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29 January 2024

UNIFIED FACILITIES CRITERIA (UFC)

STANDARD PRACTICE FOR CONCRETE PAVEMENT CONSTRUCTION

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STANDARD PRACTICE FOR CONCRETE PAVEMENT CONSTRUCTION

Indicate the Military Department Preparing Activity responsible for the document.

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING SYSTEMS COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER CENTER

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	Date	Location

This UFC supersedes UFC 3-250-04, *Standard Practice for Concrete Pavements*, dated 16 January 2004.

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FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States, its territories, and possessions is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA). Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Military Department's responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Systems Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Technical content of UFC is the responsibility of the cognizant DoD working group. Defense Agencies should contact the respective DoD Working Group for document interpretation and improvements. Recommended changes with supporting rationale may be sent to the respective DoD working group by submitting a Criteria Change Request (CCR) via the Internet site listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide website https://www.wbdg.org/ffc/dod.

Refer to UFC 1-200-01, *DoD Building Code*, for implementation of new issuances on projects.

AUTHORIZED BY:

PETE G. PEREZ, P.E., SES
Chief, Engineering and Construction
U.S. Army Corps of Engineers

S. KEITH HAMILTON, P.E., SES
Chief Engineer and Director
Planning, Design and Construction
Naval Facilities Engineering Systems Command

DAVID H. DENTINO, SES
Deputy Director of Civil Engineers
DCS/Logistics, Engineering &
Force Protection (HAF/A4C)
HQ United States Air Force

MICHAEL McANDREW, SES
Deputy Assistant Secretary of Defense
(Construction)
Office of the Secretary of Defense

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CHAPTER 1 INTRODUCTION

1-1 REISSUES AND CANCELS.

This document replaces UFC 3-250-04, 16 January 2004.

1-2 PURPOSE AND SCOPE.

This UFC provides guidance for preparing drawings and specifications for roads and airfields to construct rigid pavements using portland cement concrete (PCC) materials. It provides useful information for military and civilian design engineers, laboratory personnel, and project managers concerning mix design, materials, production, and placement of concrete mixtures. This UFC documents the standard practice for rigid airfield pavement construction and follows the chapter outline of Innovative Pavement Research Foundation Report IPRF-01-G-002-1, *Best Practices for Airport Portland Cement Concrete Construction (Rigid Airport Pavement)*, April 2003. This UFC provides supplementary clarification, requirements, and specific guidance for DoD concrete pavements. If there is conflicting guidance, DoD standard practice for military airfields takes precedence over IPRF guidance. This standard practice document aids in the use, interpretation, and implementation of Unified Facility Guide Specifications (UFGS) for DoD concrete pavement construction efforts and aids in resolving field construction problems. The requirements in this UFC produce a pavement of quality sufficient to support all DOD and allies' aircraft and missions.

This UFC prescribes materials, mix design procedures, and construction practices for concrete pavements. This UFC includes discussion of the advantages and disadvantages of techniques, practices, or materials when several choices exist. This includes possible methods and materials to mitigate or eliminate distresses or premature failures. This UFC is specifically tailored for military airfields and other heavy-duty pavements. It may be used for PCC road pavements, but airfield pavement guidance and requirements are generally much more stringent than for road pavements. Commercial construction practices and material quality permissible in civilian roadway construction do not suffice to meet the demands placed on military airfields.

1-3 APPLICABILITY.

The requirements of this UFC should be used for all DoD-owned or -funded organizational airfield pavements, heavy-duty roads, and hardstands. State specification requirements may only be substituted for nonorganizational parking, roads, streets, and driveways where the design index is less than 5. This UFC applies to all DOD military engineering and construction units, Title II on DOD construction efforts, as well as civilian design and construction personnel and companies working on DoD-owned or -funded airfield and other heavy duty pavement construction or repair.

1-4 GENERAL BUILDING REQUIREMENTS.

Comply with UFC 1-200-01, *DoD Building Code*. UFC 1-200-01 provides applicability of model building codes and government-unique criteria for typical design disciplines and building systems, as well as for accessibility, antiterrorism, security, high-performance and sustainability requirements, and safety. Use this UFC in addition to UFC 1-200-01 and the UFCs and government criteria referenced therein.

1-5 ROLLER COMPACTED CONCRETE PAVEMENT.

Appendix E contains information regarding the construction of roller-compacted concrete pavement (RCCP). RCCP is prohibited for airfield pavement use unless approved by the USACE TSC or appropriate Tri-Service Pavements Discipline Working Group (TSPDWG) Service representative.

1-6 GLOSSARY.

Appendix F contains acronyms, abbreviations, and terms.

1-7 REFERENCES.

Appendix G contains a list of references used in this document. The publication date of the code or standard is not included in this document. Unless otherwise specified, the most recent edition of the referenced publication applies.

CHAPTER 2 CONSIDERATION OF DESIGN ISSUES

2-1 INTRODUCTION.

The factors affecting long-term concrete pavement performance are broadly divided into the following categories:

- Adequate design of pavement structure
- Use of quality materials
- Use of proper construction procedures
- Timely maintenance and repair

The pavement designer controls several parameters and details that greatly impact pavement construction. These will be discussed individually in the following paragraphs. When there is a conflict between design requirements and field conditions, any modifications to the design to accommodate field conditions should be reviewed by the original designer to ensure the modifications comply with the original design intent.

2-2 DESIGN CONSIDERATIONS.

Design procedures for airfield pavements are described in the UFC 3-260-02, *Pavement Design for Airfields*. Design procedures for other concrete pavements are described in UFC 3-250-01, *Pavement Design for Roads and Parking Areas*.

2-2.1 Pavement Foundation.

Provide a firm foundation to support concrete construction activities, such as slipform pavers, forms, concrete delivery truck traffic, and other heavy vehicles or equipment. Designers will consider the anticipated field soil support and moisture conditions during construction and select base courses to support concrete placement activities. UFC 3-260-02 mandates use of base courses on pumping susceptible subgrade soils, which generally include the silts and clays that are the most troublesome during construction. However, the designer may include a base course to ensure a viable construction platform for soils such as those classified as SM, SC, GC, or SP by the Unified Soil Classification System (ASTM D2487). These may not be stable under construction traffic or during wet construction conditions.

A designer assesses the characteristics of the subgrade soil at a project location to determine whether a base course is required to support construction activities. Extend base courses far enough beyond the edge of the pavement to accommodate construction activities such as slipform paver tracks or provide space to place and anchor forms. Only use stabilized bases on airfields when there is a specific need, such as lack of suitable local base material, all-weather construction platform, or other structural requirements. Verify that designers working on design-build contracts are aware of this difference at initial design meetings.

2-2.2 Concrete Strength.

Traditionally, calculating the design strength for pavement thickness equates to the ASTM C78/CRD-C 16 flexural strength at 90 days. While modern concrete mixtures can achieve very high strength, this can introduce adverse setting and handling characteristics or shrinkage. Therefore, specify no flexural strength less than 600 psi (4136 kPa) or greater than 700 psi (4826 kPa) for military airfields without prior approval from the TSPDWG. Specifying a 90-day strength allowed designers to take advantage of strength gains between 28 and 90 days before allowing traffic or for minimal traffic. Most modern portland cement chemistry and grinding produce very modest strength increases between 28 and 90 days; however, concretes that use supplemental cementitious materials such as fly ash and ground-granulated blast furnace slag can gain substantial strength after 28 days.

Projects often require reopening pavement to traffic early. A designer balances the desired strength, the time to achieve this strength, and other factors such as durability, against specific project requirements. For pavement that must open early to traffic, the designer should calculate the effect of the limited early age traffic on the total pavement life to select reasonable strengths before allowing traffic. Simply requiring the normal 90-day strength at some very early age can generate a concrete mixture possessing troublesome working characteristics.

2-2.3 Pavement Dimensions.

Concrete pavements for any application are normally jointed plain concrete pavements. Only reinforce odd-shaped slabs or for special circumstances or applications, such as continuously reinforced concrete. Airport concrete pavements are typically designed on the basis of mixed aircraft loadings to minimize maintenance service for multiple decades. The pavements are designed on the basis of expected aircraft repetitions over the design period. For many airfield pavements, the concrete thickness may range from 400 to 500 mm (16 to 20 in.) and transverse joint spacing may range from 4.6 to 6.2 m (15 to 20 ft). Typical longitudinal joint spacing can also range from 4.6 to 6.2 m (15 to 20 ft).

Current practice uses dowel bars for load transfer in all longitudinal construction joints. For concrete pavements subjected to only light aircraft loads, slab thickness may range from 125 to 300 mm (5 to 12 in.) and transverse and longitudinal joint spacing may range from 2.4 to 4.6 m (8 to 15 ft). Slab dimensions in design manuals are set to minimize curling stresses from non-load-associated factors. Failure to adhere to these limits leads to unwanted cracking due to the combined effect of curling stresses and load-related flexural stresses. For these reasons, common practice limits the maximum slab size to 6.1 m (20 ft) as research shows that slab joint spacing equal to or greater than 7.6 m (25 ft) increases the risk of uncontrolled cracking.

2-2.4 Legacy Slabs.

On older airfield pavements with 7.6 m (25 ft) slabs, strict adherence to this policy may create mismatched slab joints. Where joint patterns of abutting pavement facilities do not match, partial reinforcement of slabs may be necessary. Using reinforcement at mismatched joints in such junctures is based upon the type of joint between the two pavement sections. Designers should develop repair projects with a cost-effective joint pattern that minimizes and mitigates mismatch between larger slabs and smaller slabs by incorporating appropriate protective measures, such as expansion joints or reinforcing. See further discussion in UFC 3-260-02.

2-3 DESIGN PROCESS.

The terms “base” and “subbase” often designate the layer directly under the concrete slab. In this UFC, the layer immediately below the slab is called the base. The layer between the base and the subgrade is called the subbase. The overall process of designing a concrete pavement involves the following steps.

2-3.1 Soil Investigation.

Soil borings determine the properties of the subsurface strata and depth to groundwater. Soil samples are obtained for soil classification and laboratory testing (see UFC 3-260-02).

2-3.2 Evaluate Subgrade Support at Design Grade.

The information from the soil investigation indicates the subgrade conditions at and below the design grade.

2-3.3 Design Pavement Section.

After determining the appropriate base type (i.e., stabilized or non-stabilized) and thickness, use the appropriate design procedure to calculate the required PCC pavement thickness.

2-3.4 Select Jointing Plan.

Develop appropriate longitudinal and transverse joint details based on the calculated slab dimensions. Proper construction details are required for joints and transition slabs that tie-in to existing pavements.

2-3.5 Develop Plans and Specifications.

Further develop the design details into complete plans and specifications.

2-3.6 Critical Design Features.

Critical design features that influence long-term concrete pavement performance include:

- Subgrade support uniformity and stability
- Base and subbase uniformity (type and thickness), including drainage

- PCC pavement layer thickness
- PCC properties, as specified
- Uniformity (ability of concrete to produce consistent properties)
- Workability (ability of concrete to be placed, consolidated and finished)
- Strength (ability of concrete to support traffic & environmental conditions)
- Durability (ability of concrete to provide long-term service)
- Jointing details
- Slab dimensions
- Load transfer at joints
- Joint sealing provisions

2-3.7 Construction Variability.

Throughout the design process, recognize that variability in the properties of key design elements significantly affects pavement performance. While some variability is unavoidable, excessive variability during construction induces random pavement performance and higher contractor costs. Make effective use of quality management plans to control construction variability. For each project, the design engineer establishes the acceptable parameters for each design variable. Construction work must meet or exceed the specified quality. Typically, when several marginal features are incorporated into a pavement structure through a design deficiency, poor construction techniques, or a combination thereof, premature failure results or it performs poorly throughout its service life.

2-4 CRITICAL CONSTRUCTION OPERATIONS.

Examples of critical construction operation include the following.

2-4.1 Grading.

Grading is important. Proper grading facilitates drainage and placement of successive layers. Grading issues are discussed in Chapters 4, 5, and 6.

2-4.2 Jointing.

Jointing controls slab cracking, which minimizes the potential for random cracking. Random cracking is a maintenance concern and can reduce the load capacity of pavement. Shallow joint sawing and late sawing can induce random cracking. If dowel bars are misaligned or bonded to the concrete, joints do not function and adjacent slab panels can develop random cracking. Joint sawing, load transfer, and joint sealing practices are discussed in Chapter 9.

2-4.3 Subgrade, Subbase, and Base Quality.

If the compaction of the subgrade, subbase, and base is compromised, the pavement may deflect excessively under aircraft loading and develop corner cracking. Subgrade, subbase, and base construction practices are presented in Chapters 4 and 5, respectively.

2-4.4 PCC Strength.

Low-strength concrete results in early fatigue cracking of the pavement. Concrete flexural strength at 28 days for airfield paving is typically 4,100 to 5,200 kPa (600 to 750 psi). For fast-track construction, these strength levels may be required earlier. Concrete practices, including strength requirements, are discussed in Chapters 6 and 7.

2-4.5 Concrete Durability.

Concrete that is not durable (a result of poor or reactive materials, a poor air-void system, or due to over-finishing) deteriorates prematurely. Concrete durability issues are discussed in Chapters 7 and 8.

2-4.6 Concrete Curing.

Improperly cured concrete can deteriorate prematurely and generate early age spalling. Chapter 8 discusses concrete curing practices.

2-4.7 Concrete Finishability.

Concrete that is over-finished or requires excessive manipulation to provide an acceptable finish deteriorates prematurely. Poorly finished concrete may also generate poor surface conditions. See Chapter 8.

2-4.8 Paver Operation.

Paver operations significantly impact pavement smoothness and in-place concrete quality. Chapter 8 discusses paver operation practices.

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CHAPTER 3 PRE-CONSTRUCTION ACTIVITIES

3-1 CONSTRUCTION SPECIFICATION ISSUES.

Pavement construction specifications provide guidance and establish minimum requirements that, when adhered to, facilitate building a quality pavement. The acceptable level of quality for a rigid airfield pavement comprises desirable surface characteristics and a surface free from foreign object generators (FOG) for the service life of the pavement. FOGs result from distresses in the concrete pavement. A FOG that results in foreign object damage (FOD) is a very critical item for airfield concrete pavements. However, good design features, well-developed plans and specifications, and quality construction can minimize or eliminate FOG (and FOD) development.

As a result, it is important that construction specifications clearly define the requirements that promote long-term performance of concrete pavement and exclude arbitrary requirements. The UFGSs are detailed and cover all aspects of concrete paving, including materials and mixture design issues and required construction techniques and inspection requirements. It is important for the specifier and contractor to review military specifications in detail prior to construction.

3-2 PLANNING CONSTRUCTION LOGISTICS.

A successful construction project plans all logistical support in advance and pays attention to the smallest details, including the following:

- Ensuring readiness of all operations, including grade control
- Concrete plant set-up and traffic flow
- Concrete plant capacity and production rate
- Haul road availability and serviceability
- Security and site access requirements
- Availability of crews
- Availability of equipment and materials
- Construction and airfield traffic management
- Concrete placement needs (rate of placement)
- In-pavement structures
- Acquisition of in-pavement electrical items (affects fast track construction)
- Inspection and testing requirements
- Subcontractor readiness – crew and equipment availability
- Project phasing, if any
- On-site testing laboratory
- Other needs related specifically to fast-track paving

Include all parties involved in a construction project in the communication network. Regardless of project size, pavement construction is a team effort that includes operators and users.

3-3 EARLY PAVEMENT TRAFFICKING.

The UFGSs define when a concrete pavement may open to construction traffic and the design aircraft or vehicle traffic. Do not open pavement to aircraft or other design traffic for at least 14 days or longer, depending upon the loading, concrete mixture, and curing conditions. The requirement to allow equipment to operate on the pavement edges is for test specimens molded and cured in accordance with ASTM C31/CRD-C 11, attaining a minimum flexural strength of 400 psi (2.8 MPa) when tested in accordance with ASTM C78/CRD-C 16. Absent strength testing, use a 14-day aging requirement. Also, complete seven days of curing before allowing hauling equipment to use new concrete, and seal or otherwise protect all joints. Consider the following additional factors regarding construction traffic.

a. Develop specific criteria for typical construction equipment for different concrete pavement thicknesses and for edge and interior loading. For example, for large military 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 thinner pavements that are 12 in. (300 mm) or less in thickness.

b. 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 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 to install dowel bars along the longitudinal joint face of pilot lanes. Drilling is typically not initiated until the concrete attains sufficient strength to reduce/eliminate micro-cracking and excess spalling around the drilled holes.

3-4 PRE-BID MEETINGS.

Pre-bid meetings allow the owner to review project requirements with contractors interested in bidding on a project. Although pre-bid meetings primarily tend to review administrative and contractual matters, it is important to highlight modifications of guide specifications implemented in the plans and specifications. Also address critical material supply and availability issues, the schedule, and specific acceptance testing requirements. It is good practice for contractors to attend pre-bid meetings. Distribute meeting minutes to all potential bidders (those requesting bid documents) whether they attend or not. Paving-related discussion items include:

- Owner and contractor organizational hierarchy
- Value engineering issues

- Project overview
- Phasing plan
- Scheduling criteria, including which areas are accessible and when
- Scheduling milestones, with incentives and disincentives
- Expected and unexpected delay resolution
- Alternate bid items
- Restrictions on site access and working hours
- Plant and staging area locations
- Paving sequence for cross-taxiway areas
- Access and egress locations, haul road locations, and construction traffic control
- QA, acceptance testing, and QC requirements
- Water, phone, and power connection locations
- Issuance of design and specification changes
- Provisions for protection of stabilized layers from freeze conditions
- Fast-track changes; thicker slab and stiffer base versus higher concrete strength
- Early age cracking, joint spalling, and edge slump
- Establish acceptability criteria
- Guidelines for corrective measures
- Dowel misalignment testing and resolutions
- Test strip construction requirements and acceptance criteria

3-5 PRE-AWARD MEETINGS.

Some agencies hold a pre-award meeting with the selected contractor. As part of these meetings, the contracting officer 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 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 contracting officer and contractor to review the contract line items. Based on the discussions with the contracting officer, the contractor has an opportunity to withdraw the bid if it is determined that the bid may have included erroneous pricing.

3-6 PRE-CONSTRUCTION MEETINGS.

The contracting officer will host pre-construction meetings to review specific project requirements and project planning with the contractor. Review the following items:

- Issue resolution hierarchy – Appendix A
- Construction logistics – Appendix A
- Installation and airfield access and movement – Appendix A
- Security clearance requirements – Appendix A
- Checklist of critical material supply and availability issues – Appendix A
- Project specifications – Appendix A
- Approval of materials – Appendices A and B
- Schedule – Appendix A
- Inspection and testing requirements – Appendices A, B, and C
- Quality management (or contractor quality control) plan – Appendices A and B

Discuss concrete pavement-related items during the pre-construction meetings as a separate agenda. A concrete paving pre-construction meeting is the last opportunity to discuss concrete paving process issues before equipment starts moving. If items are discussed up front before construction begins, the parties can review potential problems and create solutions that work for everyone. Distribute meeting minutes to all parties. Pavement-related discussion items are listed in Appendix A. For projects involving more than 42,000 m^2 (50,000 yd^2) of concrete paving, conduct a half-day concrete pavement construction workshop using this UFC along with 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. Workshops ensure that all involved parties have the same understanding of project requirements and are committed to a successful project.

DoD installations or units can fund and schedule the USACE Transportation Systems Center (TSC) to conduct on-site airfield paving workshops and post-award teleconferences, provide on-site technical support during construction, review PCC mix designs, hot mix asphalt (HMA) job mix formulas (JMF), and warm mix asphalt (WMA) JMF. A list of services and required fees are described in USACE ER 1110-34-1, *Transportation Systems Mandatory Center of Expertise*.

3-7 QUALIFYING CONSTRUCTION MATERIALS.

In some localities, the state Department of Transportation (DOT) has information on materials approved for concrete pavement construction. Evaluate state DOT records for performance history and certification. State DOT certifications together with other documentation can facilitate the material approval review process. If current independent testing certificates cannot be obtained through material suppliers, DoD installations, DoD units, designers, or construction contractors may contract with third-party commercial laboratories accredited to perform the required materials testing. DoD installations, DoD units, designers, or construction contractors may alternatively contract with the U.S. Army Engineering Research and Development Center, (ATTN: CEERDC-GM-C), 3909 Halls Ferry Road, Vicksburg, Mississippi, 39180-6199, to qualify a cement or pozzolan for use in DoD pavement construction on a reimbursable basis. Prior to bid solicitation, the design engineer should address material availability and cost. If alternate materials are proposed in lieu of those specified, the contractor must ensure fulfillment of the specification testing requirements. Testing requirements for concrete aggregates may have long lead times and scheduling conflicts can 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 must meet the requirements of ASTM C33/CRD-C 133. However, for airfield and heavy-duty pavement additional restrictions and requirements exist. The fineness modulus of the fine aggregate, the limits on deleterious materials, the sample size, and order of testing differ from ASTM C33/CRD-C 133. Limits on deleterious materials are an order of magnitude lower than those in ASTM C33/CRD-C 133 for DoD airfields; thus, larger samples are required. Some key items follow.

a. 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.

b. The minimum nominal maximum aggregate (NMA) size is 38 mm (1.5 inch). For airfield and other heavy-duty pavements, the combined gradation must have a minimum of 10 percent mass retained on the 25mm (1 inch) sieve or must be a combination of #4, #67, and fine aggregate.

c. In areas where D-cracking in pavements is a known problem, use a smaller nominal maximum aggregate size or import aggregate from outside the area.

d. Aggregates for roads generally need to meet the requirements and contain no more than the specified percentages of deleterious materials listed in ASTM C33/CRD-C 133. For DoD airfield pavements, limits on deleterious materials are an order of magnitude lower than those in ASTM C33 (see Tables 3-1 and 3-2). Furthermore, the sample size and test sequence must meet additional requirements.

3-7.1.1 Airfield Coarse Aggregate Deleterious Materials Testing Sequence:

The minimum test sample size of the coarse aggregate is 90 kg (200 pounds) for the 19 mm (3/4 inch) and larger maximum size and 12 kg (25 pounds) for the 4.75 to 19 mm (No. 4 to 3/4 inch) coarse aggregate.

1. Step 1: Wash each full sample of coarse aggregate for material finer than the 0.075 mm (No. 200) sieve. Discard material finer than the 0.075 mm (No. 200) sieve.

2. Step 2: Test remaining full sample for clay lumps and friable particles and remove.
3. Step 3. Test remaining full sample for chert and cherty stone with SSD density of less than 2.40 specific gravity. Remove lightweight chert and cherty stone. Retain other materials less than 2.40 specific gravity for Step 4.
4. Step 4: Test the materials less than 2.40 specific gravity from Step 3 for lightweight particles (Sp. GR. 2.0) and remove. Restore other materials less than 2.40 specific gravity to the sample.
5. Step 5: Test remaining sample for clay-ironstone, shale, claystone, mudstone, siltstone, shaly and argillaceous limestone, and remove.
6. Step 6: Test a minimum of one-fifth of the remaining full sample for other soft particles.

3-7.1.2 Airfield Fine Aggregate Deleterious Materials Testing Sequence:

The minimum test sample size for fine aggregate is 5 kg (10 pounds). The fineness modulus must not be less than 2.50 nor more than 3.40.

1. Step 1: Wash each full sample of fine aggregate for material finer than the 0.075 mm (No. 200) sieve. Discard material finer than the 0.075 mm (No. 200) sieve.
2. Step 2: Test remaining full sample for clay lumps and friable particles and remove.
3. Step 3. Test remaining full sample for lightweight particles (Sp. GR.2.0).

Table 3-1 Categorization of Weather Severity

Weather Severity	Air Freezing Index, Coldest year in 30[1]	Average Precipitation for any Single Month During the Freezing Period
Moderate	500 or less	Any amount
Moderate[2]	501 or more	Less than 25 mm (1 in.)
Severe	501 or more	25 mm (1 in.) or more

[1] Calculated as described in UFC 3-260-02. See ASTM C33/CRD-C 133 for a simplified map of CONUS weather severity.
[2] In poorly drained areas, the weather should be considered severe even though the other criteria indicate a rating of moderate.

Table 3-2 Deleterious Material Limits in Airfield Aggregates - Percent Mass

Material	Coarse Severe Weather	Coarse Moderate Weather	Fine Aggregate All Weather
Clay lumps and friable particles (ASTM C142)	0.2	0.2	1.0
Shale[1] (ASTM C295/CRD-C 127)	0.1	0.2	-
Material finer than 0.075 mm (No. 200 sieve) [2] (ASTM C117)	0.5	0.5	3.0
Lightweight particles[3] (ASTM C123)	0.2	0.2	0.5
Clay ironstone[4] (ASTM C295)	0.1	0.5	-
Chert and cherty stone (SG less than 2.40 – SSD)[5] (ASTM C295/CRD-C 127)	0.1	0.5	-
Claystone, mudstone, and siltstone[6] (ASTM C295/CRD-C 127)	0.1	0.1	-
Shaly and argillaceous limestone[7], (ASTM C295/CRD-C 127)	0.2	0.2	-
Other soft particles (CRD-C 130)	1.0	1.0	-
Total of all deleterious substances, exclusive of material finer than 0.075 mm (No. 200) sieve	1.0	2.0	-
Total for fine aggregate including material finer than 0.075 mm (No. 200) sieve	-	-	3.0

[1] Shale is defined as a fine-grained, thinly laminated or fissile sedimentary rock. It is commonly composed of clay or silt or both. It has been indurated by compaction or by cementation, but not so much as to have become slate.

[2] Limit for material finer than 0.075 mm (No.200 sieve) will be increased to 1.5 percent for crushed aggregates if the fine material consists of crusher dust that is essentially free from clay or shale.

[3] The separation medium will have a density of 2.0 mg/m^3 (SG of 2.0). This limit does not apply to coarse aggregate manufactured from blast-furnace slag unless contamination is evident.

[4] Clay ironstone is defined as an impure variety of iron carbonate, iron oxide, hydrous iron oxide, or combinations thereof, commonly mixed with clay, silt, or sand. It commonly occurs as dull, earthy particles, homogeneous concretionary masses, or hard-shell particles with soft interiors. Other names commonly used for clay ironstone are “chocolate bars” and limonite concretions.

[5] Chert is defined as a rock composed of quartz, chalcedony, or opal, or any mixture of these forms of silica. It is variable in color. The texture is so fine that the individual mineral grains are too small to be distinguished by the unaided eye. Its hardness is such that it scratches glass but is not scratched by a knife blade. It may contain

impurities such as clay, carbonates, iron oxides, and other minerals. Other names commonly applied to varieties of chert are flint, jasper, agate, onyx, hornstone, porcellanite, novaculite, sard, carnelian, plasma, bloodstone, touchstone, chrysoprase, heliotrope, and petrified wood. Cherty stone is defined as any type of rock (generally limestone) that contains chert as lenses and nodules, or irregular masses partially or completely replacing the original stone.

[6] Claystone, mudstone, or siltstone is defined as a massive fine-grained sedimentary rock that consists predominantly of indurated clay or silt without laminations or fissility. It may be indurated either by compaction or cementation.

[7] Shaly limestone is defined as limestone in which shale occurs as one or more thin beds or laminae. These laminae may be regular or very irregular and may be spaced from a few inches down to minute fractions of an inch. Argillaceous limestone is defined as a limestone in which clay minerals occur disseminated in the stone in the amount of 10 to 50 percent by weight of the rock. When these make up from 50 to 90 percent, the rock is known as calcareous (or dolomitic) shale (or claystone, mudstone, or siltstone).

3-7.2 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 can produce significant expansion and cracking of the concrete. The methodology to determine the susceptibility of aggregate to alkali-silica reactivity (ASR) and the effectiveness of mitigation measures is based on the Portland Cement Association's *Guide Specification for Concrete Subject to Alkali-Silica Reactions* (1998). However, for airfield pavements, the DOD doubles the immersion time of the test to 28 days versus the typical 14 days for roads and sets the expansion limit to 0.08 percent in lieu of 0.1 percent for roads. DoD requires these alterations to reduce the risk of false negative results and ensure deleterious expansion from slowly reactive materials is detected prior to incorporation into DoD airfield pavements.

3-7.3 Service History (Field Performance).

Performance history is a source of information on the susceptibility of an aggregate to ASR. When evaluating a service history as an indicator of the susceptibility of an aggregate to ASR, document the following (if this information cannot be affirmed and documented, the service history may be insufficient to evaluate the aggregate):

- The current supply of the aggregate is representative of that used in the existing historical placements.
- The existing historical placements are exposed to the same severity of exposure condition as the proposed placement.
- The existing historical placements have been exposed to this severity condition for at least 15 years.

- The existing historical placements have the same cement content with the same alkali content of the cement and the water/cementitious material (w/cm) ratio of the concrete equal to or greater than proposed concrete mix placement.
- The existing historical placements have the same pozzolans in both class and content as well as total equivalent alkali content and SiO_2 + Al_2O_3 + Fe_2O_3 content.

3-7.4 Laboratory Evaluation.

In the absence of an adequate history of field performance or for airfield or other heavy-duty paving, test both fine and coarse aggregates as follows.

3-7.4.1 ASTM C1260/CRD-C 174.

For roads, results per this test that yields a mean 14-day mortar bar expansion less than or equal to 0.10 percent contains acceptable aggregate and may be used for concrete production. When the mean 14-day expansion is greater than 0.10 percent, the aggregate is suspect and additional testing is warranted before the aggregate is approved for used. For military airfield and heavy-duty paving projects, expansion is limited 0.08 percent after 28 days of submersion for aggregate to be acceptable without mitigation.

3-7.4.2 ASTM C295/CRD-C 127.

This test supplements the results of ASTM C1260/CRD-C 174. This test identifies and quantifies the reactive mineral constituents in the aggregate. Reactive constituents include strained or microcrystalline quartz, chert, opal, and natural volcanic glass in volcanic rocks.

3-7.4.3 ASTM C1293/CRD-C 175.

This is an optional test to verify results of ASTM C1260/CRD-C 174. An aggregate that produces a mean expansion at one year exceeding 0.04 percent is considered potentially reactive. Although the time required for this test generally makes it impractical to use for a specific job, some aggregate suppliers can provide test results specific to their aggregates. The suppliers must demonstrate that the test results represent the aggregate currently being produced from their quarry.

3-7.4.4 ASTM C1567.

