Concrete Jointing and Details: Thickness is Only the Start

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Agenda

- Why Are Joints Needed in Concrete Pavement?
- Types of Joints
- Joint Load Transfer
- Joint Layout Guidelines
- Recommended Jointing Plan
- Joint Sealing
- Methods for Making a Joint

*Slides compiled from NRMCA, ACPA, and PCA documents.*
ACI 330: Parking Lots

Guide for the Design and Construction of Concrete Parking Lots

Reported by ACI Committee 330

American Concrete Institute®
ACI 325.12R: Streets and Roads

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

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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 subjected to similar 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 in 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.

Joining 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 bleed 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 pavements 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.
Guide for Optimum
JOINT PERFORMANCE
of Concrete Pavements

July 2012

National Concrete Pavement Technology Center

Iowa State University
Jointed Plain Concrete Pavement (JPCP)
Where can JPCP be used?

- Urban Highway/Interstates
- Ramps & Shoulders
- Intersections & Roundabouts
- Industrial Areas, Truck Stops, Weigh Stations
- Airport Runways, Taxiways, Aprons
- Parking Lots
- Streets & Roadways
- Overlays
Pavement Design

Surface Smoothness or Rideability

Longitudinal Joint

Transverse Joint

Surface Texture

Concrete Materials

Dowel Bars

Tiebars

Subgrade

Subbase
What Causes Pavement Distress?

- Traffic Loading
- Environmental Conditions
- Material Properties of Pavement Layers

Stress, Strain, and Deflection: 
\((\sigma, \varepsilon, \partial)\)

Environmental Conditions

Tensile, Compressive, Shear or in 3-D space
Design to Minimize Key Distresses

Other Possible Concrete Distresses:

- Longitudinal Cracking
- Spalling of Joint or Crack
- Plastic Shrinkage Cracking*
- Scaling*
- Dusting*
- Crazing*
- Early Age Cracking*

(*These are not directly associated with traffic loading.)
Environmental and Loading Stresses

- Tensile stresses crack concrete slabs.
- Environment-related mechanisms causing tensile stresses:
  - shrinkage and warping,
  - curling.
- Load related mechanisms:
  - load mass, and
  - load location on slab.
- Environment and load stresses are additive.
- Where joints are located and when they are placed affect pavement stresses.
Concrete volume change (and cracking) behavior is the basis of many jointing and construction procedure recommendations.
Shrinkage + Restraint = Cracking

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

…whenever resulting tensile stresses exceed tensile strength.
Why Are Joints Needed in Concrete Pavement?

- Control the location, width, and appearance of expected cracks.
- Accommodate normal slab movements.
- Reduce stress build up.
- Provide load transfer where needed.
- Minimize performance implications of any random (unexpected) cracks.
How to determine…

JOINT SPACING
Joint Design & Layout Affect Performance

Spacing Issue
Joint Spacing

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

Recommended Spacing

<table>
<thead>
<tr>
<th>Pavement thickness, in. (mm)</th>
<th>Maximum spacing, ft (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4, 4.5 (100, 113)</td>
<td>10 (3.0)</td>
</tr>
<tr>
<td>5, 5.5 (125, 140)</td>
<td>12.5 (3.8)</td>
</tr>
<tr>
<td>6 or greater (150 or greater)</td>
<td>15 (4.5)</td>
</tr>
</tbody>
</table>

Exception: good design may call for even closer joint spacing due to load transfer considerations.
Rules of Thumb for Jointing & Slab Dimensions

- **Spacing:**
  - Recommendation of 2.5 times the depth in feet
  - For example: 4” thick = 10’ maximum (4 x 2.5)

- **Panel shall be kept as square as possible**
  - L:W of 1½:1 (Maximum length to width ratio)
Experience indicates that there is an increase in transverse cracking when the ratio $L/\ell$ exceeds 4.44 ($L=$slab length).
Using the criterion of a maximum $L/\ell$ ratio of 4.44, the allowable joint spacing would increase with increased slab thickness but decrease with increased (stiffer) foundation support conditions.
TYPES OF JOINTS
Definitions - Joints

- Contraction/Sawcut
- Construction
- Longitudinal
- Isolation
Types of Joints: Schematic Representation

- Contraction or Control
- Construction
- Isolation
Expansion Joints

Pavement expansion joints are only needed when:

1. the pavement is divided into long panels (60 ft or more) without contraction joints in between to control transverse cracking.

