Concrete Pavement Jointing Design

Brian Killingsworth, P.E.
National **R**eady **M**ixed **C**oncrete **A**ssociation

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References

Selected Titles for Reference

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American Concrete Pavement Association (ACPA)

American Concrete Pavement Association
CONCRETE INFORMATION

Design and Construction of Joints for Concrete Streets

To ensure that the concrete pavements we are building now will continue to serve our needs well into the future, it is essential to take into account all design and construction aspects. This includes thickness design, subgrade and subbase preparation, and jointing. This publication addresses the design and construction of jointing systems for concrete street pavements. Two other ACPA publications, *Design of Concrete Pavements for City Streets* and *Subgrades and Subbases for Concrete Pavements*, address city street thickness design and subgrade/subbase preparation.

Typically street pavement slabs range from 5 to 8 in. (125 to 200 mm) in thickness. The recommendations for jointing in this publication are for pavements within this general range and purpose. Special considerations for other concrete pavement joint systems (highways, parking areas, and airports) are covered in other ACPA publications. A proper jointing system for concrete street pavements ensures that the structural capacity and riding quality of the pavement is maintained at the highest level at the lowest annual cost. A proper jointing system will:

1. control cracking.
2. divide the pavement into practical construction increments.
3. accommodate slab movements.
4. provide load transfer.

The development of concrete pavement joint design has evolved from theoretical studies, laboratory tests, experimental pavements, and performance evaluations of in-service pavements. A careful study of the performance of pavements subject to similar traffic and environmental conditions as the proposed pavement is of great value and should be considered in the design of slab dimensions and jointing details.

Jointing Considerations

The need for a jointing system in concrete pavements results from the desire to control the location and geometry of transverse and longitudinal cracking. Cracking results from stresses caused by concrete drying shrinkage, temperature and moisture differentials, and applied traffic loadings. If these stresses are not relieved, uncontrolled cracking will occur.

In determining a proper jointing system, the designer must consider climate and environmental conditions, slab thickness, load transfer, shoulder/curb and gutter construction, and traffic. Past performance of local streets is also an excellent source for establishing joint design. Moreover, improvements to past designs using current technology can significantly improve performance.

Proper and timely construction practices, in addition to proper design, are key in obtaining a properly performing jointing system for street pavements. Late or inadequate joint formation may cause cracks to develop at locations other than those intended. In most cases, sealing is necessary to assure the proper function of street joints.

Jointing for Crack Control

Proper jointing is based on controlling cracks that occur from the natural actions of the concrete pavement. Joints are placed in the pavement to control the crack location and pattern. Observing the slab behavior of unjointed plain pavements in service for many years can illustrate how joints are used to control cracking.

To attain adequate workability for placing and finishing concrete, more mixing water is used than is needed to hydrate the cement. As the concrete consolidates and hardens, most of the excess water bleeds to the surface and evaporates. With the loss of water, the concrete contracts and occupies somewhat less volume. A second major source of early shrinkage is caused by the pavement's temperature change. The heat of hydration and temperature of the concrete normally peak a short time after final set. After peaking, the temperature of concrete declines due to reduced cement hydration and lower air temperature during the first night of pavement life. As the temperature drops, the concrete pavement contracts.

The pavement's contraction is resisted by subgrade friction, which creates tensile stresses in the concrete slab. These tensile stresses cause a transverse crack pattern like that shown in Figure 1.

R&T UPDATE
Concrete Pavement Research & Technology
#10.01

Plate Dowels

An Innovation Driven by Industrial Concrete Paving

Introduction

Round steel dowel bars have long been the standard load transfer device for concrete pavements with thicknesses of about 8 in. (200 mm) or greater. In general, round steel dowels have performed very well in street, road, highway, and airport pavement applications. Over decades of observing pavement performance, the industry has learned of several challenges if round dowels are not designed and installed properly. The three primary issues are: steel corrosion; loss of effectiveness stemming from looseness (Figure 1); and panel cracking due to restraint stresses caused by dowel misalignment, particularly when multiple panels are linked together (Figure 2) [1, 2, 3].

The challenge with corrosion of round steel dowel bars has been reduced significantly through research and application of various alternative materials and coatings, including epoxy coatings, stainless and low-carbon, chromium steel bars, and zinc coated steel bars [2, 4, 5]

Loss of effectiveness (or load transfer) occurs when dowels become loose. Each load induces bearing pressures on the dowel bars and these pressures stress the concrete embedding the bar. If the bar diameter is too small or the loads are greater and more frequent than anticipated in design, the bearing stresses may break down the concrete in time (years), resulting in a gap or void around the bar. Once loose, dowel bars do not transfer loads from slab to slab as effectively and they allow more differential slab deflection under load.

Improved emphasis on dowel alignment during construction has improved an already excellent track record, as has the ease of locating bars using modern testing equipment. Mechanical dowel insertion and basket placement generally provide excellent results and slab cracking due to misaligned bars is rare.

In the early 1990's the ACPA adopted diameter sizing recommendations to avoid excessive bearing stresses with round dowel bars. In recent years, elliptical dowel shapes also have been investigated within the industry as an alternative to improve bearing capacity [6]. To date, elliptical bars have not gained acceptance, even when combined with a corrosion-resistant material; this is most likely due to placement and availability concerns.

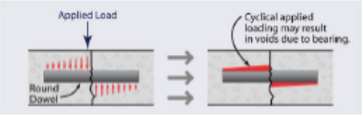


Figure 1. Illustration of how high bearing stresses at the top and bottom of a dowel bar may result in a void above and below the dowel after many applications of heavy loads.

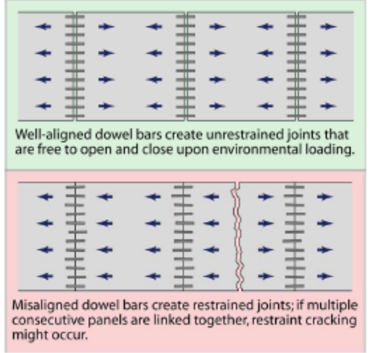
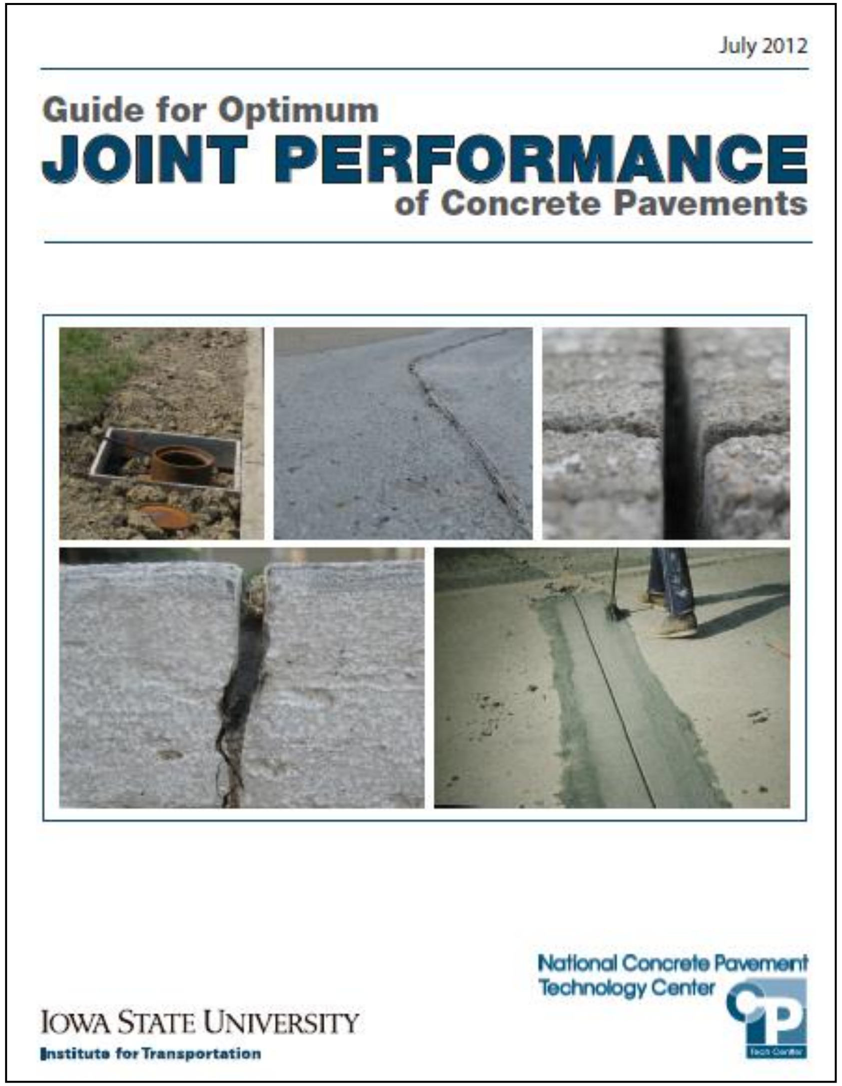
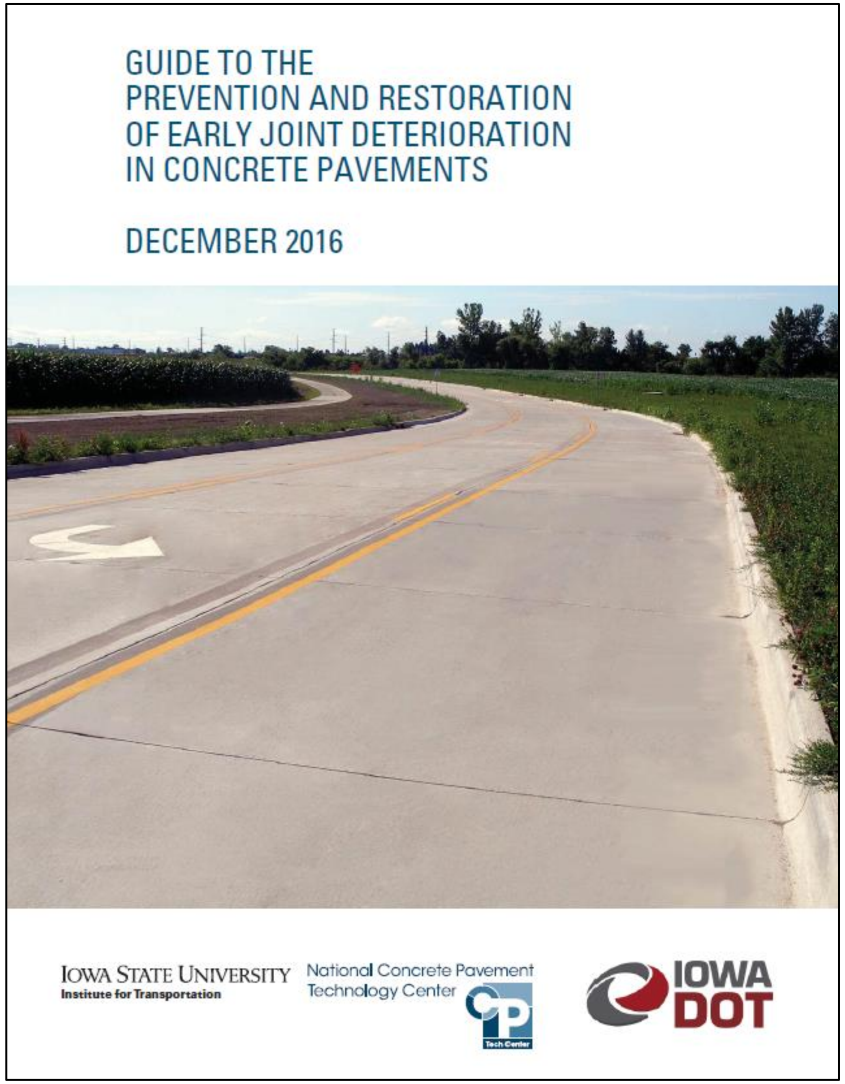


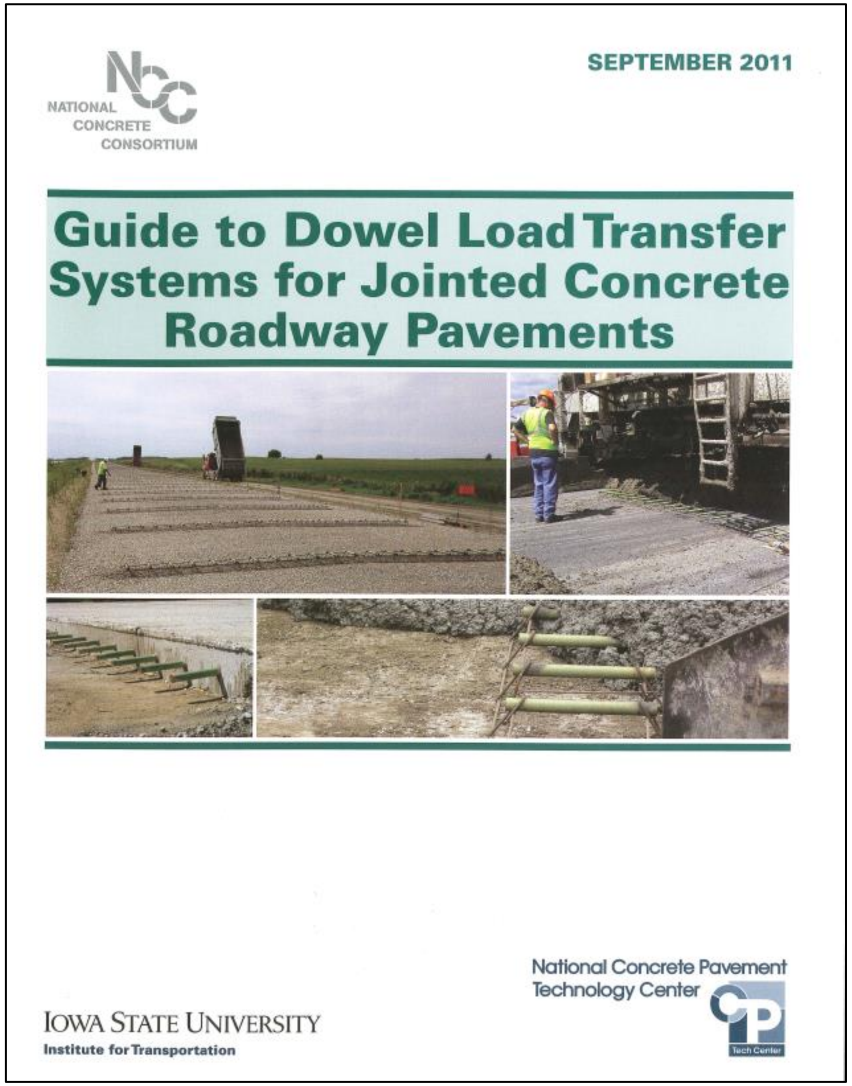
Figure 2. Illustration of a potential effect of misaligned round dowel bars on multiple consecutive joints.

ACPA

Concrete Pavement Technology Center: Jointing Guides







FHWA and NCHRP

Concrete Pavement Joints January 2019

U.S. Department of Transportation
Federal Highway Administration

Technical Advisory

Subject

Concrete Pavement Joints

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Date:	January 2019
Responsible Office:	HIF

CP ROAD MAP
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July 2019
ROAD MAPTRACK 6

PROJECT TITLE
Optimized Joint Spacing for Concrete Overlays with and without Structural Fiber Reinforcement

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The Long-Term Plan for Concrete Pavement Research and Technology (CP Road Map) is a national research plan developed and jointly implemented by the concrete pavement stakeholder community. Publications and other support services are provided by the Operations Support Group and funded by the Federal Highway Administration.

Moving Advancements into Practice (MAP) Briefs describe innovative research and promising technologies that can be used now to enhance concrete paving practices. The July 2019 MAP Brief provides information relevant to Track 6 of the CP Road Map: Concrete Pavement Construction, Reconstruction, and Overlays.

This MAP Brief is available at www.cproadmap.org/publications/MAPbriefJuly2019.pdf.

"Moving Advancements into Practice"
MAP Brief July 2019
Best practices and promising technologies that can be used now to enhance concrete paving

Optimized Joint Spacing for Concrete Overlays with and without Structural Fiber Reinforcement

for Low-Volume Roads

Introduction

Iowa has the highest number of miles (over 2,200) of concrete overlays in the United States, mainly on county roads (typically in the range of 750 Annual Daily Traffic [ADT] with 75 Annual Average Daily Truck Traffic [AADTT]), with some on state and city roadways. Concrete overlays were thought to be successful; however, until recently there was not a clear understanding of their overall performance. In response, the Iowa Highway Research Board (IHRB) funded TR-698, Concrete Overlay Performance on Iowa's Roadways. This was the first phase of a two-phase study, which consisted of a comprehensive and quantitative evaluation of concrete overlay performance. Concrete overlay performance was measured by analyzing the Pavement Condition Index (PCI) and the International Roughness Index (IRI). This study was completed in July 2017 and showed that the majority (89%) of overlays in Iowa were in good to excellent condition.

The second phase was the Optimized Joint Spacing for Concrete Overlays With and Without Structural Fibers. The purpose of the second phase was to try to determine why some contraction joints in concrete overlays on low volume roads (75AADTT) did not activate (crack did not deploy under the saw cut), in some cases for years.

