An *IPRF* Research Report

Innovative Pavement Research Foundation

Airport Concrete Pavement Technology Program

Report IPRF-01-G-002-1

Best Practices for Airport Portland Cement Concrete Pavement Construction (Rigid Airport Pavement)

Programs Management Office
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Washington, DC 20001

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Highlight boxes

This manual includes highlight boxes that provide special alerts. These boxes highlight elements of the concrete paving process that have direct influence on the end product.

QUALITY ALERT:

Highlights key items related to obtaining quality in the paving process.

PAVING ALERT:

Warns of items that have a potential for negative impact on the construction process and/or pavement performance.

Test standards

Test standards referred to are typically American Society for Testing and Materials (ASTM) standards. These standards are designated in the text by numbers only. The full title of each standard referred to is given in appendix A. Unless designated, the references to the standards are for the most current version.

Acronyms

The following organization related acronyms are used in the manual:

ACI – American Concrete Institute
AASHTO – American Association of State Highway and Transportation Officials
ACI – American Concrete Institute
ACPA – American Concrete Pavement Association
ASTM – American Society for Testing and Materials
DOD – Department of Defense
DOT – Department of Transportation
FAA – Federal Aviation Administration
PCA – Portland Cement Association
UFGS – Unified Facilities Guide Specifications (used by the U.S. Army Corps of Engineers, Naval Facilities Engineering Command, and the Department of the Air Force)

References

References, except for copyright purposes, are not cited in this manual. This manual is a best practices document and the information presented is compiled from many sources – published and non-published. A list of primary source documents used may be found at the end of the manual.

EXECUTIVE SUMMARY

Well-designed and well-constructed airport concrete pavements for runways, taxiways, and apron areas can be expected to provide excellent long-term performance under a range of operational and site conditions. With most major civilian airports operating at capacity, the airports cannot afford to have poorly performing pavements and risk gate closures or reduced landing/takeoff capacity because of frequent maintenance and repairs. Similarly, at military airfields, the need for operational readiness mandates pavements that perform well over the expected service life of these pavements. It is well recognized that even if a pavement is designed to the highest standards, it will not perform well if it is not constructed well. In short, quality is built into the pavement.

With respect to construction of airport concrete pavements, various forms of best or standard practice guidelines have been developed over the years. Some guidelines have been translated into construction specifications that mandate certain requirements for various construction activities. In recent years, many agencies are requiring contractor quality control and as a result, the construction specifications in those situations do not provide substantial guidance for airport concrete pavement construction. The lack of an updated best standards of construction practice document and the need to continually train a new generation of design, construction, and inspection personnel make it critical to have available a comprehensive best practices manual for portland cement concrete (PCC) airport pavement construction that will be accepted and implemented by all segments of the industry.

The information presented here is a compendium, prepared in a user-friendly format, of construction and inspection practices that, when used, result in long-term pavement performance. The use of improved equipment and materials should be encouraged as long as the basic requirements of good construction are complied with, provided that the quality of the finished product is comparable or better. However, regardless of the improvements in equipment and materials, successful construction can only be achieved if skilled and dedicated crews are involved in all aspects of the construction. The quality of a newly constructed concrete pavement is a direct reflection of the workmanship.

Implementation of best practices for construction of airport concrete pavements may have cost implications and these costs will vary from region to region because of the availability of pavement quality local materials. Therefore, airport owners, design engineers, and contractors need to work together to achieve a proper balance between project cost and expected pavement performance.

Airport agencies and contractors are encouraged to implement a review of ***best construction practices*** by means of a ½-day training workshop based on the information presented in this manual. Such a workshop incorporating specific project requirements can ensure that all parties involved in the construction project have a similar understanding, and therefore expectations, of how to achieve a successful project.

1. INTRODUCTION

The first concrete pavement for airport use was constructed during 1927 and 1928 at the Ford Terminal in Dearborn, Michigan. Since then, concrete pavements have been widely used for constructing runways, taxiways, and apron areas at airports. The design and construction procedures used for airport pavements evolved through experience, practice, field trials, and application of theoretical considerations. Concrete pavements have a long and successful history of use at civilian airports and at military airfields in the United States.

Air transportation is one of the key industries in the United States. The high cost of shutdowns for pavement maintenance and rehabilitation at airports results in significant impact on local and regional economies, in addition to unnecessary delays to the traveling public. A similar concern exists at military airfields where operational readiness can be impacted by poor pavements. For airport pavements to perform well, it is essential that these pavements are designed and constructed to a high degree of quality. A well-designed and constructed concrete pavement will withstand the anticipated aircraft loadings under the local climatic conditions over the desired period of time with minimum maintenance and repair.

Desirable concrete pavement performance can be obtained by ensuring that the occurrences of various distresses that can develop are minimized. Distresses that may develop in airport concrete pavements include the following:

- Cracking (corner, longitudinal, transverse, durability/materials related)
- Joint related (spalling, pumping, joint seal damage)
- Surface defects (scaling, popouts, map cracking).

The development of concrete pavement distresses can be minimized by:

1. Selecting the proper pavement thickness
2. Providing adequate foundation support including a free draining non-erodible base
3. Performing proper joint layout and installation
4. Designing and installing adequate load transfer at joints
5. Selecting proper constituents for the concrete
6. Ensuring adequate concrete consolidation
7. Providing proper finishing to the concrete surface
8. Maintaining joint sealant in good condition.

Another important concern for concrete pavement construction is minimizing the probability of early-age distress, typically in the form of cracking and spalling. This is accomplished by the use of sound design principles and by implementing good construction techniques.

1.1 PURPOSE

The information presented here is a compendium of good construction and inspection practices that lead to long-term pavement performance. In addition to highlighting good construction practices, this manual also includes a discussion of practices that are known to result in poor pavement performance. Simply stated, good construction practices mean the systematic application of the collective know-how derived through years of field experience and application of technical knowledge.

This manual does not directly address concrete pavement design issues. However, it is emphasized that both good structural and good geometric design elements are critical to successful early age and long-term performance of airport concrete pavements. Pavements that will perform to expectations will only occur when good designs are implemented through good construction practices.

1.2 SCOPE

This manual presents construction practices that are accepted by the industry as practices that produce quality concrete pavements. Specifically, the scope of this manual includes the following:

1. Documentation of good construction techniques and practices.
2. Discussion of advantages and disadvantages of techniques or practices where more than one method is available.
3. Identification of practices that result in long-term performance of airport PCC pavements.
4. Identification of practices that result in early age or premature failures and poor long-term performance and discussion on how to mitigate problems when they do occur.
5. Discussion of commonly encountered problems in meeting project specifications.

1.3 DISCLAIMER

This manual is not a construction specification guide nor does it provide detailed instructions on conducting specific construction-related activities. It does not constitute a standard, specification, or regulation. This manual should not be used in lieu of a project specification. The specific requirements of plans and specifications for a project have precedence.

1.4 QUALITY IN CONSTRUCTED PROJECTS

A fundamental assumption made during the preparation of this manual is that a quality pavement performs well. Quality is an inherent property of a well-constructed pavement. Quality is not a hit or miss proposition. As defined by the American Society of Civil Engineers (ASCE),

> **“Quality is never an accident. It is always the result of high intentions, intelligent direction, and skilled execution. It represents a wise choice amongst many alternatives.”**

Quality construction requires dedication from the project management down to the execution by labor. The management, as well as the field crews, needs to buy into the concept of quality in construction, not necessarily because it is mandated, but because it is the right approach. The contractor needs to emphasize teamwork and collective accountability for constructing long lasting pavements.

Good materials and construction practices are vital for producing high quality and long lasting airfield concrete pavements. Even if a pavement is designed to the highest standards, it will not perform well if it is not constructed well. A pavement that is constructed well will require less maintenance and repairs over the years. As such, construction requirements and specifications need to be well defined, able to be measured, and not arbitrary. The project specifications need sufficient flexibility to allow for innovations by the contractor.

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.

Airport concrete pavements are typically jointed plain concrete pavements. Very few agencies specify jointed concrete pavements incorporating steel or continuous reinforcement for production paving. This manual focuses on jointed plain concrete pavements.

Airport concrete pavements are typically designed on the basis of mixed aircraft loadings to provide low maintenance service for 20 to 30 years. The pavements, typically plain jointed concrete pavements, are designed on the basis of expected aircraft repetitions over the design period. For larger commercial airports that receive wide-body aircraft, pavement thickness may range from 16 to about 20 in. (400 to about 500 mm) and transverse joint spacing may range from 15 to 25 ft (4.6 to 7.6 m). Longitudinal joint spacing may range from 12.5 to 25 ft (3.8 to 7.6 m). Also, most designers now specify dowel bars for longitudinal construction joints. For general aviation airports, slab thickness may range from 5 to 12 in. (125 to 300 mm) and transverse and longitudinal joint spacing may range from 8 to 15 ft (2.4 to 4.6 m).

2.2 CONSTRUCTION VARIABILITY

Pavement performance is significantly affected by the variability in the properties of key design features. While a certain amount of variability is unavoidable, excessive variability in the construction process can lead to random performance of pavements, as well as higher cost to the contractor. Construction variability can be controlled by making effective use of quality management plans.

2.3 SUMMARY

A successful airport concrete pavement project depends on ensuring that the design process (plans and specifications) has been optimized and quality in construction has been implemented. The design engineer needs to ensure that pavement designs and associated construction specifications are practical and the quality requirements are achievable and necessary. Also, methods to measure specific requirements need to be well defined. Finally, it is advisable that on larger or time-sensitive projects, the design engineer or his representative be available on site on a regular basis to resolve design-related issues that develop during layout and construction.

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.

3. PRE-CONSTRUCTION ACTIVITIES

3.1 CONSTRUCTION SPECIFICATION ISSUES

The purpose of pavement construction specifications is to provide guidance and establish minimum requirements that, when adhered to, enable a quality pavement to be built. The following is a reasonable target quality for airport concrete pavements.

> **The airport concrete pavement will provide the desirable surface characteristics and a surface free from foreign object generators (FOGs) for the service life of the pavement.**

FOGs are a result of distresses that may develop in the concrete pavement. A FOG that subsequently may result in foreign object damage (FOD) is a very critical item for airport pavements. However, good design features, well-developed plans and specifications, and quality construction can assure that the FOG (and FOD) development is eliminated or significantly minimized. It is, therefore, important to have well-developed construction specifications that clearly define the requirements that result in long-term performance of the concrete pavement and do not incorporate arbitrary requirements.

3.1.1 Civil (Private Sector) Construction Specifications

Most civil airport pavement construction work in the United States is performed in accordance with the provisions of FAA Advisory Circular No. AC: 150/5370-10A: *Standards for Specifying Construction of Airports*. The items covered by the advisory circular relate to materials and methods for earthwork, drainage, paving, turfing, lighting, and incidental construction. Pavement projects funded under the Federal Airport Improvement Program (AIP) are typically developed in accordance with the requirements contained in the advisory circular in conjunction with and supplemented by specific project needs and local practices.

The significant items applicable to construction of civilian airport concrete pavements are listed in table 3.1. These items provide guidance on the following, as applicable:

1. Materials (including Composition and Material Requirements)
2. Construction Methods
3. Method of Measurement (for compliance with specifications)
4. Basis of Payment
5. Testing Requirements.

This manual provides guidance on how best to meet the requirements of project specifications based on the AC: 150/5370-10A provisions.

It should be noted that several airport agencies and regional FAA offices will modify the AC: 150/5370-10A provisions, specifically Item P-501, to develop specifications that address local material availability and regional/geographic concerns. Design engineers and contractors should make sure that they are aware of the differences in project specifications implemented between localities.

Also, airport agencies as entities typically perform acceptance testing and do not perform quality assurance (QA) testing. QA is used to verify the contractor's quality control (QC) testing.

Table 3.1 – List of items from FAA's AC: 150/5370-10A

Designation	Item
Section 100	Contractor Quality Control Program
Section 110	Method of Estimating Percentage of Materials Within Specification Limits (PWL)
Item P-151	Clearing and Grubbing
Item P-152	Excavation and Embankment
Item P-154	Subbase Course
Item P-155	Lime-Treated Subgrade
Item P-208	Aggregate Base Course
Item P-209	Crushed Aggregate Base Course
Item P-210	Caliche Base Course
Item P-211	Lime Rock Base Course
Item P-212	Shell Base Course
Item P-213	Sand-Clay Base Course
Item P-301	Soil Cement Base Course
Item P-304	Cement Treated Base Course
Item P-306	Econocrete Subbase Course
Item P-501	Portland Cement Concrete Pavement
Item P-605	Joint Sealing Filler

Note: Agencies may use different designations for the items listed above.

3.1.2 Military Construction Specifications

The *Guide Specification for PCC Pavements for Airfields and Other Heavy Duty Pavements* (UFGS-02753), published during 2003, consolidates the previous specifications issued by each branch of the military. The specifications are detailed and cover all aspects of concrete paving, including materials and mixture design issues and required construction techniques and inspection requirements. The specifications are generally similar to the FAA AC: 150/3750-10A provisions. However, differences between military and FAA documents do exist. It is important for the specifier and the contractor to review a military specification in detail if they have not worked on a military project or do not have recent military experience.

3.2 PLANNING CONSTRUCTION LOGISTICS

A successful construction project requires that all logistics be planned and attention given to the smallest detail. Key items that need to be addressed include:

1. Ensuring readiness of all operations, including grade control
2. Concrete plant set-up and traffic flow

3. Concrete plant capacity and production rate
4. Haul roads availability and serviceability
5. Security and site access requirements
6. Availability of crews
7. Availability of equipment and materials
8. Construction and airport traffic management (both at airside and at landside)
9. Concrete placement needs (rate of placement)
10. In-pavement structures
11. Acquisition of in-pavement electrical items (affects fast track construction)
12. Inspection and testing requirements
13. Subcontractor readiness – crew and equipment availability
14. Project phasing, if any
15. On-site testing laboratory
16. Other needs related specifically to fast track paving.

All parties involved in the construction project must be included and be a part of the communication network. Even on smaller airports, pavement construction is a team effort and that team includes the fixed based operators. For commercial airports, the airline tenants, including cargo, need to be involved.

3.3 FAST TRACK CONSTRUCTION AND OPENING PAVEMENT TO TRAFFIC

From time to time, paving projects need to be carried out on a fast track basis because of the need to re-open the facility to aircraft operations as soon as possible. Fast track projects may involve new construction/re-construction or major rehabilitation. Fast track construction can involve many techniques to shorten the construction time. These techniques range from contractor incentives/disincentives to use of modified materials such as high early strength concrete. Fast track construction requires a high degree of detail in planning, optimizing of construction specifications, and teamwork among all parties involved in the construction project.

The possible changes to project activities to shorten concrete pavement construction time are listed in table 3.2. Fast track construction may involve use of high early strength concrete. Specific concrete mixture design issues related to fast track paving are addressed in chapter 6.

3.3.1 Opening Pavement to Traffic

Most construction specifications include a requirement that defines when a concrete pavement may be opened to construction traffic or to aircraft traffic. This requirement may be based on time (e.g., number of days after concrete placement) or minimum strength. Typically, most agencies require that the pavement not be opened to traffic until test specimens molded and cured in accordance with ASTM C 31 have attained a flexural strength of 550 psi (3,800 kPa) when tested in accordance with ASTM C 78. If strength testing is not conducted, then the age of 14 days is often used.

Table 3.2 – Changes to project activities to shorten concrete pavement construction time (courtesy ACPA)

Project Component	Possible Changes
Planning	• Implement partnering-based project management. • Consider night construction and/or schedule extended closures. • Allow contractor to use innovative equipment or procedures to expedite construction. • Specify more than one concrete mixture for varied strength development. • Develop alternate design sections that incorporate thicker slab and stronger base without requiring very high early strength concrete. • Provide options to contractors, not step-by-step procedures. • Investigate use of time-of-completion incentives and disincentives.
Concrete Materials	• Evaluate use of different cementitious materials and admixtures. • Use a controlled aggregate grading. • Keep water-cementitious ratio below 0.43.
Jointing & Sealing	• Consider use of green sawing with ultra-light saws. • Use dry-sawing blades. • Use step-cut blades for single pass joint sawing. (Note: this practice is not allowed on military projects.) • Use a sealant compatible with high moisture and not sensitive to reservoir cleanliness.
Concrete Curing & Temperature	• Specify blanket curing to aid strength gain when ambient temperatures are cool. • Monitor concrete temperature and understand relationship of ambient, subgrade, and mixture temperature on strength gain. • Elevate concrete temperature before placement.
Strength Testing	• Use nondestructive methods to supplement cylinders and beams for strength testing. • Use concrete maturity or pulse-velocity testing to predict strength.
Opening Criteria	• Allow use of concrete strength criteria without concrete age restrictions. • Channel initial traffic loads away from slab edges.

OPENING TO TRAFFIC ISSUES:

The opening of a pavement to traffic typically revolves around construction and not aircraft traffic. The following should be considered:

1. Develop specific criteria for typical construction equipment for different concrete pavement thickness and for edge and interior loading. For example, for large military or commercial facilities with concrete pavement thickness of 16 in. (400 mm) or greater, construction traffic may induce flexural stresses in the range of 100 to 150 psi (700 to 1,000 kPa). However, similar construction equipment may induce higher stresses on the thinner general aviation type pavements or pavements that are 12 in. (300 mm) or less in thickness.
2. Consider trade-offs between a higher strength requirement and extra thickness for critical areas that require fast track construction. Develop alternate designs for fast track areas – for example, a thicker slab and a cement stabilized base without higher concrete strength versus use of an asphalt treated base or a granular base and higher strength concrete.

Another consideration for early age strength levels is drilling for installation of dowel bars along the longitudinal joint face of pilot lanes. Drilling is typically not initiated until the concrete has attained sufficient strength to reduce/eliminate micro-cracking and excess spalling around the drilled holes.

3.4 PRE-BID MEETINGS

Pre-bid meetings provide an opportunity for the owner to review project requirements with the contractors who may have an interest in bidding for the project. Although pre-bid meetings tend to be primarily a review of administrative and contractual matters, it is important to use them to highlight modifications of guide specifications implemented in the plans and specifications. Critical material supply/availability issues, schedule, and specific acceptance testing requirements also need to be addressed. It is good practice for the contractors to attend the pre-bid meeting. Minutes of the meeting should be distributed to all potential bidders (those who have requested bid documents) whether they are in attendance or not. Paving related items for discussion include:

1. Owner/contractor organizational hierarchy
2. Value engineering issues
3. Project overview
    a. Phasing plan
    b. Scheduling criteria, including which areas are accessible and when
    c. Scheduling milestones with incentives/disincentives
    d. Expected and unexpected delay resolution
    e. Alternate bid items

f. Restrictions on site access and working hours
g. Plant and staging area locations
h. Paving sequence for cross-taxiway areas
i. Access/egress locations, haul road locations, and construction traffic control
j. QA, acceptance testing and QC requirements
k. Water, phone, and power connection locations
l. Issuance of design and specification changes
m. Provisions for protection of stabilized layers from freeze conditions
n. Fast track changes – thicker slab/stiffer base versus higher concrete strength
o. Early age cracking, joint spalling and edge slump – what is acceptable? Establish guidelines for corrective measures
p. Dowel misalignment testing and resolutions
q. Test strip construction requirements and acceptance criteria.

3.5 PRE-AWARD MEETINGS

Some airport agencies hold a pre-award meeting with the selected contractor. As part of these meetings, the airport agency may perform an on-site survey of the contractor's facilities or previous projects. The survey helps to verify the data and representations submitted with the bid documents and to determine if the contractor understands and has overall capabilities to adequately meet the contract requirements.

A pre-award meeting is also an opportunity for the airport agency and the contractor to review the contract line items. Based on the discussions with the owner's representatives, the contractor has an opportunity to withdraw his/her bid if it is determined that the bid may have included erroneous pricing.

3.6 PRE-CONSTRUCTION MEETINGS

The owner will host pre-construction meetings to review specific project requirements and project planning with the selected contractor. The owner should review the following items with the contractor:

1. Issue resolution hierarchy
2. Construction logistics
3. Checklist of critical material supply/availability issues
4. Project specifications
5. Approval of materials
6. Schedule
7. Inspection and testing requirements
8. Quality management (or contractor quality control) plan.

Concrete pavement related items need to be discussed as part of the pre-construction meetings, as a separate agenda. The concrete paving pre-construction meeting is the last opportunity to discuss concrete paving process issues before the equipment starts moving. If items are discussed up front before construction begins, the parties are able to go over potential problems and create solutions that work for everyone on the project. Meeting minutes need to be distributed to all parties. The pavement related meeting discussion items are presented in more detail in appendix B.

