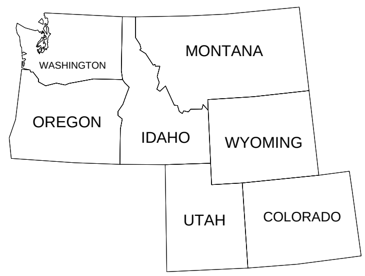


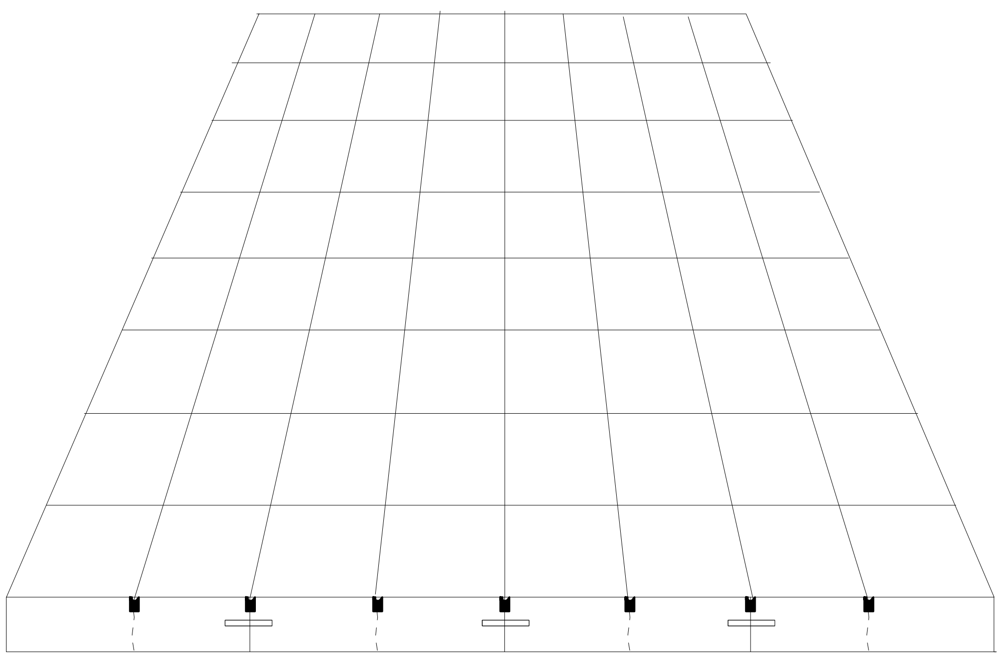
DESIGN GUIDE SUPPLEMENT PORTLAND CEMENT CONCRETE

AIRPORT PAVEMENTS

FAA, NORTHWEST MOUNTAIN REGION

Jack A Scott, P.E.

October 2003



DESIGN GUIDE SUPPLEMENT
PORTLAND CEMENT CONCRETE
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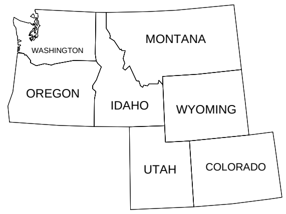

DESIGN GUIDE SUPPLEMENT
PORTLAND CEMENT CONCRETE
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Introduction

Portland cement concrete pavement (PCCP) is one of the most common pavement types used on airports. The purpose of this document is to supplement AC 150/5320-6 and AC 150/5320-5 for guidance in designing a PCC pavement. The jointing and construction of PCCP causes the design to be more complicated than an asphalt pavement section. Understanding of the pavement construction is necessary to properly design the joints, layout and grades. This document addresses non-reinforced pavements since it has been the most economical; however, much of the discussion is applicable to reinforced pavement.

Life Cycle Cost Analysis

A life cycle cost analysis (LCC) should be accomplished for all pavement designs. Equivalent load bearing sections have to be compared for various pavement types. This analysis should be conducted early in the project formulation in order to properly budget. In many cases, asphalt would be used since it provides a lower initial cost but may not be the most cost effective in the life cycle analysis.

Costs in the analysis have to include future maintenance, repairs, rehabilitations, user expenses from the loss of usage, and initial cost. Also included are estimated costs that will be incurred as a result of the project by the airport and the airport users (airlines, fixed base operators, etc.) through traffic delays, reroutings, etc. The use of LCC benefits the sponsor since maintenance is not eligible for federal funding but is considered in the analysis.

Although the pavement structural life is anticipated to be 20 years from the FAA design tables, different pavements and wearing courses vary. The life of a pavement varies with specific conditions including climate, soils, traffic, and other factors, such as fuel spillage. The analysis should use a pavement life based on past experience and may extend 30 to 40 years. A good source of information can be obtained from Pavement Condition Index (PCI) data. AC 150-5320-6D contains the requirement and method to do LCC analysis. A comparative analysis of the costs for the various alternatives will indicate the pavement that is the most economical. An example is as follows:

<u>CASE 1:</u>

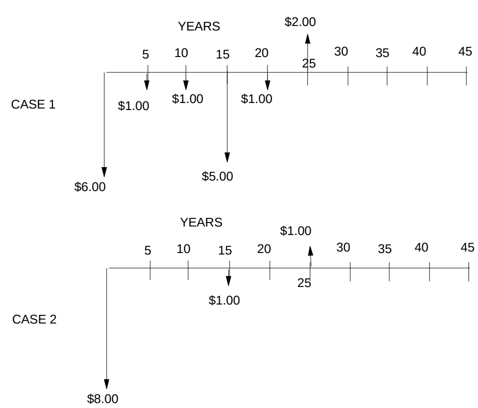
INITIAL COST			= $6.00
$1.00 (P/F,4%,5 YRS)	{.8219}	= $0.822	
$1.00 (P/F,4%,10 YRS)	{.6756}	= $0.676	
$5.00 (P/F,4%,15 YRS)	{.5533}	= $2.767	
$1.00 (P/F,4%,20 YRS)	{.4564}	= $0.456	
$2.00 (P/F,4%,25 YRS)	{.3751}	= <$0.750>	

PRESENT WORTH= <u>$9.97 /SY</u>

<u>CASE 2:</u>

INITIAL COST			= $8.00
$1.00 (P/F,4%,15 YRS)	{.5533}	= $0.555	
$1.00 (P/F,4%,25 YRS)	{.3751}	= <$0.375>	

PRESENT WORTH= <u>$8.18 /SY</u>



*******   CASE 2 IS THE MOST ECONOMICAL, EVEN WITH THE GREATEST INITIAL COST.**

Thickness Design
All pavements are to be designed for anticipated loadings and mixture of aircraft. In some cases, a limited budget may provide incentive to use a thinner section than required, but this will reduce the pavement life and add to the cost of the pavement over its life. One inch of PCCP generally will double the life, so reducing thickness cannot be justified economically. A more cost effective alternative for insufficient budgets would be to reduce the pavement area until additional funding can be obtained.

Frost designs are to be used in all pavement designs. In milder climate areas, the frost depth may be less that the total thickness required. One important consideration with frost design is the **transition of frost-susceptible material** within the frost zone (see Figure 1). Not providing a transition of the material over a long enough length will result in differential frost heave. A transition of 10 Horizontal (H) to 1 Vertical (V) is recommended below pavements and 5H to 1V in shoulders. Designs (plans) should contain adequate sections showing these transitions especially where abutting existing pavements. Care should also be taken to place drains in lower locations of the subgrade where water may accumulate.