While similar to ASTM C1260/CRD-C 174, this test includes supplementary cementitious materials and is used to determine the proportioning of these supplementary cementitious materials to mitigate ASR. Furthermore, the limits and test length for airfield paving are 0.08 percent after 28 days of submersion for the mitigation to be acceptable.

3-7.4.5 CRD-C 662.

If evaluating lithium nitrate as a means to mitigate ASR expansion, with or without supplementary cementitious materials (SCM), test in accordance with CRD-C 662.

3-8 MITIGATION MEASURES.

For roads, if the aggregate demonstrates potential reactivity by ASTM C295/CRD-C 127, ASTM C1260/CRD-C 174, ASTM C1293/CRD-C 175, or by previous field performance, it may be used if an appropriate mitigation measure is effective. Specify and test several combinations of cementitious materials to allow the contractor as much flexibility as possible to meet the other requirements of the project. For military airfield construction, any combination that produces a mean 28-day expansion of 0.08 percent or less when tested according to ASTM C1567 is considered an acceptable method of controlling expansion due to ASR. The cement used for testing must be the same type and brand used on the project. Possible mitigation measures include incorporating a supplementary cementitious material. These materials include low-calcium Class F fly ash (calcium oxide [CaO] content less than 8 percent), slag, silica fume, or natural pozzolan in combination with portland cement.

3-8.1 D-Cracking.

D-cracking describes the distress in concrete that results from the disintegration of coarse aggregates after they become saturated and are subjected to repeated cycles of freezing and thawing. For pavements subject to freezing conditions in service, reject or beneficiate aggregate susceptible to D cracking to remove particles of susceptible size; generally, these are larger particles. Most rock types associated with D-cracking are of sedimentary origin. If the performance history of a proposed aggregate is unknown and the pavement is subject to numerous cycles of freezing during a season, test the aggregate using ASTM C 666/CRD-C 20 (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 testing aggregate for D-cracking include increasing the number of cycles to 350 and calculating the durability index from the expansion of the specimens.

3-8.2 Lead Time Required for Aggregate Testing.

Table 3-3 gives the time required for testing of ASR and freeze-thaw (D-cracking). Typically, about 60 days' lead-time is available from contract award to start of work, so aggregate acceptance must be done within that time or before award. Design engineers must specify ASTM C1260/CRD-C 174 if ASR testing is required. Design engineers must emphasize the test time requirements if aggregate qualification tests are needed. ASTM C1260/CRD-C 174 can test the effectiveness of mitigation measures, as described in this UFC. Test several combinations of cementitious materials simultaneously to save time and allow flexibility to meet other job requirements.

Table 3-3 Testing Time Required

Test Method (ASTM)	Time for Test Result
C1260/CRD-C 174	16 days
C1293/CRD-C 175	1 year for potential aggregate reactivity; 2 years to test effectiveness of mitigation measures
C666/CRD-C 20	2 to 3 months

3-9 AVAILABILITY/CERTIFICATION OF CEMENTITIOUS MATERIALS.

3-9.1 Cementitious Materials.

Secure cement supplies to ensure supply during peak construction season. If the cement source is changed, conduct additional mix design and compatibility testing. 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 or triethanolamine. In hot weather, these effects are more pronounced. Mixture designs should be pre-qualified using different cementitious materials in the event a substitution is necessary, alternate mix design data is available, and new materials can be accommodated without delay.

3-9.2 Portland Cement.

The various types and requirements of cement are given in ASTM C150/CRD-C 201. The cement types are presented in Table 3-4. ASTM C150/CRD-C 201 also specifies optional chemical requirements, such as limits on the maximum alkali content, and optional physical requirements, such as heat of hydration. Specify these requirements judiciously, if at all, since they often increase the cost or limit the available options. Frequently there are equally acceptable or even preferable alternatives. For example, deleterious expansions due to ASR may be controlled as well or better by a combination of cement with Class F fly ash or slag instead of low-alkali cement. Generally, do not 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 used. Sulfate resistance may be obtained with 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 using a combination of slag, Class F fly ash, and natural pozzolan with Portland cement. If the cement is used alone (that is, without supplementary cementitious materials), specify the optional requirement for false set; however, evaluate the setting characteristics for the concrete.

Table 3-4 Types and Uses of Portland Cements

Designation	Application
Type I	Most widely available; used when other special properties are not required.
Type II	For general use, especially when moderate sulfate resistance or heat of hydration is required. Some cements meeting requirements for both I and II are designated Type I/II.
Type III	Used for high early strength.
Type IV	Used when low heat of hydration is required.
Type V	Used when high sulfate resistance is required.

3-9.3 Blended Cement.

The types and requirements of blended cements are given in ASTM C595/CRD-C 203. The types of blended cements are listed in Table 3 5. All cements designated Type I under ASTM C595/CRD-C 203 have comparable strength requirements at early ages as do those specified by ASTM C150/CRD-C 201 for Type I cement. However, the actual strengths at early ages are generally lower because slag and pozzolans included in blended cements react more slowly than cement alone. Type IL (10) and IL (15) cements contain up to 10 or 15 percent limestone ground with the cement clinker. This material provides similar performance to Type I cement but can be slightly more porous. It also has a lower embodied carbon content than similarly produced Type I cement.

Table 3-5 Types of Blended Cements

Designation	Composition
Type IL (10) (15)	Contains 10 to 15 percent ground limestone
Type IS	Contains 25 to 70 percent blast furnace slag
Type P and Type IP	These contain 15 to 40 percent pozzolan (fly ash or natural pozzolan). Type P is used when higher early strengths are not needed.
Type I (PM)	Contains less than 15 percent pozzolan.
Type I (SM)	Contains less than 25 percent slag.
Type I (PM) and Type I (SM)	Should not be used when the special properties of pozzolan or slag are desired, as they don’t contain enough of these materials.
Type S	Contains at least 70 percent slag

3-9.4 Hydraulic Cement.

The various types of hydraulic cements are given in ASTM C1157/CRD-C 271. The types of hydraulic cements are given in Table 3-6.

Table 3-6 Types of Hydraulic Cements

Designation	Use
Type GU	For general use
Type HE	For high early strength
Type MS	For moderate sulfate resistance
Type HS	For high sulfate resistance
Type MH	For moderate heat of hydration
Type LH	For low heat of hydration

3-9.5 Supplementary Cementitious Materials.

Supplementary cementitious materials offer the potential for improved performance of concrete and reduced cost. They provide benefits more economically and sometimes more effectively than the appropriate choice of ASTM C150/CRD-C 201 cement. The benefits include:

- Control of expansions due to ASR
- Reduced permeability
- Sulfate resistance
- Reduced heat of hydration

3-9.5.1 Pozzolans.

ASTM C618/CRD-C 255 defines pozzolans as “siliceous or siliceous and aluminous materials which in themselves possess little or no cementitious value but will, in finely divided form, and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.” Fly ashes and natural pozzolans must meet the requirements of ASTM C618/CRD-C 255. Class F fly ash with $SiO_2 + Al_2O_3 + Fe_2O_3 > 70$ percent, CaO content less than 8 percent, and loss of ignition not exceeding 3 percent is the preferred choice for controlling ASR and provides sulfate resistance. Class C fly ash is not permitted for concrete pavement.

3-9.5.2 Dosage.

Typical dosages for Class F fly ash are generally between 15 percent and 35 percent by mass of cementitious materials. Evaluate sources to determine actual chemical composition to establish typical usage rates. For treatments below 25 percent replacement, the $SiO_2 + Al_2O_3 + Fe_2O_3$ content must be greater than 70 percent. At 15 percent replacement, the $SiO_2 + Al_2O_3 + Fe_2O_3$ content must be greater than 90 percent.

3-9.5.3 Weather Effects.

In cool weather, concrete with Class F fly ash may not gain strength quickly enough to allow joint sawing before shrinkage cracks form.

3-9.5.4 Alkali-Silica Reactivity.

If fly ash is used to control expansions due to ASR, a lower CaO content is more effective. Ideally, the CaO content should be less than 8 percent. Test the fly ash to verify effectiveness and dosage requirements. Only use Class F fly ash with a total equivalent alkali content less than 4 percent when mitigating ASR potential in DoD airfield pavement. Only use Class F fly ash with a loss on ignition not exceeding 3 percent when mitigating ASR potential in concrete using air entraining admixtures in DoD airfield pavement.

3-9.5.5 Mixture Property Control.

Natural pozzolans are available either as components of Type IP cement or as additives. They can be effective in controlling expansions due to ASR and in reducing heat of hydration.

3-9.5.6 Slags.

Finely ground granulated blast furnace (GGBF) slag must meet the requirements of ASTM C989/CRD-C 205. Table 3-7 lists the three grades of GGBF slag. The three grades of GGBF slag are based on their activity index. Typical dosage of slag is between 25 percent and 50 percent of cementitious materials. For airfields, the minimum dose is 40 percent and the maximum is 50 percent. Note that concrete strength at early ages (up to 28 days) trends lower than slag-cement combinations, particularly at low temperatures or at high slag percentages. Establish the desired concrete properties while considering the importance of early strengths; the curing temperatures; and the properties of the slag, cement, and other concrete materials.

Table 3-7 Grades of GGBF Slag

Designation	Properties
Grade 80	Least reactive, not normally used for airfield pavements
Grade 100	Moderately reactive
Grade 120	Most reactive, through finer grinding. Difficult to obtain in some locations in U.S. and Canada

3-10 CERTIFICATION OF ADMIXTURES AND CURING COMPOUNDS.

3-10.1 Admixtures.

3-10.1.1 General.

Chemical admixtures are ingredients commonly used in paving concrete to obtain or enhance specific properties of concrete. For concrete with multiple admixtures, purchase the admixtures 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. Not all admixtures work well in all applications. For example, the low slumps typical of paving concrete make certain air-entraining admixtures less effective. The contractor should seek the advice of the manufacturer on applying and using admixtures. Obtain batching requirements, mixing procedures, and recommended dosages from the manufacturer. Use trial batches to determine exact dosages for the particular concrete mixture design. Placement temperature affects the required dosages of chemical admixtures. Develop trial batches accordingly. Never use admixtures to compensate for marginal concrete mixtures. The specifier and the contractor must consider if adjustments to the concrete mixture design are preferable to admixtures. As an example, obtain the effects of accelerating and retarding admixtures by adjusting the quantity and composition of the cementitious materials in the mix. Blend admixtures separately into the concrete. Do not place admixtures directly on dry aggregate or on dry cement as they can be absorbed and are not available to readily mix with the concrete. Consult the manufacturer for information about potential interactions between admixtures. In higher dosages, some water reducers may retard setting or strength gain. Chemical admixtures must meet the requirements of ASTM C260/CRD-C 13 or ASTM C494/CRD-C 87.
ASTM C260/CRD-C 13 specifies the requirements for air-entraining admixtures. The types of admixtures specified by ASTM C494/CRD-C 87 are given in Table 3 8.

Table 3-8 Types of Admixtures

Designation	Use
Type A	Water-reducing admixtures
Type B	Retarding admixtures
Type C	Accelerating admixtures
Type D	Water-reducing and retarding admixtures
Type E	Water-reducing and accelerating admixtures
Type F	Water-reducing and high range admixtures
Type G	Water-reducing, high range, and retarding admixtures

3-10.1.2 Air-Entraining Admixtures.

Air-entraining admixtures entrain a system of finely divided air bubbles in the cement paste. They are an essential protection for concrete exposed to freezing as they provide outlets for freezing water to expand and not disrupt the internal structure of the concrete. Air-entraining admixtures can also improve the workability of fresh concrete. They reduce water demand, bleeding, and segregation. Select an admixture appropriate for pavement use; some admixtures are used only in concretes with higher slump allowances than typical for airfield pavements. Higher air content in concrete reduces its strength. If the air content of the production concrete is higher than specified in the approved mix design, it may reduce the strength of in-place concrete and strength samples. Typically, a 1 percent increase in air results in a 5 percent loss in compressive strength.

3-10.1.3 Accelerating Admixtures.

Accelerating admixtures are classified as Type C and Type E by ASTM C494/CRD-C 87. They accelerate the setting and early strength gain of concrete. Typically, they are used only in cold weather or 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 primarily affect the setting time, heat evolution, and strength development. The strength at later ages may decrease, and in aggressive environments the durability may be adversely affected. Alternate means of obtaining early strength development include:

- Use of Type III cement
- Higher cement contents
- Heating the water or aggregates
- Improving curing and protection
- Some combination of the above

3-10.1.4 Retarding Admixtures.

Retarding admixtures delay the initial and final setting times; however, they do not reduce the rate of slump loss. They affect the rate of strength gain for as little as one or two days, or as long as seven 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 results in cracking of the pavement because the concrete begins to crack due to drying before gaining sufficient strength to saw the joints.

3-10.1.5 Water-Reducing Admixtures.

Water-reducing admixtures, as defined in ASTM C494/CRD-C 87 as Types A, D, and E, are used in concrete pavement applications. 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 is increased when using water-reducing admixtures. Some water-reducing admixtures enhance the effectiveness of air-entraining admixtures so a lower dosage achieves the required air content. High-range water reducers are typically not used in pavement concrete. Types A, D, and E can be used to:

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

3-10.2 Curing Compounds.

Curing compounds (liquid membrane-forming compounds) need to conform to the requirements of ASTM C309/CRD-C 304 and CRD-C 300, as applicable.
ASTM C156/CRD-C 306 specifies a method for determining the efficiency of curing compounds, waterproof paper, and plastic sheeting. 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 selected curing compound should contain a white pigment to reflect the sun's heat. Properly applied curing compounds must have the following properties:

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

3-11 QUALITY CONTROL/QUALITY ASSURANCE REQUIREMENTS.

The development of specifications for contractor quality control/quality assurance (CQC/QA) is discussed in this section. The implementation of specific project CQC/QA requirements is discussed in Chapter 10.

3-11.1 Basic CQC/QA Definitions.

3-11.1.1 Contractor Quality Control (CQC).

CQC, also called process control, refers to the contractor's roles and responsibilities. The goal of the CQC program is to provide testing, monitoring, and reporting of information to adequately document that the contractor 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 CQC plan that is available for review and approved by the Contracting Officer.

3-11.1.2 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 government from a serviceability and maintenance perspective. QA refers to the government's roles and responsibilities. The goal of the QA program is to verify that the results from the contractor's CQC plan are truly representative of the actual material being placed and that the contractor is "doing the right things." The government will develop a written QA plan and distribute it to all project personnel, including the contractor.

3-11.1.3 Acceptance Testing.

Acceptance testing describes the QA tests conducted to determine the degree of compliance with contract requirements and is linked to pay items. Acceptance testing can be part of the QA or CQC plan or both. For example, CQC may be responsible for fabricating and field curing concrete strength samples, but QA is responsible for transporting, laboratory curing, and testing. Clearly define all acceptance testing procedures and responsibilities prior to starting any work.

3-11.2 General Issues.

Important quality-related concrete pavement construction items include:

- Testing crew training/certification (typically ACI certification)
- Testing laboratory certification (as per ASTM C1077/CRD-C 553)
- Plant certification
- Plant operator certification
- Test equipment calibration: flexural strength test machine calibration and other laboratory testing equipment
- Role of QA/acceptance or verification/resolution of conflicts between QA and QC test results
- Use of control charts by contractors
- Development of a CQC plan
- Management of CQC data
- Timely review and processing of CQC data
- Ability of construction team to make decisions quickly with changing project conditions

3-11.3 CQC Plan.

One of the most important activities of a concrete pavement construction project is the contractor's development of a comprehensive CQC plan. The contractor must implement and adhere to the CQC plan throughout the course of the construction project. Meetings between the CQC and QA representatives prior to construction help resolve conflicts and identify gaps in the inspection process. The components of a good CQC plan include:

1. Introduction
    - Project description

- Key contact information (contractor, owner, and owner's representative)
- Contract plans and specifications highlights

2. Purpose of CQC
3. Organization chart (Clearly delineate the chain of responsibility from top management.)
    - CQC roles (testing laboratory, contractor)
    - 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 CQC/supplemental items
10. Placement agreement form
11. Appendices (as needed)

3-11.4 Review of CQC Plan.

Write the CQC plan clearly to minimize any misunderstanding. Review the plan for ambiguity with respect to sampling locations, number of tests, test procedures, special provisions, and acceptance limits. Make copies of all test procedures cited in the plan readily available at the project site or at the project test facility. The management of each organization must fully support the CQC process. Without management support, urgent deadlines and outside pressures can dominate project activities and CQC testing and inspection will suffer. An inspection and testing checklist is provided in Appendix B. The following are items to review in 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 are tested?
- What actions are taken when test results are unacceptable or outside of project action or suspension limits?
- What are the documentation procedures and timelines?
- How and to whom are the test results reported?
- How are nonconforming test results 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 use and placement of portable light plants?
- Does the plan provide the chain of command for decision making?

3-11.5 CQC Versus QA Testing Responsibilities.

Contractors and inspectors must be aware of testing requirements and how test results are used. QA testing is used for acceptance and pay adjustments while the contractor's test results are used for process control. This can create conflicting situations. Minimize the potential for conflicts between QA and QC through timely communications. Once the CQC and QA plans are created, reviewed, and approved, the contractor and the inspection teams will meet to review and resolve any potential conflicts or gaps in the plans. For example, the CQC plan may assume that the owner is making flexural strength samples for opening to traffic while the QA plan assumes it is the responsibility of the contractor. Or the QC plan may call out storage of traffic samples at the paving location and the QA plan defines storage in the laboratory. An often-overlooked part of any construction project is 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. Track any missing information and resolve as soon as possible. Missing items are difficult to locate if the project team waits until the end of the project. In addition to the types of documents submitted, the schedule for submission and the review process must be determined before construction begins.

3-12 TEST SECTION CONSTRUCTION.

Test sections are mandatory for all design-build paving projects, all airfield paving projects, and for other paving projects where the pavement thickness is 250 mm (10 in.) or greater and constructed using slipform paving. The designer and the using agency decide where the test section will be constructed. Use the test section to evaluate the concrete batching, transporting, placement, finishing, and curing processes. The specification clearly identifies the objectives for test section construction and establishes the construction monitoring and acceptance plan requirements. Develop the acceptance plan in accordance with project requirements. Clearly define test section dimensions and construction location. The designer and using agency must decide whether to place the test section near the project site or allow its use as part of the final pavement, provided it is placed at an outer edge location. Both the contractor and the government must have senior representatives present during the test section placement as this event establishes the acceptable and unacceptable procedures. The government must give the contractor timely notification of acceptance or a clear explanation of what is rejected.

3-12.1 Test Section Details.

Consider including the following construction details in the test section.

- Pave at the paving width anticipated for the project.
- Allow sufficient length (typically 122 m [400 ft]) for the contractor to demonstrate their paving operation.
- Place in conditions anticipated during pavement construction.
- Use the same equipment and concrete haulers as used during construction.
- Include blockouts to evaluate paving processes where light cans and embedded steel are located.
- Include at least one construction header to evaluate starting and ending.
- Include tie-down (mooring point) and ground point if the paving project includes them.
- For large projects, test strip construction should also include hand placement.

3-12.2 Test Evaluation Items.

Construct test sections using the same procedures as for production paving. The following paragraphs contain the items to evaluate during test section placement.

3-12.2.1 Pre-Paving Preparation and Inspection Activities.

Accomplish the following activities prior to starting paving operations.

- Base condition (grade and surface)
- Grade controls (stringline setup, paver track-line)
- Joint locations
- Dowel bar baskets, embedded steel, and tie bars, if used

- Blockouts
- Concrete aggregate (for gradation and moisture content)
- Equipment for transporting, placing, consolidating, finishing, texturing, and curing
- Vibrators on pavers (for frequency and amplitude).

3-12.2.2 Batch Plant Operations.

Evaluate the following batch plant charging and concrete mixing processes prior to the start of paving operations.

3-12.2.2.1 Plant Production Rate.

Batching through the plant at expected production rates will evaluate whether additional loaders are required and stockpile management plans are acceptable. Establish and approve mixing times based on plant uniformity testing.

3-12.2.2.2 Concrete Uniformity.

If difficulties in mixing or concrete uniformity are encountered, changes to the plant, changes in the mixing process, changes to the concrete mixture designs, or additional plant uniformity testing should be considered. Difficulties in concrete mixing at the design w/cm ratio, non-uniform concrete between the front and rear of the 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

3-12.2.3 Concrete Delivery.

Evaluate the following concrete delivery processes before starting paving operations.

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 stops and waits for concrete delivery.
c. Compare concrete material batch quantities with the approved mixture design quantities.

d. Deliver concrete using the same equipment as used in production (agitator, open-end dump trucks, as well as other material-handling vehicles and equipment).

3-12.2.4 Concrete Placement.

Evaluate the following concrete placement operations before starting paving operations.

a. Concrete dumped from trucks, chuted from agitator trucks, or spread using belt spreaders should not drop more than 1.5 m (5 ft).

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, observe the alignment procedures to ensure the baskets are being properly located and installed.

3-12.2.5 Quality Assurance/Quality Control.

Evaluate the following concrete sampling and QA/QC operations before starting paving operations. Address deficiencies noted concerning acceptance, QA and QC, concrete sampling, transporting, beam fabrication, initial and final curing procedures, and subsequent testing, and implement corrective action.

a. Sample concrete in front of the paver and test for slump, air content, initial concrete temperature, and plastic unit weight in accordance with the project requirements. Check concrete air content behind the paver. Document ambient air temperatures.

b. Properly transport concrete samples for beam or cylinder if concrete beams are fabricated and initially cured at a central location. Fabricate extra samples for testing at different ages. Early-age strength tests can verify strength gain relative to the mixture design and establish relative opening times for construction equipment.

c. Fabricate beams and cylinders at intervals more frequently than the sublot limits. This provides a better indication of variability due to any minor changes in batch quantities and changes throughout the day.

3-12.2.6 Consolidation and Finishing.

Evaluate the following concrete consolidation and finishing operations before starting paving operations.

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, or the paver operation.

b. Adjust the vibrator frequency, spacing, and elevation if problems with consolidation are encountered. Supplementary vibrators may be necessary at longitudinal construction joints if excessive entrapped air voids or honeycombing are observed along vertical edges.

c. If problems in consolidation are attributed to the concrete, conduct slump tests at the plant to establish slump loss. There may be an incompatibility problem between cement, liquid admixtures, and supplementary cementitious materials if concrete exhibits a high slump loss (generally considered greater than 25 mm [1 in.]). Verify aggregate moisture monitoring.

d. Dowel bar inserters are prohibited on DoD airfield projects.

e. Verify pavement thickness by probing or by stretching piano wire across string line pins and using a ruler.

f. Transfer transverse joint stations from the base or sides of forms to the pavement surface as references for joint sawcutting.

g. Observe paving at blockouts for movement of the blockout from the planned position. Check embedded steel behind the paver to ensure the steel is properly secured to the base and is not disturbed by paver vibrators.

h. Examine the surface directly behind the paver screed or the tube float to ensure the surface is not tearing. Surface tearing is associated with excessive concrete slump loss, excessive concrete slump, a poorly adjusted paving machine, or excessive paver speed. Closing tearing cracks during finishing operations may not prevent them from reflecting to the surface.

i. Examine the surface behind the paver screed or tube float to ensure 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. Measure edge slump at frequent intervals. Increasing the coarse aggregate content, decreasing the water content, 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. Examine the concrete, after finishing but prior to any texture operations, with a straight edge. The surface must be closed. Avoid adding 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 or excessive water application. 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.

3-12.2.7 Texturing.

The method of texturing must be inspected for uniformity in appearance. If burlap is used, it must 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.

3-12.2.8 Curing.

Consider the following concrete curing operations before starting paving operations.

a. Establish curing compound coverage rates prior to test strip construction. The coverage rate depends on the surface texture applied.

b. The application of curing compound must 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, or an insufficient number of passes.

3-12.2.9 Sawcutting.

Consider the following concrete sawcutting operations before paving.

a. Periodically monitor the temperature of fresh concrete if maturity meters, infrared guns, or surface thermometers are used to establish sawcutting times. Sample temperatures approximately every 20 minutes until joints are ready.

b. If the maturity meter technique is used to establish sawcutting times, insert thermocouples into the plastic concrete as soon as possible after texturing. Thermocouples are inserted into the pavement per the manufacturer's instructions. To obtain representative temperatures, the thermocouples should be positioned at least 0.6 m (2 ft) inward from pavement edges.

c. Allow sawcut operators to initiate cutting when concrete is slightly too green to calibrate temperature or maturity measurements.

d. Cut several meters (feet) to allow a visual rating or quantify joint raveling. Repeat this process until representatives for the owner, contractor, and inspector agree that sawcuts meet project requirements.

e. Document conditions of sawcuts and photograph to avoid future disputes over excessive raveling. Document the maturity and temperature when "acceptable" sawcuts can be made for production paving.

f. Check sawcut depths for each saw used on the test strip. Carry transverse sawcuts through the longitudinal free edges or as close to forms as possible.

3-12.2.10 Test Section Acceptance.

After test strip construction, perform a final inspection of the pavement. Items to inspect include:

- Condition of the surface and slipformed edges
- Texture and curing compound coverage
- Headers and sawcut joints
- Blockout areas (light can penetrations or other utilities)
- Edge slump and profile (straight edge or profile testing)
- Cores (for thickness and assessing consolidation and segregation).

See ASTM D6938, *Standard Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth).*

3-12.2.11 Adjustments to Quality Control/Quality Assurance Operations.

Document and discuss any deficiencies noted during test section construction or post-construction inspection and testing techniques. Hold meetings between the contracting officer and the contractor to review the test section results. Agree on actions to address and resolve deficiencies before commencing production pavement construction. Consider making any necessary changes in the CQC plan and operations.

CHAPTER 4 SUBGRADE PREPARATION

4-1 INTRODUCTION.

The subgrade provides the foundation for the entire pavement system. Uniformity and stability of the subgrade affect the long-term performance of the pavement and the construction process. Subgrade stability is needed to provide adequate support of the pavement section and to provide an acceptable construction platform. Pavement design begins with identification of the pavement foundation. Construction begins with foundation preparation. Important elements of subgrade preparation include evaluating subgrade stability, subgrade modification to improve stability, and evaluating surface tolerances. A geotechnical engineer experienced in subgrade preparation can address issues with:

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

Implement all measures within the limits of construction to control water pollution, soil erosion, and siltation as shown on the plans or required by applicable permit. Follow all pertinent local, state, and federal laws.

4-2 GRADING AND COMPACTING SUBGRADE.

4-2.1 Grading.

4-2.1.1 Pre-Grading Activities.

Mass grading is the first phase of subgrade preparation. It removes high points and fills low areas to achieve the desired finish elevation. The cut/fill items are typically addressed in the design phase of the project. Construction staking is the second phase of pre-grading. It is a good practice for the owner/engineer to perform an independent verification of the staking accuracy. Automated grading equipment using global positioning is 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. Important items to consider include the following.

a. Fill material is usually obtained from cut operations. Use the geotechnical report to evaluate the potential of this material for engineered fill.

b. If the in-place material is not of sufficient quantity or has unacceptable material properties, identify alternate borrow areas to source fill material.

c. It is incumbent upon the contractor to inform themselves regarding local subgrade conditions related to pre-grading and other construction activities.

4-2.1.2 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 consider the following actions:

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

4-2.1.3 Protection of Grade.

During grading operations, protect the grade by performing two essential activities, as follows.

1. Provide temporary drainage: trenches, drains or ditches necessary to divert or intercept surface water. If water ponds on the subgrade, the material softens and is 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.

4-2.1.4 Grading Operations.

Grading operations for a concrete pavement may require an embankment.

a. The embankment is constructed by placing material in successive horizontal layers for the full width of the cross-section.

b. Most specifications include a maximum loose depth of fill placement. Using thicker fill layers requires a contractor to demonstrate to the engineer that the thicker fill layer can be compacted to the specified density.

c. During construction of the embankment, 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.

d. In the construction of embankments, begin layer placement at the deepest portion of the fill. As placement progresses, construct layers approximately parallel to the finished pavement grade line.

e. In areas where subgrade transitions occur, mix the subgrade materials by disc at the boundary of the transition zone. Perform subgrade mixing over a distance of about 30 m (100 ft) along the transition zone (15 m [50 ft] on either side of the transition). This practice reduces the potential for differential settlement or frost heave.

4-2.2 Compaction.

4-2.2.1 Compaction Requirements.

Subgrade compaction is essential to building a stable work platform. Due to the weight of construction equipment, it is good practice to compact all subgrade materials to 95 percent of the maximum density using the modified Proctor test (ASTM D1557/CRD-C 162); this helps provide a stable working platform. Field density control is 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 are used to check the maximum density. Typical compaction requirements are as follows.

a. Use the modified Proctor test (ASTM D1557/CRD-C 162) to determine the maximum density for pavements trafficked by aircraft/vehicles greater than 27,215 kg (60,000 lb) in weight. Use the standard Proctor test (ASTM D698/CRD-C 653) for lighter aircraft/vehicles.

b. Cohesive soil use in fill sections: When a cohesive soil (plasticity index [PI] greater than 5 or a liquid limit [LL] greater than 25) is used, compact the entire fill to 90 percent maximum density.

c. Cohesive soils in cut sections: Compact the top 150 mm (6 in.) to 90 percent maximum density.

d. Cohesionless soil use in fill sections: When a cohesionless soil (PI equal to or less than 5 and a LL equal to or less than 25) is used, compact the top 150 mm (6 in.) of fill to 100 percent maximum density, with layers below compacted to 95 percent maximum density.

e. Cohesionless soil use in cut sections: Compact the top 150 mm (6 in.) to 100 percent maximum density and compact the next 450 mm (18 in.) to 95 percent maximum density.

f. If the natural subgrade exhibits densities equal to or greater than the specified densities, no compaction is required other than that required for a smooth surface, usually with only surface rolling.

4-2.2.2 Moisture Control.

Moisture control is essential to obtain a stable subgrade. Adhering to the following requirements promotes maximum soil density.

a. 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.

b. For expansive soils, moisture content must be 1 to 3 percent above optimum before compaction to reduce swell potential.

c. For fine-grained soils that do not exhibit swelling properties, keep the moisture content at 1 to 2 percent below optimum.

d. Cohesive soils compacted wet of optimum can become unstable under construction traffic even when the target density is achieved.

4-2.2.3 Moisture Compaction Relationships.

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 the following.

