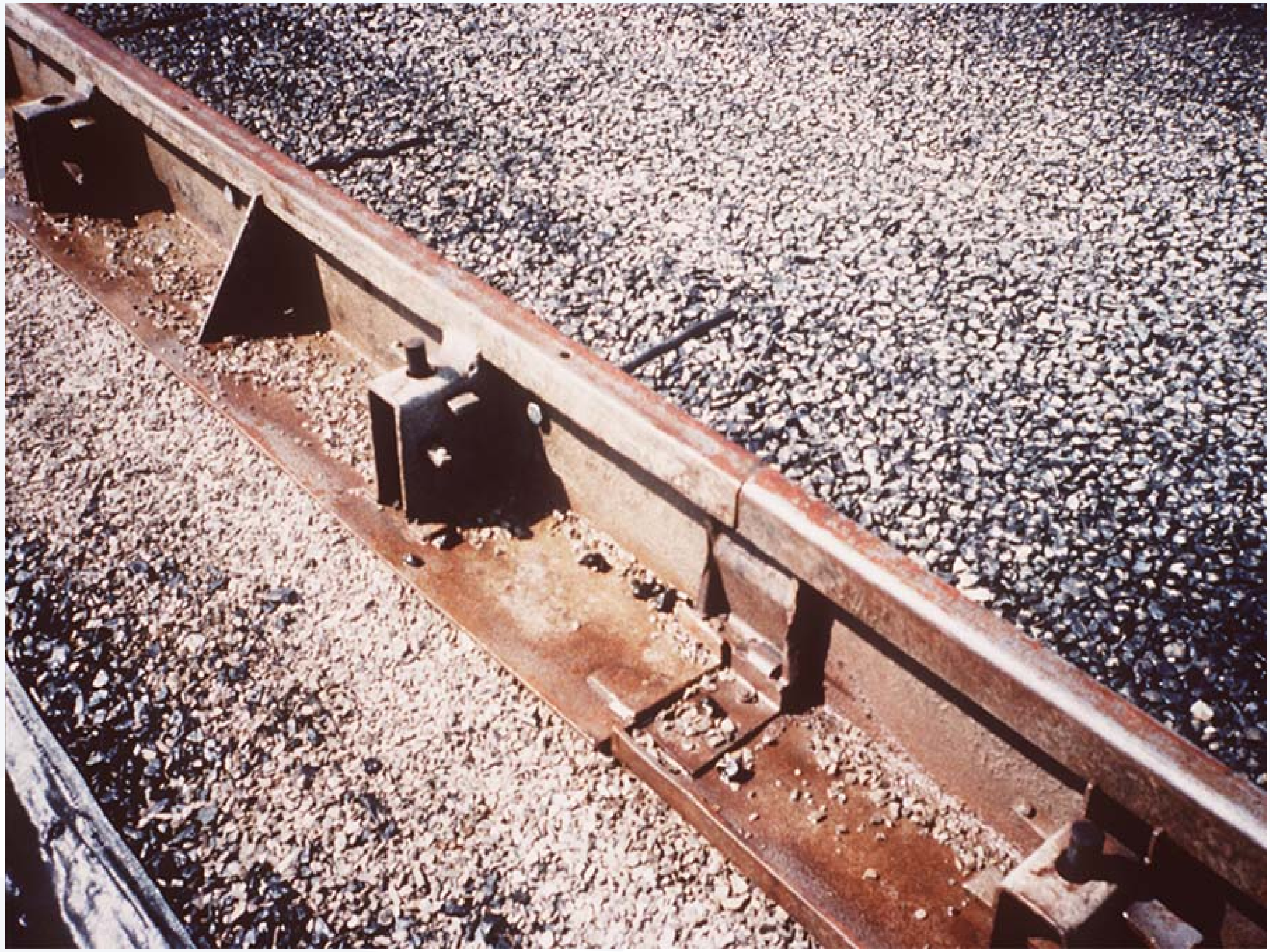

# Grade Preparation

Grade trimming.

# Concrete Production

- Concrete paving projects can utilize both stationary plants and transit mixers, sometimes a combination.
- Plqnt production must match the requirements of the job.
- Siting of the plant, environmental regulations, set-up, calibration and maintenance are all critical factors.


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# Concrete Delivery

- Delivery must be matched to the job type and location
- The paver is the determining factor in the volume of concrete required and therefore generally controls the method of delivery


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# Equipment Operation

- Regardless of the type of equipment used, the paving machine should be operated in a consistent manner.
  - Properly calibrated sensor system (if so equiped).
  - Controlled and uniform speed.
  - Limited starting and stopping (preferably none).
  - Consistent consolidation.

# Paver Sensor System

- Check thoroughly for proper operation
- Set wands level and plumb
- Set counterbalance

# Consolidation

- The internal vibrators on the paver fluidize the concrete for extrusion.
- Adequate consolidation:
  - Required around dowels and tie bars.
  - Throughout the slab.

# Internal Vibration of PCC

Good Consolidation

Poor Consolidation

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# Consolidation

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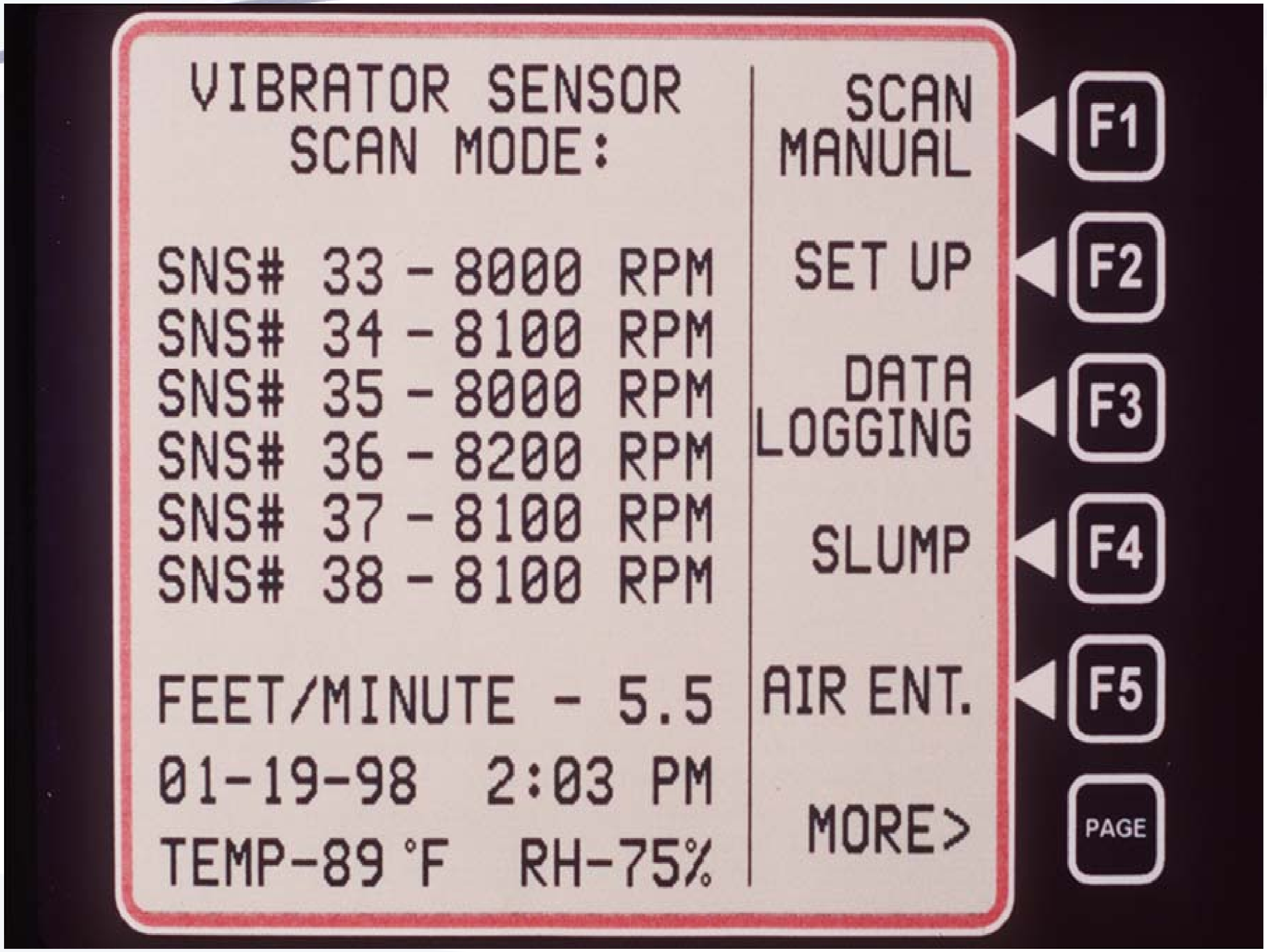
# Vibrator Monitors



# Set Ahead Steel Placement - Dowels

Dowels on Baskets.