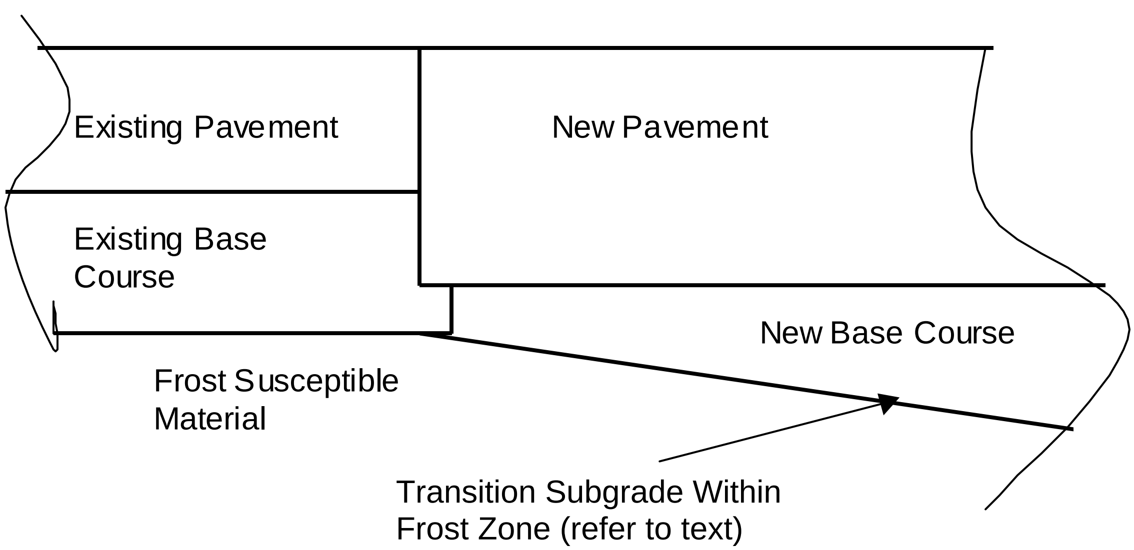


Figure 1 - Frost Subgrade Transition

Stabilized subbase courses are required for aircraft greater than 100,000 pounds. The use of 100% crushed aggregate (P-209) is an acceptable alternative to this requirement. For some PCC sections, a bond-breaker and/or smaller joint spacing may be required on top of the stabilized cement treated subbases to prevent any potential for reflective cracking into the PCC.

Exploration

Subgrade and foundation exploration should be adequate for the area's size and consistency to identify the soil types and conditions. The subgrade soils should also be examined extensively for uniform frost heave potential any time a reduced subgrade strength design method is used. Other information required includes bedrock, moisture, perched ground water, drainage, resistivity for grounding, soils analysis data including filter design, and existing pavement sections. Exploration is also important to identify other potential problems such as **expansive soils** or **soluble sulfates**. Higher sulfate contents could react with lime, cement, or flyash stabilization and expand or cause deterioration in Portland cement concrete structures and pavements that are exposed to the subgrade.

Material investigations are necessary to evaluate cement, flyash, aggregate, and concrete sources. The concrete strength, assumed in the design, has to be produced consistently locally in the area to be economical. Investigations of the strength potential should be done to insure that the suppliers can produce concrete that will attain on average strength above that specified. Aggregate quality should be examined for PCC strength producing potential as well as quality characteristics such as deleterious materials, freeze-thaw durability, alkali-silica reactive, or alkali-carbonate reactivity potential.

Subsurface Drainage

Drainage of the subgrade and bases is one of the most important factors in a pavement's life. The FAA has a standard for drainage which includes **subsurface drains** (AC 150/5320-5). All pavements shall have subsurface drainage installed.

Water infiltration can occur from the surface (rain or snow melt) or adjacent soils even in arid climates. Although joints are sealed, infiltration will occur and the quantity will increase with time. In addition, snow melt occurs at the most critical time when frost melt is occurring and the subgrade is at the weakest condition. Ground water or perched water planes is another source of water infiltration into the base and subgrade. Frost action can also cause upward movement of the water into the pavement section.

Water in the subgrade will present problems starting with construction, through the life of the pavement. Designers or sponsors sometimes would like to eliminate subdrains where the ground water table is encountered above this elevation. This is not acceptable justification to omit drains but rather a reason why they are needed, especially during construction. Drains improve the subgrade condition during construction and eliminate the need to over excavate to replace material with excessive moisture. This also minimizes compaction problems and possible contract claims. The compaction problems from excessive subgrade moisture is not limited to the subgrade but also compaction of the bases and surface courses. The water problem can be so severe without subdrains that water will eventually pump out through cracks and joints in the pavement.

Normally longitudinal edge drains are used and located directly below the full strength pavement edge and below the frost line. Transverse drains are not commonly used in airfield pavements but may be needed to intersect isolated ground water infiltration or low areas in the subgrade where water may accumulate. Subdrains should be encompassed in open graded pea gravel (surrounded by filter material) which intersects the base and subbase courses. Subgrades should be graded to the drains to avoid any bathtub effect (ponding in the subgrade). Plans should also contain an adequate number of cross-sections as a means to insure that the design accounts for subgrade drainage.

Filters

Filters are provided for water to pass but prevent migration of materials from one pavement layer to another or into drain systems. These filters can be granular or a geotextile fabric. Geotextiles are not recommended on soils with greater than 85 percent passing the No. 200 sieve. Durability of some geotextile materials may be a problem in acidic or alkali soils. In these cases, granular filter layers may have to be used. Typically, the subgrade should be filtered to the base courses. Adjusting the subbase gradations may provide for filter criteria or an additional layer may be needed. Filter criteria should also should be applied between the open drain material and the subgrade and subbases. AC 150/5320-5 and Airport Drainage Report DOT/FAA/RD-90/24 contain criteria for filter design.

Paving Layout

The constructability of the pavement should always be considered when designing the joint layout and grades. Figure 2 shows an example of paving layout where the grades cannot be constructed. A swale cannot be constructed when it is skewed from the direction of paving. The paver screed cannot build this type of grade since the depression is not in line with the paving direction. Any attempt to pave this type of layout would partially fill the swale and the grades will not be met. Drainage swales have to follow a construction joint line as shown in Figure 3. Similar discussion is also included in the paragraph titled "Grades".

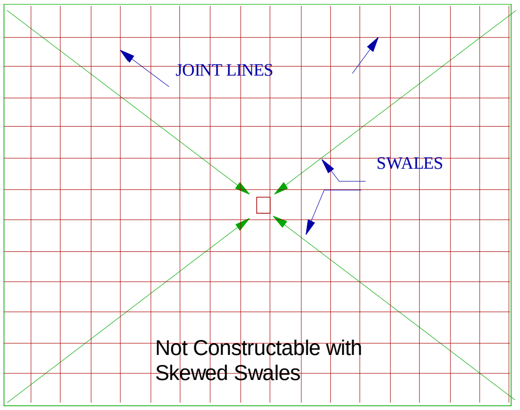


Figure 2 - Pavement Grading

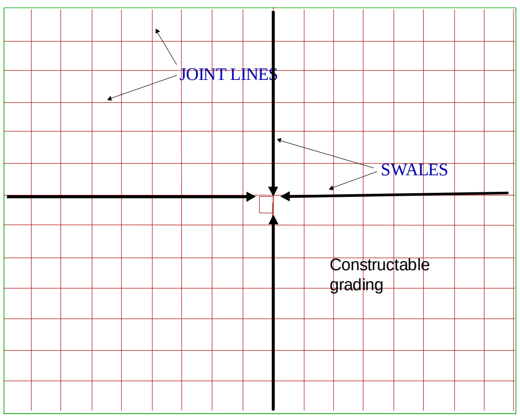


Figure 3 - Pavement Grading

Joint Patterns

The joints should be laid out as square as possible and should never exceed a length to width ratio of 1.25 without being reinforced. Reinforced odd-shaped panels should be kept to a minimum. The reinforcement does not prevent the cracking, only maintaining it closed. These panels are labor intensive and more expensive to construct. AC 150/5320-6 contain the spacing for various thicknesses, but should never exceed 20 feet. Slabs in excess of 20 feet will probably experience edge curl and are more likely to crack. Also for pavement thicknesses between 7 and 12 inches the maximum joint spacing should be 15 feet. The spacing on stabilized bases should be reduced per AC 150/5320-6. Care also should be taken to not disrupt the cross sectional area from nonuniform milling depths or other sectional changes that may induce an unplanned random crack.