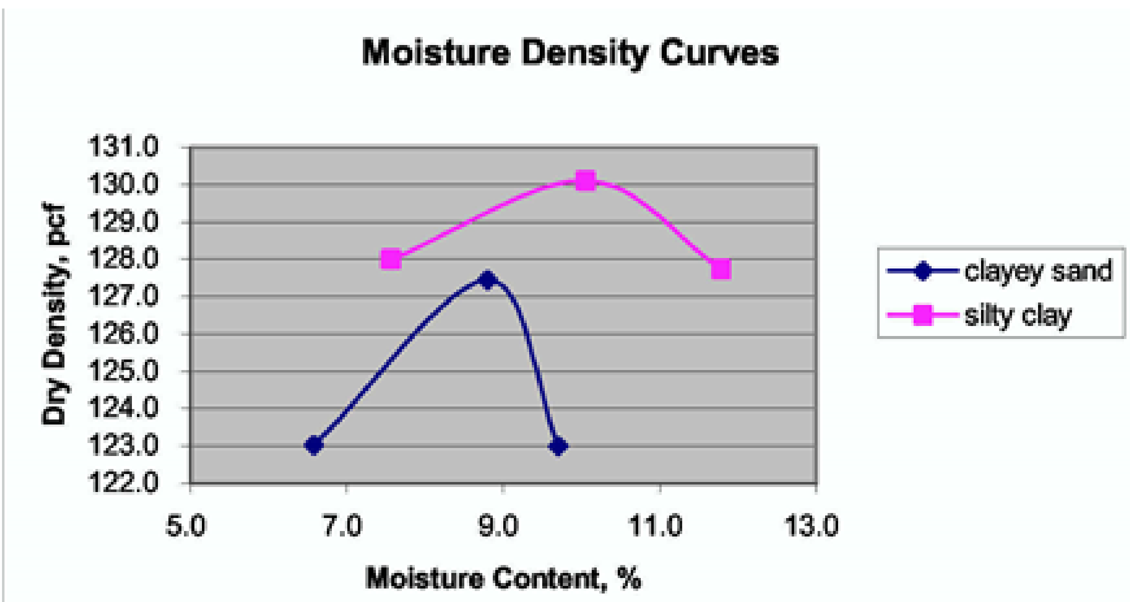
a. Use sheepsfoot rollers for cohesive soil. The pads must penetrate 70 percent of the lift thickness.

b. Discing of cohesive soil is necessary to control moisture.

c. Use static steel drum rollers to smooth the surface of the grade after compaction.

d. Use vibratory steel drum rollers for cohesionless soil. If the water table is close to the surface or if subgrade soils are saturated, use vibration with caution.

Figure 4-1 Typical Moisture-Density Curves.



4-2.2.4 Nuclear Density Gauge.

Nuclear density testing can check the density of the compacted soil. Calibrate gauges to local materials. If problems achieving density are encountered, use the following troubleshooting techniques:

- Perform additional moisture density testing to ensure the proper maximum density value is used to control field compaction.
- Use a sand cone or volume measure to perform the density tests.

- Use traditional methods to determine moisture content.
- Probe the subgrade to determine if soft layers are present below the problem area.

4-3 SUBGRADE STABILIZATION.

Subgrades are often stabilized for one of the following reasons: (a) to improve low strength soil, (b) reduce swelling potential, and (c) improve construction conditions. Unsuitable subgrade conditions can delay construction work due to the time required to implement appropriate measures. Having a stabilized subgrade facilitates staying on schedule. This is important on construction projects that require timely pavement opening to traffic. Find details on stabilization in UFC 3-250-11, *Soil Stabilization and Modification for Pavements*. If the site contains fine-grained soils, prepare a contingency plan for stabilization if unsuitable soils are encountered in localized pockets. Usually, fine-grained soils with unconfined compressive strengths of 190 kPa (2 tsf) or less present stability problems. For localized areas, consider the following procedures:

- Remove soft or disturbed material and replace with subgrade material from adjacent areas. This method works for surficial disturbance.
- Remove soft or disturbed material and replace with crushed stone. If the layer has a unconfined compressive strength less than or equal to 96 kPa [1 tsf]), use geotextile fabric to prevent intrusion of the subgrade into the stone layer.
- Place a geogrid over the soft area. Place and compact 250 mm (10 in.) of crushed stone on top of the geogrid to distribute the load to the subgrade.

4-4 ACCEPTANCE OF GRADE.

For unstabilized materials, consider scarifying, cutting, or filling areas to adjust the grade, if needed. With stabilized materials, filling in thin lifts is not possible. Therefore, with stabilized materials, construct the grade high and trim to final grade. For large projects, consider the use of an autograder or trimmer to minimize grade problems. Use the following criteria to accept a finished grade:

- Surface deviation: Maximum deviation of 10 mm (3/8 in.) (based on 3.6 m [12 ft] straightedge)
- Surface elevation: Maximum deviation of ±13 mm (0.5 in.)

4-4.1 Protection of Grade.

Once the grade is accepted, implement a traffic control plan. Heavy construction trucks traveling on the prepared surface can damage the grade. Enforce traffic management if logistics require use of the prepared grade by construction equipment. Smooth and re-compact all ruts or rough places that develop in a completed subgrade prior to placing the subbase.

4-5 ADVERSE WEATHER CONDITIONS

4-5.1 Drainage.

Implement provisions for drainage at each stage during the subgrade preparation. Maintain a positive slope to assure drainage. When the subgrade moisture content is above optimum, consider discing and drying to reduce the moisture content. If rain is expected after the subgrade is prepared for compaction, seal the subgrade surface using a rubber-tired or steel drum roller. If this is not done in time, serious problems can develop due to excess moisture in the subgrade.

4-5.2 Freezing Temperatures.

If a subgrade is subject to freezing, scarify the surface of the subgrade to a depth of at least 150 mm (6 in.) and re-compact. If the grade preparation was halted for winter, scarify the exposed subgrade surface to a depth of at least 150 mm (6 in.) and recompact prior to continuing grading the following spring.

4-5.3 Troubleshooting Guide.

Table 4-2 lists various subgrade problems, probable causes, and corrections.

Table 4-1 Troubleshooting Guide for Subgrades

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

CHAPTER 5 BASE AND SUBASE CONSTRUCTION

5-1 INTRODUCTION.

The layer immediately below the pavement surface is the base course. The term subbase designates layer(s) below the base and above the subgrade.

5-2 SUBGRADE PROTECTION.

Subbase and base course granular layers left exposed over a winter in a wet-freeze region can cause softening of the subgrade. Cover these layers with the pavement. If this is not possible, use caution when resuming construction. Construction traffic can make a subgrade unstable.

5-3 SUBBASE COURSE.

Subbase materials are generally granular materials that are natural material or crushed. Their stability in CBR values ranges from 20 to 100. These materials are generally used as subgrade protection layers (frost protection) or to provide drainage above the subgrade. In frost areas, limit the percent of the material less than 0.075 mm (passing the No. 200 sieve) to 3 percent. Important elements for subbase placement include the following.

a. Start placement along the centerline or high point to maintain drainage during construction.

b. Perform placement using automated equipment or a stone box on a bulldozer.

c. Develop moisture density relationships in the laboratory using the modified Proctor test (ASTM D1557/CRD-C 162) for aircraft/vehicle traffic greater than 27,215 kg (60,000 lb) in weight. Use the standard Proctor test (ASTM D698/CRD-C 653) for lighter aircraft/vehicles. Moisture control is critical to achieving compaction. It is the best practice to keep material within 1 percent of the optimum moisture. For free-draining subbase materials, consider a lower moisture content to avoid adding excess water to the subgrade during compaction of the subbase.

d. Layer thickness must be three to four times the largest aggregate size. A layer thickness close to the largest aggregate size adversely affects density, grading, and smoothness.

e. Prior to subbase placement, evaluate the subgrade for stability. Repair any soft areas.

f. Implement traffic management in front of placement to eliminate potential problems.

g. Nuclear gauges are permitted to monitor subbase density.

h. Verify density values using one-point tests at the delivered moisture content. Perform one-point tests twice a day.

i. The grade tolerance for subbase is 13 mm (0.5 in.) using a 4.8-m (16 ft) straightedge.

- Laser auto-graders or auto-trimmers are recommended on larger projects.
- For projects where automated equipment cannot be justified, it may be necessary to relax the surface tolerances.

j. Once the subbase layer is placed, protect the surface.

- Provide drainage so water does not pond on the surface.
- If dry conditions prevail, watering may be necessary.

k. Rolling can be accomplished with vibratory drum rollers. If compaction is difficult, use rubber tire rollers, as the kneading action of wheels aids in compaction.

5-4 BASE COURSE.

A good base course is important to avoid or minimize construction difficulties. Base course materials are similar to subbase materials, but are usually of higher quality in terms of crushed aggregate content, deleterious material, and gradation. The requirements for bases under rigid concrete pavement are less restrictive than for flexible pavements. Therefore, the designer must select the correct requirements and guide specifications for concrete pavements. The requirements for proof rolling of the completed base course are given in UFC 3-260-02. The critical elements for placement of a base course are the same as those described for subbase materials. In addition, consider the following items.

a. Check the underlying course (subgrade or subbase) before placing and spreading the base course. Correct and compact any ruts and soft or yielding areas (due to improper drainage conditions, hauling, or any other cause) to the required density before placing the base.

b. Do not place the base if the underlying course is wet, muddy, or frozen.

c. Suspend work on the base course during freezing temperatures or if the base material contains frozen material.

d. Use vibratory rollers, rubber tire rollers, and static wheel rollers for compaction of base material. With some material, the vibratory roller may be used alone to obtain compaction and a smooth, even surface.

e. Grade tolerance for base layers is 10 mm (3/8 in.) across a 4.8 m (16 ft) distance. Automated placement methods are usually required to attain the tight tolerances.

5-5 CHEMICALLY STABILIZED BASE COURSES.

DoD does not require stabilized base courses under concrete pavements. The need for stabilization is determined on a project-by-project basis. There are several types of stabilized bases. Cement stabilization is the most commonly used stabilizer, although asphalt cement, lime, or other materials are also used. The properties and qualities of a cement stabilized material depend upon the amount of cement added. The strength and stiffness of the stabilized layer will increase with increasing amounts of cement. The stiffness of stabilized base layers has an impact on the performance of concrete pavements. They affect the curling/warping behavior of a slab and they increase the restraint on the slab during the initial curing period. With higher amounts of cement, the stiffness of a lean concrete base 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. However, a well-designed and -constructed stabilized base increases the fatigue life and improves the constructability of a concrete pavement. Details are available in UFC 3-250-11.

5-5.1 Material Cautions.

Lean porous concretes such as cement treated base (CTB) courses are more susceptible to sulfate attack than pavement concretes. During the design phase of the project, consider investigating possible detrimental effects on the CTB caused by sulfates present in the soil, groundwater, or aggregates. Cover a CTB layer with the pavement layer before winter or a freezing event. If a CTB layer must remain exposed, it must first attain its design strength. Before construction resumes in the spring, check the grade.

5-5.2 Strength.

The primary issue with lean concrete is the strength of the mixture. If the compressive strength is greater than 10 MPa (1,500 psi), the flexural strength is greater than 2.5 MPa (350 psi), or the amount of material passing the 0.075 mm (No. 200) sieve is 15 percent or less, the material is a lean concrete rather than stabilized material. Restrict traffic on lean concrete until attaining a compressive strength of 2,400 kPa (350 psi).

5-5.3 Reflective Cracking.

As the maximum compressive strength achieved in the lean concrete increases, the potential for cracking, and therefore reflective cracking, increases. One method to counteract cracking is to design joints in the layer. The design of the jointing pattern in the lean concrete must match the joint pattern of the pavement or reflective cracking may occur. Take care to align the joints when placing the concrete pavement. Another method of preventing reflective cracking is by applying a double application of wax-based curing compound to the surface of the lean concrete. The double application reduces the potential for bonding between the lean concrete and the pavement and minimizes the potential for random cracking in the pavement.

5-6 DRAINAGE LAYERS.

By default, rigid pavement designs incorporate a drainage layer unless the existing subgrade is highly permeable. Normally, place the concrete pavement directly on the drainage layer. Drainage layers may be open-graded materials, either unstabilized or stabilized, with subgrade or asphalt cement, open-graded with a finer choke stone surface, or a rapid-graining material that limits fines but includes some sand-sized fraction to provide better stability under traffic. Construction on unstabilized open-graded materials may require special equipment and operations. Consequently, requirements for drainage layers must be clear in the project plans and specifications so the contractor can prepare a realistic bid. The common practice is to use cement or asphalt stabilized drainage layers. Match the porosity of the drainage layer to the anticipated needs for the quick evacuation of water. The design balances the need for stability against the need for porosity, with stability taking precedence. 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) are common. If an unstabilized open graded layer is necessary, place it deeper in the pavement structure to reduce stresses on the layer. The thickness of the drainage layer is typically 100 to 150 mm (4 to 6 in.) in thickness with no individual layer less than 75 mm (3 in.) in thickness.

5-7 CONSTRUCTION ISSUES.

Stabilized bases provide rigid paving platforms and 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 construction specifications of a concrete pavement on top of a stabilized base course. For cement stabilized materials, an application of a double coat of wax-based curing membrane or a geotextile will reduce restraint. If the surface is trimmed after curing, apply another coat of curing membrane. As the strength of a cement stabilized layer is increased, reduce the joint spacing of the pavement and saw cut joints as soon as possible.

5-8 TROUBLESHOOTING GUIDE.

Table 5-1 provides a list of various stabilized base problems, the probable causes, and suggested corrective actions.

Table 5-1 Troubleshooting Guide for Stabilized Base Courses

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

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CHAPTER 6 CONCRETE PAVING PREPARATION

6-1 INTRODUCTION.

This chapter discusses pre-paving construction items, 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. The following critical elements should be in place before production paving starts.

- Check all equipment in the paving train to assure it is operational.
- Verify that an acceptable length of grade is available for concrete paving.
- Check that approved test reports are available for all materials in storage at the job site and the plant site.
- Verify that backup testing equipment is available. Develop extra equipment backup plans.
- Verify that all necessary concrete placement tools are available, such as hand tools, straight edges, hand floats, edgers, and hand vibrators.
- Verify that extra vibrators and joint-sawing equipment are available in case the original equipment breaks down during construction.
- Verify that radio/telephone communication with the plant is operational.
- Verify that equipment is available to water the grade, if necessary.
- Monitor the string line regularly and re-tension as necessary.
- Verify that the day’s work header is in place (needed or just saw off excess).
- Develop an extreme weather management plan.
- Check the weather forecast for each day of paving.
- Make sure a sufficient length of plastic covering is available in case of sudden and unexpected rain.
- Verify positive drainage within the plant site.

6-2 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 to check.

a. Check elevation tolerances for each pavement layer. Elevations and tolerances are shown on plans for the compacted subgrade, stabilized and non-stabilized layers, and top of pavement.

b. Consider the following items prior to paving:

- Effect of grade on as-placed concrete volume; materials cost impact if final grade is low.
- Effect of grade on pavement thickness variability. If final grade is variable, it will affect thickness determined through core sampling. Minimize concrete thickness variability as it may affect payment for thickness.
- Remove loose debris on the base before paving.

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

6-3 CONCRETE PLANT OPERATION.

Concrete is a manufactured product, whose quality and uniformity are sensitive to quality control variation during manufacture. A plant must be in good condition, operate reliably, and produce acceptable concrete uniformly from batch to batch.

6-3.1 Quality and Uniformity.

Concrete quality and uniformity are greatly affected by aggregate segregation and varying moisture content of the aggregates. Batch plants and equipment must meet ASTM C94/CRD-C 31. Key items listed in ASTM C94/CRD-C 31 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.
- Cement and water added to an accuracy of ± 1 percent of the required total mass.
- Aggregate added to an accuracy of ± 2 percent of the required total mass.
- Admixture added to an accuracy of ± 3 percent of the required total mass.

6-3.2 Pre-production Inspection.

The engineer should inspect the concrete plant before the start of paving using the National Ready Mixed Concrete Association (NRMCA) checklist in *Certification of Ready Mixed Concrete Production Facilities*. Inspect plants before the start (or re-start) of each paving project and when uniformity or strength problems are encountered during production. The concrete plant inspection should include the following:

- Check foundations of stockpiles for proper separation and adequate drainage.
- Check bins for adequate partitions to prevent intermingling of aggregates.

- Check scales with test weights throughout range to be used.
- Check scales for seals by approved agency.
- Check water meter for accuracy.
- Check for leakage of lines.
- Check capacity of boilers and chillers if their use is anticipated.
- Check admixture dispensers for accuracy.
- Check mixers for hardened concrete around blades.
- Inspect concrete hauling units for cleanliness.
- Check to ensure all concrete-making materials have been certified and approved for use.
- Observe stockpiling operations; verify that segregation and contamination will not occur.
- Observe charging of the bins; verify that segregation and contamination will not occur
- Review aggregate moisture tests.
- Observe batching operations at start and periodically during production.
- Check scales for zeroing.
- Check to ensure proper batch weights are set on the scales

6-3.3 Traffic Flow.

Optimize the traffic flow at the plant. Consider the following:

- Delivery of raw materials.
- Delivery of concrete to the paver.
- CQC/QA-related traffic operations and testing personnel safety.
- Operation of equipment for managing the aggregate stockpiles.
- Plant safety requirements.

6-3.4 Managing the Aggregate Stockpile.

Develop and implement stockpile management procedures. 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.

a. Handle and store aggregates in a way that minimizes segregation and degradation and prevents contamination by deleterious substances.

b. Closely monitor and maintain aggregate stockpiles to keep moisture content at or above saturated surface dry condition. This is particularly important for absorptive aggregates used during hot weather.

c. If aggregate moisture varies throughout the day, increase the frequency for determining moisture content. Moisture content variability increases when loaders retrieve aggregates from one area of the stockpile or if water-sprinkling of stockpiles is not uniform.

d. The water added at the mixer must be adjusted for the moisture of the aggregate. In hot weather, use of chilled water may be considered.

e. Limit the aggregate drop height when building up a stockpile. Build stockpiles up in layers of uniform thickness. When removing aggregate from a pile (with a front-end loader), remove the material vertically from bottom to top so that each load contains a portion of each layer.

f. Stockpiles should be separated from one another. If there is not enough space between them to keep size fractions separate, use a wall.

g. Bulldozers should not be allowed on stockpiles because they break down the aggregate and segregate the particle sizes.

h. 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. Stabilize haul roads and dump area to minimize aggregate contamination from trucks. Aggregate contamination may also occur if loaders charging aggregate bins scrape the bottom of the pile.

i. Visually examine stockpiles for segregation. If apparent, perform gradation testing from representative areas of the stockpile to verify segregation. Reject segregated material.

6-3.5 Concrete Uniformity Testing.

Conduct concrete uniformity testing before the start of paving. Uniformity testing establishes minimum mixing times. Truck mixers must meet ASTM C94/CRD-C 31. Uniformity tests compare differences in concrete sampled at approximately 15 percent and 85 percent drum discharge. Differences between concrete discharged at 15 percent and 85 percent should be less than the maximum allowable differences stated in ASTM C94 for five of six tests. Test batch (stationary) plants in accordance with CRD-C 55. This test method differs from ASTM C94 in that it requires three samples from an individual batch. Minimum mixing times for production are established by the concrete uniformity tests. The six tests required for each method are:

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

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

6-4 PAVING EQUIPMENT ISSUES.

Check the paving equipment for the following:

a. 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 onsite.

b. Ensure equipment is in proper working order. The equipment requiring inspection include concrete haulers, concrete placers, concrete spreaders, slipform pavers, curing/texture rigs, and sawcutting equipment.

c. Inspect slipform pavers to ensure they achieve proper consolidation through vibration. Check vibrator frequency and amplitude prior to paving. Spud vibrators under no load must have a frequency of no less than 135 Hz (8000 vibrations per minute) and an amplitude of 0.75 mm (0.03 in.), as determined in CRD-C 521. Tube vibrators under no load must have a frequency of no less than 80 Hz (5000 vibrations per minute) and an amplitude of 0.75 mm (0.03 in.). Establish vibrator elevations that do not interfere with pre-placed dowel baskets.

d. Check curing application equipment to ensure a uniform and proper application of curing compound.

e. Blades for joint sawing must be suitable for the aggregate type used in the mix.

6-5 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 provides an accurate reference for elevation and alignment control of the grade trimming, subbase/base placement, and concrete paving train. The final product reflects any error in the stringline. 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 7.6 m (25 ft) will usually result in a good product. A tighter interval is necessary to produce smooth pavements on vertical curves and is based on the rate of change of curvature.

6-5.1 Stringline Aids.

The following aid in establishing a proper stringline:

- Use rigid stakes

- Use quality line
- Avoid knots and splices
- Prevent perceptible sagging
- Eyeball for staking errors and irregularities
- Monitor, protect, and maintain line
- Adjust stake spacing to fit conditions

6-5.2 Stringline Type.

Stringline materials and their properties and behaviors are listed:

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

CHAPTER 7 CONCRETE MIXTURE

7-1 INTRODUCTION.

Concrete mixture design considerations are discussed in this chapter. The quality of concrete is usually defined in terms of workability, strength, and durability. Strength requirements are often mistakenly emphasized above quality requirements because concrete strength is an important component of the pay schedule. It is preferable to optimize all three aspects of concrete quality. Specific information on concrete mixture design is in TSPWG M 3-250-04.97-05, *Proportioning Concrete Mixtures with Graded Aggregates for Rigid Airfield Pavements*.

7-2 CONCRETE HIGHLIGHTS. `

Concrete is a two-component mixture: 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, less water improves the quality of the concrete. A maximum w/cm ratio is typically specified to avoid excess water and ensure 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 are 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

7-3 CONCRETE MIXTURE REQUIREMENTS.

A 90-day flexural strength is specified for airfield and heavy-duty pavement design purposes. However, this can be reduced to 28 days if required and approved by the Service-specific TSPDWG representative. A 28-day flexural strength may be specified for roads. Compressive strength testing can be used for field acceptance of strength provided correlations between compression and flexural tests have been developed. 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. Requirements are established for aggregates (coarse and fine), cementitious materials, admixtures, concrete mixture design, and concrete acceptance. The following are a few of the required attributes for concrete used for airfield and heavy-duty pavement:

- Maximum design flexural strength cannot exceed 650 psi (4.5 MPa) at 90 days. Actual field measured strength may be higher.
- Minimum cement content of 280 kg/m^3 (470 lb/yd^3) and 310 kg/m^3 (517 lb/yd^3), if pozzolan is used.
- Maximum w/cm ratio of 0.45. For severe sulfate exposure areas, the practice is to limit the w/cm ratio to 0.40.
- Maximum slump for fixed-form concrete is 50 mm (2 in.). Adjust slump for slipform concrete as needed to meet tolerances for smoothness, joint face deformation, and edge slump.
- Air content is based on exposure condition and the maximum aggregate size.
- Fine aggregate fineness modulus between 2.5 and 3.4.

7-4 LABORATORY MIXTURE DESIGN PROCESS.

The following is a discussion of the procedure for proportioning concrete mixtures adapted from the Portland Cement Association (PCA) mixture design procedure.

a. Obtain required information (for example gradation, absorption, specific gravity) for the materials to be used.

b. Identify project requirements for maximum w/cm ratio, nominal air content, slump, sulfate resistance, and strength.

c. Choose slump. For slipform paving, it must be in the 13 to 38 mm (0.5 to 1.5 in.) range to minimize edge slump.

d. Choose maximum size of aggregate. Use the largest size of aggregate that is economically available and can be placed and consolidated.

e. Estimate mixing water and air content.

f. Select w/cm ratio. Determine the w/cm ratio needed to meet the requirements for strength and durability. It may need to be lower to resist sulfate attack.

g. Calculate cementitious materials content. Estimate the proportions of the various cementitious materials used according to the properties desired.

h. Estimate coarse and fine aggregate contents.

i. Adjust for aggregate moisture condition.

j. 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 adjustment to achieve the required air content and slump when the laboratory batch is scaled up to the sized field batch.

7-5 MIXTURE DESIGN ISSUES.

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 ensure workability for the given mixture characteristics, the project paving equipment, and expected ambient conditions at time of paving. 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 0.3 and 0.15 mm (No. 50 and No. 100) sieves and also with respect to the fineness modulus. The contractor must review these requirements at the time of the concrete mixture design phase. ASTM C33/CRD-C 133 provides guidance.

7-5.1 Mix Design Guides.

The following are general guidelines to use when developing a mix design.

a. 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).

b. Monitor slump loss during trial batching. Excessive slump loss (25 mm [1 in.] in 15 minutes) may indicate false setting or a material incompatibility problem.

c. Conduct early-age strength tests (at 3, 7, and 14 days) to evaluate potential problems for 28 days.

d. Monitor a well-insulated concrete cylinder temperature during the first 12 hours. A temperature increase of less than 10 °F (Δ5.5 °C) may indicate a retardation due to material incompatibility.

e. Concrete for hot weather placement should contain less cement and more supplementary cementitious materials, preferably Class F fly ash, calcined clay, or slag. Trial batches for hot-weather concreting also must include the use of retarders to verify the dosages and their effects on setting time.

f. Concrete for cold weather placement must 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 Type III cement, using warm water, or reducing the w/cm ratio. Trial batches for cold-weather placement must include accelerating admixtures to verify the dosages and their effects on setting time.

g. Trial batches must be tested for the range of temperatures anticipated over the project duration.

7-6 CONCRETE MIXTURE DESIGN ISSUES.

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

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

7-6.1 Workability.

Workability is an essential characteristic of concrete. Workability is the ease of placing, consolidating, and finishing 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.

7-6.1.1 Factors Affecting Workability.

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:

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

7-6.1.2 Mixture Components Affecting Workability.

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

- Aggregate: size, grading, particle shape, water demand, variability
- Cement: cement content, water demand
- Fly ash (if used): effect on initial set, water demand, effect on finishing
- Slag cements and GGBF slag: effect on finishing and saw cutting
- Water: total water demand
- Admixtures: air-entrained concrete exhibits better workability; water reducers reduce water demand while improving workability

7-6.2 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. Mixture designs must also be developed for hand-placed (fixed-form) areas. These mixtures have workability requirements different from mechanically placed mixes. However, the strength and durability requirements must be the same as the production concrete.

7-6.2.1 Weather Conditions.

For hot or cold weather placements, the heat of hydration is a concern. Trial batches must 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 paragraphs 8-16 and 8-17, respectively, for details on the specific concerns that must be addressed for hot and cold weather job conditions.

7-6.2.2 Fast Track Concrete.

The following list contains considerations and requirements for placement and use of fast-track concrete.

a. 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.

b. Fast track concrete is best suited for bridging the areas incorporating cross taxiways or high traffic volume apron areas.

c. The production of high early-strength concrete can be achieved using normal locally available concrete-making ingredients and conventional construction methods.

d. 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.

e. 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.

f. High early-strength concrete can be produced using proprietary cements and admixtures.

g. When high early-strength concrete is specified, the early age strength requirement is typically defined in terms of compressive strength, as follows:

- About 5 to 7 MPa (750 to 1,000 psi) in about four to six hours.
- About 14 to 21 MPa (2,000 to 3,000 psi) in about 24 hours.

h. There may still be a requirement to meet a specified flexural strength at 14, 28, or 90 days.

7-6.3 Sulfate Resistance.

The potential for severe sulfate attack exists when concrete is exposed to water-soluble sulfate (SO_4) in soil or water (as determined by CRD-C 403 and ASTM D516/CRD-C 408) in excess of 0.20 percent or 1,500 parts per million. The potential for moderate sulfate attack exists for sulfate contents in excess of 0.10 percent or 150 parts per million. If the soils or groundwater contain sulfates, the cementitious material(s) must be appropriately resistant to sulfate attack and the w/cm ratio needs to be reduced appropriately. Also, as previously discussed, use of pozzolans or slags should be considered. For sulfate resistance, the main consideration is the tricalcium aluminate (C_3A) content of the cement. A supplementary cementitious material with high CaO and aluminum oxide (Al_2O_3) contents, however, may effectively add to the C_3A content of the system, making it more vulnerable to sulfate attack. For DoD construction, test for durability per ASTM C88. The maximum limit of sulfate soundness loss is 12 percent after five cycles, or for magnesium sulfate, 18 percent after five cycles

7-6.4 Air Entrainment.

Concrete 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 C231/CRD-C 41 (pressure method) or ASTM C173/CRD-C 8 (volumetric method), these methods do not distinguish between a good air void system and a poor one. Consider the following items.

a. Produce trial batches to determine the correct dosage of the admixture for the conditions, including temperature, expected on the job site.

b. Typical air content requirements for pavements range from 5 percent to 7 percent, depending on exposure.

c. The volume of air required for frost protection increases with decreasing aggregate size because of the corresponding increase in paste content.

d. All other factors being equal, an increase in air content results in a decrease in concrete strength.

e. Test the air-void system parameters on the hardened concrete according to ASTM C457/CRD-C 42.

- An air-void spacing factor of 0.20 mm (0.008 in.) or less is necessary
- For concretes containing supplementary cementitious materials, an air void spacing factor of 0.15 mm (0.006 in.) or less is necessary.

f. Allow the trial batch concrete to sit for a length of time representative of the haul time and then measure 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.

g. 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.

h. Typical slipform paving operations reduce air content by 1 to 2 percent during consolidation.

7-7 BLENDED CEMENT/SUPPLEMENTARY CEMENTITIOUS MATERIAL.

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.

a. Class C fly ash is not permitted for paving concrete.

b. Slags contain sufficient calcium to have some cementitious properties of their own. 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 rapid for the conditions of the job and that setting times are acceptable.
- If the concrete loses slump rapidly, consider reducing the dosage of fly ash, using a different fly ash, using a different cement, or using a different water reducer.

c. Class F fly ash and natural pozzolans react with water and calcium hydroxide from the hydration of subgrade cement to form calcium silicate hydrate.

d. 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 firmness.

e. Purely pozzolanic Class F fly ash and natural pozzolans tend to produce a lower heat of hydration and lower strengths at early ages than subgrade cement.

f. Slag generally lowers the heat of hydration and the early-age strength.

g. Most supplementary cementitious materials increase the strengths at later ages.

h. Appropriate supplementary cementitious materials, appropriately used, can provide the following benefits:

- Reduce the tendency for thermal cracking by reducing the heat of hydration.
- Increase the strength (particularly at later ages).
- Reduce concrete permeability and diffusivity.
- Control expansions due to ASR and increase resistance to sulfate attack.

i. For a particular application, some supplementary cementitious materials are better than others, and some may be completely inappropriate.

j. Natural pozzolans can provide excellent performance, somewhat like Class F fly ashes.

k. If the aggregate selected is susceptible to ASR, consider incorporating a Class F fly ash to control it. The CaO content of the Class F fly ash should be less than 8 percent. Test the combination of aggregate, cement, and fly ash to determine the quantity of fly ash required.

l. Class F fly ash is considered to the most effective supplementary cementitious material for control of heat of hydration, control of ASR, and resistance to sulfate attack.

m. Some supplementary cementitious materials make things worse. Therefore, test each combination of cementitious materials, aggregates, and admixture.

n. Blended cements containing Class F fly ash, slag, calcined clay, or silica fume may also be used for control of heat of hydration, control of ASR, and resistance to sulfate attack.

o. If the available blended cement does not meet the requirements for control of ASR or sulfate resistance, incorporate additional supplementary cementitious material of the same or different kind at the mixer as necessary.

p. Ternary mixtures that 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.

