

Concrete Intersections A Guide for Design and Construction

Introduction

Traffic causes damage to pavement of at-grade street and road intersections perhaps more than any other location. Heavy vehicle stopping and turning can stress the pavement surface severely along the approaches to an intersection. The pavement within the junction (physical area) of an intersection also may receive nearly twice the traffic as the pavement on the approaching roadways.



An intersection reconstructed with concrete.

At busy intersections, the added load and stress from heavy vehicles often cause asphalt pavements to deteriorate quickly. Asphalt surfaces tend to rut and shove under the stress or load of busses and trucks stopping and turning. These deformed surfaces become a safety concern for drivers and costly maintenance problems for roadway agencies.

Concrete pavements better withstand the loading and turning movements of heavy vehicles. As a result, city, county and state roadway agencies have begun rebuilding deteriorated asphalt intersections with concrete pavement. These agencies are extending road and street system maintenance funds by eliminating the expense of intersections that require frequent maintenance.

At-grade intersections along business, industrial, and arterial corridor routes are some of the busiest and most vital pavements in an urban roadway network. Closing these roads and intersections for pavement repair creates costly traffic delays and disruption to local businesses. Concrete pavements provide a long service life for these major corridors and intersections.

Concrete pavements also offer other advantages for intersections, including:

1. A long-term pavement solution.
2. Low maintenance costs.
3. No softening or deterioration caused by oil and/or fuel drippings.
4. Better light reflectivity than asphalt, enhancing pedestrian and vehicle safety at night and in inclement weather.
5. A durable and skid resistant surface.

Successful construction of concrete intersections is challenging, especially in urban areas, where accommodating traffic and adjacent business needs often must supersede other engineering or construction factors. However, modern technology, including fast-track construction, simplifies these challenges.

Design Considerations

When building or rebuilding an intersection, the new concrete pavement should cover at least the entire functional area of the intersection. The functional area includes the longitudinal limits of any auxiliary lanes (Figure 1).^(1,2) Normally, the distress caused by heavy vehicles braking and turning will occur within an intersection's functional boundaries.

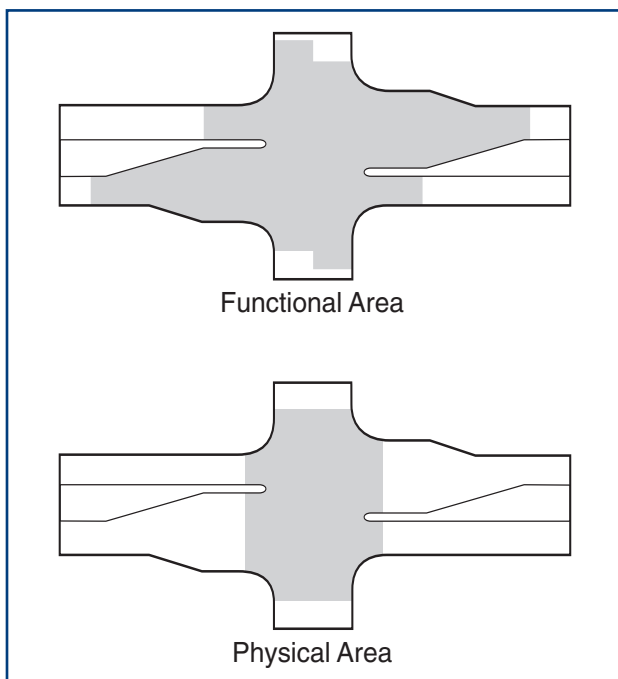


Figure 1. Physical and functional areas of an intersection.

As a rule, it is important to evaluate the existing pavement condition before choosing limits for the new concrete pavement. On busy routes, it may be desirable to extend the limits for the new concrete pavement beyond the intersection's functional boundaries. Traffic congestion at a busy intersection may extend the distance where vehicles start and stop, which may extend the length of distressed pavement. The length that pavement distress extends beyond the intersection's functional boundaries will depend upon the number, speed, and type of vehicles that use the intersecting roadways. A similar extension of distress is possible where trucks cause damage while accelerating slowly up a steep grade away from an intersection.

If significant changes to an intersection are required, it is ideal to extend the new pavement to the boundaries of the intersection's new functional area. Traffic patterns change with modifications to an intersection's through-lanes, auxiliary lanes, and acceleration and deceleration tapers. Therefore, the location where vehicles cause damage also may change from the location in the existing intersection configuration.

As a standard, some agencies extend the new concrete pavement 100 to 200 ft (30 to 60 m) beyond the intersection's physical area on each leg of the intersection for all traffic lanes. Others extend the new pavement approaching the intersection farther than the new pavement leaving the intersection. In the latter cases, the concrete lanes approaching the intersection may begin 200 to 400 ft (60 to 120 m) from the intersection's physical area, while lanes leaving the intersection terminate about 50 ft (15 m) beyond the physical area. For intersections carrying moderate traffic volumes and a low percentage of heavy vehicles, 50 to 100 ft (15 to 30 m) of new pavement is usually sufficient to replace the distressed pavement.



Figure 2. These before (top) and after images show a concrete inlay extending well beyond the physical area of an intersection in Western Michigan.

■ Concrete Slab Thickness

Because an intersection's physical area carries traffic from both roadways, the concrete slab thickness in the physical area of the intersection may need to be greater than the thickness on any approaching roadway. The need for extra thickness will depend on the roadway or street classification and the average daily truck traffic (ADTT) that each route carries.

Table 1 defines six roadway (street) classifications. These classifications depend on traffic volume, vehicle type(s) and maximum axle loading.

Designers should consider increasing the slab thickness for at-grade intersections of industrial and arterial roadways. The physical area will likely require 0.5 to 1.0 in. (12 to 25 mm) of additional thickness (see Table 2).

When traffic warrants extra concrete thickness in the intersection's physical area, it is generally easier to change the thickness at a location before the radii for the intersection. The slabs near the intersection's radii are built using fixed forms and separate hand-pours in most cases. A transition length of about 3 to 6 ft (1 to 2 m) for changing the thickness is usually adequate. The decision on precisely where to change thickness should be left to the contractor. Requiring the transition to be at a specific location may

Table 1. Street classifications⁽³⁾

Street class	Description	Two-way average daily traffic (ADT)	Two-way average daily truck traffic (ADTT)	Typical range of slab thickness
Light residential	Short streets in subdivisions and similar residential areas – often not through-streets.	Less than 200	2 – 4	4.0 – 5.0 in. (100 – 125 mm)
Residential	Through-streets in subdivisions and similar residential areas that occasionally carry a heavy vehicle (truck or bus).	200 – 1,000	10 – 50	5.0 – 6.0 in. (125 – 150 mm)
Collector	Streets that collect traffic from several residential subdivisions, and that may serve buses and trucks.	1,000 – 8,000	50 – 500	5.5 – 8.0 in. (135 – 200 mm)
Business	Streets that provide access to shopping and urban central business districts.	11,000 – 17,000	400 – 700	6.0 – 8.0 in. (150 – 200 mm)
Industrial	Streets that provide access to industrial areas or parks, and typically carry heavier trucks than the business class.	2,000 – 4,000	300 – 800	6.5 – 9.5 in. (165 – 240 mm)
Arterial	Streets that serve traffic from major expressways and carry traffic through metropolitan areas. Truck and bus routes are primarily on these roads.	4,000 – 15,000 (minor) 4,000 – 30,000 (major)	300 – 600 700 – 1,500	6.5 – 9.5 in. (165 – 240 mm) 7.0 – 10.0 in. (175 – 250 mm)

Table 2. Slab thickness considerations for the physical area of at-grade intersections. Note that in this table, thickness T3 is greater than T2, and T2 is greater than T1.

Intersecting roadway 1	Intersecting roadway 2	Physical area thickness*
Low ADTT (T1)	Low ADTT (T2)	T2
Low ADTT (T1)	High ADTT (T3)	T3
High ADTT (T3)	High ADTT (T3)	T3 + 0.5 – 1.0 in. (12 – 25 mm)**

* Assumes thickness (T1, T2 or T3) for intersecting roadways based on anticipated traffic and calculated in a rational design procedure such as that of AASHTO,⁽⁴⁾ StreetPave Software,^(3,5) or MEPD.

** The AASHTO thickness design procedure⁽⁴⁾ shows that doubling the traffic loading requires about an additional 1 in. (25 mm) of concrete pavement thickness. The ACPA design procedure^(3,5) shows that an extra 0.5 in. (12 mm) of slab thickness is required when doubling traffic.

complicate construction and conflict with other job site factors, such as providing access to adjacent businesses.

At-grade intersections of light residential, residential, collector, and business roadways should not require any extra concrete thickness in the physical area. The intersection thickness should be the same as the thicker of the two approaching roadways.

■ Jointing

Joint design is arguably the most important design aspect for concrete pavement intersections. At-grade intersections often introduce jointing challenges that do not exist along tangent sections of concrete roadway or street pavements. However, these complications can be overcome by applying simple jointing fundamentals.

Joints are necessary primarily to control the location of cracks that occur from natural actions on concrete pavement. When designed correctly, joints accommodate the expansion and contraction of concrete slabs caused by temperature fluctuations, and account for stresses that develop from slab curling and warping.⁽⁶⁾ During construction, joints also divide the pavement into suitable placement increments or elements for the contractor. Certain joints also accommodate slab movement against fixed structures.

For at-grade intersections, a designer should consider three major joint design elements: joint spacing, joint type, and joint layout. Each factor can influence the long-term performance of the pavement. In addition, other factors to consider include: dowel bars for load transfer, tiebars for tying lanes, and sealing joints.*

Joint Spacing – For unreinforced concrete pavement, joint spacing or slab length depends on slab thickness, concrete aggregate, subbase/subgrade, and climate.^(6,7) In most areas, the typical maximum transverse joint spacing for unreinforced (plain) pavement is about 15 ft (4.5 m). Longitudinal joints on two-lane and multilane

street pavements are typically about 10 to 13 ft (3.0 to 4.2 m) apart, and serve the dual purpose of crack control and lane delineation.

Equation 1 determines the maximum allowable joint spacing based on slab thickness and subbase type. Slabs kept to dimensions shorter than the equation determines will have curling and warping stresses within safe limits to ensure minimal risk of random cracking.

$$ML = T \times C_s \quad (\text{Eq. 1})$$

where:

ML = Maximum length between joints
(See Notes 1 and 2).

T = Slab thickness
(Either English or metric units).

C_s = Support constant.

Use 24 for subgrades or unstabilized (granular) subbases.

Use 21 for stabilized subbases, or existing concrete or asphalt pavement (for conventional overlays).

Use 12 to 15 for ultra-thin overlays of asphalt
(See Note 3).

Notes:

1. The spacing of transverse joints in plain (unreinforced) concrete pavement should not exceed 15 ft (5 m) for slabs less than 10 in. (250 mm) thick.
2. A general rule-of-thumb requires that the transverse joint spacing should not exceed 150% of the longitudinal joint spacing. This ratio is difficult to maintain within intersections due to islands, medians, auxiliary lanes, and curved areas, and can be disregarded in favor of common-sense jointing patterns to accommodate these elements within the intersection.
3. The spacing of transverse and longitudinal joints in ultrathin and thin overlays range from 4 to 6 ft (1.33 to 2.0 m) depending upon overlay thickness, support conditions, and lane width.

The climate and concrete aggregate common to some geographic regions may allow transverse joints to be further apart, or require them to be closer together than Equation 1 determines. For example, concrete made from granite and limestone coarse aggregate is much less sensitive to temperature change than concrete made from siliceous gravel, chert, or slag aggregate. A less temperature-sensitive concrete does not expand or contract much with temperature change, which allows a longer spacing between pavement contraction joints without any greater chance of random cracking. However, unless experience

* Joints should be sealed to minimize infiltration of water and incompressible particles if local experience indicates it is necessary. The effectiveness of joint sealing depends upon the sealant type, installation technique, maintenance, concrete properties and joint configuration. For pavements with joints spaced less than 15 ft (4.5 m), the impact of the sealant on pavement performance is not as critical as it is for longer spacing. The impact of joint sealing on pavement performance also may be more noticeable in urban areas and Northern climates if pavements carry heavy traffic and receive sand or salt applications for snow and ice control. See Reference 8, in the sources listed at the end of this document, for more details on joint sealing techniques and materials.

with local conditions and concrete aggregates indicates otherwise, use Equation 1 to determine the maximum allowable transverse joint spacing for unreinforced pavements.

A transverse joint spacing up to 30 ft (9 m) is allowable for pavements reinforced with distributed steel reinforcement. The purpose of distributed steel is to hold together any intermediate (mid-panel) cracks that will develop in the long panels between transverse joints.** Distributed steel neither adds to the load-carrying capacity of the pavement nor compensates for poor subgrade conditions.

Joint Types – There are three basic joint types for concrete pavements: contraction, construction, and isolation. Specific design requirements for each type depend on orientation to the direction of the roadway (transverse or longitudinal). Most concrete intersections will require each of the three joint types in both longitudinal and transverse orientations. Figure 3 provides cross-sections detailing each type.