For projects involving more than 50,000 sq. yd (46,000 sq. m) of concrete paving, it is recommended that a ½-day concrete pavement construction workshop be conducted using this manual and project specific plans and specifications. Attendees at this workshop can include key staff from the contractor's field crew and the testing and inspection crews. A workshop such as this will ensure that all involved parties have the same understanding of project requirements and that all parties are committed to a successful project.

3.7 QUALIFYING CONSTRUCTION MATERIALS

For most localities, the State Department of Transportation (DOT) may have the necessary information on materials approved for concrete pavement construction. It is recommended that State DOT records be evaluated for performance history and certification. State DOT certifications together with other documentation can help facilitate the materials approval review process.

Materials availability and the cost of materials should be addressed by the design engineer prior to bid solicitation. If alternate materials are to be proposed in lieu of specified, the contractor needs to ensure the testing requirements of the specification are fulfilled. Testing requirements for concrete aggregates may have long lead times and scheduling conflicts could arise if materials are not pre-qualified in a timely manner. Lead times for aggregate testing are discussed later in this chapter.

3.7.1 Evaluation of Local Aggregates

The coarse and fine aggregates need to meet the requirements of ASTM C 33. The key items are:

1. The largest maximum size consistent with the requirements for placing the concrete will produce the most economical concrete with the least tendency to crack due to thermal effects or autogenous, plastic, or drying shrinkage.
2. The maximum size is not to exceed ¼ the thickness of the pavement or 2½ in. (64 mm), whichever is less.
3. In areas where D-cracking in pavements is known to be a problem, a smaller size should be used.
4. Aggregates need to contain no more than the specified percentages of deleterious materials listed in ASTM C 33. For military construction, the limits for deleterious materials listed in UFGS 02753A are to be observed.

Alkali-Silica Reactivity

Alkali-silica reaction is a deleterious chemical reaction between the reactive silica constituents in the aggregates and alkali in the cement. The product of this reaction often results in significant expansion and cracking of the concrete. The methodology for determining both the susceptibility of the aggregate to alkali-silica reactivity (ASR) and the effectiveness of mitigation measures are based on the Portland Cement Association's *Guide Specification for Concrete Subject to ASR* (1998).

The best available information on the susceptibility of an aggregate to alkali-silica reaction is a history of performance. When evaluating the service history, the following items should be determined:

1. Are the cement content of the concrete, the alkali content of the cement, and the water/cementitious (w/cm) ratio of the concrete the same as or higher than proposed?
2. Is the field concrete at least 15 years old?
3. Are the exposure conditions of the field concrete at least as severe as those for the proposed?
4. Were pozzolans (of comparable class and content) used in the concrete being considered for a historical record?
5. Is the current supply of the aggregate representative of that used?

In the absence of an adequate history of field performance, both fine and coarse aggregates need to be tested as follows:

1. ASTM C 1260
    - Mean 14-day mortar bar expansion less than or equal to 0.10 percent - aggregate is acceptable and may be used for concrete production.
    - Mean 14-day expansion greater than 0.10 percent - aggregate is suspect and additional testing is warranted before aggregate can be allowed to be used.
2. ASTM C 295 (to supplement results of ASTM C 1260)
    - To identify and quantify the reactive mineral constituents in the aggregate. Reactive constituents include strained or microcrystalline quartz, chert, opal, and natural volcanic glass in volcanic rocks.
3. ASTM C 1293 (optional; used to verify results of ASTM C 1260)
    - An aggregate that produces a mean expansion at 1 year exceeding 0.04 percent is considered potentially reactive. Although the time required for this test would generally make it impractical to use for a specific job, some aggregate suppliers can provide test results specific to their aggregates. It is necessary for the suppliers to demonstrate that the test results represent the aggregate currently being produced from their quarry.

ASTM C 227 is usually not employed because it is not considered a reliable test. The test may pass aggregates that are reactive.

If the aggregate is demonstrated to be potentially reactive by ASTM C 295, ASTM C 1260, ASTM C 1293, or by previous field performance, it may still be used provided an appropriate mitigation measure is considered. Possible mitigation measures include the following:

1. Use of low-calcium (usually Class F) fly ash, slag, silica fume, and/or natural pozzolan in combination with portland cement. The supplementary cementitious material may be added separately or included as a component of blended cement.
2. Use of blended cements combined with additional supplementary cementitious material of the same or different type. (Note: For military projects, the use of blended cement is not allowed as mitigation for ASR because of concerns with variability related to use of fly ash).
3. Use of low-alkali cement. These cements are not always effective in controlling alkali-silica reaction. Some reactive aggregates still exhibit too much expansion even when used with low-alkali cements.
4. Use of lithium nitrate as an admixture. This is a new technique and field performance data are not yet available to assess the cost-effectiveness of this technique.

Several combinations of cementitious materials should be specified and thereby tested to allow the contractor as much flexibility as possible to meet the other requirements of the project. Any combination that produces a mean 14-day expansion of 0.10 percent or less when tested according to ASTM C 1260 may be considered an acceptable method of controlling expansion due to ASR. The cement used for the testing must be of the same type and brand to be used on the project.

D-Cracking

D-cracking is the term used to describe the distress in concrete that results from the disintegration of coarse aggregates after they have become saturated and have been subjected to repeated cycles of freezing and thawing. For pavements that will be subject to freezing conditions in service, aggregate that is susceptible to D-cracking need to be either rejected or beneficiated so that the particles of susceptible size are removed. Generally, these are the larger particles.

LEAD TIME REQUIRED FOR ASR AND FREEZE-THAW TESTING:

ASTM C 1260 - 16 days for testing.

ASTM C 1293 - 1 year to test aggregate for potential reactivity; 2 years to test effectiveness of mitigation measures.

ASTM C 666 - 2 to 3 months.

Notes:

1. Typically, about 60 days lead-time is available from contract award to start of work, so aggregate acceptance needs to be done within that time or before the award.
2. Design engineers need to specify ASTM C 1260 if ASR testing is required. Design engineers also need to emphasize the test time requirements if aggregate qualification tests are needed.
3. ASTM C 1260 can be used to test the effectiveness of mitigation measures, as described in this manual. Several combinations of cementitious materials can be tested simultaneously to save time and allow flexibility to meet the other job requirements.

Most rock types associated with D-cracking are of sedimentary origin. If the performance history of a proposed aggregate is unknown and the pavement will be subjected to numerous cycles of freezing during a season, the aggregate must be tested. The following tests may be considered:

1. ASTM C 666 (either Procedure A or Procedure B). This method tests the durability of concrete under cycles of freezing and thawing in conditions likely to saturate the concrete. Modifications for the purpose of testing aggregate for D-cracking include increasing the number of cycles to 350 and calculating the durability index from the expansion of the specimens.
2. Iowa Pore Index Test. The aggregate is sealed into the pot of an ASTM C 231 air meter. Water is added to a certain level in the transparent tube at the top of the pot. Air pressure is then applied to force the water into the pores of the aggregate. The decrease in the volume is called the pore index. A high pore index indicates a non-durable aggregate.

3.7.2 Availability and Certification of Cementitious Materials

Cementitious Materials

Cements need to conform to one of the following ASTM standards:

1. ASTM C 150 (portland cement)
2. ASTM C 595 (blended cement)
3. ASTM C 1157 (hydraulic cement).

ASTM C 150 specifies five types of cement, not all of which are available in all areas of the United States and Canada. The cement types are:

1. Type I, the most widely available, is used when the special properties of the other types are not required.
2. Type II is for general use, but particularly when either moderate sulfate resistance or moderate heat of hydration is required. Some cements meet the requirements for both types and are designated Type I/II.
3. Type III cement is used for high early strength.
4. Type IV is used when low heat of hydration is required.
5. Type V is used for high sulfate resistance.

ASTM C 150 also specifies optional chemical requirements, such as limits on the maximum alkali content, and optional physical requirements, such as heat of hydration. These need to be specified judiciously, if at all, since they will often add to the cost and/or limit the available options. Frequently there are equally acceptable or even preferable alternatives. For example, deleterious expansions due to alkali-silica reaction may be controlled as well or better by a combination of cement with Class F fly ash and/or slag than with low-alkali cement. It is generally not advisable to specify a maximum limit on the alkali content of the cement. This may not be sufficient to control deleterious expansions. In some cases, higher alkali content may be desirable to increase the rate of hydration during cool weather or when supplementary cementitious materials are being used.

Sulfate resistance may be obtained by the use of sufficient quantities of slag or an appropriate fly ash as well as (or better than) a Type II or Type V cement. Heat of hydration may be reduced by the use of some combination of slag, Class F fly ash, and/or natural pozzolan with portland cement. If the cement is to be used on its own (that is, without supplementary cementitious materials), it may be advisable to specify the optional requirement for false set. However, setting characteristics need to be evaluated on concrete.

ASTM C 595 specifies blended cements as follows:

1. Type IS cement contains 25 to 70 percent blast furnace slag.
2. Types IP and P cements contain 15 to 40 percent pozzolan (fly ash or natural pozzolan). Type P cement is used when higher strengths at early ages are not required.
3. Type I (PM) cement contains less than 15 percent pozzolan.
4. Type I (SM) cement contains less that 25 percent slag.
5. Types I (PM) and I (SM) should not be used when the special properties conferred by pozzolan or slag, respectively, are desired, as they do not contain sufficient quantities to produce these properties.
6. Type S cement contains at least 70 percent slag and would not produce the strengths required for pavements unless combined with portland cement.

MATERIALS SUPPLY DURING PEAK CONSTRUCTION SEASON:

Cement supplies need to be secured to ensure supply during the peak construction season. If the cement source is changed, additional mix design and compatibility testing is required.

Problematic combinations often include cements with relatively low sulfate contents or with sulfates available only in forms that are not readily soluble. While such cements may perform satisfactorily alone, they may be prone to early stiffening if used with water-reducing admixtures containing lignosulfonates and/or TEA. Combinations of such cements with Class C fly ashes having high alumina contents may also result in early stiffening. In hot weather these effects are more pronounced.

It is advisable to pre-qualify mixture designs using different cementitious materials so that if a substitution needs to be made, the mix design data are already available and the new materials can be accommodated without delay.

All of the cements designated Type I under ASTM C 595 have comparable strength requirements at early ages as those specified by ASTM C 150 for Type I cement. However, the actual strengths at early ages will generally be somewhat lower because slag and pozzolans included in blended cements react more slowly than cement alone. Blended cements are available in many parts of the United States.

ASTM C 1157 is a performance standard that includes six types of portland and blended cements as follows:

1. Type GU is for general use.
2. Type HE is for high early strength.
3. Type MS is for moderate sulfate resistance.
4. Type HS is for high sulfate resistance.
5. Type MH is for moderate heat of hydration.
6. Type LH is for low heat of hydration.

Supplementary cementitious materials offer the potential of improved performance of concrete and/or reduced cost. They provide some benefits more economically and sometimes more effectively than the appropriate choice of ASTM C 150 cement. The benefits include:

1. Control of expansions due to alkali-silica reaction.
2. Sulfate resistance.
3. Reduced heat of hydration.

Pozzolans

Fly ashes and natural pozzolans must meet the requirements of ASTM C 618. However, care should be taken in applying ASTM C 618, as it is rather broad. Class F fly ash is the preferred choice for controlling ASR and it also provides sulfate resistance.

Key items related to pozzolan use are:

1. Typical dosages for Class F fly ash would generally be between 15 percent and 25 percent by mass of cementitious materials. Sources must be evaluated for typical usage rates.
2. In cool weather, concrete with Class F fly ash may not gain strength rapidly enough to allow joint sawing before shrinkage cracks begin to form.
3. Some Class C fly ashes perform very well, while others have been problematic. Sources must be evaluated independently.
4. If fly ash will be used to control expansions due to ASR, the lower the CaO content the more effective it will be. Ideally, the CaO content should not exceed 8 percent. The fly ash effectiveness and dosage requirements should be verified by test.
5. Class C fly ashes with high Al_2O_3 contents may cause problems with premature stiffening, particularly in hot weather.
6. Natural pozzolans are available either as components of Type IP cement or as additives. They can be effective in controlling expansions due to alkali-silica reaction and in reducing heat of hydration.

Slags

Finely ground granulated blast furnace slags (GGBFS) must meet the requirements of ASTM C 989. The following three grades are based on their activity index:

1. Grade 80. This is the least reactive and is typically not used for airport projects.
2. Grade 100. This is moderately reactive.
3. Grade 120. This is the most reactive, with the difference obtained primarily through finer grinding. Grade 120 is often difficult to obtain in some regions of the U.S. and Canada.

Typical dosages of slag would be between 25 percent and 50 percent of cementitious materials. It should be noted that concrete strength at early ages (up to 28 days) may tend to be lower using slag-cement combinations, particularly at low temperatures or at high slag percentages. The desired concrete properties must be established considering the importance of early strengths; the curing temperatures; and the properties of the slag, the cement, and other concrete materials.

3.7.3 Availability and Certification of Admixtures & Curing Compounds

Admixtures

Chemical admixtures are ingredients commonly used in paving concrete and their use is well established. They are used to obtain or enhance specific properties of concrete. The following uses and practices related to chemical admixtures should be observed:

1. For concretes with multiple admixtures, the admixtures need to be purchased from the same manufacturer. The large manufacturers test their own admixtures for incompatibility and other interactions and can provide helpful advice for avoiding undesirable reactions.
2. Not all admixtures work well in all applications. For example, the low slumps typical of paving concrete make certain air-entraining admixtures less effective.
3. The contractor is encouraged to seek the advice of the manufacturer on applying and using admixtures. Batching requirements, mixing procedures, and recommended dosages need to be obtained from the manufacturer. Exact dosages for the particular concrete mixture design need to be determined through the use of trial batches.
4. Placement temperature affects the required dosages of chemical admixtures. Trial batches should be developed accordingly.
5. Admixtures are never used to compensate for marginal concrete mixtures. The specifier and the contractor must consider if adjustments to the concrete mixture design would be preferable over the use of admixtures. As an example, the effects of accelerating and retarding admixtures can be obtained by adjusting the quantity and composition of the cementitious materials in the mix.
6. Chemical admixtures must meet the requirements of ASTM C 260 or ASTM C 494. ASTM C 260 specifies the requirements for air-entraining admixtures. The types of admixtures specified by ASTM C 494 include:
    a. Type A, water-reducing admixtures
    b. Type B, retarding admixtures
    c. Type C, accelerating admixtures
    d. Type D, water-reducing and retarding admixtures
    e. Type E, water-reducing and accelerating admixtures
    f. Type F, water-reducing, high range admixtures

    g. Type G, water-reducing, high range, and retarding admixtures.
7. The admixtures must be added separately to the concrete. Admixtures should not be put directly on dry aggregate or on dry cement, as they may be absorbed and not available to readily mix with the concrete.
8. Consult the manufacturer for information about potential interactions between admixtures.
9. Some water reducers may retard setting and/or strength gain when used in higher dosages.

Air-entraining admixtures entrain a system of finely divided air bubbles in the cement paste. They are essential protection for any concrete that will be exposed to freezing, as they provide outlets for freezable water to expand so that it does not disrupt the internal structure of the concrete. Air-entraining admixtures may also be used to improve the workability of fresh concrete. They reduce water demand, bleeding, and segregation.

The selection of an admixture needs to be appropriate for pavement use; some admixtures are meant to be used only in concretes with higher slump allowances than that typical of airfield pavements.

STRENGTH LOSS WITH INCREASING AIR CONTENT:

It is well known and documented that higher air content in the concrete leads to a reduction in strength. If the air content of the production concrete is higher than that indicated in the approved mix design, it may reduce the strength of in-place concrete and that of strength samples. Typically, a 1 percent increase in air may result in about 5 percent loss in compressive strength.

Accelerating admixtures are classified as Type C and Type E by ASTM C 494. They accelerate the setting and/or early strength gain of concrete. Normally they would be used only in cold weather or for in repairs when the reduction of an hour or two in the setting time is important. They are also used when some increase in the early-age strength is needed. If any of these properties are needed over the course of the job, it is preferable to design the concrete accordingly rather than rely on accelerating admixtures.

Accelerating admixtures affect primarily the setting time, heat evolution, and strength development. The strength at later ages may decrease, and in aggressive environments the durability may also be adversely affected. Alternate means of obtaining early strength development include:

1. Use of Type III cement
2. Higher cement contents
3. Heating the water and/or aggregates
4. Improving curing and protection
5. Some combination of the above.

Retarding admixtures delay the initial and final setting times. They do not reduce the rate of slump loss, however. They affect the rate of strength gain for as little as 1 or 2 days, or as long as 7 days, depending on the dosage. They may be used in hot weather, when long haul times are unavoidable, or to prevent the formation of cold joints. Changes in temperature may require adjustments in admixture dosage to maintain the desired setting time. In hot weather, the dosage may be increased to the point where excessive retardation occurs. In some cases this has resulted in cracking of the pavement because the concrete began to crack due to drying before it had gained sufficient strength for the joints to be sawed.

Water-reducing admixtures (ASTM C 494 - Types A, D, and E) may be used to obtain any one of the following:

1. Reduce the water/cement ratio at a given workability.
2. Increase the workability for a given water content.
3. Reduce the water and cement contents for a given workability.

Some Type A water-reducing admixtures act as Type D (water-reducing and retarding) admixtures at higher dosages. High amounts of water-reducing admixtures may lead to excessive retardation. The rate of slump loss may be increased when water-reducing admixtures are used. Some water-reducing admixtures enhance the effectiveness of air-entraining admixtures so that a lower dosage achieves the required air content. High-range water reducers are typically not used in pavement concrete.

Curing Compounds

Curing compounds (liquid membrane-forming compounds) need to conform to the requirements of ASTM C 309 and ASTM C 1315 (or CRD 300 for military projects), as applicable. ASTM C 156 specifies a method for determining the efficiency of curing compounds, waterproof paper, and plastic sheeting. Curing compounds, properly applied, need to have the following properties:

1. Maintain the relative humidity of the concrete surface above 80 percent for 7 days.
2. Be uniform and easily maintained in a thoroughly mixed solution.
3. Not sag, run off peaks, or collect in grooves.
4. Form a tough film to withstand early construction traffic.

Pigmented curing compounds are recommended because they make it easy to verify proper application. For concrete placement on sunny days and in hot weather, the curing compound selected should contain a white pigment to reflect the sun's heat.

3.8 SPECIFYING PROJECT QMP/CQC REQUIREMENTS

In this section, the development of specifications for contactor quality management/contractor quality control (QMP/CQC) is discussed. In a companion section (chapter 10), discussion is presented on the implementation of specific project QMP/CQC requirements.

3.8.1 Basic QMP/CQC Definitions

Quality Assurance (QA) – QA consists of all actions necessary to provide a reasonable level of confidence that the final product will meet the intent of the sponsoring agency from a serviceability and maintenance perspective. QA typically refers to the owner's or sponsoring agency's roles and responsibilities. The goal of the QA program is to verify that the results from the contractor's QC plan are truly representative of the actual material being placed and that the contractor is "doing the right things." If the QA process is being used, the owner's representatives should develop a written QA plan and distribute it to all project personnel, including the contractor.

Quality Control (QC) – Contractor QC, which is sometimes called process control, typically refers to the contractor's roles and responsibilities. The goal of the QC program is to provide testing, monitoring, and reporting of information to adequately document that the contract is meeting the project specifications and to allow the contractor to make timely adjustments to the construction process. The contractor needs to develop a written QC plan that is available for review and approved by the owner.

Acceptance Testing – Acceptance testing describes those tests that are conducted to determine the degree of compliance with contract requirements and are typically linked to pay items. Acceptance testing can be part of the QA or QC plan or both. For example, QC may be responsible for fabricating and field curing concrete strength samples but QA is responsible for transporting, laboratory curing, and testing. All acceptance testing procedures and responsibilities need to be clearly defined prior to starting any work.

When the contractor is responsible for acceptance testing, the process is referred to as contactor quality control (CQC). The CQC process is routinely used for military construction projects. For civilian airport construction projects, acceptance testing is typically performed by the owner and the owner may or may not perform QA testing.

3.8.2 General Issues

The important items related to quality airport concrete pavement construction include:

- Testing crew training/certification (typically ACI certification)
- Testing laboratory certification (as per ASTM C 1077)
- Plant certification
- Plant operator certification
- Test equipment calibration – Flexural strength test machine calibration, etc.
- Role of QA/Acceptance or verification/Resolution of conflicts between QA and QC test results
- Use of control charts by contractors
- Development of a Quality Management Plan (QMP) (or CQC Plan for military projects)
- Management of QMP/CQC data
- Timely review and processing of QMP/CQC data
- Ability of construction team to make decisions quickly with changing project conditions.