2. the pavement is constructed while ambient temperatures are below 40°F (4°C).

3. the contraction joints are allowed to be infiltrated by large incompressible materials.

4. the pavement is constructed of materials that in the past have shown high expansion characteristics.

Under most normal concrete paving situations, these criteria do not apply. Therefore, expansion joints should not normally be used.
Also called sawcut joints…

CONTRACTION (CONTROL) JOINTS
Joint Sawing/Forming
Tooleled Control Joints

**Advantages:**
- Simplest to make.
- Most reliable crack initiation.

**Disadvantages:**
- Most noticeable joint.
- Not smoothest for rolling wheels.
- Not designed for sealers / fillers.
Insert Control Joints

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

**Disadvantages:**
- Learning curve for crew.
- Can ravel or spall if not installed plumb.
Spalling Results If The Insert Is Not Plumb
Sawcut Control Joints

Advantages:
• Makes best sealant reservoir.
• Not as noticeable as tooled.
• Smoothest for wheels.

Disadvantages:
• Timing is critical to success - least reliable crack initiation with gravel aggregates.
• Expensive to make.
Rules of Thumb for Sawcut Joints

- Depth:
  - Conventional Sawing:
    - Minimum of \( \frac{1}{4} \) of the depth: e.g. 8” thick = 2” deep
    - Recommended \( \frac{t}{3} \)
  - Early Entry Sawing:
    - Typical 1” to 1.5” depth
Timing of Joint Sawing—A Critical Factor

Sawcut joints with conventional saws must be made within 4-12 hours after final finishing.

This joint was sawed at correct time

This one was sawed too late
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.

- Very thin blades (~2 to 3 mm) may be used when joint sealing is not specified.
Early Entry “Dry Cut” Saws

- Designed to initiate cracks with a shallow cut made much earlier than with wet-cut saws.
- Timing - “window of opportunity” is 1 to 2 hours.
No Speeding!

- Sawing speed controls cut depth; hard aggregate might require a slower speed.

- Speed typically controlled by saw’s self-propelling mechanism.

- Saw operators that attempt to speed up cutting may tend to push a saw too fast, causing the blade to ride up out of its full cut… not cutting to proper depth = risk for cracking!

Source: ACPA
CONSTRUCTION JOINTS
Use of Construction Joints

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

Butt joints are recommended for most parking lots where load transfer needs are minimal.
Keyway Dimensions

1:4 Slope

Trapezoidal

Half-round

No longer recommended for light traffic pavements!
Keyway Construction Joints in 5” Thick Pavements
ISOLATION JOINTS
Isolation Joints

...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 without damaging the pavement.
Improper Use of Isolation Joints

- If isolation joints are used as routine joints:
  - Slabs “crawl” as isolation joints compress.
  - Adjacent control joints open and fill with debris.
  - No load transfer.
  - Failure of sealants.
  - Water intrusion.

- Common issue in construction practice.
Common Details for Isolation of Fixtures

**Square**
- Isolation joint
- Reinforcing bars recommended to hold cracks tight

**Diagonal**
- Isolation joint

**Circular**
- Isolation joint

**Square with Fillets**
- Isolation joint

**None**
- Isolation joint around perimeter

**Telescoping Manhole**
- No boxout or isolation joint necessary

**Inlet - Round**
- Isolation joint
Examples - Isolation of Fixtures
LONGITUDINAL JOINTS
Longitudinal Joints

- Spacing Criteria:
  - Spacing of 12 to 15 feet serves as both crack control and lane delineation.
  - Lanes (driveways) that are greater than 15’ require a longitudinal joint.

