JOINTING BASICS FOR CONCRETE PAVEMENTS

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56th Iowa Concrete Paving Workshop

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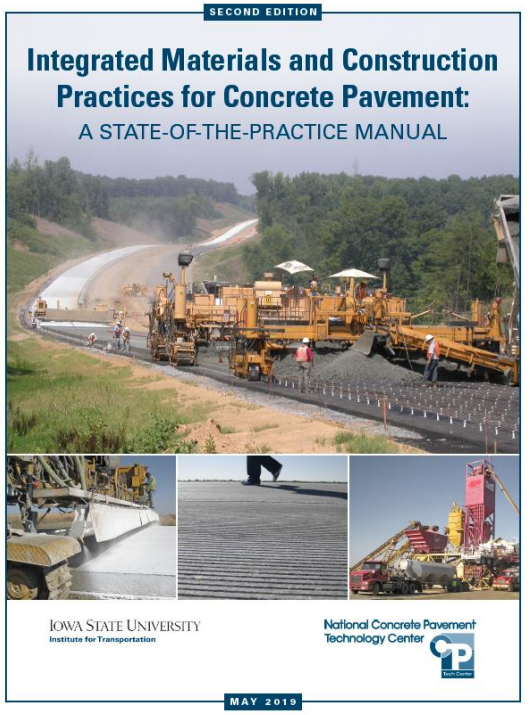
ICPA IOWA CONCRETE PAVING ASSOCIATION

ConcreteState

ACKNOWLEDGMENTS

- American Concrete Pavement Association
  - Wikipave.org
- National CP Tech Center
  - New in 2019: 2nd Edition IMCP Manual
- Iowa DOT & SUDAS



AGENDA

- Why is jointing important for concrete pavements?
- What do I need to do to make sure joints are designed correctly?
- What do I need to do to make sure joints are constructed correctly?
- Special jointing applications and cases

WHY IS JOINTING IMPORTANT?

- If you place concrete without joints…

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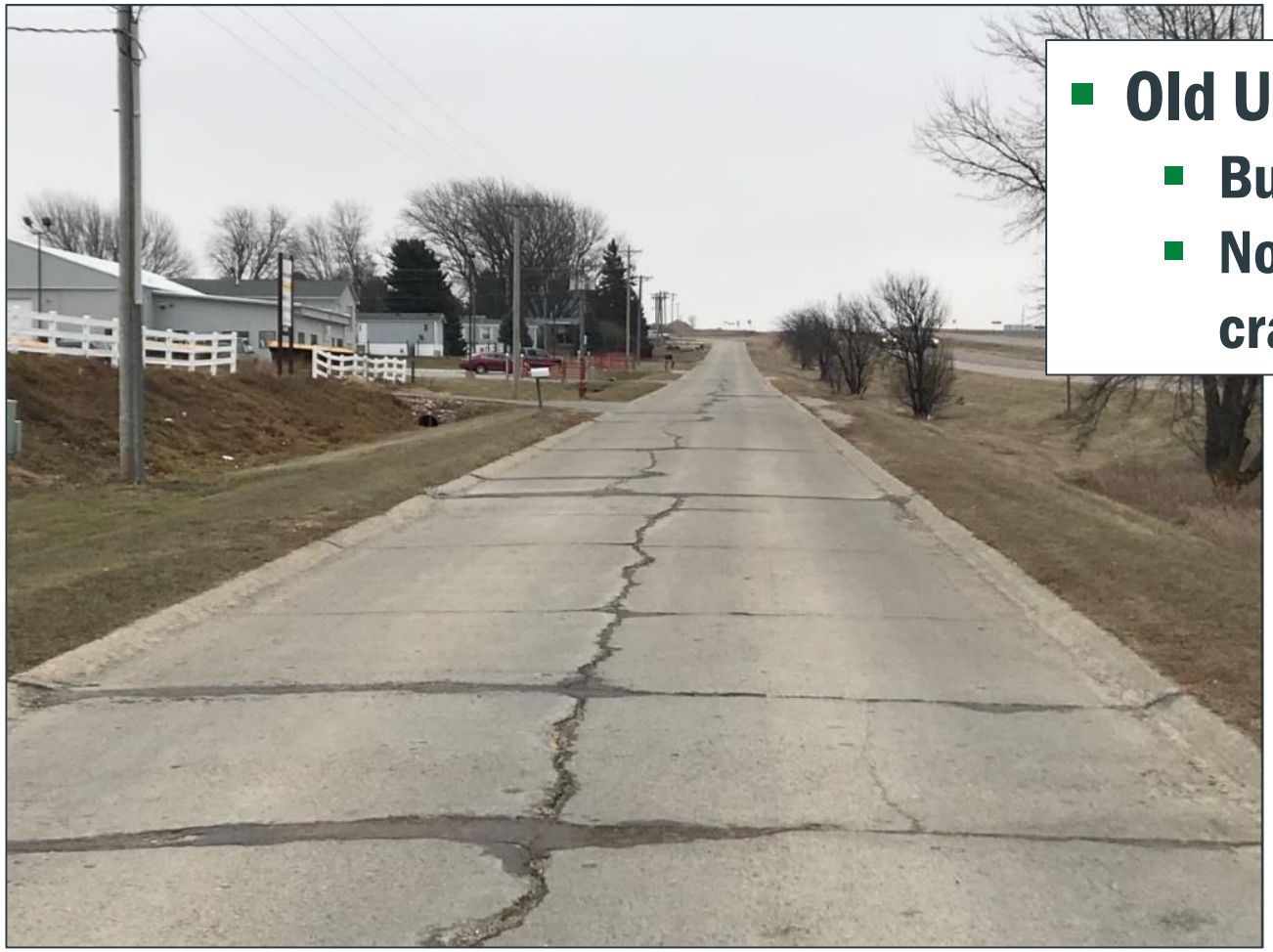


- Old US 20, Moville
  - Built in 1921!
  - No joints - allowed to crack on its own

WHY IS JOINTING IMPORTANT?

- Why does concrete crack at an early age?
  - Soon after mixing, concrete begins to shrink
  - Shrinkage due to moisture loss is most significant
    - Water content is the most mix property related to shrinkage: more water, more shrinkage

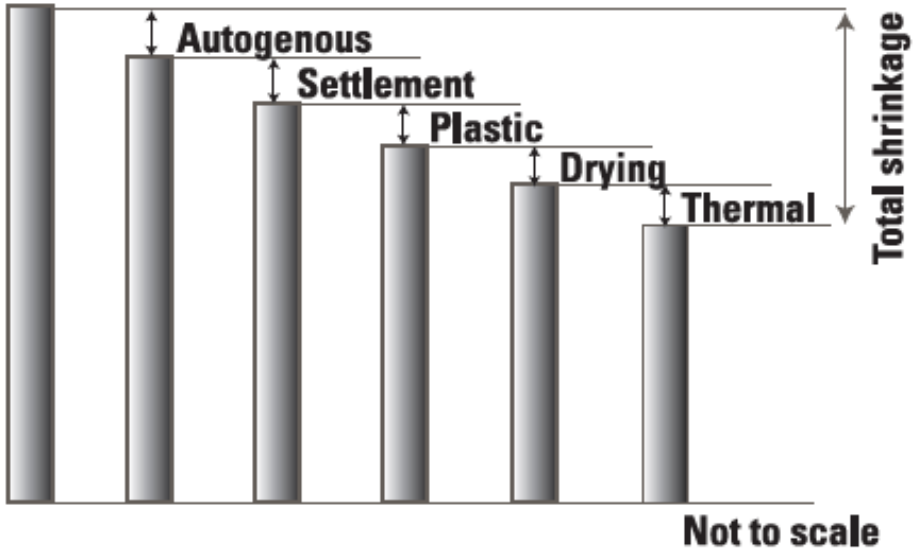


Image: CTL Group

WHY IS JOINTING IMPORTANT?

- Why does concrete crack at an early age?
  - If concrete could expand and contract freely, shrinkage wouldn't be a problem…

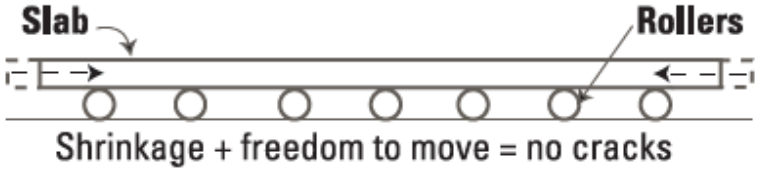


Image: ACPA

WHY IS JOINTING IMPORTANT?

- Why does concrete crack at an early age?
  - If concrete could expand and contract freely, shrinkage wouldn't be a problem…
  - …unfortunately, gravity and friction → restraint → cracks

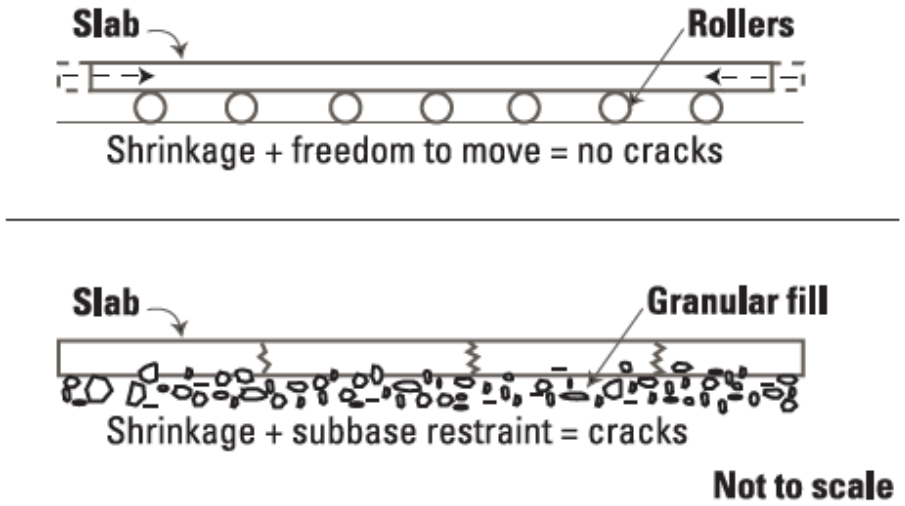
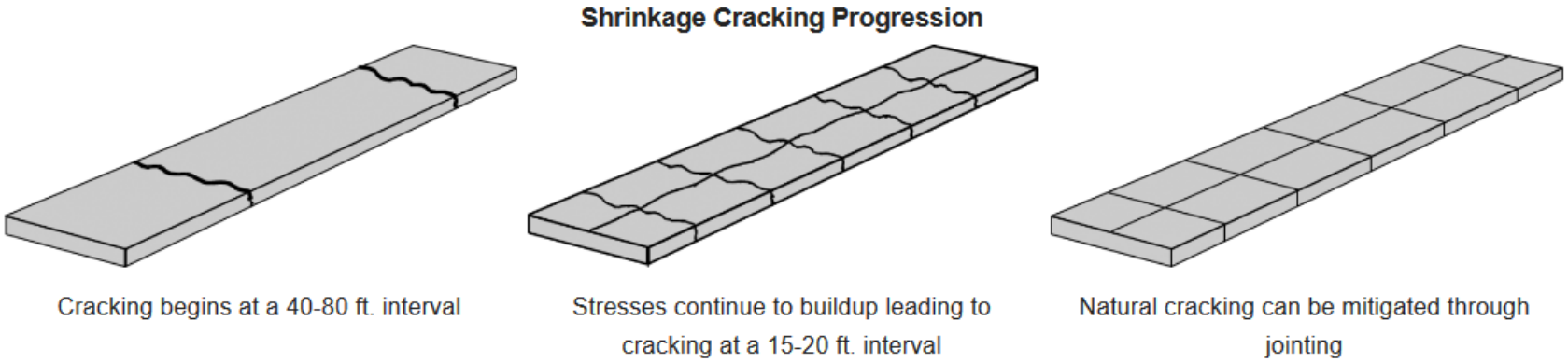


Image: ACPA

WHY IS JOINTING IMPORTANT?

- Typical crack progression
  - In the first few days after placement, tensile stresses develop in the slab from shrinkage + subbase/subgrade restraint
  - The concrete gains strength as it hydrates, but eventually stresses > strength



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WHY IS JOINTING IMPORTANT?

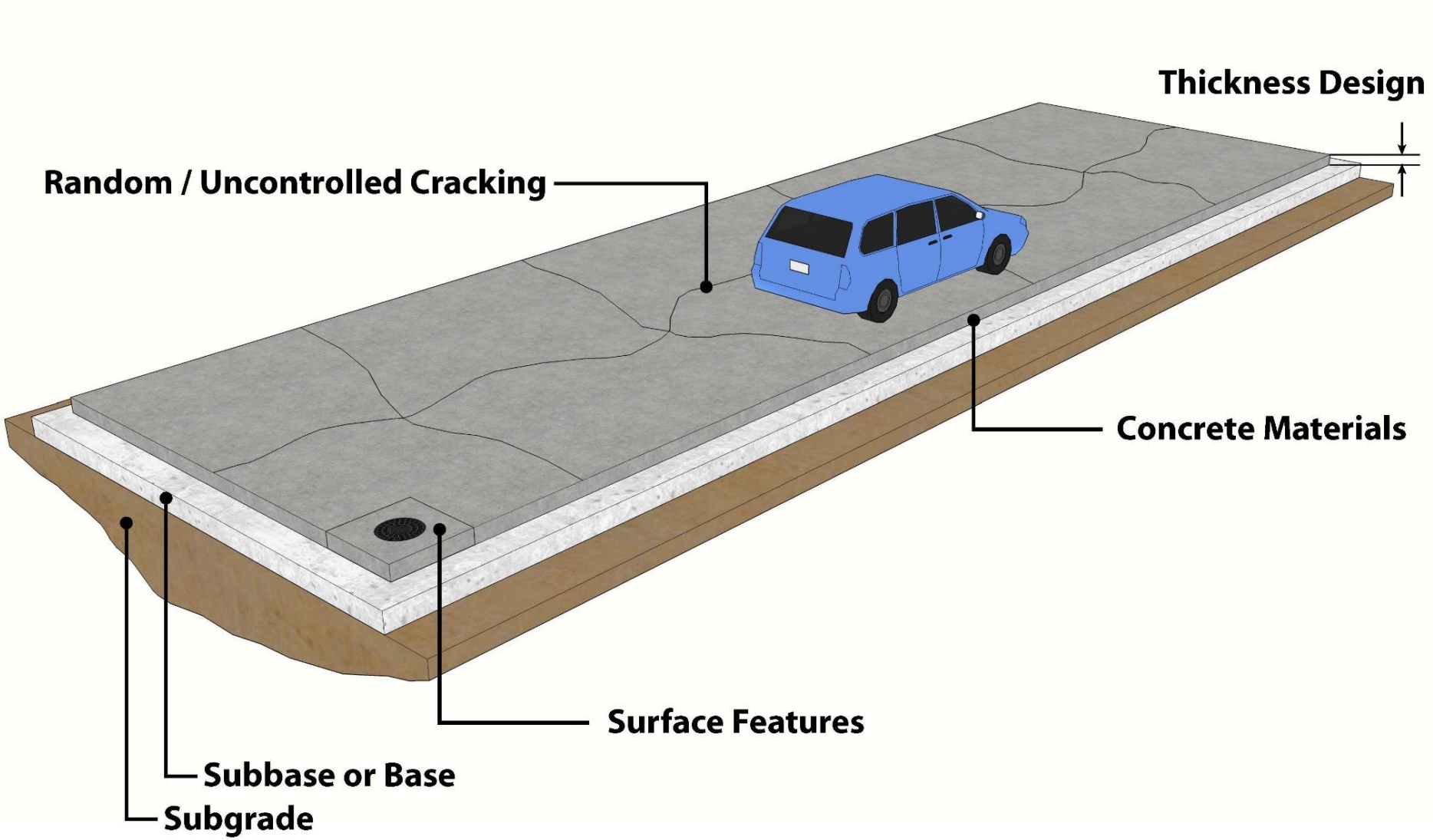


Image: CP Tech Center

WHY IS JOINTING IMPORTANT?