Joint Layout

The joint layout should be as uniform as possible and provide flexibility to the contractor for paving directions. Joints have to be placed in line with disruptions such as building edges and other structures. Movements will occur at these disruption locations and cause random cracking without a planned joint (see Figure 4 and the following photograph). These disruptions will be critical in the joint layout and spacing. Width of construction joints should be as consistent as possible to minimize changes in paver widths. A more economical pavement layout will provide the option of placing multiple lanes and sawing the longitudinal contraction joints. This is also effected by grade changes, as discussed in the following paragraph.

In-pavement light layouts should be overlaid on the joint plan to verify conflicts with joints. It is easier to modify the light can or joint locations during design rather than during construction. Lights should be a minimum of 2 feet from any joint.

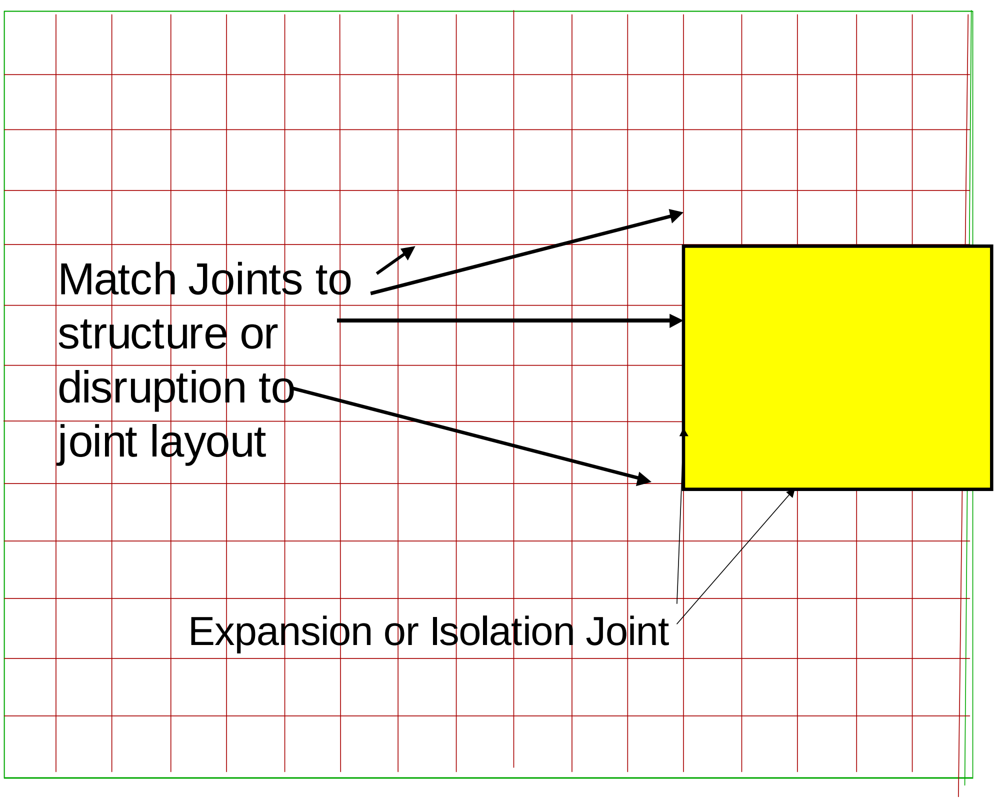


Figure 4 - Joint Pattern

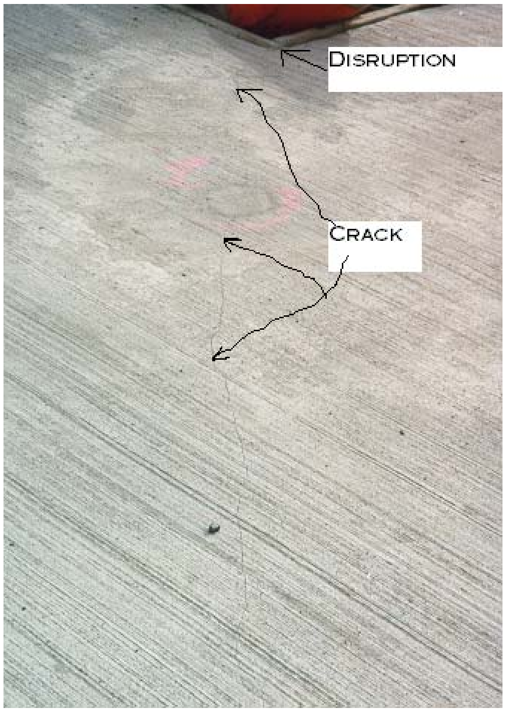


Photo 1 - Pavement Crack

Long stretches of taxiways or runways will move longitudinally from seasonal temperature changes. It is important to isolate these pavements and prevent shoving of other pavements that abut in the transverse direction. This is accomplished using a thickened edge expansion (or isolation) joint. The most common instance for this is where connecting taxiways abut runways or parallel taxiways. Refer to Figure 5.

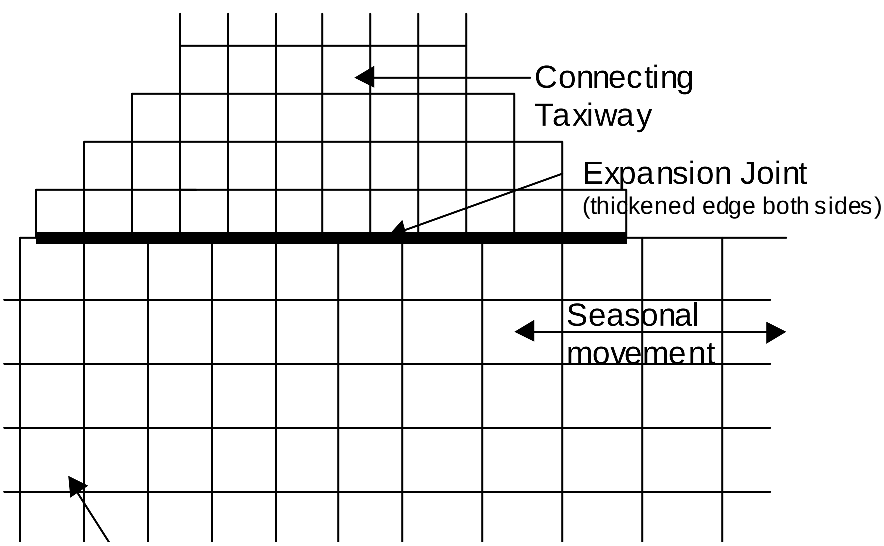
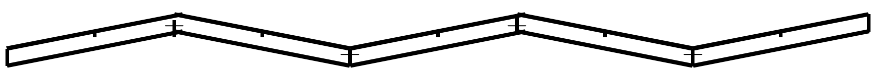


Figure 5 - Joint Pattern

Grades

The pavement grades should be established with consideration of the constructability. As an example, transverse grade changes have to occur at construction joints (shown in Figure 6). If grades change at every longitudinal joint, a construction joint will have to be used rather than a contraction joint. This will increase construction costs since each lane will have to be placed separately. Some paving machine screeds can be adjusted to for grade breaks in the center and thereby constructed as a contraction joint. This however, has to be done with a consistent grades and can increase the cost.



Grade Changes Located at Construction Joints

Figure 6 - Grade Changes

Elevations should be shown on the plan view especially at locations where changes occur. Typically, this can easily be done at the joint intersections where it is most useful in setting forms or wirelines. This information can easily be calculated during the design phase and will simplify the construction and inspection. Figure 7 is a sample method for showing the elevations at the joint intersections. Note that slopes do not change between elevations.