7-8 MATERIALS INCOMPATIBILITY.

Some concretes exhibit undesirable characteristics because of incompatibility among different concrete materials. These undesirable characteristics include: (a) early loss of workability (early stiffening), (b) delayed set (retardation), (c) early-age cracking due to excessive autogenous and drying shrinkage of concrete, and (d) lack of proper air-void system. 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 components increases. The problem is compounded because:

- Factors that result in incompatibility among various cementitious materials and admixtures are not well known.
- Material incompatibility may be induced by temperature changes. Therefore, test trial batches at the extremes of temperature anticipated at the project site.

7-8.1 Early Stiffening.

Early stiffening occurs when there are insufficient 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.

7-8.2 Retarded Concrete.

Although retarded concrete is 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.

7-8.3 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.

7-8.4 Air Void System.

Problems related to the use of certain air-entraining agents include:

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

7-8.5 Reducing Incompatibility.

It is advisable to have hot and cool weather mixture designs in locations where seasonal differences in temperature are usually significant. Other steps to minimize incompatibility problems include the following.

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

7-9 AGGREGATE REQUIREMENTS.

7-9.1 Aggregate Grading.

The grading of the aggregate can have a substantial effect on the properties of the concrete mixture. 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 increase the water demand of the concrete and the required dosage of air-entraining admixture.

7-9.1.1 Well-graded Aggregate.

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

- Reduce the need for water
- Provide and maintain adequate workability
- Require minimal finishing
- Consolidate without segregation
- Enhance strength and long-term performance

7-9.1.2 Gap-graded Aggregate.

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

- Segregate easily
- Contain more fines
- Require more water
- Increase their susceptibility to shrinkage
- Limit long-term performance

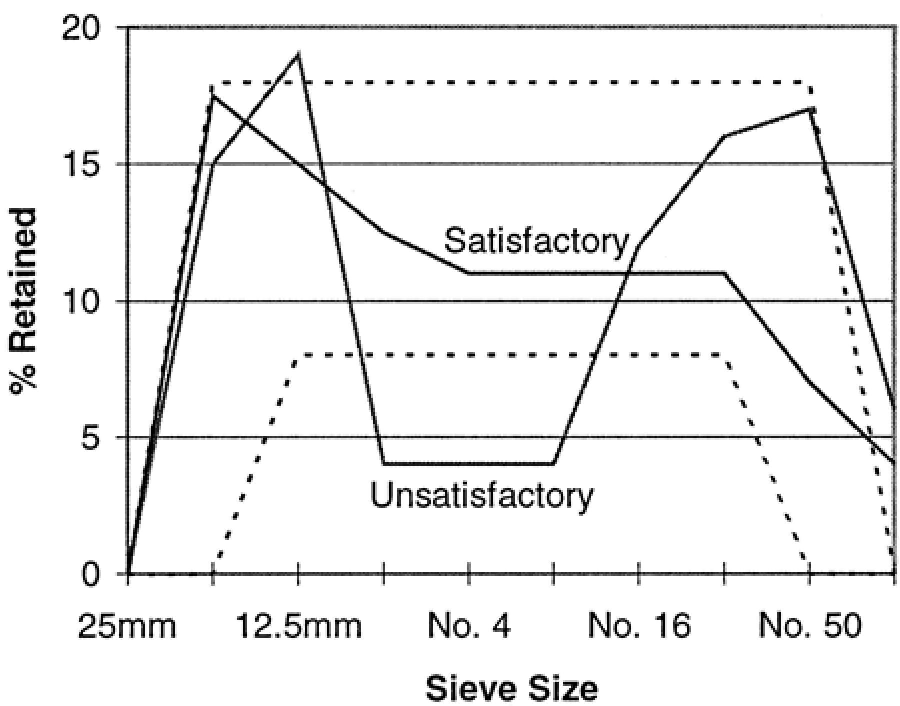
7-9.1.3 Combined Aggregate Grading.

Proportion the concrete mixture so the requirements for workability and finishability are met. Also, proportion the mixture as a well-graded combined aggregate such that the minimum requirements for air content and the water cementitious ratio are met.

7-9.1.4 Percent Combined Aggregate Retained Graph.

Grading reports should include the following sieve sizes: sieves used for the analysis include 50 mm, 37.5 mm, 25 mm, 19 mm, 12.5 mm, 9.5 mm, 4.75 mm, 2.36 mm, 1.18 mm, 0.6 mm, 0.3 mm, and 0.15 mm (2 in., 1 1/2 in., 1 in., 3/4 in., 1/2 in., 3/8 in., No. 4, No. 8, No. 16, No 30, No. 50, and No. 100, respectively). Plot the selected proportions for the combined gradation on a graph as the percentage retained for each reporting sieve size (y axis) versus the considered sieve size (x axis). The plot of the graph should be a line showing a relatively smooth transition between coarse and fine aggregate. The maximum and minimum percent retained limits, represented by the dotted lines in Figure 7 1, are a guide and the plot should not have no significant valleys or peaks between the 9.5 mm (3/8 in.) sieve size and the finest reporting sieve size. An example of the percent aggregate retained graph, including a satisfactory and unsatisfactory combined aggregate gradation plot, is shown in Figure 7-1.

Figure 7-1 Percent Combined Aggregate Retained



7-9.1.5 Coarseness Factor / Workability Factor.

Use the combined aggregate grading to calculate a coarseness factor and a workability factor. Determine the coarseness factor for a particular combined aggregate gradation by dividing the amount retained above the 9.5 mm (3/8 in.) sieve by the amount retained above the 2.36 mm (No. 8) sieve and multiplying the ratio by 100. The workability factor is the percentage of combined aggregate finer than the 2.36 mm (No. 8) sieve. Determine this factor by using the percentage passing the 2.36 mm (No. 8) sieve from the combined aggregate sieve analysis. Increase the workability factor by 2.5 percent for each 56 kg/m^3 (94 lb/yd^3) of cementitious material used in excess of the baseline amount of 335 kg/m^3 (564 lb/yd^3) of cementitious material. Only adjust the workability factor upwards, because 335 kg/m^3 (564 lb/yd^3) is the minimum amount of cementitious material permitted for rigid airfield pavement mix designs. The combined aggregate grading is used to calculate the coarseness factor and the workability factor as follows.

Equation 7-1. Coarseness Factor and Workability Factor

$$Coarseness\ Factor = 100\left(\frac{\%\ retained\ above\ 9.5\ mm\ \left(\frac{3}{8}\ in.\right) sieve}{\%\ retained\ above\ 2.36\ mm\ (\#8)\ sieve}\right)$$

$$Workability\ Factor = \%\ passing\ 2.36\ mm\ (\#8)\ sieve + 2.5\% *$$
$$each\ 56\frac{kg}{m3}\left(94\frac{lb}{yd3}\right) of\ cementitious\ material\ above\ 335\ kg/m^3\ \left(564\frac{lbs}{yd^3}\right)\quad (7-9.1.5.)$$

The coarseness and workability factors are plotted on a chart similar to that shown in Figure 7-2. The coarseness factor should not be greater than 80 nor less than 30. The plot of the workability factor and the coarseness factor is a single point that is to be above the control line and within the workability box, as shown in Figure 7-2. Obtain the following information from an examination of where the aggregate mixture factors plot, as shown in Figure 7-2.

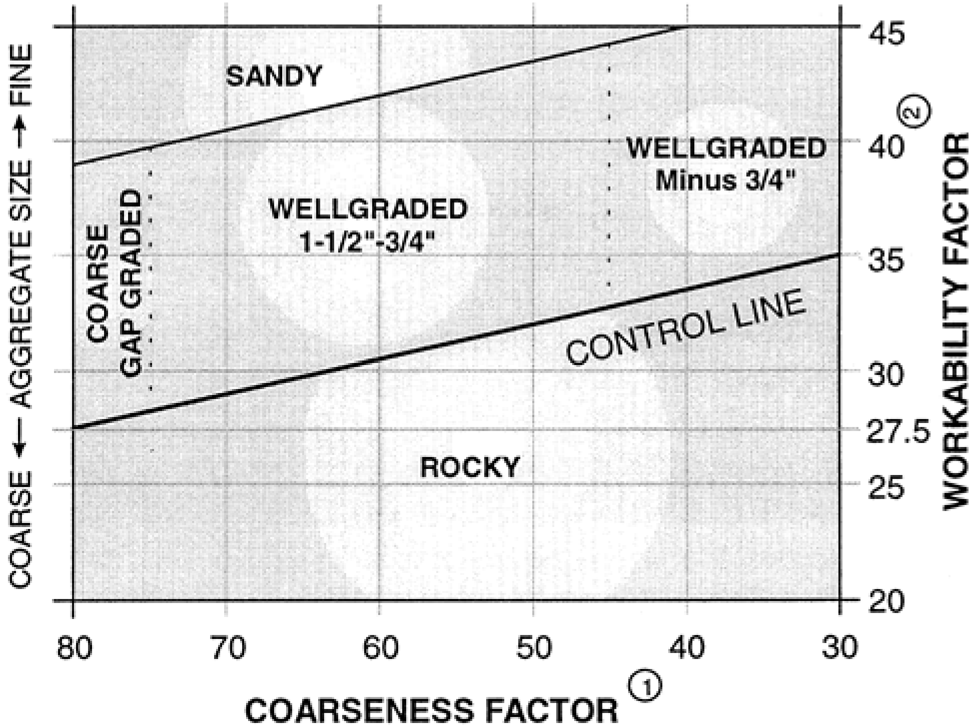
a. Aggregate blends that plot close to the bottom boundary line may tend to have too much coarse aggregate, producing rocky mixtures with inadequate mortar.

b. Aggregate blends above the top boundary line (Area D) will produce sandy mixtures with high amounts of fines requiring higher water content and potential for segregation.

c. Aggregate blends with coarseness factors higher than 75 (Area E) will produce gap-graded mixtures with inadequate workability and high potential for segregation.

d. For aggregate sizes less than 19 mm (0.75 in.), the areas will slide to the right within the given control lines.

Figure 7-2 Aggregate Proportioning Guide



7-9.1.6 Aggregate Proportioning Guide.

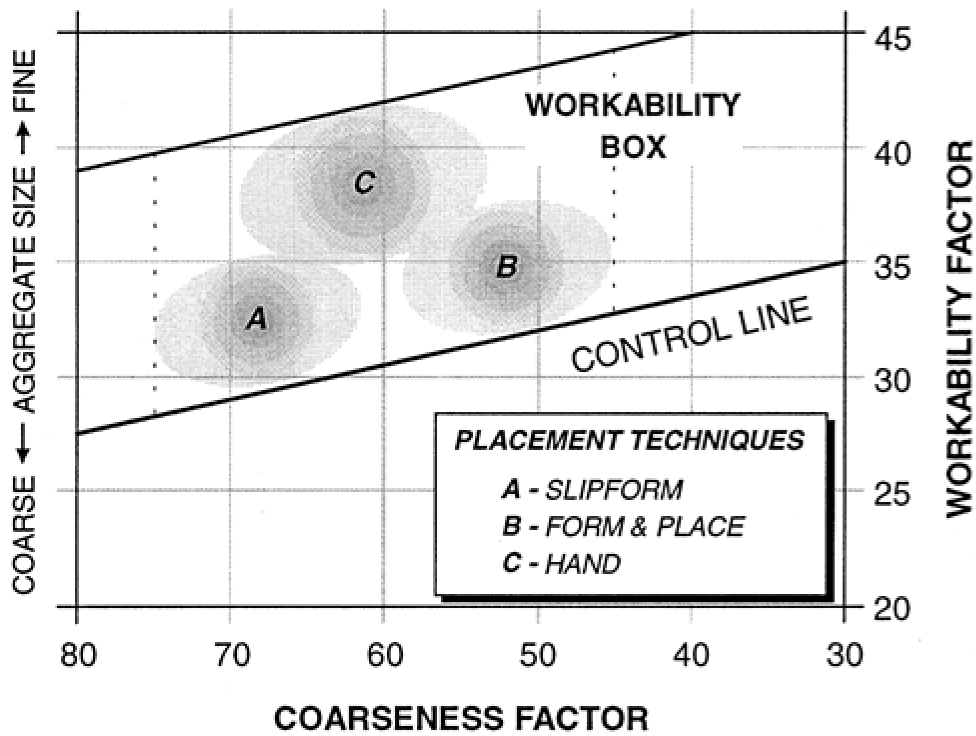
When a combined aggregate grading appears to meet the criteria of the percent retained graphic, then assess the location in the workability box that is best suited to the method of placement. Evaluate the workability factor and coarseness factor, as shown in Figure 7-3, as follows.

a. Aggregate blends that plot at the lower left of the box near the control line (Area A) produce mixtures suitable for slipform paving. However, based on texture and shape, aggregates falling in other regions of the chart can be acceptable for slipform paving.

b. Aggregate blends that fall at the lower right corner of the workability box (Area B) produce mixtures suitable for fixed form paving. This assumes that smaller aggregate sizes are needed to move the coarseness factor to a lower number and increase workability.

c. Aggregate blends that fall at the top of the box (Area C) produce mixtures suitable for hand-placed areas.

Figure 7-3 Workability Box within Aggregate Proportioning Guide



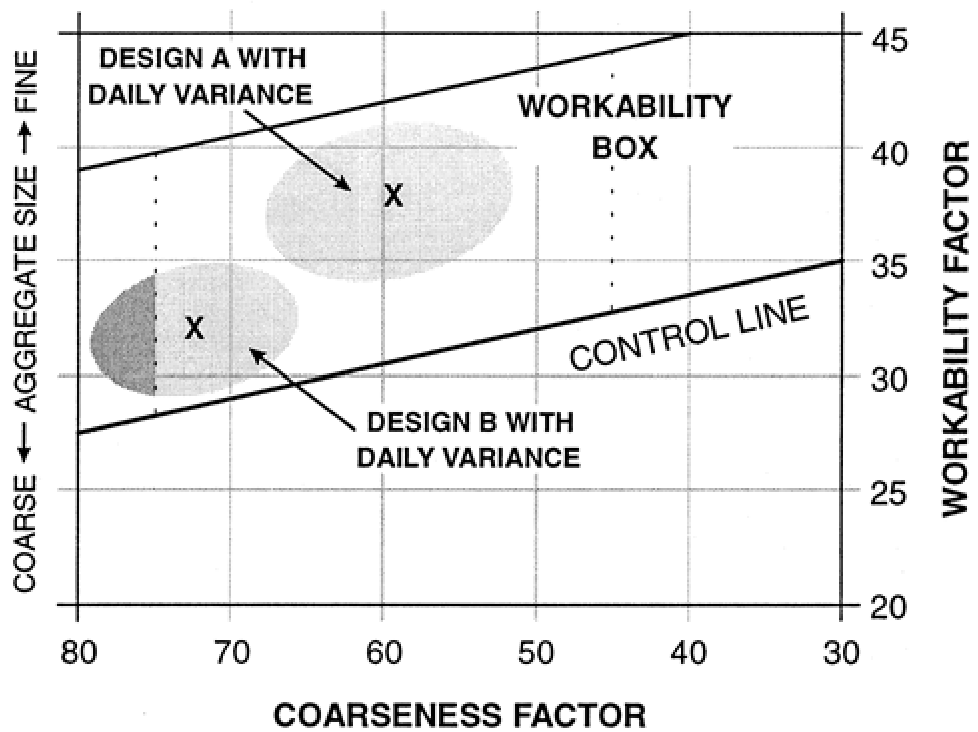
7-9.1.7 Controlling Factors.

The above criteria is not exact because the aggregate proportioning guide for grading does not take other "workability" factors into account. The shape of the fine aggregate particles will affect workability, but this is not reflected in the grading. When using the coarseness/workability chart it is assumed that particles are rounded or cubical shaped. Flat and elongated aggregates typically limit workability and finishing characteristics. Rounded or cubical shaped aggregates typically enhance workability and finishing characteristics. While the entrained air content directly affects workability, it is not considered in the aggregate proportioning guide. Chemical admixtures adjust the workability of the mixture and should not be neglected in the final selection of a concrete mixture for subgrade ability. Use the aggregate proportioning guide as a guide and not as a rule. It is necessary that the person doing the mixture proportioning be familiar with the method of placement and the characteristics of the mixture best suited to that method. In a similar fashion, the person evaluating the mixture proportioning study must balance the data presented and the results of previous paving projects. The final test, for both the contractor and the engineer, are the characteristics and the response of the mixture to the method of placement as observed at a test strip placement.

7-9.1.8 Gradation Variations.

An important consideration in selecting the final design aggregate grading, using the aggregate proportioning guide, is the location of the design grading relative to the expected daily variance of the concrete mixture materials. Changes in coarse, blend, and fine aggregate gradations could place the plot outside of the workability box, as illustrated in Figure 7-4. A normal variance of about 5 percent on the coarseness factor and about 3 percent on the workability factor should be considered in the final selection of an aggregate blend. Therefore, Design A would be a better choice than Design B, considering the daily variance.

Figure 7-4 Daily Variance within Workability Box for Aggregate Proportioning



7-9.1.9 Slag Aggregates.

Properly aged iron ore blast-furnace slag aggregates have a history of good performance. However, control of moisture content is 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. **Note:** Never use slag from open hearth steel mills as concrete aggregate or for econocrete/lean concrete base because of the expansive nature of the steel slag aggregates.

7-9.1.10 Recycled Concrete Aggregates.

Recycled concrete, or crushed concrete, is a feasible source of aggregates if 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 concrete with virgin aggregates. Recycled aggregate may also require added cement to achieve desired workability. A potential problem with recycled aggregate is that the variability in the properties of the old concrete may affect the properties of the new concrete. Recommend evaluating recycled concrete aggregates by petrographic examination. Identify why the recycled concrete was removed. Do not incorporate problematic recycled concrete into new concrete mix. Recycled concrete cannot contain rebar.

7-10 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 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. 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).

7-10.1 New Mixture Design Implementation.

If a new mixture design is developed because of changes in concrete materials, allow the contractor to proceed with paving once the early-age breaks indicate that the new mixture provides 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 for the new mixture to satisfy. Required concrete characteristics include mixing, placing, consolidation, and finishing under the job site conditions. Verify setting times. If pavement construction spans more than one season, it is advisable to develop more than one mixture design.

7-10.2 Differences in Laboratory and Plant Mixing.

Note the following differences between laboratory and plant mixing.

a. Differences in the size of a batch and type of mixer produce different mixing efficiencies. It may be necessary to adjust chemical admixtures dosages to obtain the desired workability and air content.

b. Normal laboratory mixing procedures obscure any tendency of a 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 three minutes of mixing and compare to the slump after final mixing to check the tendency to false set.

c. Temperature can significantly affect workability, water demand, slump loss, air content, and setting. Conduct laboratory mixture designs at the temperature(s) anticipated in the field.

d. 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.

e. Long haul times may necessitate an initial air content higher than required at placement to compensate for the loss of air during transit.

f. Avoid mixture designs that are excessively sensitive to elevated placement temperatures, variations in aggregate moisture content, or slight variations in batching.

g. The manufacturer's maximum recommended dosage of water reducer should not be routinely required for acceptable workability in the laboratory, as there is no possibility of increasing the dosage in the field without affecting the setting time.

h. Closely monitor the concrete material properties as well as the fresh concrete properties during the early stages of a job to make quick adjustments if needed.

i. 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 problems 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.

j. If plant mixture behavior differs from the laboratory mixture, causes 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

k. 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 in a laboratory

7-10.3 TROUBLESHOOTING GUIDE.

Observations and documentation are important tools to isolate and solve construction problems. Look for patterns that appear to connect cause and effect. For example, if everything works well until the weather becomes hot or a new shipment of cement arrives, the most recent change may be a clue to the root cause of the problem. Alternatively, if construction practices are marginal, the last change may simply tip the balance to unacceptable performance. In hot weather or cold weather, certain types of problems predominate. Paragraph 8-20 discusses common problems and possible remedies.

CHAPTER 8 CONCRETE PLACEMENT, FINISHING, TEXTURING, AND CURING

8-1 PAVING EQUIPMENT.

Paver-finishing machines accomplish concrete paving for mainline pavement and large fillets. Handwork areas are those areas too small to use a machine. Heavy and light pavers are used for machine paving. Slipform pavers are heavy machines. Only use light-weight machines, such as bridge deck finishers, clary screeds, truss screeds, or roller screeds if the contractor can show that they can produce satisfactory pavement with this type of equipment.

8-1.1 Slipform Pavers.

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

- Self-propelled with four tracks
- Generally weigh at least 3,280 kg/m (2,200 lb/ft) of paving lane width
- Variable-speed hydraulically controlled internal vibrators
- Ability to carry a head of concrete in front of the screed
- Continuous auger or hydraulic plow-pans to distribute concrete in front of the screed
- Finishing attachments

8-1.2 Manual Paving.

Labor-intensive manual paving is typically carried out only for small areas such as fillets.

8-1.3 Differences Between Slipform and Bridge Deck Paving Machines.

The differences between slipform and bridge deck paving machines are summarized below.

a. The bridge deck paver production capacity is significantly less than a slipform paver.

b. The bridge deck paver is most economical when paving lanes wider than 12 m (40 ft) and in geometrically constrained areas. Bridge deck pavers are capable of placing concrete up to 15 m (50 ft) wide.

c. 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.

d. A major difference between the pavers is the method of consolidation.

- The single vibrator of a bridge deck paver consolidates the concrete by plowing transversely across the truss.
- Combined with the forward travel of the paver, the concrete is plowed in a zigzag pattern.

e. 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.

- 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.
- Concrete mixtures are uniquely designed for fixed form paving. Slipform paver concrete mixtures do not work for fixed form paving and vice versa.

8-2 CRITICAL FACTORS FOR CONCRETE PAVING:

The following are critical factors affecting concrete paving.

- A good grade for paving; trimmed and compacted to specification
- Stringline management; monitor and maintain stringline at regular intervals
- Continuous supply of concrete to the paver
- Consistent concrete workability
- Well-maintained paving equipment
- Proper operation of paving equipment
- Controlled density of concrete; just the right level of vibration to consolidate concrete and provide enough fines at surface for a tight finish
- Most importantly, a skilled and dedicated crew

8-3 CONCRETE DELIVERY AT THE SITE.

Before and during concrete delivery, the following should be considered:

a. Inspect the grade for acceptance before depositing concrete. Remove loose debris and repair any base damage.

b. Verify string line elevations.

c. 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.

d. When pulling slipform pavers off headers, a slightly higher slump concrete should be used to facilitate hand consolidation and finishing operations.

e. Encourage the use of agitator trucks because they usually provide more uniform concrete placement and minimize concrete segregation.

f. 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, use additional trucks or reduce the paver speed.

8-4 CONCRETE PLACEMENT.

Acceptable concrete placement practices include the following.

a. Deposit concrete 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.

b. Place the concrete such that one side of the paving lane is not overloaded with concrete.

c. In formed areas, place the concrete as close as possible to its final position to minimize the potential for concrete segregation.

d. Concrete is either dumped on grade in front of the paver or onto belt placers and side-loading spreaders.

- If dumping on grade, control rate of dumping by controlling the tailgate opening.
- It is poor practice to spread concrete in front of a paver using an end loader.

e. The advantage of dumping directly in front of pavers or spreaders is that concrete head in front of the machine auger is easily maintained.

f. The disadvantages of directly unloading in front of the paver are the following.

- Trucks backing into the paver may disturb the compacted granular base.
- Dowel baskets must 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. The safety of laborers fastening baskets in areas between the forward-moving paver and backward-moving dump trucks must be considered.
- When placing baskets just ahead of the paver, a full-time inspector may be required to check dowel bar placement and alignment.
- 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.

g. When using a belt placer:

- Swing the belt back and forth to maintain a uniform head of concrete in front of the paver
- If the paver is low on concrete, back up placer to place more material where needed

h. When a spreader is used, do not advance more than 7.5 m (25 ft) ahead of the paver and thus allow timely adjustment if the head of concrete at the paver is too low or too high.

i. The paver operator must control the level of concrete in the grout box by raising or lowering the strike-off blade when required.

j. The following may reduce the potential for dowel bar misalignment associated with the forward-moving concrete head in front of the paver or spreader:

- 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.
- Do not dump concrete by trucks directly on basket assemblies.

8-4.1 Concrete Head.

Concrete head must 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.

8-4.2 Paver Speed.

a. Slow and constant speed of the paver results in smooth pavements.

b. 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.

c. The paver should not be stopped frequently during the paving operation.

d. Generally, the forward speed should be a minimum of 30 m (100 ft) per hour.

8-4.3 Filler Lane Placement.

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 result in small comer breaks/spalls. If pilot lane joint widths are greater than 6 mm (0.25 in.), use backer rod, duct tape, or asphalt mastic to cover the joint openings. Although filler lanes may 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

8-5 EMBEDDED STEEL AND TIE-BAR PLACEMENT.

Use chairs to securely support embedded steel bars or mesh typically used in fillet areas and other odd-shaped panels. Space the chairs close enough to support the steel without sagging. Support tie bars used as embedded steel and positioned around penetrations on chairs within tolerances of the specified elevation. Welded wire fabric must 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 must be strong enough to support the weight of laborers during concrete consolidation. Prior to concrete placement accepted by inspectors, verify 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.

8-5.1 Tie Bars.

Tie bars are not permitted on airfield pavements. Use tie bars only for road and street projects.

8-5.2 DOWEL BAR INSTALLATION.

During dowel bar installation, consider the following.

a. Dowel bars at transverse contraction joints are pre-positioned using dowel bar baskets secured to the base. Installing these dowels by dowel inserters attached to the paver or by any other means of inserting the dowels into the plastic concrete is not permitted.

b. Dowel bars at longitudinal sawed contraction joints can be pre-positioned using basket assemblies. Dowel bars at longitudinal sawed contraction joints cannot be injected using a dowel bar jammer on airfield or other heavy-duty pavement.

c. Dowel bar inserters are prohibited at longitudinal construction joints due to the high potential for misalignment and undesirable air pockets.

d. Dowel bars at longitudinal construction joints and transverse headers are installed using a drill and epoxy technique. Holes are drilled into vertical edges.

8-5.2.1 Dowel Bar Alignment.

Dowel bar alignment is a critical item and must be checked on a regular basis. Dowel misalignment has a significant effect on pavement performance. Table 8-1 lists the types of dowel bar misalignment and their impact on performance. Figure 8-1 illustrates these types of misalignments. Important dowel installation items are as follows.

8-5.2.1.1 Typical Alignment Specifications.

- 10 mm/m (1/8 in./ft) or less out of alignment in the vertical and horizontal plane
- 15 mm (5/8 in.) or less horizontal or longitudinal translation
- 13 mm (1/2 in.) or less vertical translation

8-5.2.1.2 Basket Assembly Stations.

Verify the assemblies to ensure they are centered at joint locations.

8-5.2.1.3 Dowel Bars at Longitudinal Joints.

Inspect bars to ensure the specified clearance from the ends of transverse joint dowel bars is maintained.

8-5.2.1.4 Reduce Restraint at Slab Corners.

To reduce restraint at slab corners, position dowel bars at longitudinal joints at least 150 mm (6 in.) and preferably 300 mm (12 in.) away from the ends of dowel bars in the transverse joints.

8-5.2.1.5 Dowel Baskets.

Securely fasten baskets to the base.

- Clips are generally adequate when fastening a basket to stabilized base.
- Long stakes are required to securely fasten baskets in granular and open graded bases.

8-5.2.1.6 Longitudinal Dowel Basket Wires.

Crimp wires instead of cutting. Crimping reduces cross-sectional area while maintaining basket stability.

8-5.2.1.7 Verify Dowel Bar Alignment.

Verify alignment by:

- Exposing dowels in plastic concrete
- Coring over dowel bar ends
- Using a magnetic rebar cover meter.
- Nondestructive testing such as GPR.

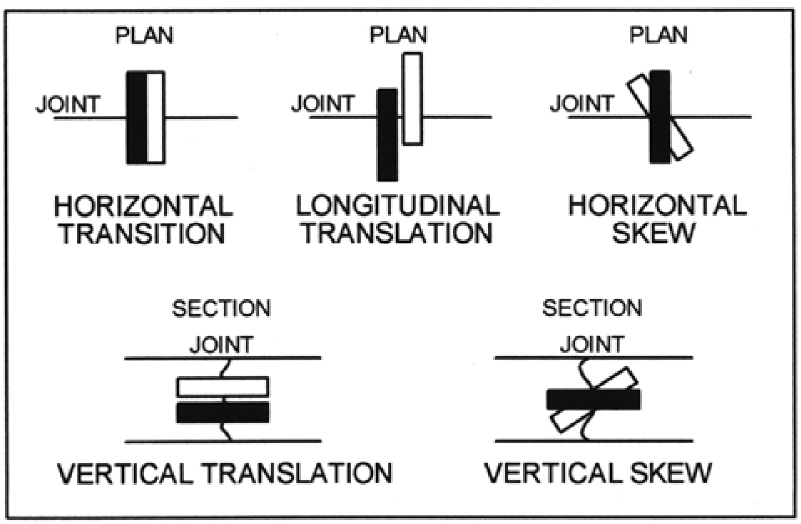
8-5.2.1.8 Prior to Paving.

Inspect dowel bars 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, inspect the coverage before concrete placement.

Table 8-1 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 skew	Yes	Yes	Yes

Figure 8-1 Dowel Bar Misalignment Categories



8-5.2.2 Basket Versus Inserted Dowels.

A method specification is typically used for dowel baskets.

- 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 GPR.

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.

8-5.2.3 Dowel Bars at Construction Joints.