Transverse Joints – Transverse contraction joints run transverse to the pavement centerline and are essential to control cracking from stresses caused by shrinkage,

thermal contraction, and moisture or thermal gradients. Typically these joints are at a right angle to the pavement centerline and edges. However, some agencies skew transverse contraction joints to decrease the dynamic loading across the joints by eliminating the simultaneous crossing of each wheel on a vehicle's.^(6,7) Right-angle transverse contraction joints are preferable to skewed joints for concrete intersections because they do not create complex jointing patterns within the intersection's physical area. Skewing joints is not a substitute for the load transfer provided by dowels, (smooth round bars).

The need for dowels in transverse contraction joints depends upon the roadway or street classification. Undoweled contraction joints (Type A-1, Figure 3) are usually sufficient for light residential, residential, or collector pavements. Industrial and arterial streets that will carry heavy truck traffic for long periods require doweled contraction joints (Type A-2, Figure 3).⁽⁷⁾ Doweled contraction joints are also necessary in pavements with distributed steel reinforcement, and should be considered for slabs longer than 20 ft (6 m). Table 3 provides recommended dowel sizes.

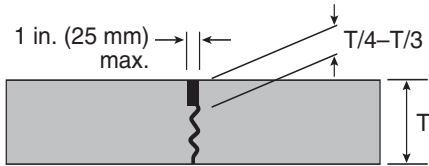
Table 3. Dowel sizes for plain pavements and pavements reinforced with distributed steel.

Slab thickness in. (mm)		Dowel diameter in. (mm)		Minimum dowel length in. (mm)	
Plain (unreinforced) pavements†					
< 7	(< 180)	not necessary		not necessary	
7 – 7.9	(180 – 195)	1.00	(25)	14	(360)
8 – 9.9	(200 – 249)	1.25	(32)	14	(360)
≥ 10	(≥ 250)	1.50	(38)	14	(360)
Distributed steel reinforced pavements					
6	(150)	0.75	(19)	14	(360)
6.5	(165)	0.875	(22)	14	(360)
7	(180)	1.00	(25)	14	(360)
7.5	(190)	1.125	(28)	14	(360)
8 – 9.9	(200 – 249)	1.25	(32)	14	(360)
≥ 10	(≥ 250)	1.50	(38)	14	(360)

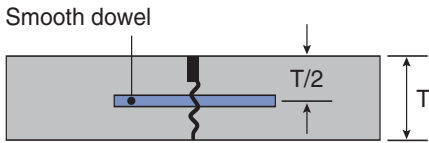
† Assumes thickness is based on anticipated traffic and is calculated in a rational design procedure such as that of AASHTO,⁽⁴⁾ ACPA^(3,5) or MEPDG.

** Pavements with distributed steel are often called jointed reinforced concrete pavements (JRCP). In JRCP, the joint spacing is purposely increased and reinforcing steel is used to hold together intermediate cracks. If there is enough distributed steel within the pavement (0.10 to 0.25% per cross-sectional area), the mid-panel (sometimes called “mesh”) cracks do not detract from the pavement's performance.⁽⁹⁾ However, if there is not enough steel, the steel can corrode or rupture and the cracks can start to open and deteriorate.

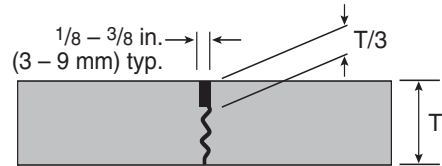
Contraction:



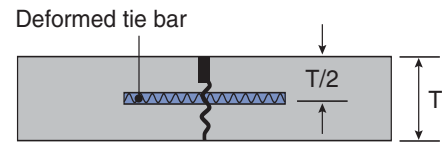
Undoweled – Transverse (Type A-1)



Doweled – Transverse (Type A-2)

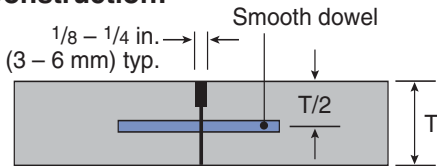


Untied – Longitudinal (Type A-3)

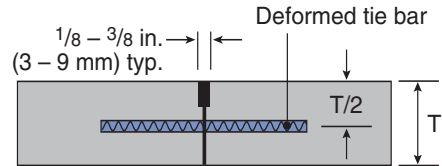


Tied – Longitudinal (Type A-4)

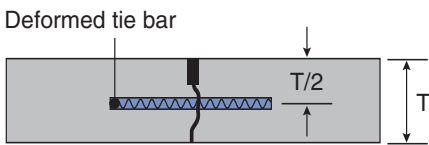
Construction:



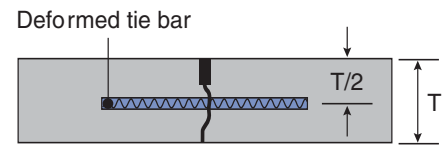
Doweled butt – Transverse (Type B-1)



Tied butt – Longitudinal (Type B-2)

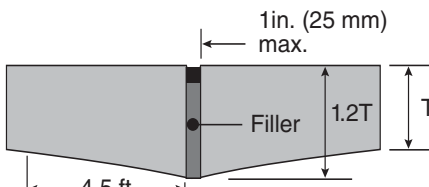


Tied – Transverse (Type C-1)
(Keyway optional)

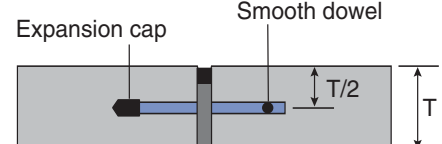


Keyed – Longitudinal (Type C-2)
(Deformed tie bar optional)

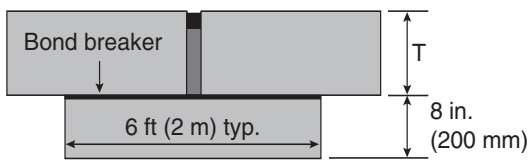
Isolation:



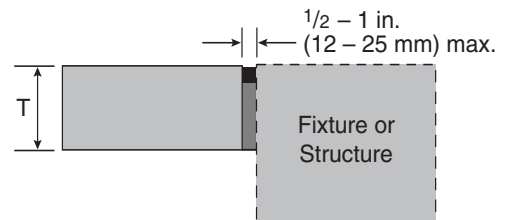
Thickened edge – Transverse (Type D-1)



Doweled – Transverse (Type D-2)



Sleeper slab – Transverse (Type D-3)



Undoweled – Longitudinal (Type D-4)

Figure 3. Cross sections of different joint types.

Transverse construction joints (Type B-1, C-1, Figure 3) are necessary at the end of a paving segment, or at a placement interruption for a driveway or cross road. A doweled butt joint (Type B-1) is preferable. It should be used whenever the construction joint will correspond to the location of a contraction joint or construction joint in an adjacent lane. Sometimes it is not feasible to match the location of a transverse joint in the adjacent lane, which necessitates use of a tied construction joint (Type C-1). The deformed tiebars in a Type C-1 joint prevent the joint from opening and causing sympathy cracking in adjacent lane(s).

Longitudinal Joints – Longitudinal contraction joints (Type A-3, A-4, Figure 3) also are necessary to control cracking from stresses caused by concrete volume changes and moisture or thermal gradients. These joints run parallel to the pavement centerline and usually correspond to the edge of a driving lane. On two-lane and multilane pavements, a spacing of 10 to 13 ft (3.0 to 4.0 m) serves the dual purpose of crack control and lane delineation.

For unusual or special locations, such as ramps and turning areas between median islands, the maximum recommended slab width (distance between longitudinal contraction joints) is 15 ft (4.5 m). However, this may be excessive for thinner slabs, in which case Equation 1 should be used to determine the maximum allowable longitudinal joint spacing.

The need to tie longitudinal contraction joints will depend on the degree of lateral restraint available to prevent the joints from opening permanently. Most longitudinal contraction joints on roadway tangent sections contain No. 4 or No. 5 (#13M or #16M) deformed reinforcing bars.[†] The deformed bars are usually about 24 to 30 in. (600 to 750 mm) long and are spaced at 30 to 40 in. (750 to 1000 mm) intervals. Where there are curbs on both sides of the pavement, it may not be necessary to tie the joints unless local experience indicates otherwise.

[†] For very wide roadways, there is a limit to width of pavement that can be tied together without concern for cracking. Current recommendations⁽⁷⁾ limit the tied width of highway pavement to about 48 ft (14.5 m) based on the subgrade drag theory. However, there has been good field performance of certain intersections with up to 70 ft (21 m) of tied pavement. If local-experience records are not available for intersection design, consider using an untied contraction joint (Type A-3) or construction joint (Type C-2) near the centerline of roadway sections that exceed 48 ft (14.5 m).

Longitudinal construction joints (Type B-2, C-2, Figure 3) join pavement lanes that are paved at different times. Concrete intersections require these joints because of the numerous pours necessary to place pavement around islands and medians, and between the curves connecting the two roadways.

The optional keyway for a tied longitudinal construction joint can be difficult to construct correctly in thin pavements. Therefore, some agencies avoid placing keyways in slabs less than 10 in. (250 mm) thick.⁽⁷⁾ Keyway shear failures can occur in thin slabs when keyways are too large or too close to the slab surface. Some contractors report that half-round keyways are easier to construct and less prone to problems than trapezoidal keyways. Where a keyway is deemed necessary, the dimensions indicated in Figure 4 will afford the optimum load-transfer performance.

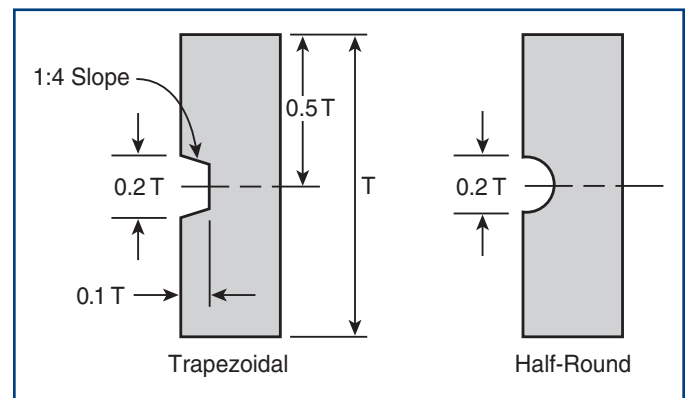


Figure 4. Keyway standard dimensions.

Isolation Joints – Isolation joints (Type D-1, D-2, D-3, D-4, Figure 3) are essential at asymmetrical and T-intersections to isolate the side road from the through street (Figure 5, page 8). Isolation joints also are needed where the pavement abuts certain manholes, drainage fixtures, sidewalks, aprons, and structures. Certain agencies and contractors also prefer to use isolation joints at crossroad intersections. Where used, the isolation joint will allow independent movement of the pavement and the structure without any connection that could cause damage. To be effective, the preformed compressible filler should meet the requirements of ASTM^{††} D1751, D1752, or D994, and must cover the entire depth of the concrete slab.

^{††} ASTM is now the official name of the organization originally called the American Society for Testing and Materials. Equivalent Canadian standards for all ASTM standards addressed in this publication, as well as the Canadian equivalent, are listed on page 28.

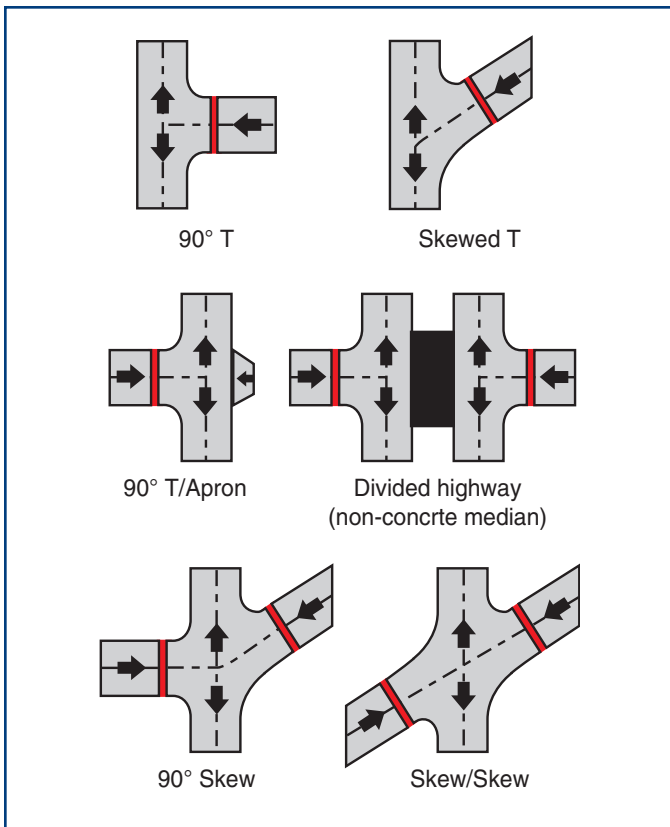


Figure 5. Asymmetrical and T-intersections that require isolation joints.

