Tech Brief

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FIELD CONTROL OF CONCRETE PAVING MIXTURES

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INTRODUCTION

The variability of a concrete paving mixture can have a significant impact on the performance of the concrete pavement and impact its overall service life. Mixture variability can lead to inconsistent workability, poor consolidation, built-in roughness, and areas of weaker, less durable concrete, all of which can negatively affect pavement performance (Fick et al. 2012). Well-defined and implemented field control of concrete paving mixtures is extremely important to produce, deliver, and place a consistent concrete pavement mixture that meets design criteria and increases the chance of achieving durability goals.

This Tech Brief summarizes guidance on the concrete-making process from batching through placement on grade. It draws from key reference documents on field control of concrete mixtures including:

- *Integrated Materials and Construction Practices for Concrete Pavement: A State-of-the-Practice Manual* (Taylor et al. 2006).
- *Concrete Pavement Field Reference, Pre-Paving* (ACPA 2008).
- *Concrete Pavement Field Reference, Paving* (ACPA 2010).
- *Field Reference Manual for Quality Concrete Pavements* (Fick et al. 2012).
- *Effective Quality Assurance for Concrete Paving Operations* (Taylor 2016).
- *Design and Control of Concrete Mixtures* (Kosmatka and Wilson 2016).

ACPA (2008) provides a pre-paving checklist covering key items to consider and inspect during pre-paving operations, including some attributes of the concrete mixture and ACPA (2010) provides an additional checklist that focuses on all elements of the concrete paving operation itself. Together, these references serve as a good starting point to establish necessary controls to produce, transport, and place quality paving concrete.

The following six elements are important in the production, transportation, and placement of quality concrete paving mixtures: 1) quality, 2) plant operations, 3) mixing, 4) transporting and placing, 5) field verification, and 6) field adjustments.

QUALITY

According to TRB E-Circular 235, quality assurance (QA) encompasses, “all those planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service” (TRB 2018). As noted by Fick et al. (2012), it was common in the past to incorrectly use the term “Quality Control/Quality Assurance (QC/QA)” synonymously with QA; however, QA is the overall process or system for the construction of a long-lasting facility of which QC is one element. Both the agency/owner and contractor play important roles in QA, and both have a vested interest in ensuring that the project is constructed to high-quality standards. Taylor (2016) provides an excellent description of the roles of the agency and contractor in the effective execution of a QA system.

The QC element under the QA program is largely under the purview of the contractor, who must integrate QC throughout the entire operation, from the highest levels of management to the lowest paid member of the production staff. As stated by

Fick et al. (2012), “true quality can only be achieved by a trained labor force utilizing materials that conform to specifications, and which are supported by a QC staff and program that provide timely feedback.” The contractor must aim to continuously improve every aspect of the entire production process.

The agency’s primary role under the QA program is acceptance. This means respecting the contractor’s QC role and leaving the elements of production under the control of the contractor. In this environment, the agency engages proactively by monitoring the contractor’s QC activities and ensuring conformance with the contractor’s own quality control plan (QCP). The QCP is necessary to monitor consistency and acceptability of the concrete properties and to make adjustments during production, delivery, and placement of concrete paving mixtures.

According to Fick et al. (2012), one of the most important concepts regarding QA is to understand the difference between contractor QC testing and agency acceptance testing. The former is being done with the purpose of guiding the contractor to improve the project quality, recognizing that not all QC testing results will be in compliance with the specifications. The latter is conducted by the agency (or by an agency representative) to assess overall quality, and is based on an established sampling plan.

Construction QC requires the use of field tests to monitor the properties of the concrete being delivered and placed, allowing the contractor to make changes, as needed, to remain within the specified ranges in order to produce concrete with the desired properties. As mentioned, it is common that the contractor provides an approved QCP for all paving work (Taylor et al. 2006). The QCP guides the construction of the project, being a project-specific document that identifies all QC personnel and procedures to be used to control the construction process and meet the agency specification requirements. Specific items to be included in the QCP include (Fick et al. 2012):

- Reference to the applicable specifications for each item of work.
- Action limits (these are not specification limits) that dictate when the process can be maintained but should be adjusted.
- Suspension limits that define when the process should be stopped and adjusted before resuming production.
- A description of corrective actions to be taken when the process is deemed to be out of control.

Fick et al. (2012) provides a template QCP as an example that can be used as a guide when preparing a project specific QCP.