Install dowel bars at construction joints using the drill and epoxy grout procedure. Side injected dowel bars are prohibited on airfield pavements. Install dowel bars after the concrete has cured sufficiently to allow:

- The new pavement to support drilling equipment weight.
- Hole drilling without excessive chipping and spalling (> 12.5 mm [0.5 in.]) or beyond the diameter of the grout retention disc. Expect minor chipping.

Important items in the installation process include the following.

a. Use gang drills to simultaneously drill several holes.

b. Slightly over-size holes, about 3 to 6 mm (1/8 to 1/4 in.) larger than the dowel bar diameter.

c. Spot-check the depth of drilled holes to ensure the dowels are nominally inserted halfway into holes.

d. Inject epoxy at the back of the drilled holes and twist the dowel as it is pushed into the hole. Applying epoxy by hand to dowel bars before insertion is a prohibited technique.

e. Grout retention disks may be used to prevent epoxy from flowing out of the holes.

f. Inspect dowel bars to verify adequacy of the epoxy coverage. Proper epoxy grouting is important to ensure the dowels are bearing on a sound interface and voids do not exist. Otherwise, load transfer effectiveness is compromised.

g. Oil the exposed ends of the dowel bars before concrete placement. Do not use grease to coat the exposed ends of dowel bars.

8-6 CONCRETE CONSOLIDATION.

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

a. Slipform pavers consolidate concrete in the grout box using gang-mounted vibrators.

b. For larger pavers, vibrators are hydraulically driven. Electric or hydraulic vibrators may be used for small slipform pavers.

c. Inadequate consolidation results in lower concrete strength and honeycombing. Inadequate vibration can be due to:

- Poorly functioning or dead vibrator
- Paver speed too high
- A concrete mix with poor workability

d. Over-consolidation can lead to freeze-thaw durability problems if the air void system is adversely altered. Over-consolidation can be due to:

- Excessive vibrator frequency
- Reducing paver forward speed without an adjustment to vibrator frequency
- Concrete mix properties of poor workability

e. Vibrators are generally positioned no more than 100 mm (4 in.) below the finished pavement surface. Setting vibrators too low results in air being trapped under the grout box head, leading to delamination or blistering of the concrete surface.

f. Vibrators are generally positioned at an attitude of 5 to 10 degrees. As the paver moves forward, the angled vibrators plow the concrete.

g. Vibrator spacing is a function of the radius of the zone of influence. The zone of influence and vibration energy input into concrete is a function of paver speed, vibrator rotor force, and frequency (set by equipment operator).

h. Before each day of paving, vibratory frequencies and amplitudes must be checked under no load. Large deviations between vibrators are indicative of poorly functioning vibrators.

8-6.1 Verifying Consolidation.

Examine cores drilled in the test strip or initial stages of placement 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. Examine cores between and in vibrator paths for:

- Evidence of aggregate segregation in vibrator trails
- Excessive entrapped air
- Differences in hardened concrete density

8-6.2 Vibration for Consolidation.

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. Evaluate the response of the concrete mixture to vibration on the first day of paving or after the test strip construction. Eliminate large pockets of entrapped air (honeycombing) and aggregate segregation by changing the following:

- Vibrator frequency
- Forward travel speed of paver
- Vibrator depth
- Vibrator spacing

Smart vibrator systems that continuously monitor individual vibrator frequencies during paving operations are available. Use of a smart vibrator system 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.

8-7 CONCRETE FINISHING.

Concrete finishing is a critical step in the paving process. Concrete finishing is the hand finishing 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. The following can aid in obtaining a good finish:

- Minimize excessive handwork
- Do not apply water to help finish the surface
- Surface does not need to be excessively smooth or 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 as follows.
    - The need for concrete finishing is minimized by:
        - Selecting a workable concrete mixture
        - Properly operating the paving equipment
    - Excessive hand finishing will work water to the surface and can affect surface smoothness and concrete durability.
    - Problems closing the surface behind the paver are indicative of:

        - Inadequate volume contained in the grout box or concrete setting up in the grout box
        - Fine to coarse aggregate volume or paste volume too low
        - The finishing pan angle needing adjustment
        - The paver speed being too high
        - Vibrators needing adjustment
    - If water is 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.

8-7.1 Hand Finishing.

Excessive hand finishing or adding mortar and water to the surface of the pavement are indicators of mixtures with an undesirable combined gradation. Continuing these practices produces pavements that are FOD generators, such as scaling and spalling. Adjust mixture proportions and finishing techniques whenever necessary to minimize hand finishing.

8-8 CONCRETE TEXTURING.

Concrete pavements require a surface texture that provides the desired level of skid resistance. The primary functions of surface texture are to provide (a) paths for water to escape from beneath tires and (b) a 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 a 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.

8-8.1 Brush or Broom Finish.

- Applied when the water sheen (bleed water) has just disappeared
- Applied transversely across the pavement
- Corrugations should be uniform in appearance and 1.5 mm (1/16 in.) deep
- The textured surface must not exhibit tears and be unduly rough
- Burlap or Astroturf drag finish

Macrotexture of the finished concrete surface should have a mean depth of 1 mm (0.04 in.) when measured by ASTM E965. Burlap drags are the most common texture techniques for airfield pavements.

- The burlap rating should be about 500 gm/m^2 (15 oz/yd^2).
- The trailing edge of burlap must have a heavy buildup of grout to produce the desired longitudinal striations on the surface.

- Operate the drag with the fabric moist and clean, or changed as required to keep clean.
- The corrugations produced by burlap drag must be uniform in appearance and about 1.5 mm (1/16 in.) deep.

8-8.2 Wire Combing (Rigid Steel Wires).

- Use wire combing to provide a deeper texture in the plastic concrete.
- Steel wires are about 100 mm (4 in.) long, 0.8 mm (0.03 in.) thick, and 2 mm (0.08 in.) wide.
- Continuous tracks are approximately 3 mm by 3 mm (1/8 in. by 1/8 in.) and spaced 13 mm (0.5 in.) center to center.
- Brush, broom, or burlap finish is not necessary before providing wire tining.
- Wire combing is not a substitute for grooving. It does not provide for improved surface drainage.

8-8.3 Wire Tining (Flexible Steel Bands).

- Use wire tining to provide a deep texture in the plastic concrete.
- Flexible steel bands are about 130 mm (5 in.) long, approximately 6 mm (0.25 in.) wide and spaced 13 mm (0.5 in.) apart.
- Brush, broom, or burlap finish is not necessary before providing wire combing.
- Wire tining is not a substitute for grooving. It does not provide for improved surface drainage.

8-9 GUIDANCE FOR TEXTURING AND GROOVING.

The designer must select the type of texturing desired. If no guidance is given, the usual default method is burlap drag. For airfield paving projects, do not specify artificial turf, wire comb, or surface grooving textures.

8-9.1 Grooving.

Spring tine grooving is limited to use on roads and streets only. Grooving of airfield pavement must be sawcut. Use either the FAA's standard or trapezoidal grooving patterns. For the standard groove pattern, grooves are approximately 6 mm by 6 mm (0.25 in. by 0.25 in.) and spaced 37 mm (1.5 in.) center to center for airfield pavements and spaced 50 mm (2 in.) for roads. Trapezoidal grooves are spaced 57 mm (2.25 in.) center to center, 6 mm (0.25 in.) deep, 6 mm (0.25 in.) wide at the bottom, and 12 mm (0.5 in.) wide at the top.

Do not groove within 152 mm (±76 mm) (6 in. [±3 in.]) of the runway centerline, crown, Transverse joints, working cracks or light fixture. Do not groove within 6.1 m (20 ft) of the aircraft arresting system cable. Grooves are not required to cross joints. Do not groove through compression seals. Replace any compression seals cut or otherwise damaged by the grooving operations. Terminate grooves within 1.5 to 3 meters (5 to 10 feet) of the pavement edge to allow for operation of the grooving equipment.

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). Four important keys to proper application of a curing material are (a) proper mixing, (b) uniformity of application, (c) timing of application, and (d) yield check (rate of application). Important issues related to proper concrete curing are addressed below.

8-10.1 Timing of Curing Application.

Timing is critical, especially during hot weather. Apply curing compound as soon as free water disappears from the concrete surface after finishing and texturing. When using fly ash and slag, free water may not form.

8-10.2 Curing Compounds Spraying.

Uniform coverage and coverage rates are critical for sprayed curing compounds.

a. Apply spray curing using spray equipment mounted on a self-propelled frame that spans the paving lane.

b. Limit hand spray curing to hand-placed concrete areas.

c. Employ overlapping coverage that provides a two-coat application at a coverage.

d. Uniformity of white-pigmented curing compounds are subject to visual examination, but verify application rates by measuring the volume used for a given area and compare it to the specifications.

e. Apply curing to exposed concrete faces after slipforming or removing forms.

f. Apply curing to joint surfaces immediately after sawing and cleaning.

g. If using moist curing, maintain the entire concrete surface continuously wet for the entire curing period (typically seven days) or until a curing compound is applied.

See additional discussions related to curing for hot and cold weather concrete placement in paragraphs 8.16 and 8.17.

8-11 MINIMIZING EDGE SLUMP.

Detect excessive edge slump while concrete is 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 6 mm (0.15 in.) or if any edge slump exceeds 10 mm (3/8 in.).

Minimize edge slump occurrences because it impacts joint efficiency and performance. 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, stop paving and implement measures to correct excessive edge slump. Factors that affect edge slump include:

- Concrete consistency
- Concrete mixture compatibility with placement techniques
- Paver adjustments and operation
- 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 or isolated areas such as fillets or irregular pavements and employs machine pavers or manual placement. Important considerations include the following.

8-12.1 Steel Forms.

Position forms on the finished base and check top elevations.

8-12.1.1 Granular Base.

a. If grade along the forms is low, place and compact additional base material.

b. If grade along the forms is too high, rework the base to lower the grade.

c. Correcting high spots in granular material only near form edges is poor practice. High spots between the forms will result in a lower concrete thickness away from forms that result in variable thickness.

8-12.1.2 Stabilized Base.

a. If grade along forms is low, shim forms to maintain horizontal alignment during concrete placement. If more than 25 mm (1 in.) shimming is needed, remove and replace the base in low areas to achieve the required base elevation.

b. For high areas in cement treated base, cut down cement-treated open graded and open graded asphalt stabilized bases with a motor grader blade.

c. Grind high areas in lean concrete (econocrete) and asphalt concrete bases to elevation.

d. Lowering base elevations only in the vicinity of forms results in a thin concrete cross-section away from forms that produces variable thickness.

e. Consider a bond breaker layer of broadcast sand or double application of waxed-based curing compound in areas that are ground and thereby reduce the potential for bonding between the base and the concrete.

8-12.2 Set Forms.

Mechanically tamp forms and stake them securely into the base with stakes no more than 900 mm (36 in.) apart.

8-12.3 Check Transition Joints.

Ensure that no significant deviation affects the finished concrete smoothness between forms.

8-12.4 After Forms are Connected.

Check vertical and horizontal alignment.

8-12.5 Damage.

To minimize damage during form-removal operations, spray forms with form release oil not more than four hours before paving.

8-12.6 Spalling.

To prevent corner spalling and damage to concrete, forms are not normally removed earlier than 12 hours after concrete placement; however, remove forms no later than 24 hours. Removing forms later than 24 hours may affect concrete curing of vertical edges adjacent to forms.

8-12.7 Exposed Sides.

Spray exposed sides with curing compound within 30 minutes after form removal. Coat edges at coverage rates used for the pavement surface.

8-13 PAVING AND IN-PAVEMENT STRUCTURES.

8-13.1 Lighting Fixtures.

The most common in-place structures in airfield concrete paving are light cans. Layout in-pavement lighting systems to minimize interference with proposed pavement joints. For conflicts with pavement joints, make use of pavement blockouts to construct in-pavement lighting structures near a joint. Normally, a blockout is required when the centerline of the light base can is within 750 mm (2.5 ft) of a pavement joint. Light cans may be installed using one of the following techniques.

8-13.1.1 Blockouts.

a. Install blockouts at light can locations and place the pavement around the blockouts.

b. Check blockouts elevations for grout box clearance.

c. Place filler material used to stabilize blockouts within 75 mm (3 in.) or less of the finish elevation.

d. After construction, remove any filler material, position light cans, and backfill the blockout area with concrete.

e. 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 reduce the potential for crack spalling. Position tie bars between the upper third and half depth of pavement. Securely tie bars to chairs fastened to the base.

8-13.1.2 Split Cans and Coring.

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 as follows.

1. Position partial can in the base.
2. Pre-place concrete at the base of the partial cans to anchor the cans.
3. Pave the lane.
4. Drill a 100 mm (4 in.) diameter core to determine the exact center of the can.
5. Drill a 360 to 460 mm (14 to 18 in.) hole for the can top section.
6. Complete light can installation.

8-13.1.3 Cookie Cutter.

This technique is similar to the coring method: light cans are anchored in place and paving is placed over them. The steps involved are as follows.

1. After the paving machine passes over a light base, a “cookie cutter” is pressed into the plastic concrete by a worker sitting on a bridge suspended over the pavement.
2. After the concrete sets (sufficiently rigid for the reservoir to retain its shape but plastic enough to allow surface finishing), the cookie cutter is removed, the concrete inside the impression is removed and discarded, and the surrounding surface is hand finished.

8-13.1.4 Implications of Improperly Installed Light Bases.

Benefits to the paving contractor include time and cost savings when light base installation deficiencies are detected before concrete paving. It is relatively cost free to check a light base before paving; it is an expensive proposition to remove a light base after the pavement is placed and finished. The height setting of a light base is the most common cause of a deficient installation. When the light base is set too high, there is no satisfactory mitigation other than to remove and replace. Therefore, checking the height before concrete paving is a critical step.

On some projects, the uniformity of the concrete surface surrounding the light base has been observed to distort to the extent that height tolerances become difficult to establish and high spots block the light beam. The specific cause or causes of this problem are not known and the condition is only detected during inspection after paving is complete. The surface of the concrete around light base locations must be carefully inspected immediately after pavement finishing and during the time that the concrete is plastic.

8-14 OTHER STRUCTURES.

Other in-place structures commonly encountered with airfield 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 must be used around the structure for crack control. Additional items to consider for the design and construction of in-place structures include the following.

a. Design details for in-place structures must account for expansion of concrete pavements adjacent to the structure and for moisture infiltration into the structure.

b. Larger in-place structures (such as utility manholes, hydrant pits, or drainage trenches) must be located at least 1.2 m (4 ft) 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 1.2 m (4 ft) dimension, place the structure at the pavement joint along with appropriate load transfer (thickened edge) and concrete slab expansion details.

c. 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 750 mm [2.5 ft] from the pavement joint.

d. 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.

e. Trench drain walls must be designed to be stiff enough to resist concrete pavement expansion. Struts in trench drains may be required if concrete expansion movement at the trench drain is anticipated to be high.

8-15 PAVING AT FLEXIBLE PAVEMENT INTERFACES.

Matching elevations is a common problem where concrete and flexible pavement sections abut one another.

8-15.1 Techniques for a Smooth Interface.

a. Sawcut flexible pavement vertically full depth where it abuts new concrete to minimize disturbance to the base layer under the asphalt layer.

b. If the flexible system is sawcut significantly ahead of paving, shore up the vertical face of the flexible pavement system to minimize loss of base associated with unsupported granular layers sloughing.

c. Alternatively, over cut the flexible pavement, pave along the planned flexible pavement interface, and replace the flexible pavement at the over cut. If possible, use a buried concrete slab tied to the concrete pavement along the over cut area.

d. To minimize the potential for faulting at the interface construction joint, compact the base adjacent to forms and along the cut flexible pavement edge using pole tampers and plate compactors.

e. To minimize the hand-finishing effort when matching elevations, start paving at the flexible pavement edge and move the paver away from the edge.

f. Do not allow slipform equipment to track on the unsupported flexible pavement edges.

g. 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, consider the following:

    - Grind the flexible pavement down to the planned concrete elevation.
    - Place concrete higher and thin mill or resurface the flexible pavement.
    - During compaction of the surface layer of asphalt, do not allow the steel roller to run on the concrete edge.

8-16 HOT-WEATHER CONCRETE PLACEMENT.

ACI defines hot weather as a period longer than three consecutive days exhibiting the following conditions:

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

8-16.1 Concrete Mixture.

Only use a concrete mixture for hot weather 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:

- Rapid slump loss
- Reduced air contents
- Premature stiffening
- Plastic shrinkage cracking
- Thermal cracking

8-16.2 Hot Weather Concreting.

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

b. Retarding admixtures if their performance is verified during trial batches. High dosages of water reducers (even high-range water reducers) can retard setting.

c. Substitute slag, Class F fly ash, or natural pozzolans for part of the cement. These materials hydrate more slowly and generate lower heats of hydration than cement, thus reducing problems with slump loss, premature stiffening, and thermal cracking.

d. Correct air content by increasing the dosage of air-entraining admixture.

e. Early-age thermal cracking may be prevented by ensuring the temperature of the plastic concrete is as low as practical. It should not exceed 32 °C (90 °F).

   - Aggregates may be cooled by sprinkling with water. Corrections for the aggregate moisture are required.
   - Aggregates must be batched in a saturated surface dry condition to avoid absorbing mixture water.

f. Hot cement or fly ash provided by the supplier should not be used.

g. Mixing water may be chilled or chipped ice may be used to substitute for some of the water. Ensure all ice melts during mixing.

h. Mixing and transporting equipment may be painted white or a light color to minimize the heat absorbed from the sun.

i. Concrete placements can be scheduled for nighttime.

j. The base should be moistened before the concrete is placed to keep the temperature down and keep it from absorbing water from the concrete.

k. 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.

l. Steps should be taken during hot weather to reduce the rate of evaporation from the concrete. The likelihood of plastic shrinkage cracking increases with the 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:

- Air temperature
- Concrete temperature
- Relative humidity
- Wind speed

m. Calculate the rate of evaporation using the American Concrete Pavement Association's (ACPA) Evaporation Rate Calculator (http://www.apps.acpa.org/apps/EvaporationCalculator.aspx) or the High PERformance Concrete PAVing (HIPERPAV) software. Current data from an on-site weather station should be used.

n. When the rate of evaporation is predicted to be above 1.0 kg/m^2/hr (0.2 lb/ft^2/hr), provide fog spraying or use an approved evaporation retardant, as appropriate.

o. 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.

p. Refer to ACI 305, *Hot Weather Concreting*, for additional information.

8-17 COLD WEATHER CONCRETE PLACEMENT.

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

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

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

c. 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. Consider the following for cold weather concreting.

- Concrete mixture designs developed for placement at cooler temperatures normally have higher cement content than those used in hot weather.

- The use of slag, fly ash, and pozzolans should be reduced or eliminated unless they are required to control ASR or provide some degree of resistance to sulfate attack. In the latter case, the total cementitious materials content may need to be increased or the cement changed to Type III instead of Type I/II.
- The required dosage of air-entraining admixture should be lower than the dose at normal temperatures.
- 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.
- An accelerating admixture conforming to ASTM C494/CRD-C 87 Type C or E may be used, provided its performance has been previously verified by trial batches.
- Do not use admixtures containing added chlorides. Also, do not use calcium chloride.
- Aggregates must be free of ice, snow, and frozen lumps before being placed in the mixer.
- The temperature of the mixed concrete should equal or exceed 10 °C (50 °F).
    - The mixture water and aggregates may be heated to less than 66 °C (150 °F).
    - The material must be evenly heated.
- Concrete should not be placed when the temperature of the air at the site or the surfaces on which the concrete is to be placed is less than 4 °C (40 °F).
- Covering and other means of protecting the concrete from freezing must be available before starting placement.
- The concrete temperature should be maintained at 10 °C (50 °F) 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 20 MPa [3,000 psi]). Corners and edges are the most vulnerable to freezing.
- Completely remove and replace concrete damaged by freezing.
- Concrete placed in cold weather gains strength slowly. Concrete containing supplementary cementitious materials gains strength very slowly.
    - Sawing of joints to opening to traffic may be delayed.
    - 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.

- Refer to ACI 306, *Cold Weather Concreting*, for additional information.

8-18 PROTECTING CONCRETE AGAINST RAIN DAMAGE.

The paving team and the inspector must be knowledgeable of procedures to protect fresh concrete in the event of rain. Consider the following.

a. Protective coverings, such as polyethylene sheeting or tarpaulins, must be available onsite at all times.

b. When it starts to rain, batching and placing operations should stop. The fresh concrete must be covered so the rain does not indent the surface or wash away the cement paste.

c. There are two primary consequences of rain during pavement placement:

- 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.
- 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.

d. Should a rainstorm occur before the curing membrane is effective, the damage is usually limited to the surface.

e. Stiff, low-slump, paving-quality concrete that has been consolidated, struck off, and finished may sustain only minor surface blemishes from light rain.

f. When the rain is light, water will not soak into the concrete and result in an increase in the w/cm ratio.

g. 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 3 mm (1/8 in.).

h. Any concrete exposed to significant rain while it is loose or unconsolidated must not be used in the pavement as it can absorb water.

i. Once the unprotected pavement surface is exposed to rain there should be no attempt to finish or texture the surface.

j. Removal of extra surface water prior to covering should not be attempted. Water removal operations often increase the erosion of paste at the surface.

k. Adding dry cement or floating dry cement into the surface should not be attempted. Adding cement extends the time the surface is exposed, increasing the potential for additional surface damage. Working dry cement into the surface can also alter the entrained air void system that is required for freezing and thawing protection.

l. 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 texture the surface.

m. 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.

n. If unconsolidated concrete exposed to rain has been incorporated into the pavement, it must be removed.

o. Use of early entry saws or skip sawing (discussed in Chapter 9) to quickly install joints prior to incoming rain should be considered.

p. Installing joints as quickly as possible reduces the potential for early-age cracking attributed to restraint stresses generated with rapid surface cooling.

q. Once rain has ceased and surface coverings removed, needed joints are sawed as quickly as possible.

r. If a rainstorm catches an unprotected pavement, it is crucial that paving stop. The best precaution to avoid rain damage or random cracking is to quickly cease paving operations. On larger airfield projects, contractors may rely on weather stations at the airfield or subscribe to meteorological weather forecasting services to monitor current weather information.

8-18.1 Assessing Rain Effects.

Consider the following guidelines in assessing rain effects.

8-18.1.1 Mist.

An intermittent light mist may be beneficial, as long as no significant water is added to the unconsolidated concrete in front of the paver or to the concrete surface to be finished.

8-18.1.2 Accumulated Water.

If rain is sufficient to accumulate any water at all on the surface of freshly placed concrete prior to finishing, stop paving and take protective measures.

8-18.1.3 Hard Rain.

If rain is sufficiently hard to mark freshly placed concrete, it is past time to stop paving.

8-19 TESTING RAIN-EXPOSED SURFACE.

Evaluate any rain damage and establish the extent of damage. The rain-damaged concrete must be removed if the surface is determined to be not durable in terms of abrasion, skid resistance (surface texture), or freezing and thawing. 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 establish the limits of and disposition of damaged concrete. Generally, surfaces are not deemed durable for abrasion if damage extends down more than 3 mm (1/8 in.). For freeze-thaw durability, the air-void spacing factor should be less than 0.20 mm (0.008 in.). Other tests assess scaling and abrasion potential.

8-20 TROUBLESHOOTING GUIDE.

Common problems encountered at the job site and possible remedies are described in Table 8-2.

Table 8-2 Troubleshooting Placement, Finishing, Texturing, Curing

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 • High placement temperatures • Lignosulfonates in water-reducing admixture • Triethanolamine (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, absorptive 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 para. 8.17. • In hot weather, use the hot weather mixture design. • 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 must 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

Problem	Probable Cause(s)	Action
		times should not exceed allowable time.
Slump loss greater than 25 mm (1 in.) 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 • 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	• 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. • 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.

Problem	Probable Cause(s)	Action
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 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	• Check batching procedures. • Check aggregate grading. • Improve construction procedures. • Minimize delays in concrete delivery.

Problem	Probable Cause(s)	Action
	• Use of light paver	• 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.

Problem	Probable Cause(s)	Action
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, and screeds	• Improve construction practice.
Low strength concrete samples	• Errors in batching 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.

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CHAPTER 9 JOINT SAWING AND SEALING

9-1 INTRODUCTION.

Joint sawing and sealing require an experienced crew to correctly perform associated tasks. Although improved guidelines are available for estimating when sawing can begin, speed of sawing, blade condition, and operator care combine to influence the final product. Find additional information in UFC 3-250-08, *Standard Practice for Sealing Joints and Cracks in Rigid and Flexible Pavements*.

9-2 JOINT DESIGN.

There are three pavement categories: isolation, construction, and contraction (Figure 9-1). Find detailed guidance for jointing roads and parking areas in UFC 3-250-01. Refer to UFC 3-260-02 for guidance on airfield pavement jointing.

9-2.1 Isolation/Expansion Joints.

The purpose of an isolation/expansion joint is to separate intersecting pavements, isolate embedded fixtures within the pavement such as pavement drains, or when pavements abut buildings.

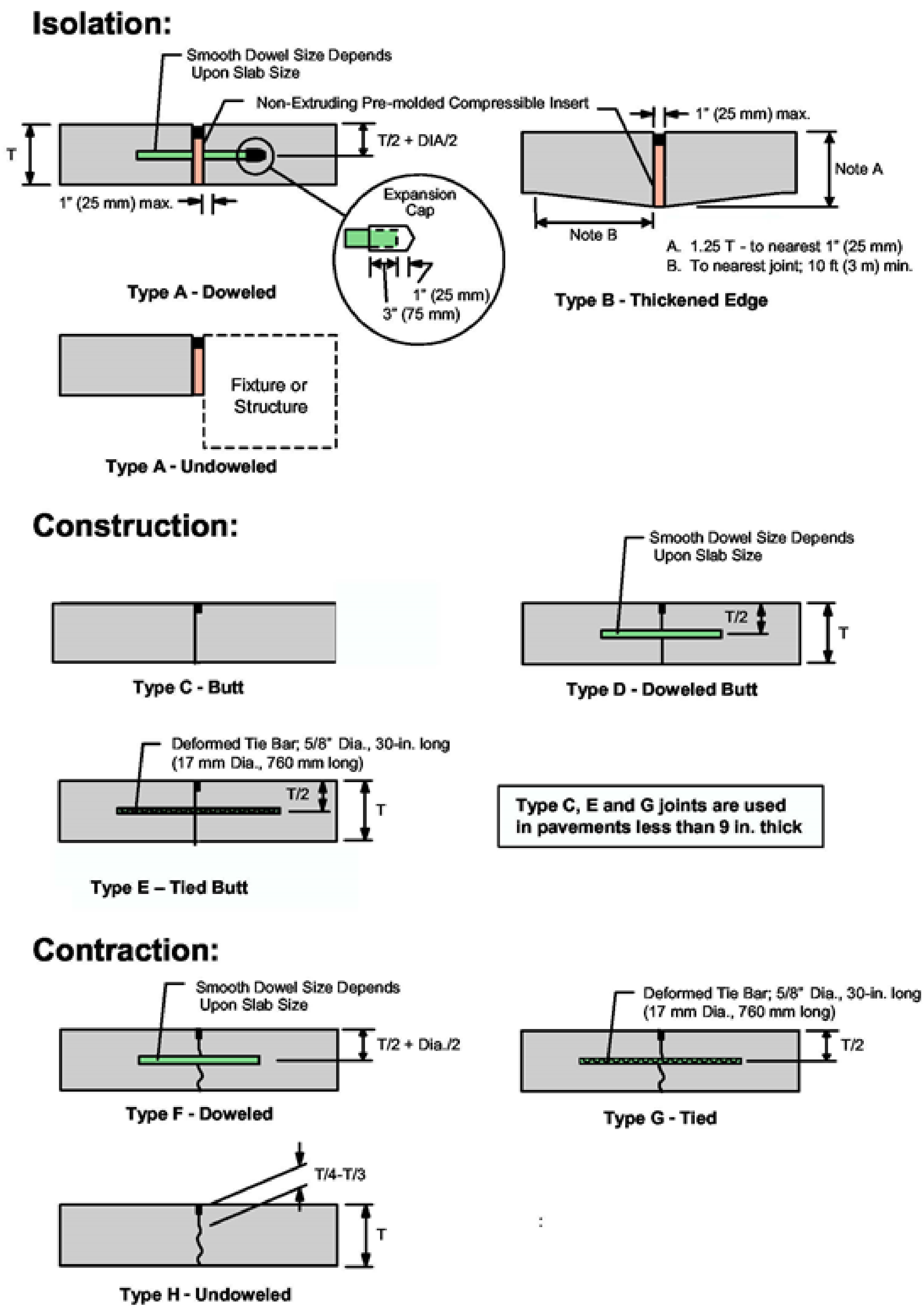
9-2.2 Construction Joints.

Construction joints separate abutting construction placed at different times, such as the end of a day’s placement or between paving lanes.

9-2.3 Contraction Joints.

Contraction joints control the location of pavement cracking caused by drying shrinkage or thermal contraction. Contraction joints also reduce stress caused by slab curling and warping.

Figure 9-1 Concrete Pavement Joint Types



9-3 JOINT LAYOUT PRACTICES.

Consider the following items when planning the 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 1.2 m (4 ft) from joints, when possible.

9-3.1 Joint Layout Considerations.

The following are necessary considerations.

9-3.1.1 Inspection.

Inspect the project drawings for the location of dowel bars and tie bars. If any problems are noted, discuss these elements with the engineer before paving.

9-3.1.2 Jointed Plain Concrete.

For jointed plain concrete pavements, do not exceed a slab length to width ratio of 1.25.

9-3.1.3 Odd-Shaped Panels.

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.

9-3.2 Factors Affecting Joint Spacing.

The primary function of all joints is crack control. Plain concrete pavement joints are spaced to reduce thermal and shrinkage restraint stresses such that no uncontrolled cracking occurs between joints due to these restraint stresses. The restraint stress magnitude influencing joint spacing depends on:

- Concrete temperature and moisture gradients (top and bottom of slab)
- Concrete temperature drop (relative to temperature at concrete final set)
- Concrete shrinkage
- Slab/base interface friction
- Modulus of base/subgrade reaction
- Pavement thickness

9-3.2.1 Concrete Properties Affecting Joint Spacing.