- Why aren't we ok with random cracks?
  - They're ugly
  - They can become a source of ingress for fluids and incompressible materials (bad for long-term durability)
  - We need to be able to transfer heavy traffic loads from slab to slab (bad for long-term pavement performance)

WHY IS JOINTING IMPORTANT?

- Early age cracking is controlled through **jointing**
- Good jointing practices can go a long way to help prevent cracking at later ages as well!

- Saw cut → Weakened plane → controls location where crack forms

Image: PCA

WHY IS JOINTING IMPORTANT?

- Jointed Plain Concrete Pavement (JPCP):

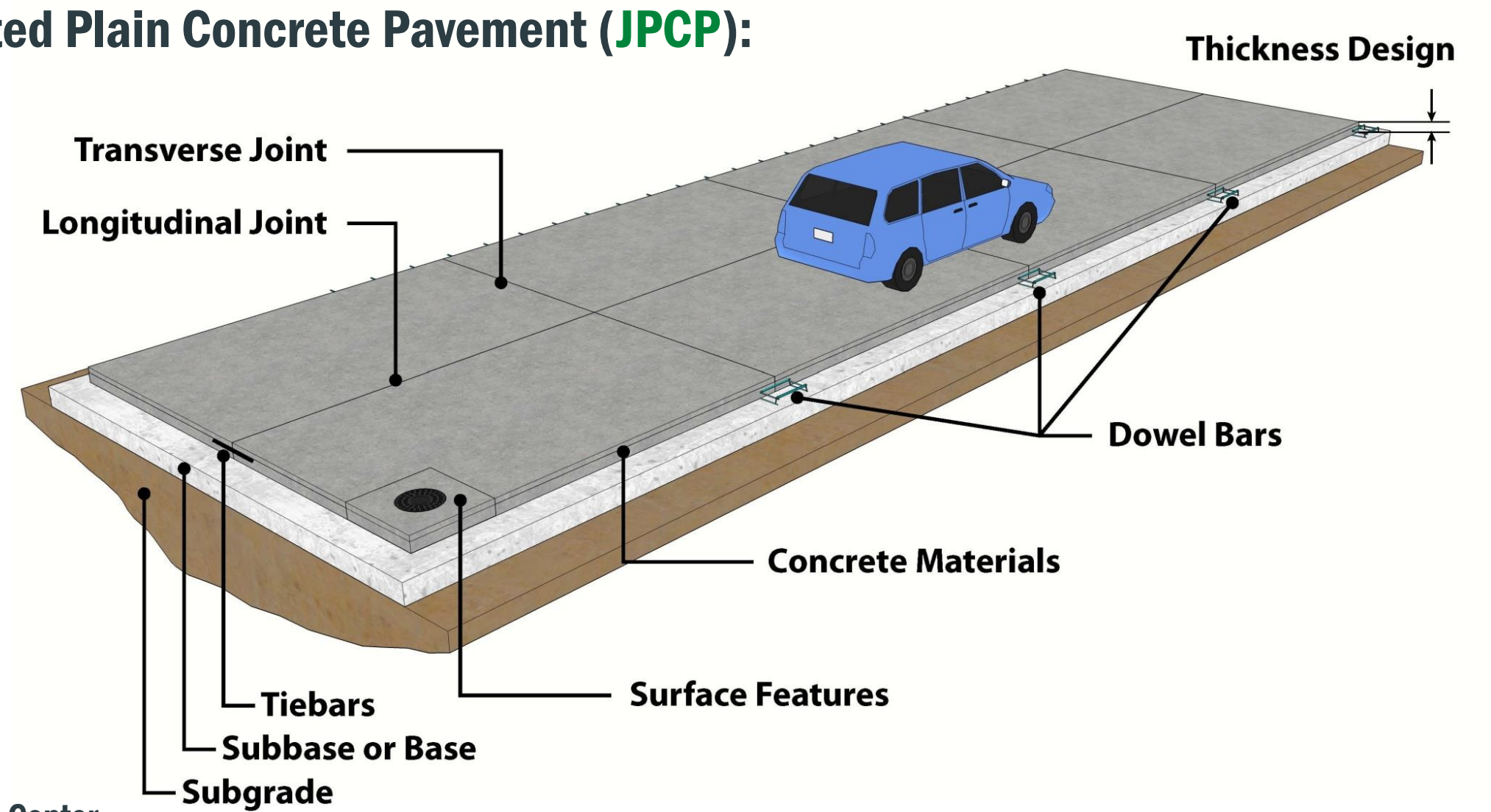


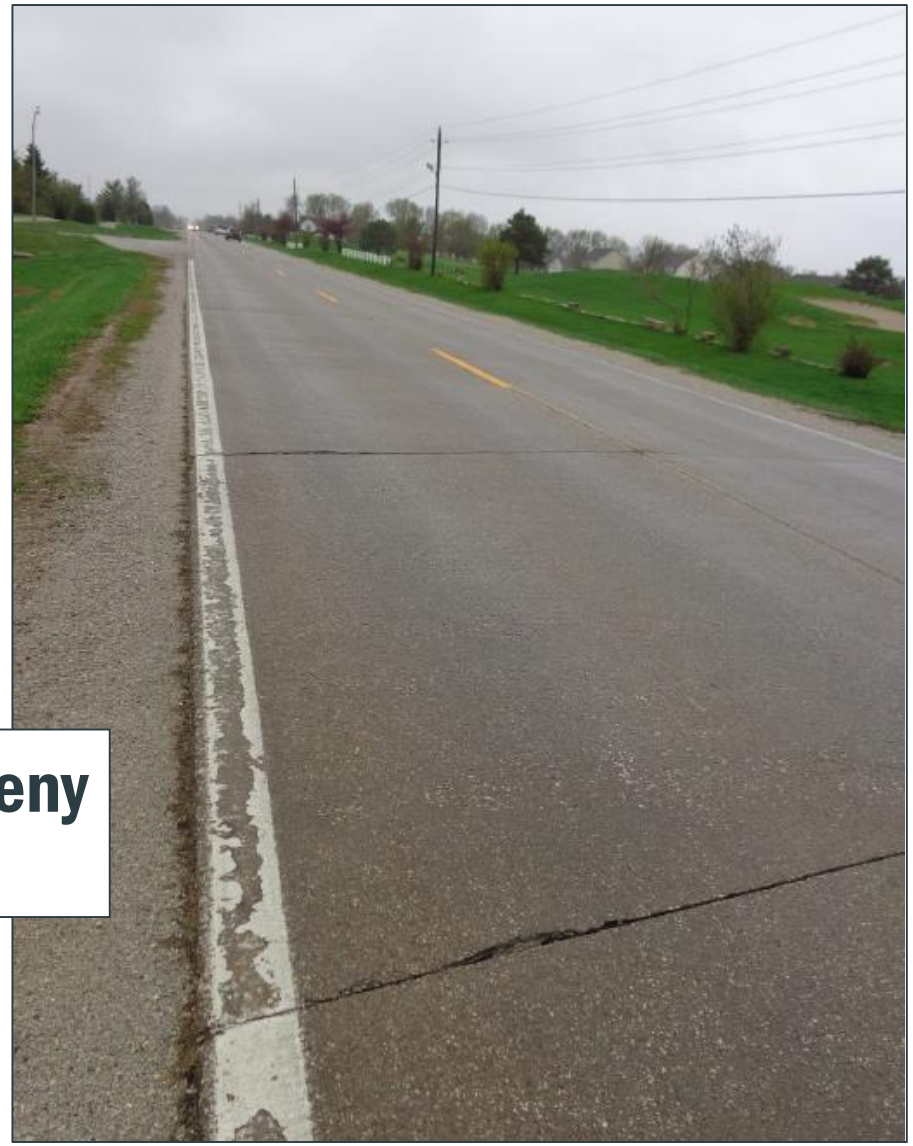
Image: CP Tech Center

WHY IS JOINTING IMPORTANT?

- Main purposes:
  - Controls the location of the natural cracking from internal stresses so that it only occurs at designated locations (joints)
  - Accommodates slab movements
  - Provides load transfer between slabs
  - Mitigates curling and warping stresses
  - Impacts ride quality, deflections & stresses under traffic
  - Easier to fill/seal saw cuts to protect against intrusion of water and incompressible materials

WHY IS JOINTING IMPORTANT?

- **Proper design, location and construction of joints is crucial to the long-term performance of concrete pavements!**



- **Delaware Avenue, Ankeny**
  - **Built in 1976**

DESIGN AND LAYOUT

- Types of joints:
  - Contraction
  - Construction
  - Isolation/Expansion

  - These may all be placed in the longitudinal (parallel to traffic) and transverse (perpendicular to traffic) directions

DESIGN AND LAYOUT

- Transverse contraction joints
  - Spacing important to pavement performance
  - Responsible for load transfer between slabs in the direction of traffic

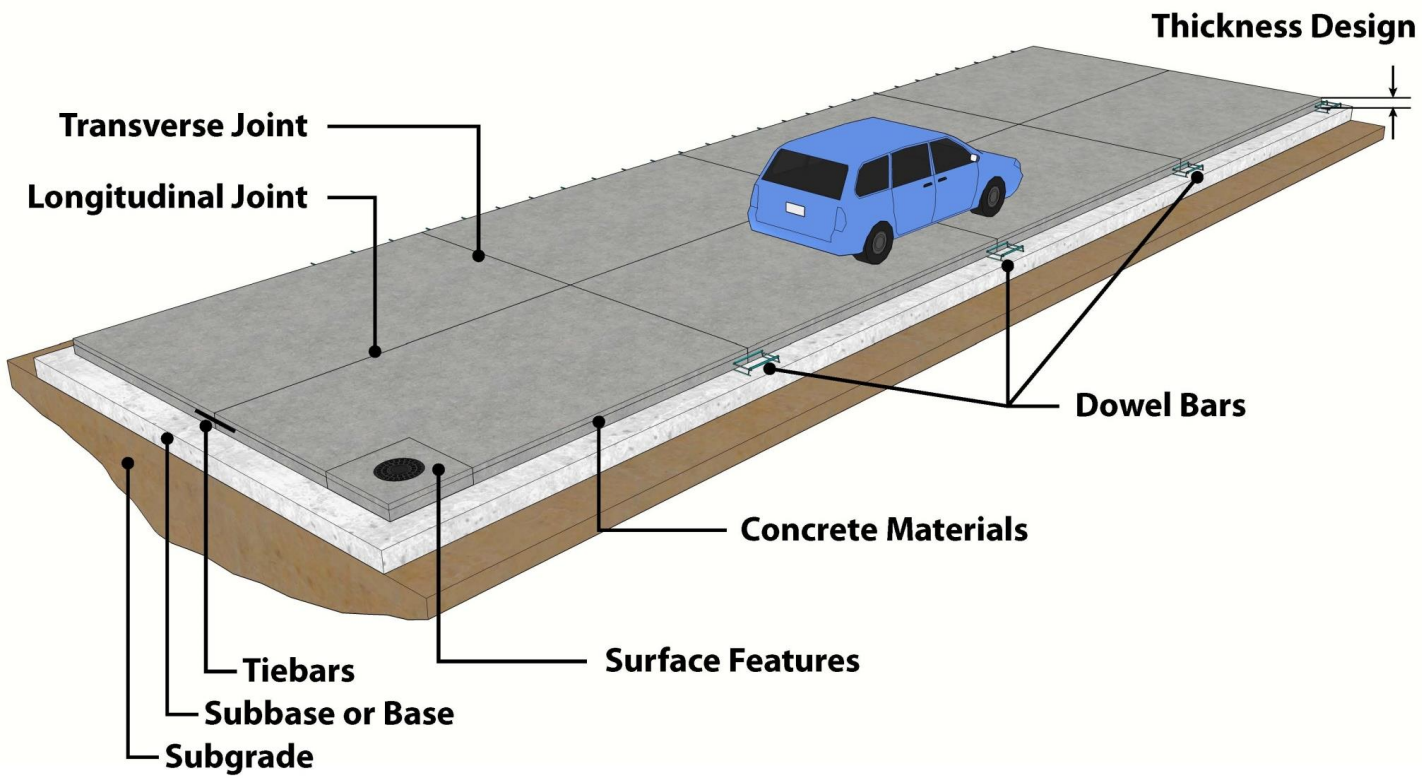
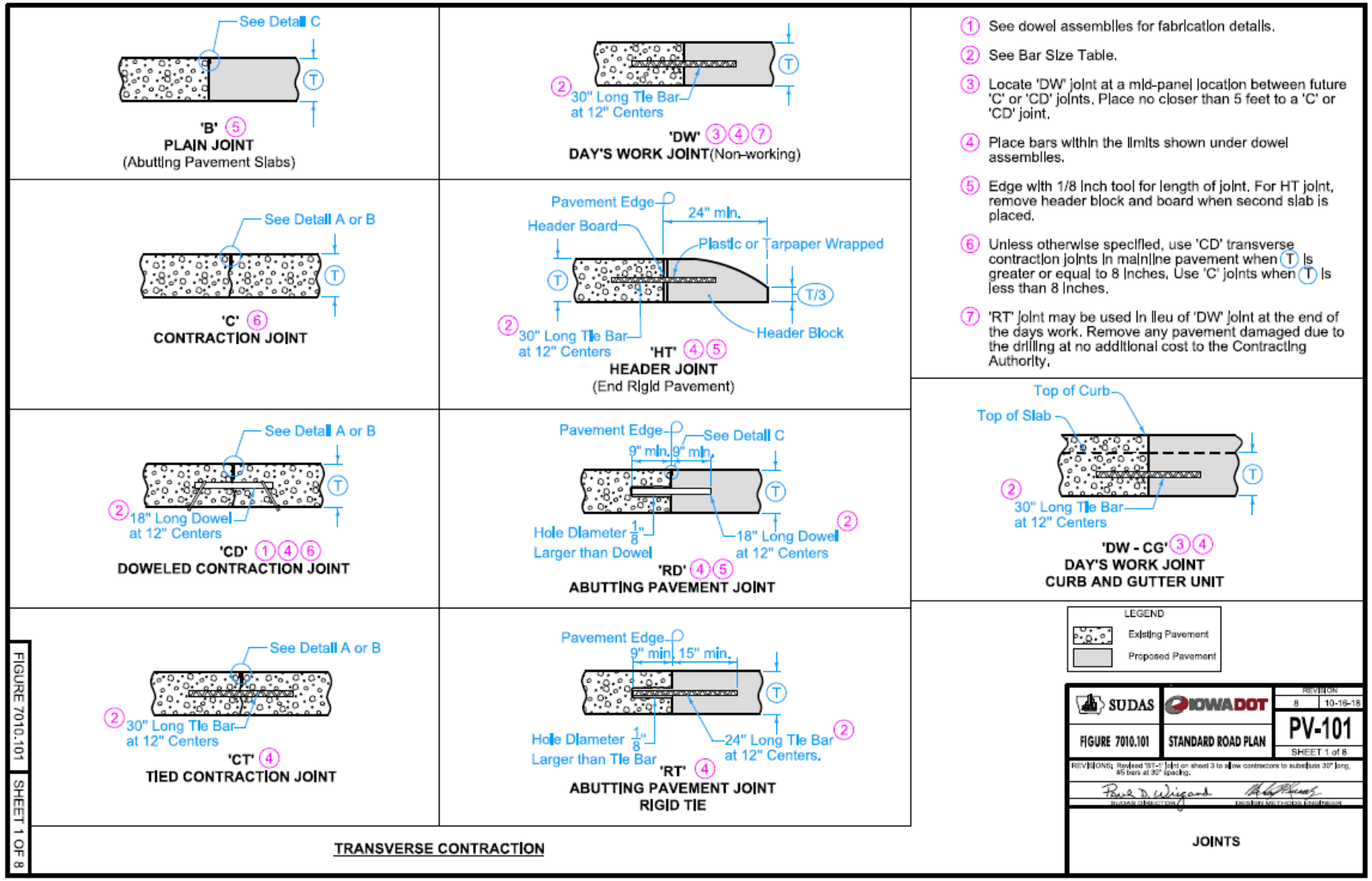
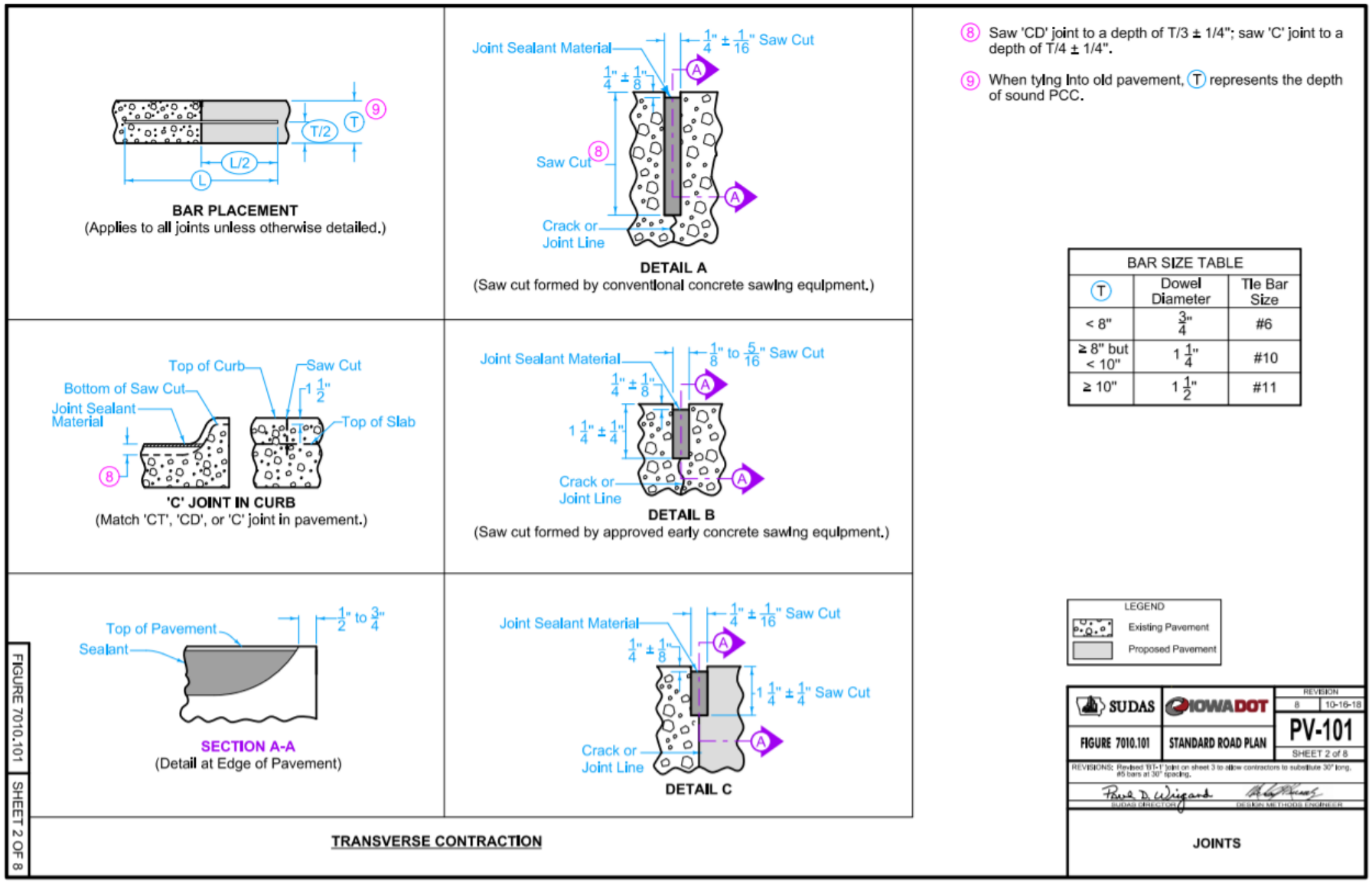