# Forces on Dowel Basket Assembly

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# Anchoring the Dowel Basket

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# Anchoring the Dowel Basket

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# Dowel Bar Placement with DBI

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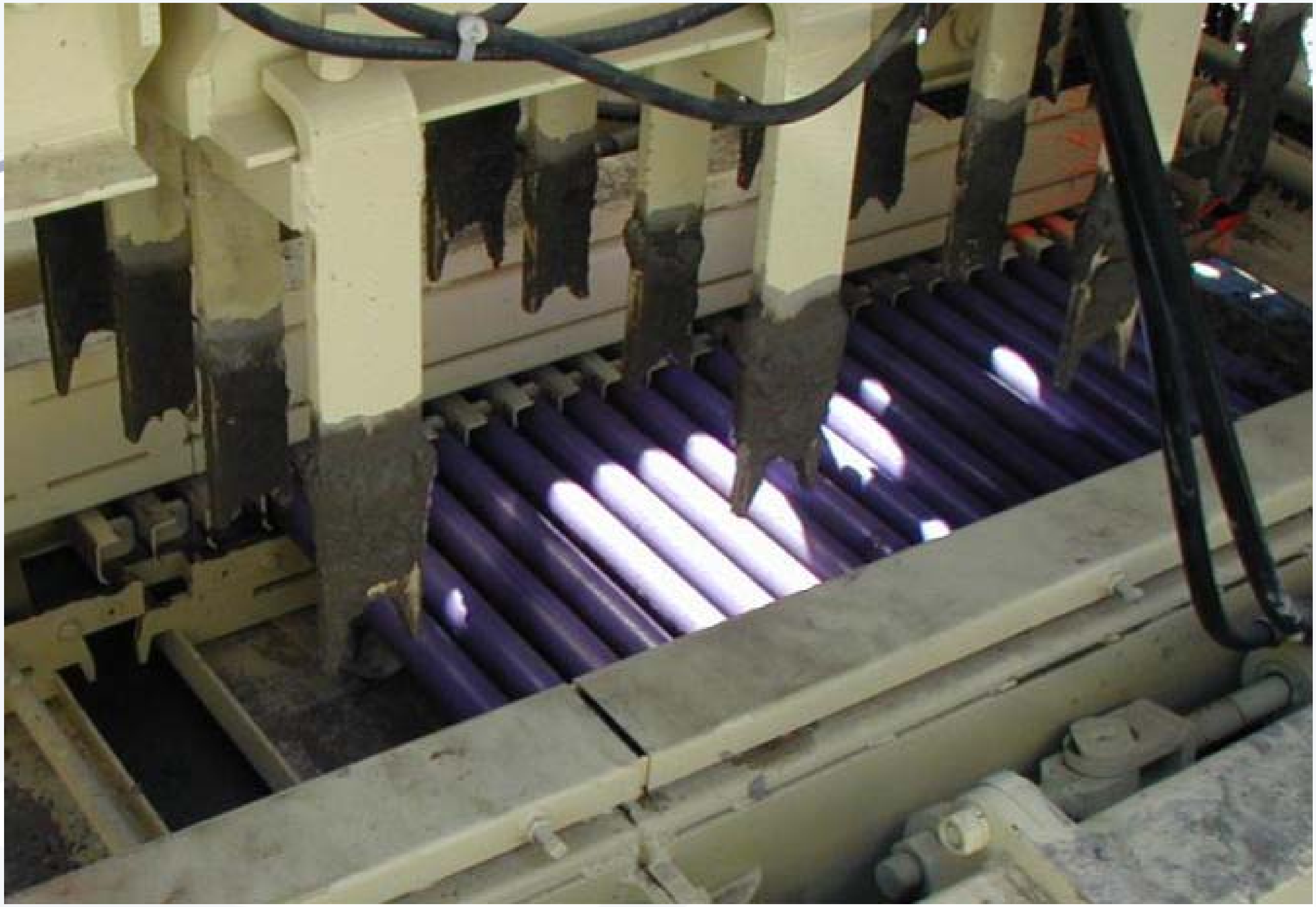

# Tie Bar Insertion


GP 2600
GOMACO
GOMACO
GOMACO


PS-350
83-35

# Finishing and Texturing Operations

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# Finishing Operations

- Finishing does not generally mean hand finishing in the traditional sense
- “Closes” the surface of the concrete
- Mechanized or hand work depending on specific operation
- Straight edging to remove high spots following paver

# Finishing Operations

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# Finishing Operations

# Finishing Operations

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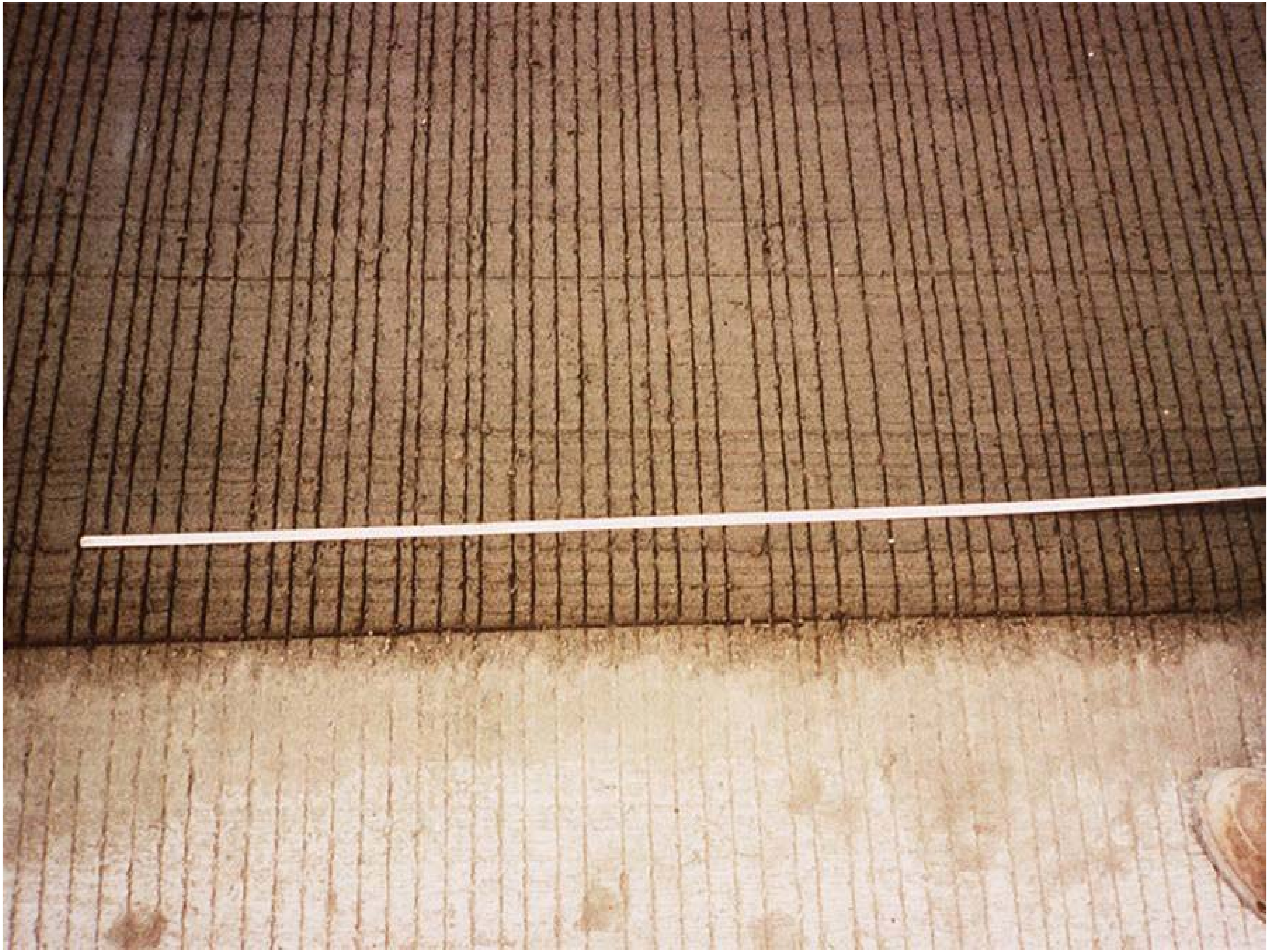
# Why Do We Texture