Background

Once Phase 1 of the study was concluded, it was apparent that the design, joint spacing, and construction practices instituted years ago are correct for overlays greater than 6 in., as outlined in the 2014 Guide for Concrete Overlays. The 2014 Guide recommends joint spacing in feet from 1.5 to 2 times the overlay thickness in inches, which typically results in nominal 6 ft by 6 ft joint spacing for overlay thicknesses in the 4 in. to 6 in. range. However, it was documented in the Phase 1 report that not all small spacing of transverse contraction joints had activated for thin (4 in. to 6 in.) overlays and in some cases did not activate until years after construction. Contraction joints that do not activate may be considered an inefficient design. If less than the majority of joint activation does not occur in a reasonable period, then the joint spacings may be too close together, which results in unnecessary joints, increases the costs of installation and maintenance, results in the formation of highly spaced predominant joints that widen up over time, and promotes loose load transfer. At the same time, long joint spacing can lead to an increase in shrinkage and curling stresses in the overlay, which can cause additional cracking and higher IRI (lower rideability). If 100% joint activation occurs soon after construction, it normally indicates the joint spacings are too large and other mid-panel cracking could be forthcoming.

The objective of the Phase 2 study was to provide guidance on the optimum joint spacing for thin concrete overlays based on traffic loading, concrete overlay thickness, support system, presence of fibers, and concrete overlay types. In this study, optimum joint spacing means having as close to 100% joint activation as possible over a reasonable period (less than a year).

Work Plan

The database developed in Phase 1 was also used for Phase 2. The Phase 2 study was conducted in three steps:

Step 1: Analytical Investigation

An analytical investigation was performed using pavement design programs (AASHTOWare, Pavement ME, and BCOA-ME) to analyze the impact of joint spacing on predicted concrete overlay performance.

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP SYNTHESIS 568

Portland Cement Concrete Pavement Joint Sealant Practices and Performance

A SYNTHESIS OF HIGHWAY PRACTICE

Jinho Kim
AND
Dan G. Zollinger
Texas A&M Transportation Institute
College Station, TX

Subscriber Categories
Materials • Pavements

Research sponsored by the American Association of State Highway and Transportation Officials in cooperation with the Federal Highway Administration

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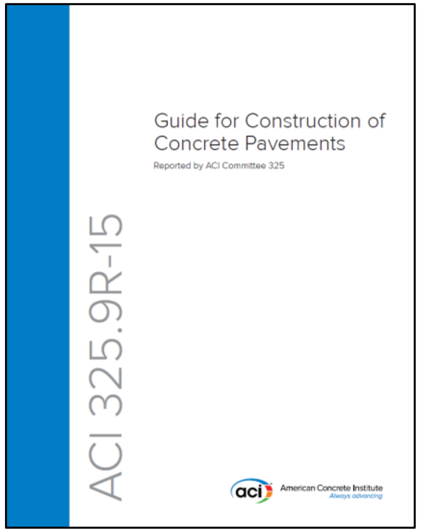
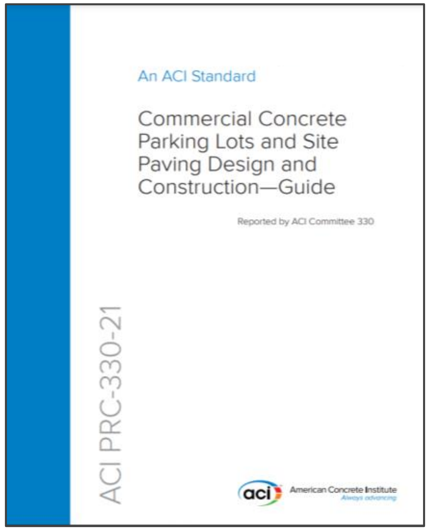
2021

ACI Committees for Pavement Design & Construction

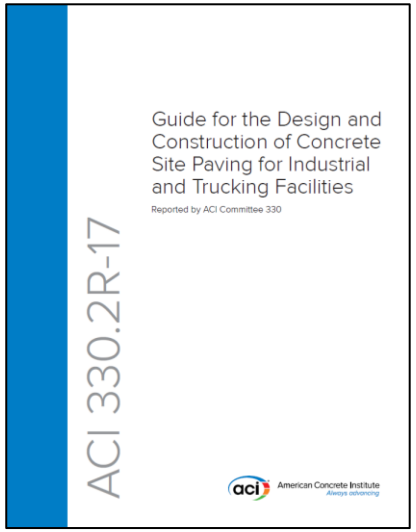
325: Streets & Roads



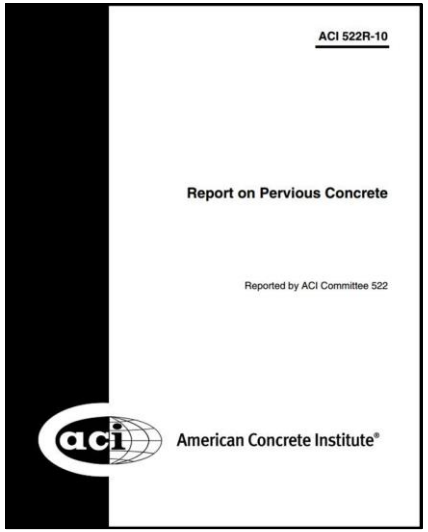
325: Construction



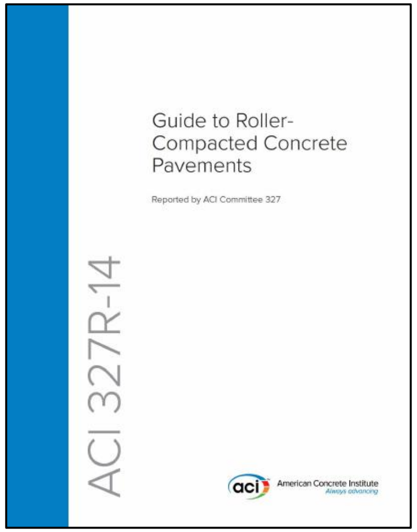
330: Parking Lot



330: Industrial



522: Pervious



327: Roller Compacted

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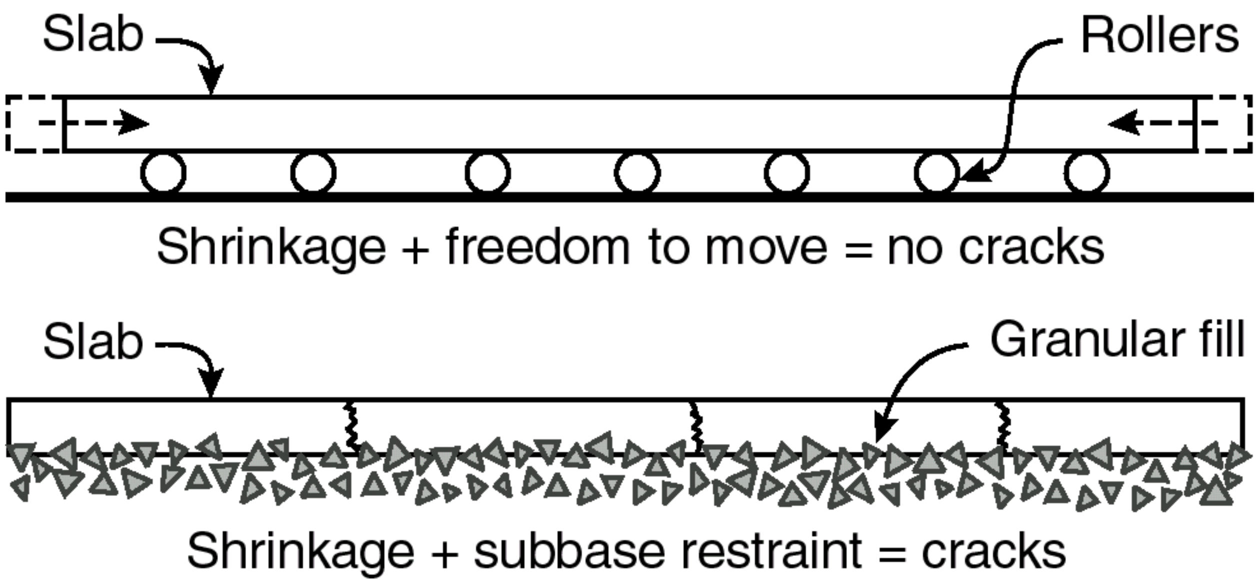
Jointing Background

Drying Shrinkage and Cracking



Shrinkage + Restraint = Cracking

Cracking results from combined effects of restraint and shrinkage (drying and/or thermal)…
…resulting in tensile stresses exceed tensile strength.

Jointing Design and Placement Considerations

- Transverse and Longitudinal Spacing
- Slab-to-Slab Transfer of Load (Aggregate Interlock or Enhanced Load Transfer)
- Longitudinal Joint Reinforcement (e.g., tie bars)
- Type of Saw and Blades (Conventional or Early Entry Saws)
  - Depth of Sawcut
- Method and Sequence of Construction and Sawing Plan
- Joint Sealing
  - Seal or No-Seal
  - Type of Seal Material
  - Joint Well Depth / Width

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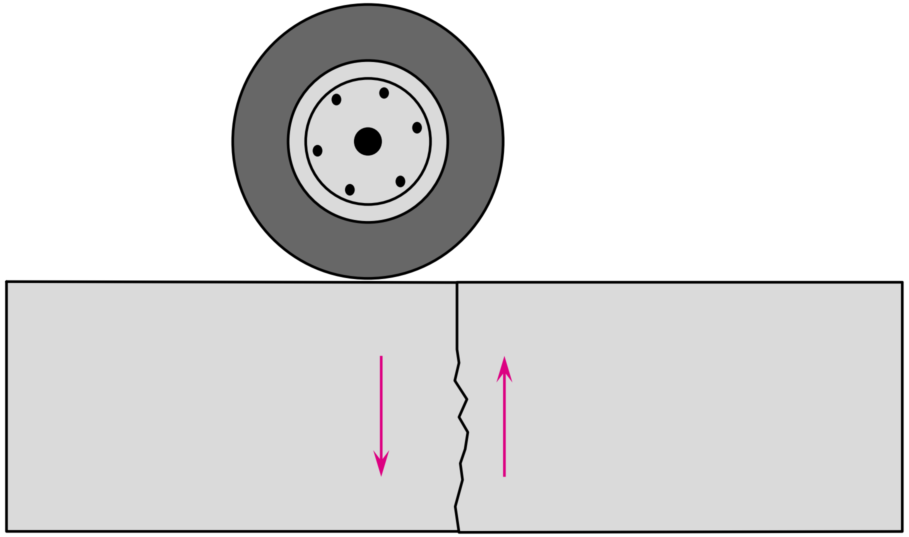
Joint Load Transfer: Aggregate Interlock



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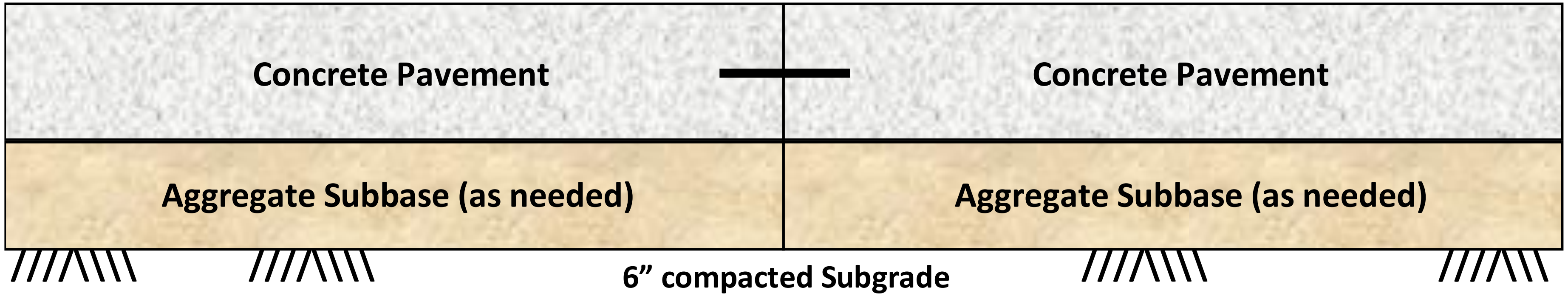
Joint Load Transfer: Enhanced With Subbase & Dowels



1. **Dowel bars at transverse joints may be required for load transfer enhancement.**
2. **Concrete pavement thickness based on underlying support, traffic, and concrete strength.**

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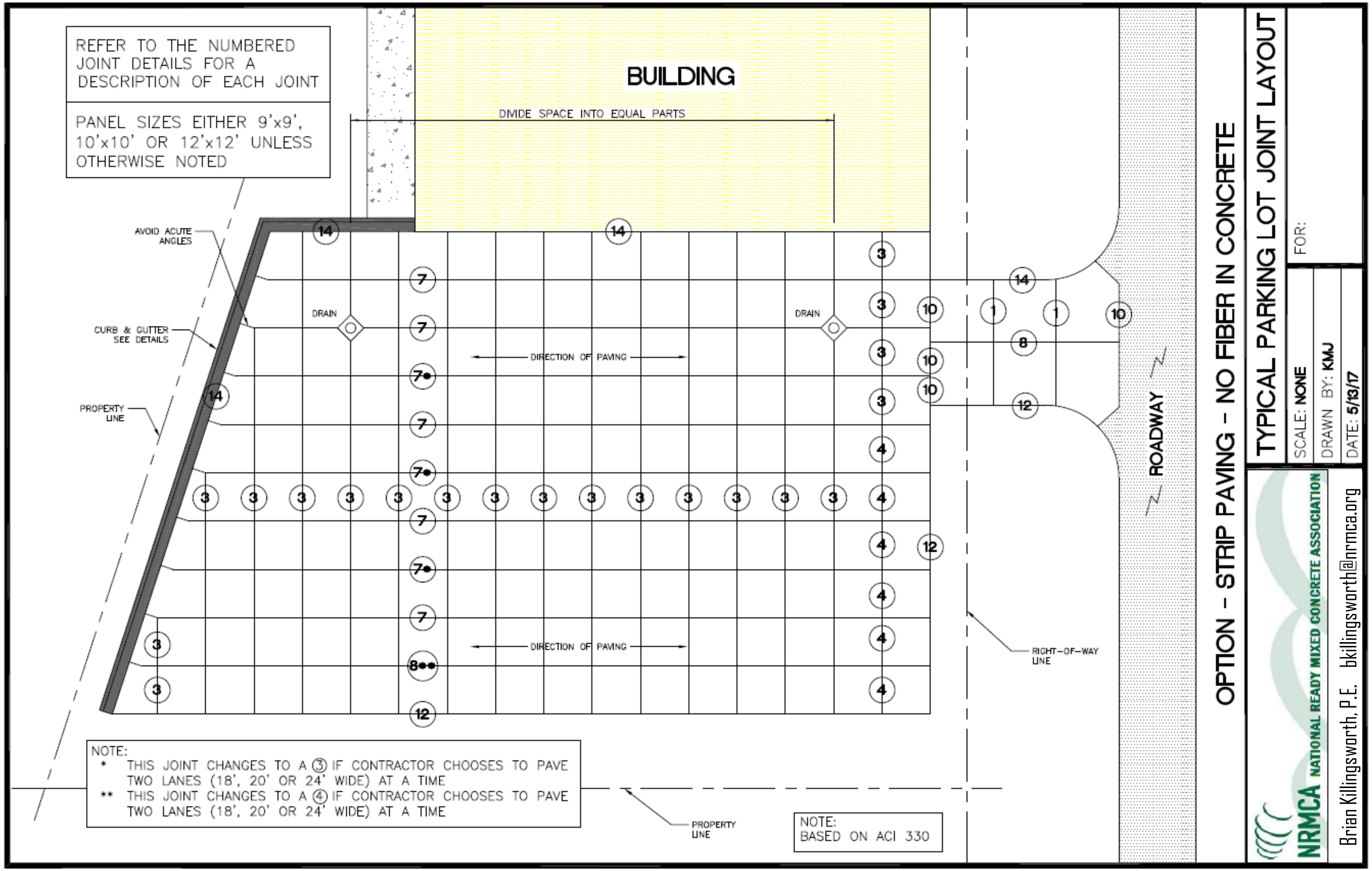
The Importance of a Proper Jointing Plan



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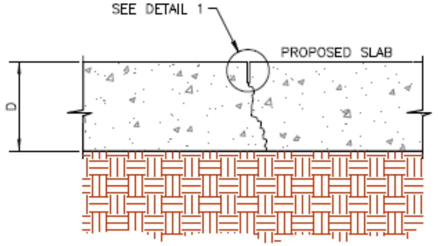
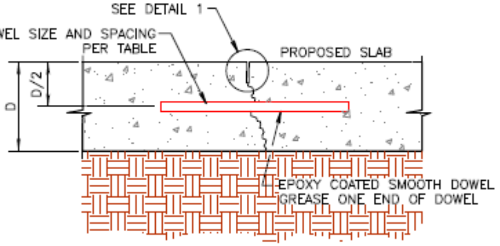
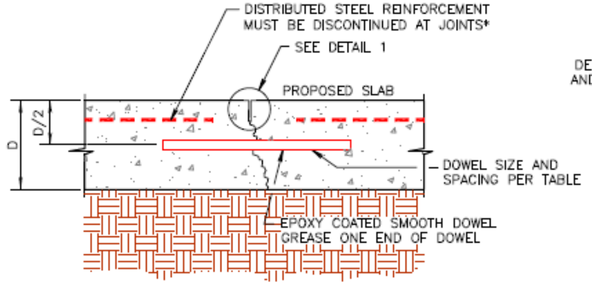
The Importance of Proper Joint Details



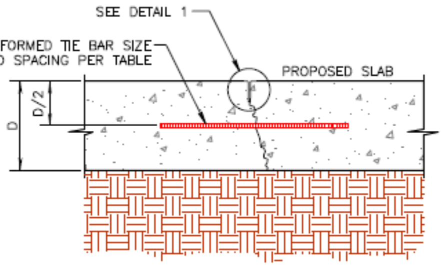
1 **PLAIN PAVEMENT CONTRACTION JOINT, UNDOWELED**
(ALL PAVEMENTS, SHORT SPACING)



3 **PLAIN PAVEMENT CONTRACTION JOINT, DOWELED**
(NORMALLY FOR HEAVY DUTY PAVEMENTS, 7" OR GREATER)



2 **REINFORCED PAVEMENT CONTRACTION JOINT, DOWELED**
(LONG JOINT SPACING OR ODD-SHAPED SLABS)
* MACRO FIBERS CAN BE USED INSTEAD OF DISTRIBUTED STEEL – SEE NOTES



4 **HINGED CONTRACTION JOINT**
MAY BE USED FOR A LONGITUDINAL JOINT NEAR PAVEMENT EDGE TO PREVEDNT SLAB MIGRATION OR FOR A TRANSVERSE JOINT THAT DOES NOT ALIGN WITH THE REGULARLY SPACED JOINTS N ADJACENT LANES.

