2. CONSIDERATION OF DESIGN ISSUES

2.1 INTRODUCTION

Factors affecting long-term airport pavement performance can be broadly divided into the following categories:

1. Adequate design of pavement structure
2. Use of quality materials
3. Use of proper construction procedures
4. Timely maintenance and repairs.

Airports in the United States are either civil airports or military airports. Guidelines for the design of pavements at civil airports are provided in FAA Advisory Circulars 150/5320-6D: *Airport Pavement Design and Evaluation* and 150/5320-16: *Airport Pavement Design for the Boeing 777 Airplane*. Design procedures for military airports are described in the Unified Facilities Criteria (UFC) Document 3-260-02: *Pavement Design for Airfields*.

The overall process of designing a concrete pavement at an airport involves the following steps:

1. Soil Investigation: Soil borings are performed to determine the properties of the subsurface strata and to obtain depth to groundwater. Soil samples are obtained for soil classification and laboratory testing.
2. Evaluate Subgrade Support at Design Grade: The information obtained from the soil investigation is used to evaluate the subgrade conditions at and below the design grade.
3. Design Pavement Section: An appropriate base type (i.e., stabilized or non-stabilized) and thickness are determined. Then the appropriate design procedure is used to obtain the thickness of the PCC pavement.
4. Select Jointing Plan: A slab size has to be selected and a jointing plan has to be developed. Appropriate longitudinal and transverse joint details have to be developed. Also, proper details are required for joints and transition slabs at tie-ins to existing pavements.
5. Develop Plans and Specifications: The design details are translated into plans and specifications.

BASE VERSUS SUBBASE:

The terms base and subbase are often used to designate the layer directly under the concrete slab. For purpose of this manual, the layer immediately below the slab is referred to as the base. The layer between the base and the subgrade is referred to as subbase.

The critical design features that influence the long-term performance of concrete pavements:

1. Subgrade support uniformity and stability.
2. Base and subbase uniformity (type and thickness), including drainage provisions.

3. Pavement thickness.
4. Concrete properties, as specified
    a. Uniformity (ability of concrete to produce consistent properties).
    b. Workability (ability of concrete to be placed, consolidated and finished).
    c. Strength (ability of concrete to support traffic and environmental conditions).
    d. Durability (ability of concrete to provide long-term service).
5. Jointing details
    a. Slab dimensions.
    b. Load transfer at joints.
    c. Joint sealing provisions.

For each project, the design engineer establishes the acceptable parameters for each of the design variables. It is then expected that during construction, the quality of the design will be provided as expected (in terms of specifications) or better. It is a common experience that when several marginal features are built into a pavement, either because of design deficiency or because of poor construction or a combination of both, then the pavement will exhibit premature failures or provide less than expected performance over the long term.

PAVEMENT FUNCTION DEFINED:

An important pavement function is to provide acceptable service over its design life with a low level of maintenance and rehabilitation (M&R). An airport pavement's function is typically defined in terms of functional [smoothness, safety, foreign object generator (FOG), foreign object damage (FOD)] and structural (distress, structural response) characteristics. The characteristics that affect pavement function include the following:

1. Initial condition – Directly attributed to construction practices and quality in construction.
2. Premature distress
    a. Within about 90 days after concrete placement and due primarily to materials or construction practices.
    b. Within 3 to 5 years of opening to traffic and may be due to poor design features and marginal as-built pavement properties.
3. Fatigue distress – These develop gradually over a period of time due to fatigue as a result of repeated aircraft loadings and environmental conditions and are anticipated. Fatigue distress occurs at the end of the pavement life.
4. Durability related distress – Distress may develop due to use of marginal materials (e.g., alkali-silica reactivity, d-cracking).

Several examples are given to illustrate the criticality of various construction operations:

1. Grading – Proper grading is an important construction item. Proper grading facilitates drainage and placement of successive layers. Grading issues are discussed in chapters 4, 5, and 6.
2. Jointing – Jointing is provided to control slab cracking. This minimizes the potential for random cracking. Random cracking is a maintenance concern and may affect the

load capacity of the pavement. Shallow joint sawing and late sawing are some of the causes of random cracking. If dowel bars are misaligned or bonded to the concrete, joints will not function and random cracking can develop in adjacent slab panels. Joint sawing, load transfer and joint sealing practices are discussed in chapter 9.

3. Subgrade and Subbase/Base Quality – If the compaction of the subgrade, subbase and base is compromised, the pavement may deflect too much under aircraft loading and corner cracking may develop. Subgrade and base/subbase construction practices are presented in chapters 4 and 5, respectively.
4. Concrete Strength – Low strength concrete will result in early fatigue cracking of the pavement. Concrete flexural strength at 28 days for airport paving is typically 600 to 750 psi (4,100 to 5,200 kPa). For fast track construction, these strength levels may be required at an earlier age. Concrete practices including strength requirements are discussed in chapters 6 and 7.
5. Concrete Durability – Concrete that is not durable (a result of poor or reactive materials, a poor air-void system, or due to over-finishing) may deteriorate prematurely. Concrete durability issues are discussed in chapters 7 and 8.
6. Concrete Curing – Concrete that has not cured adequately can deteriorate prematurely. Poorly cured concrete can also result in early age spalling. Concrete curing practices are discussed in chapter 8.
7. Concrete Finishability – Concrete that is over-finished or requires excessive manipulation to provide finishability will deteriorate prematurely. Poorly finished concrete may also result in poor surface condition. Concrete finishing practices are discussed in chapter 8.
8. Paver Operation – The paver operation has a significant impact on pavement smoothness and in-place quality of concrete. Paver operation practices are discussed in chapter 8.

SLAB CURLING:

Concrete slabs curl and warp. Slab dimensions are typically selected by the design engineer to minimize curling and warping effects. However, if excessive curling and warping take place at an early age (e.g., within about 72 hours of concrete placement), the concrete strength at that time may not be high enough to prevent cracking. This is especially critical for thinner concrete pavements at general aviation airports. Excessive early age curling and warping may take place if one or more of the following conditions occur:

1. Slab dimensions are excessive.
2. Curing is not adequate or is not applied in a timely manner.
3. Large temperature swings take place within about 72 hours of concrete placement.
4. The concrete is susceptible to differential early age shrinkage.
5. The concrete pavement is constructed on a rigid base.
6. Joint sawing operation is accomplished outside the window of opportunity.

GUIDELINES ON CONSTRUCTION VARIABILITY:

Variability is an inherent part of any construction process. While it is commonly assumed that variability in test results are indicative of variable material, other sources of variability can be the cause. Sources of construction variability include:

- Material variability
- Process variability
- Testing variability (precision and bias).

Almost all of the sources of variability have a negative impact on the property being measured. It is important that the design engineer and the contractor understand the magnitude of the different sources of variability and attempt to reduce the mean magnitudes of the variability. Expected levels of variability, in terms of standard deviation, for some of the important construction measures are listed below:

Property	**Low Value**	**High Value**	**Test Precision**
Subgrade Density (standard Proctor test), lb/cu. ft (kg/cu m)	1 (16)	3 (48)	NA
Base/Subbase Density (modified Proctor test), lb/cu. ft (kg/cu m)	1 (16)	3 (48)	NA
Concrete Thickness, in. (mm)	0.25 (6)	0.50 (13)	NA
Concrete Flexural Strength, psi (650 psi concrete) (kPa (4,500 kPa concrete))	40 (280)	60 (420)	40 (SO) (280)
Concrete Compressive Strength, psi (4,000 psi concrete) (Mpa (27 Mpa concrete))	300 (2.1)	500 (3.4)	100 (SO) (0.7)
Concrete Air Void, % (7% air void concrete)	0.50	1.00	0.28 (MO)
Pavement Smoothness (Profilograph), in. (mm)	0.2 (5)	0.5 (13)	NA
Grade/Straight Edge, in. (mm)	0.2 (5)	0.3 (8)	NA

Note: The above values are based on a broad range of experience. Higher levels of variability may indicate that the construction process is not under control or that testing procedures are marginal. The precision values refer to single operator (designated as SO) or multiple operator (designated as MO) standard deviation.

6. GETTING READY FOR CONCRETE PAVING

The following critical elements should be in place before production paving starts:

1. Check all the equipment in the paving train to make sure it is in operational condition.
2. Verify that an acceptable length of grade is available for concrete paving.
3. Check that approved test reports are available for all materials in storage at the job site and the plant site.
4. Verify that backup testing equipment is available – develop extra equipment backup plans.
5. Verify that all necessary concrete placement tools are available, such as hand tools, straight edges, hand floats, edgers, and hand vibrators.
6. Verify that radio/telephone communication with the plant is operational.
7. Verify that equipment is available to water the grade, if necessary.
8. Monitor the string line regularly and re-tension as necessary.
9. Verify that the day's work header is in place (needed or just saw off excess).
10. Develop extreme weather management plan.
11. Check weather forecast for each day of paving.
12. Make sure a sufficient length of plastic covering is available in case of sudden and unexpected rain.

Several pre-paving construction items are discussed in this chapter, including grade control and acceptance, concrete plant operation inspection, and paving equipment inspection. Addressing these items early on may help avoid problems associated with concrete quality, pavement thickness, and concrete placement and finishing operations.

6.1 GRADE ACCEPTANCE

The grade is accepted after the base layer is placed, trimmed, leveled, and compacted. Proper base grade ensures that nominal pavement thickness is achieved and final profiles and elevations are consistent with contract documents. The following are grade issues that should be checked:

1. Typically, elevation tolerances are required to be met for each pavement layer. Elevations and tolerances are shown on plans for the compacted subgrade, stabilized and non-stabilized layers, and top of pavement.
2. The primary items to consider prior to paving are:
    a. Effect of grade on as-placed concrete volume – Materials cost impact if final grade is low.
    b. Effect of grade on pavement thickness variability – If final grade is variable, it will affect thickness determined through core sampling. Concrete thickness variability needs to be minimized as it may affect payment for thickness. The thickness pay item may be based on percent within limits (PWL) specification. In that case, variability could significantly impact acceptance for payment.
    c. Loose debris on the base needs to be removed prior to paving.

3. Proper base grade control is critical as it affects drainage during construction and the service life of the pavement.

6.2 CONCRETE PLANT OPERATION

Concrete is a manufactured product, the quality and uniformity of which depend upon the control exercised over its manufacture. The plant needs to be in good condition, operate reliably, and produce acceptable concrete uniformly from batch to batch. A typical plant layout is shown in Figure 6.1.

Figure 6.1 – Common concrete plant layout

Concrete quality and uniformity are greatly affected by aggregate segregation and a varying moisture content of the aggregates. The batch plant and equipment is generally specified to meet ASTM C 94 - Standard Specification for Ready-Mixed Concrete. Key items listed in ASTM C 94 for batch plants are as follows:

- Separate aggregate bins for each size coarse aggregate with a capability of shutting off material with precision.
- Controls to monitor aggregate quantities during hopper charging.
- Scales accurate to ±0.2 percent tested within each quarter of the total scale capacity. Adequate standard test weights for checking scale accuracy should be available.
- Water added to an accuracy of 1 percent of the required total mixing water.

The owner's representative should inspect the concrete plant prior to the start of paving using the National Ready Mixed Concrete Association (NRMCA) checklist. Plants should be inspected prior to the start (or re-start) of each paving project and when uniformity or strength problems are encountered during production.

The traffic flow at the plant should be optimized. Items to consider include:

1. Delivery of raw materials

2. Delivery of concrete to the paver
3. QMP/CQC-related traffic operations and testing personnel safety
4. Operation of equipment for managing the aggregate stockpiles
5. Plant safety requirements.

Finally, positive drainage within the plant site must be provided.

CONCRETE PLANT CHECKLIST:

1. Check foundations of stockpiles for proper separation and adequate drainage.
2. Check bins for adequate partitions to prevent intermingling of aggregates.
3. Check scales with test weights throughout range to be used.
4. Check scales for seals by approved agency.
5. Check water meter for accuracy.
6. Check for leakage of lines.
7. Check capacity of boilers and chillers if their use is anticipated.
8. Check admixture dispensers for accuracy.
9. Check mixers for hardened concrete around blades.
10. Inspect concrete hauling units for cleanliness.
11. Check to assure that all concrete making materials have been certified and approved for use.
12. Observe stockpiling operations – verify that segregation and contamination will not occur.
13. Observe charging of the bins – verify that segregation and contamination will not occur
14. Review aggregate moisture tests.
15. Observe batching operations at start and periodically during production.
16. Check scales for zeroing.
17. Check to ensure proper batch weights are set on the scales.

6.2.1 Managing the Aggregate Stockpile

Stockpile management procedures must be developed and implemented. Procedures must address construction of stockpile storage pads, keeping loader buckets off the floor, truck unloading, maximum stockpile heights, bin charging, quality control sampling, water sprinkling, aggregate washing, and aggregate moistures. The following are key items related to aggregate stockpile management:

1. Aggregates need to be handled and stored in a way that minimizes segregation and degradation and prevents contamination by deleterious substances.
2. Aggregate stockpiles need to be closely monitored and maintained to keep the aggregate moisture content at or above saturated surface dry condition. This is particularly important for absorptive aggregates used during hot weather.
3. If aggregate moisture varies through the day, the frequency for determining moisture content should be increased. Moisture content variability increases when loaders retrieve aggregates from one area of the stockpile or if water sprinkling of stockpiles is not uniform.

4. The water added at the mixer needs to be adjusted for the moisture of the aggregate. In hot weather, use of chilled water may be considered.
5. Limit the height the aggregate is dropped when building up the stockpile. Stockpiles need to be built up in layers of uniform thickness. When removing aggregate from a pile (with a front-end loader), the material needs to be removed vertically from bottom to top so that each load contains a portion of each layer.
6. Stockpiles should be separated from one another and if there is not enough space between them to keep size fractions separate, a wall should be used.
7. Bulldozers should not be allowed on stockpiles because they break down the aggregate and segregate the particle sizes.
8. Proper stockpile management reduces the likelihood of aggregate contamination. Contamination generally occurs when clay and mud are tracked with trucks unloading aggregates. Aggregate contamination can also occur if aggregates are not unloaded onto belt placers but stockpiled by end loaders. Haul roads and dump area should be stabilized to minimize aggregate contamination from trucks. Aggregate contamination may also occur if loaders charging aggregate bins scrape the bottom of the pile. Examples of aggregate stockpiles are given in Figures 6.2 and 6.3.

Figure 6.2 – Working the aggregate stockpile

Figure 6.3 – An excessively high stockpile

6.2.2 Concrete Uniformity Testing

Concrete uniformity testing should be done prior to the start of paving using ASTM C 94 as a guide. Uniformity testing is also used to establish minimum mixing times. Uniformity tests compare differences in concrete sampled at approximately 15 percent and 85 percent drum discharge. These tests include:

1. Density (unit weight)
2. Air content
3. Slump

4. Coarse aggregate content
5. Air-free mortar unit weight
6. 7-day concrete compressive strength.

Differences between concrete discharged at 15 percent and 85 percent should be less than the maximum allowable differences stated in ASTM C 94 for five of six tests. Minimum mixing times for production are established by the concrete uniformity tests.

6.3 PAVING EQUIPMENT ISSUES

The following are checks for paving equipment:

1. Check availability of required pieces of equipment. For example, the number of trucks hauling concrete will affect slipform production rates. In the event of mechanical breakdown, extra equipment (such as concrete saws) should be on site.
2. Ensure equipment is in proper working order.
   - Equipment inspected needs to include concrete haulers, concrete placers, concrete spreaders, slipform pavers, curing/texture rigs, and sawcutting equipment.
3. Inspect slipform pavers to ensure proper consolidation can be achieved through vibration. Vibrator frequency and amplitude need to be checked prior to paving. Typically, vibrators under no load need to have a frequency of 6000 to 12,000 vibrations per minute and an amplitude of 0.025 to 0.05 in. (0.6 to 1.3 mm). Vibrator elevations must be fixed to a height that will not interfere with pre-placed dowel baskets.
4. Curing application equipment must be checked to assure that there is a uniform and proper application of curing compound.
5. Blades for joint sawing need to be suitable for the aggregate type used in the mix.

6.4 STRINGLINE ISSUES

The accuracy of the elevations and offset distances for grade reference points is important to the final smoothness of the pavement surface. These elevations and offsets provide the basis for establishing the stringline. The stringline is used to provide an accurate reference for elevation and alignment control of the grade trimming, subbase/base placement, and concrete paving train. Any error in the stringline will be reflected in the final product.

Setting up the stringline takes careful planning. The interval between stakes is important, particularly on vertical curves. On tangent sections, a maximum staking interval of 25 ft (7.6 m) usually will result in a good product. A tighter interval is necessary to produce smooth pavements on vertical curves and the needs must be based upon the rate of change of curvature.

STRINGLINE AIDS:

- Use rigid stakes
- Use quality line – New or good condition
- Avoid knots and splices
- Prevent perceptible sagging
- Eyeball for staking errors and irregularities
- Monitor, protect and maintain line
- Adjust stake spacing to fit conditions.

STRINGLINE TYPE:

Stringline material may include the following:

1. Braided nylon (polyester, Kevlar, polyethylene) line
    a. Typically, 1/8 in. (3 mm) diameter braided string
    b. Lightweight, but good pull strength
    c. Does not crimp like wire
    d. Does not result in hand injury (cuts)
    e. Develops a sag
    f. Has a stretch over time
    g. Requires frequent monitoring
2. Aircraft cable
    a. Typically, 3/32 in. (2.5 mm) galvanized cable
    b. Splicing not as simple as nylon string
    c. Less sag
    d. Less affected by weather (humidity)
    e. Less stretching over time

7. CONCRETE MIXTURE

7.1 INTRODUCTION

The quality of concrete is usually defined in terms of workability, strength, and durability. All three aspects of concrete quality should be optimized for a given project. Many design engineers and some contractors mistakenly emphasize the strength requirements above the quality requirements because concrete strength is an important component of the pay schedule.

Concrete mixture design considerations are discussed in this section. However, specific information on how to perform concrete mixture designs is not included. Appropriate guides for this purpose are referenced.

