MINNESOTA CONCRETE COUNCIL

CRT Concrete Consulting, LLC

WHO IS CRT CONCRETE CONSULTING, LLC?

BACKGROUND OF TULL

- BS in Civil Engineering from Cornell University
- Industry Experience:
  - *Concrete Contractor (3 years)*
  - *Construction Manager (3 years)*
  - *Ready Mix Concrete (17 years)*
- ACI Member
  - 330 Parking Lots
  - 302 Slab Construction
  - 332 Residential Concrete
  - 327 Roller Compacted Concrete
  - 522 Pervious Concrete
- Registered Professional Engineer in Indiana
- LEED AP

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SPECIALTY AREAS

- Seminars and Training
- Parking Lot Design
- Concrete Street Design
- Concrete Construction
- Ready Mix Concrete
  - Mix designs
  - Production efficiencies
- Slab on Ground Issues

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AGENDA

- Why Concrete Pavements?
- General Information
- Design Theory
- Two Documents
  - ACI 330
  - ACI 325
- Common Items to both 330 and 325
- Parking Lot Design
- Concrete Street Design
- Joints
- Curing

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WHY CONCRETE PAVEMENTS?

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Why choose concrete over asphalt?

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In the past:
Truck, Trucks, Trucks

SUSTAINABILITY

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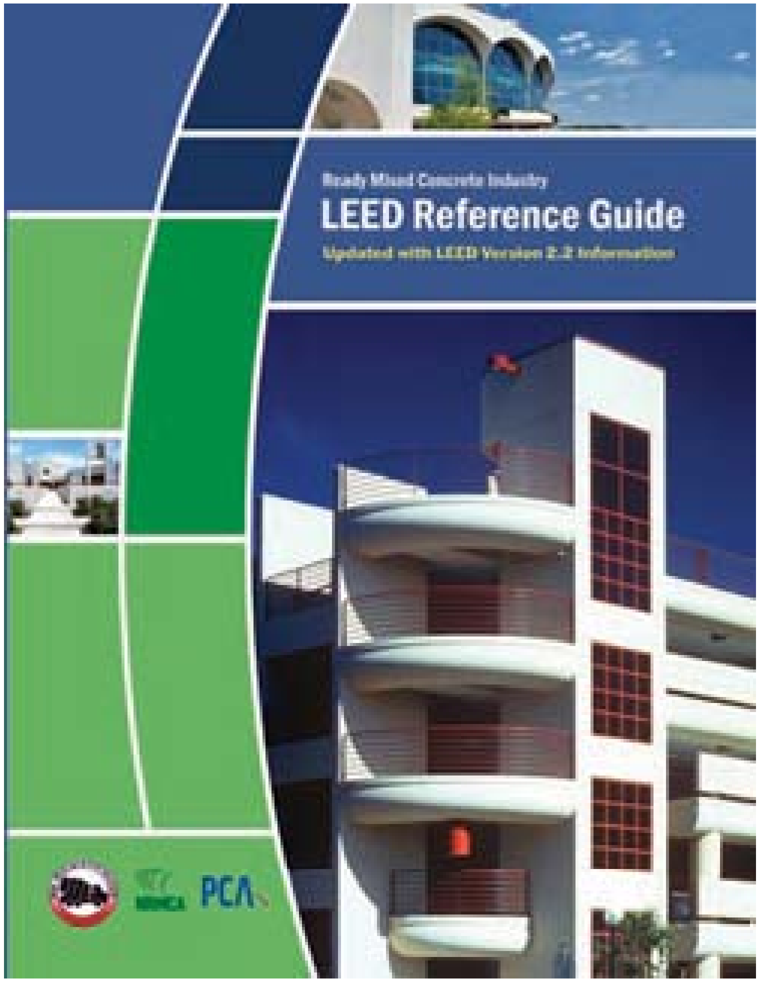
Sustainable



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LIGHTING AND REFLECTIVITY

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Brighter!

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Lighting and Reflectivity

- **One of the advantages of specifying and designing concrete parking areas is the decrease in the amount of lighting equipment that will be required. The lighter color of concrete reflects more light than a black asphalt area.**

- **Concrete's reflectivity, or ability to reflect light, provides a marketable benefit over the use of asphalt in parking areas. Studies have shown that concrete parking areas require up to 50% less lighting equipment than a comparable asphalt surface.**

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Benefits of Better Lighting:

- Savings in initial equipment expense
- Reduced continued energy cost
- A brighter, cleaner parking area
- Increased safety at night
- What types of projects would this benefit the developer?

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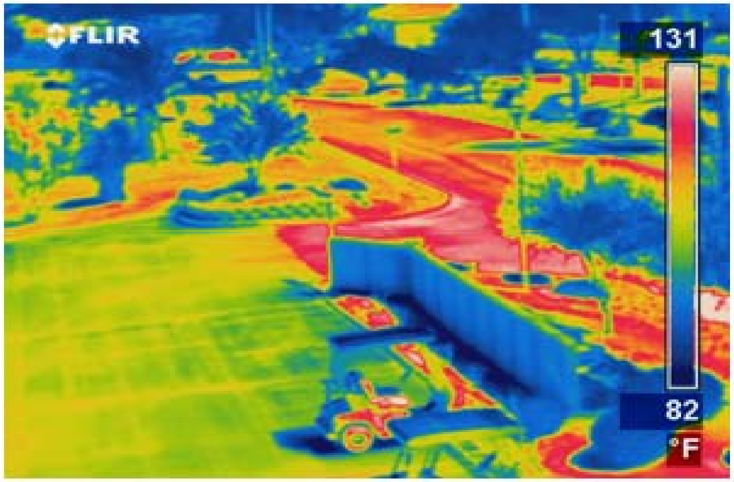
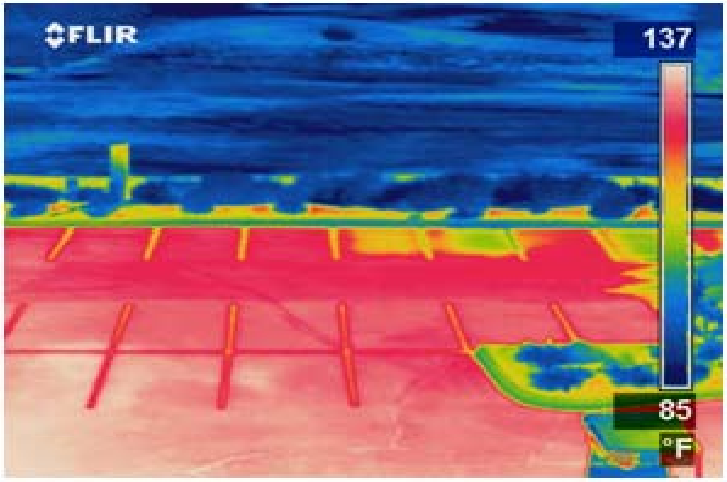
REDUCED HEAT ISLAND

Concrete Pavements Are Cooler





There was a 30-degree difference in temperatures between the asphalt and the concrete surfaces. The photo on the top right was taken of an asphalt parking lot adjacent to a golf course. Note the 85-90 degree temperature of the grass and the 135 degree temperature of the asphalt; the photo below it represents the same scene.

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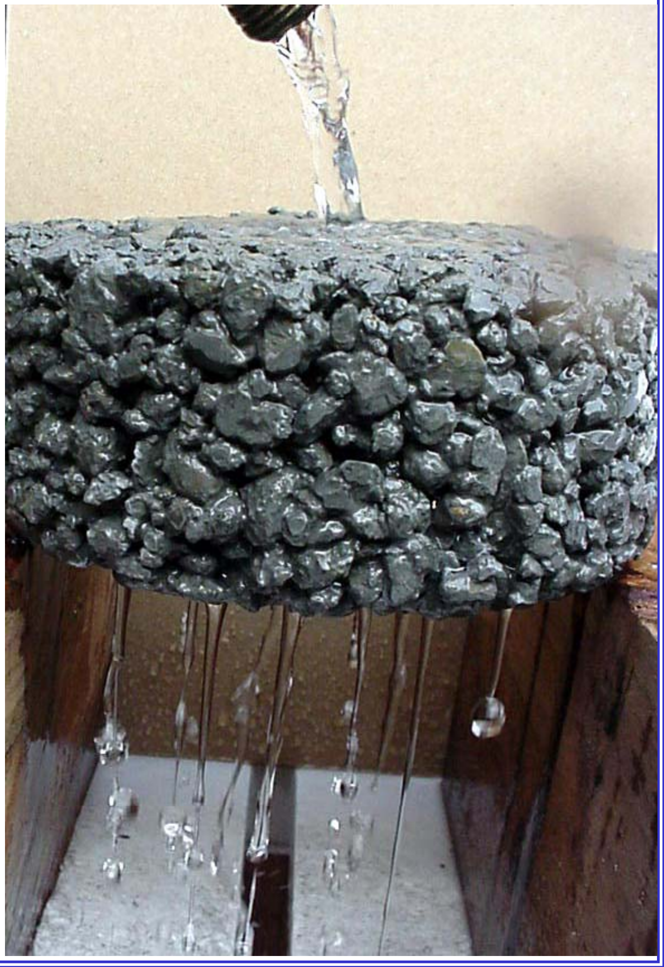
Pervious Concrete



LITTLE OR NO MAINTENANCE

Low Maintenance

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No Dependence of Oil

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WHAT'S CHANGED TODAY?

COMPETITIVE UP FRONT COSTS

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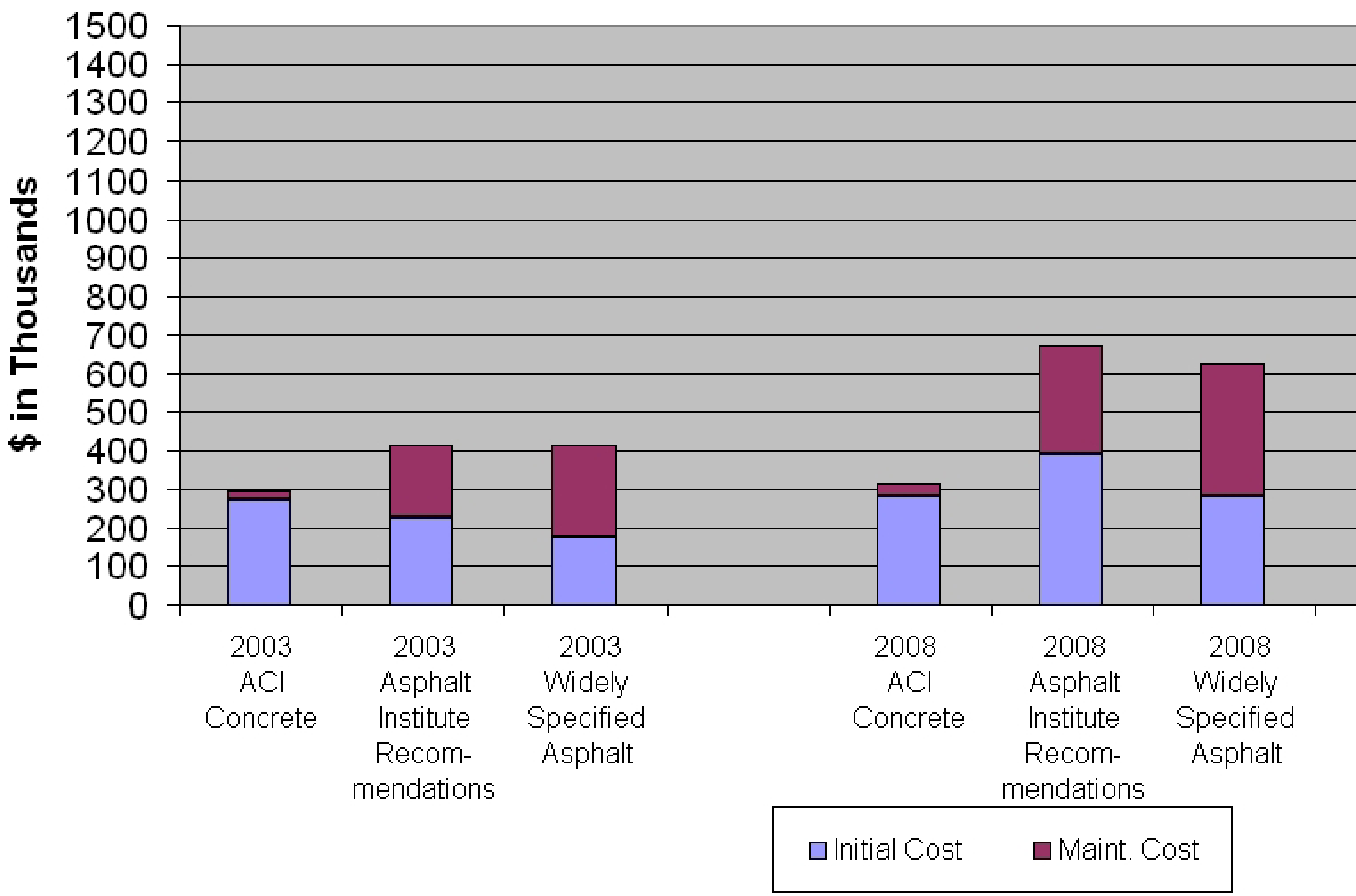
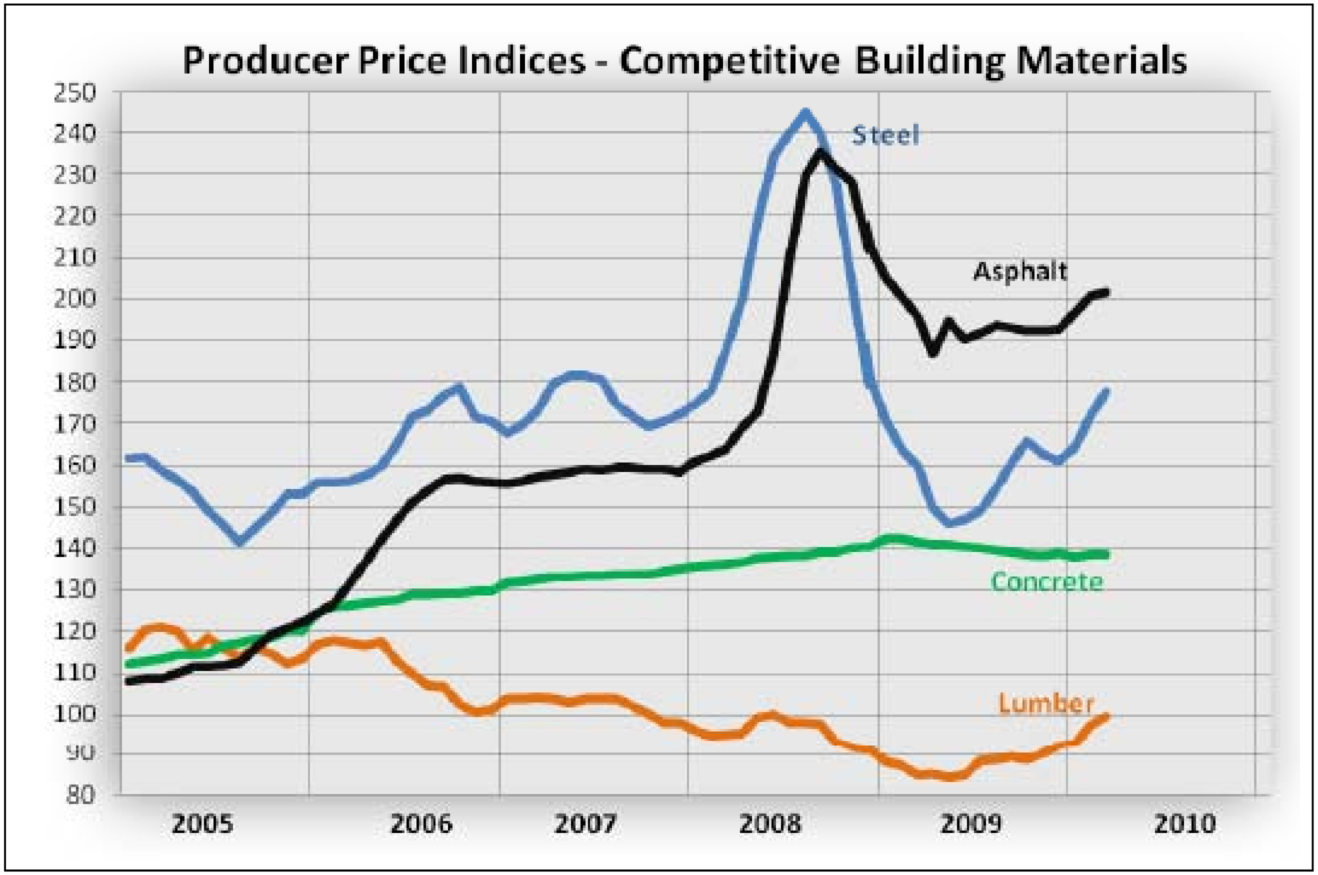
Economical



$ in Thousands
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
2003 ACI Concrete
2003 Asphalt Institute Recom-mendations
2003 Widely Specified Asphalt
2008 ACI Concrete
2008 Asphalt Institute Recom-mendations
2008 Widely Specified Asphalt
Initial Cost
Maint. Cost