3.8.3 Quality Management Plan

One of the most important activities of an airport concrete pavement construction project is the development of a comprehensive QMP or CQC Plan by the contractor. The QMP/CQC Plan needs to be implemented and adhered to throughout the course of the construction project. The components of a good QMP/CQC Plan are as follows:

1. Introduction
    - Project Description
    - Key Contact Information (contractor, owner, and owner's representative)
    - Contract Plans and Specifications Highlights
2. Purpose of QMP
3. Organization Chart – Clearly delineating the flow of responsibility from ground up to top management
    - QMP Roles (testing laboratory, contractor, etc.)
    - Project Personnel
4. Duties and Responsibilities
    - QC Manager
    - QA or Acceptance Testing Administrator, as applicable
    - Project Engineers
    - Technicians/Inspectors
5. Inspections (paving related) (Include Tests Required and Frequency and Acceptance Criteria)
    - Material Inspections
    - Excavation and Embankment Inspection
    - Concrete Paving Inspection
    - Demolition of Existing Pavement
6. QC Test Schedules/Testing Plans
    - Report Submittals
7. Deficiencies Reporting
8. Conflict Resolution
9. Changes to the QMP/Supplemental Items
10. Placement Agreement Form
11. Appendices (as needed).

QMP/CQC PARTNERING:

A joint meeting between the QC and QA (or Acceptance Testing) representatives before construction starts will help resolve conflicts and identify gaps in the inspection process prior to the start of construction.

The QMP/CQC Plans need to be clearly written to minimize the potential for misunderstanding. The plans also need to be reviewed for ambiguity with respect to sampling locations, number of tests, test procedures, special provisions, and acceptance limits. It is important that copies of all test procedures referred to in the plans be readily available at the project site or at the project test facility.

The following are some of the items that should be reviewed for QMP/CQC Plans:

- Are all required tests discussed?
- Are proper standards for each test referenced?

- Are testing requirements clearly defined and understood?
- Are all procedures clearly defined?
- What items will be tested?
- What actions will be taken when test results are unacceptable or outside of project action or suspension limits?
- What are the documentation procedures and timeline?
- How and to whom are the test results reported?
- How will nonconforming test results be handled?
- Does the paving plan address hot and cold weather construction activities?
- If nighttime construction is anticipated, does the plan properly address the procedures for the use and placement of portable light plants?
- Does the plan provide the chain of command for decision making?

The management of each organization needs to fully support the QMP/CQC process. Without the support of management, urgent deadlines and outside pressures may dominate the project activities and the QMP/CQC testing and inspection could suffer. An inspection and testing checklist is given in appendix C.

3.8.4 Contractor QC versus Agency QA (or Acceptance) Testing Responsibilities

Contractors and inspectors must be aware of testing requirements and how test results will be used. It is common for the owner's testing to be used for acceptance and pay adjustments while the contractor's test results are used for process control. This may create conflicting situations. The potential for conflicts between QA, Acceptance Testing, and QC can be minimized through timely communications.

Once the QMP (or CQC) and QA plans have been created, reviewed, and approved, the contractor and the inspection teams should meet to review and resolve any potential conflicts or gaps in the plans. For example, the QC plan may assume that the owner is making flexural strength samples for opening to traffic, while the QA plan assumes that is the responsibility of the contractor. Or the QC plan may have the opening to traffic samples being stored at the location of the paving and the QA plan, meanwhile, has them being stored in the laboratory.

An often-overlooked part of any construction project is QMP/CQC data management. Data management includes items necessary to document the construction process. These items include test results and procedures, consignment forms, laboratory control charts, and requests for information. It is important to track documents and resolve any missing information as soon as possible. If the project team waits until the end of the project, missing items will be difficult to locate. In addition to the types of documents submitted, the schedule for submission and the review process need to be determined before construction begins.

3.9 TEST STRIP CONSTRUCTION

Many agencies require the construction of test strips before the concrete paving operation may proceed. The test strip is used to evaluate the concrete batching, transporting, placement, finishing, and curing processes. If the construction of a test strip is specified, the engineer needs to clearly identify the objectives for the test strip construction and establish the test strip construction monitoring and acceptance plan. The acceptance plan needs to be developed in accordance with project requirements. The test measures must be clearly defined and the location for the test strip construction be identified.

TEST STRIP REQUIREMENT:

There is a debate related to the need for a test strip and the disposition of the test strip. The following options are typically considered:

1. Build the test strip and remove it.
2. Consider the first day of paving as a test strip.
3. Consider the first day of paving as a test strip and remove the first 200 ft (60 m).

If test strip construction is not specified, the first day of concrete placement should be considered as a default test strip. All key parties should observe the concrete placement operations. A debriefing should be held at the end of the first day's paving, and quality and specification related issues should be discussed and resolved.

3.9.1 Test Strip Details

Key test strip details are:

1. Pave at the paving width anticipated for the project.
2. Allow sufficient length (typically 500 ft (150 m)) for the contractor to demonstrate his/her paving operation.
3. Place in conditions anticipated during pavement construction.
4. Use the same equipment and concrete haulers that will be used during construction.
5. Include blockouts to evaluate paving processes where light cans and embedded steel are located.
6. Include at least one construction header to evaluate starting and ending.
7. For large projects, test strip construction should also include hand placement.

The test strip needs to be constructed using the procedures that are to be used for the production paving. The items that should be evaluated in the test strip construction are:

1. Pre-paving preparation and inspection activities – The following should be checked:
    a. Base condition (grade and surface)
    b. Grade controls (stringline setup, paver track-line)
    c. Joint locations
    d. Dowel bar baskets, embedded steel, and tie bars, if used
    e. Blockouts
    f. Concrete aggregate (for gradation and moisture content)
    g. Equipment for transporting, placing, consolidating, finishing, texturing, and curing

    h. Vibrators on pavers (for frequency and amplitude).

2. Batch plant charging and concrete mixing processes
    a. Plant production rate – Batching through the plant at expected production rates will evaluate whether additional loaders are required and stockpile management plans are acceptable. Approved mixing times based on plant uniformity testing must be established and used.
    b. Concrete uniformity – Difficulties in concrete mixing at the design water-cementitious ratio, non-uniform concrete between the front and rear of drum during discharge, and excessive loss in slump may indicate the following possible problems:
        - Materials not sequenced properly into the drum
        - Too large a batch size relative to drum capacity
        - Inadequate mixing times
        - Liquid admixture incompatibility with cement or supplementary cementitious materials
        - Sensitivity to initial concrete temperature
        - Sensitivity to stockpile moisture changes.

    If difficulties in mixing or concrete uniformity are encountered, changes to the plant, changes in the mixing process, changes to the concrete mixture designs, and/or additional plant uniformity testing should be considered.

3. Concrete delivery process
    a. The time between the addition of water and depositing concrete on grade must be checked to verify that the concrete can be batched, transported, and dumped on grade within specified time limits.
    b. Additional concrete haulers are required if the paver has to stop and wait for concrete delivery.
    c. Concrete material batch quantities need to be compared with the approved mixture design quantities.
    d. Concrete needs to be delivered using the same equipment to be used in production (agitator, open end dump trucks, etc.).

4. Concrete placement
    a. Concrete dumped from trucks, chuted from agitator trucks, or spread using belt spreaders should not drop more than 5 ft (1.5 m).
    b. Concrete dumped on grade or placed in front of the paver using belt placers or spreaders must be examined for aggregate segregation. If the concrete appears segregated, uniformity testing on coarse aggregate content must be conducted.
    c. Significant differences in aggregate content between samples of concrete from the same truck indicate that concrete transport or dumping processes may need to be modified.
    d. When concrete is dumped in front of the paver or spreader and dowel baskets are placed during slipforming, the alignment procedures need to be observed to assure that the baskets are being properly located and installed.

5. Concrete sampling and quality assurance/quality control
    a. Concrete needs to be sampled in front of the paver and tested for slump, air content, initial concrete temperature, and plastic unit weight in accordance with the project requirements. Concrete air content behind the paver should be checked. Ambient air temperatures should be documented.
    b. Concrete for beam and/or cylinder samples is to be properly transported if concrete beams are to be fabricated and initially cured at a central location. Extra samples need to be fabricated for testing at different ages. Early-age strength tests can then be used to verify strength gain relative to the mixture design and establish relative opening times for construction equipment.
    c. Beams and/or cylinders should be fabricated at more frequent intervals than the sublot limits. This allows for a better indication of variability due to any minor changes in batch quantities and changes throughout the day.

    Deficiencies noted concerning acceptance, quality assurance and quality control, concrete sampling, transporting, beam fabrication, initial and final curing procedures, and subsequent testing must be addressed and corrective action implemented.

6. Concrete consolidation and finishing
    a. Difficulties in placing, consolidation, maintaining a smooth pavement, maintaining a tolerable edge slump, closing the surface and edges, and surface tearing indicate problems with concrete, concrete mixture design, and/or the paver operation.
    b. Vibrator frequency, spacing, and elevation may need adjustment if problems with consolidation are encountered. Supplementary vibrators may be necessary at longitudinal construction joints if excessive entrapped air voids and/or honeycombing are observed along vertical edges.
    c. If problems in consolidation are attributed to the concrete, slump tests need to be conducted at the plant to establish slump loss. The concrete may have an incompatibility problem among cement, liquid admixtures, and supplementary cementitious materials if concrete exhibits a high slump loss (generally considered greater than 1 in. (25 mm)). Aggregate moisture monitoring must be verified.
    d. Dowel bar positions need to be verified when the dowel bar inserter is used for transverse contraction joints. Excessive mortar and lack of coarse aggregate over dowel bars indicate excessive vibration from inserter prongs. Shadowing or excessive bleed water over inserted dowels after placement and finishing are indicative of plastic settlement (depressions at surface), excessive vibration (excessive bleed water and mortar), or inadequate vibration (poorly closed surface).
    e. Pavement thickness may be verified by probing or by stretching piano wire across string line pins and using a ruler.
    f. Transverse joint stations must be transferred from the base or sides of forms to the pavement surface to be used as references for joint sawcutting.
    g. Paving at blockouts needs to be observed for movement of blockout from the planned position. Embedded steel needs to be checked behind the paver to ensure

that the steel is properly secured to the base and was not disturbed by paver vibrators.

h. The surface needs to be examined in front of the paver screed or on handwork the tube float to ensure that the surface is not tearing. Tearing of the surface is associated with excessive concrete slump loss, too low a concrete slump, a poorly adjusted paving machine, and/or a paver speed that is too high. Closing tearing cracks during finishing operations may not prevent them from reflecting to the surface.

i. The surface also needs to be examined behind the paver screed or tube float to ensure that it is closed. Difficulty in closing the surface is indicative of one or more of the following:
    - Premature concrete stiffening (possible admixture incompatibility)
    - Insufficient paste/mortar content
    - Vibrator frequencies set too high
    - Vibrator elevations set too low
    - Paving speed too high
    - Inadequate mortar quantities maintained in the grout box.

j. Edge slump must be measured at frequent intervals. Increasing the coarse aggregate content, decreasing the water content, and/or decreasing the mortar content can reduce edge slump. Paver side form batter can sometimes be adjusted to compensate for edge slump. Reducing paver speed may also help reduce edge slump.

k. The concrete, after hand floating and finishing but prior to any texture operations, needs to be examined with a straight edge. The surface needs to be closed. It is not a good practice to use water to aid in the finishing operation. If additional water is required during hot weather, a minimal amount of water addition is tolerable only if applied in a fine mist. An excess of surface laitance after finishing is indicative of excessive finishing and/or excessive application of water. Finishing efforts need to be just enough to provide a smooth closed surface. An excessive amount of finishing leads to a non-durable concrete surface.

7. Pavement texturing – The method of texturing must be inspected for uniformity in appearance. If burlap is used, it needs to be wet enough to provide a rough surface texture without exposing or rolling any coarse aggregates. Ponding of laitance or the depositing of thick films of water is indicative of the burlap being excessively wet.

8. Concrete curing
    a. Curing compound coverage rates must be established prior to test strip construction. The coverage rate depends on the surface texture to be applied.
    b. The application of curing compound needs to be uniform along the pavement surface and vertical edges.
    c. A non-uniform application is indicative of spray nozzles set too low, clogged nozzles, cure rig speed set too fast, insufficient mixing of curing compound, and/or an insufficient number of passes.

9. Joint sawcutting
    a. The temperature of the fresh concrete should be periodically monitored if maturity meters, infrared guns, or surface thermometers are utilized in establishing sawcutting times. Temperatures need to be sampled approximately every 20 minutes until joints are ready to be sawcut.
    b. If the maturity meter technique is used to establish sawcutting times, thermocouples need to be inserted into the plastic concrete as soon as possible after texturing. Thermocouples are inserted approximately 2 in. (64 mm) down into the surface. To obtain representative temperatures, the thermocouples need to be positioned at least 2 ft (0.6 m) inward from pavement edges.
    c. Sawcut operators should be allowed to initiate cutting when concrete is slightly too green to calibrate temperature or maturity measurements.
    d. Several feet (meters) need to be cut to allow a visual rating or quantification of joint raveling. This process needs to be repeated until representatives for the owner, contractor, and inspector agree that sawcuts meet project requirements.
    e. Conditions of sawcuts need to be documented and photographed to avoid future disputes over excessive raveling. The maturity and temperature of when "acceptable" sawcuts can be made must be documented for use in production paving.
    f. Sawcut depths need to be checked for each saw utilized on the test strip. Transverse sawcuts need to be carried through longitudinal free edges or as close to forms as possible.

3.9.2 Test Strip Acceptance

A final inspection of the pavement needs to be done following test strip construction. Items to inspect are:

1. Condition of the surface and slipformed edges
2. Texture and curing compound coverage
3. Headers and sawcut joints
4. Blockout areas (light can penetrations, etc.)
5. Edge slump and profile (straight edge or profile testing)
6. Cores (for thickness and assessment of consolidation and segregation).

3.9.3 Consideration of Changes in Contractor and QMP/CQC Operations

Any deficiencies noted during test strip construction or post construction inspection and testing techniques need to be documented and discussed. Meetings should be held between the owner's representatives and the contractor to review the test strip results. Actions to address and resolve deficiencies need to be agreed to prior to commencing production pavement construction. This is also the time to review any changes that may be needed in the QMP/CQC Plan and operations.

4. GRADE PREPARATION

4.1 INTRODUCTION

Grade preparation lays the foundation for the entire pavement system. Uniformity and stability of the subgrade affect both the long-term performance of the pavement and the construction process. Stability of the subgrade is needed to provide adequate support of the pavement section and to provide an acceptable construction platform. The pavement design begins with the identification of the pavement's foundation. The construction begins with the preparation of that foundation.

Important elements of subgrade preparation include:

1. Evaluation of subgrade stability
2. Subgrade modification to improve stability
3. Evaluation of surface tolerances.

Areas where the assistance of a geotechnical engineer experienced in subgrade preparation may be required are:

1. Variability of soil condition
2. Soil with low bearing strength (≤ 1 ton/square foot [tsf]) (≤ 96 kPa)
3. Organic soil
4. Swelling/expansive soil
5. Frost-susceptible soil.

SUBGRADE PREPARATION:

- Review and understand the geotechnical report.
- Consider the need for subgrade modification.
- Assess moisture sensitivity of the subgrade material.
- Proof-roll grade prior to fill operations.
- Ensure correct grade of the subgrade.

4.2 GRADING AND COMPACTING SUBGRADE

4.2.1 Pre-Grading Activities

Mass grading is the first phase of subgrade preparation. It is the actual cutting of high points and filling of low areas to achieve the desired finish elevation. The cut/fill items are typically addressed in the design phase of the project.

Important items to consider include the following:

1. Fill material is usually obtained from cut operations. The geotechnical report may be used to evaluate the potential use of this material as engineered fill.
2. If the in-place material is not of sufficient quantity or it has material properties that are adverse to good pavement performance, borrow areas need to be identified to obtain fill material.
3. The contractor needs to be aware of the local subgrade conditions as they relate to pre-grading and other construction activities.

The second phase of pre-grading is the construction staking process. It is a good practice for the owner/ engineer to perform an independent verification of the staking accuracy. Automated grading equipment using global positioning are commonly used to establish the grade. If these systems are employed, it is a good practice to periodically verify the results through the use of conventional surveying.

4.2.2 Removal of Unsuitable Subgrade

When preparing the grade, unsuitable soil can be encountered. Materials such as peat, organic silt, silt, and soil with high organic content are classified as unsuitable. To deal with these materials the following actions can be taken:

1. Remove and replace with soil similar to the surrounding subgrade.
2. Remove and replace with granular material.
3. Alter the properties through compaction or stabilization.

MANDATORY REQUIREMENTS:

Measures to control water pollution, soil erosion, and siltation that are shown on the plans or that are needed for the site should be provided. All pertinent local, State, and federal laws should be followed.

4.2.3 Protection of Grade

During grading operations, protect the grade by performing two essential activities:

1. Provide temporary drainage - trenches, drains or ditches necessary to divert or intercept surface water. If water ponds on the subgrade, the material will soften and can be damaged by construction traffic. This results in delays and the need for repairs.
2. Implement procedures to manage site traffic over the grade. Do not use channelized traffic patterns over one portion of the grade. Make sure the traffic is distributed over the grade.

4.2.4 Grading Operations

The grading operation for an airport pavement may involve construction of an embankment.

1. The embankment is constructed by placing material in successive horizontal layers for the full width of the cross section.
2. Most specifications include a maximum loose depth of fill to be placed. Use of thicker fill layers may require the contractor to demonstrate to the engineer that the thicker fill layer can be compacted to the specified density.
3. During construction of the embankment, the hauling equipment needs to travel evenly over the entire width of the embankment. If equipment travel is channelized, permanent deformation and shear failure can occur.

4. In the construction of embankments, layer placement should begin at the deepest portion of the fill. As placement progresses, layers should be constructed approximately parallel to the finished pavement grade line.
5. In areas where subgrade transitions occur, the subgrade materials are mixed by disc at the boundary of the transition zone. Subgrade mixing must be performed over a distance of about 100 ft (30 m) along the transition zone (50 ft (15 m) on either side of the transition). This practice reduces the potential for differential settlement or frost heave.

4.2.5 Compaction Requirements

Compaction of the subgrade is essential to building a stable work platform. Typical compaction requirements are:

1. For pavements trafficked by aircraft greater than 60,000 lb (27,000 kg), the Modified Proctor procedure (ASTM D 1557) needs to be used to determine the maximum density. The Standard Proctor procedure (ASTM D 698) may be used for pavements used by light-weight aircraft.
2. Cohesive soils used in fill sections: Entire fill compacted to 90 percent maximum density.
3. Cohesive soils in cut sections: The top 6 in. (150 mm) to be compacted to 90 percent maximum density.
4. Cohesionless soil used in fill sections: The top 6 in. (150 mm) of subgrade is compacted to 100 percent maximum density, the remainder of fill to 95 percent maximum density.
5. Cohesionless soil used in cut sections: Top 6 in. (150 mm) compacted to 100 percent maximum density, and next 18 in. (450 mm) compacted to 95 percent maximum density.

SUBGRADE COMPACTION:

Due to the weight of construction equipment, it is a good practice to compact all subgrade materials to 95 percent of the maximum density using the Modified Proctor method. This assists in providing a stable working platform.

If the standard proctor method is used to control compaction, subgrade instability can occur.

Moisture control is essential to obtaining a stable subgrade. The following items should be adhered to:

1. Specifications for compaction usually require the moisture content in the subgrade to be within ± 2 percent of optimum moisture content before rolling to obtain the prescribed compaction.
2. For expansive soils, moisture content needs to be 1 to 3 percent above optimum prior to compaction to reduce swell potential.
3. For fine-grained soils, that do not exhibit swelling properties, it is best to keep the moisture content at 1 to 2 percent below optimum.
4. Cohesive soils compacted wet of optimum can become unstable under construction traffic even when the target density is achieved.

Moisture density curves of typical soils can provide insight into field performance. In figure 4.1, the shape of the curve suggests that clayey sand soil is moisture sensitive. A small change in moisture content results in compaction difficulty. Additional compaction related items to consider include:

1. Sheepsfoot rollers need to be used for cohesive soil. The pads need to penetrate 70 percent of the lift thickness.
2. Discing of cohesive soil is necessary if moisture is to be controlled.
3. Static steel drum rollers can be used to smooth the surface of the grade after compaction.
4. Vibratory steel drum rollers are used for cohesionless soil. If the water table is close to the surface, or if subgrade soils are saturated, vibration should be used with caution.