CONCRETE HIGHLIGHTS:

Concrete is basically a mixture of two components: aggregates and paste. In this mixture, the aggregate particles are completely coated with the paste. The paste consists of cementitious materials and water and incorporates entrapped air or purposely entrained air. Aggregates make up about 60 percent to 75 percent of the total volume of concrete.

The quality of the concrete depends on the quality of the aggregates and paste and the bond between the two. The quality of the paste is significantly influenced by the amount of water used – typically, the less water used, the better the quality of the concrete. A maximum water-cementitious material ratio is typically specified to avoid excess water and to ensure that good quality paste is achieved. Cleanliness of the aggregates also influences paste/aggregate bond and the quality of the concrete.

The properties of freshly mixed (plastic) concrete can be changed by adding chemical admixtures to the concrete, usually in liquid form, during batching. Chemical admixtures are commonly used to improve or control the following attributes:

- Workability
- Entrained air
- Water demand
- Setting time
- Other properties.

When properly mixed, placed, and cured, concrete has the strength and durability to provide long-term pavement performance under a range of service conditions.

7.1.1 Concrete Mixture Requirements

For commercial airfield pavements, the provisions of FAA P-501 are typically used to establish the requirements for paving concrete. The requirements are established for aggregates (coarse and fine), cementitious materials, admixtures, concrete mixture design, and concrete acceptance. The following attributes are typically required for concrete used for airport pavement:

- Minimum flexural strength of 600 psi (4 MPa) at 28 days (or minimum 28-day compressive strength of 4,400 psi (30 MPa) for pavements designed to accommodate aircraft with gross weights of 30,000 lb (13,600 kg) or less).
- Minimum cement content of about 500 lb/cu. yd (300 kg/cu m).
- Maximum w/cm ratio of 0.50 (Note: a w/cm ratio not to exceed 0.45 needs to be used for severe freeze-thaw areas. For severe sulfate exposure areas, the practice is to limit the w/cm ratio to 0.40).
- Slump for side-form concrete of 1 to 2 in. (25 to 50 mm) and for slip-form concrete of ½ to 1½ in. (13 to 38 mm).
- Air content is based on exposure condition and the maximum aggregate size.
- Fine aggregate fineness modulus between 2.5 and 3.4.

MILITARY REQUIREMENTS:

The Corps of Engineers uses a 90-day flexural strength for pavement design purposes, but allows the use of compressive strength testing for field acceptance of strength. Project specific correlations are developed during the concrete mix design phase. Seven-day compressive strength testing is performed for QC and 14-day testing is performed for QA.

MIXTURE DESIGN ISSUES:

1. Mixture design procedures typically do not directly address concrete workability. They do, however, indirectly attempt to define workability in terms of the slump test. The slump test is not a true indicator of concrete workability, especially for slipform concrete. The contractor must recognize that in addition to designing the mixture to meet the requirements of strength, slump, and air, the mixture must be designed to assure workability for the given mixture characteristics, the project paving equipment, and expected ambient conditions at time of paving.

2. Mixture design requirements do not address the issue of aggregate gradation. There may be conflicting requirements related to allowable fine aggregate gradation, in terms of material passing the No. 50 and No. 100 sieves and also with respect to the fineness modulus. The contractor needs to review these requirements at the time of the concrete mixture design phase. ASTM C 33 provides some guidance.

8. CONCRETE PLACEMENT, FINISHING, TEXTURING, AND CURING

8.1 INTRODUCTION

Concrete paving is accomplished by both machine paving and handwork. Machine paving is used for the mainline pavement, connecting taxiways, and large fillets. Handwork areas are those areas too small to use a machine. For machine paving, two classes of pavers are used, heavy and light. Heavy machines are slipform pavers. The lighter machines include bridge deck pavers, generally side form (fixed form) machines, and vibratory screed or tube rollers.

Slipform Pavers

Common elements of the slipform paver include:

1. Self-propelled with either two or four tracks
2. Generally weigh about 2,000 lb or more per foot (3,000 kg/m) of paving lane width.
3. Variable speed hydraulically controlled internal vibrators
4. Ability to carry a head of concrete in front of the screed
5. Continuous auger or hydraulic plow-pans to distribute concrete in front of the screed
6. Finishing attachments.

Slip-form pavers can be used in side form applications by stretching the paver width beyond the forms. Slipform pavers can be stretched to about 45 to 50 ft (14 to 15 m), depending upon model and available attachments, but most are commonly used at a 25 to 37.5 ft (8 to 11 m) width. Slipform pavers are usually used for airfield concrete pavement that is 8 in. (200 mm) or more in thickness. Slipform pavers provide the consolidation required for deep lift concrete pavement.

Bridge Deck Pavers

Bridge deck pavers consist of a truss system with a suspended screw auger to spread concrete, an oscillating vibrator, and a roller. The roller acts to compact and finish the surface. Some paving machines incorporate a texture device to follow the roller assembly. A typical bridge deck paver is shown in figure 8.1. Common elements of bridge deck pavers include:

1. Ride on the forms or on self-propelled wheels
2. Have one or two vibrators that move transversely in front of the screed
3. May also use fixed vibrators near the form edges
4. Do not carry a head of concrete in front of the moving screed
5. Generally weigh less than 1,000 lb per foot (1,500 kg/m) of paving width.

Figure 8.1 – Typical bridge deck paving operation

Lightweight Finishing Machines

Lightweight finishing machines utilizing a truss screed or roller screed, typically used for thin concrete pavement, are not normally employed for production paving of airport pavements. These machines are best suited for non-critical small area paving. The machines are usually fitted with a vibrator pan for finishing and may either be fitted with a cable crank for forward motion, or will be able to vibrate themselves forward. The machines require manual strike-off, manual vibration, and considerable bull floating behind the screed. The later practices bring excessive amounts of mortar to the surface and usually remove entrained air near the pavement surface.

Manual Paving

Labor-intensive manual paving is typically carried out only for small areas such as fillets. Figure 8.2 shows a fillet pavement placement using manual techniques.

Figure 8.2 – A typical fillet construction operation

Differences between slipform and bridge deck paving machines are summarized below:

1. The bridge deck paver has a production capacity significantly less than a slipform paver.
2. The bridge deck paver is most economical when paving lanes wider than 40 ft (12 m) and in geometrically constrained areas. Bridge deck pavers are capable of placing concrete up to 50 ft (15 m) wide.
3. A bridge deck paver is more mobile and maneuverable and may be used when paving constrained areas such as cross-taxiways or restricted aprons area.
4. A major difference between the pavers is the method of consolidation.
    a. The single vibrator of a bridge deck paver consolidates the concrete by plowing transversely across the truss.
    b. Combined with the forward travel of the paver, the concrete is plowed in a zigzag pattern.
    c. For a constant radius of action with the vibrator, depending on forward speed, the amount of vibration energy and coarse aggregate distribution may not be as uniform as achieved using vibrators that are uniformly spaced and plowing in one direction as on slipform pavers.
5. Vibrators on bridge deck pavers may have smaller offset weights that allow higher vibration frequencies than desired. Higher frequencies increase the potential for disrupting the air void system, increasing the potential for durability problems.
6. Concrete mixtures need to be uniquely designed for fixed form paving. Concrete mixtures used with slipform pavers will not work for fixed form paving and vice versa.

CRITICAL FACTORS FOR CONCRETE PAVING:

1. A good grade for paving – Trimmed and compacted to specification.
2. Stringline management – Monitor and maintain stringline at regular intervals.
3. Continuous supply of concrete to the paver.
4. Consistent concrete workability.
5. Well maintained paving equipment.
6. Proper operation of paving equipment.
7. Controlled density of concrete – Just the right level of vibration to consolidate concrete and provide enough fines at surface for a tight finish.
8. Most importantly, a skilled and dedicated crew.

8.2 CONCRETE DELIVERY AT THE SITE

Before and during concrete delivery consider the following:

1. The grade must be inspected for acceptance prior to depositing concrete. Loose debris is removed and any base damage is repaired.
2. String line elevations are to be verified.

3. Concrete should be deposited on grade within reasonable time after the addition of mixing water. When placed, there should be time remaining for consolidation, strike-off, and finishing before initial set.
4. When pulling slipform pavers off headers, a slightly higher slump concrete should be used to facilitate hand consolidation and finishing operations.
5. The use of agitator trucks should be encouraged because there is usually a more uniform concrete placement and concrete segregation is minimized
6. The consistent delivery of concrete is necessary to minimize stopping and starting of the paver. If paving operations are stopped to wait for concrete from the batch plant, additional trucks must be used or the paver speed should be slowed.

8.2 CONCRETE PLACEMENT

Acceptable concrete placement practices include:

1. Concrete needs to be deposited close to and uniformly in front of the paver or front spreader, taking care to minimize disturbance to the base, embedded steel, dowel bars, and side forms.
2. The concrete needs to be placed such that one side of the paving lane is not overloaded with concrete.
3. In formed areas, the concrete needs to be placed as close as possible to its final position to minimize the potential for concrete segregation.
4. Concrete is either dumped on grade in front of the paver or onto belt placers and side loading spreaders.
    a. If dumping on grade, control rate of dumping by controlling the tailgate opening.
    b. The use of an end loader to spread concrete in front of the paver is not a good practice
5. The advantage of dumping directly in front of pavers or spreaders is that concrete head in front of the machine auger can be easily maintained.
6. The disadvantages of directly unloading in front of the paver are:
    a. Trucks backing into the paver may disturb the compacted granular base.
    b. Dowel baskets need to be placed just ahead of the paver – placing dowel baskets just ahead of the paver may not allow time to verify dowel bar alignment or verify that baskets are securely fastened to the base. Safety of laborers

CONCRETE HEAD:

- Needs to be consistent and of proper height for the paver size and concrete mix.
- A heavier paver generally produces a smoother concrete pavement since it is less affected by surges of concrete coming into the paver.
- Figure 8.3 shows examples of good and poor concrete placement practices.

PAVER SPEED:

- Slow and constant speed of the paver results in smooth pavements.
- The rate of placement (speed of the paver) should coincide with the capability of the batch plant and the rate of delivery of concrete to the paver.
- The paver should not be stopped frequently during the paving operation.

fastening baskets in areas between the forward moving paver and backward moving dump trucks needs to be considered.

   c. When placing baskets just ahead of the paver, a full time inspector may be required to check dowel bar placement and alignment.
   d. Stringlines may have to be broken on at least one side of the paver to allow trucks to back in and pull forward away from the paver.

7. When using a belt placer:
   a. Swing the belt back and forth to maintain a uniform head of concrete in front of the paver.
   b. If the paver is low on concrete, back up placer to place more material where needed.
8. When a spreader is used, it should not get more than 25 ft (7.5 m) ahead of the paver and thus allow timely adjustment if the head of concrete at the paver gets too low or too high.
9. The paver operator must control the level of concrete in the grout box by raising or lowering the strike-off blade when required.
10. The following may reduce the potential for dowel bar misalignment associated with the forward-moving concrete head in front of the paver or spreader:
    a. Deposit small amounts of concrete carefully over pre-positioned baskets fastened to the base to minimize the weight associated with the forward-moving head of concrete in front of the paver or spreader.
    b. Do not dump concrete by trucks directly on basket assemblies.

a. Use of end loader is a poor practice.

b. Maintaining uniform distribution is a good practice

Figure 8.3 – Concrete placement ahead of paver

8.4 EMBEDDED STEEL AND TIE-BAR PLACEMENT

Embedded steel bars or mesh, typically used in fillet areas and other odd shaped panels, need to be securely supported on chairs. Chairs need to be spaced close enough to allow steel to be supported without sagging. Tie bars used as embedded steel and positioned around penetrations are be supported on chairs within tolerances of the specified elevation. Welded wire fabric needs to be flat and meet specified elevations within tolerances after fastening to chairs.

Supplementary consolidation with spud vibrators is commonly used around wire mesh, therefore chairs need to be strong enough to support the weight of laborers during concrete consolidation.

FILLER LANE PLACEMENT:

Although filler lanes appear to be reasonably easy to place, the paving contractor must be aware of the potential for cracking within the filler lanes because of restraint from:

- Doweled longitudinal joints
- Friction from pilot lane joint faces
- Possible use of higher slump concrete – More shrinkage potential
- Shorter window for sawing joints.

If pilot lane joints are open wide at the time of filler lane placement, then mortar from the filler lane can seep into the joints and could result in small corner breaks/spalls. If pilot lane joint widths are greater than ¼ in. (6 mm), use backer rod, duct-tape or asphalt mastic to cover the joint openings.

Prior to concrete placement, the embedded steel bar diameter, length, presence of epoxy coatings, absence of breaks in epoxy, location, elevation, clearance of embedded steel (from other steel or dowel/tie bars at joints), and frequency of chairs need to be verified and accepted by inspectors.

Self-loading tie bar inserters mounted on slipform pavers can be used along longitudinal sawed contraction joints when paving multiple lanes. Injectors push rebar into plastic concrete and vibrate the concrete above bars. Distance meters are used to trigger the tie bar insertion at pre-determined spacing. Longitudinal positioning of bars needs to be observed to ensure that the minimum specified distance from transverse joints is maintained.

Embedded steel depth can be verified by exposing bars in plastic concrete or by coring over ends of rebar, by using a magnetic rebar cover meter, or by utilizing nondestructive testing ground penetrating radar.

8.5 DOWEL BAR INSTALLATION

When doing dowel bar installation, the following items must be considered:

1. Dowel bars at transverse contraction joints are either pre-positioned using dowel bar baskets secured to the base or inserted during paving operations using a dowel bar inserter.
2. Dowel bars at longitudinal sawed contraction joints can be pre-positioned using basket assemblies or injected using a dowel bar jammer.

3. The use of dowel bar inserters at longitudinal construction joints is typically not allowed. Most agencies have witnessed misalignment problems and undesirable air pockets around inserted dowel bars.
4. Dowel bars at longitudinal construction joints and transverse headers are installed using a drill and epoxy technique. Holes are drilled into vertical edges.

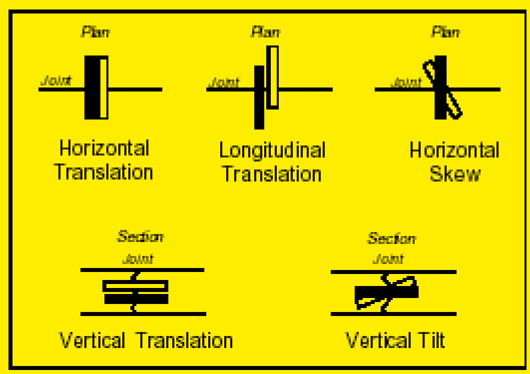
Dowel bar alignment is a critical item and must be checked on a regular basis. Dowel misalignment does have a significant effect on pavement performance. Important dowel installation items are:

1. Specifications for alignment typically are:
    a. ¼ in./ft (20 mm/m) or less out of alignment in the vertical and horizontal plane.
    b. ±1 in. (25 mm) or less vertical, horizontal, or longitudinal translation.
2. Basket assembly stations need to be verified (centered at joint locations).
3. Dowel bars at longitudinal joints are to be inspected to ensure that the specified clearance from the ends of transverse joint dowel bars is maintained.
4. To reduce restraint at slab corners, dowel bars at longitudinal joints should be positioned at least 6 in. (150 mm) and preferably 12 in. (300 mm) away from the ends of dowel bars in the transverse joints.
5. Dowel baskets must be securely fastened to the base.
    a. Clips are generally adequate when fastening a basket to stabilized base.
    b. Long stakes are required to securely fasten baskets in granular and open graded bases.
6. Longitudinal dowel basket wires may be crimped instead of being cut. Crimping reduces cross-sectional area while maintaining basket stability.
7. Dowel bar alignment can be verified by:
    a. Exposing dowels in plastic concrete
    b. Coring over dowel bar ends
    c. Using a magnetic rebar cover meter
    d. Nondestructive testing (e.g., ground penetrating radar).
8. Prior to paving, dowel bars must be inspected for breaks in the epoxy coating. Field kits are used to cover exposed dowel bar steel at basket welds and chips in the coating. If a

Types of Dowel Bar Misalignment and Impact on Performance

Type of Misalignment	Effect on Spalling	Cracking	Load Transfer
Horizontal Translation	—	—	yes
Longitudinal Translation	—	—	yes
Vertical Translation	yes	—	yes
Horizontal Skew	yes	yes	yes
Vertical Tilt	yes	yes	yes

Categories of dowel misalignment are illustrated below.



Misalignment categories.

light coat of form release oil or other de-bonding agent is specified, the coverage must be inspected prior to concrete placement.

DOWEL ISSUES – BASKET USE VERSUS INSERTED DOWELS:

- A method specification is typically used when dowel baskets are used.
  - Positive tie-in to subbase is specified.
  - Inspection of basket stability and dowel alignment is performed before concrete placement.
  - Dowel placement (depth) for first few joints per day may be checked using a covermeter or ground penetrating radar.
- For inserted dowels, prior inspection is not possible.
  - As a result, the contractor takes a risk because a check of dowel misalignment is only possible after concrete has hardened.
  - The dowel placement (depth) for the first few joints of the day must be inspected using a covermeter.
  - Also, there is typically not enough guidance in specifications for inspection of inserted dowels. The contractor should bring up this issue at the pre-bid meeting if the inserted dowel technique is to be used.

8.5.1 Dowel Bars at Construction Joints

Dowel bars at construction joints are installed using the drill and epoxy grout procedure. Use of the side injected dowel bars is not usually employed because of potential for misalignment problems.

Dowel bars may be installed after the concrete has cured sufficiently to allow:

1. Loading of the new pavement by the drilling equipment.
2. Drilling of the holes without excessive chipping and spalling. Some minor chipping should be expected.

Important items in the installation process include:

1. Gang drills, as shown in Figure 8.4, are used to simultaneously drill several holes.
2. Holes are slightly oversized, about 1/8 to 1/4 in. (3 to 6 mm) larger than the dowel bar diameter.
3. Depth of drilled holes must be spot checked to ensure that dowels are nominally inserted halfway into holes.
4. Epoxy is injected at the back of the drilled holes and the dowel twisted as it is pushed into the hole. Applying epoxy by hand to dowel bars before insertion is not an acceptable technique.
5. Grout retention disks may be used to prevent epoxy from flowing out of the holes.
6. Dowel bars need to be inspected to verify adequacy of the epoxy coverage. Proper epoxy grouting is important to ensure that the dowels are bearing on a sound interface and voids do not exist. Otherwise, load transfer effectiveness may be compromised.