At asymmetrical or T-intersections, undoweled, thickened-edge or sleeper-slab isolation joints (Type D-1 or D-3, Figure 3) are preferable to doweled isolation joints, because they each permit independent lateral movement of the through-street concrete slabs. The sleeper slab and thickened edge designs each provide improved support to compensate for the absence of dowel bars. For a thickened edge joint, the abutting edges of the concrete slabs should be 20% thicker at the joint and taper back to the nominal thickness over at least 4.5 ft (1.5 m).

At locations inaccessible to heavy vehicle loads, such as those between a pavement and a structure, a thickened-edge joint is not necessary. A butt joint with a non-extruding, preformed compressible material is adequate.

For utility fixtures such as manholes, catch basins, and drainage inlets, the need for isolation will depend upon the casting design and potential for differential movement. Non-telescoping manholes with ribbed cylinder walls usually require a boxout with a perimeter isolation joint to allow independent vertical and horizontal slab

movement. Common square boxouts sometimes cause cracks to form at the corners of the boxout. To avoid crack-inducing corners, consider using rounded boxouts or placing fillets on the corners of square boxouts. It is advantageous to place welded-wire fabric or small-diameter reinforcing bars in the concrete pavement around any interior corners at square boxouts to hold cracks tightly should they develop. Figure 6, page 9 shows details for boxing out in-pavement fixtures.

In some circumstances, boxing out fixtures may be undesirable. For instance, boxouts can impede fast-track construction because more time is needed to place concrete around the casting after the pavement gains strength. It is also very difficult to maintain a uniform joint pattern if there are too many manholes randomly positioned in an intersection. In these cases it may be best to cast the fixtures into the concrete.

To isolate a fixture without a boxout, some contractors and agencies wrap the casting with pliable expansion joint filler or a suitable bond breaker. If no differential movement is expected, the manhole can be cast directly into the concrete. Telescoping manhole fixtures have a two-piece casting, which allows vertical movement.

Concrete pavement performance suffers if the pavement contains too many transverse expansion (isolation-type) joints. Outdated specifications sometimes require expansion joints spaced uniformly along tangent sections. These joints create maintenance problems because nearby transverse contraction joints open excessively as the expansion joint closes gradually over time. The open contraction joints then lose load transfer and develop distresses like faulting. Transverse expansion joints at regular intervals may be needed when:

1. The pavement is divided into long panels [60 ft (18 m) or more] without contraction joints in-between.
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.

In most situations, these criteria do not apply. Therefore, transverse expansion joints should not normally be used.

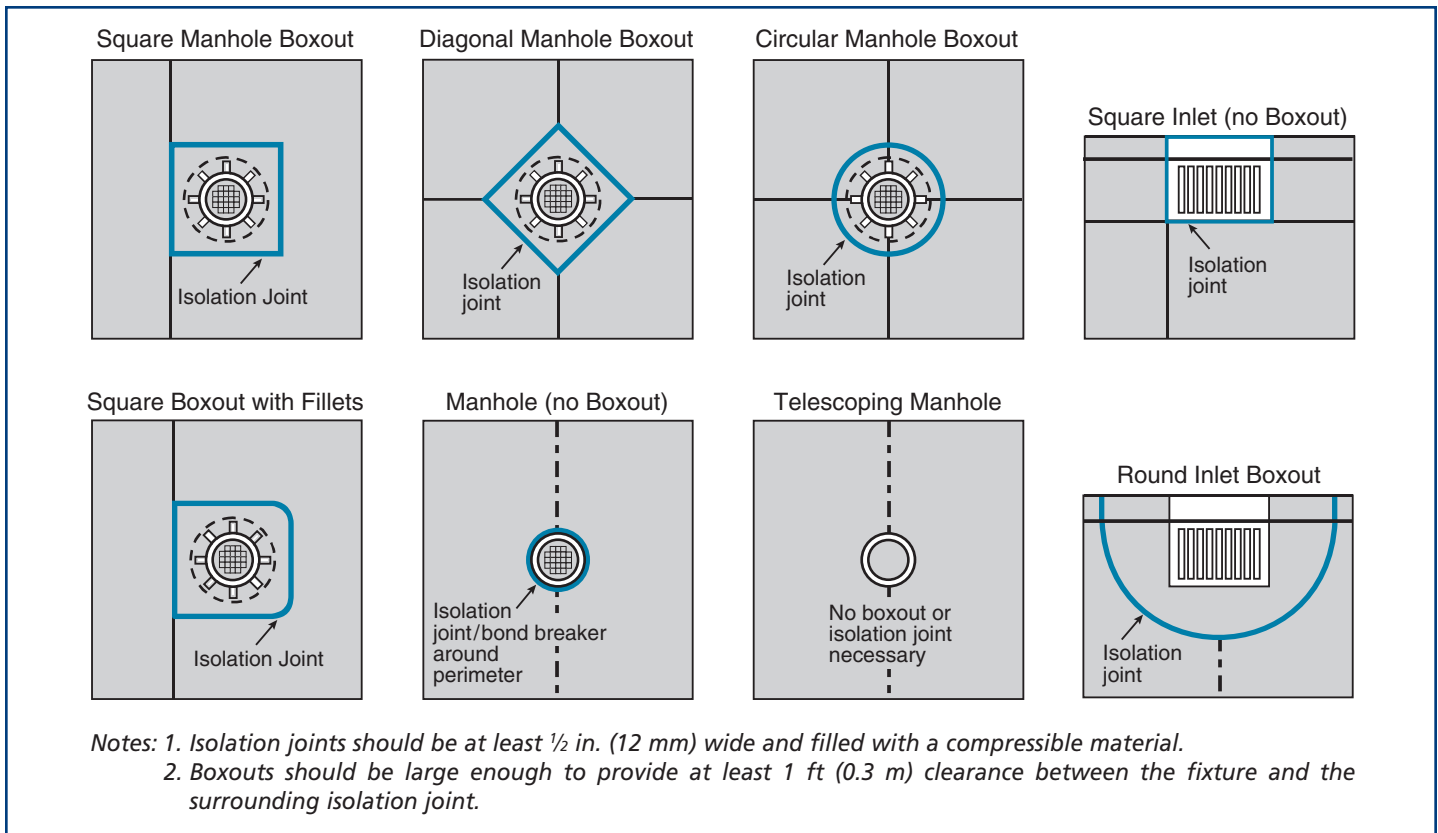


Figure 6. Details for boxing out fixtures.

Joint Layout – A well-designed joint layout contributes to good long-term performance of at-grade intersections. A good jointing plan will ease construction by providing clear guidance to the contractor. It is common practice for some designers to leave intersection joint layout to the field engineer and contractor. These designers often justify this practice by citing the many field adjustments that occur during construction, which they contend negates the usefulness of a jointing plan. However, it is not desirable to eliminate the jointing plan entirely, except for very simple intersections. A jointing plan and appropriate field adjustments are both important for more complex intersections, because islands, medians, and auxiliary turning lanes complicate joint layout and require some forethought before construction. A plan also enables contractors to bid new projects more accurately.

During construction, it is likely that location changes will be necessary for some joints within an intersection. The primary reason is to ensure that joints pass through embedded fixtures such as manholes or drainage inlets. It is common for the actual location of manholes or drainage inlets to vary from the location shown on the plans. It will be necessary for the construction crew to adjust the location of some joints during construction so that they coincide with the actual location of a nearby manhole or inlet. The designer should consider placing a note on the plan to give the field engineer and contractor the latitude to make appropriate adjustments. Reference 10 provides a ten-step method for laying out joints for concrete intersections.

Another important aspect of laying out intersection joints is determining where to use dowel bars or tiebars near the intersection's physical area. Figure 7, page 10 shows examples of dowel and tiebar use in intersections.

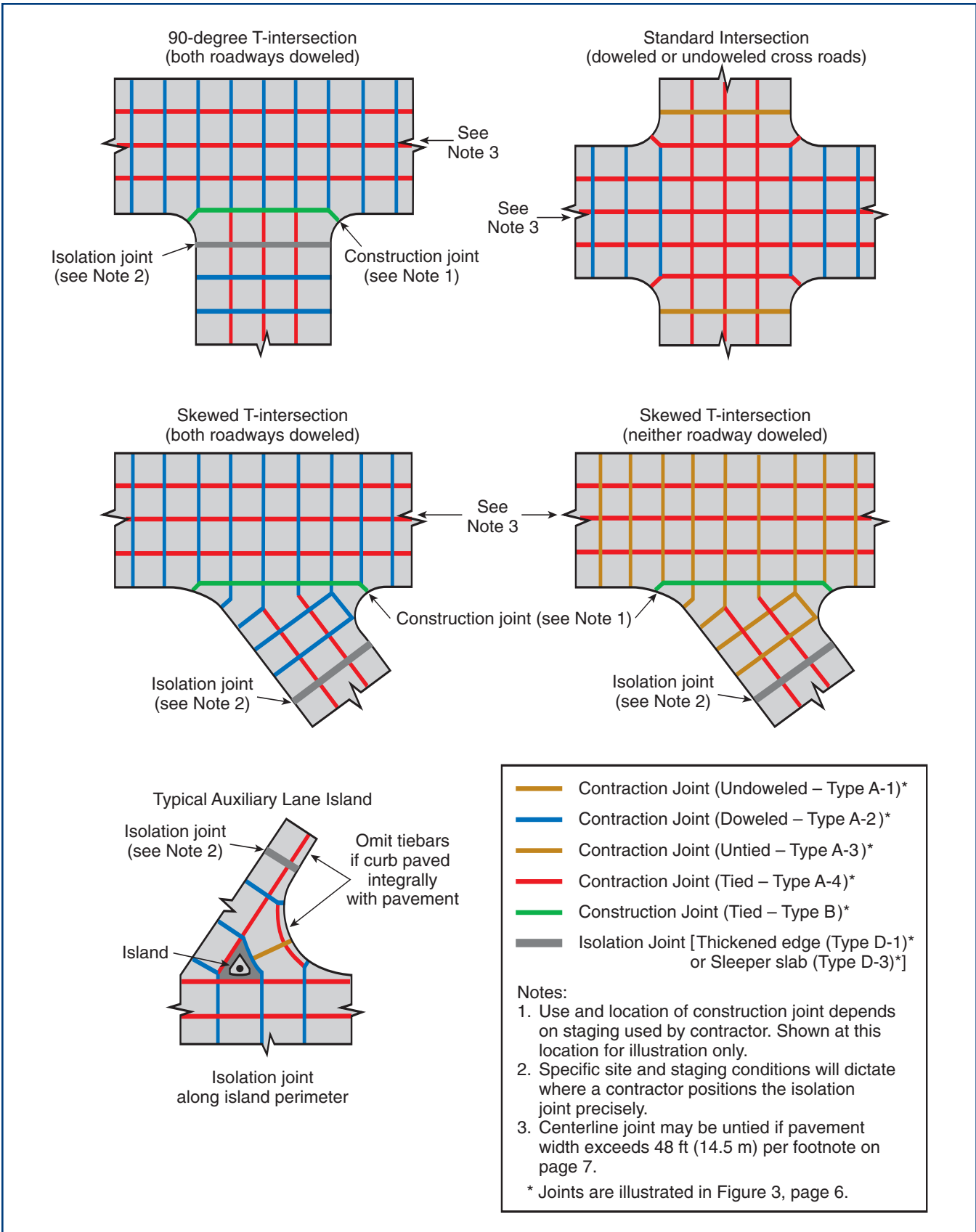


Figure 7. Use of dowel bars and tiebars in intersections.

Phasing Construction – Phasing is almost always a key element of intersection construction plans. The need for a refined phasing plan depends upon the need to maintain traffic flow through the intersection during construction. There are four basic construction staging options: complete closure with detours, partial closure with detours, complete closure during time-windows, and construction under traffic.

Intersections of rural or other low-traffic roadways do not usually require the same level of consideration necessary for intersections that carry high volumes of traffic. Closing low-traffic intersections for the duration of construction is often the optimal solution and should always be considered. In some cases, the availability of convenient alternate routes (e.g., frontage roads) may even permit closing an intersection that carries a high traffic volume without significant concern for traffic flow or business disruption.

For the contractor, complete closure is ideal. Complete closure eliminates complex work-zone lane configurations, which increases the safety of the construction work zone. Complete closure also allows the contractor to place more pavement in a continuous operation, generally increasing pavement smoothness, improving quality, and reducing construction time.

Completely closing an intersection for construction requires developing a detour plan. Clear and understandable signing along the detour route will make the detour more acceptable to motorists. A sign indicating the date when the intersection will re-open also can improve public relations.

Unfortunately, closing intersections for the entire construction period is often not viable along urban arterial or corridor routes. For example, the lack of traffic over an extended period might cause businesses near the closure to lose customers. In these circumstances, one option is to limit complete intersection closure to non-business hours. If it is feasible to divert traffic around the intersection, even for a few hours, the contractor can complete critical construction phases quickly and expedite the entire project.

Some agencies develop phasing plans that allow complete intersection closure during specific periods (windows). Usually the window will begin at about 6 p.m. and last until about 6 a.m. the following morning. The starting and ending time depends upon the local rush-

hour traffic pattern. Within the window the contractor may close and occupy the entire intersection. At the end of the window, public traffic must be able to use the intersection. In this manner, the closure will not hinder morning, evening, or daytime traffic flow. Under time-window phasing plans, contractors perform each sequential construction operation during successive time-windows. For example, if the project includes removal of an existing pavement, the contractor may place a temporary pavement after removing the existing material during one 12-hour window. The temporary pavement carries traffic until the contractor removes it to pave the new concrete roadway in a subsequent time window.