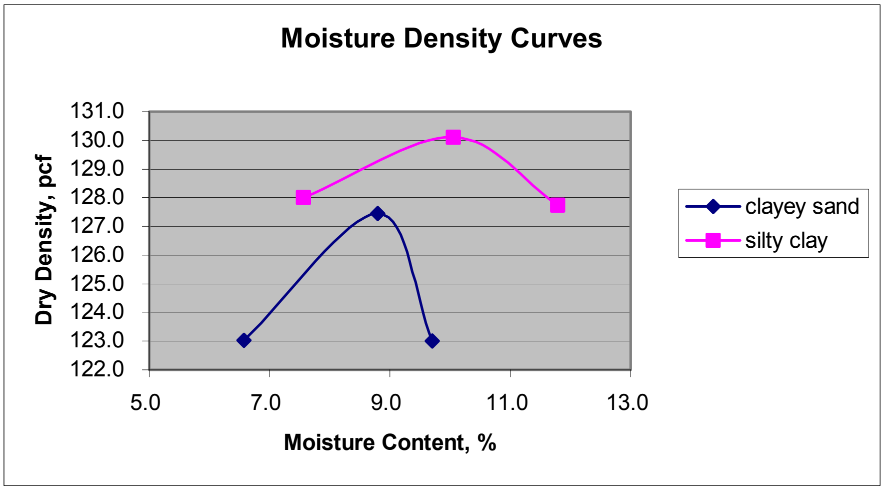


Figure 4.1 – Typical moisture-density curves showing the effect of moisture content on density

Nuclear density testing procedure can be used to check the density of the compacted soil. Gauges need to be calibrated to local materials. If problems achieving density are encountered, the following techniques can be used to troubleshoot:

1. Perform additional moisture density testing to ensure that the proper maximum density value is being used to control field compaction.
2. Use a sand cone or volume measure to perform the density tests.
3. Use traditional methods to determine moisture content.
4. Probe the subgrade to determine if soft layers are present below the problem area.

Field density control must be a full time function. This allows observation of the material as it is placed. If the material appears to change, one-point field Proctor tests can be used to check the maximum density.

4.3 SUBGRADE STABILIZATION

Subgrades may need to be stabilized for a number of reasons. The primary reasons are:

1. To improve low strength soil
2. Reduce swelling potential
3. Improve construction conditions.

Unsuitable subgrade conditions can delay construction work, as appropriate measures have to be taken to address such areas. Having a stabilized subgrade may promote staying on schedule. This can be important on construction projects that require opening pavements to traffic on time.

HIGH VOLUME AND HEAVY LOAD PAVEMENTS:

It is recommended that the subgrade be stabilized to provide stable and uniform support condition. In any case, subgrade soil with a CBR of 5 or less should be stabilized or a granular layer be used to enhance constructability.

4.3.1 Lime Stabilization

Lime stabilization is frequently used to stabilize cohesive subgrade (clayey soil) that has a high moisture content. A mix design must be performed in order to determine the optimum lime content. For clay soil with a Plasticity index (PI) greater than 10, the lime content range required is usually 3 to 5 percent.

The equipment required to perform lime stabilization include a spreader for the lime or lime slurry, mixing or pulverizing equipment, sprinkling equipment, and rollers. When hydrated lime is specified as a stabilizing agent, the specifications may allow either "dry placing" or "slurry placing."

For dry placing, the following must be considered:

1. The lime needs to be spread uniformly over the top of the subgrade by a truck equipped with a spreader box.
2. The amount of lime spread needs to be the amount required for mixing to the specified depth, based on the job mix formula.

LIME STABILIZATION ISSUES:

Stabilization of soils containing soluble sulfates can cause an expansive condition. If the sulfate content is greater than 0.3 percent, mitigation is required. See ASTM D516 for determination of sulfate content.

For stabilization of non-swelling soils, compaction of the lime soil mixture can take place immediately after mixing.

For swelling soils, mellowing periods of 3 to 7 days may be required.

Lime kiln dust may also used, but may require more quantity as it typically consists of 20-25 percent CaO, while high calcium quicklime consists of about 90 percent CaO. When using lime kiln dust the quality should be checked regularly.

Check depth of mixing with phenolphthalein.

3. Dry placing is difficult in the airport environment. The wind condition in the large open areas usually results in a large dust cloud. This may result in a safety issue and usually the wind will result in the use of larger amounts of lime.

For slurry placing, the following need to be considered:

1. The lime needs to be mixed with water in trucks and applied as a thin water suspension or slurry through a distributor.
2. The distributor truck needs to continually agitate the slurry to keep the mixture uniform.
3. The lime is distributed by making successive passes until the proper amount of lime has been spread.
4. The amount of lime spread needs to be the amount required for mixing to the specified depth based on the job mix formula.

The in-place mixing and compaction procedures for both dry placing and slurry placing are similar. The following are the essential considerations:

1. The mixing machine must be capable of mixing the full depth of the treated subgrade or the subgrade material must be stabilized in lifts.
2. The mixing of the material must immediately follow the application of lime. The period between applying the lime and mixing the subgrade should be less than 6 hours.
3. Water is be added to the subgrade during mixing to provide moisture content above the optimum moisture of the material and to ensure chemical action of the lime and subgrade.
4. Final mixing can follow preliminary mixing, except that some heavy clays may require 24 to 48 hours of moist curing prior to final mixing.
5. It is important that compaction of the mixture occur within 30 minutes after final mixing.
6. The material needs to be within ± 2 percent of the optimum moisture content prior to compaction and may need to be aerated or sprinkled.
7. The lime soil mixture needs to be compacted to 93 to 95 percent of the maximum density determined in the mix design. The in-place field density should be checked with a nuclear gauge using the direct transmission mode.
8. If the specified compaction level is not achieved, and the subgrade shows signs of movement during compaction, a weak subgrade layer may be present below the stabilized layer.
    a. This weak layer may prevent adequate compaction of the stabilized layer.
    b. If such conditions exist, the depth of subgrade stabilization may need to be increased.
    c. If such conditions are encountered, an assessment of the strength of the underlying soil needs to be made (e.g., by plate load test or by performing dynamic cone penetrometer [DCP] tests).

Verification tests are required to check if the stabilization is effective to the required depth. This is accomplished with a quick field test using phenolphthalein solution. The lime content of the uncured soil-lime mixture needs to be determined according to ASTM D 3155 using a sample obtained from the mid-depth of the lime modified layer.

If the lime-treated section is a structural layer, it needs to be cured for a minimum of 7 days before further courses are added or any traffic is permitted on the layer. Curing includes one of the following:

1. Moist curing - moist curing consists of maintaining the surface in a moist condition by sprinkling water.
2. Membrane curing - membrane curing consists of applying a bituminous coat to the prepared subgrade.

4.3.2 Cement Stabilization

Cement is normally used to stabilize coarse-grained soil or soil high in silt content. For clayey soils, lime stabilization is usually more economical than cement stabilization. A laboratory mix design needs to be performed to determine the amount of cement to be added for stabilization. The performance of in-place cement stabilization is similar to the lime stabilization procedures. Uniformity of the mixture and proper application rate are the key steps in producing a good cement stabilized layer. Curing of the stabilized layer is also required. A membrane cure using an asphalt emulsion is a common practice.

Cement stabilization can also be performed using an on-site pug mill or mixing plant. These are the preferred methods if the cement stabilized subgrade is to serve as the subbase or base layer.

4.3.3 Contingencies for Localized Areas

If the site contains fine-grained soils, it is a good practice to have a contingency plan for stabilization if unsuitable soils are encountered in localized pockets. Usually fine-grained soils with unconfined compressive strengths of 2 tsf (190 kPa) or less will present stability problems. For localized areas the following procedures may be considered:

CEMENT STABILIZATION ISSUES:

Stabilization should not be performed when the temperature is below 35 °F (2 °C) .

Compaction needs to take place within 30 to 40 minutes of mixing.

Unlike lime stabilization, no mellowing period or reaction period is required.

Wind conditions can cause dust problems and loss of cement. Do not apply cement during high winds.

For coarse-grained soil, the quantity of cement is in the range of 4 percent to 8 percent by weight. When the percentage of fine-grained material increases, so does the required cement content

1. Remove soft or disturbed material and replace with subgrade material from adjacent areas. This method works for surficial disturbance.
2. Remove soft or disturbed material and replace with crushed stone. If the layer is very soft (≤ 1 tsf [96 kPa]), use geotextile fabric to prevent intrusion of the subgrade into the stone layer.
3. Place a geogrid over the soft area. Material on top of the geogrid should be a 10 in. (250 mm) lift of crushed stone to distribute the load to the subgrade.

4.4 PROOF-ROLLING

Project specifications may require proof-rolling to verify grade preparation. It is a good practice to implement proof-rolling as it does locate isolated soft areas not detected in the grade inspection process. Proof-rolling should always be used if the concrete pavement is to be placed on an unstabilized base.

Proof-rolling is the driving of a heavy pneumatic tired vehicle over the prepared surface, while observing for rutting or deformation. A fully loaded tandem axle truck or a loaded rubber tired loader may be used as the proof-roller. Steel drum rollers are not recommended for proof-rolling since they may potentially distribute the load across soft areas. For airport pavement the following guide may be used for proof-rolling:

1. Rutting less than ¼ in. (6 mm) – The grade is acceptable.
2. Rutting greater than ¼ in. (6 mm) and less than 1.5 in. (40 mm) – The grade needs to be scarified and re-compacted.
3. Rutting greater than 1.5 in. (40 mm) – Removal and replacement is strongly recommended.
4. Deformation greater than 1 in. (25 mm), which rebounds – This indicates a soft layer near the surface. These areas should be probed to determine underlying conditions.

4.5 ACCEPTANCE OF GRADE

The finished grade is typically accepted using the following criteria:

1. Surface Deviation – typically 1/2 to 1 in. (13 to 25 mm) (based on 16 ft (5 m) straightedge)
2. Surface Elevation – typically 0.05 to 0.10 ft. (15 to 30 mm)
3. For small projects, surface deviation and elevation tolerances may be set at 0.10 ft (30 mm), especially when automatic grading equipment cannot be used.

GRADE ACCEPTANCE:

For large projects the use of an autograder or trimmer should be considered to minimize most grade problems.

For unstabilized materials, scarifying, cutting or filling areas can be considered if grade adjustment is needed. With stabilized materials, filling in thin lifts is not possible. Therefore, with stabilized materials, the grade should be constructed high and trimmed to final grade.

4.6 PROTECTION OF GRADE

Once the grade is accepted, a traffic control plan must be implemented. Heavy construction trucks traveling on the prepared surface can damage the grade. Traffic management must be enforced if logistics require use of the prepared grade by construction equipment. All ruts or rough places that develop in a completed subgrade should be smoothed and re-compacted prior to placing the subbase.

4.7 ADVERSE WEATHER CONDITIONS

Provisions for drainage should be implemented at each stage during the preparation of the subgrade. The grade should be maintained so that a positive slope is provided for drainage. When the subgrade moisture content is above optimum, discing and drying may be required to reduce the moisture content. If rain is expected after the subgrade has been prepared for compaction, the subgrade surface should be sealed using a rubber tired or steel drum roller. If this is not done in time, serious problems due to excess moisture in the subgrade may develop.

If the subgrade is subjected to freezing, the surface of the subgrade must be scarified to a depth of at least 6 in. (150 mm) and re-compacted. If the grade preparation was halted for winter, the exposed subgrade surface should be scarified at least to a depth of 6 in. (150 mm) and re-compacted prior to continuing grading during the following spring.

4.8 TROUBLESHOOTING GUIDE

Problem	Probable Cause	Corrective Action
Surface appears loose	Low density	Check moisture content and density Re-condition to optimum moisture and re-compact area
Depressions or excessive movement under roller	High moisture content Weak layer under surface	Check moisture content and re-condition to optimum moisture if high Probe grade with DCP to find weak layer Stabilize area
Surface varies from coarse to fine	Segregation of imported material Change of material	Perform sieve analysis to check gradation Mix surface and re-compact

5. BASE AND SUBBASE CONSTRUCTION

5.1 INTRODUCTION

For this document, the layer immediately below the pavement surface is the base course. The term subbase is used to designate layer(s) below the base and above the subgrade.

5.2 SUBBASE COURSE

Subbase materials are generally granular materials that may be either natural materials or crushed. Their stability in terms of CBR values range from 20 to 100. These materials are generally used as subgrade protection layers (frost protection) and/or to provide drainage above the subgrade. In frost areas, the percent of the material passing the No. 200 sieve must be limited to 3 to 5 percent.

Important elements for subbase placement are:

1. Placement should begin along the centerline or the high point to maintain drainage during the progress of construction.
2. Placement may be performed using automated equipment, or using a stone box on a bulldozer.
3. Moisture density relationships must be developed in the laboratory using the standard or the modified Proctor test. As noted in chapter 4, for projects that will be used by heavier aircraft, it is a good practice to use the modified Proctor test.
4. Moisture control is critical to achieving compaction. Keeping the material within 1 percent of the optimum is the best practice. For free draining subbase materials, lower moisture content needs to be considered to avoid adding excess water to the subgrade during compaction of the subbase material.
5. Layer thickness needs to be 3 to 4 times the largest aggregate size. If the layer thickness is close to the largest aggregate size, grading and smoothness can be affected.
6. Prior to subbase placement, it is important to evaluate the subgrade for stability. Any soft areas must be repaired.
7. Traffic management in front of placement is to be implemented to eliminate potential problems.
8. Nuclear gauges may be used to monitor subbase density.
9. The density values can be verified using one-point tests at the delivered moisture content. One-point tests should be performed about twice a day.
10. The grade tolerance for subbase is typically 0.5 in. (12 mm) using a 16 ft (5 m) straightedge.
    - Trimming using lasers or autotrimmers is recommended on larger projects.

ACHIEVING DENSITY:

Moisture control is essential for granular subbase or base construction.

Without proper moisture content, compaction can be difficult to achieve

    - For projects where automated equipment cannot be justified, it may be necessary to relax the surface tolerances.

11. Once the subbase layer is placed, the surface needs to be protected.
    - Drainage needs to be provided so water does not pond on the surface.
    - If dry conditions prevail, watering may be necessary.
12. Rolling can be accomplished with vibratory drum rollers. If compaction is difficult, rubber tire rollers can be used, as the kneading action of the wheels aid in compaction.

5.3 MECHANICALLY STABILIZED BASE COURSE

These materials are similar to subbase materials, but are usually of higher quality in terms of crushed aggregate content, deleterious material, and gradation. The critical elements for placement are the same as those described for the subbase materials. In addition, the following items should be considered:

1. The underlying course (subgrade or subbase) must be checked before placing and spreading the base course. Any ruts and soft or yielding areas (due to improper drainage conditions, hauling, or any other cause) need to be corrected and compacted to the required density before the base is placed.
2. Placement of the base must not begin if the underlying course is wet, muddy, or frozen.
3. Work on the base course is to be suspended during freezing temperatures or if the base material contains frozen material.
4. Vibratory rollers, rubber tire rollers, and static wheel rollers may be used for compaction of base material. With some material, the vibratory roller may be used alone to obtain compaction and a smooth even surface.
5. Grade tolerance for base layers is typically 3/8 in. (10 mm) in 16 ft (5 m). Automated placement methods are usually required to attain the tight tolerances.

EXPOSED GRANULAR BASE/SUBBASE:

Granular layers left exposed over a winter in a wet freeze region can cause softening of the subgrade.

It is best to cover these layers with the pavement. If this is not possible, caution should be used when construction resumes. Construction traffic could cause the subgrade to become unstable.

5.4 CHEMICALLY STABILIZED BASES

Several types of stabilized bases are used in airport concrete pavement construction. The most commonly used materials include soil cement, cement treated base, econocrete (lean concrete), and asphalt treated base. These materials provide an excellent base over a properly prepared subbase or subgrade.

The stiffness of stabilized base layers has an impact on the performance of the concrete pavements. They affect the curling/warping behavior of the slab and they increase the restraint on the slab during the initial curing period. In the case of econocrete, the base stiffness can be extremely high. The result is an increased potential for random cracking, reflective cracking, or cracking due to unsupported edges of the pavement slabs. But, a well designed and constructed stabilized base will increase the fatigue life and improve the constructability of a concrete pavement.

5.4.1 Cement Treated Base

Soil cement and cement treated base are two different materials that can be used for base course material. Soil cement is usually of a slightly lower quality as it uses on-site subgrade or fill material, while cement treated base (CTB) is typically made from processed material.

A laboratory mix design is used to establish the optimum cement content. In freezing environments, a freeze thaw durability test is also performed. This process requires 20 to 25 days assuming that the aggregate is durable. If there is little experience with the local materials, more than one mix should be programmed into the test schedule.

THE CASE FOR MAXIMUM STRENGTH:

Specifications attempt to address the potential for a cracking problem by limiting the strength of the stabilized layers. This works to a degree, but there are times the strength is needed. Other methods are used to reduce the cracking potential. Alternate methods are discussed at the end of this section.

CTB materials are nominally designed for a 7-day compressive strength of 750 psi (5,200 kPa). Material at this strength level usually passes the freeze thaw test and is not susceptible to shrinkage cracking. If a higher strength is required to pass the freeze thaw test, positive steps must be taken to reduce the potential for random cracking in the base.

Important mixing and placement procedures include:

1. CTB is mixed in a central mixing plant.
    - Water and cement are introduced into a pug mill mixer at the appropriate amounts to achieve the mix design proportions.
    - Cement introduction needs to be performed so that balling of the material does not occur.
2. The optimum moisture and density properties of the mix are determined using ASTM D 558 procedures.
3. Delivery and placement equipment need to be matched to allow compaction of the mix to occur within 60 minutes of initial mixing.
4. Final grading and compaction needs to be completed within 2 hours of mixing.
5. It is essential to monitor density using a nuclear density gauge. A density of 97 to 98 percent of the maximum is a recommended target.

MATERIAL ALERT:

Lean porous concretes such as cement treated base courses are more susceptible to sulfate attack than pavement concretes.

Consideration should be given during the design phase of the project to investigating possible detrimental effects on the cement treated base caused by sulfates present in the soil, groundwater, or aggregates.

6. The moisture content should be within 2 percent of the optimum. For summertime construction conditions, a moisture content of +2 percent is recommended. Mechanical spreaders or bulldozers with automated blades are typically used to place the material.
7. The placement plan needs to be developed to minimize the number of longitudinal and transverse joints.
8. A transverse header is constructed at the end of the day or when continuing placement is interrupted for more than 60 minutes. Full-depth saw cutting is the easiest method to form the transverse joint.
9. Longitudinal joints are formed by saw cutting the free edge.
10. The temperature at the time of placement needs to be greater than 40 °F (4 °C). If temperatures are expected to fall below 35 °F (2 °C) within 24 hours of placement, placement should be suspended.
11. The CTB compacted layer thickness is typically limited to 8 in. (200 mm). However, some compaction equipment can effectively compact layers up to 12 in. (300 mm). The effectiveness of the equipment must be matched to the lift thickness.
12. A combination of rubber tired and vibratory compaction will get the best results.
13. If multiple lifts are needed to obtain the thickness, the surface of the underlying layer must be kept moist until the next lift is placed. Using water trucks with side spray bars is an acceptable method to accomplish the sprinkling of the surface.

WINTER EXPOSURE:

It is best that a CTB layer be covered with the pavement layer prior to winter and/or a freezing environment. If a CTB layer must be left exposed, it must have attained design strength.

Before construction resumes in the spring, check the grade.

14. Finished grade tolerance is typically 3/8 in. (10 mm) when tested with a 16 ft (5 m) straight edge.
    - Using a trimmer is the best way to achieve the required grade tolerance.
    - Since CTB is a rigid material, it is not practical to re-grade after compaction. Thus, care needs to be taken to achieve the specified tolerance the first time.
15. CTB must be cured. The curing seal is usually an asphalt emulsion applied as soon as possible after final compaction. The surface of the CTB is be kept moist until the layer is sealed. The seal should be protected for 7 days or until the open to traffic strength is attained.

5.4.2 Lean Concrete (Econocrete)

Econocrete or lean concrete base consists of aggregate and cement uniformly blended together and mixed with water. The term econocrete is used because the materials used are of marginal quality. The mixtures typically use 2 to 3 bags of cement per cubic yard (per cubic meter) of material. The resulting mixture should pass the freeze thaw durability test and yet can be placed using concrete paving equipment. The procedures used for placing econocrete are the same as conventional concrete.

The primary issue with lean concrete/econocrete is the strength of the mixture. Typical strength limitations are as follows:

1. 7-day minimum strength of 750 psi (5,200 kPa).
2. 28-day maximum strength of 1,200 psi (8,300 kPa). Limiting the strength to a 1,200 psi (8,300 kPa) value reduces the potential for reflection cracking in the pavement.