JOINT SPACING TABLE

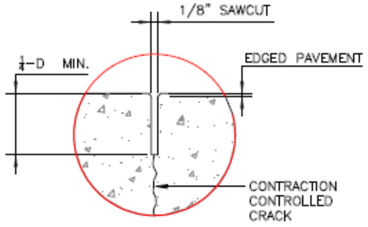
PAVEMENT THICKNESS (INCHES)	MAXIMUM SPACING (FEET)*	RECOMMENDED SPACING (FEET)
4	8x8	6x6
4.5	10x10	8x8
5	12.5x12.5	10x10
5.5	12.5x12.5	12x12
6	15x15	12x12
7 OR MORE	15x15	13x13

* PER ACI 330

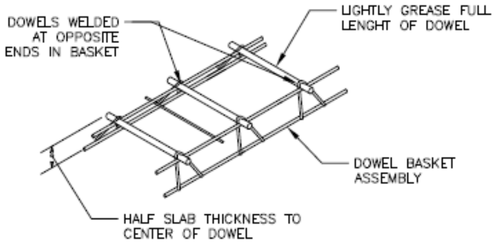
LOAD TRANSFER DOWEL SIZE AND SPACING FOR CONSTRUCTION AND CONTRACTION JOINTS (IF REQUIRED)*

PAVEMENT THICKNESS (INCHES)	IMPERIAL BAR SIZE	DOWEL DIA. (INCHES)	CONSTRUCTION JOINT DOWEL LENGTH (INCHES)	CONTRACTION JOINT DOWEL LENGTH (INCHES)
LESS THAN 5"	NOT REQUIRED			
5–6	#6	0.75	10	13
7	#8	1.0	13	16
8	#8	1.0	13	16
9–11	#10	1.25	15	18

* TABLE BASED ON ACI 360R–10. MAXIMUM JOINT OPENING OF 0.20 INCHES. DOWEL SPACING IS 12" ON CENTER. SPACINGS ARE BASED ON DOWELS IN DIRECT CONTACT WITH A THIN BOND BREAKER (GREASE). CAREFULLY ALIGN AND SUPPORT DOWELS DURING CONCRETE OPERATIONS. MISALIGNED DOWELS MAY LEAD TO CRACKING. TOTAL DOWEL LENGTH INCLUDES ALLOWANCES MADE FOR JOINT OPENING AND MINOR ERRORS IN POSITIONING DOWELS.



DETAIL 1 - CONTRACTION JOINTS
NO SCALE



DOWEL BASKET ASSEMBLY
NO SCALE

LENGTHS AND SPACINGS FOR #4, ½" DIA. TIE BARS*

PAVEMENT THICKNESS (INCHES)	TIE BAR LENGTH (INCHES)	TIE BAR SPACING (INCHES) – DISTANCE TO NEAREST FREE EDGE OR TO NEAREST JOINT WHERE MOVEMENT CAN OCCUR: 12 FEET OR LESS	14 FEET	16–24 FEET
4–5	24	30	30	28
5.5	24	30	30	25
6	24	30	30	23
6.5	24	30	30	21
7	24	30	30	20
7.5	24	30	30	18
8	24	30	28	17
8.5	24	30	26	16
9	30	36	30	24

* PER ACI 330

JOINT DETAILS AND NOTES 1
FOR:
SCALE: NONE
DRAWN BY: KMJ
DATE: 5/13/17

NRMCA NATIONAL READY MIXED CONCRETE ASSOCIATION
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Joint Related Concrete Pavement Distress

Pavement: Design & Construction Recommended Responsibilities

- Owner / Architect:
  - Loads (vehicle count & growth)
- Civil Engineer:
  - Concrete strength
  - Joint spacing
  - Joint details & load transfer
  - Drainage details & layout
- Geotechnical Engineer:
  - Thickness recommendations based on subgrade support
- Structural Engineer
  - Reinforcement, if used
- Contractor
  - Construction method (as allowed by spec)
  - Joint layout plan

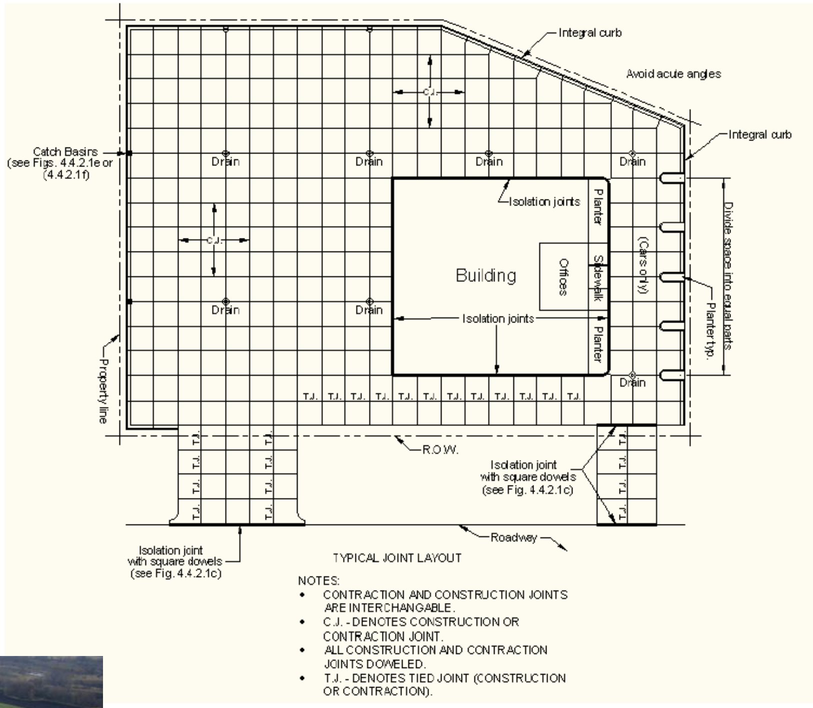

Fig. 4.6.3a - Typical joint layout.

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Pavement: Design & Construction Recommended Responsibilities

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  - Loads (vehicle count & growth)
- Civil Engineer:
  - Concrete strength
  - Joint spacing
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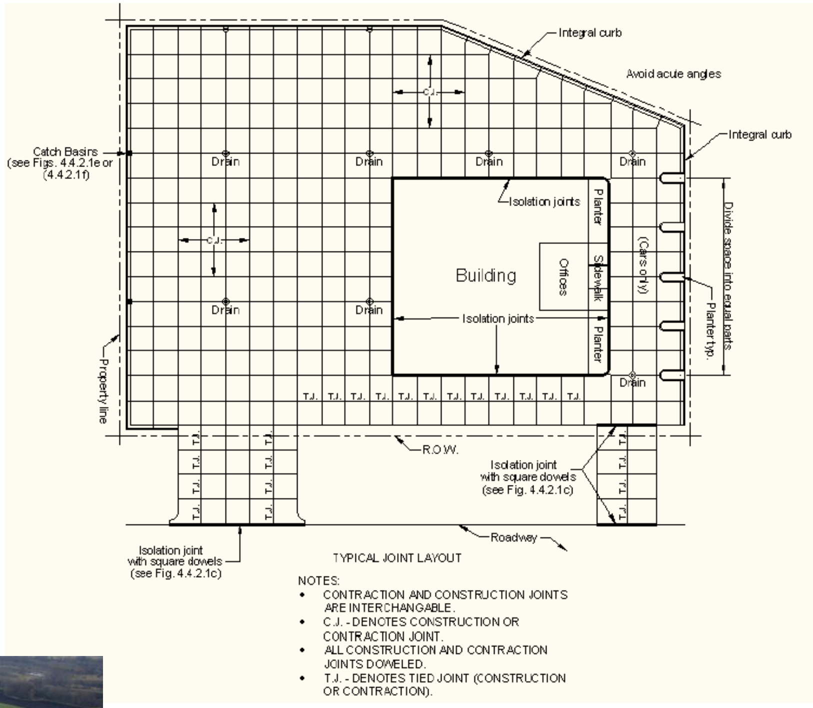

Fig. 4.6.3a - Typical joint layout.

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Joint Spacing

Rules of Thumb for Jointing & Slab Dimensions

- Spacing:
  - Recommendation of 2.0 to 2.5 times the depth in feet
    - For example: 5” thick = 10’ (5 x 2) to 12.5’ maximum (5 x 2.5)
  - Alt: 21 for stabilized (cement or asphalt) bases or 24 for subgrades or granular bases
    - For example: 5” thick = 8.75’ (5 x 21 = 105”) to 10’ maximum (5 x 24 = 120”)
- Panel shall be kept as square as possible (i.e., avoid long and narrow)
  - L:W of 1½:1 (Maximum length to width ratio)

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Slab Length & Related Design Factors

$$\ell = \sqrt[4]{\frac{Eh^3}{12(1-\nu^2)k}} \quad \text{in.-lb units}$$

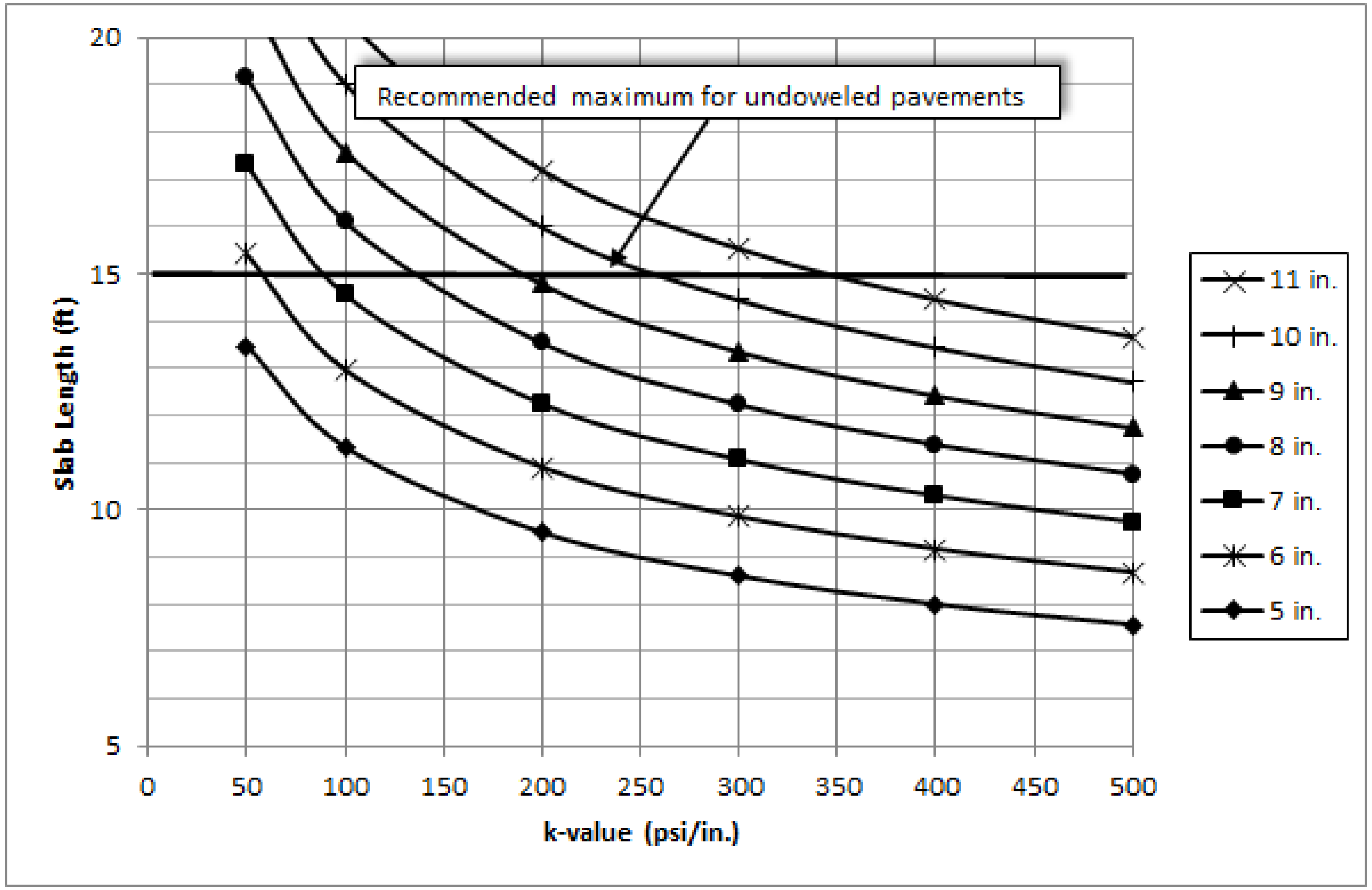
$$\ell = \sqrt[4]{\frac{1000 \cdot Eh^3}{12(1-\nu^2)k}} \quad \text{SI units}$$

where

ℓ = radius of relative stiffness, in (mm);
E = concrete modulus of elasticity, psi (MPa);
h = pavement thickness, in. (mm);
ν = Poisson's ratio of the pavement (≈ 0.15); and
k = modulus of subgrade reaction, psi/in. (MPa/m).

Experience indicates that there is an increase in transverse cracking when the ratio L/ℓ exceeds 5.25 (L=slab length).
L/ℓ factors ranging from 4.44 to 7.0 have been reported / used.

Slab Length vs. Pavement Thickness Relationships



Using the criterion of a maximum L/ℓ ratio of 5.25, the allowable joint spacing would increase with increased slab thickness but decrease with increased (stiffer) foundation support conditions.