Another option to avoid closing an entire intersection is to close one leg of the intersection at a time. This is often feasible for intersections between residential and collector streets. Detours along the closed residential street are usually short and not a burden to local residents.

On some roadways, it may be unacceptable to close the entire intersection at any time. Many agencies have had good success replacing busy intersections with concrete pavement while maintaining normal traffic volumes. Figure 8 (page 12) shows possible options for phasing construction under traffic.

These options may reduce the number of available through-lanes and may somewhat limit turning movements during construction. However, the degree of these restrictions depends upon the number of lanes on the approaching roadways. None may be necessary if the approaching roadways have at least three through lanes in each direction. A detour for one leg of the intersection or special alternating traffic signals will be necessary if one or both of the approaching streets has just one lane in each direction.

Construction under traffic can generally start on any leg of an intersection. However, if an intersection includes a major road and a minor cross road, the driving lanes of the major roadway usually are built before the cross road. Concentrating on the major roadway pavement generally produces a smoother-riding intersection. After the major roadway pavement lanes are finished, other pavement areas are built without affecting the smoothness through the intersection. Typically, this method is more productive because the contractor can place more pavement in a continuous operation without gaps or changes in the pavement width.

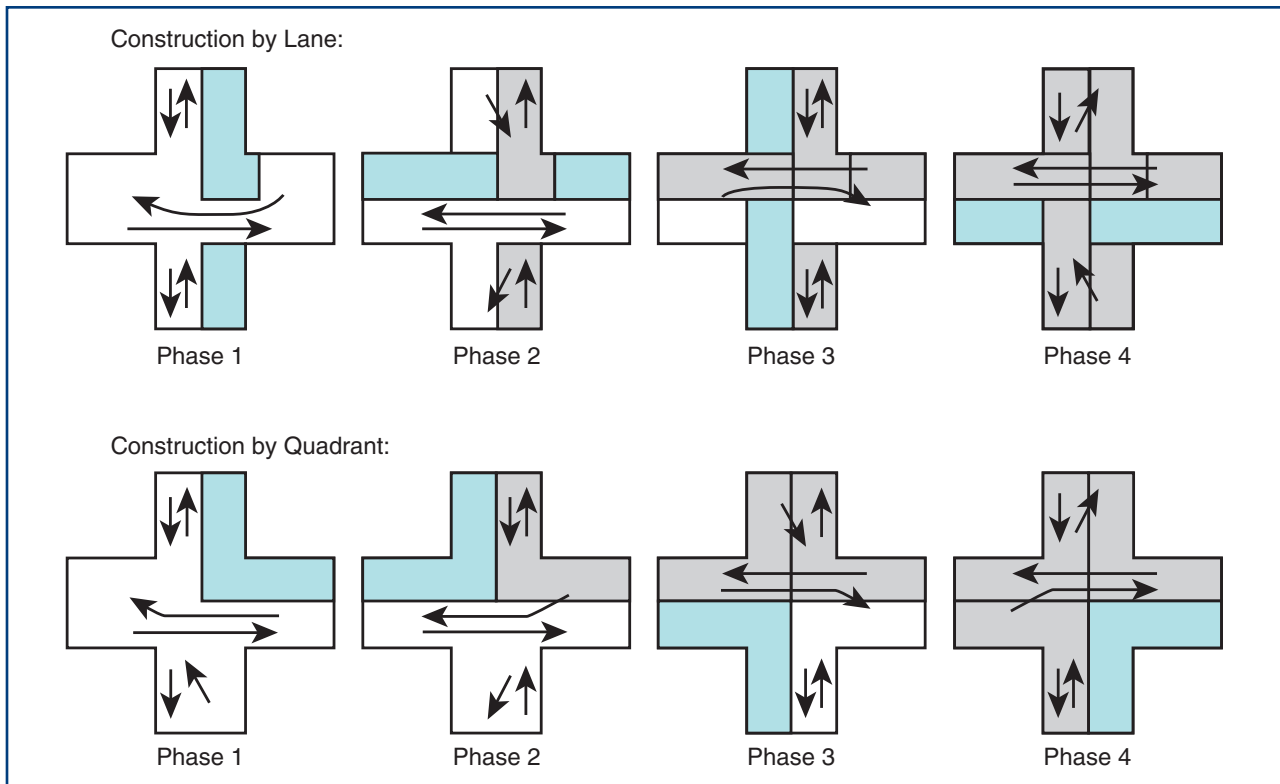


Figure 8. Possible options for phasing construction under traffic.

Quality Concrete Mixtures

A suitable concrete mixture is necessary to ensure the success of the construction phasing plan. Whether the contractor or agency determines the concrete mixture proportions, the concrete must be capable of meeting strength requirements reliably within any specified time windows for construction, and must have adequate long-term durability. The contractor should have some latitude to adjust the mixture proportions during construction if the mixture does not work properly for the required construction phasing plan. Before construction, contractors also may offer valuable suggestions or value-engineering options to expedite construction.

Strength – Compressive strength testing (ASTM C39) is the most common and easiest way to evaluate concrete strength. Concrete with a 28-day compressive strength averaging 3000 to 4000 psi (20 to 30 MPa) is adequate for most intersections. During construction, the pavement may be opened to traffic at a strength somewhat less than the 28-day target value (see table 7, page 23).

Some highway agencies use flexural strength (ASTM C78) as the structural strength criterion to evaluate load capacity. Flexural strength provides an assessment of the

tensile strength at the bottom of the slab, more appropriately modeling the stresses due to wheel loads. However, challenges associated with casting and testing beam specimens properly, discourage many engineers and contractors from using this test method in the field.

Durability – Strength is not a reliable measure of concrete's durability. In frost-affected areas, a concrete pavement must be able to withstand many cycles of freezing and thawing and the effects of deicing salts. This requires quality aggregate, a low water-cementitious material ratio, an adequate cement factor, and a sufficient quantity of entrained air bubbles. The percentages of total air content necessary for weather-resistant concrete are shown in Table 4 (page 13). These recommendations vary depending on the exposure condition of the concrete. Adequate curing measures also are necessary for developing durable concrete pavement.

In addition to making the hardened concrete pavement weather resistant, entrained air bubbles improve the concrete while it is still in a plastic state by:

1. Reducing water required for satisfactory workability.
2. Preventing segregation.
3. Reducing bleeding.

Table 4. Recommended* total air contents.⁽¹¹⁾

Nominal maximum aggregate size in. (mm)	Target** percentage air content for exposure		
	Severe†	Moderate†	Mild†
2 (50)	5	4	2
1½ (37.5)	5.5	4.5	2.5
1 (25)	6	4.5	3
¾ (19)	6	5	3.5
½ (12.5)	7	5.5	4
⅜ (9.5)	7.5	6	4.5

* Canadian standards differ; refer to CSA Standard A23.1.

** A tolerance of -1% to +2% is typical for paving concrete.

† Severe exposure is an environment where concrete pavement is exposed to wet freeze-thaw conditions or deicers. Moderate exposure is an environment where concrete pavement is exposed to freezing but will not be continually moist, exposed to water for long periods before freezing, or in contact with deicers. Mild exposure is an environment where concrete pavement is not exposed to freezing conditions or deicers.

Because of these beneficial and essential effects in both plastic and hardened concrete, it is wise to consider using entrained air even in mild exposure conditions.

The quantity of water in the mixture also has a critical influence on the durability and weather resistance of hardened concrete.⁽¹¹⁾ For a given quantity of cementitious materials, a lower quantity of water will produce a more durable mixture in most cases. However, an adequate quantity of water is necessary to produce a workable concrete. Satisfactory pavement durability is generally achieved with:

1. A water-cementitious material ratio not exceeding 0.53 with a minimum cementitious material content of 520 lb/yd³ (310 kg/m³) for mild exposure conditions.
2. A water-cementitious material ratio not exceeding 0.49 with a minimum cementitious material content of 560 lb/yd³ (330 kg/m³) for moderate-to-severe exposure conditions (frequent freezing and thawing, and application of deicing agents).

Careful aggregate selection is important to avoid future problems with alkali aggregate reactions or D-cracking. Coarse or fine aggregates that are susceptible to alkali-silica or alkali-carbonate reactivity require special mixture proportions to produce durable concrete. Many agencies specify special mixtures when using locally available aggregates known to have reactivity potential. It is also possible to test a proposed concrete mixture to determine if there is reactivity potential. For more information, refer to References 12 and 13.

Fast-track Concrete Mixtures – Fast-track concrete mixtures develop strength rapidly and are beneficial when early opening of the pavement is necessary. For intersections, there are several practical options available to produce concrete that gains strength rapidly. The mixture components can be selected or proportioned for rapid strength gain, and the mixture water can be heated so cement hydration begins quickly.

Although proprietary cements are available, fast-track mixtures do not necessarily require these special materials. Rapid strength development is possible by using greater-than-normal quantities of ordinary ASTM C150 Type I and Type II cements, but high-early-strength ASTM C150 Type III cement may be used. Most aggregates and admixtures available locally also can be used in fast-track mixtures if combined in the proper proportions.^(14,15) Table 5 shows example proportions of a fast-track mixture.

Table 5. Typical fast-track mixture proportions.⁽¹⁴⁾

Material	Type	Quantity*
Cement	ASTM C150 Type I	700 – 800 lb/yd ³ (415 – 475 kg/m ³)
	ASTM C150 Type II	700 – 800 lb/yd ³ (415 – 475 kg/m ³)
	ASTM C150 Type III	600 – 750 lb/yd ³ (360 – 450 kg/m ³)
Fly ash	ASTM C618	10 – 20% by weight of cement
Water	ASTM C94	See note below
Air-entraining admixture	ASTM C260	As necessary
Accelerating admixture	ASTM C494	As necessary
Water-reducing admixture	ASTM C494	As necessary

* Use quantity of water appropriate to produce sufficient workability and maintain desired strength gain. Water-cementitious material ratio should not exceed 0.37 – 0.43 under most circumstances.

The sooner the concrete temperature rises, the faster it will develop strength. One way to raise the temperature of plastic concrete is to heat the mix water. This may be practical for intersection projects that do not require a large quantity of concrete.

Several factors influence the water temperature needed to produce a desirable mixture temperature at placement. The critical factors are: ambient air temperature, aggregate temperatures, aggregate free-moisture content, and portland cement type. When necessary, ready-mix concrete producers heat water to 140 to 150°F (60 to 66°C) to elevate mixture temperature sufficiently for cool-weather construction. The same practice will accelerate strength development in warmer ambient temperatures. However, to avoid a flash set using this method, combine the hot water and aggregates before adding the cement to the concrete mixer.⁽¹⁴⁾

Though hot water does facilitate early cement hydration, its benefits may be short-lived. Several hours of heat containment with insulating blankets may be necessary to achieve the desirable strength gain, particularly when cool weather conditions prevail.

Mixtures for Thin Overlays – The concrete mixture for thin overlays is often selected based on requirements for opening to traffic. A normal thin-overlay mixture includes: cement, coarse, and fine aggregate; air-entraining agent; admixtures (water-reducers or plasticizers); fibers (as specified); and a low water-cementitious materials ratio. Compared to aggregate used for thicker concrete pavements, the top-size of coarse aggregate for thin bonded or unbonded concrete overlays^(16,27) is reduced appropriately to account for the smaller thickness. When fibers are used in such a mixture, the fiber contents are usually in the range appropriate for the specific fiber type, although on some projects higher-than-normal dosages have been used.

Construction

Various methods and machines are used to build concrete pavement intersections, including slipform and fixed-form construction equipment. Unlike mainline roadway paving, intersection construction work usually necessitates some use of fixed-form placement. Contractors may elect to use slipform equipment in an intersection if the paving area is large enough to warrant its use, or if staging allows the contractor to build the driving lanes of the major roadway through the physical area of the intersection.

Despite the variety of possible equipment, the following construction steps are typical for nearly all types of concrete pavement.

1. Removing or planing an existing pavement (where necessary).
2. Preparing the grade.
3. Setting forms (where used).
4. Placing in-pavement objects (dowels, tiebars, and boxouts, where used).
5. Placing and finishing the concrete.
6. Texturing the pavement surface.
7. Curing the concrete.
8. Jointing the pavement.

■ Removing or Planing Existing Pavement

The first step in the complete reconstruction of an intersection is to remove the existing pavement.

The options for removing existing asphalt include: cold milling, scarifying, and excavating the material with equipment such as a front-end loader or bulldozer. Cold milling offers productivity and suitable grade control. Cold milling equipment uses carbide teeth mounted on a rotary drum. The teeth chip away existing asphalt as the drum rotates. The size of the broken material depends upon the tooth configuration, drum rotation speed, forward machine speed, and removal depth. Particle size also varies with the temperature, condition, and asphalt content of the old hot-mix asphalt. The ability to control particle size is helpful when the asphalt millings are reused on the project for fill or subbase.