An alternative to limiting the maximum compressive strength is to design joints in the econocrete layer. The design of the jointing pattern in the econocrete must match the joint pattern of the pavement or reflective cracking may occur. Care must be taken to align the joints when the concrete pavement is placed.

The econocrete must be cured. This is typically done by applying a double application of wax-based curing compound. The double application helps to reduce the potential for bonding between the econocrete and the pavement. By doing this, the potential for random cracking in the pavement is reduced.

Traffic is typically not permitted on the econocrete until the econocrete attains a compressive strength of 750 psi (5,200 kPa).

5.4.3 Asphalt Treated Base

An asphalt treated base consists of aggregate and bituminous materials mixed at a central mixing plant. The following are considerations for constructing asphalt treated bases:

1. The asphalt and the aggregates used in the asphalt mix need to meet the requirements that are listed in the project specifications.
2. The asphalt mix needs to satisfy the job mix formula specified for the project.
    - The asphalt mix needs to be sampled and checked to see if it meets the job mix formula (e.g., Marshall density, theoretical maximum density, air voids, and asphalt content).
3. The layer thickness of asphalt treated bases is normally limited to 4 to 5 in. (100 to 125 mm).
    - Some compaction equipment may be able to compact these materials to a depth of 6 in. (150 mm). A test strip may be constructed to verify the contractor's ability to compact a thicker layer. The compaction is verified by coring and checking the top and bottom core density.
4. The density after compaction can be checked using a nuclear density gauge.
5. The layer thickness and air voids are determined by obtaining cores.
6. Asphalt layer placement must be stopped if the temperature is below 40 °F (4 °C). If asphalt is being placed in cold weather, it is important that compaction begin immediately after placement by keeping the rollers close to the paving machine.

Asphalt treated layers affect the early age performance of the pavement. In summer conditions, the surface of these layers can reach 140 °F (60 °C). The excessive heat impacts both the strength gain and the shrinkage rate of the fresh concrete. Therefore, these layers should be whitewashed using a lime-water solution before concrete placement to reduce their surface temperature. A wax based curing compound should not be used because of the high surface temperature. Also, trimming of these layers with a milling machine is not usually employed. This process leaves a coarse surface texture, thus increasing concrete pavement frictional restraint forces that in turn increase the potential for random cracking.

5.5 DRAINAGE LAYERS

Some rigid pavement designs incorporate a drainage layer. When a drainage layer is used, the pavement or the base is placed directly on this layer. The drainage layers may be stabilized or not stabilized.

The common practice is to use cement or asphalt stabilized drainage layers. The stabilized layer provides better stability during construction. The porosity of the drainage layer needs to be matched to the anticipated needs for the quick disposition of water. A balance between the need for stability and the need for porosity must be considered in the design with stability taking precedence. The thickness of the drainage layer is typically 4 to 6 in. (100 to 150 mm).

RECOMMENDED MATERIAL:

Stabilized drainage layers are necessary for constructability.

Unstabilized material may pose difficult construction problems because of poor stability.

Drainage layers can increase restraint forces resulting in early cracking.

The use of unstabilized open graded aggregate drainage layer is not recommended for pavements used by wide-body aircraft. These layers do not provide the necessary stability and construction related problems (rutting due to construction traffic, etc.) are common. If an unstabilized open-graded layer is necessary, it should be placed deeper in the pavement structure to reduce stresses on the layer.

5.6 STABILIZED BASE ISSUES

Stabilized bases provide rigid paving platforms and thus uniform pavement support. However, they also have the potential to increase slab warping, curling and frictional restraint forces on the concrete slab. This shortens the window of joint sawing opportunity and increases the potential for random cracking in the pavement. The designer must consider these issues in the joint layout and in construction specifications.

CEMENT TREATED BASE:

Apply a double coat of wax-based curing membrane or a geotextile to reduce restraint.

If the CTB is trimmed after curing, apply another coat of curing membrane.

Reduce the joint spacing of the pavement.

Saw cut joints as soon as possible.

LEAN CONCRETE (ECONOCRETE):

Apply a double coat of wax-based curing membrane or a geotextile to reduce restraint.

If strength exceeds 1,250 psi (8,600 kPa), provide for joints in the econocrete and match them with the pavement joint pattern.

Reduce the joint spacing of the pavement.

Saw cut joints as soon as possible.

ASPHALT TREATED BASE:

Whitewash the surface to lower base surface temperature at the time of paving.

If milling is used to correct the grade of ATB, specify a following leveling layer.

Reduce the joint spacing of the pavement.

Saw cut joints as soon as possible.

5.7 TROUBLESHOOTING GUIDE

Problem	Probable Cause	Corrective Action
Granular base and subbase: Surface appears loose	Low density Layer (lift) too thick for compaction Insufficient rolling	Check moisture content and density Re-condition to optimum moisture and re-compact area
Granular base and subbase: Depressions or excessive movement under roller	High moisture content Weak layer under base or subbase	Check moisture content and re-condition to optimum moisture if high Probe grade with DCP to find weak layer Stabilize area
Bird baths on finished grade	Improper grade control	Perform grade survey and correct deficient areas

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.

7.1.2 Laboratory Mixture Design Process

The following is a discussion of the procedure for proportioning concrete mixtures adapted from the PCA mixture design procedure:

1. Obtain required information (e.g., gradation, absorption, specific gravity, etc.) for the materials to be used.
2. Identify project requirements for maximum water/cement ratio, nominal air content, slump, sulfate resistance, and strength.
3. Choose slump. For slipform paving, it needs to be in the ½ to 1½ in. (13 to 38 mm) range to minimize edge slump.
4. Choose maximum size of aggregate. Use the largest size of aggregate that is economically available and can be placed and consolidated.
5. Estimate mixing water and air content.
6. Select water/cementitious materials (w/cm) ratio. Determine the w/cm ratio needed to meet the requirements for strength and durability. For concrete exposed to freezing, the w/cm ratio is not to exceed 0.45. It may need to be lower to resist sulfate attack.
7. Calculate cementitious materials content. Estimate the proportions of the various cementitious materials used according to the properties desired.
8. Estimate coarse and fine aggregate contents.
9. Adjust for aggregate moisture condition.
10. Conduct trial batches. These will determine the exact proportions of desired properties to obtain, as well as the admixture dosages required. The admixture dosages may require some adjustment to achieve the required air content and slump when the laboratory batch is scaled up to the full-sized field batch.

MIX DESIGN GUIDES:

- Develop mixes with different w/cm ratios to establish sensitivity of flexural strength with a slight change in w/cm ratio (establish a 3 point curve).
- Monitor slump loss during trial batching. Excessive slump loss (1 in. (25 mm) in 15 minutes) may indicate false setting or a material incompatibility problem.
- Conduct early-age strength tests (at 3, 7, and 14 days) to evaluate potential problems for 28 days.
- Monitor a well insulated concrete cylinder temperature during the first 12 hours. A temperature increase of less than 10 °F (-12 °C) may indicate a retardation due to material incompatibility.
- Concrete for hot weather placement should contain less cement and more supplementary cementitious materials, preferably Class F fly ash, calcined clay, and/or slag. Some Class C fly ashes may be acceptable for hot-weather concreting, but some may be problematic. Trial batches for hot-weather concreting also need to include the use of retarders to verify the dosages and their effects on setting time.
- Concrete for cold weather placement needs to contain more cement and less of the slow-reacting supplementary cementitious materials (Class F fly ash, slag). If these materials are required for other purposes, such as control of ASR, the early strength can be obtained by increasing the total cementitious materials content, using a Type III cement, using warm water, or reducing the w/cm ratio. Trial batches for cold-weather placement need to include accelerating admixtures to verify the dosages and their effects on setting time.
- Trial batches need to be tested for the range of temperatures anticipated over the project duration.

7.2 CONCRETE MIXTURE DESIGN ISSUES

The best concrete mixture design results in a concrete with the following characteristics:

1. Easily mixed, placed, consolidated, and finished under the job conditions.
2. Attains the required compressive or flexural strength at the desired time.
3. Will be durable in the service environment. The durability concerns often outweigh the limitations imposed by the strength requirements.

7.2.1 Workability

Workability is an essential characteristic of concrete. Workability is the ease of placing, consolidating, and finishing of freshly placed concrete without segregation. Workability is also typically and erroneously specified in terms of slump measurement. However, because of the many factors that affect today's concrete, slump is not considered an adequate measure of workability and the contractor should not rely on the slump measurement alone to assess the workability of the project concrete.

WORKABILITY FOR SLIPFORMED CONCRETE:

The concrete mix design process should not focus solely on meeting the strength and slump requirements. Achieving acceptable workability is equally critical. Workability related factors include the following:

1. Segregation during transport and placement.
2. Ease of consolidation that will result in a well-distributed concrete matrix.
3. Well-formed slipformed edges with little or no edge slump.
4. Minimum hand finishing required behind the paver to manipulate the surface for tightness and smoothness.

Obtaining the desirable workability for a given mix requires consideration of the following items:

1. Aggregate – Size, grading, particle shape, water demand, variability.
2. Cement – Cement content, water demand.
3. Fly ash (if used) – Effect on initial set, water demand, effect on finishing.
4. Slag cements and granulated ground blast furnace slag (GGBFS) – Effect on finishing and saw cutting.
5. Water – Total water demand.
6. Admixtures – Air-entrained concrete exhibits better workability; water reducers reduce water demand while improving workability.

7.2.2 Strength

The pavement designer establishes the strength requirement for the concrete that meets the intent of the design. The strength requirement may be in terms of flexural strength or compressive strength at ages of 14, 28, or 90 days. The standard deviation for the strength needs to be established to provide guidance on the target strength levels to be achieved during the mixture design phase. The concrete also needs to be produced uniformly from batch to batch to keep the lot standard deviation as small as possible. A higher standard deviation for a lot may result in a reduction in the strength-related pay factor.

For hot or cold weather placements, the heat of hydration is a concern. Trial batches need to verify that the proposed mixes will achieve the desired strengths for cold weather placements and not generate excessive heat in hot-weather placements. Refer to sections 8.15 and 8.16, respectively, for details on the specific concerns that need to be addressed for hot and cold weather job conditions.

Mixture designs also need to be developed for hand placed (fixed form) areas. These mixtures have workability requirements different from mechanically placed mixes. However, the strength and durability requirements need to be the same as the production concrete.

FAST TRACK CONCRETE REQUIREMENTS:

- Although fast track paving does not necessarily mean high early-strength concrete, there are many situations when fast track concrete or high early-strength concrete may be specified or is necessary.
- Fast track concrete is best suited for bridging the areas incorporating cross taxiways or high traffic volume apron areas.
- The production of high early-strength concrete can be achieved using normal locally available concrete making ingredients and conventional construction methods.
    - Typically, a conventional high early-strength concrete mix incorporates higher cement factor, optimized w/cm ratio, uniform aggregate gradation, and admixtures as needed. A Type III cement may also be considered.
    - There are no specific or unique mix designs for achieving high early-strength concrete. A wide range of mixes can be designed to meet project needs.
    - High early-strength concrete can be produced using proprietary cements and admixtures.
- When high early-strength concrete is specified, the early age strength requirement is typically defined in terms of compressive strength, as follows:
    - About 750 to 1,000 psi (5 to 7 MPa) in about 4 to 6 hours.
    - About 2,000 to 3,000 psi (14 to 21 MPa) in about 24 hours.
- There may still be a requirement to meet a specified flexural strength at 14, 28 or 90 days.

FLEXURAL STRENGTH VERSUS PWL REQUIREMENTS:

The FAA P-501 guide specification uses flexural strength acceptance criteria in terms of PWL statistical criteria. Under this procedure, the payment for meeting the specified flexural strength requirement is greatly influenced by both the lot average flexural strength and the lot standard deviation. The lot average strength needs to be sufficiently higher that the specified strength and/or the lot standard deviation needs to be significantly lower to qualify for full or bonus payment. This requires good control over the concrete production process as well as over the flexural beam testing process. The P-501 requires the PWL to be 90 to qualify for full payment for a lot. The pay factor has a potential benefit to the contractor above a production quality level (PWL) of 96.

An example computation is given below to illustrate how the lot pay factor is affected by the strength statistics.

Specified flexural strength: 650 psi (4.5 MPa)
Lower flexural strength tolerance limit (93 percent): 604.5 psi (4.2 MPa)
Standard deviation: 50 psi (350 kPa) (representing good quality control) based on 4 tests

Lot Average Strength, psi	Lot PWL	Lot Pay Factor
625 (4.31 MPa)	64	77.6
650 (4.48 MPa)	81	95.5
675 (4.65 MPa)	97	106.0

As seen in the above example, in order to qualify for the 100 percent pay factor for a lot, the target flexural strength of the concrete needs to be about 660 psi (4.55 MPa) or higher versus the specified strength of 650 psi (4.48 MPa), even when the standard deviation is limited to 50 psi (350 kPa) (representing good control over the production as well as the testing processes). Therefore, it is important that the contractor considers both the average flexural strength and the concrete uniformity/consistency. The contractor can achieve a lower standard deviation (reduce variability) by controlling concrete production at all of the different phases, by producing concrete with consistent properties from batch to batch, and by ensuring that proper procedures are followed to fabricate, handle, store, and test specimens.

7.2.3 Sulfate Resistance

If the soils or groundwater contain sulfates, the cementitious material(s) need to be appropriately resistant to sulfate attack *and* the water/cementitious materials ratio needs to be reduced appropriately. Also, as discussed previously, use of pozzolans or slags needs to be considered. For sulfate resistance, the main consideration is the C_3A content of the cement. A supplementary cementitious material with high CaO and Al_2O_3 contents, however, may effectively add to the C_3A content of the system, making it more vulnerable to sulfate attack. Some Class C fly ashes can reduce the resistance of the concrete to sulfate attack. However, if the same Class C fly ash is incorporated into blended cement with sufficient gypsum, it can provide excellent sulfate resistance.

7.2.4 Air Entrainment

Concrete that is subject to freezing must contain a well-distributed system of finely divided air voids to protect it from frost damage. While the specifications typically provide a required volume of air as measured by ASTM C 231 (pressure method) or ASTM C 173 (volumetric method) these methods do not distinguish between a good air void system and a poor one. The following items need to be considered:

1. Trial batches need to be done to determine the correct dosage of the admixture for the conditions, including temperature, expected on the job site.
2. Typical air content requirements for pavements range from 5 percent to 7 percent depending on exposure.
3. The volume of air required for frost protection increases with decreasing aggregate size because of the corresponding increase in paste content.
4. All other factors being equal, an increase in air content results in a decrease in concrete strength.
5. The air-void system parameters should be tested on the hardened concrete according to ASTM C 457
    a. An air-void spacing factor of 0.008 in. (0.20 mm) or less is necessary
    b. For concretes containing supplementary cementitious materials, an air void spacing factor of 0.006 in. (0.15 mm) or less is necessary.
6. The concrete for the trial batch should be allowed to sit for a length of time representative of the haul time and then be measured at the end of that period to ensure that testing accounts for loss of air. When concrete is delivered to the site in non-agitating trucks, the loss of air can range from 1 to 2 percentage points.
7. In a no-freeze environment, if air is entrained solely to facilitate workability, the minimum air contents required for frost damage protection do not apply.
8. Typical slipform paving operations reduce air content by 1 to 2 percent during consolidation.

7.3 BLENDED CEMENTS AND SUPPLEMENTARY CEMENTITIOUS MATERIALS

The judicious use of supplementary cementitious materials, either as components of blended cements or added at the mixer, can greatly enhance the properties of the concrete. Key issues related to the use of cementitious materials and blended cements are summarized below:

1. Class C fly ash and slag contain sufficient calcium to have some cementitious properties of their own.
2. Class F fly ash and natural pozzolans react with water and calcium hydroxide from the hydration of portland cement to form calcium silicate hydrate.

3. The reactivity of the cementitious materials and the rate of strength gain of concrete containing them can vary significantly depending on their chemical and mineralogical composition and on their fineness.
4. Purely pozzolanic Class F fly ash and natural pozzolans tend to produce a lower heat of hydration and lower strengths at early ages than portland cement.
5. Class C fly ash may produce a lower or higher heat of hydration and lower or higher early-age strength than portland cement.
6. Slag generally lowers the heat of hydration and the early-age strength.
7. Most supplementary cementitious materials increase the strengths at later ages.
8. Appropriate supplementary cementitious materials, appropriately used, can provide the following benefits:
    a. Reduce the tendency for thermal cracking by reducing the heat of hydration.
    b. Increase the strength (particularly at later ages).
    c. Reduce concrete permeability and diffusivity.
    d. Control expansions due to ASR and increase resistance to sulfate attack.
9. For a particular application, some supplementary cementitious materials may be better than others, and some may be completely inappropriate.
10. Natural pozzolans can provide excellent performance, somewhat like Class F fly ashes.
11. If the aggregate selected is susceptible to ASR, a Class F fly ash could be the best way to control it, other things being equal. The combination of aggregate, cement, and fly ash needs to be tested to determine how much fly ash is needed.
12. Class F fly ash is considered to be the most effective supplementary cementitious material for control of heat of hydration, control of ASR, and resistance to sulfate attack.
13. It is important to note that some supplementary cementitious materials may make things worse, not better. Therefore each combination of cementitious materials, aggregates, and admixture needs to be tested.
14. Blended cements containing Class F fly ash, slag, calcined clay, and/or silica fume may also be used for control of heat of hydration, control of ASR, and resistance to sulfate attack.
15. If the available blended cement does not meet the requirements for control of alkali-silica reaction or sulfate resistance, additional supplementary cementitious material of the same or different kind may be added at the mixer as necessary.
16. Ternary mixtures, which contain three cementitious materials, may offer the best alternative in some applications. For example, a Type IS cement may not be sufficient on its own for the required sulfate resistance, but the addition of either slag or Class F fly ash at the mixer can improve its performance.

THE CASE OF CLASS C FLY ASH:

Class C fly ash may be detrimental to the performance of the concrete, causing premature stiffening of the fresh concrete, thermal cracking, and/or reduced sulfate resistance. Class C fly ash is generally not effective in controlling expansions due to ASR. The potential for early stiffening in the presence of certain water reducers and in hot weather can be verified as follows:

- Test the concrete by making trial batches at the highest temperature anticipated.
- Verify that slump loss is not too rapid for the conditions of the job and that setting times are acceptable.
- If the concrete loses slump too rapidly, consider reducing the dosage of fly ash, using a different fly ash, using a different cement, or using a different water reducer.

7.4 MATERIALS INCOMPATIBILITY

Some concretes exhibit undesirable characteristics because of incompatibility among different concrete materials. Undesirable characteristics are:

1. Early loss of workability (early stiffening)
2. Delayed set (retardation)
3. Early-age cracking due to excessive autogenous and drying shrinkage of concrete
4. Lack of proper air-void system.

INCOMPATIBILITY MANIFESTATIONS:

Early Stiffening of Concrete – Early stiffening occurs when there are not enough sulfates in solution at the right time to control the hydration of the aluminates. The early stiffening leads to loss of workability, as indicated by loss of slump. Workability loss leads to difficulties in concrete placement and consolidation. The tendency to early stiffening may be attributed not only to the individual cementitious materials, but also to interactions among the various cementitious materials and the chemical admixtures and ambient temperatures.

Retarded Concrete – Although not a common phenomenon, from time to time some paving projects experience concrete setting problems. At these projects, setting may be delayed by a few hours to more than 12 hours. A consequence of this problem is the inability to perform joint sawing in a timely manner leading to uncontrolled cracking.

Concrete Shrinkage – Premature cracking in concrete can be caused by a host of factors. Shrinkage can occur in the fresh (plastic) or hardened concrete. Plastic shrinkage cracking results as water rapidly evaporates from the surface of the fresh concrete. Cracking may also occur somewhat later in the life of the pavement due to excessive autogenous and drying shrinkage.

Concrete Air Void System – Problems related to the use of certain air-entraining agents include:

1. Accumulations of air voids around the aggregate particles leading to strength loss.
2. A poor quality air void system in the hardened concrete that affects long-term freeze-thaw durability.

These incompatibility-related problems affect construction productivity and long-term concrete performance. As concrete mixtures become more complex with the use of supplementary cementitious materials and combinations of chemical admixtures, the likelihood of incompatibility among cementitious materials and admixtures increases with the number of ingredients added to the mix. The problem is compounded because:

1. Factors that result in incompatibility among various cementitious materials and admixtures are not well known.
2. Tests to determine material incompatibility are lacking.

3. Material incompatibility may be induced by temperature changes. Therefore, trial batches need to be tested at the extremes of temperature anticipated at the project site.