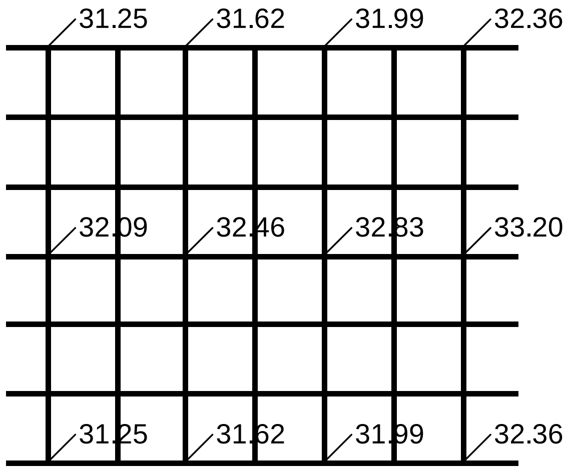


Figure 7 - Grade Elevations at Joint Intersections

Odd-shaped Slabs in PCC

Odd-shaped slabs should be kept to a minimum when designing PCC pavements. Figures 8, 9, and 10 show the three different methods used at intersections with fillets. The preferred method is to stair step the slabs with full-size panels. The odd shaped slabs are more costly to construct since they are labor intensive. They also can result in additional expenses for future expansion since they have to be removed and replaced with full-size panels. The most critical section of the pavement for loads is at the edge. The use of odd-shaped slabs could result in having the main aircraft gear run along the entire edge of pavement. This decreases the life of the small slabs since the loading is distributed over a smaller area. Curved odd-shaped slabs are even more difficult to form. This creates a conflict with the standard specification since wood has to be used to form the curve and the specifications require steel be used.

In the following figures, note the joint lines should always intersect edges at nearly right angles to prevent corner cracking. Joints also should not terminate in the pavement, as shown in Photo 2, otherwise a crack can extend from the end (even in reinforced panels).

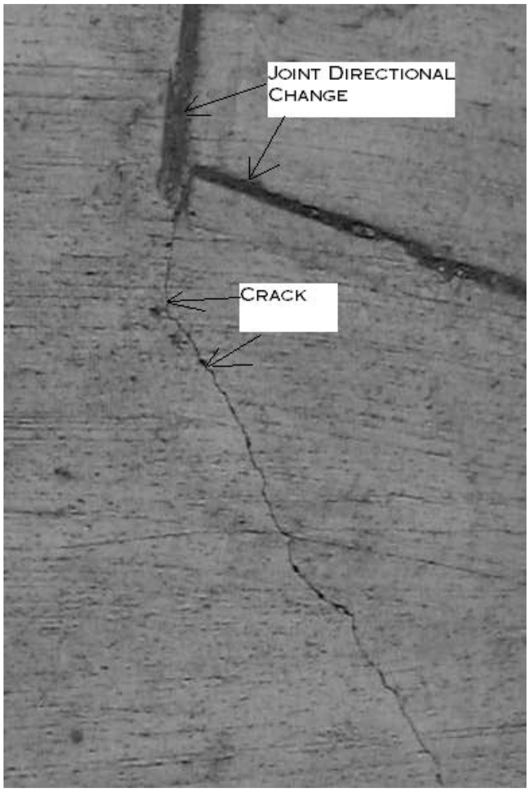


Photo 2 - Pavement Crack

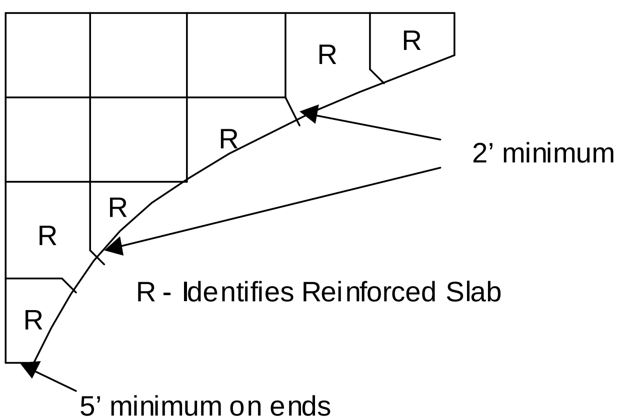


Figure 8 - Odd-Shaped Slab with Curved Edge

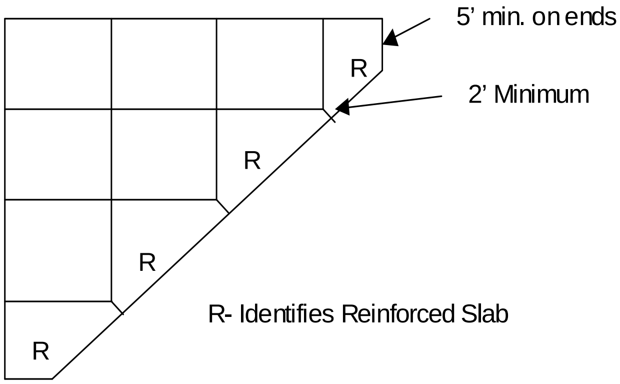


Figure 9 - Odd-Shaped Slab with Straight Edge

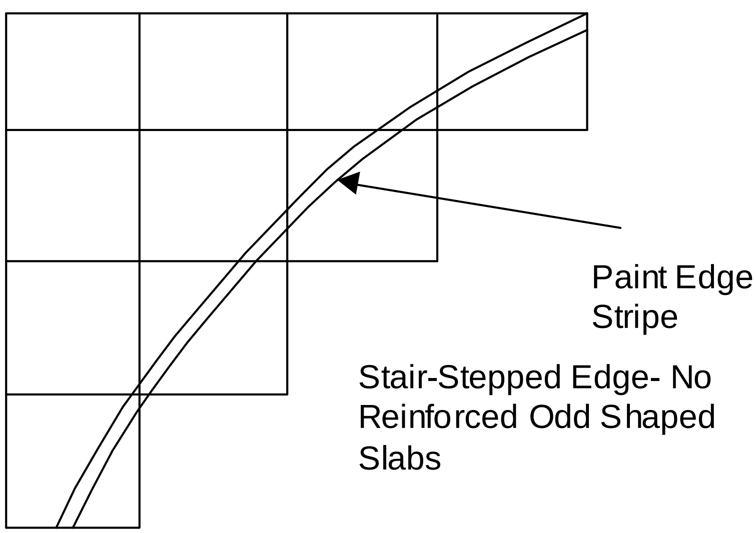


Figure 10 - Odd-Shaped Slab with Stair-Stepped Edge

Transitions
Existing joint patterns and spacing will not usually match the new concrete. Transitional sections are used to provide load transfer and change the joint pattern. The transition panels are doweled on one side and the opposite side is a thickened edge expansion joint. The doweled joint is used to provide the load transfer from the existing

to the new PCC while maintaining the existing joint pattern (see Figure 11). A thickened edge expansion (or isolation) joint is then used to change the joint pattern without promoting cracking at the mismatched joints.