Producer Price Indices
Competitive Building Materials



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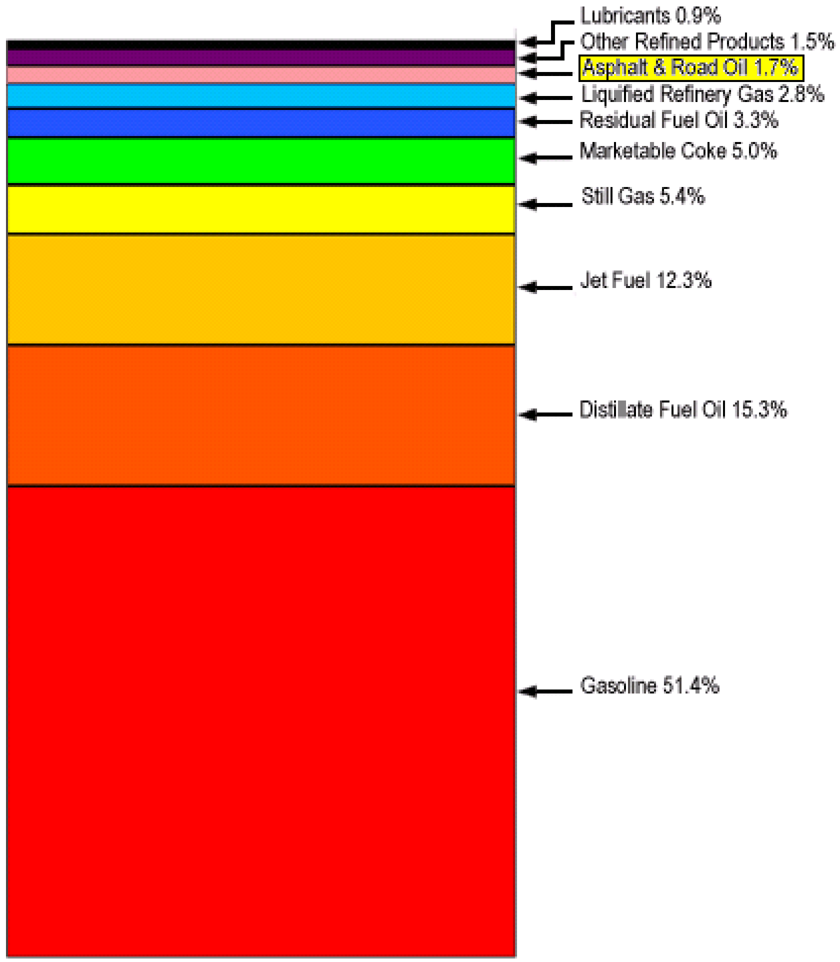
Barrel of Oil Breakdown.



www.swederski.com

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The Trends are Positive

In a world where customers care more and more about the environment and always care about price:

- Concrete costs less.
- Concrete increasingly recognized as "green"
- Asphalt increasingly recognized as having environmental problems
- Asphalt increasingly expensive and unstable

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Concrete, today enjoys a position never before experienced by our industry

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CONCRETE PAVEMENTS:
GENERAL INFORMATION

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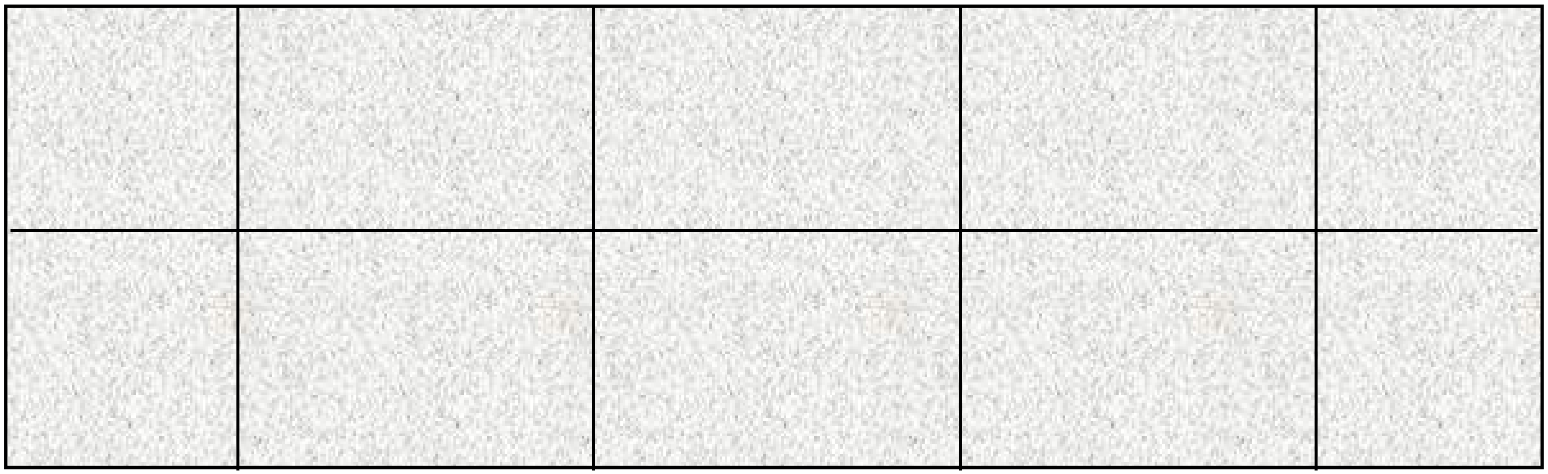
Jointed - unreinforced (plain) pavement

Plan



Profile

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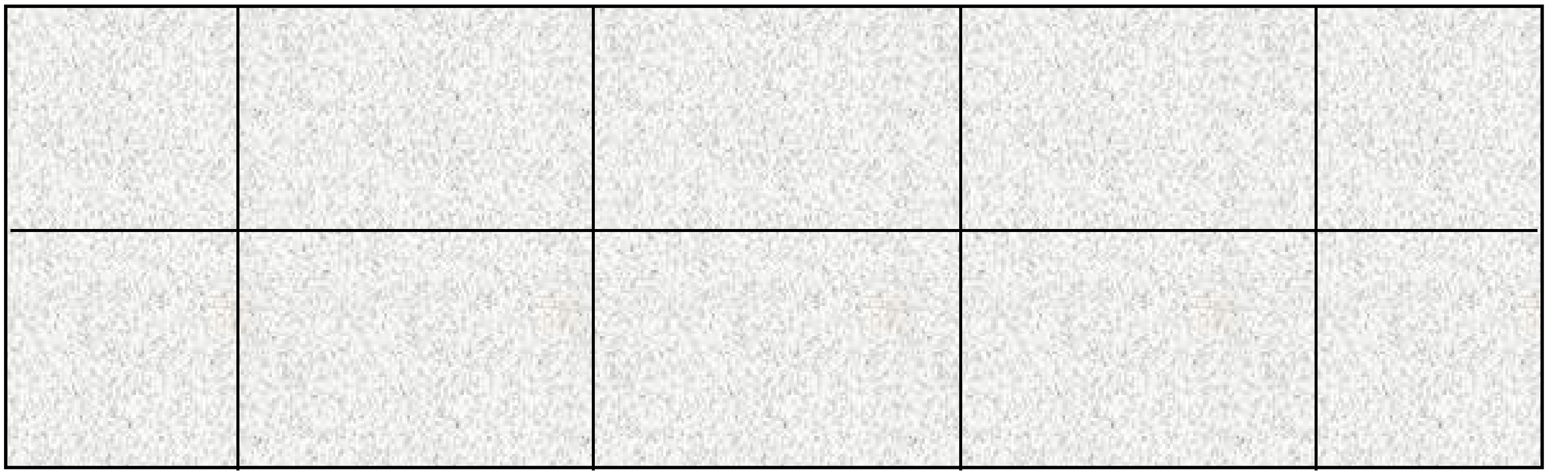
Jointed & Doweled Pavement

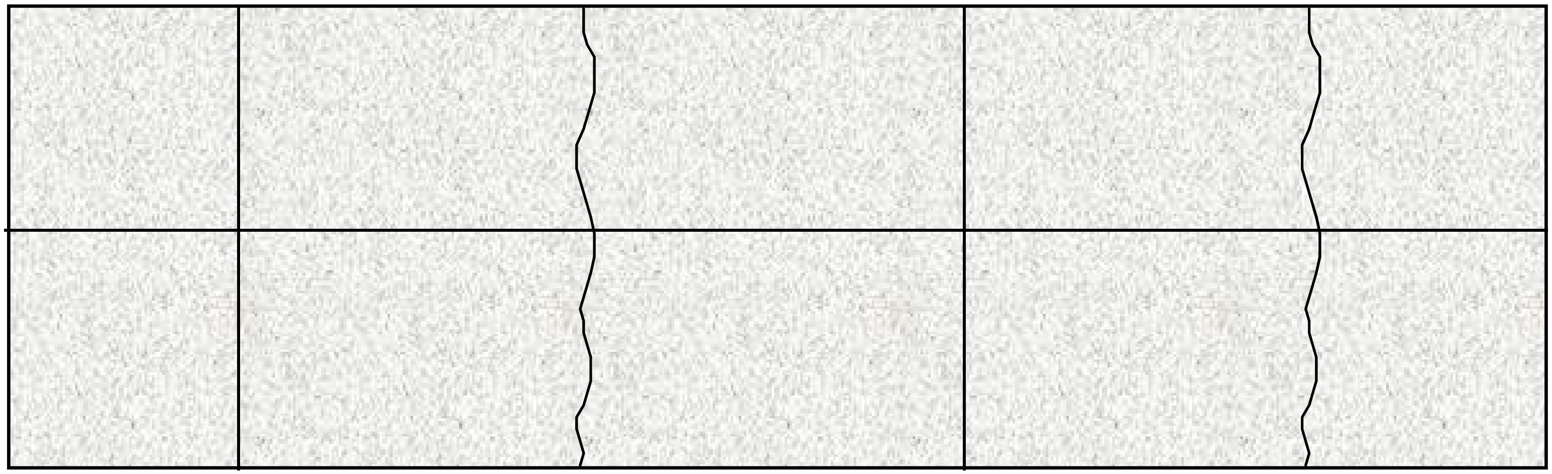
Plan



Profile

Jointed - reinforced pavement

Plan



Profile

Distributed steel reinforcement is used to prevent the opening of expected random cracks between joints.

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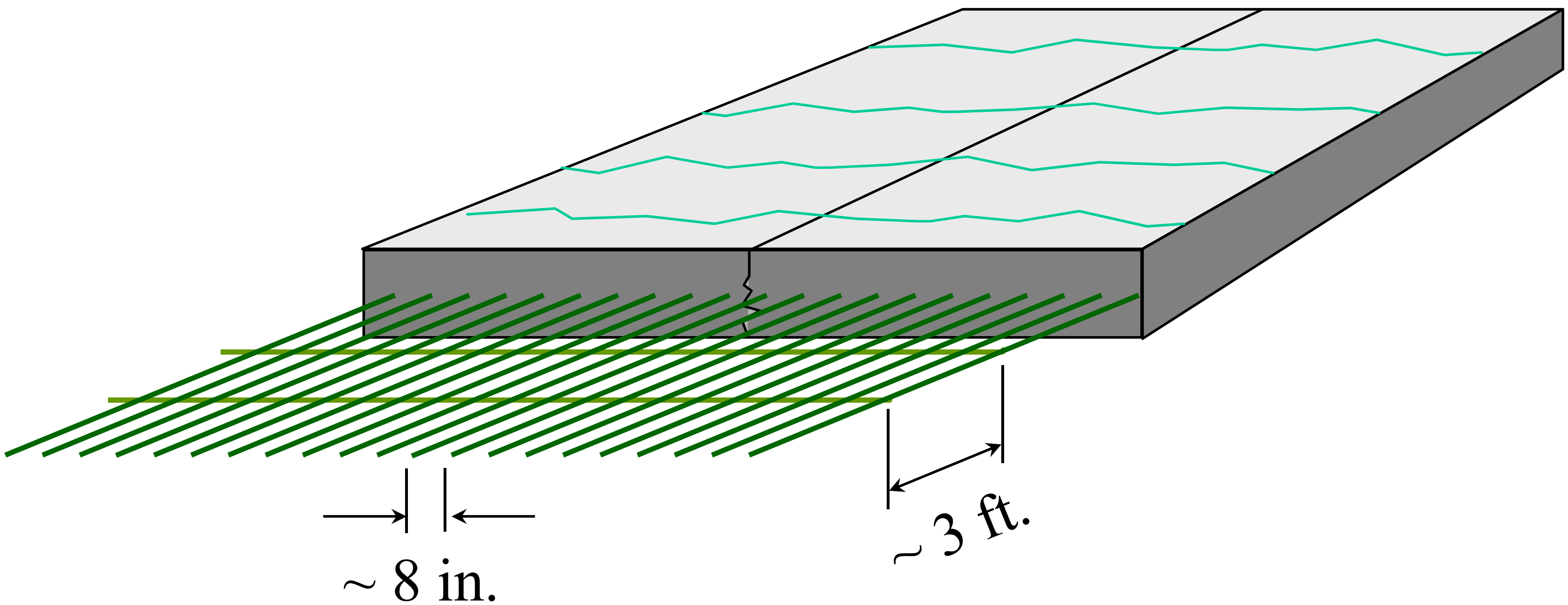
Continuously reinforced concrete (CRC) pavement

- Heavily reinforced without joints
- Stable transverse cracks develop every 3-6 feet.



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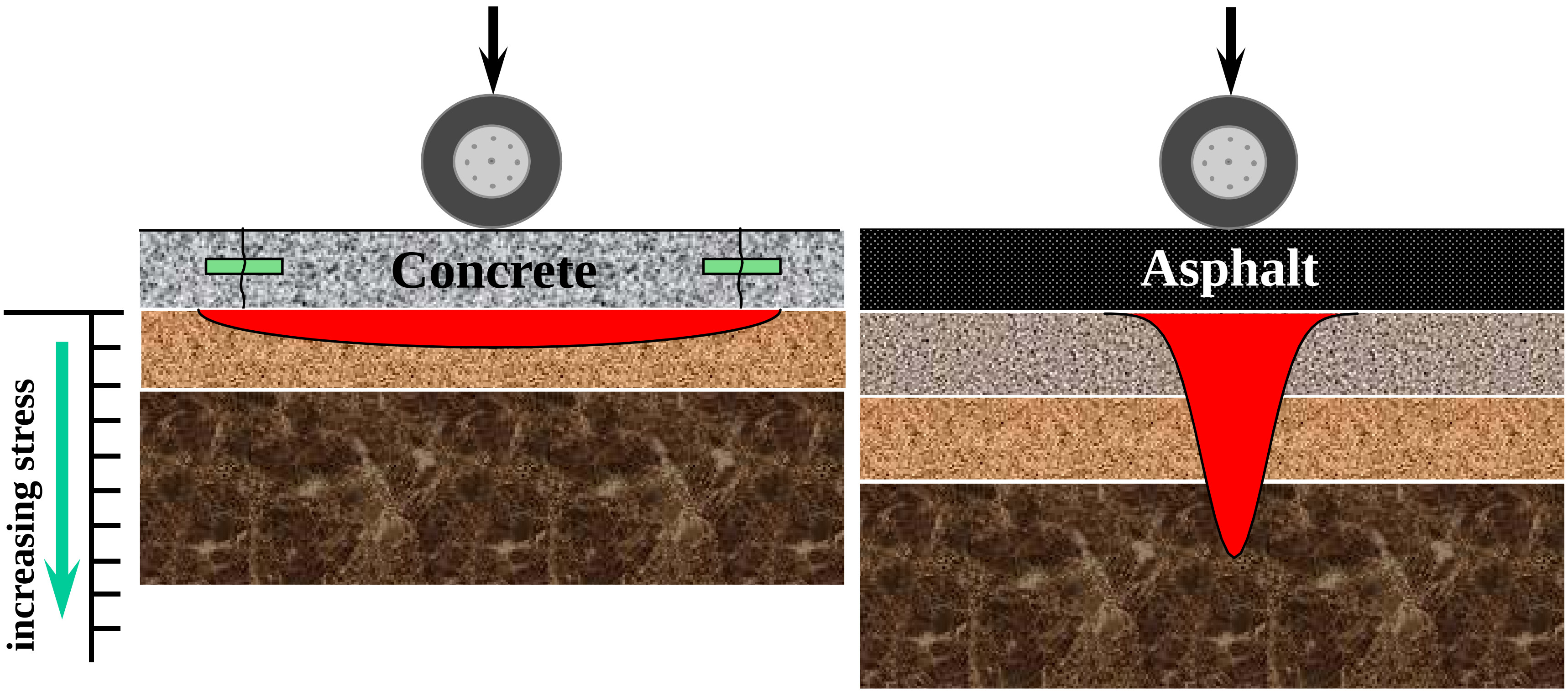
Pavements & loads
Concrete vs. Asphalt

Subgrade stresses differ considerably.



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DESIGN THEORY

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Pavement Engineering

Pavement engineering is the art of molding materials we do not wholly understand into shapes we cannot precisely analyze, so as to withstand forces we cannot assess, in such a way that the community at large has no reason to suspect our ignorance.