Specific test methods used for QC are many and varied, and described in detail in numerous documents (ACPA 2008; ACPA 2010; Fick et al. 2012; Taylor 2016; Kosmatka and Wilson 2016). All testing conducted, whether for QC or acceptance testing, must utilize trained and certified or qualified personnel and qualified laboratories. Table 1 provides a summary of tests that can be used for QC of concrete mixtures, but note that test methods that are exclusively used for material approval or acceptance testing are not included.

CONCRETE PLANT OPERATIONS

Proper field control begins during the concrete plant setup phase as upfront planning, layout design, and setup are essential activities for safe and effective plant operations (Fick et al. 2012). The following are key items to monitor during plant setup (Fick et al. 2012):

- Plant setup and component inspections should be carried out per the manufacturer’s recommendations.
- Scales should be calibrated and certified after plant setup is complete.
- Batch tickets should be reviewed for proper proportions and verify constituent materials (admixture and cementitious materials) match approved mix design.
- Trial batches should be developed and appropriate QC testing conducted to ensure mixture consistency.

Taylor et al. (2006) and ACPA (2010) provide detailed concrete plant inspection checklists for when a plant starts producing mixture for a project or when concrete mixture consistency or strength issues are encountered during production. Additionally, the National Ready Mixed Concrete Association provides an inspection and certification program for concrete plants and agitator trucks (NRMCA 2016).

Material Handling

Proper handling of constituent materials and aggregate stockpile management at the plant site are required for production of a consistent concrete mixture for paving operations. These requirements are similar for central plant mixtures and transit mixtures. Different cementitious materials should be stored in separate silos (Taylor et al. 2006). Likewise, different aggregates should be stored separately in properly constructed stockpiles that minimize contamination with adjacent aggregates as well as from underlying materials. Aggregates in stockpiles must not be segregated and must be maintained with uniform moisture content. Good stockpile management includes the following (Taylor et al. 2006; ACPA 2010; Fick et al. 2012):

- Use a firm and well-drained base to minimize the presence of mud (clay) balls from the subgrade below. Ensure that front-end loaders and other equipment are clean and operating consistency, as aggregates contaminated with soil or clay can result in low concrete strengths in addition to the development of clay balls in the concrete.
- Construct stockpiles in layers to minimize segregation and minimize free-fall heights of aggregates.

Table 1. Summary of test methods that can be used for field control of concrete mixtures (from ACPA 2008; Fick 2008; ACPA 2010; Taylor 2016).

Property	Test Method	Comment
Aggregate Properties	AASHTO T 27: Gradation	Used to determine combined aggregate grading. Can be used as both a QC and acceptance test.
	AASHTO T 255: Aggregate moisture content	Used to determine aggregate moisture content. Can be used as both a QC and acceptance test.
Workability	AASHTO T 119: Slump test	Most commonly used measure of consistency. Can be used as a QC test.
	Box test (see AASHTO PP 84)	Newly developed test methods to assess concrete consolidation under vibration. Can be used by the contractor for QC of mixture response under vibration or by agencies in the mix qualification process.
	V-Kelley test (see AASHTO PP 84)	Newly developed test methods to assess concrete consolidation under vibration. Can be used by the contractor for QC of mixture response under vibration or by agencies in the mix qualification process.
Air Content and Air-Void System Parameters	AASHTO T 152: Pressure meter	Most commonly used test for measure of total air content in fresh concrete. Can be used as both a QC and acceptance test.
	AASHTO T 121: Unit weight	Provides an excellent measure of mixture consistency. Can be used as both a QC and acceptance test. Can help identify changes in the physical makeup of the mixture.
	AASHTO TP 118: SAM meter (see AASHTO PP 84)	Test based on pressure meter but uses sequential pressure to provide additional information related to air-void system characteristics. Can be used as both a QC and acceptance test.
	ASTM C457: Microscopical evaluation of air voids	Measures air-void system parameters in hardened concrete. Can be used as both a QC and acceptance test.
Strength Development	AASHTO T 318: Microwave water content	A measure of concrete water content. Can be used as both a QC and acceptance test.
	AASHTO T 97: Flexural strength	Conventional strength testing used as a common measure of concrete quality. Can be used as both a QC and acceptance test.
	AASHTO T 22: Compressive strength	Conventional strength testing used as a common measure of concrete quality. Can be used as both a QC and acceptance test.
	AASHTO T 325: Maturity	Estimates concrete strength through the use of a maturity index. Can be used by the contractor for QC for time to opening.
Transport Properties	AASHTO T 338: Concrete resistivity (see AASHTO PP 84)	Electrical methods to determine concrete resistivity from which the F factor can be determined. Can be used as both a QC and acceptance test.
Heat of Hydration	AASHTO T 309: Concrete Temperature	Measures temperature of fresh concrete. Can be used as both a QC and acceptance test.
	ASTM C1753: Semiadiabatic calorimetry	Monitors the heat liberated by the exothermic cement hydration reactions. Can be used by the contractor for QC of cement and supplementary cementitious materials sources. Can help identify changes in the chemical makeup of the mixture.