7. The exposed ends of the dowel bars need to be oiled prior to concrete placement. Grease is not used to coat exposed ends of dowel bars.

Figure 8.4 – Dowel bar installation along a longitudinal construction joint

8.6 CONCRETE CONSOLIDATION

Proper use of internal vibrators, shown in Figure 8.5, is important to properly consolidate the concrete without adversely affecting the concrete strength and durability. Important items related to concrete consolidation are summarized below:

1. Slipform pavers consolidate concrete in the grout box using gang-mounted vibrators.
2. For larger pavers, vibrators are hydraulically driven. Electric or hydraulic vibrators may be used for small slipform pavers.
3. Inadequate consolidation results in lower concrete strength and honeycombing. Inadequate vibration can be due to:
    a. Poorly functioning or dead vibrator
    b. Paver speed too high
    c. A concrete mix with poor workability.
4. Over consolidation can lead to freeze-thaw durability problems if the air void system is adversely altered. Over consolidation can be due to:
    a. Excessive vibrator frequency
    b. Reducing paver forward speed without an adjustment to vibrator frequency
    c. Concrete mix properties of poor workability.
5. Vibrators are generally positioned no more than 4 in. (100 mm) below the finished pavement surface. Setting vibrators too low results in air being trapped under the grout box head, leading to delaminations or blistering of the concrete surface.
6. Vibrators are generally positioned at an attitude of 5 to 10 degrees. As the paver moves forward, the angled vibrators plow the concrete.
7. Vibrator spacing is a function of the radius of action. The radius of action and vibration energy input into concrete is a function of paver speed, vibrator rotor force, and frequency (set by equipment operator).

8. Prior to each day of paving, vibrator frequencies and amplitudes need to be checked under no load. Large deviations between vibrators are indicative of poorly functioning vibrators.

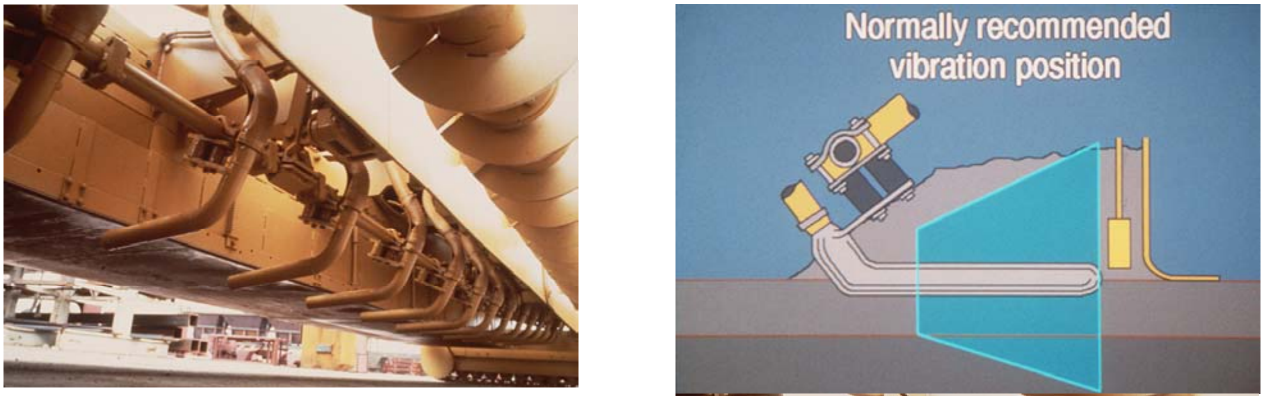


Figure 8.5 –Vibrator layout and position

Cores drilled in the test strip or initial stages of placement need to be examined to ensure that for the paving variables (vibrator depth, attitude angle, frequency under load, spacing, grout box head, and travel speed), the consolidation is acceptable. Cores between and in vibrator paths should be examined for:

1. Evidence of aggregate segregation in vibrator trails
2. Excessive entrapped air
3. Differences in hardened concrete density.

Large pockets of entrapped air (honeycombing) and aggregate segregation, as shown in Figure 8.6, may be eliminated by changing the following:

1. Vibrator frequency
2. Forward travel speed of paver
3. Vibrator depth
4. Vibrator spacing.

Figure 8.6 – Honeycombed concrete

Slipformed vertical edges should not exhibit excessive entrapped air voids. With slipform and fixed form pavers, supplementary vibrators may need to be positioned close to vertical edges to ensure adequate consolidation.

Smart vibrator systems that continuously monitor individual vibrator frequencies during paving operations are available. Use of a smart vibrator system (example shown in Figure 8.7) is recommended since this allows continuous verification of frequency uniformity. Vibrator frequency in the range of 6,000 to 8,000 vibrations per minute (under load) will usually result in acceptable consolidation for a properly designed mix.

Concrete mixtures that employ gradation control mar require less vibrator frequency. The response of the concrete mixture to vibration should be evaluated on the first day of paving or after the test strip construction.

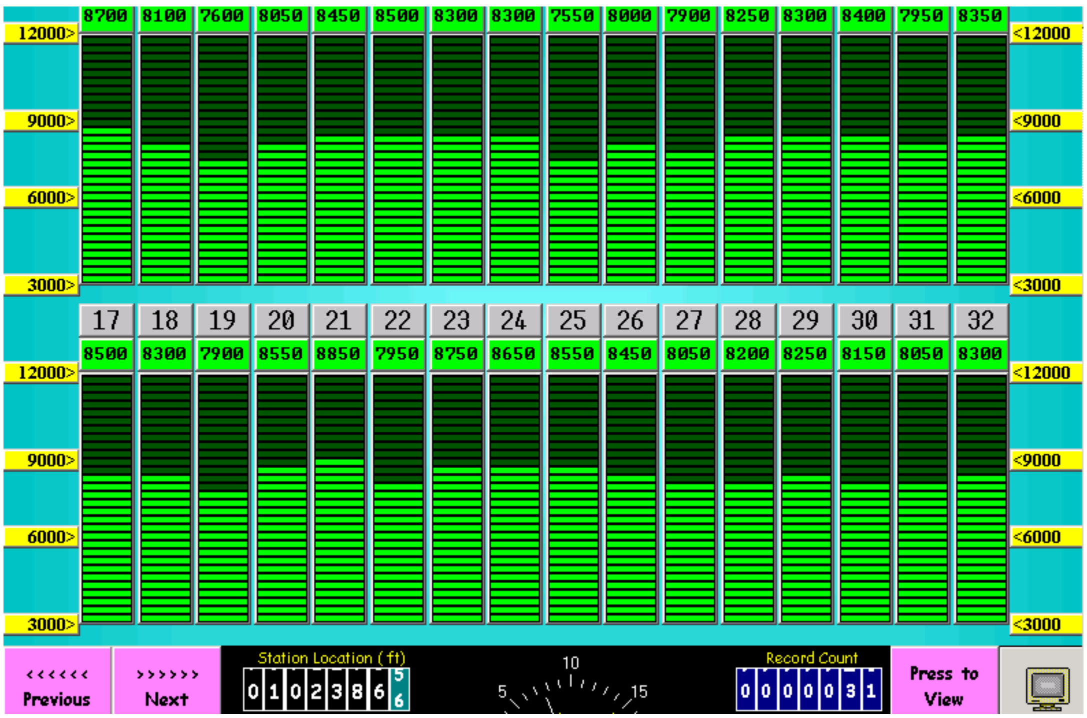


Figure 8.7 – Output from a smart vibrator system showing the frequency of each vibrator

8.7 CONCRETE FINISHING

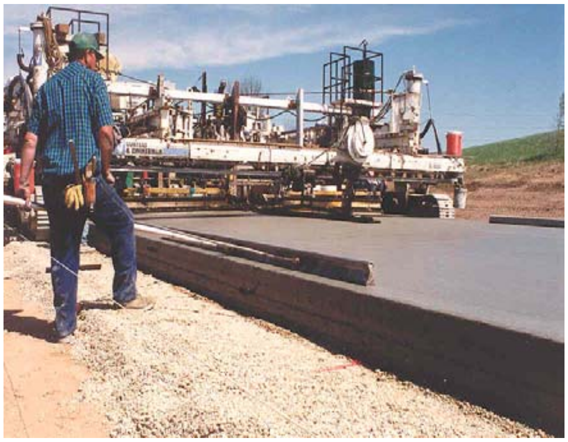
Concrete finishing is a critical step in the paving process. Concrete finishing is the hand finishing that is typically applied to obtain a smooth surface necessary to correct any unevenness behind the paver. Concrete finishing efforts are to be kept to a minimum. Ideally, the correct concrete mixture will result in an acceptable surface finish behind the paver. The concrete surface does not need to be very tight and every small blemish on the surface does not need to be corrected. Examples of good and poor finishing practices are shown in figure 8.8.

FINISHING AIDS:

- Minimize excessive handwork.
- Do not apply water to help finish the surface.
- Surface does not need to be super-smooth nor very tight.
- Too much paste at the surface results from:
    - Too much water applied to the surface
    - Over-vibration (high frequency)
    - Paver speed too slow for vibratory effort
    - Over finishing.

Important items related to finishing are:

1. The need for concrete finishing is minimized by:
   a. Selecting a workable concrete mixture
   b. Properly operating the paving equipment.
2. Excessive hand finishing will work water to the surface and can affect surface smoothness and concrete durability.
3. Problems closing the surface behind the paver are indicative of:
   a. Too small a volume contained in the grout box and/or concrete setting up in the grout box
   b. Fine to coarse aggregate volume or paste volume too low
   c. The finishing pan angle needing adjustment
   d. The paver speed being too high
   e. Vibrators needing adjustment.
4. If water is to be used to assist with finishing, it needs to be fogged, not sprayed, over the surface and should not be worked into the surface with floats.



a. Good practice

b. Poor practice

Figure 8.8 – Finishing operations (hand finishing and addition of additional material must kept to a minimum)

8.8 CONCRETE TEXTURING

Concrete pavements must have a surface texture that will provide a desired level of skid resistance. The primary functions of surface texture are to provide:

1. Paths for water to escape from beneath the aircraft tires.
2. Degree of sharpness at the surface necessary for the tire to break through the residual film that remains after the bulk water leaves.

Concrete texturing is the most common technique used to provide concrete with high skid resistant pavement surface. However, texturing will not prevent hydroplaning. Texturing is applied while the concrete is still in plastic condition. Texture methods include the following:

1. Brush or broom finish
   a. Applied when the water sheen (bleed water) has just disappeared.
   b. Applied transversely across the pavement.
   c. Corrugations are to be uniform in appearance and about 1/16 in. (1.5 mm) deep.
   d. The textured surface must not exhibit tears and be unduly rough.

2. Burlap or astro turf drag finish
   a. The burlap rating should be about 15 ounces/sq yd (500 gm/sq m).
   b. The trailing edge of burlap needs to have a heavy build up of grout to produce the desired longitudinal striations on the surface.
   c. The corrugations produced by burlap drag need to be uniform in appearance and about 1/16 in. (1.5 mm) deep.

3. Wire combing (rigid steel wires)
   a. Used to provide a deeper texture in the plastic concrete.
   b. Steel wires are about 4 in. (100 mm) long, 0.03 in. (0.8 mm) thick, and 0.08 in. (2 mm) wide
   c. Continuous tracks are approximately 1/8 in. by 1/8 in. (3 mm by 3 mm) and spaced ½ in. (13 mm) center to center.
   d. Brush, broom, or burlap finish is not necessary before providing wire tining.
   e. Wire combing is not a substitute for grooving. It does not provide for improved surface drainage.

4. Wire tining (flexible steel bands)
   a. Use to provide a deep texture in the plastic concrete.
   b. Flexible steel bands are about 5 in. (130 mm) long, approximately ¼ in. (6 mm) wide and spaced ½ in. (13 mm) apart.
   c. Brush, broom, or burlap finish is not necessary before providing wire combing.
   d. Wire tining is not a substitute for grooving. It does not provide for improved surface drainage.

8.9 CONCRETE GROOVING

Forming grooves in plastic concrete or cutting grooves in hardened concrete is a proven and effective technique for minimizing the potential of hydroplaning during wet weather. Factors considered to determine the need for grooving include:

1. History of accidents and incidents related to hydroplaning at the airport.
2. Storm frequency (rainfall rate and intensity).

3. Texture characteristics of the concrete surface and polishing nature of concrete aggregates.

Grooves are approximately 1/4 in. by 1/4 in. (6 mm by 6 mm) and spaced 1½ in. (38 mm) center to center. Grooves are not continuous across joints and are terminated at 6 in. (150 mm) from joints. Grooving methods include:

1. Sawcut grooving.
   a. Method provides well formed grooves and consistent groove depth.
   b. Grooved surface is more durable as the grooved faces include coarse aggregate in the concrete matrix.
2. Care needs to be taken when cutting grooves adjacent to in-pavement light fixtures.
3. Plastic grooving using vibrating ribbed plate.
   a. Vibration allows redistribution of aggregate at the concrete surface.
   b. Method provides well-formed grooves.
4. Plastic grooving using ribbed roller.
   a. Method does not provide well-formed grooves.
   b. Depth of groove may not be consistent.

8.10 CONCRETE CURING

Curing is the maintenance of adequate moisture and temperature regimes in freshly placed concrete for a period of time immediately following finishing. Improper curing can have serious detrimental effects on near-term (plastic shrinkage cracking) and long-term properties of hardened concrete (less durable surface, excessive warping).

CURING KEYS:

- Proper mixing
- Uniformity of application
- Timing of application
- Yield check (rate of application).

Important issues related to proper concrete curing are addressed below:

1. Timing of curing application is critical, especially during hot weather. Curing needs to be applied as soon as free water has disappeared from the concrete surface after finishing and texturing. When using fly ash and slag, free water may not form.
2. When using sprayed applied curing compounds, uniform coverage and coverage rates are critical.
   a. Spray curing needs to be applied using spray equipment mounted on a self-propelled frame that spans the paving lane.
   b. Hand spray curing should be limited to hand placed concrete areas.
   c. When using white-pigmented curing compounds, uniform application can be visually examined but application rates need to be verified by measuring the volume used for a given area and comparing it to the requirements either specified or recommended by the manufacturer.
   d. Curing needs to be applied to exposed faces of the concrete after slipforming or after forms are removed.

   e. Curing needs to be applied to joint surfaces immediately after sawing and cleaning.
3. If moist curing is to be used, the entire concrete surface needs to be maintained continuously wet for the entire curing period (typically seven days) or until curing compound is applied.

Additional discussion related to curing is given in section 8.16 – Hot Weather Concrete Placement and section 8.17 – Cold Weather Concrete Placement.

8.11 MINIMIZING EDGE SLUMP

Excessive edge slump is detected while concrete is still in the plastic state. Edge slump is considered excessive if more than 15 percent of the joint length for a single slab exhibits edge slump greater than 1/4 in. (6 mm) or if there is any edge slump in excess of 3/8 in. (10 mm). Edge slump occurrences must be minimized because it impacts joint efficiency and performance.

Factors that affect edge slump are:

1. Concrete consistency
2. Concrete mixture compatibility with placement techniques
3. Paver adjustments and operation
4. Excessive finishing.

The correction of edge slump is discussed in chapter 11.

> EDGE SLUMP CORRECTION:
>
> The continual correction of excessive edge slump in fresh concrete can lead to unacceptable levels of joint spalling in the finished concrete. If such a problem develops, paving should be stopped and measures determined to correct excessive edge slump.

8.12 FIXED FORM PAVING

Fixed form paving is typically used to pave short lengths and/or isolated areas such as fillets or irregular pavements and using machine pavers or manual placement.

Important items related to fixed form paving follow:

1. Steel forms are positioned on the finished base and top elevations checked.
2. For granular base:
   a. If grade along the forms is low, additional base material needs to be placed and compacted.
   b. If grade along the forms is too high, the base can be reworked to lower the grade.
   c. Correcting high spots in granular material near form edges only is not a good practice. High spots between the forms will result in a smaller concrete thickness away from forms that result in variable thickness.
3. For stabilized base:

a. If grade along the forms is low, forms need to be shimmed to maintain horizontal alignment during concrete placement. If more than 1 in. (25 mm) shimming is needed, the base in low areas needs to be removed and replaced to achieve the required base elevation.
b. High areas in cement treated, cement-treated open graded, and open graded asphalt stabilized bases can be cut down with a motor grader blade.
c. High areas in lean concrete (econocrete) and asphalt concrete bases should be ground to elevation.
d. Lowering base elevations only in the vicinity of forms will result in a thin concrete cross-section away from forms that produces variable thickness.
e. The use of a bond breaker layer of broadcast sand or double application of waxed-based curing compound must be considered in areas that are ground and thereby reduce the potential for bonding between the base and the concrete.

4. Forms need to be set by mechanically tamping them and staking them securely into the base with stakes no more than 36 in. (900 mm) apart.
5. The transition joints between forms must be checked to ensure that no significant deviation will affect the finished concrete smoothness.
6. After forms are connected, they are to be checked for vertical and horizontal alignment. Deviations of more than 5 degrees from the vertical may result in alignment problems for dowel bars inserted through forms into the plastic concrete.
7. To minimize damage during form removal operations, forms must be sprayed with form release oil not more than 4 hours prior to paving.
8. To prevent corner spalling and damage to concrete around inserted dowel bars, forms should not normally be removed earlier than 12 hours after concrete placement. However, forms must be removed no later than 24 hours. Removing forms later than 24 hours may affect concrete curing of vertical edges adjacent to forms.
9. Exposed sides need to be sprayed with curing compound within 30 minutes after form removal. Edges need to be coated at coverage rates used for the pavement surface.

8.13 PAVING AND IN-PAVEMENT STRUCTURES

The most common in-place structures in concrete paving are light cans. Light cans may be installed using one of the following techniques:

1. Blockouts – blockouts at light can locations are installed and the pavement is placed around blockouts, as illustrated in Figure 8.9.
    a. Blockouts elevations need to be checked for grout box clearance.
    b. Filler material used to help stabilize blockouts needs to be filled to within 3 in. (75 mm) or less of the finish elevation.