Image: CP Tech Center

DESIGN AND LAYOUT

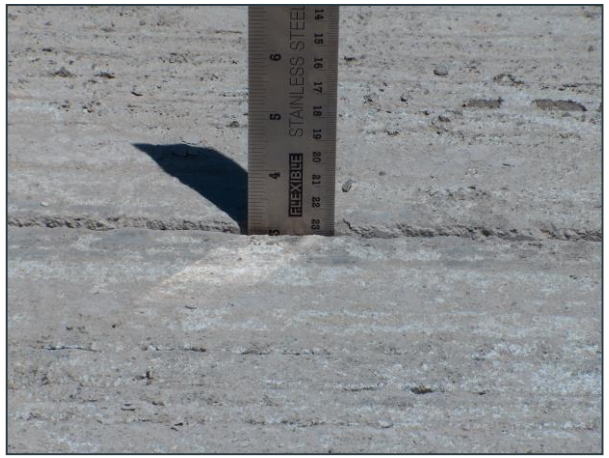


DESIGN AND LAYOUT



DESIGN AND LAYOUT

- Transverse contraction joints
  - "C" joint for pavements typically less than 8 in. thick carrying fewer than 100 trucks per day per lane
  - "CD" joint for pavements typically 8 in. or greater and more than 100 trucks per day per lane
    - Reinforced with dowel bars



Conventional saw

Width = 1/4" ± 1/16"
Depth = T/4 ± ¼" (C joint)
Depth = T/3 ± ¼" (CD joint)

Early-entry saw

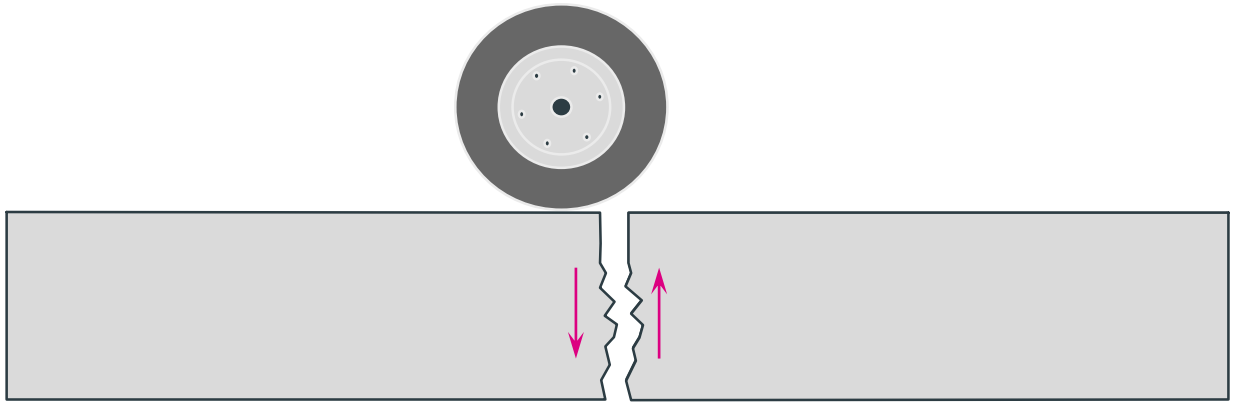
Width = 1/8" to 5/16"
Depth = 1 ¼" ± ¼"

Images: CP Tech Center

DESIGN AND LAYOUT

- **Load transfer**
  - **Aggregate interlock (undoweled)**
    - **Interaction of aggregate particles on either side of the crack opening beneath the saw cut governs load transfer in compression and shear and slab alignment**
    - **Improves with use of longitudinal tie bars, stiff/uniform subgrades, use of crushed stone aggregates**

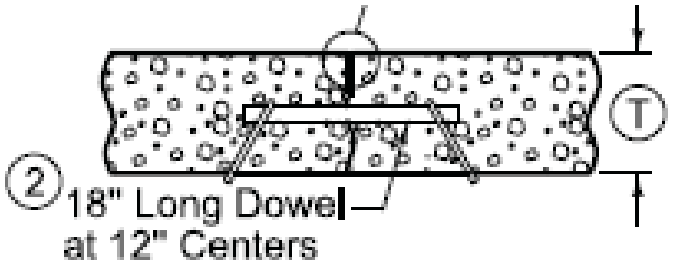
Joint Opening Below Saw Cut	Joint Efficiency
1/16”	>50%
1/8”	<50%
1/4"	0%



Images: CP Tech Center

DESIGN AND LAYOUT

- Load transfer
  - Dowel bars
    - Help keep slabs in horizontal and vertical alignment
    - Daily and seasonal joint openings have less effect on load transfer
    - Lowers deflections and stresses in slabs
    - Superior long-term performance under heavy traffic loads than aggregate interlock



BAR SIZE TABLE		
T	Dowel Diameter	Tie Bar Size
< 8"	$\frac{3}{4}$"	#6
≥ 8" but < 10"	$1\frac{1}{4}$"	#10
≥ 10"	$1\frac{1}{2}$"	#11

DESIGN AND LAYOUT

- Iowa: bars are placed all the way across the slab

DESIGN AND LAYOUT

- In some states, design is optimized to only reinforce in the wheel path

- Utah DOT:

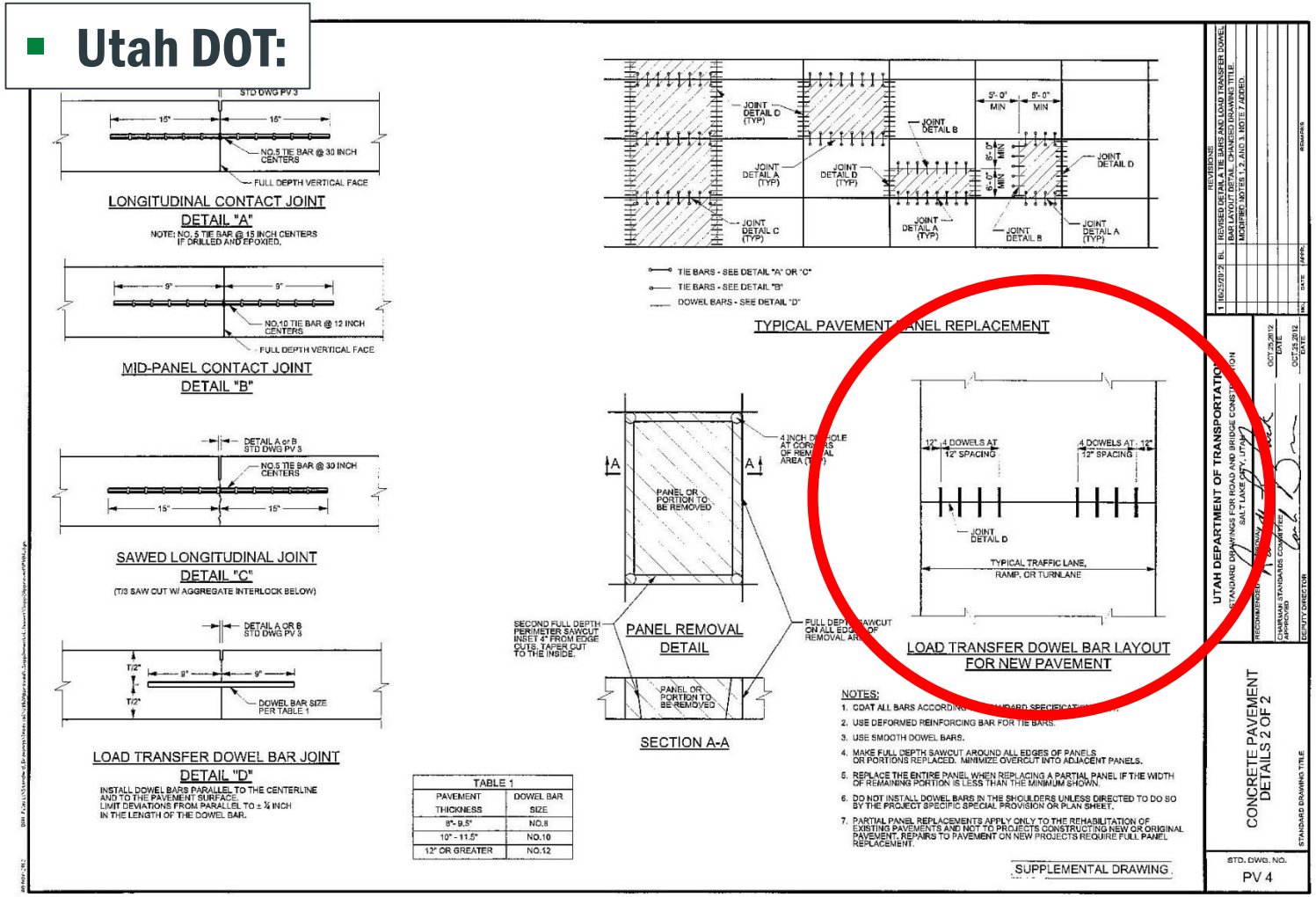
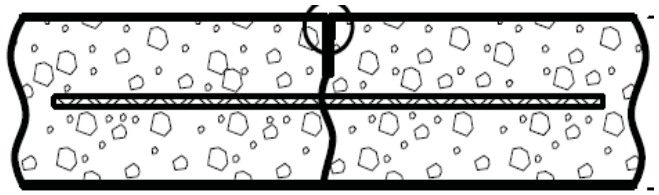


Image: Todd LaTorella, MO/KS ACPA

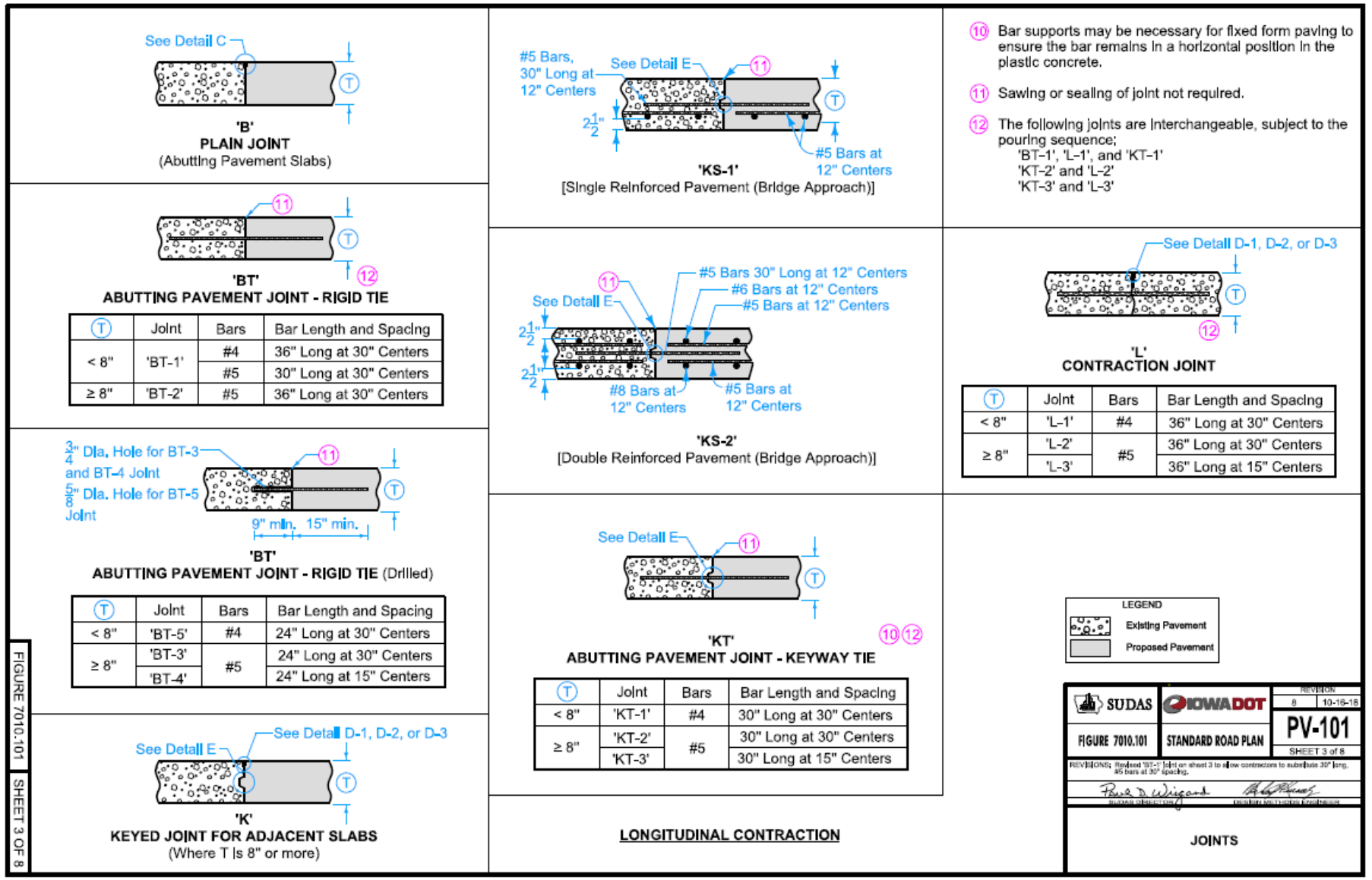
DESIGN AND LAYOUT

- **Longitudinal contraction joints**
  - **Reinforced with tie bars**
  - **Hold aggregate interlock and allow “hinge” between slabs**
  - **Delineate traffic lanes**