Steps to minimize incompatibility problems include the following:

1. All admixtures used on the project need to be from the same manufacturer to ensure compatibility among them. Do not exceed the recommended dosages.
2. Ensure all cementitious materials meet project specifications and/or the requirements of appropriate ASTM standards.

It is also advisable to have hot and cool weather mixture designs in locations where seasonal differences in temperature are usually significant.

7.5 AGGREGATE REQUIREMENTS

7.5.1 Aggregate Grading

Concrete mixtures produced with a well-graded aggregate combination tend to:

1. Reduce the need for water
2. Provide and maintain adequate workability
3. Require minimal finishing
4. Consolidate without segregation
5. Enhance strength and long-term performance.

Concrete mixtures produced with a gap graded aggregate combination tend to:

1. Segregate easily
2. Contain higher amounts of fines
3. Require more water
4. Increase susceptibility to shrinkage
5. Limit long-term performance.

The grading of the fine aggregate fraction is also important – too little fines make the concrete difficult to extrude and finish as well as more prone to bleeding; excess fines increases the water demand of the concrete and the required dosage of air-entraining admixture.

The combined aggregate grading is used to calculate the coarseness factor and the workability factor as follows.

$$CoarsnessFactor = 100\left(\frac{\%\ \mathrm{Re}tained\ \ Above\ 9.5mm\ (3/8\ in.)\ Sieve}{\%\ \mathrm{Re}tained\ \ Above\ 2.36mm\ (\#8)\ Sieve}\right)$$

$$Workability\ \ Factor = \%\ Pas\sin g\ \ 2.36mm\ (\#8)\ Sieve$$

Note: The workability factor needs to be increased by 2.5 percent for each increase of 94 lb (43 kg) of cementitious material over 564 lb per cu yd (335 kg/cu m).

The workability factor is plotted against the coarseness factor as shown in Figure 7.1 and is evaluated as follows:

1. Aggregate blends with a point in the middle to the top of Box A and from the bottom to the middle of Box B will produce mixtures suitable for slipform paving. However, based on texture and shape, aggregates falling in other regions of the chart may also be acceptable for slipform paving.
2. Aggregate blends that fall in the left third of Box A will produce mixtures that are suitable for fixed form paving.
3. Aggregate blends that fall in the middle region of Box B will produce mixtures that are suitable for hand placed areas.
4. Aggregate blends that plot close to the bottom boundary line may tend to have too much coarse aggregate.

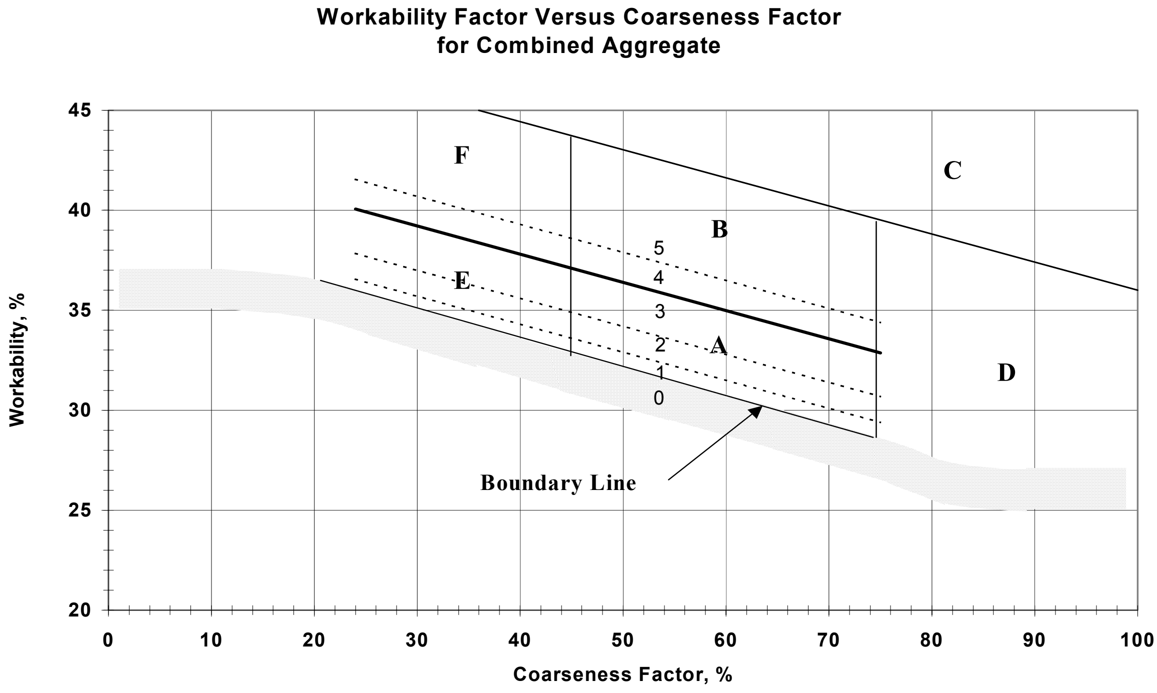


Figure 7.1 – Aggregate workability factor (courtesy of the Iowa Department of Transportation)

5. Aggregate blends with a point below the bottom boundary line will produce rocky mixtures with inadequate mortar.

6. Aggregate blends above the top boundary line (Area C) will produce sandy mixtures with high amounts of fines requiring higher water contents and having the potential for segregation.
7. Aggregate blends that plot close to the top of Box B will tend to take on characteristics of those in Area C.
8. Aggregate blends with coarseness factors higher than 75 (Box D) will produce gap graded mixtures with inadequate workability and high potential for segregation.
9. Aggregate blends with a point in Box E or F, respectively, relate to Box A and B for aggregate sizes less than 3/4 in. (19 mm).

When using the coarseness/workability chart it is assumed that particles are rounded or cubical shaped. Rounded or cubical shaped aggregates typically enhance workability and finishing characteristics. Flat and elongated aggregates typically limit workability and finishing characteristics.

7.5.2 The Case of Slag Aggregates

Properly aged iron ore blast-furnace slag aggregates have a good history of performance. However, control of moisture content is very important when slag aggregates are used. Potential problems include variations in workability and consolidation. If slag aggregate moisture is not managed well, the in-place concrete may exhibit honeycombing and poorly formed edges.

Slag from open hearth steel mills should not be used as concrete aggregate or for econocrete/lean concrete base because of the expansive nature of the steel slag aggregates.

7.5.3 The Case of Recycled Concrete Aggregates

Recycled concrete, or crushed concrete, is a feasible source of aggregates, provided that it meets the project specific aggregate requirements. Recycled concrete generally has a higher absorption than virgin aggregates and may require more water to achieve the same workability and slump than for concrete with virgin aggregates. Recycled aggregate may also require added cement to achieve desired workability. A potential problem with recycled aggregate use is that the variability in the properties of the old concrete may affect the properties of the new concrete. It is advisable to have the recycled concrete aggregates evaluated by petrographic examination.

7.6 FIELD ADJUSTMENTS OF CONCRETE MIXTURE DESIGN

Shortages of cement or other concrete-making ingredients may occur during the construction season. If any changes in type, source, or brand of cementitious material, admixtures, or aggregate source need to be made, trial batches need to be carried out to verify that the required properties are retained. Certain minor adjustments to the concrete mixture proportions may be necessary due to changes in the weather and to maintain the required workability and air content. However, if air content is increased or water is added above the design w/cm ratio, the concrete strength may decrease.

LABORATORY MIXTURE DESIGN VERSUS PLANT MIXTURES:

The following differences between laboratory and plant mixing need to be noted:

- Differences in the size of the batch and the type of mixer will result in differences in efficiency of mixing. It may be necessary to adjust the dosages of the chemical admixtures to obtain the desired workability and air content.
- Normal laboratory mixing procedure will obscure any tendency of the concrete mixture to false set. A concrete mixture that behaves appropriately in the laboratory may false set when mixed in the batch plant. In the laboratory, test the slump after the initial 3 minutes of mixing and compare to the slump after final mixing to check the tendency to false set.
- Temperature can have a significant effect on workability, water demand, slump loss, air content, and setting. Laboratory mixture designs should be conducted at the temperature(s) anticipated in the field.
- Test the slump and air content every 10 to 15 minutes for a sufficient amount of time after initial mixing to simulate the longest anticipated haul time.
- When long haul times are anticipated, the initial air content may need to be higher than required at placement to compensate for the loss of air during transit.
- The mixture design should not be too sensitive to elevated placement temperatures, variations in aggregate moisture content, or slight variations in batching.
- The manufacturer's maximum recommended dosage of water reducer should not be routinely required for acceptable workability in the laboratory, as there will be no possibility of increasing the dosage in the field without affecting the setting time.
- Monitor closely the properties of the concrete materials as well as the properties of the fresh concrete during the early days of the job so that adjustments can be made quickly if needed.
- Perform 3-, 7-, and 14-day strength tests using field concrete. If results are not tracking the laboratory 3-, 7-, and 14-day results, then potential problem may exist. Stop the paving operation and redesign the concrete mixture. In this case, only a few days of concrete may potentially be of concern.
- If plant mixture behavior is different than the laboratory mixture, possible reasons may include:
    - Ambient temperature
    - Mixing time
    - Material differences (laboratory materials are cleaner, different cement characteristics)
    - Mixing process differences (drum vs. laboratory mixer)
    - Aggregate moisture content
    - Material charging differences.
- Hot (fresh from the mill) cement use during peak construction season may result in:
    - Tendency to false set
    - Admixture demand change – May need more in the field than required in the laboratory.

Adjustments of admixture dosages are acceptable provided the maximum dosages do not exceed the manufacturer's maximum recommended dosage. The dosage of air-entraining admixture required to entrain a given volume of air will vary with the temperature of the concrete. If the required dosage was determined in the laboratory at 70 °F (20 °C), it can be decreased by approximately 30 percent for placement temperatures of 40 to 50 °F (4 to 10 °C) and increased by approximately 30 percent for placement temperatures of 100 to 110 °F (40 to 45 °C).

If a new mixture design needs to be developed because of changes in concrete materials, the contractor should be allowed to proceed with paving once the early-age breaks indicate that the new mixture will provide the specified strength at the specified age. It is advisable that the contractor use a higher strength mixture temporarily until all the new mixture strength results are available.

Note that concrete strength is not the only criterion that needs to be satisfied for the new mixture. The concrete needs to be capable of being mixed, placed, consolidated, and finished adequately under the job conditions. Setting times need to be verified. If the pavement construction is expected to span more than one season, it is also advisable to develop more than one mixture design.

7.7 TROUBLESHOOTING GUIDE

Good observations and documentation help greatly in isolating and solving construction problems. Look for patterns that appear to connect cause and effect. If everything was working well until the weather got hot, a new shipment of cement came in, etc., the most recent change may be a clue to the cause of the problem. However, it may be that the construction practices were marginal to begin with, and the last change was simply the one that tipped the balance. In hot weather or cold weather, certain types of problems are more likely. Common problems and possible remedies are discussed at the end of chapter 8.

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

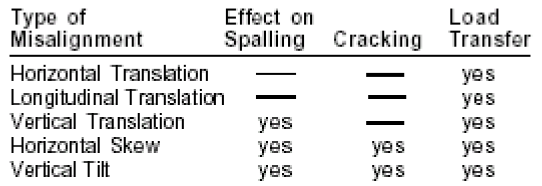
When doing dowel bar installation, the following items must be considered:

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.

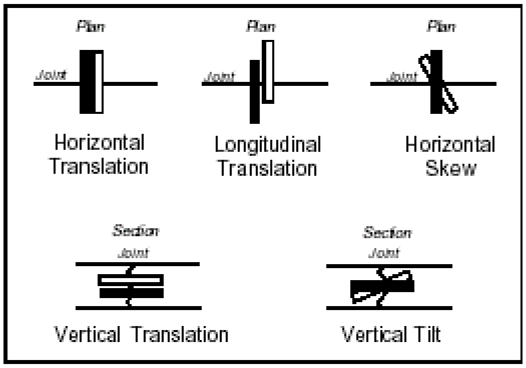
Dowel bar alignment is a critical item and must be checked on a regular basis. Dowel misalignment does have a significant effect on pavement performance. Important dowel installation items are:

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.

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

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.

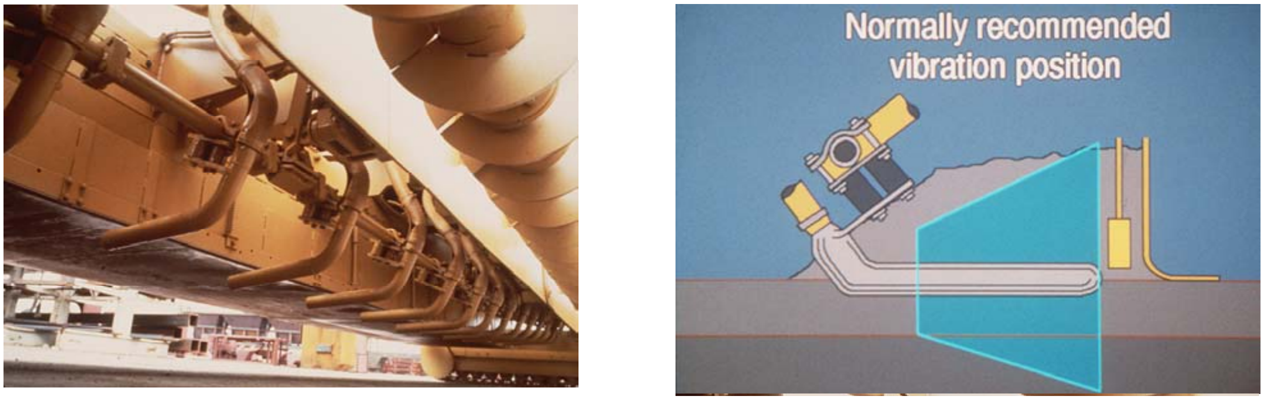


Figure 8.5 –Vibrator layout and position

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.

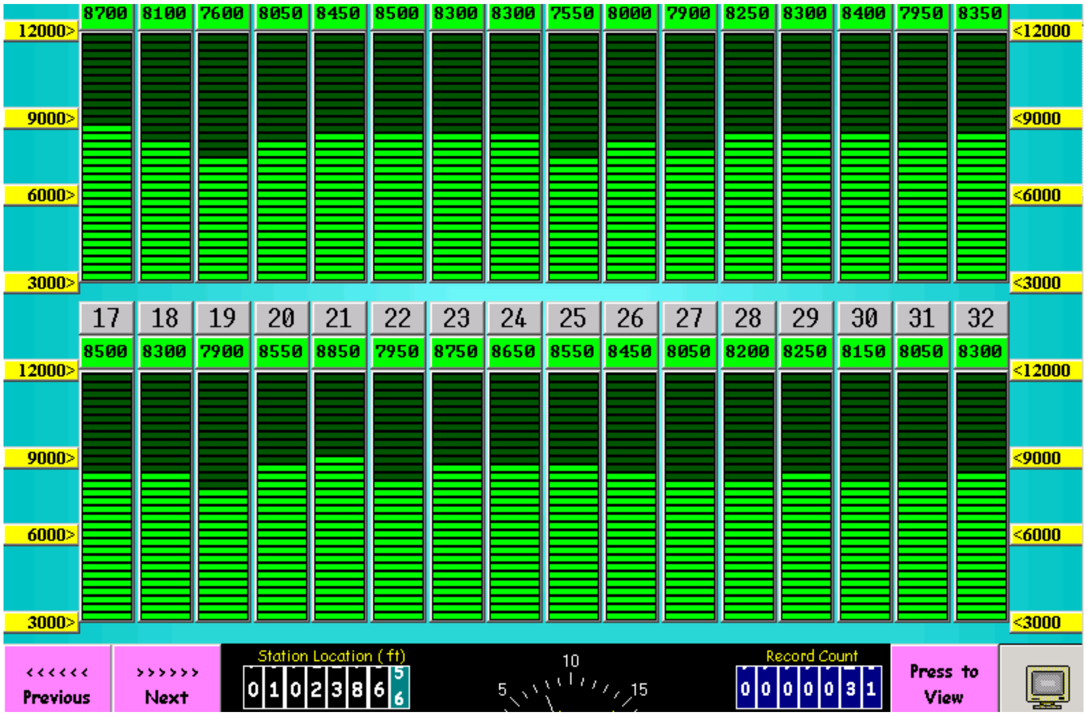


Figure 8.7 – Output from a smart vibrator system showing the frequency of each vibrator

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.

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.

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.

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.

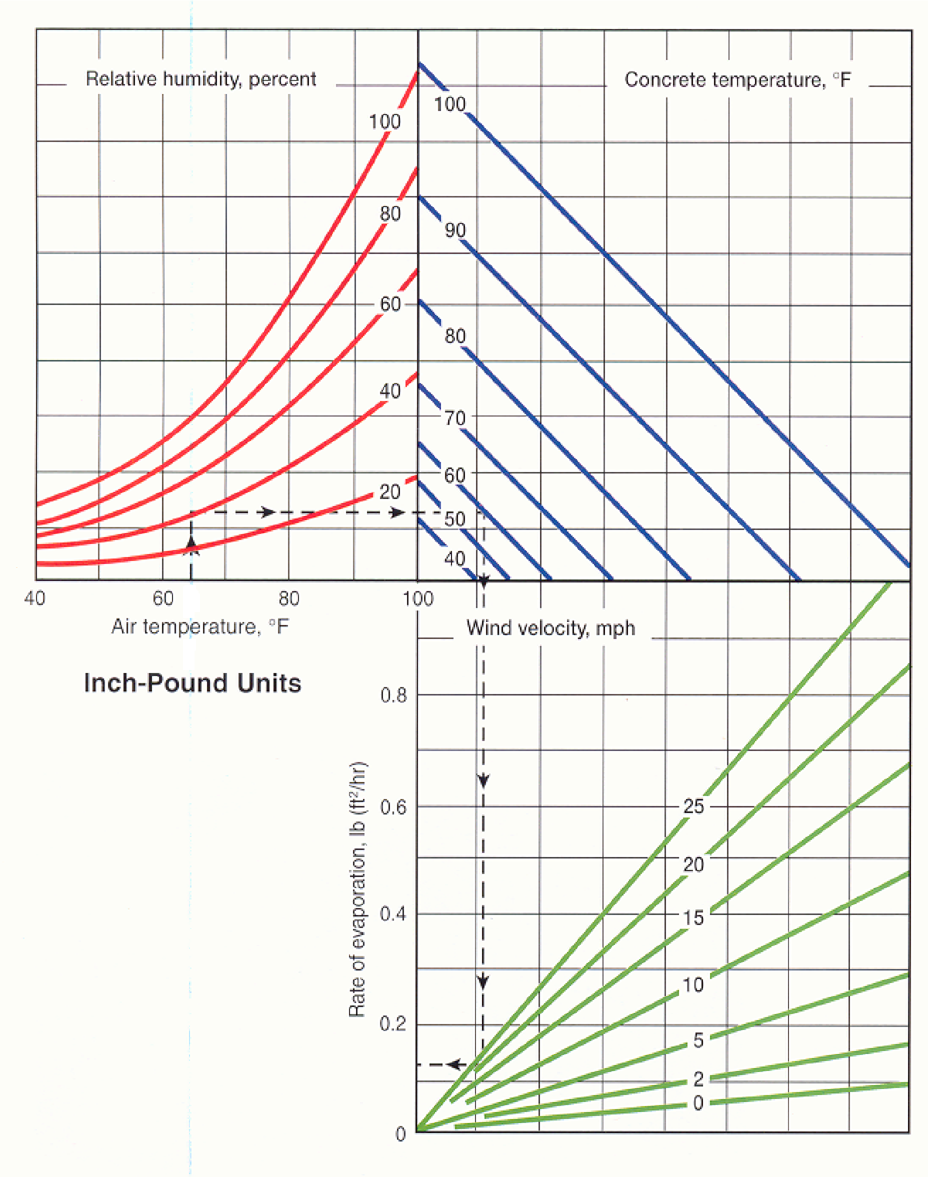
During hot weather, problems that are likely to occur include:

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.

8.18 TROUBLESHOOTING GUIDE

Common problems encountered at the job site and possible remedies follow.