Fig. 4.5—Longitudinal joints. (Note: use butt joint with tie bar for pavements 150 mm [6 in.] thick or less.)
# Tie Bar Dimensions and Spacing (US)

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

<table>
<thead>
<tr>
<th>Slab thickness, in. (mm)</th>
<th>Tie bar size × length, in. (mm)</th>
<th>Tie bar spacing, in. (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Distance to nearest free edge or to nearest joint where movement can occur</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 ft (3.0 m)</td>
</tr>
<tr>
<td>5 (130)</td>
<td>#4 x 24 (13M × 600)</td>
<td>30 (760)</td>
</tr>
<tr>
<td>6 (150)</td>
<td>#4 x 24 (13M × 600)</td>
<td>30 (760)</td>
</tr>
<tr>
<td>7 (180)</td>
<td>#4 x 24 (13M × 600)</td>
<td>30 (760)</td>
</tr>
<tr>
<td>8 (200)</td>
<td>#4 x 24 (13M × 600)</td>
<td>30 (760)</td>
</tr>
<tr>
<td>9 (230)</td>
<td>#5 x 30 (16M × 760)</td>
<td>36 (900)</td>
</tr>
<tr>
<td>10 (250)</td>
<td>#5 x 30 (16M × 760)</td>
<td>36 (900)</td>
</tr>
<tr>
<td>11 (280)</td>
<td>#5 x 30 (16M × 760)</td>
<td>36 (900)</td>
</tr>
<tr>
<td>12 (310)</td>
<td>#5 x 30 (16M × 760)</td>
<td>36 (900)</td>
</tr>
</tbody>
</table>

*Corrosion protection should be used in an area where deicing salts are used on the pavement on a regular basis.
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.
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.
Jointing Layouts:
Corners, acute angles, edges with extreme curvature

- Carry joint through curb (integral curb shown)
- Intersect joints (Avoids acute angles)
- Intersect at corners
Jointing Layouts:

Corners, acute angles, edges with extreme curvature

Meet structures at corners

Avoid acute angles (Intersect at perpendicular)
Thickened Edges

Concrete at pavement edges or along isolation joints that will support wheel loads may be thickened to provide extra support.
JOINTING AND LOAD TRANSFER
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.

**Without load transfer:**
Excessive deflections and flexure - same as free edge loading.

**With load transfer:**
Deflections and flexural stresses are reduced.
Load Transfer Efficiency (LTE)

LTE = \frac{\text{deflection at B}}{\text{deflection at A}}
\text{when load is at A}
Load Transfer

Load Transfer is a Function of:

- Aggregate Interlock
- Stiffness of Supporting Layers
- Mechanical Devices (i.e. Dowels)
Aggregate Interlock

- Effectiveness depends on the crack width and the spacing between joints.

- Good for lighter traffic.

- For ADTT greater than 100, aggregate interlock may not be sufficient.
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!
Stabilized Subgrades or Subbases in Relation to Joint Considerations

- Reduces:
  - Potential joint deflection,
  - Erosion potential.

- Improves working surface, if necessary.

- Use caution when using as permeable layers.

- Extend 2’ beyond an unsupported slab edge.
Doweled Joints

- Not needed on low volume streets and roads.
  - Especially when transverse joint spacing is less than 15 feet.
- May be justified when k values are less than 75 psi/in.
- Generally, pavement must be at least 8” thick to accommodate conventional dowels.
Dowels...

Dowels provide load transfer and allow the joints to move.

Generally not used in low volume situations. May be needed when there is poor subgrade and/or many trucks.
Smooth Round Dowels

<table>
<thead>
<tr>
<th>Slab thickness, in. (mm)</th>
<th>Dowel diameter, in. (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 (180)</td>
<td>1 (25)</td>
</tr>
<tr>
<td>8 (200)</td>
<td>1-1/4 (32)</td>
</tr>
<tr>
<td>9 (230)</td>
<td>1-1/4 (32)</td>
</tr>
</tbody>
</table>

*All dowels spaced at 12 in. (300 mm) centers, with minimum total length of 14 in. (360 mm) and minimum embedment length of 6 in. (150 mm) on each side of joint, with allowance made for joint openings and for minor errors in positioning dowels.*
## Dowel Bar Recommendations

<table>
<thead>
<tr>
<th>Thickness (in)</th>
<th>Diameter (in)</th>
<th>Length (in)</th>
<th>Spacing (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 10</td>
<td>1.25</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td>10 or greater</td>
<td>1.50</td>
<td>18</td>
<td>12</td>
</tr>
</tbody>
</table>
Round Dowels in Baskets
Round Dowels in Baskets
Plate Dowels – Widely Used in Floor Slabs

- 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 than round dowels.
- Efficient use of steel.
- Diamond shapes for formed construction joints.
- Trapezoidal shapes in baskets for control joints.
Diamond dowels for construction joints:
Dowel receptacle is nailed to form prior to placement.