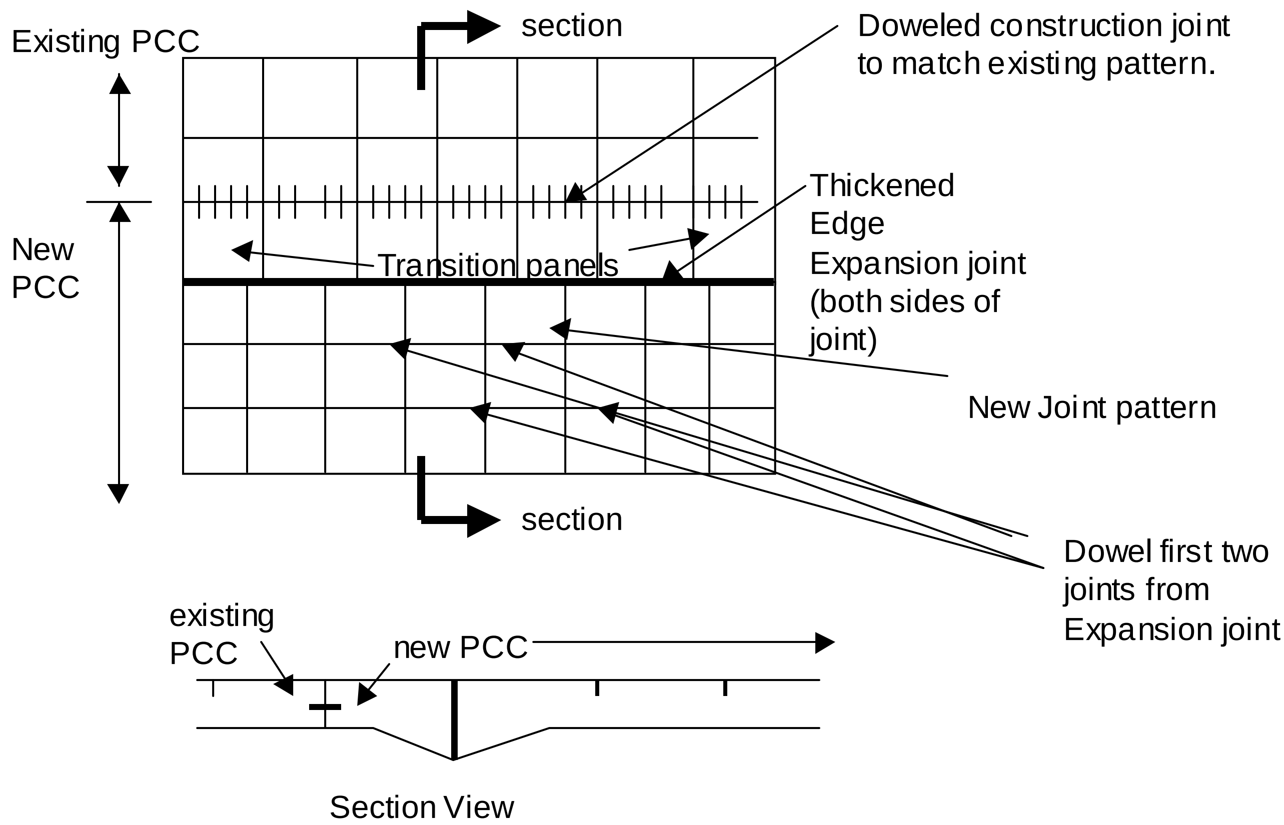


Figure 11 - Transition Joint Plan

Blockouts for lights or manholes can present a construction problem if they conflict with the joint locations. The joint, electrical, and utility plans have to be coordinated during the design phase. Electrical cans cannot be installed in a joint without resulting in future cracking or locking up the joint from moving.

Joints

There are two basic joint types: construction and contraction. A construction joint is a transverse or longitudinal joint where two adjacent but separate placements of concrete meet. **Contraction joints** are installed within the placement to control the cracking of the pavement at designated locations. The cracks are normally induced from an initial sawcut and occasionally preformed fillers are used.

Load transfer is necessary across **construction joints** since no bond or aggregate interlock exists between the placements. Contraction joints normally provide sufficient load transfer thorough the aggregate interlock from the irregular face of the crack if the joint is held closed.

Load transfer at construction joints is normally accomplished with devices such as smooth dowel bars and keys. If the load transfer cannot be maintained at the joint (such as expansion or isolation joints), the panel edge should be thickened by 25% on both sides to account for the additional tensile stress in the upper half of the slab. The thickened edge should be tapered back to the normal thickness to the next joint, but not less than 10 feet. Refer to Figures 12, 13, and 14 for the various joint types.

The **thickened edge construction joint** is normally used with expansion joint material or slip-joint material to isolate a joint pattern or structure. The expansion joints should be kept to a minimum since they require extensive maintenance. Thickened edges can also be used at the edge of pavements where extensions are planned for the future. Dowels should never be installed across an expansion or isolation joint since it defeats the purpose of isolating the panels to prevent movement or reflective cracking across the joint.

The following are the typical joints that would be used in a project design. The use of any other types should be reviewed by the FAA Airports District Office.

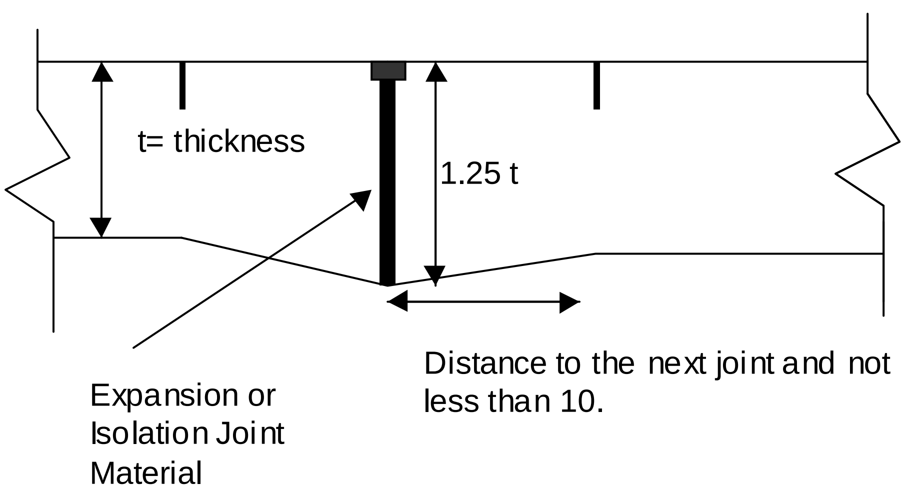


Figure 12 - Thickened Edge Construction (Expansion / Isolation) Joint

Keyed joints are rarely used for load transfer in construction joints. They are not recommended for thin pavements (less than 9 inches) and have not been found to perform as well as dowels for heavy-loaded sections. Tie bars are not always used on keyed joints; however, they serve the purpose of preventing the joint from losing load transfer due to excessive opening.

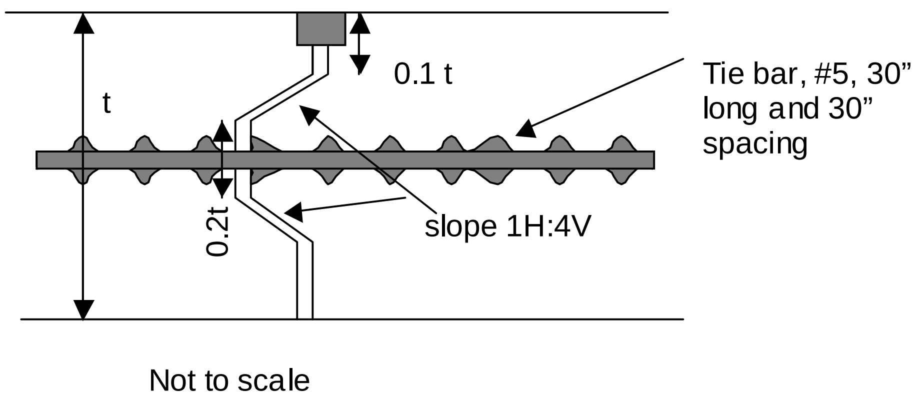


Figure 13 - Keyed Construction Joint

The **doweled joint** is the most common and reliable method in transferring loads in construction joints.