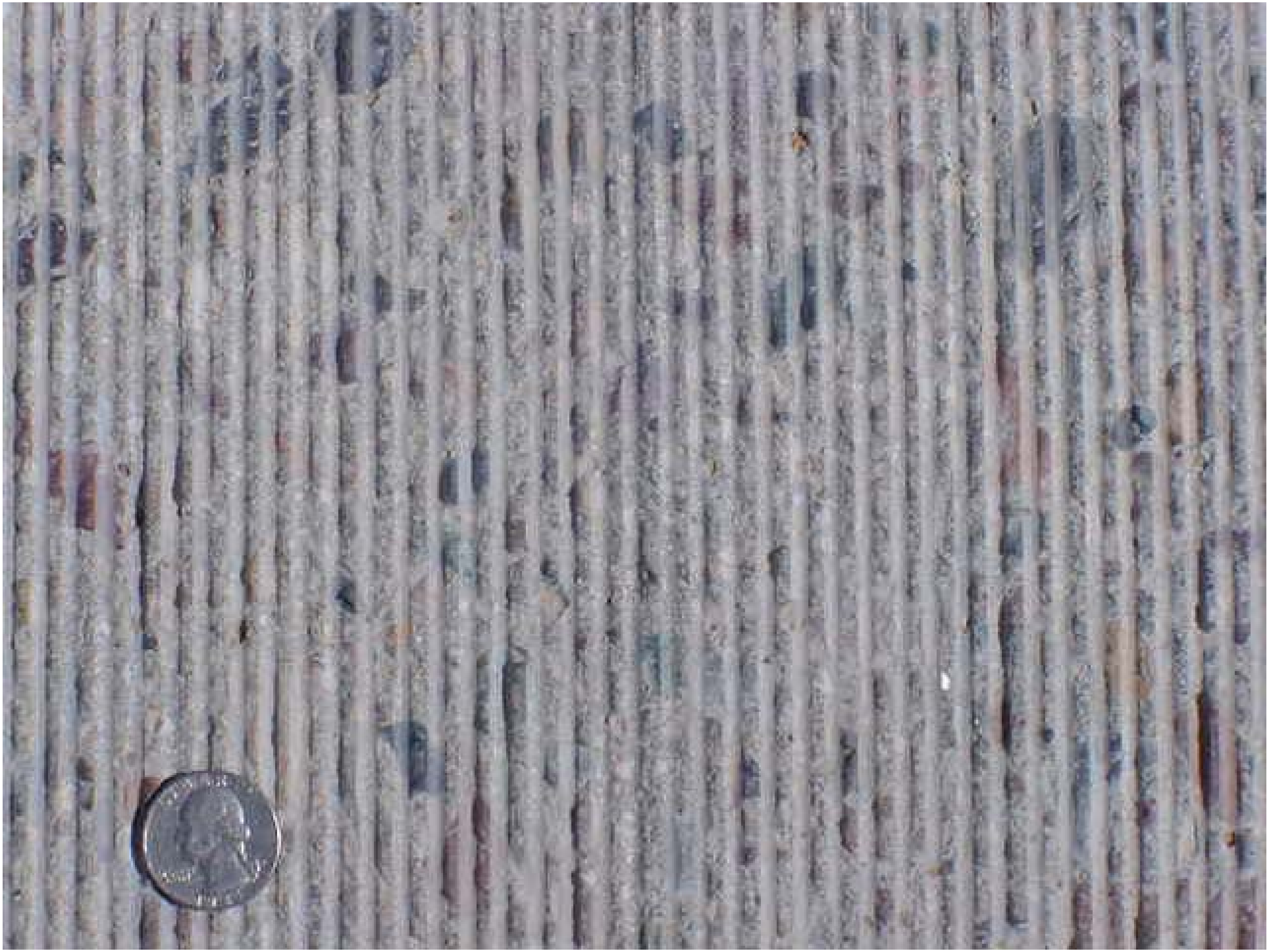
- Safety!!!!
  - Vehicle Control (Lateral Stability)
  - Safe Stopping Distances
- Remove Water from the Pavement
- Provide Benefits During Inclement Weather
- Improve Micro and Macro Texture
- Noise Control

# Texturing

- Texturing options:
  - Drag textures
  - Longitudinal tining
  - Transverse tining
  - Diamond grinding
  - Innovative techniques


L8000
425





# Curing

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# Curing Concrete

Curing includes the following:

- Temperature
- Time
- Moisture

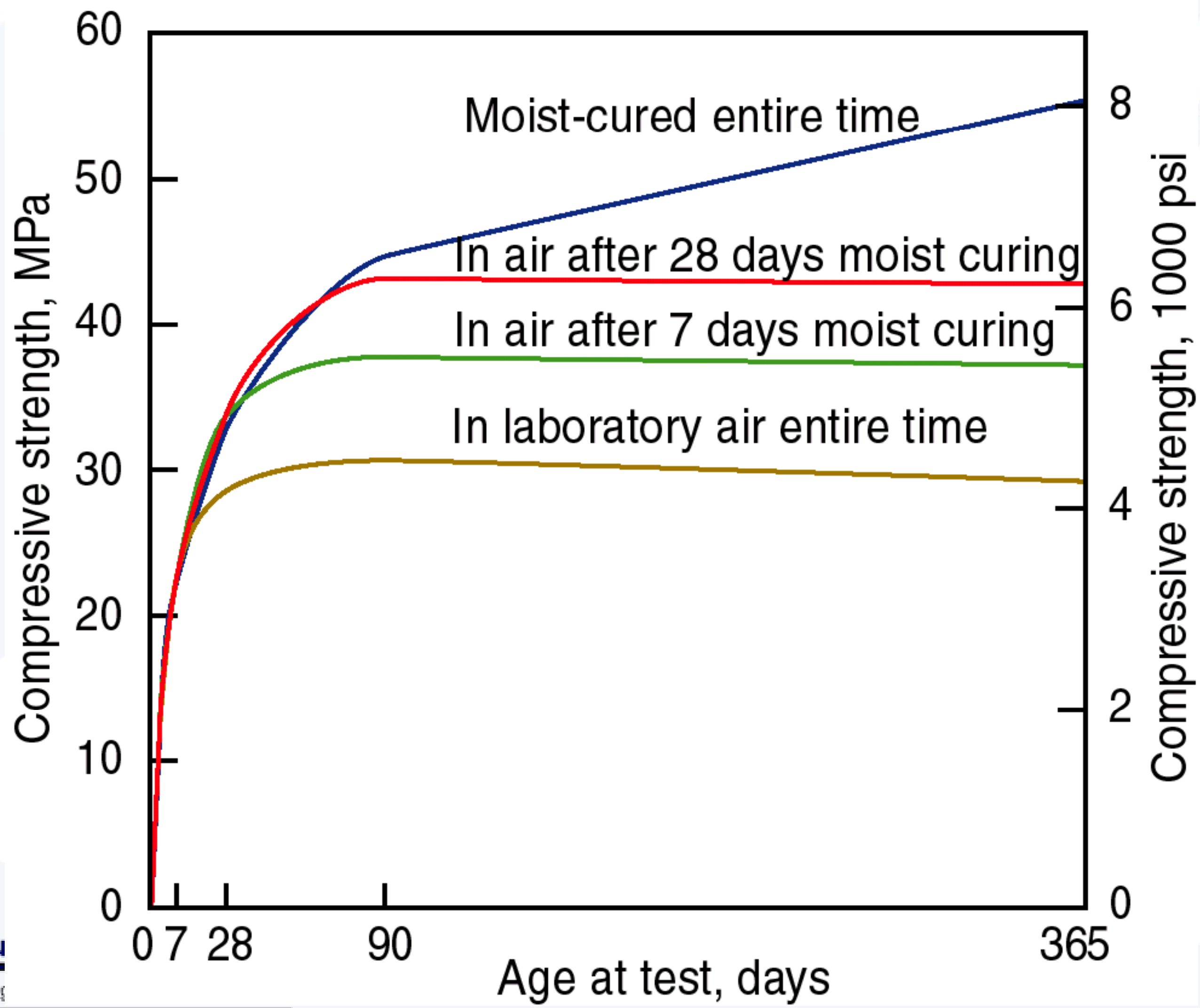
If any of these factors are neglected, the desired properties will not develop

# Effect of Adequate Curing on Hardened Concrete

Adequate curing results in the following:

- Higher strength
- Increased watertightness (decreased permeability)
- Better abrasion resistance
- Increased freeze-thaw resistance
- Better volume stability

# Effect of Moist Curing

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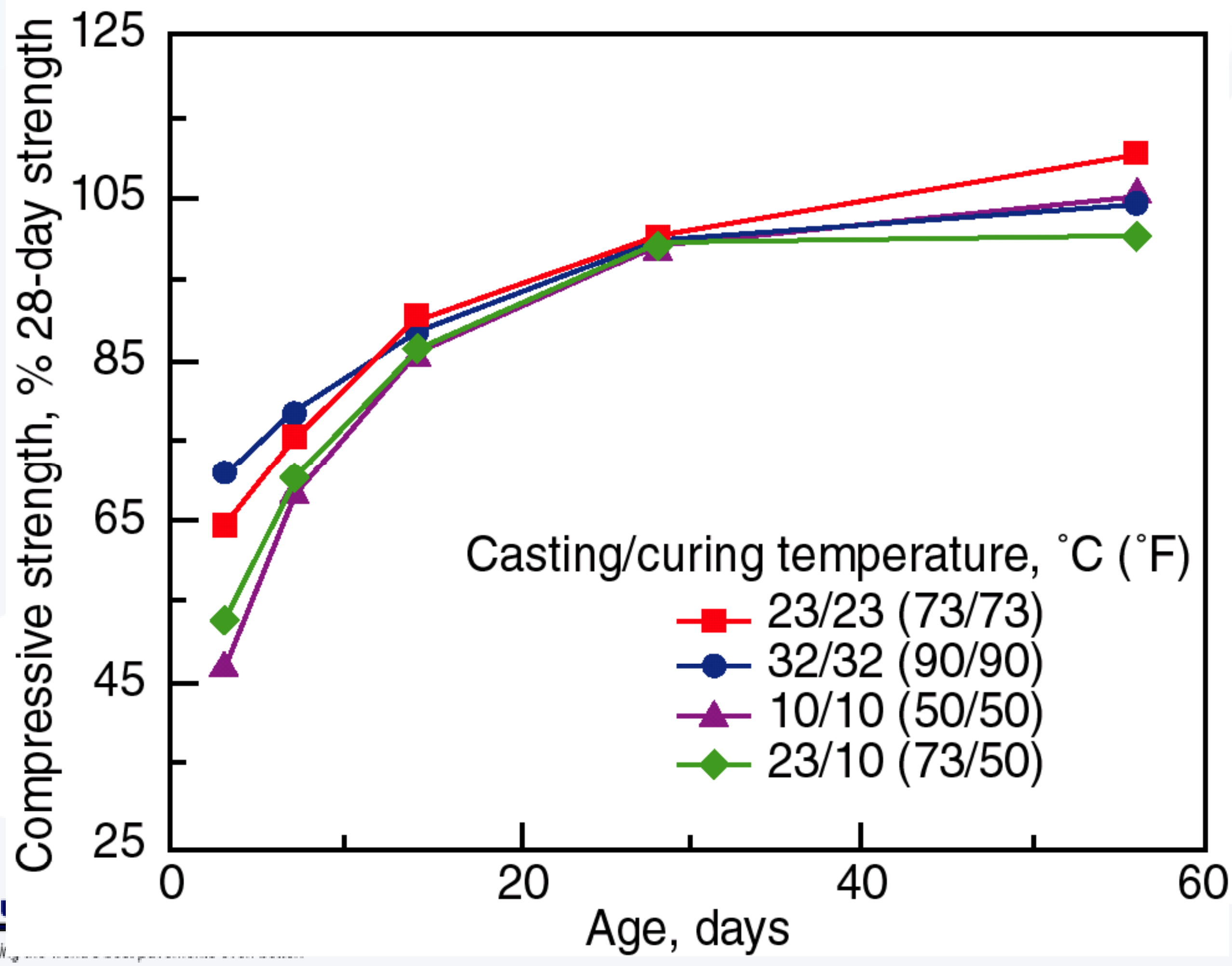
# Effect of Curing Temperature on Strength