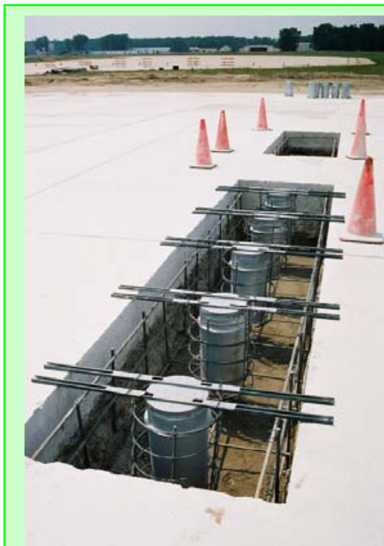


Figure 8.9 – Blockout Method

c. After construction, the filler material, if used, is removed, light cans are positioned, and the blockout area is backfilled with concrete.
d. Fixed blockouts can restrain slab movement and increase restraint stresses associated with moisture and thermal changes. Use deformed tie bars around diamond-shaped blockouts to hold any restraint cracks tight and to reduce the potential for crack spalling. The tie-bars should be above half the depth of pavement and below 1/3 of the slab. Bars must be securely tied to chairs fastened to the base.

2. Split cans and coring – Use of this technique allows the pavement to be slipformed with pre-placed light cans. Can elevation adjustments can be made after concrete placement. The steps involved are:
    a. Position partial can in the base.
    b. Pre-place concrete at the base of the partial cans to anchor the cans.
    c. Pave the lane.
    d. Drill a 4 in. (100 mm) diameter core to determine exact center of can.
    e. Drill a 14 to 18 in. (360 to 460 mm) hole for the can top section.
    f. Complete light can installation.

Various steps of the split can and coring technique are shown in Figure 8.10.

Figure 8.10 - Split can coring technique

The layout for in-pavement lighting systems should be designed to minimize interference with the proposed pavement joints. However, should conflicts occur with the pavement joints, use of pavement blockouts, discussed above, can be made to construct in-pavement lighting structures near a joint. Normally, a blockout is required when the centerline of the light base can is within 2.5 ft (750 mm) of a pavement joint.

Other in-place structures commonly encountered with airport pavements include hydrant pits, utility manholes, and drainage structures (trenches). These are typically installed using the blockout method or pre-placed with concrete around the structure. In both cases, embedded steel needs to be used around the structure for crack control. Additional items to consider for the design and construction of in-place structures include:

1. Design details for in-place structures must account for expansion of concrete pavements adjacent to the structure and for moisture infiltration into the structure.
2. Larger in-place structures (such as utility manholes, hydrant pits, or drainage trenches) need to be located at least 4 ft (1.2 m) from a transverse or a longitudinal joint to minimize potential for cracking. If it is not feasible to locate a larger structure outside of the 4 ft (1.2 m) dimension, the structure should be placed at the pavement joint and appropriate load transfer (e.g., thickened edge) and concrete slab expansion details must be accounted for.
3. Smaller slab penetrations, such as monitor wells and under drain cleanouts, can be located closer to the pavement joints, in a similar manner to an in-pavement light fixture (no less than 2.5 ft (750 mm) from the pavement joint.
4. An isolation joint around an in-place structure must be used to accommodate concrete slab expansion. Load transfer between the concrete slab and the adjacent structure must also be accounted for.
5. Trench drain walls must be designed to be stiff enough to resist concrete pavement expansion. Use of struts in trench drains may be required if concrete expansion movement at the trench drain is anticipated to be high.

8.14 PAVING AT FLEXIBLE PAVEMENT INTERFACES

Matching elevations is a common problem at interfaces of concrete and flexible pavements. To provide a smooth interface, the following techniques should be used:

1. The flexible pavement is sawcut vertically full depth where it is to abut up to the new concrete.
    a. Full depth sawing minimizes disturbance to the base layer under the asphalt layer.
    b. If the flexible system is sawcut significantly ahead of paving, the vertical face of the flexible pavement system needs to be shored up to minimize loss of base associated with sloughing of the unsupported granular layers.

    c. Alternatively, it may be possible to over cut the flexible pavement, pave along the planned flexible pavement interface, and then replace the flexible pavement at the over cut. A buried concrete slab that is tied to the concrete pavement may be used along the over cut area.
2. To minimize the potential for faulting at the interface construction joint, compaction, using pole tampers and plate compactors, is provided to the base adjacent to forms and along the cut flexible pavement edge.
3. To minimize hand finishing effort when matching elevations, it is best to pave starting at the flexible pavement edge and moving the paver away from the edge.
4. Do not allow slipform equipment to track on the unsupported flexible pavement edges.
5. When paving parallel to the flexible pavement, match elevations between the concrete and flexible pavements, and manipulate the concrete during finishing. Depending on cross slope drainage requirements, the following should be considered:
    a. Grinding of the flexible pavement down to the planned concrete elevation
    b. Placing concrete higher and thin milling or resurfacing of the flexible pavement.
6. During compaction of the surface layer of asphalt, do not allow the steel roller to run on the concrete edge.

8.15 HOT-WEATHER CONCRETE PLACEMENT

Hot weather is defined by ACI as a period when, for more than 3 consecutive days, the following conditions exist:

1. The average daily air temperature is greater than 77 °F (25 °C). The average daily temperature is the mean of the highest and the lowest temperatures occurring during the period from midnight to midnight.
2. The air temperature for more than one-half of any 24-hour period is not less than 86 °F (30 °C).

The concrete mixture that is to be used for hot weather must have been previously verified as appropriate by using trial batches mixed and cast at temperatures representative of typical hot weather conditions for the site.

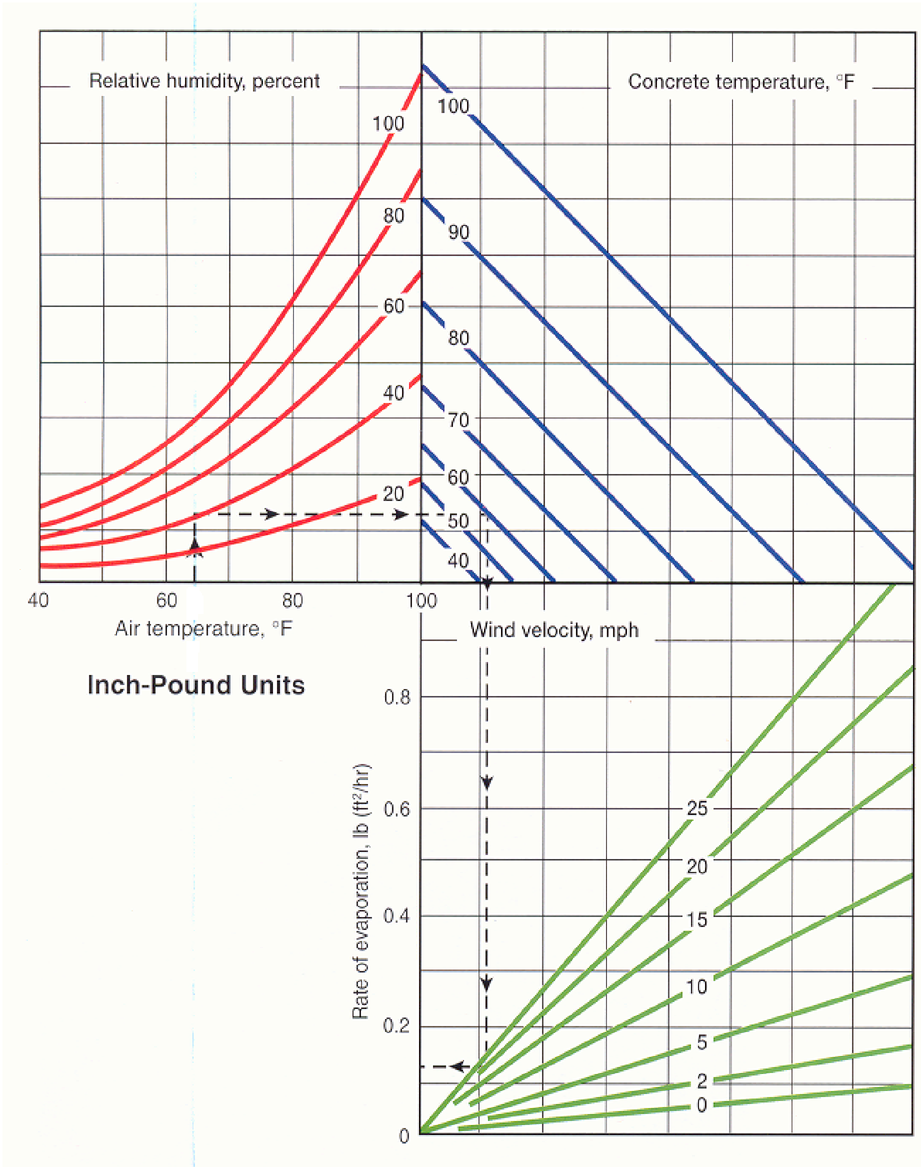
During hot weather, problems that are likely to occur include:

1. Rapid slump loss
2. Reduced air contents
3. Premature stiffening
4. Plastic shrinkage cracking
5. Thermal cracking.

Consider the following during hot weather concreting:

1. Do not exceed the maximum allowable w/cm ratio or the manufacturer's maximum recommended dosage of any admixture.

2. Retarding admixtures may be used if their performance have been verified during trial batches. High dosages of water reducers (even high range water reducers) may result in retarded set.
3. The use of slag, Class F fly ash, and/or natural pozzolans in substitution for part of the cement may be an option. These materials hydrate more slowly and generate lower heats of hydration than cement, thus reducing problems with slump loss, premature stiffening, and thermal cracking.
4. Class C fly ashes with high contents of Al_2O_3 may cause problems associated with premature stiffening.
5. Air contents can be corrected by increasing the dosage of air-entraining admixture.
6. Early age thermal cracking may be prevented by ensuring that the temperature of the plastic concrete is as low as practical. It should not exceed 90 °F (32 °C).
    a. Aggregates may be cooled by sprinkling with water. Corrections for the aggregate moisture are required.
    b. Aggregates need to be batched in a saturated surface dry condition to avoid absorbing mixture water.
7. Avoid the use of hot cement or fly ash provided by the supplier.
8. Mixing water may be chilled, or chipped ice may be used in substitution for some of the water. Be sure that all of the ice melts during mixing.
9. Mixing and transporting equipment may be painted white or a light color to minimize the heat absorbed from the sun.
10. Concrete placements can be scheduled for nighttime.
11. The base should be moistened before the concrete is placed to keep the temperature down and to keep it from absorbing water from the concrete.
12. The concrete should be placed and finished as rapidly as possible and curing compound applied at the earliest possible time. The use of a white curing compound will reflect the sun's heat. If there is any delay in applying the curing compound, use a fog spray or evaporation retardant to keep the surface from drying out.
13. Steps should be taken during hot weather to reduce the rate of evaporation from the concrete. The likelihood of plastic shrinkage cracking increases with rate of evaporation. Plastic shrinkage cracking results from the loss of moisture from the concrete before initial set. The rate of evaporation is a function of:
    a. Air temperature
    b. Concrete temperature
    c. Relative humidity
    d. Wind speed.
14. Calculate the rate of evaporation using (Figure 8.11). Current data from an on-site weather station should be used.
15. When the rate of evaporation is predicted to be above 0.2 $lb/ft^2/hr$ (1.0 $kg/m^2/hr$), provide fog spraying or use an approved evaporation retardant as appropriate.
16. If conditions of temperature, relative humidity, and wind are too severe to prevent plastic shrinkage cracking, or corrective measures are not effective, paving operations must be stopped until weather conditions improve.
17. Refer to ACI 305 – Hot Weather Concreting for additional information.



(1 °F = 0.56 °C; 1mph = 1.6 km/h; 1 lb/ft^2/hr = 5.0 kg/m^2/hr)

Figure 8.11 - Rate of evaporation as affected by ambient conditions (courtesy of the Portland Cement Association)

8.16 COLD-WEATHER CONCRETE PLACEMENT

Cold weather is defined by ACI as a period when, for more than 3 consecutive days, the following conditions exist:

1. The average daily air temperature is less than 40 °F (4 °C). The average daily temperature is the mean of the highest and lowest temperatures occurring during the period from midnight to midnight.

2. The air temperature is not greater than 50 °F (10 °C) for more than one-half of any 24-hour period.

When concrete is to be placed in cold weather, or at a time of year when cold weather is likely, plans to maintain the concrete at the appropriate temperature must be made well before the temperature is expected to drop below freezing. The following is to be considered for cold weather concreting:

1. Concrete mixture designs developed for placement at cooler temperatures normally have higher cement content than those used in hot weather.
2. The use of slag, fly ash, and pozzolans should be reduced or eliminated unless they are required to control alkali-silica reaction or to provide some degree of resistance to sulfate attack. In the later case, the total cementitious materials content may need to be increased, or the cement changed to Type III instead of Type I/II.
3. The required dosage of air-entraining admixture should be lower than the dose at normal temperatures.
4. Because the concrete will take longer to set, there is also some danger of plastic shrinkage cracking, especially if the concrete is much warmer than the ambient air or if the wind is blowing.
5. An accelerating admixture conforming to ASTM C 494 Type C or E may be used, provided its performance has been previously verified by trial batches.
6. Do not use admixtures containing added chlorides. Also, do not use calcium chloride.
7. Aggregates must be free of ice, snow, and frozen lumps before being placed in the mixer.
8. The temperature of the mixed concrete should not be less than 50 °F (10 °C).
    a. The mixture water and/or aggregates may be heated to less than 150 °F (66 °C).
    b. The material must be heated evenly.
9. Concrete should not be placed when the temperatures of the air at the site or the surfaces on which the concrete is to be placed are less than 40 °F (4 °C).
10. Covering and other means of protecting the concrete from freezing must be available before starting placement.
11. The concrete temperature should be maintained at 50 °F (10 °C) or above for at least 72 hours after placement and at a temperature above freezing for the remainder of the curing time (when the concrete attains a compressive strength of 3,000 psi [20 MPa]). Corners and edges are the most vulnerable to freezing.
12. Completely remove and replace concrete that is damaged by freezing.
13. Concrete placed in cold weather gains strength slowly. Concrete containing supplementary cementitious materials gains strength very slowly.
    a. Sawing of joints to opening to traffic may be delayed.
    b. Verify the in-place strength by a maturity method, temperature-matched curing, nondestructive testing, or tests of cores from the pavement before opening the pavement to traffic.
14. Refer to ACI 306 – Cold Weather Concreting for additional information.

8.17 PROTECTING CONCRETE AGAINST RAIN DAMAGE

The contractor and the inspector must be knowledgeable of procedures to follow to protect fresh concrete in the event of rain. The following are to be considered:

1. Protective coverings such as polyethylene sheeting or tarpaulins must be available on site at all times.
2. When it starts to rain, batching and placing operations should stop. The fresh concrete must be covered so that the rain does not indent the surface or wash away the cement paste.
3. There are two primary consequences of rain during pavement placement:
    a. Rain can damage the surface by leaving imprints or washing away paste at the surface. Damage is generally minimal once the concrete has achieved final set.
    b. Rain-induced rapid surface cooling after final set could lead to a more rapid development of thermal restraint stresses. Even if sawcutting is begun in a timely manner, an increase in the potential for early-age uncontrolled cracking exists. Joint sawing is discussed in chapter 9.
4. Should a rainstorm occur before the curing membrane is effective, the damage is usually limited to the surface.
    a. Stiff, low-slump paving-quality concrete that has been consolidated, struck off, and finished may sustain only minor surface blemishes from light rain.
    b. When the rain is light, water will not soak into the concrete and result in an increase in the water-cement ratio.
    c. If the concrete was textured prior to the rainfall, the texture may be compromised. This surface blemishing and texture damage, if light, can generally be taken care of by diamond grinding the surface to a depth of about 1/8 in. (3 mm).
5. Any concrete exposed to significant rain while it is loose or unconsolidated must not be used in the pavement as it can absorb water.
6. Once the unprotected pavement surface is exposed to rain there should be no attempt to finish or texture the surface.
    a. Removal of extra surface water prior to covering should not be attempted. Water removal operations often increase the erosion of paste at the surface.
    b. Adding dry cement or floating dry cement into the surface should not be attempted. Adding cement extends the time that the surface is exposed, increasing the potential for additional surface damage. Working dry cement into the surface also can alter the entrained air void system that is required for freezing and thawing protection.
7. As soon as the surface has dried, the curing membrane can be applied. Once the curing period is over, the surface exposed to rain should be diamond ground to remove the surface blemishes and to texture the surface.
8. Any attempt to finish or texture the surface during or after the rain event runs the risk of working water into the surface of the concrete. This will make a minor surface problem into a serious problem.
9. If unconsolidated concrete exposed to rain has been incorporated into the pavement, it must be removed.

10. Use of early entry saws or skip sawing (discussed in chapter 9) to quickly install joints prior to incoming rain should be considered.
    a. Installing joints as quickly as possible reduces the potential for early-age cracking attributed to restraint stresses generated with rapid surface cooling.
    b. Once rain has ceased and surface coverings removed, joints need are sawed as quickly as possible.
11. If a rainstorm catches a pavement that is unprotected, it is crucial that paving stop. The best precaution to avoid rain damage and/or random cracking is to cease paving operations quickly. On larger airport projects contractors may rely on weather stations located at the airport or subscribe to meteorological weather forecasting services to monitor current weather information.

TESTING RAIN EXPOSED SURFACE:

- The engineer must visually evaluate any rain damage and establish the extent of damage. Cores can be drilled for petrographic examination to determine if rain has altered the surface hardness or entrained air-void system. Cores should be recovered from the beginning and end of the damaged surfaces.
- Results from the petrographic examination can be used to establish the limits of and disposition of damaged concrete. Generally surfaces are not deemed durable for abrasion if damage extends down more than 1/8 in. (3 mm). For freeze-thaw durability, the air-void spacing factor should be less than 0.008 in. (0.20 mm)
- Surface scaling tests on core top surfaces can also be conducted in accordance with ASTM C 672. The test should be run without deicers since concrete would not have been subjected to deicing chemicals.
- Abrasion testing – Test three cores from rain damaged area and three cores from good areas – embed the cores in a 1 ft (300 mm) square concrete bed and perform abrasion testing.