Ⓣ	Joint	Bars	Bar Length and Spacing
< 8"	'L-1'	#4	36" Long at 30" Centers
≥ 8"	'L-2'	#5	36" Long at 30" Centers
	'L-3'		36" Long at 15" Centers

DESIGN AND LAYOUT



DESIGN AND LAYOUT

- **Contraction joint spacing – rules of thumb**
  - **Transverse joints**
    - 6 to 7 inch thickness: spacing 2x thickness in ft
    - 8 to 9 inch thickness: 15 ft
    - 10 inches+ and DOT highways: **17 ft** maximum
    - **Concrete overlays** less than 6 inches thick: 1.5x thickness in ft
  - **Longitudinal joints**
    - Typically spaced at 10 to 12 ft (lane width) or at third- or quarter-points
    - Not usually recommended to extend beyond 12.5 ft, especially slabs < 9 inches thick

$ML = T \times C_s$
ML = Maximum length between joints (in.)
T = Slab thickness (in.)
C_s = Support constant
(24 for subgrades or unstabilized subbases)
(21 for ATB, CTB or existing concrete or asphalt)

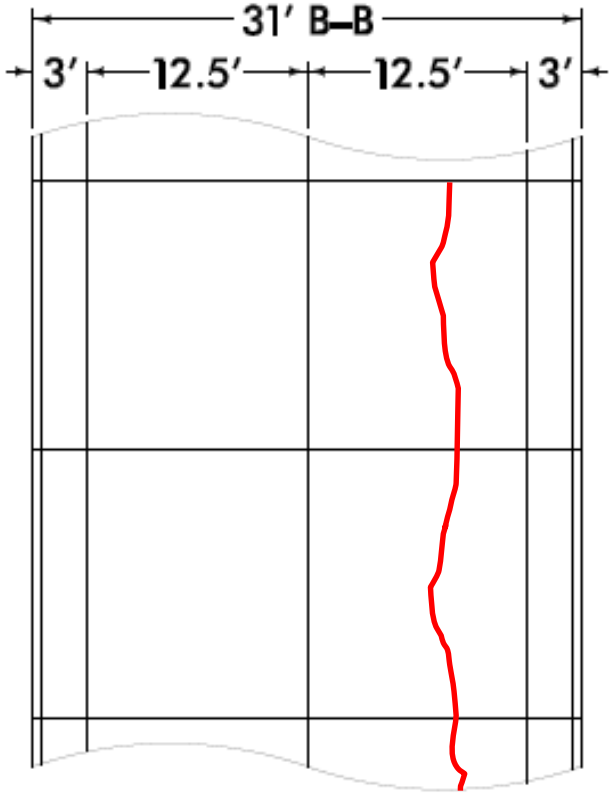
DESIGN AND LAYOUT

- Too-wide panel/longitudinal spacing:

Image: Todd LaTorella, MO/KS ACPA

DESIGN AND LAYOUT

- Use of gutterline joints is not recommended for pavements with thickness less than 9 inches
  - Thinner pavement may not crack through at the gutter joint, causing a longitudinal crack to occur mid-panel
  - Saw depth critical to ensure joint activation



Gutterline Jointing

Image: SUDAS

DESIGN AND LAYOUT

- Proper joint spacing also mitigates curling/warping stresses
  - + Reduces potential for corner breaks under traffic with slabs that are too large
  - + Improves ride quality compared to too-long slabs

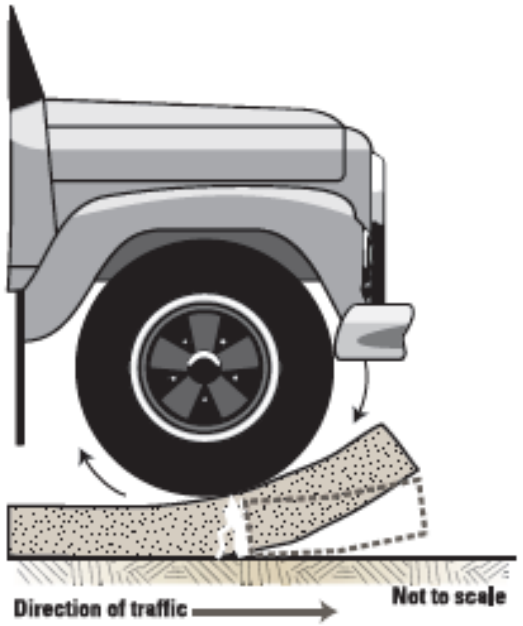


Image: PCA

DESIGN AND LAYOUT

- Construction joints
  - At edge of pour (longitudinal)
  - At end of pour (transverse)

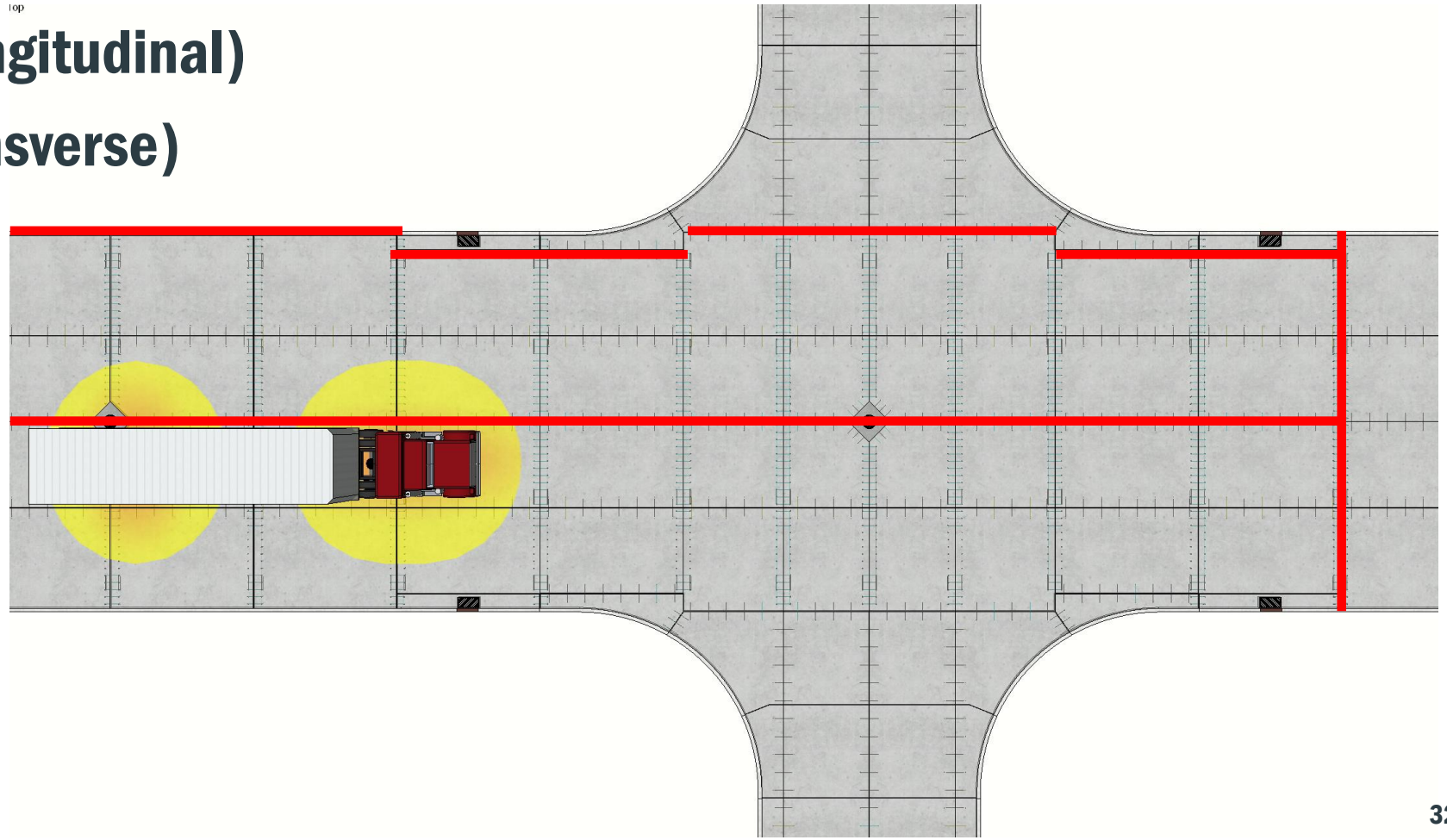
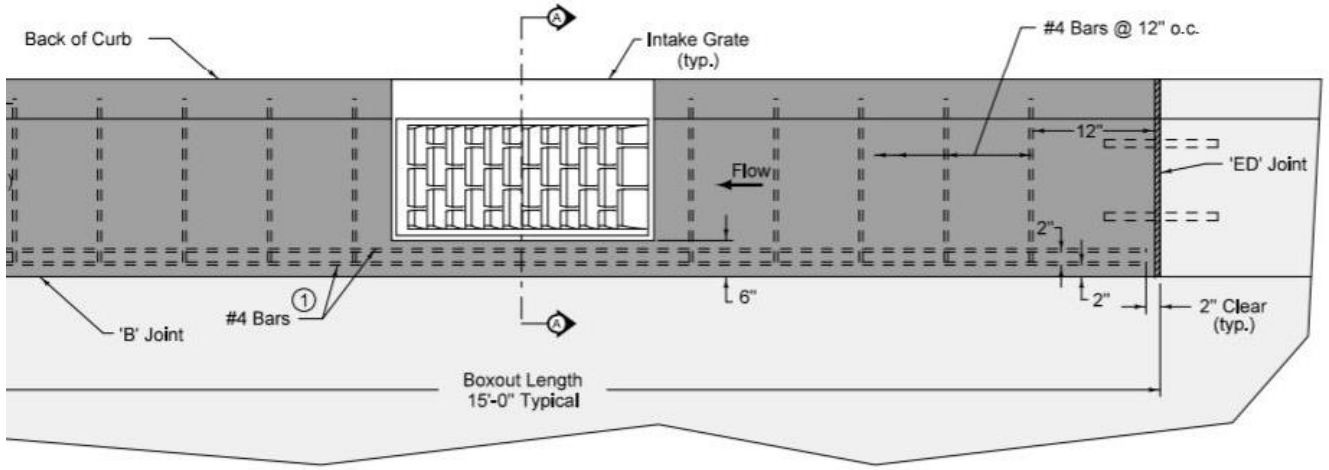


Image: CP Tech Center

DESIGN AND LAYOUT

- **Isolation/expansion joints**
  - Used to isolate the pavement from fixed structures
  - Allow the pavement to move without damaging adjacent pavement/structure
  - Full-depth, full-width joints

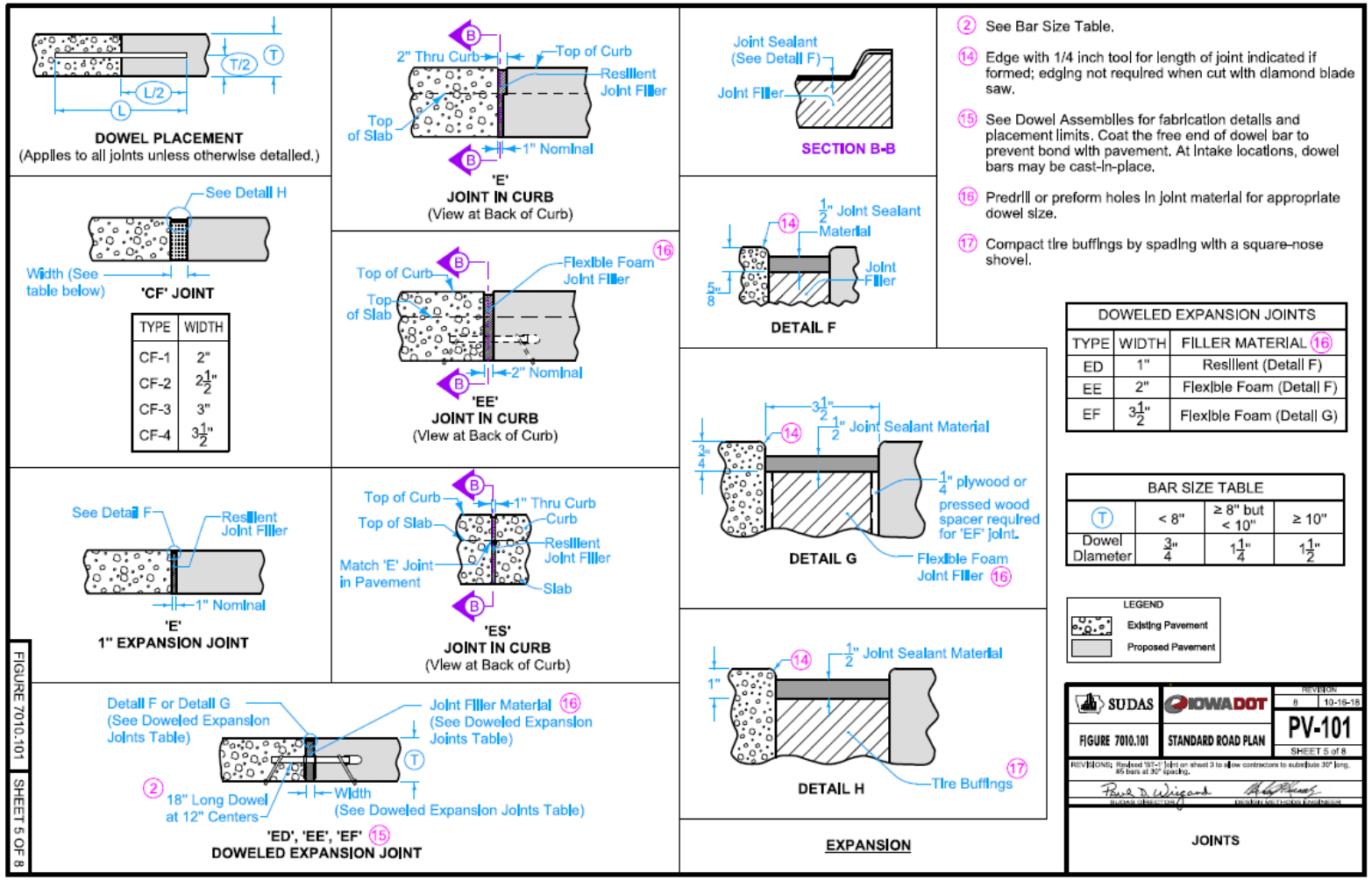
Use of Isolation/ Expansion Joints to mitigate expansion (bridge approaches)