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# Curing to Maintain Moisture

- Maintain moisture in concrete:
  - To facilitate hydration
  - To prevent surface (map) cracking
  - To allow the PCC to reach its design strength
  - Others

# Curing Methods

Supply additional water:

- Ponding or immersion
- Spraying or fogging
- Saturated wet coverings

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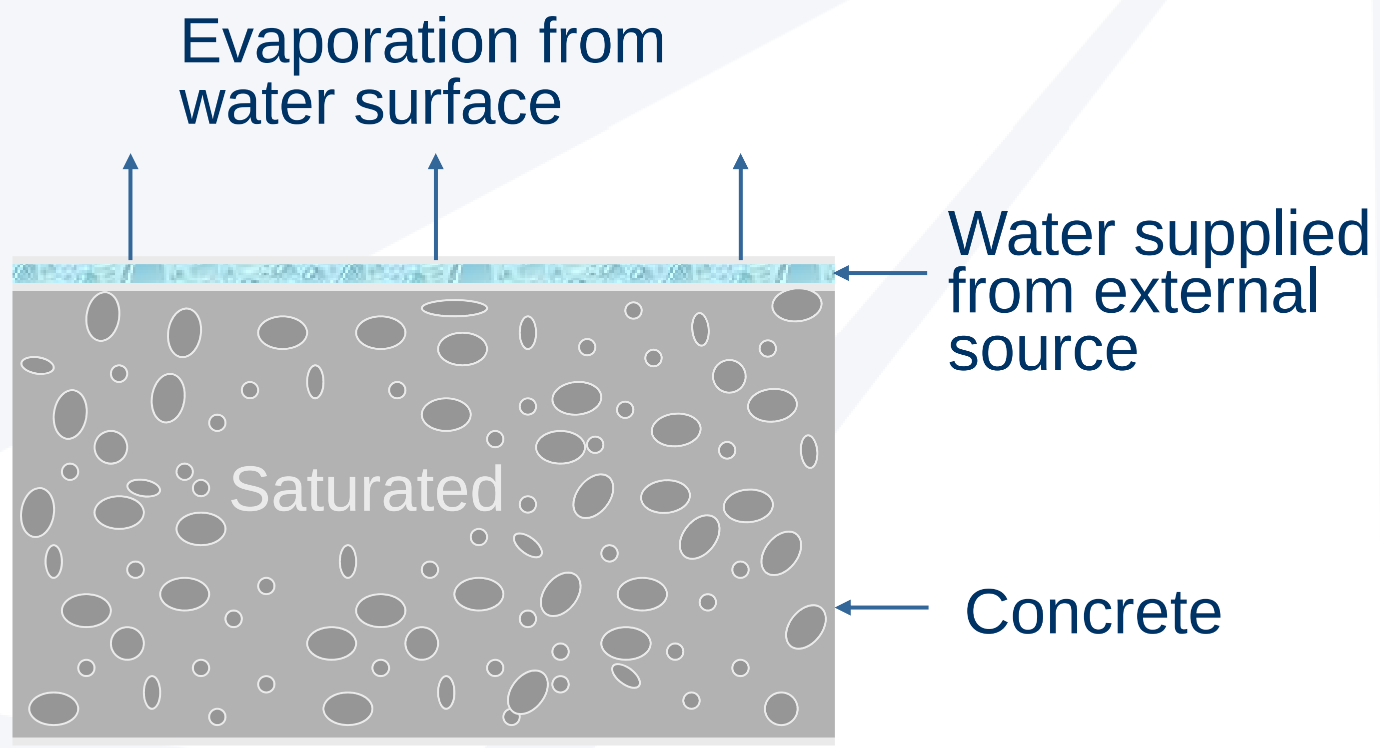
# Curing of Concrete by Supplying External Water

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# Curing Methods (cont.)

Seal in mixing water:

- Plastic sheets
- Membrane-forming curing compounds

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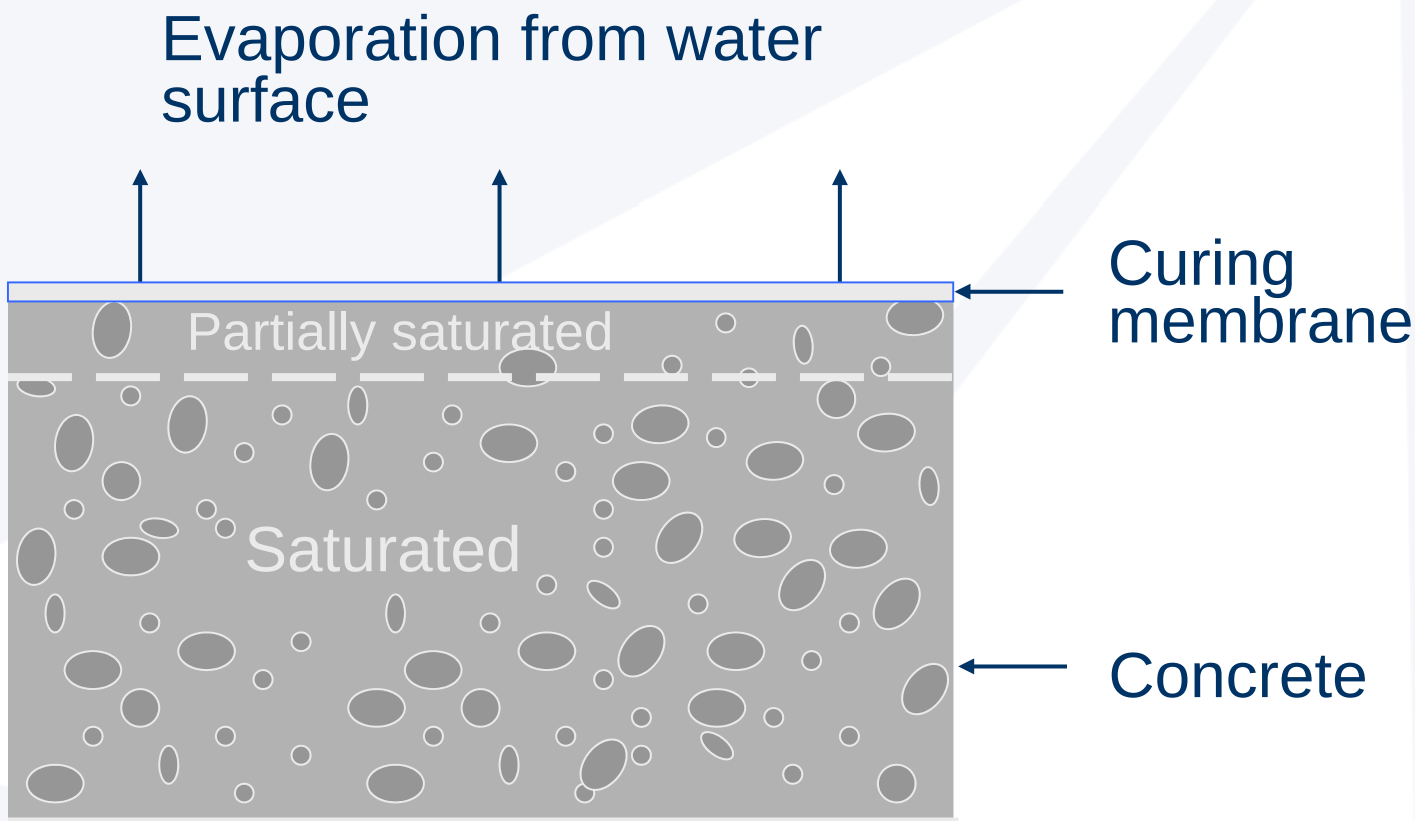
# Membrane Curing of Concrete

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# Is This Adequate Curing?????