Attaining the desired removal depth may require several milling passes. Commonly available machines can remove 6 in. (150 mm) of asphalt material in one pass.

Scarifying or ripping is also common for removing thin layers of existing asphalt. This method uses motor-graders or bulldozers equipped with scarifying equipment. While scarifying is less expensive than cold milling, there is also less ability to control removal depth or grade. Nevertheless, scarifying equipment is adequate when the removal goes below the depth of all asphalt layers.

There also are three methods for removing existing concrete or composite pavements:

1. Break the concrete into small fragments for removal by backhoe and hand tools.
2. Lift the concrete out of place in large segments.
3. Scarify the concrete with large milling machines.

At urban intersections, the optimal method depends upon the size of the intersection, the allowable time for removal, the land use in the surrounding area, and concerns about noise and dust generation. The presence of sensitive utility pipes, conduits, or cables beneath the pavement also may discourage use of equipment that imparts impact vibrations. In general, the selection of the most productive removal method should be left to the contractor based on experience and available equipment.

If an existing asphalt intersection will receive a concrete pavement overlay, removal of the existing asphalt should stop short of the subbase or subgrade. Because cold milling offers excellent grade control, it is the best choice for removing controlled layers of existing asphalt pavements. The rough surface from milling also provides an excellent bonding surface for the overlay.^(16,17,27) For bonded concrete overlays less than 4 in. (100 mm) thick, current recommendations^(16,27) suggest that at least 3 in. (75 mm) of asphalt thickness remain after milling to promote composite action.

■ Preparing the Grade

A reasonably uniform subgrade or subbase, with no abrupt changes in support, is ideal for any concrete pavement. Achieving this condition after pavement removal operations will require some effort even in the relatively confined work area of an intersection. The first step is to ensure as much as is practicable, so that the subgrade soils are of uniform material and density.

Compacting the subgrade surface adequately requires a compactor heavy enough to achieve 95 percent of maximum density determined through ASTM D698. However, it may be difficult to maneuver large compactors in a trench created by removing an older pavement for an intersection. A more effective strategy in a confined area may be to apply more compaction effort using smaller equipment.

The soil moisture content should be reasonably uniform during compaction; excessively wet or dry spots require correction to produce reasonable uniformity. For most soils, compaction should be accomplished at moisture contents at or slightly above optimum.

Soft spots in the subgrade often become visible after removing an old pavement. It is not acceptable to merely place a granular layer over these soft areas; excavation and

removal is necessary. Ideally, the replacement soil should be of the same type as in the surrounding subgrade to develop uniform support.

Contractors must pay particular attention to sections of the subgrade overlying any utility installations such as sewers, telephone and power conduits, and water lines. Careless compaction of fill materials in these trenches often causes soft spots in the subgrade. Controlled low-strength fill (flowable-fill) materials are an economical alternative for these areas.

Flowable-fill materials do not need compaction and flow easily to fill a trench. The mixtures contain portland cement, sand, fly ash, and water and typically develop 28-day compressive strengths of about 50–100 psi (0.35–0.70 MPa). Flowable-fill materials provide enough strength to prevent settlement, but are easy to remove using a bucket on a backhoe or front-end loader if future excavation is necessary.

Subbase – A subbase is a thin layer of engineered material placed on top of the prepared subgrade. Subbases provide uniform support to the pavement and a stable platform for construction equipment. Subbases also help prevent mud-pumping of fine-grained subgrade soils at transverse pavement joints in roads subject to a large volume of unidirectional truck traffic. Intersections at residential streets and even some streets that may carry heavier vehicles usually do not require a subbase.

Where used, unstabilized subbase thicknesses should not exceed 4 to 6 in. (100 to 150 mm). A thicker subbase is not necessary or economical under most conditions. Good dense-graded, granular-subbase materials have a plasticity index of 6 or less, and contain a maximum of 15 percent fine particles that pass the No. 200 (75 μ m) sieve. For stability, the subbase requires compaction to 100 percent maximum density as determined by ASTM D698 (Figure 9).



Figure 9. Compacting subbase.

Trimming – The method for trimming or shaping the grade varies by project and may depend upon intersection size. Typical specifications⁽¹⁸⁾ require:

1. A subgrade surface that does not vary from the design elevation by more than 0.5 in. (12 mm).
2. An unstabilized subbase surface with deviations that do not exceed 0.5 in. (12 mm), longitudinal or transverse, by a 10 ft (3 m) straightedge.

On large intersections, contractors may use automatic trimming equipment to shape the subbase or subgrade and deposit any excess material outside the paving area. For fixed-form paving, the automatic trimming machine rides on the forms after they are fastened into place. For slipform paving, the trimming machine references the stringline(s) for the slipform paving machine.

On small projects and in confined work zones, it may not be practical to use automatic trimming equipment, and the contractor will probably trim the grade with a motor grader or small loader.

Because final trimming disturbs the subgrade or subbase surface slightly, additional compaction rolling is usually necessary (Figure 9).

■ Placing Forms

Fixed-form paving is almost always necessary for the short paving segments, varying paving widths, and curved paving areas common to intersections.

Form placement at intersections does not vary much from form placement along straight pavement sections. Straight sections require standard 10-ft (3-m) steel forms that fasten to the subgrade with three pins or stakes (Figure 10). A stringline set to the top elevation of the pavement determines the location and height for the forms. A stake spacing for the stringline of about 25 ft (7.5 m) will produce good results for straight sections.⁽¹⁹⁾

Each straight metal form must be clean and unmarred to produce a smooth pavement. Contractors should examine forms with a straightedge or stringline before using the forms on a project. Straight form sections that deviate by more than 0.125 in. (3 mm) along the top, or 0.25 in. (6 mm) along the inside edge should be replaced.



Figure 10. Forms should rest on a level surface, and should be fastened securely and pinned in place.

The quality of the support beneath the form depends upon the trueness of the subgrade or subbase surface. The base of the form should bear against the subbase or subgrade surface completely and not lie on any clumps of dirt or large rocks. After setting the forms, the form crew should visually check to ensure the forms are aligned and fully supported, as well as to be sure the form ends are locked together securely. Adequately securing forms is a crucial step because the forms must support equipment and remain in place until the concrete has hardened. For ease of removal and cleaning, forms require a thin application of form-release oil before paving.

Standard 10-ft (3-m) straight forms are acceptable for forming compound-radius curves and curve radii exceeding 100 ft (30 m), but smaller radii require curved steel or flexible wooden forms.⁽¹⁹⁾ Short, 5-ft (1.5-m), straight forms also produce acceptable results on curves less than 100 ft (30 m).⁽²⁰⁾

Curved sections require a tighter stringline staking interval than straight sections. To ensure the forms meet the design location and surface elevation, a stringline staking interval of 5 ft (1.5 m) is ideal for curve radii less than 50 ft (15 m). Additional bracing is also sometimes necessary to secure forms around smaller curves; where necessary a bracing interval of 2 ft (0.6 m) is usually sufficient.

■ Placing In-Pavement Objects

Ideally, in-pavement objects should be in position before placing the concrete. This includes utility boxouts, cast-in-place fixtures, traffic signal handholds, dowel assemblies (baskets), tiebars, and welded wire fabric. However, in some cases it is necessary for the contractor to use the prepared grade to haul concrete to the paving equipment, requiring placement of fixtures as work progresses.

Contraction-joint dowel assemblies should be fastened to the subbase using steel staking pins for granular materials or nailing clips for stabilized materials. Care in positioning the baskets is necessary so that the dowels align with the pavement centerline. A permanent mark indicating the location of the dowel baskets is necessary for reference when later sawing the contraction joints.

In some cases for longitudinal joints, contractors elect to place tiebars into position ahead of paving. Straight deformed bars on supporting chairs fasten to the subbase or subgrade in a manner similar to dowel baskets. In fixed-form construction, standard deformed tiebars or two-piece bars with a threaded coupling may be inserted through holes in side forms for longitudinal construction joints.

Cast-in-place utility fixtures and boxout forms that are within the paving area should be in position and secured before paving. For either fixed-form or slipform paving, the boxout's top surface must be about 0.5 in. (12 mm) below the finished height of the slab. This allows a paver or screed to pass over the boxout without problems and eases surface shaping to provide proper drainage.

The two-piece casting of a telescoping manhole has several height positions. A position that places the casting's surface below the pavement surface also allows the paver or screed to pass. Just after the paving equipment passes over the fixture, workers must raise the casting into final position from a construction bridge that spans the pavement.

Large-diameter [up to 50 in. (1270 mm)] coring equipment is another available option, which reduces construction preparation time. The equipment can core concrete around existing or planned manholes and eliminate the need to place utility boxouts before paving.

In Northern regions, consideration should be given to leaving manholes 0.25–0.5 in. (6–12 mm) below the pave-



Figure 11. Dowels, tiebars and utility fixtures in position for fixed-form paving.

ment elevation to ensure that snowplows do not catch on the manhole lids.

■ Placing the Concrete

Regardless of placing equipment, the paving steadiness impacts the finished pavement smoothness and quality.⁽¹⁹⁾ Consistent delivery of concrete to an intersection project site is an important element. Dense urban areas require careful evaluation to predetermine whether traffic delays will hamper concrete delivery. Consideration of the concrete mixture is also necessary, with normal-setting mixtures allowing longer travel times than fast-track mixtures.

Good batch-to-batch consistency of the concrete also improves the quality of the finished pavement. Batch-to-batch consistency allows the paving machine operator to maintain the paver at a steady forward speed, and produces uniform extrusion pressure. Both stationary (ready mix) plants and on-site batching and mixing plants can produce concrete with consistent properties.

Before placing concrete, moisten the subbase or subgrade surface. A dry surface may absorb water from the concrete and lead to unwanted shrinkage cracking in the pavement. For larger paving areas, a water truck is generally available for this purpose. Ready-mix trucks also have a tank that can supply the water necessary to moisten the subgrade in small paving areas.

When placing a concrete overlay on a milled asphalt surface, no moistening is normally necessary. Concrete overlays less than 4 in. (100 mm) thick, which rely on bonding to the asphalt, require a dry surface. However, thicker overlays, which do not rely on bond, may require whitewashing to cool a dark asphalt surface. The need for whitewash depends upon the ambient and asphalt-surface temperature. More information on whitewash is available in Reference 17.

Fixed-Form – There are a variety of fixed-form paving machines. The less complex equipment such as hand-operated and self-propelled vibratory screeds, single-tube finishers, and revolving triple tubes, are useful for almost all complex paving areas. The external (surface) vibration that this equipment produces is adequate to consolidate most pavement slabs. However, supplementary internal vibration with hand-operated spud vibrators is usually necessary for adequate consolidation of non-reinforced concrete slabs thicker than 10 in. (250 mm). A combination of internal and surface-vibration is preferable for reinforced slabs of any thickness.⁽¹¹⁾ Because surface vibration of concrete is least effective near the forms, it is beneficial to consolidate concrete along the forms with a spud vibrator.

Larger, form-riding machines can place and consolidate the concrete between forms in one pass. These machines either ride on the forms or pipes laid outside the forms. Since form-riding paving equipment cannot produce acceptable results riding on wooden forms, most of the curved areas joining intersecting pavements require use of hand-placement equipment, such as vibratory or roller screeds.

Evenly depositing concrete onto the grade in front of the fixed-form placement machine eases paving. Piling too much concrete in front of the machine leads to strikeoff difficulty. The concrete should not overly exceed the height of the forms. However, piling too little concrete in front of the machine may produce low spots in the pavement surface. Although it is ideal to distribute the concrete evenly with the chute from the ready mix or other concrete hauling truck, some distribution of the concrete with hand tools is usually necessary. Shovels are preferable to other hand tools for this purpose because they are less likely to cause concrete segregation.

When necessary, supplemental vibration with handheld spud vibrators should precede the placement screed. Standard practice for thicker slabs calls for vertical plunges of the vibrator head. For thin slabs, it is preferable to insert the vibrator head at an angle or horizontally to keep it

completely immersed in the concrete. Operators should neither drag spud vibrators through the concrete nor attempt to move the concrete laterally, as either will segregate the mixture.

