JOINTING BASICS FOR CONCRETE PAVEMENTS

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ACKNOWLEDGMENTS

- American Concrete Pavement Association
  + Wikipave.org
- National CP Tech Center
- Iowa DOT & SUDAS
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...
WHY IS JOINTING IMPORTANT?

- If you place concrete without joints... it will crack!
WHY IS JOINTING IMPORTANT?

× If you place concrete without joints... it will crack!

- 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
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
WHY IS JOINTING IMPORTANT?
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):

  - Transverse Joint
  - Longitudinal Joint
  - Dowel Bars
  - Concrete Materials
  - Tiebars
  - Subbase or Base
  - Subgrade
  - Surface Features
  - Thickness Design

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

BAR PLACEMENT
(Appplies to all joints unless otherwise detailed.)

DETAIL A
(Saw cut formed by conventional concrete sawing equipment.)

DETAIL B
(Saw cut formed by approved early concrete sawing equipment.)

Bar Size Table

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Bar Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 8&quot;</td>
<td>#8</td>
</tr>
<tr>
<td>8&quot; but &lt; 10&quot;</td>
<td>#10</td>
</tr>
<tr>
<td>≥ 10&quot;</td>
<td>#11</td>
</tr>
</tbody>
</table>

LEGEND
- Existing Pavement
- Proposed Pavement

Saw 'CD' joint to a depth of T/3 ± 1/4"; saw 'C' joint to a depth of T/4 ± 1/4".

When tying into old pavement, represents the depth of sound PCC.
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

<table>
<thead>
<tr>
<th>Method</th>
<th>Width</th>
<th>Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional saw</td>
<td>1/4” ± 1/16”</td>
<td>T/4 ± 1/4” (C joint)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T/3 ± 1/4” (CD joint)</td>
</tr>
<tr>
<td>Early-entry saw</td>
<td>1/8” to 5/16”</td>
<td>1 ¼” ± 1/4”</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Joint Opening Below Saw Cut</th>
<th>Joint Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/16”</td>
<td>&gt;50%</td>
</tr>
<tr>
<td>1/8”</td>
<td>&lt;50%</td>
</tr>
<tr>
<td>1/4”</td>
<td>0%</td>
</tr>
</tbody>
</table>
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
DESIGN AND LAYOUT

- Iowa: bars are placed all the way across the slab
In some states, design is optimized to only reinforce in the wheel path.
DESIGN AND LAYOUT

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

<table>
<thead>
<tr>
<th>Joint</th>
<th>Bars</th>
<th>Bar Length and Spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 8&quot;</td>
<td>'L-1'</td>
<td>#4</td>
</tr>
<tr>
<td>≥ 8&quot;</td>
<td>'L-2'</td>
<td>#5</td>
</tr>
<tr>
<td></td>
<td>'L-3'</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>36&quot; Long at 30&quot; Centers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>36&quot; Long at 30&quot; Centers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>36&quot; Long at 15&quot; Centers</td>
</tr>
</tbody>
</table>
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 x Cₛ
ML = Maximum length between joints (in.)
T = Slab thickness (in.)
Cₛ = 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
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
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
**DESIGN AND LAYOUT**

- **Construction joints**
  - At edge of pour (longitudinal)
  - At end of pour (transverse)
**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)*
Isolation/expansion joints:

- **Dowel Placement** (Applies to all joints unless otherwise detailed.)

- **Joint in Curb**
  - (View at back of Curb)
  - Top of Curb
  - Top of Slab
  - Dowel Placement

- **Detail F**
  - Joint Sealant
  - Joint Filler
  - Flexible Foam

- **1" Expansion Joint**
  - Top of Curb
  - Top of Slab
  - Dowel Placement

- **Detail G**
  - Joint Sealant Material
  - Joint Filler Material

- **Detail H**
  - Joint Sealant Material
  - Flexible Foam

- **Section B-8**
  - Joint Sealant
  - Joint Filler

- **Dowelled Expansion Joints**
  - Type Width
  - Filler Material

- **Bar Size Table**
  - Dowel Diameter
  - Joint Filler Material

- **Legend**
  - Covering Placement
  - Proposed Placement
**How do I choose which type of joint to specify?**

+ SUDAS Design Guide Section 5G-2, Table 2.02:

<table>
<thead>
<tr>
<th>Joint</th>
<th>Type</th>
<th>Method of Load Transfer</th>
<th>Thermal Movement</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>C</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CD</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT</td>
<td>x</td>
<td>x</td>
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<tr>
<td>DM</td>
<td>x</td>
<td>x</td>
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<td>DT</td>
<td>x</td>
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<td></td>
</tr>
<tr>
<td>HT</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BT-1</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BT-2</td>
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<td></td>
</tr>
<tr>
<td>BT-4</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BT-5</td>
<td>x</td>
<td>x</td>
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</tr>
<tr>
<td>K</td>
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<td></td>
</tr>
<tr>
<td>KG</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KE-1</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KE-2</td>
<td>x</td>
<td>x</td>
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<td>KE-3</td>
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<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ES</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 2.02: Summary of Joints (Derived from the Iowa DOT Design Manual, Section 7A-2, Tables 1 and 2)*
How do I choose which type of joint to specify?

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

SUDAS Design Guide Section 5G-2, Table 2.02:
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
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:

Images: ACPA
• 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
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**
The most crucial elements to proper construction of concrete pavement joints are saw cut timing and depth!