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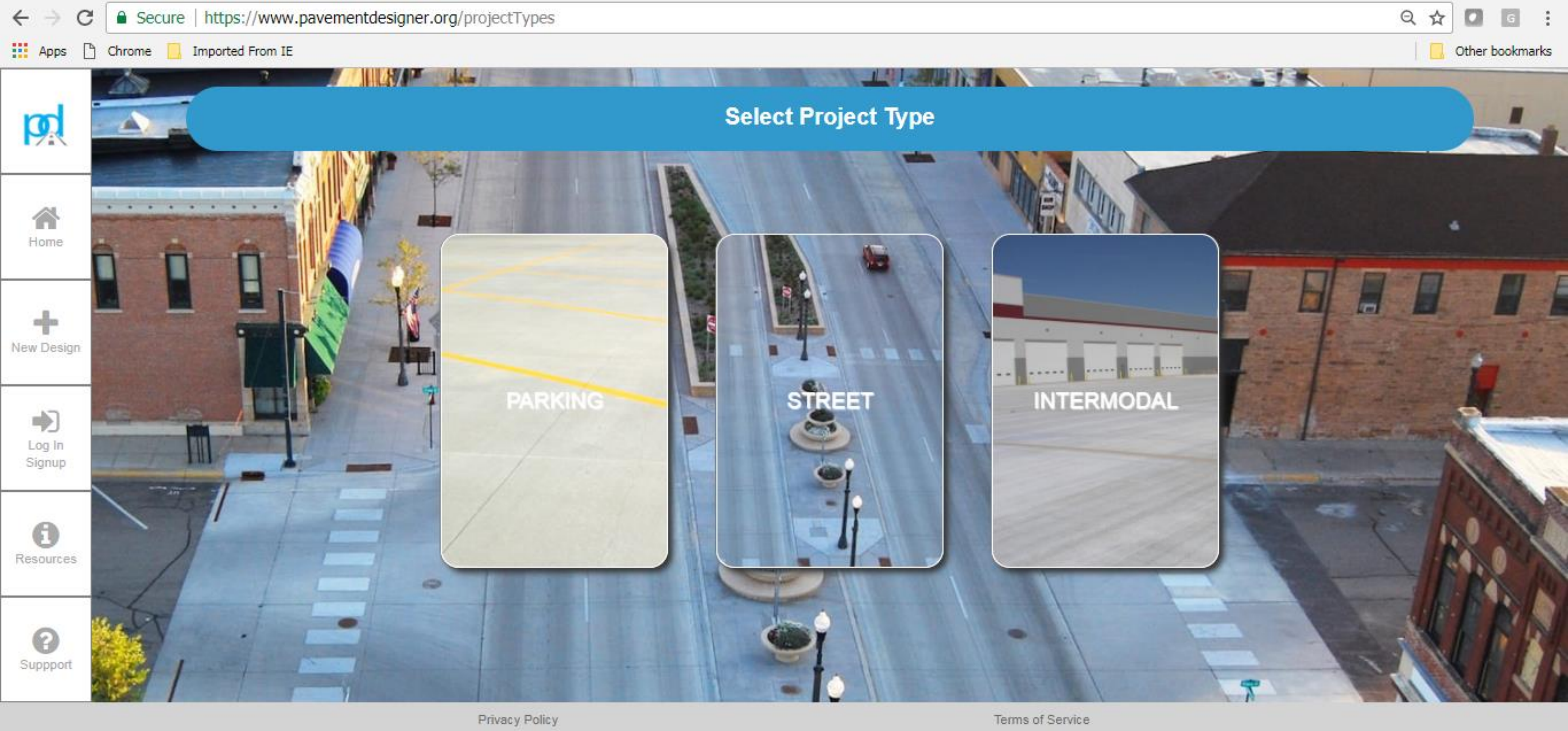
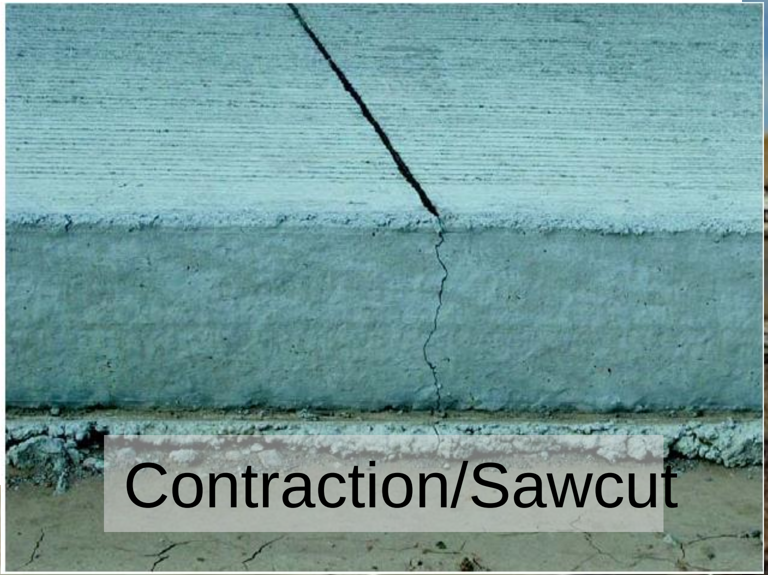
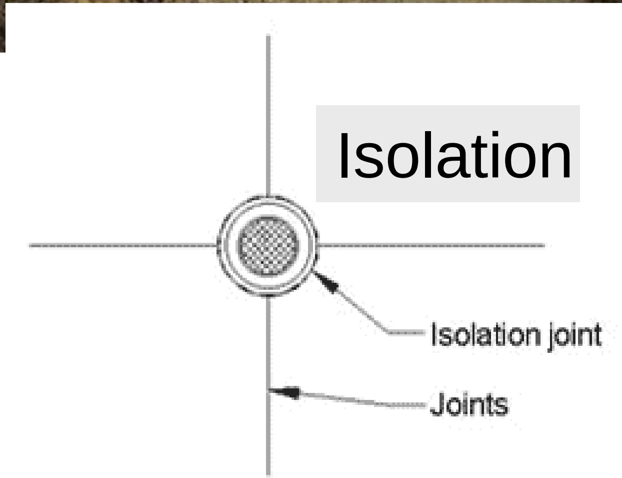


Joint Types

Definitions - Joints





Jointing – Contraction Joints

Source: ACI

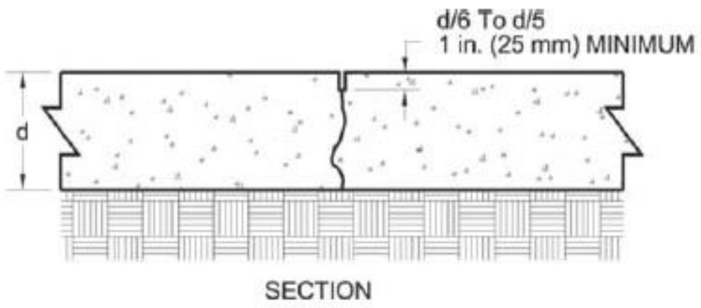


Fig. 4.4.2.3a—Contraction joint (early-entry saw).

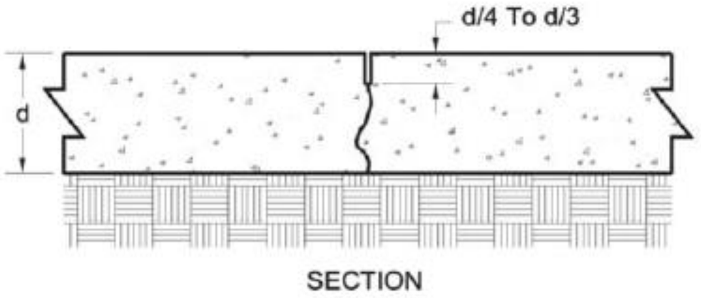


Fig. 4.4.2.3b—Contraction joint (conventional saw).

Saw cuts should be made within 8 to 12 hours after placement for conventional saws and 1 to 2 hours after placement for early entry saws.

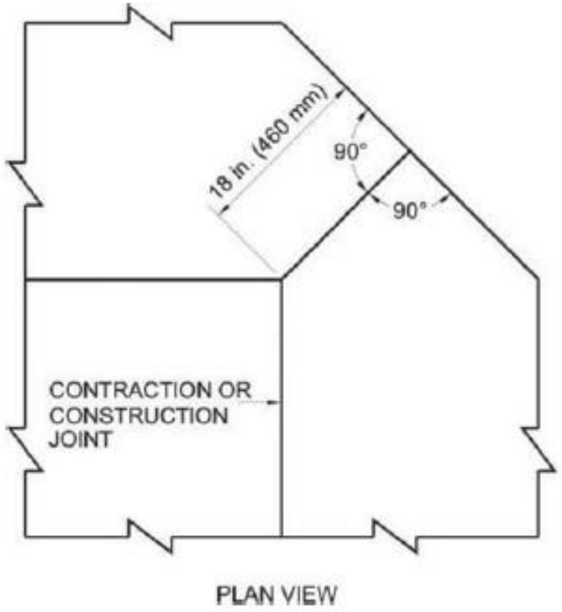


Fig. 4.4.2.3c—Illustration of avoiding acute angles.

Isolation Joints

Source: ACI

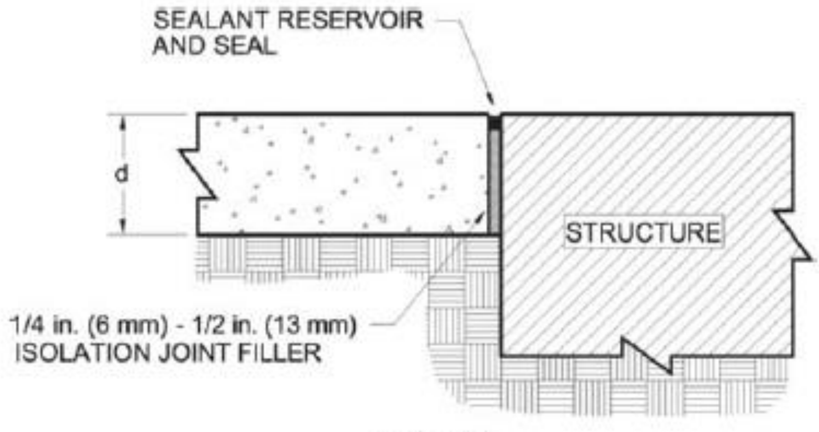


Fig. 4.4.2.1a—Isolation joint.

Isolate fresh concrete from a fixed structure

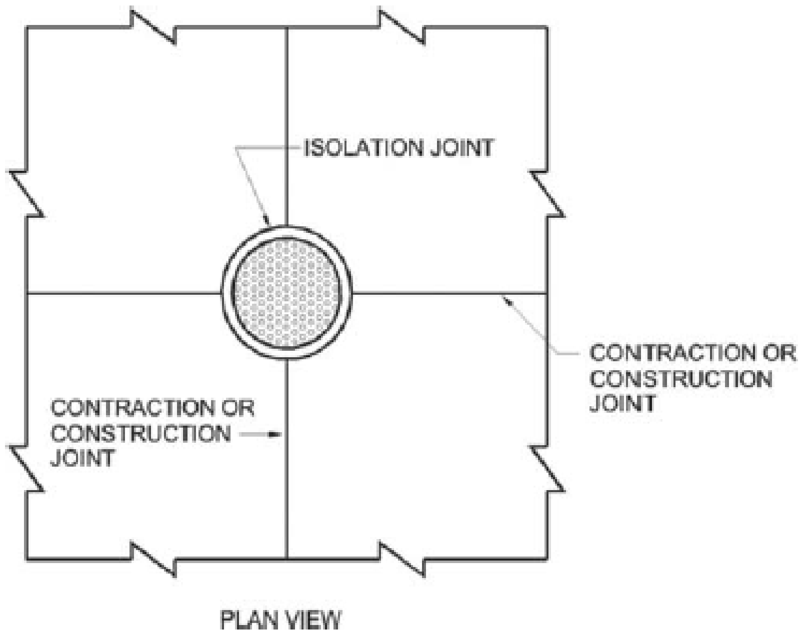


Fig. 4.4.2.1d—Manhole or drop inlet boxout.

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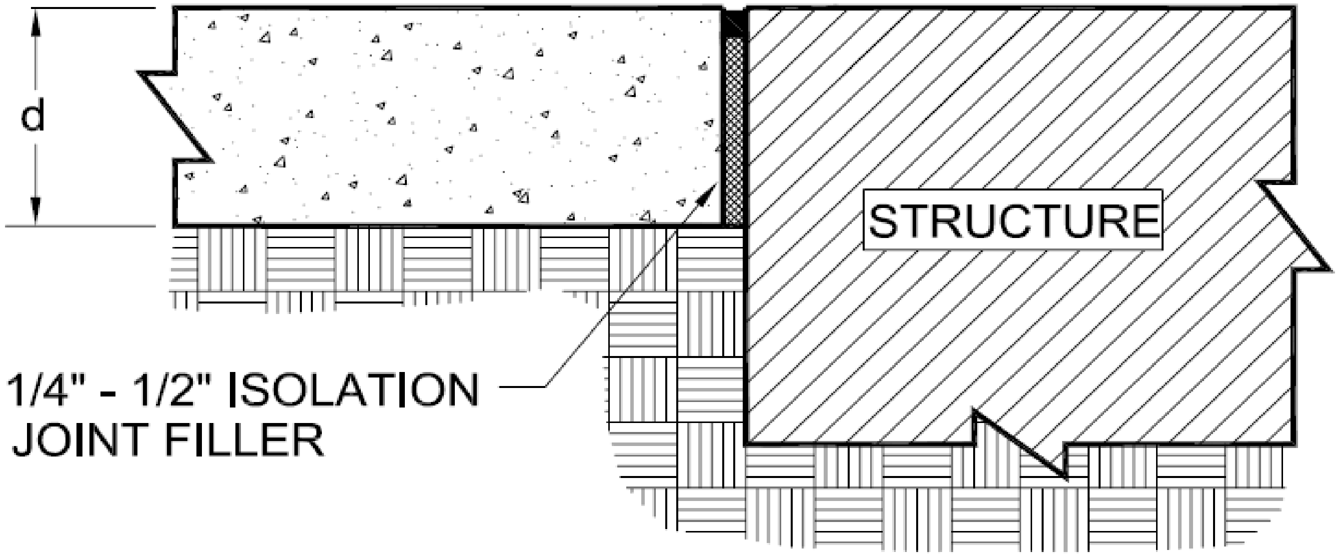
Isolation Joints

Source: ACI

…are sometimes called expansion joints but should generally not be used to provide for expansion. They provide no load transfer and should not be used as regularly spaced joints in a joint layout. Their proper use is to isolate fixed objects, providing for slight differential settlement and thermal movements without damaging the pavement.



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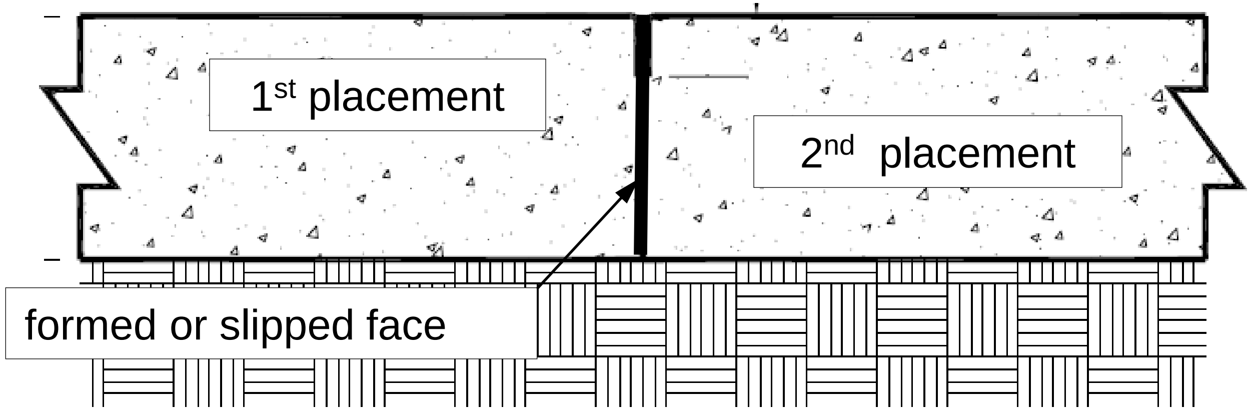
Jointing – Construction Joints

Source: ACI

Construction joints are used between separate concrete placements, typically along placement lane edges.



Butt joints are recommended for most parking lots or low volume streets where load transfer needs are minimal.

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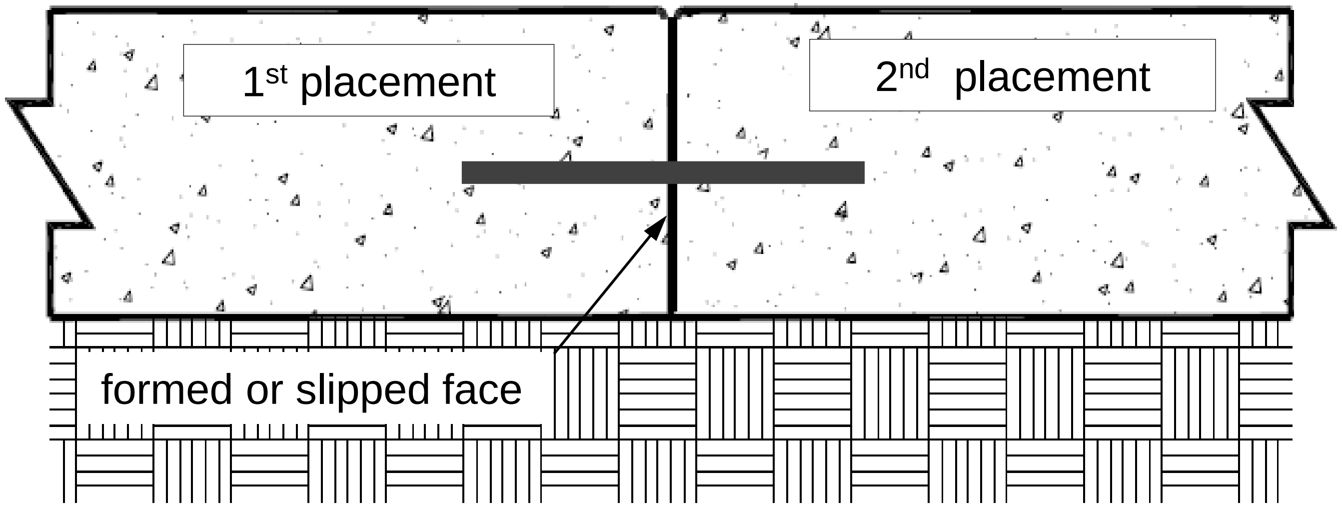
Jointing – Construction Joints

Source: ACI



Doweled joints are recommended for high truck traffic roadways or driveways where load transfer enhancement is needed.