- Perform regular testing to monitor and manage variable moisture content. Aggregate stockpiles should be inspected for moisture content and segregation (gradation). Loader operator should work the stockpile to provide uniform aggregate (moisture and gradation) while keeping segregation to a minimum (see figure 1 [Fick et al. 2012]).
- Water stockpiles as necessary in the case of highly absorptive coarse aggregates.

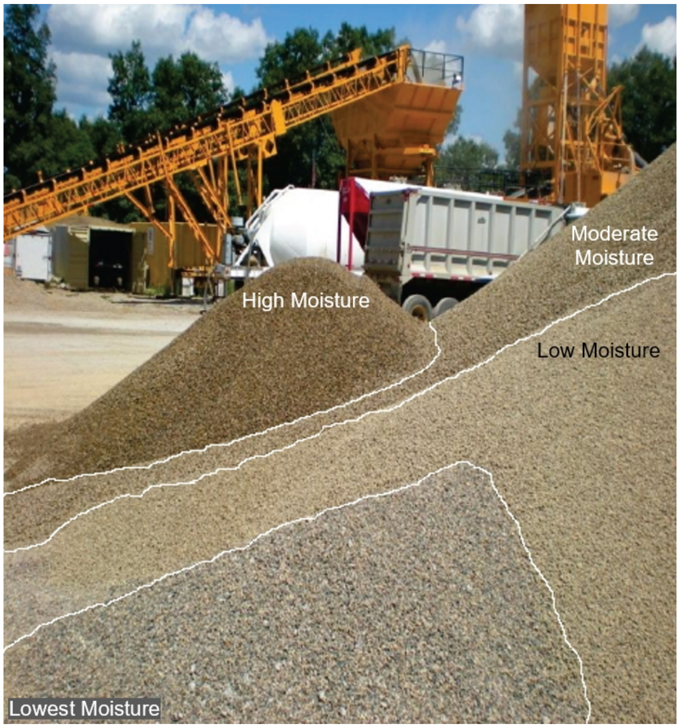

Figure 1. Variations in shades of stockpiled aggregate indicate variations in moisture content.

Quality control measures that should be exercised with regards to aggregate stockpiles include sieve analysis (AASHTO T 27) and moisture content (AASHTO T 255) to ensure compliance with specifications.

Batching

Batching the concrete mixture is an important step in controlling the mixture properties as incorrect materials and/or quantities can lead to an out-of-specification mixture and undesirable mixture properties. Batching of dry ingredients should be according to weight whereas water and chemical admixtures should be batched by volume. The order in which materials are introduced into the mixer must be consistent and conform to the sequence used during trial batching to ensure batch to batch mixture consistency. Typical batching sequences are discussed by Taylor et al. (2006). The following checks are recommended to ensure proper batching (ACPA 2010; Fick et al. 2012):

- Verify that mixing equipment is well-maintained, calibrated, inspected, and in operable condition.
- On a daily basis, verify the batch proportions of constituent materials against the mix design and material sources should also be confirmed.
- Ensure adequate material inventories to reduce chance inconsistencies in material properties.
- Check that moisture compensation represents condition of aggregates being batched. This should be verified at least twice per day or more frequently when conditions dictate.
- Verify that the drum is clean and free of loose material. Remove excess free water or release compounds from drums after rain events or washing.

Common quality control tests during the batching process include:

- Sieve analysis of aggregate (AASHTO T 27).
- Aggregate moisture content (AASHTO T 255).

Mixing

Concrete is mixed using one of the following methods (Taylor et al. 2006; Kosmatka and Wilson 2016):

- Central plant – Mixing takes place at a central plant with fresh concrete delivered to the project site via a mixing truck with a low drum speed, agitator truck, or non-agitator truck.
- Continuous mixing – Concrete is batched in a plant by volume and delivered as a continuous supply of constituent materials to an auger that blends materials into a uniform mixture.
- Shrink mixing – Partial mixing takes place in a stationary mixer and then a truck mixer finishes the mixing process and transports the material to the paving site.
- Truck mixing – All mixing takes place within the truck that transports the concrete to the paving site.

Refer to ASTM C94 for standard guidance on truck mixing operations and to ASTM C685 for standard guidance for concrete mixtures produced using the continuous mixing process.