BOXOUT IN PCC CURB AND GUTTER

DESIGN AND LAYOUT

- **Isolation/expansion joints:**



DESIGN AND LAYOUT

- How do I choose which type of joint to specify?
  - SUDAS Design Guide Section 5G-2, Table 2.02:

Table 5G-2.02: Summary of Joints
(Derived from the Iowa DOT Design Manual, Section 7A-2, Tables 1 and 2)

	Type			Method of Load Transfer				Thermal Movement				
Joint	Transverse	Longitudinal	Isolation/Expansion	Aggregate Interlock	Key	Tie Bar	Dowel Bar	Doweled to allow movement	Tied to prevent movement	Isolation/Expansion joint allows movement	Lack of reinforcing	Comments
B	x	x									x	Used between dissimilar materials or when other joints are not suitable.
C	x			x							x	Transverse joint used when T < 8 inches.
CD	x			x			x	x				Transverse joint used when T ≥ 8 inches.
CT	x			x		x			x			Specialty tied contraction joint.
DW	x					x			x			Used by contractor as a stopping point.
HT	x					x			x			Used at the end of rigid pavement prior to placement of second slab.
RD	x						x	x				Joint between new and existing pavements, dowels are used.
RT	x					x			x			Joint between new and existing pavements, tie bars are used.
BT-1		x							x			Longitudinal joint used when T < 8 inches, interchangeable with L-1 depending on paving sequence.
BT-2		x							x			Used when L-2 and the KT-2 are not possible, T ≥ 8 inches.
BT-3		x							x			Joint used between new and existing pavements. Tie bars are used when T ≥ 8 inches.
BT-4		x							x			Joint used between new and existing pavements. Tie bars are used when T ≥ 8 inches.
BT-5		x							x			Joint used between new and existing pavements. Tie bars are used when T < 8 inches.
K		x			x						x	T > 8 inches, minimal usage.
KS		x			x				x			Used in reinforced pavements.
KT-1		x			x				x			Longitudinal joint used when T < 8 inches, interchangeable with L-1 depending on paving sequence.
KT-2		x			x				x			Longitudinal joint used when T ≥ 8 inches, interchangeable with L-2 depending on paving sequence.
KT-3		x			x				x			Longitudinal joint used when T ≥ 8 inches, interchangeable with L-3 depending on paving sequence.
L-1		x		x					x			Longitudinal joint used when T < 8 inches, interchangeable with BT-1.
L-2		x		x					x			Longitudinal joint used when T ≥ 8 inches, interchangeable with KT-2 depending on paving sequence.
L-3		x		x					x			Longitudinal joint used with pavements of large width, interchangeable with KT-3 depending on paving sequence.
CF	x		x							x		4 inch expansion joint.
E	x	x	x							x		1 inch expansion joint.
ED	x		x				x	x		x		1 inch doweled expansion joint.
EE	x		x				x	x		x		2 inch doweled expansion joint.
EF	x		x				x	x		x		4 inch doweled expansion joint.
ES			x							x		Used in curb to match expansion joint in pavement.

DESIGN AND LAYOUT

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B	x	x									x	Used between dissimilar materials or when other joints are not suitable.
C	x			x							x	Transverse joint used when T < 8 inches.

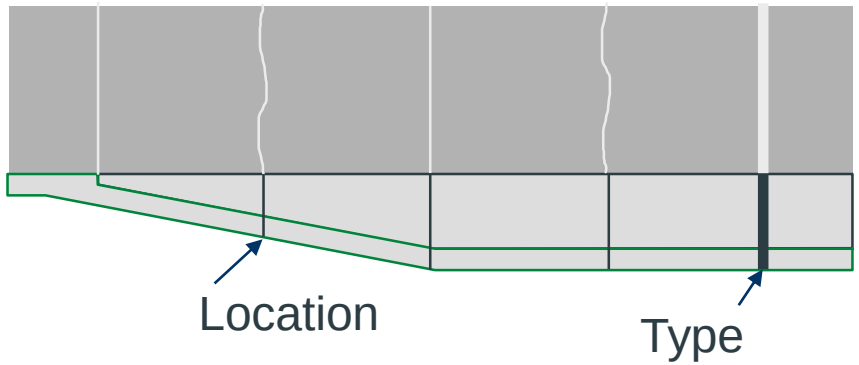
DESIGN AND LAYOUT

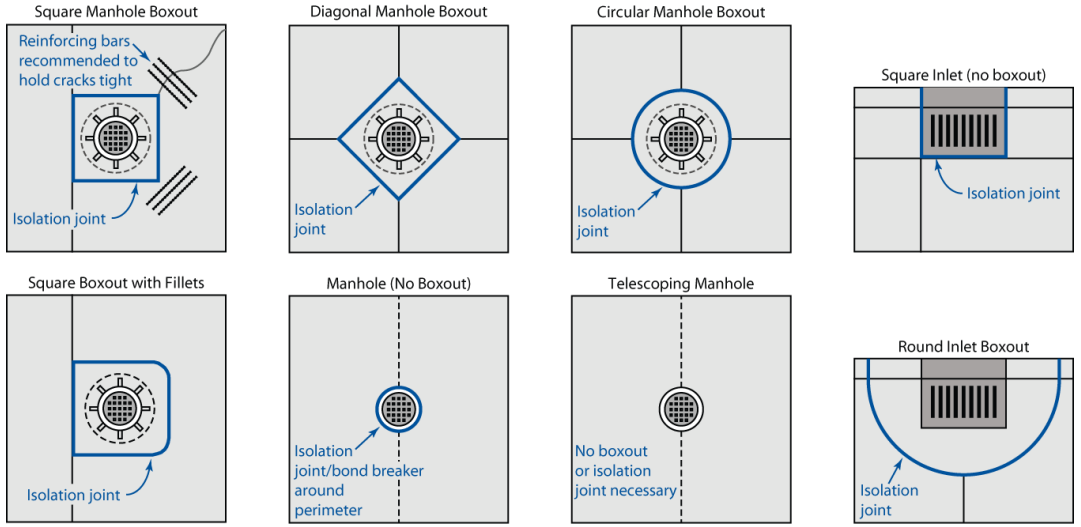
- How do I choose which type of joint to specify?
  - SUDAS Design Guide Section 5G-2, Table 2.02:

KS		X			X				X			Used in reinforced pavements.
KT-1		X			X				X			Longitudinal joint used when T < 8 inches, interchangeable with L-1 depending on paving sequence.
KT-2		X			X				X			Longitudinal joint used when T ≥ 8 inches, interchangeable with L-2 depending on paving sequence.
KT-3		X			X				X			Longitudinal joint used when T ≥ 8 inches, interchangeable with L-3 depending on paving sequence.
L-1		X		X					X			Longitudinal joint used when T < 8 inches, interchangeable with BT-1.
L-2		X		X					X			Longitudinal joint used when T ≥ 8 inches, interchangeable with KT-2 depending on paving sequence.
L-3		X		X					X			Longitudinal joint used with pavements of large width, interchangeable with KT-3 depending on paving sequence.
CE	X		X							X		4 inch expansion joint.

DESIGN AND LAYOUT

- General layout rules
  - Match existing joints/cracks – location AND type!
  - Place joints to meet in-pavement structures such as manholes & intakes
  - Don't exceed maximum spacing
  - Place isolation joints where needed

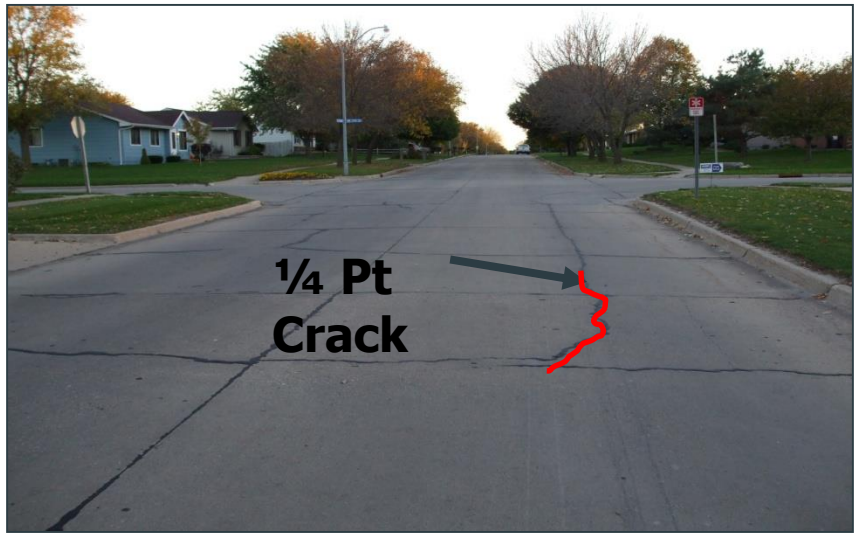




Images: CP Tech Center, ACPA

DESIGN AND LAYOUT

- General layout rules
  - Failing to match joints:



Images: CP Tech Center

DESIGN AND LAYOUT

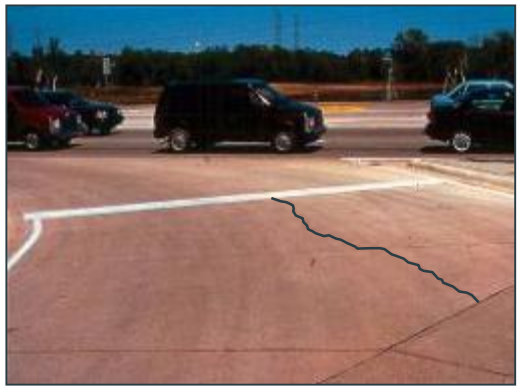
- General layout rules
  - Proper location around in-pavement structures:

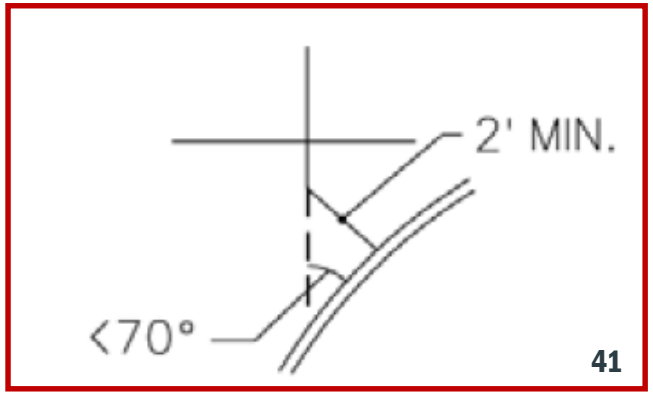
vs.

Images: ACPA

DESIGN AND LAYOUT

- General layout rules
  - Slabs ≤ 12.5 ft wide when thickness < 9 inches
  - Angles > 70° (90° is best)
  - Avoid creating interior corners
  - Try to keep slabs nearly-square
    - Length no more than 1.5x width





Images: CP Tech Center

DESIGN AND LAYOUT

- **Reinforced pavement?**
  - For a regular jointed plain concrete pavement, streets or parking lots, reinforcement is not necessary
  - Reinforcement can help hold cracks together after they develop
  - No changes to recommended joint spacing

CONSTRUCTION

- The most crucial elements to proper construction of concrete pavement joints are saw cut timing and depth!

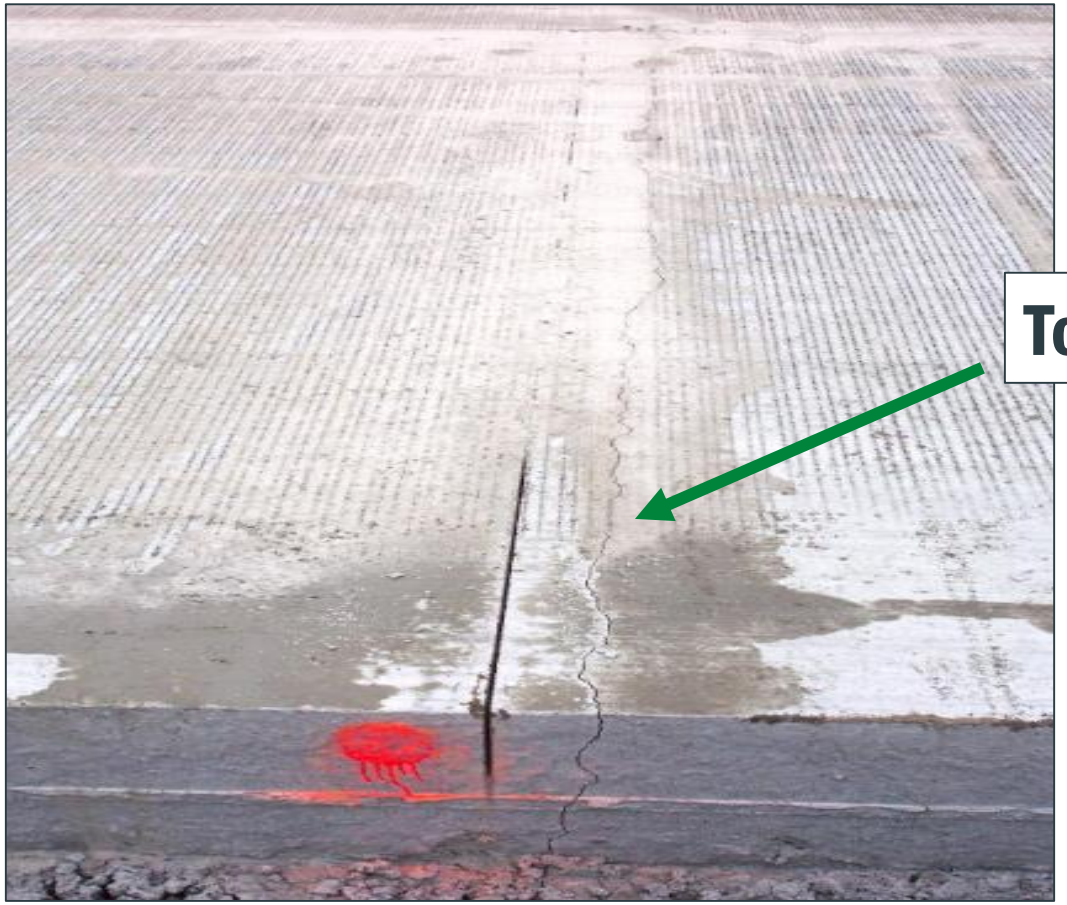
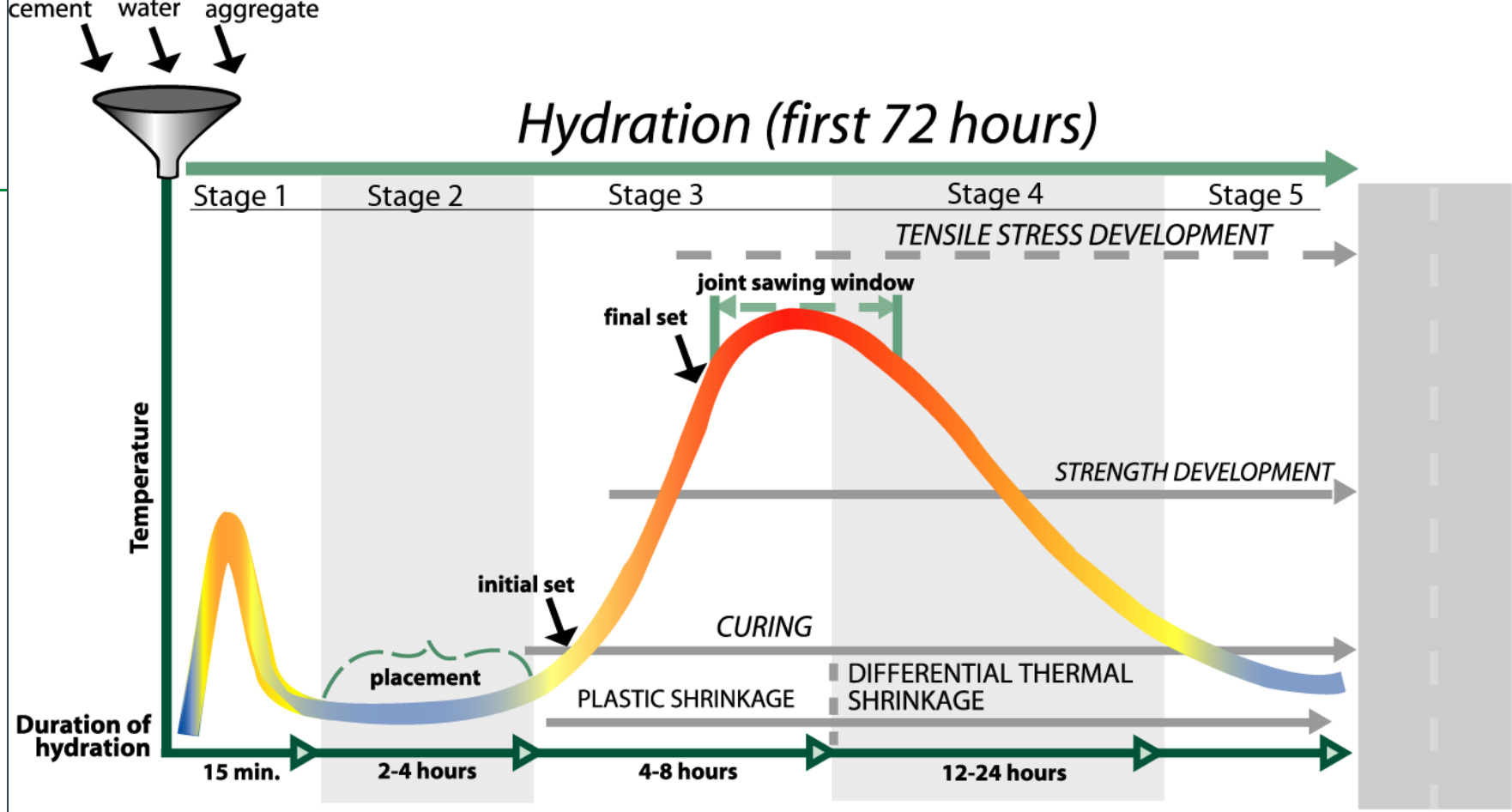