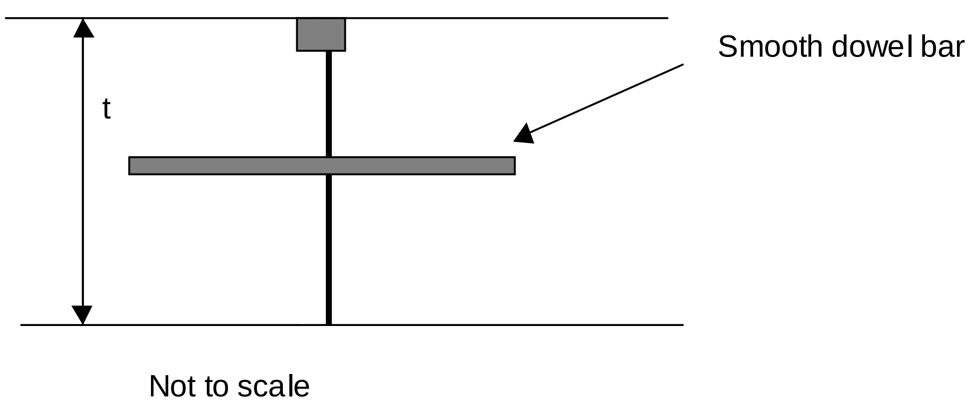


Figure 14 - Doweled Construction Joint

A dowel plan detail (Figure 15) should be included in the plans that indicate the location of the construction joint dowels in relation to the intersecting contraction joints. The construction dowels should be spaced as indicated in the pavement design AC, but also within 6 to 10 inches from the contraction joint. No dowel should be located on or within 6-inches from the joint. The ideal design would meet these spacing criteria but also have a consistent drilling pattern for the entire length of the joint. This would be the most constructible for a gang drilling operation.

The detail should also show the location of any contraction joint dowels and include the spacing and clearance to the intersecting construction joint dowels. The contraction joint dowels should be spaced a minimum of 2-inches from the intersecting dowel. As an example, for 20-inch long dowels, the contraction joint dowel should be at least 12 ½ -inches from the joint (20″ dowel divided by 2, plus 2-inch clearance, plus ½ - inch for the radius of the dowel).

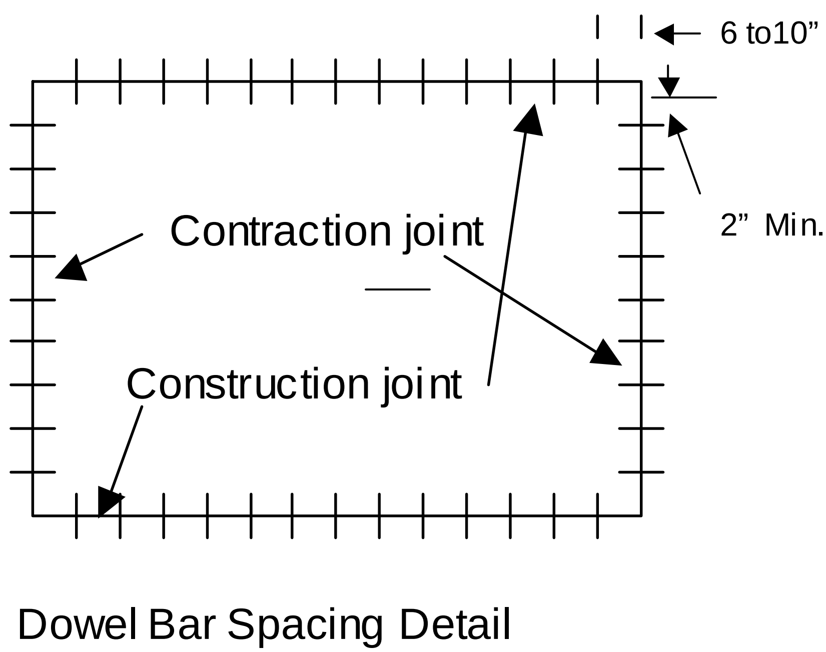


Figure 15 – Dowel Plan

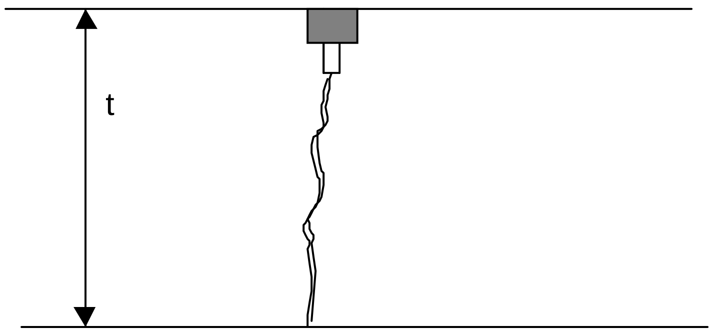


Figure 16 - Plain Contraction Joint

Contraction joints are at locations where a planned crack is induced. Contraction joints will normally provide load transfer through the crack from aggregate interlock (see Figure 16). In some cases, this joint can be tied or doweled (Figures 17 & 18). In apron areas and taxiways for wide body aircraft, dowels are used in contraction joints to extend the pavement life by improving load transfer. This is done at joints where the main gear traffics and in parking areas. Dowels are located in both directions at these locations and designs have to provide details for spacing at the corners so they do not conflict. These dowels, at the corners, should be separated by at least 6 inches to the nearest point to prevent corner cracking.

Most often the dowels are placed in contraction joints using wire cages. The cages are partially maintained rigid by welding every-other dowel end to the cage. If the wrong welded or fixed end is oiled, the joint can be locked and it will result in cracking. To avoid the problem, a detail to paint and oil the entire dowel should be shown.

The last two transverse joints at the end of long pavement runs can be tied to prevent excessive joint opening (walking) or dowel the last three joints for load transfer. Slab walking is where the joint continues to open from seasonal expansion and contraction. The tiebars allows the joint to open and close from thermal changes, but they will hold the joint together enough to maintain aggregate interlock. Doweling the last three joints is the preferred alternative since the tied panels may move away as a group. In no case should more than 75 feet total pavement width be tied together.