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Joint Plans

Joint Plans

Source: ACI

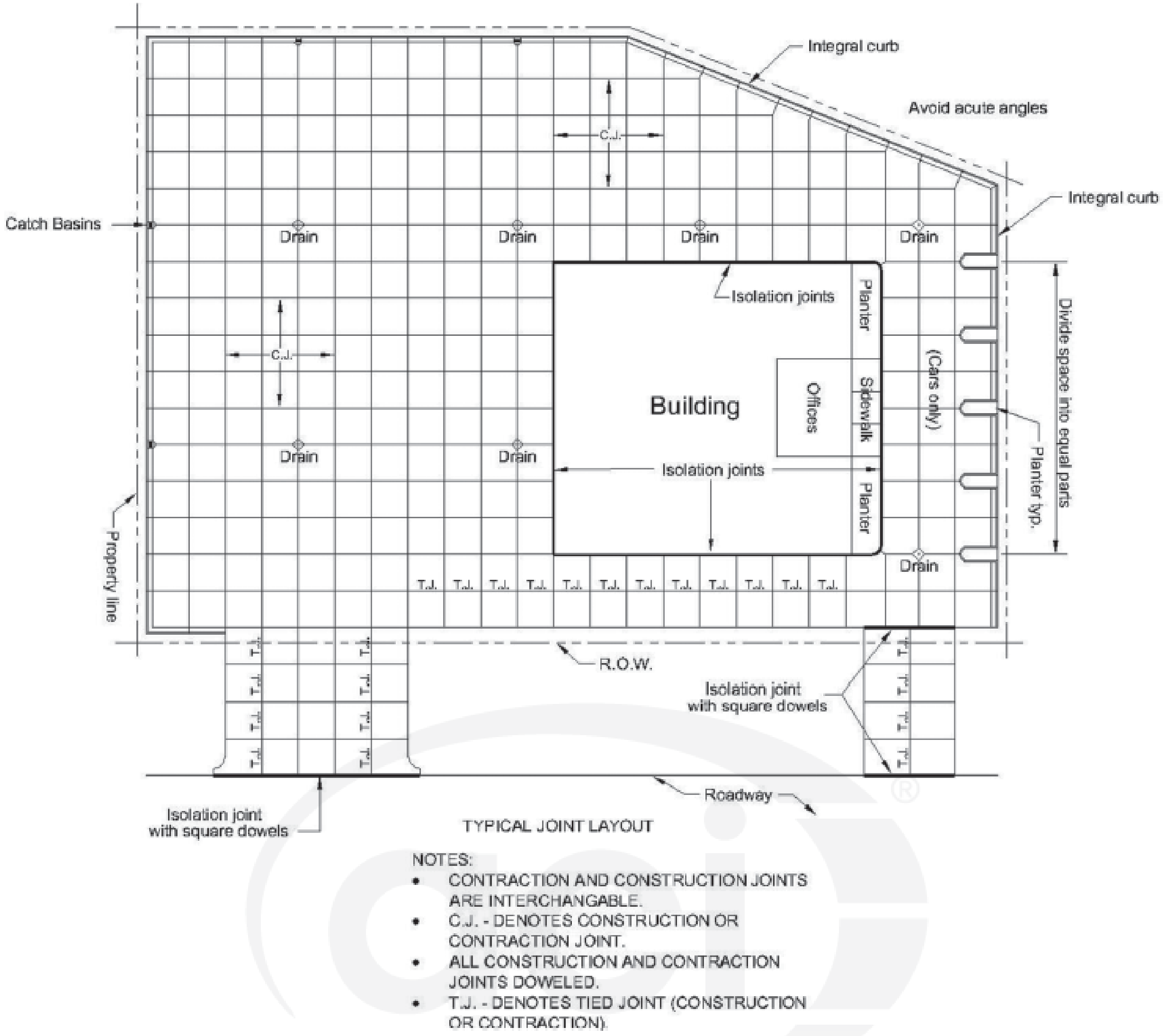

Fig. 4.6.3a—Typical joint layout.

Jointing Plans and Details

- Designer provides basic recommendations regarding joint layout and other joint considerations that affect pavement performance. May also provide jointing plan.
- Materials and construction specifications provide requirements for acceptable joint placement methods and the equipment that may be used.
- Contractor implements the above requirements by following or developing a comprehensive jointing plan.

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Joint Layout Guidelines

- **What You Should 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.

- **What You Should Avoid:**
  - Jointing plan left to field personnel 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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Avoiding Acute Angles

Source: ACI

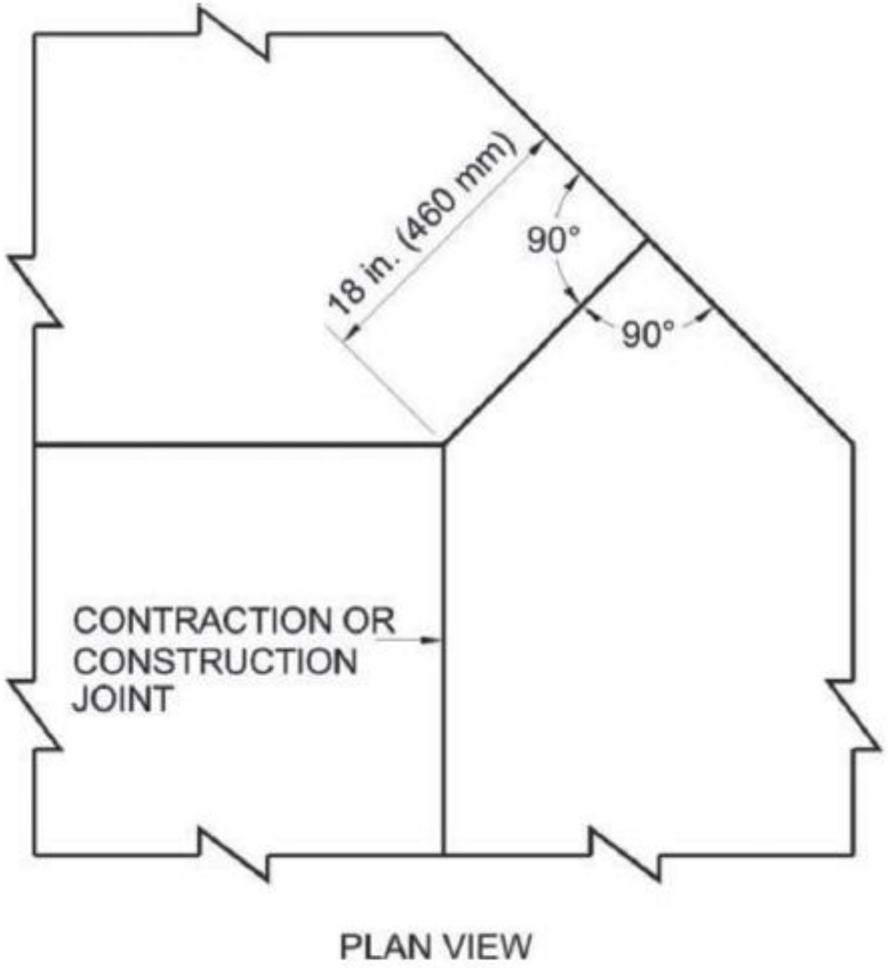

Fig. 4.4.2.3c—Illustration of avoiding acute angles.

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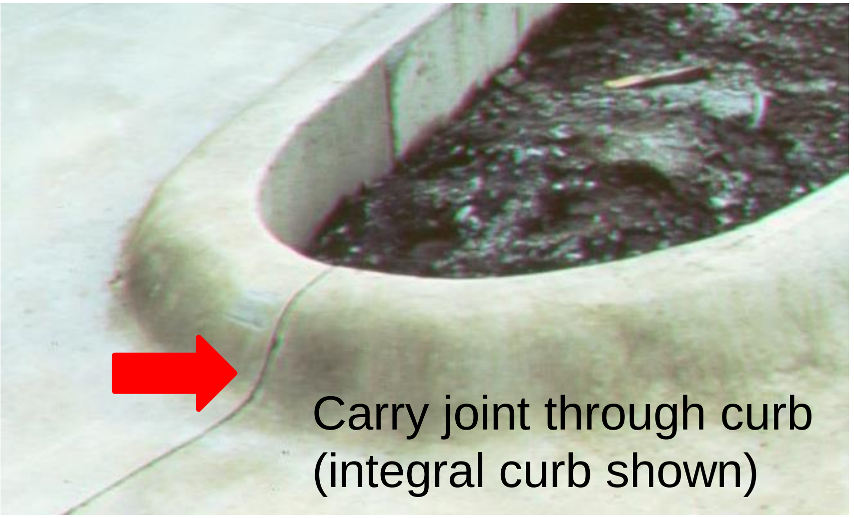
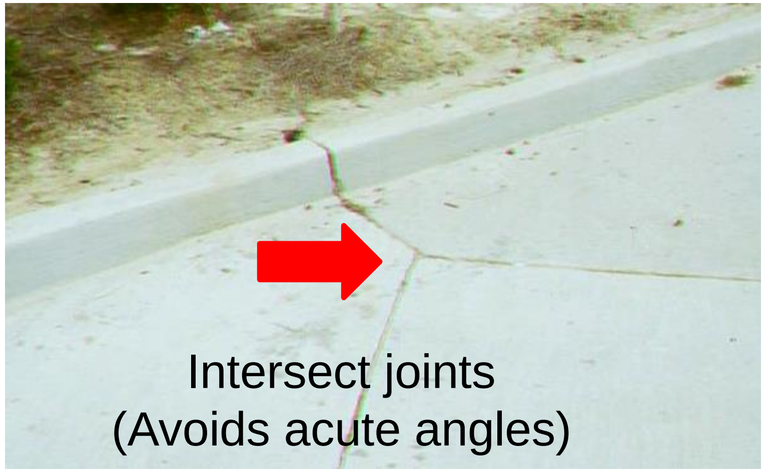
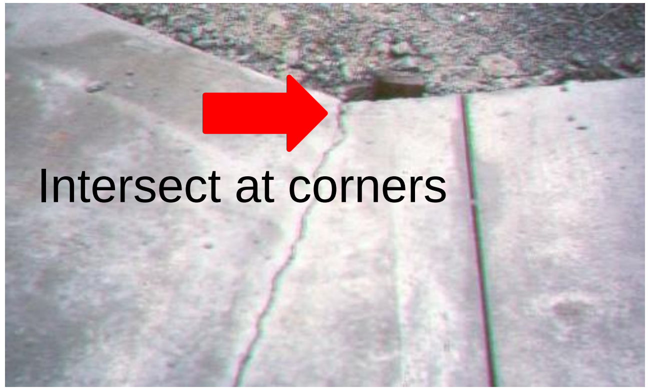
Jointing Layouts:

- Corners,
- Acute angles,
- Edges with extreme curvature.







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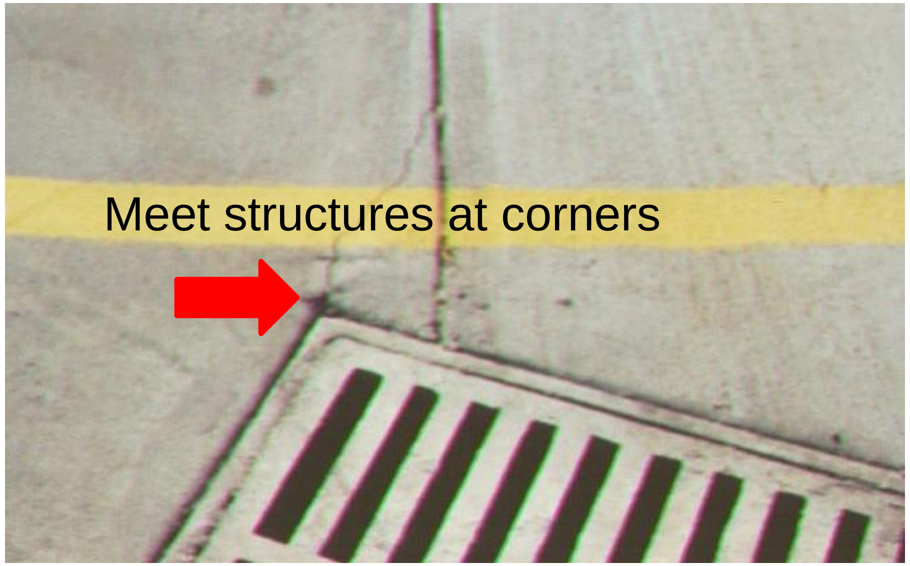
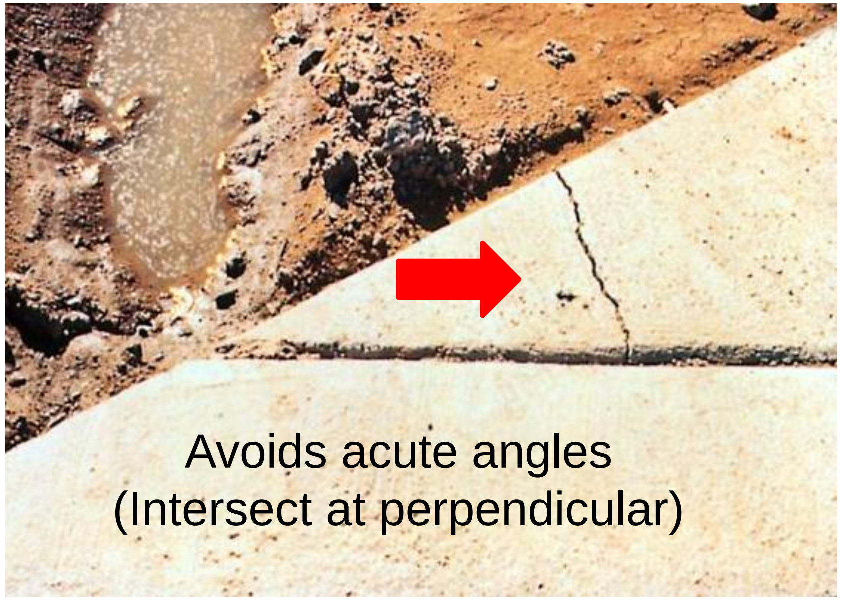


Jointing Layouts:

- Corners,
- Acute angles,
- Edges with extreme curvature.



Joint Load Transfer

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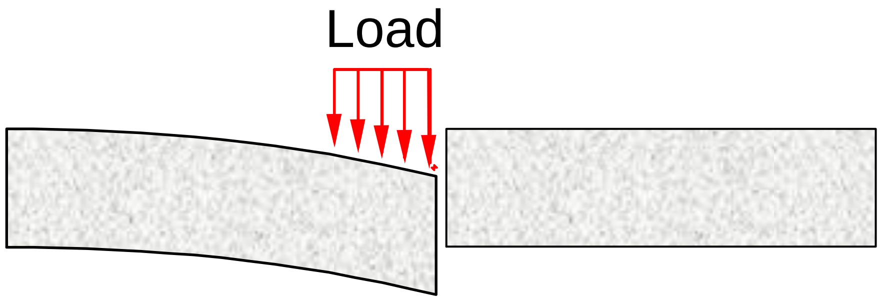
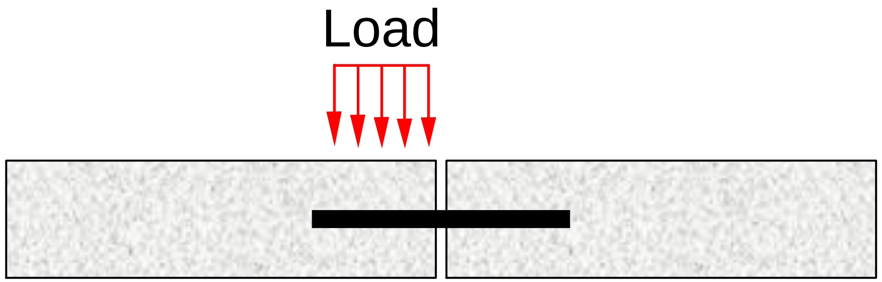
Definition – Load Transfer

- Shear strength provided at joints (or cracks) by dowels or other features, aggregate interlock, or contact friction.
- Significantly reduces load-related deflection.

<u>Without load transfer</u>:
Excessive deflections and flexure - same as free edge loading.



<u>With load transfer</u>:
Deflections and flexural stresses are reduced.



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Factors That Enhance Aggregate Interlock Effectiveness

- Larger coarse aggregate sizes
- Angular coarse aggregate texture (crushed vs. natural)
- Thicker slabs
- Shorter joint spacing
- Stiff subbases
- Edge support
- Coarse-grained subgrade soils
- Functioning drainage system

Aggregate interlock load transfer may not be sufficient for high volumes of heavy truck traffic!

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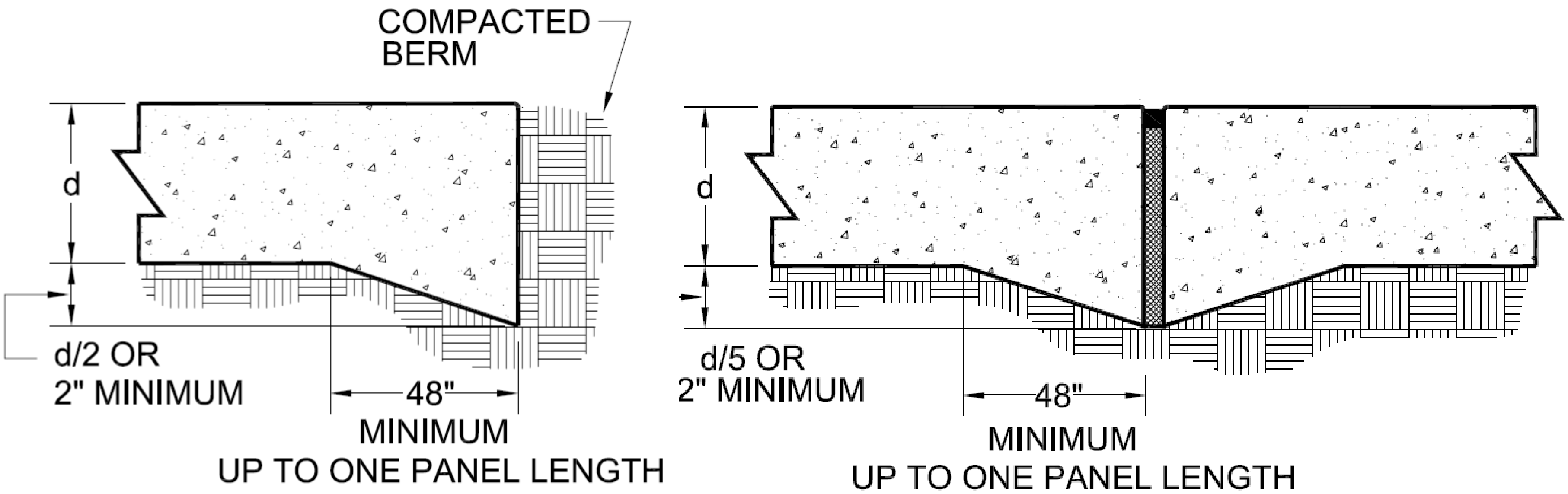
Thickened Edges

Source: ACI

Concrete at pavement edges or at isolation joints that support wheel loads could be thickened to provide extra support.