The rain damaged concrete needs to be removed if the surface is determined to be not durable in terms of abrasion, skid resistance (surface texture), or freezing and thawing.

The following guidelines may be considered in assessing rain effects:

1. An intermittent light mist may be beneficial as long as no significant water is being added to the unconsolidated concrete in front of the paver or to the concrete surface to be finished.
2. If rain is sufficient to accumulate any water at all on the surface of freshly placed concrete, prior to finishing, it is time to stop and take protective measures.
3. If rain is sufficiently hard to mark freshly placed concrete, it is past time to stop paving.

9. JOINT SAWING AND SEALING

Joint sawing and sealing is an art rather than a science. It requires an experienced crew to carry out the associated tasks correctly. Although improved guidelines are available for estimating the time at which sawing can begin, speed of sawing, blade condition, and operator care all combine to influence the final product.

9.1 JOINT LAYOUT PRACTICES

The following are the necessary considerations:

1. Inspect the project drawings for the location of dowel bars and tie bars. If any problems are noted, discuss these elements with the Engineer prior to paving.
2. For jointed plain concrete pavements, the allowable ratio of slab length to slab width is typically 1.25. If the dimensions of slabs shown on the plans exceed this ratio, check with the design engineer prior to paving.
3. Where rectangular shaped slabs cannot be constructed (odd-shaped panels), embedded steel is placed in both directions at a ratio of at least 0.05 percent. The embedded steel will not prevent odd-shaped slabs from cracking, but can minimize crack openings to reduce infiltration of debris and future spalling maintenance.
4. The three joint types utilized in airfield concrete paving are contraction, construction, and isolation joints (figure 9.1).
    a. Contraction joints control the location of pavement cracking caused by drying shrinkage and/or thermal contraction. Contraction joints are used to reduce the stress caused by slab curling and warping. Dowel bars may be used for load transfer at contraction joints under certain conditions. However, load transfer is expected to be accomplished by aggregate interlock. Contraction joints need to be sawcut.
    b. Construction joints separate abutting construction placed at different times, such as at the end of a day's placement, or between paving lanes. Load transfer is achieved by the use of dowel bars. For airport slipform paving, a transverse construction joint is usually formed by sawcutting the slab end to full depth and removing the overrun.
    c. Isolation joints are used to separate intersecting pavements and to isolate the pavement penetrations, such as in-pavement lights. There are two types of isolation joints: Type A and Type B.

> JOINT LAYOUT:
>
> Check the plans for any conflicts with dowel bars and tie bars.
>
> Make sure joints line up across pilot lanes.
>
> Spot survey several locations to make sure joints will line up.
>
> Plan paving lanes such that only one longitudinal joint is sawcut.
>
> Plan blockouts and situate them more than 4 ft (1.2 m) from joints when possible.
>
> Saw cut depth should be D/3 when stabilized bases are used. On granular base, use D/4.

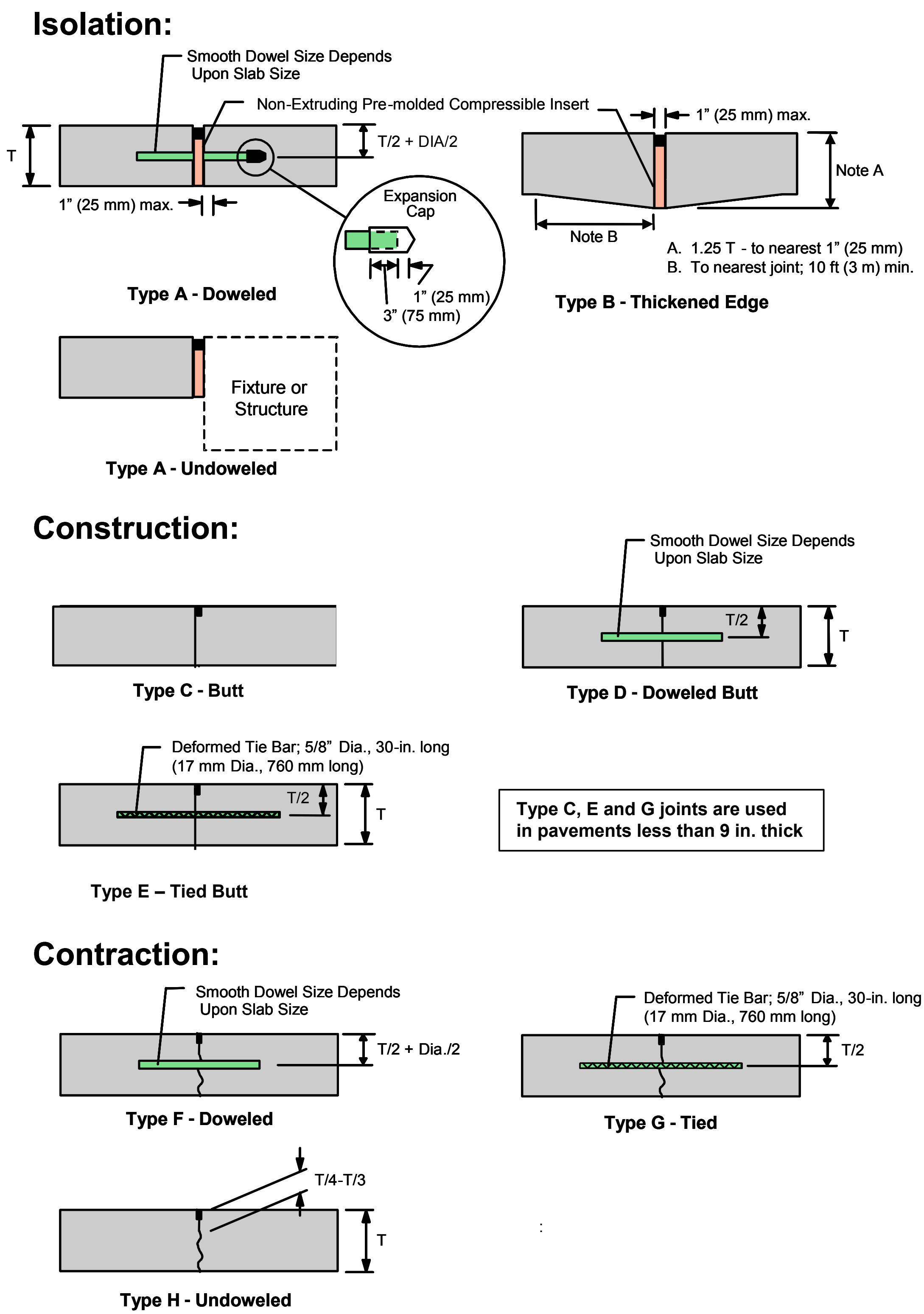


Figure 9.1 – Airport Concrete Pavement Joint Types (courtesy of the American Concrete Pavement Association)

i. Type A isolation joints provide load transfer with dowel bars. A 0.75-in. (19-mm) non-extruding compressible material provides the separation between two abutting pavements.
ii. Type B isolation joints do not use dowel bars and instead use increased thickness along the joint to reduce tensile stresses in the slab. This type of isolation joint is preferable where the pavement abuts a structure (i.e., building) or where horizontal and vertical differences in movement of the pavements are anticipated. Separation is provided with a non-extruding compressible material similar to a Type A isolation joint.

The primary function of all joints is to control cracking. Plain concrete pavement joints are spaced to reduce thermal and shrinkage restraint stresses such that no uncontrolled cracking occurs between joints as a result of these restraint stresses. The restraint stress magnitude that influences joint spacing is dependant on:

1. Concrete temperature and moisture gradients (top and bottom of slab)
2. Drop in concrete temperature (relative to temperature at concrete final set).
3. Concrete shrinkage.
4. High slab/base interface friction.
5. High modulus of base/subgrade reaction (i.e., k > 300 pci (80 kPa/mm)).
6. Pavement thickness.

Joint spacing requirements are also affected by concrete properties. Concrete properties that affect restraint stress magnitudes are:

1. Modulus of elasticity (generally ranging from 3.5 to 5.5 million psi (24,000 to 38,000 MPa); assumed to be 4.0 million psi (27,000 MPa) for most design solutions).
2. Coefficient of contraction (generally ranging from 5.0 to 6.5 x 10^{-6} in./in./deg. F).
3. Shrinkage coefficient (generally ranging from 250 to 350 x 10^{-6} in./in.).
4. Density (generally 142 to 150 lb/ft^3 for air-entrained concrete).

The recommended maximum joint spacing for pavements on aggregate (granular) bases are listed in table 9.1.

Table 9.1 – Recommended maximum joint spacing on aggregate (granular) base.

Slab Thickness, in.	Slab Thickness, mm	Joint Spacing, ft	Joint Spacing, m
6	150	12.5	3.8
7-9	175-230	15	4.6
9-12	230-305	20	6.1
>12	>305	25	7.6

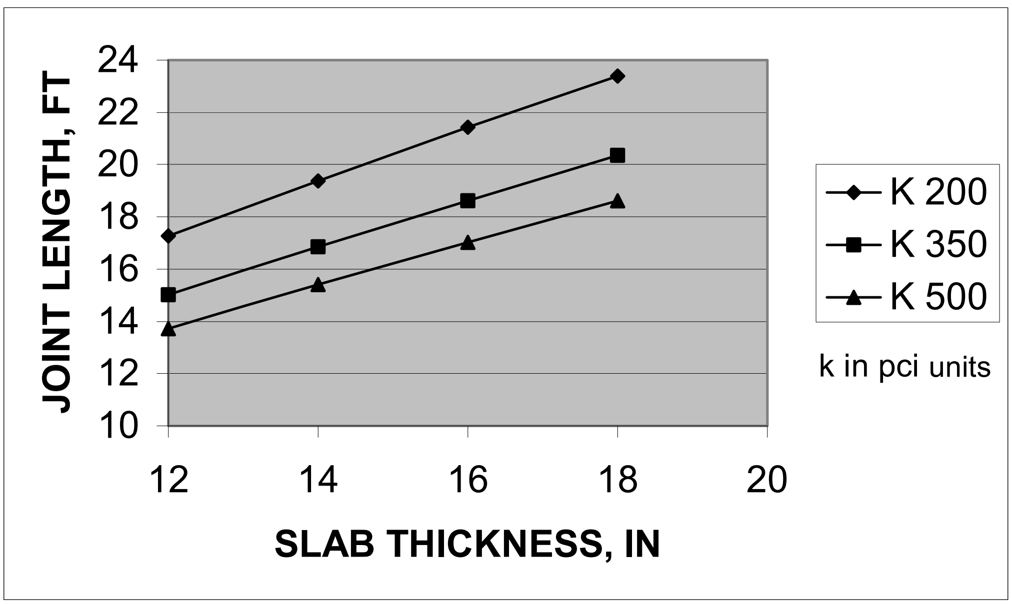
Stresses in pavements increase with a greater modulus of base/subgrade reaction (k) value. For high strength stabilized bases, the allowable joint spacing needs to be designed in the range of 4 to 6 times (typically 5 times) the pavement radius of relative stiffness (l).

The pavement radius of relative stiffness is determined as follows:

$$l = \{ E * h^3 / [12 (1 - \mu^2) k] \}^{0.25} \quad \textit{(English units)}$$

Where l = radius of relative stiffness, in.
E = concrete modulus of elasticity, psi
h = slab thickness, in.
μ = concrete Poisson's ratio (generally 0.15)
k = modulus of base/subgrade reaction (top of stabilized subbase), $lb/in.^3$

Based on the above considerations, the joint spacing is plotted in Figure 9.2 as a function of slab thickness and modulus of base/subgrade reaction. The joint length decreases with increasing stiffness of the base/subgrade. This chart was developed using a concrete modulus of elasticity value of 4,000,000 and joint spacing equal to five times the radius of relative stiffness.



Note: This figure is not to be used for design – for example demonstration only.
(1 ft = 305 mm; 1 in. = 25 mm; 1 pci = 0.27 kPa/mm)

Figure 9.2 – Typical joint spacing for pavements on stabilized bases

Pavements with light cans require special attention. Blockouts, used to install light cans, can restrain slab movement and increase restraint stresses associated with moisture and thermal changes. Design engineers typically add embedded steel to slabs containing light cans. While the embedded steel will not prevent restraint cracking around light can blockouts, the steel will hold any cracks that may develop tight and reduce the potential for crack spalling. Since most slab movements occur near longitudinal and transverse joints, if possible, jointing patterns need to be such that light cans are located more than 4 ft (1.2 m) from planned joints. Cracks tend to emanate from light cans if the light cans are positioned closer than 4 ft (1.2 m) to joints.

Joint locations should be marked on the base, edge of the slab, or on the forms. When paving a runway or wide taxiway, it can be difficult to transfer the joint locations across pilot lanes. Surveying can be used to transfer joint locations across paving lanes. Small deviations in transferring joint locations across the pavement can result in joints at a skew. Joint locations need to be carefully marked and joints need to be constructed at the proper locations.

9.2 TIMING OF JOINT SAWING

FACTORS THAT SHORTEN THE JOINT SAWING WINDOW:

- Sudden temperature drop
- High wind, low humidity
- High friction bases
- Bonding between base and slab
- Porous base
- Retarded set
- Paving fill in lanes
- Delay in curing application

Timing of sawcutting is very critical. The following items must be considered:

1. Sawing needs to commence as soon as the concrete has hardened sufficiently to permit cutting of concrete without chipping, spalling or tearing.
2. Factors that influence the rate of hardening of concrete are:
   a. Air and concrete temperatures during placement
   b. Cement content of mixture
   c. Mixture characteristics.
3. The contractor must be prepared to saw as soon as concrete is ready for sawing regardless of the time of day or night.
4. During warm weather, concrete will usually be ready for sawing between 4 to 12 hours after placement. In cold weather, or when mixture water is below 50 °F (10 °C), sawing could be delayed as long as 24 hours.
5. Generally, concrete mixtures with soft coarse aggregate (e.g. limestone) do not require as much strength development prior to sawing as mixtures with hard coarse aggregates.
6. If sawing is delayed, random cracking may occur.
7. Several factors can reduce the length of the joint sawing window. If the window becomes to short, random cracking may develop. The joint sawing window is illustrated in Figure 9.3.
8. When sawing is performed on concrete, the concrete must be capable of supporting the weight of the sawing equipment and the personnel involved in the operation.
9. During sawing, if spalling occurs along the sawcut, or if the sawcut tears the aggregate from the surface rather than go through the coarse aggregate, it is an indication that the concrete has not hardened sufficiently.

Joint Sawing Window Factors

1. The earliest time to cut joints is usually determined based on the sawing equipment operator’s scratch test or observation of the raveling or spalling at joints while making the initial cut.

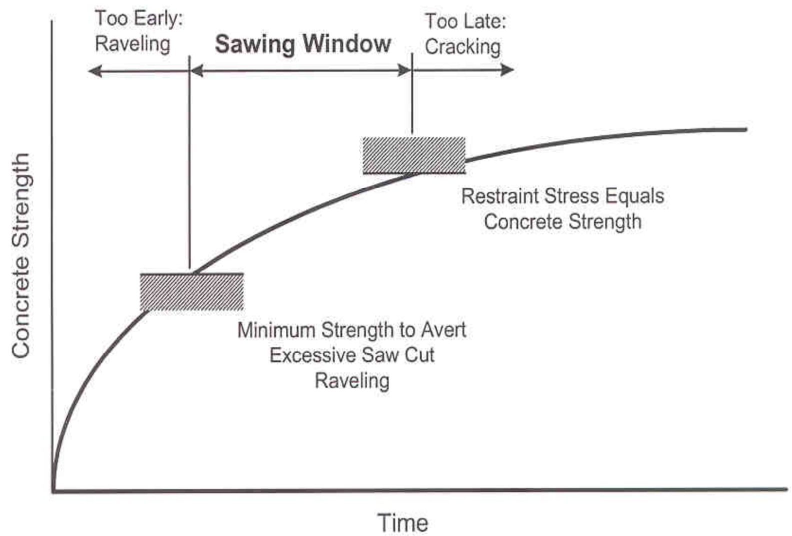
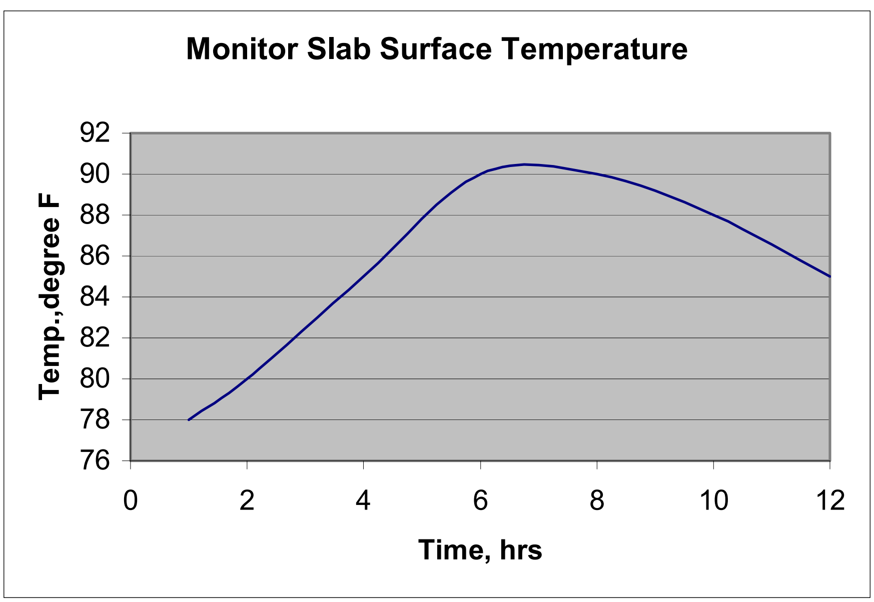


Figure 9.3 – Joint sawing window of opportunity

2. A rule of thumb for the last limit of sawing opportunity is to sawcut before the surface concrete temperature decreases significantly.
   a. Under most paving conditions, the top surface temperature will start to decrease (Figure 9.4), while sub-surface concrete temperatures continue to increase.