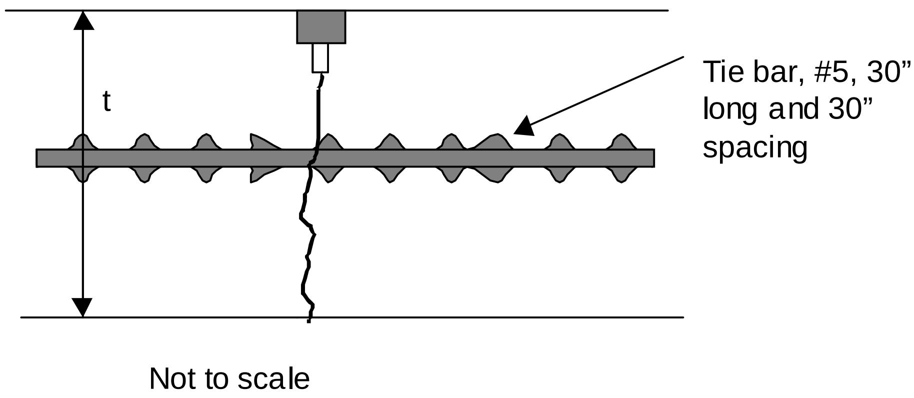


Figure 17 - Tied Contraction Joint

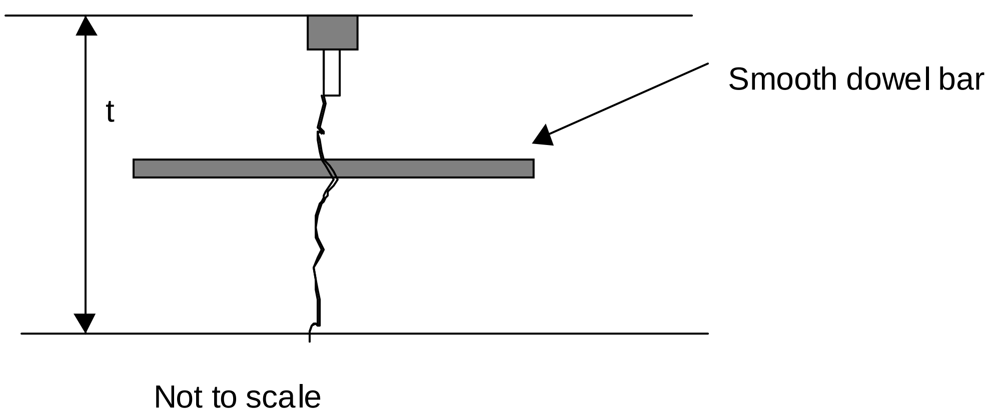


Figure 18 - Doweled Contraction Joint

Joint Seals

Joint seals are used to prevent water and debris from entering the joint while providing for movement. Elastomeric preformed joint seals (Figure 19) have provided the longest life (approximately 20 years) and are resistant to jet fuel. Silicone sealants, even though they are not jet fuel resistant, have provided about 5 to 7 years of life. The silicone will become soft when exposed to fuel but it does not deteriorate and it returns to its original state after the fuel evaporates. In all cases, a life cycle analysis is required when selecting and designing the joint seal. Care has to be taken to size the preformed seal correctly since they stay in position by pressure from the side of the joint. The Northwest Mountain Notice provides a specification with sizing criteria. If joint openings occur from extreme cold temperatures, the seal can dislodge if it is not sized correctly. Sufficient space below the preformed seal is required to avoid contact when the seal compresses during warm temperatures.

Other poured types require a bond breaker below the bottom of the sealant to prevent bonding to the PCC and maintain the correct reservoir shape (refer to Figure 20).

Sawcutting is the most common method to control cracking at contraction joints. The depth and timing of the initial saw cut is critical to prevent random cracking. The depth of the initial 1/8-inch-wide sawcut should be in the range of the thickness divided by 4 or 5 (t/4 or t/5) with a minimum of 2 inches. In some cases (such as when preformed joint seals are used or on a stabilized base) t/3 may be used to insure that all joints crack.

Edge spalling has been experienced at transverse and longitudinal joints from snow plowing and high pressure tire traffic. Chamfering the joint reservoirs has proved effective in eliminating the spalling. A 1/4-inch chamfer on both sides of the reservoir should be required and shown in the design.

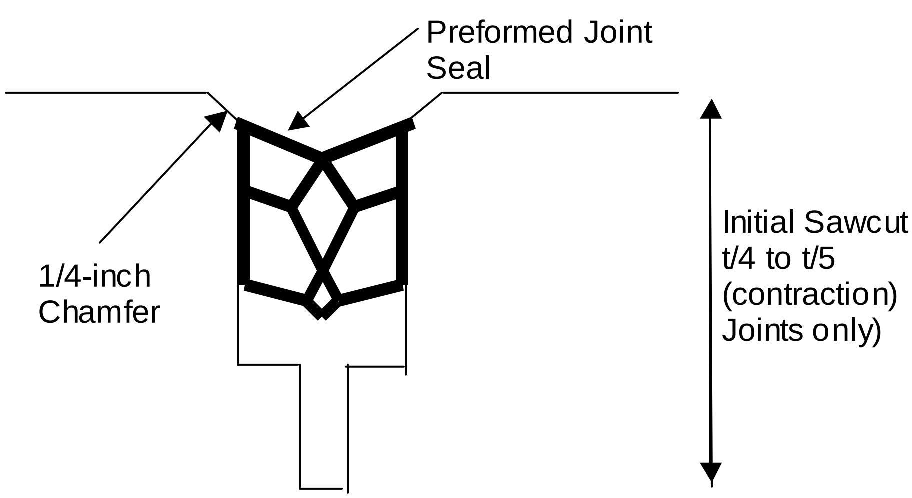


Figure 19 - Preformed Joint Seal

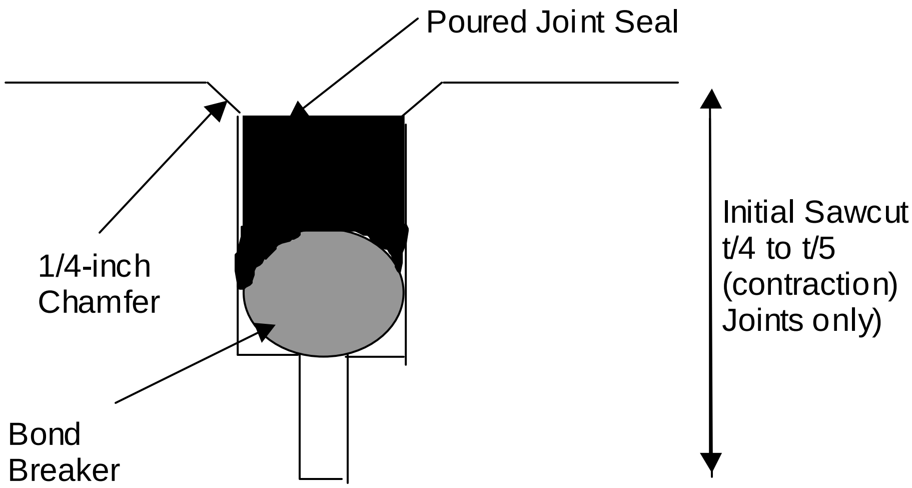


Figure 20 - Joint Seal

Patching of spalls should be accomplished without having any non-compressible material enter the crack or joint opening. If the crack opening is not maintained, any patch material will compress when the temperatures increase any result in a spall. See Figure 21. This applies to electrical conduits or any other items prohibiting the joint from opening or closing as shown in Photo 3.

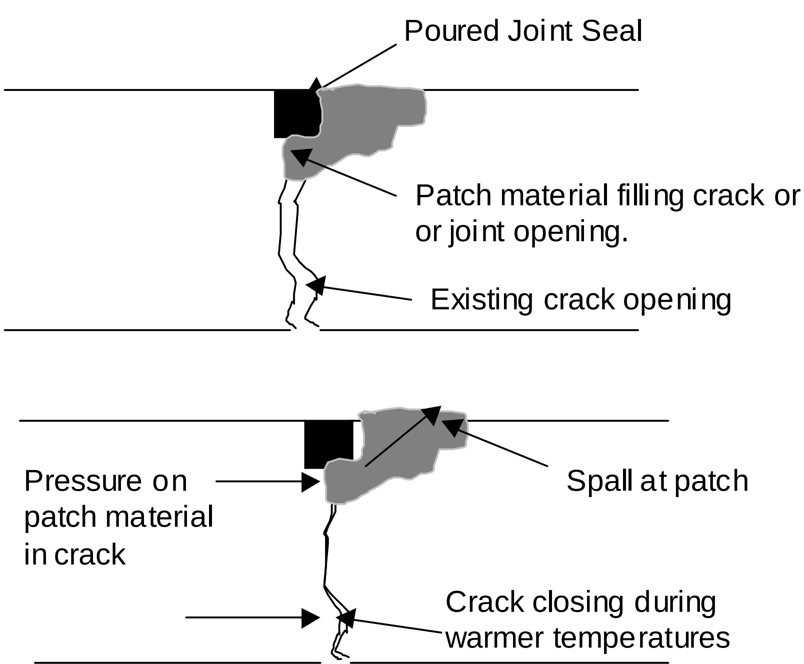


Figure 21 - Spall Patching

Photo 3 - Joint Spall at Electrical Duct

Many projects will include repair or replacement of existing PCC pavements. The following table is a guide for typical problems, probable cause and repair.