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Thickness Design Procedures

- Empirical Design
  - Based on observed performance
    - AASHO Road Test
- Mechanistic Design
  - Based calculated pavement responses
    - PCA Design Procedure (PCAPAV)
    - StreetPave (ACPA Design Method)
    - ACI 330 Design Tables
    - ACI 325 Design Tables

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Source of Much of What We Know About Pavement Design

- AASHO Road Test
- Late 50's and early 60's
- Ottawa, Illinois

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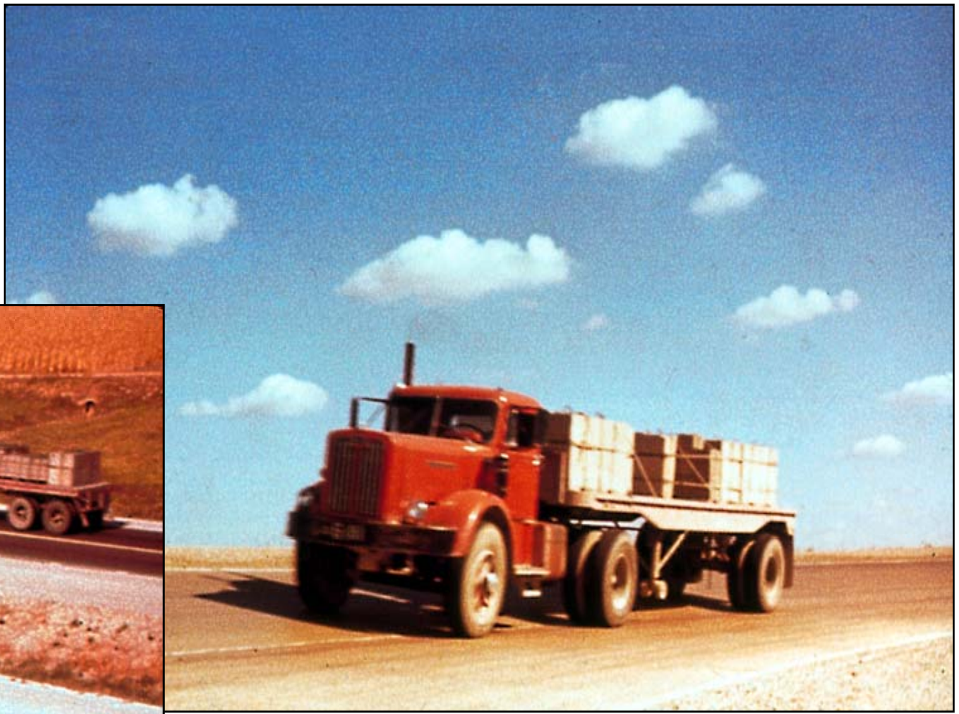
AASHO Test Traffic

Max Single Axle



Max Tandem Axle

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AASHTO
'93 Guide

- Pavements Can be Compared at Roughly Equivalent Levels of Reliability
- Principles in both versions are identical for new construction

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1986-93 Rigid Pavement Design Equation

$$\log(ESALs) = Z_R * s_o + 7.35 * \log(D + 1) - 0.06 + \frac{\log\left[\frac{\Delta PSI}{4.5 - 1.5}\right]}{1 + \frac{1.624 * 10^7}{(D+1)^{8.46}}}$$

$$+ (4.22 - 0.32p_t) * \log\left[\frac{S'_c * C_d * \left[D^{0.75} - 1.132\right]}{215.63 * J * \left[D^{0.75} - \frac{18.42}{(E_c / k)^{0.25}}\right]}\right]$$

Standard Normal Deviate

Overall Standard Deviation

Change in Serviceability

Terminal Serviceability

Modulus of Rupture

Drainage Coefficient

Load Transfer

Modulus of Elasticity

Modulus of Subgrade Reaction

DEPTH

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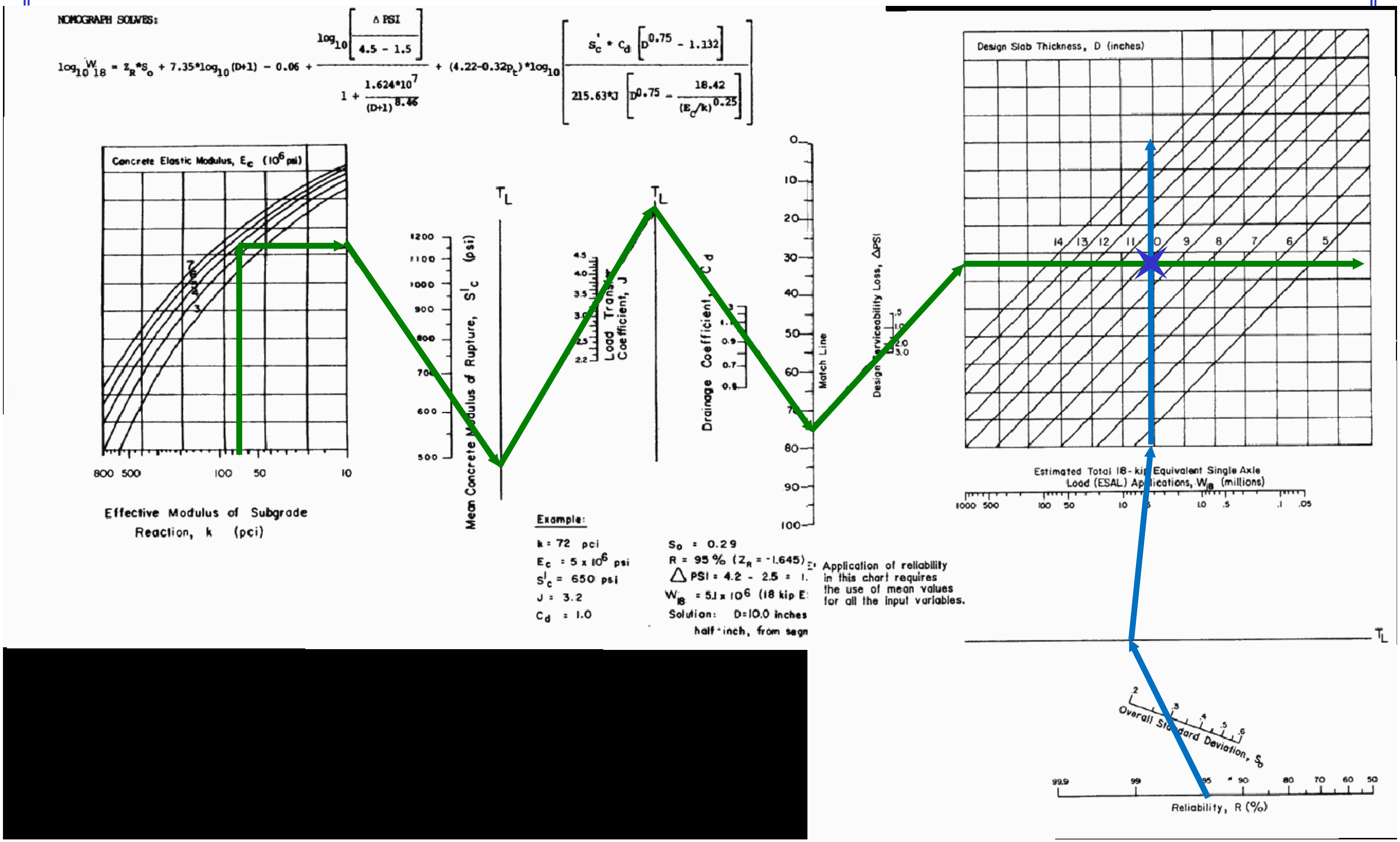
Rigid Design Nomograph



What About Concrete Structural Coefficients?

- Based on Louisiana AASHO satellite studies
- Used principally for overlay design
- Value set at 0.50 for old concrete
- Calculations from the AASHTO equations incorporating reliability concepts for new pavement show a minimum value of 0.47 to 0.74 depending on strength for plain pavement

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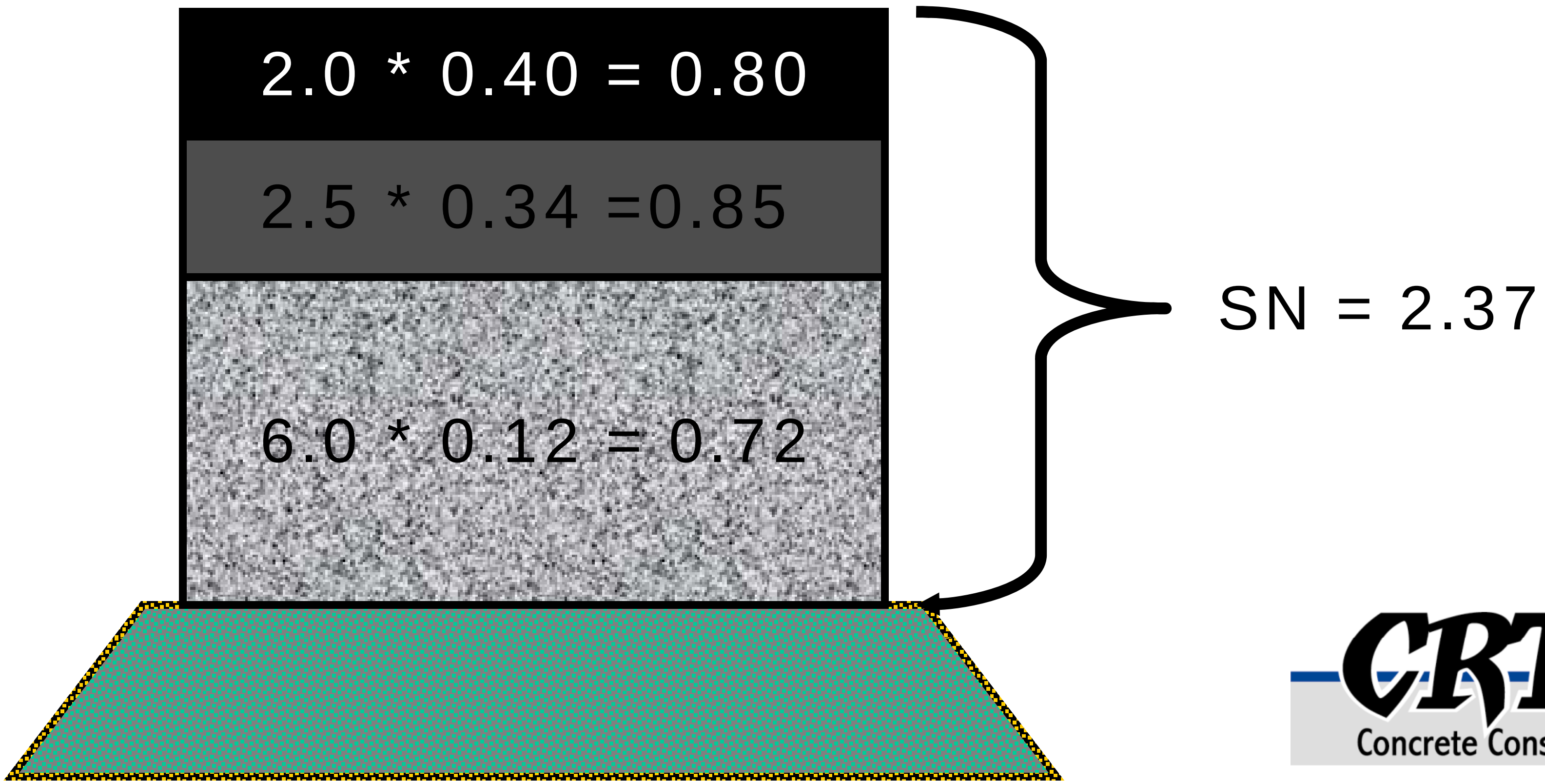
The Structural Number

$$\textbf{S.N.} = a_1 {*} t_1 + a_2 {*} t_2 + a_3 {*} t_3 \ldots$$



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Bituminous Structural Coefficients

Source: Chapter 54, IL D.O.T. Design Manual, 2000

STRUCTURAL MATERIALS	MINIMUM STRENGTH REQUIREMENTS			COEFFICIENTS③		
	MS①	IBR	CS②	a_1	a_2	a_3
Bituminous Surface						
Road Mix (Class B)				0.20		
Plant Mix (Class B)						
Liquid Asphalt				0.22		
Asphalt Cement	900			0.30		
Class I Bituminous Concrete	1700			0.40		
Base Course						
Aggregate, Type B						
Uncrushed		50			0.10	
Crushed		80			0.13	
Aggregate, Type A		80			0.13	
Waterbound Macadam		110			0.14	
Bituminous Stabilized Granular Material	300				0.16	
	400				0.18	
	800				0.23	
	1000				0.25	
	1200				0.27	
	1500				0.30	
	1700				0.33	
Class I Binder	1700				0.33	
Pozzolanic, Type A			600		0.28	
Lime Stabilized Soil			150		0.11	
Select Soil Stabilized			300		0.15	
with Cement			500		0.20	
Cement Stabilized Granular Material			650		0.23	
			750		0.25	
			1000		0.28	
Subbase						
Granular Material, Type B		30				0.11
Granular Material, Type A						
Uncrushed		50				0.12
Crushed		80				0.14
Lime Stabilized Soil			100			0.12

Notes:

① *Marshall Stability (MS) index or equivalent.*

② *Compressive strength (CS) in pounds per square inch (psi). For cement stabilized soils and granular materials, use the 7-day compressive strength that can be reasonably expected under field conditions. For lime stabilized soils, use the accelerated curing compressive strength at 120°F for 48 hours. For Pozzolanic, Type A, use the compressive strength after a 14-day curing period at 72°F.*

③ *For materials with strengths other than those shown, the coefficients may be determined from Figures 54-5O, 54-5P, and 54-5Q. Other approved materials of similar strengths may be substituted for those presented in Figure 54-5N.*

COEFFICIENTS FOR MATERIALS IN NEW FLEXIBLE PAVEMENT STRUCTURES

AASHTO '93 Local Roads Catalog Designs

Table 4.7. Flexible Pavement Design Catalog for Low-Volume Roads: Recommended Ranges of Structural Number (SN) for Six U.S. Climatic Regions, Three Levels of Axle Load Traffic and Five Levels of Roadbed Soil Quality—Inherent Reliability: 75 percent

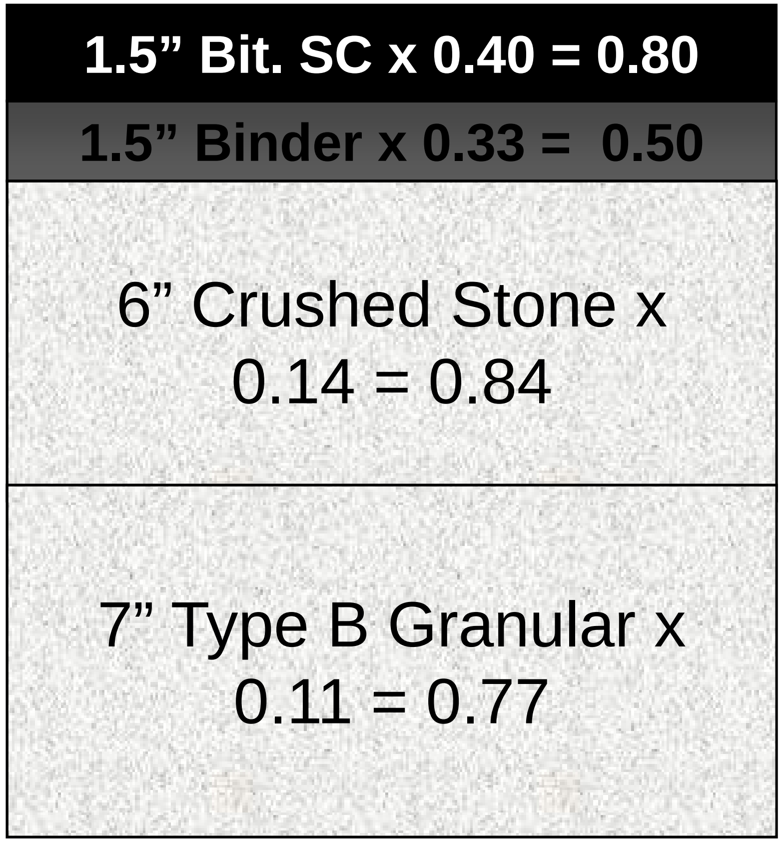
Relative Quality of Roadbed Soil	Traffic Level	U.S. Climatic Region I	II	III	IV	V	VI
Very good	High	2.6–2.7*	2.8–2.9	3.0–3.2	2.4–2.5	2.7–2.8	3.0–3.2
	Medium	2.3–2.5	2.5–2.7	2.7–3.0	2.1–2.3	2.4–2.6	2.7–3.0
	Low	1.6–2.1	1.8–2.3	2.0–2.6	1.5–2.0	1.7–2.2	2.0–2.6
Good	High	2.9–3.0	3.0–3.2	3.3–3.4	2.7–2.8	3.0–3.1	3.3–3.4
	Medium	2.6–2.8	2.7–3.0	3.0–3.2	2.4–2.6	2.6–2.9	2.9–3.2
	Low	1.9–2.4	2.0–2.6	2.2–2.8	1.8–2.3	2.0–2.5	2.2–2.8
Fair	High	3.2–3.3	3.3–3.4	3.4–3.5	[illegible]	[illegible]	3.4–3.5
	Medium	2.8–3.1	2.9–3.2	2.7–3.3	[illegible]	[illegible]	3.0–3.3
	Low	2.1–2.7	2.2–2.8	2.3–2.9	2.[illegible]–2.6	2.1–2.7	2.3–2.9
Poor	High	3.5–3.6	3.6–3.7	3.7–3.9	3.4–3.5	3.5–3.6	3.7–3.8
	Medium	3.1–3.4	3.2–3.5	3.4–3.6	3.0–3.3	3.1–3.4	3.3–3.6
	Low	2.4–3.0	2.4–3.0	2.5–3.2	2.3–2.8	2.3–2.9	2.5–3.2
Very poor	High	3.8–3.9	3.8–4.0	3.8–4.0	3.6–3.8	3.7–3.8	3.8–4.0
	Medium	3.4–3.7	3.5–3.8	3.5–3.7	3.3–3.6	3.3–3.6	3.3–3.6
	Low	2.6–3.2	2.5–3.3	2.6–3.3	2.5–3.1	2.5–3.1	

*Recommended range of structural number (SN).