Concrete properties affect joint spacing. Concrete properties affecting restraint stress magnitudes are:

- Modulus of elasticity (generally 24,000 to 38,000 MPa (3.5 to 5.5 million psi); assumed as 27,000 MPa (4.0 million psi) for most design solutions)
- Coefficient of contraction (generally ranging from 9.0 to 11.8 x 10^{6} mm/mm/deg. C (5.0 to 6.5 x 10^{-6} in./in./deg. F)
- Shrinkage coefficient (generally ranging from 250 to 350 x 10^{6} in./in.)
- Density (generally 690 to 730 kg/m^2 (142 to 150 lb/ft^2) for air-entrained concrete)

Table 9-1 lists the maximum joint spacing.

Table 9-1 Maximum Joint Spacing

Slab Thickness, in.	Slab Thickness, mm	Joint Spacing, ft	Joint Spacing, m
< 9	230	12.5–15[1]	3.8–4.6
9–12	230–305	15–20	4.6–6
> 12	> 305	20	6

[1] 10–15 ft (3.0–4.6 m) for roads and parking lots

9-3.3 In-Pavement Structures.

9-3.3.1 Light Cans.

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 does not prevent restraint cracking around light can blockouts, the steel holds any cracks that develop tight and reduces the potential for crack spalling. Since most slab movements occur near longitudinal and transverse joints, establish jointing patterns such that light cans are located more than 1.2 m (4 ft) from planned joints. Cracks tend to emanate from light cans if the light cans are positioned closer than 1.2 m (4 ft) to joints.

9-3.3.2 Marking Joint Locations.

Mark joint locations on the base, edge of the slab, or on the forms. When paving a runway or wide taxiway, it is challenging to transfer joint locations across pilot lanes. Use surveying instruments to transfer joint locations across paving lanes. Small deviations in transferring joint locations across pavement can skew joint alignment. Carefully mark joint locations and construct joints at the proper locations.

9-4 TIMING OF JOINT SAWING.

Proper timing of sawcutting is critical to optimize joint performance. Consider the following factors.

9-4.1 Timing.

Commence sawing as soon as the concrete hardens sufficiently to permit cutting without chipping, spalling, or tearing.

9-4.2 Hardening.

Factors that influence the rate of concrete hardening:

- Air and concrete temperatures during placement
- Cement content of mixture
- Mixture characteristics

9-4.3 Readiness.

Regardless of the time of day or night, a contractor must be prepared to saw when concrete is ready.

9-4.4 Weather.

During warm weather, concrete is usually ready for sawing between 4 to 12 hours after placement. In cold weather, or when mixture water is below 10 °C (50 °F), sawing can be delayed as long as 24 hours.

9-4.5 Aggregate.

Generally, concrete mixtures with soft, coarse aggregate, like limestone, do not require as much strength development before sawing compared to mixtures with hard, coarse aggregates.

9-4.6 Delay.

If sawing is delayed, random cracking can occur.

9-4.7 Opportunity.

Several factors can reduce the length of the joint sawing window. If the sawing window becomes short, random cracking can develop.

9-4.8 Equipment.

When sawing, the concrete must support the equipment weight and associated personnel.

9-4.9 Hardness.

Spalling along a sawcut or aggregate tearing from the surface indicates inadequate concrete hardness.

9-5 EFFECTS FROM STABILIZED BASES.

Concrete pavement placed on a stabilized base is sensitive to sawcut timing. Inadequate precautions allow high slab/base interface friction to develop, producing uncontrolled cracking. A rapid overnight temperature drop causes shrinkage stresses in the concrete that can exceed the tensile strength of the concrete and lead to uncontrolled cracking. When adverse conditions are expected, saw as soon as possible and continue until complete. Conversely, the surface of a subbase can become hot during summer conditions. This increase in the temperature gradient through the slab significantly decreases sawing time. For asphalt treated bases, whitewash the surface of the material to increase reflectivity.

9-6 FACTORS THAT DECREASE SAWING TIME.

Factors that shorten the time frame available for joint sawing include:

- 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

9-6.1 Determining When to Saw.

It is difficult to determine when to saw. Sawing must occur before the concrete cracks on its own but after achieving sufficient strength to allow the saw to cut aggregate without dislodging.

9-6.1.1 Saw Equipment.

Determining the earliest time to cut joints is usually based on the equipment operator’s scratch test or observation of the raveling or spalling while making the initial saw cut.

9-6.1.2 Temperature.

As a rule of thumb, the limit of sawing is to cut before the surface concrete temperature significantly decreases.

a. Under most paving conditions, the top surface temperature starts to decrease while sub-surface concrete temperatures continue to increase. Once the concrete surface temperature decreases and a thermal gradient is generated, thermal curling restraint stresses start to develop. Concrete cracking results if the restraint stresses exceed the concrete tensile strength.

b. If saw cuts are installed before significant surface cooling, curling restraint stresses remain low and cracking develops only at planned joint locations.

c. Use surface thermometers or infrared guns to monitor concrete surface temperatures.

d. On larger projects, monitor slab surface temperature decreases to establish guidelines for allowable surface temperature changes.

- For example, assuming relatively constant paving conditions, if no slab cracking results in sections with a 5 degree drop in surface temperature, establish the last limit guideline for saw cuttings at a temperature drop of 5 degrees.
- Follow this guideline until weather condition changes or other data warrant establishment of new maximum allowable temperature decreases.
- The factor of safety is reduced as the maximum allowable temperature decrease increases.

9-6.1.3 Maturity Meter.

An improved method to establish the early limit window of opportunity uses a concrete maturity meter. The maturity method accounts for the combined effects of temperature and time on concrete strength development.

a. Concrete maturity meters use thermocouples installed in plastic concrete and automatically record temperatures at given time intervals.

b. Accounting for both curing temperature and time assumes that a given concrete mix has the same strength at equal maturities independent of curing time and temperature histories.

c. Thermocouples are typically inserted approximately 50 mm (2 in.) deep, as soon as possible after finishing operations. Set maturity meters to acquire temperatures at 15- to 30-minute intervals. The meters automatically calculate maturity. Early-age strength development is a function of ambient conditions, initial concrete temperatures, cement type, cement quantity, coarse aggregate type, and water-cementitious ratio. Maturity values can also establish early sawcutting times correlated with acceptable amounts of raveling or visual ratings.

9-7 JOINT SAWING OPERATION.

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

9-7.1 Initial Saw Cutting.

Items to be considered for the initial sawcut are as follows.

a. Make the first sawcut (early sawcut) with a single narrow blade (approximately 3 mm [1/8 in.] in width).

b. Perform early sawcuts made during rising concrete temperatures to the full design sawcut depth in one pass.

c. Early cuts made during falling concrete temperatures require special attention as concrete shrinkage occurs with falling temperatures.

d. Cuts to full design sawcut depth during falling concrete temperatures may cause random cracking (pop-off cracking) to occur ahead of the saw.

- It may be possible to avoid this problem by use of two sawcuts. Perform the first cut to one-half the design depth followed by a second pass to design depth.
- Discontinue sawing in any joint where a crack develops ahead of the sawcut.

e. Saw transverse joints consecutively in the same sequence as the concrete is placed in the lane.

- Sometimes a practice called skip sawing is used to control cracking. This practice involves cutting every other or every third joint.
- Skip sawing can result in variable joint width.
- Excessive sealant stresses may occur in those joints initially sawed.
- Before sawing each joint, examine the concrete closely for cracks. Do not saw planned joints if a crack appears near the planned joint.

9-7.2 Reservoir Cutting.

The following considerations are for the reservoir cut.

a. A second sawcut accommodates joint sealing material (reservoir cut).

b. A wide blade makes a second cut to the required depth.

c. Do not use gang blades to make the second cut. The gang blade system stability is insufficient to minimize spalling potential of the joint.

d. The second sawcut (in a single pass or two passes) is made at any time before sealant installation. However, the later in the concrete age the sealant reservoir is formed, the better the condition of the joint face.

e. Assure that the depth and width of the second sawcut 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.

f. During both the early sawcut as well as during the second cut, periodically check the sawcut to verify proper depth.

- Saw blades tend to wear as well as ride up when hard aggregates are encountered.
- Periodically measure blade diameter to monitor blade wear.

9-7.3 Shape Factor.

The joint sealant shape factor is based on the width of the reservoir divided by the depth (W/D). The value of this factor is based primarily on the type of sealant, such as hot-poured, silicone and two-component cold pour, and preformed compression seals.

9-7.4 Cleaning the Saw Cuts.

Wet sawing leaves a slurry on the surface of the concrete and on the joint face. For the first cut, flush the slurry with low-pressure water followed by low-pressure air blasting. Once the slurry is removed, reapply the curing compound along the joint. For the reservoir cut, follow the same process except increase the air and water pressures since the concrete is hard and curing compound is not required if sufficient curing has occurred.

9-7.5 Sawcutting Equipment.

Sawcutting involves several types of equipment. Longitudinal contraction joints are installed with walk-behind saws or early age entry saws. Transverse contraction joints use one of the following:

- Spansaws
- Conventional walk-behind saws
- Early entry saws
  - Do not use water.
  - Are generally capable of sawing at earlier ages than spansaws or walk-behind saws.
  - Depending on paving conditions and early-age concrete strength gain, early-age entry sawcutting is generally possible before any surface cooling and development of tensile restraint stresses.

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

Other joint sawing items to consider include the following.

a. Both the longitudinal and transverse joints are cut at about the same time.

b. When concrete is slipformed, extend the transverse sawcuts completely through the longitudinal edge.

- 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.
- When metal pavement forms are used, the saws must get as close to the forms as possible.

c. The risk of early-age restraint cracking before installing sawcuts increases if the concrete strength gain is retarded (slow strength gain) or the concrete surface temperatures rapidly decrease (surface cooling from rainfall).

d. If sawcuts cannot be installed quickly enough due to low strength gain or in relation to rapid generation of restraint stresses, consider concrete skip sawing.

- Installing every third or every other transverse joint may reduce the potential for random cracking. However, this can lead to variable crack widths at the planned transverse joints. Place roofing felt or a geotextile fabric over cracks that open significantly before placing an abutting lane.
- Only use skip sawing when there are no options.
- Consider adjusting the concrete mixture or paving procedure before using a skip saw technique.

e. Joint reservoir beveling (chamfering) at transverse joints increases angles at joint corners from 90 to about 120 degrees.

- Beveling reduces the potential of damage from snow removal equipment.
- A major disadvantage is the cost increase to install a beveled sealant reservoir.
- If beveling is used, calculate the shape factor based on the depth of sealant at the point where the joint face is vertical.

9-8 JOINT CLEANING BEFORE SEALING.

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

a. Immediately before sealing, thoroughly clean joints of all laitance, curing compound, and other foreign material.

b. Use sandblasting, wire brushing, water blasting, or some combination of these tools to clean the joint.

- Sandblasting or wire brushing is preferred.
- Prime joint faces immediately after cleaning.
- Perform sandblasting with great care because of the risk of sand particles filling the joint.
- The procedure for sandblasting applies it only to the joint face where the sealant will adhere.
- When sandblasting, hold the nozzle at an angle to prevent penetration of sand particles deeper into the joint.

c. Air blasting is the final cleaning step. The air stream must be free of oil. Many modem compressors automatically insert oil into the air lines to lubricate air-powered tools. For joint cleaning, disconnect this line and install an effective oil and moisture trap. In most cases, the inside of the hose of a lubricating air compressor is coated with oil. Use new hoses to clean joints. When air blasting, hold the nozzle no more than 50 mm (2 in.) from the pavement surface to blow debris at the front of the nozzle.

d. Once air blasting is complete, backer rod installation and sealant application can take place. Repeat air blasting at those joints remaining open overnight or for extended periods.

9-9 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. Other joint sealing considerations include the following.

a. Joint sealants are used in concrete pavement joints to keep out damaging material and minimize infiltration of water.

b. 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.

c. The size and shape of the sealant cross-section affects the sealant material performance.

d. In refueling locations and any airfield pavement area subject to fuel spillage, jet-fuel-resistant sealants are necessary.

e. Timing of sealing operations may vary from:

- As soon as possible
- Prior to placing the adjacent lane
- When the pavement achieves the minimum flexural strength for construction traffic
- Prior to grooving operations

f. Overall, it is better to wait as long as possible to seal the joints:

- Hard debris can infiltrate a green cut, causing spalling.
- The benefits of waiting to seal joints can outweigh the disadvantage of debris intrusion.
- Use a temporary filler such as backer rod or rope to prevent debris from infiltrating joints.
- Temporary filling of joints is a good practice to minimize infiltration by construction debris.

g. Clean joints are necessary for all sealant materials to perform properly.

9-9.1 Hot-Poured Joint Sealing Material.

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

a. Install the closed-cell backer rod to the appropriate depth to achieve the right shape factor.

b. The backer rod should not bond to the concrete or sealant. If bonding occurs, it induces stress into the seal.

c. The backer road must be compressed about 25 percent if it is to maintain its position in the joint.

d. The heating kettle should be an indirect heating type. Direct heating elements can cause changes in materials properties. Kettles also need agitators to prevent localized overheating. Overheated material can lose plasticity. Discarded overheated material.

e. Fit the application wand with a re-circulation line. Otherwise, sealant in the hose can drop below application temperature.

f. Fill the reservoir from bottom to top. Take care to apply the sealer so the material is solid, with no entrapped air.

g. Conduct a trial installation to verify the sealant can achieve a good bond.

h. The sealant must recess from the surface to provide protection from early traffic.

9-9.2 Cold-Poured Joint Sealing Material.

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

a. 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 injects the material into the joint.

b. Silicone is either self-leveling or non-self-leveling. These materials cure by chemical reaction, transforming from a liquid state to a solid state.

c. Check the potential for incompatibility between silicone seals and the concrete aggregates. A silicone sealant that does not develop proper bond with aggregates is going to fail.

d. Aggregate surface moisture at the time of sealing can affect the bond between silicone and concrete. Consider the use of a joint primer provided by the manufacturer to ensure the silicone seal develops a satisfactory bond.

e. Cold-poured materials are generally more sensitive to moisture in the reservoir; therefore, it is essential to ensure reservoirs are dry when installing sealant.

f. Cold-applied joint sealing compounds are applied by pressure equipment that forces the sealing material to the bottom of the joint and completely fills the joint without spilling material on the pavement surface.

g. Non-self-leveling sealants require additional tooling to maintain the required depth of sealant. Employ tooling on non-self-leveling sealants before the material cures.

9-9.3 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 include the following.

a. 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 (it is always in compression).

b. Follow the sealant manufacturer’s recommendations for sealant sizing and installation.

c. Insert the sealant using a device that uniformly compresses the sealant with nominal stretch.

d. The sealant must be lubricated, straight, vertical, and not damaged.

e. The installation device should not stretch the sealant. Stretching reduces the allowable sealant compression and sealant failure can occur. The maximum stretch is 2 percent.

f. There are two ways to check for stretching.

    1. First, insert the sealant in a known length of joint and then remove the material and measure the extracted length.

    2. 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.

9-10 TROUBLESHOOTING GUIDE.

Early age cracking problems are discussed in Appendix D. These problems may be due to a single cause or a combination of causes. The troubleshooting guide in Table 9-2 discusses the non-cracking problems associated with joint sawing and sealing.

Table 9-2 Troubleshooting Guide for 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 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

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CHAPTER 10 IMPLEMENTING CQC REQUIREMENTS

10-1 INTRODUCTION.

The implementation of CQC programs in this chapter is limited to the framework of the project CQC plans in Chapter 3. Operational issues are presented instead of actual test performance.

10-2 CQC TESTING AND PRODUCTION PLANS.

The CQC plan should be specific and contain enough detail to implement during construction. For example, basic requirements of a QC plan for slump testing in fresh concrete may 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 C143/CRD-C 5
- Test frequency:
    - First three trucks each day
    - One test per 50 yd^3 (40 m^3)
- Responsibility: QC paving technician
- Specified tolerance: 40 mm ±25 mm (1.5 in. ±1.0 in.) (action limits) and ±38 mm (±1.5 in.) (suspension limits)
- Corrective action:

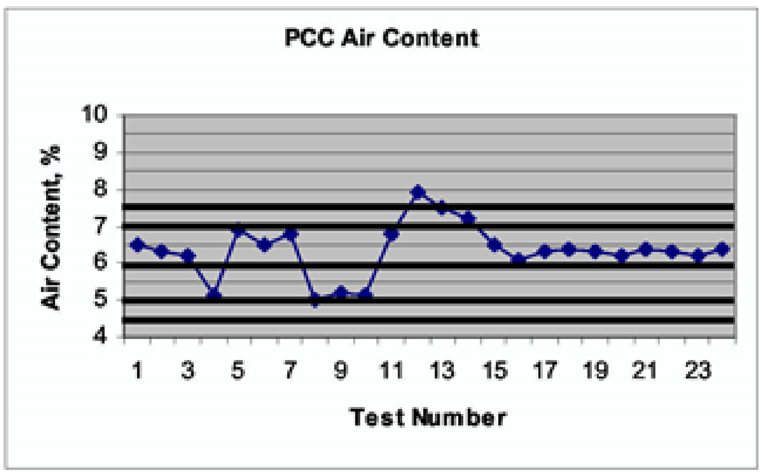
    If one individual slump test is outside the action limits, test the next three trucks. If those tests are within the action limits, then resume the normal testing frequency. If at any time one individual slump test is outside the suspension limits or two consecutive slump tests are outside the action limits, halt production and test each truck enroute. If the slump of any of the remaining trucks is outside the action limits, reject the loads. If the slump tests for the remaining trucks are acceptable, place the material. Production paving should not be resumed until the contractor has identified the problem and implemented corrective action. After concrete placement resumes, test the first three trucks for slump. If those tests are within the action limits, resume the normal testing frequency.

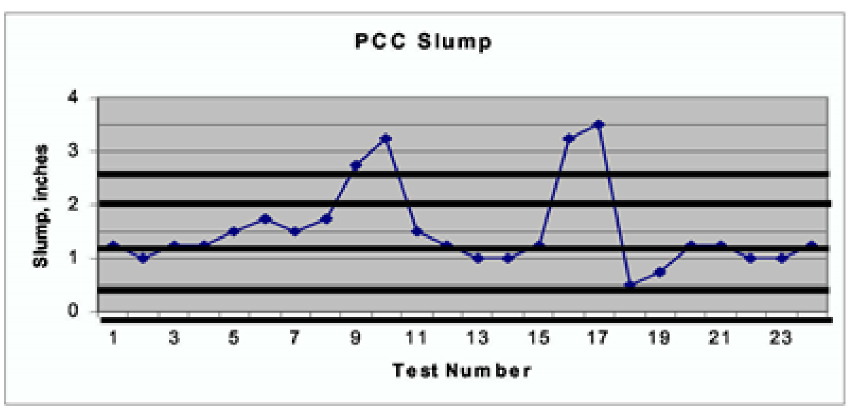
    Although it is impossible to account for all scenarios in the CQC plans, it is important to outline the procedures for known or possible recurring problems. CQC plans fail when there is no clear corrective action plan for each tested item.

10-3 CONTROL CHARTS.

Control charts (Figure 10-1) provide the inspection and testing team and senior management 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 CQC plan must contain a detailed procedure identifying which items require control charts, the information presented on each control chart, the required posting time, and distribution. Control charts should include individual test results, the average of all test results, and action limits at 3 standard deviations (3s). Action limits should not be based on specification requirements. Each contractor's process has a unique variability that dictates where to place the 3s limits.

Figure 10-1 Example Control Charts





10-4 TESTING PROCESS.

Field laboratories follow the same standards as permanent facilities for each test conducted (for example ASTM C1077/CRD-C 553 requirements). Items to address for a field laboratory include:

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

10-4.1 Definitions.

When test methods are specified and the variability in a test method affects the pay factor, it is important that the engineer and contractor understand the limitations inherent in the test methods as stated in their precision and bias statements. The following definitions are derived from ASTM E177.

10-4.1.1 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.

10-4.1.2 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.

10-4.1.3 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.

10-4.1.4 Components of Variability.

Variability in a measured construction attribute may be due to:

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

10-4.2 Achieving Quality.

Three conditions must be consistently met to achieve high levels of quality.

1. The process is stable (only common cause variability is present).
2. The process is capable (common cause variability must be small enough to permit consistent results within the specified tolerances).
3. The process is on target (the process is consistently performing near the specified target).

10-4.3 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. A smooth, uniform pavement starts at the subgrade. The uniformity of these layers affects the overall performance of the pavement. If failed material is placed on the grade, typical remediation blends in loads of good material. However, to maximize quality, remove the failed material to reduce material variability. Items to address in CQC plans include:

- Density requirements for each material lift
- Density requirement for each different subgrade type
- Maximum and minimum placement thickness
- How to determine the target density for each material type
- Gradation requirements for each material
- Testing frequency and location for all tests
- Mix design requirements for stabilized layers
- Process for documenting, reporting, and distributing all test results, including schedule
- Action list for handling failed test results

10-4.4 Fresh Concrete Testing.

Take representative samples of concrete placed for paving. Collect from several different discharge areas. Remix the sample before performing any tests and keep the sample covered with a plastic sheet to prevent evaporation. Testing of fresh concrete typically includes assessing the air content, slump, temperature, and the unit weight. Consider the following items for concrete testing.

a. Properly calibrate meters for air content testing (ASTM C231/CRD-C 41, *Pressure Method*, and ASTM C173/CRD-C 8, *Volumetric Method*). Pressure meter accuracy depends on the altitude at which it is calibrated. Repeat tests before considering concrete out of specification.

b. The slump test (ASTM C143/CRD-C 5) determines consistency, but not necessarily the workability of concrete. Clean and pre-wet the cone for each test. Repeat test using another sample before deciding concrete is off specification.

c. Record the temperature of the fresh concrete (ASTM C1064/CRD-C 3) every time strength specimens are made and whenever concrete temperatures are suspected of nearing specification limits.

d. The density of the fresh concrete (ASTM C138/CRD-C 7) can indicate a possible change in air content and determines yield. Properly calibrate the container.

e. Although these tests are widely used and understood, often the details of the testing requirements are not. It is important for the contractor and inspectors to review testing standards and agree on testing procedures. Describe these details and logistics in detail in the CQC plans. Items to address in the CQC plans include:

- Testing frequency
- Testing location (**Note:** Testing is conducted at the plant or onsite to determine the effect transporting the concrete has on basic concrete material properties.)
- The process for updating and distributing control charts
- 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. Take the fresh concrete sample from the center one-third of the batch. The 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. Create action and suspension limits for each test and in the CQC plans address the specific actions to take when test results are outside the action or suspension limits.

10-4.5 Thickness Testing.

Pavement thickness is tested in several ways. It is checked by using paving stringline as a guide, performing destructive testing by excavating non-stabilized material or taking cores from stabilized material and concrete layers, or surveying elevations before and after placement. Coring is the preferred method. Preferably, label and store cores (typically 100 mm [4 in.] in diameter) onsite until the end of the project. Items to address in CQC plans include:

- Testing frequency and location
- Clearly defined procedures for locating, measuring, and reporting the test results
- For projects with stabilized open-graded drainable bases, agree on the procedure to determine the bottom of the core

- Avoiding thickened edges and transition areas for test locations

10-4.6 Aggregate Tests (Gradation and Moisture Content).

Aggregate gradation testing varies based on the specifications for bases, stabilized bases, trench backfill, and concrete. Since projects use large quantities of aggregate, testing the gradations can become overwhelming. Items to address in the CQC plans include:

- Testing frequency
- Requirements for stabilized bases and concrete mixture verifications
- Sampling location (stockpiles or individual trucks)
- Aggregate moisture content tests - frequency (ASTM C70/CRD-C 111, ASTM C566/CRD-C 113)
- Gradation in fresh concrete, washed gradations
- Clearly defining action items when the aggregate fails the gradation tests
- How to determine the limits of unacceptable material
- Developing a clear reporting process to ensure timely distribution of test results
- Verifying bulk specific gravity of each aggregate at designated times throughout the project. This is not practical on a smaller project (less than 42,000 m^2 [50,000 yd^2])

10-4.7 Strength Testing.

Strength testing may include flexural and compressive testing.

10-4.7.1 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 that can lead to increased variability and, in some cases, suspect results. The test machine must be calibrated and operators must understand the testing requirements. Check the beam tester for the correct load and rate of loading and check for uniformity of loading (load distribution) between the two supports and across the width of the beam. Field supervisors must monitor the handling of the test specimens at the job site, during transportation, and at the laboratory. Beams are vulnerable to damage in handling and transport. Damaged beams will yield low strength results. Items to address in the CQC plans include:

- Location of material sampling, such as at the plant or delivery truck, or on-grade in front of the paver
- Sample fabrication location
    - Near the material sampling point

  - Onsite laboratory

- Ensuring that requirements concerning the time allowed between material sampling and beam fabrication are met
- Dimensions of beam samples. Typically, 150 by 150 by 530 mm (6 by 6 by 21 in.) specimens are used
- Type of beam molds allowed: plastic or steel
- Fabrication procedures
- Field curing, transportation, and laboratory procedures
- Frequency of testing
- Number of beams per sample location
- Determination of sample locations
- Curing requirements for additional beams to be made for other reasons, such as opening to traffic (field cured or laboratory cured)
- Use of a consignment form that tracks each concrete sample from fabrication, field curing, transportation to laboratory, laboratory curing, and testing
- Procedure for disposition of possibly damaged beams and results of known bad tests

10-4.7.2 Compressive Strength Testing.

Compressive testing may be required in addition to flexural strength testing. Even if not required, it may be preferable to make companion sets of cylinders along with 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 CQC plans include most of the flexural strength testing items previously discussed. Cylinder specimens are less vulnerable to damage in handling and transport than beam specimens. Coring, core conditioning, and core testing are conducted in accordance with ASTM C42/ CRD-C 26 and the use of the splitting tensile strength test is conducted in accordance with ASTM C496/CRD-C 77.

10-4.7.3 Core Strength Testing.

When beam or cylinder strength tests are not performed adequately or if test results are suspect, consider core strength testing to determine the strength quality of the in-place concrete. If core testing is used, consider the following items.

a. Test cores for compressive or splitting tensile strength.

b. Use core strength test results in accordance with established procedures, as defined in the specifications. These procedures typically involve use of project-specific correlations between the core strength and the beam or cylinder strength.

c. Initiate core testing at a test age close enough to the specified test age for the flexural or compressive strength testing.

d. Core conditioning before testing is important.

- Air-dry conditioning typically results in higher compressive or split tensile strengths.
- However, condition cores as defined in the project specifications.

10-5 EDGE SLUMP/JOINT FACE DEFORMATION/PROFILE TESTING.

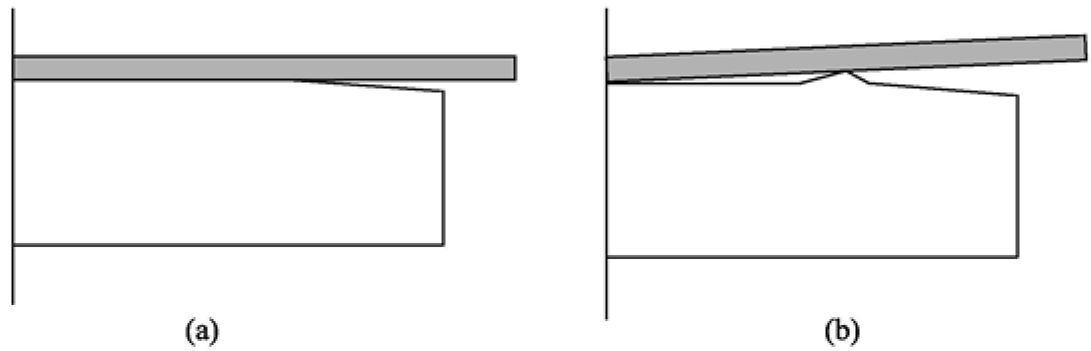
Excessive edge slump and joint face deformations under slipform paving are indications of improper concrete mixture proportioning, improper concrete placement, or improper equipment operation.

10-5.1 Edge Slump Testing.

Typical specifications require that edge slump not exceed 6 mm (0.25 in.) over 15 percent of the joint length and that edge slump be no greater than 10 mm (3/8 in.). Checking for edge slump requires a straight edge and level adjusted for the cross-slope, as shown in Figure 10-1. Edge slump can be measured on either fresh or hardened concrete. The straight edge must be of sufficient length, typically 3.1 to 3.7 m (10 to 12 ft), to support itself on the central portion of the slab and away from the area of edge slump, 300 to 600 mm (12 to 24 in.). Inspectors must be aware that small bumps or deviations, exaggerated in Figure 10-1 (b), might yield incorrect results. Items to address in the CQC plans include:

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

Figure 10-2 Measurement of Edge Slump



10-5.2 Joint Face Deformation.

Items to address in the CQC plans include:

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

10-5.3 Surface Smoothness Testing.

Conduct surface smoothness testing, per the project specifications, that may use a straight edge or a profilograph.

Items to address in the CQC plans include:

- Type of equipment allowed
- Method of evaluation used
- Are the criteria different for different facilities?
- Are any areas excluded?
- Are headers included in the smoothness evaluation?
- How soon after paving is profile testing conducted?
- If a straightedge is used, will the testing be continuous, random, or subjective?
- If using a rolling straightedge, 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?
- If multiple passes are required, are these per lane or per paving width (which may incorporate two or more lanes)?

10-6 DOWEL BAR ALIGNMENT AND INSPECTION.

Specifications for dowel bar misalignment limit the skew misalignment and horizontal and vertical displacements. Items related to dowel bar placement to address in the CQC plans include:

- Dowel bar material transmittals and bond-breaker coatings
- Detailed procedures for transporting, storing, inspecting, installing, and securing dowel bars
- Detailed procedures for dowel bar inserters (roadways only) that include random checks to ensure equipment is operating properly
- Checking dowel bar assembly for trueness to eliminate skewed bars
- Allowable dowel bar misalignment and how to measure
- Joint saw cut line deviation: How much is acceptable with regards to dowel bar embedment?
- Permissible number of misaligned dowel bars per joint per panel

Note that dowel bar alignment is measured only for pre-placed baskets before concrete placement and for drill and grouted dowels along the longitudinal construction joints. The inspector must 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. For drill and grouted dowel bars, check the alignment after the epoxy grout sets. Cut and install new dowels for any dowel bars that are misaligned beyond the allowable limits. For machine-inserted dowel bars, as well as the pre-placed dowel bars, ground penetrating radar (GPR) can check the alignment after the concrete is about one day old. However, GPR testing can only determine vertical dowel bar alignment to an accuracy of 3 to 6 mm (1/8 to 0.25 in.); therefore, coring may be required for complete verification of dowel bar placement.