Problem	Probable Cause(s)	Action
Premature stiffening of concrete with little evolution of heat.	False setting cement.	Do not add water. Plasticity can be restored with additional mixing. Notify cement supplier.
Premature stiffening of concrete with evolution of heat, lack of working time.	Any of the following could contribute to this problem: ▪ Cement with too little or the wrong form of sulfates ▪ Class C fly ash with high Al_2O_3 content ▪ High placement temperatures ▪ Lignosulfonates in water-reducing admixture ▪ TEA in water-reducing admixture ▪ Use of accelerator ▪ Wrong mixture design for hot weather (high cement content, Type III cement, no supplementary cementitious materials) ▪ Dry, sorptive aggregates absorbing water from the mix. ▪ Hot (fresh) cement.	If using an accelerator, stop using it or reduce the dosage. Reduce the placement temperature of the concrete by any convenient method(s). See section 8.15. In hot weather, use the hot weather mixture design. If using Class C fly ash, reduce the dosage. Make sure the aggregates are damp at the time of batching. Switch to a water reducer that does not contain lignosulfonates or triethanolamine (TEA). (Consult the admixture supplier for advice.)
Slump out of specifications or varying	Change in water content or aggregate grading, concrete temperature too high.	Check aggregate moisture contents and grading. Stockpiles should be of consistent grading and aggregates need to be moist. Make sure batch water is adjusted for aggregate moisture content. Check whether extra water was added at the site. Perform mixer uniformity test. Note the batch time on the concrete delivery ticket. Haul times should not exceed

		allowable time.
Slump loss greater than 1 in. (25 mm) between the plant and the paver	False setting tendency or material incompatibility	Check cement composition Check mixing time Check admixture compatibility
Inconsistent Air content	Variations in pozzolan (Class C fly ash can vary in carbon content, which strongly affects the required dosage of air-entraining admixture). Change in cement source, type, or brand Change in sand grading. Inadequate or variable mixing due to worn mixer blades, an overloaded mixer, or varying mixing times. Concrete temperature effects.	If using Class C fly ash, expect variations in the required dosage of the air-entraining admixture. Monitor air contents closely and adjust admixture dosages as necessary. If the air contents drop between the cool morning and hot afternoon, it may be due to the change in concrete temperature. In that case, increase the dosage of air-entraining admixture as the temperature rises. If a sudden change seems permanent, look for a change in the materials supplied (cement, admixtures, etc.). Check the sand stockpile to see whether the grading has changed. Examine the mixer (fins) and mixing procedures. Contamination of one of the ingredients with organics can also effect a sudden change in the required dosage of the air-entraining admixture. Try to isolate the source.
Excessive concrete temperature	Ingredients may be hot at batching: aggregates, cement, fly ash. Long haul times. Hot weather.	Follow hot weather concreting practice as appropriate. Minimize haul times.
Failure to set	Organic contamination, excessive retarder, excessive water reducer, retarder not dispersed, and cold weather.	Check for contamination of water, aggregates, and equipment. Reduce dosage of retarder and water reducer. Improve mixing to disperse

		retarder. Follow cold weather concreting practices if appropriate.
Sticky mix	Use of higher dosages (>5 percent) of silica fume. Sand too fine. Using wood float on air-entrained concrete.	Change sand source. Use magnesium or aluminum floats.
Honeycombing	Hot weather may induce premature stiffening. Inadequate vibration. Changes in aggregate grading will affect workability. Dry aggregates. High paver speed.	Follow hot weather concreting practices if appropriate. Check that all vibrators are working properly, and at the right frequency and amplitude. Paver speed should not be too high. Check aggregate grading.
Edge slump	Poor and/or nonuniform concrete. Improper operation of paving equipment.	Verify mixture design and batching procedures. Check aggregate grading and moisture. Check concrete placement procedures.
Smoothness problems	Nonuniform concrete. "Stop and go" paver operation. Too much or too little concrete in front of paver. Frequent use of construction headers. Use of light paver.	Check batching procedures. Check aggregate grading. Improve construction procedures. Minimize delays in concrete delivery. Add extra haul trucks, if necessary, or slow paver. Improve paver operation.
Popouts	Unsound aggregates. Clay balls.	Check aggregates for soundness. Check for inter-mixing of aggregate with soil.
Scaling, dusting	Over-finishing. Premature finishing. Early freezing of concrete.	Improve finishing technique. Protect concrete from freezing. Concrete damaged by freezing needs to be removed and replaced.
Plastic shrinkage cracking	Excessive loss of moisture from fresh concrete.	Use an accelerator to make concrete set faster. Protect concrete from loss of moisture both before and after placement: fog spray or immediate application of

		evaporation retardant or curing compound. Make sure absorptive aggregates are kept moist. Refer to hot weather concreting practices if appropriate.
Random cracking	Shallow sawcut/ late sawing. Dowel misalignment. Bonding with stabilized base. Sudden cold front. Excessive joint spacing.	Saw sooner and check sawcut depth. Check dowel alignment. Take cores to check interface bond. Review joint spacing.
Raveling of sawcut	Sawing too soon.	Wait longer to saw. Check blade compatibility. Use early entry dry saw.
Joint spalling	Excessive hand finishing; trying to fix edge slump of low spots by hand manipulated concrete; nonuniform concrete resulting in wavy longitudinal joint that spalls when sawed; and collateral damage from equipment, slipform paver tracks, screeds, etc.	Improve construction practice.
Low strength concrete samples	Errors in batching and/or mixing of concrete. Incompatibility between cement and air-entraining admixture causing coalescence of air voids around aggregate particles. Improper sample preparation, curing, handling, or testing.	Verify entire process of making, curing, handling, and testing. Flexural specimens are particularly vulnerable to poor handling and testing procedures. Verify entire batching and mixing process. Trial batches can help eliminate the possibility of incompatibility. A quick visual examination of a cut specimen will identify any coalescence of air voids.

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.

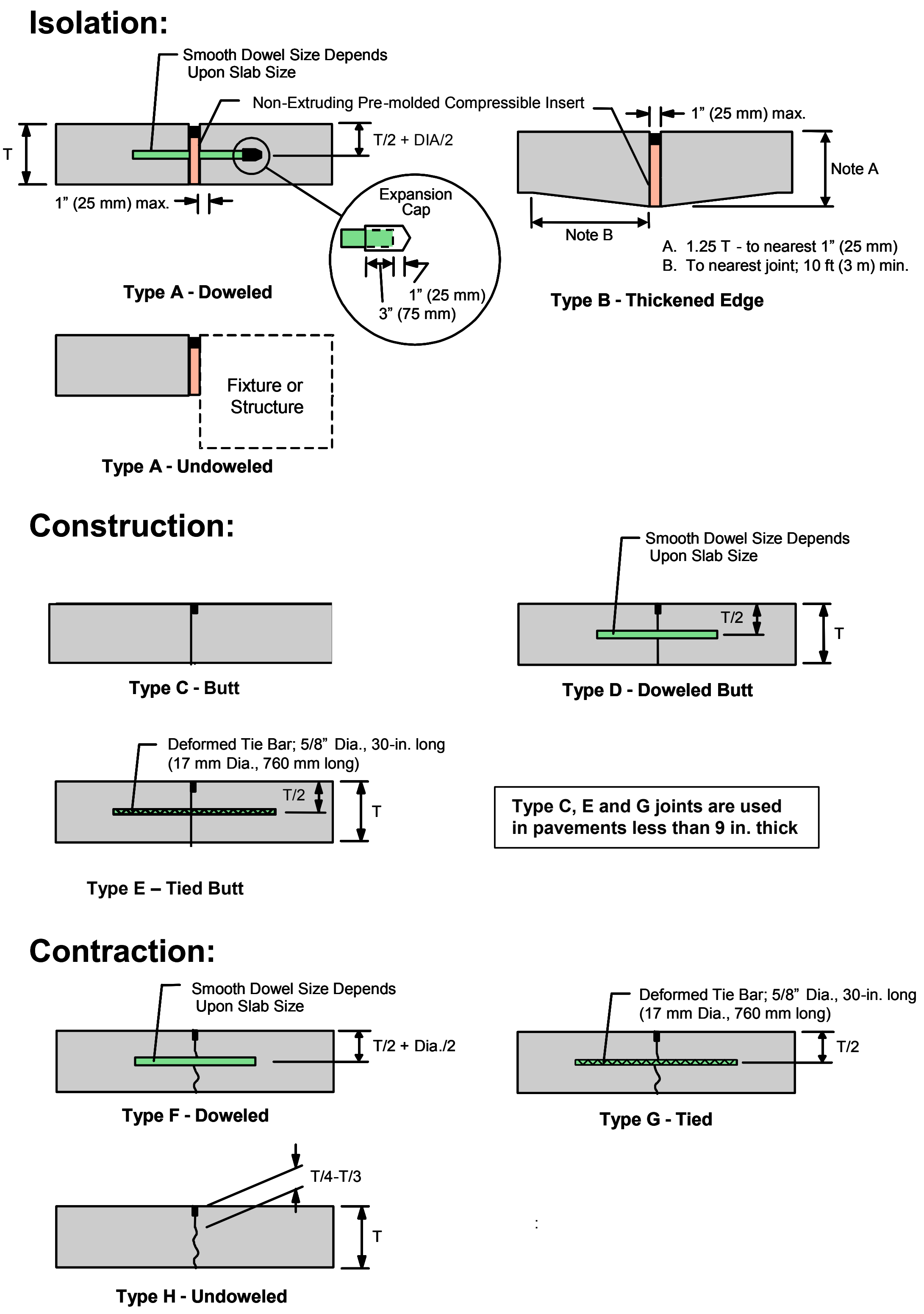


Figure 9.1 – Airport Concrete Pavement Joint Types (courtesy of the American Concrete Pavement Association)

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

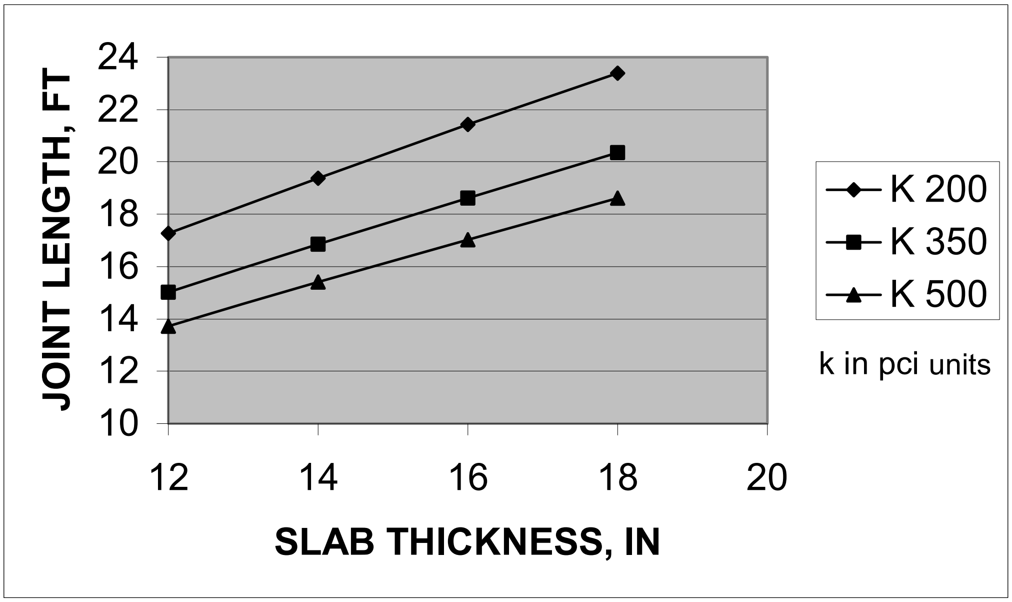
Stresses in pavements increase with a greater modulus of base/subgrade reaction (k) value. For high strength stabilized bases, the allowable joint spacing needs to be designed in the range of 4 to 6 times (typically 5 times) the pavement radius of relative stiffness (l).

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

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.

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

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.

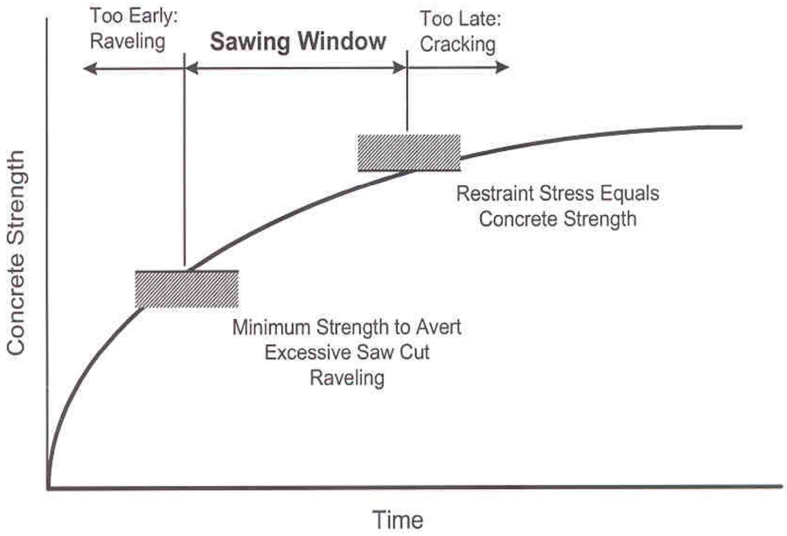
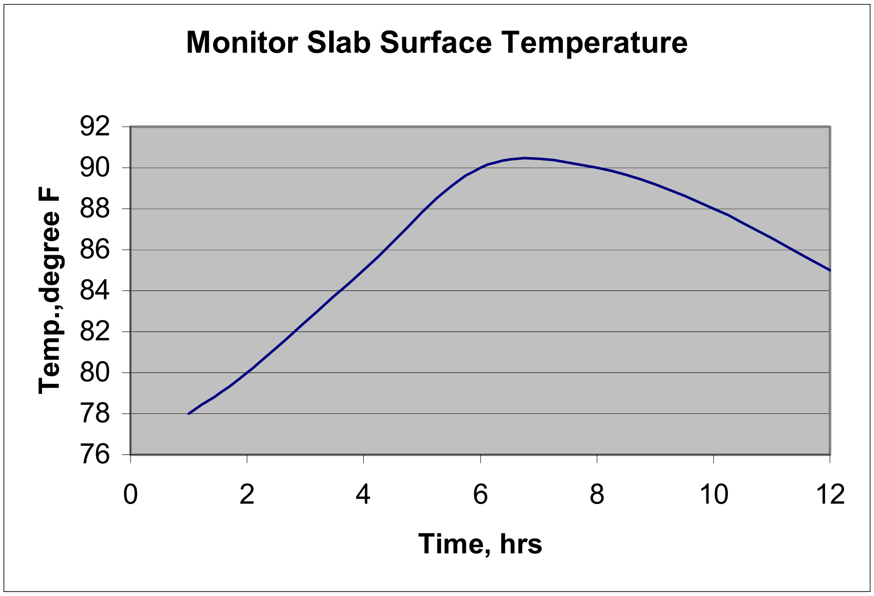


Figure 9.3 – Joint sawing window of opportunity

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.

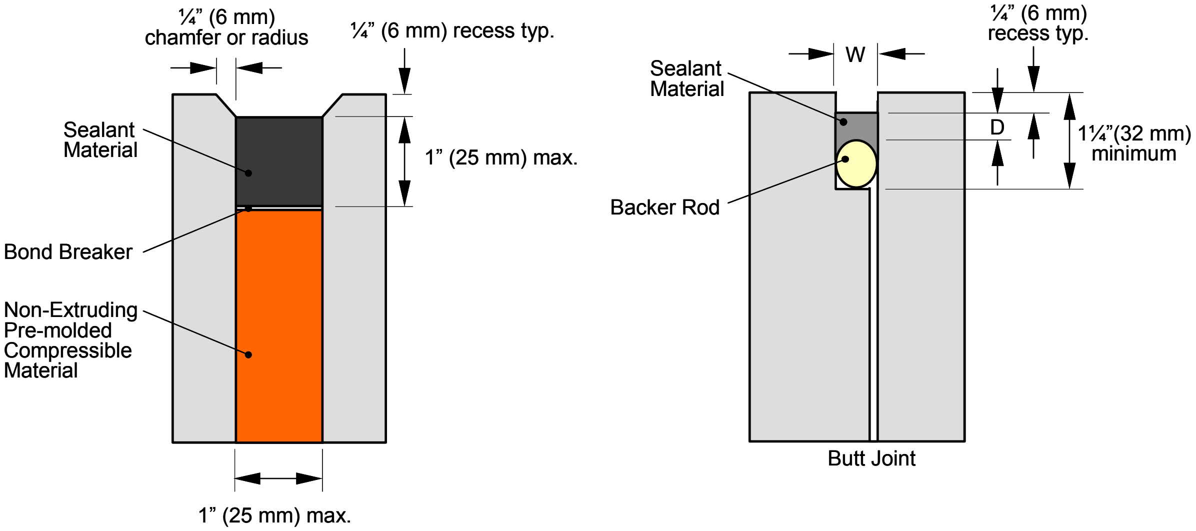
JOINT SEALANT SHAPE FACTOR (W/D):

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

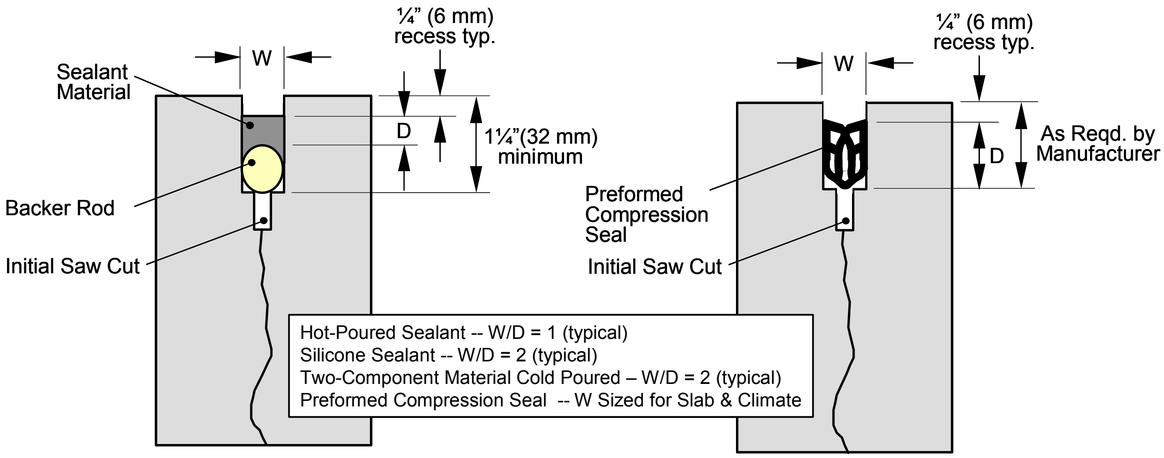
Hot poured asphalt based sealants typically need a reservoir shape factor (width/depth ratio) of 1.

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.



Detail 1 – Isolation Joint **Detail 2 – Construction Joint**



Hot-Poured Sealant -- W/D = 1 (typical)
Silicone Sealant -- W/D = 2 (typical)
Two-Component Material Cold Poured – W/D = 2 (typical)
Preformed Compression Seal -- W Sized for Slab & Climate

Field Poured Sealant **Preformed Seal**

Detail 3 – Contraction Joints

Note: Chamfered joints are acceptable for all joint types

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.

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.

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

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)

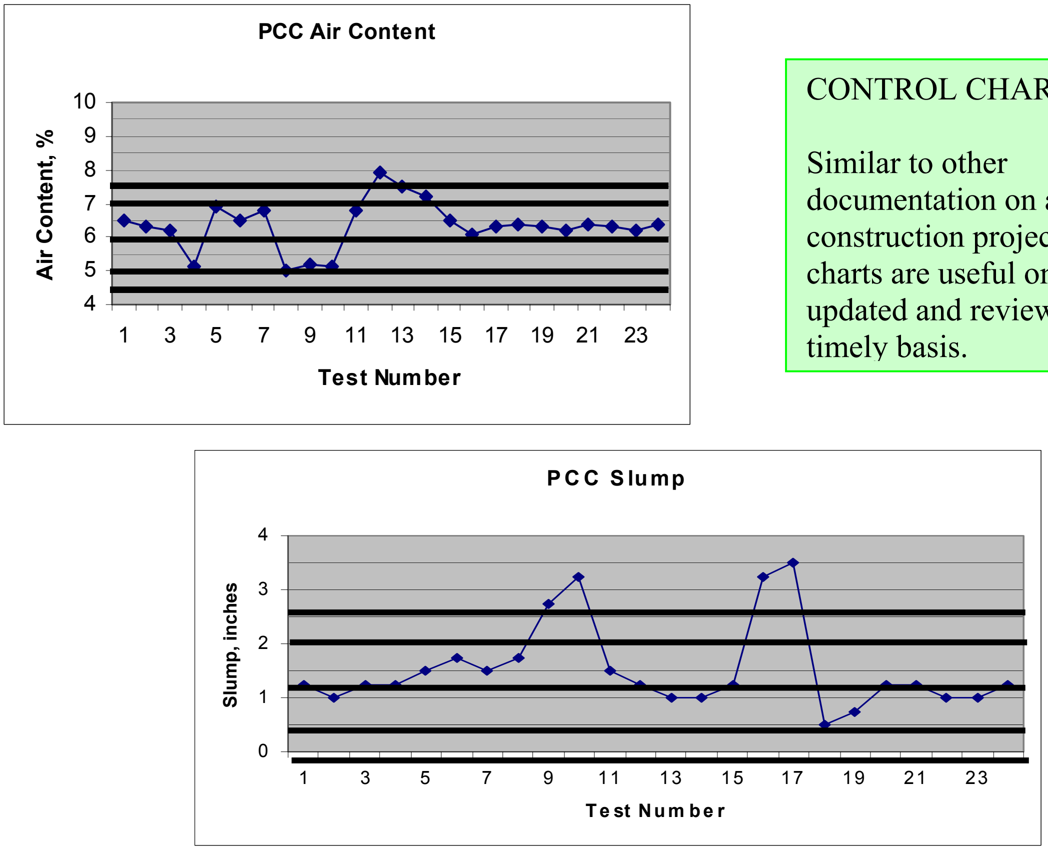
Corrective Action
If one individual slump test is outside the action limits, the next three trucks need to be tested. If those tests are within the action limits, then the normal testing frequency can be resumed. If at any time one individual slump test is outside the suspension limits or two consecutive 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)).