Say 2.9

Concrete C

Let’s Build an Asphalt Section



SN = 0.8 + 0.5 +0.84 + 0.77= 2.91

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AASHTO '93 Local Roads Catalog Designs

Table 4.9(b). Rigid Design Catalog for Low-Volume Roads: Recommended Minimum PCC Slab Thickness (Inches) for Three Levels of Axle Load Traffic and Five Levels of Roadbed Soil Quality

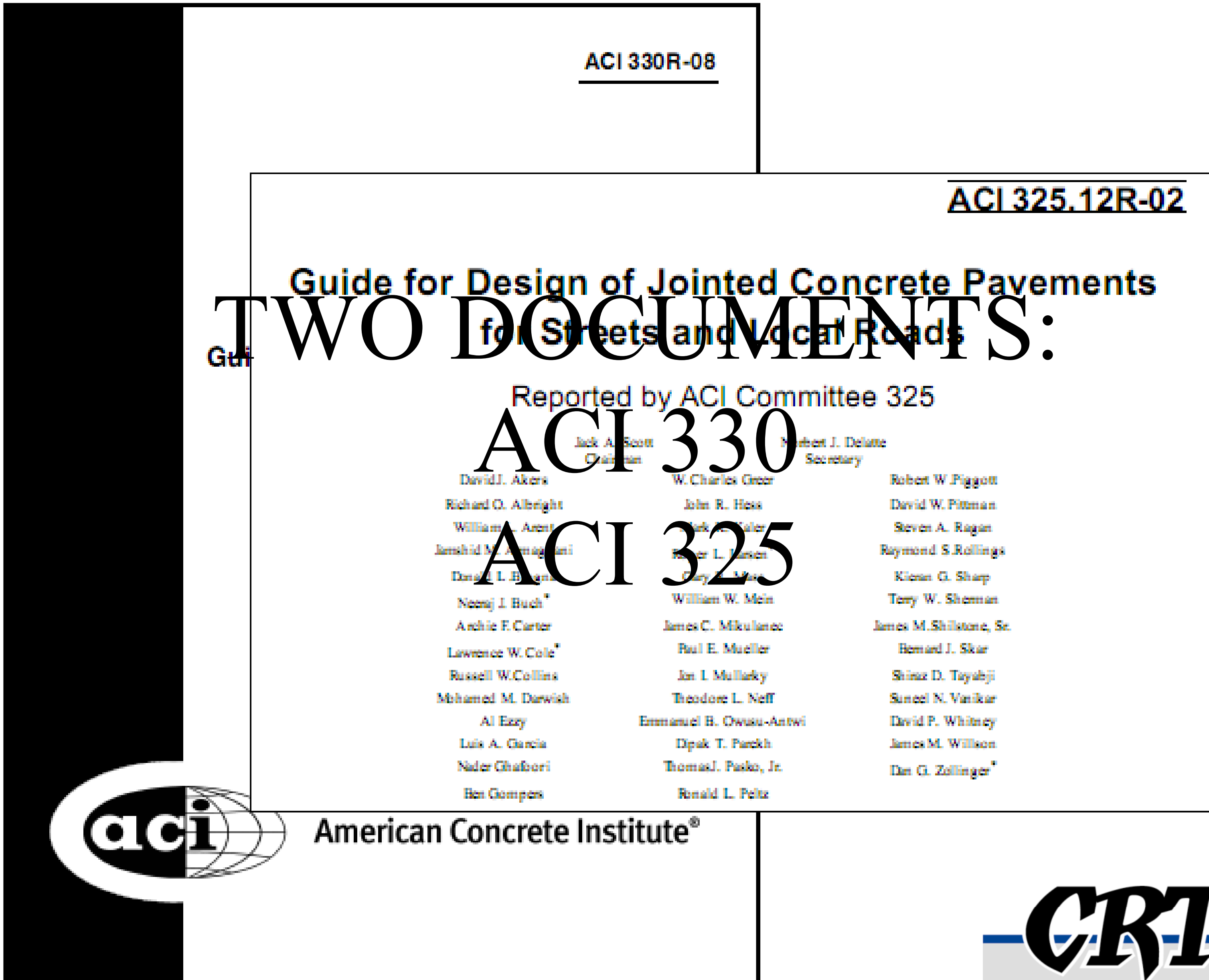
Inherent reliability: 75 percent.
With Granular Subbase

Load Transfer Devices	**No**				**Yes**			
Edge Support	No		Yes		No		Yes	
S'_c (psi)	600	700	600	700	600	700	600	700
Relative Quality of Roadbed Soil	**Low Traffic**							
Very good & good	5.5	5	5	5	5	5	5	5
Fair	5.75	5.25	5	5	5	5	5	5
Poor & very poor	5.75	5.25	5	5	5	5	5	5
	Medium Traffic							
Very good & good	6.25	5.75	5.75	5.25	6	5.5	5.5	5
Fair	6.5	5.75	6	5.5	6.25	5.5	5.5	5
Poor & very poor	6.5	6	6	5.5	6.25	5.75	5.[illegible]	[illegible]
	High Traffic							
Very good & good	7.25	6.5	6.5	6	6.75	6	6	[illegible]
Fair	7.25	6.5	6.5	6	6.75	6	6	[illegible]
Poor & very poor	7.25	6.75	6.75	6	6.75	6.25	6.[illegible]	[illegible]

TWO DOCUMENTS:

ACI 330

ACI 325


ACI 330R-08

Gui

American Concrete Institute®

ACI 325.12R-02

Guide for Design of Jointed Concrete Pavements for Streets and Local Roads

Reported by ACI Committee 325

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Norbert J. Delatte, Secretary

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COMMON ITEMS IN ACI 330 AND ACI 325

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Common Items:

- Pavement Stresses
- Subbase Support
- Concrete Properties
- Secondary Reinforcement

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3.2 Pavement Stresses

- Higher when wheels are at or near an unsupported edge.
- Highest stresses occurs at the intersection of a joint and an unsupported edge

Thickness design of pavement is intended to limit slab tensile stresses produced by vehicular loading. Model studies, as well as full-scale accelerated traffic tests, have shown that maximum tensile stresses in concrete pavement occur when vehicle wheels are close to a free or unsupported edge of the pavement. Stresses resulting from wheel loadings applied near interior joints are generally less severe due to load transfer across the joints. The critical stress condition occurs when a wheel load is applied near the intersection of a joint and the pavement edge. Because parking areas have relatively little area adjacent to free edges and vehicle loads are applied mostly to interior slabs, pavements should be designed assuming supported edges. At the outside edges or at entrances, integral curbs or thickened edge sections can be used to decrease stresses. Thermal expansion and contraction of the pavement and warping or curling caused by moisture and temperature differentials within the pavement cause other stresses that are not addressed directly in thickness design. Proper jointing reduces these stresses.

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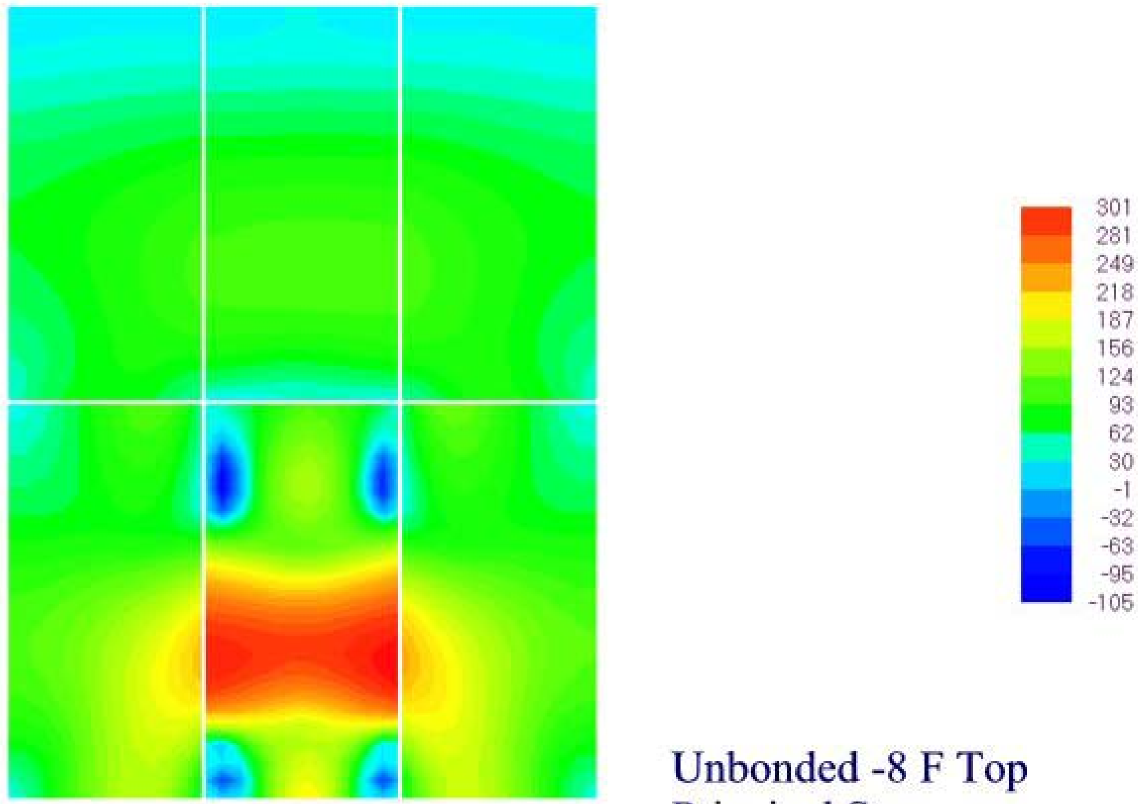
Principal Stresses



Unbonded -8 F Top
Principal Stresses

CONCRETE PROPERTIES

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Concrete materials

- Strength
  - Consistent with design
  - More is not necessarily better
- Durability
  - Entrained air for freeze/thaw
  - Sulfates, AAR considerations if applicable
- Other performance requirements
  - Economy
  - Workability
  - Lowest shrinkage potential
    - Water content, slump
    - Aggregate size & grading

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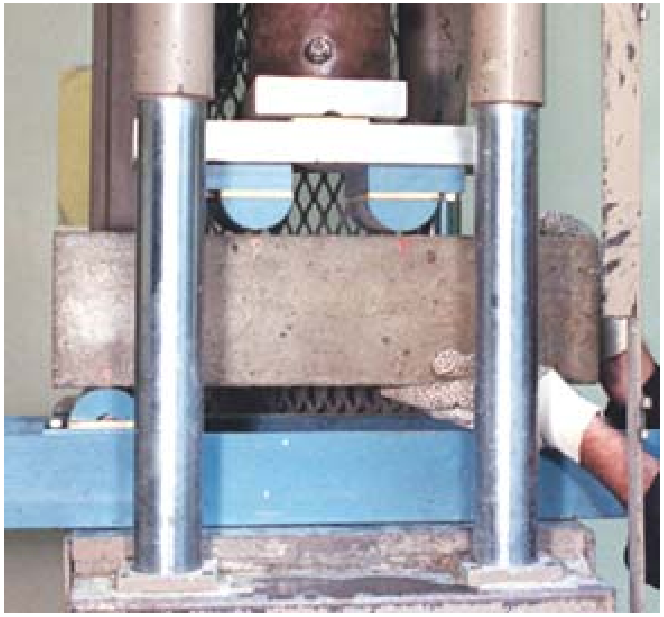
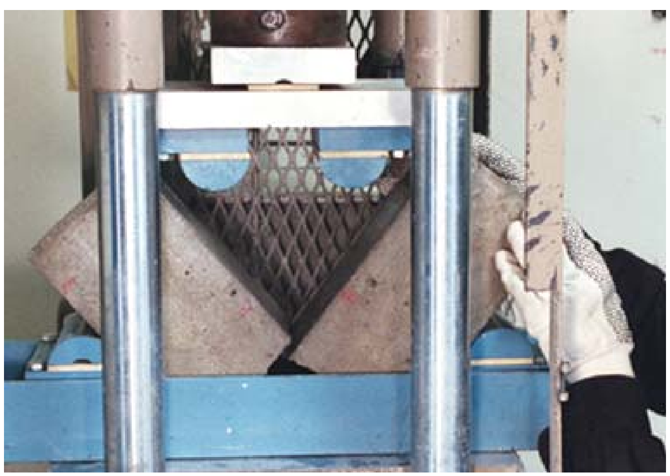
Concrete strength



While compressive strength (f'_c) is specified and used for quality control on most projects, modulus of rupture (M_R) is used for thickness design. The M_R of a concrete mix may be estimated using typical relationships ($M_R \approx 8$ to $10 \times \sqrt{f'_c}$) or actual data from tests using proposed materials.



SPLIT TENSILE

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M_R estimation, (pg 6, ACI 330R)

Round Aggregate

$$MOR\ (psi) = 8\sqrt{f'_c} \quad (in.\text{-}lb\ units)$$

(3-1)

$$MOR\ (MPa) = 0.7\sqrt{f'_c} \quad (SI\ units)$$

Angular Aggregate

$$MOR\ (psi) = 10\sqrt{f'_c} \quad (in.\text{-}lb\ units)$$

(3-2)

$$MOR\ (MPa) = 0.8\sqrt{f'_c} \quad (SI\ units)$$

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Durability??

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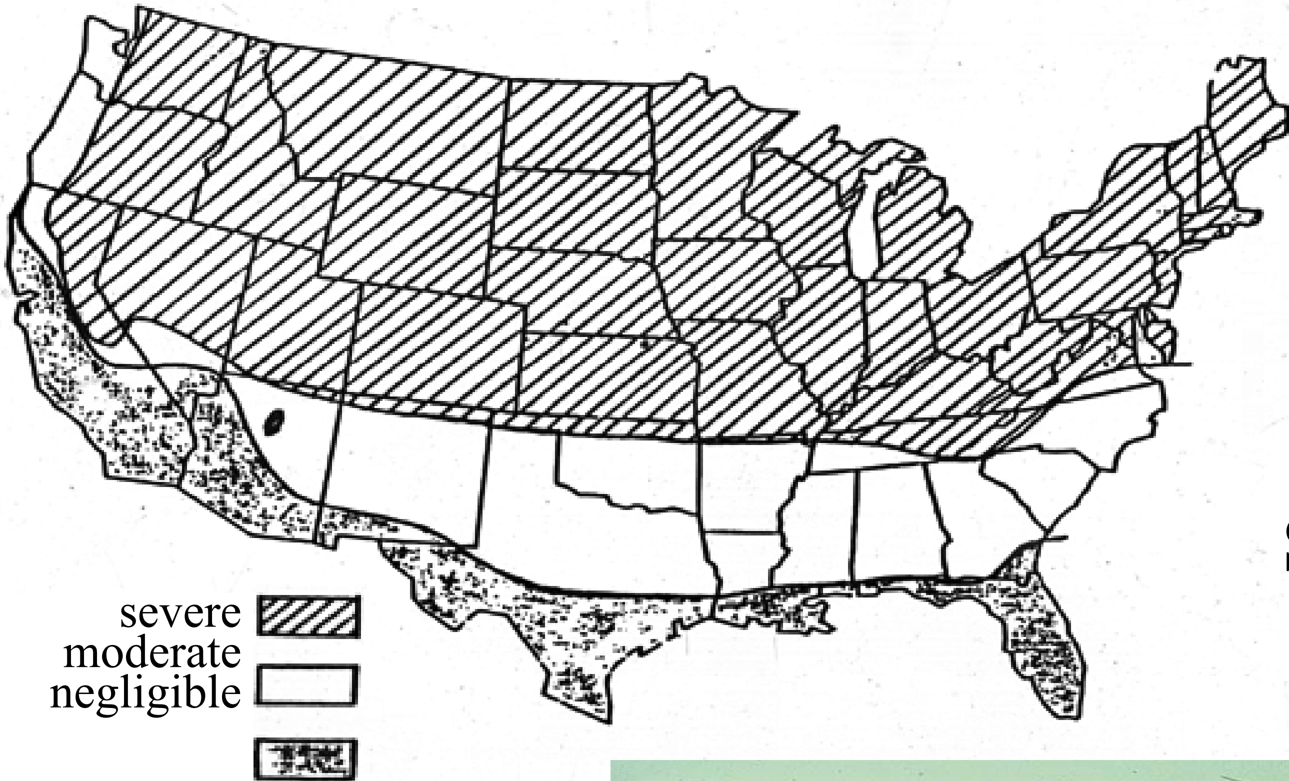

Freeze-thaw severity zones

Entrained air

- Used for f/t durability
- AHTD: 6% ± 2%
- Requires extra QC attention, testing

SECONDARY STEEL REINFORCEMENT

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ACI 330

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3.81 Distributed Steel Reinforcement

3.8.1 *Distributed steel reinforcement*—When pavement is jointed to form short panel lengths that will minimize intermediate cracking, distributed steel reinforcement is not necessary. The practice of adding distributed steel to

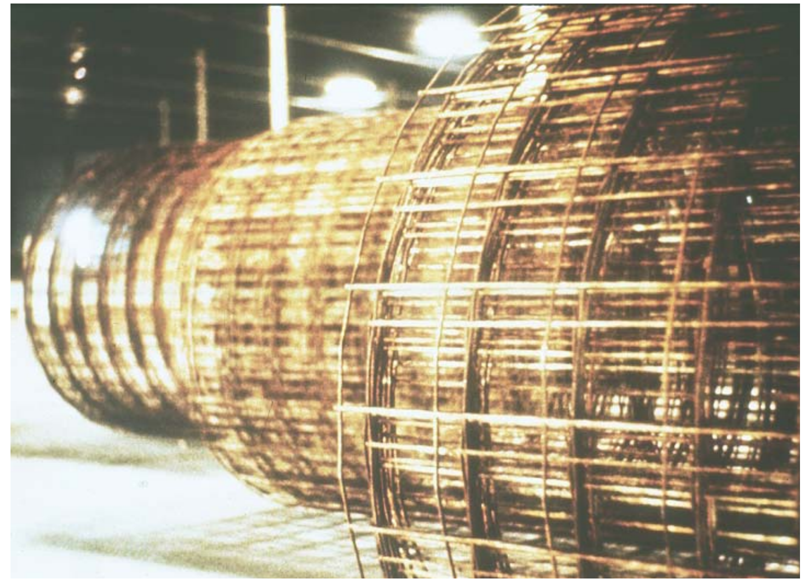
. . .