CHAPTER 11 EARLY DISTRESS REPAIR

11-1 INTRODUCTION.

Concrete pavements can exhibit early distress. This occurs while the concrete is in plastic state or soon after hardening. When early distress is observed, identify the cause of the failure and take appropriate corrective measures to reduce the potential for reoccurrence. It is good practice to discuss the disposition of slabs that exhibit early distress at the pre-construction meetings. Commonly encountered early distress are:

- Plastic shrinkage cracking
- Edge slump
- Joint spalling
- Full-depth cracking

11-2 PLASTIC SHRINKAGE CRACKING.

Plastic shrinkage cracking is surface cracking that may develop if the rate of evaporation at the surface is high. Plastic shrinkage cracking typically manifests as shallow 25 to 75 mm (1 to 3 in.) deep, closely spaced parallel cracks. In some cases, the cracking may extend deeper than 75 mm (3 in.) but it is unusual for the cracks to be full depth. It is recommended to take 100-mm (4 in.) -diameter cores over a few cracks to determine the depth of cracking. Repair plastic shrinkage cracking by injecting low-viscosity epoxy or high molecular weight methacrylate in each crack after concrete has hardened. Follow epoxy injection procedures in accordance with the epoxy manufacturer’s instructions. The gravity-fed epoxy technique is not recommended, as the crack penetration is not fully effective. Cracking deeper than 75 mm (3 in.) or extensive cracking requires slab removal and replacement (paragraph 11-5).

11-3 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 excessive edge slump occurs, adjust 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 can affect joint performance.

11-3.1 Plastic Repair.

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. Important items to consider are as follows.

a. The edge must be formed along the repair area.

b. If additional material has to be added to repair the edge slump, the added material must contain a mixture of aggregate particles. Plain mortar addition is not allowed.

c. The repair area material must be vibrated into the existing material.

d. Repair should not be attempted after the curing compound has been applied as the repair area concrete can become contaminated with the curing compound.

e. If initial set has occurred, vibration is ineffective; it is too late to make a plastic edge slump repair.

f. Use of plain mortar or addition of material to hardened concrete may lead to spalling.

g. After vibrating the repaired concrete, screed and finish as uniformly as possible with the surrounding concrete.

h. Texture and cure the repaired area using the same processes as the surrounding concrete.

i. Plastic repairs should be the exception.

Note: Edge slump repairs should be isolated problems and not routine occurrences. If excessive edge slump is occurring, stop the paving until the problem is corrected.

11-3.2 Hardened Pavement.

If edge slump repair cannot be done in a timely manner, it may be necessary to allow the affected slab panels to harden and repair by:

- Sawing the slumped edge and performing a partial-depth repair at the surface depression
- Removing and replacing the slab with excessive edge slump

11-4 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 with the concrete mixture used for paving. If the spalling is severe and excessive in length, consider replacing the affected slab.

11-5 FULL-DEPTH CRACKING.

Localized full-depth cracking may result from the following causes:

- Late transverse joint sawing or insufficient depth of sawing
- Misaligned dowel bars
- Excessive curling or warping
- Rapid surface cooling
- Early-age loading by construction equipment
- Excessive drying shrinkage

- Excessive base frictional restraint

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

a. Replace panels in critical pavement areas with full-depth cracking that extends the full width or length of the slab panels. Critical pavement areas are those areas subject to aircraft landing gear loading.

b. Full-depth cracking in non-critical pavement areas (most exterior lanes of a runway or taxiway) may be left in place at the option of the owner. Rout and seal the crack.

c. Treat full-depth cracking in critical pavement areas that extends less than one-third the width or length of the slab as full-width cracking.

d. Repair full-depth corner cracking in critical pavement areas by full panel replacement.

e. Avoid using partial panel replacement in critical pavement areas on new pavement.

f. Follow proper procedures for slab removal and replacement. The procedures must include the following.

  - Remove slabs without damaging adjacent sound slabs or the base.
    - Use double saw cutting along slab perimeter.
    - No heavy impact loading to break slab into small pieces.
    - Sawcut panel into smaller segments and lift out.
  - Inspect the base for damage and correct before concrete placement.
  - Restore load transfer along all joints with dowel bars using the drill and epoxy grouting technique.
  - Use approved concrete mixtures for hand placement operations.
  - Use vibration to consolidate the concrete.
  - Use proper techniques to finish, texture, and cure the replacement slab.

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APPENDIX A PRECONSTRUCTION REVIEW CHECKLIST

A-1 GENERAL ITEMS.

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

A-2 BATCHING ACTIVITIES.

- Stockpile management.
- Aggregate moistures and added mixture water.

A-3 SUBGRADE.

- Review 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.

A-4 SOIL STABILIZATION (IF APPLICABLE).

- Review soil stabilization QC plan.
- Review soil data regarding stabilization requirements.
- Mix design submittals (per soil type).

- Field testing requirements and frequency (soil gradation, minus No. 200, plasticity, density, strength, lime/cement/fly 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.

A-5 STABILIZED BASE.

- Review base stabilization in 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 on-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 action to be taken if grade is a concern).

A-6 CONCRETE PAVING/PLACING/FINISHING/TEXTURING/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.

A-7 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.

A-8 CQC ACTIVITIES.

- Review 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.
- Using control charts.
- Concrete mixture designs and w/cm ratio effects on strength.
- Concrete beam sampling, fabrication, curing, and testing procedures.
- Sampling 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 B INSPECTION AND TESTING CHECKLIST

B-1 INSPECTION.

B-1.1 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.

B-1.2 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.

B-1.3 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.

B-1.4 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.

B-1.5 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.

B-1.6 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 evaporative retardants (hot weather) are available.
- Polyethylene sheeting (or other approved covering) available in the event of rain.

B-1.7 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.

B-1.8 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.

B-1.9 Concrete Placement Tolerances.

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

B-1.10 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.

B-1.11 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.

B-1.12 Opening to Construction Traffic.

- Minimum strength and time requirements.

B-1.13 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.

B-1.14 Joint Sealing.

- Sealant reservoir dimensions.
- Reservoir cleanliness.
- Backer rod placement.
- Sealant curing temperatures meet manufacturer's recommendations.
- Recessed sealant depths.

B-1.15 Grooving.

- Groove depth and spacing requirements.
- Clearance requirements at joints.

B-1.16 Cracking, Spalling, and Acceptance.

- Unacceptable cracking and spalling criteria.
- Repair of cracking and spalling.

B-2 TESTING.

B-2.1 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.

B-2.2 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.

B-2.3 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.

B-2.4 Core Length (Thickness) Testing.

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

B-2.5 Smoothness Testing.

- Straightedge and profile equipment.
- Recommended timing.
- Grinding limits.

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APPENDIX C JOINT SAWING CHECKLIST

C-1 EQUIPMENT.

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

C-2 INSPECTION ITEMS.

- Test strip sawing.
- Planned versus 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.

C-3 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.

C-4 POST-CUTTING ISSUES.

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

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APPENDIX D DECISION TREE FOR EARLY-AGE CRACKING

D-1 INVESTIGATION.

Determine cause(s) of early age-cracking immediately and action items to minimize/eliminate causes or their effects implemented before proceeding further with paving. Early-age cracking is typically classified as any cracking within the first seven days after concrete placement. However, some cracking may initiate at the slab bottom that is not visible for days or weeks. Table D-1 contains the types of cracks and possible causes and investigative techniques for each type of crack. The following are types of early-age cracking.

- Plastic shrinkage cracking
- Random cracking (no orientation)
- Longitudinal cracking
- Transverse cracking
- Corner cracking
- Cracks just ahead of sawing (pop-off cracks)
- Later age cracking (early age slab bottom cracking propagating to surface)
- Sympathy cracks
- Settlement cracks over dowel bars or tie bars
- Re-entrant cracks

Note the following when early age cracking develops:

a. Some cracking has an obvious cause and requires immediate corrective actions.

b. Marginal conditions can cause cracking.

   - Correcting one marginal condition may resolve an immediate problem but may not reduce the cracking potential for subsequent paving.
   - 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 as possible.

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

1. Gather relevant information.
2. Identify if the distress manifests as isolated or systematic (widespread) occurrences. If the distress is systematic, undertake a thorough review of the design features as well as all key construction procedures.

3. Work through an iteration of logical steps to pinpoint one or more causes. This involves a process of elimination, starting with obvious factors verified by field and laboratory personnel. As causes are eliminated, additional steps may require more rigorous evaluation of data, coring, and laboratory testing.

D-2 GATHER RELEVANT INFORMATION.

D-2.1 Design Information.

- Pavement thickness as designed.
- Pavement thickness as constructed.
- Joint spacing.
  - Transverse
  - Longitudinal
- Base type.

D-2.2 Concrete Mix Information.

- Cement type and source.
- Cement grind history: fresh grind / not fresh grind.
- Supplementary cementitious materials.
  - Type F fly ash source
  - Slag source
- Cement content.
- Supplementary cementitious content.
  - Type F fly ash
  - Slag
- Aggregate data.
  - Gradation: uniform / gap graded / other
  - Gradation description
  - Coarse aggregate type, source and amount
  - Fine aggregate type, source and amount
  - Coarse aggregate coefficient of thermal expansion
- Admixture manufacturer, type and dosage.
  - Air entraining
  - Water reducer
  - Other admixture

D-2.3 Environmental Data.

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

D-2.4 Construction Data.

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

D-2.5 Other Relevant Data.

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

Table D-1 Early Age Cracking Types/Possible Causes/Investigation

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 (not allowed on airfields)	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 (not allowed on airfields)	Rigid penetrations (in-place structures)
	Dry aggregates	Reflection cracking (from base cracking)	Slabs too wide in relation to thickness and length	Slabs too long in relation to thickness and 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					
	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	Poor aggregate gradation (sand too fine; gap gradation)						

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 (not allowed on airfields)	Re-entrant Cracks
			Infill lane restraints	High shrinkage concrete						
			Late or inadequate curing	Early loading						
			High-shrinkage concrete							
			Slab to base bonding							

APPENDIX E ROLLER-COMPACTED CONCRETE PAVEMENTS

E-1 APPLICATION.

Procedures and criteria described in this appendix are applicable to the design and construction of roller-compacted concrete (RCC) pavement (RCCP). RCCP is prohibited for airfield pavement use unless approved by the USACE TSC or appropriate TSPDWG Service representative.

E-2 GENERAL.

RCCP is a concrete paving process that involves laydown and compaction of a no-slump PCC mixture using techniques similar to that used for hot-mix asphalt (HMA) pavement. RCC combines existing HMA paving and cement treated base construction procedures with the final product of a PCC pavement. This construction technique can place a large amount of concrete quickly with no forms, dowels, or reinforcing steel. Construction cost savings of 10 to 30 percent, or even more, of the cost of slipformed or fixed formed concrete pavements have been realized. The surface smoothness and surface texture of RCC pavement is somewhat rougher and coarser than conventional concrete pavement and this tends to limit RCC pavement applications to areas where low-speed, heavy-load traffic is the primary user of the pavement. Non-pavement applications that employ a similar construction method include slope protection of embankment or dams, providing an impermeable lining for sludge drying basins or wastewater lagoons, platforms for handling containerized freight, for recycling yards, for composting yards, for log sorting yards, and for mine storage areas.

E-3 CONSTRUCTION PROCESS.

RCC is typically mixed in a continuously mixing pugmill plant located near the paving site. In the plant, the aggregates, cement, and fly ash are weighed with belt scales or volumetrically proportioned on a continuous conveyer belt, which dumps the dry materials in the pugmill, where the water is added. The pugmill provides the vigorous mixing action necessary to evenly distribute the relatively small amount of water throughout the relatively stiff, no slump concrete mixture. The freshly mixed RCC is discharged into dump trucks equipped with protective covers for hauling to the paving site. At the paving site, the base course material is graded and compacted to form a smooth, firm working platform for the RCC pavement. The surface of the base course is moistened with water just before placing the RCC and setting up stringlines along the paving lanes to guide the height of the paving screed during placement. The RCC is placed with a paving machine to a uniform density and smoothness. Immediately after placement, the fresh RCC is compacted with several passes of a dual-drum vibratory roller to the specified final densities. After the compaction, make several passes of a rubber-tired roller to tighten the surface texture of the pavement. In some instances, finish rolling with steel-drum rollers to remove roller marks. When the rubber-tire rolling is complete, keep the surface of the RCC moist using water trucks equipped with fogger spray bars until an irrigation sprinkler system is set up by the end of the day. The sprinkler system keeps the surface of the RCC pavement continuously moist for the duration of the curing period, usually seven days (although 14 days is better).

Membrane-forming curing compounds and asphalt emulsions are also successful. Cold joints are construction joints formed between paving lanes placed more than one hour apart and always between two separate days of paving. Perpendicular cold joints are formed between lanes placed perpendicular to each other, longitudinal cold joints are oriented in the direction of paving, and transverse cold joints are located perpendicular to the direction of paving, between lanes oriented in the same direction. Transverse cold joints are constructed by sawing across the ends of the paving lanes, which have been rounded off from rolling, and removing the excess material. Finally, transverse contraction joints may be cut with a concrete saw within four to 20 hours after the RCC is placed and compacted. Historically, the standard practice has been to allow the RCC pavement to crack; however, current practice is to sawcut contraction joints to improve pavement aesthetics and ease the application and maintenance of joint sealants.

E-4 SUBGRADE AND BASE COURSE PREPARATION.

The subgrade and base course should conform to the requirements outlined in UFC 3-250-01 and UFC 3-260-02. The freeze-thaw durability of RCC is not fully understood, but the long-term performance of non-air-entrained RCCP is generally satisfactory, despite marginal laboratory performance. For this reason, in areas where the pavement or base course might be subject to seasonal frost action, give particular attention to providing a base course that adequately drains any water infiltrating through the pavement or subgrade. The base course should provide sufficient support to permit full consolidation of the RCCP through its entire thickness upon compaction.

E-5 SELECTION OF MATERIALS.

E-5.1 General.

One of the most important factors in determining the quality and economy of concrete is the selection of a suitable aggregate source. The recommended RCC gradation is shown in Table E-1. This gradation is similar to gradations used for asphalt concrete. This gradation should produce an RCCP surface with relatively few surface voids. Conventional PCC mixtures are generally obtained by combining coarse and fine aggregates. The well-graded blend of aggregates given in Table E-1 may be difficult to produce from two groups due to segregation of the different-sized aggregate particles. When possible, using more than two aggregate groups (coarse and fine) at the plant provides more flexibility in blending aggregates to control the gradation of the RCC.

Table E-1 Recommended Combined RCC Gradation

Sieve Size, mm (in.)	Cumulative Percent Passing, by Weight
25 (1)	100
19 (3/4)	85–100
12.5 (1/2)	70–95
9.5 (3/8)	55–85
4.75 (No. 4)	40–65
2.36 (No. 8)	30–55
1.18 (No. 16)	20–45
0.60 (No. 30)	15–35
0.30 (No. 50)	10–25
0.15 (No. 100)	5–15
0.075 (No.200)	2–10

E-5.2 Coarse Aggregate.

The coarse aggregate may consist of crushed or uncrushed gravel, recycled concrete, crushed stone, or a combination thereof. The quality of coarse aggregate used by the Corps of Engineers to date in RCCP generally complies with ASTM C33, although satisfactory RCC is possible with coarse aggregate not meeting these requirements. Local state highway department coarse aggregate grading limits, for example, are generally acceptable. Primarily, regardless of the grading limits imposed, the grading of aggregate delivered to a project must be relatively consistent throughout the production of RCC. This is an important factor to maintain control of the concrete mixture's workability. The nominal maximum aggregate size normally should not exceed 19 mm (0.25 in.), particularly if pavement surface texture is a consideration. Using aggregate larger than 19 mm (0.75 in.) results in segregation and rock pockets are likely.

E-5.3 Fine Aggregate.

Fine aggregate may consist of natural sand, manufactured sand, or a combination of the two, and should be composed of hard, durable particles. Base fine aggregate quality on the limits given in ASTM C33 except give consideration to relaxing the maximum 5.0 percent limit of material finer than the 0.075 mm (No. 200) sieve. Canada has increased the amount of material passing the 0.075 mm (No. 200) sieve to 8 percent of the total weight of aggregates with acceptable results. Sands with higher quantities of nonplastic silt particles may be beneficial as mineral filler and may allow some reduction in the amount of cement required. However, mixtures made with fine aggregates having an excessive amount of clay may have a high water demand, with attendant shrinkage, cracking, and reduced strength. Determine the specific gravity and absorption of these sands with high quantities of fines according to Note 3 in ASTM C128. Expedient construction with RCC can utilize minimally processed aggregates such as pit- or quarry-run aggregates to produce an RCC pavement. This RCC pavement may require greater water content, be less durable, and have a lower flexible strength.

E-5.4 Other Aggregates.

Recent experience with RCC shows that aggregate produced for uses other than PCC are successful as aggregate for RCC. Material produced for asphalt paving and base courses are effective as RCC aggregate. These materials typically have a higher percentage of fines passing the 0.075 mm (No. 200) sieve than conventional concrete aggregates and, as a result, may produce a “tighter” pavement surface texture. Because these aggregates range in size from 19 mm (0.75 in.) to the 0.075 mm (No. 200) sieve, control of the grading may be more difficult due to segregation. Therefore, direct due attention toward stockpile formation and subsequent handling of a single size group aggregate.

E-5.5 Cement.

The Portland cement for use in RCC must meet the requirements of ASTM C595, Type I or II.

E-5.6 Admixtures.

A proper air void system prevents frost damage in concrete that freezes when critically saturated. Research indicates that air-entrained RCC pavement mixtures can be successfully produced in the laboratory; however, field production and placement have only been tried on a very limited basis. The most widely used method to minimize freezing and thawing damage to RCC pavement is to combine a low w/cm ratio with a highly compacted RCC. The low w/cm ratio and good compaction ensure the concrete has a minimum amount of freezable water in the capillaries and has low permeability. This makes it difficult for sufficient water to enter the RCC and reach critical saturation. A free-draining base under the RCC pavement will further prevent water from saturating the RCC pavement. As long as the RCC pavement is not critically saturated, freezing and thawing will cause no damage. Laboratory studies show that water-reducing or -retarding admixtures are successful with RCC but not as effective as in conventional concrete because they affect the paste content of the mixture. RCC contains less paste than conventional PCC mixtures. If these admixtures are proposed, base such use on investigations demonstrating that the benefits outweigh the cost.

E-6 MIXTURE PROPORTIONING.

E-6.1 General.

The basic mixture proportioning procedures and properties of conventional concrete and RCC are essentially the same; however, conventional concrete cannot be reproportioned for use as RCC by any single action such as (1) altering proportions of the mortar and concrete aggregates, (2) reducing the water content, (3) changing the w/cm ratio, or (4) increasing the fine aggregate content. Differences in mixture proportioning procedures and properties are mainly due to the relatively dry consistency of the fresh RCC and the selected use of nonconventionally graded aggregates. The primary differences in the properties of RCC are (1) RCC generally is not air entrained, (2) RCC has a lower water content, (3) RCC has a lower paste content, and (4) RCC generally requires a higher fine aggregate content to limit segregation. Several methods are available to proportion RCC pavement mixtures, including those found in CRD-C 161, ASTM D 558, EM 1110-2-2006, ACI 211.3, and ACI 207.5R. The first two of these methods treat the material as cement stabilized soils rather than concrete and establishes a relationship between moisture and the density obtained from a particular compactive effort. The latter three methods follow an approach similar to that used in proportioning conventional concrete. Currently, CRD-C 161 is the method recommended for RCC pavement mix design. The procedures for RCC pavement mixture proportioning are not as well defined as for conventional concrete. The key to successfully selecting an RCC trial batch that performs well in the field is the experience of the laboratory personnel conducting the proportioning study.

E-6.2 CRD-C 161 Method.

This method covers the procedures for proportioning RCC mixtures with 19 mm (0.75 in.) nominal maximum size aggregates and having a workability suitable for placement with the vibratory screed of an asphalt paving machine. Select RCCP mixture proportions based on test data or experience with the materials actually used. Where such data or experience is limited or not available, estimates given in this standard practice provide a first approximation for air-entrained or non-air-entrained RCCP mixture proportions. Check these proportions by trial batches in the laboratory or field and adjust, as necessary, to achieve the desired RCC characteristics.

E-6.3 ASTM D558 Method.

A proportioning based on ASTM D558 has produced satisfactory RCC mixtures. The method produces the optimum moisture content necessary to obtain maximum density for a particular set of materials and compaction procedures. Previous tests indicate that the optimum moisture content obtained by CRD-C 653 may produce a mixture too wet to allow efficient operation of a vibratory roller.

E-6.4 ACI 207.5R Method.

The method in ACI 207.5R, with some modifications, is used on many RCC mixtures. The primary consideration for this method is proper selection of the ratio (Pv) of the air-free volume of paste (Vp) to the air-free volume of mortar (Vm). This selection is based primarily upon the grading and particle shape of the fine aggregate. The Pv affects both the compactability of the mixture and the resulting surface texture of the pavement. Ratios of 0.36 to 0.41 are satisfactory for mixtures having a nominal maximum size aggregate of 19 or 38 mm (0.75 or 1.5 in.). Include the fraction of fine aggregate finer than the 0.075 mm (No. 200) sieve in Vp when calculations use Pv.

E-7 MIXTURE PROPERTIES.

E-7.1 Handling Characteristics.

The workability of RCC determines its capacity for successful mixing, placement, and compaction. It embodies the concepts of compatibility and to some degree moldability and cohesiveness. The same factors that affect the workability of conventional concrete affect RCC: the grading, particle shape, and proportion of the aggregate; the cementitious material content; and the presence of chemical and mineral admixtures in the mixture. However, the effect of each factor is not necessarily of the same magnitude for RCC as for conventional concrete. When placing RCC or conventional concrete, the consistency of the mixture is important. The slump test measures the consistency of conventional concrete. The slump test is not meaningful for RCC since it has no slump. Make a preliminary judgment of the workability, placeability, and compatibility of RCC pavement mixtures during mixture proportioning studies by determining the optimum moisture content using soil compaction concepts. Use the soil compaction procedures described in CRD-C 161, paragraphs 7.1 through 7.6, to determine the optimum moisture content. Experience indicates that the actual optimum RCC water content necessary may need to be slightly greater than the lab-determined optimum moisture content. This is probably due to the loss of water from the mixture due to evaporation during transport and placement operations or to different compaction in the field. Ambient conditions determine the water content variation of a mixture. Typically, moisture increases are 0.1 to 0.5 percent above optimum. Construct a test section for each RCC project to adjust the mixture proportions as necessary to achieve the required workability.

E-7.2 Sample Fabrication.

Primarily, the w/cm ratio and the degree of compaction attained control the strength of an RCC mixture. All RCC pavement mixtures placed by the Corps of Engineers to date had w/cm ratios ranging from 0.30 to 0.40. Fabricate cylindrical laboratory test specimens for strength determinations per ASTM C1176 or CRD-C 160. There is no standardized procedure for fabricating RCC beam specimens to determine concrete flexural strength. However, as described in CRD-C 161, some success has been achieved by filling beam molds in two layers. Consolidate by vibrating each layer on a vibrating table having a frequency of 3,600 vibrations per minute under a surcharge of 57 kg (125 lb). Uniformly distribute the surcharge over the entire specimen area during molding and vibrate until a ring of mortar forms around the complete periphery of the mold. Cure all specimens fabricated in the laboratory according to ASTM C192.

E-7.3 Strength Results.

Test specimens fabricated and cured in the laboratory generally exhibit higher strengths than those cored or sawn from an RCCP. This is probably due to the higher unit weights typically obtained with the fabricated specimens and the more efficient laboratory moist curing. Laboratory test specimens generally have unit weights that are 98 to 99 percent of the theoretical maximum (air-free) weight of the mixture, while core samples taken from RCCP typically have unit weights ranging from 95 to 98 percent of the theoretical weight. Therefore, during the laboratory mixture proportioning studies, consider fabricating a companion set of test specimens having the lowest relative density allowed by the contract specifications.

E-8 THICKNESS DESIGN.

E-8.1 General.

The thickness design procedure for RCC pavement is outlined in UFC 3-250-01 and UFC 3-260-02. The primary difference in the approaches to RCC pavement and plain concrete pavement thickness design is the assumption of no load transfer at any joint or crack in the RCC pavement. Limited load transfer tests conducted at Fort Hood, Texas and Fort Stewart, Georgia revealed average load transfer at transverse contraction cracks of 16 to 19 percent. The load transfer at longitudinal and construction joints will be lower and all were less than the 25 percent used for plain concrete pavement design for parking areas, open storage areas, and airfields. Placement of RCC pavement immediately adjacent to existing structures is not practical. Conventional formed concrete should be used between the structure and the RCC pavement. The RCC pavement can be placed first and cut back to the desired line or the RCC can be placed against the previously placed formed concrete. Beams sawn from various RCCP at various locations have shown that the actual flexural strength of the pavement was 20 to 50 percent higher than the typical strength assumed in the design for those pavements. This suggests that the thickness design for compacted RCCP could be modified based upon the 28-day strength of beams sawn from a test section constructed using the same aggregate, cement, and construction procedure as planned for the entire work. However, until additional performance records and testing procedures are developed for RCCP, conventional pavement thickness design will be used.

E-8.2 Lift Thickness.

The maximum thickness of a lift of RCCP is governed by the ability of the pavers to place the RCCP in a smooth and continuous fashion. This maximum uncompacted thickness is usually 250 to 300 mm (10 to 12 in.). The maximum uncompacted thickness can be approximated by multiplying the design thickness by 1.25, thus accounting for the reduction in thickness due to compaction. The minimum thickness of any lift should be 100 mm (4 in.).

E-8.3 Two-Lift Construction.

If the total uncompacted thickness exceeds the capacity of the paver, the RCCP should be placed in two or more lifts, thus creating a horizontal joint (or horizontal plane between the layers) in the RCCP. Sufficient bond develops at a fresh horizontal joint in RCCP (top lift placed within one hour of bottom lift) to allow the use of a monolithic thickness design. If the top lift is not placed within one hour of the bottom lift, the thickness should be designed as a rigid overlay of a rigid base pavement. The surface of the lower lift should be kept moist and clean until the upper lift is placed, and the upper lift should be placed and compacted within one hour of compacting the lower lift to ensure a bond between lifts is formed. In two-lift construction, the uncompacted thickness of the first lift should be two-thirds the total uncompacted height of the RCCP (or the maximum lift thickness the paver can handle, whichever is smaller). The thinner section in the upper lift aids in creating a smoother final surface, and because of the smaller volume of material, allows the paver placing the second lift to move quicker than and follow closer behind the paver placing the first lift. Multiple lifts will be necessary if the total uncompacted thickness of the RCCP is greater than twice the maximum lift capacity of the paver.

E-9 TEST SECTION.

E-9.1 General.

A test section must be constructed to determine the ability of the contractor to mix, haul, place, compact, and cure RCC pavement. The test section must be constructed of the same material using the same equipment intended to be used in production placement. The test section must be constructed at a location near the jobsite at least 10 days before construction of the RCC pavement. The test section should be large enough to establish the rolling pattern for the vibratory and finish rollers, the correlation between laboratory and nuclear gauge densities, and the correlation between the number of passes and relative density. The density tests should be obtained with a nuclear gauge in accordance with ASTM C1040. The test section should contain both longitudinal and transverse cold joints and a fresh joint. A suggested minimum size is two 3.7- to 4.3-m (12 to 14 ft) -wide lanes, with each joint type a minimum of 38 m (125 ft) long, with one and one-half lanes placed the first day and the rest placed the next day.

E-9.2 Optimum Number of Rolling Passes.

During the test strip construction, use a nuclear gauge operated in the direct transmission mode and standardized with a calibration block to determine the optimum number of passes with the vibratory roller to reach maximum density. The density should be measured by inserting the nuclear gauge probe into the same hole after each pass of the vibratory roller. The hole should be made with an instrument specifically designed for the purpose, and should be formed using the same method throughout the test section and main construction. This rolling and measuring procedure should be continued until there is less than a 1 percent change in successive readings. These data may be used in conjunction with correlation between the nuclear gauge and the laboratory density to determine the minimum number of passes needed to achieve or slightly exceed the specified density in the RCCP construction. However, a minimum of four vibratory passes should be used, and this minimum will probably prevail in most cases.

E-9.3 Nuclear Density Gauge/Lab Density Correlation Calibration Block.

Use a calibration block each day before paving begins to calibrate the full-depth readings of the nuclear density gauges. The block should be fabricated from the RCC mixture to be used in the project before the test section construction begins. The block size should be 460 mm by 460 mm (18 in. by 18 in.) by the maximum thickness of one lift, plus 25 mm (1 in.). The block should be compacted to between 98 and 100 percent of the maximum wet density determined in accordance with ASTM D1557. The block should be measured and weighed to determine the actual density (unit weight) and used to check the calibration of the nuclear density gauge. After drilling a hole in the block to accommodate the nuclear density gauge probe, three full-depth nuclear density gauge tests should be performed in the direct transmission mode and the results averaged. This average nuclear density gauge reading should then be compared with the measured unit weight of the block and the difference used as a correction factor for all readings taken that day. If the adjusted nuclear gauge density is less than the specified density, additional passes with the vibratory roller should be made on the fresh RCC until the specified density is reached. Two nuclear density gauges should be calibrated (using the same holes) during the test section construction, so that an extra one is available during construction.

E-9.4 Strength Tests.

Pavement strength is determined from samples obtained from the test section. The testing should determine the flexural and splitting tensile strength of the RCC pavement. If the design strength requirements are not met, adjust the mix proportions (or the compaction procedure or curing altered, and another test section built) until the strength results meet specifications.

E-10 BATCHING, MIXING, AND TRANSPORTING.

RCC requires a vigorous mixing action to disperse the relatively small amount of water evenly throughout the matrix. This action has been best achieved by using a twin shaft pugmill mixer as commonly used in asphalt concrete mixing. RCC may be produced successfully in either a continuous mixing plant or batch-type plant. The continuous mixing plant is recommended for mixing RCC because it is easier to transport to the site, takes less time to set up, and has a greater output (or production) capacity than the batch-type plant. The batch-type plant allows more accurate control over the proportions of material in each batch, but generally does not have enough output capacity for larger paving jobs. The most widely used and recommended equipment is a continuous plant with weight controls (belt scales) for the materials. The output of the plant should be such that the smooth, continuous operation of the paver(s) is not interrupted. Generally, for all but the smaller jobs (840 m^2 [1,000 yd^2] or smaller), the capacity of the plant should be no less than 225 metric tons (250 tons) per hour. The output of the plant should match the laydown capacity of the paver(s) and the rollers. The plant should be located as close as possible to the paving site, but in no case should the haul time between the batch plant and the paver(s) exceed 15 minutes. The RCC should be hauled from the mixer to the paver(s) in dump trucks. These trucks should be equipped with protective covers to guard against adverse environmental effects on the RCC, such as rain or extreme cold or heat. The truck should dump the concrete directly into the paver hopper.