Mixing equipment should be operated within the range of manufacturers' recommendations. Mixing time varies depending on many factors including specifications, equipment type, constituent materials, and temperature. Typical mixing times for a central batch plant are in the range of 60 to 90 seconds. Shorter mixing times may not entrain sufficient air and lead to non-uniform mixtures, whereas mixing at high speeds and for long durations, coupled with the addition of water, can lead to loss of strength, entrained air, slump, and mixture temperature increase. Mix time is typically the first item to consider when troubleshooting mix problems such as bleeding, finishing, and segregation (Taylor et al. 2006; Kosmatka and Wilson 2016).

Fick et al. (2012) recommends the following mix properties be evaluated at least once per day at the mixing plant and compared to the properties at the onsite point of delivery:

- Concrete temperature (AASHTO T 309).
- Concrete unit weight (AASHTO T 121).
- Air content (AASHTO T 152).

TRANSPORTING AND PLACING CONCRETE

Transporting

Transporting concrete to the paving site is important with respect to maintaining mixture uniformity and supporting paving operation. For example, inconsistent delivery intervals can lead to variable paving rates, thereby affecting the quality of finished concrete product. Some key factors in transport operations (Taylor et al. 2007; Fick et al. 2012; Kosmatka and Wilson 2016) include:

- Delivery time – Rural and urban deliveries require different considerations as traffic congestion in urban areas may delay deliveries.
- Number of trucks – In slipform paving operations, the number of trucks typically controls the paver speed so the number of trucks must be sufficient to keep the paver moving. Adjustments to the number of trucks may be necessary as haul time changes.
- Concrete stiffening – This must be taken into consideration when planning or adjusting haul times. In addition, hot weather may reduce set times while cold weather may increase set times. The as-placed mix temperature of concrete can have a significant effect on the subsequent strength development and other characteristics of the material.
- Mixer revolutions and speed – ASTM C94 places limits on truck mixer revolutions and mixing speed.
- Mixture segregation – This must be avoided.

The National Ready Mixed Concrete Association provides an inspection and certification program for mixing trucks and plants (NRMCA 2016). In addition, agencies may also have specific inspection requirements.

Retempering Concrete and Admixture Additions

It is typical for specifications to provide an allowable range for slump for concrete paving mixtures at time of delivery. ASTM C94 allows a one-time addition of water to be added prior to discharge of the concrete as long as the maximum values for slump, water-to-cementitious materials ratio (*w/cm*), mixing revolutions, and mixing time are not exceeded. If water is added, the mixture should be subjected to additional mixing revolutions per ASTM C94 or project specifications (Kosmatka and Wilson 2016). Additional guidance on retempering is provided by Taylor et al. (2006) and by Kosmatka and Wilson (2016).

In some cases, admixtures may need to be added at the jobsite. If permitted by the specifications, admixtures can be added using a truck-mounted dispenser (calibrated storage tank) that includes a pressurized injection nozzle to dispense the admixture thoroughly into the drum. Another method includes the use of a field dispenser (wand, pump, and measuring unit). When admixtures are added, the amount should be recorded on the delivery ticket. Dispensers should be properly inspected, cleaned, maintained and calibrated and operation should be by qualified personnel (ACI 2013).

Placing Concrete

Prior to concrete placement, the grade and stringline should be checked, dowel baskets should be properly affixed, and the grade wetted (ACPA 2010; Fick et al. 2012). For slipform paving operations, concrete mixtures are usually discharged directly from the truck onto the grade in front of a placer/spreader unit or the slipform paver. Alternatively, a belt conveyor, such as shown in figure 2, can be used to transport the concrete from an adjacent paving lane to the front of the paver. Regardless of the method utilized, the concrete as placed must not be segregated and a proper head of concrete must be continually maintained in front of the paver to ensure consistent paving operations.

Figure 2. Concrete placement through the use of a belt conveyor.

Key concrete materials QC activities conducted at time of concrete placement include (Fick et al. 2012):

- Concrete temperature (AASHTO T 309).
- Slump (AASHTO T 119).
- Concrete unit weight (AASHTO T 121).
- Air content (AASHTO T 152).
- Specimens for strength testing, either compressive (AASHTO T22) or flexural (AASHTO T97).

FIELD VERIFICATION

Field verification consists of QC measures that ensure that the concrete mixture is suitable for its intended use in addition to meeting specification limits. The QC test matrix and frequency of testing is described in the QCP, and is dependent on the type of paving job (interstate, state highway, rural roadway, etc.), with the interstate paving jobs requiring a higher level of testing and frequency. Field verification also serves as a means to identify the need for field adjustments to the concrete mixture proportions.