In general, proper consolidation of air-entrained concrete takes less time than consolidation of non air-entrained concrete, even when both mixtures are prepared with the same consistency (slump). The vibration time necessary to achieve adequate consolidation also depends upon the size and type of vibrator. For most equipment, leaving the

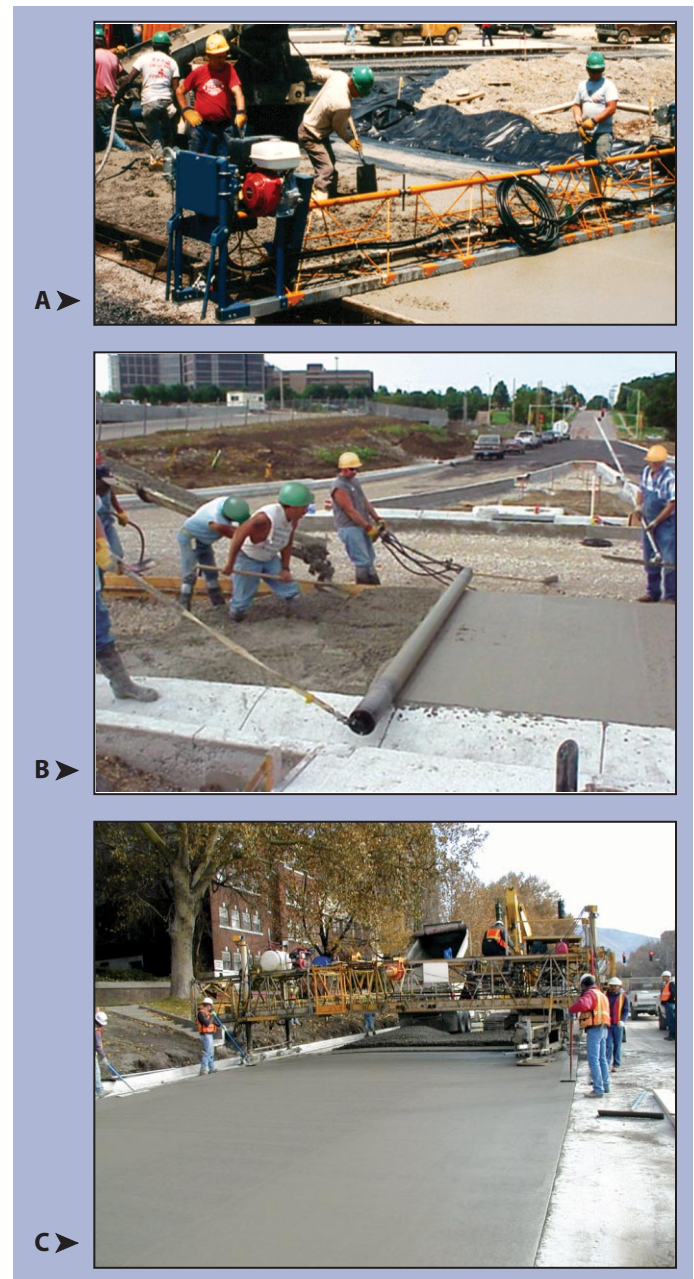


Figure 12. (A) Vibrating screed, (B) Roller screed, (C) Form-riding paver.

vibrator head inserted for 5 to 15 seconds is usually adequate.^(11,19)

Slipform – Use of slipform paving equipment for intersection reconstruction is not very common. However, a contractor may elect to use slipform equipment in an intersection if the paving area is large enough to warrant its use. Paving the curb and gutter is another common use of a slipform machine for intersection construction.

There are many sizes of slipform paving machines, with many smaller models available for urban paving. Slipform paving machines spread, consolidate, screed, and float-finish the concrete in one pass without the need for fixed side forms. Generally, contractors preset stringlines to establish the line and grade control for the paver.

Like fixed-form paving, depositing concrete in front of the paver evenly will improve the resulting pavement. A slipform paver must further spread and consolidate the concrete as it moves forward and cannot produce adequate results if it must push a large pile of concrete. When operating properly, a well-consolidated and properly-shaped slab emerges behind the slipform paver as it moves steadily forward.

Certain slipform paving equipment can pave curbs and gutters and easily pave around curves between intersecting roadways. Some slipform paving machines can place curbs integrally with the driving lanes (Figure 13). In such cases, the contractor must attach a curb mule to the paver so that the curb section will extrude out as the paver moves forward. Integral curbs eliminate a separate forming or placing operation that is otherwise necessary for most urban roadways.

More detailed information on properly setting up and operating slipform equipment is available in Reference 19.

■ Finishing the Surface

After the paving equipment passes, it may be necessary to further finish the concrete surface to remove small imperfections and smooth any bumps. There are a number of different automatic and hand-operated finishing tools available for this purpose. In the tight work zones typical of intersection construction, most contractors will opt for hand finishing tools.

Finishing is necessary earlier with air-entrained concrete than non-air-entrained concrete because air-entrained concrete develops much less bleed water. It is customary to wait until all bleed water leaves the concrete slab surface before finishing non-air-entrained concrete.

Checking the surface behind the paving equipment with a 10 to 16 ft (3 to 4.8 m) hand-operated straightedge is a recommended procedure.⁽¹⁹⁾ Successive straightedging should overlap by one-half the length of the straightedge to ensure that the tool removes high spots and fills low spots in the surface. Experienced finishers can use the straightedge to remove noticeable bumps by employing a scraping motion. Otherwise, they use a long-handled float to smooth bumps and disturbed places in the surface.

Edging is necessary for any concrete placed against fixed forms. The small edging tool effectively smooths the slab corner and separates the concrete from the form. Without separation, the concrete may adhere to the top of the form, and tear or spall upon form removal.

Particular attention also may be necessary for finishing around boxed-out fixtures and cast-in-place fixtures. Ideally, the height adjustment and supplemental vibration around the object are complete before workers need to finish the pavement surface. If properly positioned, the object should easily blend into the surrounding pavement. Some surface warping may be necessary if the object is too high or too low.

Smoothness Requirements – Smoothness or rideability requirements can be applied to intersection projects. However, less stringent requirements are necessary than



Figure 13. Slipform pavement with integral curb.

are normally required for high-speed highways. Warping of slabs to meet fixtures (manholes, drainage inlets, etc.), existing curb and gutter, and cross- or side-road connections make meeting highway-standard smoothness requirements very difficult in most cases.

For California profilograph testing of intersection projects, the acceptable rideability index should be relaxed, and certain areas should be excluded from measurement. Those areas at intersections which should be excluded from testing include: acceleration and deceleration tapers, auxiliary (right and left turn) lanes, sections less than 50 ft (15 m), and locations that require surface warping that make profile testing irrelevant. For more information, see Reference 21.

For small projects, excluded areas, and odd-shaped areas, surface testing with a 10-ft (3-m) straightedge [$\frac{1}{8}$ to $\frac{3}{16}$ in. (3 to 5 mm) allowable deviation] will produce acceptable smoothness.

■ Texturing the Surface

The surface texture necessary for intersection pavements depends upon the speed limit of the approach roadways. For low-speed residential, municipal collector, or urban business streets, a burlap, turf-drag, or coarse broom surface texture is usually sufficient to provide the microtexture necessary for wet weather stopping.⁽²²⁾ High-speed [i.e., +50 mph (+80 km/h)] arterial roadways also require a good macrotexture to reduce the water film thickness enough to prevent hydroplaning.[‡]

The texture chosen for the intersection must be applied after finishing and before curing the concrete. Either mechanical or hand-operated equipment can adequately apply the texture; however, confined intersection work zones may limit the practical use of mechanical equipment.

■ Curing the Concrete

Curing is the treatment or protection given concrete during the hardening period. Curing measures are necessary to maintain a satisfactory moisture and temperature condition in the concrete because internal temperature and moisture directly influence both early and ultimate concrete properties.^(11,14) Proper curing measures prevent rapid water loss from the mixture and allow more thorough cement hydration. Therefore, to maximize concrete quality, it is necessary to apply curing measures as early as possible after placing concrete.^(11,14) Curing is also critical to providing a durable pavement surface that will retain surface texture.

A variety of curing methods and materials are available for concrete pavement, including: water spray or fog, wet burlap sheets, plastic sheets, insulating blankets, and liquid-membrane-forming compounds.

The application of a liquid-membrane-forming compound to seal the concrete surface is the most common curing method for concrete pavement. A liquid-membrane-forming compound that meets ASTM C309 material requirements is adequate for most situations when applied at the following rates:

1. 200 ft²/gal (5.0 m²/L) for normal paving applications.
2. 150 ft²/gal (3.75 m²/L) for fast-track concrete.
3. 100 ft²/gal (2.5 m²/L) for thin overlays.

White-pigmentation in the compound is preferable to a clear compound so coverage is easily seen. The pigment also reflects solar radiation that may otherwise heat the concrete surface excessively.

The first few hours after paving — when the concrete remains plastic — are the most critical for good curing. As such, the contractor should apply a curing compound as

[‡] For concrete pavement, macrotexture refers to texture added to the surface of slabs by mechanical means. All state agency specifications require concrete pavement to have a surface texture that aids stopping in wet weather. The specific texture varies greatly among agencies, but the state-specified texture is usually meant for high speed highways and is commonly either transverse or longitudinal tining. Uniform spaced transverse tining typically produces a tire whine at high speeds but can produce acceptable noise levels on lower speed roads. The characteristic whine can also be used as an acoustical warning of an approaching intersection if that is desirable. For noise sensitive areas, drag textures such as astro turf or burlap drag or tined textures such as longitudinal tining or narrow spaced transverse tining $\frac{3}{8}$ to $\frac{1}{2}$ in. (9 to 12 mm) can be used. When selecting a texture, safety needs to be balanced with the noise issues to ensure proper frictional properties are achieved. For tining operations, typical requirements are a tine depth of $\frac{1}{8}$ to $\frac{1}{4}$ in. (3 to 6 mm) and a tine width of $\frac{1}{8}$ in. (3 mm). Longitudinal tining is typically placed on $\frac{3}{4}$ in. (19 mm) center-to-center spacing.⁽²²⁾

soon as possible after the water sheen has left the surface and texturing is complete. A variety of spraying equipment is available, but on most intersection projects, simple hand sprayers are the likely choice.

The initial application of curing compound should coat both the top and edges of slipformed concrete. For fixed-form paving, the curing compound should initially coat the exposed concrete surface. If removing forms early, a second coat should be applied to any exposed vertical edges of the slab to provide a complete seal.

Insulating blankets are sometimes also necessary for curing fast-track concrete in intersection work. The purpose of insulating fast-track concrete with blankets is to aid early strength gain in cool weather conditions. The blankets reduce heat loss and lessen the influence of both air temperature and solar radiation on the pavement temperature. The blankets are not a substitute for curing compound, which is still needed to contain moisture for thorough hydration. Table 6 indicates when insulation is recommended for fast-track concrete.^(14,15)

Normal curing measures without insulation are acceptable where rapid strength gain is not required. However, special precautions are necessary when the intersection is being constructed either in very cold or hot weather. More information on curing, including wet curing, blanket insulation, and cold-weather and hot-weather construction techniques, is available in References 11, 14 and 15.

■ Jointing the Pavement

At-grade concrete intersections usually require every joint type. The design details and specific purpose of each type are defined in “Jointing” on page 4. Typical construction methods are described below.



Figure 14. Curing blankets moved aside for sawing fast-track concrete.

Construction Joints – At intersections, transverse construction joints typically are built by hand at predetermined locations. This requires a form (header board) that can contain the concrete, and secure dowels or tiebars positioned and aligned properly (Figure 11). Vibration of concrete near the construction joint is important to ensure good encapsulation of the steel bars. If the construction joint provides a transition from concrete to asphalt pavement, special transition forming may be necessary (see page 25, “Concrete-to-Asphalt Transition”).

For either fixed side forms or slipform construction, the slab edge provides the longitudinal construction joint. The contractor will pre-position tiebars and keyways for fixed-form construction. While most fixed forms come with pre-drilled holes for the tiebars, the contractor will probably have to attach a board to the side forms to make a keyway. A contractor can equip a slipform paver with a tool to form a keyway along the slab edge as the paver progresses forward. Where required, tiebars are inserted into the slipformed edge while the concrete is plastic, or after hardening they can be anchored into holes drilled in the pavement edge.

Table 6. Recommended conditions requiring insulating blankets.^(14,15)

Minimum air temperature during time period	Opening time, hr				
	8	16	24	36	48
<50°F (<10°C)	Yes	Yes	Yes	Yes	No
50 – 65°F (10 – 18°C)	Yes	Yes	Yes	No	No
65 – 80°F (18 – 27°C)	Yes	No	No	No	No
>80°F (>27°C)	No	No	No	No	No

Isolation Joints – T- and asymmetrical intersections may require a thickened edge or sleeper-slab isolation joint. The thickened edge isolation joint is usually preferable to a sleeper-slab isolation joint to avoid the additional time necessary to build and cure the sleeper. Specific site and staging conditions will dictate where a contractor positions the isolation joint. The joint filler material must stand vertically, extend completely through the entire slab thickness, and be held firmly in position (usually by stakes driven into the subgrade.) The isolation joint material is usually a non-absorbent foam board or bitumen-treated fiberboard. A width from 0.5 to 1.0 in. (12 to 25 mm) is adequate.