The use of distributed steel reinforcement will not add to the load-carrying capacity of the pavement and should not be used in anticipation of poor construction practices.

. . .

joints. The sole function of the distributed steel reinforcement is to hold together the fracture faces if cracks form. The

Steel reinforcement



Steel reinforcement

It is almost impossible to place rolled wire mesh in the upper thickness where it can function. Rebar on chairs or welded rigid mats perform better if steel is called for.
Secondary steel reinforcement is often misunderstood and can rarely be justified in flatwork that is properly jointed.

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ACI 325

ACI 325 Paragraph 2.2.5

The use of reinforcement is only recommended for low-volume applications on a limited basis. These limited cases occur when irregular panel shapes are used or when joint spacings are in excess of those that will effectively control shrinkage cracking. Although reinforcing steel cannot be used to address cracking caused by nonuniform support conditions, distributed reinforcement steel may be included to control the opening of unavoidable cracks. The sole function of the steel is to hold together the fracture faces if cracks should form. The quantity of steel varies depending on joint spacing, slab thickness, coefficient of subgrade resistance, bar size, and the tensile strength of the steel. Refer to Chapter 4 for further details of pavement reinforcement design.

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DESIGN

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ACI 330R thickness table (pg. 7, table 3.4)

Table 3.4—Twenty-year design thickness recommendations, in. (no dowels)

		k = 500 psi/in. (CBR = 50; *R* = 86)				*k* = 400 psi/in. (CBR = 38; *R* = 80)				*k* = 300 psi/in. (CBR =26; *R* = 67)			
	MOR, psi:	650	600	550	500	650	600	550	500	650	600	550	500
Traffic category*	A (ADTT =1)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.5
	A (ADTT = 10)	4.0	4.0	4.0	4.5	4.0	4.0	4.5	4.5	4.0	4.5	4.5	4.5
	B (ADTT = 25)	4.0	4.5	4.5	5.0	4.5	4.5	5.0	5.5	4.5	4.5	5.0	5.5
	B (ADTT = 300)	5.0	5.0	5.5	5.5	5.0	5.0	5.5	5.5	5.0	5.5	5.5	6.0
	C (ADTT = 100)	5.0	5.0	5.5	5.5	5.0	5.5	5.5	6.0	5.5	5.5	6.0	6.0
	C (ADTT = 300)	5.0	5.5	5.5	6.0	5.5	5.5	6.0	6.0	5.5	6.0	6.0	6.5
	C (ADTT = 700)	5.5	5.5	6.0	6.0	5.5	5.5	6.0	6.5	5.5	6.0	6.5	6.5
	D (ADTT = 700)†	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
		k = 200 psi/in. (CBR = 10; *R* = 48)				*k* = 100 psi/in. (CBR = 3; *R* = 18)				*k* = 50 psi/in. (CBR = 2; *R* = 5)			
	MOR, psi:	650	600	550	500	650	600	550	500	650	600	550	500
Traffic category*	A (ADTT =1)	4.0	4.0	4.0	4.5	4.0	4.5	4.5	5.0	4.5	5.0	5.0	5.5
	A (ADTT = 10)	4.5	4.5	5.0	5.0	4.5	5.0	5.0	5.5	5.0	5.5	5.5	6.0
	B (ADTT = 25)	5.0	5.0	5.5	6.0	5.5	5.5	6.0	6.0	6.0	6.0	6.5	7.0
	B (ADTT = 300)	5.5	5.5	6.0	6.5	6.0	6.0	6.5	7.0	6.5	7.0	7.0	7.5
	C (ADTT = 100)	5.5	6.0	6.0	6.5	6.0	6.5	6.5	7.0	6.5	7.0	7.5	7.5
	C (ADTT = 300)	6.0	6.0	6.5	6.5	6.5	6.5	7.0	7.5	7.0	7.5	7.5	8.0
	C (ADTT = 700)	6.0	6.5	6.5	7.0	6.5	7.0	7.0	7.5	7.0	7.5	8.0	8.5
	D (ADTT = 700)†	7.0	7.0	7.0	7.0	8.0	8.0	8.0	8.0	9.0	9.0	9.0	9.0

*ADTT = average daily truck traffic. Trucks are defined as vehicles with at least six wheels; excludes panel trucks, pickup trucks, and other four-wheel vehicles. Refer to Appendix A.
k = modulus of subgrade reaction; CBR = California bearing ratio; *R* = resistance value; and MOR = modulus of rupture.
†Thickness of Category D (only) can be reduced by 1.0 in. (25 mm) if dowels are used at all transverse joints (that is, joints located perpendicular to direction of traffic).
Note: 1 in. = 25.4 mm; 1 psi = 0.0069 MPa; and 1 psi/in. = 0.27 MPa/m.

Concrete Consulting, LLC

Select Traffic Category

Table 2.3—Traffic categories*

1. Car parking areas and access lanes—Category A (autos, pickups, and panel trucks only)		
2. Truck access lanes—Category A-1		
3. Shopping center entrance and service lanes—Category B		
4. Bus parking areas, city and school buses Parking area and interior lanes—Category B Entrance and exterior lanes—Category C		
5. Truck parking areas—Category B, C, or D		
Truck type	Parking areas and interior lanes	Entrance and exterior lanes
Single units (bobtailed trucks)	Category B	Category C
Multiple units (tractor trailer units with one or more trailers)	Category C	Category D

*Select A, A-1, B, C, or D for use with Table 2.4.

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Traffic category	k = 200 (CBR = 10) M_R				k = 100 (CBR = 3) M_R				k = 50 (CBR = 2) M_R			
	650	600	550	500	650	600	550	500	650	600	550	500
A (ADTT= 0)	3.5	3.5	3.5	4.0	3.5	3.5	3.5	4.0	4.0	4.0	4.0	4.0
A-1 (ADTT =1)	4.0	4.0	4.5	4.5	4.0	4.5	4.5	5.0	4.5	5.0	5.0	5.5
A-1 (ADTT = 10)	4.5	5.0	5.5	5.5	5.0	5.5	6.0	6.0	5.5	6.0	6.5	7.0
B (ADTT = 25)	4.5	5.0	5.5	6.0	5.0	5.5	6.0	6.5	5.5	6.0	6.5	7.0
B (ADTT = 300)	5.0	5.5	6.0	6.5	5.5	6.0	6.5	7.0	6.5	6.5	7.0	7.5
C (ADTT = 100)	5.5	5.5	6.0	6.5	6.0	6.0	6.5	7.0	6.5	7.0	7.5	8.0
C (ADTT = 300)	5.5	6.0	6.5	7.0	6.0	6.5	7.0	7.5	6.5	7.0	7.5	8.0
C (ADTT = 700)	6.0	6.0	6.5	7.0	6.5	6.5	7.0	7.5	7.0	7.5	8.0	8.5
D (ADTT = 700)	7.0	7.0	7.0	7.0	8.0	8.0	8.0	8.0	9.0	9.0	9.0	9.0

*ADTT = average daily truck traffic. Trucks are defined as vehicles with at least six wheels; excludes panel trucks, pickup trucks, and other four-wheel vehicles. See Appendix A. For thickness conversion to SI units, see Appendix E.

CRT Concrete Consulting, LLC

Flexural Strength Sensitivity = ½”

Table 2.4—Twenty-year design thickness recommendations, in. (no dowels)

Traffic category	$k = 500$ (CBR = 50) M_R				$k = 400$ (CBR = 38) M_R				$k = 300$ (CBR = 26) M_R			
	650	600	550	500	650	600	550	500	650	600	550	500
A (ADTT= 0)*	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	4.0
A-1 (ADTT =1)*	3.5	3.5	4.0	4.0	3.5	4.0	4.0	4.0	4.0	4.0	4.0	4.5
A-1 (ADTT = 10)	4.0	4.5	4.5	5.0	4.5	4.5	5.0	5.0	4.5	4.5	5.0	5.5
B (ADTT = 25)	4.0	4.5	4.5	5.0	4.5	4.5	5.0	5.5	4.5	4.5	5.0	5.5
B (ADTT = 300)	5.0	5.0	5.0	5.5	5.0	5.0	5.5	6.0	5.0	5.5	5.5	6.0
C (ADTT = 100)	4.5	5.0	5.5	6.0	5.0	5.0	5.5	6.0	5.0	5.5	5.5	6.0
C (ADTT = 300)	5.0	5.5	5.5	6.0	5.0	5.5	6.0	6.0	5.5	5.5	6.0	6.5
C (ADTT = 700)	5.5	5.5	6.0	6.0	5.5	5.5	6.0	6.5	5.5	6.0	6.0	6.5
D (ADTT = 700)	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5

Traffic category	$k = 200$ (CBR = 10) M_R				$k = 100$ (CBR = 3) M_R				$k = 50$ (CBR = 2) M_R			
	650	600	550	500	650	600	550	500	650	600	550	500
A (ADTT= 0)	3.5	3.5	3.5	4.0	3.5	3.5	3.5	4.0	4.0	4.0	4.0	4.0
A-1 (ADTT =1)	4.0	4.0	4.5	4.5	4.0	4.5	4.5	5.0	4.5	5.0	5.0	5.5
A-1 (ADTT = 10)	4.5	5.0	5.5	5.5	5.0	5.5	6.0	6.0	5.5	6.0	6.5	7.0
B (ADTT = 25)	4.5	5.0	5.5	6.0	5.0	5.5	6.0	6.5	5.5	6.0	6.5	7.0
B (ADTT = 300)	5.0	5.5	6.0	6.5	5.5	6.0	6.5	7.0	6.5	6.5	7.0	7.5
C (ADTT = 100)	5.5	5.5	6.0	6.5	6.0	6.0	6.5	7.0	6.5	7.0	7.5	8.0
C (ADTT = 300)	5.5	6.0	6.5	7.0	6.0	6.5	7.0	7.5	6.5	7.0	7.5	8.0
C (ADTT = 700)	6.0	6.0	6.5	7.0	6.5	6.5	7.0	7.5	7.0	7.5	8.0	8.5
D (ADTT = 700)	7.0	7.0	7.0	7.0	8.0	8.0	8.0	8.0	9.0	9.0	9.0	9.0

*ADTT = average daily truck traffic. Trucks are defined as vehicles with at least six wheels; excludes panel trucks, pickup trucks, and other four-wheel vehicles. See Appendix A.
For thickness conversion to SI units, see Appendix E.

Concrete Consulting, LLC

Subgrade Sensitivity = 1”

Table 2.4—Twenty-year design thickness recommendations, in. (no dowels)

Traffic category	k = 500 (CBR = 50) M_R				k = 400 (CBR = 38) M_R				k = 300 (CBR = 26) M_R			
	650	600	550	500	650	600	550	500	650	600	550	500
A (ADTT= 0)*	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	4.0
A-1 (ADTT =1)*	3.5	3.5	4.0	4.0	3.5	4.0	4.0	4.0	4.0	4.0	4.0	4.5
A-1 (ADTT = 10)	4.0	4.5	4.5	5.0	4.5	4.5	5.0	5.0	4.5	4.5	5.0	5.5
B (ADTT = 25)	4.0	4.5	4.5	5.0	4.5	4.5	5.0	5.5	4.5	4.5	5.0	5.5
B (ADTT = 300)	5.0	5.0	5.0	5.5	5.0	5.0	5.5	6.0	5.0	5.5	5.5	6.0
C (ADTT = 100)	4.5	5.0	5.5	6.0	5.0	5.0	5.5	6.0	5.0	5.5	5.5	6.0
C (ADTT = 300)	5.0	5.5	5.5	6.0	5.0	5.5	6.0	6.0	5.5	5.5	6.0	6.5
C (ADTT = 700)	5.5	5.5	6.0	6.0	5.5	5.5	6.0	6.5	5.5	6.0	6.0	6.5
D (ADTT = 700)	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5

Traffic category	k = 200 (CBR = 10) M_R				k = 100 (CBR = 3) M_R				k = 50 (CBR = 2) M_R			
	650	600	550	500	650	600	550	500	650	600	550	500
A (ADTT= 0)	3.5	3.5	3.5	4.0	3.5	3.5	3.5	4.0	4.0	4.0	4.0	4.0
A-1 (ADTT =1)	4.0	4.0	4.5	4.5	4.0	4.5	4.5	5.0	4.5	5.0	5.0	5.5
A-1 (ADTT = 10)	4.5	5.0	5.5	5.5	5.0	5.5	6.0	6.0	5.5	6.0	6.5	7.0
B (ADTT = 25)	4.5	5.0	5.5	6.0	5.0	5.5	6.0	6.5	5.5	6.0	6.5	7.0
B (ADTT = 300)	5.0	5.5	6.0	6.5	5.5	6.0	6.5	7.0	6.5	6.5	7.0	7.5
C (ADTT = 100)	5.5	5.5	6.0	6.5	6.0	6.0	6.5	7.0	6.5	7.0	7.5	8.0
C (ADTT = 300)	5.5	6.0	6.5	7.0	6.0	6.5	7.0	7.5	6.5	7.0	7.5	8.0
C (ADTT = 700)	6.0	6.0	6.5	7.0	6.5	6.5	7.0	7.5	7.0	7.5	8.0	8.5
D (ADTT = 700)	7.0	7.0	7.0	7.0	8.0	8.0	8.0	8.0	9.0	9.0	9.0	9.0

*ADTT = average daily truck traffic. Trucks are defined as vehicles with at least six wheels; excludes panel trucks, pickup trucks, and other four-wheel vehicles. See Appendix A. For thickness conversion to SI units, see Appendix E.