As noted earlier, common field tests for concrete paving mixtures include the following:

- Concrete temperature can be measured using AASHTO T 309 to monitor conformance to temperature requirements.
- Workability is most often assessed using the slump test (AASHTO T 119), although it is a better indicator of consistency.
- The total air content of fresh concrete is normally assessed using the pressure method (AASHTO T 152).

While typically performed after concrete has been placed, the following tests can lead to changes in the concrete mixture proportions for the remainder of the paving job:

- Maturity – In-place concrete strength can be estimated using the maturity method (ASTM C1074). This method can be used to determine the time to begin subsequent construction activities such as opening of pavements to construction/vehicular traffic.
- Strength – Flexural strength (AASHTO T 97) and compressive strength (AASHTO T 22) are commonly assessed at 28-days. Testing may also be specified at earlier or later ages.
- Resistivity – The surface resistivity (AASHTO T 358) is appearing in some agency specifications as an indicator of the concrete's resistance to chloride ion penetration.

It is recognized that the aforementioned tests, commonly used to assess the "quality" of the concrete, have limitations. For example, challenges using the slump test to assess workability of concrete placed using slipform pavers have been noted, as the slump test does not directly assess the ability of the concrete to be consolidated under vibration (Cook et al. 2013). Recently developed tests to assess workability for concrete paving mixtures include the Box Test (Cook et al. 2013; Cook, Ghaeezadeh, and Ley 2014) and the V-Kelly Test (Taylor, Wang, and Wang 2015). Air content can also be measured using the Super Air Meter (SAM) (AASHTO TP 118). These test methods are featured in AASHTO PP 84.

FIELD ADJUSTMENTS

Concrete constituent material properties are inherently variable, and thus they should be closely monitored during production, as should the properties of the fresh concrete. Field adjustments to concrete mixture proportions are often required (as allowed by specifications) to maintain concrete uniformity and consistency of the final product. Taylor et al. (2006) provides a discussion of the following key areas that typically lead to the need for field adjustments.

Ambient Temperatures

Differences in daily and seasonal temperatures affect the fresh and hardened concrete properties. For example, concrete set time is shortened and strength gain is accelerated in hotter temperatures and retempering concrete may be necessary to maintain workability. The opposite occurs in colder temperatures, an effect that can be exacerbated when supplementary cementitious materials (SCMs) are used.

Material Variability

Inherent variability exists within the different proportions of concrete paving mixtures and thus adjustments may be necessary to maintain fresh concrete properties such as workability. The following highlight areas that potentially require field adjustments:

- Stockpile moisture content is typically the first item requiring field adjustment and plants should be able to adjust water to account for changes in free water in the aggregate.
- Stockpiles may need to be reworked if they become segregated.
- The aggregate batch proportions may need to be adjusted if the combined gradation is out of range.
- While there is no current field method to assess the variability of cementitious materials, adjustments to cementitious material may be necessary based on feedback from the paving crew. In these cases, adjustments to water and admixtures may be necessary to maintain desired properties of fresh and hardened concrete.

Material Supply Changes

Source material changes in concrete mixtures are not always avoidable during concrete production. Good planning and communication at the plant can minimize the chances for material substitution. However, a number of factors may necessitate material substitution, such as material shortages, changes in material properties, and out-of-specification constituent materials. In cases where materials are replaced, trial mixtures are highly recommended and may be required by specifications. If time permits, laboratory batching and testing of modified concrete mix designs should be performed prior to a trial batch or production. If laboratory testing is not feasible beforehand, increased quality control measures should be applied during initial production with the modified mixture design.

CONCLUDING REMARKS

Variability of concrete paving mixtures can have a significant impact on the performance of concrete pavements and ultimately impact its overall service life. Well defined and implemented field control of concrete paving mixtures are extremely important to produce, deliver, and place a consistent concrete pavement mixture that meets design criteria and increases the chance of achieving durability goals. This Tech Brief describes key aspects of field control of concrete paving mixtures, provides guidance, and cites important source materials for additional guidance and information.

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Contact—For more information, contact:

Federal Highway Administration (FHWA)
Office of Preconstruction, Construction and Pavements
Tom Yu (Tom.Yu@dot.gov)

Researcher—This Tech Brief was developed by Thomas J. Van Dam (NCE) and prepared under FHWA's Concrete Pavement Best Practices Program (DTFH61-14-D-00006). Applied Pavement Technology, Inc. of Urbana, Illinois served as the contractor to FHWA.

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