A longitudinal isolation joint is necessary wherever the pavement abuts sidewalks, driveways, or aprons. The joint will permit differential movement that might otherwise damage the pavement or curb. Against aprons and older driveway pavements, the isolation joint eliminates “sym-

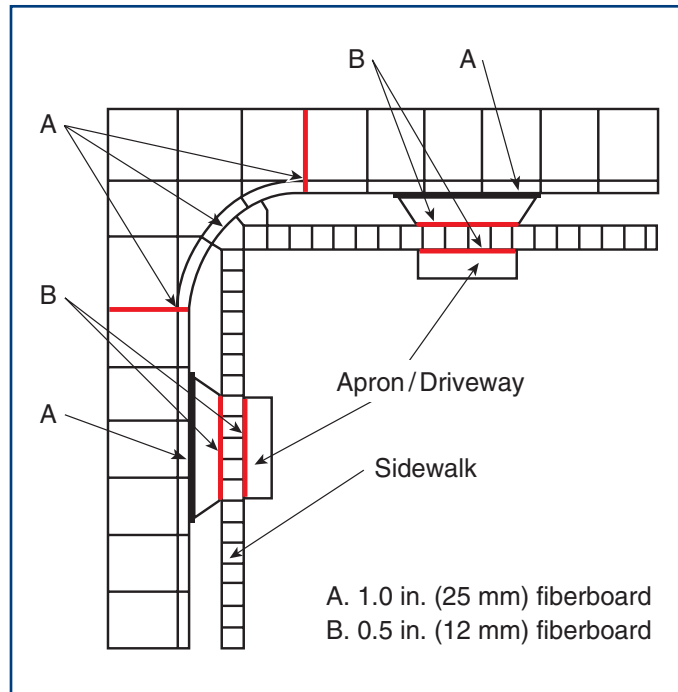


Figure 15. Location of isolation joint for curb and gutter, aprons and driveways near concrete intersections.

pathy” cracking where it is not possible to match the joints in the other pavement. The contractor must position a section of joint filler against the back of the curb before placing the concrete for new aprons, driveways or walks. If the new concrete pavement will directly abut an older concrete pavement, the filler must rest against the older pavement before starting construction. A wider isolation filler is recommended between the roadway pavement

and an abutting sidewalk or apron than is recommended between sidewalks and apron or driveway pavement (Figure 15).

Contraction Joints – After paving and curing the concrete, the final step is to place the longitudinal and transverse contraction joints. Although there are several methods to form these joints in the plastic concrete, sawing the concrete after hardening is by far the most common method. Contractors have successfully cut contraction joints using wet-, dry-, and early-age-sawing equipment.^(14,23)

The saw cut provides a plane of weakness where cracking will begin. Using conventional saws, a cut depth of at least one-fourth the slab thickness ($T/4$) and $1/8$ in. (3 mm) wide generally controls crack formation for transverse contraction joints. However, for pavement on stabilized subbases, an increase in the initial saw cut to a depth equivalent to one-third the slab thickness ($T/3$) is required for transverse contraction joints. The extra cut depth accentuates the plane of weakness to overcome additional frictional restraint and higher curling stresses in the concrete caused by the stabilized subbase. Longitudinal contraction joints require a cut depth equivalent to one-third of the slab thickness ($T/3$) regardless of the subbase.

The time of sawing is critical for proper contraction joint formation. Sawing too soon results in spalling and raveling along the joint face. Sawing too late results in random cracking elsewhere in the slab. Joint sawing with conventional saws should begin whenever the concrete strength is adequate and the saw blades will not excessively ravel the concrete surface. This occurs sometime between 4 to 24 hours after paving, but usually within the first 12 hours. Weather (temperature, wind, humidity, and direct sunlight) has a large influence on concrete strength gain and the optimal time to begin sawing.

The concrete mixture itself also affects the optimal time to begin sawing. Mixtures made with softer limestone aggregates require less strength before sawing than do mixtures with harder coarse aggregates.⁽²⁴⁾ Fast-track mixtures that gain strength quickly also require sawing to begin much sooner than normal-setting mixtures.

Early-age saws allow cutting after compressive strengths reach about 150 psi (1.0 MPa), usually about an hour or two after paving. Most currently available early-age saws provide a shallow cut at about 1 to $1\frac{1}{4}$ in. (25 to 33 mm) deep. The shallow cut has been shown to control cracking effectively at transverse joints when made early, before the final set of the concrete.⁽²³⁾

The time of sawing is usually not quite as critical for longitudinal contraction joints as it is for transverse contraction joints. However, longitudinal contraction joint sawing should follow closely behind sawing of transverse contraction joints whenever practicable. This will reduce the possibility of uncontrolled longitudinal cracking.

If the transverse contraction joints contain dowels, the saw operator should reference the markers on either side of the slab to determine where the baskets are and where to position the saw cut. For typical dowel-jointed pavements with 15-ft (4.5-m) panels, there is usually 2 to 3 in. (50 to 75 mm) tolerance on either side of the true center of the dowels, depending upon dowel length. Saw cuts that are within the tolerance provide the typical minimum 6 in. (150 mm) of dowel embedment necessary for effective load transfer.

The presence of tiebars along the longitudinal contraction joint necessitates similar care by the saw operator to center the cut over the steel tiebars.

Soon after wet-sawing, the crew should flush sawed joints with water to remove saw slurry. If left in place, the slurry will eventually harden and become more difficult to remove. In some conditions, the hardened slurry may even impede joint closure during warm periods.

■ Opening to Traffic

The basis for deciding when to open a concrete intersection to construction or public traffic should be the concrete's strength and not an arbitrary time from placement.^(14,15) Strength directly relates to the pavement's load bearing capacity.

As slab support or pavement thickness increases, stress in the concrete will decrease for a given load. This relationship allows different opening strength criteria for different pavement designs and early traffic loads.^(14,15,24)

Table 7 provides traffic opening criteria for public vehicles on concrete pavement. The table assumes a 2.0-ft (0.6-m) offset of traffic from the lane or pavement edge. Wide truck lanes, tied concrete shoulders, and curbs and gutters can all serve to reduce load stresses to levels equivalent to a 2.0 ft (0.6 m) traffic offset. If the pavement design does not include these features, the contractor can place barricades to prevent edge loads. After the concrete compressive strength reaches 2500 psi (17 MPa), or flexural strength reaches 450 psi (3.0 MPa), the contractor generally may remove the barricades. However, it may be necessary to wait for concrete to gain full design strength on thin municipal pavements.

A correlation between compressive strength and flexural strength can be made in the laboratory for each unique

Table 7. Strength necessary to open concrete pavement to public traffic (based on References 14 and 15).

Slab thickness	Foundation support*	Opening strength**	
		Compressive*** psi (MPa)	Flexural (3rd-point) psi (MPa)
6.0 in. (150 mm)	Unstabilized	3600 (24.8)	540 (3.7)
	Stabilized	1690 (11.7)	370 (2.6)
8.0 in. (200 mm)	Unstabilized	1350 (9.3)	330 (2.3)
	Stabilized	1100 (7.6)	300 (2.1)
10.0 in. (250 mm)	Unstabilized	1100 (7.6)	300 (2.1)
	Stabilized	1100 (7.6)	300 (2.1)

* Unstabilized (granular) foundation assumes a Modulus of Subgrade Reaction, $k = 100 \text{ psi/in. (27 MPa/m)}$. Stabilized foundation assumes $k = 500 \text{ psi/in. (135 MPa/m)}$.

** Assumes there will be 500 one-way equivalent single axle load (ESAL) repetitions between time of opening and time concrete reaches design strength (28-day strength).

*** There was no compressive strength criteria in the original research (Reference 14). The values shown here were developed using the correlation equation described in this section with $C = 9.0$. It is strongly recommended to develop a unique correlation between flexural and compressive strength for new mixtures.

concrete mixture. Equation 2 is an example of a relationship between compressive strength and third-point flexural strength. This relationship was developed from a finite set of mixtures, and may not be valid for your particular mixture.⁽²⁵⁾

$$f_r = C \cdot (f'_{cr})^{0.5} \quad (\text{Eq. 2})$$

where:

f_r = flexural strength (modulus of rupture) in third-point loading, psi (MPa).

f'_{cr} = required average compressive strength, psi (MPa).

C = A constant between 8 and 10 psi (for normal mixtures) [for high-strength concrete C ranges from 7.5 to 12 psi (11.7 recommended)].

Non-destructive Testing – Some agencies, consultants, and contractors use non-destructive strength testing to evaluate concrete pavement at early ages. Maturity and pulse velocity testing methods are common on fast-track concrete pavement projects.^(14,15)

Maturity testing provides strength evaluation through monitoring of internal concrete temperature in the field. The basis of maturity is that each concrete mixture has a unique strength-time/temperature relationship. Therefore, a mixture will have the same strength at a given maturity no matter what conditions (time or temperature) occur before measurement.^(14,15) To implement maturity on a project, technicians must develop a calibration curve in the laboratory or in the field prior to start of paving. The calibration curve is used to estimate strength values from field temperature measurements.

Pulse-velocity is another non-destructive test available for determining concrete strength at early ages. It is a true non-destructive test that measures the time required for an ultrasonic wave to pass through concrete from one transducer to another. The velocity of the wave correlates to concrete strength or stiffness.^(14,15) Like maturity testing, pulse-velocity testing requires laboratory calibration to produce meaningful field information. In the laboratory, technicians make pulse-velocity measurements through a representative number of cast concrete specimens, test the specimens for strength, and plot the results against the pulse-velocity readings to create a calibration curve.

Non-destructive test methods may be better suited to evaluate opening strength of concrete intersections and other pavement because there is no delay between sampling and testing the concrete. With standard cylin-

ders or flexural beams, specimens must be prepared and sometimes transported to a testing laboratory. Furthermore, unlike conventional strength tests that measure the potential strength under standard conditions, non-destructive test methods give an indication of the in-place strength. References 14 and 15 provide more information on non-destructive test methods.

Vehicle Detector Loop Installation

Traffic signal design is based largely on the traffic volumes and the geometrics of the intersection. Most heavily-traveled intersections require traffic control signals with traffic-sensing detectors. Presently, the most common vehicle detector is the inductive loop detector.⁽²⁶⁾ These detectors can be installed into saw cuts in the pavement surface, cast into the concrete, or fastened to the grade in preformed loops.

Vehicle-detector loops that install into saw cuts can last for many years after proper installation. A 0.25-in. (6-mm) wide saw cut to a depth of 2 in. (50 mm) is necessary to recess the detector below the pavement surface. Figure 16A shows three common configurations. After sawing, detector system manufacturers recommend flushing the saw cuts with water to remove saw slurry, then using compressed air to remove debris that may puncture the wire insulation. Rounding the corners of diagonal or rectangular loops with additional saw cuts or 0.75-in. (18-mm) diameter core holes will ease insertion of the detector wire and allow the wire to remain more flexible, preventing rupture.

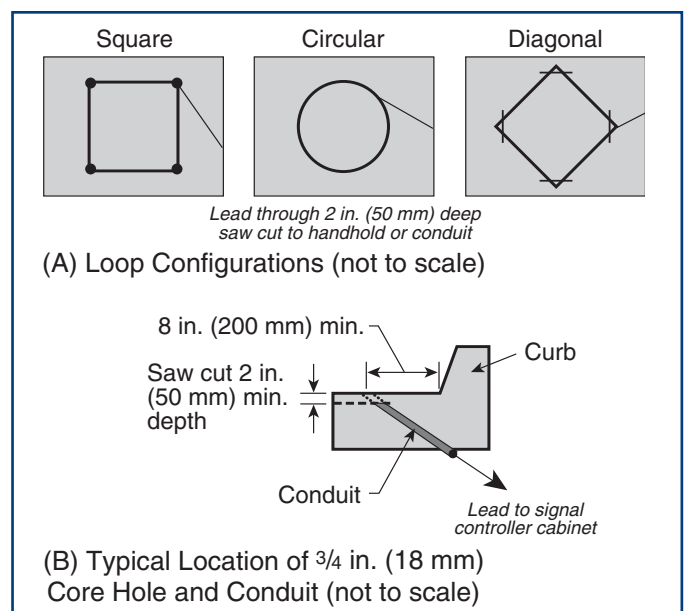


Figure 16. Vehicle detector loop configurations.

Detector system manufacturers⁽²⁶⁾ recommend installing 16 AWG stranded wire with a coating suitable for the sealant. An outer jacket of 0.050 in. (1.25 mm) polyester wire insulation with an additional

A polyester coating of 0.032 in. (0.8 mm) provides protection from melting to 400°F (204°C) and is suitable for hot-applied sealants. Cold-applied sealants and epoxies that are specifically formulated for installing loop detectors also are readily available.

The detector wire should be flexible enough to give with pavement movement but provide enough tension to remain in the bottom of the saw cut. A backer rod placed above the wires is recommended by detector system manufacturers to ensure the wires remain in place.

Preformed loops can be cast into concrete and do not require sawing. In a preformed loop, PVC pipe encapsulates the detector wires for protection and provides rigidity to the loop during installation. The loops must be fastened securely into position before paving at a minimum of 2 in. (50 mm) above any reinforcing steel. If the slab contains welded wire fabric or bar mats, the pipes should not align with the reinforcement grid (Figure 17). Any reinforcing steel that aligns with the pipes will interfere with the inductive loop.

The detector wires often break near the conduit that brings them to a signal handhold or the signal controller cabinet. To avoid breakage, it is advantageous to core drill this location to provide a larger recess (Figure 16B).