(1 °F = 0.56 °C)

Figure 9.4 – Slab surface temperature at early age

b. Once the concrete surface temperature decreases, and a thermal gradient is generated, thermal curling restraint stresses start to develop. Concrete cracking will result if the restraint stresses exceed the concrete tensile strength.
c. If sawcuts are installed prior to significant surface cooling, curling restraint stresses remain low and cracking develops only at planned joint locations.
d. Monitoring of concrete surface temperatures can be done using surface thermometers or infrared guns.
e. On larger projects, slab surface temperature decreases can be monitored to establish guidelines for allowable surface temperature decreases.
    i. For example, assuming relatively constant paving conditions, if no slab cracking results in sections with a 5-degree drop in surface temperature, the last limit guideline would be established at a temperature drop of 5 degrees.
    ii. This guideline would be followed until weather condition changes or other data warrant establishment of new maximum allowable temperature decreases.
    iii. The factor of safety is reduced as the maximum allowable temperature decrease increases.

3. An improved method to establish the early limit window of opportunity is to use concrete maturity meters. The maturity method accounts for the combined effects of temperature and time on strength development of the concrete.
    a. Concrete maturity meters (Figure 9.5), use thermocouples installed in plastic concrete and automatically record temperatures at given time intervals.
    b. By accounting for both curing temperature and time, it is assumed that a given concrete mix will have the same strength at equal maturities independent of curing time and temperature histories.
    c. Thermocouples are typically inserted approximately 2 in. (50 mm) deep as soon as possible after finishing operations. Maturity meters then need to be set to acquire temperatures at approximately 15 to 30 minute intervals. The meters automatically calculate maturity. Early age strength development are a function of ambient conditions, initial concrete temperatures, cement type, cement quantity, coarse aggregate type, and water-

> SPECIAL ATTENTION TO SAWCUT TIMING:
>
> Concrete pavement placed on a stabilized base is sensitive to sawcut timing. The high slab/base interface friction that can develop if adequate precautions are not taken can result in uncontrolled cracking.
>
> Rapid overnight temperature drop will cause shrinkage stresses in the concrete that can exceed the tensile strength of the concrete and lead to uncontrolled cracking. When adverse conditions are expected, sawing needs to take place as soon as possible and continue until complete. This is especially important for PCC placed over stabilized base.
>
> The surface of the subbase can become hot during summer conditions. This increases the temperature gradient through the slab. Sawing time will be decreased dramatically when these conditions occur. For asphalt treated bases, the surface of the material can be white washed to increase reflectivity.

cementitious ratio. Maturity values can also be used to establish earliest sawcutting times correlated with acceptable amounts of raveling or visual ratings.

Figure 9.5 – Maturity meter testing

9.3 JOINT SAWING OPERATION

A two-step process is typical for sawing joints. In the first step, the initial cut is made to relieve restraint stresses and allow the cracking to develop at planned locations. A second cut is made to form the sealant reservoir after the hydration process is complete.

Items to be considered for the initial sawcut are:

1. The first sawcut (early sawcut) is made with a single narrow blade (approximately 1/8 in. (3 mm)).
2. Early sawcuts made during rising concrete temperatures may be performed to the full design sawcut depth in one pass.
3. Early cuts made during falling concrete temperatures require special attention, as concrete shrinkage will occur with falling temperatures.
4. Cuts to full design sawcut depth during falling concrete temperatures may cause random cracking (pop-off cracking) to occur ahead of the saw.
    a. It may be possible to avoid this problem by use of two sawcuts, the first performed to one-half the design depth followed by a second pass to design depth.

JOINT SEALANT SHAPE FACTOR (W/D):

Joint sealant reservoir design options for airport concrete pavements are illustrated in Figure 9.6.

Hot poured asphalt based sealants typically need a reservoir shape factor (width/depth ratio) of 1.

Silicone and two-component cold poured sealants typically need a reservoir shape factor of 2.

Compression sealant reservoirs are formed to provide an average of 25 percent compression of the sealant at all times.

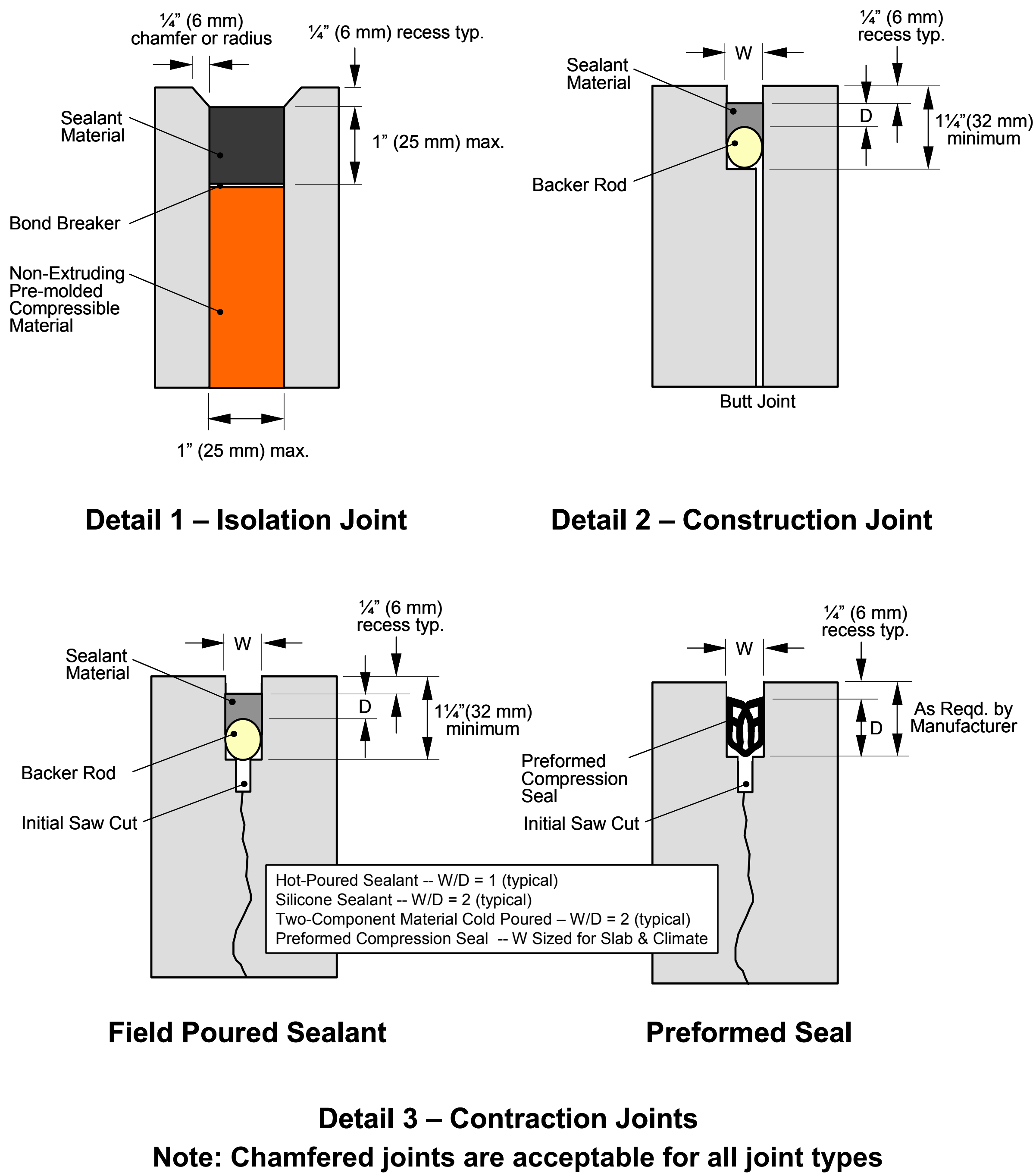


Figure 9.6 – Joint sealant reservoir design options for airport concrete pavements (courtesy of the American Concrete Pavement Association)

    b. Sawing will be discontinued in any joint where a crack develops ahead of the sawcut.
5. Transverse joints are sawed consecutively in the same sequence as the concrete is placed in the lane.
    a. Sometimes a practice called skip sawing is used to control cracking. This practice involves cutting every other or every third joint.
    b. Skip sawing can result in variable joint width.
    c. Excessive sealant stresses may occur in those joints initially sawed.
    d. Before sawing each joint, the concrete will be examined closely for cracks. Planned joints will not be sawed if a crack has appeared near the planned joint.

The following considerations are for the reservoir cut:

1. A second sawcut is made to accommodate the joint sealing material (reservoir cut).
2. The second cut is made with a wide blade set to a required depth.
3. Gang blades are not recommended for making the second cut. The stability of the gang blade systems is not sufficient to minimize spalling potential of the joint.
4. The second sawcut (in a single pass or two passes) is made at any time prior to sealant installation. However, the later in the concrete age the sealant reservoir is formed, the better the condition of the joint face.
5. The depth and width of the second sawcut should be such that it meets the shape factor (width to depth ratio) requirements of the sealant. The satisfactory performance of the joint sealant depends on the shape factor of the sealant.
6. During both the early sawcut as well as during the second cut, the sawcut needs to be periodically checked to assess for proper depth.
    a. Saw blades tend to wear as well as ride up when hard aggregates are encountered.
    b. Periodic measurement of blade diameter can be performed to monitor blade wear.

Wet sawing leaves a slurry on the surface of the concrete and on the joint face. For the first cut, the slurry must be flushed with low-pressure water followed by low-pressure air blasting. Once the slurry is removed, curing compound must be re-applied along the joint. For the reservoir cut, the same process is followed except the air and water pressures can be increased since the concrete is hard.

Several types of sawcutting equipment are used in concrete pavement sawcutting. Transverse joints are installed using one of the following:

1. Spansaws
2. 65 hp walk-behind saws
3. Early entry saws
    a. Early age entry saws do not use water.
    b. Early age entry saws are generally capable of sawing at earlier ages than spansaws or walk-behind saws.
    c. Depending on paving conditions and early age concrete strength gain, early age entry sawcutting is generally possible prior to any surface cooling and development of tensile restraint stresses.

   d. Also, since sawcuts can be installed earlier, the minimum depth requirements for the initial cut may be less. Current maximum depths for early entry saws are 4 in. (100 mm). This can limit their use to pavements less than 16 in. (400 mm) thick on aggregate base.

Longitudinal contraction joints are installed with walk-behind saws or early age entry saws.

Other joint sawing items to pay attention to include:

1. Both the longitudinal and transverse joints are cut at about the same time.
2. When concrete is slipformed, transverse sawcuts should extend completely through the longitudinal edge.
   a. If a sawcut is stopped short of the longitudinal edge, the transverse sawcut at the edge is not as deep and the potential for random cracks initiated at outside corners increases.
   b. When metal pavement forms are used, the saws must get as close to the forms as possible.
3. The risk of early age restraint cracking prior to installing sawcuts increases if the concrete strength gain is retarded (slow strength gain) or the concrete surface temperatures rapidly decrease (e.g. surface cooling with rain).
4. If sawcuts cannot be installed quick enough due to low strength gain or in relation to rapid generation of restraint stresses, concrete skip sawing may be considered.
   a. Installing every third or every other transverse joint may reduce the potential for random cracking.
   b. However, this can lead to random shrinkage crack widths at the joints.
   c. Skip sawing should only be used when there are no options.
   d. Adjustments to the concrete mixture or paving procedure should be considered before using a skip saw technique.
5. Joint reservoir beveling (chamfering) at transverse joints increases angles at joint corners from 90 to about 120 degrees.
   a. Beveling reduces the potential of damage from snow removal equipment.
   b. A major disadvantage is the increase in cost to install a beveled sealant reservoir.
   c. If beveling is used, the shape factor has to be calculated based on the depth of sealant at the point where the joint face is vertical.

9.4 JOINT CLEANING PRIOR TO SEALING

Joint reservoir cleaning before joint sealing ensures long-term service of the sealant. The following items are essential for sealing work:

1. Immediately before sealing, the joints are to be thoroughly cleaned of all laitance, curing compound, and other foreign material.
2. Sandblasting, wire brushing, water blasting or some combination of these tools may be used to clean the joint.
   a. Sandblasting or wire brushing is the preferred method of cleaning.

b. The joint faces can be primed immediately after cleaning.
c. When sandblasting is used, it must be performed with care because of the possibility of sand particles filling the joint.
d. The procedure for sandblasting is to apply it only to the joint face where the sealant will adhere.
e. When sandblasting, the nozzle is to be held at an angle to prevent penetration of sand particles deeper into the joint.

3. Air blasting needs to be used as the final cleaning step. When air blasting, the nozzle is to be held no more than 2 in. (50 mm) from the pavement surface to blow debris at the front of the nozzle.
4. Once the air blasting is completed, backer rod installation and sealant application can take place. Air blasting must be repeated at those joints remaining open over night or for extended periods.

CLEAN AIR - CLEAN JOINT FACE:

The air stream needs to be free of oil. Many modern compressors automatically insert oil into the air lines to lubricate air-powered tools. For joint cleaning, this line needs to be disconnected and an effective oil and moisture trap needs to be installed.

In most cases, the inside of the hose of a lubricating air compressor is coated with oil. New hoses should be used to clean joints.

9.5 JOINT SEALING ISSUES

Critical issues regarding joint sealing for pavement include timing of reservoir widening, beveling, joint cleaning, depth of sealant, and timing of sealing.

PREVENT INCOMPRESSIBLES:

Temporary filling of joints is a good practice to minimize infiltration by construction debris.

Cleanliness of the joint is necessary for performance of all sealant materials

Some items for joint sealing include:

1. Joint sealants are used in concrete pavement joints to keep out damaging material and minimize infiltration of water.
2. To perform to expectations, sealant materials must be capable of withstanding repeated extension and compression as the pavement slabs expand and contract with temperature and moisture changes.
3. The size and shape of the sealant cross-section affects the sealant material performance.
4. In refueling locations and any airport pavement area subject to fuel spillage, jet fuel resistant sealants are necessary.
5. Timing of sealing operations may vary from:
   a. As soon as possible.
   b. Prior to placing the adjacent lane.
   c. When the pavement achieves the minimum flexural strength for construction traffic.
   d. Prior to grooving operations.
6. Overall, it is better to wait as long as possible to seal the joints.

a. However, hard debris that can infiltrate the green cut may cause spalling.
b. The benefits of waiting to seal joints outweigh the disadvantage of debris intrusion.
c. Temporary filler such as backer rod and/or rope can be used to prevent debris from joint infiltration.

9.5.1 Hot-Poured Joint Sealing Material

Hot-poured sealants usually consist of some combination of asphalt, coal-tar, and rubber. Before sealing the joints, the contractor needs to demonstrate that the equipment and procedures for preparing and placing the sealant will produce a satisfactory joint seal. The sealant needs to bond to the concrete surface of the joint walls, have no voids, and needs to be tack-free after a specified time period. The key to achieving good joint sealing include:

1. Install the closed-cell backer rod to the appropriate depth to achieve the right shape factor.
2. The backer rod should not bond to the concrete or sealant. If bonding occurs it induces stress into the seal.
3. The backer road needs to be compressed about 25% if it is to maintain its position in the joint.
4. Heating kettle needs to be an indirect heating type kettle. Direct heating elements can cause changes in materials properties. The kettle also needs an agitator to prevent localized overheating. Material that is overheated can loose plasticity. It is recommended that any material that is over heated be discarded.
5. The application wand needs to be fitted with a re-circulation line. Otherwise, sealant in the hose can drop below application temperature.
6. Filing the reservoir is accomplished from bottom to top. Care needs to be taken that the sealer is applied such that the material is solid with no entrapped air.
7. It is a good practice to have a trial installation to verify that the sealant is capable of achieving a good bond.
8. The sealant needs to be recessed from the surface to protect it if traffic needs to use the pavement soon after sealing.

9.5.2 Cold-Poured Joint Sealing Material

Cold poured sealants are usually polysulfides, polyurethanes, or silicones. The material can be one component ready to use, or it can be two-component material requiring mixing at the site. Before sealing the joints, the contractor should demonstrate that the equipment and procedures for preparing, mixing, and placing the sealant will produce a satisfactory installation. The sealant needs to bond to the concrete surface of the joint walls, have no voids, and needs to be tack-free after a specified time period. The following are the key items to consider:

1. Depending on the material, and the recommendation of the manufacturer, the cold poured materials may be mixed in a paddle wheel or other mixer, or fed from separate containers to a mixing nozzle that is also used to inject the material into the joint.

2. A silicone is either self-leveling or non-self-leveling. These materials cure by a chemical reaction from a liquid state to a solid state.
3. The potential for incompatibility between silicone seals and the concrete aggregates must be checked. A silicone sealant that does not develop proper bond with aggregates is going to fail.
4. Aggregate surface moisture at the time of sealing can affect the bond between silicone and concrete. The use of a joint primer provided by the manufacturer may need to be considered to ensure that the silicone seal develops satisfactory bond to the joint reservoir face.
5. Cold-poured materials are generally more sensitive to moisture in the reservoir. Therefore, it is essential to check that the reservoir is dry when the sealant is installed.
6. Cold applied joint sealing compound needs to be applied by means of pressure equipment that will force the sealing material to the bottom of the joint and completely fill the joint without spilling the material on the surface of the pavement.
7. Non self-leveling sealants require additional tooling to maintain the required depth of sealant. Tooling of non self-leveling sealants must be performed before the material cures.

9.5.3 Preformed Joint Sealer

Most preformed seals are made of extruded neoprene rubber. These sealants are also called compression seals. The neoprene material is compressed and inserted into the joint reservoir. The pre-compression amount is based on the anticipated movement of the joint over the service life of the sealant.

The key aspects of achieving a good preformed sealant application are as follows:

1. For the sealant to be effective during its service life, the sealant material must be maintained in the sealant reservoir at a minimum amount of compression (i.e., it is always in compression).
2. The sealant manufacturer's recommendations are to be followed for sealant sizing and installation.
3. The sealant needs to be inserted using a device that uniformly compresses the sealant with nominal stretch.
4. The sealant needs to be lubricated, straight, vertical, and not damaged.
5. The installation device should not stretch the sealant. This reduces the allowable sealant compression and sealant failure can occur. The maximum stretch is 5 percent but 3 to 4 percent is generally specified. The military specifies a maximum of 2 percent stretch.
6. There are two ways to check for stretching.
    a. First, insert the sealant in a known length of joint and then remove the material and measure the length extracted.
    b. The second method is to pre-measure a length of sealant. A permanent mark is placed on the roll. After installation, the length of the installed sealant is measured.