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# Jointing and Sawing Operations

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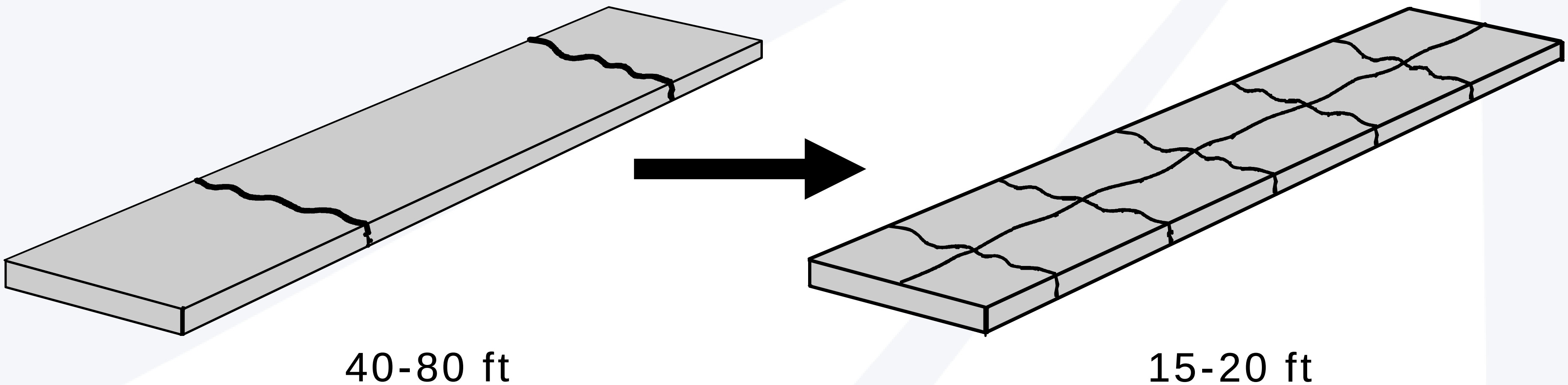
# Why Joint Concrete Pavement?

- Control natural cracking caused by internal slab stresses.
  - Stresses from:
    - Chemical shrinkage
    - Temperature gradient (curling)
    - Moisture loss (drying shrinkage/warping [relative humidity gradient])
    - Restraint to contraction (subbase friction/bond)

# Why Joint Concrete Pavement?

- Control natural transverse & longitudinal cracking from internal slab stresses.



# Why Joint Concrete Pavement?

- Other reasons we joint concrete pavements:
  - Divide pavement into construction lanes or increments.
  - Delineate lanes for drivers.
  - Accommodate slab movements.
  - Provide load transfer via placed dowels.
  - Provide uniform sealant reservoir.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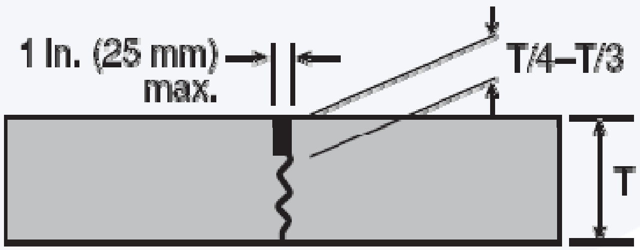
# Types of Joints

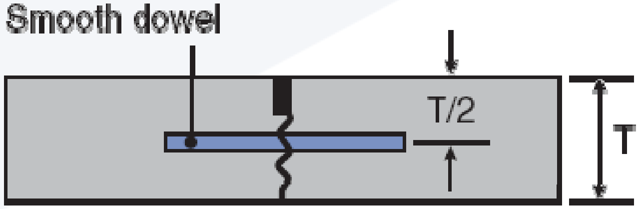
- Joint types:
  - Contraction
  - Construction
  - Isolation (and, if necessary, expansion)
- Each can occur in either the transverse or longitudinal directions.
- Also specialty joints (e.g., transitions, terminal joints in continuously reinforced, etc.).

# Types of Joints

## Transverse Contraction:



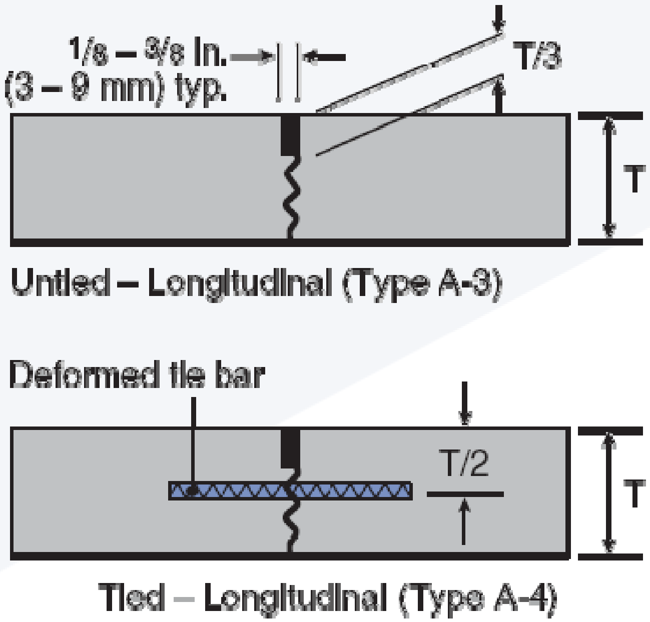

Undoweled – Transverse (Type A-1)

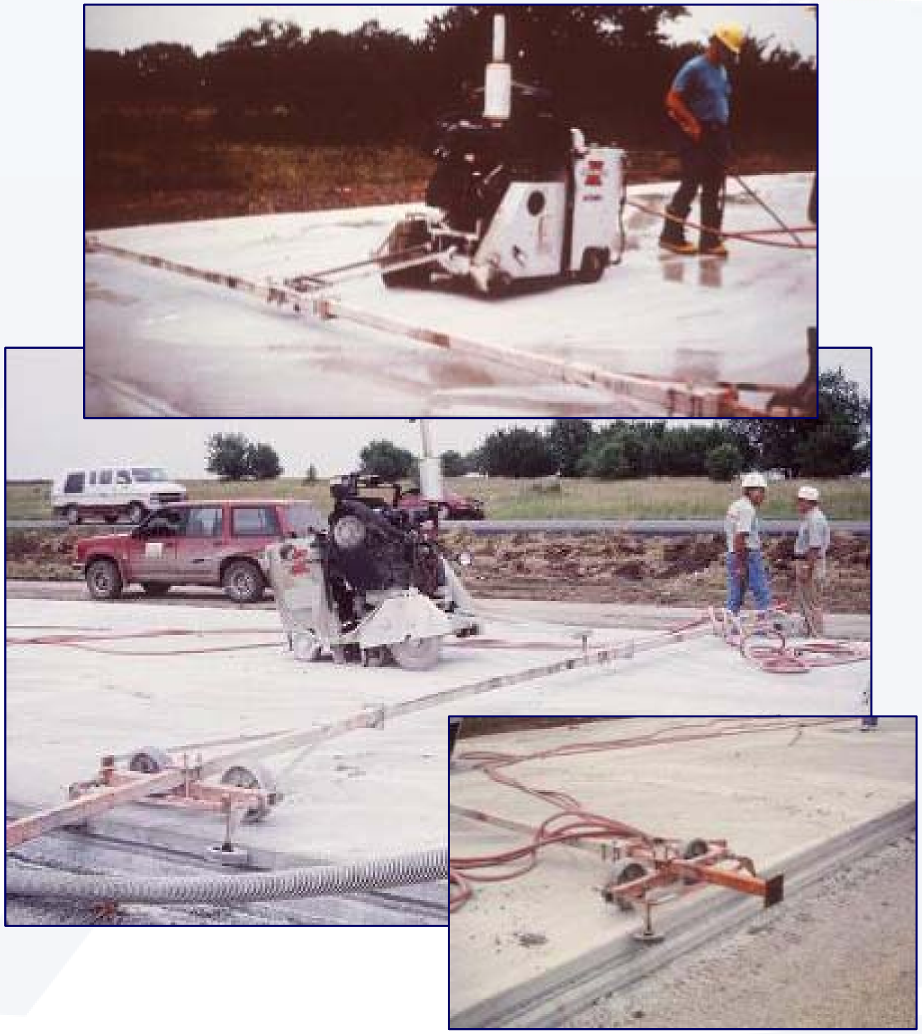



Doweled – Transverse (Type A-2)

# Types of Joints

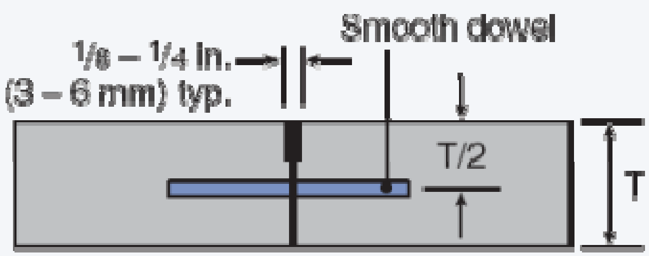
## Longitudinal Contraction:



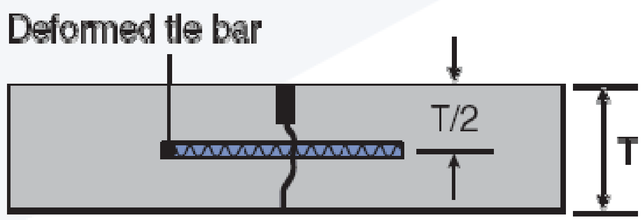



# Types of Joints

## Transverse Construction:



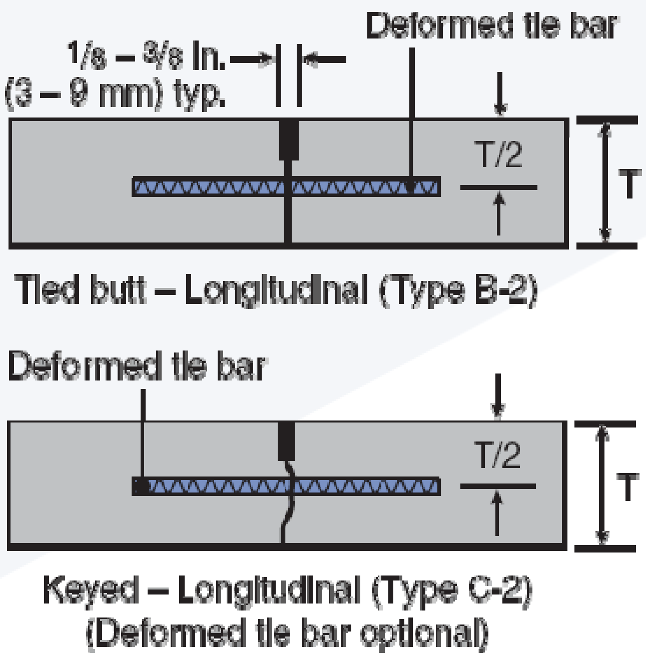

Doweled butt – Transverse (Type B-1)




Tied – Transverse (Type C-1)
(Keyway optional)

# Types of Joints

## Longitudinal Construction:

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# Formula for Maximum Joint Spacing

$$ML = T \times C_s$$

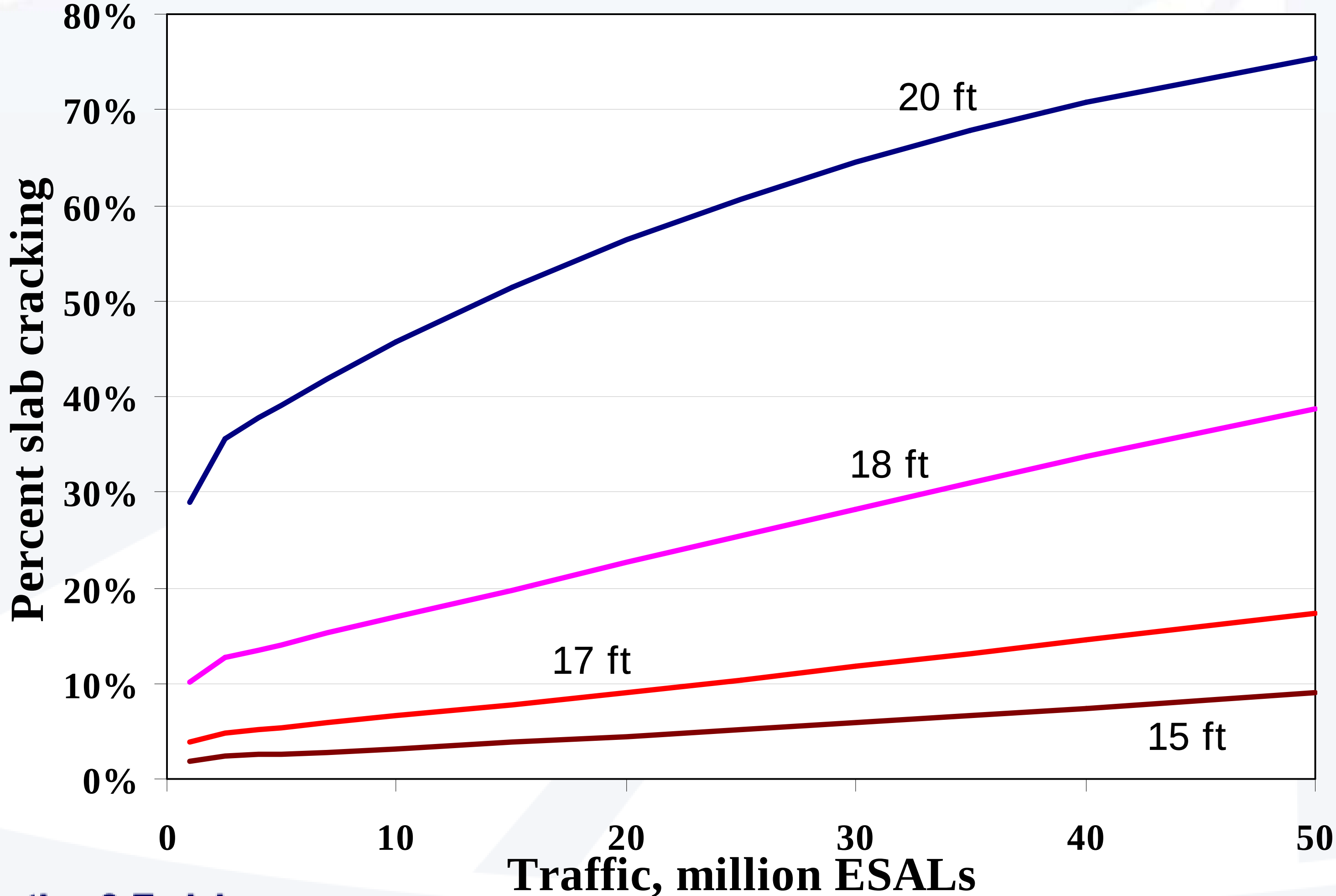
ML = Maximum length between joints (in.)

T = Slab thickness (in.)

$C_s$ = Support constant

- Use 24 for subgrades or unstabilized [granular] subbases;
- Use 21 for stabilized subbases (ATB, CTB, lean concrete) or existing concrete or asphalt pavement;
- Use 12 to 15 for thin bonded overlays on asphalt

# Effects of Joint Spacing

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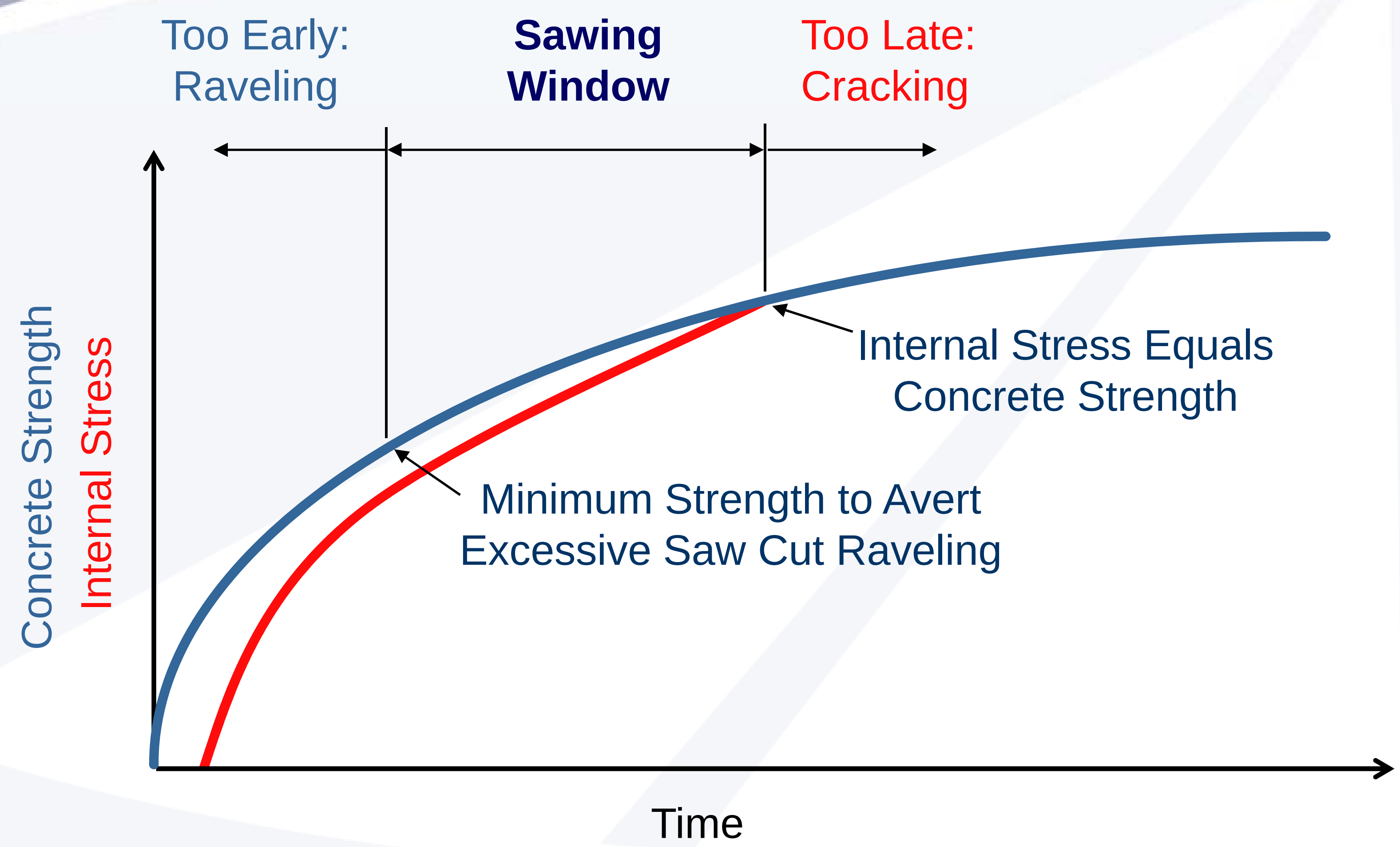
# Crack Control Window