Too late!
CONSTRUCTION

× Sawing window:

**Initial Mix**
(15 minutes)
High heat followed by rapid cooling

**Dormancy**
(24 hours)
Cool, plastic, workable

**Acceleration**
(4-8 hours)
Significant heat, less workable, begins to harden
Transport and Place
Begin curing
Cut joints

**Deceleration**
-24 hours)
Becomes hard and dense
Continue curing

**Slow Hydration**
(Indefinitely)
70 – 75% hydrated after 28 days
Can continue indefinitely, as long as water can reach un-hydrated particles

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Image: CP Tech Center
CONSTRUCTION

× Sawing window:

![Diagram](Image: ACPA)

- Too Early: Raveling
- Sawing Window
- Too Late: Cracking

- Internal Stress Equals Concrete Strength
- Minimum Strength to Avert Excessive Saw Cut Raveling

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
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
## Troubleshooting early age cracking:

**Iowa DOT Construction Manual Appendix 9-6:**

<table>
<thead>
<tr>
<th>Defect</th>
<th>Orientation</th>
<th>Location</th>
<th>Description</th>
<th>Dowelled/Undowelled Transverse Joints</th>
<th>Recommended Repair</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic Shrinkage</td>
<td>Any</td>
<td>Anywhere</td>
<td>Partial-depth and more than 0.027 in. wide</td>
<td>Either</td>
<td>Do nothing</td>
</tr>
<tr>
<td>Uncontrolled Crack</td>
<td>Transverse</td>
<td>Mid-Panel</td>
<td>Full-Depth</td>
<td>Undowelled</td>
<td>Saw/route and seal crack</td>
</tr>
<tr>
<td></td>
<td>Transverse</td>
<td>Crosses or ends at transverse joint</td>
<td>Full-Depth</td>
<td>Undowelled</td>
<td>Saw &amp; seal crack; Epoxy sawed joint if uncracked</td>
</tr>
<tr>
<td></td>
<td>Transverse</td>
<td>Parallel to &amp; within 5 ft. of joint</td>
<td>Full-Depth</td>
<td>Undowelled</td>
<td>Saw and seal crack; Seal joint</td>
</tr>
<tr>
<td>Spalled sawout or uncontrolled crack</td>
<td>Transverse</td>
<td>Anywhere</td>
<td>Spalling; more than 3.0 in wide</td>
<td>Either</td>
<td>Partial-Depth Repair</td>
</tr>
<tr>
<td>Uncontrolled Crack</td>
<td>Longitudinal</td>
<td>Relatively parallel to &amp; within 1 ft. of joint; May cross or end at longitudinal joint</td>
<td>Full-Depth</td>
<td>Either</td>
<td>Saw/route &amp; seal the crack or cross-stitch the crack; Epoxy sawed joint if uncracked</td>
</tr>
<tr>
<td>Uncontrolled Crack</td>
<td>Longitudinal</td>
<td>Relatively parallel to &amp; within wheel path; 1 - 5 ft. from joint</td>
<td>Full-Depth, hairline, or spalled</td>
<td>Either</td>
<td>Remove and replace panel or cross-stitch crack</td>
</tr>
<tr>
<td>Uncontrolled Crack</td>
<td>Longitudinal</td>
<td>Relatively parallel to &amp; further than 5 ft. from a longitudinal joint or edge</td>
<td>Full-Depth</td>
<td>Either</td>
<td>Cross-stitch crack</td>
</tr>
<tr>
<td>Spalled sawout or uncontrolled crack</td>
<td>Longitudinal</td>
<td>Anywhere</td>
<td>Spalled</td>
<td>Either</td>
<td>Partial-Depth Repair</td>
</tr>
<tr>
<td>Uncontrolled Crack</td>
<td>Diagonal</td>
<td>Anywhere</td>
<td>Full-Depth</td>
<td>Either</td>
<td>Full-Depth Repair</td>
</tr>
<tr>
<td>Uncontrolled Crack</td>
<td>Multiple per panel</td>
<td>Anywhere</td>
<td>Two or more full-depth cracks dividing panel into 3 or more pieces</td>
<td>Either</td>
<td>Remove and replace panel</td>
</tr>
</tbody>
</table>

Full-Depth repair per Specification 2539  
Partial Depth Repair per Specification 5230  
Cross-stitch repair per Construction Manual 9-27  
Repairs should be made without use of Calcium Chloride unless early opening to traffic is necessary.

**Note:** LTR = low-transfer restoration (if faulted less than 1/2")i.e., dowel bars per wheel path grouted into slots on either side of the crack; slots must be parallel to each other and the longitudinal joint. Backfill with non-shrink, cement-based grout. Diamond grit with faulting is severe.
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
Sealing/filling joints vs. no seal on contraction joints:

+ Filling helps keep fluids, incompressible materials out of the joint
- Should I always be sealing/filling joints? Are there situations where it is not necessary?

+ ACPA Technical Bulletin TB010-2018:
× ACPA: “in all cases, joint sealing/filling is highly recommended”

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
SPECIAL CASES

- Roundabouts

+ Pinwheel
SPECIAL CASES

- Roundabouts
  + Pave Through
SPECIAL CASES

× Cul-de-sacs
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
THANK YOU!

Resources:

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