Dowel is inserted into receptacle after form removal.
Construction joints using diamond dowel system
Plate/Diamond dowel system for both control joints and construction joints – prior to concrete placement
Do I or Don’t I…

JOINT SEALING
Joint Sealing

- Topic of some debate.
- Sealants must be maintained and drainage design must be effective.
- Low cost poured sealants not durable.
- Some joint types difficult to seal.
- Factors to consider in whether or not to seal joints:
  - Traffic level
  - Soil types & local performance
  - Subbase use
  - Presence of wind blown debris
Joint Sealing

Minimize surface water & incompressibles into pavement system in an attempt to reduce:

- Subgrade softening
- Pumping/Faulting
- Erosion of fines
- Spalling
To Seal or Not to Seal?

- Sealing joints & maintaining well-sealed joints **MAY** improve performance of the pavement; research into this topic is ongoing...
- … however, some agencies/owners no longer require joints to be sealed under certain conditions

[www.sealnoseal.org](http://www.sealnoseal.org)
Joint Sealants

- Three basic types are:
  - Hot poured
  - Silicone
  - Preformed

- Applicable specs for each type.

- Specialty types (e.g., jet fuel resistant, self-leveling and no tooling, etc.), and backer rods are available in literature and from manufacturers.
Sealing? Make Certain the Joint is Clean!

- 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.
It’s Not Hard to Check…

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

## Table 4.2—Joint sealant materials

<table>
<thead>
<tr>
<th>Hot-pour sealants</th>
<th>Specification</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polymeric asphalt-based</td>
<td>AASHTO M 0173</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ASTM D 3405</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SS-S-1401 C</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ASTM D 1190</td>
<td>Self-leveling</td>
</tr>
<tr>
<td>Polymeric</td>
<td>ASTM D 3405</td>
<td></td>
</tr>
<tr>
<td>Low modulus</td>
<td>Modified</td>
<td></td>
</tr>
<tr>
<td>Elastomeric</td>
<td>SS-S-1614</td>
<td></td>
</tr>
<tr>
<td>Coal tar, PVC</td>
<td>ASTM D 3406</td>
<td></td>
</tr>
<tr>
<td>Cold-pour sealants/</td>
<td></td>
<td></td>
</tr>
<tr>
<td>single components</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silicone</td>
<td>ASTM D 5893</td>
<td>Self-leveling, nonsag, low to ultra-low modulus</td>
</tr>
<tr>
<td>Nitrile rubber</td>
<td>No specifications currently exist</td>
<td>Self-leveling, nonsag</td>
</tr>
<tr>
<td>Polysulfide</td>
<td></td>
<td>Self-leveling, low modulus</td>
</tr>
<tr>
<td>Preformed polychloroprene</td>
<td></td>
<td></td>
</tr>
<tr>
<td>elastomeric (compression seals)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preformed compression seals</td>
<td>ASTM D 2628</td>
<td>20 to 50% allowable strain</td>
</tr>
<tr>
<td>Lubricant adhesive</td>
<td>ASTM D 2835</td>
<td></td>
</tr>
</tbody>
</table>
Reservoir

Fig. 4.7—Joint sealant reservoir.
Pavement Design Assistance Program

- **Concrete Parking Lots**
- **Concrete Streets and Roads**

- New Pavements, or
- Rehabilitation of Existing Pavements

- Conventional Concrete,
- Pervious Concrete,
- Roller-Compacted Concrete,
- Concrete Overlays, or
- Full Depth Reclamation.
Pavement DAP – How do I obtain a DAP Report?

http://www.concretepromotion.org/index.html
Thank You!

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http://www.nrmca.org
http://www.nrmca.org/about/Staff-Bio-BKillingsworth.asp