Concrete Consulting, LLC

Truck Traffic Sensitivity = 1½”

Table 2.4—Twenty-year design thickness recommendations, in. (no dowels)

Traffic category	k = 500 (CBR = 50) M_R				k = 400 (CBR = 38) M_R				k = 300 (CBR = 26) M_R			
	650	600	550	500	650	600	550	500	650	600	550	500
A (ADTT= 0)*	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	4.0
A-1 (ADTT =1)*	3.5	3.5	4.0	4.0	3.5	4.0	4.0	4.0	4.0	4.0	4.0	4.5
A-1 (ADTT = 10)	4.0	4.5	4.5	5.0	4.5	4.5	5.0	5.0	4.5	4.5	5.0	5.5
B (ADTT = 25)	4.0	4.5	4.5	5.0	4.5	4.5	5.0	5.5	4.5	4.5	5.0	5.5
B (ADTT = 300)	5.0	5.0	5.0	5.5	5.0	5.0	5.5	6.0	5.0	5.5	5.5	6.0
C (ADTT = 100)	4.5	5.0	5.5	6.0	5.0	5.0	5.5	6.0	5.0	5.5	5.5	6.0
C (ADTT = 300)	5.0	5.5	5.5	6.0	5.0	5.5	6.0	6.0	5.5	5.5	6.0	6.5
C (ADTT = 700)	5.5	5.5	6.0	6.0	5.5	5.5	6.0	6.5	5.5	6.0	6.0	6.5
D (ADTT = 700)	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5

Traffic category	k = 200 (CBR = 10) M_R				k = 100 (CBR = 3) M_R				k = 50 (CBR = 2) M_R			
	650	600	550	500	650	600	550	500	650	600	550	500
A (ADTT= 0)	3.5	3.5	3.5	4.0	3.5	3.5	3.5	4.0	4.0	4.0	4.0	4.0
A-1 (ADTT =1)	4.0	4.0	4.5	4.5	4.0	4.5	4.5	5.0	4.5	5.0	5.0	5.5
A-1 (ADTT = 10)	4.5	5.0	5.5	5.5	5.0	5.5	6.0	6.0	5.5	6.0	6.5	7.0
B (ADTT = 25)	4.5	5.0	5.5	6.0	5.0	5.5	6.0	6.5	5.5	6.0	6.5	7.0
B (ADTT = 300)	5.0	5.5	6.0	6.5	5.5	6.0	6.5	7.0	6.5	6.5	7.0	7.5
C (ADTT = 100)	5.5	5.5	6.0	6.5	6.0	6.0	6.5	7.0	6.5	7.0	7.5	8.0
C (ADTT = 300)	5.5	6.0	6.5	7.0	6.0	6.5	7.0	7.5	6.5	7.0	7.5	8.0
C (ADTT = 700)	6.0	6.0	6.5	7.0	6.5	6.5	7.0	7.5	7.0	7.5	8.0	8.5
D (ADTT = 700)	7.0	7.0	7.0	7.0	8.0	8.0	8.0	8.0	9.0	9.0	9.0	9.0

*ADTT = average daily truck traffic. Trucks are defined as vehicles with at least six wheels; excludes panel trucks, pickup trucks, and other four-wheel vehicles. See Appendix A. For thickness conversion to SI units, see Appendix E.

CRI Concrete Consulting, LLC

Parking Area Quick Reference

From American Concrete Institute Committee 330

Step 1:
Determine concrete compressive strength requirement. For all concrete exposed to freeze-thaw cycling and de-icers, use no less than 4000 psi. 4500 is recommended.

Step 2:
Determine Modulus of Subgrade Reactivity, *k*. Use guidelines below.

Step 3:
Determine Traffic Categories (Car parking area, entrances, etc.).

Step 4:
Determine *Average Daily Truck Traffic* (ADTT) on the pavement. It is safe to always assume at least one ADTT.

Step 5:
Read across row that corresponds to your Traffic Category and ADTT to the column that represents your concrete strength and *k* value.

Example:

- Car parking area truck access lane.
- Traffic Category A, ADTT = 1.
- Concrete strength of 4500 psi.
- Soil is sandy gravel with some clay and silt; *k* value is 130–170; therefore use *k* = 100.
- Under area with *k* = 100, read across row with "Traffic Category A (ADTT = 1)" to column under *f'c* = 4500.
- Thickness necessary for this situation is 4.5.

Modulus of Subgrade Reactivity

Type of Subgrade Soil	*k* Value	CBR
Fine-grained soils in which silt and clay-sized particles predominate	75 – 120	2.5 – 3.5
Sands and sand-gravel mixtures with moderate amounts of silt and clay	130 – 170	4.5 – 7.5
Sands & sand-gravel mixtures relatively free of plastic fines	180 – 220	8.5 – 12

Traffic Categories

Select Category A, B, C or D

Car Parking Areas & Access Lanes *(Autos, pick-ups, and panel trucks only)*		Category A
Shopping Center Entrance and Service Lanes		Category B
City & School Bus Parking Areas:		
◇ Parking area and interior lanes.		Category B
◇ Entrance and exterior lanes.		Category C
Truck Parking Areas:		
Parking Areas & Interior Lanes	Single-Unit Trucks*	Category B
	Multiple-Unit Trucks**	Category C
Entrance & Exterior Lanes	Single-Unit Trucks*	Category C
	Multiple-Unit Trucks**	Category D

* *Single-Unit Trucks = Bobtailed Trucks*
** *Multiple-Unit Trucks = Tractor-trailer units with 1 or more trailers*

Twenty-Year Design Thickness Recommendations in Inches (No Dowels)

Traffic Category*	*k* = 500 psi/in. (CBR = 50; *R* =86)				*k* = 400 psi/in. (CBR = 38; *R* =80)				*k* = 300 psi/in. (CBR = 26; *R* =67)			
f'c	5000	4500	4000	3500	5000	4500	4000	3500	5000	4500	4000	3500
MOR, psi	650	600	550	500	650	600	550	500	650	600	550	500
A (ADTT=1)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.5
A (ADTT=10)	4.0	4.0	4.0	4.5	4.0	4.0	4.5	4.5	4.0	4.5	4.5	4.5
B (ADTT=25)	4.0	4.5	4.5	5.0	4.5	4.5	5.0	5.5	4.5	4.5	5.0	5.5
B (ADTT=300)	5.0	5.0	5.5	5.5	5.0	5.0	5.5	5.5	5.0	5.5	5.5	6.0
C (ADTT=100)	5.0	5.0	5.5	5.5	5.0	5.5	5.5	6.0	5.5	5.5	6.0	6.0
C (ADTT=300)	5.0	5.5	5.5	6.0	5.5	5.5	6.0	6.0	5.5	6.0	6.0	6.5
C (ADTT=700)	5.5	5.5	6.0	6.0	5.5	5.5	6.0	6.5	5.5	6.0	6.5	6.5
D (ADTT=700)†	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5

Traffic Category*	*k* = 200 psi/in. (CBR = 10; *R* =48)				*k* = 100 psi/in. (CBR = 3; *R* =18)				*k* = 50 psi/in. (CBR = 2; *R* =5)			
f'c	5000	4500	4000	3500	5000	4500	4000	3500	5000	4500	4000	3500
MOR, psi	650	600	550	500	650	600	550	500	650	600	550	500
A (ADTT=1)	4.0	4.0	4.0	4.5	4.0	4.5	4.5	5.0	4.5	5.0	5.0	5.5
A (ADTT=10)	4.5	4.5	5.0	5.0	4.5	5.0	5.0	5.5	5.0	5.5	5.5	6.0
B (ADTT=25)	5.0	5.0	5.5	6.0	5.5	5.5	6.0	6.0	6.0	6.0	6.5	7.0
B (ADTT=300)	5.5	5.5	6.0	6.5	6.0	6.0	6.5	7.0	6.5	7.0	7.0	7.5
C (ADTT=100)	5.5	6.0	6.0	6.5	6.0	6.5	6.5	7.0	6.5	7.0	7.5	7.5
C (ADTT=300)	6.0	6.0	6.5	6.5	6.5	6.5	7.0	7.5	7.0	7.5	7.5	8.0
C (ADTT=700)	6.0	6.5	6.5	7.0	6.5	7.0	7.0	7.5	7.0	7.5	8.0	8.5
D (ADTT=700)†	7.0	7.0	7.0	7.0	8.0	8.0	8.0	8.0	9.0	9.0	9.0	9.0

* ADTT = Average Daily Truck Traffic. Trucks are defined as vehicles with at least 6 wheels; excludes panel trucks, pickup trucks, and other 4-wheeled vehicles. Refer to Appendix A.
k = Modulus of subgrade reaction; CBR = California Bearing Ratio; *R* = Resistance value; and MOR = Modulus Of Rupture.

† Thickness of Category D (only) can be reduced by 1.0 in. (25 mm) if dowels are used at all transverse joints (that is, joints located perpendicular to direction of traffic). Note: 1 in. = 25.4 mm; 1 psi = 0.0069 MPa; and 1 psi/in. = 0.27 MPa/m.

DESIGN OF JOINTED PAVEMENTS FOR LOCAL STREETS AND ROADS

(ACI 325)

CRT
Concrete Consulting, LLC

ACI 325.12R-02

Guide for Design of Jointed Concrete Pavements for Streets and Local Roads

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Al Ezzy	Emmanuel B. Owusu-Antwi	David P. Whitney
Luis A. Garcia	Dipak T. Parekh	James M. Willson
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Ben Gompers	Ronald L. Peltz	

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CHAPTER 3—PAVEMENT THICKNESS DESIGN

3.1—Basis of design

The most cost-effective pavement design is that which has been validated by road tests, pavement studies, and surveys of pavement performance. The most commonly used methods are the AASHTO design guide,[2] which was developed from performance data obtained at the AASHTO road test; and the Portland Cement Association's (PCA) design procedure,[12,13] which is based on the pavement's resistance to fatigue and deflection effects on the subgrade. The PCA procedure is recommended for use in instances of overload conditions that can yield design thicknesses beyond those provided in this chapter. Further explanations of design concepts suggested in the PCA design procedure can be found in Appendix A. A design catalog published by the National Cooperative Highway Research Program (NCHRP) may also provide useful design information.[25]

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Table 3.1—Street classification[27]

Street classification	VPD or ADT, two-way	Heavy commercial vehicles (two-axle, six-tire, and heavier)	
		%	No. per day
Light residential	200	1 to 2	2 to 4
Residential	200 to 1000	1 to 2	2 to 4
Collector	1000 to 8000	3 to 5	50 to 500
Minor arterial	4000 to 15,000	10	300 to 600
Major arterial	4000 to 30,000	15 to 20	700 to 1500
Business	11,000 to 17,000	4 to 7	400 to 700
Industrial	2000 to 4000	15 to 20	300 to 800

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3.3 Thickness Determination

- Subgrade Support
- Flexural Strength
- Traffic

3.3—Thickness determination

Proper selection of the slab thickness is a crucial element of a concrete pavement design. Inadequate thickness will lead to cracking and premature loss of serviceability. Suggested thicknesses for the design of low-volume concrete roads are listed in Table 3.2(a) and 3.2(b) as a function of subgrade support and concrete flexural strength (third-point loading). The thicknesses listed for a *k* value of 81.5 MPa/m (300 psi/in.) are considered to be minimum thicknesses for design. Pavement designs provided in these tables are assumed to be applicable to a 30-year performance period as long as minimal durability-related distresses occur. Pavement life can also be assessed from the standpoint of fatigue accumulation based on calculations illustrated in Appendix A.

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Table 3.2(a)—Pavement thickness, mm,[27] with integral or tied curb and gutter or shoulders (supported edges)

k = 13.5 MPa/m					k = 27 MPa/m						
MOR MPa					MOR MPa						
3.4	3.8	4.1	4.5	4.8	3.4	3.8	4.1	4.5	4.8	Traffic classification	
150	150	150	125	125	150	125	125	125	125	ADTT = 3	Light residential
175	175	150	150	150	175	150	150	125	125	ADTT = 10	Residential
175	175	150	150	150	175	150	150	125	125	ADTT = 20	Collector
175	175	150	150	150	175	150	150	150	125	ADTT = 50	
200	200	175	175	175	200	175	175	150	150		
225	200	200	175	175	200	175	175	175	150	ADTT = 100	Minor arterial
225	200	200	200	200*	200	200	175	175	175	ADTT = 500	
225	200	200	200	200*	200	200	175	175	175	ADTT = 100	
225	225	200	200*	200†	225	200	175	175	175*	ADTT = 500	Major arterial
250	225	225	200	200*	225	225	200	200	175	ADTT = 400	
250	250	225	225*	225†	225	225	200	200*	200†	ADTT = 800	Business
275	250*	250†	250‡	250§	250	225	225*	225*	225*	ADTT = 1500	
225	200	200	175	175	200	200	175	175	150	ADTT = 300	
225	225	200	200*	200†	200	200	175	175*	175*	ADTT = 700	Industrial
250	225	225	200	200*	225	225	200	200	175	ADTT = 400	
250	250	225	225*	225†	225	225	200	200*	200†	ADTT = 800	—
k = 54 MPa/m					k = 81.5 MPa/m						
MOR MPa					MOR MPa						
3.4	3.8	4.1	4.5	4.8	3.4	3.8	4.1	4.5	4.8	Traffic classification	
125	125	125	100	100	125	125	100	100	100	ADTT = 3	Light residential
150	125	125	125	125	150	125	125	125	100	ADTT = 10	Residential
150	150	125	125	125	150	125	125	125	100	ADTT = 20	Collector
150	150	125	125	125	150	125	125	125	125	ADTT = 50	
175	175	150	150	150	175	150	150	150	125		
175	175	150	150	150	175	150	150	150	125	ADTT = 100	Minor arterial
200	175	175	150	150	175	175	150	150	150*	ADTT = 500	
200	175	175	150	150	175	175	150	150	150*	ADTT = 100	
200	175	175	175	175*	175	175	175	175*	175†	ADTT = 500	Major arterial
200	200	175	175	175	200	175	175	175	175*	ADTT = 400	
225	200	200	175	175*	200	200	175	175*	175†	ADTT = 800	Business
225	200	200	200*	200†	200	200	200*	200*	200†	ADTT = 1500	
175	175	175	150	150	175	175	150	150	150	ADTT = 300	
200	175	175	175*	175†	175	175	150	150	150*	ADTT = 700	Industrial
200	200	175	175	175	200	175	175	175	175*	ADTT = 400	
225	200	200	175	175*	200	200	175	175*	175†	ADTT = 800	—

Note: 1 in. = 25.4 mm; and 1 psi/in. = 0.27 MPa/m.

*If doweled, thickness can be decreased by 13 mm.
†If doweled, thickness can be decreased by 25 mm.
‡If doweled, thickness can be decreased by 38 mm.
§If doweled, thickness can be decreased by 50 mm.

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Table 3.2(b)—Pavement thickness, mm,[29] without curb and gutters or shoulders (unsupported edges)

k = [illegible] MPa/m					k = [illegible] MPa/m						
MOR MPa					MOR MPa						
3.4	3.8	4.1	4.5	4.8	3.4	3.8	4.1	4.5	4.8	Traffic classification	
175	175	150	150	150	175	150	150	150	125	ADTT = 3	Light residential
200	200	175	175	150	175	175	175	150	150	ADTT = 10	Residential
200	200	200	175	175	200	175	175	150	150	ADTT = 20	Collector
200	200	200	175	175	200	175	175	175	150	ADTT = 50	
250	225	225	200	200	225	200	200	175	175	ADTT = 50	
250	225	225	200	200	225	200	200	200	175	ADTT = 100	Minor arterial
275	250	225	225	200	250	225	200	200	200	ADTT = 500	
275	250	225	225	200	250	225	200	200	200	ADTT = 100	
275	250	250	225[*]	225[*]	250	225	225	200	200[*]	ADTT = 500	Major arterial
300	275	250	250	225	275	250	225	225	200	ADTT = 400	
300	275	275	250[*]	250[†]	275	250	250	225	225[*]	ADTT = 800	Business
300	300	275[*]	275[†]	275[‡]	275	250	250	250[*]	250[†]	ADTT = 1500	
250	250	225	225	200	225	225	200	200	175	ADTT = 300	
275	250	225	225	225[*]	250	225	225	200	200	ADTT = 700	Industrial
300	275	250	250	225	275	250	225	225	200	ADTT = 400	
300	300	275	250[*]	250[†]	275	250	250	225	225[*]	ADTT = 800	—
k = 54 MPa/m					k = 81.5 MPa/m						
MOR MPa					MOR MPa						
3.4	3.8	4.1	4.5	4.8	3.4	3.8	4.1	4.5	4.8	Traffic classification	
150	150	125	125	125	150	125	125	125	125	ADTT = 3	Light residential
175	150	150	150	125	150	150	150	125	125	ADTT = 10	Residential
175	175	150	150	150	175	150	150	150	125	ADTT = 20	Collector
175	175	150	150	150	175	150	150	150	125	ADTT = 50	
200	200	175	175	150	200	175	175	150	150	ADTT = 50	
200	200	175	175	175	200	175	175	150	150	ADTT = 100	Minor arterial
225	200	200	175	175	200	200	175	175	175	ADTT = 500	
225	200	200	175	175	200	200	175	175	175	ADTT = 100	
225	200	200	200	200[*]	225	200	200	175	175[*]	ADTT = 500	Major arterial
250	225	225	200	200	225	225	200	200	175	ADTT = 400	
250	225	225	200	200[*]	225	225	200	200	200	ADTT = 800	Business
250	225	225	225[*]	225[*]	250	225	225	225[*]	225[†]	ADTT = 1500	
225	200	200	175	175	200	200	175	175	175	ADTT = 300	
225	200	200	175	175	200	200	175	175	175[*]	ADTT = 700	Industrial
250	225	225	200	200	225	225	200	200	175	ADTT = 400	
250	225	225	200	200[*]	225	225	200	200	200	ADTT = 800	—

Note: 1 in. = 25.4 mm; and 1 psi/in. = 0.27 MPa/m.

[*]If doweled, thickness can be decreased by 13 mm.

[†]If doweled, thickness can be decreased by 25 mm.