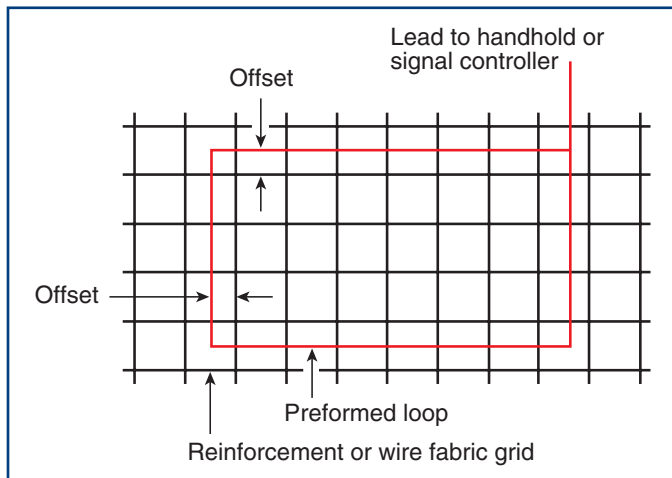


Figure 17. Aligning preformed vehicle loop detectors above reinforcing steel.

Concrete-to-Asphalt Transition

The transition between a concrete pavement intersection and an asphalt pavement can be troublesome if poorly designed. Figure 18 shows four transition details for different concrete pavements. Details A, B and C account for impact loads on the transition slab with extra thickness (Details A and B are for concrete overlays of existing asphalt pavement).

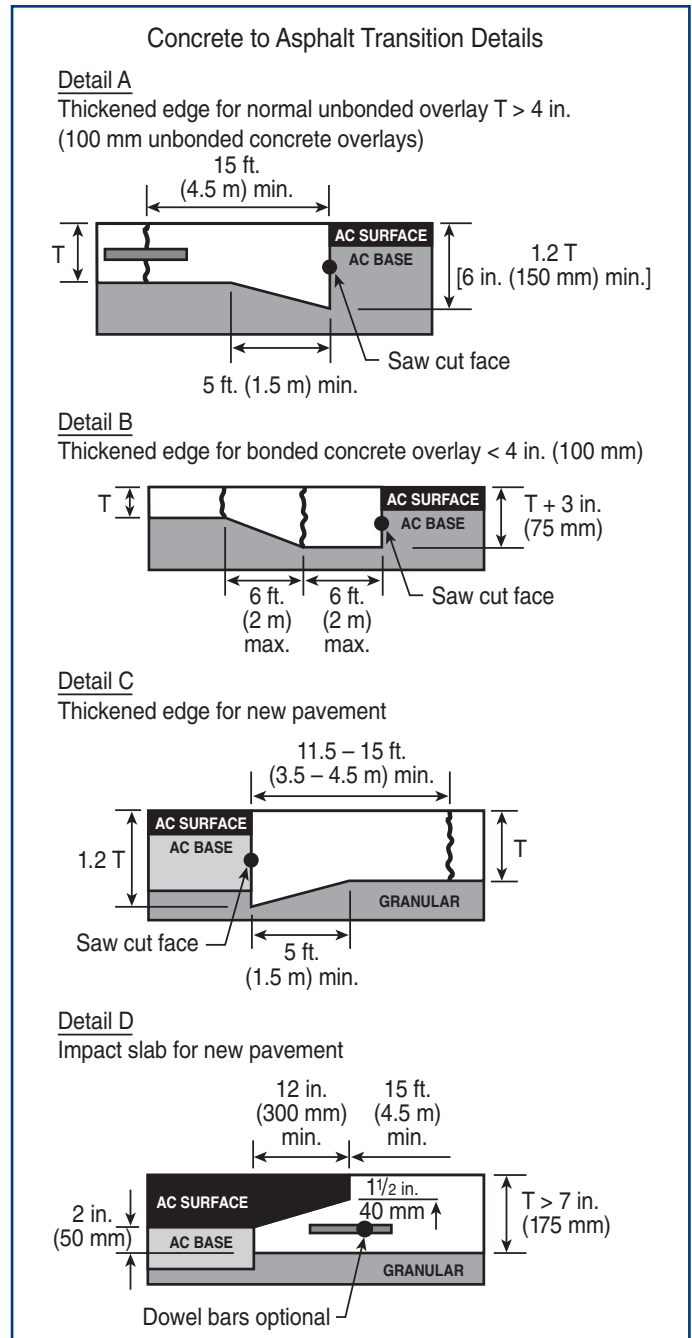


Figure 18. Transition details for concrete pavement to asphalt pavement.

Detail D shows an impact slab, meant for pavements that frequently carry heavy trucks and are thicker than 7 in. (175 mm). The impact slab protects the asphalt pavement from deformation by providing additional support at the transition. Contractors can easily create the lip in the impact slab using a false form header.

One way to keep the slabs near the transition from migrating on unstabilized subbases is to place deformed tiebars in the first three transverse contraction joints. The tiebars will hold the slabs tightly together. Slab migration is not an issue with concrete overlays on asphalt because the concrete established sufficient bond to the asphalt surface.

■ Adding Lanes to Existing Concrete Pavement

Some intersection improvements require additional concrete lanes next to existing concrete pavement or curb and gutter. For these improvements it is essential to place transverse contraction joints (Type A-1 or A-2, Figure 3 on page 6) to match any existing joints or cracks in the existing pavement (Figure 19). Without a contraction joint,

movement of the old concrete pavement may cause a sympathy crack in the new lanes.

An alternative method to avoid sympathy cracking is to place an isolation joint with a separating medium (Type D-4, Figure 3 on page 6) between the edge of the existing pavement, or curb and gutter, and the new lane.

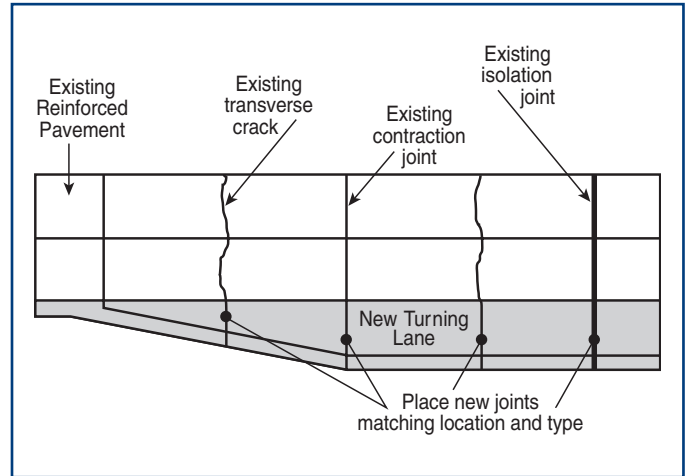


Figure 19. Aligning joints for adding auxiliary turn lanes to existing JRCPC concrete pavements.

References

1. "Driveway and Street Intersection Spacing," *Transportation Research Circular*, No. 456, Transportation Research Board, National Research Council, Washington, DC, March 1996.
2. *A Policy on Geometric Design of Highways and Streets*, American Association of State Highway and Transportation Officials, Washington, DC, 1994.
3. *Design of Concrete Pavements for City Streets*, IS184P, American Concrete Pavement Association, Skokie, IL, 2005.
4. *Guide for the Design of Pavement Structures*, American Association of State Highway and Transportation Officials, Washington, DC, 1993.
5. *Thickness Design for Concrete Highway and Street Pavements*, EB109P, Portland Cement Association, Skokie, IL, 1984.
6. *Design and Construction of Joints for Concrete Highways*, TB010P, American Concrete Pavement Association, Skokie, IL, 1991.
7. *Design and Construction of Joints in Concrete Streets*, IS061P, American Concrete Pavement Association, Skokie, IL, 1992.
8. *Joint and Crack Sealing and Repair for Concrete Pavements*, TB012P, American Concrete Pavement Association, Skokie, IL, 1993.
9. Smith, K.D., and others, "Performance of Concrete Pavements, Evaluation of In-Service Concrete Pavements," *Volume 1—Final Report*, DTFH-61-91-C-00053, Federal Highway Administration, Washington, DC, April 1995.
10. *Intersection Joint Layout*, IS006P, American Concrete Pavement Association, Skokie, IL, 2007.
11. Kosmatka, S.; Kerkhoff, B.; and Panarese, W., "Design and Control of Concrete Mixtures," 14th Edition, EB001, Portland Cement Association, Skokie, IL, 2002.
12. *Guide Specification for Concrete Subject to Alkali-Silica Reactions*, IS415TC, Portland Cement Association and American Concrete Pavement Association, Skokie, IL, 1995.

13. *Diagnosis and Control of Alkali-Aggregate Reactions in Concrete*, 1st Edition, IS413TC, Portland Cement Association and American Concrete Pavement Association and National Ready Mixed Concrete Association and National Aggregates Association, Skokie, IL 1997.
14. *Fast-Track Concrete Pavements*, TB004.02P, American Concrete Pavement Association, Skokie, IL, 1994.
15. *Accelerated Rigid Paving Techniques: State-of-the-Art Report (Special Project 201)*, FHWA-SA-94-080, Federal Highway Administration, Washington, DC, December 1994.
16. *Whitetopping—State of the Practice*, EB210P, American Concrete Pavement Association, Skokie, IL, 1997.
17. Grove, J., and others, "Bond Contribution to Whitetopping Performance on Low Volume Roads," *Transportation Research Record 1382*, Transportation Research Board, National Research Council, Washington, DC, 1993, pp. 104-110.
18. *Guide Specifications for Highway Construction*, American Association of State Highway and Transportation Officials, Washington, DC, 1993.
19. *Construction of Portland Cement Concrete Pavements Participant's Manual*, FHWA HI-96-027, National Highway Institute, Federal Highway Administration, Washington, DC, 1996.
20. "The 1996 Public Works Manual," *Public Works*, Vol. 127. No. 5, Public Works Journal Corporation, Ridge-wood, NJ, April 15, 1996.
21. *Constructing Smooth Concrete Pavements*, TB006P, American Concrete Pavement Association, Skokie, IL, 1990.
22. Snyder, M., *Pavement Surface Characteristics: A Synthesis and Guide*, EB235P, American Concrete Pavement Association, Skokie, IL, 2006.
23. Zollinger, D., and others, "Sawcut Depth Considerations for Jointed Concrete Pavement Based on Fracture Mechanics Analysis," *Transportation Research Record 1449*, Transportation Research Board, National Research Council, Washington, DC, 1995, pp.91-100.
24. Okamoto, P., and others, "Guidelines for Timing Joint Sawing and Earliest Loading for Concrete Pavement," *Volume 1 – Final Report*, FHWA-RD-91-079, Federal Highway Administration, Washington, DC, February 1994.
25. "High Strength Concrete," *ACI Manual of Concrete Practice, Part 1, Materials and General Properties of Concrete*, ACI 363R-84, American Concrete Institute, Farmington Hills, MI, 1990.
26. "Loop Installation," *Detector Systems Technical Notes*, Detector Systems, Inc., Stanton, CA, 1990.
27. "Guide to Concrete Overlay Solutions," *ACPA Publication TB021P*, National Concrete Technology Center, Ames, IA, 2007.

ASTM References and Canadian Equivalents

ASTM Designation	ASTM Title	CSA/CAN Equivalent or Specified Test
ASTM C33	Standard Specification for Concrete Aggregate	A23.1
ASTM C39	Test Method for Compressive Strength of Cylindrical Concrete Specimens	A23.2-9C
ASTM C78	Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)	A23.2-8C
ASTM C109	Test Method for Compressive Strength of Hydraulic Cement Mortar	A5
ASTM C150	Standard Specification for Portland Cement	A5
ASTM C260	Standard Specification for Air-Entraining Admixtures for Concrete	ASTM C260
ASTM C309	Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete	ASTM C309
ASTM C494	Standard Specification for Chemical Admixtures for Concrete	ASTM C494
ASTM C597	Test Method for Pulse Velocity through Concrete	A23.2-24C
ASTM C618	Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for use as a Mineral Admixture in Portland Cement Concrete	A23.5
ASTM D698	Laboratory Compaction Characteristics of Soil Using Standard Effort	ASTM D698
ASTM C803	Test Method for Penetration Resistance of Hardened Concrete	ASTM C803
ASTM C805	Test Method for Rebound Number of Hardened Concrete	ASTM C805
ASTM C900	Test Method for Pullout Strength of Hardened Concrete	ASTM C900
ASTM C1017	Standard Specification for Chemical Admixtures for Producing Flowing Concrete	ASTM C1017
ASTM C1074	Practice for Estimating Concrete Strength by the Maturity Number	ASTM C1074
ASTM C1150	Standard Test Method for the Break-Off Number of Hardened Concrete	ASTM C1150
ASTM D994	Standard Specification for Preformed Expansion Joint Filler for Concrete	ASTM D994
ASTM D1751	Specification for Preformed Expansion Joint for Concrete Paving and Structural Construction	ASTM D1751
ASTM D1752	Specification for Preformed Sponge and Cork Expansion Joint Fillers for Concrete Paving and Structural Construction	ASTM D1752
ASTM D4791	Test for Flat or Elongated Particles in Coarse Aggregate	CRD-C119

This publication is based on the facts, tests, and authorities stated herein. It is intended for the use of professional personnel competent to evaluate the significance and limitations of the reported findings and who will accept responsibility for the application of the material it contains. Obviously, the American Concrete Pavement Association disclaims any and all responsibility for application of the stated principles or for the accuracy of any of the sources other than work performed or information developed by the Association.



American Concrete Pavement Association
 5420 Old Orchard Rd., Suite A100
 Skokie, IL 60077-1059
 (847) 966-ACPA
www.pavement.com