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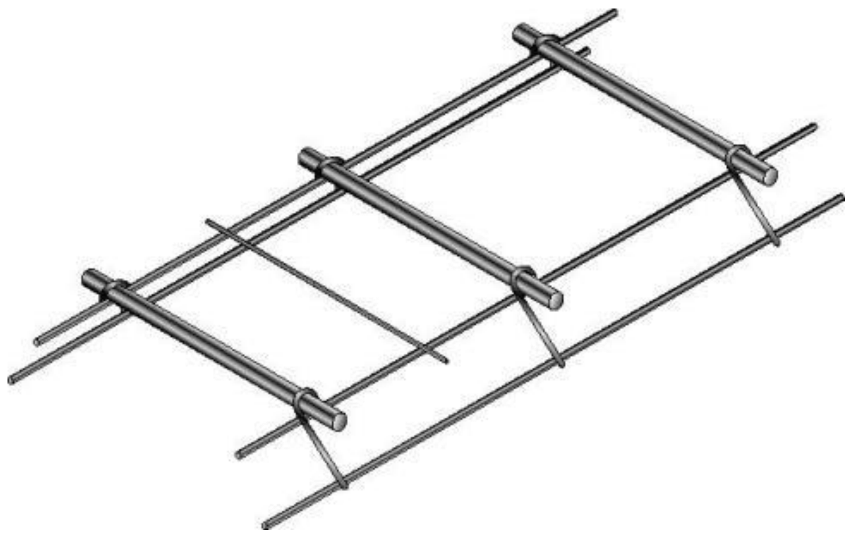
Stabilized Subgrades or Subbases in Relation to Joint Considerations

- Reduces:
  - Potential joint deflection,
  - Erosion potential.
- Improves working surface, if necessary.
- Extend 2’ beyond an unsupported slab edge.
- Note: When very stiff subgrades / subbases are used, they may also increase curling and warping.

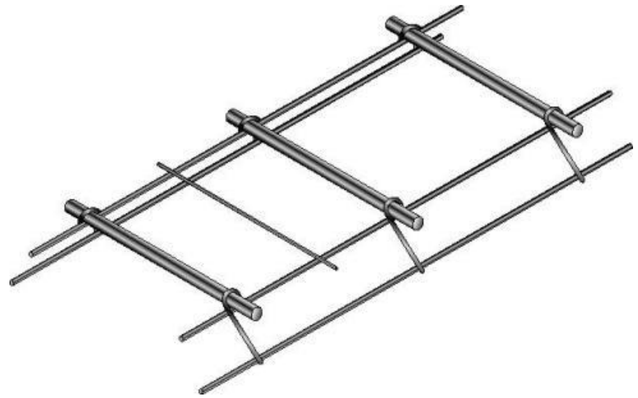
When Are Dowels Needed?

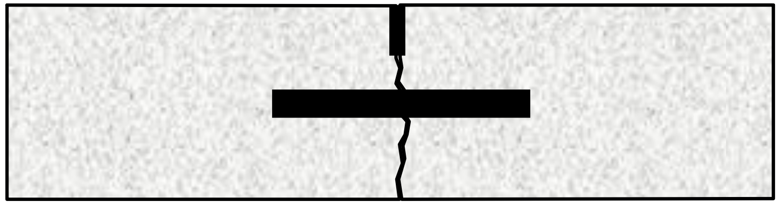
- Heavy Truck Traffic
- Weak Subgrade Conditions
- Poor Aggregate Interlock
- If Round / Square Dowels are Used:
  - – Dowel Size Should be Based on Concrete Thickness
- Plate Dowels:
  - – Can be Used for Thinner Pavements
  - – Also Can Reduce Bearing Stress Due to Larger Area



Load Transfer Devices

Source: ACI





Round Dowels
Square Dowels
Plate Dowels

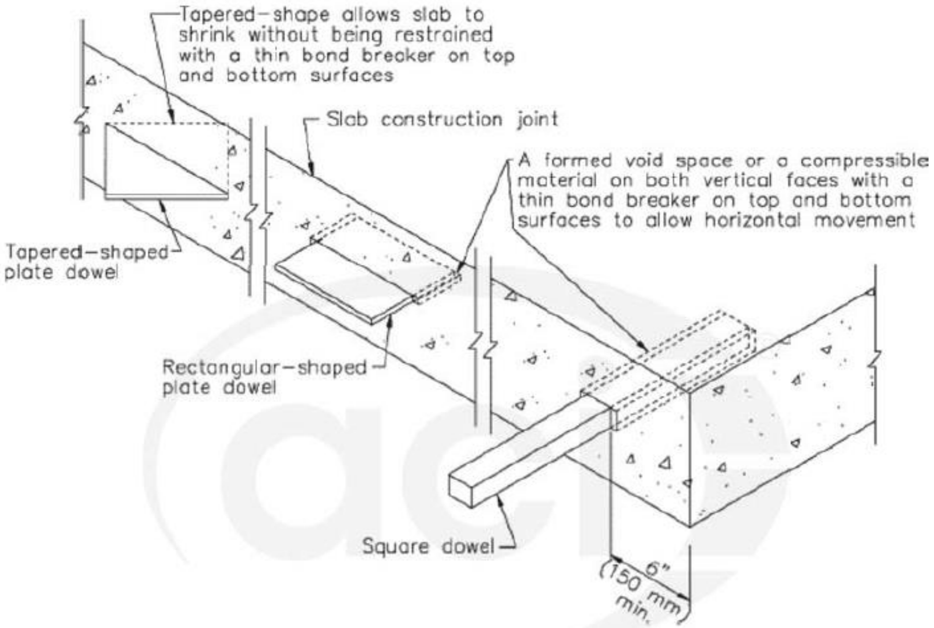


Fig. 4.6.2.3b—Isometric view indicating provisions for longitudinal movement at doweled construction joints.

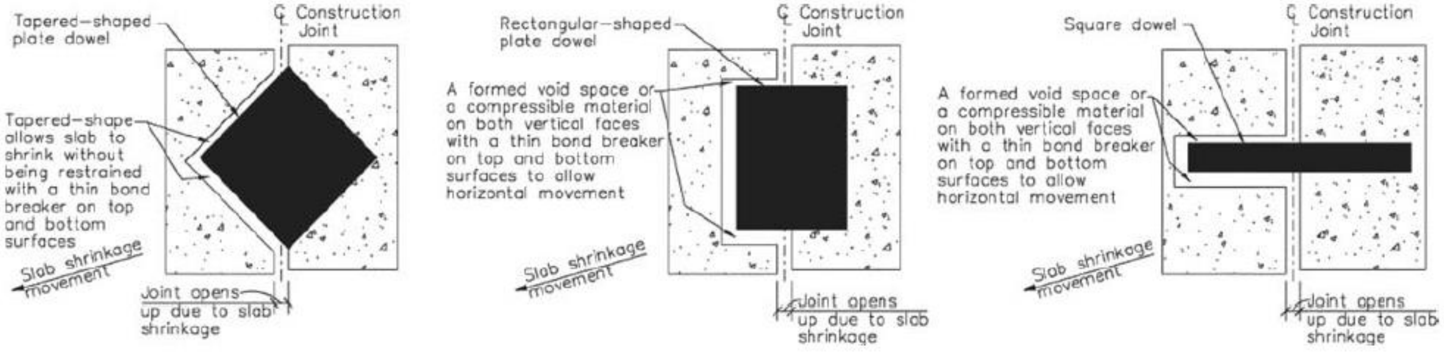


Fig. 4.6.2.3a—Plan view indicating provisions for longitudinal movement at doweled construction joints.

Dowel Spacing and Sizing

Source: ACI

Table 4.6.2.1—Dowel size and spacing for round and square dowels at construction and contraction joints*

Pavement depth, in. (mm)	Dowel dimensions, in. (mm)		Dowel dimensions, in. (mm)			Dowel spacing center to center†, in. (mm)		
	Construction joint		Contraction joint		Plate dowel	Round‡, in. (mm)	Square§‖, in. (mm)	Plate dowel
	Round‡	Square§‖	Round‡	Square§‖				
5 to <6 (130 to <150)	3/4 x 10 (19 x 250)	3/4 x 10 (19 x 250)	NR	NR	M/R#	12 (300)	14 (360)	18 (460)
6 to <8 (150 to <300)	1 x 13 (25 x 330)	1 x 13 (25 x 330)	1 x 16 (25 x 410)	1 x 16 (25 x 410)	M/R#	12 (300)	14 (360)	18 (460)
8 to <10 (200 to <250)	1-1/4 x 15 (32 x 380)	1-1/4 x 15 (32 x 380)	1-1/4 x 19 (32 x 480)	1-1/4 x 19 (32 x 480)	M/R#	12 (300)	12 (300)	18 (460)
10 to 12 (250 to 300)	1-1/2 x 18 (38 x 460)	1-1/2 x 18 (38 x 460)	1-1/2 x 22 (38 x 560)	1-1/2 x 22 (38 x 560)	M/R#	12 (300)	12 (300)	18 (460)

*Table values based on a maximum joint opening of 0.20 in. (5 mm). Carefully align and support dowels during concrete operations. Misaligned dowels can lead to cracking. Spacings are based on dowels in direct contact with a thin bond breaker. Total dowel length includes allowance made for joint opening and minor errors in positioning dowels.

†Dowel spacing up to 24 in. (600 mm) for round, square, and plate dowels have been used successfully.

‡ACI Committee 325 (1956).

§Walker and Holland (1998).

‖Square dowels should have compressible material securely attached on both vertical faces.

#M/R = manufacturers' recommendations. Because of various plate dowel geometries and installation devices available from different manufacturers, manufacturers should be consulted for their recommended plate dowel size.

Note: (NR) denotes that dowels are not recommended in contraction joints of pavements less than 6 in. (150 mm) thick.

Joint Intersections

Source: ACI

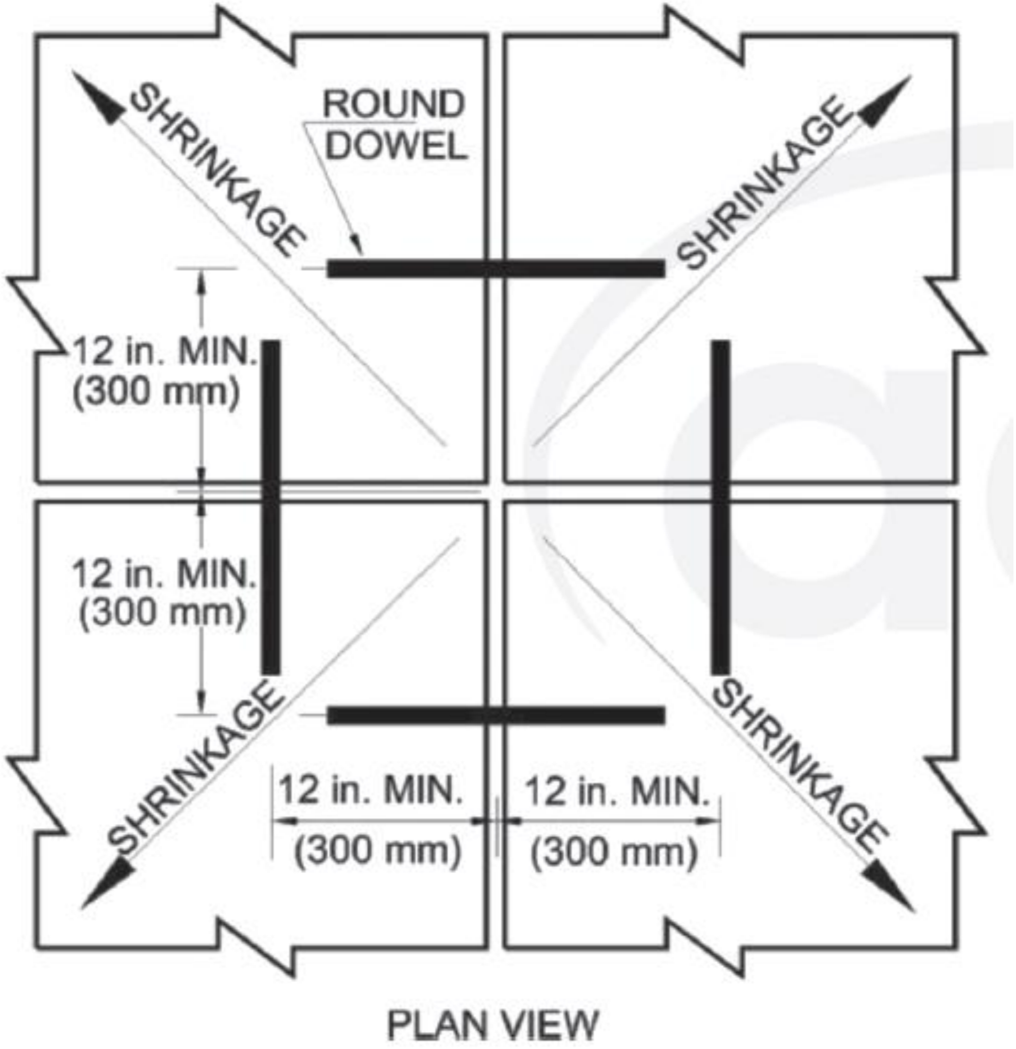


Fig. 4.6.2.1—Joint intersection with round dowel.

Alternative Doweling Systems

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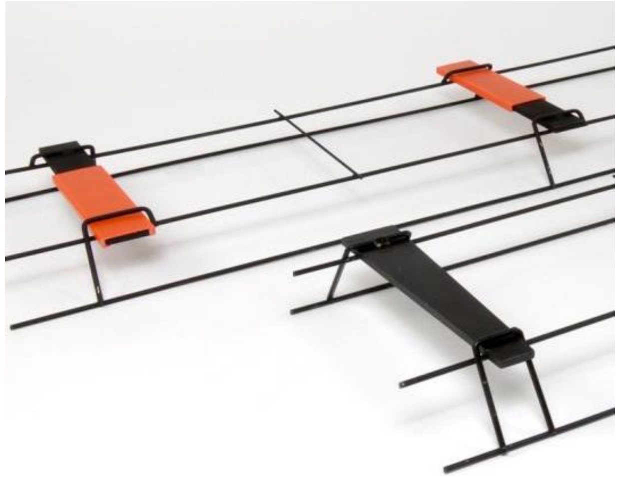
Plate and Diamond® Dowels



- Now being used in some parking areas / industrial pavements
- Accommodate some differential movement longitudinally along the joint
- Greater concrete bearing area, less stress
- Can be effectively used in thinner slabs
- Efficient use of steel
- Diamond shapes for formed construction joints
- Trapezoidal shapes in baskets for control joints
- Special attention required with consolidation around/under plate dowels

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Hollow Pavement Dowels

- Carbon steel tubular dowel
- Can be made just as rigid as a solid dowel but weigh much less
- Slight increase in dowel outer diameter with a desired wall thickness provides very similar performance to solid steel dowels for bending and bearing
- Verified by University of Pittsburg

Courtesy of Schenk Industrial: O-Dowel

NRMCA Concrete InFocus Article Fall 2020: Hollow Steel Dowel Bars

Hollow Pavement Dowels

- Lightweight tubular steel
- 11 gauge
- Welded flat rolled carbon steel tubular
- G40 has galvanized coating
- Standard epoxy coating
- “One man dowel basket”

Courtesy of Schenk Industrial: O-Dowel

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Longitudinal Joints

Longitudinal Joints

Source: ACI

- Spacing Criteria:
  - Spacing of 10 to 13 feet serves as both crack control and lane delineation.
  - Lanes (driveways) that are greater than 13' require a longitudinal joint.