10.3.5 Strength Testing

10.3.5.1 Flexural Strength Testing

Due to the importance of strength in the design and acceptance of pavements, flexural strength testing requires attention to detail. Test results are affected by minor changes in procedures, which can lead to increased variability and, in some cases, suspect results. The test machine must be calibrated, and operators must understand the testing requirements. Field supervisors should monitor the handling of the test specimens at the job site, during transportation, and at the laboratory. Items to address in the QMP/CQC plans include:

1. Location of material sampling, such as at the plant or delivery truck, or on-grade in front of the paver.
2. Sample fabrication location.
    - Near the material sampling point
    - On-site laboratory.
3. Ensuring that requirements concerning the time allowed between material sampling and beam fabrication are met.
4. Dimensions of beam samples. Typically, 6 by 6 by 21 in. (150 by 150 by 530 mm) specimens are used.
5. Type of beam molds allowed – Plastic or steel.
6. Fabrication procedures.
7. Field curing, transportation, and laboratory procedures.
8. Frequency of testing.
9. Number of beams per sample location.
10. Determination of sample locations.
11. Curing requirements for additional beams to be made for other reasons, such as opening to traffic (field cured or laboratory cured).
12. Use of a consignment form that tracks each concrete sample from fabrication, field curing, transportation to laboratory, laboratory curing, and testing.
13. Procedure for disposition of possibly damaged beams and of results of known bad tests.

FLEXURAL STRENGTH TESTING:

This is a key inspection item for large airport construction projects. Therefore, review all steps – sampling, fabrication, transportation, curing, handling, and testing.

Check the beam tester for

- Load and rate of loading
- Uniformity of loading (load distribution) between the two supports and across the width of the beam.

Beams are vulnerable to damage in handling and transport. Damaged beams will yield low strength results.

Take care during warm summer days – Technician fatigue can affect handling and fabrication.

Variability is an inherent part of all construction procedures. Flexural strength testing is particularly sensitive to variability. A well-managed layout for beam testing and curing at an on-site laboratory for a large construction project is shown in Figure 10.2.

Figure 10.2 – Field laboratory for beam fabrication and curing

10.3.5.2 <u>Compressive Strength Testing</u>

Some time, compressive testing is required. Compressive strength is typically used for military projects and for civilian airports that serve design aircraft with a maximum gross weight of less than 30,000 lb (13,600 kg). Even if compressive strength testing is not required, it may be preferable to make companion sets of cylinders along with the beams. The cylinders may help resolve future disputes over the in-place strength of the concrete pavement, if flexural strength testing is found to be questionable. Items to address in the QMP/CQC plans include most of the flexural strength testing items discussed previously. Cylinder specimens are less vulnerable to damage in handling and transport than beam specimens.

10.3.5.3 Core Strength Testing

When beam or cylinder strength tests have not been performed adequately or if tests results are considered suspect, core strength testing may be considered to determine the strength quality of the in-place concrete. If core testing is used, the following items need to be considered:

1. Cores may be tested for compressive or splitting tensile strength.
2. Core strength test results need to be used in accordance with established procedures as defined in the specifications.
    a. These procedures typically involve use of project specific correlations between the core strength and the beam or cylinder strength.
    b. The FAA Engineering Brief No. 34A (May 2002) provides guidelines for referee testing using cores and pre-established correlations.
3. Core testing needs to be initiated at a test age close enough to the specified test age for the flexural or compressive strength testing.
4. Core conditioning prior to testing is very important.
    a. Air-dry conditioning typically results in higher compressive or split tensile strengths.
    b. However, cores need to be conditioned in a manner that is defined in the project specifications.

FAA ENGINEERING BRIEF No. 34A – REFEREE TESTING OF HARDENED PCC PAVEMENT:

The brief presents a method to evaluate the strength of in-place concrete when the results of normal flexural strength testing are suspect because of suspected problems with testing, and when the acceptance criteria for concrete strength is based on PWL.

Test Method: Coring, core conditioning, and core testing in accordance with ASTM C 42 and use of splitting tensile strength test as per ASTM C 496.

Test Program: Reproduce the statistical sampling program used for the original flexural strength testing for the lot or sublot in question. The number of cores for a sublot needs to match the number of beams required to be tested for that sublot. Cores need to be nominally 6 in. (150 mm) in diameter for pavement slabs 12 in. (300 mm) or thicker.

Flexural Strength Determination: The brief provides a set of equations to convert the splitting tensile strength at time of testing to flexural strength at 28 days for three sets of concrete age. These equations are considered very conservative and the converted results may not represent the true flexural strength of the in-place concrete. It is therefore recommended that on large projects the contractor develop a project specific relationship at the time of the concrete mix design phase. Also, cores need to be obtained and tested soon after the flexural strength test results are determined to be suspect, preferably within 3 to 5 days after the specified 14- or 28-day tests.

10.3.6 Edge Slump, Joint Face Deformation, and Profile Testing and Tolerances

Excessive edge slump and joint face deformations under slipform paving are indications of improper concrete mixture proportioning, improper concrete placement, or improper equipment operation.

10.3.6.1 Edge Slump Testing

Typical specifications require that edge slump not exceed 1/4 in. (6 mm) over 15% of the joint length and that edge slump be no greater than 3/8 in. (10 mm). Checking for edge slump requires a straight edge and level adjusted for the cross slope as shown in Figure 10.3 (a). Edge slump can be measured on either fresh or hardened concrete. The straight edge needs to be of sufficient length, typically 10 ft (3.1 m), to support itself on the central portion of the slab and away from the area of edge slump, 12 to 24 in. (300 to 600 mm). Inspectors need to be aware that small bumps or deviations, exaggerated in Figure 10.3 (b), might yield incorrect results.

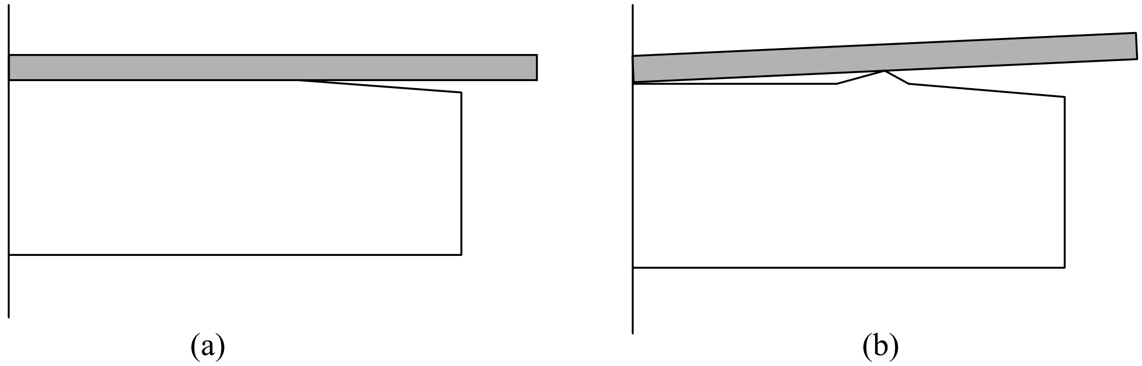

(a) (b)

Figure 10.3 – Measuring edge slump.

Items to address in the QMP/CQC plans include:

1. How soon to begin edge slump testing?
2. Frequency of edge slump testing.
3. Detailed procedure, agreed upon by QA and QC, for measuring the edge slump.
4. Agreed upon corrective action for edge slump that occurs in the fresh concrete and the hardened concrete.
5. Is the contractor allowed to correct excessive edge slump in fresh concrete?
6. Is use of temporary forms allowed in areas where edge slump is excessive?
7. Is sawing of the edges of the hardened concrete an acceptable solution for edge slump in the hardened concrete? The distance back from the edge is dependent on the amount of edge slump.

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.

BIBLIOGRAPHY

The documents used in the preparation of the manual are listed below. The information from these documents was incorporated with the project team's field observations and other experiences as well as feedback received from several reviewers of the manual.

Source	Title	Date
Federal Aviation Administration	Standards for Specifying Construction of Airports – AC 5370-10	Current version and modifications
Federal Aviation Administration – Northwest Mountain Region	Construction Manual for Airport Construction (Author: Jack Scott, P.E.)	May 1999
Department of Defense	PCC Pavements for Airfields and Other Heavy Duty Pavements - Guide Specification UFGS-02753A	2003
National Highway Institute/FHWA	Construction of PCC Pavements – NHI Course No. 13133	October 1996
Portland Cement Association	Design and Control of Concrete Mixtures, 14th Edition	2002
Department of the Army (USACE)	Design and Construction Management Practices for Concrete Pavements (ETL 1110-3-488)	March 1, 1998
Department of the Army and the Air Force	Standard Practice for Concrete Pavements (TM 5-822-7; AFM 88-6, Chapter 8))	August 1987
State DOTs (e.g., Ohio, Minnesota, Iowa)	Concrete pavement manuals	Various
Iowa DOT	Aggregate Proportioning Guide for PC Concrete Pavement (Materials IM 532)	October 29, 2002
American Concrete Pavement Association	Concrete pavement technology related publications	Various
American Concrete Institute	Applicable Manual of Practice guide documents related to concrete mixture, concrete testing, and PCC pavement construction	Various
Portland Cement Association	Concrete Pavement Construction – Inspection at the Paving Site	1980
Portland Cement Association	Concrete Pavement Construction – Inspection at the Batch Plant and Mixer	1980
Gunthert & Zimmermann, Gomaco, CMI, and other paving equipment suppliers	Technical product information, company magazines and training materials	Various
Various	Selected project plans and specifications from airport concrete pavement construction Projects	Various

INFORMATION CONTACTS/WEBSITES

Federal Aviation Administration (FAA):

Federal Aviation Administration
800 Independence Avenue, S.W.,
Washington, DC 20591

Web site: www1.faa.gov/ (home page)
Web site: www1.faa.gov/arp/engineering/ (Airport Design, Engineering, & Construction)

American Concrete Pavement Association (ACPA):

American Concrete Pavement Association
5420 Old Orchard Road
Skokie, Illinois 60077

Web site: www.pavement.com

Portland Cement Association (PCA):

Portland Cement Association
5420 Old Orchard Road
Skokie, Illinois 60077

Web site: www.cement.org

U.S. Army Corps of Engineers (USCOE):

(Home of Pavement-Transportation Computer Assisted Structural Engineering (PCASE))

U.S. Army Corps of Engineers
Transportation Systems Center
12565 West Center Road
Omaha, Nebraska 68144-3869

Web site: www.tsmcx.com
PCASE web site: www.pcase.com (engineering and design)

APPENDICES

APPENDIX A – TEST STANDARDS REFERRED TO IN THE MANUAL

APPENDIX B – PRECONSTRUCTION PROJECT REVIEW HIGHLIGHTS

APPENDIX C – QMP/CQC (INSPECTION AND TESTING) CHECKLIST

APPENDIX D – JOINT SAWING CHECKLIST

APPENDIX E – DECISION TREE FOR EARLY AGE CRACKING

APPENDIX A – TEST STANDARDS REFERRED TO IN THE MANUAL

ASTM STANDARDS

ASTM C 31/C31M-00e1 – Standard Practice for Making and Curing Concrete Test Specimens in the Field

ASTM C 33-02a – Standard Specification for Concrete Aggregates

ASTM C 42 – Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

ASTM C 70 – Standard Test Method for Surface Moisture in Fine Aggregate

ASTM C 78-02 – Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)

ASTM C 88-99a – Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate

ASTM C 94/94M-00e2 – Standard Specification for Ready-Mixed Concrete

ASTM C 136-01 – Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates

ASTM C 138 – Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete

ASTM C 143/C 143M-00 – Standard Test Method for Slump of Hydraulic Cement Concrete

ASTM C 150-02a – Standard Specification for Portland Cement

ASTM C 156-02 – Standard Test Method for Water Retention by Concrete Curing Materials

ASTM C 173/C 173M-01e1 – Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method

ASTM C 192/C 192M-02 – Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory

ASTM C 227-97a – Standard Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)

ASTM C 231-97e1 – Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method

ASTM C 260-01 – Standard Specification for Air-Entraining Admixtures for Concrete

ASTM C 295-98 – Standard Guide for Petrographic Examination of Aggregates for Concrete

ASTM C 309-98a – Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete

ASTM C 39/C 39M-01 – Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens

ASTM C 457-98 – Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete

ASTM C 494/C 494M-99ae1 – Standard Specification for Chemical Admixtures for Concrete

ASTM C 496 – Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens

ASTM C 566 – Standard Test Method for Total Evaporable Moisture Content of Aggregate by Drying

ASTM C 595-02a – Standard Specification for Blended Hydraulic Cements

ASTM C 618-01 – Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete

ASTM C 666-97 – Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing

ASTM C 672/C 672M-98 – Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals

ASTM C 989-99 – Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars

ASTM C 1064 – Standard Test Method for Temperature of Freshly Mixed Portland Cement Concrete

ASTM C 1077-02 – Standard Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation

ASTM C 1157-02 – Standard Performance Specification for Hydraulic Cement

ASTM C 1240-01 – Standard Specification for Use of Silica Fume for Use as a Mineral Admixture in Admixture in Hydraulic-Cement Concrete, Mortar, and Grout

ASTM C 1260-01 – Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)

ASTM C 1293-01 – Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction

ASTM C – 1315 Standard Specification for Liquid Membrane-Forming Compounds Having Special Properties for Curing and Sealing Concrete

ASTM D 558-96 – Standard Test Methods for Moisture-Density Relations of Soil-Cement Mixtures

ASTM D 698-00a – Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kNm/m^3))

ASTM D 1556-00 – Standard Test Method for Density and Unit Weight of Soil in Place by the Sand-Cone Method

ASTM D 1557-00 – Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kNm/m^3))

ASTM D 2167-94 – Standard Test Method for Density and Unit Weight of Soil in Place by the Rubber Balloon Method

ASTM D 3155-98 – Standard Test Method for Lime Content of Uncured Soil-Lime Mixtures

ASTM E 177 – Practice for Use of the Terms Precision and Bias in ASTM Test Methods

MILITARY SPECIFICATIONS

CRD 300 – Specifications for Membrane-Forming Compounds for Curing Concrete

ACI GUIDELINES

ACI 211 – Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete

ACI 214 – Recommended Practice for Evaluation of Strength Test Results of

ACI 305 – Hot Weather Concreting

ACI 306 – Cold Weather Concreting

ACI 306.1 – Standard Specification for Cold Weather Concreting

APPENDIX B – PRECONSTRUCTION REVIEW CHECKLIST

General Items

- Identify the chain of command in the decision making process
- Identify roles and responsibilities of key staff for all involved parties
- Review of all design and construction changes issued since bid
- Certification of materials sources
- Mix design submittals
- QMP/CQC laboratory and personnel certifications
- Batch plant certification and mixer efficiency tests
- Construction schedule
- Sub-contractor activities
- Haul roads and access points
- Conduct of a joint ½ day construction workshop

Batching Activities

- Stockpile management
- Aggregate moistures and added mixture water

Subgrade

- Review of soil testing reports
- Cut and fill plans
- Borrow and waste areas
- Acceptable fill
- Removal of organic material or unacceptable soil
- Procedures when cut depths exceeds engineer's estimate
- Review of compaction requirements and acceptance testing (moisture and density)
- Proof rolling requirements and acceptance criteria
- Expected production rates and tentative schedule

Soil Stabilization, if applicable

- Review of soil stabilization QC plan
- Review of soil data regarding stabilization requirements
- Mix design submittals (per soil type)
- Field testing requirements and frequency (soil gradation, minus 200, plasticity, density, strength, lime/cement/flay ash content, depth, grade elevation)
- Tentative division of project into various areas based on soil stabilization requirements
- Identification in field as to soil type and stabilization requirements (visual or plasticity testing)
- Who is responsible in field for approving soil stabilization requirements and acceptance
- Plasticity testing frequency or procedures to further subdivide area based on soil type
- Trimming procedures and equipment

- Disposal of trimmed material
- Initial mixing and production requirements (calendar day restrictions)
- Lime spread rates
- Minimum passes with mixing equipment
- Mellowing and curing periods
- Moisture control and limits during compaction
- Ambient temperature requirements prior to covering
- Moisture-density, soil classification, pH, lime content, liquid and plastic limit, soluble sulfate, density, strength, and thickness acceptance testing frequency and procedures
- Allowances for unprotected soil stabilization (protection requirements for various time periods and paving season)
- Allowances for finishing high then re-trimming if stabilized soil is not protected
- Expected production rates and tentative schedule

Stabilized Base

- Review of base stabilization QC plan
- Mix design submittal
- Specifications and lot areas
- Mixing procedures and quantity verification
- Water content, strength, thickness verification, and grade testing and acceptance procedures
- Weather (temperature) limitations for mixing and placement
- Non-conformance procedures (under thick, under strength, and over strength)
- Placement procedures and cold joints
- Rough grading and finish rolling procedures
- Jointing procedures
- Moist curing and curing membrane (coverage, time, and material) requirements
- Aggregate durability, soundness, abrasion, and gradation test data and requirements
- Grade survey issues – who decides on action to be taken if grade is a concern

Concrete Paving (Placement, finishing, texturing and curing)

- Placement and filler lane scheduling
- Base conditioning
- Equipment breakdown procedures
- Maximum concrete haul times
- Placement procedures
- Thickness verification during placement
- Hot/cold weather specifications and precautions
- Vibrator testing/consolidation issues
- Curing and texturing procedures
- Drill and epoxy grouting of dowel bars
- Tie bar/dowel alignment, spacing, offset verification
- Straight edge and edge slump tolerances

- Plastic shrinkage cracking, edge slump, joint spalling, and full-depth cracking treatments

Joint Sawcutting

- Review of sawcutting QC plan
- Use of early entrant saws
- Backup saws
- Rain conditions and skip sawing procedures
- Reservoir and sealing installation and acceptance procedures
- Sawcutting sequence and acceptable degree of sawcut raveling
- Initial and reservoir cut dimension tolerances and dimensions
- Joint sealant and backer rod material submittals
- Removal and flushing of joint sawing residue
- Joint beveling procedures
- Sealant and concrete curing time
- Sand blasting, reservoir cleanliness, and moisture condition requirements before sealing
- Sealant depth tolerances
- Reservoir priming material requirements
- Sealant pump, water truck, and sawcutting equipment
- Allowable ambient temperatures during sealing operations and compression seal reservoir requirements
- Joint inspection procedures

QMP/CQC Activities

- Review of contractor's QC plan
- Aggregate durability, soundness, abrasion, and gradation test data and requirements
- Reinforcing steel and dowel bar submittals
- Materials sampling and testing procedures
- Use of control charts
- Concrete mixture designs and water-cementitious ratio effects on strength
- Concrete beam sampling, fabrication, curing, and testing procedures
- Sampling, PWL, and pay factor computation overview
- Effects of strength/thickness variability on pay factor
- Determining locations for thickness tests
- Partial lots consideration
- Treatment of premature cracking and spalling
- Edge slump and smoothness testing and timing
- Actions to be taken if specification requirements are not met
- Documentation of test results and deviations
- Verification of failing acceptance tests, retesting, and referee testing

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 **actual** 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					

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