Image: CP Tech Center

CONSTRUCTION

- **Sawing window:**



Initial Mix	Dormancy	Acceleration	Deceleration	Slow Hydration
(15 minutes)	*(24 hours)*	*(4-8 hours)*	*-24 hours)*	*(Indefinitely)*
High heat followed by rapid cooling	Cool, plastic, workable	Significant heat, less workable, begins to harden	Becomes hard and dense	70 – 75%hydrated after 28 days
	Transport and Place	Begin curing Cut joints	Continue curing	Can continue indefinitely, as long as water can reach un-hydrated particles

Image: CP Tech Center

CONSTRUCTION

- **Sawing window:**

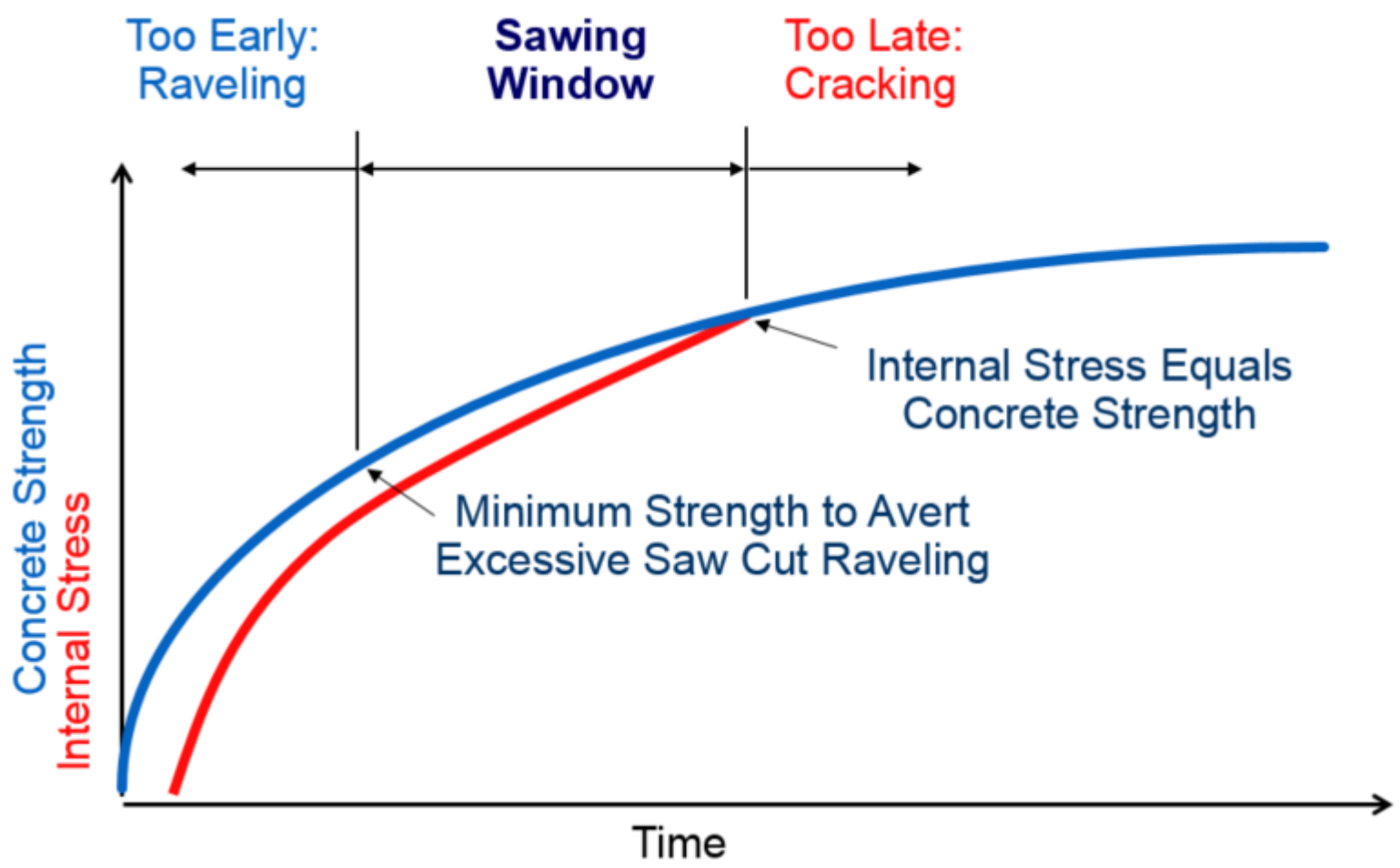
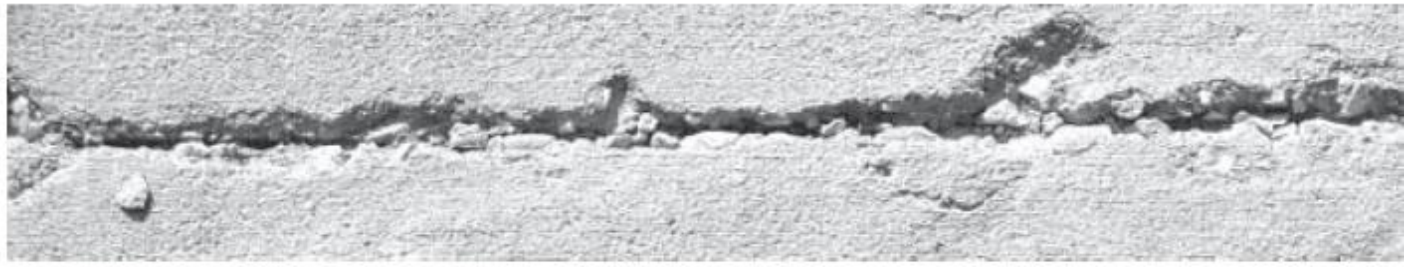


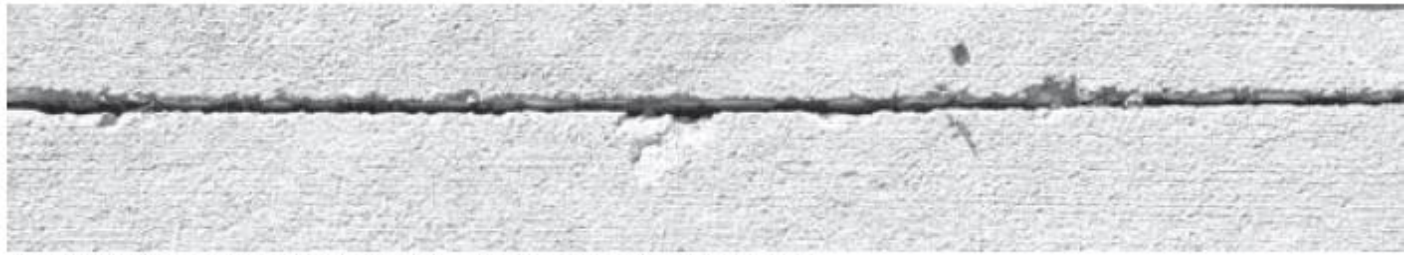
Image: ACPA

CONSTRUCTION

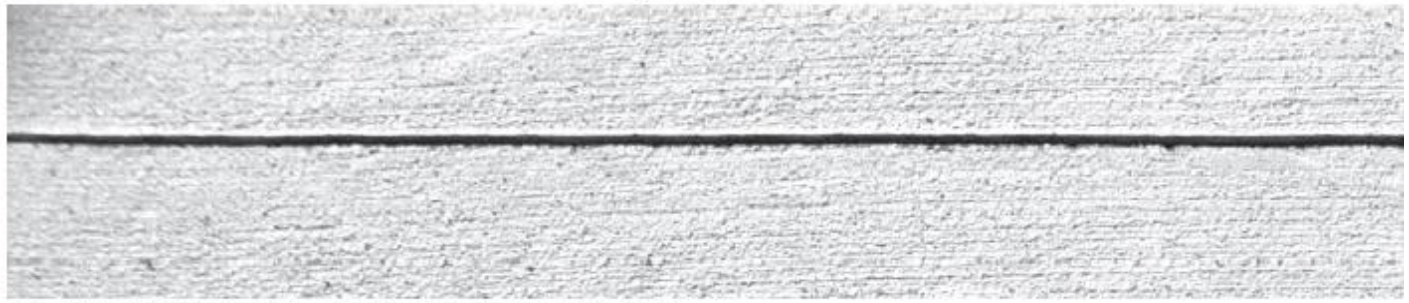
- **Sawing window:**



A. UNACCEPTABLE RAVELING - Sawed too early



B. MODERATE RAVELING - Sawed early in window



C. NO RAVELING - Sawed later in window

Image: CP Tech Center

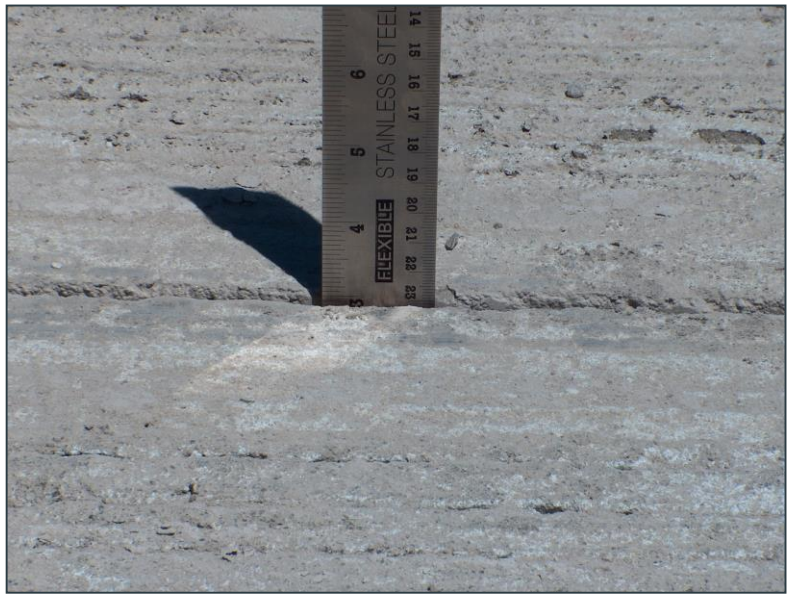
CONSTRUCTION

❖ Factors affecting the sawing window:

- **Weather:**
  - Sudden temperature drop or rain shower
  - Sudden temperature rise
  - High winds & low humidity
  - Cool temperatures & cloudy
  - Hot temperatures & sunny
- **Subbase:**
  - High friction between subbase & slab
  - Bond between subbase & slab
  - Dry surface
  - Porous aggregate subbase materials
- **Concrete Mixture:**
  - High water demand
  - Rapid early strength gain
  - Retarded set
  - Cement, water content
  - Supplementary cementitious materials
  - Fine aggregate (fineness & grading)
  - Coarse aggregate (maximum size, percentage)

CONSTRUCTION

- Saw width & depth
  - Transverse joints
    - Conventional saw:
      - Width: 1/4” ± 1/16”
      - Depth: T/4 ± 1/4” for C joints, T/3 ± 1/4” for CD joints
    - Early entry saw:
      - Width: 1/8” to 5/16”
      - Depth: 1-1/4 ± 1/4”
  - Longitudinal joints
    - Depth needs to be T/3 regardless of sawing method used



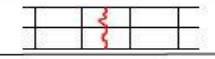
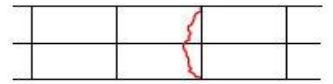
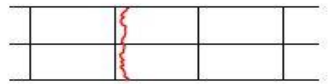
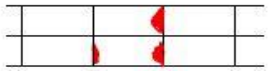
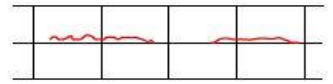
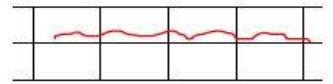
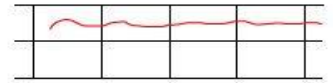
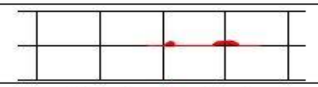
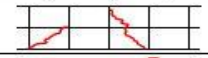
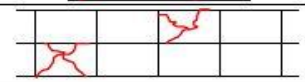
CONSTRUCTION

- Sawing practices
  - Crucial that proper depth is achieved!
    - Monitor for blades wearing out
  - Early entry saws
    - Allows for earlier/quieter/greener cut
      - Sawing window also closes earlier
    - Upward blade rotation – stop short at edge/curb
    - Skid plate is critical to good operation
  - "Leap frogging" discouraged

Images: Husqvarna

CONSTRUCTION

- Troubleshooting early age cracking:
  - Iowa DOT Construction Manual Appendix 9-6:

Defect	Orientation	Location	Description	Dowelled/Undowelled Transverse Joints	Recommended Repair	
Plastic Shrinkage	Any	Anywhere	Partial-depth and more than 0.007 in. wide	Either	Do nothing	
Uncontrolled Crack	Transverse	Mid-Panel	Full-Depth	Undowelled	Saw/route and seal crack	
				Dowelled	Full-Depth Repair or LTR[a]	
Uncontrolled Crack	Transverse	Crosses or ends at transverse joint	Full-Depth	Undowelled	Saw & seal crack; Epoxy sawed joint if uncracked	
				Dowelled	Full-Depth Repair or If crack jumps from sawcut to edge of slab within 3 feet of edge of slab, stop sawcut, saw & seal crack	
Uncontrolled Crack	Transverse	Parallel to & within 5 ft. of joint	Full-Depth	Undowelled	Saw and seal crack Seal joint	
				Dowelled	Full-Depth repair to replace crack and joint	
Spalled sawcut or uncontrolled crack	Transverse	Anywhere	Spalling; more than 3.0 in.wide	Either	Partial-Depth Repair	
Uncontrolled Crack	Longitudinal	Relatively parallel to & within 1 ft. of joint; May cross or end at longitudinal joint	Full-Depth	Either	Saw/route & seal the crack or cross-stitch the crack Epoxy sawed joint if uncracked	
Uncontrolled Crack	Longitudinal	Relatively parallel to & within wheel path; 1 - 5 ft. from joint	Full-Depth, hairline, or spalled	Either	Remove and replace panel or cross-stitch crack	
Uncontrolled Crack	Longitudinal	Relatively parallel to & further than 5 ft. from a longitudinal joint or edge	Full-Depth	Either	Cross-stitch crack	
Spalled sawcut or uncontrolled crack	Longitudinal	Anywhere	Spalled	Either	Partial-Depth Repair	
Uncontrolled Crack	Diagonal	Anywhere	Full-Depth	Either	Full-Depth Repair	
Uncontrolled Crack	Multiple per panel	Anywhere	Two or more full depth cracks dividing panel into 3 or more pieces	Either	Remove and replace panel	

Full-Depth repair per Specification 2529
Partial-Depth repair per Specification 2530
Cross-stitch repair per Construction Manual 9.27
Repairs should be made without use of Calcium Chloride unless early opening to traffic is necessary.

a LTR = load-transfer restoration (if faulted less than 1/2"); 3 dowel bars per wheel path grouted into slots sawed across the crack. Slots must be parallel to each other and the longitudinal joint. Backfill with non-shrink, cement-based grout. Diamond grind if faulting is severe.