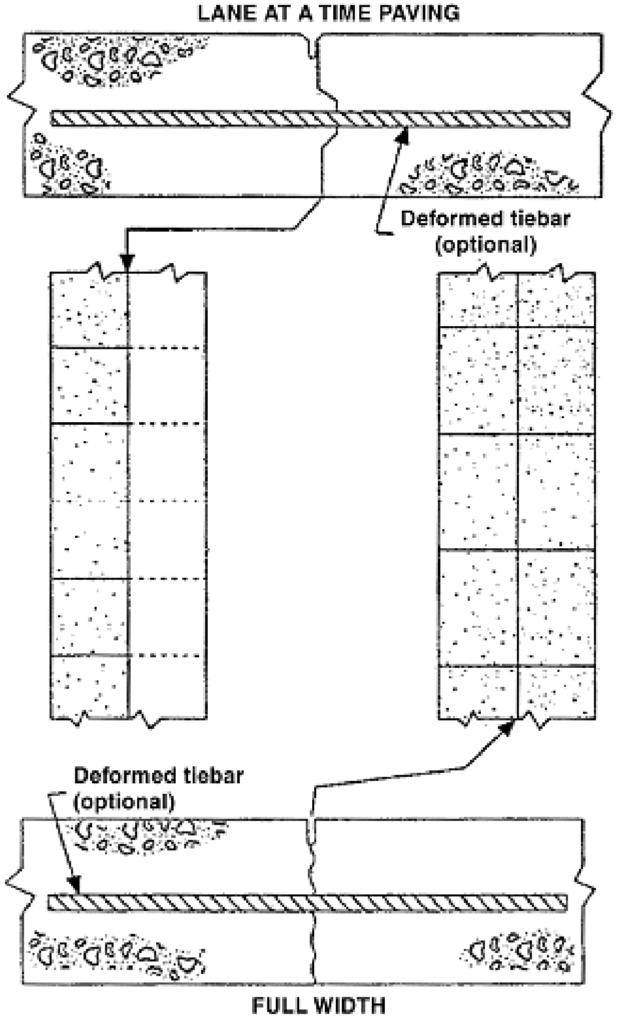

Fig. 4.5—Longitudinal joints.[33] *(Note: use butt joint with tie bar for pavements 150 mm [6 in.] thick or less.)*

Tie Bar Dimensions and Spacing (US)

Source: ACI

Table 4.1—Tie bar dimensions and spacings (commonly Grade 60)*

Slab thickness, in. (mm)	Tie bar size × length, in. (mm)	Tie bar spacing, in. (mm)			
		Distance to nearest free edge or to nearest joint where movement can occur			
		10 ft (3.0 m)	12 ft (3.7 m)	14 ft (4.3 m)	24 ft (7.3 m)
5 (130)	#4 x 24 (13M × 600)	30 (760)	30 (760)	30 (760)	28 (700)
6 (150)	#4 x 24 (13M × 600)	30 (760)	30 (760)	30 (760)	23 (580)
7 (180)	#4 x 24 (13M × 600)	30 (760)	30 (760)	30 (760)	20 (500)
8 (200)	#4 x 24 (13M × 600)	30 (760)	30 (760)	30 (760)	17 (430)
9 (230)	#5 x 30 (16M × 760)	36 (900)	36 (900)	36 (900)	24 (600)
10 (250)	#5 x 30 (16M × 760)	36 (900)	36 (900)	36 (900)	22 (560)
11 (280)	#5 x 30 (16M × 760)	36 (900)	36 (900)	34 (860)	20 (500)
12 (310)	#5 x 30 (16M × 760)	36 (900)	36 (900)	31 (780)	18 (460)

*Corrosion protection should be used in an area where deicing salts are used on the pavement on a regular basis.

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Addressing Potential Slab Movement: Lug Anchors

Source: ACI

Minimize panel sliding caused by:

- Steep pavement grades
- Sites with fine-grained subgrade soils
- Forces from braking or turning

Potential areas of concern:

- Entrance/Exit roadways
- Aprons near loading docks
- Breaking areas while moving downhill or pavement edges

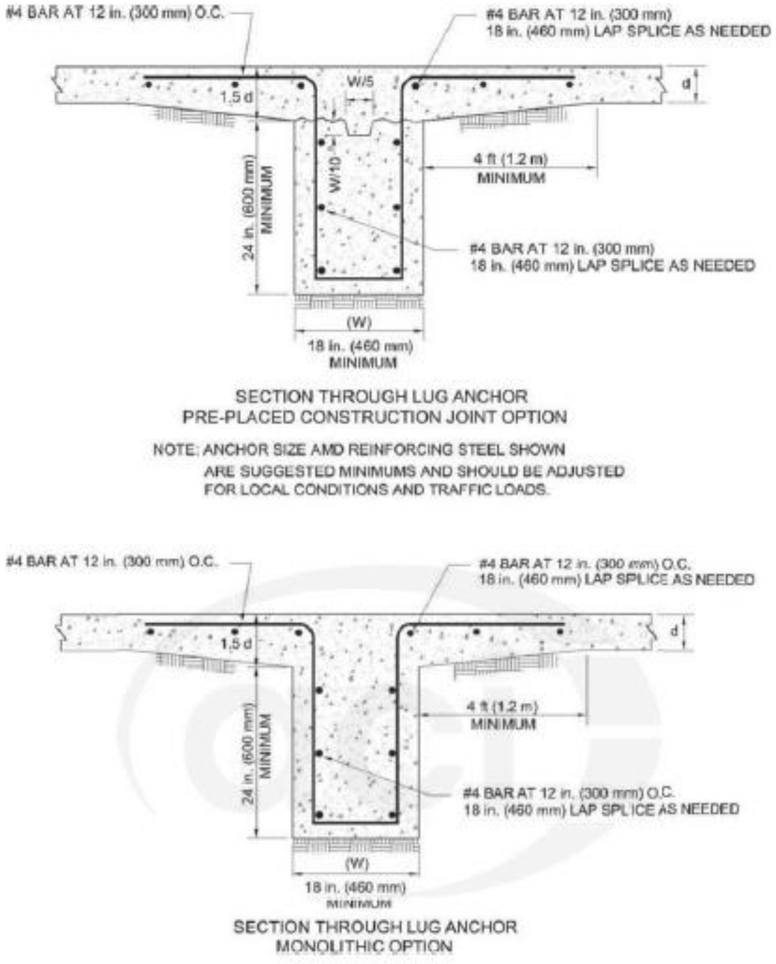

Fig. 4.8.2—Example sections of typical lug anchors.

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Special Conditions

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Industrial Concrete Pavement

Industrial Concrete Paving – Loading may not be like roadway or commercial parking.

- Standard trucks
- Industrial lift trucks
- Front end loaders
- Tracked equipment
- Straddle carriers
- Cranes
- Military equipment
- Buses & coaches
- Agricultural equipment

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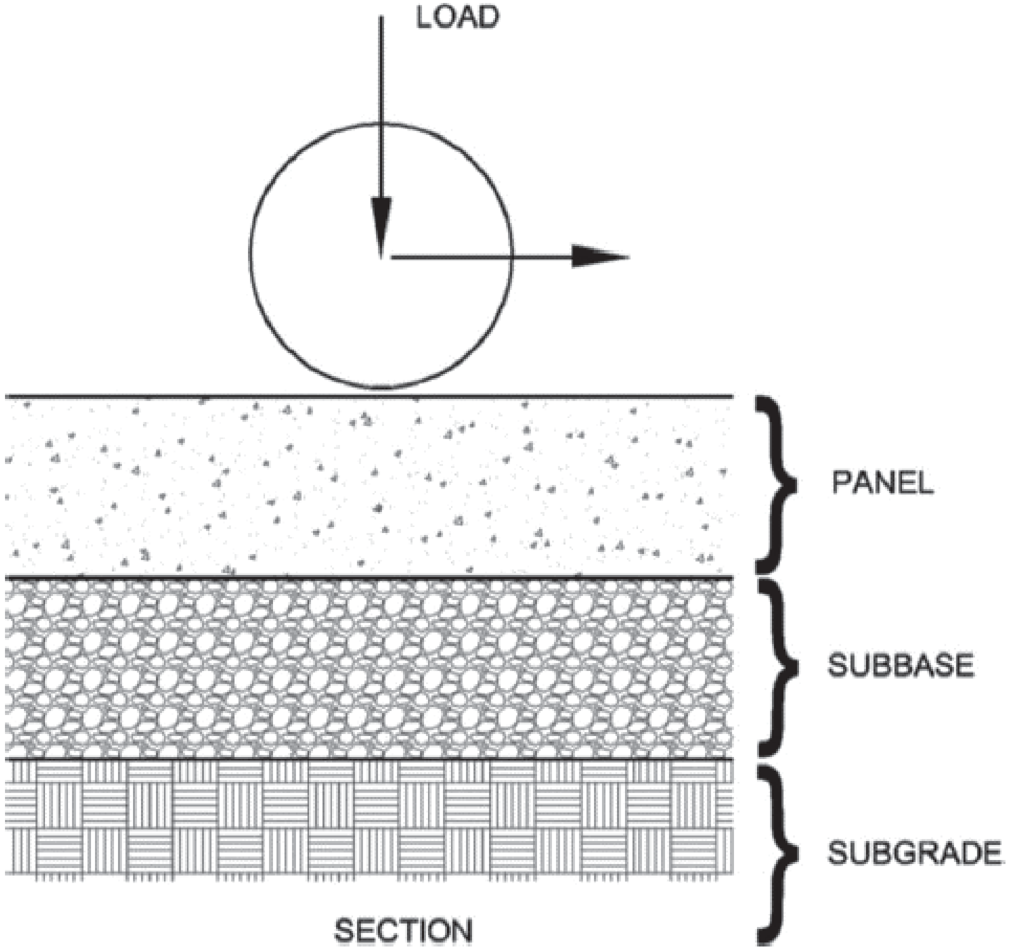
Industrial Design Considerations

- Underlying Support Conditions
- Unique Loading Conditions
- Joint Stability and Load Transfer
- Construction Methods



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Industrial Concrete Pavement: Armored Joints

Source: ACI

Traffic with hard tires such as:

- Solid rubber
- Polyurethane
- Steel

Hard wheeled vehicles:

- Apply higher contact pressures
- Can cause severe joint deterioration

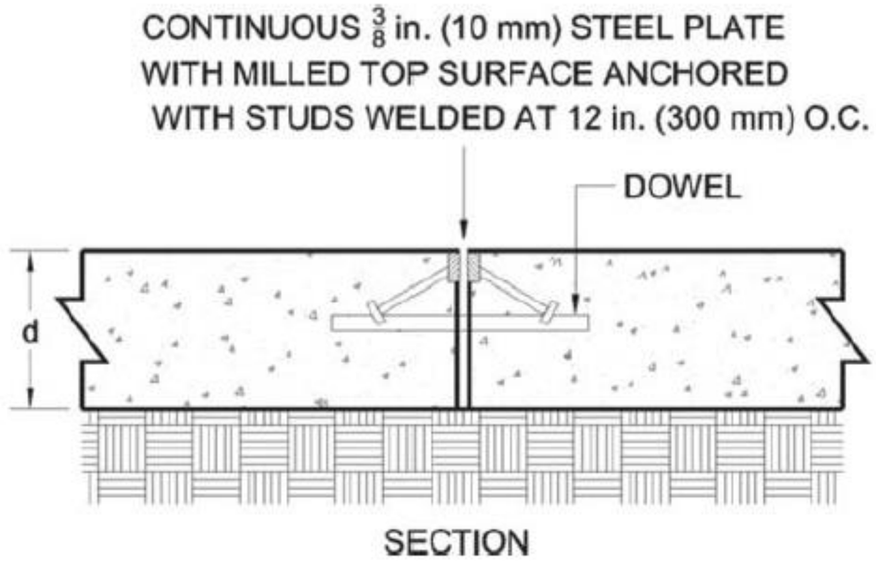

Fig. 4.2.8—Armored joint.

Can use semi-rigid joint filler to minimize joint spalling

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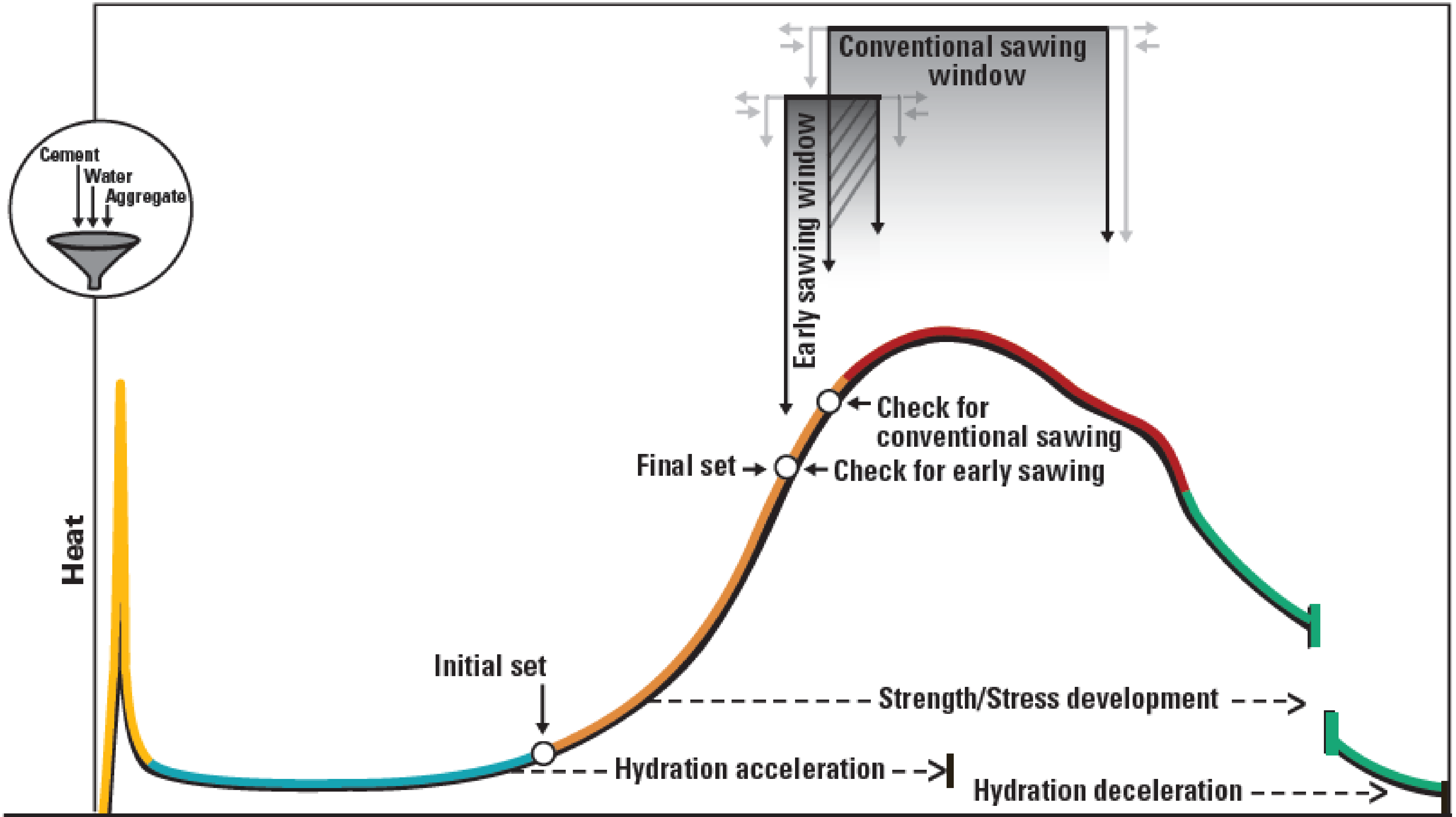
Sawing of Joints

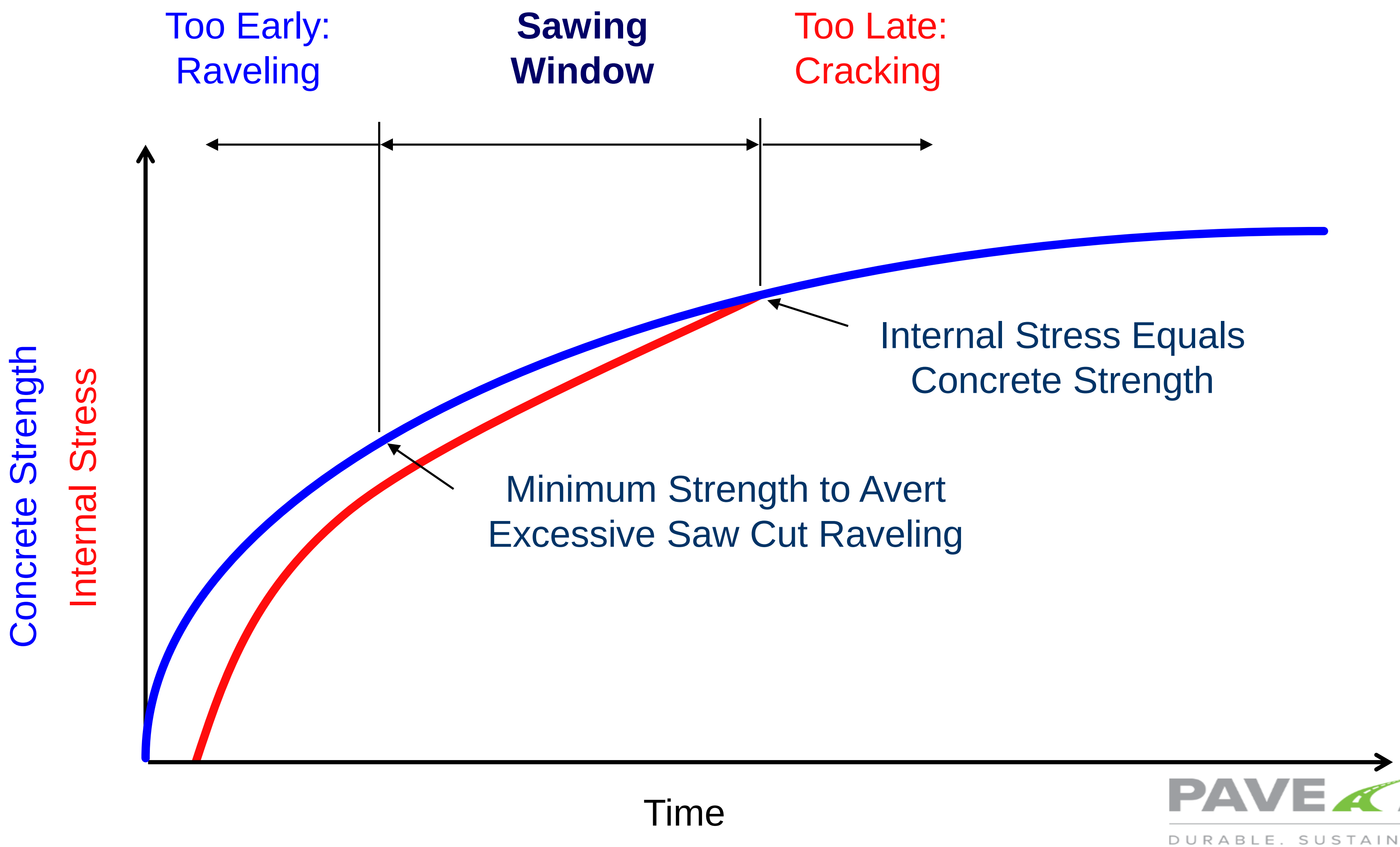
Concrete Stages of Hydration



Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Mixing	Dormancy	Hardening	Cooling	Densification
Lasts about 15 minutes	Lasts about 2–4 hours	Lasts about 2–4 hours		Continues for years

Crack Control Window

Source: Okamoto et al. 1994



Factors That Shorten the Sawing Window

IMCP: Table 8-7, pg. 237

Category	Factor
Concrete mixture	High water demand
	Rapid early strength
	Retarded set
	Fine aggregate (fineness and grading)
	Coarse aggregate (maximum size and/or percentage)
Weather	Sudden temperature drop or rain shower
	Sudden temperature rise
	High winds and low humidity
	Cool temperatures and cloudy
	Hot temperatures and sunny

Category	Factor
Subbase	High friction between the subbase and concrete slab
	Bond between the underlying subbase and concrete slab
	Dry surface
	Porous aggregate subbase materials
Miscellaneous	Paving against or between existing lanes
	Saw blade selection
	Delay in curing protection

Source: ACPA 2002

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Rules of Thumb for Sawcut Joints

- Depth:
  - Conventional Sawing:
    - Minimum of ¼ of the depth: e.g. 8” thick = 2” deep
    - Recommended: $\frac{t}{3}$
  - Early Entry Sawing:
    - Typical 1” to 1.5” depth

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Saw Blades

- Most common are industrial diamond (require water cooling) or abrasive (carborundum).