9.6 TROUBLESHOOTING GUIDE

Early age cracking problems are discussed in appendix E. These problems may be due to a single cause or due to a combination of several causes. The troubleshooting guide below discusses the non-cracking problems associated with joint sawing and sealing.

Problem	Probable Cause	Corrective Action
Poured joint sealant adhesion failure	Joint face not clean Joint shape factor not correct	Check joint face for cleanliness Check joint shape factor Replace sealant
Poured joint sealant cohesive failure	Sealant properties poor due to overheating or underheating	Reduce heat Apply proper heat Use insulated hoses Replace sealant
Loose preformed sealant	Sealant not sized properly Joint width too large Sealant stretched	Use properly sized sealant Check joint width Check sealant quality Review installation procedure
Raveling or spalling of joint face.	Sawcutting performed to early Poor Sawcutting operation Joint area not cured properly	Apply curing compound after first cut Delay the reservoir cut Review Sawcutting operation Review joint face curing process

10. IMPLEMENTING QMP/CQC REQUIREMENTS

The implementation of QMP/CQC programs in this section is limited to the framework of the project QMP/CQC Plans presented in chapter 3. The operational issues are presented instead of actual conduct of the tests.

10.1 QMP/CQC TESTING AND PRODUCTION PLANS

The QMP/CQC Plan should be specific and contain enough detail to be implemented when construction begins. For example, basic requirements of a QC plan for slump testing in fresh concrete might include the following:

Specification Item:
PCC Paving

Item Description:
Process Control Testing

Type of field or laboratory test:
Slump of fresh concrete

Test Standard:
ASTM C 143 or appropriate military standard

Test Frequency:
First three trucks each day
One test per 50 cu. yd (40 cu m)

Responsibility:
QC Paving Technician

Specified Tolerance:
1.5 in. ± 1.0 in. (40 mm ± 25 mm) (action limits) and ± 1.5 in. (± 38 mm) (suspension limits)

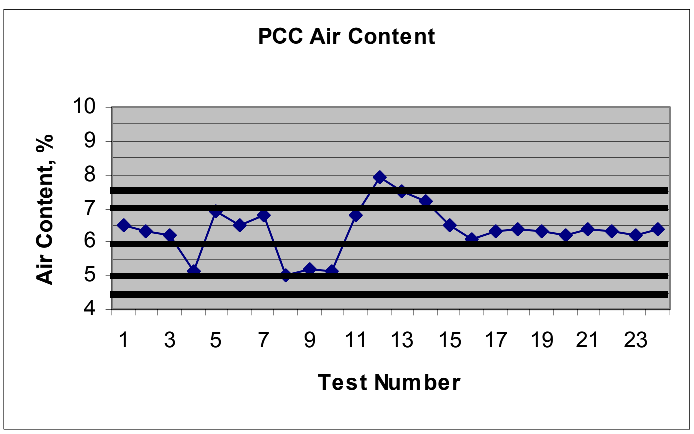
Corrective Action
If one individual slump test is outside the action limits, the next three trucks need to be tested. If those tests are within the action limits, then the normal testing frequency can be resumed. If at any time one individual slump test is outside the suspension limits or two consecutive slump tests are outside the action limits, production must be halted and each truck enroute is tested. If the slump of any of the remaining trucks is outside the action limits, the loads are to be rejected. If the slump tests for the remaining trucks are acceptable, the material may be placed. It is recommended that production paving not be resumed until the contractor has identified the problem and corrective action is implemented. After concrete placement resumes, the first three trucks are to be tested for slump. If those tests are within the action limits, then the normal testing frequency is resumed.

Although it is impossible to account for every different circumstance in the QMP/CQC Plans, it is important to outline the procedures for known or possible recurring problems. QMP/CQC plans fail when there is no clear corrective action plan for each tested item.

10.2 CONTROL CHARTS

Control charts, examples shown in Figure 10.1, provide the inspection and testing team and senior management with a summary of the construction process. Control charts are excellent tools to track trends and anticipate problems. The benefits of using control charts include the early detection of problems, monitoring variability, and establishing the process capabilities.

Similar to other documentation on a construction project, control charts are only useful when updated and adjustments implemented on a timely basis. The QMP/CQC plan needs to contain a detailed procedure identifying which items require control charts, the information to be presented on each control chart, the required posting time, and the distribution of information.



CONTROL CHARTS

Similar to other documentation on a construction project, control charts are useful only when updated and reviewed on a timely basis.

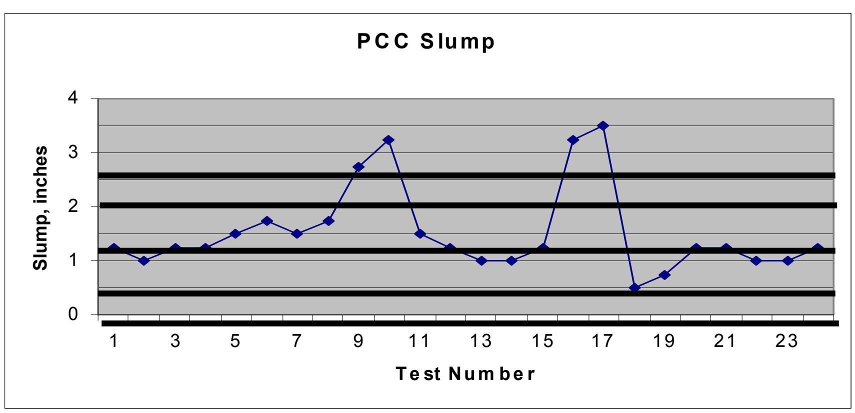


Figure 10.1 - Example control charts

10.3 TESTING PROCESS

A field laboratory must follow the same standards as a permanent facility for each test being conducted (e.g., ASTM C 1077 requirements). Items to address for the field laboratory include:

1. Sufficient capacity for properly curing beams and cylinders. If curing tanks are used, identify the method to be used to control the water temperature, water level, and lime content of the water.
2. Sufficient area for properly separating or quartering aggregates for testing.
3. Calibration of testing and monitoring equipment, including test machine scales, sieves, and laboratory thermometers, by certified/qualified source. When practical, the calibration for the QA and QC should be done by separate agencies.
4. Calibration of all field testing equipment, including air meters, slump cones, and field thermometers.

UNDERSTANDING ACCURACY, PRECISION, AND BIAS OF TEST METHODS:

The following definitions are derived from ASTM E 177:

Accuracy – Accuracy refers to how close a test result is to a reference value and incorporates both the imprecision of the measurement and the bias of the test method.

Precision – Precision refers to closeness of agreement between test results obtained under like conditions. The greater the scatter in test results, the poorer the precision.

Bias – Bias is the consistent difference between a set of test results and an accepted reference value of a property being measured. When an accepted reference value is not available, bias cannot be determined.

Components of variability – Variability in a measured construction attribute may be due to:

1. Natural (material) variability
2. Variability introduced by the construction process
3. Testing variability is introduced through the precision (or lack of precision) and bias of the test method.

When test methods are specified and the variability in a test method affects the pay factor, it is important that the engineer and the contractor be aware of the limitations inherent in the test methods as stated in their precision and bias statements.

10.3.1 Subgrade, Subbase, and Base Testing

Major testing items for subgrades, subbases, and bases include material characteristics, such as gradation and appropriate density and moisture values, thickness, and grade control. Many experienced paving professionals say that a smooth, uniform pavement starts at the subgrade. It has also been shown that the uniformity of these layers can affect the overall performance of the pavement.

Items to address in the QMP/CQC plans include:

1. Density requirements for each material lift.
2. Density requirement for each different subgrade type.
3. Maximum and minimum placement thickness.
4. How the target density will be determined for each material type.
5. Gradation requirements for each material.
6. Testing frequency and location for all tests.
7. Mix design requirements for stabilized layers.
8. Process for documenting, reporting, and distributing all test results including schedule.
9. Action list for handling failed test results.

FAILED GRADE MATERIAL:

When failed material is placed on the grade, a typical remediation action is to blend in material with loads of good material. To maximize quality, the failed material should be removed and material variability reduced.

10.3.2 Fresh Concrete Testing

Testing of fresh concrete typically includes assessing the following:

1. Air content
2. Slump
3. Temperature
4. Unit weight.

Some agencies require a concrete water content test. Unit weight can be used to calculate the yield for the concrete mix. Although these tests are widely used and understood, the details of the testing requirements may not be widely understood. It is important for the contractor and inspectors to review testing standards and agree on testing procedures. These details and logistics need to be described in detail in the QMP/CQC plans. Items to address in the QMP/CQC plans include:

1. Testing frequency.
2. Testing location (Note: Testing may be conducted at the plant or on site to determine the affect transporting the concrete has on basic concrete material properties.)
3. The process for updating and distributing control charts.
4. Clearly defined action items for test results that do not conform to the specifications or standards.

Obtaining a representative sample of fresh concrete is very important to ensure reliable test results. The fresh concrete sample needs to be taken from the center 1/3 of the batch. The QMP/CQC plans need to address the location of sampling within each batch for each type of concrete delivery vehicle.

Control charts are useful for evaluating fresh concrete test results. Action and suspension limits need to be created for each test and the QMP/CQC plans need to address what specific actions to take when test results are outside the action or suspension limits.

FRESH CONCRETE TESTING:

Sampling: Make sure sample is representative as possible. Collect from several different discharge areas. Remix sample prior to performing any tests and keep sample covered with a plastic sheet to prevent evaporation.

Slump test (ASTM C 143) – Determines consistency (but not necessarily workability) of concrete. The cone is to be clean and pre-wetted for each test. Repeat test using another sample before considering concrete is out of specification.

Air content (ASTM C 231 – Pressure Method and ASTM C 173 – Volumetric Method) – Meters need to be properly calibrated. The accuracy of the pressure meter depends on the altitude at which it was calibrated. Repeat test before considering concrete out of specification.

Density of fresh concrete (ASTM C 138) – Indicates possible change in air content and determines yield. Container must be properly calibrated.

Temperature of fresh concrete (ASTM C 1064) – Perform test every time strength specimens are made and whenever concrete temperatures are suspected of nearing specification limits. In hot weather the maximum concrete temperature is limited to 90 °F (32 °C), and in cold weather a minimum temperature of 40 °F (4 °C) is often specified.

Concrete water content (AASHTO T 23) – Performed using microwave drying oven. The publication provides information on water in cementitious materials.

10.3.3 Thickness Testing

The thickness of a pavement can be tested in several ways. It can be checked by using paving stringline as a guide, performing destructive testing by either excavating nonstabilized material or taking cores from stabilized material and concrete layers, or surveying elevations before and after placement. Coring is the preferred method. If core testing is used for thickness verification, the cores (typically 4 in. [100 mm] in diameter) need to be labeled and stored, preferably on site, until the end of the project.

Items to address in the QMP/CQC plans include:

1. Testing frequency and location.
2. Clearly defined procedures for locating, measuring, and reporting the test results.
3. For projects with stabilized open-graded drainable bases, there must be agreement on the procedure to determine the bottom of the core.
4. Avoiding thickened edges and transition areas for test locations.

CONCRETE THICKNESS PERCENT WITHIN LIMIT (PWL):

- Concrete slab thickness is a PWL pay item. Therefore variability has to be minimized.
- For situations where new ATB and milled AC base may exist within a paving lane, consider separating lots by surface type.
    - Milled surface may be milled a bit deeper or may be nonuniform, and can affect variability if included in lot that has newly placed ATB.
    - Separate the two areas as statistically different
- Consider known low base areas as separate lots or do not sample in these areas.

Effect of Thickness Variability:

- Unless the targeted slab thickness is significantly greater than the design thickness, an increased variability in lot core lengths can reduce the percentage of thickness within specification limits (PWL).
- For example, assume the lot thickness cores are 18.1, 18.2, 18.3, and 18.5 in. (460, 462, 464 and 470 mm) The thickness PWL for this lot with a lower limit thickness of 18.0 in. (457 mm) is 100, resulting in no thickness pay deductions.
    - If the lot is variable and the last core is 19.0 in. (482 mm) instead of 18.5 in. (470 mm), the PWL is 83 and a 9.6 percent thickness penalty results.
    - Even though the average lot thickness increases from 18.3 to 18.4 in. (465 to 467 mm), a penalty is incurred since the lot standard deviation is higher.

10.3.4 Aggregate Tests (Gradation and Moisture Content)

Aggregate gradation testing varies based on the specification items for bases, stabilized bases, trench backfill, and concrete. Since there is a large quantity of aggregate used on each project, testing the gradations may become overwhelming. Items to address in the QMP/CQC plans include:

1. Testing frequency.
2. Requirements for stabilized bases and concrete mixture verifications.
3. Sampling location (stockpiles or individual trucks).
4. Aggregate moisture content tests – frequency (ASTM C 70, ASTM C 566).
5. Gradation in fresh concrete, washed gradations.
6. Clearly defining action items when the aggregate fails the gradation tests.
7. How are the limits of unacceptable material determined?
8. Developing a clear reporting process to ensure timely distribution of test results.
9. Verifying bulk specific gravity of each aggregate at designated times throughout the project. This is not practical on a smaller project (less than 50,000 sq yd (42,000 sq m)).

10.3.6.2 Joint Face Deformation

This requirement is usually applicable to military construction only. Items to address in the QMP/CQC plans include:

1. Are the joint face tolerances the same for transverse and longitudinal joints?
2. How are headers handled? Are they part of the testing or are they excluded?
3. Can vertical deviations be corrected with concrete saws? If yes, do the cuts have to be full-depth?

10.3.6.3 Profile Testing

Smoothness specifications for airfields primarily rely on straightedge testing. Typical specifications are based on 16 ft (5 m) straightedge testing as follows:

1. Acceptable: 1/4 in. (6 mm)
2. Grind: 1/4 to 1/2 in. (6 to 13 mm)
3. Remove and replace affected slabs: greater than 1/2 in. (13 mm).

Current U.S. Corps of Engineers specifications and some FAA regional specifications allow use of the California profilograph shown in Figure 10.4.

Figure 10.4 – Profilograph testing in progress

. Items to address in the QMP/CQC plans include:

1. Type of equipment allowed.
2. Method of evaluation to be used.
3. Are the criteria different for different facilities, such as runways, taxiways and taxi lanes, and aprons?
4. Are any areas excluded, such as connecting taxiways?

5. Are headers included in the smoothness evaluation?
6. How soon after paving should the profile testing be conducted?
7. If a straightedge is used, will the testing be continuous, random, or subjective?
8. If a rolling straightedge is used, where will the testing occur? In the center of the slab, near the longitudinal paving lane joint, or at the third points of the slab?
9. If multiple passes are required, are these per lane or per paving width (which may incorporate two or more lanes)?

10.3.7 Dowel Bar Alignment and Inspection

Typical specifications for dowel bar misalignment limit the skew misalignment (typically 1/4 in. (6 mm) per 12 in. (300 mm) length of the bar) and horizontal [±1 in. (25 mm]), vertical (± 1 in. [25 mm]) and longitudinal (±1 in. [25 mm]) displacements. For thick airport pavements, horizontal and vertical deviation of up to ± 2.0 in. (50 mm) may be tolerated.

Items related to dowel bar placement to address in the QMP/CQC plans include:

1. Dowel bar material transmittals and bond-breaker coatings.
2. Detailed procedures for transporting, storing, inspecting, installing, and securing of dowel bars.
3. Detailed procedures for dowel bar inserters that include random checks to ensure equipment is operating properly.
4. Checking of dowel bar assembly for trueness to eliminate skewed bars.
5. Allowable dowel bar misalignment and how it will be measured.
6. Joint saw cut line deviation: How much is acceptable with regards to dowel bar embedment?
7. Number of dowel bars that can be misaligned per joint per panel.

It should be noted that dowel bar alignment can be measured only for pre-placed baskets before concrete placement and for drill and grouted dowels along the longitudinal construction joints. The inspector needs to ensure that pre-placed baskets are properly positioned and fastened and that the paver operation does not indicate any potential for moving or dragging the dowel basket assemblies. With respect to drill and grouted dowel bars, the alignment can be checked after the epoxy grout has set. Any dowel bars that are misaligned beyond the allowable levels need to be cut and new dowels installed. For machine-inserted dowel bars, as well as the pre-placed dowel bars, if there is a concern related to dowel misalignment, ground penetrating radar (GPR) can be used to check the alignment after the concrete is about one day old. GPR testing can determine vertical dowel bar alignment to an accuracy of ± 1/8 to 1/4 in. (3 to 6 mm).

11. REPAIR OF EARLY DISTRESS

Concrete pavements may occasionally exhibit early distress. This may occur while the concrete is still in plastic state or soon after concrete hardens. The most commonly encountered early distress are:

1. Plastic shrinkage cracking
2. Edge slump
3. Joint spalling
4. Full-depth cracking

When early distress is observed, the cause of the failure should be identified and appropriate corrective measures taken to reduce the potential for the failure to develop again. It is good practice to discuss the disposition of slabs that exhibit early distress at the pre-construction meetings.

11.1 PLASTIC SHRINKAGE CRACKING

Plastic shrinkage cracking, as shown in Figure 11.1, is cracking in the surface that may develop if the rate of evaporation at the surface is high. Plastic shrinkage cracking typically manifests as shallow (1 to 3 in. (25 to 75 mm) deep), closely spaced parallel cracks. In some cases, the cracking may extend deeper than 3 in. (75 mm) but it is unusual for the cracks to be full depth. It is recommended that 4 in. (100 mm) diameter cores be taken over a few cracks to determine the depth of cracking.