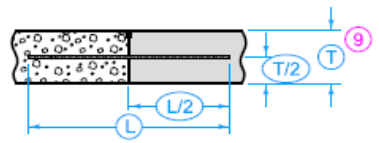
Appendix 9-6
Iowa DOT Construction Manual

CONSTRUCTION

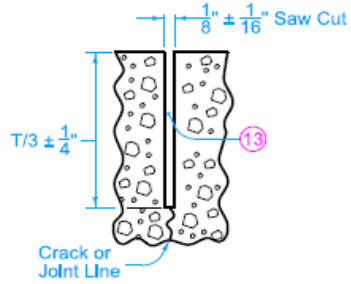
- Helpful things to consider on paving day:
  - Have a jointing plan ready going in
  - Be ready and willing to make adjustments in the field!
  - Be conscious of temperature and weather conditions – especially if it looks like things change quickly

CONSTRUCTION

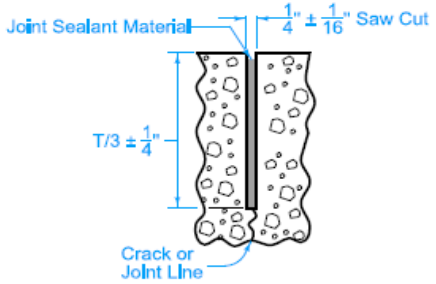
- **Sealing/filling joints vs. no seal on contraction joints:**
  - **Filling helps keep fluids, incompressible materials out of the joint**



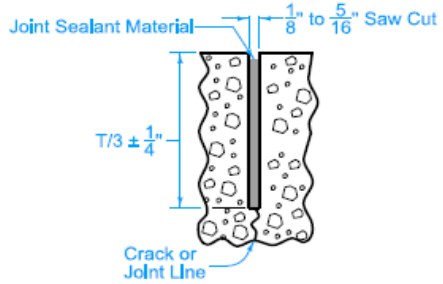
TIE BAR PLACEMENT
(Applies to all joints unless otherwise detailed.)



DETAIL D-1
(Required when specified in the contract documents.)



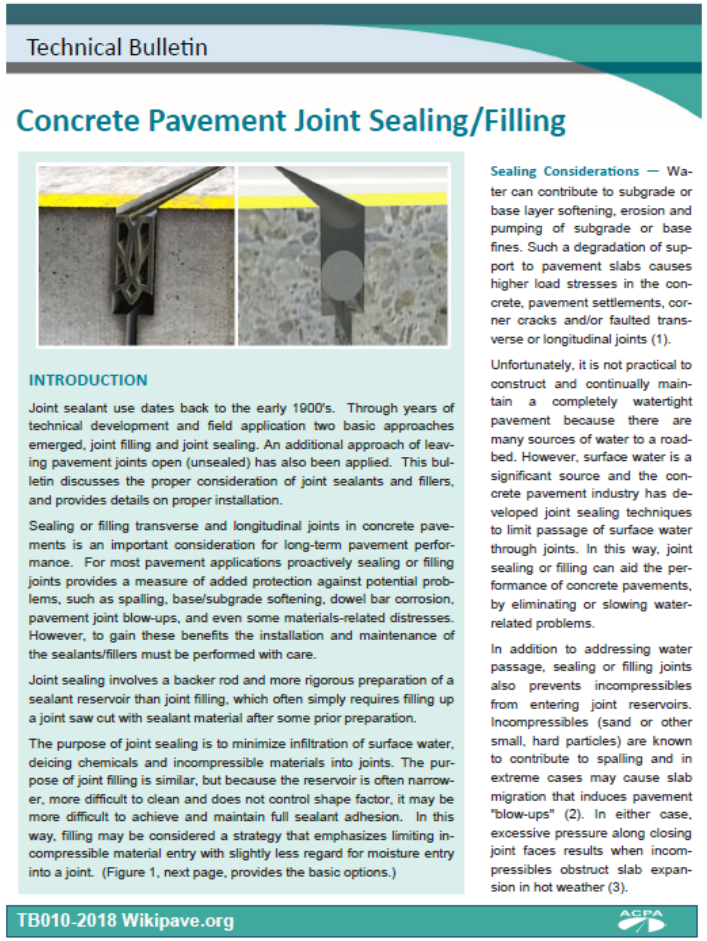
DETAIL D-2
(Required when the Department of Transportation is not the Contracting Authority, or when specified in the contract documents)



DETAIL D-3
(Required when the Department of Transportation is the Contracting Authority, or when specified in the contract documents)

CONSTRUCTION

- **Should I always be sealing/filling joints? Are there situations where it is not necessary?**
  - **ACPA Technical Bulletin TB010-2018:**



Technical Bulletin

Concrete Pavement Joint Sealing/Filling

INTRODUCTION

Joint sealant use dates back to the early 1900's. Through years of technical development and field application two basic approaches emerged, joint filling and joint sealing. An additional approach of leaving pavement joints open (unsealed) has also been applied. This bulletin discusses the proper consideration of joint sealants and fillers, and provides details on proper installation.

Sealing or filling transverse and longitudinal joints in concrete pavements is an important consideration for long-term pavement performance. For most pavement applications proactively sealing or filling joints provides a measure of added protection against potential problems, such as spalling, base/subgrade softening, dowel bar corrosion, pavement joint blow-ups, and even some materials-related distresses. However, to gain these benefits the installation and maintenance of the sealants/fillers must be performed with care.

Joint sealing involves a backer rod and more rigorous preparation of a sealant reservoir than joint filling, which often simply requires filling up a joint saw cut with sealant material after some prior preparation.

The purpose of joint sealing is to minimize infiltration of surface water, deicing chemicals and incompressible materials into joints. The purpose of joint filling is similar, but because the reservoir is often narrower, more difficult to clean and does not control shape factor, it may be more difficult to achieve and maintain full sealant adhesion. In this way, filling may be considered a strategy that emphasizes limiting incompressible material entry with slightly less regard for moisture entry into a joint. (Figure 1, next page, provides the basic options.)

Sealing Considerations — Water can contribute to subgrade or base layer softening, erosion and pumping of subgrade or base fines. Such a degradation of support to pavement slabs causes higher load stresses in the concrete, pavement settlements, corner cracks and/or faulted transverse or longitudinal joints (1).

Unfortunately, it is not practical to construct and continually maintain a completely watertight pavement because there are many sources of water to a roadbed. However, surface water is a significant source and the concrete pavement industry has developed joint sealing techniques to limit passage of surface water through joints. In this way, joint sealing or filling can aid the performance of concrete pavements, by eliminating or slowing water-related problems.

In addition to addressing water passage, sealing or filling joints also prevents incompressibles from entering joint reservoirs. Incompressibles (sand or other small, hard particles) are known to contribute to spalling and in extreme cases may cause slab migration that induces pavement "blow-ups" (2). In either case, excessive pressure along closing joint faces results when incompressibles obstruct slab expansion in hot weather (3).

CONSTRUCTION

- **ACPA: "in all cases, joint sealing/filling is highly recommended"**

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)

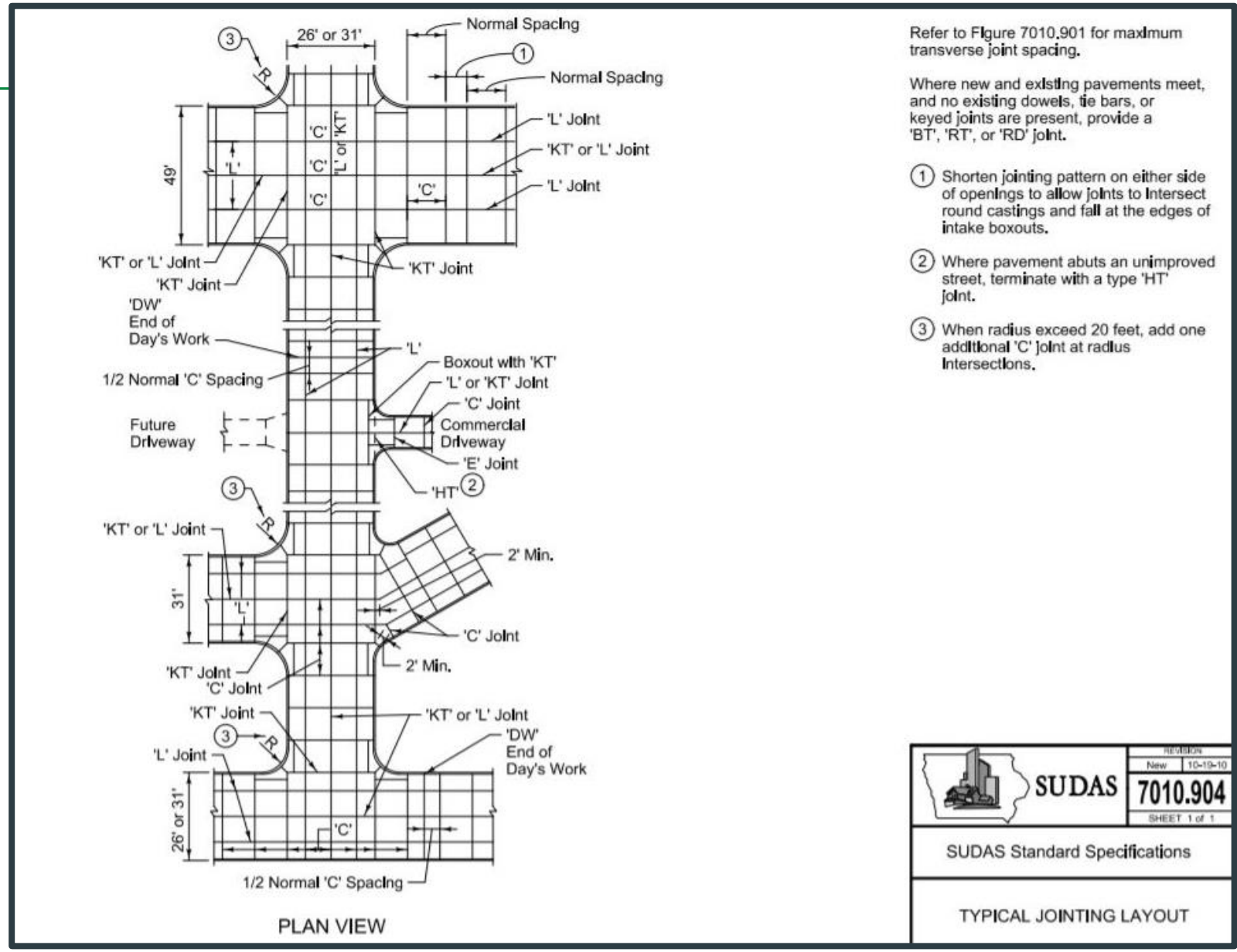
	STREETS / ROADS / HIGHWAYS							
	Any Posted Speed Limit (Unless Indicated by Note)							
Layer Below Slab	Dense-Graded Base or Subgrade Soil				Non-Erodible (2) or Free-Draining Layer (3)			
Climatic Zone	Dry No-Freeze		Other		Dry No-Freeze		Other	
Joint Spacing	≤ 6 ft (2 m)	> 6 ft (2 m)	≤ 6 ft (2 m)	> 6 ft (2 m)	≤ 6 ft (2 m)	> 6 ft (2 m)	≤ 6 ft (2 m)	> 6 ft (2 m)
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								

[4]Sealing recommended in freezing climates

[5]Sealing recommended when speed limit <45 mph

SPECIAL CASES

- Great details and guidance in SUDAS Design Guide **Section 5G**
- Step-by-step guidance also available via ACPA's **Wikipave.org**
- Intersections:



SPECIAL CASES

- **Roundabouts**
  - **Isolated circle**

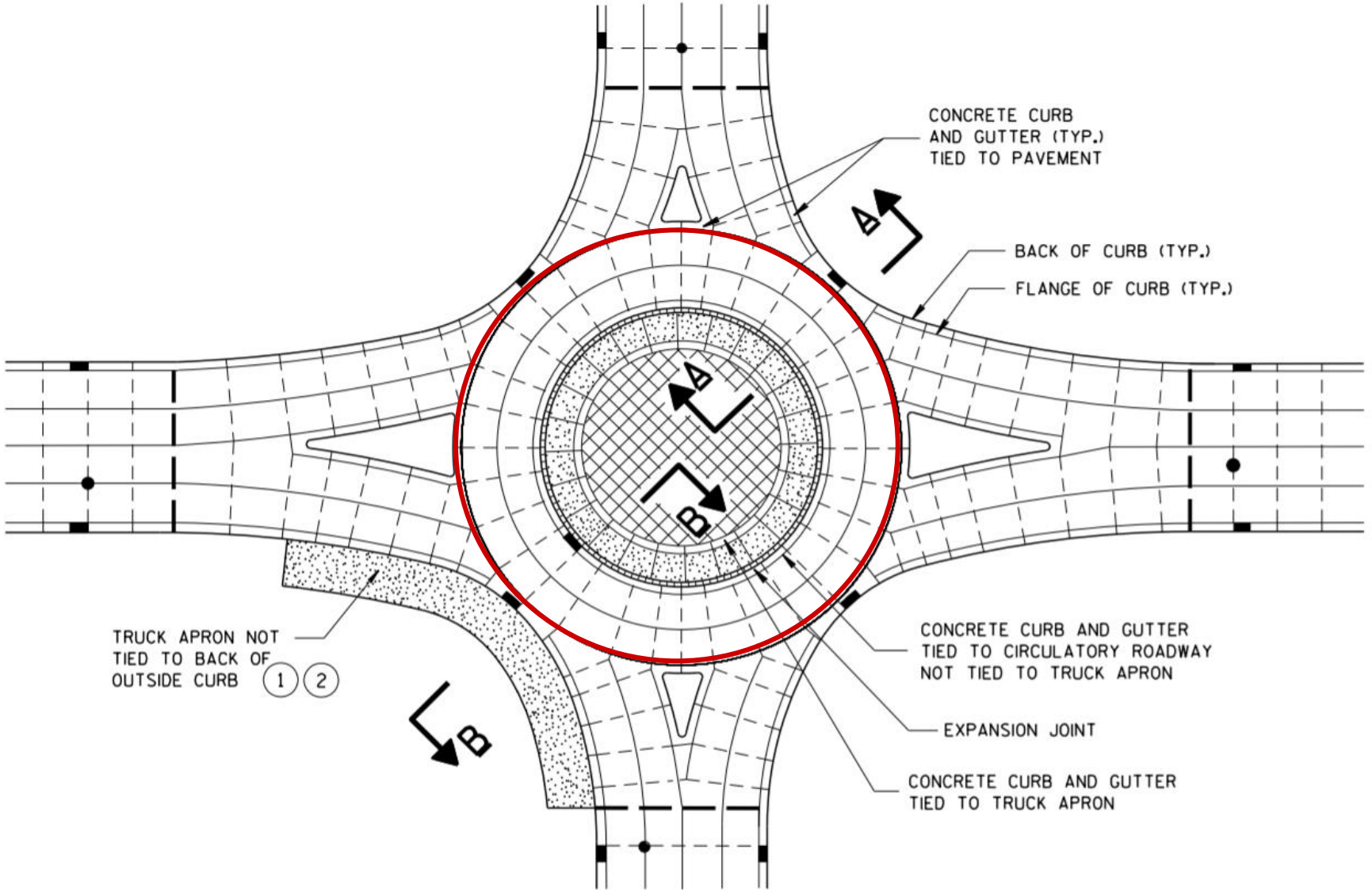


Image: Wisconsin DOT

SPECIAL CASES

- Roundabouts
  - Pinwheel

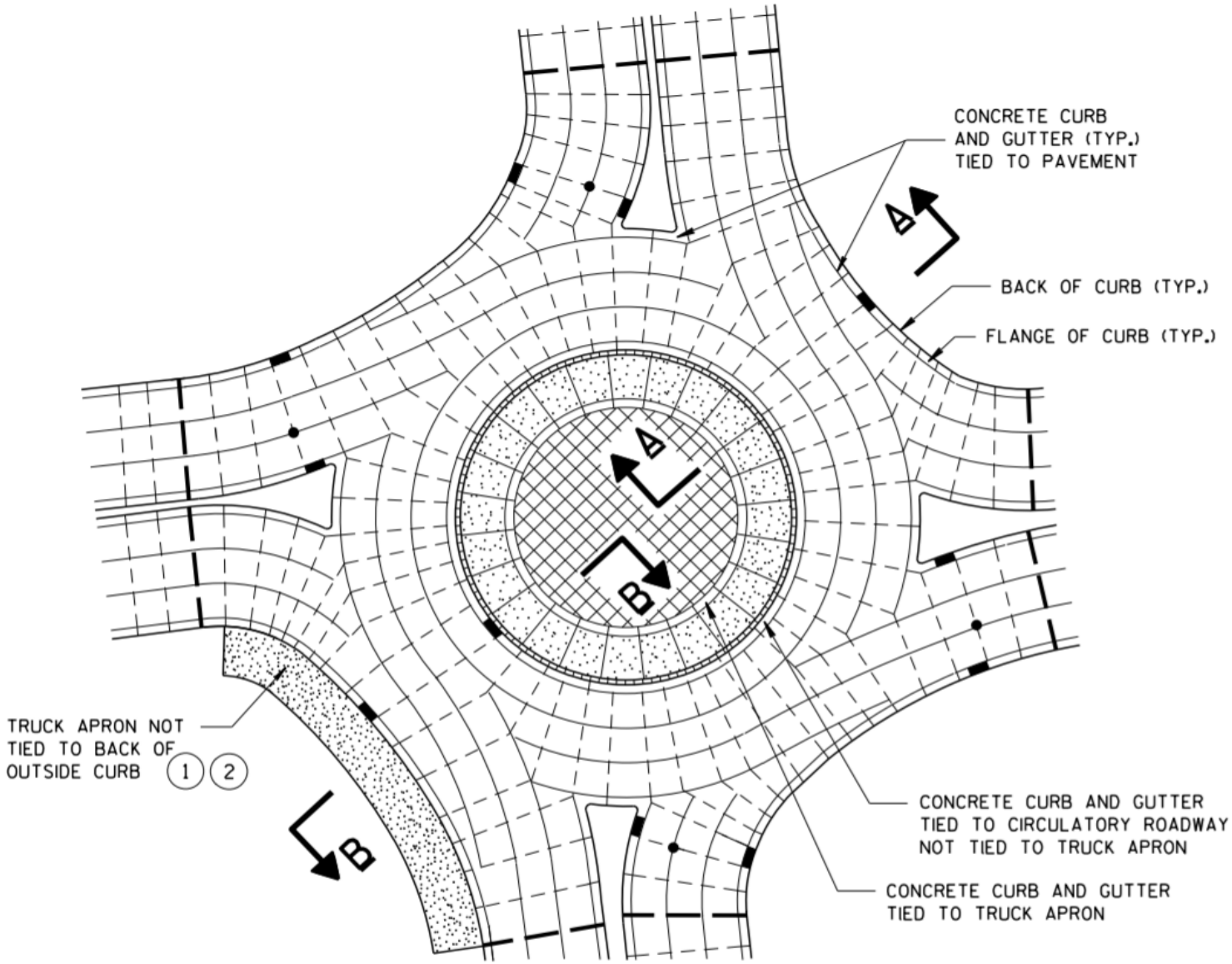
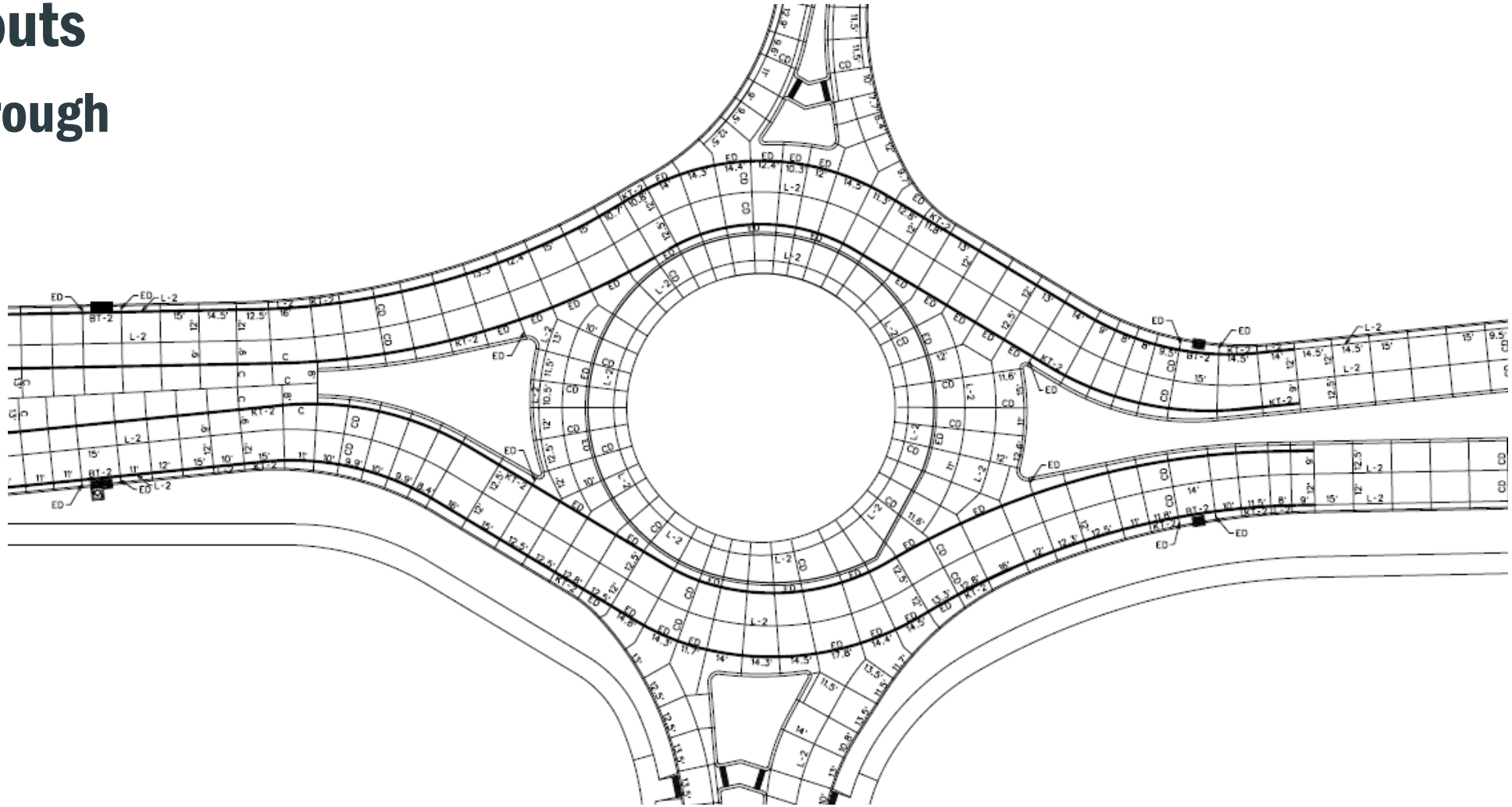


Image: Wisconsin DOT

SPECIAL CASES

- **Roundabouts**
  - **Pave Through**



SPECIAL CASES

- Cul-de-sacs

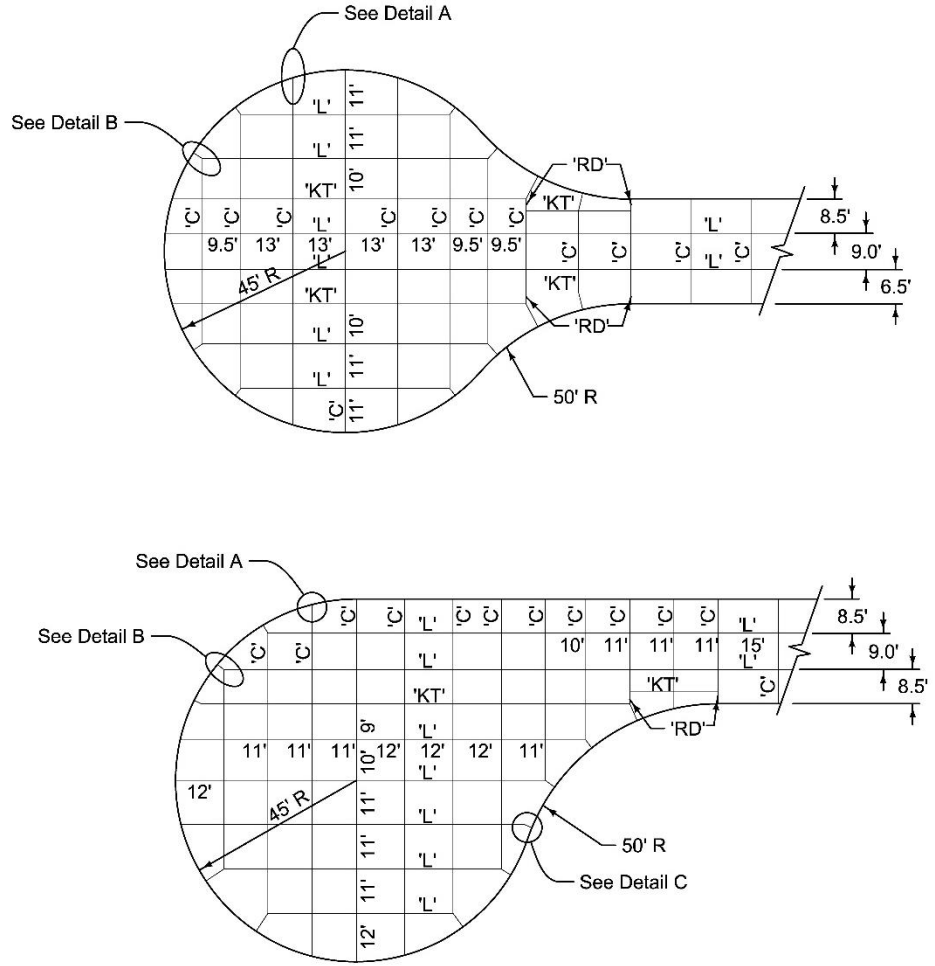


FIGURE 7010.905 SHEET 2 OF 3

SUDAS

REVISION New 10-19-10

7010.905

SHEET 2 of 3

SUDAS Standard Specifications

PCC CUL-DE-SAC JOINT LOCATIONS

SPECIAL CASES

- Parking lots
  - ACI 330 Guide for Design of Concrete Parking Lots
  - Layout features:
    - Isolate from buildings, planters, sidewalks
    - Tension ring with tie bars (absent curb)
    - Avoid acute angles
    - Dowels in areas with consistent one-way traffic

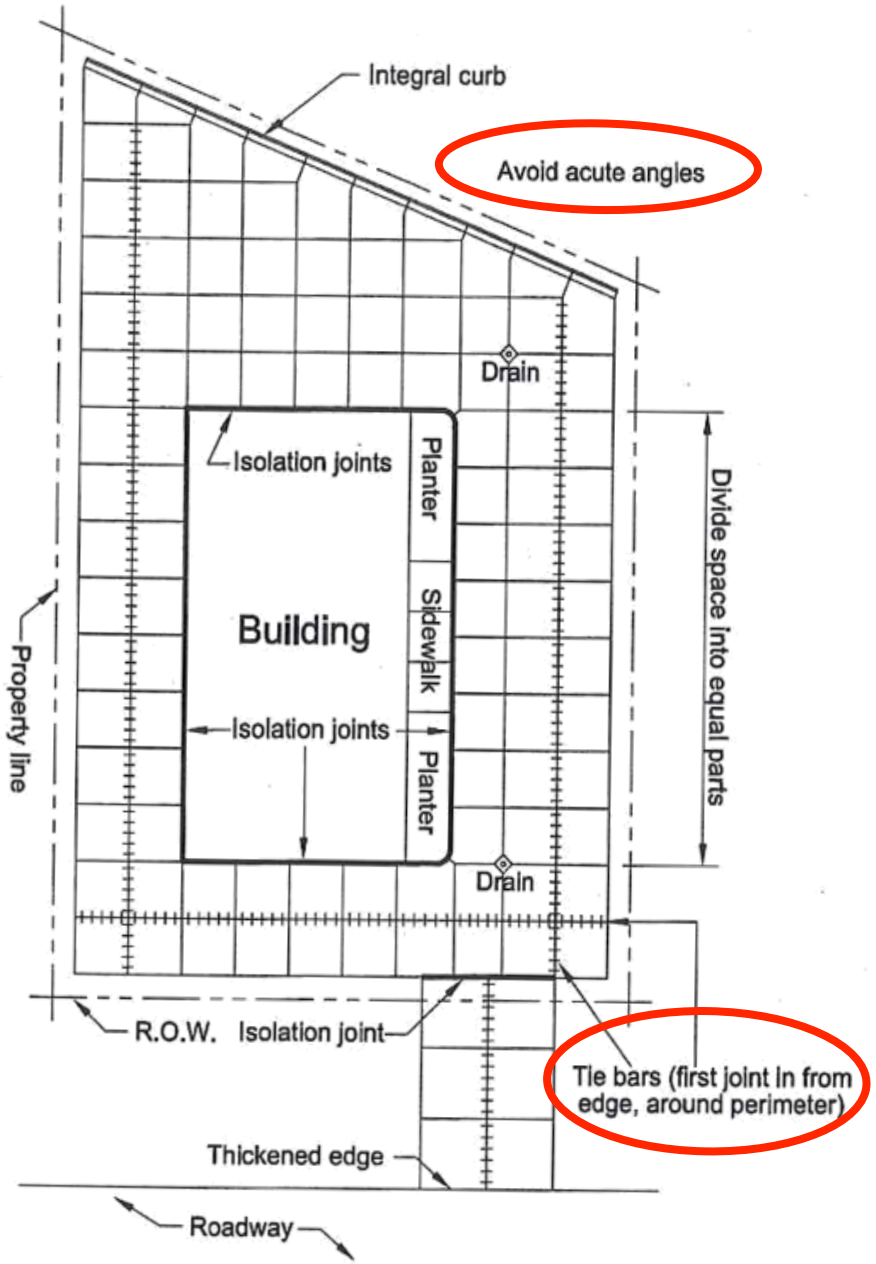


Fig. C.1—Typical joint layout for parking area.

THANK YOU!

- Resources:
  - www.cptechcenter.org/student-and-practitioner-resources/
  - www.wikipave.org
  - www.iowasudas.org