Repair Table

PROBLEM	PROBABLE CAUSE	REPAIR
Crack and joint sealer missing or not bonded to slabs	Faces of joints (cracks) not clean when filled; incorrect application temperature of sealer; wrong kind of seal material; improper joint sealant dimension.	Remove old material sealer if extensive areas affected; resaw or sandblast joints and cracks; reseal properly. (see Repair Figure 22).
Random cracking	Uncontrolled shrinkage (improper joint spacing); overstressed slabs; slab support lost; subgrade settlement.	Seal newly formed cracks; replace subbase and slab if in three or more pieces.
Surface scaling or breakup	Overworked finishing operation; **inadequate entrained air content; finishing water into surface;** inadequate curing.	Remove and replace panel; resurface with thin bonded concrete, or diamond grind surface
Joint (1) faulting or (2) spalling	(1) Variable support for unbonded slabs; loss of load transfer capability. (2) Incompressible matter in joint spaces; excessive joint finishing.	(1) Remove problem slab; replace slab (DOWEL to existing pavement). (2) Resaw or clean joint prior to resealing.
Pumping	Saturated pavement foundation; lack of subbase.	Prevent entrance of water (correct the drainage problem); clean or install subdrain system; pump slurry under slabs to re-level; replace slabs and slab foundation.

PROBLEM	PROBABLE CAUSE	REPAIR
Surface irregularities: Birdbaths Undulations	Poor placing control; broken slabs; poor finishing.	Patch or replace slabs if in local areas, or overlay if widespread.
Map cracking, Crazing,	Excessive surface finishing **or water added to surface during finishing. Check for possible Alkai-silica reaction.**	If surface deforms or breaks, resurface**, grind**.
Popouts at joints	Dowel misaligned, **excessive steel on tied joint**. Mudballs or deleterious aggregate.	Clean & fill popout hole with epoxy or non-shrink grout (recurring, may require replacement of slabs).
Slab "blowup"	Incompressible material in joints preventing slab from expanding. Check for Alkali-aggregate reactions.	Replace slab in blownup area; clean and reseal joints. Replace all slabs..
Slipperiness	Improper finish (too smooth); type of curing membrane; excessive curing membrane; polished aggregate, rubber deposits.	Grind or groove surface.
Spalled Joints	Snow plow damage or deteriorated edges.	Sawcut vertical and remove concrete adjacent to joint. Replace with epoxy mortar or PCC (if large enough area). **NOTE: The joint must be maintained open for the full depth. Any patch material entering the joint opening will result in future spalling when the joint closes.** (see Repair Figure 23).

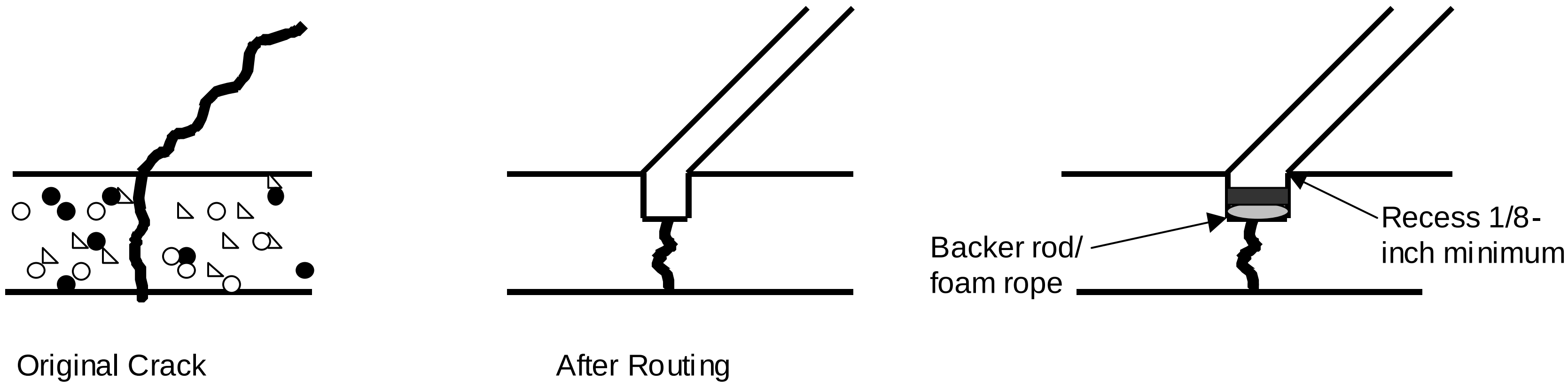


Figure 22 - Crack Repair

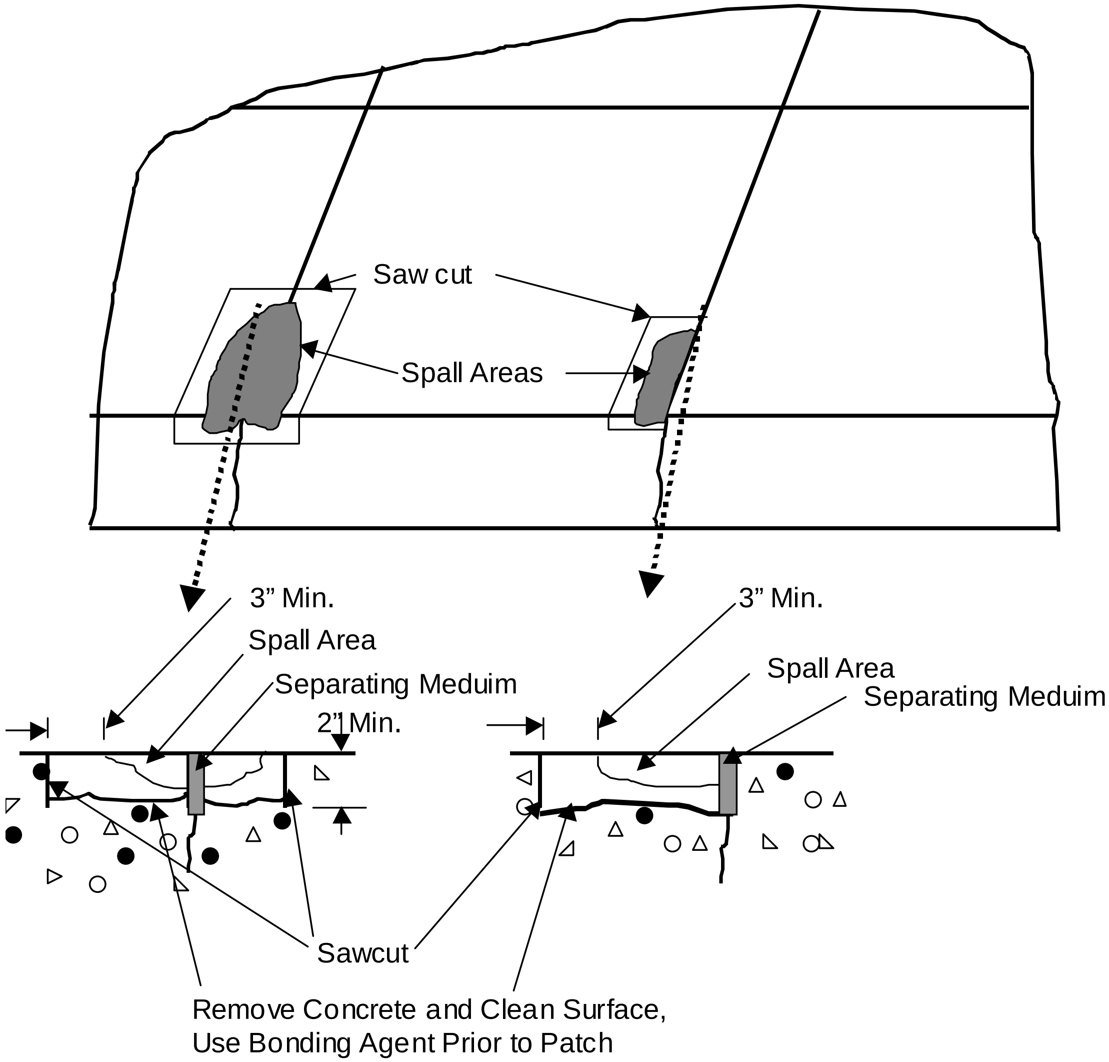


Figure 23 - Spall Repair