Figure 11.1 – Plastic shrinkage cracking

Plastic shrinkage cracking can be repaired by injecting low viscosity epoxy or high molecular weight methacrylate in each crack after concrete has hardened. Epoxy injection procedures are to be in accordance with the epoxy manufacturers instructions. The use of gravity fed epoxy technique is not recommended, as the crack penetration will not be fully effective. Cracking deeper than 3 in. (75 mm) or extensive cracking requires slab removal and replacement (section 11.4)

11.2 EDGE SLUMP

When a slipform paver pulls forward, there is a tendency for the unsupported edge to slump down at the edge with depression extending inwards on the slab. If edge slump is occurring in excess then adjustment is needed in the concrete mixture, the paving equipment, or the paving operation. Edge slump is a serious defect because it creates an area for ponding of water and could affect joint performance.

If the edge slump is detected before initial set of the concrete, a plastic repair can be attempted. The repair of edge slump must be carried out correctly to ensure durability of the repaired area. The important items to consider are:

1. The edge needs to be formed along the repair area.
2. If additional material has to be added to repair the edge slump, the added material needs to contain a mixture of aggregate particles. Plain mortar addition is not allowed.
3. The repair area material must be vibrated into the existing material.
4. Repair should not be attempted after the curing compound has been applied as the repair area concrete can become contaminated with the curing compound.
5. If initial set has occurred vibration is ineffective; it is too late to make a plastic edge slump repair.
6. Use of plain mortar or addition of material to hardened concrete may lead to spalling as shown in figure 11.2.
7. After the repair concrete has been vibrated, it should be screeded and finished as uniformly as possible with the surrounding concrete.
8. The repaired area should be textured and cured using the same processes as the surrounding concrete.
9. Plastic repairs should be the exception and not the norm.

Figure 11.2 – Shallow spalling due to improper edge slump repair

It is emphasized the edge slump repairs are isolated problems and should not be a routine occurrence. If excessive edge slump is occurring, then the paving must be stopped until the problem is corrected.

Also, if the edge slump repair cannot be done in a timely manner, it may be necessary to allow the affected slab panels to harden then perform repair by:

1. Sawing of the slumped edge and then performing a partial depth repair at the surface depression.
2. By removing and replacing the slab that has excessive edge slump.

11.3 JOINT SPALLING

Joint spalling or excessive joint raveling may develop as a result of the joint sawing operation – typically due to early joint sawing, use of wrong blade type, or poor operation of the sawing equipment. Minor or localized joint spalling is typically repaired using a partial-depth repair technique using the concrete mixture used for paving. If the spalling is severe and excessive in length, replacement of the affected slab should be considered.

11.4 FULL DEPTH CRACKING

Localized full-depth cracking may result from one or more of the following causes:

1. Late transverse joint sawing or insufficient depth of sawing.
2. Misaligned dowel bars.
3. Excessive curling and/or warping.
4. Rapid surface cooling.
5. Early age loading by construction equipment.
6. Excessive drying shrinkage.
7. Excessive base frictional restraint.

Full depth cracking that appears within 30 days is usually the result of poor construction practices, poor design, or both. The important items to consider for repair of full-depth cracking include:

1. Panels in critical pavement areas with full-depth cracking that extends the full width or length of the slab panels should be replaced. Critical pavement areas are those areas that are subject to aircraft landing gear loadings.
2. Full-depth cracking in non-critical pavement areas (e.g., most exterior lanes of a runway or taxiway) may be left in place, at the option of the owner. The crack must be routed and sealed.
3. Full-depth cracking in critical pavement areas that extends less than one-third the width or length of the slab should be treated as a full width crack.

4. Full-depth corner cracking in critical pavement areas must be repaired by full panel replacement.
5. Use of partial panel replacement in critical pavement areas on new pavement is not recommended.
6. Proper procedures need to be followed for slab removal and replacement. The procedures must include the following:
    a. Slab removal without damaging adjacent sound slabs or the base.
        - Use of double saw cut along slab perimeter.
        - No heavy impact loading to break slab into small pieces.
        - Saw cut panel into smaller segments and lift out.
    b. The base must be inspected for damage and corrected prior to concrete placement.
    c. Load transfer along all joints must be restored by using dowel bars using the drill and epoxy grouting technique.
    d. Use of approved concrete mixture for hand placement operations.
    e. Use of vibration to consolidate the concrete.
    f. Use of proper techniques to finish, texture, and cure the replacement slab.

APPENDIX C – INSPECTION AND TESTING CHECKLIST

INSPECTION

Materials
- Cement and fly ash tickets conforming to accepted and approved sources
- Approved liquid admixture type and manufacturer conforming to submitted mixture designs
- Water testing requirements (suitable for concrete)
- Approved curing compound type and source
- Approved joint sealant and type
- Approved backer rod material
- Approved expansion joint filler and dimensions
- Certifications for embedded steel and dowel bars
- Approved epoxy for dowel bar grouting

Equipment
- Batch plant inspection completed
- Certification of scales (load cells/belts), water meters, liquid admixture dispensers
- Batch plant and agitator truck mixer uniformity tests
- Concrete haulers clean and free of debris and oil
- Daily verification of slipform vibrator frequency and amplitude
- Verification of spud vibrator and pan/surface vibrating screed frequency and amplitude
- Sufficient number of saws to minimize potential for random cracking
- Curing compound coverage and uniformity tests approved
- Saw blades suitable for coarse aggregate type

Base Condition
- Grade acceptance
- No equipment damage from loose debris
- Moisture conditioning of base (granular)
- Application of bond breaker (stabilized base)
- No standing water or frost
- Transverse grade checks off of string lines or forms

Embedded Steel and Dowel Bars
- Tie bar length, diameter, and epoxy coatings
- Dowel bar length, diameter, and coatings meeting project/plan requirements
- Dowel basket location, elevation, orientation, and alignment
- Dowel baskets secured to base

Concrete Batching
- Use of stabilized pads for aggregate stockpiles (if required)
- Procedures to mitigate aggregate contamination

- Uniform stockpile loading
- Sprinkling for consistent aggregate moistures
- Utilization of actual aggregate moisture contents
- Computer printouts of date, time, mixing time, dry batch weights, water, and liquid admixtures
- Procedures to document added water after batching
- Minimum mixing times meeting mixer uniformity testing requirements

Concrete Placement Conditions

- Concrete placed within specified time after batching
- Cold weather requirements (air temperatures, no ice in aggregates, initial concrete temperatures)
- Hot weather conditions (air temperatures, initial concrete temperatures)
- Plastic shrinkage potential (air temperatures, initial concrete temperatures, relative humidity, and wind speed)
- Foggers, windbreaks, and/or evaporative retardants (hot weather) available
- Polyethylene sheeting (or other approved covering) available in the event of rain

Concrete Placement

- Uniform placement in front of paver
- No large pockets of entrapped air or voids at vertical slipformed edge
- Transferring of accurate location for sawed transverse joints
- Control chart action/suspension limits

Concrete Consolidation and Finishing

- Closed surface and adequate consolidation at inserted dowel bars
- Minimizing concrete floating/finishing after striking off and consolidation
- Minimizing application of water to surface during final finishing

Concrete Placement Tolerances

- Verify interior thickness and at slipformed edges regularly
- Check final elevation off wire stretched transversely across pavement
- Edge slump checks
- Edge shoring needs and procedures
- Straight edge testing

Concrete Curing

- Application of curing compound within 60 minutes of final finishing
- Curing compound coverage rates and uniformity
- Vertical longitudinal edges covered with curing compound
- Minimum concrete curing temperature requirements

Joint Sawcutting

- Sawcut depth (initial and reservoir cuts)
- Alignment in relation to transverse joint dowel baskets

- Acceptable amounts of spalling/raveling
- Sawcut carried through vertical edge
- Water/slurry containment

Opening to Construction Traffic
- Minimum strength and time requirements

Joint Dowel Bar Installation (Construction Joint)
- Dowel bar elevation, spacing, alignment, and minimum clearance from transverse joints
- Dowel bar diameter
- Drilled hole dimensions meeting specification/plan requirements
- Epoxy injection procedure
- Use of epoxy retainer disks

Joint Sealing
- Sealant reservoir dimensions
- Reservoir cleanliness
- Backer road placement
- Sealant curing temperatures meeting manufacturer's recommendations
- Recessed sealant depths

Grooving
- Grove depth and spacing requirements
- Clearance requirements at joints

Cracking, spalling, and acceptance
- Unacceptable cracking and spalling criteria
- Repair of cracking and spalling

TESTING

Aggregate Testing
- Gradation and durability test requirements
- Sampling for gradations at daily frequencies off belt or representative samples from stockpiles
- Control chart action/suspension limits
- Representative sampling for aggregate moistures
- Determination of aggregate moistures at specified frequencies
- Frequency for flat and elongated aggregate requirements

Concrete Sampling, Fabrication, and Curing
- Sampling location on grade, frequency, and randomness requirements
- Fresh sample transport requirements – preventing loss of moisture
- Air content and slump frequency and control chart action/suspension limits

- Beam mold water tightness, warping requirements
- Vibration and consolidation sequence
- Vibrator equipment inspection
- Initial curing moisture loss control and temperature criteria
- Transporting molded strength specimens to laboratory for final curing
- Final curing temperatures and conditioning

Concrete Flexural Strength Testing

- Machine calibration and setup
- Loading rate requirements
- Sample preparation
- Leather shims or grinding for beam testing
- Moisture control during testing
- Loading rate
- Measuring beam dimensions
- Strength calculation
- Documentation of sample deficiencies

Core Length (Thickness) Testing

- Random locations
- Number of measurements
- Average core length determination

Smoothness Testing

- Straightedge and profile equipment
- Recommended timing
- Grinding limits

APPENDIX D – JOINT SAWING CHECKLIST

Equipment

- Number of saws
- Early age entry saws
- Saw blade type – compatible with concrete aggregate type

Inspection Items

- Test strip sawing
- Planned vs. actual sawcut locations
- Acceptable raveling and spalling
- Sawcut depth (initial and reservoir)
- Timing of longitudinal joint sawing
- Sawcut carried through vertical edge
- Odd shaped slabs at radii
- High tie bar situations

Cold Weather, Rain, and Slow Concrete Setting Times

- Use of insulation or geotextile fabric
- Check fly ash usage requirements
- Consider early age entry sawing
- Consider skip sawing

Post Cutting Issues

- Flushing joints
- Re-application of curing compound
- Timing of backer-rod placement
- Early age cracking inspection

APPENDIX E - DECISION TREE FOR EARLY AGE CRACKING

Cause(s) of early age cracking must be determined immediately and action items to minimize/eliminate causes or their effects implemented before proceeding further with paving. Early age cracking for airport concrete pavements is typically classified as any cracking that may develop within the first 7 days after concrete placement. However, some cracking may initiate at the slab bottom and not be visible until days or weeks pass. The following is a list of the type of early age cracking that can develop:

1. Plastic shrinkage cracking
2. Random cracking (no orientation)
3. Longitudinal cracking
4. Transverse cracking
5. Corner cracking
6. Cracks just ahead of sawing (pop-off cracks)
7. Later age cracking (early age slab bottom cracking propagating to surface)
8. Sympathy cracks
9. Settlement cracks over dowel bars or tie bars
10. Re-entrant cracks.

The following need to be noted when early age cracking develops:

1. Some cracking may have an obvious cause and corrective actions must be initiated immediately
2. Some cracking may be the result of marginal conditions
    a. Correcting one marginal condition may resolve an immediate problem but may not reduce the cracking potential for subsequent paving
    b. It is important to identify as many marginal conditions as possible and rectify as many that are under the control of the design engineer or the contractor.

The process of investigating early age distress, for which the obvious cause is not readily apparent, involves the following steps:

1. Gather relevant information (see next page)
2. Identify if the distress manifests as isolated or systematic (widespread) occurrences. If the distress is systematic, a thorough review of the design features as well as all key construction procedures need to be undertaken.
3. Work through an iteration of logical steps to pinpoint one or more causes. This involves a process of elimination, starting with obvious factors that can be verified by field and laboratory personnel. As the process of elimination continues, additional steps may involve more rigorous evaluation of data, coring, and laboratory testing.

GATHER RELEVANT INFORMATION (FOR PAVEMENT SECTION IN QUESTION)

1. Design Information

    a. Pavement thickness as designed:
    b. Pavement thickness as constructed:
    c. Joint spacing
        i. Transverse:
        ii. Longitudinal:
    d. Base Type:

2. Concrete Mix Information

    a. Cement type and source:
    b. Cement grind history: Fresh grind/ Not-fresh grind
    c. Supplementary cementitious materials
        i. Type C fly ash source:
        ii. Type F fly ash source:
        iii. Slag source:
    d. Cement content:
    e. Supplementary cementitious content
        i. Type C fly ash:
        ii. Type F fly ash:
        iii. Slag:
    f. Aggregate Data
        i. Gradation: uniform/gap graded/other
        ii. Gradation description:
        iii. Coarse aggregate type, source and amount:
        iv. Fine aggregate type, source and amount:
        v. Coarse aggregate coefficient of thermal expansion:
    g. Admixture manufacturer, type and dosage
        i. Air-entraining:
        ii. Water reducer:
        iii. Other admixture:

3. Environmental Data

    a. Weather condition for three (3) days prior to paving to 14 days after or present, whichever is earlier:
    b. Hot/cold weather precautions taken:
    c. Temperature readings for three (3) days prior to paving to 14 days after or present, whichever is earlier (attach table)
    d. Rainfall history during and up to three (3) days after concrete paving or present, whichever is earlier:

4. Construction Data

    a. Paving history
        i. Start time:
        ii. Finish time:
        iii. Curing time:
    b. Method used for minimizing bond for stabilized base:
    c. Base surface condition:
    d. Concrete curing method:
        i. Curing compound type and rate of application (if used):
        ii. Number of days of moisture curing, if applicable:
    e. Timing of sawcut
        i. Transverse joints:
        ii. Longitudinal joint:
    f. Depth of sawcut
        i. Transverse joint – As specified: Actual range:
        ii. Longitudinal joint – As specified: Actual range:
    g. Dowel alignment verification results:
    h. Early age loading history
        i. Construction equipment loadings:
        ii. Drill rig loading:
        iii. Other:

5. Other Relevant Data

    a. Develop distress maps. Estimate or measure crack widths. Note ambient temperature at time of distress survey.
    b. Update maps regularly (every day or every few days) to determine if the distress is progressive and if cracks are getting wider.

DECISION TREE FOR EARLY AGE CRACKING

Cracking Type	**Plastic Shrinkage**	**Random Cracking (No orientation)**	**Longitudinal Cracking**	**Transverse Cracking (partial or full width)**	**Corner Cracking**	**Cracks Just Ahead of Sawing (Pop-off Cracks)**	**Late Cracking (after about 7 days to about 60 days or before aircraft loading)**	**Sympathy Cracks**	**Settlement Cracks over Dowel or Tie Bars**	**Re-entrant Cracks**
Possible Causes	High rate of evaporation - Warm temp. - Low humidity - Windy	Slab to base bonding	Late sawing for prevailing conditions	Late sawing for prevailing conditions	Early loading	Late sawing for prevailing conditions	Early age slab bottom cracking finally becoming visible	Joints in paved lane do not match joints in adjacent lanes	Higher slump concrete	Use of odd-shaped slab panels
	Dry concrete mix	Concrete slab friction against rough base or concrete penetration into open graded base	Shallow sawing of longitudinal contraction joint in relation to **actual** slab thickness	Shallow sawing of transverse contraction joints in relation to **actual** slab thickness	Excessive curling and warping due to temperature changes or moisture loss	Sawing against high wind	Frost heave	Different joint cracking patterns in adjacent lanes	Shallow dowel bars or tie bars	Rigid penetrations (in-place structures)
	Dry aggregates	Reflection cracking (from base cracking)	Slabs too wide in relation to thickness & length	Slabs too long in relation to thickness & width	Dowel bars too close to each other at transverse and longitudinal joints		Foundation settlement	Joints match in location but not in type	Delay in setting time	
	Late or inadequate curing	Late or inadequate curing	Temperature drop due to sudden cold front or rain	Temperature drop due to sudden cold front or rain	Late or inadequate curing					

Cracking Type	**Plastic Shrinkage**	**Random Cracking (No orientation)**	**Longitudinal Cracking**	**Transverse Cracking (partial or full width)**	**Corner Cracking**	**Cracks Just Ahead of Sawing (Pop-off Cracks)**	**Late Cracking (after about 7 days to about 60 days or before aircraft loading)**	**Sympathy Cracks**	**Settlement Cracks over Dowel or Tie Bars**	**Re-entrant Cracks**
	Delay in finishing	Late sawing for prevailing conditions	Misaligned or bonded dowels in adjacent longitudinal joints preventing cracked joints to function	Misaligned or bonded dowels in adjacent transverse joints preventing cracked joints to function	Misaligned or bonded dowels in adjacent transverse joints preventing cracked joints to function					
	Temperature drop due to sudden cold front or rain	Shallow sawing of contraction joints in relation to **<u>actual</u>** slab thickness	Excessive curling/ warping	Excessive curling/ warping						
	Material incompatibility leading to higher concrete shrinkage and delay in setting time	Poor aggregate gradation (sand too fine; gap gradation)	Poor aggregate gradation (sand too fine; gap gradation)	Retarded concrete						
	Poor aggregate gradation (sand too fine; gap gradation)		Early loading							

Cracking Type	Plastic Shrinkage	Random Cracking (No orientation)	Longitudinal Cracking	Transverse Cracking (partial or full width)	Corner Cracking	Cracks Just Ahead of Sawing (Pop-off Cracks)	Late Cracking (after about 7 days to about 60 days or before aircraft loading)	Sympathy Cracks	Settlement Cracks over Dowel or Tie Bars	Re-entrant Cracks
			Infill lane restraints	Poor aggregate gradation (sand too fine; gap gradation)						
			Late or inadequate curing	High shrinkage concrete						
			High shrinkage concrete	Early loading						
			Slab to base bonding							
Investigative Techniques	Check quality of curing compound	Obtain cores through base to check slab to base bond	Obtain core to check depth of cracking & aggregate breakage	Obtain core to check depth of cracking & aggregate breakage	Obtain core to check depth of cracking & aggregate breakage				Check dowel depths using a covermeter or GPR or by coring	
		Check quality of curing compound	Check quality of curing compound	Check quality of curing compound	Check quality of curing compound					