- Must match the saw blade to the concrete which is based primarily on aggregate hardness but also depends on power output of saw.

- <u>Very thin blades (~2 to 3 mm) may be used when joint sealing is not specified.</u>

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Joint Sealing

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Joint Sealing

Source: ACI

Purpose of joint sealer:

- Keep water from saturating subgrade/subbase
- Keep incompressible materials out of joints

Always recommended:

- Fuel/chemical spills may contaminate soils
- Temporary ponding zones around stormwater drainage inlets
- Minimizing the adverse effects of dowel corrosion
- Small-particle materials are spilled, mixed or stored

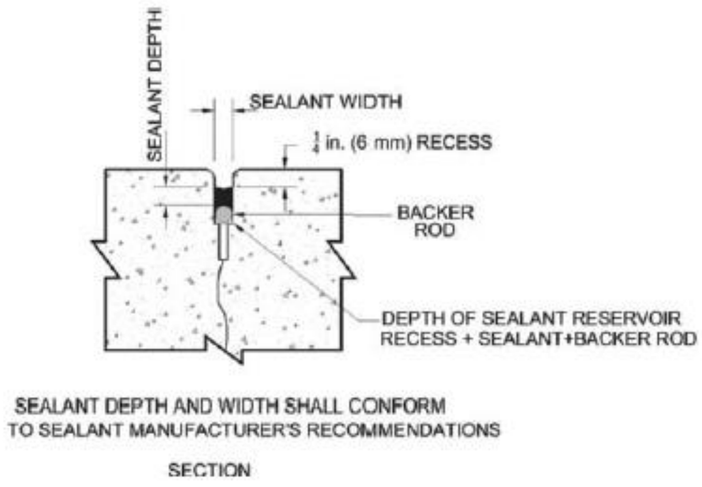

Fig. 4.4.3a—Joint sealant with backer rod.

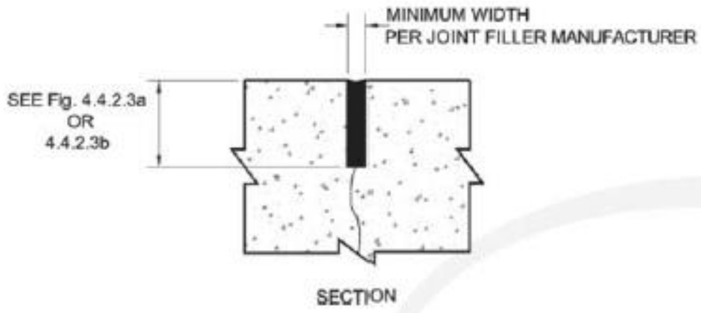

Fig. 4.4.3b—Joint filling.

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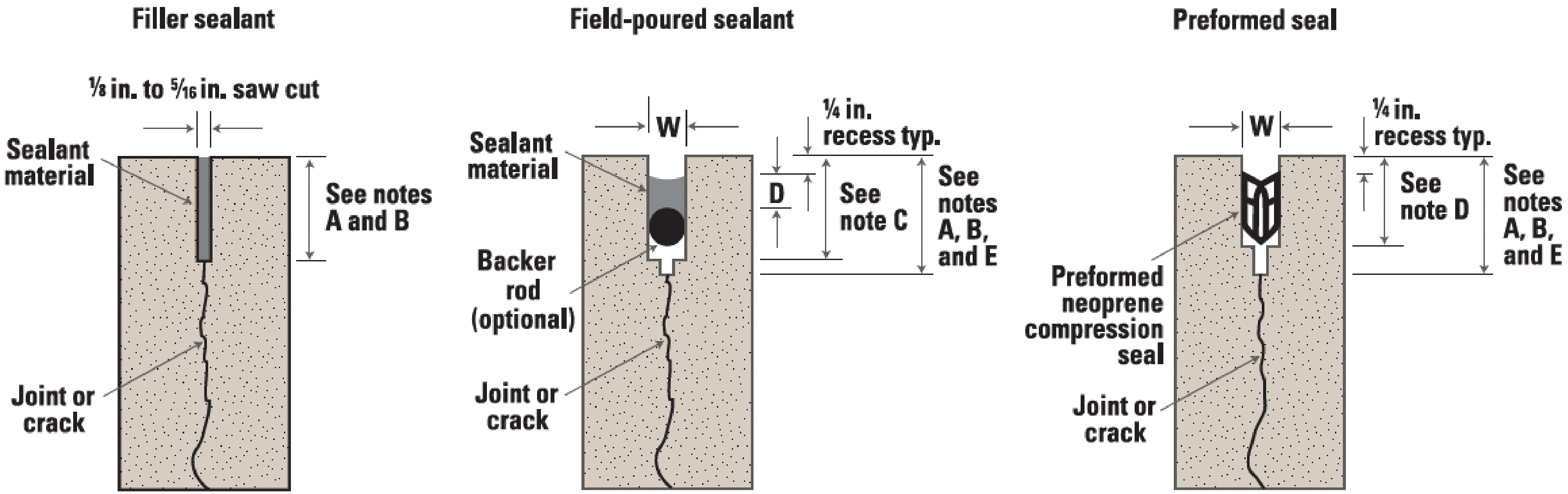
When Is Joint Sealing Required?

- Always Should be Considered; However,
  - Will the Joint Sealant be Maintained Over Time?
  - Is There Water or Wind Blown Material Present?
  - Is Subgrade Likely to Pump?
  - Is There Risk of Joints Opening (i.e. Expansive Subgrade)?
- If These Risks Can be Minimized, Joint Sealing May Not be Necessary.

Different Forms of Joint Sealant

Adapted from ACPA
IMCP: Figure 8-36, pg. 240



Hot-poured sealant: D/W = 1.0 (typical)
Silicone sealant: D/W = 0.5 (typical)
Two-component material cold poured: D/W = 0.5 (typical)

Preformed compression seal: W = sized for slab and climate

Notes:
A - Initial cut to a depth of T/4 or T/3 as required for conventional sawing.
B - Initial cut to a depth of 1¼ in. minimum for early-entry sawing.
C - As required to accomodate sealant and backer rod.
D - As required by the manufacturer.
E - A single-cut or double-cut process may be used to saw joints. The field-poured sealant and performed seal above illustrate a double cut, in which a first, narrow cut is followed by a widening cut. A single wide cut is also acceptable.

Potential Joint Performance Based on Sealing Option

IMCP: Table 8-8, pg. 239

	STREETS/ROADS/HIGHWAYS							
	Any posted speed limit (unless indicated by note)							
Layer below slab	Dense-graded base or subgrade soil				Nonerodible (2) or free-draining layer (3)			
Climatic zone	Dry no-freeze		Other		Dry no-freeze		Other	
Joint spacing	≤ 6 ft	> 6 ft	≤ 6 ft	> 6 ft	≤ 6 ft	> 6 ft	≤ 6 ft	> 6 ft
Open reservoir cut	NR	NR	NR	NR	NR	NR	NR	NR
Open narrow saw cut	▮	▮	▮	NR	▯	▯	▮ (4,5)	▮ (5)
Filled saw cut or reservoir	▯	▯	▮ (6)	▮ (6)	▯	▯	▮ (6)	▮ (6)
Sealed saw cut or reservoir	▯	▯	▯	▯	▯	▯	▯	▯

KEY:

NR = Not recommended

▮ Should perform adequately based on engineering judgment and limited experience (if sealed/filled, then also with correct installation/maintenance procedures

▯ Will perform adequately based on engineering judgment and limited experience (if sealed/filled, then also with correct installation/maintenance procedures

Source: ACPA 2018

Sealing? Make Certain the Joint is Clean!

Source: ACPA

- All sealed joints must be cleaned immediately behind saw cutting or joint widening and immediately prior to sealing operations:
  - – Removes saw-cut slurry, soil, sand, etc.
- Cleanliness of both joint faces is extremely important to concrete/sealant bond.

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It’s Not Hard to Check…

Source: ACPA

- If wiping a finger along the face picks up dirt or dust, recleaning should be done before sealing!

Sealant Selection

Source: ACI

Table 4.2—Joint sealant materials[31]

Hot-pour sealants	Specification	Properties
Polymeric asphalt-based	AASHTO M 0173	Self-leveling
	ASTM D3405	
	SS-S-1401 C	
	ASTM D1190	
Polymeric	ASTM D3405	
Low modulus	Modified	
Elastomeric	SS-S-1614	
Coal tar, PVC	ASTM D3406	
Cold-pour sealants/ single components		
Silicone	ASTM D5893	Self-leveling, non-sag, low to ultra-low modulus
Nitrile rubber	No specifications currently exist	Self-leveling, nonsag
Polysulfide		Self-leveling, low modulus
Preformed polychloroprene elastomeric (compression seals)		
Preformed compression seals	ASTM D2628	20 to 50% allowable strain
Lubricant adhesive	ASTM D2835	

Drainage: Pavement Slope

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Drainage Design

- Drainage plan should:
  - Provide a paved area that is fast-draining, quick-drying, puddle-free
  - Sheet flow stormwater to drainage inlets
  - Avoid channeling water along joint
  - Avoid “warping” pavement (increases cracking potential and difficult to build)

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Slope Recommendations

- Pavements slope:
  - 1% (⅛ inch/foot) minimum
  - 2% (¼ inch/foot) is typical
  - 6% maximum in car parking areas
  - 8% maximum for entrances to prevent “bottom outs”

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Short Slabs and Jointless Slabs

Alternatives to Conventional Concrete Pavement Joint Spacing

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Industrial Short Slab Design

- Typical slab joint spacing for unreinforced pavement:
  - 21 to 24 times the thickness or
  - 5.25 * ℓ (radius of relative stiffness)

- What happens if joint spacing is reduced to ~10 times the thickness?
- Short slabs distribute wheel loads over shorter panels.
  - Short slabs = reduced potential for curl.
  - Short slabs = reduced wheel load stress.
- Reduce thickness, maintain same load-bearing capacity.

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Industrial Short Slab Design

Houston, TX – 2021
Traffic: ~4.0M ESALs
Size: 2.7M sq.ft.
Thickness: 5.5” (14cm)

- **580psi (4.0MPa) flexural strength**
- **With macrosynthetic fibers**
- **6ft (1.8m) joint spacing**
- **8” (20cm) cement treated base**

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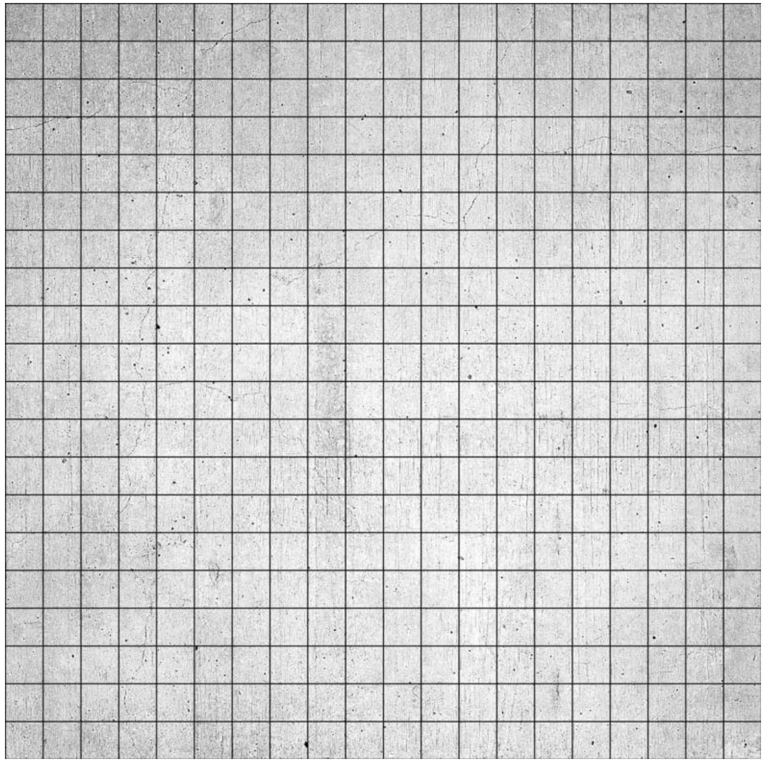
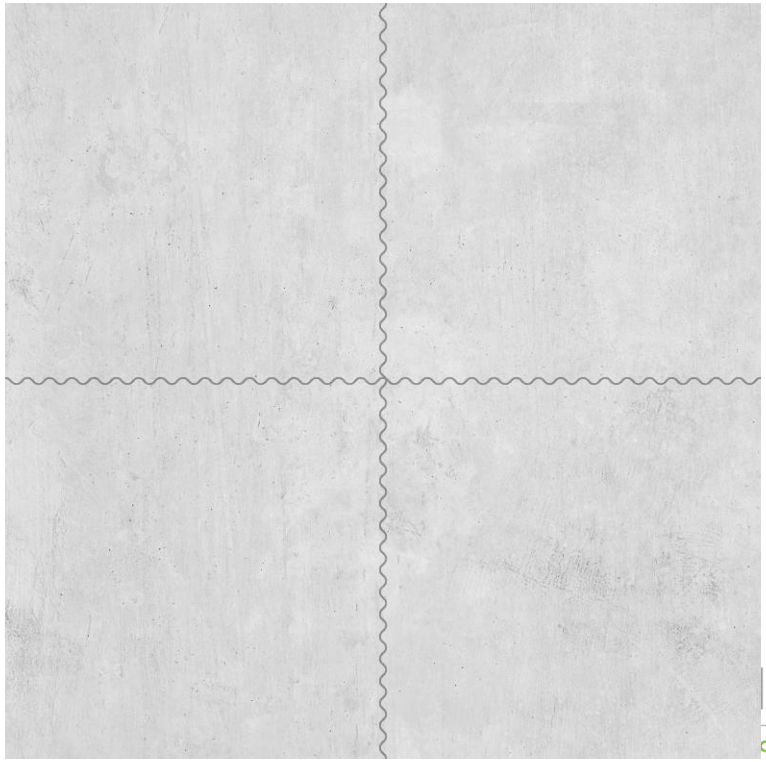
Industrial Jointless Slab Design

- Goal:
  - Eliminate joints
  - Reduce potential for curling and tensile stress (environment & load)
  - Tensile reduction can include shrinkage reduction
- Jointless Design:
  - Combination of materials formulated to reduce:
    - Shrinkage
    - Curl
  - Materials may include:
    - Admixtures
    - Specialty cements
    - Fibers
    - Nanotechnologies

Industrial Jointless Slab Design

- Slab length example 150-ft x 150-ft, but can be larger
- Armored joints at construction joints in heavy wheel load applications
- Specialized concrete design methods & proprietary mixtures





Credit: MEGASLAB®

Do You Need Assistance?

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ConcreteState

ICPA
IOWA CONCRETE PAVING ASSOCIATION

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https://paveahead.com/register/


https://paveahead.com/register/

- Design recommendations
- Cost comparisons including life cycle costs
- Specification review
- Ready mixed products:
  - Conventional concrete (full depth and overlays)
  - Pervious concrete
  - Roller compacted concrete
  - Cement slurry for full depth reclamation (FDR)

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Thank You

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