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Pavement Thickness with Integral or Tied Curb & Gutter or Shoulders

k= 50 psi/in					k= 100 psi/in					Traffic Classification	
MOR psi					MOR psi						
500	550	600	650	700	500	550	600	650	700		
6	6	6	5	5	6	5	5	5	5	ADTT = 3	Light Residential
7	7	6	6	6	7	6	6	5	5	ADTT = 10	Residential
7	7	6	6	6	7	6	6	5	5	ADTT = 20	Collector
7	7	6	6	6	7	6	6	6	5	ADTT = 50	
8	8	7	7	7	8	7	7	6	6		
9	8	8	7	7	8	7	7	7	6	ADTT = 100	Minor Arterial
9	8	8	8	8 *	8	8	7	7	7	ADTT = 500	
9	8	8	8	8 *	8	8	7	7	7	ADTT = 100	Major Arterial
9	9	8	8 *	8 †	9	8	7	7	7 *	ADTT = 500	
10	9	9	8	8 *	9	9	8	8	7	ADTT = 400	
10	10	9	9 *	9 †	9	9	8	8 *	8 †	ADTT = 800	Business
11	10 *	10 †	10 ‡	10 §	10	9	9 *	9 *	9 *	ADTT = 1500	
9	8	8	7	7	8	8	7	7	6	ADTT = 300	
9	9	8	8 *	8 †	8	8	7	7 *	7 *	ADTT = 700	Industrial
10	9	9	8	8 *	9	9	8	8	7	ADTT = 400	
10	10	9	9 *	9 †	9	9	8	8 *	8 †	ADTT = 800	-

* If doweled, thickness can be decreased by 0.5 in

† If doweled, thickness can be decreased by 1 in

‡ If doweled, thickness can be decreased by 1.5 in

§ If doweled, thickness can be decreased by 2 in

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3.7: JOINTING

Joint layout guidelines

- Things to Do
  - Jointing plan drawn by designer of record, or submitted by contractor & approved by designer
  - Match existing joints or cracks
  - Cut at the proper time
  - Place joints to meet in-pavement structures
  - Adjust spacings to avoid small panels or angles
  - Intersect curves radially, edges perpendicular
  - Keep panels square
- Things to Avoid
  - Jointing plan left to contractor with no oversight
  - Slabs < 1 ft. wide
  - Slabs > 15 ft. wide
  - Angles < 60º (90º is best)
  - Creating interior corners
  - Odd Shapes (keep slabs square)
  - Offset (staggered) joints
  - Isolation (unthickened) joints in traffic areas

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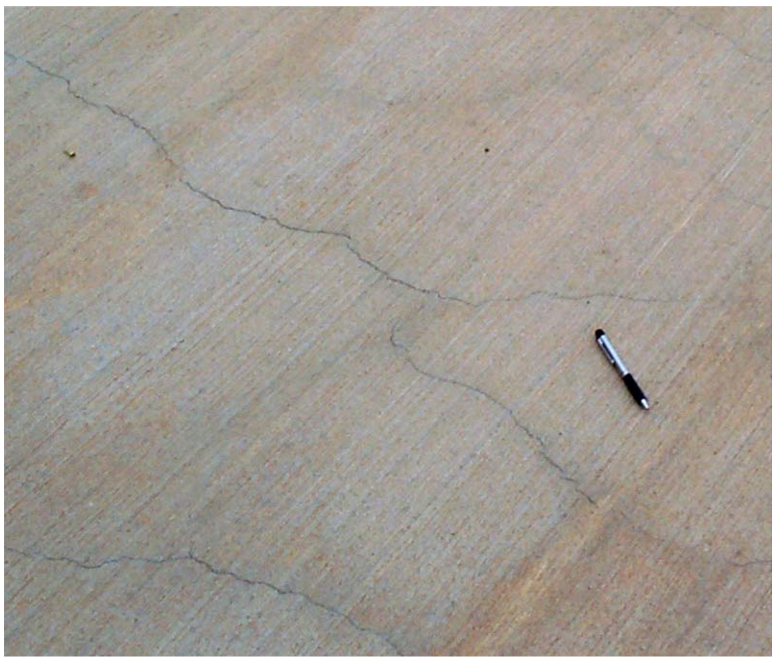
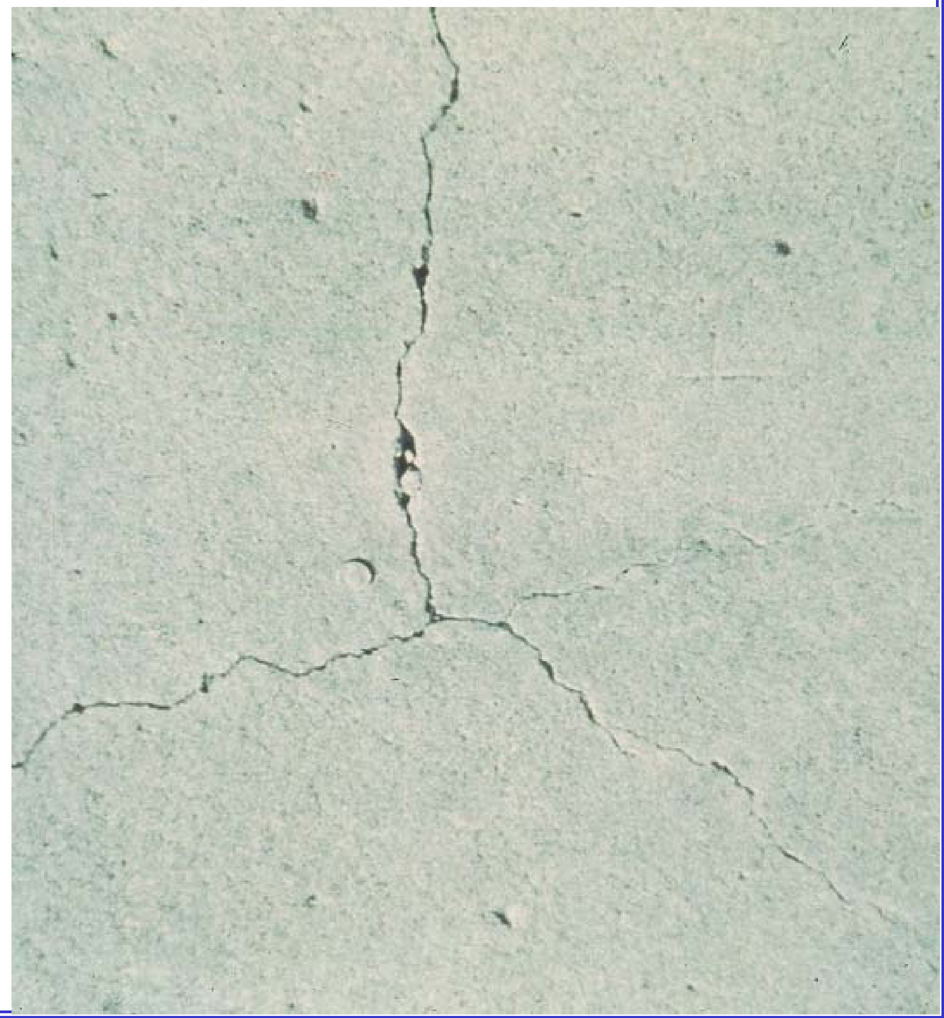
Joint design and layout affects performance…

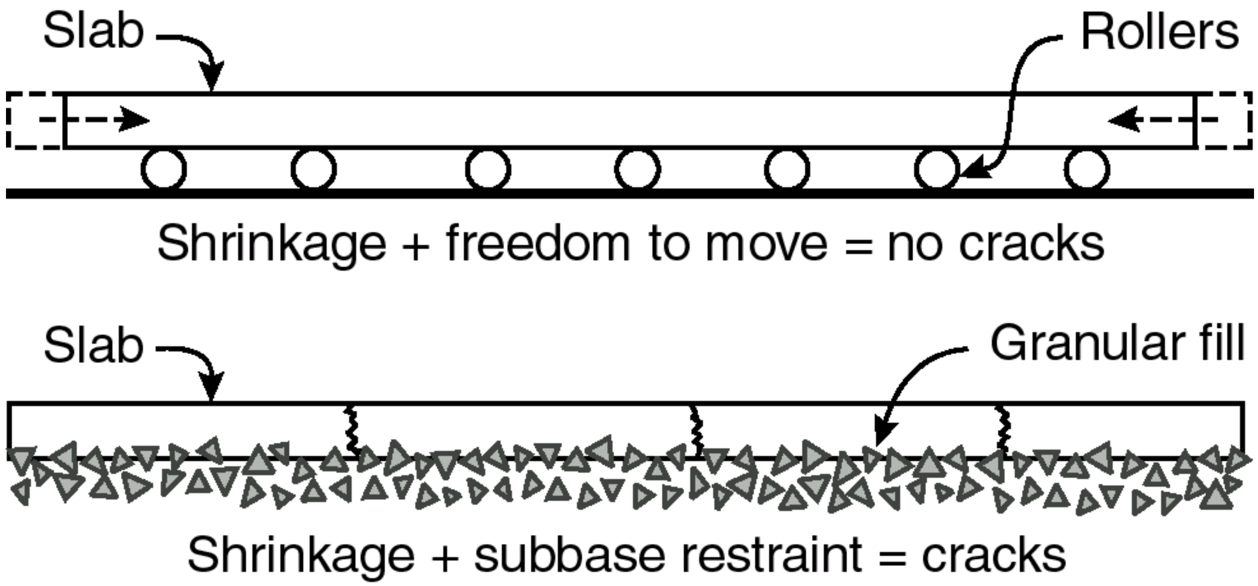
Concrete volume change effects and jointing

Concrete volume change (and cracking) behavior is the basis of many jointing and construction procedure recommendations.





Drying shrinkage and cracking



Shrinkage + Restraint = Cracking

Cracking results from combined effects of restraint and shrinkage (drying and/or thermal)…

…whenever resulting tensile stresses exceed tensile strength.

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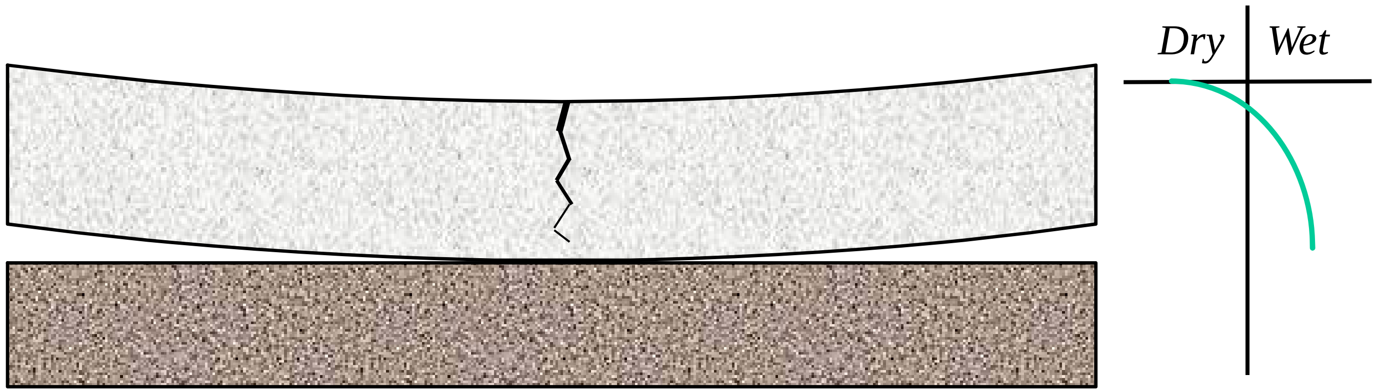
Differential shrinkage = warping or curling of slabs



- Can result from differential moisture created by surface drying while the slab bottom remains wet
- Can also result from differential temperature
- Effects become more severe with thinner slabs and/or longer joint spacings
- In severe cases, causes loss of support near panel edges, greater movement and faulting at joints, mid-panel cracking

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Objectives of jointing

- Control the location, width, and appearance of expected cracks
- Facilitate construction
- Accommodate normal slab movements
- Provide load transfer where needed
- Minimize performance implications of any random (unexpected) cracks

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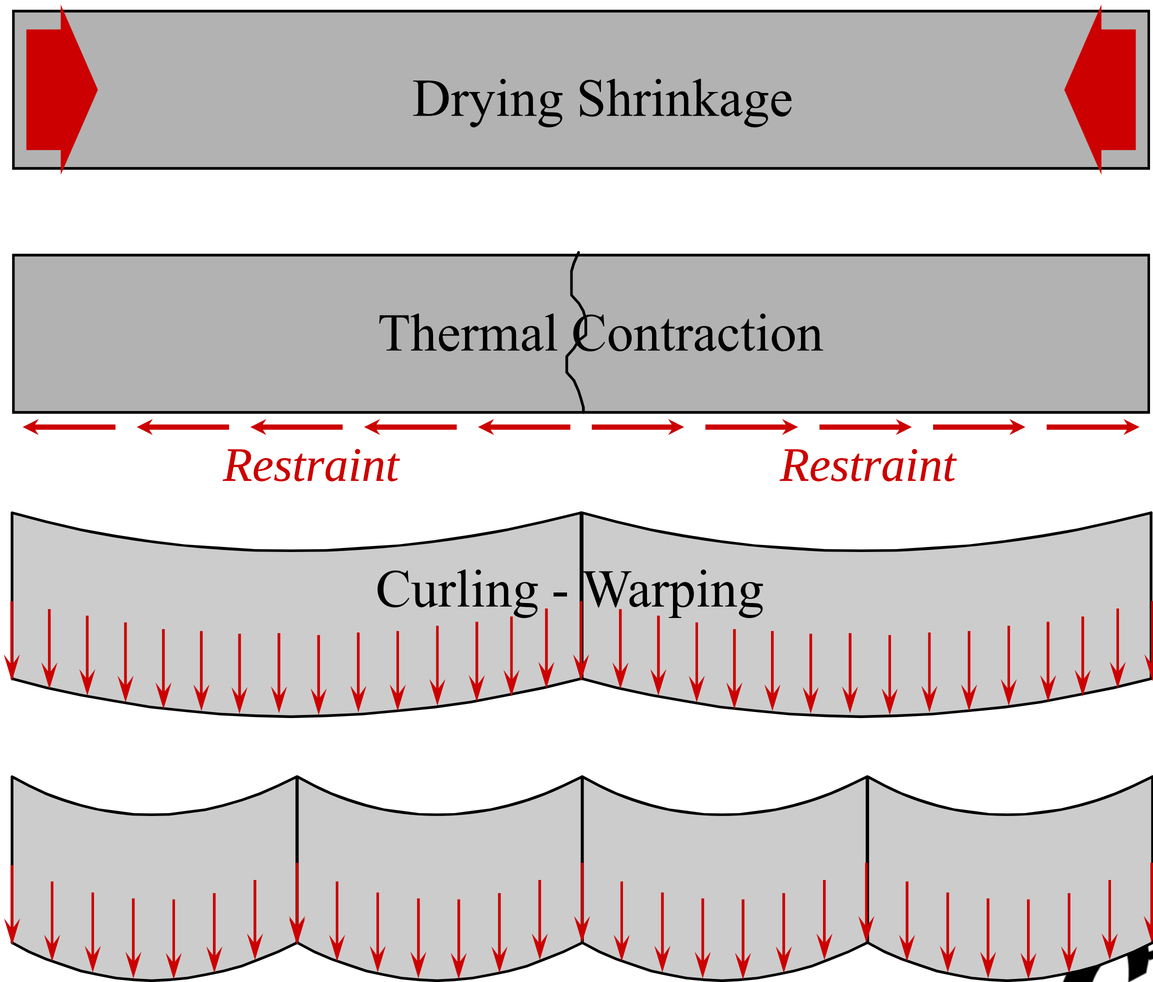
Typical crack formation sequence