E-11 PLACING.

For most pavement applications, RCC should be placed with a paving machine. The paver should be equipped with automatic grade control devices such as a traveling ski or electronic stringline grade control device. Pavers should have at least two tamping bars. These machines provide a satisfactory surface texture and some initial compaction when the RCC is placed. Necessary adjustments on the paver to handle the RCC include enlarging the feeding gates between the feed hopper and the screed to accommodate the large volume of stiff material moving through the paver, and adjusting the spreading screws in front of the screed to ensure the RCC is spread uniformly across the width of the paving lane. Care should be taken to keep the paver hopper from becoming empty to prevent any gaps or other discontinuities from forming in the pavement. The concrete should be placed and compacted within 45 minutes after water has been added to the batch. When paving adjacent lanes, the new concrete should be placed within 60 minutes of placing the first lane to form a fresh joint. This time may have to be reduced, depending on ambient conditions. If these time restraints cannot be met then a cold joint is formed. The height of the screed should be set even with the uncompacted height of the adjacent lane, thus allowing simultaneous compaction of the edges of the adjacent lanes into a fresh joint. Two or more pavers operating in echelon may reduce the number of cold joints by one-half or greater, and are especially recommended in road construction where the entire width of the road can be placed at the same time.

E-12 COMPACTION.

E-12.1 General.

RCCP has usually been compacted with a dual-drum (9 metric ton [10 ton] static weight) vibratory roller making four or more passes over the surface to achieve the design density (one back-and-forth motion is two passes). To achieve a higher quality pavement, the primary compaction should be followed with two or more passes of an 18 metric ton (20 ton) pneumatic-tired roller (620 kPa [90 psi] minimum tire pressure) to close up any surface voids or cracks. The use of a dual-drum static (non-vibratory) roller may be required to remove any roller marks left by the vibratory or pneumatic-tired roller. A single-drum (9 metric ton [10 ton]) vibratory roller has been successfully used to compact RCCP, but may require the use of a pneumatic-tired or dual-drum static roller to remove tire marks.

E-12.2 Proper Time for Rolling.

The consistency of the RCC when placed should be such that it may be compacted immediately behind the paver without undue displacement of the RCC pavement surface. If rolling has to be delayed, the cause should be investigated and the problem corrected. In no case should more than 10 minutes pass between placement and the beginning of the rolling procedure. The rolling should be completed within 45 minutes of the time the water was added at the mixing plant. A good indication that the RCC is ready for compaction is obtained by observing the displacement of the surface after two static passes with the 9 metric ton (10 ton) vibratory roller. A mixture that is too wet may appear "rubbery" under the roller, or even spread to form a deep rut after two passes. A mixture that is too dry will hardly consolidate at all under the first passes. In either case, only minor changes in the design water content should be made at the plant to correct the problem; otherwise, a new mix design may be needed. With practice, the roller operator should be able to tell whether the consistency of the RCC is satisfactory for compaction.

E-12.3 Rolling Pattern.

After making the static passes, the vibratory roller should make four vibratory passes on the RCCP using the following pattern: two passes on the exterior edge of the first paving lane (the perimeter of the parking area or the edge of a road) so that the rolling wheel extends over the edge of the pavement 25 to 50 mm (1 to 2 in.) (done to “confine” the RCCP to help prevent excessive lateral displacement of the lane upon further rolling), followed by two passes within 300 to 450 mm (12 to 18 in.) of the interior edge. This will leave an uncompacted edge to set the height of the screed for an adjacent lane, and allows both lanes of the fresh joint to be compacted simultaneously. Any remaining uncompacted material in the center of the lane should be compacted with two passes of the roller. This pattern should be repeated once to make a total of four passes on the lane (or more if the specified density is not achieved). If the interior edge will be used to form a cold joint, it should be rolled exactly as the exterior edge was rolled, taking care to maintain a level surface at the joint and not round the edge. When the adjacent lane is placed, two passes should be made about 300 to 450 mm (12 to 18 in.) from the outer edge of the lane (again, to confine the concrete) followed by two passes on the fresh joint. The first two passes should extend 25 to 50 mm (1 to 2 in.) over the outer edge of this adjacent lane if the lane will form an outer edge of the completed pavement. Any remaining uncompacted material in the lane should be rolled with two passes of the roller. This pattern should be repeated to make a total of four passes over the RCCP. Additional passes may be necessary along the fresh joint to ensure smoothness and density across the joint.

E-12.4 Compacting the End of a Lane.

When the end of a lane is reached, the roller should roll off the end of the lane, creating a rounded ramp. The recommended procedure is to cut the ramp with a power saw full depth to form a vertical face. This will eliminate hand work and lessen the possibility of damage to the in-place RCC pavement. Another method is to saw the concrete to at least one-half the depth of the pavement, then trim the lower portion of the joint by hand to form a nearly vertical face, clean from debris and loose particles.

E-12.5 Proper Roller Operation.

During vibratory compaction, the roller should never stop on the pavement with the vibrator on. Instead, the vibrator should be turned on only after the roller is in motion and should be turned off several feet before the roller stops moving. The stopping points of successive rolling passes should be staggered to avoid forming depressions in the fresh pavement surface. The roller should be operated at the proper speed, amplitude, and frequency to achieve optimum compaction. Experience has shown that the best compaction will probably occur at high amplitude and low frequency (because of the thick lifts) and a speed not exceeding 2 km (1.5 mi.) per hour. A low amplitude/high frequency combination may be necessary if the surface is disturbed during the high amplitude rolling.

E-12.6 Finish Rolling.

The vibratory compaction should be immediately followed with two or more passes of the pneumatic-tired roller so the surface voids and fissures close to form a tight surface texture. This rolling may be followed by a light dual-drum roller to remove any roller marks on the surface, but this will probably not be necessary. It is very important that all exposed surfaces of the RCCP be kept moist with a light water spray after the rolling process until the curing procedure is implemented.

E-13 COLD JOINTS.

E-13.1 General.

A cold joint in RCC pavement is somewhat analogous to a construction joint in conventional concrete pavement. It is formed between two adjacent lanes of RCC when the first lane has hardened to such an extent that the uncompacted edge cannot be consolidated with the fresher second lane. This happens when there is some time delay between placement of adjacent lanes such as at the end of the day’s construction. This hardening typically takes approximately one hour, depending on properties of the concrete and environmental conditions. The adjacent lane should be placed against the first lane and compacted within this time frame. Otherwise, the joint between the two lanes should be considered a cold joint.

E-13.2 Cold Joint Construction.

Before placing fresh concrete against hardened in-place pavement to form a longitudinal cold joint, the edge of the in-place pavement should be cut with a power concrete saw. As discussed in paragraph E-16.8, the recommended procedure is to saw full depth with a power concrete saw to form a vertical face. This will eliminate hand work and lessen the possibility of damage to the in-place pavement. Another method is to saw to at least one-half the depth of the pavement, then the lower unsawed portion of the joint should be trimmed by hand to form a nearly vertical face, clean of debris and loose particles. Care should be taken to avoid undercutting the pavement edge. This vertical face should be dampened before the placement of the fresh lane begins. The height of the screed should be set to a sufficient elevation to compensate for the reduction in thickness due to compaction. The screed should overlap the edge of the hardened concrete surface 25 to 75 mm (1 to 3 in.). The excess fresh concrete should be pushed back to the edge of the fresh concrete with rakes or lutes and rounded off so no fresh material is left on the surface of the hardened concrete before compacting the joint. The loose material should not be broadcast over the area to be compacted; this may leave a rough surface texture after rolling. The edge of the fresh lane adjacent to the hardened concrete should be rolled first in the static mode, with about 300 mm (1 ft) of the roller on the fresh concrete, to form a smooth longitudinal joint. Transverse cold joints are constructed in a similar manner. After cutting back the rounded-off edge and wetting the vertical face, the paver is backed into place and the screed set to the proper elevation using shims sitting on top of the hardened concrete. The excess material should be pushed back (as mentioned before) and a static pass made in the transverse direction across the first 300 mm (1 ft) of the freshly placed lane. The joint should be carefully rolled to ensure a smooth surface transition across the joint.

E-13.3 Sawing of Contraction Joints.

RCC pavement has been allowed to crack naturally in many previous projects to save the cost of sawing joints. However, this has probably resulted in larger crack openings, increased raveling, and higher maintenance costs than if cracking was controlled. Contraction joints may be sawn in RCC pavement to induce controlled crack formation. The weakened plane should be sawn at least one-fourth the slab depth using a 3 mm (1/8 in.) blade. Sawing of joints can commence when the concrete strength is sufficient to enable the saw to cut through the concrete with a minimum of spalling, tearing, or aggregate pullouts. The use of special green-cut saws that penetrate the pavement surface to only a depth of about 1 in. have been shown to be effective on at least one RCC paving project. The time of sawing is very important and usually ranges from 4 to 20 hours after compaction, depending on weather conditions and other factors. To date, sawn transverse contraction joints in RCC pavement have typically been spaced from 9 to 18 m (30 to 60 ft). These spacings may vary with different materials and thicker pavements, so optimum contraction joint spacing should be determined during test section construction. Local service records may also be helpful to establish a joint spacing that will effectively control transverse cracking. Joint spacing greater than 12 m (40 ft) should never be used without backup data.

E-13.4 Sealing Joints and Cracks.

Rigid pavements that do not receive adequate joint and crack seal maintenance will rapidly deteriorate due to the intrusion of water and incompressible materials that migrate through and into the pavement joints and cracks. Incompressible materials lodge between the individual pavement slabs and parts of slabs, restricting movement that allows for expansion and contraction. This restriction of movement causes spalling and cracking along the edges of the joints and cracks and can result in breakage and blowup of entire slabs. Water in the subgrade material causes a migration of fines that eventually results in loss of support under the edge of the pavement slab.

E-13.5 Load-Transfer Devices.

The stiff consistency of RCCP does not lend itself to application of load-transfer devices such as dowels or keyed joints. Until an efficient method is developed to insert and align dowels properly in RCCP, the use of dowels should be limited.

E-13.6 Vertical Joints in Two-Lift Construction.

In two-lift construction, care should be taken to align the cold transverse and longitudinal joints in the upper and lower lifts to form a uniform, vertical face through the depth of the pavement along the joint. If the edge of the upper lift is not even with the edge of the lower lift, the lower lift should be cut back even with the edge of the upper lift.

E-14 CURING.

E-14.1 General.

The relatively rough or open surface texture of the compacted RCC pavement will tend to dry very quickly. To prevent this, moist curing has been commonly recommended to prevent drying and scaling of the RCC pavement surface. For moist curing, the pavement surface should be kept continuously moist after final rolling for at least seven days by means of a water spray truck, sprinkler (fog spray) system, wet burlap, or cotton mat covering. If burlap mats are used, they should be thoroughly wetted, placed on the RCC pavement so the entire surface and exposed edges are covered, and kept continuously wet. An irrigation sprinkler system has been used to cure RCC pavement on some projects, but caution should be exercised so that the fines in the surface of the RCC pavement are not washed away by excessive pressure, particularly in the first few hours. Curing RCC pavement with water can generate considerable runoff and, if not properly handled, cause erosion or saturation of exposed subgrade. Curing with membrane-forming curing compound and asphalt emulsion applied at double the rates used on conventional concrete have been used successfully.

E-14.2 Effect of Moist Curing on Frost Resistance.

Preliminary results of laboratory freezing and thawing tests indicate that RCC having a sufficiently low w/cm ratio and moist cured for an extended period is more frost resistant. The improved frost resistance may be due to more complete hydration reducing the fractional volume of freezable water at saturation or by reducing the permeability of the RCC, making it more difficult to saturate under wet conditions.

E-14.3 Early Loading.

All vehicular traffic should be kept off the RCCP until the end of the curing period. If it is absolutely necessary, a water-spraying truck may be driven onto the pavement before that age but any turns must be kept to a minimum. Water-spraying trucks or any other traffic should be kept to a minimum.

E-15 QUALITY CONTROL/ASSURANCE.

E-15.1 General.

The UFGSs provide requirements on the construction method and outline expected QC and QA measures and limits for density, smoothness, thickness, and surface texture.

E-15.2 Quality Control Operations.

QC operations for DoD RCC pavement projects are the responsibility of the contractor. QC consists of sampling, gradation, quality, and moisture testing of aggregates going into the concrete; checking the plant calibration regularly; conducting moisture-density relationship tests (ASTM D1557) on the fresh RCC; measuring the in-place density and moisture content of the RCC by using a nuclear gauge; checking the smoothness of the finished RCC with a straightedge; taking core samples from the RCC for measurement of density, strength, and thickness; and, if desired, fabricating RCC cylinders and beams.

E-15.3 Quality Assurance Operations.

QA consists of providing the RCC mixture proportions, testing cementitious materials and aggregates for quality, and testing in-place density, smoothness, surface texture, and thickness for acceptance. QA testing by the government may also consist of randomly duplicating any QC test to determine if consistent results are being obtained. Payment is based on the results of the QA tests (density, smoothness, surface texture, and thickness) for each lot, which represents a day’s placement of pavement. If the QA test results show deficiencies in any of these four areas, the payment for the lot is reduced, and the lot is rejected if the deficiency is too great.

E-15.4 Tests at Plant.

Moisture contents of the fine and coarse aggregates should be determined daily, as necessary, and appropriate changes made in the amount of mixing water. Washed gradation tests should normally be performed on the combined aggregates three times per day: in the morning, at midday, and in the afternoon. The samples should be taken from the conveyor before the cement or fly ash is added to the combined aggregates. The amount of materials passing the 0.150 mm (No. 100) sieve should be determined during this analysis. Whenever the characteristics of the mixture change or a check on the ingredients is required, a proportioning check can be performed on the combined dry ingredients on samples taken from the conveyor belt between the cement and fly ash hoppers and the pugmill using a washout test according to procedures in ASTM C685 (paragraph 6.5). By washing the dry ingredients over the 4.75 and 0.150 mm (No. 4 and No. 100) sieves and weighing the material in each size category, the approximate proportions of coarse aggregate, fine aggregate, and cement and fly ash combined may be determined and checked against predetermined limits.

E-15.5 Field Density Tests.

Field density tests should be performed on the RCC pavement using a nuclear density gauge operated in the direct transmission mode according to ASTM D6938, with the full-depth reading being used for control and acceptance. At least one field reading should be taken for every 30 m (100 ft) of each paving lane. The readings should be taken as closely behind the rolling operation as possible. The reading should be adjusted using the correlation determined in the test section construction and checked against a specified density. Areas that indicate a deficient density should be rolled again with the vibratory roller until the specified density is achieved.

E-15.6 Obtaining Core Samples.

The acceptance criteria for the thickness of the RCC pavement are based on appropriate tests conducted on cores taken from the pavement. Take cores from the pavement when it is no less than five days old. Take one core at a random location selected within each sublot, which is one-fourth the size of a lot, and measure the thickness. Take additional cores as determined by the government for density and splitting tensile strength.

E-15.7 Smoothness.

Do not finish the surface of the RCCP outside the tolerances given in the specifications. Check the smoothness as closely behind the finish roller as possible. Correct excessive variations in the surface with the finish roller. Pay particular attention to the smoothness across fresh and cold joints because this is typically a critical area for surface variations. A skilled vibratory roller operator is essential to minimize smoothness problems.

E-15.8 Surface Texture.

The final surface texture of an RCC pavement resembles that of an asphalt concrete pavement surface: a coarse surface texture with regularly spaced voids and interconnected fissures. The final surface texture should be devoid of surface tears, check cracking, segregation, rock pockets, surface patches, pumped areas, aggregate drag marks, loose aggregate, or exposed aggregate from washed fines.

E-15.9 Cylinder and Beam Fabrication.

The fabrication of cylinders and beams during RCCP construction may be specified and is encouraged if not specified. These beams and cylinders complement the coring operation to check RCCP strength and density. When fabricated cylinders and beams are used as a QC aid during construction, determine and report a correlation between their strength and density and those obtained from cores and sawed beams obtained from the test section.

E-15.10 Method of Cylinder and Beam Fabrication.

Fabricate cylinders in the field by filling cylinder molds in three equal layers. Each layer is consolidated by vibrating each layer on a vibrating table having a frequency of 3,600 vibrations per minute, under a surcharge of 9.1 kg (20 lb). Vibrate each layer until a mortar ring is visible around the entire periphery of the surcharge. Fabricate eight cylinders for every 225 m^3 (300 yd^3) of RCC placed. Test two cylinders each at 7, 14, 28, and 90 days. Test the cylinders for splitting tensile strength according to ASTM C496. No procedure has been standardized for fabricating RCC beam specimens such as those used to determine concrete flexural strength. However, CDR-C 161 details a procedure that fills beam molds in two layers. Each layer is consolidated by vibrating each layer on a vibrating table having a frequency of 3,600 vibrations per minute, under a surcharge of 57 kg (125 lb). The surcharge is uniformly distributed over the entire specimen area during molding and vibration is continued until a ring of mortar forms around the complete periphery of the mold. Fabricate four beams during each shift of construction: two to be tested at 14 days and two at 28 days. Test the beams for flexural strength according to ASTM C78.

E-15.11 Inspectors.

Inspections are vital in QC operations. Station at least one inspector at the mixing plant and at the jobsite to ensure a quality pavement is being built. At the mixing plant, check mixing times and spot-check the consistency and appearance of the mix coming out of the plant. The inspector coordinates the aggregate moisture content tests, the gradation tests, calibration of the plant, and washout tests to see that they are performed properly and at the right frequency. At the jobsite, the inspector ensures the base course and cold joints are moistened before the RCC is placed against them and that the RCC is placed and compacted within the proper time limitations. The inspector checks the paver operation to ensure proper grade control is continuously maintained and ensures no gaps or discontinuities are left in the pavement before rolling. The inspector ensures the roller begins compaction at the proper time and that the proper rolling pattern and number of passes are used. The inspector ensures adequate smoothness across joints is achieved and that the surface texture is tight after final rolling. The inspector spot-checks the final compacted thickness of the RCCP and corrects when out of tolerance. The inspector ensures the curing procedures are implemented as specified. The inspector also ensures all exposed surfaces of the RCCP are kept moist at all times and that the curing compound, if used, is applied properly and in a continuous fashion. The inspector coordinates the nuclear gauge density test, the coring procedures, cylinder and beam fabrication, and the surface smoothness test to ensure they are performed properly and at the required frequency.

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APPENDIX F GLOSSARY

F-1 ACRONYMS.

ACI	American Concrete Institute
Al_2O_3	Aluminum Oxide
ASR	Alkali-Silica Reaction
ASTM	American Society for Testing and Materials
CaO	Calcium Oxide
CONUS	Continental United States
CQC	Contractor Quality Control
DCP	Dynamic Cone Penetrator
DoD	Department of Defense
Fe_2O_3	Iron(III) Oxide or Ferric Oxide
FOD	Foreign Object Damage
ft	Foot
GGBFS	Ground-Granulated Blast Furnace Slag
gm/m^2	Gram per Square Meter
GPR	Ground-Penetrating Radar
HMA	Hot Mix Asphalt
Hz	Hertz
in.	Inch
in./ft	Inch per Foot
IPRF	Innovative Pavement Research Foundation Report
kg/m	Kilogram per Meter
kg/m^2	Kilogram per Square Meter
kg/m^2/hr	Kilogram per Square Meter per Hour
kg/m^3	Kilogram per Cubic Meter

kPa	Kilopascal
lb/ft	Pound per Foot
lb/ft^2	Pound per Square Foot
lb/ft^2/hr	Pound per Square Foot per Hour
lb/yd^2	Pound per Cubic Yard
LL	Liquid Limit
m	Meter
m^2	Square Meter
mg/m^3	Milligram per Cubic Meter
mm	Millimeter
mm/m	Millimeter per Meter
MPa	Megapascal
oz/yd^2	Ounce per Square Yard
PCC	Portland Cement Concrete
PI	Plasticity Index
psi	Pound per Square Inch
QA	Quality Assurance
QC	Quality Control
RCC	Roller-Compacted Concrete
RCCP	Roller-Compacted Concrete Pavement
SiO_2	Silicon Dioxide (Silica)
SG	Specific Gravity
TEA	Triethanolamine
TSC	Transportation Systems Center
tsf	Ton per Square Foot
TSPDWG	Tri-Service Pavement Discipline Working Group

UFC	Unified Facilities Criteria
UFGS	Unified Facilities Guide Specification
USACE	United States Army Corps of Engineers
w/cm	Water/Cementitious Material Ratio
yd^2	Square Yard

F-2 DEFINITION OF TERMS.

Alkali-Silica Reaction (ASR): A chemical reaction between alkalis in cement and certain reactive silica minerals with aggregate that forms a gel. The gel absorbs water and expands, thereby damaging the concrete.

Compaction: The process of reducing the void volume by applying mechanical energy.

Compressive Strength: The maximum resistance of a concrete specimen to axial compressive loading.

Curing: Maintaining moisture and temperature conditions in a freshly placed cementitious mixture to allow cement hydration to occur.

Dowels: A round steel bar that extends into adjoining slabs at an expansion or contraction joint to transfer shear loads.

D-Cracking: Pattern of cracks formed parallel to a joint or linear crack due to the inability of the concrete to withstand environmental factors such as freeze-thaw cycles.

Durability: Ability of concrete to resist weathering action, chemical attack, and abrasion.

Flexural Strength: Maximum resistance of a concrete specimen to flexural loading.

Fly Ash: Fine powder that is a byproduct of burning pulverized coal in electric power generating plants. Used as a supplementary cementitious material.

Gap-Graded Aggregate: An aggregate graded so one or more intermediate-size fractions are absent.

Ground Granulated Blast Furnace Slag (GGBFS): A granular byproduct of the iron- and steel-making process, which is dried and ground into a fine powder. GGBFS is highly cementitious and high in calcium silicate hydrates.

Pozzolan: A siliceous or siliceous and aluminous material that in itself possesses little or no cementitious value, but in finely divided form and in the presence of moisture, chemically reacts with calcium hydroxide to form compounds having cementitious properties.

Silica Fume: A byproduct of producing silicon metal or ferrosilicon alloys and a very reactive pozzolan.

Slump: Measure of consistency of freshly mixed concrete equal to the subsidence of a molded specimen immediately after removal of the slump cone.

Slipform Paver: A paver that does not use fixed forms but has forms that are pulled or raised as concrete is placed.

Tie-Bar: Deformed steel bars or connectors used to hold the faces of abutting slabs in contact. Typically used at longitudinal joints.

APPENDIX G REFERENCES

UNIFIED FACILITIES CRITERIA

https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc

UFC 1-200-01, *DoD Building Code*

UFC 3-250-01, *Pavement Design for Roads and Parking Areas*

UFC 3-250-08, *Standard Practice for Sealing Joints and Cracks in Rigid and Flexible Pavements*

UFC 3-250-11, *Soil Stabilization and Modification for Pavements*

UFC 3-260-02, *Pavement Design for Airfields*

UNIFIED FACILITIES GUIDE SPECIFICATIONS (UFGS)

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EM 1110-2-2006, *Roller-Compacted Concrete*, https://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-2-2006.pdf

ER 1110-34-1, *Transportation Systems Mandatory Center of Expertise*, https://www.publications.usace.army.mil/USACE-Publications/Engineer-Regulations/udt_43546_param_orderby/Title/udt_43546_param_direction/ascending/?udt_43546_param_page=5

CRD-C Standards: https://mtc.erdc.dren.mil/standards.aspx

CRD-C 3, *Standard Test Method for Temperature of Freshly Mixed Portland Cement Concrete (C1064)*

CRD-C 5, *Standard Test Method for Slump of Hydraulic Cement Concrete (C143)*

CRD-C 7, *Standard Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete* (C138)

CRD-C 8, *Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method (C173)*

CRD-C 11, *Standard Practice for Making and Curing Concrete Test Specimens in the Field (C31)*

CRD-C 13, *Standard Specification for Air-Entraining Admixtures for Concrete (C260)*

CRD-C 16, *Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading) (C78)*

CRD-C 20, *Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing (C666)*

CRD-C 26, *Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete (C42)*

CRD-C 31, *Standard Specification for Ready-Mixed Concrete (C94)*

CRD-C 41, *Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method (C231)*

CRD-C 42, *Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete (C457)*

CRD-C 55, *Test Method for Within-Batch Uniformity of Freshly Mixed Concrete*

CRD-C 77, *Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens (C496)*

CRD-C 87, *Standard Specification for Chemical Admixtures for Concrete (C494)*

CRD-C 111, *Standard Test Method for Surface Moisture in Fine Aggregate (C70)*

CRD-C 113, *Standard Test Method for Total Evaporable Moisture Content of Aggregate by Drying (C566)*

CRD-C 127, *Standard Guide for Petrographic Examination of Aggregates for Concrete (C295)*

CRD-C 130, *Standard Recommended Practice for Estimating Scratch Hardness of Coarse Aggregate Particles (C851)*

CRD-C 133, *Standard Specification for Concrete Aggregates (C33)*

CRD-C 160, *Standard Practice for Making Roller-Compacted Concrete Specimens in Cylinder Molds Using a Vibrating Table*

CRD-C 161, *Standard Practice for Selecting Proportions for Roller-Compacted Concrete Specimens in Cylinder Molds Using a Vibrating Table*

CRD-C 162, *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3)) (D1557)*

CRD-C 174, *Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method) (C1260)*

CRD-C 175, *Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction (C1293)*

CRD-C 201, *Standard Test Method for Water Retention by Concrete Curing Materials (C150)*

CRD-C 203, *Standard Specification for Blended Hydraulic Cements (C595)*

CRD-C 205, *Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars (C989)*

CRD-C 255, *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete (C618)*

CRD-C 271*, Standard Performance Specification for Hydraulic Cement (C1157)*

CRD-C 300, *Specifications for Membrane-Forming Compounds for Curing Concrete*

CRD-C 304, *Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete (C309)*

CRD-C 306, *Standard Test Method for Water Retention by Concrete Curing Materials (C156)*

CRD-C 403, *Method of Test for Determination of Sulfate Ion in Soils and Water*

CRD-C 408, *Standard Test Method for Sulfate Ion in Water (D516)*

CRD-C 521, *Standard Test Method for Frequency and Amplitude of Vibrators for Concrete*

CRD-C 553 (C1077)

CRD-C 653, *Standard Test Method for Determination of Moisture-Density Relation of Soils*

CRD-C 662, *Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials, Lithium Nitrate Admixture and Aggregate (Accelerated Mortar-Bar Method)*

AMERICAN CONCRETE INSTITUTE (ACI)

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ACI 207.5, *Roller Compacted Mass Concrete*

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ACI 306, *Cold Weather Concreting*

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ASTM C31, *Standard Practice for Making and Curing Concrete Test Specimens in the Field*

ASTM C33, *Standard Specification for Concrete Aggregates*

ASTM C42, *Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete*

ASTM C70, *Standard Test Method for Surface Moisture in Fine Aggregate*

ASTM C78, *Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)*

ASTM C88, *Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate*

ASTM C94, *Standard Specification for Ready-Mixed Concrete*

ASTM C117, *Standard Test Method for Materials Finer than 75-μm (No. 200) Sieve in Mineral Aggregates by Washing*

ASTM C123, *Standard Test Method for Lightweight Particles in Aggregate*

ASTM C128, *Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate*

ASTM C138, *Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete*

ASTM C142, *Standard Test Method for Clay Lumps and Friable Particles in Aggregates*

ASTM C143, *Standard Test Method for Slump of Hydraulic Cement Concrete*

ASTM C150, *Standard Specification for Portland Cement*

ASTM C156, *Standard Test Method for Water Loss [from a Mortar Specimen] Through Liquid Membrane-Forming Curing Compounds for Concrete*

ASTM C173, *Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method*

ASTM C192, *Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory*

ASTM C231, *Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method*

ASTM C260, *Standard Specification for Air-Entraining Admixtures for Concrete*

ASTM C295, *Standard Guide for Petrographic Examination of Aggregates for Concrete*

ASTM C309, *Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete*

ASTM C457, *Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete*

ASTM C494, *Standard Specification for Chemical Admixtures for Concrete*

ASTM C496, *Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens*

ASTM C566, *Standard Test Method for Total Evaporable Moisture Content of Aggregate by Drying*

ASTM C595, *Standard Specification for Blended Hydraulic Cements*

ASTM C618, *Standard Specification for Coal Ash and Raw or Calcined Natural Pozzolan for Use in Concrete*

ASTM C666, *Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing*

ASTM C685, *Standard Specification for Concrete Made by Volumetric Batching and Continuous Mixing*

ASTM C989, *Standard Specification for Slag Cement for Use in Concrete and Mortars*

ASTM C1040, *Standard Test Methods for In-Place Density of Unhardened and Hardened Concrete, Including Roller Compacted Concrete, By Nuclear Methods*

ASTM C1064, *Standard Test Method for Temperature of Freshly Mixed Portland Cement Concrete*

ASTM C1077, *Standard Practice for Agencies Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Testing Agency Evaluation*

ASTM C1157, *Standard Performance Specification for Hydraulic Cement*

ASTM C1176, *Standard Practice for Making Roller-Compacted Concrete in Cylinder Molds Using a Vibrating Table*

ASTM C1260, *Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)*

ASTM C1293, *Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction*

ASTM C1557, *Standard Test Method for Tensile Strength and Young's Modulus of Fibers*

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ASTM D516, *Standard Test Method for Sulfate Ion in Water*

ASTM D558, *Standard Test Methods for Moisture-Density Relations of Soil-Cement Mixtures*

ASTM D698, *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3))*

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ASTM D2487, *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)*

ASTM D6938, *Standard Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)*

ASTM E177, *Standard Practice for Use of the Terms Precision and Bias in ASTM Test Methods*

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Certification of Ready Mixed Concrete Production Facilities

PORTLAND CEMENT ASSOCIATION (PCA)

Guide Specifications for Concrete Subject to Alkali-Silica Reactions, https://www.cement.org/