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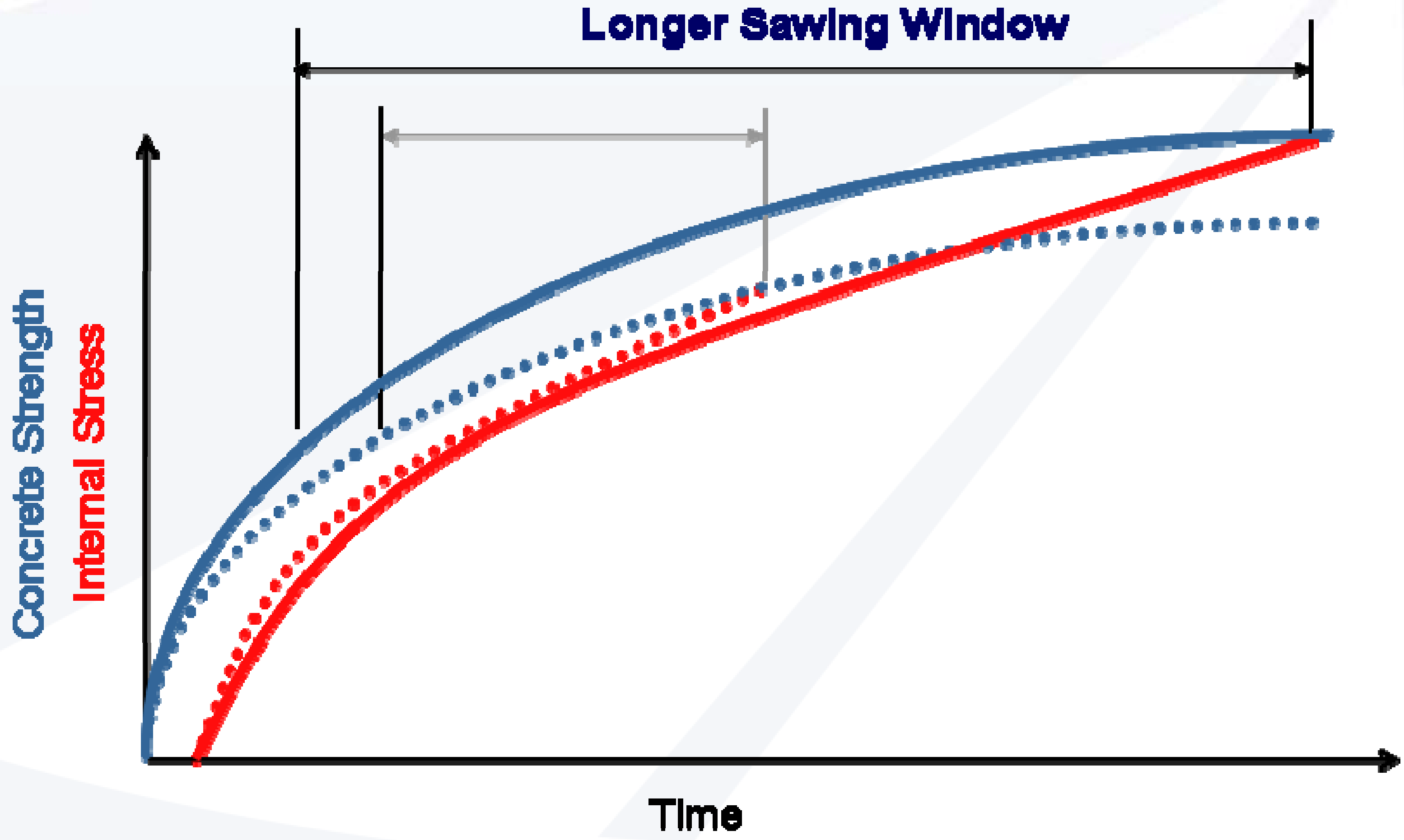
# IMPORTANCE OF CURING!

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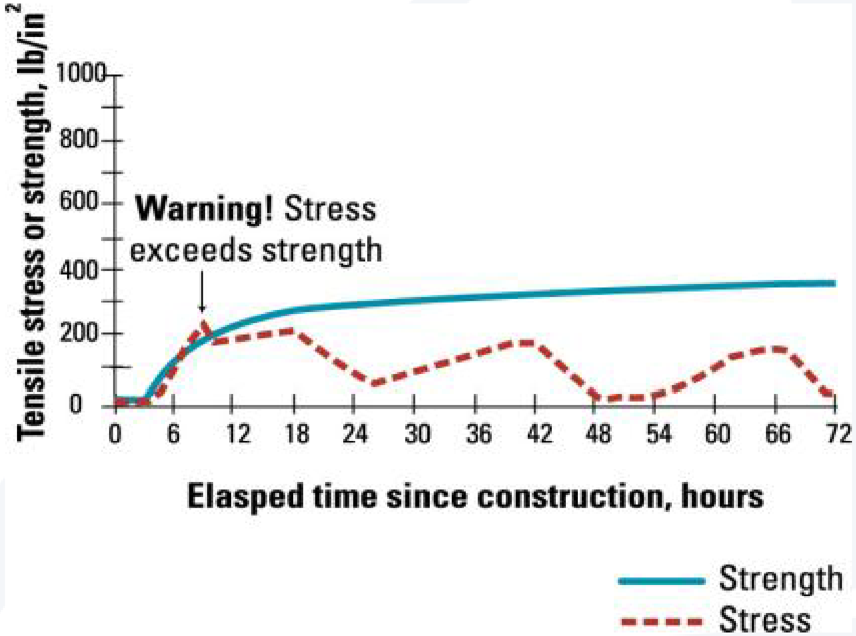
# Crack Prediction with HIPERPAV

- Visit FHWA website to download
- Many factors considered in the program.
- Input parameters are job specific.

www.hiperpav.com

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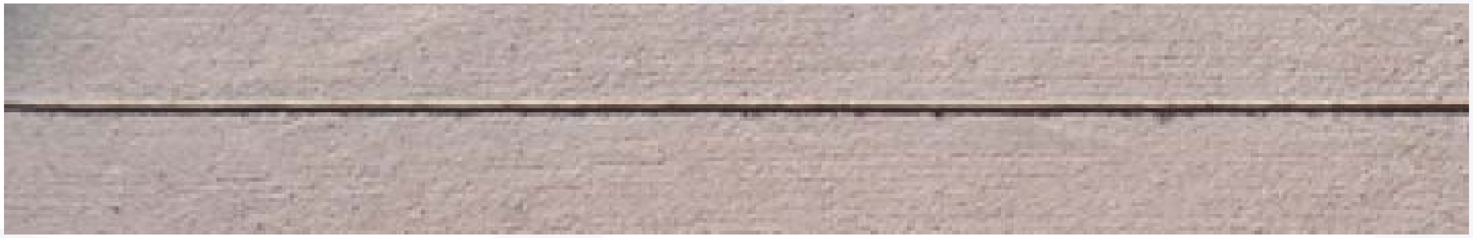
# Levels of Raveling

Unacceptable:

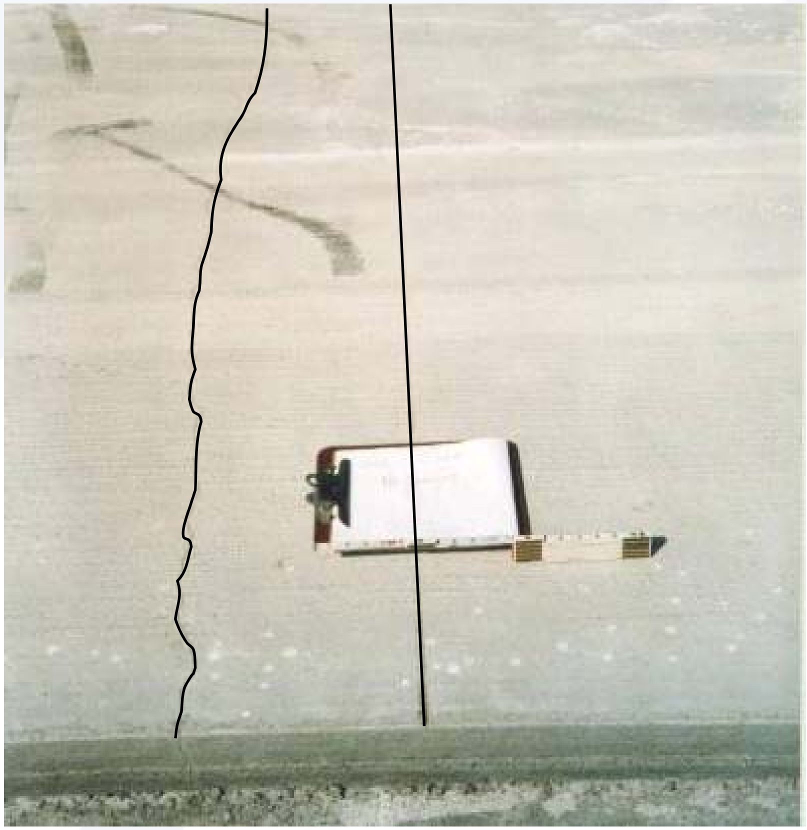
Moderate:



None:



# Not Just Timing...DEPTH!



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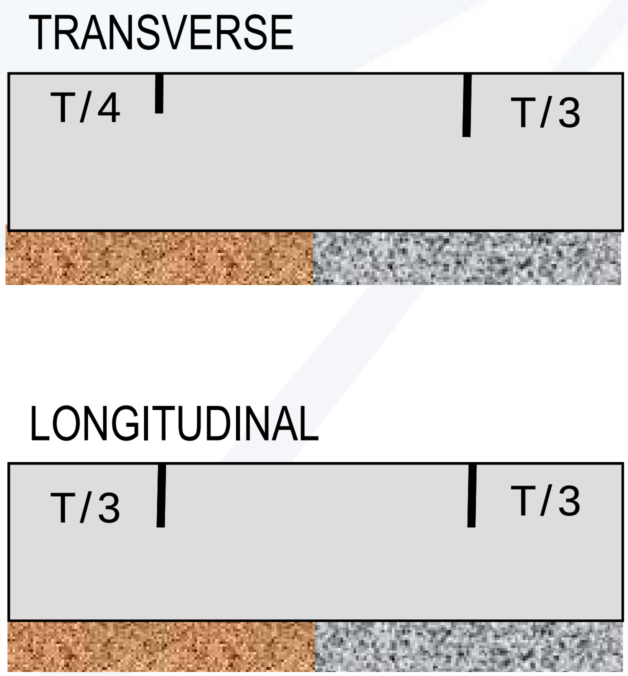
# Joint Depth Recommendations

- Transverse
  - T/4 on unstabilized
  - T/3 on stabilized
- Longitudinal
  - T/3
- Timing is a factor



# Conventional Joint Sawing

# Early Entry Joint Sawing

# Quality Control/Quality Assurance

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# Quality Control/Quality Assurance

- The process of constructing quality concrete pavements has many components:
  - Reasonable design and specifications.
  - A well executed QC/QA program for all important parameters.
  - High quality materials and uniform production/delivery.
  - Quality construction methods.

# Quality Assurance (QA)

- QA typically involves testing by the agency or its representative to determine compliance with specifications
- The most frequently used QA criteria for paving jobs include:
  - Slab thickness
  - Concrete strength
  - Entrained air content
  - Ride quality

# Quality Control (QC)

- QC generally refers to testing by the **contractor** for the purpose of process control and to ensure meeting or exceeding specifications
- A comprehensive QC program is much more involved than QA because all aspects of the project must be proactively monitored (materials, batching, placement, etc.)

# Qualifications

- QC/QA personnel must be adequately trained (and certified in a number of states)
- The testing facilities must be certified
- bRepeatability and reproducibility of results are critical for both QC and QA functions

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# Basis for Testing

- Random testing assumes that the results are normally distributed
- The mean and standard deviation of test results are used to determine if the samples are within specified limits
- Variability is due to the operator (and equipment), the test procedure, and the material being tested

# Precision and Bias

- Established test procedures (ASTM, AASHTO) have accounted for test variability through precision and bias statements
- All physical tests have built in variability that must be accounted for in some manner
- The following slide illustrates the problem in determining a “right answer”

# Precision and Bias (cont.)

| Test | Sample result | 95% lower limit | 95% upper limit |
|---|---|---|---|
| **Grading (% passing $^1/_2$")** | 28% | 24% | 32% |
| **Slump** | $2^1/_2$ in. | 2 in. | 3 in. |
| **Air content** | 5.5% | 4.9% | 6.1% |
| **Rodded unit weight for aggregate** | 120 lb/ft$^3$ | 114.5 lb/ft$^3$ | 125.5 lb/ft$^3$ |
| **Compressive strength** | 3,600 lb/in$^2$ | 3,390 lb/in$^2$ | 3,810 lb/in$^2$ |
| **Flexural strength** | 700 lb/in$^2$ | 602 lb/in$^2$ | 798 lb/in$^2$ |
| **Smoothness (0.2" blanking band) (data from DOT equipment certification)** | 4.00 in./mi | 2.58 in./mi | 5.42 in./mi |

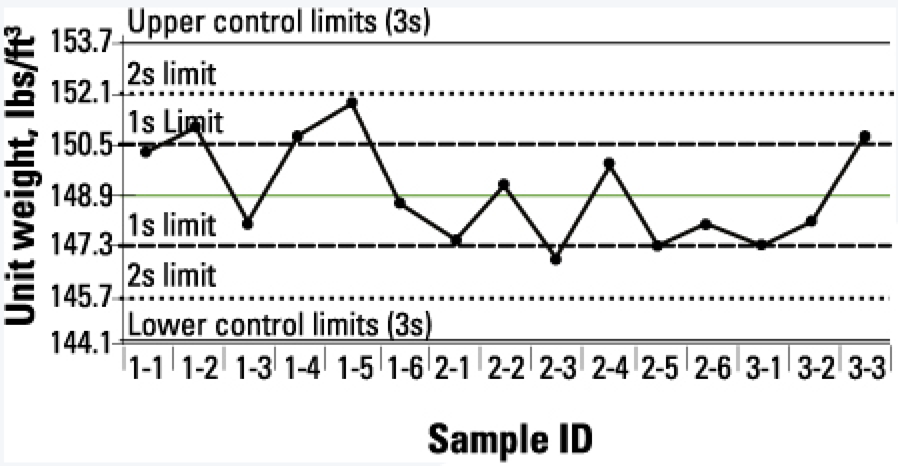
# Record Keeping

- Keeping accurate records is mandatory under QC/QA specifications and is highly desirable for any project
- Information must be clearly recorded in a logical and systematic manner
- All pertinent information should be entered as it is received to avoid confusion later

# Quality Control Charts

- Quality control charts (QCC) are statistically based and used primarily for process control
- The graphical format of QCC permit a simple and effective means to determine when a specific process is trending out of limits
- An example of standard tabular records and the corresponding QCC is shown in the following slide

# Statistical Process Control




| Sample ID | Unit weight (lb/ft³) |
|---|---|
| 1-1 | 150.3 |
| 1-2 | 151.0 |
| 1-3 | 148.0 |
| 1-4 | 150.7 |
| 1-5 | 151.7 |
| 1-6 | 148.6 |
| 2-1 | 147.4 |
| 2-2 | 149.2 |
| 2-3 | 147.1 |
| 2-4 | 149.8 |
| 2-5 | 147.2 |
| 2-6 | 147.9 |
| 3-1 | 147.3 |
| 3-2 | 148.0 |
| 3-3 | 150.7 |
| Average | 149.0 |
| Standard deviation | 1.6 |

# Concrete Batching QC

- Uniformity between concrete batches in critical in producing a smooth and long-lasting pavement
- The following parameters are routinely checked during batching:
  - Aggregate moisture
  - Water content
  - Water/cementitious materials ratio
- Plant calibration and continuous monitoring are required

# ASTM Batching Tolerances

| Constituent | Individual**, % | Cumulative***,% |
|---|---|---|
| Cementitious materials | ±1 | ±1 |
| Water | ±1 | ±3 |
| Aggregates | ±2 | ±1 |
| Admixtures | ±3 | N.R.**** |

| | |
|---|---|
| * | Batch weights should be greater than 30 percent of scale capacity. |
| ** | Individual refers to separate weighing of each constituent. |
| *** | Cumulative refers to cumulative weighing of cement and pozzolan, of fine and coarse aggregate, or water from all sources (including wash water). |
| **** | Not recommended. |

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# Construction Operations QC

Construction operations require many varied types of QC measures including the following:

- Concrete temperature at time of placement
- Entrained air content
- Consolidation (internal vibration)
- Dowel bar placement
- Potential for many others depending on specification requirements

# Test Methods for QC/QA

- Established testing procedures are generally balloted and approved by ASTM, AASHTO, or both
- Recently developed test procedures may not yet be approved but can still provide much needed information (e.g., AVA)
- Tests applicable to paving projects :
  - Materials and mix design
  - Preconstruction verification
  - Construction QC

# Summary

- Concrete paving is a "simple" process.
- The overall quality of the pavement relies on the following:
  - Pre-planning.
  - Good quality materials & equipment.
  - Following through with the plan.
  - And checking at every step in the process and making adjustments where necessary.

# Summary

High-quality concrete pavement is achieved with:

- Accurate line and grade control.
- Uniform, well compacted grade.
- Consistent concrete production and delivery.
- Consistent, uninterrupted forward motion of paver.
- Adequate internal vibration.
- Timely texturing and curing.

# Thank You!!!

Please contact Mike Ayers

with questions or comments:

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