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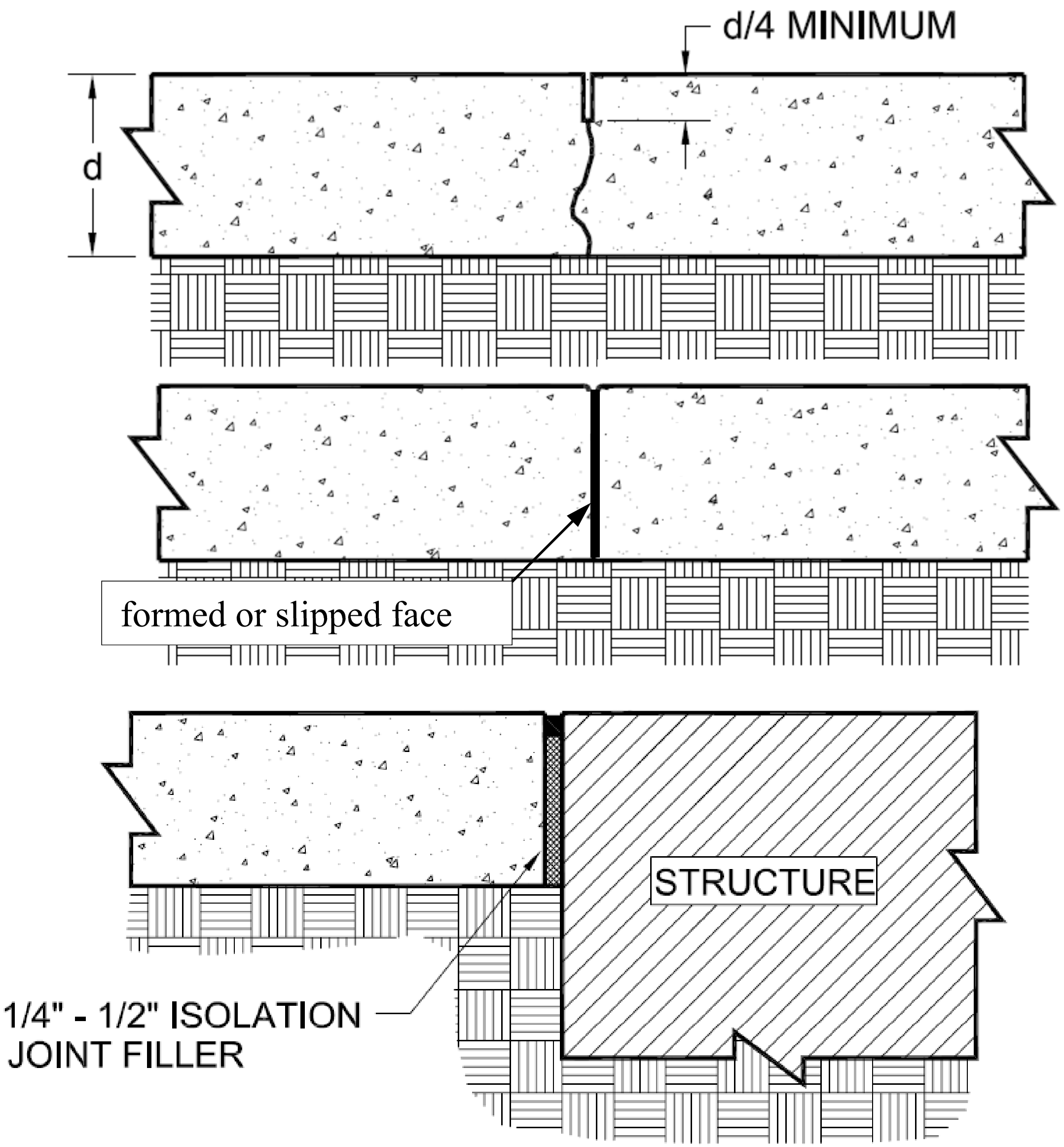
Types of joints in concrete



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Contraction (Control) joint

Construction joint

Isolation joint

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3.7.1: CONTRACTION (CONTROL) JOINTS

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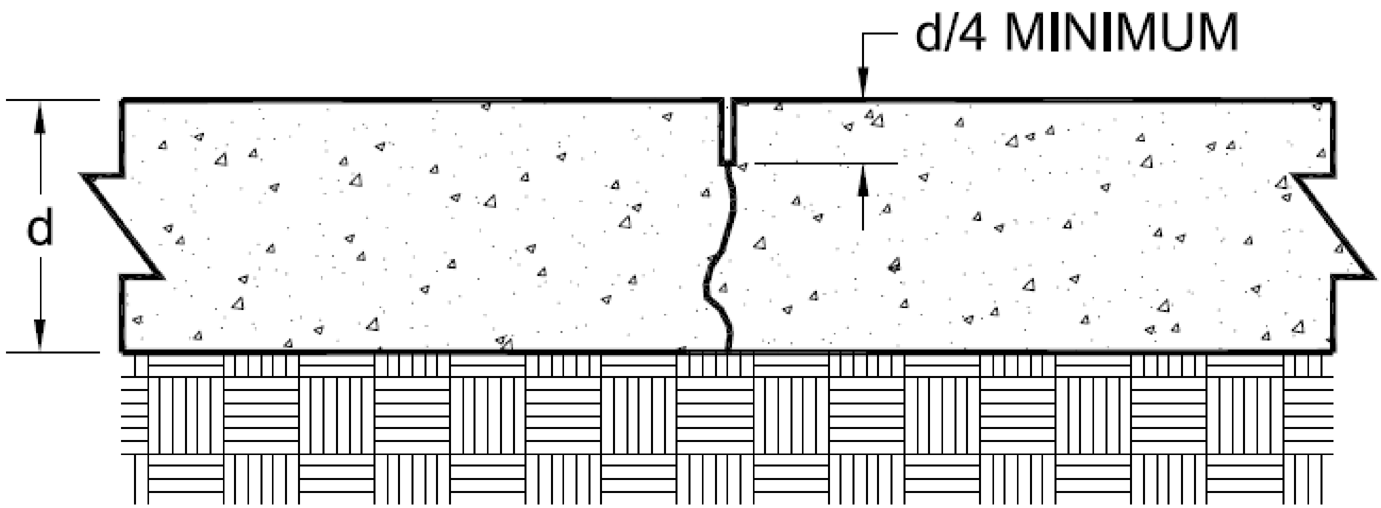
Control joint options



Control joints can be made by tooling a groove or pushing an insert into plastic concrete, or by sawing a slot in hardened concrete.

Early Entry Sawing: Depth = 1” up to a 9” pavement

Three Rules of Thumb for Control Joints.

- Spacing: Maximum of 2.5 times the depth in feet
  - 4” thick: 10’ max (4 x 2.5)
  - Maximum 15’ on center
- Depth: Minimum of ¼ of the depth: 8” thick = 2” deep
  - Early Entry may apply
- Panel shall be kept as square as possible
  - 1.5:1

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Spacing of joints based on cracking tendency

The extent of cracking due to key influences is somewhat predictable; joints can be spaced accordingly.

RECOMMENDED SPACING of JOINTS FOR CRACK CONTROL

Table 3.5—Spacing between joints

Pavement thickness, in. (mm)	Maximum spacing, ft (m)
4, 4.5 (100, 113)	10 (3.0)
5, 5.5 (125, 140)	12.5 (3.8)
6 or greater (150 or greater)	15 (4.5)

Exception: good design may call for even closer joint spacings due to load transfer considerations.

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Tooled control joints

Advantages:

- Simplest to make
- Most reliable crack initiation

Disadvantages:

- Most noticeable joint
- Not smoothest for rolling wheels
- Not designed for sealers / fillers

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Insert control joints

Advantages:

- Almost invisible
- Somewhat resistant to intrusion of water and debris even when left unsealed
- Provides good rideability
- Reliable crack initiation
- Fast and economical

Disadvantages:

- Learning curve for crew
- Can ravel or spall if not installed plumb

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Insert joint construction sequence

Spalling results if the insert is not plumb.

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Plastic strip insert joint after 12 years of service

Sawcut control joints

Advantages:

- Makes best sealant reservoir
- Not as noticeable as tooled
- Smoothest for wheels

Disadvantages:

- Timing is critical to success - least reliable crack initiation with gravel aggregates
- Expensive to make

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Timing of joint sawing – a critical factor

Sawcut joints must be made within 4-12 hours after final finishing

🡅 This joint was sawedsoon enough

This one was sawed too late ➔

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Late sawing example

Early entry "dry cut" saws

- Designed to initiate cracks with a shallow cut made much earlier than with wet-cut saws
- Timing - the "window of opportunity" is 1 to 2 hours

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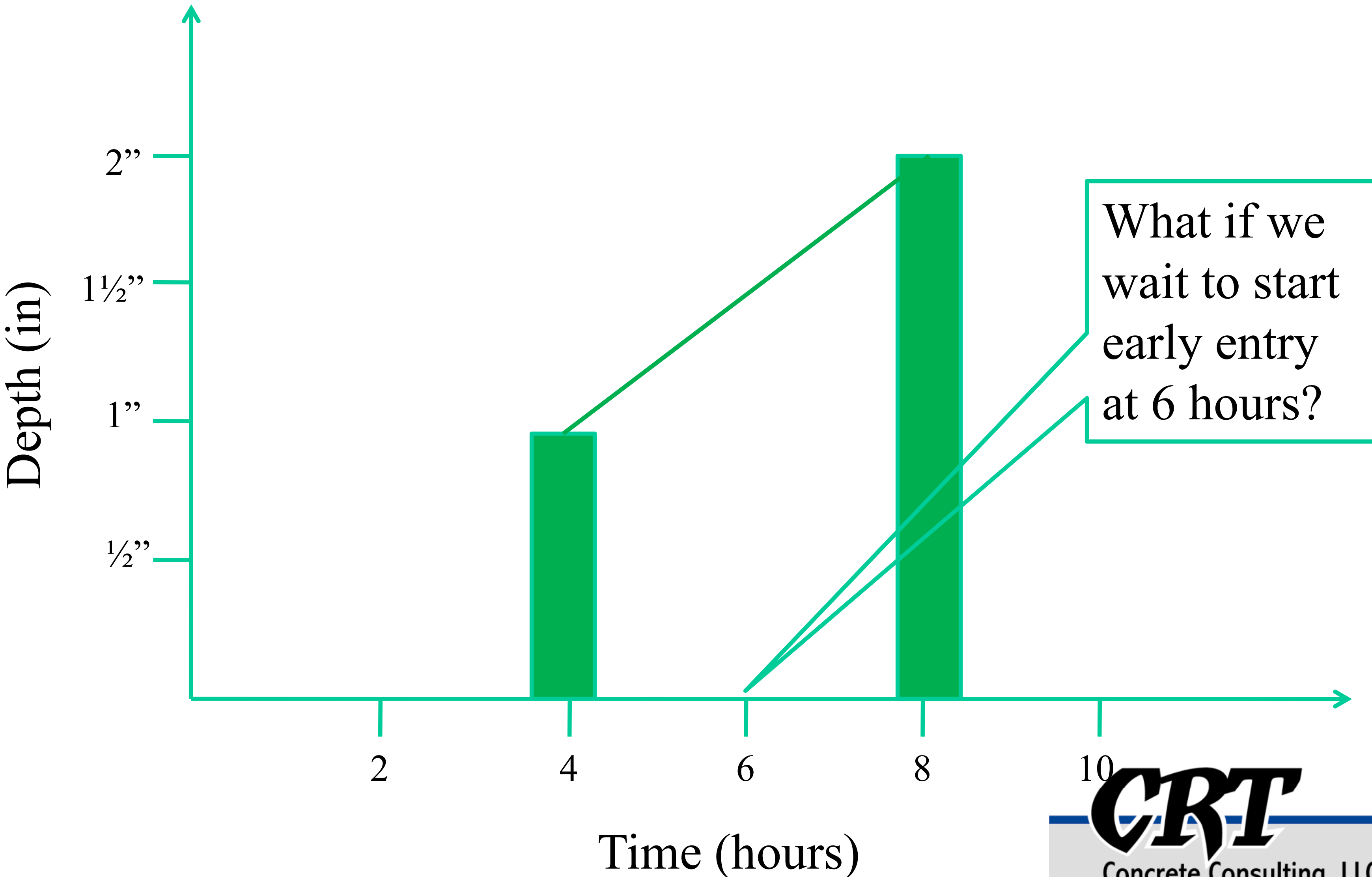
Window of Opportunity for 8” Slab



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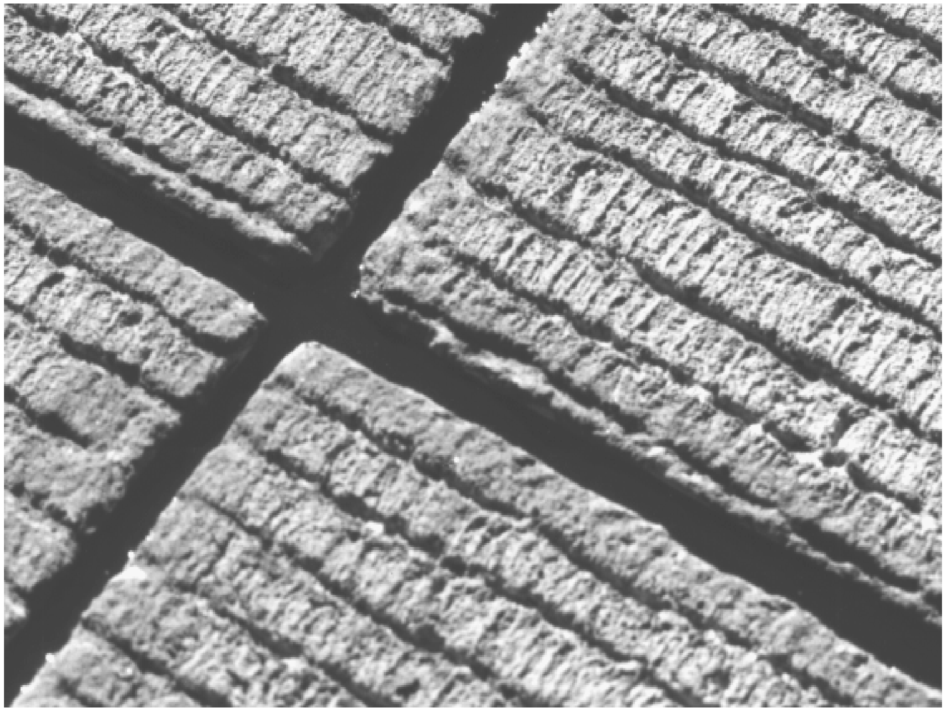
Jointing and Reinforcement



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CURING

- TIME to develop strength
- TEMPERATURE to drive chemistry
- MOISTURE for hydration

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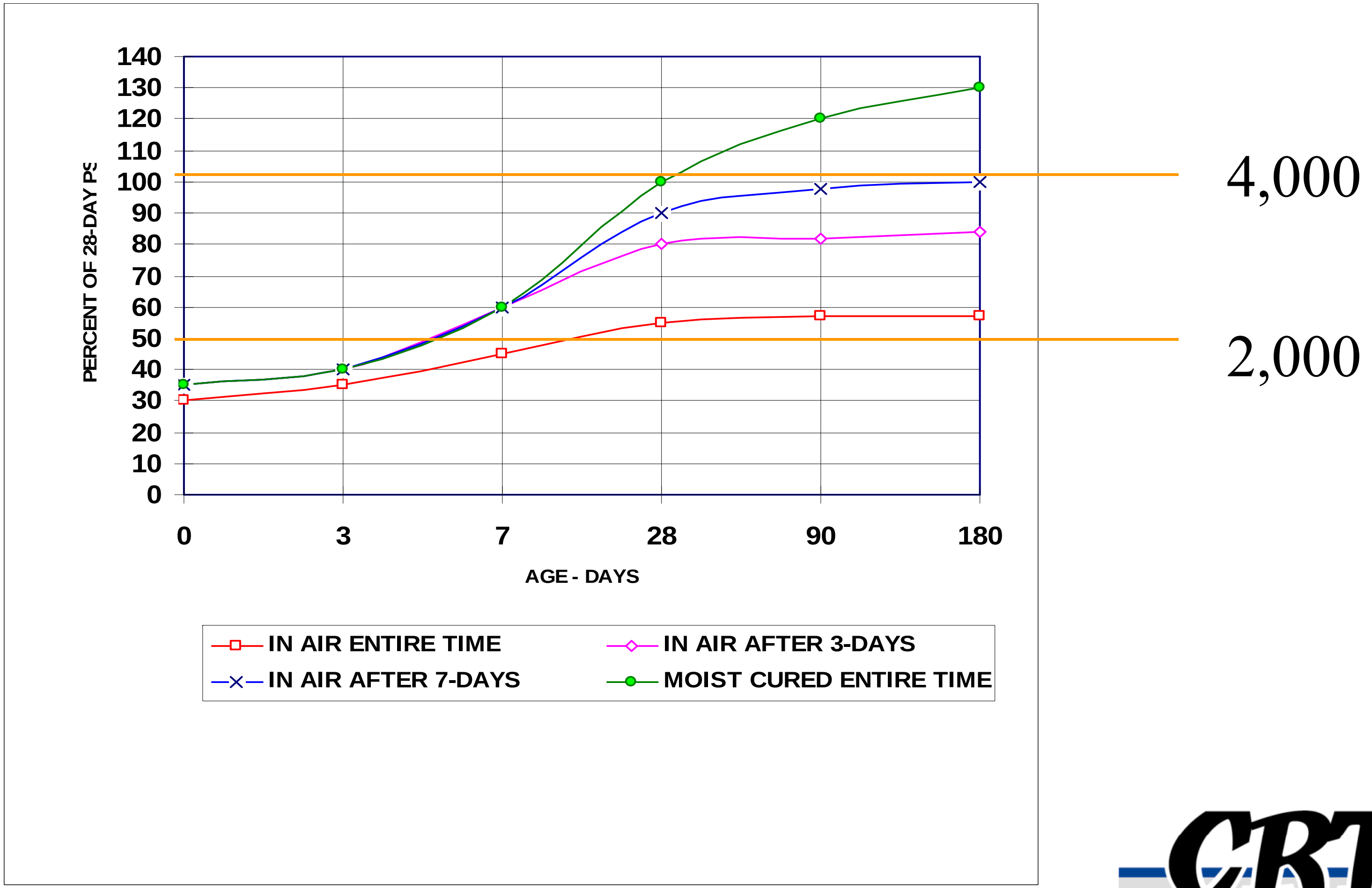
Moisture is Required….



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Curing

- Spray membrane curing compound - ASTM C 309, white pigmented preferred
- Timing is critical - spray immediately after finishing
- Suggested application rate:
  - Maximum coverage: 200 ft^2 / gal
  - Higher rate (less coverage) for windy or dry conditions

QUESTIONS?

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